Efficient Lighting Design for Multiuse Architecture Studio Classroom using Dialux Evo 9

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Abstract. Both natural and artificial lighting plays an important role in everyday human activities. Natural lighting conditions are responsible for energy consumption in buildings, where lack of natural lighting can increase electricity consumption for artificial lighting. The architectural studio classroom at the Department of Architecture, Universitas Trisakti, requires sufficient illumination so that room users able to do hand drawing, digital drawing, and lecture activities comfortably. To achieve such visual comfort, illumination level of the dominant activity in the studio classroom has to meet the SNI 03-2396-2001 standards by using an effective and efficient natural and artificial lighting systems. In the green building criteria by the Green Building Council Indonesia, the minimum standard for the daylight area is 30% of the total space area. The purpose of this paper is to design a new lamp grouping of Universitas Trisakti’s Architectural Studio Room in order to reduce energy consumption for lighting while increase visual comfort. This study conducted using DIALux Evo 9. From the simulation results offered a more efficient lighting installation grouping.

Keywords: Building Performance Simulation, Lighting Simulation, Dialux, Daylight Analysis, Artificial Lighting

1. Introduction

Natural lighting is the light obtained from direct or indirect sunlight, while artificial lighting is lighting that results from other sources, like lamp [1]. Artificial lighting is responsible for energy consumption in buildings. Krishan (2001) describes the percentage composition of the ventilation and lighting sector which reaches 45% of the total energy consumption of buildings [2]. Both lighting systems play an important role for human visual needs to see colors, textures, and also the impression of a space. Psychologically, the color produced by the light has a strong influence on human mood and emotions, making the atmosphere warm or cold, provocative or sympathetic, exciting or calming [3]. Therefore, the lighting design in buildings must be designed optimally to get good visual comfort. A building can be classified as a green building if the use of natural light is optimal, where at least 30% of the floor area/working plane has sufficient illuminance [4]. If the room has sufficient illuminance from natural lighting, energy consumption for artificial lighting can be reduced.

In architecture learning, the architecture studio room is a learning center where the room usage frequency is greater than other classrooms. Therefore, the quality of the lighting needs to be considered to increase the users’ comfort and to form the atmosphere of the room [5]. In Universitas Trisakti, the architectural studio room is not only used as a drawing room, but is also used as a regular classroom, so that there are many functions in the studio room. For some students, the lighting in this room is too bright or too dark and the lamp grouping is not based on. Therefore, an efficient lamp grouping is needed to accommodate the activity of the studio space.

In the old studio conditions, the artificial lamp grouping was not based on natural lighting conditions, so the lighting in the room was inefficient and not energy efficient. Therefore, the luminaire grouping arrangement must be adjusted based on natural lighting analysis to save electricity.
consumption. Activities that are usually carried out in the studio are dominated by the function of looking at an electronic screen (handphone & laptop), while the manual drawing work is only happens at the conceptual stage, design exploration, or schematic design phase.

The purpose of this study is to design a new lamp grouping based on daylight illuminance level. The minimum requirement of illumination is based on SNI 03-6575-2001 while minimum daylight area criteria are referred to Greenship Rating Tools by Green Building Council Indonesia.

2. Literature Review

2.1. Architecture Studio and Classroom Lighting Requirements

Good lighting can help increase productivity [6]. Based on SNI 03-6575-2001, the optimum illuminance of a drawing office 750 lux and classroom has the optimum illuminance at 250 lux. Both of them need artificial lighting with color rendering index (CRI) between 1 or 2. There are different activities and level of work detail inside each room, where drawing office is used for technical hand drawing, while classroom usually used for watching audiovisual, writing, and reading [7]. Natural lighting in the classroom can encourage and create a cheerful atmosphere [8]. In addition, in relation to the function of classrooms, good natural lighting has been shown to improve student learning performance in class [9]. In classrooms that use a whiteboard, the lighting must be ensured so that light reflection does not cause visual problems for students. Moreover, the lamp used in the classroom should preferably be a light with a neutral white light color that blends well with natural light, therefore a lamp with a temperature of about 4000 K is recommended [7].

