DESIGN AND ARCHITECTURE

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SYSTEMATIC LITERATURE REVIEW (SLR) ON THE FACTORS AFFECTING DISTRIBUTION OF NATURAL LIGHTING INSIDE CLASSROOMS

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Abstract – The natural lighting concept is to bring daylight into the area of buildings. The advantage of using natural lighting is that artificial lighting is reduced and solar energy is used directly. Adapting natural light design to a building is challenging and educational buildings are building typology that requires efficient lighting conditions. There was a huge cost burden when most educational buildings use high lighting energy consumption. Problems caused by insufficient natural lighting, result in high lighting energy consumption rates due to the use of alternative artificial lighting. It is the designer's responsibility to consider the design of daylight design building to be adapted to every construction process and design phase. Therefore, this paper aims to review a few factors that affect the distribution of natural lighting inside classrooms by using a systematic literature review (SLR) method. This paper also reviews the best practice of building natural lighting design features. A systematic review of Scopus and GoogleScholar databases identified 23 related studies. Further review of these articles resulted in six main factors that affect distribution of natural lighting inside the classroom.
Keywords - Natural Lighting, Daylighting, Educational Building, Classroom

1 INTRODUCTION

Malaysian tropical climate classifies it as a country of hot-humid tropics located at around 30N on the equator, with an approximate latitude of 10N to 60 45'N and longitude 99036'E to 104024'E (Jamaludin & Izma, 2015). The climate is perfect for harvesting natural light particularly in classroom spaces in a building. This is because according to the Building Sector Energy Efficiency Project (2013), natural light is constantly available daily from 8 am to 6 pm because there is hardly any change in seasonal availability since Malaysia is near the equator line. Stein and Reynolds, (2000) stated that all-natural light radiates from the sun and the light enters buildings with two conditions are known as either direct or reflected light.

Natural light harvesting may seem like an easy task to be implemented in a building, but it is a subject that needs to be well mastered to get efficient usage in this climate zone. Researchers showed that many daylighting design issues need to be addressed appropriately. Unfortunately, harvesting natural light in Malaysian climate is not as simple as providing large window areas on the building for its health benefits and energy savings (Fontoynont et al., 2004). Most of the lighting design standards for buildings in Malaysia are based on Malaysia Standard MS 1525:2014:-, Energy efficiency and use of renewable energy for non-residential buildings, highlight the recommended illuminance level for learning space which is from 300 to 500lux, while Uniform Building by Law (1984) recommends the Window-to-Floor Ration (WFR) for learning spaces.

Many research studies emphasize that to ensure the quality and quantity of lighting in the classroom environment is a rather complex task. To obtain a great quality of lighting in the educational building, natural light is suggested due to its benefits . There are a variety of different visual activities in the classroom, such as writing on boards either blackboard or whiteboard, reading and writing on desks, communication between students, and so on (Michael & Heracleous, 2017; Khoshbakht & Gou, 2018). To be carried out efficiently, these activities require specific visual conditions. Lighting is a crucial factor in an educational building because poor lighting does not only affect the visual comfort of the students but also leads to increased energy consumption. Hence, the purpose of this study is to identify the factors that affect the distribution of natural lighting in the classrooms.

2 ISSUES

In Malaysia, the second electricity consumption after air conditioning is lighting and it increases every year (Wang et al., 2013). It causes large amount of money spent, which nearly exceed a building's cost to illuminate spaces in the building (Koranteng & Simons, 2012). This massive electricity cost could be reduced by prioritizing natural lighting in building designs, improving human comfort and visual perception. A research conducted by Koranteng and Simons (2012), which concerned natural lighting and design in student’s accomodation found that most of these hostels' openings are poorly designed or positioned. Lighting is gained by switching on artificial means from morning to evening so that spaces can be used for an activity.

Another study by Susan and Prihatmanti (2017) was carried out in an old heritage building that has been used as a school:-, due to many obstructions identified in both schools, natural light penetrating the classrooms was below the standard level. Hence, artificial lighting was used as a supplement throughout the school hours as daylight was not distributed evenly. It can, therefore, be concluded that the unsuitable building design which failed to cater to the activities of the spaces significantly affected the level of indoor light and this could lead to problems of visual discomfort for students. Even worse, designers’ dream designs are often far from realistic situations when they fail to understand the local climate zone and living style features (Maheswaran & Zi, 2007).

