JAITA

Journal homepage: https://publisher.uthm.edu.my/ojs/index.php/jaita
e-ISSN : 2716-7097

Journal of Advanced Industrial Technology and Application

A Study of Daylight Optimization in Building Design in The Student's Residential College of UTHM Pagoh

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DOI: https://doi.org/10.30880/jaita.2020.01.01.001
Received 02 February 2020; Accepted 08 April 2020; Available online 30 June 2020

Abstract: Daylight is often used as a natural light source in order to reduce the consumption of energy in a building and maintain sustainability during the daytime. This study finds that the residential college design is lacking of passive solar control devices to control the daylight penetration into the building which causes discomfort due to direct sunlight problems. This paper identified and analyzed the daylighting performance of the residential college's living area via computer simulations. The daylight performance for the living area of the residential college has been investigated in terms of daylight factor and indoor illuminance. The excessive amount of daylight penetration in the living area can be optimized by upgrading the windows with external shading devices. An external shading device is proposed in this study to avoid the intensity of solar radiation and transfer direct sunlight into the living area. The external shading device design is chosen suitably to the building design. SketchUp software is used to simulate the building design into two 3D models, the first model is a building without shading devices and the second model is a building with shading devices. The 3D models are converted into 2D models using VELUX Daylight Visualizer software. Daylight factor and indoor illuminance are analyzed using VELUX Daylight Visualizer software to calculate the extent of daylight penetrations. Then, the results generated by VELUX Daylight Visualizer software are used to compare the building without shading devices and the building with shading devices. The results showed that the building with shading devices installation are more effective in optimizing the daylight penetration. Therefore, shading devices should be included in the design of the residential colleges to create a comfortable thermal condition for the occupants.

Keywords: shading devices, SketchUp, VELUX Daylight Visualizer, daylight factor, illuminance

1. Introduction

Daylighting is implemented in building design by the architect in order to reduce the consumption of energy during daytime. The use of natural light has been seen as important in improving the environmental quality and energy efficiency of buildings [1]. Daylight is penetrating through window openings, window glasses or other openings that admits light into the indoor environment. Shading devices is common in building design that helps control the sun radiation in order to achieve optimum indoor lighting. Other than that, shading devices also help maintain visual comfort and thermal comfort for the occupants. A good visual comfort and thermal comfort can increase productivity for the occupants inside the living area without electrical usage.

This study is based in the residential college of Universiti Tun Hussien Onn Malaysia (UTHM) Pagoh campus in Pagoh, Malaysia. The location is selected due to the students' response to the discomfort caused by the large windows opening and windows glasses that allowed excessive amount of sunlight into the living area during daytime. The

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residential college is a low-rise 5-storey building. However, only a room is selected as a research location due to the lack of time and man power to conduct the analysis.

This paper studies daylighting performance at the residential college in order to control the amount of sunlight penetrating into living area during daytime. Based on this study, there are living areas inside the residential unit that receive excessive direct sunlight due to the absence of sun shading elements on the building envelope. This paper proposes design addition that can help control sunlight problems in the residential college while maintaining energy saving. This paper will show that the residential college's buildings design needs to add on shading elements in order to improve indoor illuminance without causing discomfort to the occupants.

2. Literature Review

2.1 The Importance of Solar Control Devices.

SDs is a solar control device that helps in achieving comfort and giving privacy to the occupants. Other than that, solar control device helps to achieve optimum indoor lighting. A study in Hong Kong reported that a good external design of the building could help save 35 percent of the total air-conditioning to achieve energy efficiency [2]. External shading device are used to prevent direct sunlight into the living area. In general, SDs is used to keep the indoor environment from direct sunlight through the window or other openings. Previous studies report the effectiveness of window shingles to reduce discomfort during hot weather [3].

For this study, SDs is used as a solar control device for the residential college. To optimize daylighting in a residential college, SDs is effective to control the solar radiation on the building as the surface receives excessive exposure of sunlight. The target of SDs is to enlarge the shading ratio, especially on windows, to keep spaces conditioned, lower energy demands and reduce glare levels near windows. In general, external SDs have a higher performance than internal SDs. SDs are economical solutions as it does not require manual adjustments [4]. In addition, SDs also protects the indoor environment from sun radiation during early morning and late afternoon. Illuminance level indicator of sunlight radiation inside the living area is presented in Table 1.

Other than that, SDs is used to reduce the undesirable penetration of solar radiation. In residential buildings, an appropriate selection of SDs can control indoor illumination from daylight, solar heat gains, and glare while maintaining view out through windows. In a meantime, SDs can also help saving lighting while maintaining visual comfort and thermal comfort.

Table 1 - Illuminance level indicator [5]

Illuminance level (lux)	Interpretation
50-79	Slightly not to the brightness suitable for tasks that do not require high visibility
80-199	Brightness suitable for tasks that do not require high visibility
200-499	Brightness suitable for reading areas like office, classroom, and library
500-999	Perceived either as desirable or at least tolerable.

