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Analysis of Natural Light Distribution in the Building

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Abstract. Global warming affect the condition of the sky and also affect the temperature on the earth surface. Changes in sky conditions affect the distribution of light into the building. Sunlight is a natural light source in the morning, afternoon and evening. Utilization of natural lighting into buildings, can reduce energy use as an artificial lighting source. Phinisi Tower Building has a unique form of hyperbolic paraboloid, so it can be a guide in designing buildings. This building needs to be analyzed, how the distribution of light into the building, so it can become a guide in buildings design. The purpose of this study is how the influence of position, floor height and window openings on the building envelope to the distribution of natural light. Quantitative research method is to analyze the level of illumination inside and outside the building in the form of tables and graphs. The result of research is illuminance level of daylight depends on the sky condition and it have affect the light distribution into the building. The increased light distribution at the height of the floor. As well as of window opening on the building envelope (top lighting and side lighting) have effect on the level of illuminance in the building. The distribution of natural light will increase during the day, if the sky condition does not change in one day.

Keywords: light distribution, level illuminance, natural light

1. Introduction

The concept of energy-efficient architecture is to optimize the lighting system by considering the integration between natural lighting (daylight) and artificial (lights). The use of energy in buildings, can be reduced if it can maximize the distribution of natural light, but by considering the negative effects include: thermal, glare and brightness.

Phinisi Tower of Makassar State University is the Center Academic Building. This building implements the Hyperbolic Paraboloid Facade which is a futuristic application of scientific and technological sophistication. This building is a 3-storey podium and 12-story tower. This form of building is a screen metaphor of phinisi boat like picture 1 below.



Figure 1. Phinisi Tower of Makassar State University

The building lighting design is designed according to the illumination standard recommended by SNI 03-6575-2001. level of Illuminance at work space of 500 lux, meeting room of 500 lux and hallway as connecting space of 150 lux. The sky conditions consist of clear sky, intermediate sky and overcast sky. Light distribution in buildings, can be influenced by sky conditions, position, wide and shape window (SNI 03-2396-2001).

Based on this recommendation, the designer can determine amount of armatures required on space, according to the activities in the space. According Nurul (2012) that although it does not meet these standards, can be running well, the activities of space. Based on this, it is necessary to study the distribution of natural light on selected objects.

2. Literature Study

The Phinisi tower building uses a diagonal and horizontal facade on the building's envelope, so there is no glare and brightness in space. This building is one example of building in designing high building. In terms of aesthetics, building facade is a positive value but needs to be considered the visual comfort of space users so that work productivity can increased (Jamala N, 2017). Nakamura et al. (1985) have classified into three groups sky condition i.e. overcast, clear and intermediate sky, trying to define the luminance distribution of the intermediate sky. Local Government Rules No. 38 (2012) explained that the building envelope is a building element that surrounds the building. They are transparent or not transparent walls or the roof. Karlen & James (2006) states that the skylight from the roof operates as lighting lamps that emit light directly with the direction of light down the hole while the light from the side using vertical openings to take advantage of daylight. The recommendation standar of illuminance levels in the office room are base on recommendation value by CIE (Commision Internationalde l'Elaire) and IES (Illuminating Enginers Society). These recommendations are national and international standards of illuminance levels for design of lighting design (UNEP, 2006)

According to Satwiko (2009), Indonesia is a tropical humid region with high relative humidity characteristics (60% -80%), high radiation (80% per year), and unstable velocity (urbanized between 0-> 30 m / seconds). Tomy et al (2002) stated that the distribution of light lamination in open plan office by using general lighting and suitability of light lamination distribution. Newsham et al (2004) examined quantitative guidance of illuminance, luminance and ratio values in office buildings.

Utilization of natural lighting is closely related to the geographical position of a building because the relative movement of the sun on each coordinate on earth is different. For that needed a solar diagram that can help the observation and estimate the amount of sunlight that enters into a building. (Gunawan, 2011). Within a year there is a change in altitude angles in the sun and the sun's rotation changes the orientation of the building's orientation. In the movement of the sun there are four angle changes that is between March, June, September and December.

Soegijanto (1998) suggested that sky conditions based on the number and type of clouds can

be grouped into: (a) Clear sky is the sky without clouds; (b) Overcast sky is a sky completely covered in white or gray white clouds or partial or complete partial clouds; (c) intermediate sky is a partially clouded sky with a variety of darker clouds and numbers; and (d) Uniform sky is the sky with the same luminance in all positions not dependent on the geographic latitude and the height of the sun.

