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The Impact of Light Shelves to The Daylight Illuminance for Office Building in Malaysia

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Abstract
Daylighting illuminance provides various benefits and serves as an important strategy to incorporate into the building design. However, lacking on the efficient design strategy provides a negative impact to the daylight performance and building energy consumption. Serve as one of the effective passive daylight strategies, light shelves potentially increase the indoor daylight performance through an efficient design strategy. This study aims to investigate and evaluate the effectiveness of light shelves to the daylight performance via the computerized simulation. Energy Commission Diamond Building, Putrajaya is selected as the model to be simulated via LightStanza which is based on Malaysia Standard 1525 (MS-1525). The emergence of light shelves provide positive and negative impacts to daylight performance. Light shelves potentially reduce the excessive amount of daylight, especially areas located 1 m near to the building's facade, while it also critically reduces the existing comfortable daylight performance. The daylight performance is less than 100 lux for the areas located 5 m to 6 m from the building's facade which are lower than the standard daylight requirements by MS-1525. Further study with critical consideration on the integration with other design elements are needed that potentially will improve more on the daylight performance. Overall, the implementation of light shelves provide positive and negative impacts to the daylight performance for Energy Commission Diamond Building, Putrajaya.

Keywords: *Daylighting Illuminance, Light Shelves, Daylighting Computerized Simulation.*

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I. INTRODUCTION

Daylighting is defined as the process of using natural sunlight to penetrate into a building and serve to reduce the energy costs [1]. The process of daylighting consists of controlling the amount of natural light (both diffuse and direct) to enter the building [2]. However, a high amount of daylighting to the interior space will create other negative impacts to the occupant especially glare and uncomfortable conditions. Besides, insufficient daylight opening and strategies reduce the daylight performances which influence the spatial quality for a building design. Serve as an effective environmental strategy, daylighting creates a comfortable condition to the interior building's area [13]. One of the main purposes of implementing daylight is to mitigate the amount of electric light as well as to reduce the energy consumption. Recent studies reported that there is correlation between lighting and a building's user performance and health. Daylight not only provides visual information to the occupant but also acts as an amplifier to non-visual functions such as alertness, mental focus and cognitive performance [3]. This study shows the importance of daylighting to the building and human life in general. Therefore, it is crucial for daylighting to be planned ahead and incorporated efficiently since the early stage of the design process.

The adoption of efficient passive daylight design strategy potentially controls the daylight illuminance. Unfortunately, the penetration of daylight is uniform and deep to the certain interior space area which is required to be integrated with artificial light to increase the daylight performance [15]. Via a thorough study, the incorporation of a light shelf to the building design will improve the daylight performance. A light shelf which is considered as a passive architectural device, functions to harvest or reflect natural daylight as well as reducing the negative impacts into a building [11]. Besides, light shelves serve to reflect sunlight off a horizontal surface distributed more evenly and deeply within a space. Recent evidence suggests that a horizontal light shelf is found to increase the illuminance in the interior by an average of 21% [4] and increase daylight in the depth [5].

The adoption of light shelves to the building design improves the building energy performance throughout the year [12]. Various types of light shelves can be incorporated to the building which is normally located at the interior or exterior part of the building [16]. Architects are required to understand in implementing a light shelf especially on its characteristics such as reflectance, height, geometry and other relevance requirements [14]. On the other hand, deep study and research are needed to provide an effective light shelf to incorporate into the building design and produce a high quality of daylight performance.

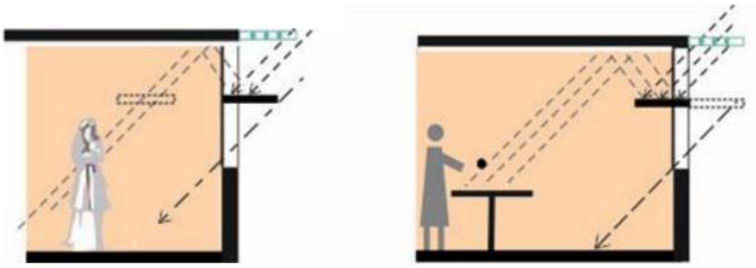


Figure 1: External and internal light shelf.
Source: Tiwari, 2018.

