

Room Gap Analysis of Thermal Comfort in Office Spaces: The Case of Office Space in The Barru Regent Tower Building, Indonesia

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Received	Reviewed	Revised	Published
20.11.2023	15.12.2023	20.12.2023	31.12.2023

<https://doi.org/10.61275/ISVSej-2023-10-12-14>

Abstract

It is common knowledge that thermal comfort must be provided by all the office spaces to ensure work productivity. Usually, an HVAC system must work in a closed room so that cold air distribution works optimally. However, in the office room of Barru Regent's Tower building in Indonesia, gaps were found on the side of the room that might cause the cold air distribution to be wasted and not work optimally affecting the user's thermal discomfort conditions. This research examines this issue of thermal comfort in office buildings. The purpose of the research is to analyze thermal comfort conditions and influence of gap factors on the thermal conditions of an office room.

It uses a quantitative approach. It generates objective data such as room temperature profile, wind speed, humidity and mean radiant temperature and subjective data such as activities and clothing. Objective analysis was obtained from the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) values through the Thermal Comfort Tool software by Center for Built Environment (CBE) and subjective analysis was obtained through a questionnaire administered with the users of the building.

The results show that the office room does not comply with ASHRAE-55 comfort standards. However, the outcomes of the questionnaire show that 74% felt comfortable and after the room gap was closed, it increased to 77%. Several factors that cause it not to comply with ASHRAE-55 standards are less than optimal distribution of cold air and the influence of gaps on the sides of the room. The results of the research when all gaps on the sides of the room were closed showed that the temperature decreased by around 0.5 °C.

Keywords: Air Temperature, Thermal Comfort, PPD, PMV, CBE.

Introduction

Several studies show that ensuring adequate thermal comfort conditions in a room is very important not only to ensure the health of its occupants but also to increase productivity and efficiency at work (Leaman and Bordass., 2006) especially in office spaces. In recent years, public attention to the problem of thermal comfort of building occupants has generated a lot thermal studies on various types of buildings, and research has been carried out in various countries with different climatic conditions.

There are now two methods for studying thermal comfort. The first approach is called the static approach which refers to the results of P.O. Fanger's 1970 thermal comfort study analysis. (Fanger, 1970). According to Fanger (1982), thermal comfort refers on metabolic levels which can be assessed with variables including activity, clothing resistance, air temperature, relative humidity, air flow speed, and light intensity. The most important findings are the basis for international standards related to room thermals, such as ISO 7730 2005 (ISO 7730, 2005), ASHRAE 55-2020 (ASHRAE Standard, 2020), and CEN Standard EN15251 (2007) (Comite'Europe'en de Normalisation, 2007). The second approach is called the adaptive approach. This approach uses user respondents, which have been adjusted to climatic conditions, this study is an effort to determine thermal neutrality, acceptance of thermal conditions, and preference for thermal conditions. The adaptive thermal model proposed by Dear and Brager (De Dear *et al.*, 1998), and Nicol and Humphreys (Nicol and Humphreys, 2010).

Based on an initial survey of office space in the Barru Regent Tower Building, in Indonesia, it was found that the HVAC system in the room was not able to work properly, especially since this office room has a gap in the side of the room. The gap in the room means the room is not completely closed. This side of the room makes the room slightly open. Perhaps this causes the cold air distribution to be less than optimal. Lee's finding that opening doors and windows while the air conditioner is running is a way to lower its efficiency and make it harder for it to regulate the temperature in the room (Lee, 2019). In addition to affecting temperature discomfort, a malfunctioning ventilation system will reduce productivity and concentration at work. (Wagner *et al.*, 2007). Initial data for an office space with a measuring area of 390 m², a height from floor to ceiling is 2.8 m and an HVAC artificial ventilation system.

The orientation of unprotected window openings facing East tends to potentially cause higher energy consumption (Karyono, 2000). Many factors cause cold air in a room to be less than optimal, such as the volume of the room, AC position, and the adequacy of cold air. Cold AC air that is wasted through the gaps in the room could be one of the factors in the distribution of cold air in a room not being optimal which results in user discomfort.

This research examines the issue of thermal comfort at the Barru Regent Tower office space with the room type HVAC system.

Its objectives are as follows.

1. To analyze the thermal comfort conditions in the Barru Regent Tower office space with the HVAC system room type and
2. To analyze the influence of gap factors on the thermal conditions of this office space

Theoretical Framework

1. Static approach thermal comfort standards

The first approach that most widely used thermal comfort index in this standard is obtained by the PMV (Predicted Mean Vote) equation proposed by Fanger (Fanger, 1970), which can predict the thermal perception of indoor users according to the seven-point thermal sensation scale proposed by ASHRAE.

ASHRAE 55-2020 comfort standard (ASHRAE Standard, 2020) and ISO 7730 (ISO 7730, 2005). In several different nations, ASHRAE-55 is commonly utilized. The ASHRAE-55 thermal comfort standard is used in this study to identify the thermal comfort of the employees of this building. The standard measures used are the perceived level of thermal comfort using a seven-point rating system which indicates: +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool), and -3 (cold) on the seven-point rating scale. The scale was also developed by Bedford (1936).

2. Adaptive approach thermal comfort standards

The second approach is adaptive approach to ascertain thermal neutrality, acceptance of thermal conditions, and preference for thermal conditions, this approach makes use of user

respondents who have been modified for climatic conditions. The Dear and Brager-proposed adaptive thermal model (De Dear *et al.*, 1998) is found to be useful for this purpose.

Review of Literature

Study of thermal comfort and building energy in Jakarta. The results of data measurements obtained neutral temperatures, namely 26.4 Ta, 26.7 To and 25.3 Tg. The difference in neutral temperature between men and women is very small and not significant at the 5% level. The orientation of window openings that are unprotected and facing east tends to potentially cause higher energy consumption and have low thermal comfort. (Karyono, 2000)

Characterized indoor climate building thermal response to human thermal comfort. Analyzing the relationship between PMV and PPD in three types of rooms, namely natural ventilation, mechanical ventilation and HVAC systems. The results showed that the PMV bias will be greater along with the degree of metabolism of activity, PMV will not experience a significant bias at an activity level of 1.4 met. Thus, the PMV bias caused by the metabolic level of activity in the office space is thought to not occur because it is within the activity level range of 1.2 met. (Van Der Linden *et al.*, 2002)

Evaluate heat loss and room temperature through an open door when the AC is on and analyze the energy that works in a room with the door closed and open. The infiltration rate when the door was open increased around 21.3 times compared to when the door was closed. When the AC temperature is set to 24°C, the room temperature with the door open is 5°C higher than the room temperature when the door is closed. (Lee, 2019).