3. Methodology

Measurements are done for 3 days, 19, 20 and 21 May 2018. The measurements are done in the morning (08.00-09.00), noon (12.00-13.00) and afternoon (16.00-17.00). Measurements begin by measuring the level of illuminance to determine the condition of the sky at the time of measurement.

The measurement results are made in the form of tables and graphs to analyze the distribution of natural light in the hall area of the connecting several room. Selected lobby area is Zone A and B located on the 1st, 2nd and 3rd floors. The orientation of building in zone A1 is east-west, while zone B is *east-west*. The point notation uses code A-B and 1-3, for example A1, A3, B2, C3 and so on, as in Figure 2 below.

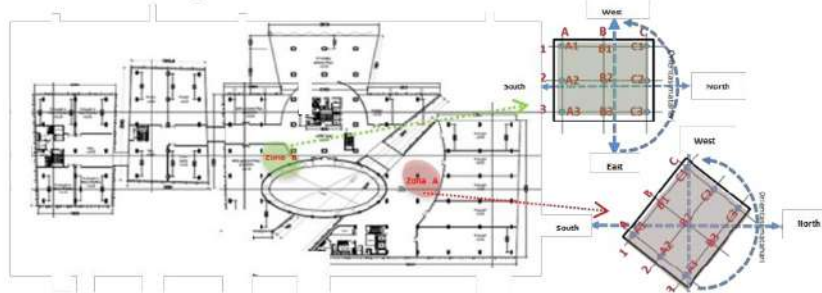


Figure 2. The position of the hall and the placement of the measuring point of the research object (Zones A and B)

4. Results and Discussions

4.1 Analysis of the sky conditions at the time of measurement

Makassar city is located in Latitude $-5,1^{\circ}$ and Longitudinal $119,5^{\circ}$ ($+8,0$). Field measurements were carried out for 3 days in the morning, afternoon and evening. The condition of the sky at the time of measurement of the difference of the sky conditions of planning. The first measurement on 19 May 2018 on outside the building has a clear sky condition of 51,000 lux (morning), 94,200 lux (noon) and 32,100 lux (afternoon). The second and third measurements were conducted on 20 and 21 May 2018 on intermediate sky conditions, as shown in Figure 3 below.

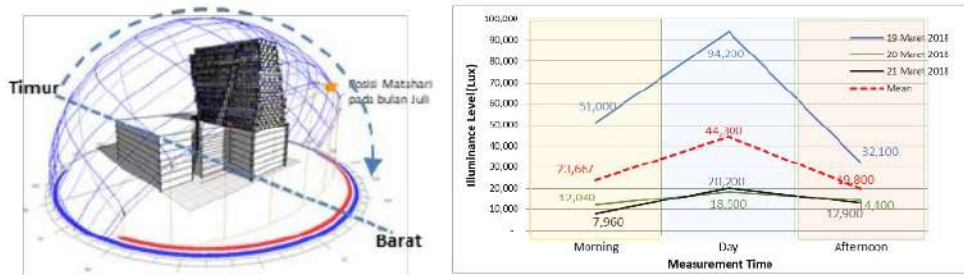


Figure 3. Kondisi langit pada pagi,siang dan sore hari

Figure 3 shows the position of the sun in May and the measurement on graph for 3 days. This grafik shows that the highest illumination rate is 94,200 lux while the lowest is 7960 lux. The average measurement results outside the building is 23,667 lux (morning), 44,300 lux (afternoon) and 19,800 lux (afternoon) .This mean value shows that the highest level of illumination outside the building is during the day The results show that the increase of natural light distribution into the building, will increase if the sky conditions increase.

4.2 Analysis of first measurement results in the morning (Zone A floors 1,2 and 3)



Figure 4. The position Zone A in the Podium Makassar State University

In Phinisi building there are several hall area as interconnecting work space. One of the selected objects is Zone A on the 1st, 2nd and 3rd floors. This area is directly related to the building envelope, but have the different models or positions. Zone A on the 3rd floor, directly related to the sunlight from the top and side of the building, while Zone B is only on the side envelope of the building. The average value of the first measurement results shows the illumination level as in the following table 1.

