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Daylight Penetration in Buildings: Issues in Tropical Climates

[1]Sholanke Anthony, [2]PelaOgheneyoma,[3]PirisolaHeritage, [4]OgunsadeAyoola, [5]AkereleFiyinfoluwa

[1, 2, 3, 4, 5]Department of Architecture, Covenant University, Ota, Ogun State, Nigeria.

Email:

[1]anthony.sholanke@cu.ed.ng;[2]yoma.pela@gmail.com;[3]oyinpirisola@gmail.com;[4]ogunsaday@gmail.com;[5]akerelestacy2@gmail.com

Abstract. Lighting is a very important aspect of buildings, especially daylighting and how it penetrates into spaces. The tropical climate happens to have an abundant supply of daylighting. Unfortunately, little attention is paid to daylighting in some climes. This paper presenteda summary of findings from literature search on "daylight penetration", with focus on factors affecting penetration, applications and design considerations for buildings in the tropics, towards developing a concise document for better understanding of issues relating to daylight penetration in tropical climates. The study is a qualitative research paper that reviewed secondary data and presents its findings in a concise manner for clarity.Data was collected from fifteen publications relating to daylight in tropical climate using google search engine through the internet and the findings presented in text format. The findings revealed that the tropical skies are not consistent and therefore allows for more sunlight which also in turn generates more heat gain and glare. Therefore, daylight penetration in the tropics must be treated with regard to these factors. Theresult also revealed that the use of light guiding shades, angle selective glazing, light shelves, horizontal and vertical light tubes, switchable glazing and active solar regulation are ways to utilise tropical daylight whilst controlling heat gain and flare in buildings. It was recommended that to maximize the penetration of daylighting into buildings in the tropics, considerations should be given to adapting the aforementioned factors.

Keywords: Daylighting, Tropics, Light Shelves, Penetration, Glazing, Sunlight and Solar.

1. Introduction

Daylighting is a method used to bring natural light into a space by maneuvering the free resource to attain essential level of illumination in the space [9]. Daylighting which is also known as passive design is the regulated allowance of natural light, uninterrupted sunlight and dispersed skylight into a building in order to decrease artificial lighting, save energy and cost [1]. Daylight, in other words is a source which conserves energy and generates a pleasing visual atmosphere for dwellers.

Applying daylight goes past only citing components to be assembled and installed like windows, skylight and so on as an integrated design approach is required [1]. Other decisions like building form, location, weather and climate, building mechanisms (fenestrations, skylight), illumination regulation, illumination design standards and aperture siting and placing, have an impact on lighting admitted into a space[1].

The tropics are located from latitudes 10 to 23 degrees and have an average typical sunlight for about 8 hours every day [2]. It has an average temperature of above 18 degrees Celsius(64 degrees Fahrenheit). Previous research works have established that tropical skies are not consistent, causing more direct sunlight and enough daylight access, making active daylight and solar regulation a vital approach to utilise tropical daylighting [11].

As a result of how important lighting is in buildings, different studies have been done highlighting the ideas of daylighting how it relates to the tropical area. Most of the papers took into

consideration daylighting in the aspects of penetration of light, factors affecting penetration of daylight, daylighting responsive agents and daylight systems in the tropics. These studies include those of [10], [11], [12], [13], [14] & [15]. Although, none of the studies looked deeper into combining the issues of daylighting penetration in buildings in general. Some other studies focused on specific areas of buildings such as: high-rise buildings, thermal comfort or the illuminance needed.But no study was found to haveprovided a concise presentation on all issues relating to day light penetration in tropical climate, which happens to be the gap this study was conducted to fill.

Consequently, the study aim was to investigate literature on daylight penetration in buildings and the factors affecting its penetration in the tropics, towards developing a concise document for better understanding of issues relating to daylight penetration in tropical climates.The study objectives include to: investigate daylight penetration in tropical climates; examine the factors affecting daylight penetration in the tropics; and to investigate new effective design considerations for shading devices for buildings in the tropics.

