Facade control systems for optimal daylighting: A case of Kerala

Govind Dev*, Aysha Saifudeen* and Aparna Sathish*

1Department of Architecture, College of Engineering Trivandrum, Kerala, India.

*Corresponding email: devgovind.r@gmail.com, ayshahabeel@cet.ac.in, aparna.sathish@cet.ac.in

Abstract. Indoor environmental quality is one of the most important aspects to be considered while designing buildings. Design decisions taken to ensure indoor environmental quality depends upon the specific location, climate, form, orientation and materials used for the construction of the building. In addition to ensuring comfort and optimal occupant conditions, these design decisions also impact the overall energy consumption of the building. The design of the building envelope is of more importance in regions that receive a huge amount of solar radiation. Kerala, falling in the Tropical belt, have buildings designed (or supposed to be designed) with sufficient roofing/shading overhangs to avoid penetration of solar radiation, and direct glare towards the inside. Well-designed shading devices provide the best shading during overheated periods thus lesser heat gain or cooling load. The form of shading devices influences day-lighting inside the building. This paper intends to explore different types of shading devices and façade control systems, and their impact on daylighting inside a selected commercial building in Kerala. It concludes by identification of the most efficient design of the device in each type identified, through BIM modelling and lighting simulation, specific to the original building location, to ensure optimal daylighting while eliminating the undesirable effects of solar radiation.

1. Introduction

Daylighting is a lighting technique used in architecture and design that brings natural light into a space through any kind of openings like windows or skylights. It reduces the quantity of artificial lighting for the indoor spaces during day times and thus induces energy efficiency [1]. More than one-fifth of total worldwide energy consumption is by the building sector and India trends in it, according to International Energy Outlook 2013. About 57 per cent of the total energy consumption is electrical energy and 40 per cent of it is consumed by building sectors in India. The expected increase of electrical energy is 76 per cent by 2040, according to the Energy Statistics of 2013 of India’s National Statistical Organization [2]. About 60 per cent increase in energy consumption has been observed for commercial buildings between 1990 and 2005 and artificial lighting accounts for 11% of total energy consumption in buildings [3]. A perfect amount of natural lighting levels could be achieved in a space without any glare using an ideal glazed window or a well-designed opening [3]. Factors like prevailing climatic conditions, site location, building orientation, and building materials used, shape the indoor environmental comfort in a building. Inattention to these factors results in occupant discomfort and increased energy consumption [4].
Countries in hot tropical climate regions are the most affected by solar radiation and it can be avoided through careful design approaches towards orientation, form, materials, opening sizes, and shading devices. Heat gain inside a building could be reduced through proper design and orientation of external shading devices. It intercepts excess solar rays during overheated periods and reduces cooling load, thereby inducing more energy savings [4]. Other than during mid-day hours, shading systems for early mornings and late evenings are very complex with deep overhangs and/or more fins, which together act as an additional envelope for the base structure. Availability of natural light during the daytime substantially decreases the overall energy consumption of a building, but a complex facade system can influence the amount of light penetrating a building. In this paper, several types of facade systems are studied for identifying optimal daylighting under selected limitations for a selected commercial building in Kerala. The least studied building type in research is commercial buildings with a 02% rate [5]. The limitations considered in the simulation are: The building is clear glazed on all sides. All materials in white colour with reflective values above 85%. The thickness of all shading devices is 50mm. The uppermost floor (third floor) is considered for simulation, at 75cm above floor level. External obstructions are considered NIL. No partitions exist in indoor spaces, except the existing 18 concrete columns.

2. Literature Studies
2.1. Solar Shading Devices
The direct, diffuse and reflected radiations are the three components of solar radiation incident on any surface of a building. The direct radiation (largest of all three) is eliminated, and the diffuse component is reduced by an external solar shading device of the building [4]. Thus, it is a form of solar control that can be used to optimize the amount of solar heat gain and visible light that enters a building [6]. Shading devices with good opening sizes provides a good view outdoors, influence visual comfort, psychological comfort and productivity of the users [19].