Table 1. The results of measurement of illuminance level in the morning on floors 1, 2 and 3

	Measurement Point	1	2	3
1 st Floor	A	164	328	690
	B	62	167	137
	C	311	315	280
2 nd Floor	A	267	665	956
	B	142	194	192
	C	186	525	417
3 rd Floor	A	1465	6200	6350
	B	3810	7150	6020
	C	4390	7250	5050

Table shows the illuminance level on the 3rd floor is the highest compared to the 1st and 2nd floors, because on Zone A on the 3rd floor is surrounded by the opening of the building envelope in the side and top lighting. The highest of illuminance level in this area is 7250 lux (C2) and the lowest is 3810 lux (B1). The illuminance level on the 2nd floor is the highest of 690 lux (A3) and the lowest is 62 lux (B1), while on the 3rd floor is the highest 956 lux (A3) and the lowest 142 lux (B1).

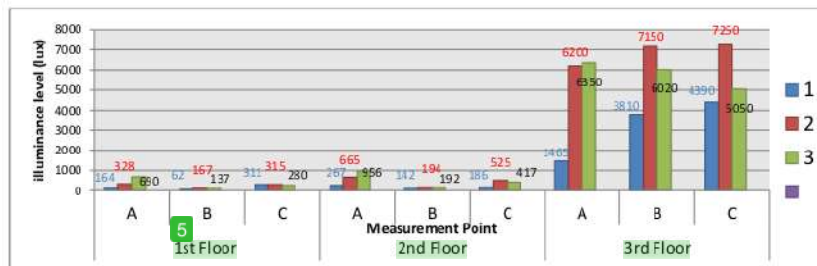


Figure 5. Nilai iluminasi pada titik ukur A1-C3 pada lantai 1,2 dan 3.

Figure 5 shows a graph of the first measurements in the morning on floors 1,2 and 3. This graph shows that the distribution of light is higher, when the openings on the building envelope are wider. The results of the analysis show that the open area effect on the distribution of natural light into the space.

Furthermore, in order to simplify the analysis of illumination values on Zone A of floor 1, 2 and 3, it is calculated the mean value at the point of A, B and C as shown in the following Fig. 6 and 7.

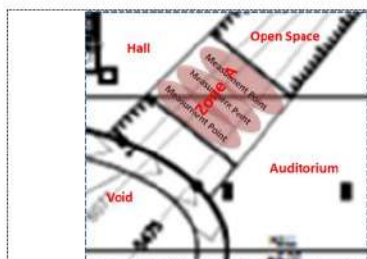


Figure 6. Block of Measurement Point at A1-A3, B1-B3 and C1-C3

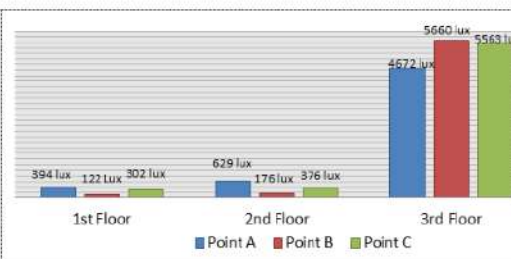


Figure 7. Average value of illuminance level on floors 1,2 and 3 in the morning

The mean values in Fig. 7 show the distribution of light at the points A, B and C on the 3rd floor is very high at 4672 lux (point A), 5563 lux (point B) and 5660 lux (point C). This description shows that the middle area of space has the highest illumination level is at point B. In Zone A floor 3 has very high illumination level, because the light distribution in this Zone has openings of building envelope that is side lighting (right and left) and Top Lighting. On floors 1 and 2 show that the distribution of natural light is lower than that of the 3rd floor Zone, since it only has a building envelope opening on the side lighting (right and left). The results of the analysis show that the area not on the building envelope affects the level of illumination in the building.

