Modelling of lighting system utilizing natural and artificial lighting using DIALux

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Abstract. The uniformity of daylight in the classroom contributes to indoor visual comfort in the learning process. A classroom that has non-uniform illuminance and is unsuitable with 350-3000 lux can affect visual discomfort. This study aims to design a classroom lighting system using daylight and artificial lighting according to Indonesian National Standard (SNI) 6197-2011 to get visual comfort. The results of this study are expected to increase the efficiency of electricity consumption and to solve the visual discomfort problem followed by SNI 6197-2011. This research using E11-210 and E11-112 classroom Universitas Negeri Semarang with the dimension about 12m x 9m x 3.5m. Based on observation, the classrooms had an illuminance of more than 20,000 lux with a uniformity less than 0.6 in the afternoon. Simulation in this study using Dialux Evo software with replacing the layouts of lamp, type of lamps and armature, modifying power of lamp, and implementing dynamics blinds. The result shows that the simulation can solve visual discomfort corresponding to SNI 6197-2011. This paper also presents that LED Tube power modification from 21 – 25 watts can save electricity costs by 37.3%.

1. Introduction
Electricity is an important role in the lighting sector. Indonesia’s electricity consumption is forecasted to grow by over 6.9% per year from 2019-2038 [1]. There have been several studies about energy-saving in the lighting sector. Those are using an on-off system of the lamp switch [2], redesign the layout of luminaries [3], replacing the type of armature and lamp [4], [5], and utilizing daylight with LED (Light Emitting Diode) to reduce electricity consumption and optimize lighting system [6]. The best lighting system can support more indoor activities, including learning activities in the classroom. The recommended classroom illuminance is 350 – 3000 lux [7], [8] with minimum permissible value of uniformity is 0.6 [9]. The illuminance can be perfect if the minimum illuminance is reached and does not glare [10]. If the illuminance is under 350 lux or over 3000 lux can affect low uniformity and visual discomfort for users.

According to the survey using luxmeter Metrel Eurotest XE in the E11 building of Electrical Engineering Department, Universitas Negeri Semarang, E11-210 and E11-112 classrooms have low uniformity. The uniformity of E11-210 was 0.2 – 0.9, while the uniformity of E11-112 was 0.5 – 0.9. There were several areas illuminances of more than 20,000 lux in E11-210 at 3 PM. At the same time, there were several areas illuminances about 700 lux in the E11-112. Those have happened because the classrooms have several windows without blinds on the western wall. So, daylight shines can impacts...
the classroom illuminance rate of over 3000 lux. Therefore, it is necessary to reduce and optimize daylight radiation for visual comfort.

Reducing and optimizing daylight radiation could be combined with LED and implemented blinds to the windows. LED can be more saving energy consumption than TL luminaires [6], [11]. Dynamic blinds could be a solution for visual discomfort without disappearing the areas illuminance [12]–[16]. The study aims to design a lighting system utilizing daylight radiation and artificial lighting in a classroom. The design will be combined daylight radiation with LEDTube and controlled dynamic blinds using Dialux Evo 9.0 software. The results of this study are expected the illuminance of the classroom to followed Indonesia National Standard (Standar Nasional Indonesia or so-called SNI). Considering SNI 6197-2011, the standard for a classroom illuminance is 350 lux.

2. Research Method
The simulation in this study using Dialux Evo 9.0 software. This study utilized E11-210 and E11-112 lighting classrooms cases in the E11 building, Universitas Negeri Semarang, Indonesia. The classrooms have the same size, 12 m x 9 m x 3.5 m, where E11-210 is on the 2nd floor and E11-112 is on the 1st floor shown in Figure 1 (a). The classrooms have been designed and simulated using Dialux Evo 9.0 software. Figure 1 (b) is the indoor design of E11-210, while figure 1 (c) is the indoor design of E11-112. The classrooms have six windows on the west wall without blinds. The window’s size is 1.65 m x 0.1 m x 0.8 m. During the learning process, the classrooms using 16 Philips TL-D 36watt lamps. The lamps were fit on 8 Artolite RM300 M2 armatures.