Source: (Hassan, 2012)

2.2 Daylight Factor

Daylight factor (DF) is a measure of internal illuminance relative to external unobstructed illuminance under standard CIE overcast sky conditions and is expressed as a percentage. It is a common measure, which permits determination of the availability of daylight in a room. DF is measured at working plane where visual tasks are likely to take place, and 0.8m above the floor. The higher the DF the more daylight is available in the room. An average DF is less than 2 % generally makes a room look dull and artificial lighting is likely to be needed, whereas an interior will look too bright when the average DF is more than 5 % and artificial lighting will most likely not be needed during daytime. Table 2 presents the accepted DF for residential buildings.

Table 2 - DF for residential buildings [6]

Room	Goulding et al. (1994)
Bedroom	0.5% (3/4 of room length)
Kitchen	2% (centre)
Living room	1% (centre)

Source: (Sacht, 2014)

Table 3 - Lighting Performance Indicator [7]

Daylight Factor	Interpretation
<1%	Unacceptably dark negligible potential for daylight utilization
1-2%	Acceptable and has a small potential for daylight utilization
2.5%	Preferable and large potential for daylight utilization
5%	Preferable and ideal for paperwork too bright for computer work total daylight autonomy

Source: (Dubois, 2001)

3. Methodology

This study seeks to identify and analyze the existing design of UTHM Pagoh's residential college. This study finds that the existing building design lacks the passive solar control device to prevent direct sunlight penetrating into the indoor environment during daytime. The existing design will be improved by adding passive solar control device to optimize daylight penetration into the building. The illuminance levels were calculated in terms of DF and indoor illuminance. Therefore, this study proposes the addition of shading devices (SDs) that can optimize daylight admittance while providing enough illumination into the living areas. The following steps are taken during this study;

Step 1 - The study is conducted by identifying the problem regarding excessive sunlight in the existing building of the residential college. Observation that has been conducted finds that the existing building design has indoor daylighting issues during daytime. After the observation, passive solar devices are proposed as an improvement in existing building design to optimize daylighting inside the residential college's living area.

Step 2 - Room C inside of apartment B303 is selected as the research location. The room is selected because the windows are facing the sun rise during daytime which allows more sunlight penetration.

Step 3 - Then, SketchUp software is used to redesign the existing building into a 3D model. Two model was redesigned, the first model is a building without shading devices and the second model is a building with shading devices. Next, the 3D model will be converted into 2D model for VELUX software analysis.

Step 4 - The 3D model are converted into 2D model in VELUX software and used to analyze the level of sun penetration into Room C, Level 3. There are five parameters used in the simulation such as orientation, location, date, weather, number of floors and floor selected. Level 3 is selected because the level is in the middle of the building, so the level is suitable as an example of the 5-storey building. Table 4 shows that overcast sky is selected automatically during DF analysis in order to analyze whether the building is receiving acceptable amount of indoor illuminance. Meanwhile, table 5 shows sunny weather is selected for Indoor Illuminance analysis. The indoor illuminance levels results will be referred to Table 1. Meanwhile, the DF results will be referred to Table 2 and Table 3. These tables are based on other studies [5-7].

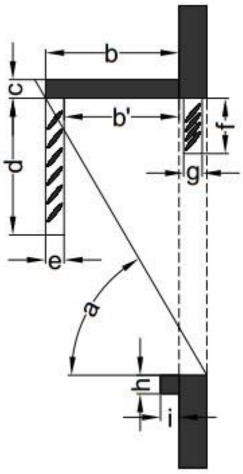
Step 5 - The analysis results are separated between the building without shading devices and the building with shading devices. The image results are shown in visualization and converted into bar graphs to be analyzed. Then, the results are referred to the standard by the previous studies. The final results of the two-building condition are compared and the effectiveness of the proposed shading devices is proven at the end of the research.

3.1 Daylight Data

Daylight data is taken hourly during daytime for predictions of daylighting under the variable sky. Sun conditions can provide a realistic measure of the true daylighting performance for the indoor environment. Daylight data is taken only a day to avoid problems of averaging. Only this method can capture the full range of short-term variation in the sky and sun conditions. This dataset was taken at 10 am, 12 pm, 2 pm, and 4 pm under sun conditions to simulate the effects of SDs proposed using advanced computer software.

