Lighting Energy Reduction by Optimizing Daylight while Maintaining Cooling Load in Tropical Educational Building, Depok, Indonesia

JSACE 1/32

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Received 2022/09/12

Accepted after revision 2023/03/13

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https://doi.org/10.5755/j01.sace.32.1.32267

Abstract

This study aims to reduce the lighting energy consumption in educational buildings while avoiding an increase in cooling load. The Faculty of Engineering building in Universitas Indonesia, Depok, West Java, Indonesia is used as a case study. Daylight optimization can have an impact on lighting energy, which is the largest energy consumer in educational buildings. However, given Indonesia's tropical climate, daylight leading to heat gain is a concern. Current passive design interventions for controlling daylight and heat gain include light shelves, clerestories, and glazing materials. Daylighting performance is simulated using DIALux software. Results of each intervention are analyzed quantitatively and qualitatively by theories and parameters, namely illuminance level, light uniformity, and overall thermal transfer value (OTTV). Light shelves result in increased uniformity and lower OTTV. Clerestories result in increased average illuminance but higher OTTV. Active intervention with a dimming and grouping system is applied after daylight increases. The combination of passive design interventions and active dimming of electric lights reduces lighting energy with the same OTTV as existing. This study recommends the use of passive and active daylighting strategies considering their effect on the cooling load of buildings.

Keywords: daylighting, lighting energy, cooling load, technical analysis, tropical climate, educational building.

Introduction

The United Nations (UN) on Sustainable Development Goals (SDGs) for Energy and Climate Change (ECC) category aims for affordable and clean energy and responsible consumption and production (UN, 2020). The building sector is responsible for 40% of the total energy consumption with the energy consumption percentage for lighting in the building sector ranging from about 20% to 45% and around 40% of the energy consumption of educational buildings consumed for lighting (IEA, 2011; Lechner, 2015). Studies on the energy efficiency of school buildings in tropical and subtropical countries have shown that air conditioning and lighting are important factors in the energy consumption (Wang, 2016). Indonesia being a country with a hot and humid climate with long sun hours of up to 12 hours provides considerable potential for the use of daylight (Tra-

Journal of Sustainable Architecture and Civil Engineering
Vol. 1 / No. 32 / 2023
pp. 145-161
DOI 10.5755/j01.sace.32.1.32267

genza, 2011). On the other hand, reducing heat gain in a region with this climate is also a challenge (IEA, 2019). Regarding energy efficiency, the Indonesian Green Building Council has called for a 40% reduction in artificial lighting through the use of natural light (GBCI, 2020). In addition, optimum daylight is needed for the health, well-being, and productivity of occupants (Boubekri, 2008; Leslie, 2003; Vasquez et al., 2022). Thus, both utilizing daylight and reducing energy consumption need to be prioritized.

The following studies about integrating daylighting and cooling strategies have been done: Chutarat (2001), Dewi et al. (2022), Gonzales and Fiorito (2015), Torres and Sakamoto (2009) have conducted studies on daylighting with shading devices, such as Window-to-Wall Ratio (WWR), double-skin facade and horizontal overhang with its Shading Coefficient (SC) which shows an effect on heat gain decrease and daylighting decrease. This shows that the study of daylight and heat gain design strategies can influence each other. Therefore, this study investigates both daylight quality and heat gain resulting from the design strategies along with its impact on the lighting energy consumption while maintaining the cooling load. Maintaining the cooling load implies preventing the increase of the existing cooling load by changing Overall Thermal Transfer Value (OTTV) value after daylighting improvement. In addition, this study also strives to distribute daylight across classrooms and corridors, which becomes an issue for deep depth classrooms with corridors in the middle (Ishaq et al., 2014).

According to Energy Performance of Buildings EN 15193, The Lighting Energy Numeric Indicator (LENI) can be used as a numerical indicator of the total annual lighting energy required by a building in a year (HM Government, 2013; Zumtobel, 2018). Appropriate classroom lighting standards for educational buildings according to Indonesian National Standard (SNI) No. 6389-2020 are at least 350 to 750 lux, depending on the activity (BSN, 2020). Illuminance levels above 1000 lux have been shown to increase visual problems causing a severely imbalanced illumination of an indoor space (Lee H, 2020; Rea, 1982). Visual discomfort can be exaggerated in rooms without uniform light (Lee H, 2020). On the other hand, the design of educational buildings tends to limit the size of transit corridors and maximize the size of classrooms, hence daylight illuminated classrooms become challenging due to deep depth rooms (Bruin-Hordijk et al., 2010). In these cases, supplemental electric light is needed, especially in spaces located far from the window (Kontadakis et al., 2018). Although the use of electric light can be hardly avoided, optimizing daylight through adequate illuminance and increasing light uniformity can reduce the need for electric light effectively and benefit the well-being and productivity of the students (Leslie, 2003). However, daylighting also brings heat into the building and results in heat gain (Lechner, 2015). Therefore, it should also be considered to reduce building energy consumption. The OTTV calculation is used to calculate the energy required for cooling the building, which measures the external heat gain transferred through the building envelope into the room (BSN, 2020).

Passive design strategy is used to reduce energy consumption and to ensure comfortable spaces as the first level of sustainable building strategy (Wibawa et al., 2021; Lechner, 2015). Passive design strategies are often applied to the building envelope as it acts as the barrier between the external and internal environment (Gibberd, 2009; Hanna, 2020). The following daylighting optimization interrelated to energy consumption cases have been applied on some educational buildings in Indonesia: Hakim et al. (2021) studies the appliance of bilateral opening to optimize daylighting in classrooms in an elementary school in Lhokseumawe, Indonesia, with shading typology to reduce cooling energy to 23-24%; Attahillah et al. (2018) investigates the use of horizontal screens to reduce glare because of daylighting in an educational building of Faculty of Engineering (FT) in Malikussaleh University, Province of Aceh; Fitriani et al. (2021) replaces the existing window glazing of an educational building in Sriwijaya University, Palembang, with reflecting coated double glazed windows, changing windows wider and higher and results in reducing 6,49 kWh/m^2/year of building electricity us; Vidiyanti (2015) reduces 12-22% energy use of an educational building in Bandung, West Java by changing the WWR percentage and window glazing. It is learned from the previous cases that windows are elements that are always involved in efforts to improve the quality of natural lighting and reduce building energy consumption.

Windows, as the transparent element of building envelopes, hold an important role in daylight-illuminated buildings and heat transfer (Sadineni et al., 2011). For typical educational building designs with a deep depth classroom, the passive lighting approaches through the window include bilateral window placements, light shelves, clerestory, and window glazing (Gary Gordon, 2003; Ishaq et al., 2014; Karlen & Benya, 2017; Karlen & Mark, 2007). Bilateral window placement is windows that face each other across the façade to evenly illuminate the space (Gary Gordon, 2003). Clerestory is a window installed high above eye level and allows light to reach the deep space used to get deep sunlight inside the building. (Ishaq et al., 2014; Karlen & Benya, 2017). Light shelves are reflective surfaces located above windows that reduce glare and direct light deep into the room and are capable of redistributing daylight deep into the space (Kontadakis et al., 2018). During its development, there are many forms of light shelves, such as curved, chamfered, and tilted (Sadineni et al., 2011). However, static horizontal light shelves are the simplest form of a light shelf with the easiest maintenance among other types, especially in the tropics (Kontadakis et al., 2018).

To maintain thermal load, the strategies of passive design with windows can be done through glazing materials and shadings (Lechner, 2015). Related to glazing material, several properties that affect and are affected by glazing include solar heat gain coefficient (SHGC) and U-Value (Gibberd, 2009). The desired glazing properties for optimizing daylight while maintaining thermal load are high light or visible transmission (VT) with low SHGC value (Anderson & Luther, 2012). Common glazing materials known for optimizing daylight are reflective glass and low emissivity (Low-E) glass (Phillips, 2014). The glazing type considered to have desired properties such as low U-value and high VT or visible transmittance is Low-E clear glass (Katherine et al., 2015). Low-E glass, compared to reflective glass with lower VT, is created to reduce the heat gain from light coming through the glass, without reducing the transmitted visible light (Jelle et al., 2007). Therefore, horizontal light shelves and clerestory are applied as interventions along with Low-E glazing.