Analysis of thermal comfort in high school buildings in tropical areas. This study shows that in a tropical Indonesian city, secondary school students are able to adapt with respect to the thermal environment, which is outside the comfort zone determined by international and national standards (Hamzah *et al.*, 2018)

Research related to thermal comfort and the environment in traditional architecture (Ibrahim and Hassan, 2023), and research examining the relationship between public space and thermal comfort (Asadi Eskandar *et al.*, 2022)

Research Methods

This research employs a quantitative method for measuring the thermal environment. Data collection was divided into two.

1. Collecting existing data (initial office space data) measurement date 4 – 8 September 2023
2. Closing room gaps using Styrofoam measurement date 11 - 15 September 2023.

Predicted Percentage of Dissatisfied (PPD), Operative Temperature (Top), and PMV (Predicted Mean Vote) are measured using the findings of environmental parameter measurements. The two conditions are compared with the computation's outcomes namely the initial existing condition and the condition when the room gap is closed tightly. According to Feriadi and Wong (2004), measurements were taken one meter above the ground. They were carried out over 5 working days in the office space on the 3rd floor of the Barru Regent's Tower Building. Thermal environmental data was collected from 08.00 – 16.00 for 5 days in initial conditions and 5 days after the gap is closed tightly in sunny weather.

Research Instruments

Several objective research instruments for measuring the thermal environment were used: 4 Hobo tools, namely Hobo Temp/RH Logger (UX100-011) to measure room temperature profiles and humidity, 1 Hobo Temp/RH/ Light / External tool (U12-012) with additional Hot Wire Anemometer (ESV106) to measure wind speed and 1 WBGT Meter heat Index 87786 tool for measuring globe temperature. The tool specifications can be seen in the Table 1.

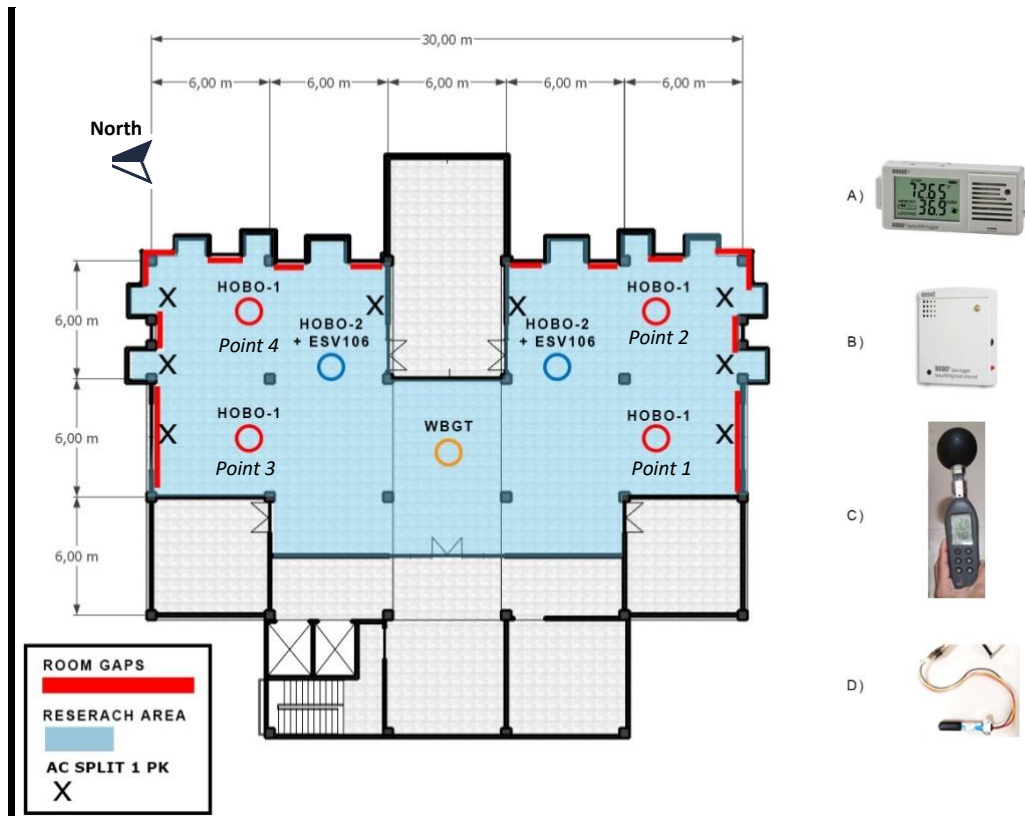


Fig. 1: Mapping of data collection points (Left) and data collection instruments (Right): a) Hobo-1, Hobo Temp / RH Logger b) Hobo-2, Hobo Temp/ RH / Light/ External, c) WBGT Meter, d) Hot Wire Anemometer (ESV106).
Source: Shapardi, 2023