3.2 The Computer Model

This study uses computer-based modeling and simulation such as SketchUp software to simulate the residential college design into 3D and shading devices to show the real-time situations in a simulation. Through an advanced computer software, VELUX Daylight Visualizer (VELUX) is used to analyze and calculate the extent of sunlight in the indoor environment. DF at any point in a space is the ratio of the (internal) illuminance at that point to the unobstructed (external) horizontal illuminance under the CIE standard overcast sky [8]. By using VELUX software, DF and indoor illuminance will be producing daylight autonomy to be analyzed. The program proved to be accurate in its simulations showing a maximal error lower than 5.13 % and an average error lower than 1.29 %.



a	60˚
b	0.72 m
b’	0.62 m
c	0.10 m
d	0.69 m
e	0.10 m
f	0.30 m
g	0.10 m
h	0.10 m
i	0.10 m

Figure 1 - Section of the horizontal panel and vertical louvre

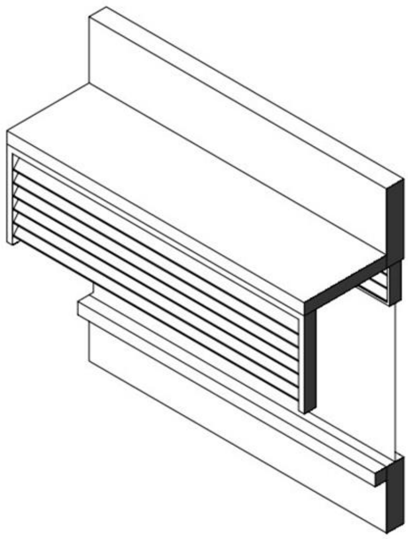
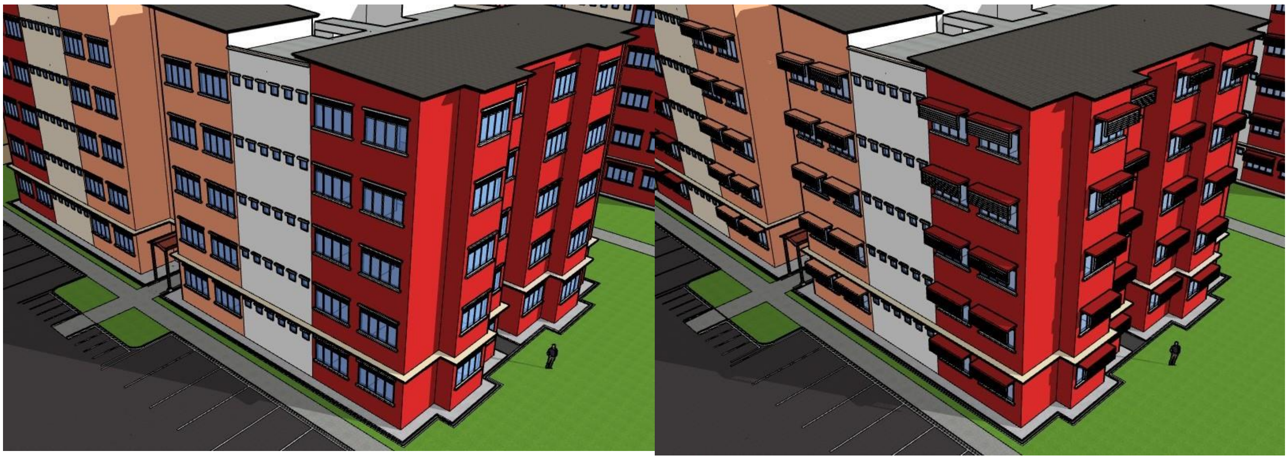


Figure 2 - Isometric plane of the horizontal panel and vertical louvre

Figure 1 shows the shading device designed to optimize the daylight problem in the residential college. The size of the window is 600mmx1200mm. The residential college used side hung windows and single panel window glasses that allows sunlight to admit into the living areas. Based on Figure 1, the horizontal panel is designed longer than the width of the window to provide sufficient space between windows and SDs. The vertical louvre is designed to shade half of the window in order to prevent the high angle of the Sun. The proposed SDs is fixed to the building walls. The angle of the louvre is 45˚ which can admit light and air, and also can keep out direct sunlight and rain. Other than that, ventilation grill is designed on top of the windows for ventilation purpose.



(a) **(b)**

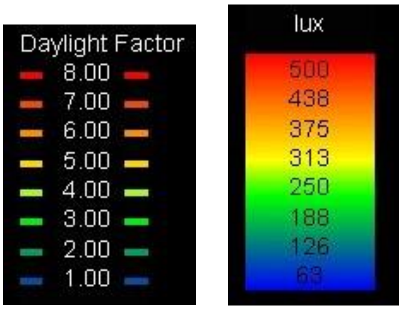
Figure 3 - (a) The existing residential college design with no SDs; (b) The residential college design that has been upgraded with SDs

(a) **(b)**

Figure 4 - (a) Existing window design at residential colleges; (b) External SDs proposed is the horizontal panel and vertical louver

3.3 Daylight Autonomy

Based on the simulation analysis by VELUX, the results of DF analysis can be seen in Figure 6 and Figure 7. Whereby, Figure 6 shows the excessive DF received according to Figure 5 which showed that the building receives more than 5% of DF. Table 3 present the indicated DF. By referring to Figure 7, the residential college received acceptable results of DF after the building is upgraded with SDs. The DF achieved the target level for residential building.

