Lighting in Tropics: The Interplay Between Reflectance, Illuminance, and Visual Perception in an Architecture Studio

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Abstract. In the Global South, architectural design is informed by environmental, material availability, and adaptability. In this context, architectural elements with light are essential for creating a comfortable visual. This study examines the relationship between surface reflectance, illuminance levels, and visual perception in two architecture studios at Institut Teknologi Sepuluh Nopember, Surabaya. A correlational strategy was used by combining field measurement, DIALux simulation, and a closed-ended questionnaire. Illuminance data were collected over four days, while simulations quantified the reflectance of walls, floors, and ceilings. User perception was evaluated using a Likert-scale questionnaire that covered brightness, distribution, glare, adequacy, relaxation, comfort, eye strain, satisfaction, productivity, and color quality. Results show that surface reflectance has a significant impact on indoor illuminance ($R^2 = 0.77$). Despite illumination levels below national standards, users perceived the lighting as neutral, indicating user adaptation to the lighting environment. A strong correlation was found between satisfaction and productivity ($\beta = 0.74$, $p < 0.001$, $R^2 = 0.55$, meaning that higher satisfaction with light is in line with high productivity in the studios. These findings demonstrate that in tropical countries, the variations in surface reflectance significantly influence illuminance and visual perception.

Keywords: Reflectance, Illuminance, Visual Perception, Architectural Elements, Tropical Climate

1 Introduction

Buildings in the Global South are shaped by environmental conditions, resource availability, and adaptive design strategies [1]. Within these conditions, lighting plays a central role in defining both the functional and perceptual qualities. Based on its source, lighting is divided into two types including daylight and artificial lighting [2]. Daylight is light from nature in the form of skylight [3]. Artificial light is produced by

M. Rachmawati and K. Hanifati (eds.), *Proceedings of the International Conference on Architectural Research and Design (ARDC 2025)*, Atlantis Highlights in Social Sciences, Education and Humanities 47,
https://doi.org/10.2991/978-94-6239-632-6_26

human-made sources, including electric lamps [4]. Both types influence users' visual perception [5]. Therefore, it's imperative to understand the relationship between the physical quantity of light and the visual experience to achieve responsive and comfortable design outcomes.

Indonesia is one of the tropical countries located in the Global South that has unique lighting challenges and opportunities. The high amount of daylight throughout the year requires strategies that control brightness and glare while maintaining adequate illumination and visual comfort. Architectural elements such as surface materials and reflectance serve as passive tools for managing indoor lighting conditions. Both daylight and artificial lighting are influenced by color and the reflectance of architectural elements and furnishings [6–8]. Previous study stated that the reflectance of the ceiling, chairs, and tables in a room influences the performance of artificial lighting in a room [6]. The type of ceiling surface, such as glossy and matte, affects the level of illumination in a room [6]. When exposed to light, a glossy white surface has a higher level of shine than a matte surface [9, 10]. Another study showed that classrooms with white walls and floors had higher levels of illumination [11]. Therefore, the use of materials with bright colors and high reflectance is recommended to improve indoor lighting performance [12]. On the contrary, if the room elements have dull colors and low reflectance, they require a lighting source with a higher illumination level to meet the lighting requirements [6]. Thus, the reflectance properties of architectural elements directly impact the indoor illuminance level.

In an education building, lighting influences learning achievement and performance [13]. Adequate lighting in classrooms supports learning activities, impacting cognitive processes, concentration, and health. Meanwhile, inadequate lighting can increase the risk of visual fatigue [14]. At the university, lighting requirements are tailored to the function of each classroom. Generally, a hybrid system that combines daylight and artificial light is used to meet lighting requirements in a university. Pedagogically, classrooms in higher education are divided into several types. Each type of classroom needs to adjust its lighting requirements based on the activities [15]. One of the pedagogies is studio-based learning, where the activities are influenced by both daylight and artificial lighting [16, 17]. According to the Indonesian National Standard (SNI) for universities, which specifies the requirements for drawing rooms, study rooms, and computer rooms, each requires a lighting intensity of 750 lux, 350 lux, and 150 lux, respectively [18]. Despite having a standard for the studio, previous studies show that the illuminance level in the architecture studios is insufficient [19–21]. These studies reveal similar results where users perceived the visual comfort inside the studio as neutral. This suggests that subjective perception does not match objective illumination levels. Previous studies examined the user perception by relying on studio light conditions, without considering how architectural surface properties, such as reflectance, affect both the physical and perceptual aspects of lighting. Therefore, this study investigates the relationship between the surface reflectance of architectural elements, illuminance levels, and visual perception in tropical studio learning environments. This study aims to demonstrate how material reflectance influences physical lighting performance and users' psychological responses, such as perceived brightness, perceived glare, eye strain, relaxed [19], spatial light distribution [22], perceived adequacy, color quality, light comfort [23], productivity, dan satisfaction [24].

