

# **Strategies to Improve Natural Lighting in Deep-Plan Cultural Heritage Buildings in the Tropics**

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## **ABSTRACT**

Tropical climate areas have an advantage in terms of utilizing natural lighting for buildings. On the other hand, deep plan buildings have limitations in natural light penetrations through the sides of the building, while making the natural light enters from the roof risks of blending in with the heat and glare. Cultural heritage buildings are an inheritance that must be preserved and protected. Nowadays, some of them switch functions to be managed as public functions. Cultural heritage buildings with deep floor plans have double problems, specifically their limitations in natural light penetrations from the sides of the building, and also how to maintain the visual appearance of the building as much as possible when renovations are being carried out. This paper aims to explore strategies that can be done to improve natural lighting in the cultural heritage buildings with a deep floor plan. A case of study of cultural heritage buildings was also used in this research to provide a description of specific natural lighting techniques that can be applied. Field measurement methods and digital simulations are used to determine the existing natural lighting conditions of the study object and provide a visualization of design recommendations. The results show that vertical lighting can be used in cultural heritage buildings without changing the building façade. This strategy is carried out by minimizing the incoming glare through the consideration of the vertical angle of the sun's shadow, as well as the reflection of light to maximize the light distributions in the building.

**Keywords:** *Natural lighting, deep-plan, cultural heritage building, tropics*

## **1. INTRODUCTION**

Natural lighting is one system that has many advantages, especially in providing visual comfort needs in buildings. The use of natural lighting systems can also reduce electricity consumption for artificial lighting in the morning to late afternoon. Natural lighting can be enjoyed throughout the year by tropical buildings. On the other hand, there are some cases of buildings that cannot make maximum use of natural lighting, for example, buildings that have a deep floor plan. Deep plan buildings cannot utilize the most natural lighting from the side of the building and can only make use of the perimeter area of the building. Top lighting is a solution for 1-story deep plan buildings. However, for building in tropical climates, such as in Indonesia, top lighting potentially welcomes the heat and glare into buildings.

For this reason, the use of top lighting in tropical buildings requires a strategy to minimize the heat and glare coming from the top of the building. It also happens to cultural heritage buildings with public functions, where some of them have deep floor plans. While the building facade is maintaining its authenticity, modifications to enhance natural lighting cannot also be carried out on the sidewall of the buildings. For this reason, top lighting can be a solution, with the limitation of not changing the shape of the building's roof too much. Unique strategies can be used

to incorporate natural light into buildings when any conventional side or top natural lighting systems cannot be used or cannot work optimally, especially in deep plan buildings, spaces that do not have windows, or even multi-story buildings [1]. These strategies include tubular skylights, light wells or shafts, beamed daylighting, and light pipes.

Several studies related to specific natural lighting strategies have been done, including examining the efficiency of light tubes with vertical and horizontal systems to illuminate spaces inside spaces as well as spaces that do not have windows in multi-story buildings [2]. Ahmed et al. [3] examining the dimensions of light wells for multi-story buildings. Rezazadeh et al. [4] reviewing strategies for natural light to enters into the deepest spaces in many deep-plan floored buildings, where windows and skylights were unable to illuminate up to near the core of the building. Likewise, Hansen and Elmonds [5] describes the advantages of light pipe technology for multi-story deep-plan buildings. On the other hand, Sikula et al. [6] explained the weakness of the use of light pipes in terms of reflecting solar heat by the mirror fields used in the inner layer. Thakkar [7] proved that the use of tubular skylights could produce better lighting than artificial lighting. Umar and Alibaba [8] examines the dimensions of skylights experimentally using Dialux lighting simulation software. Shuxiao et al. [9] examine the efficiency of using tubular daylight devices in terms of energy savings. Baglivo et al. [10] examine the

exact dimensions of the tubular skylight to avoid glare and minimize solar heat radiation entering through the light holes into the buildings. The previous strategies channel sunlight from the side and the roof through the reflected light pipes to be distributed into the room. In this case, the orientation of the natural lighting openings is important to note, considering the angle of the sun's shadow, where the angle of the sun's shadow at a particular orientation and location can be used as a reference for projecting light patches on the floor or work area [11].

