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RESEARCH ARTICLE

A Review of Architectural Design Intervention Strategies on External Shading Devices using the Sun-path Diagram Analysis in the Tropics

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ABSTRACT

Tropical building facades frequently trap excessive solar radiation, necessitating strategic architectural interventions. Central to this challenge is the sun-path diagram, a fundamental tool for understanding solar geometry to enhance building performance. This systematic review investigated optimal shading designs derived from sun-path analysis to improve Indoor Environmental Quality (IEQ) and occupant comfort in tropical buildings. Adapting the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, this study synthesized peer-reviewed literature published between 2020 and 2026, sourced from databases such as Google Scholar, ResearchGate, and other sources. The research identified specific shading design parameters that effectively mitigate solar gain and glare while enhancing user well-being. Findings revealed that shading systems designed via sun-path analysis significantly improve IEQ by reducing solar heat gain and eliminating discomforting glare. Furthermore, the integration of traditional sun-path diagrams with digital simulations and parametric modeling allows for higher precision in addressing varying climatic conditions. This evolution in design methodology enables the development of bespoke shading devices tailored to specific tropical microclimates. The review concludes that the integration of sun-path diagrams with digital simulations and parametric modeling tools significantly enhances the precision of shading design for diverse climatic conditions.

Keywords: *Shading design; Sun-path; Solar geometry; Shading device; Tropical architecture*

1. INTRODUCTION

The tropical environment is faced with an abundance of solar radiation; while it is a source of natural light, it poses significant thermal and visual challenges for occupants of a building (Gyimah, 2014). Buildings in the tropics are susceptible to overheating due to excessive heat-gain from solar radiation, which significantly affects the indoor environmental quality

(IEQ) (Pathirana, Asanka, & Rangika, 2019). It has been proven that higher efficiency in the use of energy significantly contributes to the reduction of greenhouse gas emissions (Echeta, Olotuah, Ezeji, & Onwuzuligbo, 2023). In other words, the issue of increased heat gain in buildings is directly associated with increased temperature and inadvertently caused by solar radiation on a global scale (Echeta et al.,2023).

Most buildings in the tropics are designed and executed without consideration of the climate and its effect on the building system, materials, and the most appropriate shading device that will give the desired user comfort. (Onazi, Gaiya, Ola-Adisa, & Yilme, 2018). To passively mitigate this challenge, the Architect's intervention is required; central to this is the use of the sun path diagram. (Sari & Rauzi, 2021). Sun-path: The sun-path diagram plays a vital role in architectural design. (Kheiri, 2018). It is necessary that the Architect is acquainted with the knowledge of sun analysis before justifying the building configuration. (Priatman, 2000). As the major source of heat energy, the sun's position at various latitudes would contribute to heating, which can be too excessive, and should be minimized with the use of shading devices. (Plante, 2014).

The sun path diagram helps the Architect to design window shading that will perform optimal shading design as well as excellent day-lighting without excessive heat gain. (Ardiyanto, Antonius, Hamid, & Yeri-Sutopo, 2019). Without the understanding of the sun-path diagram, a building will not be thermally comfortable in the tropics. (Sari & Rauzi, 2021).

Despite the established application of sun-path diagrams in architecture, a number of disparate studies have explored aspects of the architect's strategies in the design and application of shading devices; however, there remains a gap in the systematic synthesis of scholarly evidence regarding how the Architect applies the tool in the design of shading devices. This systematic review addresses that gap by using a PRISMA framework to review the literature to examine the role of the sun-path diagram as a tool used by the Architect in shading design.

2. MATERIALS AND METHODS

This review examines the architectural design intervention strategies on shading devices using sun-path diagram analysis. Architects can apply an understanding of solar geometry to block intense solar radiation, mitigate cooling loads, and enhance indoor environmental quality. The review includes comprehensive searches, screening, and analysis of relevant literature using the following keywords: solar geometry, sun-path diagram, shading design, shading device, tropical architecture. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (see Figure 1) was adapted for this study. This study synthesized peer-reviewed literature published between 2020 and 2026 sourced from databases such as Google Scholar, ResearchGate, and other sources. A total of 45 records were identified using relevant keywords; 4 records were removed before screening began, which included 2 duplicate records and 2 records flagged as ineligible. 41 records underwent initial screening, resulting in the exclusion of 16 records. 25 reports were sought for retrieval, and all 25 reports were successfully retrieved. 25 reports were then assessed against specific eligibility criteria. 20 reports were excluded during this stage for three specific reasons, as shown in Figure 1. Finally, 5 unique studies met all criteria and were included in the final review.