2 Methods

The present study was conducted in two architecture studios with a capacity of more than 75 students that are located at Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia (Fig. 1). To analyze the impact of architectural elements on illuminance level and the relation between each of the visual perception aspects, the present study used a correlation strategy [25]. The data were collected by field measurement, simulation, and questionnaire.

2.1 Field Measurement

Field measurements were conducted to measure the illuminance levels in both studios in their existing condition. Measurements were taken at two different locations in each studio, repeated over four consecutive days, and at consistent times from 07:30 to 16:00 (Fig. 2). The measurement process adhered to the Indonesian National Standard (SNI) for indoor lighting. Average illuminance values were recorded in lux using calibrated light meters. The measurements documented the spatial and temporal variations in light intensity, which were subsequently used as input data for lighting simulations.

2.2 Lighting Simulation

Lighting simulations were conducted using DIALux evo software to model and replicate the existing conditions of each studio (Fig. 3). The purpose of the simulation was to determine the reflectance percentage of each architectural surface, namely, the walls, floor, and ceiling. The material color and finish data collected from the field were input into the simulation model to ensure accurate representation. The accuracy of the simulation was validated by comparing simulated and measured illuminance data using statistical indicators such as Root Mean Square Error (RMSE < 10 lux), Coefficient of Determination ($R^2 > 0.95$), and Willmott's Index of Agreement ($d > 0.9$) [26]. The validated models were used as reliable data for analyzing the relationship between surface reflectance and illuminance performance.

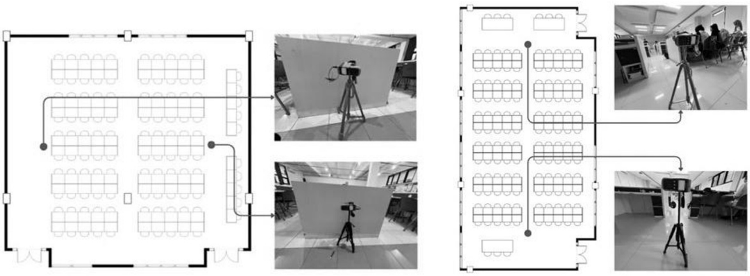
2.3 Questionnaire Survey

To gather user responses, a questionnaire was given to students during the measurement period. The questionnaire aimed to evaluate visual perception using a 7-point Likert scale (1 = very high, 7 = very low) (Fig 4) and covered ten perceptual factors: perceived brightness, spatial light distribution, adequacy, color quality, light comfort, glare, eye strain, relaxation, satisfaction, and productivity. To ensure authentic and contextual responses, respondents were asked to assess their perception during normal studio activities.

2.4 Data Analysis

Data analysis was carried out in two statistical analyses. First, a regression analysis that used to examine the relationship between the illuminance levels as a dependent variable (X) and the reflectance value of architectural elements as an independent variable (Y). The findings were interpreted using the coefficient of determination (R^2) and significance testing (p-value < 0.05) [27]. Second, a Pearson correlation test was conducted to explore the interrelationships among the visual perception aspects obtained from the survey. This analysis revealed which aspects were most strongly linked. By combining regression and correlation analysis, this study was able to identify physical and psychological aspects of lighting performance. Overall, the methodological framework ensured that the findings accurately reflected the true influence of architectural surface reflectance on lighting conditions and user perception within studios located in tropical environments.