Thus, this study selected a certified sustainable building design in Malaysia known as Energy Commission Diamond Building, Putrajaya or the Diamond Building (Figure 2). Energy Commission Diamond Building is awarded Green Building Index (GBI) Platinum Rating award [6]. The ST Diamond Building is a landmark energy-efficient and environmentally friendly building for the Malaysian Energy Commission (Suruhanjaya Tenaga) in precinct 2 in Putrajaya, Malaysia. The building underwent a genuine integrated design process with climatic design playing a key role in giving the unique shape of the building. The unique shape of the ST Diamond Building was designed according to the climate and solar path of equatorial Malaysia. The ST Diamond Building is designed 50% daylit, without glare and minimal heat entry that is achieved through an extensive facade daylighting system. The implementation of a mirror light shelf, white painted window sill, white ceiling, no interior partitions, and no suspended ceilings are some of the factors that potentially improve the daylight quality. A study suggests that the Energy Commission Diamond Building, Putrajaya managed to save energy by 42% for plug loads, 33% for cooling loads, 18% for lighting, 7% for fans and 74% less energy for office equipment using the active and passive design elements [7].

Figure 2: Energy Commission Diamond Building
Source: IEN Consultants, 2023

As one of the initial methods, literature review indicates the active and passive sustainable design being applied to the building design. Deep study on the list of passive sustainable elements has been conducted and focusing on the performance of the daylight. The adoption of a light shelf to this building at the selected building facade will be examined through the computer daylighting simulation. Here, the information of the existing daylight performance will be compared to the daylight performance after the installation of the light shelf.

II. RESEARCH METHODOLOGY

The building's 3D model is developed through Autodesk Revit based on the design and floor plan of the actual building design. Next, the complete 3D model is simulated via a daylight computer software known as LightStanza daylight analysis. All of the information is generated through LightStanza, especially on the value of illuminance which measures in lux for every 1m starting from the original building's facade.

a) Case Study
The chosen building for this study is the Energy Commission Diamond Building, Putrajaya which is certified by GBI. The east office area which provides the light shelves at level 4 is selected for the computer daylight simulation study (Figure 3).

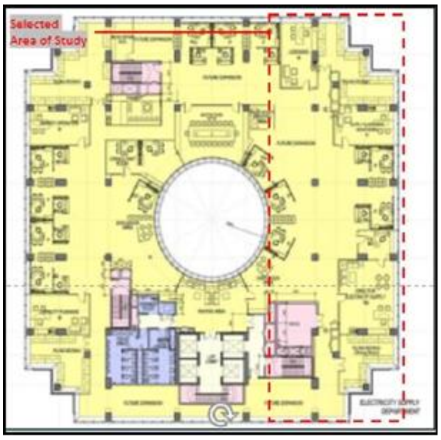


Figure 3: Typical Floor Plan - Level 4.
Source: Esfandiari et al., 2021.

b) 3D Modeling
The plans of the buildings are obtained from research publications and imported to Autodesk Revit to be rescaled and modeled. All the details for every floor, wall, window and door element are being measured and created. Two 3D models are created to show the two different approaches; one with existing light shelves and another one without existing light shelves. Once the models are finished, it is imported to LightStanza at the correct position and location.

c) Daylight Simulation
LightStanza is an online lighting simulation software that serves to simulate the lighting performance in a building design. A daylighting simulation must be performed on both models in accordance with the need to examine the daylighting performance of both approaches. In the simulation method, several phases have been established to guarantee that the operations are carried out in a systematic chronology and that accuracy may be reached in the outcomes. The process details are as follows:

Step 1: The first 3D model (existing) is generated via Autodesk Revit and exported into The LightStanza.

Step 2: Set the model's coordinate and date for simulation which is on 21 March 2022 with an interval of 1 hour from 8.00 am to 7.00 pm.

Step 3: Building material is set similarly according to the real building.

