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A Review of Aspects and Criteria of Daylighting and Visual Comfort in International Green Building Rating Tools

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Abstract
Architects and building owners are now focusing on how to make their buildings green. Many green councils around the world are currently experimenting with ingenious ways of introducing new energy-efficient buildings. They also implemented various principles and indicators to recognize buildings that contribute to sustainability, efficiency, and improve occupants' health. The paper aims to review the aspects and requirements that the Green Building Councils have recommended. This paper looks at seven of the rating systems available in terms of similarities and differences and presents new rigorous criteria for daylight performance and visual comfort.

Keywords: Daylighting, Visual Comfort, Passive Design Strategy, Rating Tools.

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1.0 Introduction

Effective daylighting is vital in achieving a sustainable building design (Ko et al., 2008). Daylight can significantly impact building performance, energy efficiency, productivity, and comfort, and provide occupants' satisfaction (Chien & Tseng, 2014). Energy efficiency is a key driver of green building movement due to significant environmental and economic benefits related to reduced energy consumption in green buildings (Dwaikat & Ali, 2018). There is a minor change in practice, particularly in hot climate regions, regardless of the global call for a paradigm shift towards new environmental awareness in urban planning (Natanian et al., 2019).

Therefore, significant challenges for the Malaysian power sector include sustainability, energy supply, and climate change. Energy-efficient initiatives in the construction sector can fix the above problems. In Malaysia, buildings consume 14,3% of total energy, and in the residential and industrial sectors, about 53% of electricity is consumed. Energy efficiency is essential for reducing energy consumption and enhancing local environmental sustainability in buildings (Shaikh et al., 2017). Reinhart et al. (2006) discuss the limitation of previous daylight metrics, focusing on individual sky conditions such as daylight's common factor. Furthermore, it has always been a problem to combine daylight with electricity, as different software packages are required for comprehensive calculations. (González & Fiorito, 2015).

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Abbreviations

LEED	Leadership in Energy and Environmental Design
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
SB Tool	Sustainable Building Tool
GBI	Green Building Index
IEQ	Indoor Environmental Quality

Daylight is one of the main components of green buildings, but no dominant metric has been created to help detect well-lit buildings (Leslie et al., 2012). It is important to maintain the best balance between energy efficiency and indoor environmental quality (IEQ) in this context (Ballarini et al., 2019).). In Europe, however, leasing coverage has generally been shortened in high-rise buildings because of the concerns about natural light penetration and views.(Ko et al., 2008).

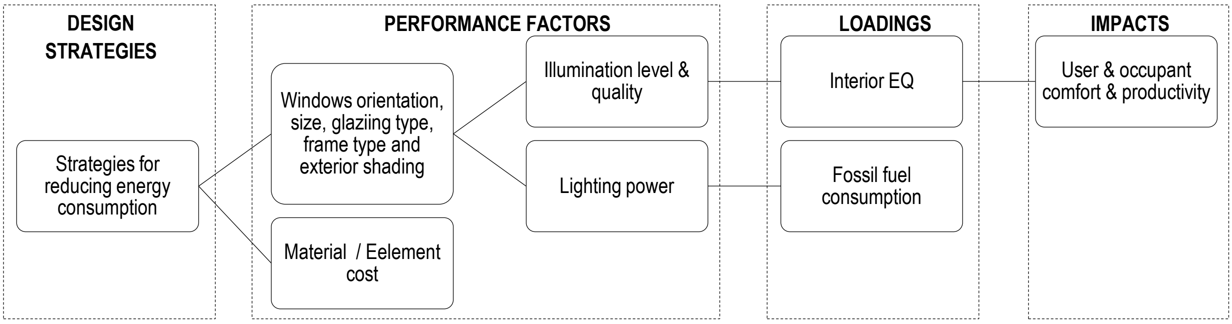

Fig. 1: The relationships between design strategies, performance factors, loadings and impacts from SB Tool rating tool
(Source: SB Tool)

1.1 Green Building Rating Tools

Directive 2010/31/EU supports the reconstruction of existing buildings with the goal of turning them into almost zero-energy buildings (nZEBs)(Ballarini et al., 2019). The rating systems for assessing the effect of buildings on the environment are improvement methodology to evaluate the impact of buildings and construction projects on the environment (Bernardi et al., 2017). These rating systems may also, in some cases, cover urban projects, community projects, and infrastructure. These schemes are intended to enable project management to allow projects more sustainable by offering guidelines with specific standards for determining the different aspects of a building's environmental effects. (Bernardi et al., 2017).