Fig. 1. Location of Institut Teknologi Sepuluh Nopember (modified from https://vemaps.com and https://beta.aino.world/)



(a) (b)

Fig. 2. Field measurement inside the studio (a) Studio A; (b) studio B

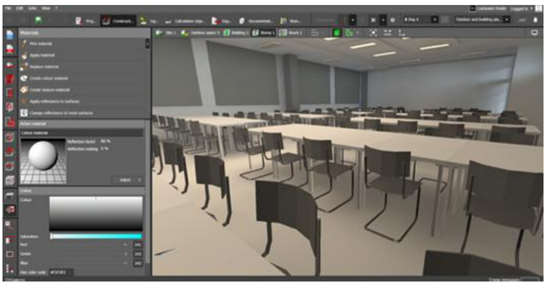


Fig. 3. The simulation model in DIALux

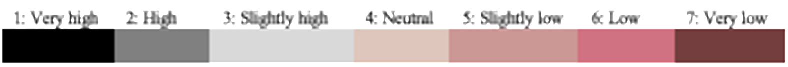


Fig. 4. Likert scale for questionnaire

3 Results and Discussion

3.1 Relationship Between Illumination Level and Surface Reflectance

The measurement results are the average illumination levels from 2 different points in each studio for 4 days. Based on the measurements, it is revealed that the average illumination levels in Studio A for each day 1, 2, 3, and 4 are 77.08 lux, 57.14 lux, 54.25 lux, and 53.36 lux, respectively (Fig. 5). These results indicate that the illumination level in Studio A does not meet SNI standards. Meanwhile, the illumination level in Studio B averaged 247.53 lux, 250.44 lux, and 210.47 lux on Days 2, 3, and 4. These results only meet the minimum requirement for computer rooms (150 lux). Overall illumination level in both studios is falling short of the standard for the drawing room (750 lux) and study room (350 lux) (Fig. 5).

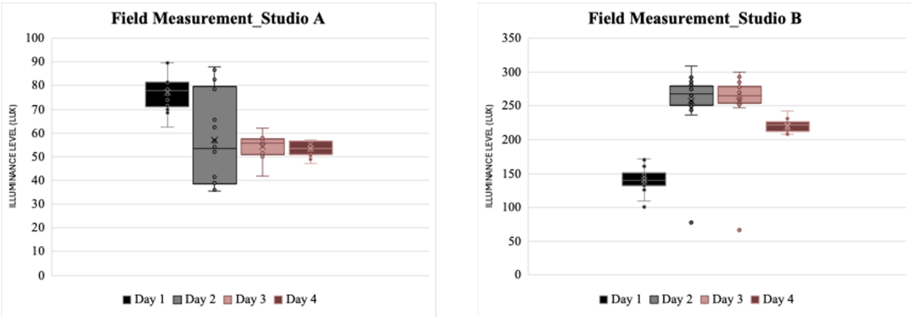


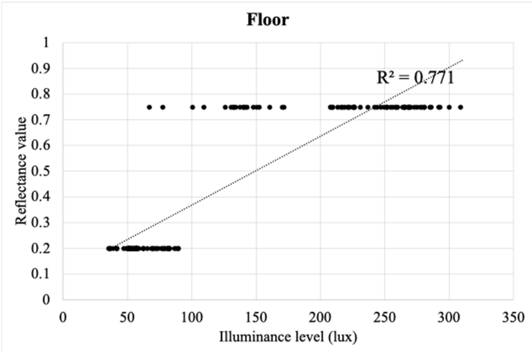
Fig. 5. Illuminance level (a) studio A; (b) studio B

The results of the illuminance level are influenced by various factors such as the light source, the surrounding environment, and the surface reflectance of architectural elements. The reflectance value of each architectural element was obtained through a 3D model in DIALux simulation. The simulation results show that B had higher reflectance values for each element, including walls (80%), floor (75%), and ceiling (76%). While in Studio A, the reflectance values for wall, floor, and ceiling were only 30%, 20%, and 30% (Table 1).