On a general note, the study sheds more light on issues relating to daylight penetration in buildings in tropical regions, providing designers with more insight on how to solve issues relating to daylight in the tropics. The study provides anewplatform on factors to consider when dealing with daylighting techniques and how to resolve issues on it. This article will be useful to built-environment professionals such as, architects, lighting practitioners, interior designers, as well as researchers, educators and students for better understanding issues relating to daylight in tropical climates.

2. Methodology

The research is a literature review that made use of qualitative research methodology. Six steps were utilised to conduct the study. Firstly, the research problem was identified as highlighted in the introduction, after which the aim of the study was determined and a specific focus channelled for the study. Secondly, three objectives weredeveloped towards achieving the aim as also stated in the introduction section.

Thirdly, as the paper is a literature review article, data was gathered mainly from secondary sources. The literature used were selected through a random search on the internet using google scholar search engine. Google search engine was utilised as a result of it being one of the most popularly used internet search engines. The keywordsused for the search are: daylighting, tropical climate, lighting penetration, daylight in the tropics and daylighting in the tropics. Open access documents published within the last twenty years were those considered for selection through a simple random selection process. Thirty documents were initially selected based on the keywords search. After a review of their abstracts, fifteen of them found to be directly related to the aim and objectives of the study were selected for further scrutiny.

Fourthly, the fifteen documents selected were examined and information geared towards achieving the objectives of the study were extracted.The fifth step involved the use of thematic textual analysisto analyse the data. The information gathered was synthesised and grouped under specific themes. And lastly, the result was presented in a descriptive manner with a table that summarised the findings for easy understanding, after which the findings were briefly discussed and a conclusiondrawn.

3. Daylighting Penetration in the Tropics

3.1. Sources of Light

Daylighting means a controlled admission of direct sunlight or natural light to the building and a proper direct relation to the complex and constantly changing patterns of outside lighting, allowing daylighting to help create a visually enhancing and efficient atmosphere for users while improving visual comfort and minimize energy consumption [16].In addition, the use of sunlight in buildings to reduce energy required for lighting, to provide natural light and to reduce the energy required for cooling is called daylight [17]. Daylighting is a huge parameter in lighting industry. It is a fundamental factor for granting the certificate of Leadership in Energy and Environmental Design (LEED). Following the history of mankind, the necessity of sunlight and daylight has been recognised, but also forgotten many times. Ancient developments understood how the basic significance of daylight was

connected with human wellbeing, happiness and health [6]. Another compositional language of architecture and manner of expression focused on making the most and celebrating the usefulness of daylight in buildings was championed by architects, such as Le Corbusier far back as the 1920's and also grasped by building engineers and designers all around the world. The quality and volume of light (lighting) undeniably affects comfort perception in a given room [18]. The requirement for the presence of direct sunlight is determined by numerous viewpoints, for example space function, user type, climatic area and sun-based geometry [12]. [11] posited that the execution of daylight being admitted into the region depends largely on a number of internal condition (position, placement and size of the windows, the state and depth of the rooms and also the colours of the interior surface) and outer variables (the light which is reflected from the ground and inverse deterrent). Every one of these variables assumes a job in affecting the measure of natural light an interior space receives.

The building profile assumes a critical job in overseeing and controlling the immediate penetration of daylight that is admitted into the interior of a building [14]. The overabundant depth of outside counterbalances created by the profile of the building during the process of planning and a window placed within such balances are frequently inadequate, thus the inhabitants might experience ill effects of the visual and thermal discomfort [13].

Daylighting framework requires an integrated approach, and goes beyond essentially listing segments to be installed. The design process for daylighting in building has to take into consideration some factors in the building, such as window, room and daylighting framework [10]. The tropical climate has an alternate sky conditions with other climates. CIE splits the sky conditions into two sorts: overcast sky and clear sky [10]. The tropical climate, however, has a sky condition among overcast and clear skies which is named cloudy sky. [11] posited that in spite of the dominance of the cloudy sky, the outside luminance levels in tropical climates reaches 10,000 to more than 20,000 lux and in turn should be maximised wisely.