2.2. Artificial Lighting

While daylighting in a working space is recommended, the use of artificial lighting is inevitable to achieve required illuminance. There are various types of lamps. In general, lamps are categorized into incandescent lamps, fluorescent lamps (including tubular lamp), metal halide lamps, mercury lamps, and sodium lamps [10]. The lamps are classified based on:

(i) The construction and how it works
(ii) The quality and color of the light produced by the lamp
(iii) Efficiency, which is generally expressed in the ratio between lumens and watts
(iv) Lamp lifetime

Tubular lamp is the most common lamp type used in classroom or office. It is classified as fluorescent lamp. It has a decent efficiency, with luminous efficacy between 70-80 lumen/Watt and it lasts up to 9000 hours. Each luminaire can consist of one to four tubular lamps.

2.3. DIALux as Daylight and Artificial Lighting Simulation Tools

DIALux is computer software for simulation and visualization of lighting in an environment. Previous lighting study in Indonesia used DIALux as it free and relatively easy to use [11], [12], [13]. It helps a user to create a virtual environment of both daylight and artificial light condition [6, 7]. It can simulate a building, a room, or even an outdoor space. It can simulate and analyze the performance of lighting system in certain geographical location and object environment, with measurement results in the form of numbers, graphs, and pictures [14]. Several analysis strategies to use DIALux as a tool to simulate lighting are shown in the following examples: Idrus (2018) made evaluation of quality of daylight integration in clear and cloudy sky conditions in office spaces [14]. Handayani, et al. (2013) used DIALux to simulate artificial lighting to achieve the required standard lighting in the workspace by making changes to the color of the room, work table, and type of lamp [15]. Kammarudin, et al (2014) conducted an analysis comparing the quality of lighting produced from CFL and LED types with DIALux to achieve energy cost savings in the case of lecture room [16]. From some of these examples it can be concluded that in lighting evaluation using DIALux provides a sufficient picture to describe an optimal lighting situation.
3. Method
This study used digital simulation DiaLux Evo 9, to calculate the light distribution and illuminance. The study methods are explained as follows:

3.1. Data Collection
The architectural studio room in this study is located on the 6th floor of Building C, Universitas Trisakti, West Jakarta, Indonesia. The opening in the room is faced to North and West. This room mostly used for design by using computers or laptops. Therefore, additional artificial light is needed in a location that is less exposed to daylight. Current condition of the grouping is less effective because it does not concur with daylight illuminance distribution. For this reason, it is necessary to group the lighting correctly. Table 1 and 2 described the architectural studio room’s dimensions and surface and lighting properties.

| Table 1. Surface and Lighting Properties |
|-----------------------------------------|
| No | Object  | Properties       |
|----|---------|------------------|
| 1  | Ceilings| White Gypsum     |
| 2  | Tiles   | White Tiles      |
| 3  | Walls   | Yellow Paint     |
| 4  | Lamps   | Philips lamps of type TBS165 G 4xTL5-14W HFS M2 |

Reference: Author’s works

| Table 2. Room Dimensions |
|---------------------------|
| No | Object            | Size (m²) |
|----|-------------------|-----------|
| 1  | Room Length (L)   | 17.426    |
| 2  | Room Width (W)    | 13.575    |
| 3  | Ceiling Height (Hc)| 2.8       |
| 4  | Suspension Height (Hs) | 0.2      |
| 5  | Working Plane Height (Hw) | 1        |

Reference: Author’s works

3.2. Modeling and Simulation by DIALux Evo 9
First, the floor plan of the architectural studio rooms is inserted, then the work plan is set. Then, the height measurement including ceiling height (Hc), suspension height (Hs), working plane height (Hw) is inserted. The next step, ceiling, tiles and walls materials is defined. Last, furniture such as tables and chairs are inserted to the model. In this simulation we use clear sky conditions. Figure 1 and 2 shows the space type setting, view, floor plan and 3D plan view.
Table 3. The steps to create a simulation using DIALux Evo 9

| No | The Steps | Information |
|----|-----------|-------------|
| 1  | Input the plan that has been provided into the DIALux Evo 9 | Figure 1. |
| 2  | Then, input the data set from the architectural studio room. | Table 2. |
| 3  | Then, create openings such as windows and doors based on the plan indicated. | Table 2. |
| 4  | After that, input the material data in the studio room. | Table 1. |
| 5  | After that, input the existing furniture in the studio room | Figure 1. |