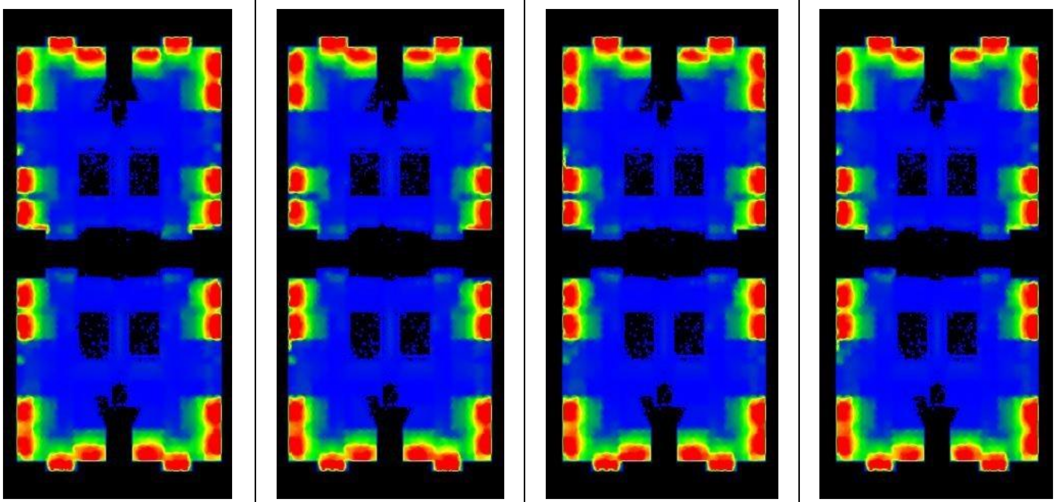


(a) **(b)**

Figure 5 - (a) DF levels indicator; (b) Indoor illuminance indicator

Table 4 - Parameter used in the simulation for DF analysis

Orientation	North-South
Location	Pagoh, Malaysia
Date	21 October 2018
Weather	Overcast sky
Number of floors	5 floors
Floor	Level 3



10 am	12 pm	2 pm	4 pm

Figure 6 - Differences of DF visualization at level 3 of the residential college for a building without SDs according to the following times

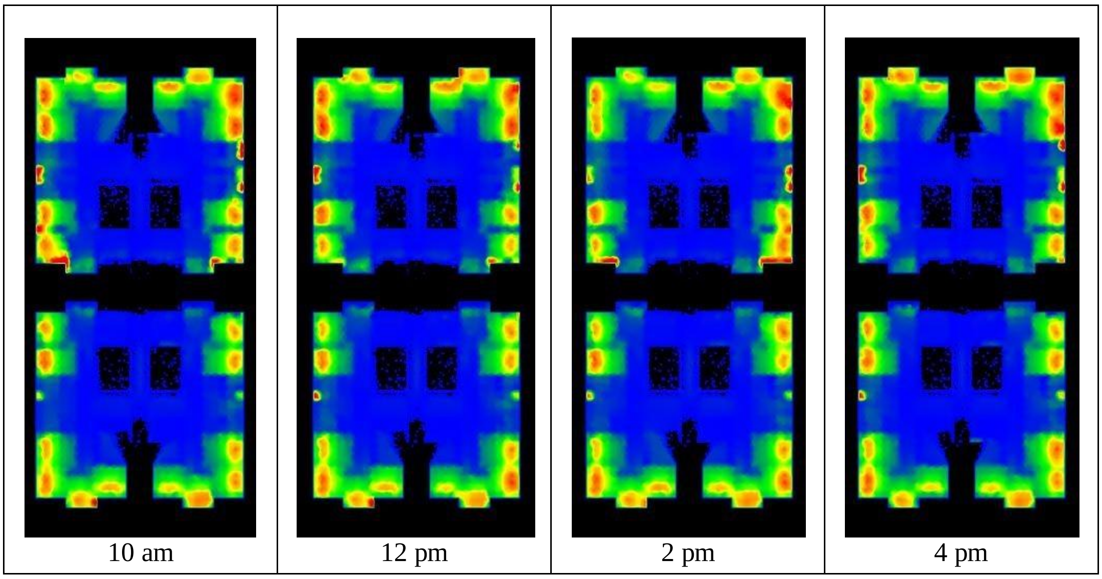


Figure 7 - Differences of DF visualization at level 3 of the residential college for a building with SDs according to the following times

Figure 8 - Floor plan for a residential uni

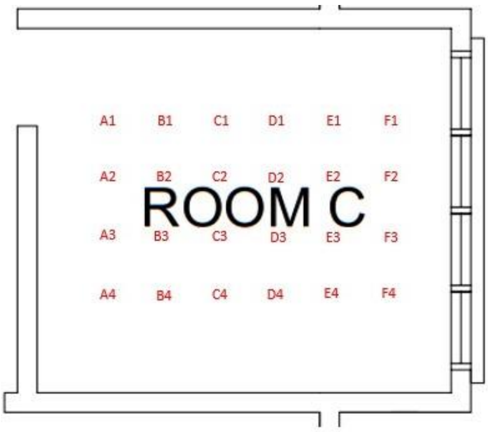


Figure 9 - Floor plan of a room inside the residential unit used as the location of this study