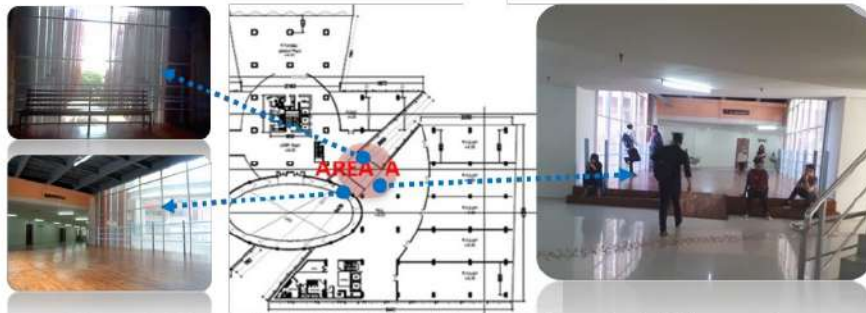


Figure 8. The position side Lighting (right and left) on the building envelope

4.3. Average value analysis for 3 days measurement in the morning

Measurements were made in the morning for 3 days with different sky conditions ie 51,000 (first) lx, 12,040 lx (second) and 7960 (third) with a mean value of 23,667 lux. Measurements made on the 1st, 2nd and 3rd floors are to know how the influence of floor height on natural light distribution. Mean value for 3 times measurement indicate that level of illumination at zone A floor 1 equal to 114-251 lux, floor 2 equal to 198-569 lux and floor 3 equal to 298 5-k5256 lux. Graph of measured average value in the morning can be seen in the following picture.

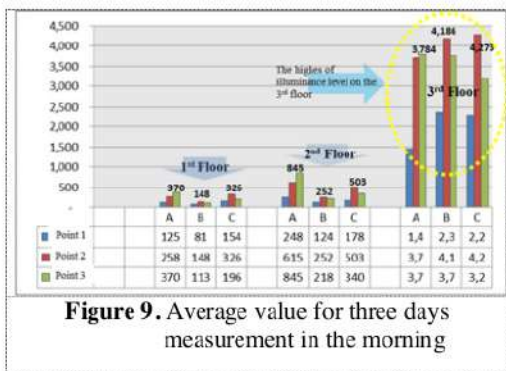


Figure 9. Average value for three days measurement in the morning

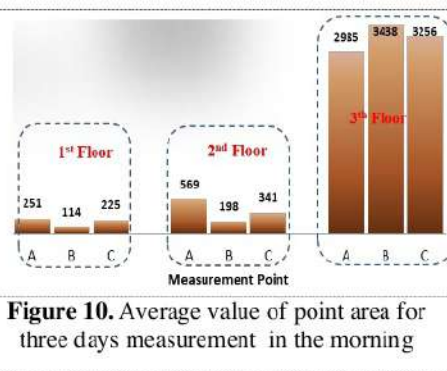


Figure 10. Average value of point area for three days measurement in the morning

The picture above shows the graph of light distribution that goes into buildings on floors 1,2 and 3 with different percentage of different light distribution. The level of illumination in the Zone A area of the 4th floor is 2985 (average point A), 3438 lux (average point B) and 3256 lux (mean of point C). this graph shows that the higher the position of the space then the level of illuminance is increasing. For example: comparison between the Zone A of the 1st and 2nd floors, where this area has a building envelope opening with the same area and shape. The level of illuminance on the 2nd floor is higher than the 1st floor with the average value of 281 lux (1st floor) and 533,3 lux (2nd floor). This shows that the distribution of natural light affects the height of the building.



Figure 11. The position of the Zone A area on the 1st, 2nd and 3rd floor

4.4. Average value analysis for 3 times measurements during the day

The average value of level illuminance on floors 1, 2 and 3, maximum of 18,706 lux (measuring point B2, floor 3) and minimum 154 lux (B2 measurement point, 1st floor). This graph can be seen in Figure 15 below.

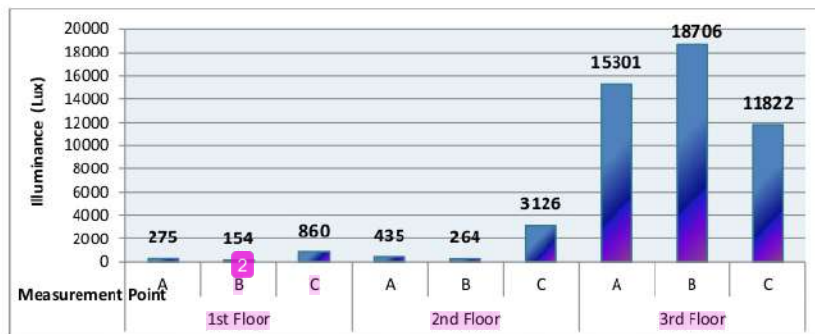


Figure 12. Average value of illuminance level on during the day

The sky conditions during the day were highest at 94,200 lux (first day), 18,500 lux (second day) and 20,200 lux (third day) so that the average value was 44,300 lux. The highest of illuminance level in the area Zone A is 860 lux (1st floor), 3126 lux (2nd floor) and 18.706 lux floor 3. The level of illuminance on the 3rd floor is the highest, because there are openings in the building envelope on top and side of the building. This indicates that the distribution of natural light into buildings influences the height of the floor and the width of the building envelope.