Worldwide, different green building rating tools have been developed, and different countries follow different laws, incentives, and regulations (Wu et al., 2019). The manner in which people plan, create, and run the building has a significant effect on people's health and the environment. Healthcare buildings have a particularly significant impact on the atmosphere with 24/7 operated, compare to other building forms (Sahamir & Zakaria, 2014). Due to the reliance on depleted fossil fuels, which eventually causes CO2 emissions, the efficient use of energy is important. Economic development and population growth are considered to impact the country's rising energy demand (Shaikh et al., 2017). Integrating daylight and energy efficiency into the design phase with optimization has always been a challenge for designers. (González & Fiorito, 2015)

There is a lack of research on setting a benchmark for creating new green building rating instruments and evaluating established green building rating instruments (Illankoon et al., 2017). Despite the promotion of green building rating tools in Australia, building environmental issues are still significant (Wu et al., 2019). Even though a daylight harvesting system is promoted in the Energy Efficiency Building Directive (EPBD), the requirements are somewhat restricted, based on EN 15193:2007. (Tsangrassoulis et al., 2017). A green building's actual energy cost is highly influenced by factors linked to actual building efficiency and potential energy cost (Dwaikat & Ali, 2018). Given the increasing interest in sustainable development worldwide, several rating systems have been developed in recent years to assess buildings' environmental effects, each with its own peculiarities and areas of applicability (Bernardi et al., 2017).

1.2 Encouraging Daylight as Passive Design Strategies

According to Feng et al. (2019), the study found that, along with other energy efficiency and renewable energy technologies, passive architecture and technologies such as daylighting and natural ventilation are mostly implemented for Net Zero Energy buildings in hot and humid climates. These facts have contributed to the energy efficiency used in AC, while this study's main advantage is to gain knowledge of daylighting in architectural design, especially in the passive design process (Indarto et al., 2017). In another study by Guan & Yan (2016), the study compared different passive architectural design strategies under the climate conditions of five representative Chinese cities using the intuitive graphic tool Temporal Map to view the annual daylight details and selected the most appropriate design scheme for each city. Various climate-responsive techniques for passive architecture were applied to the building's construction to optimize the design. These include the high-performance facade, efficient tightness of the air, and optimized window design that enables natural ventilation and daylighting to be implemented. These passive designs have reduced 20 percent in energy demand (Ng et al., 2016).

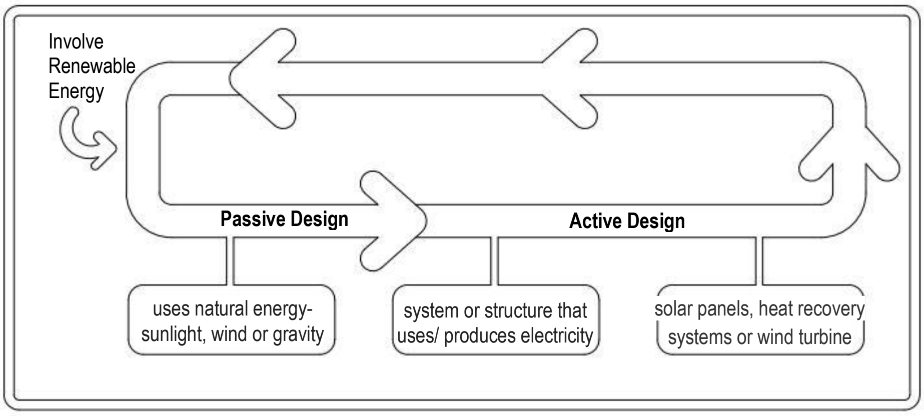

Fig. 2: The correlation between passive design and active design for low energy buildings
(Source: https://blog.se.com/building-management/2014/04/03/optimize-labs-energy-efficiency-without-compromising-compliance-safety/)