There are three types of fixed Shading Devices for a building. Those are horizontal, vertical, and egg-crate types [7]. Traditionally they were built using native materials such as clay, wood planks, bamboo and palm leaves [19].

2.1.1. Horizontal shading devices:
Architectural elements like canopies, verandas, louvres and roof overhangs are the most common types of Horizontal Shading Devices (Figure 1). These elements are optimum for northern and southern elevations. The size of these elements is determined using Vertical Shadow Angle (VSA) [7].

![Figure 1. Horizontal Shading Device.](image)
2.1.2. Vertical shading devices:
Architectural elements like pilasters, louvres and vertical fins are the most common types of Vertical Shading Devices (Figure 2). These elements are optimum for western and eastern elevations. The size of these elements is determined using Horizontal Shadow Angle (HSA) [7].

![Figure 2. Vertical Shading Device.](image)

2.1.3. Egg-crate shading devices:
Architectural elements like grill blocks and decorative screens are the most common types of Egg-crate Shading Devices (Figure 3). These elements could also be combinations of Horizontal and Vertical Shading Devices. The size of these elements is determined using both Horizontal Shadow Angle (HSA) and Vertical Shadow Angle (VSA) [7].

![Figure 3. Egg-crate Shading Device.](image)

2.2 Review of shading systems (design).
The case studies are done to explore different ways of application of three types of shading devices. All case studies are under different climatic classifications.

2.2.1. Umoja House, Dar es Salam, Tanzania (Foreign and Commonwealth Office, 2002).
The facade system (Figure 4) was designed by BDP Architects [8], preventing overall heat gain using a floating solar roof and external horizontal louvres (Horizontal Shading Device) on three elevations. Locally available materials were used for construction via local agents and contractors [9]. The facade system (as an envelope) is fully metallic and attached to the main structure with a gap in between. The louvres are slightly slanted and painted in light contrast with the white structure.
2.2.2. The Leo and Dottie Kolligian Library (Skidmore Owings & Merrill LLP, 2005).
Deep shading devices shade huge openings (Figure 5) and provide an uninterrupted view towards the exterior-campus landscape. It is a two-winged building in concrete and glass. The four-storey east wing has library and meeting rooms, and the three-storey west wing has administrative offices and student services space. It’s a LEED Gold rated building [10].

2.2.3. Uganda National Theatre and Cultural Center (Peatfield and Bodgener Architects, 1959).
The 400-seat theatre was designed by Peatfield and Bodgener Architects, and it is the first modern theatre in Uganda (Figure 6). It was opened on the 2nd of December 1959 as a part of the Uganda National Cultural Centre (UNCC) [11]. The three-storey structure has this round-shaped egg-crate shading system on a curved front façade.
2.2.4. Punjab and Haryana High Court (Le Corbusier, 1955).
It’s a linear block with the main façade facing Piazza (Figure 7). The ‘Parasol’-like roof and alternating grid-egg-crate shading systems shade the entire façade. The parasol roof projects out to shade the taller uppermost floor of the building. The building houses Courtrooms, offices of all Administrative Branches (Registrar’s Office, Establishment Branch, Gazette Branch and Copying Branch etc.) [12].

Figure 7. Punjab and Haryana High Court [12].

2.3. Advantages due to a shading device.
An efficient shading system reduces unwanted solar gains, provide UV protection, reduce the cooling load in summer, reduce overall electricity consumption, provide quality daylighting without glare, give outer vision, provide external shaded spaces (as verandas/balconies). It also gives privacy and provides better aesthetic appeal to the built form [6].

2.4. Shadow Angles.
Shadow angles are determined from the depth (or size) of a specific type of shading device concerning the Sun’s position and orientation of the selected building façade [4].

Two types of shadow angles are considered to shade an opening. Those are [4]:

2.4.1. Horizontal Shadow Angle (HSA)
Horizontal shadow angle (HSA) is the difference between Azimuth (AZI) and Orientation (ORI) (1) of the building face considered for analysis. The performance of a vertical shading device is determined by HSA (Figure 8). It is positive when Sun is in the clockwise direction (when AZI>ORI) and negative when Sun’s position is in anticlockwise direction from the orientation of the building façade (when AZI<ORI) [4].

\[
\text{HSA} = \text{AZI} - \text{ORI},
\]

Where AZI= Azimuth angle, ORI= Orientation of façade/opening.