4.5 Average value analysis for 3 times measurement in the afternoon

Measurements in the afternoon conducted for 3 days, so that the measurement results are mean to determine the effect of the illuminance level on certain variables.

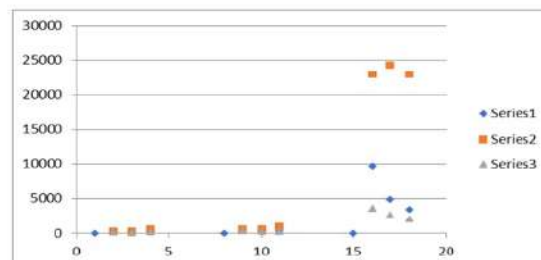


Figure 13. Measurement result of illuminance level in the afternoon

Figure 14 shows the average value of illuminance in the afternoon. The average value of the illuminance in the afternoon has the highest value on the 3rd floor, because the distribution of light on the top of building envelope is not blocked, so that the level illuminance is very high. The level of illuminance in the Zone A of 3rd floor is at least 12,220 lux (group A) and at least 9522 lux (group C). the graph shows a very high degree of level illuminance on the 3rd floor, because the building cover is bigger than the 1st and 2nd floors. The average value on the 1st and 2nd floors has the highest value in area group C (front of the building envelope) which is 347 lux (group C, floor 1) and 531 lux (group C, 2nd floor). The level of illuminance in this area is higher than others, because the building faces to the west and the sun sets in the afternoon

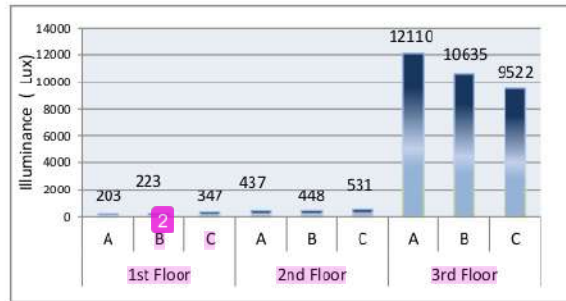


Figure 14. Average value in the afternoon for three days

4.5. Illumination value analysis on Zone A floor 1,2 and 3 in the morning, day and afternoon

The average value of the levels illuminance in Zone A on the floors 1, 2 and 3 shows the ratio of illuminance levels in the lobby area in the morning, afternoon and evening. The measurement results show that the highest sky conditions that is during the day, with the average value of illuminance rate of 44,300 lux. The distribution of light in the morning, afternoon and evening can be seen in Figure 17 below.

	Point	Morning	Day	Afternoon
1st Floor	Point A	251	275	203
	Point B	114	154	223
	Point C	225	860	347
2nd Floor	Point A	569	435	437
	Point B	198	264	448
	Point C	341	3126	531
3rd Floor	Point A	2985	15301	9980
	Point B	3438	18706	10635
	Point C	2890	11822	9522

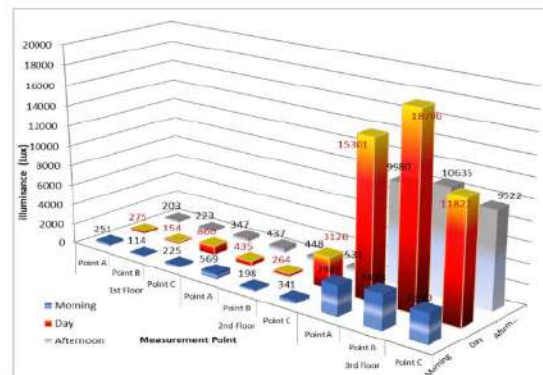


Figure 13. Measurement result on Zone A for three time

The average value of illuminance level in zone A area 1, 2 and 3 shows that the illuminance level during the day is higher than in the morning and afternoon. The analysis of the condition of the sky, also shows that the illuminance level at noon is higher than the morning and evening. Based on this, it can be seen that the distribution of light into the building is related to the sky condition. The level of illuminance in the zone A zone fluctuates, so it only analyzes on

the 4th floor, because it has the highest of level illuminance compared on the 1st and 2nd floors.