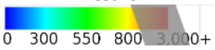
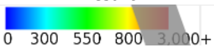
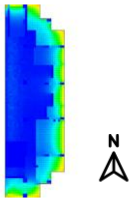
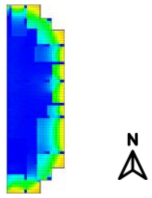
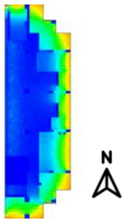
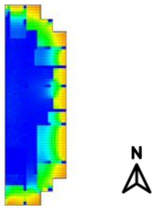
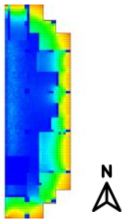
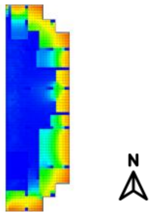
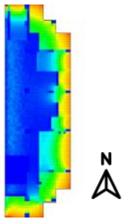
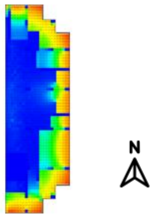
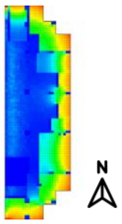
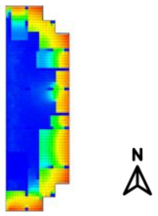
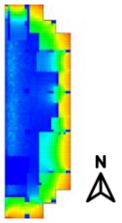
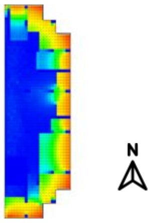
Step 4: The simulation is conducted via the overcast sky condition to receive the best result for daylight performance while mimicking Malaysia's climate. The data is then generated through the LightStanza simulation.

Step 5: An Excel document is used to convert the results from the simulation process to be analyzed.

Step 6: Step 1 to 6 is repeated for the second 3D model without the installation of light shelves. Data from both simulations are analyzed and synthesized to receive the overall daylight performance.

d) Analyzation of Data Based on Guidelines.
The data that has been simulated and tabulated will be examined and cross-referenced with standard requirements from MS 1525 (300 lux – 400 lux) [8] and JKR standard (500 lux) [9].

III. RESULT AND DISCUSSION

TIME	WITH LIGHT SHELVES		WITHOUT LIGHT SHELVES	
	Result 	**Summary**	**Result** 	**Summary**
8.00am		Illuminance : Avg : 183.9 lux Max : 752.6 lux Min : 0.0 lux Daylight factor : Avg : 1.3% Max : 9.0% Min : 00 %		Illuminance : Avg : 217.5 lux Max : 894.0 lux Min : 0.0 lux Daylight factor : Avg : 2.6% Max : 15.9% Min : 00 %
9.00am		Illuminance : Avg : 264.2 lux Max : 1262.0 lux Min : 0.0 lux Daylight factor : Avg : 1.3% Max : 9.0% Min : 00 %		Illuminance : Avg : 313.1 lux Max : 1272.8 lux Min : 0.0 lux Daylight factor : Avg : 2.6% Max : 15.9% Min : 00 %
10.00am		Illuminance : Avg : 328.1 lux Max : 1574.2 lux Min : 0.0 lux Daylight factor : Avg : 1.3% Max : 9.0% Min : 00 %		Illuminance : Avg : 386.9 lux Max : 1575.5 lux Min : 0.0 lux Daylight factor : Avg : 2.6% Max : 15.9% Min : 00 %
11.00am		Illuminance : Avg : 367.7 lux Max : 1738.0 lux Min : 0.0 lux Daylight factor : Avg : 1.3% Max : 9.0% Min : 00 %		Illuminance : Avg : 437.3 lux Max : 1765.9 lux Min : 0.0 lux Daylight factor : Avg : 2.6% Max : 15.9% Min : 00 %
12.00pm		Illuminance : Avg : 386.2 lux Max : 1836.0 lux Min : 0.0 lux Daylight factor : Avg : 1.3% Max : 9.0% Min : 00 %		Illuminance : Avg : 454.3 lux Max : 1853.7 lux Min : 0.0 lux Daylight factor : Avg : 2.6% Max : 15.9% Min : 00 %
1.00pm		Illuminance : Avg : 374.9 lux Max : 1729.0 lux Min : 0.0 lux Daylight factor : Avg : 1.3% Max : 9.0% Min : 00 %		Illuminance : Avg :443.8 lux Max : 1805.3 lux Min : 0.0 lux Daylight factor : Avg : 2.6% Max : 15.9% Min : 00 %