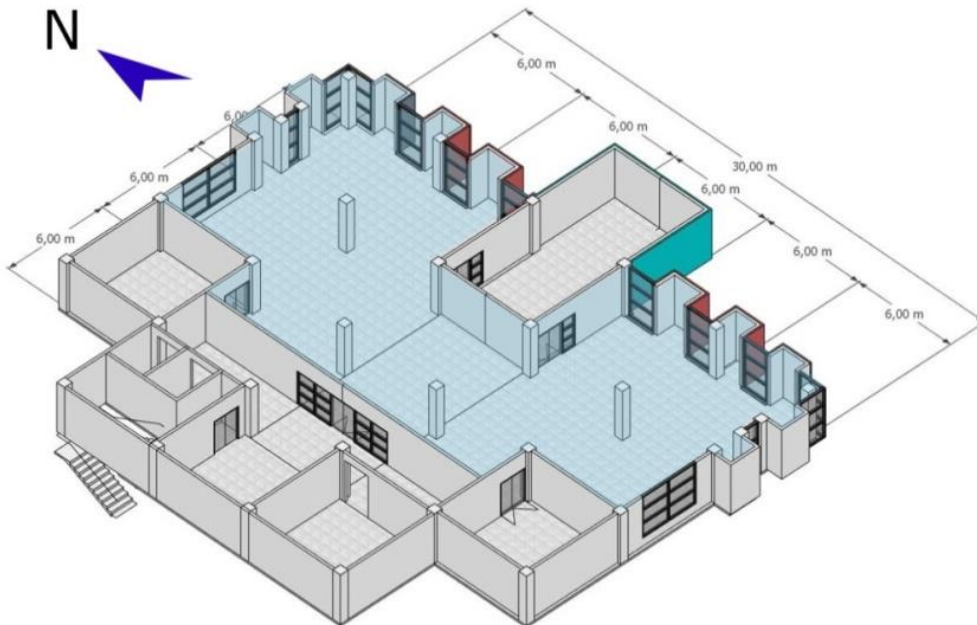


Fig. 2: Office room 3D isometry
Source: Shapardi, 2023

Table 1: Specifications of the research instruments used.

Source: Authors, 2023

No	Instrument Name	Range	Accuracy	Resolution
1	Hobo Temp / RH Logger (UX100-011) - Air temperature profile - Humidity	Temperature range: -20°C to +70°C Humidity range: 5% RH ~ 95% RH	Accuracy: ±0,21°C Accuracy: ±2,5 %	Resolution 0,024°C Resolution 0,05%
2	Hobo Temp/ RH / Light/ External (U12-012) - Air temperature profile - Humidity	Temperature range: -20°C to +70°C Humidity range: 5% RH ~ 95% RH	Accuracy: ±0,21°C Accuracy: ±2,5 %	Resolution 0,024°C Resolution 0,05%
3	Hot Wire Anemometer (ESV106) - Airflow speed	Air Velocity range: 0,01 – 20 m/s	Not Available	Resolution 0,01 m/s
4	WBGT Meter Heat Index 87786 - Globe Temperature	Globe Temp range: 0°C to +80°C	Accuracy: ±1°C (15-40 °C)	Resolution 0,1°C

The respondents' degree of thermal comfort was ascertained by a subjective measuring survey. The questionnaire used for the survey was modified from one created by Wong and Khoo, (2003) and Hamzah *et al.* (2016).

Table 2: Clo value insulation

Source: Al-Ajmi, 2008

Insulation	Clo
Walking shorts, short-sleeve shirt	0,36
Typical summer indoor clothing	0,50
Knee-length, skirt, short-sleeve, shirt, sandals, underwear	0,54
Trousers, Short sleeve shirt, socks, shoes, underwear	0,57
Trousers, Long-sleeve shirt	0,61
Knee-length skirt, long-sleeve shirt, full slip	0,67
Sweat pants, long-sleeve, sweatshirt	0,74
Jacket, trousers, long-sleeve shirt	0,96
Typical winter indoor clothing	1,00

The insulation value of clothing is adopted from Al-ajmi *et al.* (2008) and this value is obtained from the ASHRAE55-2020 standard (ASHRAE Standard, 2020). The value of clothing for 35 employee respondents is that they wear civil servant uniforms, namely clothing with long trousers or long skirts and long-sleeved uniforms for women and short sleeves for men with a value of 0.74 clo. Reading and sitting are the most common activities when collecting measurements and conducting the surveys. This type of activity has a metabolic rate of 1.0 according to the ASHRAE standard.



Fig. 3: Situation and thermal measurements of the office room.

Source: Author's documentation, 2023

Results

Analysis of thermal performance in the office room.

After measuring 4 points where the room AC setting was kept at 16°C, the point with the highest temperature was point 4. which was in the North-East area and point 3 was in the North area. The graphic data results also show that point 3 and point 4 have a slightly higher temperature than the points 1 and 2. Point 2 is in the East-South area and point 1 is in the South area. At 08.00 AM, the sun shines directly on the Eastern and Northern areas, causing an increase in temperature at point 3 and point 4. The positions of the points can be seen in the Figure 1.

Table 3: Results of measuring the room's thermal environment at each point existing condition.

Source: Shapardi, 2023

Point	Variable & Time	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
1	Temp - Avg °C	27,48	27,41	27,37	27,55	27,69	27,68	27,66	27,65	27,64
2	Temp - Avg °C	27,56	27,56	27,42	27,36	27,39	27,35	27,31	27,34	27,41
3	Temp - Avg °C	27,69	27,49	27,86	28,14	28,19	28,16	27,99	28,06	27,97
4	Temp - Avg °C	28,14	28,19	28,40	28,56	28,59	28,51	28,35	28,36	28,34

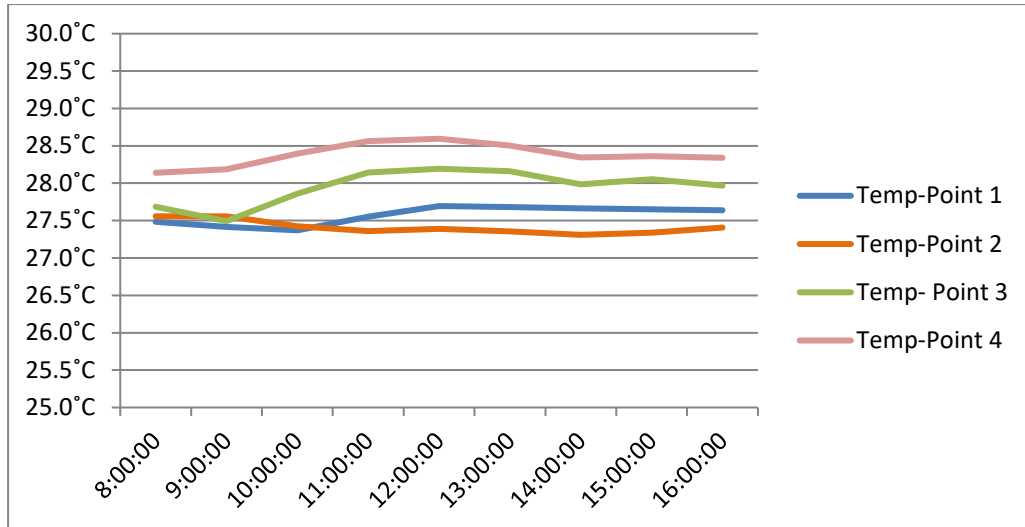


Fig. 4: Graph of air temperature measurement results at each point of existing condition.