![Figure 1. Dimension of (a) outdoor classrooms design, (b) indoor E11-210 design, and (c) indoor E11-112 design.](image)

The variables in this study were lamp types, dynamic blinds and LED dimmed. There were three lighting conditions of the simulation. Those were daylight condition, artificial lighting condition and combining both lighting conditions. The classroom illuminance standard in this study referred to follow SNI 6197-2011. The uniformity of classroom illuminance was concerned to follow EN 12464-1-2011. The illuminance measurement referred to follow SNI 16-7062-2004 [17], about general measurement and task area measurement. Because the classrooms have an area of 108 m², the distance between the
measuring points was 3 m in the general measuring. It can be seen in Figure 2 (a), while task area’s measurements were on student and lecturer desk as shown in Figure 2 (b).

**Figure 2.** The illuminance measurement: (a) General Measurement Points and (b) Task Area Measurement Points

The lighting conditions were simulated using Dialux Evo 9 from 7 AM to 7 PM. The modeling of artificial lighting was redesigned of the layout of the 2x8 Philips TL-D 36W 2500 lm to 4x4 layouts using LEDTube 26W 3900 lm. The layout referred to reference [3]. According to the reference, the spacing of the lamps in the room was double spacing between the lamp and the wall. The LEDTube was fit on Powerbalance RC360B armature. Figure 3 (a) is a layout for the 2x8 TL-D 36W, while figure 3 (b) is one of the layouts of the design to be carried out, which is a 4x4 layout.

**Figure 3.** Artificial Lighting layout (a) 2x8 layouts and (b) 4x4 layouts

The simulation with blinds implementation aimed to optimize daylight radiation and artificial lighting. The blinds were roller, horizontal, and vertical blinds. The blinds color was khaki with RGB 240/230/140 as shown in figure 4 (a) – (c). Figure 4 (a) is the roller blinds design. The opening of roller blinds screen was designed each 5% at 0% – 100%. Figure 4 (b) is horizontal blinds design, while figure
4 (c) is vertical blinds. The horizontal blinds' angle was arranged each 5° at 0°–90°. As for the vertical blinds' angle position was determined each 5° at 0°–180°.

![Diagram of blinds](image)

**,Figure 4.** The blinds implementation in simulation: (a) Roller Blinds; (b) Horizontal Blinds; (c) Vertical Blinds Design

The lamp power modification has been used to reduce the illuminance and increased the efficiency of electricity consumption. The dimming lamp power was combined lighting with dynamic blinds implementation. This study also provides the expenditure projection of the E11-210 and E11-112 lighting for annual power and efficiency of electricity consumption at the cost of IDR 1,444.70 per KWH (Kilo-Watt-Hour)[18]. The efficiency of electricity costs was the savings cost from using a new electricity consumption system compared to the existing lighting system. The amount of power consumption and electricity costs were based on reference [19], while the daily electricity efficiency value was based on reference [20].

3. Result and Discussion

Daylight in the E11-210 and E11-112 classrooms can be useful for classroom lighting. But the daylight in the classrooms could not follow 350 lux uniformly. This fact was supported by simulation results using Dialux Evo 9.0 software which can be discovered in Table 1. Based on Table 1, it can be known that the daylight in the classroom was about 1–336 lux in the afternoon. Although there was a high illuminance, the uniformity value was only around 0.1 – 0.49. Therefore, the classrooms need to implement artificial lighting to reach 350 lux and more than 0.6 for uniformity.
The results of the simulation utilizing daylight and TL-D 36W could not follow 350 lux. TL-D 36W is the existing lamps in E11-210 and E11-112 classrooms. Table 2. shows that the illuminance was 147 – 535 lux in the E11-210 classroom and was 126 – 398 lux in the E11-112 classroom in the afternoon. The uniformity of the illuminances was around 0.56 – 0.98. There were differences between observation and simulation results. The difference was caused by reflectance values, type of armature, maintenance factor values, and lamp life. The illuminances were less than 350 lux and the uniformity less than 0.6 so those rooms needed to redesign the luminaire.