## 2. RESEARCH METHODS

A cultural heritage building was used as a case study, named the National Press Monument Building, Surakarta, Central Java, Indonesia. The object of this study consists of a building group that has several buildings in the category of cultural heritage buildings and non-cultural heritage buildings. In this study, the multipurpose room contained in the main building has the status of a cultural heritage building, and its natural lighting problems and solutions are examined.

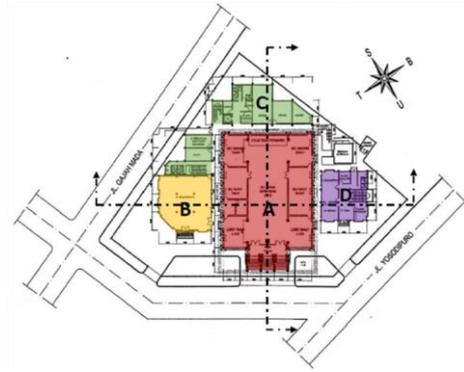
This research explores strategies to improve the performance of natural lighting in deep plan buildings, especially cultural heritage buildings that cannot be modified on their sidewalls. Field measurements are carried out using a luxmeter to determine the level of existing natural lighting at the height of 75 cm from the floor surface with a distance between points of 6 meters. The results of field measurements in the multipurpose study area are then compared with the results of digital simulations to show relative errors. The calculation of relative error was using the formula of the simulation results divided by the results of measurements of natural lighting levels at several measurement points, then multiplied by 100%. Digital simulations with DIALux 4.12 software were also carried out to determine the performance of the natural lighting strategies. The lighting strategy is determined based on the consideration of the vertical shadow angle at the location of the building coordinates in the city of Surakarta, Central Java, Indonesia.

## 3. RESULTS AND DISCUSSION

Cultural heritage buildings with deep floor plans have limitations in natural light penetrations through windows on the sidewalls. On the other hand, cultural heritage buildings are preserved visually, so that when they are being repurposed and require more lighting, not so many changes can be made to maximize its natural lighting. In contrast, the use of artificial lighting consumes electrical energy and produces a different atmosphere and visual quality compared to natural lighting.

The Surakarta National Press Monument Building, under the management of the Ministry of Communication and Information, has a building that is included in the category

of cultural heritage. The building is being maintained for its authenticity on its shape and appearance (Figure 2). The multipurpose room is an inner function in the category of cultural heritage buildings within the Surakarta National Press Monument building complex (Figure 1). It is usually used as a venue for exhibitions, meetings, and seminars. However, due to its deep floor plan, it is challenging to distribute natural lighting evenly through side lighting.



**Figure 1** The Surakarta National Press Monument building layout: A. non-cultural heritage building; B, C, D. cultural heritage building.



**Figure 2** The facade of the cultural heritage building.

The field measurements in the multipurpose room were taken three times at 8 AM, 12 PM, and 4 PM. The results show that the level of natural lighting ranges from 3 to 374 lux, which means that the natural lighting conditions are uneven, and several zones tend to be dark (Figure 3). It refers to the standard lighting level requirements for the function of watching seminars, speeches, and those likelihood ranging from 300-600 lux, viewing movies or videos between 200-350 lux, and viewing exhibits between 300-500 lux.

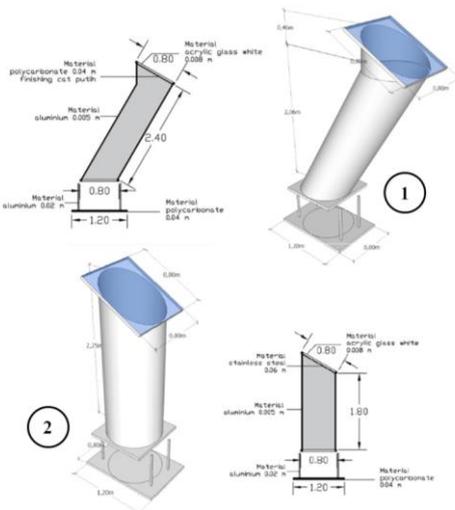


**Figure 3** The interior of the cultural heritage building

Field measurements are carried out twice at the same time on different days, with a standard deviation of 1 in the measurement results in the morning, 1.25 for measurement results in the noon, and 0.66 for measurement results in the afternoon. The results of the field measurements are then compared with the simulation results using DIALux 4.12 software to determine the relative magnitude of the error. The results of the comparison at 13 measuring points show an insignificant relative error, which is less than 1%, namely 0.91% on the first-day measurement and 0.90% on the second day.

