

The evaluation of daylighting performance in the university classroom. An experimental study

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ABSTRACT

This study aims to optimize natural and artificial lighting in classrooms that use curtains. The method used is to measure the lighting intensity in the room by using natural and artificial lighting with curtain wall variations. The results showed that the level of natural lighting that can reach the entire space is obtained by opening all curtains. At the front measuring point (near the blackboard) comes to 284 to 325 lux. However, the side of the window gets very high light from 3100 to 3340 lux (TU 10, 11, and 12). If the curtain is partially open (50%), the light only reaches the center of the room (TU 7,8,9). The lights play little because the lighting level does not match the standard.

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1. Introduction

The use of wide glass on buildings, especially high buildings still in demand for architects. This is because buildings with wide glass can increase the use of natural lighting, views, and image of the building as magnificent and modern buildings [1][2]. In addition, a glass-covered building can also save energy use for room lighting [3][4].

However, for tropical areas such as Indonesia that have daylight throughout the year, the light that enters the building and solar radiation come together. Thus causing the burden of cooling in the building to become larger. In Indonesia, the use of energy for electricity in the building is between 15% to 27%, whereas AC is equal to 55% to 65%. So, when the natural light is maximized, it will significantly increase the cooling load.

Besides, humid tropical areas are challenging in architectural design because they have high

temperatures and relative humidity that cross ASHRAE's comfort limits throughout the year. Therefore, protecting the façade of the building against overheating and sun glare in a tropical country is a must. The tropical climate has different weather conditions from other climates. Despite the dominance of cloudy weather, outdoor lighting in tropical climates reaches 10,000 to more than 20,000 lux.

The use of natural light for buildings, especially in Indonesia, is often done, such as in school and office buildings. Research on this building is mainly done to see the lighting intensity in the room. Whether it complies with SNI or not, such as the standard of light for classes is 250 lux.[9]

The factors affecting the exposure level are also discussed, such as outside lighting levels (sky factor) and wide openings. In addition to natural lighting, it is also concerned about artificial light (the use of lamps) when natural lighting is insufficient in the room. However, this study

had no opening/window experiments with new curtains. [10]

The factors that cause a lack of indoor lighting are the obstructed position of the room, only obtaining light from one side, the room's depth, the positioning of the opening or window, the building barrier, and the Window Wall Ratio (WWR). [11]

The tower building is one of the buildings at Mercu Buana University that uses the principle of sustainable design using natural lighting. Almost all of the building's façades have wide glass openings. But on the inside, using a protective curtain.

The question is whether natural light in buildings is excessive. After using the curtain, then on the inside of the building was used artificial lighting. Is the use of electrical energy in buildings still relatively efficient? And whether the classroom lighting level is sufficient. This research will see the extent to which natural lighting can be utilized for classroom lighting and, when using artificial light, how many percent of openings should be closed.

2. Material and Methods

The research was carried out on the Tower building of Mercu Buana University, Jakarta, because it is a new building with a veil dominated by glass walls. The building consists of seven floors where the ground floor/Sub-basement is the floor for computer laboratories, the ground floor for the main lobby and marketing, the second floor for management, the third and fourth floors for a lecture, a fifth and sixth floors for Library and the seventh floor for the auditorium.

The study was conducted in the lecture room/class third and fourth floors. The rooms on both floors have the same shape and breadth (typical). The difference is one row of rooms

faces north and once again faces south. The classrooms are typical, and the type of wall is a curtain wall with an aluminum frame. Each classroom's area of openings/windows is the same as 100% (WWR 100%). The selected space is room T311 and T 405. The tower's typical plan is as the following figure:

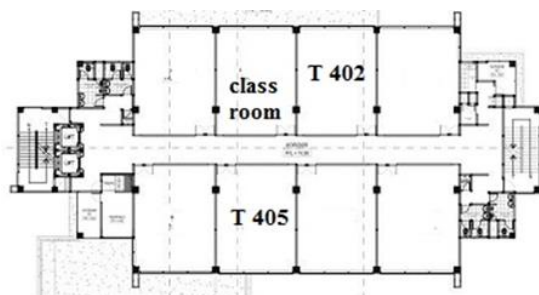


Figure 1. Typical floor plan at Mercu Buana Tower Building, West Jakarta, Indonesia

The rooms are arranged in a double-load corridor system. In this row of rooms facing north and south, the rooms at the left and right ends are utility facilities.