However, only a few studies in educational buildings focused on evaluating and improving daylight design features. The findings of the research study conducted by Axarli and Meresi (2008) came from an evaluation of the quality of lighting in 9 classrooms of 5 schools in Greece. Despite high daylighting levels in all the cases under study, as a result of the use of unsuitable shading devices, research indicated that there were insufficient light distribution and glare problems during summer. A similar study was also carried out for classrooms in Greece (Theodosiou & Ordoumpozanis, 2008). The study revealed that, as a result of closed curtains, artificial lighting was used during working hours to control glare issues. Unfortunately, these studies were proven by Jamaludin and Izma (2015) in their studies which revealed that the effectiveness of implemented daylight design features in a building was rarely evaluated once they were passed on to their owners or users. Kamaruzzaman et al. (2015) evaluated the Klang District Office in Malaysia regarding tropical skies and found that there was an average lighting consumption savings of 37% due to daylight. However, it is important to note that occupancy and usage trends will affect energy savings.

Daylighting helps in two ways. It improves the interior environment on the one hand and can significantly reduce lighting energy in a commercial building on the other (Khoshbakht & Gou, 2018). However, providing a higher level of daylight light does not increase visual acuity, but also creates glare and visual discomfort (Lapus et al., 2010). Daylight assessment in one classroom in Italy using the Daylight Factor (DF) as a methodological instrument as well as Daylight Autonomy and Annual Sunlight Exposure vibrant climatic-based metrics (Pellegrino et al. 2015) showed inadequate daylight efficiency in schools. A view of the bright sky is a major concern in tropical climates. This research aims to review the features of daylighting design and the factors in terms of designing that affect the distribution of daylight in the classroom.

3 SYSTEMATIC LITERATURE REVIEW (SLR) PHASES

According to Armstrong et al., (2011), systematic reviews are a sort of literature review using descriptive techniques for collecting secondary data, critically evaluating studies, and qualitatively or quantitatively synthesizing results. The objective of systematic reviews is to tackle these issues by identifying, assessing and incorporating the results of all appropriate, high-quality individual studies that address one or more study issues. A Systematic Literature Review (SLR) was used to obtain related literature on the factors affecting the classroom’s natural lighting. The reviewers used the SLR methodology to produce a suggested design features for daylighting, especially on the classroom educational building. The SLR method contains four phases as shown in Figure 1 below.

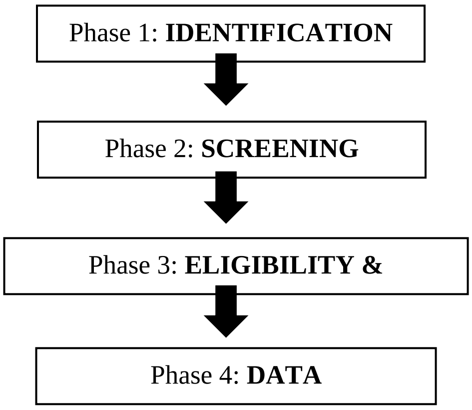


Figure 1 Phases Involved in SLR
(Source: Azril *et al.*, 2018)

Daylighting is a method which delivers natural light into a building through openings so that sufficient internal lighting is implemented by natural daylight (Fontoynont et al., 2004). The classroom design is analyzed for certain parameters: size and the depth-height ratio of the classroom, orientation of the window, direction of lighting and position of the desk. These are the factors that have a significant impact on natural lighting performance and quality inside classrooms (Syaheeza et al., 2018). According to several researchers, there are many other factors that affect the distribution of natural light in the classroom. Thus, this paper will explain a few other factors that are related to the daylighting design in the classroom using SLR methods.

3.1 Phase 1: Identification of Literature

The first phase of SLR is to address a comprehensive search for related subjects or terms related to daylight design features. Identification was performed by searching queries that enable systematic searching through established databases of publications. The reviewers used Scopus and GoogleScholar to identify literature review or query searching, justified by the large abstracts and citations databases of peer-reviewed publications. Relevant published papers were searched from the two search engines for databases at this phase. During the search, the keywords used were "natural lighting design features," "daylighting design," "daylighting classroom design" and "natural classroom light". Over 10,000 journals available are covered in these two databases. Table 1 below compiles the search string.

