The Effect of Height and Building Orientation on Thermal Comfort Sensation using PMV and Anova

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Abstract. Unsuitable thermal conditions affect unproductive indoor activities, and cause hyperthermia or hypothermia, so that the level thermal becomes significant. The research aimed to compare the effect of building's orientation and height on the sensation of thermal comfort at Building C FTSP Universitas Trisakti. It was the effort to identify the level of comfortable sensation naturally in the room with reading, writing, standing and typing activities, and the users generally wear trousers, short-sleeve shirt, socks, shoes, and underwear. The method was descriptive quantitative assisted with PMV (Predictive Mean Vote) analysis and one-way ANOVA test, and digital multi-meters and heat stress meter were as a data collection tool. The results showed that with an average tipping window opening of 47 cm: 1) the average room temperature at 6th, 7th and 9th floors exceeded 6,6°C-7,3°C from the standard; the average of wind velocity was below and exceeds (0.2m/s and 5.06m/s); the average room's humidity (48%-85%) was in the standard range; 2) the average thermal sensation was in the warm-hot range, but PMV index values in the west and south was neutral-slightly warm;3) the orientation and height of the building floor had no significant effect on the comfortable sensation.

Keywords: building orientation, building floor height, thermal comfort sensation

1. Introduction

Thermal comfort can affect health, welfare, and work productivity [1]. Tarantini et al [2] found that a comfortable room increases operational work, reduces production defects and worker health costs. Meanwhile, Hughes et al [3] proved a relationship between low indoor temperature and the health of elderly. Based on these considerations, research related to thermal comfort is considered essential to improve the comfort quality of the educational building of the Faculty of Civil Engineering and Planning, Universitas Trisakti.The building is intensively used by around 900-1100 students/academic year.

The orientation and height of the building influence the sensation of indoor thermal comfort [4], Kakon et al [5]. Another influencing factor is the use of wall materials, facades, and furniture [6]; the level of outdoor material's albedo, radiated power, and heat reflection [7]; walls' type and material, ventilation system, roof, and bottom structure; geographic position, opening's dimension [8] [9]. The openings impact outdoor noise levels and the comfort level of indoor audio [10].

This study aims to compare the sensation of thermal comfort on the sixth, seventh, and ninth floors in Building C, Faculty of Civil Engineering and Planning, Universitas Trisakti, based on differences in building mass orientation and floor height. Albatayneh et al [11] stated that orientation impacts the overall thermal performance of the building. The sun's north-northeast and west-southwest orientations have the potential to increase the indoor temperature in the case of Binus University located at coordinates E106°38'47.04", S6°13'27.84" [12]. Buildings with an orientation facing southeast have a better level of thermal comfort than other orientations[4].

The density and height of the building affect the potential temperature, the average radiant temperature, and the PMV distribution. So that the vegetation on the ground floor and roof has a relatively high cooling effect [13]. Air molecules with warmer temperatures decrease in density (the stretched distance between molecules) so that their density (mass per unit volume) becomes relatively lighter, and the air will float to the top [14]. Kakon et al [5], using the numerical simulation tool 3d ENVI-met, proved that temperatures at an altitude of 8-9 floors are more comfortable than those at the height of 4-5 floors in the case of Dhaka, Bangladesh. According to Diem [15], the steeper the angle of fall of sunlight, the greater the heat energy received. Likewise, an area with a larger area and higher intensity of sun exposure means more heat it receives.

In this study, the effect of building orientation and height on the sensation of thermal comfort in rooms on floors 6,7 and 9 will be compared through PMV analysis and the One Way ANOVA test. The CBE Thermal Comfort Tool is an analytical tool to help calculate, visualize, and predict thermal comfort sensation according to ASHRAE Standards 55, ISO 7730:2005, and EN 16798–1:2019. The CBE Thermal Comfort Tool combines major thermal comfort models, including Predicted Mean Vote (PMV). The thermal comfort sensation through PMV can be predicted, assuming that humans have an average comfort level in a certain range. Six factors that determine thermal comfort sensation are air temperature, radiation temperature, metabolic rate, clothing insulation, air velocity, and humidity [16]. PMV is an index that indicates the sensation of cold (cold) to hot felt by humans on a scale of +3 to -3. PMV can be used as a tool to estimate the sensation of thermal comfort in a particular room by using the ASHRAE-55 standard thermal comfort component index [17]. The criteria for thermal comfort zones according to ASHRAE-55, 2010, include effective temperature (23°C–27°C), air humidity (30% - 90%), wind speed (0.2 m/s – 0.8 m/s), PMV ($-0.5 < \text{PMV} < +0.5$) and PPD (< 10). Research is limited to natural lighting by ignoring heat radiation generated by artificial light and air conditioning. Thermal sensation solely relies on the standards set by ASHRAE-55, and the condition of the room is empty.