The following is the front view of the tower building, which is dominated by a curtain wall (Figure 2.). The glass area in each classroom is 7.00 m x 3.60 m. The net height from floor to floor is 3.60 m.

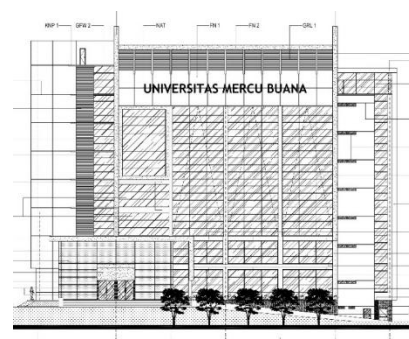


Figure 2. The North Elevation Of The Tower Building

For data collection, experimental points are arranged the figure 3 as follows.:

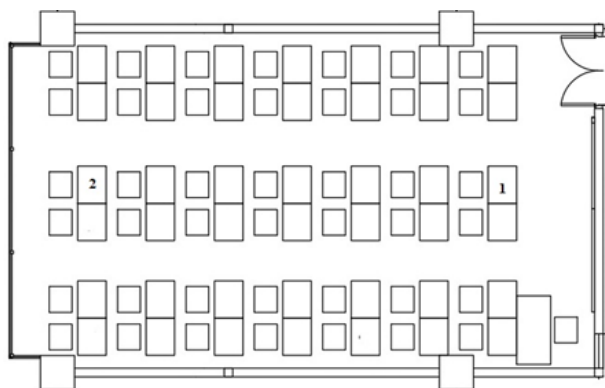


Figure 3. Plan the measurement points at the classroom

Measurements were conducted from December 2018 to February 2019. The measurements are carried out according to the lesson hours, i.e., from 7.30 AM. to 10.00 AM, 10.15 AM to 12.45 PM, 01.15 PM to 03.45 PM. Then in the afternoon from 04.00 PM to 06.30 PM. In addition to measuring the level of lighting inside, it also measured outside lighting.

The measurement of artificial lighting is also done in room T404. Measurements were carried out at 12-point measurements as in the following figure: using the same equipment. The scenario is:

1. All the lights are turned on. In this scenario, all lights are turned on (see Figure 2 for the lamp distribution). It's representative of general lighting at night.
2. Some of the lights are turned on. In this scenario, only the lights in the south are turned on. This representative for general lighting of artificial lighting is carried out when natural light is insufficient for lighting the room.

Natural light measurements are carried out by setting the measuring point (TU) on the study table. The specified number of TU is 12 points, where each table row is defined as three measuring points. For natural light levels, measurements are performed in 3 scenarios: closed curtains, partially open, and the curtain

opening entirely. Artificial light intensity measurements were performed at night, so there was no natural light contribution to the measuring value. While artificial lighting measurements are also done in three scenarios, the curtain is closed, the light is partially switched on, and the lights are all switched on. The curtains are partially open, the light is partially switched on, and the lights are all turned on. The curtains are fully open, the light is partially switched on, and the lights are all turned on.

For natural and artificial lighting, optimization is done by combining the lighting with the scenario as follows: the curtain is closed; without lights, the light is partially switched on, and the lights are all turned on. Curtains are partially open; without lights, the lights are partially switched on, and lights are all turned on. Curtains are fully open; without lights, the lights are partially lit, and the lights are all room.

The measurement is carried out with the tool Light Meter LX 105. Photosensor All measurements are performed at the study table with a height of 80 cm. Photosensors are placed on the central table in turns. To ensure the accuracy of altitude and alignment.

3. Results and Discussions

3.1. Indoor Daylight Levels

The weather conditions in table 3.1. are bright, while in table 3.2 is initially slightly dim but, at the end of the measurement is very bright. This is evident from the lighting level on the measuring point (TU) 10, 11, and 12, very high from the range from 4370 to 4440 Lux.