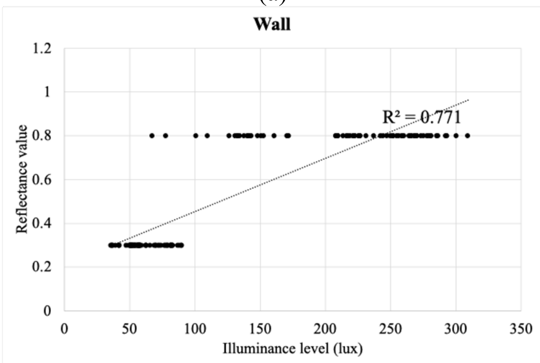
Table 1. Reflectance value in studio A and studio B

Element	Element’s reflectance (%)	
	Studio A	Studio B
Wall	30	80
Floor	20	75
Ceilling	30	76

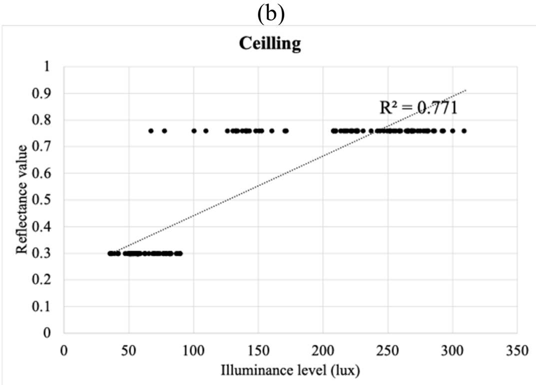
To analyze the relationship between the surface reflectance and illuminance level, regression was used with the measured illuminance as the dependent variable (X) and the reflectance percentage as the independent variable (Y). The results of the regression analysis show that the color of the floor, wall, and ceiling influences illuminance level, with a coefficient of determination (R^2) of 0.771 (Fig. 6). The R^2 value indicates that the three-room elements, namely the floor, walls, and ceiling, explain 77.71% of the illuminance in the studios. This result is categorized as high influence, indicating that surface reflectance has a significant influence on enhancing lighting performance. This is aligned with previous studies where rooms with high reflectance affect the illumination levels [6, 11, 12]. Additionally, regression results are the same due to each element's color, using white with a nearly identical reflectance range.



(a)



(b)



(c)

Fig. 6. The influence of (a) floor, (b) wall and (c) ceiling surface value on lighting

3.2 Assessing Visual Perception of Lighting Quality

The quality of light was identified by subjective assessment using Likert-scale closed-ended questionnaire. The results show that students in Studio A tended to choose a neutral scale in almost all aspects. Variation was found only in the eye strain aspect on day 2 (Fig. 6), where the illumination level at an average of 47.14 lux, but some students reported having lower eye strain. Generally, insufficient light could cause eye fatigue [28, 29]. Contrary to this study, a lower illumination level has a positive impact on reducing the risk of eye fatigue. In Studio B, perception patterns varied more across all aspects, with at least one day where some of the students chose the neutral. A quite visible difference was found in the relaxed aspect on day 2 (Fig. 6). even though the illumination met the standard for computer rooms, respondents reported feeling slightly less relaxed. The overall results of lighting quality were rated neutral in studios A and B. These results indicate that, despite being below the standard, students in both studios tended to perceive the lighting conditions as neutral. This finding supports previous research that stated that studio users felt neutral and comfortable with lighting conditions that fell below the SNI standard [19]. Based on the results, it is suspected that the choice of a neutral scale was due to the duration of use of the space. In both studios, students spent at least 5 hours in the studios twice a week. Previous research suggests that time spent in the room influences perception of lighting [30].

To analyze the correlation between one aspect and another, a Pearson correlation test was conducted (Table 2). In Studio A, satisfaction was the aspect with the highest correlation with other aspects. Student satisfaction influenced spatial light distribution, perceived adequacy, productivity, light comfort, and color quality. The highest correlation value was found between satisfaction and productivity, with $\beta = 0.74$, $p < 0.001$, $R^2 = 0.55$. These results indicate that increasing user satisfaction with lighting will increase productivity. In Studio B, the most influential aspects were light comfort and color quality. Color quality based on lighting conditions significantly influenced perceived comfort ($\beta = 0.62$, $p < 0.001$), with $R^2 = 0.39$. These results indicate that an increase in perceived color quality directly impacts the visual comfort in the studio. The analysis of the relationships between aspects of the two studios showed that the correlation between psychological aspects was higher than between physiological aspects, like brightness and glare. This suggests that during prolonged spatial engagement, users' psychological adaptation plays a more significant role in shaping overall comfort perception in the architecture studio.