Figure 1. Floor plan and Room Plan of Architecture Studio Room

Reference: Author’s works

Figure 2. Window settings in DIALux Evo 9

Reference: Author’s works

4. Findings and Discussion
4.1. Lamp Grouping

The first step is to collect information related to the architectural studio space, such as the material and dimensions of the room itself. Trisakti Architecture Studio Room measuring 22.5 x 17.4 x 3 m. The wall colors are bright yellow and have a fair amount of reflection. Meanwhile, the floor is made of white ceramic material. The optimum illuminance of this space type is 250 lux according to SNI-03-6575-2001 and 300 lux according to IESNA Lighting Handbook 10th Edition, where the selected space type is as reading room that can be use also for looking at laptop or a screen. The current condition of the
studio room has openings on the North and West sides of the room, and an artificial lighting system in the form of a Philips downlight lamp type TBS165 G 4xTL5-14W HFS M2 which in one armature consists of 4 TL5 lamps with a luminous efficacy of 47.1 lm/W.

First simulation is the daylighting condition where no lamp is active. The simulation is needed to design lamp grouping based on daylight illuminance. The lighting condition simulated for four different time of room usage: 08.00 WIB, 12.00 WIB, 14.00 WIB and 16.00 WIB. From this simulation, it is known that this studio room has good lighting throughout the day, unless before 08.00 WIB and after 16.00 WIB. At the 4 times above, 12.00 shows the highest average Illuminance (604 lx), while 16.00 shows the lowest average Illuminance (292 lx). The daylight illuminance distribution in false color of 4 light scenes can be seen in Figure 3. In Figure 3, it can be seen that the more orange an area in the plan is, the higher the illuminance value. On the other hand, the greener it is, the lower the illuminance value. It is also known that the lower-right Southeast area is an area that consistently has illuminance below the classroom’s natural lighting standards, so it requires artificial lighting all the time. Meanwhile, the table in the first and second rows on the North side and the first column from the West side consistently get sufficient natural lighting, so it doesn’t require artificial lighting from 8.00 WIB to 16.00 WIB. Figure 3 and 4 will be used as reference for the new artificial lamp grouping. The lamp grouping will separate the row or column that do not need artificial lighting are in one group with those that consistently require artificial lighting are grouped into different groups.

Figure 3. False colors result in daylighting condition using DIALux Evo 9
Reference: Author’s works
Table 4. Daylight Area of Architecture Studio Room

| No | Time  | Max (Lx) | Min (Lx) | Average (Lx) |
|----|-------|----------|----------|--------------|
| 1  | 08.00 | 1701 Lux | 62.3 Lux | 303 Lux      |
| 2  | 12.00 | 3384 Lux | 124 Lux  | 604 Lux      |
| 3  | 14.00 | 2906 Lux | 106 Lux  | 518 Lux      |
| 4  | 16.00 | 1637 Lux | 59.9 Lux | 292 Lux      |

Reference: Author’s works based on simulation using DIALux Evo

To design the lamp grouping, the second simulation is conducted on daylighting conditions (no active lamp), artificial lighting with 9 active armatures, and 12 active armatures at 14:00 WIB. Based the second simulation, it is known that working plane in B1, B5, D1, D5 (light green), and working plane in B1, B4, D1, D4 (dark green) in Figure 4 are the areas least exposed to sunlight throughout the day. Therefore, additional lighting is needed so that the lighting can be evenly distributed in the room. From both artificial lighting scenes, it is known that in the worst daylighting condition at 14:00 WIB needs 12 active armatures to achieve sufficient illuminance, since in 9 active armatures scene, area C5-D5 are still below the illuminance standard (shown by light green shade).

Figure 4. False colors result on three different light scenes; 1) No Active Lamp, 2) 9 active armatures, 3) 12 active armatures

Reference: Author’s own works
Table 5. Artificial Area of Architecture Studio Room

| No | Time             | Max (Lx) | Min (Lx) | Average (Lx) |
|----|------------------|----------|----------|--------------|
| 1  | 14.00 (Daylight) | 2906 Lux | 106 Lux  | 518 Lux      |
| 2  | 14.00 (9 Armatures) | 2915 Lux | 208 Lux  | 660 Lux      |
| 3  | 14.00 (12 Armatures) | 2931 Lux | 210 Lux  | 705 Lux      |

In the initial condition of lamp grouping, grouping did not consider the daylight illuminance. In Figure 5, the initial lamp grouping and proposed lamp grouping are presented. The initial lamp grouping consists of six groups of 3-4 armatures, while the proposed lamp grouping consists of 7 groups of 3 armatures, which are grouped by the pattern of daylight illuminance distribution. Each proposed lamp group did not exceed 200 watts.