3.2. Factors Affecting Choice of Systems for Daylight Penetration in the Tropics

A number of factors, as discussed in the previous section influences daylight penetration in the tropics. [8] recognised a number in their article on performance of daylight through various fenestrations in different buildings. They include: (i) *Building Orientation* – A good introduction of the building is the main consideration, which affects the execution of daylight penetration. Building design must follow sun movement to boost penetration of daylight. (ii)*Window Type* –Windows play a huge role on the quantity of daylight penetration. The chosen type of windows must suit the lighting needs of the building. (iii)*Type of Glazing:*The glazing or glass that is used for windows in building provides light and allows vision. Different glass types have distinctive energy-execution trademark. It is important to know the measure of Ultra Violence (UV), Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) of the window, in order to choose right windows in request to amplify daylight viability and inhabitant comfort. It is also important to know the transparency level of the glazing material that is being employed in the building.

Secondly, according to [15], some factors that must be considered when selecting the right technology include: (a)*Position of the sun* – The position of the sun in the sky dependably changes regularly, which influences accessibility of daylight. The sun's movement from east to west, the angle of the sun to the opening and the angle the sun strikes at, allinfluence the measure of daylight penetration to the building.(b) *Function of Systems* –It is imperative to know the function of the daylight system being adopted, be it multiple function or single function. Every system can either perform singular functions or be able to perform multiple functions like admitting light and providing privacy. (c) *Location* – The location of the system is also important to the penetration of light. Penetration is dependent on whether it is located on the exterior or on the interior. (d) *Ability to Change* –The ability of a system to change also affects the penetration and performance of light. This is dependent on whether the system is fixed with no change or fixed with change, can be adjustable or can be recessed.

3.3. Daylight Responsive Lighting Control System

At the point when satisfactory ambient lighting is given from daylight, electric lighting power is lessened [14]. Fenestrations must be designed in a way that maintains a strategic distance from direct

sun admittance on task surfaces or into users' eyes (e.g. bedrooms). Alternatively, reasonable glare remediation gadgets, for example, day blinds or shades must be accessible.

The best daylighting systems could be to streamline building orientation and frame and also to enhance window size and position [8]. Due to overcrowded urbanisation, it has turned out to be increasingly hard to utilise techniques that let natural light enter profound into the interior space. This is the place the requirement for daylight responsive lighting control frameworks becomes possibly the most important factor [11].

Various ongoing advancements in optical lighting frameworks like daylight tubes, daylight pipes, light shelves offer re-established opportunities for solid optical daylighting sources with wide applicability and high adequacy in daylight penetration [15]. Light shelves have allowed for the successful improvement of uniformity of daylight whilst still permitting for enough daylight for visual comfort and energy saving. Dynamic control of the light shelf is needed as sky conditions change dynamically [11]. The tropics have the overcast, clear and intermittent skies and the light shelves implemented must be adapted to suit these conditions at various times.

3.4. Effects of Artificial Lighting on Emotion

The utilisation of various kinds of frameworks for daylight design can be utilised concurrently to accomplish the lighting required for prerequisites in space in its application. Daylight, like structural engineering both underlay similar material and geometrical design parameters. Be that as it may, with daylight it manifests itself in an unexpected way [7]. This is the “advanced daylight framework” or, in other words, a skylight and window design which directs and in turn, shapes the conveyance and level of rooms lighting to meet the illumination prerequisites [3].

One of the attractions of using artificial light in industrial facilities, workplaces and different buildings has dependably been its stability and its predictability. Daylight is a variable factor and is frequently capricious. It is these very characteristics, which account for individuals' liking for daylight and for the radiance that daylight brings to the interior of a building, which additionally makes it challenging to work with.

According to [2],order daylight frameworks dependent on the availability and non-availability of shading gadgets. Daylighting frameworks with shading capacity gives covering against glare and immediate or diffused light. This framework is isolated into two classes:frameworks which do not allow for direct daylight and only use diffused skylight. For example, venetian and prism blinds; and frameworks that allow direct daylight, guide it to the ceiling or anywhere beyond eye level. For instance, blinds and louvers, anabolic system and light shelves.