Table 1. Daylight’s illuminance distribution in simulation

| Time   | E11-210 Classroom | E11-112 Classroom |
|--------|------------------|------------------|
|        | General Measurement | Task Area Measurement | General Measurement | Task Area Measurement |
| 07.00  | 33 – 182         | 25 – 169         | 3 – 21             | 1 – 19              |
| 09.00  | 54 – 293         | 46 – 336         | 3 – 28             | 1 – 25              |
| 11.00  | 35 – 174         | 23 – 160         | 3 – 30             | 1 – 28              |
| 13.00  | 42 – 125         | 23 – 131         | 5 – 52             | 2 – 47              |
| 15.00  | 61 – 184         | 27 – 173         | 10 – 115           | 4 – 114             |
| 17.00  | 31 – 81          | 13 – 82          | 16 – 51            | 9 – 247             |

The result of the redesign luminaire with utilizing daylight in the classrooms can be seen in Table 3. Shown in the Table 3. that the illuminance of the 4x4 layout design with LED Tube 26W on Power balance RC360B has followed 350 lux. The illuminance of LED Tube 26W on Power balance RC360B armature helped to coordinate the illuminance uniformly. The simulation results of using Power balance armature were related to reference [5] about the Power balance type armature could support to increase the illuminance. It was gain from the implementation of mutually proving light interference on the grids of the armature.

Table 2. Illuminance Distribution from daylight and TL-D 36W based on observation

| Time   | E11-210 Classroom | E11-112 Classroom |
|--------|------------------|------------------|
|        | General Measurement | Task Area Measurement | General Measurement | Task Area Measurement |
| 07.00  | 274 – 416        | 153 – 400        | 243 – 262          | 126 – 247           |
| 09.00  | 300 – 535        | 180 – 516        | 242 – 269          | 126 – 253           |
| 11.00  | 279 – 376        | 150 – 364        | 242 – 272          | 126 – 256           |
| 13.00  | 284 – 357        | 152 – 352        | 243 – 293          | 127 – 278           |
| 15.00  | 302 – 426        | 160 – 404        | 249 – 356          | 129 – 344           |
| 17.00  | 320 – 273        | 147 – 313        | 259 – 293          | 134 – 398           |

Table 3. Illuminance distribution and uniformity from utilizing daylight and LED Tube 26W.

| Time   | E11-210 Classroom | E11-112 Classroom | E11-210 Classroom | E11-112 Classroom |
|--------|------------------|------------------|------------------|------------------|
|        | General Measurement | Task Area Measurement | General Measurement | Task Area Measurement |
| 7 AM   | 450 – 604        | 373 – 597        | 473 – 489        | 384 – 510        | 0.86          | 0.75          | 0.98          | 0.83          |
| 9 AM   | 475 – 723        | 402 – 725        | 473 – 497        | 384 – 515        | 0.83          | 0.74          | 0.97          | 0.83          |
| 11 AM  | 453 – 569        | 370 – 566        | 473 – 499        | 384 – 519        | 0.87          | 0.75          | 0.97          | 0.82          |
| 1 PM   | 459 – 564        | 368 – 582        | 475 – 521        | 385 – 539        | 0.87          | 0.74          | 0.95          | 0.81          |
| 3 PM   | 478 – 649        | 377 – 650        | 481 – 583        | 388 – 606        | 0.82          | 0.72          | 0.90          | 0.78          |
| 5 PM   | 448 – 544        | 361 – 556        | 487 – 522        | 392 – 650        | 0.88          | 0.76          | 0.96          | 0.78          |
Based on Table 3, it can be known that the illuminance distribution in the E11-210 classroom was around 383 – 725 lux with the uniformity of 0.72 – 0.99. At the same time, the E11-112 classroom’s illuminance distribution was around 361 – 650 lux with uniformity of 0.78 – 0.98. These results are consistent with reference [11] regarding the simulation of LED Tube combined with daylight in the E11-210 classroom. Even though the rooms have several illuminances that over than SNI 6197-2011 at 3 PM. Consequently, it contrasts the rooms and decreased the uniformity. Therefore, applying blinds on the western window of the classrooms was needed to reduce daylight.

The results of applying three blinds in E11-210 and E11-112 classrooms at 3 PM can be seen in Figure 5. Figure 5. shows that the lowest average illuminance from the implementation of roller blinds was around 491 lux in the E11-210 classroom and 457 lux in the E11-112 classroom with 100% closing curtain position. In the vertical blinds implementation, the lowest average illuminance in the E11-210 was around 492 lux and 457 lux in the E11-112 classroom with 0˚ angle position. Meanwhile, the lowest average illuminance of implementation horizontal blinds in the E11-210 was around 483 lux and 451 lux in the E11-112 with the 85˚ angle position. The uniformity of the blinds implementation was around 0.76 – 0.99. The result of the dynamic blinds implementation was related to reference [15] regarding dynamic shading devices. The dynamic shading device could provide a better shadow than the static shading device.