Source: Shapardi, 2023

Data collection was carried out on September 4-8 when the sun's path was along the equator slightly to the North. The office space sample is in the Barru district, where the area is approximately ± 550 km to the South of the equator. Thus, the office space areas that have a direct impact on heat transmission are the Eastern and Northern areas. The glass openings in the office space are in the North, South, and East areas which interact directly with the outside environment. Room heat transfer comes from sunlight penetrating the glass, heat penetrating the walls, and heat from inside the room (people and electronic equipment).

If the 2 measurement points in the Eastern area (points 2 and 4) are Compared, Point 4 has a higher temperature value than the point 2. The measurement data from the point 2 is most likely influenced by the electronic equipment or cupboards that block the glass openings in the South-East area. Thus, the measurement results have lower temperature values than the point 4 which is both in the East area. Where the point 4 exists, there are no obstacles/furniture at all. Thus, the heat of the sun directly enters the room.

Analysis of Thermal Performance after the Gap is Closed.

Data collection was carried out after closing the room gaps in the floor area and ceiling or ceiling gaps with cork or styrofoam along the side of the office room. Thickness of the styrofoam is 2 cm.



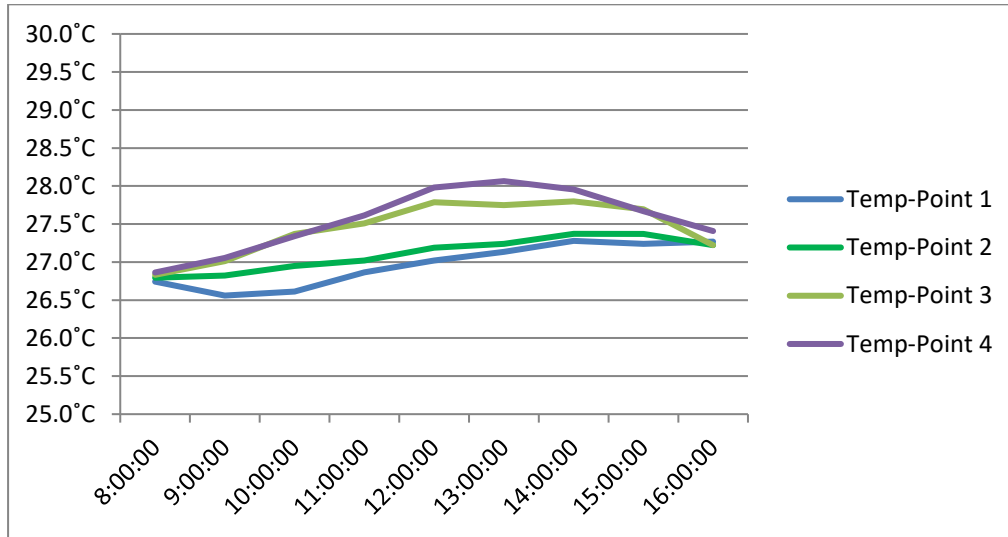
Fig. 5: the office room situation by closing room gaps using cork styrofoam.

Source: Author's documentation, 2023

Table 4: Results of measuring the room's air temperature at each point after the gap is closed.

Source: Shapardi, 2023

Point	Variable & Time	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
1	Temp - Avg °C	26,74	26,56	26,61	26,86	27,02	27,13	27,28	27,24	27,27
2	Temp - Avg °C	26,79	26,82	26,95	27,02	27,19	27,24	27,37	27,37	27,22
3	Temp - Avg °C	26,83	27,01	27,37	27,51	27,78	27,75	27,80	27,70	27,22
4	Temp - Avg °C	26,86	27,06	27,34	27,61	27,98	28,06	27,96	27,67	27,41

**Fig. 6:** Graph of air temperature measurement results at each point after the gap is closed.

Source: Shapardi, 2023

After the room gap was closed using styrofoam, the room temperature decreased by around 0.5 °C. The condition after the room gap is closed makes the room better than the previous condition. The identification results also show that the placement of the AC is very close to the gap in the room. Thus it is very likely that cold air leaks into other rooms and this is the reason why the distribution of cold air is less than optimal. This factor can be an influence on the user's thermal discomfort.

Table 5: T-test paired samples to test from IBM SPSS 26.

Source: Shapardi, 2023

		Paired Samples Test								
		Paired Differences				95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper				
Pair 1	Temperature existing - Temperature after the gap is closed	,56167	,31250	,05208	,45593	,66740	10,784	35	,000	

T-test results were obtained to identify a significant relationship between existing conditions and conditions after the gap in the room is closed. The results of the paired sample test show that the significance level of this value is 0.00. If the significance value is below 0.05, it means that the conditions before and after the room gap was closed had a significant temperature change.

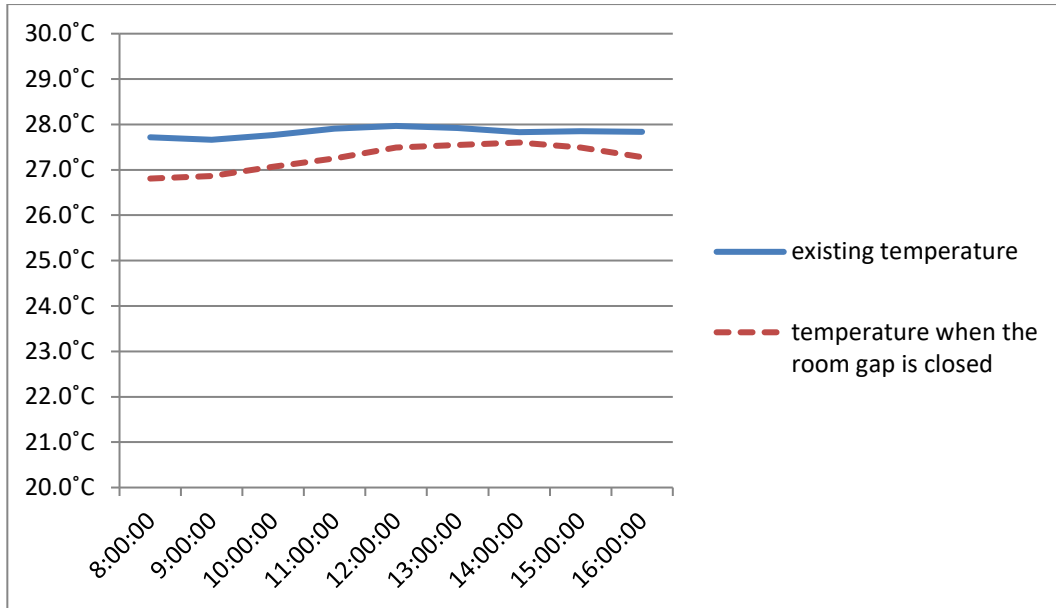


Fig. 7: Graph of average air temperature results before and after the gap is closed.
Source: Shapardi, 2023