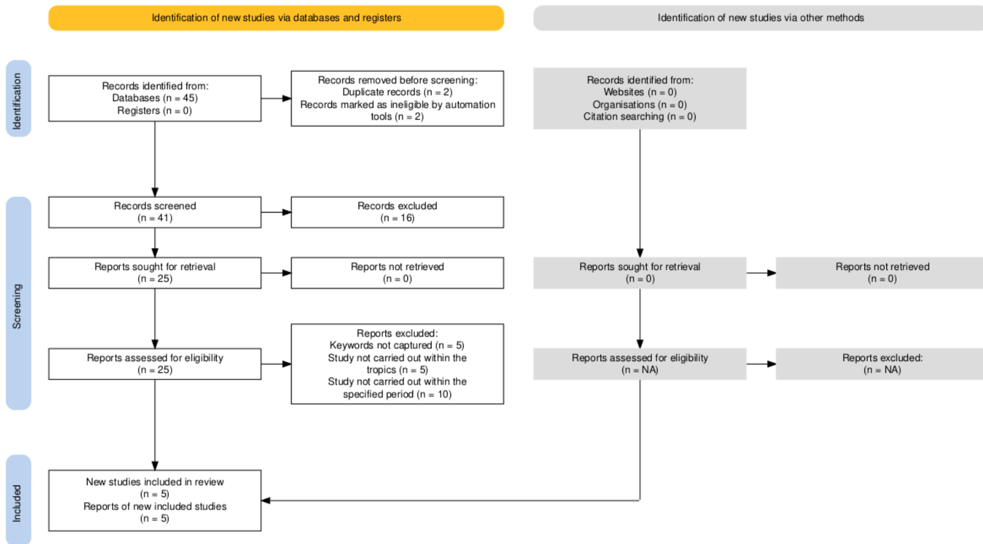

Figure 1. Flow diagram of the review of architectural intervention strategies on external shading devices using the sun-path diagram analysis in the tropics

3. RESULTS AND DISCUSSION

Solar Geometry and Sun-Path Diagram in the Tropics

In a climatic zone like the tropics, which is predominantly hot and humid with a high level of direct solar radiation, an understanding of solar geometry and sun-path diagrams is essential for architectural design of shading devices. Building geometry is directly linked to energy consumption; therefore, incorporating shading devices as an architectural intervention strategy from the early design stages can significantly reduce heating and cooling demands, highlighting the importance of sun-path diagrams as a tool that supports design decisions (Bertagna, Piccioni, & D'Acunto, 2023).

A geometrical foundation for the graphical method of solar control has been established, and it emphasizes the relevance of a bioclimatic approach to architecture, one that understands the effects of climate on users as a principle for design (Bertagna, Piccioni, & D'Acunto, 2023). The understanding of sun-path diagrams allows designers to identify solar exposure periods for each façade, trace shadow patterns, analyze shading depths, and design shading devices (Frota, 2004). With these skills, architects develop strategies consistent with the local climate and user requirements, hence improving the indoor environmental quality. The sun-path diagram is a basic tool for studying solar geometry, as it represents the Sun's apparent paths throughout the year for a given latitude in a two-dimensional format. The main methods for representing solar geometry include orthographic, equidistant, and stereographic projections (Esposito & Rossi, 2026). The equidistant representation functions as a radial coordinate system, while orthographic projection shows limited resolution for low solar positions due to the concentration of altitude circles near the horizon (Szokolay, 2007). In contrast, stereographic projection adopts the nadir as the projection center, preserves solar paths as circular arcs, and can be constructed for any latitude, which explains its widespread use in sun-path-based designs.