The overall results show that material reflectance has impacts on both the illuminance level and visual perception aspects in the architecture studio as a learning environment in tropical country. Studio with high-reflectance surfaces achieves a higher illumination level. Moreover, despite illumination levels below the recommended SNI standards, users still reported neutral to positive perceptions of visual comfort. This highlights a form of psychological adaptation among users who regularly occupy the same environment for long durations, consistent with a previous study that stated long-term exposure influences perceptual tolerance towards lighting variations [28]. Therefore, beyond simply meeting numerical standards, lighting design for educational spaces in tropical climates should focus on improving material reflectance and perceptual harmony. Combining quantitative lighting control with perception assessment offers a more comprehensive approach to attaining visual comfort in architecture studios and other learning environments.

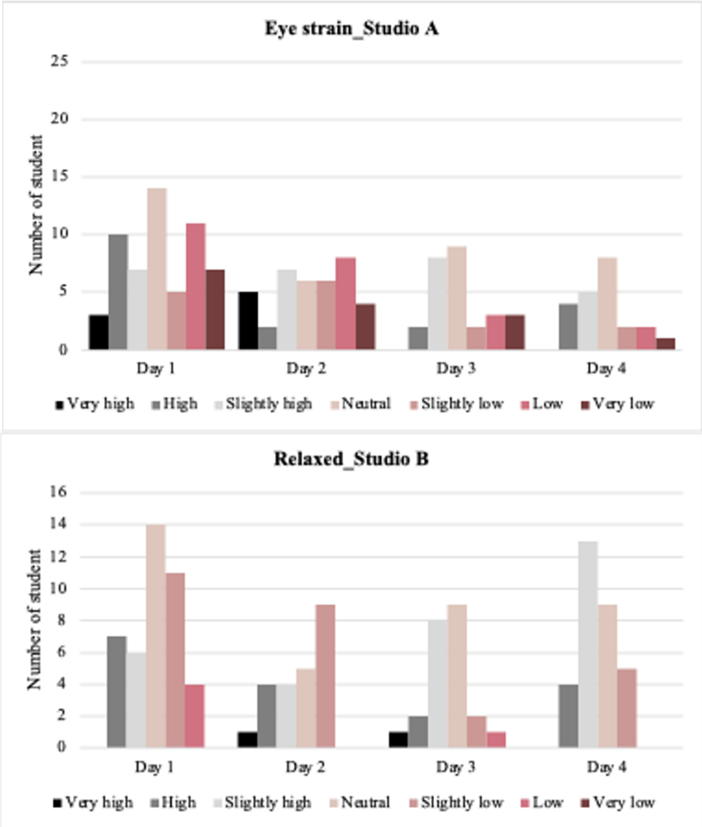


Fig. 7. The visual perception results in studio A and studio B

Table 2. The relation of visual perception aspects

Visual perception aspects	β	p-value	R^2
Studio A			
Perceived brightness – Spatial light distribution	0.55	8.78×10^{-13}	0.30
Spatial light distribution - Satisfaction	0.58	3.29×10^{-14}	0.33
Spatial light distribution - Productivity	0.54	4.55×10^{-12}	0.29
Perceived adequacy - Satisfaction	0.58	1.79×10^{-14}	0.34
Satisfaction - Productivity	0.74*	2.78×10^{-26}	0.55
Satisfaction - Light comfort	0.57	1.48×10^{-13}	0.57
Satisfaction - Color quality	0.55	1.43×10^{-12}	0.30
Productivity - Light comfort	0.55	6.80×10^{-13}	0.31
Relaxed - Light comfort	0.68	4.56×10^{-21}	0.47

Visual perception aspects	**β**	**p-value**	**R^2**
Studio B			
Color quality - light comfort	0.62*	$3{,}35 \times 10^{-14}$	0.39
Color quality - relaxed	0.53	$7{,}68 \times 10^{-10}$	0.28
Color quality - satisfaction	0.52	$1{,}29 \times 10^{-9}$	0.27
Light comfort - relaxed	0.59	$1{,}45 \times 10^{-12}$	0.35
Light comfort - satisfaction	0.52	$1{,}02 \times 10^{-9}$	0.27