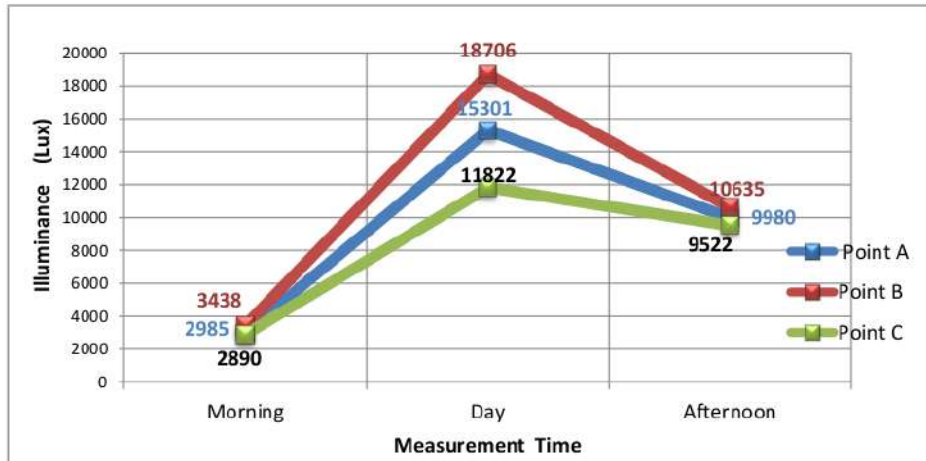


Figure 16. Average value of measurement result on Zone A area

Figure 16 shows the average value of illumination level on the 4th floor. The analysis of the light distribution on the 4th floor shows that the highest illuminance level occurs at noon with a value of 18706 lux (point A), 15302 lux (point A) and 1822 lux (point C). the lowest illuminance level is in the morning at 3438 lux (point B), 2985 lux (point A) and 2890 lux (point C).

4.7 Illumination level analysis in Zone B

Zone A and B area conditions are closely related to having openings on both the left and right sides of the building envelope. The orientation of the window is different ie Zone A on east-west whereas Zone B on Southwest-Northeast (figure 17)

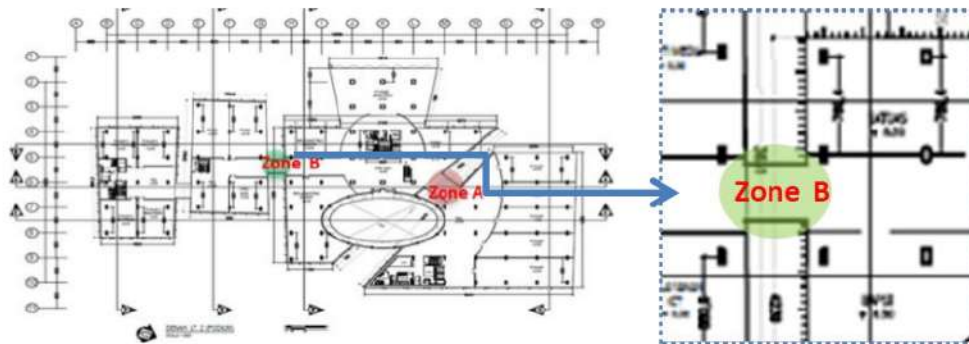


Figure 17. The position of the Hall in Zone B

Measurements conducted for 3 days in the morning, during the day and afternoon. the average value of the measurement results can be seen in Figure 19 below. Level of illuminance In Zone B has the highest value on the 3rd floor compared to the level of illumination on the 1st and 2nd floors. The measurement results show that the highest illumination level is during the day time is 323 lux (floor), 559 lux (2nd floor) and 4240 lux (3rd floor). in the Zone B has the lowest of the illuminance level at noon that is 300 lux (1st floor), 371 lux (2nd floor) and 1306

lux (3rd floor).

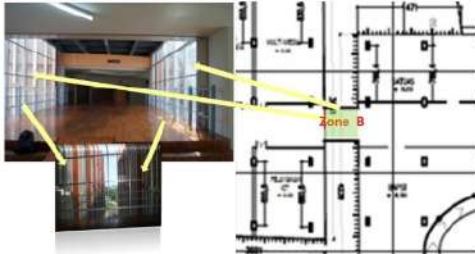


Figure 18. Window opening on the building envelope (Side Lighting)

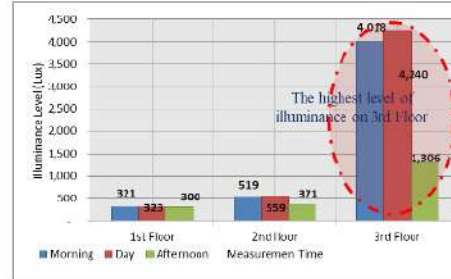


Figure 19. Average level of illuminance on 1st, 2nd and 3rd Floor

4.8 Results of comparison analysis of natural light distribution in Area A and B

The results of the analysis show that there is no difference in the rules of light distribution in Zone A and B, although the orientation of the building envelope is not the same but resembles to have a similar light distribution (figure 20).