![Figure 5. Initial Grouping Lamp (left, purple lines) and Proposed Grouping Lamp (Right, orange lines)](Reference: Author’s works)

Table 6. Comparison between the situation before and after being optimized

| No | Time                  | Max (Lx) | Min (Lx) | Average (Lx) |
|----|-----------------------|----------|----------|--------------|
| 1  | Initial Grouping Lamp | 3005 Lux | 179 Lux  | 690 Lux      |
| 2  | Proposed Grouping     | 3016 Lux | 174 Lux  | 735 Lux      |

Reference: Author’s works based on simulation using DIALux Evo 9

The optimum illuminance standard of drawing-room did not applicable in this case because the studio room have to provide another activity. By following the regular classroom standard, unwanted glare because of artificial lighting can be avoided most of the time. Energy-wise, in artificial lighting simulations at 14.00, 16.00, and 20.00, Philips lamps of type TBS165 G4xTL5- 14W HFS M2 are used in 20 light points that are evenly distributed, with Ra 80 and color temperature of 4000 K (Neutral White). One armature consists of 4 energy-efficient TL5 lamps, with a luminous efficacy of 47.1 lm / W. During the day, if you turn on 9 lamps, the energy consumption will be 1400-2050 kWh/year, while 12 lamps require 1850-2800 kWh/year. Both of these figures remain below the target of 12,000 kWh / year. This value obtained from 3700 hours of space usage time a year multiplied by SNI requirements of 15 W / m2 for classroom functions.
4.2. Sufficient daylight area percentage

Figure 6 and Table 4 show Daylight Area Percentage of the architectural studio room. Based on GBCI Greenship Ratings, a room is considered as green if the Daylight Area Percentage takes up 25-30% of the total space area. In all four daylight simulation scenes at 08.00 WIB, 12.00 WIB, 14.00 WIB and 16.00 WIB, the daylight area reaches 30% throughout the day. By this means, this room has met the green criteria. However, the area near the openings needs more attention, since discomfort glare can be happened, especially in row B-7 and C7 where the lights are come from behind the working plane. Figure 6 shows the isolines line of 300 lux, while table 3 shows. Natural lighting conditions at the moment have met the criteria of the green, but the arrangement of artificial lighting, lamp grouping is not adapted to the analysis of natural lighting so it tends to wasteful energy consumption.

Figure 6. Daylight Area Percentage in Architecture Studio Room is shown by the isolines line of 300 lx

Reference: Author’s works

Figure 7. Daylight Area Visualisation in actual condition and Simulation

Reference: Author’s
5. Conclusion
From this study, it can be concluded that the lamp grouping should be considering the daylighting illuminance to achieve an energy-efficient lighting system. Moreover, the lighting design of multiuse space must be considering the dominant task in that area. Whenever higher illuminance is needed, it can be provided by task lighting.

Based on the results of the analysis, the following conclusions can be drawn:

1. Natural Lighting System
   a. The window opening area has met the green standard according to the GBCI, so that sunlight can enter optimally.
   b. Areas B1, B5, D1, D5 (light green), and areas B1, B4, D1, D4 (dark green) are the areas least exposed to sunlight throughout the day.

2. Artificial Lighting System
   a. Lighting standards for the room must follow the most dominant function used in the room, this can be taken based on the hours of use.
   b. Grouping lights are needed so that lighting can be efficient in the room.
   c. The lamp grouping must be based on a natural lighting analysis to find the point where the lighting is most necessary.
   d. Areas B1, B5, D1, D5 (light green), and regions B1, B4, D1, D4 (dark green) are areas that require grouping of lights.