*: highest correlation value

4 Conclusion

Lighting has major rules for shaping the quality of an interior in the tropics, especially in learning environments like architecture studios. An architecture studio is a space that requires light to optimize its function to accommodate learning processes and design-based activities. This study examined how architectural surface reflectance affects illuminance levels and visual perception of users in two studios at Institut Teknologi Sepuluh Nopember, Surabaya. The results indicate that the illuminance level in the studios does not meet the SNI lighting standards for a drawing room (750 lux). However, Studio B, which had higher surface reflectance values, reached illumination levels suitable for computer room standards (150 lux), with average measurements of 247.53 lux, 250.44 lux, and 210.47 lux. Regression analysis shows that the reflectance value of wall, floor, and ceiling significantly influenced lighting performance, with $R^2 = 0.771$. Indicating that 77.1% of the variance in illumination could be explained by surface reflectance. This finding highlights that bright-coloured and highly reflective materials, particularly white finishes, improve indoor lighting.

Regardless of the lower illuminance level below the standards, students gave neutral and positive assessments. Indicate student adaptation to the studio environment. The aspects with the highest correlation are satisfaction and productivity, with $\beta = 0.74$, $p < 0.001$, $R^2 = 0.55$. It can be concluded that psychological aspects can explain subjective assessments of lighting conditions based on user perception. The findings emphasize that architectural surface reflectance is a vital passive approach for enhancing lighting quality and visual comfort in tropical educational environments. However, this study only used studio spaces with predominantly white surface colors. Therefore, the regression results obtained were the same for each relationship between illumination levels and spatial elements. Thus, future research could use studios with a wider variety of surface colors to explore the broader impacts of material variation on illumination and perception. Combining reflectance-based design strategies with an experiment user-centered strategy.

References

1. Cruz AS, López-Guerrero RE, Mendes VF, et al (2025) How feasible is climate-resilient building design within the Global South context? Insights from Latin American residential sector. Energy Build 347:. https://doi.org/10.1016/j.enbuild.2025.116277
2. Jihan, Ferdinand (2023) Application of Artificial Light in the Interior Design of Green Lake City Cluster East Asia Residential House in Tangerang. International Journal of Application on Sciences, Technology and Engineering 1:536–548. https://doi.org/10.24912/ijaste.v1.i2.536-548
3. Knoop M, Stefani O, Bueno B, et al (2020) Daylight: What makes the difference? Lighting Research and Technology 52:423–442. https://doi.org/10.1177/1477153519869758
4. Ismail IC, Rahim R, Hamzah B (2021) Integration of Natural and Artificial Light on Energy Efficiency of the Mega Bank Makassar Tower Building. EPI International Journal of Engineering 4:71–80. https://doi.org/10.25042/epi-ije.022021.10
5. Liu Q, Huang Z, Li Z, et al (2020) A field study of the impact of indoor lighting on visual perception and cognitive performance in classroom. Applied Sciences (Switzerland) 10:1–17. https://doi.org/10.3390/app10217436
6. Nugroho P (2022) JARINA-Journal of Artificial Intelligence in Architecture The Effect of the Reflective Interior Elements on the Illuminance Level in Classrooms. 1:
7. Pracki P, Dziedzicki M, Komorzycka P (2020) Ceiling and wall illumination, utilance, and power in interior lighting. Energies (Basel) 13:. https://doi.org/10.3390/en13184744
8. Ticleanu C (2021) Impacts of home lighting on human health. Lighting Research and Technology 53:453–475. https://doi.org/10.1177/14771535211021064
9. Franklin, A. M., & Ospina-Rozo, L. (2021). Gloss. Current biology : CB, 31(4), R172–R173. https://doi.org/10.1016/j.cub.2020.11.065
10. Hébert M, Hélou-De La Grandière P, Pozzi Y, et al (2023) Wide-field gloss scanner designed to assess appearance and condition of modern paintings. https://doi.org/10.2352/lim.2023.4.1.23ï
11. Escobar I, Orduna-Hospital E, Aporta J, Sanchez-Cano A (2024) Efficient Daylighting: The Importance of Glazing Transmittance and Room Surface Reflectance. Buildings 14:. https://doi.org/10.3390/buildings14103108
12. Makaremi N, Schiavoni S, Pisello AL, Cotana F (2019) Effects of surface reflectance and lighting design strategies on energy consumption and visual comfort. Indoor and Built Environment 28:552–563. https://doi.org/10.1177/1420326X18793170
13. Mogas-Recalde J, Palau R (2021) Classroom lighting and its effect on student learning and performance: Towards smarter conditions. In: Smart Innovation, Systems and Technologies. Springer Science and Business Media Deutschland GmbH, pp 3–12