Shadow Angle Protractor (HSA and VSA)

Controlling the indoor environmental quality of buildings has always been part of the architectural design process. External shading devices can eliminate the beam component and reduce the diffuse component. (Bahadori, 1985). When attempting to shade a window, two important shadow angles must be considered; these are the horizontal shadow angle (HSA) and vertical shadow angle (VSA) (Ashok, Senthamil, Satheesh, & Jeganathan, 2016). These angles express the sun's position in relation to a building façade at a given orientation and can be used to show the performance of a given shading device based on the shade it produces (Chauhan & Shah, 2008).

The condition of the building envelope, the size of openings, the building's orientation on site, together with consideration of local weather conditions, play a role in the design of shading devices. Sun-path diagrams are used to determine the solar angle (compass direction) and azimuth (height above the horizon) of the sun at given times throughout the year. With the aid of the sun-path diagram, the Architect can look up the position of the sun on a certain day and at a particular time (or across a time frame), collect the solar angle and azimuth for that scenario, and design the building to manage sunlight accordingly (Richards, 1981). Initially, these charts were supplied in published tabular forms but are now available electronically. Furthermore, this electronic dataset can now be uploaded into simulation software to test various design parameters, or it can be used to extract precise solar details.

When working with the sun-path diagram in Architecture, the direction of incident sunlight is commonly resolved into two components: the Horizontal Shadow Angle (HSA) and the Vertical Shadow Angle (VSA) (see Figure 2). This approach reflects the representation of solar geometry by aligning it with conventional architectural drawings. The horizontal component corresponds to the building plan and is analysed on a horizontal plane, while the vertical component relates to elevations and sections and is analysed on a vertical plane. By dividing the solar angle into these vectors, architects can more effectively evaluate solar penetration and design appropriate shading systems.

The conversion of solar position data into HSA and VSA is typically facilitated by a solar shading protractor, a graphical tool used to derive shadow angles from solar geometry (see Figure 3). Similar to the role of logarithmic tables in mathematical calculations, the solar protractor enables the rapid determination of shading parameters without complex trigonometric computations. This technique allows solar information from sun-path diagrams to be directly integrated into architectural design, supporting the development of climate-responsive shading strategies that enhance the indoor environmental quality.

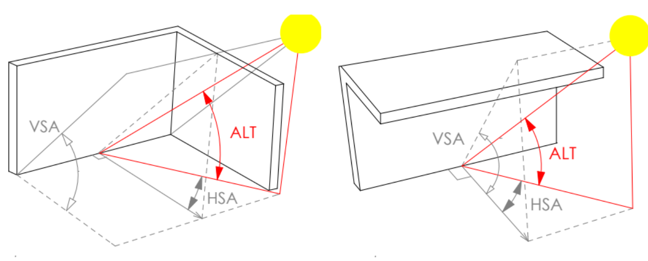

Figure 2. Horizontal shadow angle and Vertical shadow angle. Source: (Chauhan & Shah, 2008)

The solar protractor (as shown in Figure 3) is commonly printed on a transparent sheet and overlaid on a building floor plan, with its crosshairs positioned at the point of analysis and aligned to true north. The protractor graphically relates solar position to building orientation, enabling the determination of the Horizontal Shadow Angle (HSA) by projecting façade orientations onto the protractor scale. The corresponding Vertical Shadow Angle (VSA) is obtained from the same date-time reference using the solar altitude scale. Together, HSA and VSA provide a simplified representation of solar incidence on building façades, supporting the analysis of solar exposure and the design of effective shading devices.