The level of lighting in the classrooms at 08.00 AM only TU 10, 11, and 12 got high intensity which is between 385 to 409 lux for the condition of the curtains all close. Whereas if the curtain opened partially (50% open) on the

obtained intensity between 360 and 1295 lux with TU from 7 to 12. When the curtain opened, all (100% open) received lighting between 300 to 3340 lux.

Table 3.1. Results of daylight level measurements in classrooms at 08.00 AM

Measurements Points	Curtain All Closed	Curtain Partially Opened	Curtain All Opened
1	20	82	300
2	20	79	325
3	20	90	284
4	37	169	633
5	38	128	693
6	36	154	640
7	104	360	1422
8	90	333	1420
9	108	333	976
10	409	1335	3100
11	206	1765	3370
12	385	1295	3340
Average	122.7	510.2	1375.2



 Illumination level above 250 lux

Table 3.2. Results of daylight level measurements in classrooms at 10.00 AM

Measurements Points	Curtain All Closed	Curtain Partially Opened	Curtain All Opened
1	11	95	238
2	11	119	287
3	13	111	267
4	21	190	483
5	19	223	566
6	16	206	501
7	29	435	1181
8	36	551	1558
9	50	438	1161
10	95	2020	4370
11	104	2680	5460
12	194	1666	4440
Average	49.9	727.8	1709.3

 Illumination level above 250 lux

Different from 08.00 AM, at 10.00 AM, the lighting in the classroom for closed curtains has no value above 250, as indicated by SNI regarding natural lighting. Measuring points that meet SNI requirements occur at TU 7 with magnitudes from 435 to 1666 Lux with partially open curtains (50% open). The lighting level for

open curtains is loaded from TU 2 to 12 with intensity between 287 to 4440 Lux.

The following table presents the measurement results of lighting levels at 2.00 PM and 4.00 PM. Weather conditions during noon hours at 2.00 PM and afternoon at 2.00 PM are different from the weather conditions in the morning. The weather is a little cloudy and cloudy in the afternoon. During daylight hours of 2.00 PM, the level of illumination in the classrooms does not reach the minimum standard, which is 250 lux, when the curtains are covered.

Table 3.3. Natural lighting level measurement results at 02.00 PM

Measurements Points	Curtain All Closed	Curtain Partially Opened	Curtain All Opened
1	9	52	127
2	12	72	171
3	14	72	167
4	20	123	299
5	17	110	294
6	14	91	231
7	25	179	463
8	31	247	653
9	40	264	681
10	144	2004	1824
11	43	1279	1693
12	56	864	1339
Average	35.4	446.4	661.8

 Illumination level above 250 lux

However, if the curtain is partially open, the exposure level reached 264 Lux in 2004. However, at the same point sequence, there is a difference. Likewise, on the open curtains state, not all are above the standard. The measurement conditions of 02.00 PM and 04.00 PM are almost the same lighting level in the space. The measurement at 4.00 PM is as follows:

Table 3.4. Daylight level measurement results at 16.00 PM

6	27	27	29
7	42	50	60
8	196	210	209
9	87	104	98
10	262	238	234
11	63	72	56
12	8	12	14
Average	91.2	93.8	88.1

The table above shows that the artificial lighting level in the room does not comply with the SNI standard about exposure. This happens not only in partially lit lighting but also in full illumination in the classroom. The use of indoor curtains does not help with artificial lighting. Only two measuring points in the space meet the standard, namely TU 10. With curtains covered and partially open. While the curtains open slightly below, the 250 lux is 246 lux. The following is the measurement of the lighting level in the classroom with artificial light all on.

 Illumination level above 250 lux

Measurements Points	Curtain All Closed	Curtain Partially Opened	Curtain All Opened
1	12	45	148
2	12	50	148
3	12	52	181
4	21	103	281
5	24	95	258
6	24	84	225
7	48	158	478
8	52	258	681
9	58	247	544
10	174	985	1020
11	81	975	1202
12	124	738	1020
Average	53.5	315.8	515.5

Table 3.6. The results of the measurement of the level of room lighting conditions with the lights on entirely on the T404 room.