Then, a shading simulation is carried out to determine whether there is an influence of shadowing by surrounding buildings. The results show that the surrounding buildings do not overshadow the object of study building significantly to the upper side of the building so that natural lighting still has the potential to be optimized through specific natural lighting strategies.

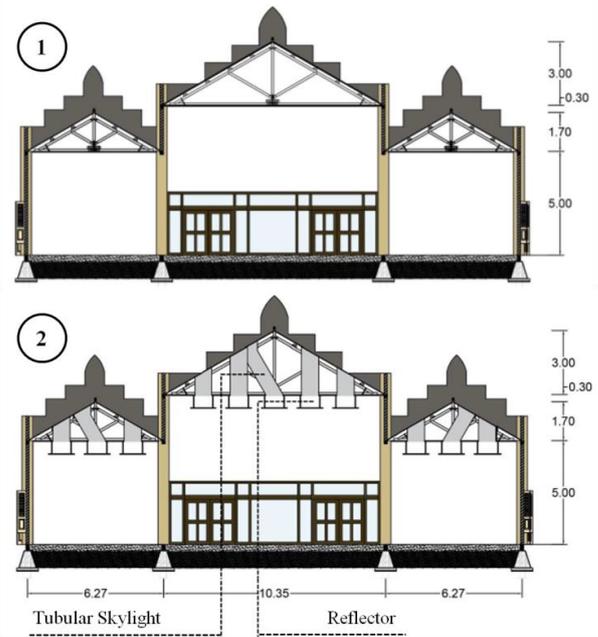
Several natural lighting strategy scenarios are created to increase the intensity of natural lighting that enters the building without much alteration on the building façade. The strategy of specific natural lighting through the roof was chosen. The additional light tunnel can be made square or circle with a highly reflective coating material to help distribute the light into the building. In this study, the tubular skylight opening was chosen, which uses the circle shape with a height of 3-4 meters, as illustrated in Figure 4. Figure 5 explains the application of the design recommendation to the building.



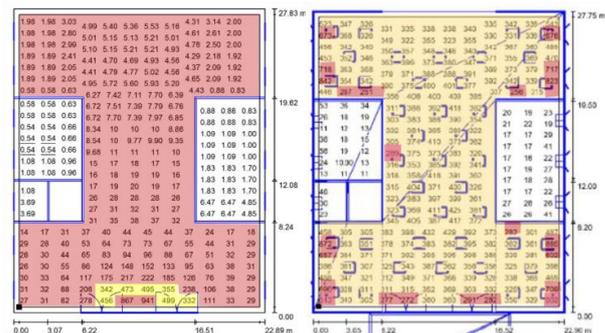
**Figure 4** The applied tubular skylight model on the researched multifunction room: 1. Inclined, 2. Perpendicular.

Before conducting a design recommendation, some simulations of the existing conditions were done at critical times of the sun's position on the earth. Those include a) March 21, to represent the equinox position; b) June 21, to represent the position of the sun against the earth in the northernmost position; and c) December 21, to represent the position of the sun towards the earth in the

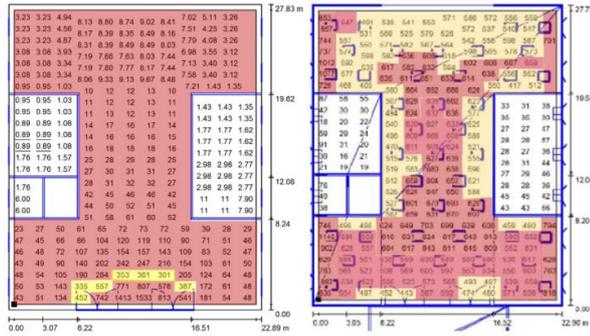
southernmost position. It was done to compare the performance of natural lighting before and after applying the tubular skylight. The comparative analysis is carried out to determine the performance of the tubular skylight, by referring to the standard according to the function in each area, as well as the minimum natural lighting intensity of 300 lux. The results show that the intensity of natural lighting in the existing conditions is very low due to the closing of the window by other supporting spaces, and the deepness of the room exceeds 20 meters. The results of the comparison of the light distribution can be seen in Figure 6 to 13