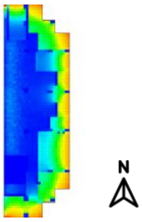
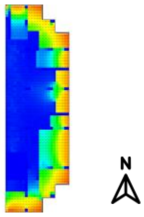
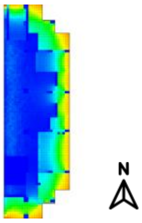
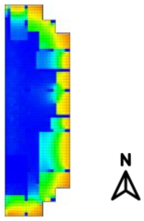
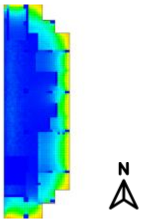
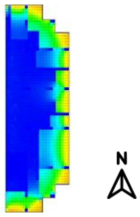
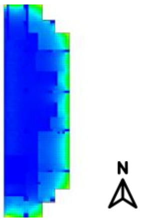
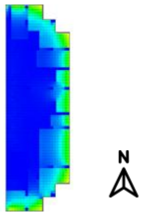
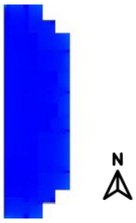
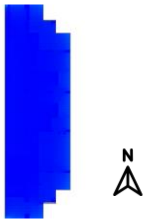
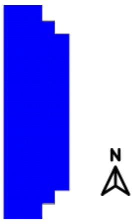
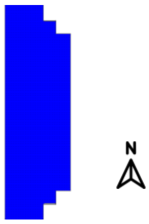
2.00pm		<u>Illuminance :</u> Avg : 339.7 lux Max : 1625.0 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 1.3% Max : 9.0% Min : 00 %		<u>Illuminance :</u> Avg : 400.9 lux Max : 1640.3 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 2.6% Max : 15.9% Min : 00 %
3.00pm		<u>Illuminance :</u> Avg : 280.3 lux Max : 1351.1 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 1.3% Max : 9.0% Min : 00 %		<u>Illuminance :</u> Avg : 335.0 lux Max : 1370.3 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 2.6% Max : 15.9% Min : 00 %
4.00pm		<u>Illuminance :</u> Avg : 205.0 lux Max : 974.0 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 1.3% Max : 9.0% Min : 00 %		<u>Illuminance :</u> Avg : 243.1 lux Max : 1000.8 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 2.6% Max : 15.9% Min : 00 %
5.00pm		<u>Illuminance :</u> Avg : 114.9 lux Max : 557.5 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 1.3% Max : 9.0% Min : 00 %		<u>Illuminance :</u> Avg : 137.2. lux Max : 567.5 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 2.6% Max : 15.9% Min : 00 %
6.00pm		<u>Illuminance :</u> Avg : 17.7 lux Max : 71.0 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 1.3% Max : 9.0% Min : 00 %		<u>Illuminance :</u> Avg : 21.1 lux Max : 86.5 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 2.6% Max : 15.9% Min : 00 %
7.00pm		<u>Illuminance :</u> Avg : 0 lux Max : 0 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 1.3% Max : 9.0% Min : 00 %		<u>Illuminance :</u> Avg : 0 lux Max : 0 lux Min : 0.0 lux <u>Daylight factor :</u> Avg : 2.6% Max : 15.9% Min : 00 %

Table 1: Result of the daylight performance for both of the simulation approaches

Table 1 indicates the daylight data performances acquired through LightStanza for both approaches which are the installation with light shelves and without the light shelves. Via Table 1, it indicates the detailed information especially on the illuminance daylight information and daylight factor. Detail analysis is shown through Figure 4 to provide the overall daylight performance between both simulation approaches.

With Light Shelves

Depth of room(m) from window	8.00 am	9.00 am	10.00 am	11.00 am	12.00 am	1.00 pm	2.00 pm	3.00 pm	4.00 pm	5.00 pm	6.00 pm	7.00 pm
1m	753	1102	1357	1551	1596	1542	1435	1179	861	484	73	0
2m	412	604	754	850	840	835	753	639	464	265	40	0
3m	256	376	444	509	535	518	483	406	300	154	25	0
4m	167	241	281	322	338	340	311	254	185	98	15	0
5m	111	164	203	228	231	226	215	173	124	70	11	0
6m	84	123	154	170	182	177	162	135	97	53	8	0

Without Light Shelves

Depth of room(m) from window	8.00 am	9.00 am	10.00 am	11.00 am	12.00 am	1.00 pm	2.00 pm	3.00 pm	4.00 pm	5.00 pm	6.00 pm	7.00 pm
1m	894	1284	1584	1795	1859	1820	1642	1373	1005	559	84	0
2m	544	776	949	1089	1139	1104	1000	829	608	342	52	0
3m	295	414	518	584	615	602	545	456	327	185	27	0
4m	177	246	309	347	358	355	318	266	194	111	16	0
5m	138	162	203	227	238	231	211	177	129	72	10	0
6m	100	137	170	194	200	191	176	150	106	59	8	0

LEGEND <100 Lux | 100 - 300 Lux | 300 - 600 Lux | 600 - 900 Lux | 900 - 1200 Lux | 1200 - 1800 Lux | >1800 Lux

Table 2: Average daylight illuminance level with and without the installation of light shelves.