Hourly illuminance data are shown in Figure 9 which presented 24 calculation points in room C of the residential unit. Figure 9 presents the zoning method used in this study. Zoning method helps to give a clear picture of sunlight extent penetrate from the windows. Daylight autonomy represented as a percentage of annual daytime hours that a given point in a room space is above a specified illumination level. Daylight illuminance admitted through windows and extend across the room space of the residential room. To evaluate the effectiveness of the shading device, simulation tools are necessary to calculate the daily development of indoor illuminance levels due to daylight.

Table 5 - Parameter used in the simulation for indoor illuminance analysis

Orientation	North-South
Location	Pagoh, Malaysia
Date	21 October 2018
Weather	Sunny
Number of floors	5 floors
Floor	Level 3

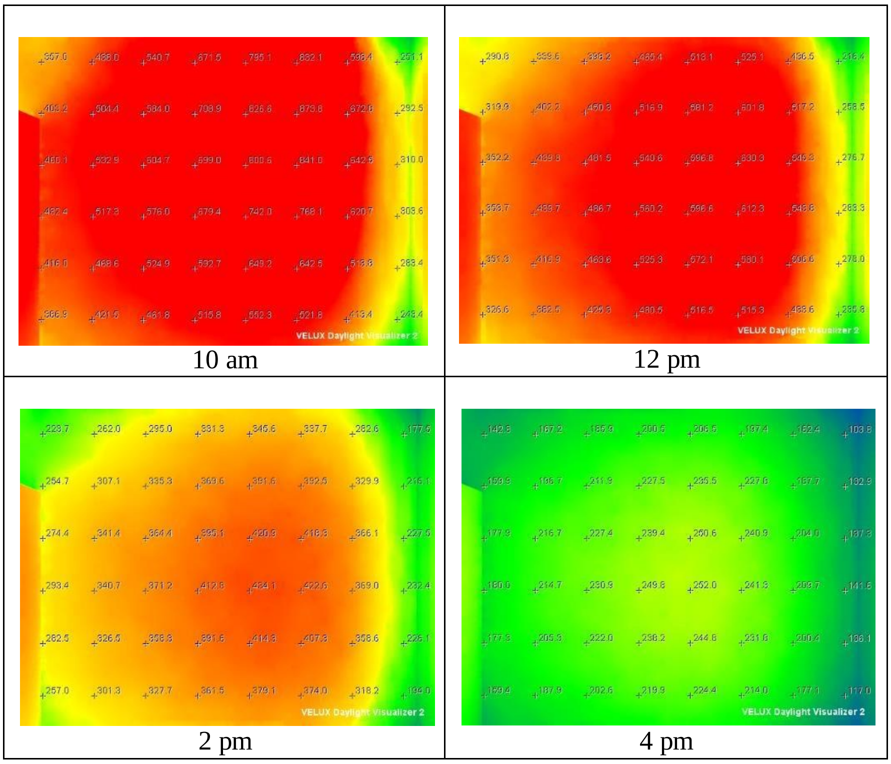


Figure 10 - Daylight autonomy of room C without SDs

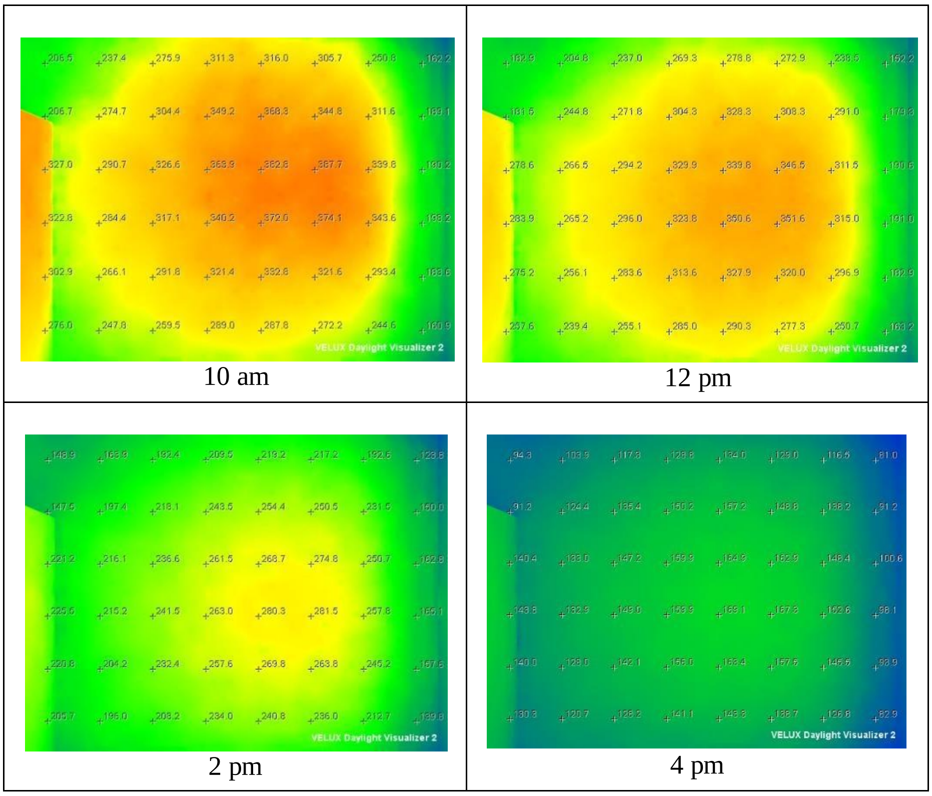


Figure 11 - Daylight autonomy of room C with SDs

4. Results and Discussions

Figure 12-15 show the results of indoor illuminance level using VELUX software. The figure below shows the comparison of indoor illuminance between two room conditions which is window without SDs and window with SDs. The results are differentiated between zones from zone A to zone F to show the performance of daylight admittance inside the residential room.