2. Methods

The research approach was descriptive statistics using PMV analysis displayed on psychometric charts on the CBE Thermal Comfort Tool, and a one-way ANOVA test was used to compare the result of PMV analysis. Research population was the point in all rooms on floors 6,7, and 9, Building C, Faculty of Civil Engineering and Planning, Universitas Trisakti. While the sample was the measurement points representing the area near the inlet, center area of the room, and area near the outlet. Research variables included

- independent variables (orientation and height of the building floor);
- dependent variables (value of Predicted Mean Vote analysis); and
- moderate variables (temperature, wind speed, humidity, metabolic rate, and clothing insulation).

The research instruments were four 3 in 1 digital anemometers and a heat stress meter. Measurements were set at 12 points with three different points in each room positioned according to the four cardinal directions – north, west, east, and south (see Figure 1). Outdoor points were installed at the height of ± 60cm above the floor level and ± 1 m for indoor points. The measurement time was at 11:30 – 14:30, and when measuring, the windows were opened as wide as ± 47cm and did not use artificial ventilation but natural ventilation.

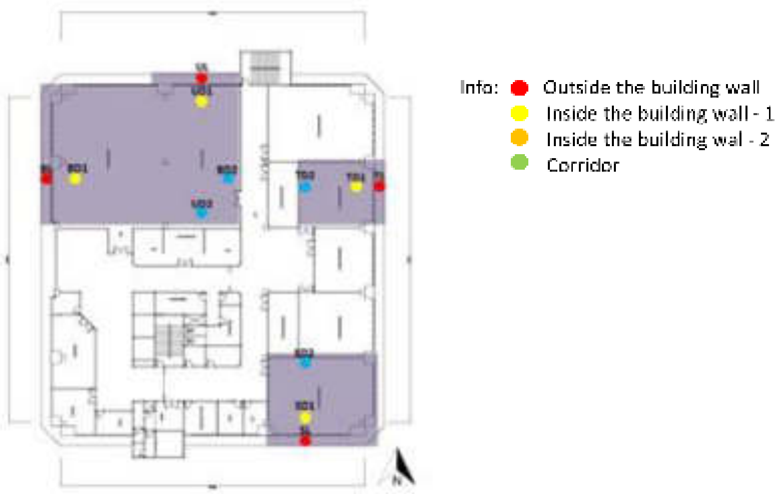

Figure 1. Location of measurement points on the 6th floor (also applies to 7th, and 9th floors)
(Source: Alfiah, 2021)

3. Results

3.1 PMV analysis results

The measurement results on the 6th floor showed that the highest (35.2°C) and lowest (29.6°C) temperatures were rooms oriented to the west. The room with east orientation had the highest humidity (73.5%), while the lowest (56.7%) was in the west and east-oriented rooms. The highest wind velocity was in the rooms oriented to the east of 4.73 m/s.

Figure 2. Thermal sensation zoning on 6th, 7th, and 9th floors

On the 7th floor, the room with the highest temperature (38.5°C) had the north orientation, while the lowest temperature (29.1°C) was the room oriented towards the east. The highest (76.5%) and the lowest (53.5%) air humidity occurred in a room oriented to the north, while the highest wind velocity (5.06 m/s) was in the room oriented to the east. On the 9th floor, the highest room temperature (36.7°C) was in the east and west, while the lowest (28.6°C) was in the west. The highest room air humidity (85%) was in the west orientation, the lowest (48%) was in the east and north, and the highest inlet wind velocity (4.93 m/s) was in the west and north rooms.

Based on the PMV value analysis, the room on the 6th floor with a south orientation has a PMV value of 3.04 (hot) and a western orientation of 0.39 (neutral). The highest PMV value on the 7th floor is in a room with a north orientation of 4.23 (hot) and the lowest -0.01 (neutral) in an east orientation. While on the 9th floor, the highest PMV value is in a room with an east orientation (4.03, hot), and the lowest value is a room with a west orientation (-0.20, neutral). Of the three floors, the higher the floor height, the average thermal sensation felt is warm to hot, and the lower the floor height, the thermal sensation felt is neutral to slightly warm (see figure 2).