Reducing lighting energy in educational buildings is crucial, especially if there are classrooms with deep depth, as it is one of the largest energy consumed by educational buildings (IEA, 2011; Lechner, 2015). Optimizing daylight through passive design interventions, namely horizontal light shelves and clerestory, can help increase daylight illuminance and uniformity (Jelle et al, 2007; Katherine et al, 2015). Daylighting is needed because it also benefits the students' well-being and productivity (Boubekri, 2008; Leslie, 2003; Vasquez et al., 2022). Standard average illuminance needed for classrooms and corridors based on SNI 6197-2020 is 350 lux and 100 lux respectively with uniformity of at least 0.6 to light the room evenly (BSN, 2020). The improved daylighting quality in the room can support the use of dimming and grouping lighting systems, hence reducing artificial light use (Lechner, 2015; Leslie, 2003). However, the heat gain also increases as daylight enters into the building. The maximum overall thermal transfer value in Jakarta based on SNI 6389-2020 is 35 W/m^2 (BSN, 2020). Thus, a glazing material with high VT and low U-value, namely low-e glass, can help maintain the cooling load. In addition, light shelves serve another function as shading.

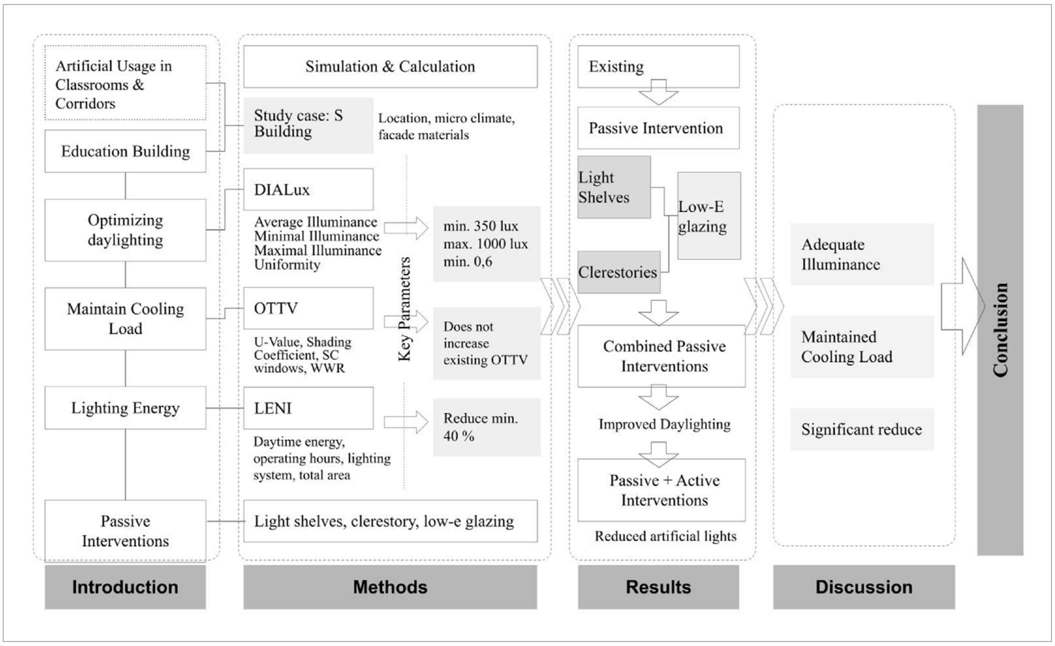
This study aims to discover the strategy to reduce lighting energy by optimizing daylight while maintaining the cooling load for educational buildings. The case study is one of the retrofitting buildings at the Faculty of Engineering, University of Indonesia (FTUI). It is used as a shared lecture hall, namely S Building, located in Depok, West Java, Indonesia. The building layout includes classrooms with a corridor in the middle. These spaces within the building use electric lighting during the day thereby being potentially high-energy consumption for lighting.

Methods

Research Framework

This research utilizes simulation and calculations to analyze the performance of the building. The first strategy involves passive design interventions, namely light shelves, clerestory, and low-e glazing. Daylighting performance is simulated using DIALux with average, minimum, maximum illumination, and uniformity as variables. DIALux has been used to simulate and investigate the building daylighting performance, including illuminance and uniformity of light (Elisa Van Kenhove et al., 2015; Bunjongjit, 2018; Nurrohman et al., 2021; Pratiwi et al., 2021; Hangga et al., 2022). OTTV calculation is done for cooling load while lighting energy is calculated using the LENI formula. The targets to be achieved become the key parameters, namely adequate illuminance (350-1000 lux of average illuminance), maintained cooling load (under 35 W/m^2), and reduced minimum 40% lighting energy. The first simulation done is for the existing condition. The daylighting performances as well as the cooling load of each intervention including the combination of interventions are subsequently simulated. Performance that matches or is the closest to the lighting standard and proceeds to maintain cooling load based on key parameters is performed in the next intervention. Furthermore, the amount of reduced electric lights by applying light grouping is examined based on the increased daylighting areas. Next step is calculating the lighting energy consumption and cooling load of the final strategy. The final strategy is ultimately reviewed based on key parameters.

Fig. 1
Research Framework

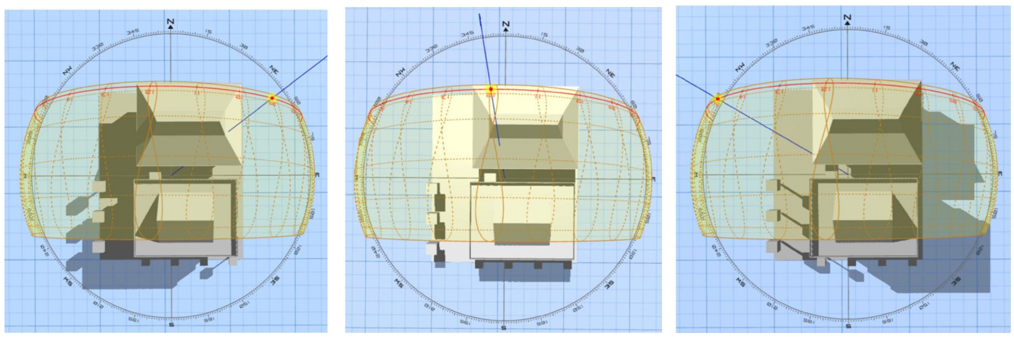


Simulation and Calculations

The modeling used for simulation in DIALux evo version 10.1 software is conducted with various variables based on the existing condition, namely U-value, SC (shading coefficient), WWR (Window-to-Wall Ratio), location, and surroundings, such as trees and other buildings. The building is located in Depok, West Java in coordinate 6.36°S 106.82°E. The climate and weather conditions collected from web climate data (www.meteoblue.com) shows that the maximum sunny days shall occur in August and this is used in this study as measurement time. The north side of the S building is parallel to another building that is located about 4 meters away. Several lush trees of around 3-10m diameters and 5-6 m diameter palm trees can be found on the south side. As Indonesia is in the tropic region, the sun is higher than the equinox, somewhere between the east and north, the sunset between the west and the north, and the sun is above the horizon for more than 12 hours (Tragenza, 2011). The sun path at that location needs to be checked to see the availability of daylight, which can be overviewed by the Sky View Factor (SVF) (Chatzipoulka et al, 2018). It is defined as the fraction of the sky visible from a point on a surface or the ground (IEA, 2014). SVF for each orientation is calculated by the ratio of the open and covered areas to check the daylight availability of each orientation (**Table 1**). The south side has the highest daylight availability compared to all other sides (68%) followed by the east (42%) and west (30%). This is due to the tree size on the east side, which are not so large and positioned far from other buildings. The lowest daylight ability is on the north side (10%) due to the close proximity of another building. The sun path of the location at 09:00 a.m. shows that the sun position tends to be on the northeast where the east and north facades receive the most sunlight without any hindrance (**Fig. 2. a**). The sun's position at noon tends to be on the north side while being largely blocked by another building (**Fig. 2. b**). The sun's position at 03:00 pm tends to be on the west-northwest so that the north and west facade receives more sunlight (**Fig. 2. c**).