A variety of sustainable designs for passive architecture have been integrated into Zero Carbon Buildings (ZCB) design, and energy-efficient active systems have been applied to building construction. These include the low OTTV high-performance facade, efficient airtightness, and optimized window design that enables natural ventilation and daylighting operation (Ng et al., 2016). Further study by Palarino & Piderit (2020) assesses passive solar design techniques' applicability, focusing on those guidelines that optimize daylight penetration while shielding occupants from direct solar glare threats. Through using natural daylight as the vital source of lighting for buildings, researchers have tried to minimize reliance on non-renewable energy lighting. Most of these studies have concentrated on optimizing buildings' interior for daylight (Samadi et al., 2020). The research indicates that active and passive systems should be incorporated into building design to maximize energy efficiency. In particular, passive architecture is used on a broad scale to enable significant energy changes (Sun et al., 2018).

RQ: What criteria have been identified from rating tools that contribute to the daylight performance and visual comfort in the office building?

2.0 Methodology

In Table 1, these seven rating instruments are extensively analyzed to examine similarities and differences between them and, ultimately, to establish daylight performance criteria for building design. To achieve this the rating schemes chosen are grouped into homogeneous categories, and all requirements are compared within two categories of Indoor Environmental Quality (IEQ) and Energy. Finally, general conclusions are achieved.

.Table 1. The aspects and criteria of daylighting and visual comfort.

Name of Rating Tool	**Developer**	**Category: Indoor Environmental Quality**	**Category: Energy**
LEED, 2017	US Green Building Council (USGBC) and Green Building Certification Institute (GBCI)	1.Interior Lighting -Lighting Control -Lighting Quality 2.Daylight -Spatial Daylight Autonomy (simulation) -Illuminance Calculations (simulation) 3.Measurement 4.Quality Views	1.Optimize Energy Performance
BREEAM	Building Research Establishment (BRE)	1.Visual comfort -Daylight Factor -Daylighting Uniformity Criteria -Average Daylight Illuminance -View Out -Internal Lighting -External Lighting -Lighting Zoning and occupant control -Reflectance for room depth and window head height -Glare Control	1.External Lighting

CASBEE	Japan Sustainable Building Consortium (JSBC)	1.Lighting & Illumination 2.Daylight -Daylight Factor -Opening by Orientation -Daylight Devices 3.Anti-Glare Measures -Daylight Control -Reflection Control 4.Illuminance Level 5.Lighting Controllability	1.Natural Energy Utilization
SB Tool	International Initiative for a Sustainable Built Environment (ISBE)	1.Daylight and Illumination -Appropriate daylighting in Occupancy Area -Control of glare from daylighting - Appropriate illumination levels and quality of lighting	
Green Mark	Building and Construction Authority (BCA)	1.High Frequency Ballast	1.Artificial Lighting 2.Energy Efficient Practice & Features
Green Star	The Green Building Council of Australia (GBCA) -Green Star	1.Daylight 2.Daylight Glare Control 3.External Views 4.Electric Lighting Levels 5.High Frequency Ballast	1.Lighting 2.Lighting Control 3.Efficient External Lighting
GBI	Malaysia Institute of Architects (PAM) and the Association of Consulting Engineers Malaysia (ACEM)	1.Daylight 2.Daylight Glare Control 3.Electric Lighting Levels 4.High Frequency Ballasts 5.External Views	1.Lighting Zoning

(Source: Researcher Analysis)

Differences and similarities between the following well-known rating tools are further explored: Energy and Environmental Design Leadership (LEED) (USGBC, 2017), Environmental Assessment Phase of the Building Research Institution (BREEAM) (BRE Global Limited, 2014), Comprehensive Environmental Performance Assessment System for Building (CASBEE) (Japan Sustainable Building Consortium, n.d.), SB Tool (International) (Larsson, 2015), Green Mark, NZ Green Star (Green Building Council Australia, 2011) and Green Building Index (GBI) (INDEX, 2009). These seven rating tools were chosen. After all, they are internationally adopted and recognized as trustworthy because they are reflective of significant nations. Such labeling systems can be considered the world's most popular and well-known and studied to demonstrate the basic daylight efficiency requirements. This will make it possible to understand which metrics have a more significant effect on daylight performance and provide useful feedback to improve the current rating tools.