Table 1 SLR Search String

Database	Keywords
Scopus	"natural light" OR "daylight" AND "design*" AND "failure*" OR "poor" OR "inefficient" OR "inappropriate"
GoogleScholar	"natural light design in the classroom" OR "daylight design in the classroom" OR "daylight strategies on educational building" OR "daylighting design failure" OR "poor daylighting design on classroom" OR "inefficient daylighting design" OR "inappropriate daylighting design"

(Source: Authors' Research., 2019)

3.2 Phase 2: Screening of the Identified Literature

The literature identified was subsequently screened to suit the context of daylighting design issues in the classroom. The topic of this paper was 2,158 literature out of 2,164 literature, which is the failure of daylighting design in the classroom. The screen prohibited any duplicates of literature (similar authors, the comparable title of research) and non-English publications as well as the timeline of the paper published which is limited to 2013 till 2019 only.

3.3 Phase 3: Eligibility and Exclusion

During this phase, based on the country scope, the remaining 2,158 literatures were extracted throughout and 1,932 literatures were removed. The literature did not have the information on daylighting design in the classroom. Therefore, there were only 220 remaining literatures. After an extensive review, 23 literatures found to be related to this topic as tabulated in Table 1 below. Data or the Items were analysed and abstracted.

Table 1 Factors affecting daylighting

Factors / Authors		Built form			Orientation	Window design				Reflectance			Shading					Obstruction	
		Site & Building shape	Building layout	Room depth & height	Orientation	Size window	Shape window	Location window	Glazing type	Color of surfaces	Material of surfaces	Furniture	Overhang	Lightshelves	Tinted	Louvres	Blind	Trees	Façade
1	Mangkuto et al., (2015)				✓	✓		✓		✓	✓								
2	Lim & Ahmad, (2014)													✓					
3	Mousavi et al., (2016)											✓							
4	Mangkuto et al., (2016)			✓															
5	Mandala, (2019)									✓									
6	Babu et al., (2019)																✓		
7	Syaheeza et al., (2018)		✓	✓															
8	Ekasiwi et al., (2018)			✓		✓													
9	Al-Ashwal et al., (2017)					✓			✓										
10	Manurung (2017)		✓		✓														
11	Susan & Prihatmanti (2017)											✓						✓	✓
12	Al-Sallal (2010)			✓				✓											
13	Matham uthu et al., (2014)		✓			✓													
14	Ibrahim et al., (2018)		✓					✓				✓							
15	Talarosha & Marisa (2018)					✓	✓												
16	Wagdy & Fathy (2015)			✓												✓			
17	Zomorodian et al., (2016)			✓		✓								✓					
18	Inan (2013)					✓	✓	✓											
19	Meresi (2016)													✓		✓			
20	Lee et al., (2017)												✓	✓		✓			
21	Jeong & Tai (2013)												✓	✓					
22	Chiang et al., (2015)															✓			
23	Boubekri & Lee (2017)												✓			✓			
TOTAL		0	4	6	2	7	2	4	1	2	1	3	3	5	0	5	1	1	1
		10			2	14				6			14					2	

(Source: Authors' Research., 2019)

Based on Table 1 above, among the six checklist items, window design and shading are the highest results from the research findings of the factors affecting the distribution of natural lighting in the classroom. Several studies have been done on the effect of window design with regard to factors such as window size and shaping, position and glazing properties. Window design is a critical factor that should be considered during the design phase compared to shading elements. This is because the window is the element on a building that permit daylighting to enter a space.

3.4 Phase 4: Items Abstraction

Abstraction is the last phase. There are six (6) checklist items to identify the factors affecting the distribution of natural lighting in the classroom by using contextual analysis. The suggested Check List Items were tabulated as Table 2.

Table 2 Suggested Check List Items for Daylighting Design Factors

Checklist	**Built Form**	**Building Orientation**	**Window Design**	**Reflectance**	**Special Elements**	**Obstruction**
Items	• Site size and shape • Building size and shape • Depth of room • Height of room	• Building facing • North/South • East/West	• Position • Size • Shape	• Colour of surfaces • Material of surfaces • Arrangement of furniture	• Overhang • Light shelves • Louvres • Blind • Tinted	• Trees • Facade

(Source: Authors' Research, 2019)

3.4.1 Built Form

Daylight which is a combination of sunlight and skylight is admitted into building through the opening. The first step of making decisions in designing, the architect or designer will include daylight design features to develop overall building shape as it affects the potential use of daylight. Daylight of a level sufficient to be valuable for a given façade will penetrate the building to a certain depth. Thus, in both plan and section, the dimensions of the building have fundamental consequences for the degree to which it can be daylit (Trisha & Ahmed, 2017). The site places constraints on the choice of built form, which will affect the circumstances to optimize daylighting. The site's shape and size may affect the building's shape. For building depth and height, a rule of thumbs as shown in Figure 1 below could be used to measure the depth of daylighting penetrate interior spaces. Daylight depth is twice the height of the top window from the floor. Daylight Rule of Thumb (DRT) is often examined inviolable in sustainable building design, thus providing the sole quantitative justification for room proportions and orientation of facade openings as shown in Figure 2 below.