Table 1
Daylight availability on S building

Orientation	East	West	South	North
SVF	42%	30%	68%	10%



(a) (b) (c)

Fig. 2
Existing sun path
(a) 9:00 AM
(b) 12:00 Noon
(c) 15:00 PM

The S building has six floors, where floors two to five are typical. Each typical floor has two classrooms with a capacity of 40 students (60.8m^2) and three classrooms with a capacity of 70 students (121.6m^2). The floor-to-ceiling height is 3.4m (**Fig. 4**). All openings have overhang shadings with a depth of 1m. The materials of the facade consist of brick walls finished with concrete, Autoclaved Aerated Concrete (ACC) bricks, and yellow paint (**Fig. 4**). The windows are mostly installed on the south and

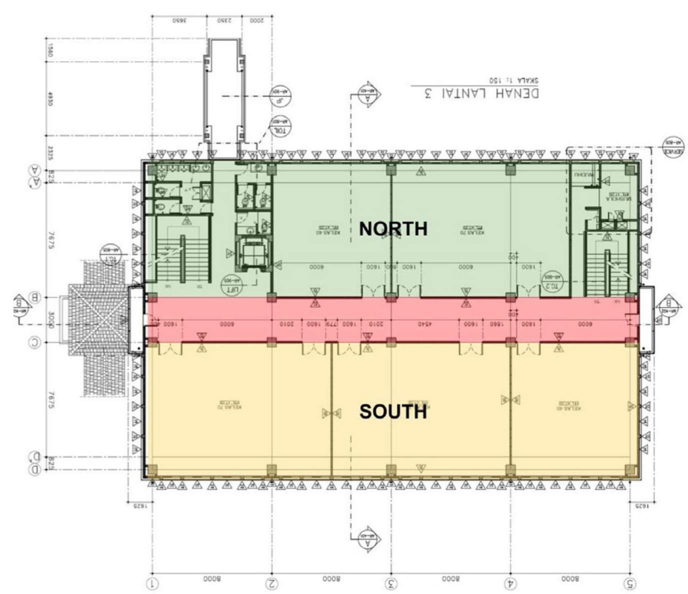


Fig. 3
Floor plan of classrooms and corridor layout

Fig. 4
S building facade

north side where classrooms are located. The glazing materials used is 6mm clear glass with windows size with the area of 1.38m^2 and 2.07m^2 for each opening. The investigation is conducted for floors two to five where classrooms are located along the corridors. This study separates the classroom areas between the north and south facing parts of the building to understand the different illuminances of each area (**Fig. 3**).

Cooling load is calculated by OTTV using the following equation (SNI 03 – 6389 – 2020):

$$OTTV = \frac{\propto [(Uw \; x \; (1 - WWR)] \; x \; TDek + (SC \; x \; WWR \; x \; SF) + (Uf \; x \; WWR \; x \; \Delta T)}{A} \quad (1)$$

(SNI 03-6389-2020)

$\propto$ – Sun radiation absorption; $TDek$ – Equivalent Temperature Difference (K); Uf – Fenestration thermal transfer (W/m^2.K); Uw – Opaque wall thermal transfer (W/m^2.K) ; SF – Solar Factor (W/m^2) ; SC – Shading Coefficient ; WWR – Wall-to-Window Ratio ; ΔT – outside and inside temperature difference ; A – façade area (m^2).

The OTTV of a building should not exceed 35W/m^2 (SNI 03-6389-2020). The existing glazing material of the S building is 5mm clear glass. Its U-value is 5.8W/m^2 with a VT of 89%. The properties of Low-E glazing used for intervention are 80% of VT, SHGC 67%, SC 0.82, and U-value 3.6W/m^{2}K, with a thickness of 6mm (Katherine et al, 2015). Meanwhile, the lighting energy consumption is calculated by the LENI with the following equation (Zumtobel, 2018):

$$LENI = \frac{Ep + Ed + En}{A} \quad (2)$$

(HM Government, 2013; Zumtobel, 2018)

Ep – parasitic energy use; Ed – daytime energy; En – night-time energy use;

Ep is 0 as there is no lighting control system; En is not included in the calculation, as the building is not occupied at night; Ed is calculated based on the following formula.

$$Ed = \frac{Pl \; x \; Fo \; x \; Fd \; x \; Fc \; x \; Td}{1000} \quad (3)$$

(HM Government, 2013; Zumtobel, 2018)

Pl – total power of lighting (watt); Fo – occupancy factor; Fd – factor of daylight; Fc – illuminance factor; Td – Operating hours during daylight time (hours) (HM Government, 2013). Fo is considered 1 as there is no automatic control used. Fd is 1 as there is no daylight-linked dimming system. Fc is 0.9 for the considered maintenance factor (HM Government, 2013).

The operating hours of the building during daytime are 8 hours for 5 days a week with assumed active lecture times of 9 months in a year, resulting in 1,440 hours in total. The total calculated area is 2,520 m^2. According to EN 15193, the recommended maximum LENI for buildings with 1,500 hours is 7.70kWh/m^2/year (HM Government, 2013). The artificial lights used in the S Building for the classroom are TKO-TL lamps with 2x36W power and recessed TL lamps with 4x18W power for the corridor. The lighting system used is the single switch system and is frequently turned on when the classroom is occupied. It is assumed that the areas are occupied during the day. For the intervention, the size of horizontal light shelves can be determined based on the ratio between the height of the light shelf and the work plane with the following ratio (Kontadakis et al., 2017).

$$d_{interior\ lightshelf} = h_{clerestory} \quad (4)$$

(Kontadakis et al., 2017)

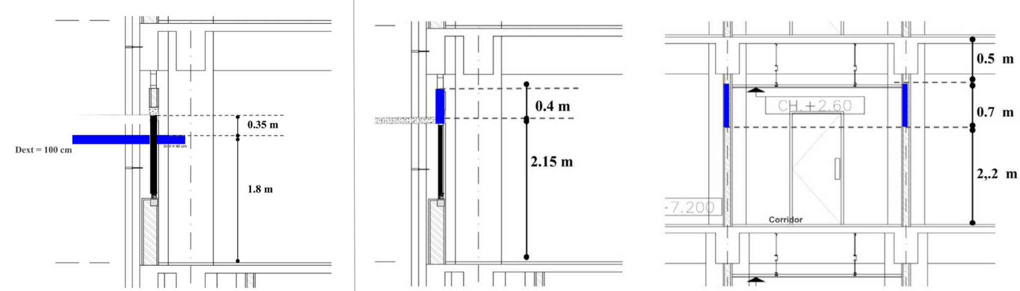
$d_{interior\ lightshelf}$ - length of interior light shelf surface ; $h_{clerestory}$ – clerestory height.

$$d_{exterior\ lightshelf} \leq h_{lightshelf} - h_{work\text{-}plane} \quad (5)$$

(Kontadakis et al., 2017)

$d_{exterior\ lightshelf}$ - length of exterior light shelf surface; $h_{lightshelf}$ – floor to light shelf height; $h_{work\text{-}plane}$ – floor to work-plane height.

The light shelves used have an external length of 100cm and an internal length of 40cm, placed above the floor at 1.8m and the remaining window is 0.35m. (Fig. 5. a). The shelf material is translucent polycarbonate of diffused type with a reflection level of 82. Clerestories are applied to facades and walls between classrooms and corridors to spread light into the corridors. The height is determined according to the height of the ceiling and doors. The clerestories dimension in the facade area measured 40cm in height (Fig. 5. b). The clerestories in the corridor wall are 70cm in height.