**Figure 5** Cross-section of the building; 1. Existing drawing, 2. With tubular skylight addition drawing.

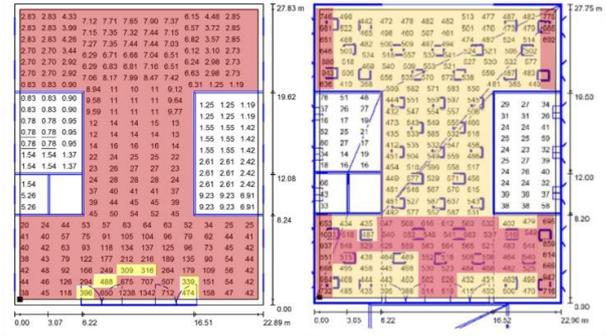


**Figure 6** The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on March 21 at 08:00 AM.



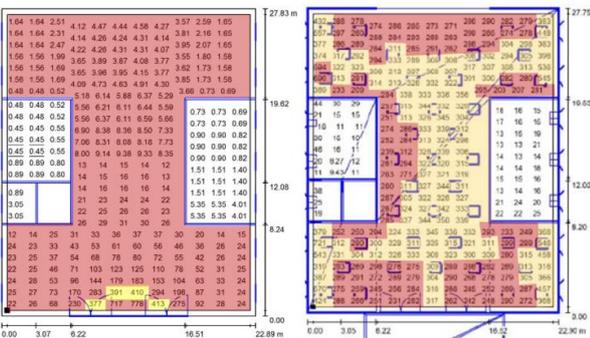
Does not fulfill the standard

Figure 7 The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on March 21 at noon



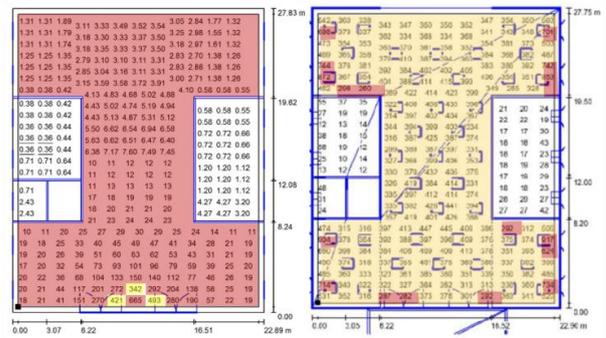
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Figure 10 The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on June 21 at noon



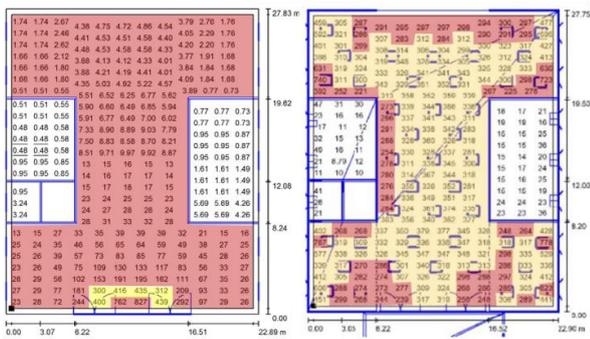
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Figure 8 The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on March 21 at 04:00 PM.



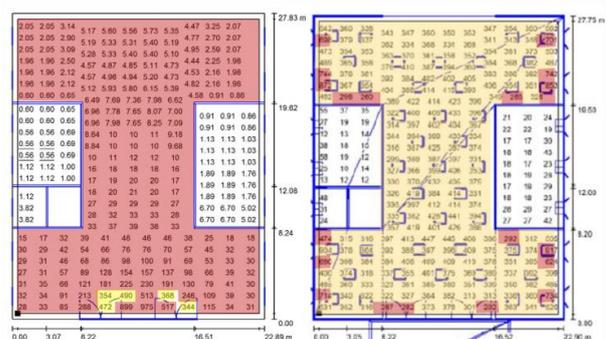
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Figure 11 The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on June 21 at 04:00 PM.