After covering all the gaps in the room using styrofoam on the floor and ceiling areas, the room temperature decreases by approximately 0,5°C. This is most likely due to the distribution of cold air which is more optimal compared to the initial condition of the existing room with a gap which was less than optimal.

Perceptions of the Thermal Environment Before and After the Room Gap is Closed.

perceptions in both conditions were compared to ascertain how much impact changes in the thermal environment have had on the user's perceptions. A comparison of these perceptions can be seen in the Figures 8,9 and 10.

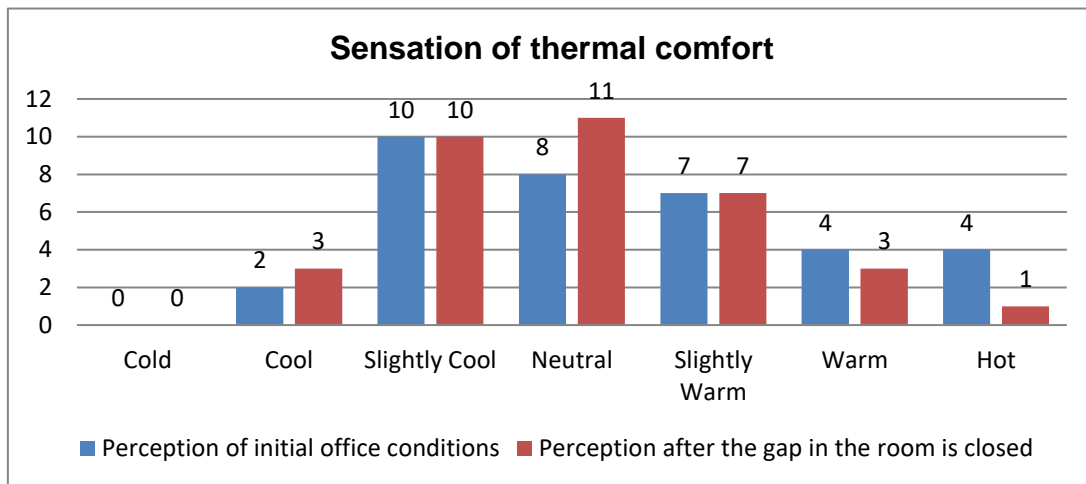


Fig. 8: The sensation of thermal comfort of the initial condition room and engineering space (after the gaps are closed).
Source: Shapardi, 2023

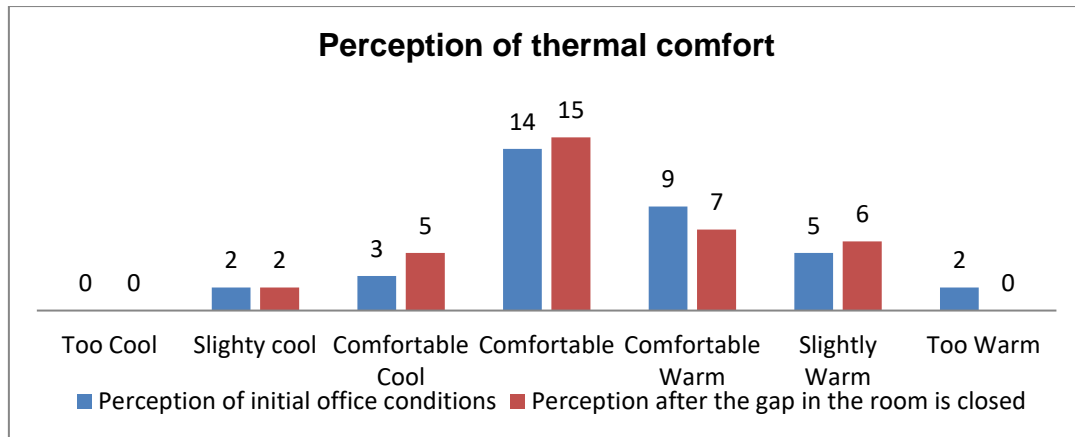


Fig. 9: Perception of initial condition room thermal comfort and after gaps are closed.
Source: Shapardi, 2023

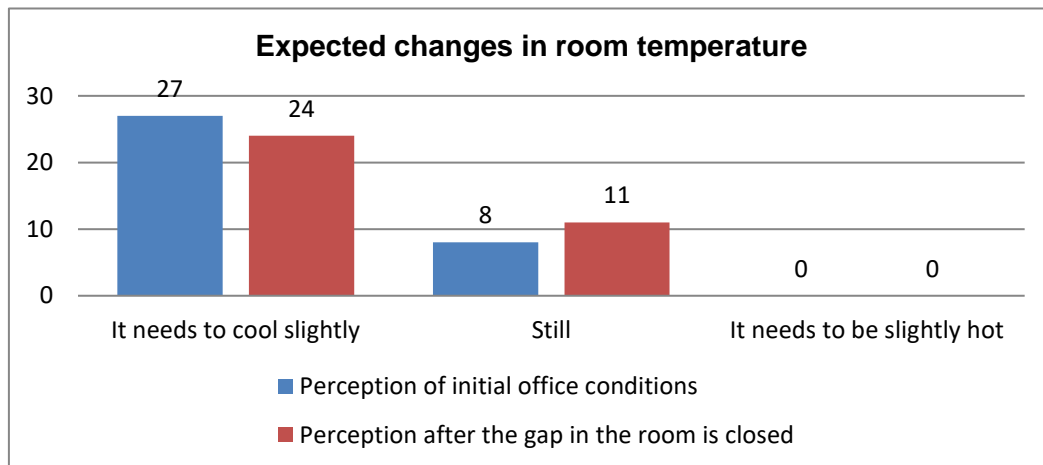


Fig. 10: Expected changes in initial condition room temperature and after gaps is closed.
Source: Shapardi, 2023