While daylighting framework in the absence of shading is designed in order to guide light to zones that are from openings, be it skylights or windows. This framework is separated into: diffused light guiding framework, e.g., anabolic systems, light shelf, angle framework, coordinate light guiding frameworks, light scattering systems or diffusing systems and light transport frameworks.The use of light guiding shades, angle selective glazing, light shelves, horizontal and vertical light tubes, switchable glazing and active solar regulation is a way to utilise tropical daylight whilst controlling heat gain and flare in tropical buildings.

[15] asserted ways to get the uniform conveyance of illumination from diffused light on the deep floor plan. Daylight innovations without shading devices that rely on redirecting or guiding diffused light are required. This makes diffused light guiding framework a very practical daylight innovation for deep floor plan building in tropical climates.

3.5. Summary of Key Findings from Literature Reviewed

The Table below provides asummary of findings from theliterature reviewed with a highlight of gaps identified in each of the studies that provided a basis for this study.

***Table 1**: Summary of Key Findings from Literature Reviewed*

SN	Author/ Date	Topics	Paradigm/ Method	Purpose	Findings	Gaps
1	Trupti and Vinayak	*The impact of building*	Qualitative	Intended to deduce the	A minimum and maximum	Did not consider

	(2018).	*profiles on the performance of daylight and indoor temperatures in low-rise residential building for the hot and dry climatic zones.*		appropriate measurement of how deep the offsets which are the most important in order to establish the balcony areas of the housing units of a particular 'Type Design' to accomplish maximum daylight and thermal comfort.	depth was established which aided the liveable area without compromising the indoor comfort and maximization of daylighting considering orientation of the building; highlighted the significance of daylighting to the reduction of electrical loading.	any other thing apart from comfort of users and lighting penetration with relation to balconies.
2	Achsani, Wonorahardjo and Soelami(2018).	*A Vision of Daylight Technologies for High-Rise Residential Building in the Tropics.*	Qualitative	The study shed light on different advancements in optical framework also considering deeper floor plans.	Things like daylight tubes, daylight pipes, light shelves were seen to give opportunities for solid optical daylighting sources, giving appropriate daylighting penetration ability. Also highlighted factors to consider in selecting daylight technology including things like; position of the sun, function of systems, location of systems and ability to change.	Only considered high-rise residential building.
3	Lim,Hamdan and Ossen(2013).	*Internal shading for efficient tropical daylighting*	Qualitative	The study was done in order to provide insight on high-rise open	Internal conditions to be considered when admitting daylighting	Focused on only a particular type of building

		in existing high-rise open plan office.		floor plan office buildings, looking at the internal and external conditions.	include position, placement and size of the windows, the state and depth of the rooms and also the colours of the interior surface and the outer variables include the light which is reflected from the ground and inverse deterrent.	and space.
4	Ng andAkasah, (2013).	*Post Occupancy Evaluation of Energy-Efficient Buildings in Tropical Climates.*	Qualitative	The study aimed at identifying issues with energy efficiency in design affecting comfort ofoccupants.	Visual and thermal discomfort can be experienced due to inadequate counterbalancing of building profiles and placement of windows.	No particular solutions were provided for the issues faced.
5	International Commission on Illumination (2013).	*Towards a new century of light.*	Qualitative	A conference proceeding to gain insight on several ideas on lighting in buildings to build a clearer picture of lighting in the 21st century.	Factors to consider with regards todaylighting in buildings include; building, window, room and daylighting framework. The sky conditions also matter. This includes	The study did not provide in-depth information on the stated factors.

					overcast sky and clear sky.	
6	Mayhoub (2012).	*Guidelines for daylight guidance systems application.*	Qualitative	The establishment of guidelines in order to guide designers and lighting enthusiasts through.	Numerous viewpoints are to be considered when dealing with direct sunlight like climate, function of space, types of users and geometry of sun.	The guidelines did not further explain in an extensive manner all the viewpoints stated.
7	Husin and Harith (2011).	*The Performance of Daylight through Various Windows for Residential Buildings.*	Quantitative	Establishing the idea of daylighting as it penetrates through windows with residential buildings as its focus.	Factors affecting choice of systems include; Building orientation, window type and type of glazing. Also, best daylighting systems have been narrowed down to orientation, frame, window size and position.	No broader view provided. Focus only on residential buildings and windows as major entry points.
8	Benya, Schwartz and New Building Institute. (2003).	*Advanced lighting guidelines.*	Qualitative	Explaining the elements of good building design with regards to lighting.	An advanced lighting framework was made, which is a skylight and window design turning direct sunlight into the building meeting the level of illumination needed in the space.	The guidelines were limited to only windows and skylights.
9	Aschehoug, Christofferse n,Edmonds,J akobiak, Johnsen, Kischkoweit-	*A source book on daylighting systems and components.*	Mixed method	The study focused on highlighting daylighting systems and components	Daylight frameworks depending on the availability or otherwise of shading	Focused majorly on building framework and shading