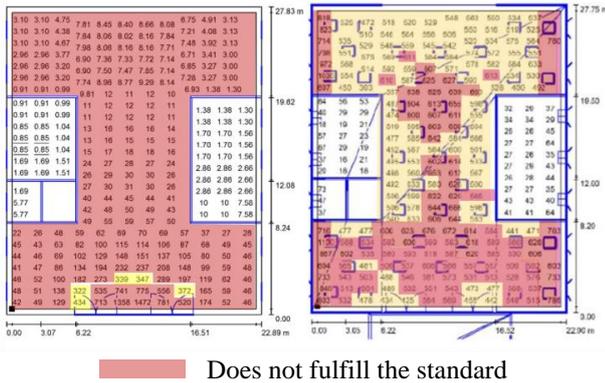
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Figure 9 The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on June 21 at 08:00 AM.

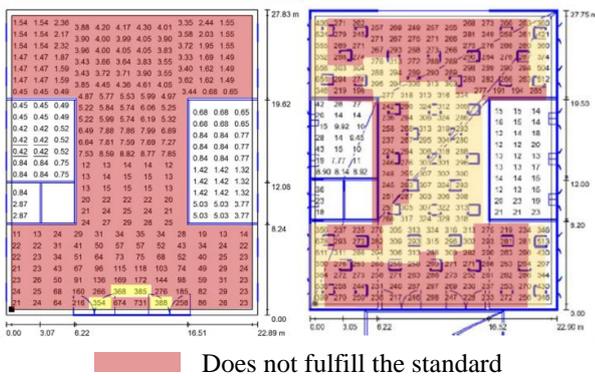


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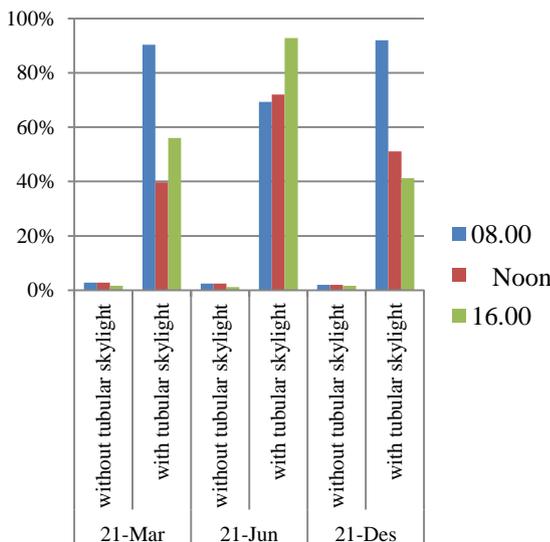
Figure 12 The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on December 21 at 08:00 AM.



**Figure 13** The result of existing natural lighting simulation and the tubular skylight addition at the multifunction room on December 21 at noon



**Figure 14** The result of existing natural lighting simulation and the tubular skylight addition in the multifunction room on December 21 at 04:00 PM.



**Figure 15** The comparison of existing natural lighting intensity with tubular skylight addition in the multifunction room.

The addition of tubular skylight increases the area that meets the lighting level standard, which initially ranged from 6% - 14% become 39.69% - 92.76%, as shown in Figure 15.

#### 4. CONCLUSION

The application of tubular skylight to the study object of Multifunction Room in the building of deep plan cultural heritage was able to increase the area of the space that meets the lighting standards up to 92.76%. The light entering the room through tubular skylight has been through the reflection process so that it can reduce the glare and heat from the sun. On the other hand, glare and heat cannot be avoided entirely considering the way light inserted vertically from above, especially for countries in the equator region such as Indonesia. For that reason, further research related to the effects of solar thermal radiation entering through the light holes on the roof needs to be done to optimize the alternative design of tubular skylights in thick-edged buildings in tropical climates.

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