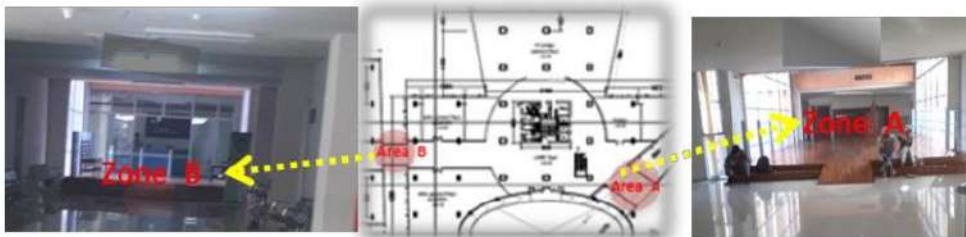


Figure 20. Window opening on the building envelope in Zone B area

Overall it shows that the Zone A has a higher of illuminance level than the Zone B, since the Zone A positions have partially openings of the building envelope surrounded by open space and serve as a void. In the Zone B area has openings on the building envelope from the left and right, but is blocked by the building resulting in a reduction in the distribution of natural light. This can be seen in Figure 21 below.

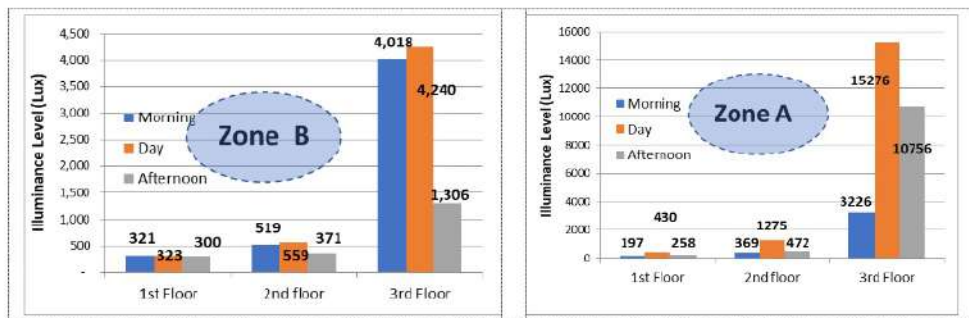


Figure 141. Illuminance Levels in Zone A and B

Figure 21 shows that Overall Illumination Level In Zone A is higher than Zone B. The

level of illuminance on Zone A of floor 4 is between 3226-15276 lux while in Zone B is between 1306-4240 lux. Overall, the illumination level in Zone A on floors 1, 2 and 3 are higher than the Zone B on Floors 1, 2 and 3. The illumination level in Zone A is between 282-4240 lux whereas in Zone B is between 197-15267 lux. The level of illuminance in the Zone A on floors 1, 2 and 3 are the same that is the highest during the day, as well as in the B on floors 1, 2 and 3.

5. Conclusion

The level of illuminance outside the building depends on the condition of the sky (clear sky, intermediate sky and overcast sky) The sky conditions affect the distribution of light into the building and the distribution of light that increasing in the height of the floor of the building. As well as of wide opening on the building envelope (top lighting and side lighting) have effect on the level of illuminance in the building. Example in this research, that the level of illuminance in Phinisi building hall area is higher on the 3rd floor compared to the 1st and 2nd floor.

The opening position on the building envelope also affects the distribution of natural light. If there is no building or other near the building envelope, then the distribution of light can be maximally in to the building. For example: the ratio of illuminance levels in the Zone A is higher than the illumination level in the Zone B

The results of the analysis concluded that the distribution of natural light will increase during the day, if the condition of the sky does not change in one day. Zone A and B area conditions are close to the same ie have openings on the left and right side of the building envelope and orientation of window opening is different ie area Zone A east-west direction while Zone B direction of Southwest-Northeast, but the procedure of distribution of light is same.

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