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References
[1] M. K. Fahmi, “PERBEDAAN TINGKAT PENCAHAYAAN ALAMI DAN BUATAN RUANG LABORATORIUM KOMPUTER TERHADAP KENYAMANAN SISWA PADA PROSES BELAJAR MENGAJAR,” Universitas Pendidikan Indonesia, 2013.
[2] Krishan, Arvind, ed. Climate responsive architecture: a design handbook for energy efficient buildings. Tata McGraw-Hill Education, 2001.
[3] I. H. Marsya and A. W. Angraita, “Studi Pengaruh Warna pada Interior Terhadap Psikologis Penggunanya, Studi Kasus pada Unit Transfusi Darah Kota X,” J. Desain Inter., vol. 1, no. 1, p. 41, 2016, doi: 10.12962/j12345678.v1i1.1461.
[4] Green Building Council Indonesia, “Perangkat Penilaian GREENSHIP (GREENSHIP Rating Tools),” Greensh. New Build. Versi 1.2, no. April, 2013.
[5] A. R. Mandala, Ariani, E.B.Handoko Sutanto, “DAN KREATIVITAS RUANG KERJA (Objek Studi : Ruang Studio Perancangan Arsitektur di Universitas Katolik Parahyangan, Bandung ) Disusun Oleh : Ariani Mandala , ST., MT E. B. Handoko Sutanto , Ir., MT Amirani Ritva S , Ir. , MT Lembaga Penelitian dan Pe,” no. lii, pp. 1–19, 2018.
[6] Z. Poursafar, N. R. Devi, and L. L. R. Rodrigues, “Evaluation of color and lighting preferences in architects’ offices for enhancing productivity,” Int. J. Curr. Res. Rev., vol. 8, no. 3, pp. 1–6, 2016.
[7] SNI 03-6575-2001, Tata Cara Perancangan Sistem Pencahayaan Buatan pada Bangunan Gedung. 2001.
[8] L. E. Mavromatidis, X. Marsault, and H. Lequay, “Daylight factor estimation at an early design stage to reduce buildings’ energy consumption due to artificial lighting: A numerical approach based on Doehlert and Box- Behnken designs,” Energy, vol. 65, pp. 488–502, 2014, doi: 10.1016/j.energy.2013.12.028.
[9] Lisa Heschong, California Energy Commission. Public Interest Energy Research Program (PIER), I. New Buildings Institute, and Heschong Mahone Group, “Windows and classrooms: a study of student performance and indoor environment: technical report,” CLIMA 2007 Wellbeing Indoors, vol. 2, no. 2, p. 15, 2003.
[10] S. T. M. T. Nur Laela Latifah, *Fisika Bangunan* 2. GRIYA KREASI.
[11] A. Mandala, “Lighting Quality in the Architectural Design Studio (Case Study: Architecture Design Studio at Universitas Katolik Parahyangan, Bandung, Indonesia),” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 238, no. 1, 2019, doi: 10.1088/1755-1315/238/1/012032.
[12] D. D. A. Wijaya, S. S. Utami, G. S. Adi, and B. Prayitno, “Optimization of Natural and Artificial Lighting System Design in the Library of the Faculty of Economics and Business, Universitas Gadjah Mada,” *ICETAS 2019 - 2019 6th IEEE Int. Conf. Eng. Technol. Appl. Sci.*, 2019, doi: 10.1109/ICETAS48360.2019.9117347.
[13] P. Satwiko, “Pemakaian perangkat lunak,” vol. 9, nomor 2, pp. 142–154, 2011.
[14] I. Idrus, “Evaluasi Kondisi Pencahayaan Integrasi Manual Pada Ruang Kantor Menara Balaikota Makassar,” *J. Linears*, vol. 1, no. 1, pp. 1–11, 2019, doi: 10.26618/j-linears.v1i1.1312.
[15] D. Handayani, L. D. Fathimahhayati, Suhendrianto, S. Pina, and I. G. B. B. Dharma, “Analisis Pencahayaan Ruang Kerja: Studi Kasus Pada Usaha Kecil Mikro dan Menengah (UMKM) Batik Tulis di Yogyakarta,” *Din. Rekayasa*, vol. 9, no. 1, pp. 6–9, 2013.
[16] M. A. Kamaruddin, Y. Z. Arief, and M. H. Ahmad, “Energy Analysis of Efficient Lighting System Design for Lecturing Room Using DIAlux Evo 3,” *Appl. Mech. Mater.*, vol. 818, pp. 174–178, 2016, doi: 10.4028/www.scientific.net/amm.818.1