Based on the figure 10, it can be said that thermal environmental measurements do not yet meet ASHRAE-55 comfort standards. However, questionnaire results show that during the initial condition of the room, the users felt comfortable at 74%. However, after the room gap was closed, the users felt comfortable at 77%. This study is in line with research conducted by Baharudin (Hamzah *et al.*, 2018) that in tropical regions in Indonesia, employees can adapt to thermal environments beyond thermal comfort standards. On the other hand, the users want the room temperature to be less. Thus, this is an indication of the user's expectation that the room temperature needs to be slightly lower. Indeed, the users can adapt to uncomfortable thermal environments. This is aimed at most employees who have been in the office for more than 2 years.

Thermal Environment Before and After the Room Gap is Closed.

Data analysis was carried out based on data on thermal environmental conditions that had been obtained (T_a , RH, and V) and calculated (MRT and T_{op}), which had been collected. They were then compared with the ASHRAE 55 standard (ASHRAE Standard, 2020), using the PMV method through the CBE Thermal Comfort Tool (University of California Berkeley (USA), 2020). Next, to find out the Mean Radiant Temperature (MRT) value, a calculation is carried out using data from measurements of Globe Temperature (T_g), and Air Flow Speed (V), as follows (*Mean radiant temperature*, 2020):

$$MRT = Tg + 2.42 \times V \times (Tg - Ta) \dots\dots\dots(1)$$

Where; MRT is Mean Radiant Temperature [°C], Tg is globe temperature [°C], V is air flow velocity [m/s], and Ta is air temperature [°C].

Operative temperature (Top) is the average temperature of the room's dry air and radiation temperature. Mathematically, the calculation of operating temperature (Top) can be shown as follows (ISO 7726, 1998):

$$Top = \{MRT + (Ta \times \sqrt{10V})\} / 1 + \sqrt{10V} \dots\dots\dots(2)$$

Where; Top is the operating temperature [°C], MRT is the Mean Radiant Temperature [°C], Ta is the air temperature [°C], and V is the air flow velocity [m/s].

Next, the measurement results from 4 data points (Hobo-1), 1 data point (hobo-2) and 1 data point from the WBGT meter data collection were combined and then averaged over 5 days (4 - 8 September 2023) and over 5 days after the gap is closed (11-15 September 2023) then converted in the time variable from 08.00 to 16.00 as follows:

Table 6: The results of measuring the thermal environment of the existing data
Source: Shapardi, 2023

Variable & Time	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
Temp - Avg °C	27,72	27,66	27,76	27,91	27,97	27,92	27,83	27,85	27,84
RH - Avg %	52,77	50,72	51,40	53,66	55,92	56,75	57,28	57,98	57,18
Air Velocity (m/s)	0,06	0,09	0,10	0,11	0,11	0,06	0,06	0,06	0,06
Temp Globe - Avg °C	27,66	27,74	27,94	28,10	28,16	28,12	28,10	28,02	27,82
MRT °C	27,65	27,76	27,98	28,15	28,21	28,15	28,14	28,04	27,82
Temp - Operative °C	27,66	27,74	27,93	28,09	28,15	28,11	28,09	28,01	27,82
PMV	1,04	0,99	1,05	1,09	1,14	1,23	1,22	1,21	1,13
PPD	28%	26%	28%	30%	32%	37%	36%	36%	32%
Sensation	SW	SW	SW	SW	SW	SW	SW	SW	SW

Table 7: The results of measuring the thermal environment of the room after the room gap is closed.
Source: Shapardi, 2023

Variable & Time	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
Temp - Avg °C	26,81	26,86	27,07	27,25	27,49	27,55	27,60	27,49	27,28
RH - Avg %	78,71	78,13	78,92	79,31	78,85	78,63	77,86	77,21	74,92
Air Velocity (m/s)	0,18	0,14	0,12	0,13	0,14	0,17	0,16	0,17	0,16
Temp Globe - Avg °C	26,78	27,00	27,24	27,48	27,74	27,78	27,70	27,54	27,40
MRT °C	26,77	27,05	27,29	27,55	27,83	27,87	27,74	27,56	27,45
Temp - Operative °C	26,78	26,99	27,23	27,46	27,72	27,76	27,69	27,54	27,39
PMV	0,76	0,98	1,03	1,10	1,23	1,13	1,13	1,04	1,00
PPD	17%	25%	28%	30%	37%	32%	32%	28%	26%
Sensation	SW	SW	SW	SW	SW	SW	SW	SW	SW