Based on Table 2, the daylighting performance with light shelves and without light shelves produced different patterns of daylight illuminance. Both of the daylight performances for with or without the installation of light shelves, received less than 100 lux from 6.00pm until 7pm which required to depend on the artificial light. It also happens due to the source of natural light and the sun path orientation to the building's space. The daylight performance, located 1 m from the original building facade, are mostly provided above the requirement from MS1525 and JKR Standard for both of the simulation approaches from 8.00am to 4.00pm. Fortunately, light shelves functionally reduced the excessive amount of daylight illuminance at these areas. It indicates that most of the area located 1 m from the building facade can be considered as the insufficient working space area due to the glare issue. Further research and simulation study need to be conducted to provide a better daylight performance as it will maximize the working space area. It is important to effectively utilize this area that provides a view outside which influences the working performance.

Distances 2 m to 4 m from the building's facade provide efficient daylight performance at a certain area for both simulation approaches. The implementation of light shelves successfully provides an efficient daylight illuminance level especially for areas that are slightly higher from the standard daylight requirement by MS 1525. However, some areas that provide efficient daylight performance have reduced the daylight illuminance due to the installation of light shelves. The daylight performance without the light shelves produced a slightly more efficient daylight amount. It indicates that the light shelves are insufficient especially to provide more area that received effective daylight amount based on MS 1525 for area 2 m to 4m from the building facade. Occupants will have a more efficient working space area as well as reduce the dependence on artificial light. The emergence of light shelves for these areas are not totally providing an effective daylight performance especially in maintaining the existing efficient daylight illuminance that suits the standard.

Areas located 5 m to 6 m from the building's facade produced less amount of daylight compared to the building without light shelves. The daylight performance without the light shelves provides a better daylight amount which is less than the standard requirement set by MS1525. 5 m to 6 m areas are not effectively producing a comfortable daylight performance due to the less amount of daylight by the light shelves. Office areas located within 5 m to 6 m from the building's facade are required to depend on artificial light everyday due to the insufficient daylight penetration to these areas. Definitely, these areas which are located far from the building's facade, serve as the major factor that increases the electrical loads as well as contribute to the energy consumption.

IV. CONCLUSION

Based on the simulation result, the adoption of light shelves are needed to mitigate the excessive amount of daylight, especially for office areas which are located 1 m from the building's facade. The distance of 1 m area is considered as insufficient working area due to the glare issue. Both of the simulation approaches failed to provide a comfortable daylight performance to achieve the requirement by MS 1525. Additional building's elements that incorporate the light shelves may reduce the daylight amount to be within 300 lux to 400 lux. Beside, it is another challenge to maintain or to enhance the existing efficient daylight level for area 2 m until 4 m from the building's facade. The installation of light shelves also contributes in providing less daylight level and against the standard daylight requirements. Via the daylight simulation result, there are certain areas which possessed a slightly lower daylight value with the installation of light shelves. Here, we learn that the implementation of light shelves does not totally provide a comfortable daylight performance due to its function in harvesting the direct sunlight.

The overall result shows that light shelves provide a better daylight performance based on the average daylight illuminance. Light shelves potentially provide a better daylight level as needed by the office space area. Besides, it shows that light shelves can provide longer hours for workers to spend their working time at the office space area especially within 2 m to 4 m from the building's facade. Office areas located 5 m to 6 m from the building's facade provide less than 300 lux for both of the simulation approaches. Light needs to be provided through the electrical sources that create other issues on the energy usage and carbon emission. The integration with other daylight devices are necessary to improve the daylight penetration to these areas. Hence, it will enhance the sustainability of this building due to the effectiveness of the daylight strategy.

Light shelves potentially serve to reduce the excessive daylight illuminance for this building design as reported through the computer simulation. The positive result via the average and daylight factor indicate the importance of light shelves for this building. Further study will improve more to increase the daylight performance especially on the efficient daylight distribution and daylight penetration located deep inside the office area. This study proved the importance of light shelves for mitigating and controlling daylight illuminance for office buildings in Malaysia.

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