14. Dang R, Liu Y, Chang S (2023) The impact patterns of classroom lighting parameters on visual fatigue and a mathematical model. Build Environ 234:. https://doi.org/10.1016/j.buildenv.2023.110193
15. Castilla N, Llinares C, Bisegna F, Blanca-Giménez V (2018) Affective evaluation of the luminous environment in university classrooms. J Environ Psychol 58:52–62. https://doi.org/10.1016/j.jenvp.2018.07.010
16. Sholanke A, Fadesere O, Elendu D (2021) The Role of Artificial Lighting in Architectural Design: A Literature Review. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing Ltd
17. Emara ME, Mayhoub M, Mahmoud HA, et al (2024) Lighting impact on architecture student experience in higher education buildings in Egypt. Alexandria Engineering Journal 108:108–121. https://doi.org/10.1016/j.aej.2024.07.067
18. SNI 03-6575-2001 (2001) Tata cara perancangan sistem pencahayaan buatan pada bangunan gedung.
19. Mandala A (2019) Lighting Quality in the Architectural Design Studio (Case Study: Architecture Design Studio at Universitas Katolik Parahyangan, Bandung, Indonesia). In: IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing
20. Musa AR, Abdullah NAG, Che-Ani AI, et al (2012) Indoor Environmental Quality for UKM Architecture Studio: An Analysis on Lighting Performance. Procedia Soc Behav Sci 60:318–324. https://doi.org/10.1016/j.sbspro.2012.09.386
21. Kong Z, Jakubiec JA (2019) Instantaneous and long-term lighting design metrics for higher education buildings in a tropical climate. In: Building Simulation Conference Proceedings. International Building Performance Simulation Association, pp 1083–1090
22. Sokol N, Martyniuk-Peczek J, Matusiak B, et al (2023) 'Personas for lighting'. Three methods to develop personas for the indoor lighting environment. Energy Build 278:. https://doi.org/10.1016/j.enbuild.2022.112580
23. Yang W, Jeon JY (2023) Effects of lighting and sound factors on environmental sensation, perception, and cognitive performance in a classroom. Journal of Building Engineering 76:. https://doi.org/10.1016/j.jobe.2023.107063
24. Yang Z, Becerik-Gerber B, Mino L (2013) A study on student perceptions of higher education classrooms: Impact of classroom attributes on student satisfaction and performance. Build Environ 70:171–188. https://doi.org/10.1016/j.buildenv.2013.08.030
25. Groat, L. N., & Wang, D. (2013). Architectural Research Methods. New Jersey: John Wiley & Sons, Inc.
26. Aghajari S, Chen CC (2025) Optimizing Classroom Lighting for Enhanced Visual Comfort and Reduced Energy Consumption. Buildings 15:. https://doi.org/10.3390/buildings15081233
27. Kwak S (2023) Are Only p-Values Less Than 0.05 Significant? A p-Value Greater Than 0.05 Is Also Significant! J Lipid Atheroscler 12:89–95. https://doi.org/10.12997/jla.2023.12.2.89

28. Tanzila RA, Arista D (2023) The Correlation Between Light Intensity, Age, And Working Period With Eye Fatigue In Computer Users. MAGNA MEDICA Berkala Ilmiah Kedokteran dan Kesehatan 10:1. https://doi.org/10.26714/magnamed.10.1.2023.1-8
29. Chasanah U, Widodo A (2023) Analysis of Classroom Light Intensity as an Indicator of Effects of Eyestrain in the Effectiveness of the Learning Process at the Universitas Muhammadiyah Lamongan. Jurnal Pendidikan Fisika dan Keilmuan (JPFK) 9:141. https://doi.org/10.25273/jpfk.v9i2.17716
30. Nikookar N, Sawyer AO, Goel M, Rockcastle S (2024) Investigating the Impact of Combined Daylight and Electric Light on Human Perception of Indoor Spaces. Sustainability (Switzerland) 16:. https://doi.org/10.3390/su16093691