(a) (b)

Fig. 5
Interventions application
(a) Light shelves.
(b) Clerestories

Results

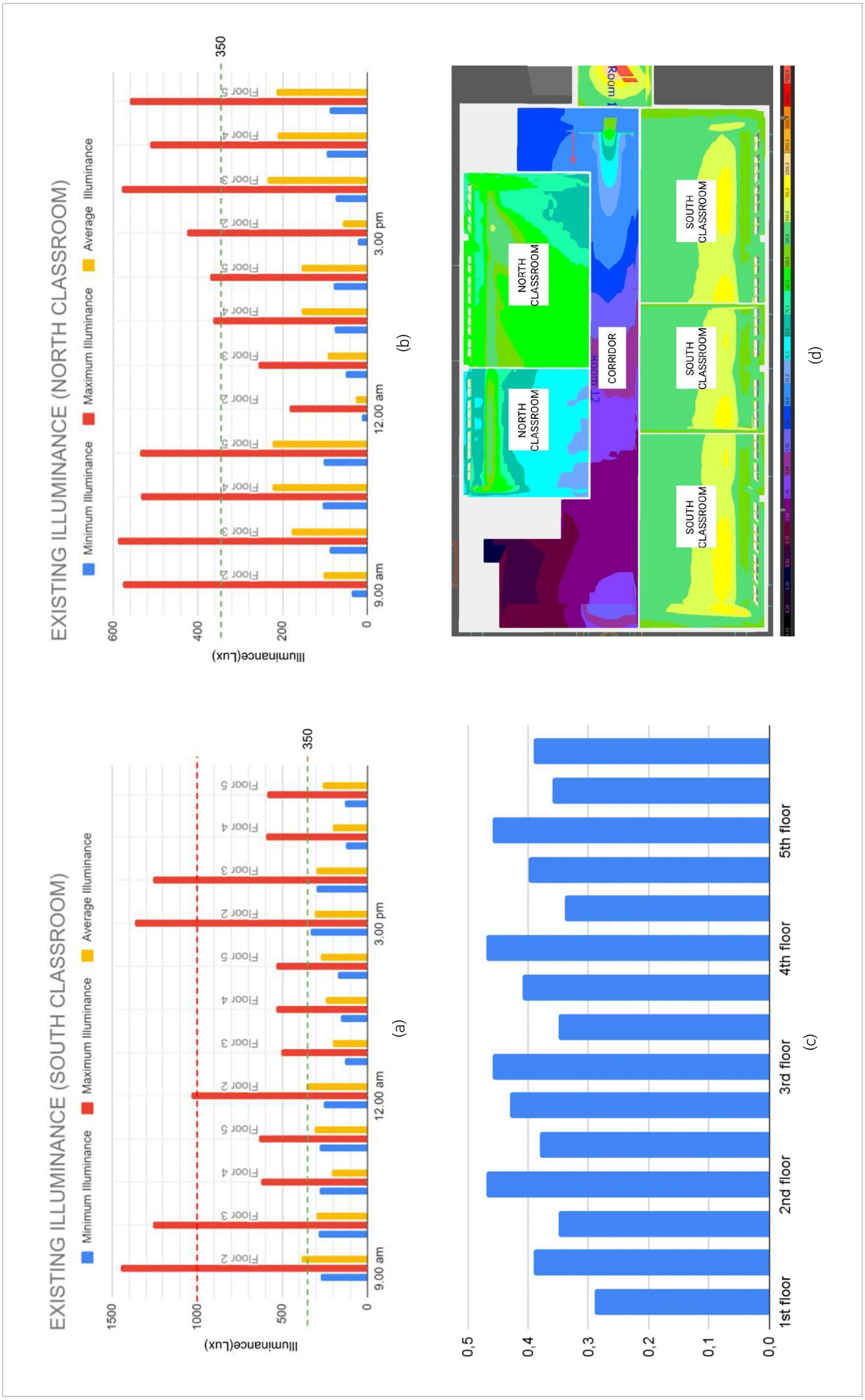
Existing Condition

The simulation of the existing condition results in uneven illuminance and uniformity. Average illuminance in south classrooms is below 350lux with minimum illuminance ranging between 132-289lux and maximum illuminance ranging between 504-1450lux (Fig. 6. a). The illuminance of north classrooms is much lower, average illuminance between 30-236lux with a minimum between 13-105lux and a maximum between 183-577lux (Fig. 6. b).

The uniformity is between 0.29-0.47 while the standard is 0.6 for the classroom (Fig. 6. c). As seen in Fig. 6. d, the corridors do not receive much daylight as it is positioned between the deep depth classrooms. This is due to solid walls between classrooms and corridors that do not allow daylight to penetrate into the corridor. Other elements on the site and building facade can affect how the building receives the light, showing that the placement of elements on the site can provide a shading effect and reduce the penetration of sunlight on the upper floors (Mahaputeri AH, 2010). In this case, full grown palm trees on the site higher than 3rd floors have a canopy around 3-5 meters (Balakrishnan & Jakubiec, 2020; Jamala et al., 2017).

Fig. 6

Existing daylight illuminance.
(a) South.
(b) North.
(c) Uniformity.
(d) Corridor illuminance



As for the cooling load, the OTTV calculation of the existing condition is 32W/m^2 which is still considered below the allowed maximum value. The total power of lighting within the existing S building area is 18,432W or 18.43kW. The calculated LENI of the existing condition is 8.42kWh/m^2/year. It exceeds the recommended maximum LENI, hence the lighting energy consumption of the current usage has scope for improvement.

Intervention with Light Shelves and Low-E Glazing

The simulation with light shelves (LS) intervention along with low-E glazing results in decreased maximum illumination to under 1000lux in both south and north classrooms (Fig. 7. a and 7. b) and increased uniformity to 0.62 (Fig. 7. c). The average illumination does not show a significant increase, while all of the average illuminance levels do not reach 350lux. Based on this result, it is found that light shelves implementation is more effective in distributing daylight evenly than increasing the illuminance of daylight. Thus, light shelves alone are still not enough to optimize daylight use.

For the cooling load, the OTTV results in a decreased value. It decreases to 30.9W/m^2 of total OTTV which is 1.4W/m^2 lower than the existing OTTV. This reduction is due to the multifunctional light shelves that provide shading as well as a reflective surface for daylight.

Intervention with Clerestories and Low-E Glazing

The light shelves simulation result shows that the average illuminance levels decrease while the uniformity increases. Therefore, clerestories are added to increase daylighting in the classrooms. The intervention of clerestories along with low-e glazing resulted in much more increased illuminance. The average illuminance in south classrooms increases up to 543lux while the minimum illuminance increases up to 356lux (Fig. 8. a). The illuminance increase is observed in the north classrooms as well but it barely achieves 350lux (Fig. 8. b). The result for the corridor while showing an increase is still insufficient with the minimum illumination still under 100lux (Fig. 8.d). Therefore, the height of the clerestories is proposed to be wider for further intervention.

However, it also results in decreased uniformity (Fig. 8. c) and an increase in OTTV. The result of OTTV is 32.6W/m^2, which is higher than the existing OTTV by a value of 0.3W/m^2. Based on the result, the clerestories implementation alone is not effective to maintain the thermal transfer of the S building. Thus, the study recommends the combination of applying both light shelves and clerestories as well as Low-E for further intervention.

Combined Passive Interventions

This intervention combines both light shelves and clerestories along with low-E glazing. For the corridors, the clerestories are widened to a maximum height of 2.2m. In other words, it is proposed to change the wall material between the classroom and the corridor to transparent material. To keep the privacy of the classroom, a blind or curtain might be applied. The result shows an increase in illuminance values that reached 350lux, especially on the south and the corridor (Fig. 9. a). The result shows that the maximum illumination is between 618-1010lux for the south side of the classroom, the minimum illumination is between 105-169lux, and the average illumination is between 222-274lux. The uniformity also increases to between 0.6-0.7 (Fig. 9. c). The illuminance of the corridor increases to 154lux, which is already sufficient (Fig. 9. d).