Measurements Points	Curtain All Closed	Curtain Partially Opened	Curtain All Opened
1	116	110	121
2	110	121	123
3	120	135	136
4	172	167	172
5	151	130	138
6	154	150	151
7	108	105	97
8	214	228	233
9	124	114	106
10	286	250	246
11	110	84	84
12	245	236	227
Average	159.1	152.5	152.8

3.2. Levels of Artificial Lighting In the Classroom

Artificial lighting level measurements are performed at night to eliminate influences from daytime light through windows and curtains. The following table is the result of artificial lighting level measurement results in the classroom.

Table 3.5. The result of a measurement of room lighting level with a partial light condition on the T404 room.

Measurements Points	Curtain Entirely Closed	Curtain Partially Opened	Curtain Entirely Opened
1	9	8	9
2	34	34	38
3	122	120	46
4	134	151	158
5	111	100	106

 Illumination level above 250 lux

Similar to previous measurements, the room's lighting level does not meet SNI standards. Only two measuring points meet SNI when the lamp is turned on all and there at a measuring point 10.

Table 3.7. The result of a measurement of room lighting level with a partial light condition in the T408 room.

Measurements Points	Curtain Entirely Closed	Curtain Partially Opened	Curtain Entirely Opened
1	13	14	14
2	40	38	27
3	70	82	93
4	194	202	182
5	122	85	104
6	34	32	34
7	95	60	69
8	196	184	163
9	95	56	82
10	274	236	252
11	54	77	67
12	15	13	10
Average	100.1	89.9	91.4



 Illumination level above 250 lux

Table 3.8. The results of the measurement of the level of room lighting conditions with the lights on entirely on T408 room.

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	136	127	125
2	140	134	158
3	113	111	116
4	229	200	168
5	149	139	112
6	247	234	24
7	124	134	139
8	212	221	242
9	98	87	104
10	277	236	252
11	106	100	97
12	235	226	250
Average	172.1	162.4	147.5

 Illumination level above 250 lux

To obtain natural and artificial lighting optimization, then natural and artificial lighting experiments are performed simultaneously. Here are the results of the experiment:

- a. The measurements are carried out at 8:00 AM with all curtains closed.

The exposure level in the morning with the enclosed curtains combined with the lamp experimentation was given that only a measuring point of 12 got the standard exposure (above 250 lux) in the morning. This is the case with the lights off, living partially, or living lights of all.

Table 3.9. The results of exposure level measurements in classrooms with closed curtains all at 08.00 AM

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	20	78	82
2	20	163	158
3	20	53	89
4	37	48	154
5	38	62	143
6	36	120	145
7	104	126	176
8	90	92	294
9	108	124	166
10	409	372	532
11	206	211	311
12	385	497	550
Average	122.7	162.1	233.3



 Illumination level above 250 lux

Table 3.10. The results of exposure level measurements in classrooms with partial open curtains at 08.00 AM

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	82	72	157
2	79	79	266
3	90	113	132
4	169	234	329
5	128	246	256
6	154	139	316
7	360	375	413
8	333	594	755
9	333	505	433
10	1335	1996	2480
11	1765	1816	1730
12	1295	1638	2280
Average	510.2	650.5	795.5

 Illumination level above 250 lux

When the curtain is partially opened, the TU 7 to 12 gets the standard light accordingly. Meanwhile, TU 4 to 6 has good lighting when the lamp is lit up entirely. In the experiments

with curtains that were opened completely, almost the entire measuring point was exposed to an exposure that exceeded the standard, except measuring point 1 with the lighting conditions entirely lit.

b. Measurements at 10:00 AM with a closed curtain.

In an experiment at 10.00 AM with a closed curtain combined with a lamp experiment, the results were obtained that at this time, only measuring points 8 and 12 got the lighting according to standard (above 250 lux). The experiment results are shown in Table 3.12 as follows:

Table 3.11. The lighting level measurements in classrooms with curtains opened entirely at 08.00 AM

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	300	272	215
2	325	265	393
3	284	278	270
4	633	474	437
5	693	515	531
6	640	370	472
7	1422	1000	938
8	1420	1611	1201
9	976	1103	690
10	3100	2140	1800
11	3370	2410	1770
12	3340	1930	1680
Average	1375.2	1030.6	866.4



 Illumination level above 250 lux

Table 3.12. The results of lighting level in the classroom with curtains completely closed at 10:00 AM

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	14	22	108
2	14	36	167
3	14	99	122
4	26	190	125
5	28	121	221

6	26	52	145
7	54	96	122
8	40	248	253
9	59	129	127
10	181	282	255
11	121	150	163
12	153	185	291
Average	60.8	134.1	174.9

 Illumination level above 250 lux

The results of the lighting level experiment in the classrooms with curtains covered entirely are as in table 3.12. it indicates that almost all the measuring points are under the standard 250 lux.