The illuminance from the blinds in the E11-210 was higher than the illuminance in class E11-112. It happened because E11-210 classroom is on the 2nd floor, while E11-112 is on the 1st floor. The lower illuminance in the E11-112 was affected by the trees in the westside park of E11-112. But at the same time, the E11-210 was not affected by the trees. So, the solar radiation into E11-210 was only reduced.
by the blinds. The efficient position of the blinds for reducing daylight was the fully closed position, where the screen on the roller blinds was 100% closing, the fins of vertical blinds were at an angle of 0˚ or 180˚, and the fins of horizontal blinds were at an angle of 85˚. Despite the significant reduction in illuminance, the fully closed position of the blinds made no exterior visuality.

The recommended design from the simulation of blinds was horizontal blinds. In the implementation of horizontal blinds, the average illuminance for horizontal blinds were lower average illuminance than the roller and vertical blinds. It was because the fins of the horizontal blind reflected solar radiation horizontally. So, it reversed into the ceiling of the room. Reflection of solar radiation was beneficial because the task area received indirect lighting. The low illuminance from the horizontal blinds was related to reference [16]. Horizontal blinds can reduce more radiation than other blinds. The best design was horizontal blinds with an angle of 60˚ positions. It could be reduced the average illuminance to 501 lux in room E11-210 and 461 lux in room E11-112. The illuminances were equivalent to the level of illumination at 90% of the roller blinds screen. At an angle of 60˚, the horizontal blinds were not fully closed and kept exterior visuality. Based on Figure 6 (a)-(d), it can be known that a dimensional design of the 60˚ horizontal blinds and its implementation with illuminance distribution colour in the E11-210 classroom.

Figure 6. Design of (a) Horizontal blinds with 60˚; (b) Implementation horizontal blinds with 60˚ at E11-210; and illuminance distribution colour (c) at E11-210 and (d) at E11-112

The lighting condition of utilizing daylight and LED Tube 26W with horizontal blinds 60˚ was followed SNI 6197-2011 with uniformity of more than 0.6. However, the condition could be optimized
by modifying of LED Tube power. Table 4. was result of illuminance in the E11-210 and E11-112 classrooms from power modification using simulation. Based on the Table 4., the illuminance and the uniformity were still the standards even though the lamp powers were modified. The illuminance of the classrooms was around 350 – 680 lux with uniformity 0.7 – 0.9. The lamp power modification was around 21 – 25W. The dimming LED Tube was implemented to optimize and increase the efficiency of electricity cost. It was executed by paid attention to the illuminance and uniformity’s standards. It was carried out to kept visual comfort.

Table 4. Illuminance distribution and uniformity from utilizing daylight and dimmable LED Tube

| Time  | E11-210 Classroom | E11-112 Classroom |
|-------|------------------|------------------|
|       | Power of lamps (watt) | Illuminance Distribution (lux) | Uniformity | Power of lamps (watt) | Illuminance Distribution (lux) | Uniformity |
| 7 AM  | 22               | 353 – 573        | 0.8 – 0.9 | 25               | 363 – 479        | 0.8 – 0.9 |
| 9 AM  | 21               | 357 – 680        | 0.7 – 0.8 | 25               | 363 – 481        | 0.8 – 0.9 |
| 11 AM | 23               | 363 – 553        | 0.8 – 0.9 | 25               | 363 – 459        | 0.8 – 0.9 |
| 1 PM  | 23               | 358 – 524        | 0.8 – 0.9 | 25               | 364 – 488        | 0.8 – 0.9 |
| 3 PM  | 23               | 357 – 526        | 0.7 – 0.9 | 24               | 350 – 466        | 0.8 – 0.9 |
| 5 PM  | 24               | 359 – 493        | 0.8 – 0.9 | 24               | 350 – 466        | 0.8 – 0.9 |

According to the calculation of electricity costs in Table 5. and Table 6., it could be seen that the electricity cost of LED Tube 26W implementation in E11-210 classroom would be decreased by 27.7%. In the modifying power LED Tube implementation, the electricity cost decreased by 37.3%. Those were because the LED Tube has lower power with larger luminous flux than TL-D. This result was related to reference [6]. Furthermore, the LED Tube could be dimmed with utilizing daylight. So, the electricity cost decreased without totally reducing the illuminance. With the same calculation, the electricity cost of modifying power LED Tube in the E11-112 classroom was decreased by 31.2%. The value of electricity cost-efficiency in both classrooms was different. It happened because the E11-112 classroom was on the 1st floor and the western windows were covered by the trees. Consequently, the utilizing daylight was lower than daylight utilization in the E11-210 classroom.