However, the illuminance in the north has still not increased to 350 lux (Fig. 9. b) and illuminance in the south is also much lower at noon. In short, electric lighting is still needed to reach standard illuminance. However, with improved daylighting, the use of electric lights can be reduced through a dimming and grouping system. Therefore, the need for electric lighting is simulated as the final intervention. The OTTV of combined passive intervention resulted in the same value as the existing, which is 32.3 W/m^2.

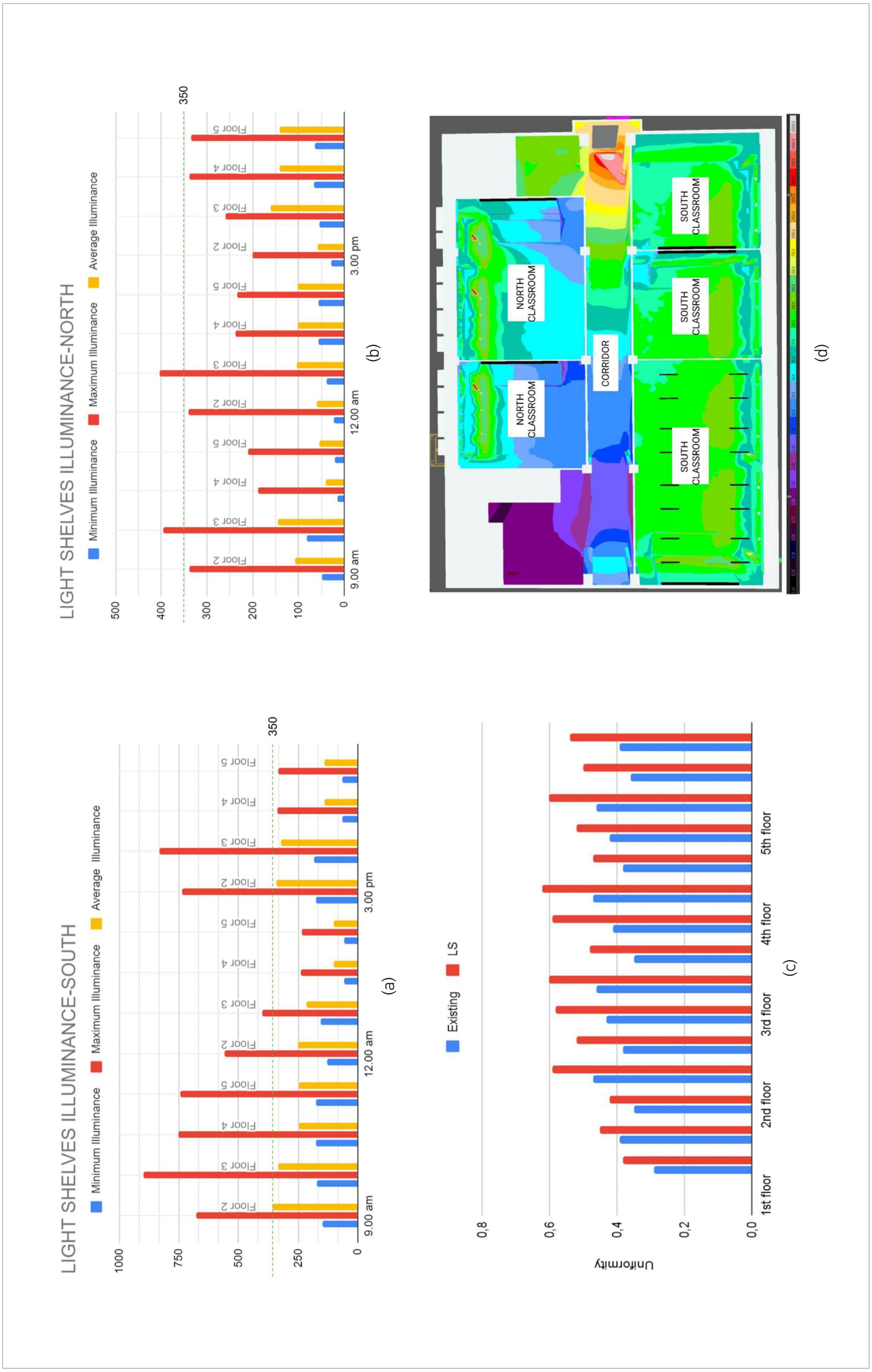


Fig. 7

Daylight Illuminance with light shelves.
(a) South.
(b) North.
(c) Uniformity.
(d) Corridor illuminance

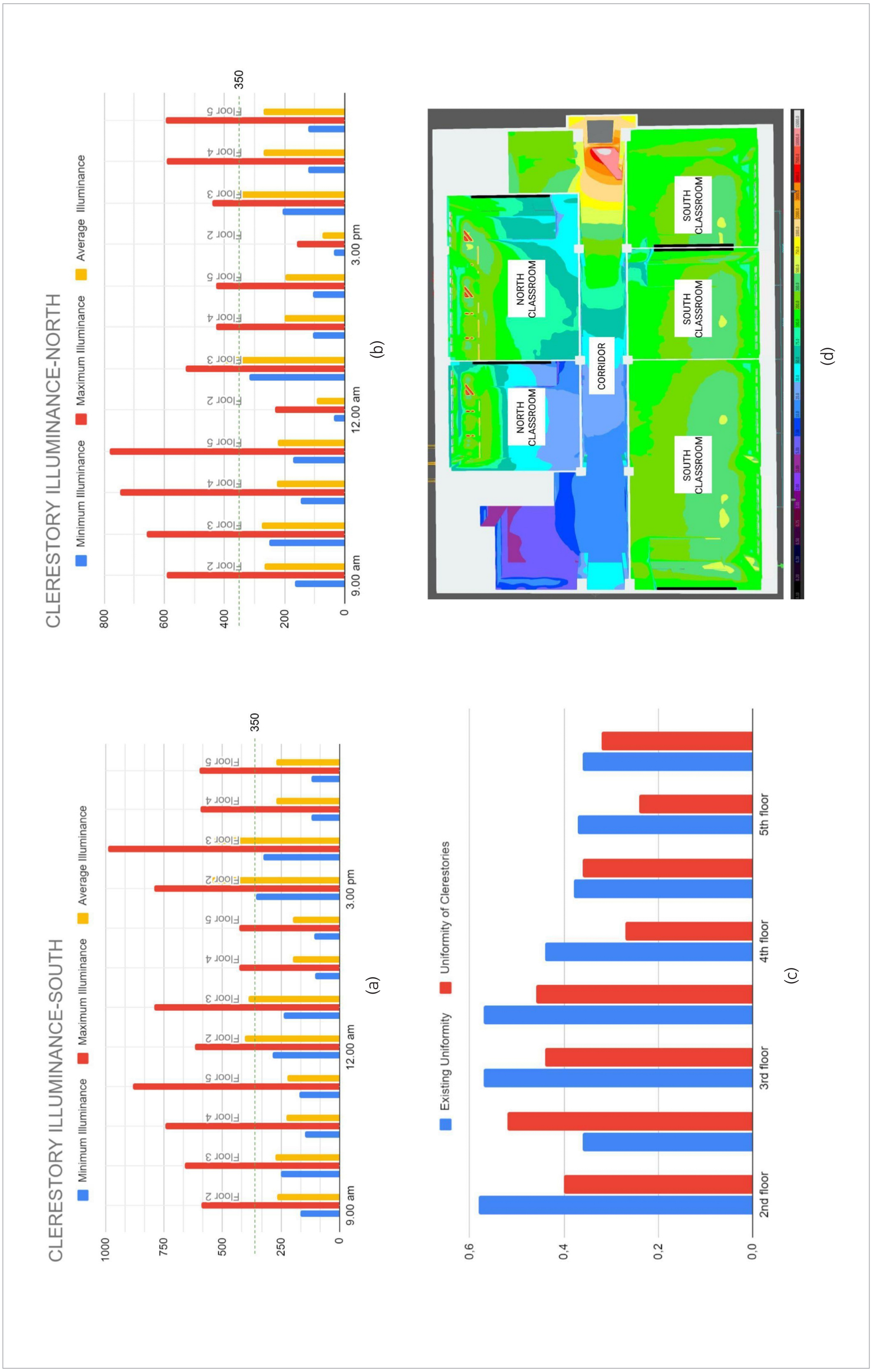


Fig. 8

Daylight illuminance with clerestories.
(a) South.
(b) North.
(c) Uniformity.
(d) Corridor illuminance