The sunlight penetration extends along with the distance from the windows. Based on the figures below, indoor illuminance of windows without SDs causes higher levels of illuminance and shows its range between 450- 900 lux. Due to the variation of intensity, it should be evaluated together with DF. The DF of this study shows that the interior of the residential college received accepted amounts of radiance according to Table 2.

Based on Table 1, the range between 200-499 lux and 500-999 lux are only suitable at reading areas and very least tolerable for residential areas. Minimum levels for tasks and activities inside residential rooms must be between 200 to 500 lux. Due to the excessive lighting, SDs is used to optimize the daylighting problem. The results show that indoor illuminance levels of every hour taken is reduced after the building design is upgraded with SDs. The illuminance results are in a range between 200-400 lux. The results show that the SDs successfully optimized the daylighting.

Based on Figure 12-15, the bar charts show the decrease of sunlight admittance after the addition of SDs to the building design. The results show that the indoor illuminance levels decrease from >800 lux to <400 lux at 10 pm, from >600 lux to <400 lux at 12 pm, from >400 lux to >300 lux at 2 pm, and from 250 lux to <200 lux at 4 pm. According to the bar charts shown, indoor illuminance levels at 10 am is high because the windows at room C is facing the sun, based on Figure 10. So, the room will be warm during the late evening as the sun is switching sides to the west. From the result, it can be concluded that SDs is effective to optimize the daylight in the residential college of UTHM Pagoh campus.

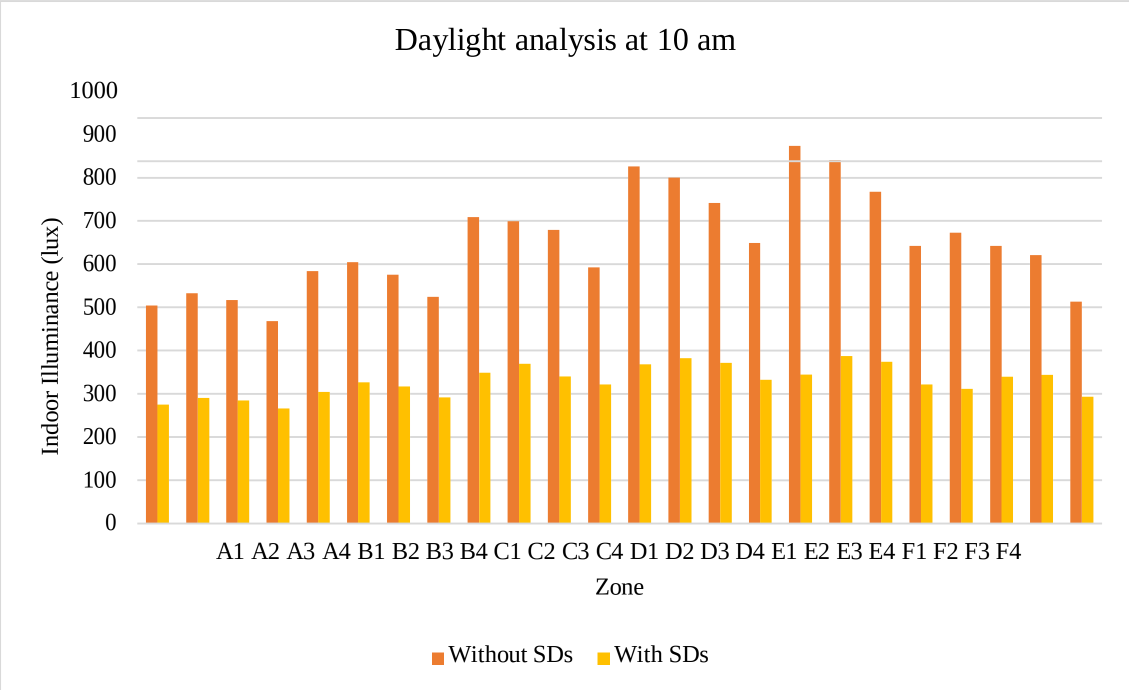


Figure 12 - Comparison of indoor illuminance levels between windows without SDs and windows with SDs at 10 am