Table 5. Calculation of electricity cost in E11-210 classroom

| Time  | Lamp | Total Cost per kWh (IDR) | TL-D 36W | LED Tube 26W | LED Tube with Power Modification |
|-------|------|--------------------------|----------|-------------|---------------------------------|
|       |      |                          | Lamp power (watt) | Total lamp power usage (kWh) | Cost per kWh (IDR) | Lamp power (watt) | Total lamp power usage (kWh) | Cost per kWh (IDR) | Lamp power (watt) | Total lamp power usage (kWh) | Cost per kWh (IDR) |
| 7 AM  |      |                          | 36        | 0.576       | 832               | 0.416            | 601               | 0.352            | 509               |
| 8 AM  |      |                          | 36        | 0.576       | 832               | 0.416            | 601               | 0.352            | 509               |
| 9 AM  | 16   | 1,444.70                 | 36        | 0.576       | 832               | 0.416            | 601               | 0.352            | 509               |
| 10 AM |      |                          | 36        | 0.576       | 832               | 0.416            | 601               | 0.352            | 509               |
| 11 AM |      |                          | 36        | 0.576       | 832               | 0.416            | 601               | 0.352            | 509               |
| 12 AM |      |                          | 36        | 0.576       | 832               | 0.416            | 601               | 0.352            | 509               |
| 1 PM  | 23   | 363 – 553                | 26        | 0.416       | 601               | 0.352            | 509               |
| 2 PM  |      |                          | 26        | 0.416       | 601               | 0.352            | 509               |
| 3 PM  |      |                          | 26        | 0.416       | 601               | 0.352            | 509               |
| 4 PM  |      |                          | 26        | 0.416       | 601               | 0.352            | 509               |
| 5 PM  |      |                          | 26        | 0.416       | 601               | 0.352            | 509               |
|       |      | Total daily cost         | 9,152     | Total daily cost | 6,611               | Total daily cost | 5,735               |

The LED Tube power modification has been implemented using the Pulse Width Modulation (PWM) and Fuzzy Logic methods. This study was the initial step for making PWM and Fuzzy Logic algorithms.
So, the next step should be to focus on making algorithms and implementing an automatic lamp power and opening blinds modification system in the classrooms.

**Table 6. Calculation of electricity cost in E11-112 classroom**

| Time  | Lamp Total | Cost per kWh (IDR) | TL-D 36W | LED Tube 26W | LED Tube with Power Modification |
|-------|------------|-------------------|-----------|--------------|----------------------------------|
|       |            | Lamp power (watt) | Total lamp power usage (kWh) | Lamp power (watt) | Total lamp power usage (kWh) | Lamp power (watt) | Total lamp power usage (kWh) | Cost per hour (IDR) |
| 7 AM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 8 AM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 9 AM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 10 AM | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 11 AM | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 12 AM | 16         | 1,444.70          |          |              |                   |                          |                |                        |                    |
| 1 PM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 2 PM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 25             | 0.400                  | 578                 |
| 3 PM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 24             | 0.384                  | 555                 |
| 4 PM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 24             | 0.384                  | 555                 |
| 5 PM  | 36         | 0.576             | 832       | 26           | 0.416             | 601                      | 24             | 0.384                  | 555                 |

Total daily cost 9,152 Total daily cost 6,611 Total daily cost 6,289

**4. Conclusion**

This research declares that the E11-210 and E11-112 classrooms can use daylight and artificial lighting with horizontal blinds implementation to decrease the electricity cost regarding SNI 6197-2011. This study finds that LED Tube power modification from 21 – 25 watts can save electricity costs by 37.3%. For future research, we will make algorithms and implement an automatic lamp power and opening blinds modification system in the classrooms.

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