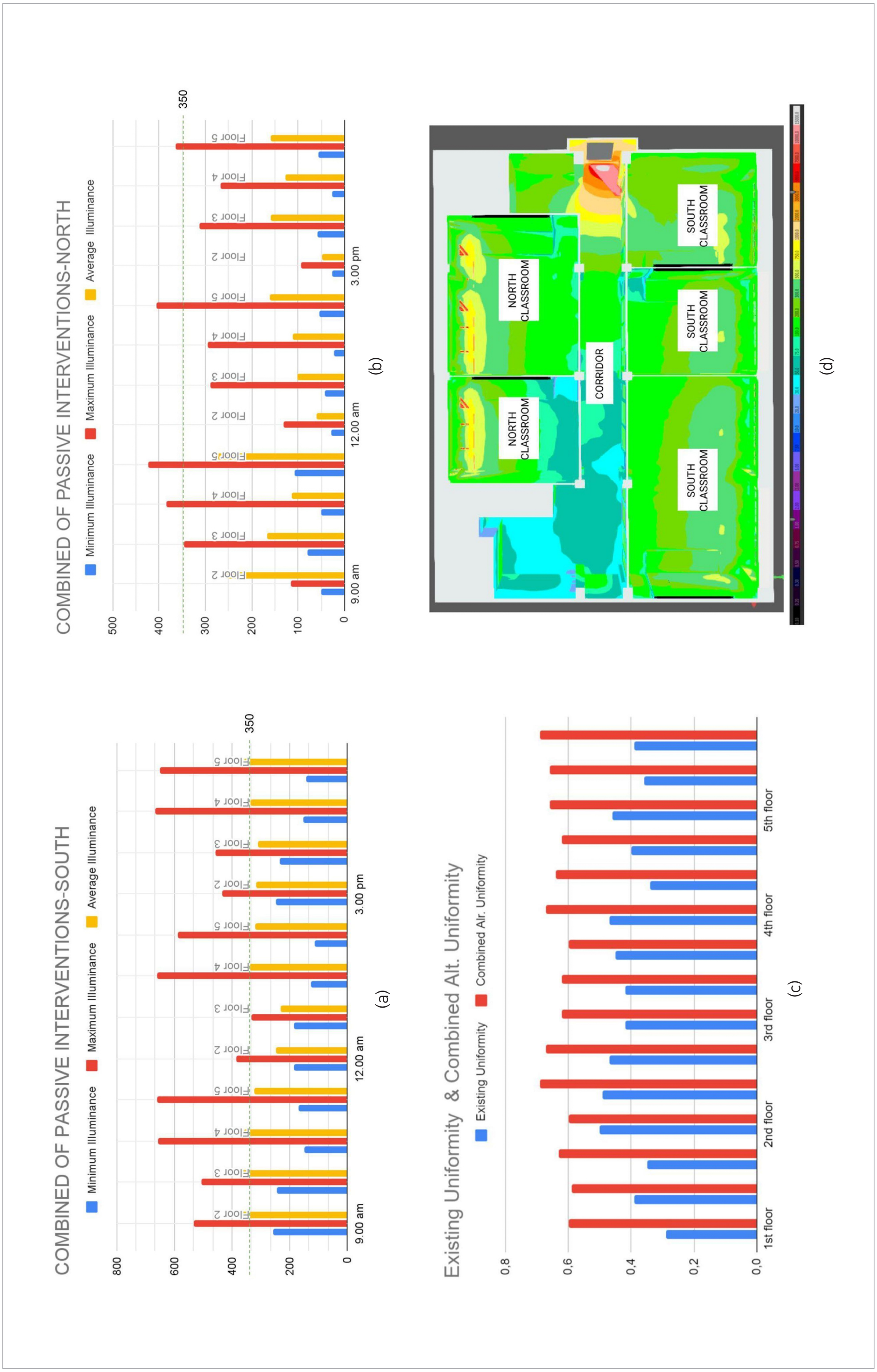


Fig. 9

Daylight illuminance of combined passive.
(a) South.
(b) North.
(c) Uniformity.
(d) Corridor illuminance

Final Intervention

From the previous simulation, the result shows that the corridors do not need electric lights during the day since daylighting alone from combined passive intervention is sufficient. The amount of electric lights can be reduced in the increased daylighting area. To meet the different needs of electric lighting, grouping and dimming are needed as other active lighting technologies. For the south side of the building, the area near the window does not use electric lighting and the area near the corridor is dimming 50% of electric lighting (Fig. 10). For the north side of the building, the electric lighting needed is 25% for the area near the window and 75% for the area near the corridor, while the corridor does not require electric lighting in the average daylight condition.

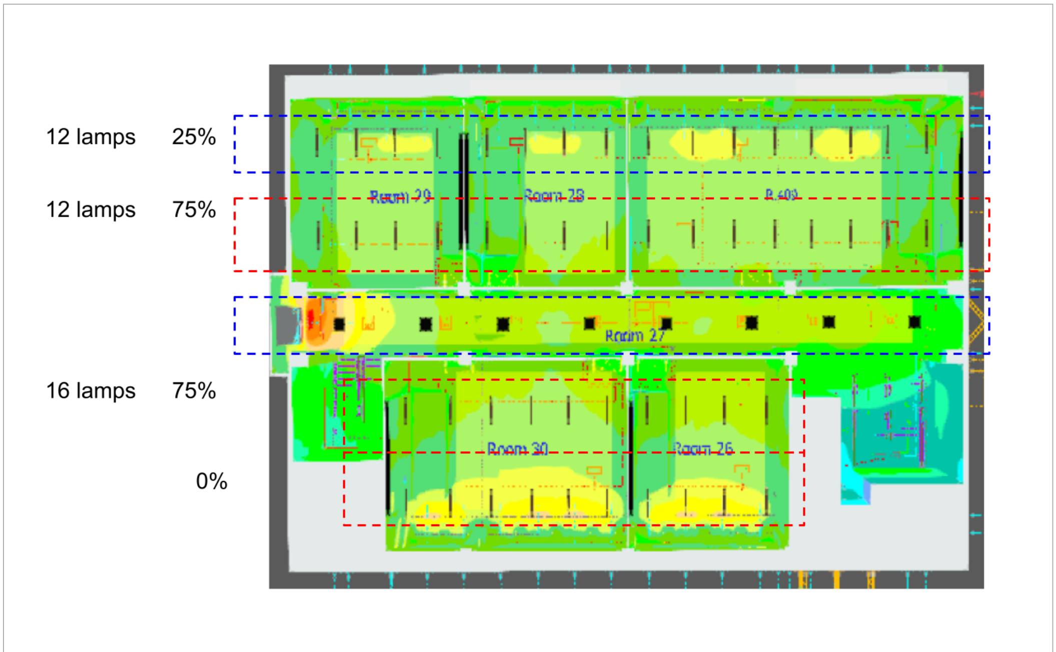


Fig. 10
Grouping and dimming after improved daylighting

As for the final lighting energy consumption, the LENI becomes 3.82kWh/m^2/year, which is below the recommended maximum LENI value (7.7kWh/m^2/year). In addition, it is reduced to 54% or 4.2kWh/m^2/year compared to existing lighting energy consumption.