3.0 Result and Discussion

This study's result can be summarized in Table 1 which shows the aspects and criteria of daylighting and visual comfort from seven international green building rating tools: LEED, BREEAM, CASBEE, SB Tool, Green Mark, Green Star, and GBI. The criteria related to daylight performance and visual comfort were tabulated from the rating tools and involving two main categories: IEQ and Energy. The criteria are further explained below.

3.2 The Comparison of daylight performance criteria of Green Building Rating Tools

Table 2. The comparison of daylight and visual comfort criteria among rating tools.

NO	Daylight Performance Indicator	LEED	BREEAM	CASBEE	SB TOOL	GREEN MARK	GREEN STAR	GBI	*Total "A"*
	Country of Origin	**USA**	**UK**	**Japan**	**International**	**Singapore**	**New Zealand**	**Malaysia**	
1	Daylight Factor/Autonomy	X	X	X			X	X	***5***
2	Openings by Orientation			X					***1***
3	Daylight Strategies	X		X					***2***
4	Lighting Zoning		X					X	***2***
5	Glare Control		X	X	X		X	X	***5***
6	Illuminance Level	X	X	X	X		X	X	***6***
7	Exterior Views	X	X				X	X	***4***
8	Lighting Controllability	X	X	X			X		***4***
9	High Quality Ballast	X			X	X	X	X	***5***
10	External Lighting		X				X		***2***
11	Materials & Construction		X	X		X			***3***
	Total "B"	***6***	***8***	***7***	***3***	***2***	***7***	***6***	

(Source: Researcher Analysis)

With reference to Table 2, seven rating tools is comparatively assessed and observed. The frequencies from the comparison are presented, showing the total frequency of Aspect 1, the Daylight Performance criteria, representing the total "A" and Aspect 2 of Rating Tools in total "B." Aspects 1 of Daylight Performance indicate the three highest criteria in frequency are Illuminance Level, Daylight Factor, Glare Control, and High-Quality Ballast. These criteria were found in almost all seven rating tools presented. The criteria that were found with the least frequency are Opening by Orientation, Daylight Strategies, Lighting Zoning, and External Lighting. Aspect 2, representing the rating tools in Total "B", shows that BREEAM has the highest value and almost completes the 11 criteria of daylight performance followed by the CASBEE and Green Star. Green Mark and SB Tool are representing the least of daylight performance and visual comfort criteria.

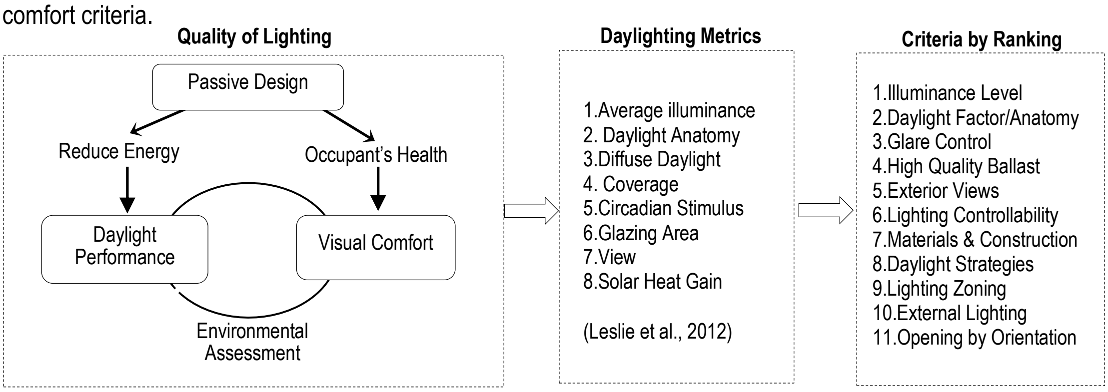

Fig. 3: The context of Quality of Lighting and Rating Tools Criteria of Daylight and Visual Comfort.
(Source: Researcher Analysis)