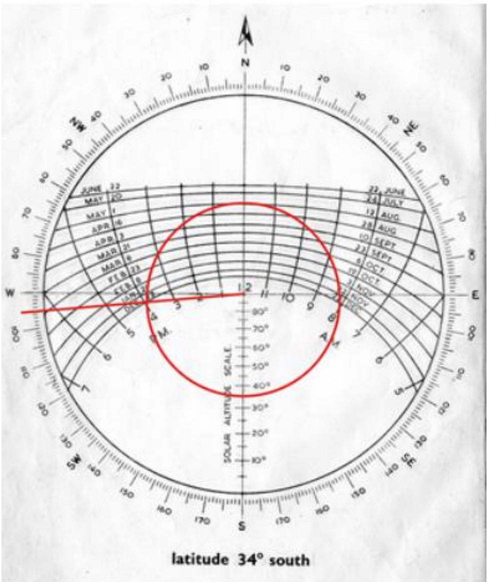

Figure 3. Solar Protractor

External Shading Devices and Typologies

Buildings in the tropics are exposed to solar radiation; it is important to have the ability to manipulate the amount of sunlight admitted into a building. (Lau, Salleh, Lim, & Sulaiman, 2016). The fundamental purpose of introducing shading devices in buildings is to create a relaxed indoor environment. Shading devices are advocated for buildings in the tropical region, it is beneficial in reducing glare and cooling load; however, they could obstruct views (Mustapha & Halil , 2017).

Mustapha and Halil (2017) posited that different types of shading devices exist that can be integrated into a building. Before designing, the architects should take into consideration the following: 1. Understanding the sun path of the environment. 2. Determine the shading design dimensions to understand horizontal and vertical shadow angles 3. Selecting the shading type based on sun-path analysis (Mustapha & Halil , 2017). External shading devices are elements incorporated into the building shell to prevent the admittance of direct solar radiation and its impact on a building interior (Olugbenga, Ayomipo , & Segun , 2015). Predominantly, external shading devices are used in institutional buildings, commercial buildings, and high-rise residential apartments. External shading devices can broadly be grouped into fixed and movable devices. Examples of fixed shading devices are: horizontal and vertical overhang, fins and egg-crate, while the movable shading device includes; the vertical and horizontal louvers, awnings, retractable canopy, external venetian blinds (Olugbenga, Ayomipo , & Segun , 2015).

Horizontal Overhang: These are devices placed horizontally above and across an opening as a form of protection against incident solar radiation. In Nigeria, when combined with a vertical component, they are referred to as "window hood". An increase in the depth results in greater shade. For effectiveness, the depth of the overhang is determined with consideration to the solar altitude of the building locale (Olugbenga, Ayomipo , & Segun , 2015).

Vertical Fins: A vertical protrusion from the building shell at varying depth, adjacent and across openings. Usually designed based on calculations carried out with the solar azimuth of the building location. (Olugbenga, Ayomipo , & Segun , 2015).

Egg crate: A combination of fixed horizontal and vertical projections, mostly made out of concrete or aluminum (Olugbenga, Ayomipo , & Segun , 2015).

Shading Design Steps

To design effective shading, the Architect needs to know the periods when to let in the sun or to let it out. (Rassam, 2004). To accurately design a shading device, it is pertinent that the Architect notes and follows these outlined steps:

1. Identify the Overheated Period: Begin by defining the specific dates and times during which shading will be required. For this analysis, the shading is intended for all months between 9 AM and 4 PM.
2. Consult the Sun Path Diagram: Utilize the relevant sun path diagram for the location to ascertain the azimuth and altitude of the sun during the specified periods.
3. Employ the Solar Shading Protractor: Utilize a solar shading protractor to determine the Horizontal Shadow Angle (HSA) and Vertical Shadow Angle (VSA). These values can also be computed using the established equations.
4. Design the Shading Device: Design a shading device that fulfills the necessary performance specifications based on the calculated angles.

This methodology serves as a valuable tool in the early stages of the design process, allowing for the determination of optimal shading device geometry by taking into consideration the sun's position (United Nations Human Settlements Programme, 2018).

4. CONCLUSION

This review systematically examined architectural design intervention strategies for solar shading in tropical climates, with particular emphasis on the application of sun-path diagrams as a basis for climate-responsive design. The synthesis of existing literature demonstrates that solar shading remains one of the most effective passive design measures for mitigating solar heat gain, reducing glare, and enhancing indoor environmental quality. Findings further reveal that the sun-path diagram provides a rigorous and intuitive framework for analysing solar geometry, enabling the accurate determination of façade-specific shading requirements across varying building orientations and tropical latitudes. Consequently, the integration of sun-path analysis into the design process supports the development of optimised shading solutions that improve occupant comfort, reduce cooling energy demand, and enhance overall building performance.

5. COMPETING INTEREST

None to declare

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