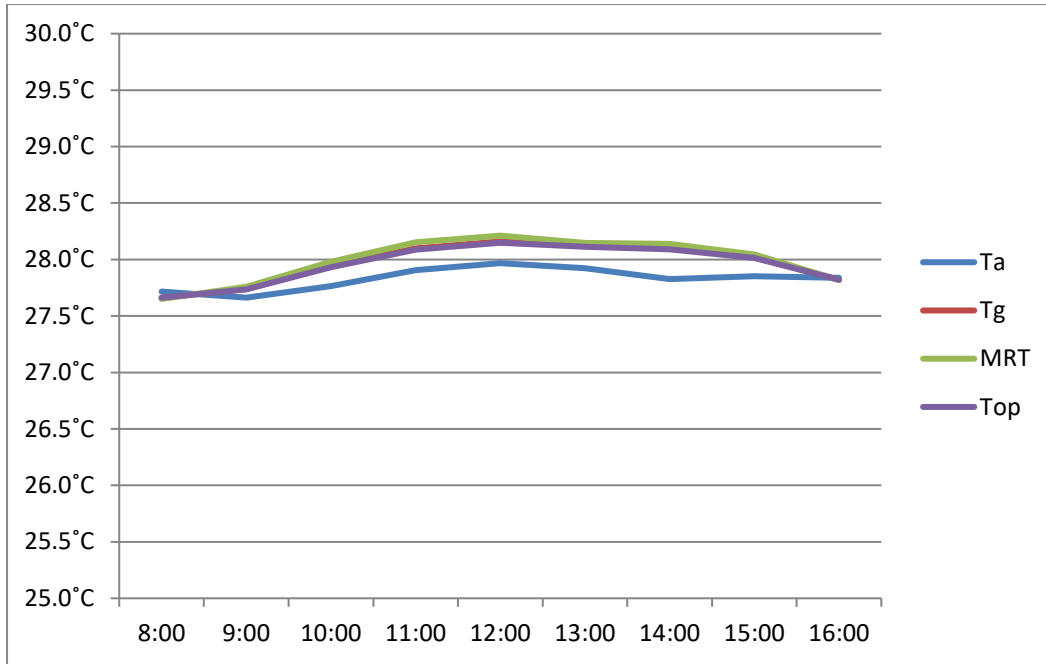


Fig. 11: Profile of air temperature (Ta) [°C], MRT [°C], operative temperature (Top) [°C], and globe temperature (Tg) [°C], humidity [%] existing data.

Source: Shapardi, 2023

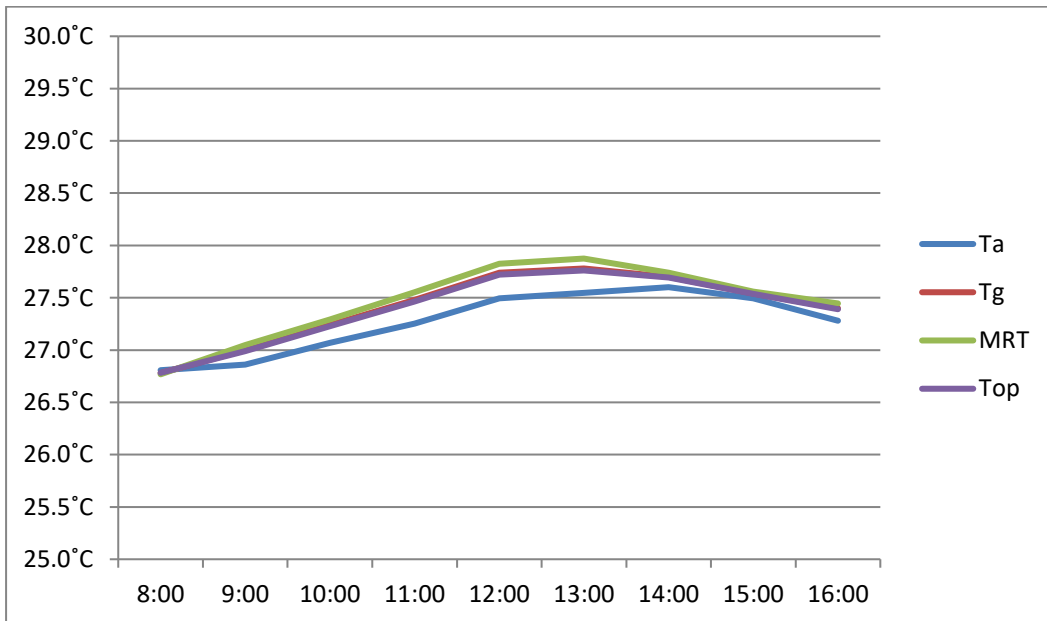


Fig. 12: Profile of air temperature (Ta) [°C], MRT [°C], operative temperature (Top) [°C], and globe temperature (Tg) [°C], humidity [%] data after the gap is closed.

Source: Shapardi, 2023

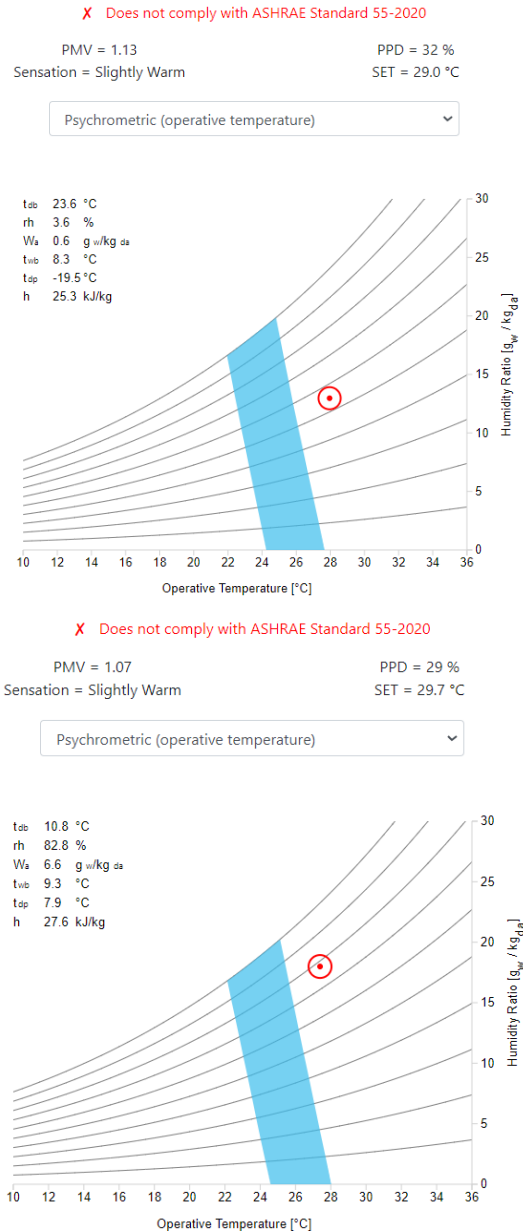


Fig.13: ASHRAE55-2020 standard PMV and PPD psychmetrics of office room before (left) and (right) after the gap is closed.

Source: Shapardi, 2023

The psychrometric results or the images above show that the office space after the gap is closed based on thermal environment calculations does not meet the ASHRAE-55 standards. The average PMV after the gap is closed from morning to evening is +1.07 whereas the thermal comfort sensation was slightly warm (SW) and the PPD value was 29%. The PMV value before was +1.13, where slightly warm (SW) sensation and the PPD value was 32%.

PMV and PPD Thermal environment before and after the room gap is closed.

The following is a graph of PMV (Predicted Mean Vote) and PPD (Percentage Predicted Dissatisfied) values on existing data and office space engineering data (closing room gaps).