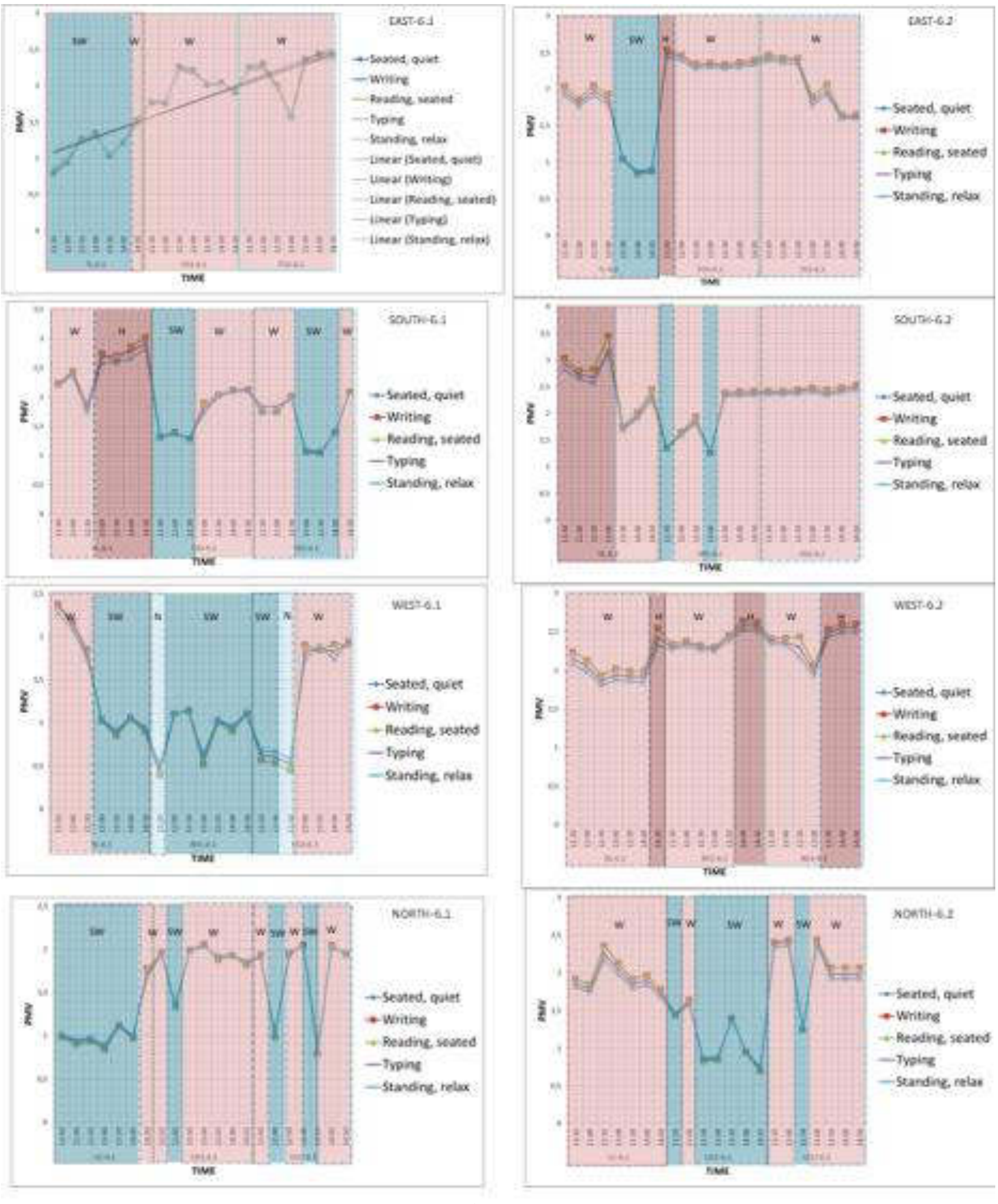

Figure 2. Thermal sensation zoning on 6th floor (east, south, west, north) - as an example of research results (Source: Alfiah, 2021)

3.2 One way ANOVA test results

According to the validity test criteria, if the Sig value is less than 0.05, there is a significant difference. In the ANOVA test results, the sig value for building floor height obtained was 0.108 > 0.05 and for building orientation was 0.827 > 0.05, indicating no significant difference in PMV values between the rooms on the three floors studied. So it can be concluded that the floor height and building orientation had no significant effect on the PMV value.

Table 1. One Way ANOVA test result based on differences in Building Floor Height

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,291	2	,146	2,695	,108
Within Groups	,648	12	,054		
Total	,939	14			

Source: Alfiah,2021

Table 2. One Way ANOVA test based on differences in building orientation

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,081	3	,027	,296	,827
Within Groups	,726	8	,091		
Total	,806	11			

Source: Alfiah,2021

4. Conclusion

The average room temperature on the sixth, seventh and ninth floors (30.3°C-33.6°C) exceeds 6.6°C - 7.3°C of the thermal comfort standard (23°C -27°C), the lower threshold of the average wind speed is 0.08 m/s below the standard (0.2 m/s), but the upper threshold exceeds the standard (0.8 m/s) which is 5.06 m/s, humidity the room average of 48%-85% is in the standard range of 30%-90% humidity. The higher the building floor, the predicted average thermal sensation is in the warm-hot range, but the PMV index shows a dominant neutral-slightly warm in the west and south. Through the one-way ANOVA test, the orientation and height of the building floor in the case studied did not significantly affect the comfortable sensation calculated through PMV analysis. Thus, indoor thermal comfort cannot rely entirely on natural thermal conditions, so additional tools are needed to increase the movement of wind speed in the room.

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