Discussion

The lighting in the existing condition has not reached the target average illuminance value yet, which is below 350 lux and uniformity of below 0.6, especially in the northern classroom. The existing corridor space does not receive daylight because there is no transparent fenestration between the walls while it is positioned in the middle of south and north classrooms. This requires the use of electric lights during the day. Hence, the existing LENI still exceeds the efficiency limit (8.42kWh/m^2/year). However, the existing cooling load is still adequate as the OTTV value is below the maximum standard (32.3W/m^2). Passive interventions are simulated as the first strategy to increase daylighting. The first passive intervention with light shelves in addition to low-E glazing successfully increased the light distribution and reduced glare risk with existing uniformity up to 0.62 and reduced maximum illuminance to below 1000lux. The OTTV value of the light shelves intervention is lower than the existing one (30.9W/m^2). However, the average illuminance decreases which means that light shelves application only is not effective for increasing daylighting illuminance. The second passive intervention with clerestory along with low-E glazing showed a further increase in average illuminance compared to light shelves, which is up to 543lux. However, the maximum illuminance and OTTV values also increased. Subsequent interventions combining light shelves and clerestories resulted in increased average illuminance up to 274lux and uniformity value to 0.7. Meanwhile, the OTTV value is maintained at 32.3W/m^2. With increased daylighting and maintained cooling load, electric lights are reduced by dimming and grouping and manage to reduce the LENI value by up to 54% from the existing LENI.

Other cases of optimizing natural lighting in educational buildings in Indonesia also involve intervening windows and dimming and grouping lighting. Passive intervention steps, in the form of increasing the percentage of WWR and replacing window glazing have been proven to optimize daylighting in the classroom. However, a combination of other passive interventions with light shelves and clerestories in the room and integration with dimming and grouping lighting can optimize the distribution of light to the corridors. In addition, the energy for cooling the building is maintained or does not increase after the intervention. In terms of the economic feasibility, a study on integrating passive strategy with windows design and dimming control results in a simple payback period in 2.8 years and internal rate of return of 26% (Li et al, 2009; Onubogu et al, 2021). Another study investigates the cost-saving of passive daylighting strategy with a glazing system combined with dimming and grouping system results in payback period ranging between 2.1-4.5 years (Kirankumar et al, 2021). The economic feasibility of light shelves have yet to be studied. However, a study conducted on the office building in Tangerang, Java, Indonesia, has applied light shelves for the office rooms and results in reduced electricity consumption to 1,68% (Elizabeth & Gunawan, 2018). Another study analyzed implementation of light-shelves, light-pipes, and mirror ducts in Indonesia and found that light shelves are the most preferred by the respondents in terms of natural lighting utilization (Rumondang et al, 2022). Therefore, the integration of passive lighting strategies (in the form of clerestories, window glazing, and light shelves) with active lighting strategies (in the form of group and dimming lighting) has potential to reduce the lighting energy consumption while avoiding an increase in cooling load. However, the application designs will have to be planned carefully before implementing the strategies.

Conclusion

Daylight in educational buildings is important as it supports the energy saving as well as productivity of students. The light shelves can be applied as an intervention to increase daylighting uniformity of the classroom. The clerestories and bilateral window placement are applied to increase and deliver lighting into deep depth classrooms and corridors, which relatively provides even illumination as well. The results show that the final interventions have optimized daylighting performance but electric lights are still needed. However, optimal daylighting decreases the use of electric lights. As the consideration of thermal load, low-E glazing material is applied to the windows of the S Building facade and multifunctional light shelves that serve as shadings. It results in a maintained cooling load. Thus, the optimization of daylighting in this study does not increase the cooling load of the building. The study results in a decreased lighting energy of S Building to 54%. The result obtained from the study is that integrating passive and active interventions to reduce lighting energy can be done by optimizing daylight by a combination of light shelves and clerestories and reducing electric lights used during the day by dimming and grouping system.

As for maintaining the cooling load through the windows, this can be achieved through multifunctional light shelves that serve as shading and by applying low-e glazing. Consequently, the requirement of lighting can be met while maintaining the thermal load. In addition, adequate daylighting can lead to dimmer lighting systems, which reduce the use of electric lights. Thus, the energy consumption for lighting can be reduced without adding more energy for air conditioning. The combination of passive interventions on windows with active interventions on electric lighting can be applied to optimize daylighting and maintain or reduce energy for cooling in educational buildings. However, as the implementation of passive interventions such as clerestories and light shelves for existing buildings can be challenging, the application for such retrofitting requires further investigation and careful planning for successful implementation.

Recommendation

This research has conveyed the importance of coordinated daylighting strategies with cooling loads to achieve adequate daylighting without increasing the cooling load of a building. Therefore, the efficiency of building energy consumption and the benefits of daylighting for student's well-being can be achieved concurrently. However, this study did not conduct a subjective assessment of visual comfort and is only based on the existing standard level of illuminance. In addition, this result may not necessarily be widely applicable, as it has considered only one case study. Thus, further research should be conducted on various cases to investigate the illuminance subjectively since the visual comfort levels of people can vary. The strategy also needs to consider the overall building facade design.

References

Anderson T., Luther M. Designing for thermal comfort near a glazed exterior wall. Architectural Science Review, 2012; 55: 1-10. https://doi.org/10.1080/00038628.2012.697863

Attahillah, Wijayanti, S., Hassan, s. m., Simulasi desain fasad optimal terhadap pencahayaan alami pada gedung prodi Arsitektur Universitas Malikussaleh, 2018; 4(1). https://doi.org/10.29080/emara.v4i1.228

Badan Standar Nasional. Standar Nasional Indonesia 6197-2020 about energy conservation in lighting systems. 2020.

Badan Standar Nasional. Standar Nasional Indonesia 6389-2020 about energy conservation of building envelopes in Buildings. 2020.

Balakrishnan, P., Jakubiec, J. A.,Trees in Daylight Simulation - Measuring and Modelling Realistic Light Transmittance through Trees. 2022; leukos, https://doi.org/10.1080/15502724.2022.2112217

Boubekri, Mohamed. Daylighting, architecture and health, building design strategies. Architectural Press, Elsevier: Oxford; 2008. https://doi.org/10.4324/9780080940717

Bruin-Hordijk, T., Groot, E Lighting in schools report. International Energy Agency (IEA), Energy conservation in buildings and community systems. Guidebook on energy efficient electric lighting for buildings. Annex 45. 2010.

Bunjongjit, S., Ngaopitakkul, A. Feasibility study and impact of daylight on illumination control for energy-saving lighting systems. Sustainability; 2018: 10(11): 4075. https://doi.org/10.3390/su10114075

Christina Chatzipoulka, Marialena Nikolopoulou. Urban geometry, SVF and insolation of open spaces: London and Paris. Building Research & Information; 2018: 46(8): 881-898. https://doi.org/10.1080/09613218.2018.1463015

Culp, Thomas D., Widder, Sarah H., and Cort, Katherine A. Thermal and optical properties of low-e storm windows and panels. United States: N. p., 2015. https://doi.org/10.2172/1226413

Chutarat, A. Experience of light: the use of an inverse method and a genetic algorithm in daylighting design. USA: Massachusetts Institute of Technology. 2001.https://doi.org/10.56261/jars.v1.168929

Elizabeth, M., Gunawan, R., Evaluation of light shelf design performances to the daylight's sunlight penetration on sinar mas land plaza building tangerang to increase the green mark assessment, Jurnal RISA, 2018; 2; 388-404.https://journal.unpar.ac.id/index.php/risa/article/view/3049. https://doi.org/10.26593/risa.v2i04.3049.388-404

E. S. Rumondang, Y. V. Regina, Y. R. Angela, D. Larasati, Analysis study of light shelves, light pipes, mirror ducts utilization and implementation in Indonesia. Earth and Environmental Science; 2022; 1007; 012011. https://doi.org/10.1088/1755-1315/1007/1/012011

Fitriani, H., Rifki, M., Indriyati, C., Rachmadi, A., Muhtarom, A., Energy Analysis of the Educational Building in Palembang Indonesia, Civil Engineering and Architecture, 2021; 9(3); 778-788. https://doi.org/10.13189/cea.2021.090319

Gary Gordon. Interior lighting for designers, 4th edition. John Wiley & Sons, Inc: New Jersey. 2003.