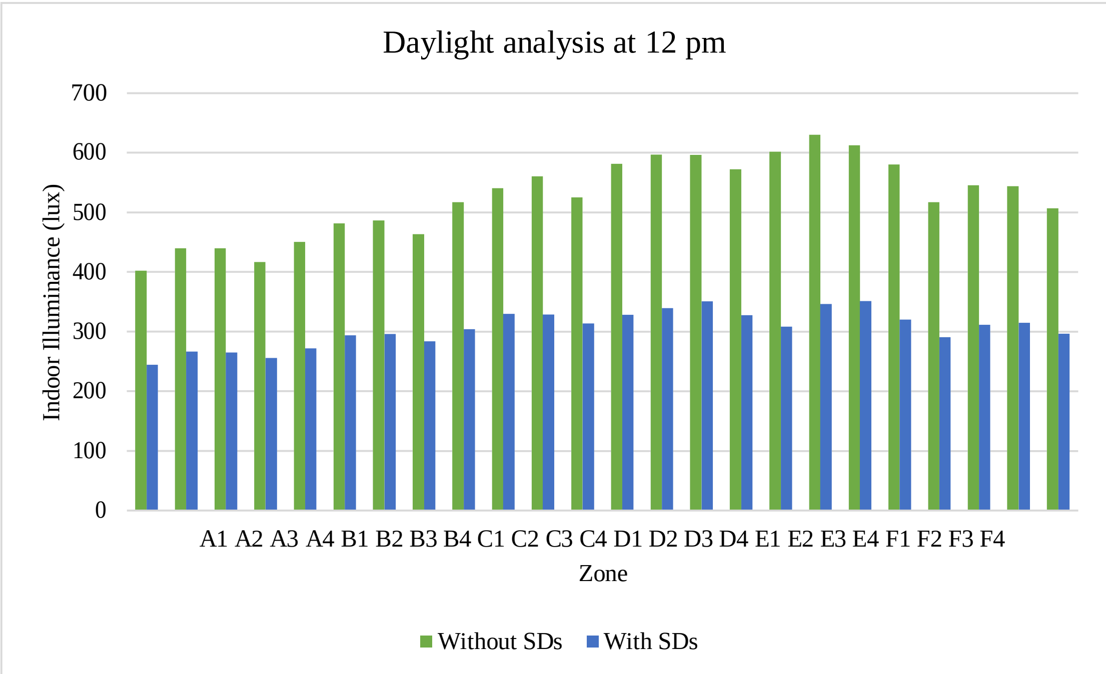


Figure 13 - Comparison of indoor illuminance levels between windows without SDs and windows with SDs at 12 pm