Leslie et al. (2012) proposed daylight metrics, visual representation of potential design to meet eight design goals: average illuminance, coverage, diffuse daylight, the autonomy of daylight, circadian stimulus, glazing area, view and gain of solar heat. This metric makes it possible to make informed decisions early in the conceptual phase of design and highlights design aspects that may need further development. At the same time, there is still an opportunity to make changes. These eight goals should be prioritized for individual projects, rating systems, or code requirements as appropriate. This performance indication of conceptual design alternatives is likely to guide architects to better-daylit buildings. Based on the case study of two selected Singaporean offices, Chien & Tseng (2014) found four design categories of exemplified passive design: surface reflectance, glazing visual transmittance, light shelves, and shading control. Both Leslie et al. (2012) and Chien & Tseng (2014) reviews correspond to the 11 criteria for daylight performance criteria extracted from the seven rating tools worldwide.

These results can be used as design guidelines for producing sustainable buildings that promote daylight and visual comfort to ensure the best performance in both areas. Its implementation should help designers and policymakers contextualize concepts of almost zero energy buildings and define new criteria and objectives. (Natanian et al., 2019). This research suggests that active and passive strategies for optimizing energy performance should be integrated into building design. In particular, passive design is used on a large scale to make significant energy improvements (Sun et al., 2018). The review also presents some actions to promote the efficiency and conservation of building energy (Shaikh et al., 2017).

Wu et al. (2019) recommended promoting governmental incentives. To improve the capacity of green rating systems for sustainability assessment purposes, a further in-depth research is anticipated to focus more on economic and institutional factors. (Doan et al., 2017). Mostly, passive strategies may have longer payback periods. It should be noted that zero-energy buildings were a test-bedding project; therefore, considering the scale of applications, the findings on passive design cost-effectiveness should be carefully interpreted (Sun et al., 2018). Furthermore, eliminating some of the uncertainties associated with sustainable buildings is expected to increase stakeholders' transparency and facilitate their acceptance (Reed et al., 2009).

4.0 Conclusion

To achieve a sustainable and yet healthy environment, daylight performance and visual comfort must complement each other, and the best way to achieve them is by passive design. From the findings of Aspect 1, it can be concluded that there are 11 important criteria of Daylight and Visual Comfort from the two aspects of daylight design and visual comfort. These 11 criteria are the comprehensive and holistic criteria from IEQ and Energy category of the green building rating tools. Aspect 2 regarding the rating tools shows that Green Mark have the least criteria of Daylight Performance, while BREEAM shows the highest criteria achieved in their rating tools. Based on the locality context, United Kingdom has limited daylight due to the temperate climate of and the criteria outlined in BREEAM is to maximize daylight availability fully. While Singapore is located in tropical weather, it has an abundance of natural lighting and less emphasis of rating tool criteria on IEQ. Further study is recommended to establish the aspects and criteria of daylight and visual comfort from Malaysia's local authority guidelines and government bodies such as the Public Work Department (PWD).

Paper Contribution to Related Field of Study

This paper may provide guidance on the further development of the promotion of successful daylight in green building tools to organisations such as the Green Building Council of Malaysia. In addition, the need to encourage green daylighting and passive design measures to promote green building growth could be realised by state governments and federal governments in Malaysia. In addition, a comprehensive approach to combining sustainable and green construction policies that will direct and become standard and acknowledged by owners, architects, building managers, and occupiers should also be considered by governing bodies. It offers a way for customers, construction professionals and government regulators to determine the environmental impact of a specific building that reduce energy use and maximises the applicability of renewable energy. The growing interest in the principles and practises of green building has prompted a number of organisations to develop guidelines, codes and rating systems for green construction. However, to ensure the system is practical and useful to produce an environment responsive building, it is a must for the developer of the rating systems to outline and encourage the daylight efficient strategies and integrate with energy performance. Future research on the applicability of each criteria provided in this research, specifically focusing on daylight requirements for tropical climates such as Malaysia, need to be considered.

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