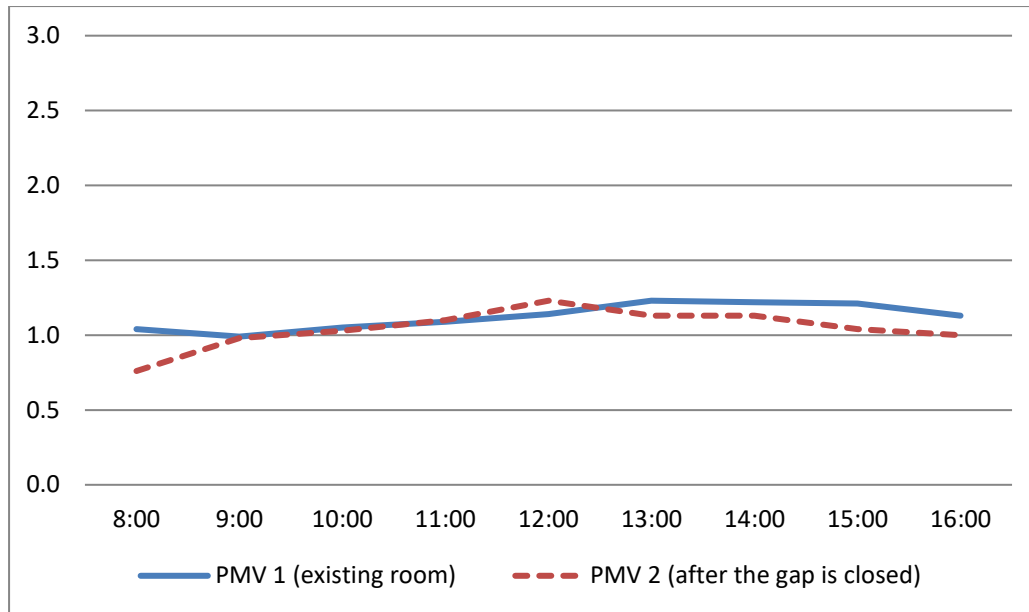


Fig. 14: PMV graph of initial existing room and engineering space (after the gap is closed).
Source: Shapardi, 2023

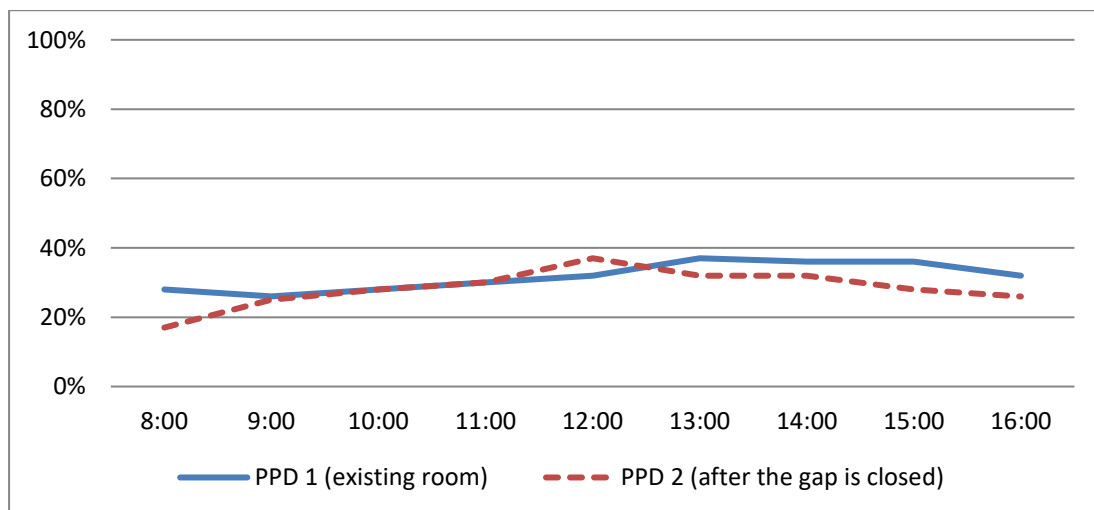


Fig. 15: PPD graph of the initial existing room and engineering space (after the gap is closed).
Source: Shapardi, 2023

The change in PMV and PPD in the room is most likely caused by the maximum distribution of cold air throughout the room as a result of closing all the gaps in the room. After closing the gap, it succeeded in reducing the room temperature by approximately 0.5 - 1 °C. Thus, it had an impact on changes in humidity and the speed of cold air in the office room. The change in these variables makes the thermal environment more comfortable than the previous room conditions.

Conclusions

Based on the results of the analysis and discussion of the thermal comfort of the office space in the Barru Regent Tower building, it can be concluded that the results of the thermal environment analysis shows that the office room did not comply with the ASHRAE 55 thermal comfort standards. However, in the previous conditions with the thermal comfort perceptions at 74%, it was felt comfortable. After the room gap was closed, the increased temperature at 77% was also felt comfortable. The change in PMV and PPD in the room is most likely caused

by the maximum distribution of cold air throughout the room as a result of closing all the gaps in the room. The room after the gap is closed that has been carried out has succeeded in reducing the room temperature by approximately $\pm 0,5$ °C. When the room temperature decreases as a result of the closed room gap in the HVAC system, it has an impact on the thermal comfort value.

Based on the calculation results, the PMV in the exiting condition is +1.13: where the sensation of thermal comfort is slightly warm (a bit hot) and the PPD value is 32%. The average operating temperature shows a temperature of 27.9 °C, humidity 54.8% and wind speed 0.07 m/s. Meanwhile, the PMV after the gap was closed was +1.07, where the thermal comfort sensation was slightly warm and the PPD value was 29%. The average operating temperature shows a temperature of 27.39 °C, humidity 78.8% and wind speed 0.15 m/s. The clo value is 0.74 and the activity is 1 met.

This research has several limitations, especially in the availability of research tools. Future research will need to use more research instruments to collect data about the thermal environment.

Acknowledgments

We would like to thank to Dr. Rosady Mulyadi and Prof. Baharuddin Hamzah at the Laboratory of Building Science and Technology, the Department of Architecture, Hasanuddin University, especially to Mr. John, and Mr. Hafid Malik, who were involved in the data collections.

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