Lopin, Selkowitz (2000).	generally seen in buildings.	gadgets.	devices.

4. Discussion

This review has shown that the abundance tropical daylight has not been fully utilised in buildings, most likely because it is usually concurrently perceived with intense solar heat gain. Also, most reviews on daylighting have been directed towards developed countries with temperate climate, where the luminous condition of the sky is different from that of the tropics. The effectiveness of daylighting design in the tropics is very dependent on the sun path, sky cover, building envelope and type of fenestrations. All of these factors highly affect the penetration of daylight in the tropical regions and should be properly handled to find a balance between daylight penetration and heat gain.

Daylight is very dynamic and thus one solution cannot be preferred for all conditions, as adaptable systems must be largely dependent on sky cover at particular times. Shading devices also perform very differently under different sky conditions. A very important approach to maximise daylight in the tropics is to employ dynamic daylight and solar control in order to allow for optimisation of daylight in the tropics.

To achieve the best design, different systems which would best suit the design should be combined. The use of light guiding shades, angle selective glazing, light shelves, horizontal and vertical light tubes, switchable glazing and active solar regulation is a way to utilise tropical daylight whilst controlling heat gain and flare in tropical buildings. However, these must all be used dynamically to suit varying scenarios.

The dynamism of daylight and sky conditions cause for a wide variety in the choice of internal daylighting systems as these have a huge influence on daylight penetration. Tropical daylighting has different performance on different sky conditions and building orientation. The design of whichever system from the range discussed would be employed must be very adjustable and flexible in responding to whichever condition it is subjected to in the tropical climate.

5. Conclusion

This study is a literature review that aimed at investigating daylight penetration in buildings and the factors affecting daylighting infiltration with a focus on buildings tropical climates. This study was conducted to provide a better understanding of varieties of issues relating to daylighting penetration in the tropics, towards the development of a concise document for the benefit of stakeholders involved in the practice and educational development within the built-environment. The study was necessitated due to the paucity of information in this regard in existing literature. The study provided a broader insight for understanding daylighting in the tropics with regards to its penetration, control and systems to apply to influence its impact in buildings.

The findings show that factors affecting daylight performance are: building orientation, type of window and type of glass. Factors and technologies that can affect daylighting performance are: the position of the sun, function of systems, location and ability to change. Daylighting has a connection with human wellbeing, happiness and health. For deep floor plans, redirection of lighting is necessary.Building profiles assume a critical job in overseeing and controlling the immediate penetration of daylight admitted in buildings. Also, daylighting framework is dependent on the availability and non-availability of shading gadgets which are, frameworks which do not allow for direct daylight and frameworks that allow for direct daylight.

In general, daylighting application has gone past only citing components to be assembled and installed such as, windows and skylight as expected in an integrated design approach. Critical conditions are being considered in the decision-making processes concerning daylighting, e.g., building form, building mechanism, location, weather and climate, illumination design standards and regulations, and so on. This has obviously made designing for daylighting in buildings a phase of architecture that needs more consideration, attention and encouragement, so as to harness its benefits.

Regardless of the contributions of the study, relying strictly on open access secondary documents, searched using only goggle search engines on the internet to gather data,is considered a limitation of the research. Therefore, similar studies canbe conducted using a wider scope to provide a broader

insight on the topic. Future studies can also explore the possibility of gathering primary field data toexamine existing built-forms to provide more insight on the extent to which daylight penetration impact on buildings, their occupants and activities conducted in the buildings. Such studies will serve as a reliable feedback mechanism in evaluating the performance of daylight penetration in existing architecture.

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