When the curtains in the experiment were partially opened, the results of exposure were more than before, which were at a measuring point of 10, 12, and 12. Besides, some are in points 6, 7, 8, and measuring point 4.

The lighting level that meets SNI standards is obtained for experiments with open curtains, which is 250 lux and above.

Table 3.13. The results of lighting level measurements in the classroom with the curtains open partially at 10.00 AM

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	54	64	150
2	60	82	221
3	60	133	160
4	100	297	297
5	110	205	219
6	133	128	282
7	197	251	220
8	310	429	414
9	218	418	324
10	950	1000	1518
11	1127	1041	1620
12	733	670	1090
Average	337.6	393.1	542.9


 Illumination level above 250 lux

Table 3.14. The results of lighting level measurements in the classroom with the curtains open entirely at 10.00 AM

Measurements Points	Curtain All Closed	Curtain Opened Partially	Curtain All Opened
1	255	190	405
2	251	286	453
3	228	371	469
4	292	459	768
5	640	450	720
6	436	264	721
7	939	620	1149
8	1534	1270	1548
9	1209	954	1272
10	2420	2340	3240
11	2600	2370	3320
12	1848	1855	2490
Average	1054.3	952.4	1379.5

 Illumination level above 250 lux

3.3. Discussion

From the data obtained from the experiments conducted, natural lighting levels in classrooms, it can be seen that at 8.00 AM and 10.00 AM and when the conditions are bright (indoor lux reaches 3370 lux), all measuring points get sufficient or even excessive lighting. For open blinds, almost half of the measuring points from the front row of the whiteboard to measurement points 1 to 6 (second row) do not get light, according to SNI. But when the curtain opens completely, all the measuring points earn enough or even excessive lighting.

When the weather is cloudy at 2.00 PM and 4.00 PM, measuring points 8 to 12 get the appropriate light. When the curtain is opened completely, the measuring point that reaches the standard moves to TU 4 to 6, and the measuring points 1 to 3 (the row of seats close to the board) do not get enough light.

1. The level of artificial lighting in the classroom

Almost all intensity achieved for an artificial lighting level does not meet the standard, except

at point 10. The variation of the curtain openings, whether closed, partially open, or open, does not influence the intensity of the indoor light.

2. Levels of natural and artificial lighting in the classroom

The lighting is either partially or entirely not affecting the exposure level for natural and artificial lighting levels in the classroom. Except for measuring points 10 and 11, get light from the curtain gaps. But when the curtain is partly opened, measuring point 7 has enough lighting. When the lamp is lit completely, the lighting level shifts to TU 2.

When the curtain is opened entirely, almost all measuring points get even more adequate exposure. It can be concluded that natural light is a very large effect on the classroom indoor lighting level. When the curtain is partially closed, artificial lighting does not have much impact on the indoors.

4. Conclusion

From the explanation above, based on the data and the results of the analysis of the data obtained, several conclusions are:

1. The natural light source during the Day in the average classroom is only 46 lux which means less than the recommended light intensity, so it is appropriate to use a light source from the lamp even though activities in the class are conducted during Day.
2. From the planning side, the use of FL 36-watt lamps with the amount in each classroom that was used as a sample meets the standard in SNI 03-6197-2000 where the power installed per unit area is not more than 15 watts/m produced has more than 250 Lux.

3. The existing condition at the time of research shows the intensity of light in the classroom to be less than 250 lux. It shows that the lamps installed are not in the performance that should be so advised to do Replacement.
- 4.
5. From the current market's existing LED Light specification research, we recommend replacing it with the same type of lamp as before, an FL 36-watt lamp.

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