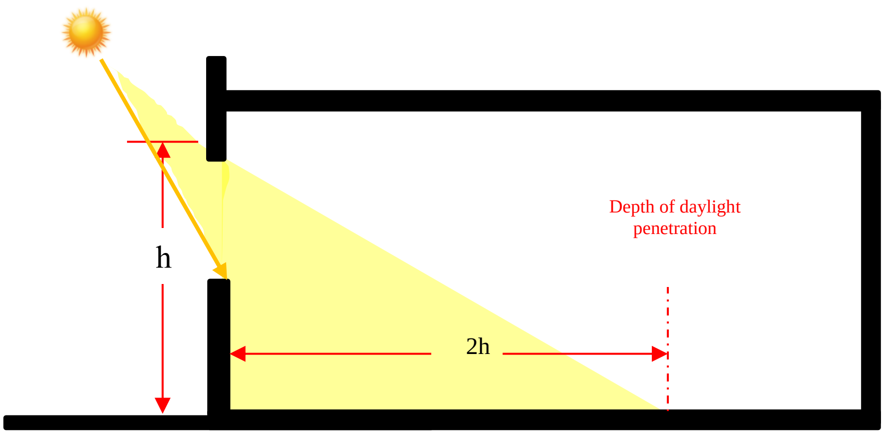


Figure 2: Rule of thumb of daylighting measurement
(Source: Trisha & Ahmed, 2017)

3.4.2 Building Orientation

Orientation is one of the important factors for the use of daylight and energy conservation in building design. Well-oriented buildings maximize the admission of daylight by building facades and reduce the requirement for artificial lighting (Mahdavi, Inangda & Rao, 2016). Due to the high percentage of relative humidity and high temperature exceeding the ASHRAE comfort limit for most of the year, the hot-humid area is one of the toughest architectural climates (Hyde, 2008; Ahmed et al., 2011). The biggest challenge facing architects in designing window processes is to protect the building façade from overheating and sunshine in tropical countries such as Malaysia as well as achieve the right amount of daylight. Regardless of the climate, the main facades of the building have the advantages of facing north and south rather than east and west. This is because when the main façades face east and west, these orientations do not work almost as well for daylight as, it provides plenty of light in the morning and afternoon, but often comes with plenty of glare and excess heat.

3.4.3 Window Design

This is a very important factor in allowing daylight to enter an interior space. The position, shape and size of the windows in the room have a great influence on daylight distribution. As Seinre et al., (2014) indicated, all daylight radiates from the sun and the light entering the building under two conditions, either from the top or from the side of the building. Daylight distribution improves with the higher position of the window as it provides an even daylight distribution. According to many researchers, the larger the opening size is the better as it increases the amount of daylight penetration into the spaces. However, the view of the occupants, the excess heat and the glare problems that will occur must be taken into account. According to Taylor et al., (2009), there are four types of glazing which are clear glass, tinted glass, reflective glass and low-E glass. The choices of glazing for a window is based on the function and activity of the building.