Gibberd, Jeremy. Green building handbook for South Africa Chapter: Building envelope and water conservation. CSIR Built Environment, 2009. https://www.researchgate.net/publication/30511221.

Gonzalez, J. and Fiorito, G. (2015). Daylight design of office buildings: optimization of external solar shadings by using combined simulation methods. Buildings. 2015; 201(5): 560-580. https://doi.org/10.3390/buildings5020560

Green Building Council Indonesia (GBCI). Greenship existing building version 1.1. 2016. http://www.gbcindonesia.org/.

Hakim, F. N., Muhamadinah, Y., Atthaillah, Mangkuto, R. A., Sudarsono, A. S, Building Envelope Design Optimization of a Hypothetical Classroom Considering Energy Consumption, Daylight, and Thermal Comfort: Case Study in Lhokseumawe, Indonesia, International Journal of Technology. 2021; 12; 6. https://doi.org/10.14716/ijtech.v12i6.5203

Hangga, A., et al. Modelling of lighting system utilizing natural and artificial lighting using DIALux. Earth and Environmental Science, 2022; 969(1): 012024. https://doi.org/10.1088/1755-1315/969/1/012024

HM Government. Non-domestic building services compliance guide. Energy performance of building standard - Energy requirements for lighting. Wales; 2013.

IEA. World energy outlook. Paris: OECD Publishing. Progress of implementing the IEA 25 Energy Efficiency Policy; 2014.

IEA. The Future of Cooling in Southeast Asia; 2019.

Ishaq M., Wafa N. The Design of the Optimal light shelf in educational setting simulation vs. optimization in assessing daylight performance. Sustainable Built Environment SBE16-Cairo 2016 At Cairo, Egypt; 2014.

Jamala, N., Rahim, R., Mulyadi, R., Analysis of illuminance level on Phinisi Tower Building, 2017.

Jelle, B. P., Gustavsen, A., Nilsen, T. N., & Jacobsen, T. Solar material protection factor (SMPF) and solar skin protection factor (SSPF) for window panes and other glass structures in buildings. Solar energy materials and solar cells; 2007. https://doi.org/10.1016/j.solmat.2006.10.017

Karlen, Benya. Lighting design basics; 2017: page 33.

Karlen, Mark. Dasar-dasar desain pencahayaan. Erlangga; 2007.

Kirankumar G., Saboor S., Karolos J. K., Domenico M., Venkata R. M., Sharmas V. S., Sustainable reflective triple glazing design strategies: Spectral characteristics, air-conditioning cost savings, daylight factors, and payback periods, Journal of Building Engineering, 2021; 42; 103089. https://doi.org/10.1016/j.jobe.2021.103089

Kenhove, E. V., Laverge, J., Boydens, W., Janssens, A. Design optimization of a GEOTABS office building. Energy Procedia, 2015; 78: 2989-2994. https://doi.org/10.1016/j.egypro.2015.11.701

Koenigsberger O., Ingersoll T.G., Mayhew A., Szokolay S.V. Manual of tropical housing and building - climatic design. London: Longman Group; 1973.

Kontadakis, A., Tsangrassoulis, A., Doulos, L., & Zerefos, S. A review of light shelf designs for daylit environments. Sustainability, 2018; 10(1): 71. https://doi.org/10.3390/su10010071

Lechner, Norbert. Heating, cooling, lighting. New Jersey: Wiley & Sons; 2015.

Lee H. A Basic Study on the Performance evaluation of a movable light shelf with a rolling reflector that can change reflectivity to improve the visual environment, 2020. https://doi.org/10.3390/ijerph17228338

Li, D. H. W., Mak, A. H. L., Chan, W. W. H., Cheng, C. C. K., Predicting energy saving and life-cycle cost analysis for lighting and daylighting schemes. International Journal of Green Energy, 2009; 6; 359-370. https://doi.org/10.1080/15435070903107015

Meteoblue. Climate and weather data. Accessed on June, 10th, 2022. https://www.meteoblue.com/.

Natalia Giraldo Vasquez, Ricardo Forgiarini Rupp, Rune Korsholm Andersen, Jørn Toftum. Occupants' responses to window views, daylighting and lighting in buildings: A critical review. 2022; 219: 109172. https://doi.org/10.1016/j.buildenv.2022.109172

Nurrohman, M. L., Feros, P., Wahyuning, Madina, R. F., Pratiwi, N. Efficient lighting design for multiuse architecture studio classroom using DIALux Evo 9. Earth and environmental science, 2021; 78(1). https://doi.org/10.1088/1755-1315/738/1/012034

Onubogu, N. O., Chong, K. K., Tan, M. H., Review of active and passive daylighting technologies for sustainable building. international journal of photoenergy, 2021; 27. https://doi.org/10.1155/2021/8802691

Ova Candra Dewi, Kartika Rahmasari, Tika Ardina Hanjani. (2022). Window-to-Wall Ratio as a mode of daylight optimization for an educational building with opaque double-skin façade. Journal of Sustainable Architecture and Civil Engineering, 2022; 1(30): 142-152. https://doi.org/10.5755/j01.sace.30.1.29744

Phillips, Derek. Daylighting, Natural light in architecture. Oxford: Architectural Press; 2004.

Pratiwi, N., Djafar, A. G. Analysis of lighting performance in the hall of the faculty of engineering, state university of gorontalo by using the DIALux Evo 9.0 simulation. Earth and environmental science; 2021: 738(1). https://doi.org/10.1088/1755-1315/738/1/012032

The Government of the Province of Jakarta Capital Special Territory. Jakarta green building user guide Vol. 3 lighting system; 2011.

Rea, M. S. An overview of visual performance. Lighting design and application, 1982; 12(11): 35-41.

Recommendation. International Energy Agency; 2011.

R.P. Leslie. Capturing the daylight dividend in buildings: why and how? 2003; 18(2): 381-385. https://doi.org/10.1016/S0360-1323(02)00118-X

Sadineni, S.B., Madala, S., Boehm, R. F. Passive building energy savings: A review of building envelope components. Renewable and Sustainable Energy Reviews, 2011; 15: 3617-3631. https://doi.org/10.1016/j.rser.2011.07.014

Sara Pasquier, Aurelien Saussay. Progress of implementing the IEA 25 Energy efficiency policy recommendation. International Energy Agency. 2011.

Wang. A study on the energy performance of school buildings in Taiwan. 2016; 133: 810-822. https://doi.org/10.1016/j.enbuild.2016.10.036

Tregenza P. & Wilson M. Daylighting: architecture and lighting design. USA & Canada: Routledge, 2011.

Torres, S., Sakamoto, Y. Facade design optimization for daylight with a simple genetic algorithm. Proceedings of Building Simulation, 2007. 1162-1167.

United Nations. Sustainable Development Goals. 2020. https://sdgs.un.org.

Vidiyanti, C. Kajian Retrofit bangunan sebagai upaya mereduksi konsumsi energi operasional, Jurnal Arsitektur, Bangunan, dan Lingkungan, 2015; 5(1); 1-9. https://www.neliti.com/publications/265314/kajian-retrofit-bangunan-sebagai-upaya-mereduksi-konsumsi-energi-operasional-stu.

Wibawa B.A., Saraswati R.S. Chandra B.A. Energy Optimization on Campus Building Using Sefaira. IOP Conf. Ser.: Earth Environ. Sci., 2021: 738 012015. https://doi.org/10.1088/1755-1315/738/1/012015

Zumtobel. The Lighting Handbook. 2018 https://www.zumtobel.com.

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