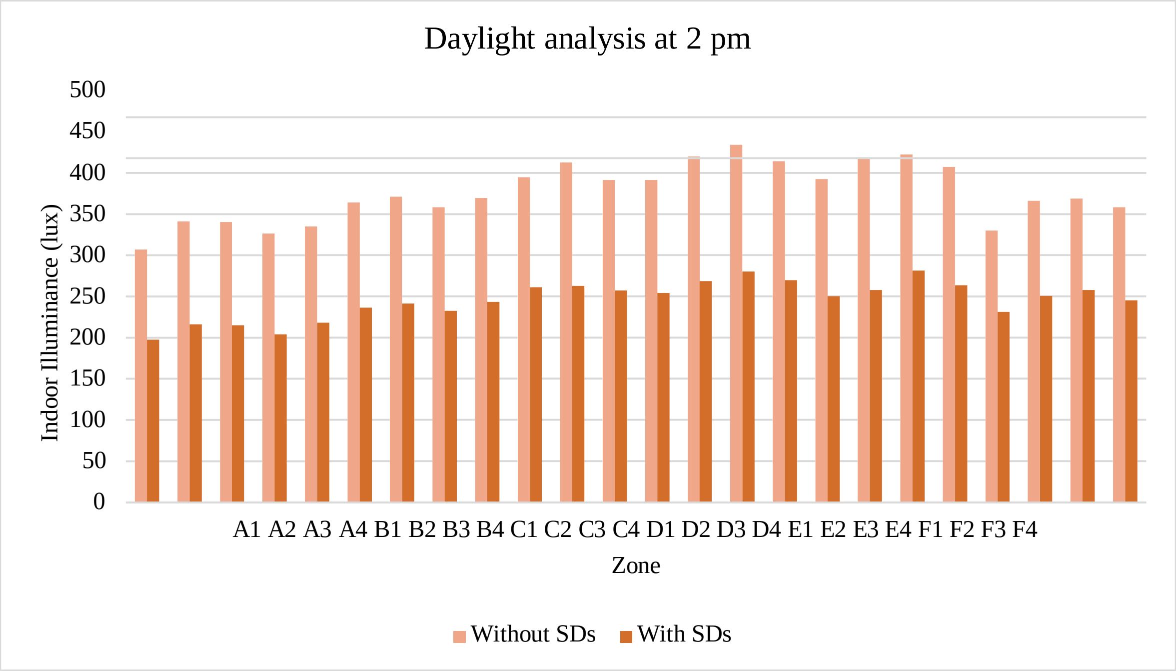


Figure 14 - Comparison of indoor illuminance levels between windows without SDs and windows with SDs at 2 pm

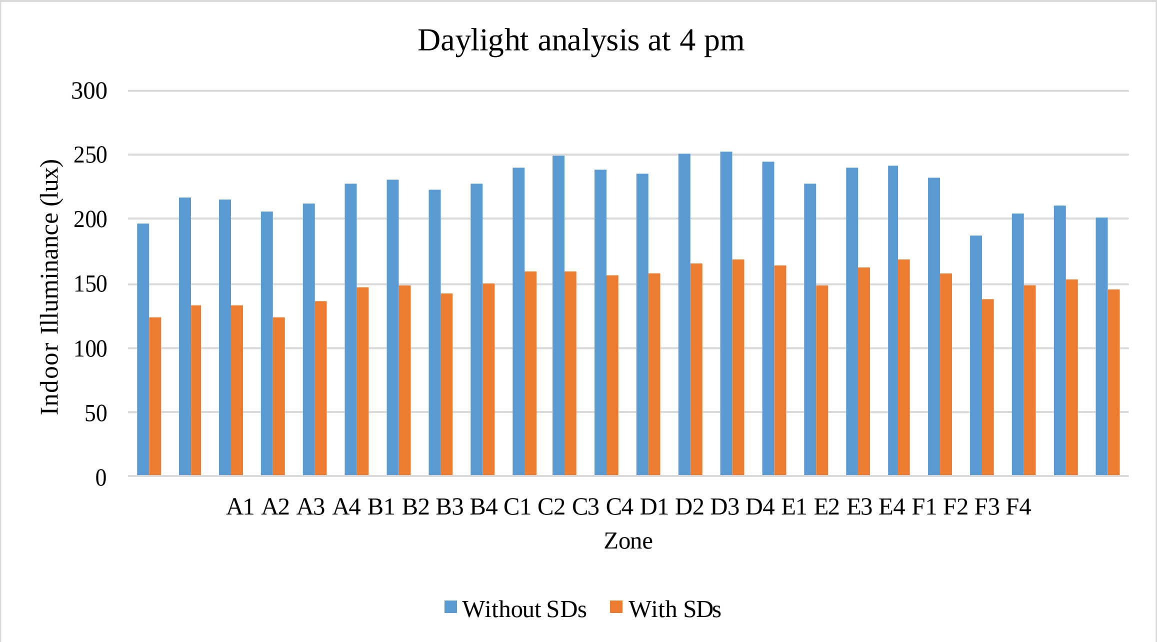


Figure 15 - Comparison of indoor illuminance levels between windows without SDs and windows with SDs at 4 pm

5. Conclusions

The aim of this study was to recommend the effective passive SDs to optimize the daylight penetration inside the residential college and increase energy savings while balancing daylighting and visibility. Though the SDs reduce the distance of penetration, it can still allow illuminance to be reached which are slightly higher than the acceptable level. The shading devices can reduce glare effectively through the degree of glare which is highly dependent on many issues such as the exposed area of the window, the outdoor and indoor luminance and the viewing angle of the observer [3]. The existing building design is successfully upgraded by installing SDs to the windows opening as a passive solar control device. Thus, the design of external SDs demands a comprehensive solution which includes admitting sufficient daylight into the living area, reducing the direct view of the sky, and providing a suitable interior design [3].

The recommendation made in this study will be useful for developing more effective SDs for residential college. The recommendations are as follows:

1. Adjustable SDs are proposed for all exposed facing windows in all the sunlight levels throughout the day where the fixed SDs is proposed.
2. The proposed design from this study may be installed into other residential college design for optimizing daylighting purpose.
3. Perform a simulation analysis for a week to see more changes on the illuminance levels.
4. Differentiate several types of SDs and study their performance of optimizing the daylight penetration into the residential living area using VELUX software.
5. Use Revit software to simulate the daylight performance of the proposed SDs design for advanced daylight analysis.

Acknowledgement

The author would like to express sincere gratitude to the staff members of the Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), for the guidance and encouragement in carrying out this research and also in providing valuable suggestions and useful comments throughout the report preparation.

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