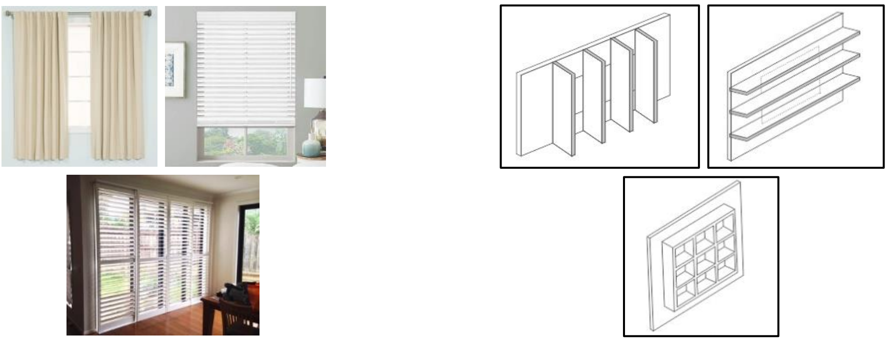
3.4.4 Reflectance

The reflectance in the building is referred to like the colour and material of surfaces, as well as the arrangement of furniture. As for the colour of surfaces, dark surfaces will reflect less light compared with bright surfaces. This is because dark surfaces will absorb the light and transmit it less than the incidence light reflect. In the context of the material, this refers to the finishes on the wall, ceiling and floor. For example, if the building has a glossy finish, it will reflect the light as the mirror does, while matt surfaces like wood and plaster reflect light in all directions equally (Baker & Steemers, 2002). When light enters into a building, it will not only reflect on building surfaces but also the furniture. The colour and arrangement of the building's furniture affect the reflection of light because if the furniture is not properly arranged, the amount of daylight will decrease.

3.4.5 Special Elements

Special elements are added to the building to regulate sunlight penetration and in other words, they are shading devices. There are several effects when solar radiation enters a room which is radiation is absorbed on to room surfaces and will lead to an increase in air temperature. Then, there will be an increase in mean radiant temperature experienced by solar radiation falling straight to an occupant. Besides, high intensities of radiation from direct sunlight or even the diffused sky can be the cause of discomfort glare or disability glare where an occupant's visual performance will be impaired. Shading devices have the purpose of eliminating these impacts and increasing the comforts of the building's occupants.

According to Wong et al., (2014), the position of shading devices on the building is both inside and outside. The internal sun shading devices are generally adjustable and enable occupants to control the quantity of direct light entering their room. Figure 3(a) below shows the example of internal sun shading such as curtains, blinds, and louvres. External sun shading devices are most thermally effective as they control externally the quantity of radiation that enters the building. External sun shading devices are installed on building in three ways which are the horizontal, vertical and egg-crate shape as shown in Figure 3(b).



(a) (b)

Figure 3 (a)Internal shading; curtains, blinds and louvres. (b)External shading; vertical, horizontal and egg-crate.

(Source: www.wbdg.org, 2019)

3.4.6 Obstruction

The obstruction is part of shading because it shades the direct sunlight from entering into the building. External reflections and obstructions from the building site's surrounding elements (buildings, vegetation, ground surface, etc.) will affect the quantity of daylight reaching the building's interior as shown in Figure 4.

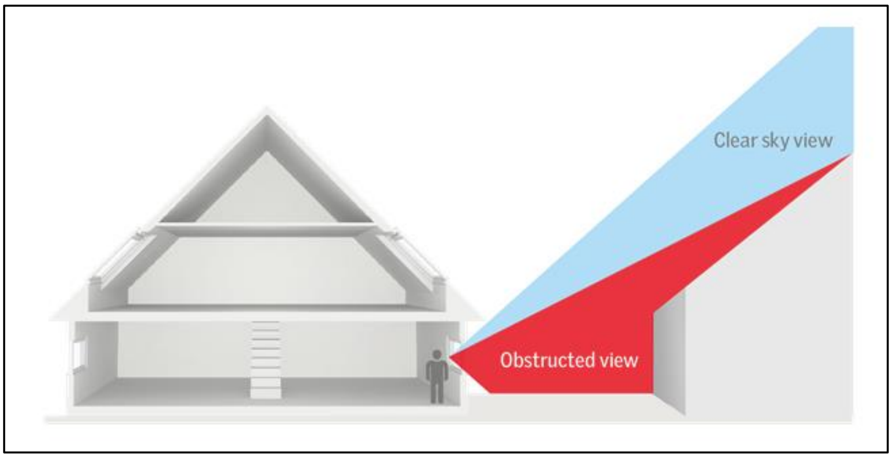


Figure 4 Components of view
(Source: www.velux.com)

4 CONCLUSION

This systematic literature review highlights the factors that affect the distribution of daylighting in a room. It can be summarized that the factors found are daylighting design features have to be considered during the designing process by the architect or designer to get the maximum amount of daylight. There are many complaints about daylighting and each complaint points to some factors which are from the whole scale of building design to interior detail.

According to data extraction, six factors will affect the distribution of daylighting which are built form, building orientation, window design, reflectance, shading and obstruction. These six features could be considered to get the maximum amount of daylight. Yet, the factors need to be tested quantitatively. There is no universal criterion of daylight quantity because what is found to be satisfactory depends on the function of the building, its architectural nature and the culture of the users.

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