2.4.2. Vertical Shadow Angle (VSA)
Also known as profile angle, the Vertical Shadow Angles (VSA) (eq. 02) are measured on planes perpendicular to the building facade, and exists when HSA is between -90\(^\circ\) and +90\(^\circ\) (Figure 8). When Sun’s position is directly on the opposite side, AZI=ORI (HSA=0\(^\circ\)), then VSA=Solar Altitude Angle (ALT). In other cases, ALT is projected parallel to the building facade onto the perpendicular plane, hence VSA>ALT [4].

\[
\text{VSA} = \arctan\left(\frac{\tan(\text{ALT})}{\cos(\text{HSA})}\right),
\]

Where ALT=Altitude, HSA= Horizontal shadow angle.
2.5. Steps for designing shading devices.

- Determine overheated period (the dates and times when shading is required) for the specific location.
- Identify the Azimuth and Altitude angles of the Sun at each cut-off period, using a sun-path diagram or computer-aided software.
- Determine HSA and VSA using equations (1) and (2).
- Design final form of the device considering HSA, VSA and identified optimum type/style of the device.

3. Methodology

A detailed solar study is carried out for the specific location, for generating HSA and VSA. Four different building envelopes are case studied, selected, analysed and redesigned for the simulation. The optimum designs are then wrapped onto the base skeleton building model, resulting in the formation of six different façade system designs. Six different simulations are carried out and indoor light levels are analysed for identifying the optimum façade design. The flow chart of the methodology follows (Figure 9):
Figure 9. Methodology for the identification of optimum facade system design.

3.1. Case Study

3.1.1. Building Study
The prototype building selected for the study is under the commercial occupancy category (Figure 10), designed by Ar. Nijasmon K.S of Hayath Architects, Changanassery, Kerala. It has four floors, oriented North-South on the longer axis, with a total area of 7100 sq. ft. The project is under the completion stage as of June 15, 2021.

3.1.2. Location & Climate Study
It is located at 09.45°N 76.54°E, adjacent to Bypass Road, SH 183, Changanassery, Kottayam District, Kerala. The location comes under Tropical monsoon climate (Am) of Koppen climate classification and warm-humid climate under National Building Code (NBC) classification [13]. The hot season is during the period March to May, the south-west monsoon is during June to September, the Retreating monsoon season is during October and November and the northeast monsoon is during December to February. The average annual rainfall is 3130.33m [14]. The highest average temperature is 34.4°C in March [15].
3.2. HSA and VSA
The external shading devices are designed for all the months between 08:00 AM to 05:30 PM. Two solar extremes, summer solstice and winter solstice were considered to determine HSA (Table 1) and VSA (Table 2).

Using ‘equation (1) and [16]’,

| Time  | Direction | Azimuth | Orientation | HSA |
|-------|-----------|---------|-------------|-----|
| 08:00AM | North | 68.46° | 0° | 68.46° |
|        | East   | 68.46° | 90° | 21.54° |
| 05:30PM | North | -67.62° | 0° | 67.62° |
|        | West   | -67.62° | -90° | 22.38° |

Using ‘equation (2) and [16]’,

| Time  | Direction | Altitude | cos (HSA) | VSA |
|-------|-----------|----------|-----------|-----|
| 08:00AM | North | 25.33° | 0.37° | 52.22° |
To reduce glare, the altitude angles of East and West directions are considered $15^\circ$ [18].

The optimum values of HSA and VSA inferred are as shown in Table 3:

### Table 3. Shadow angles for facade systems of the prototype building.

| Direction | VSA | HSA |
|-----------|-----|-----|
| North     | $35^\circ$ | $67^\circ$ |
| East      | $16^\circ$ | $21^\circ$ |
| West      | $16^\circ$ | $22^\circ$ |
| South     | $33^\circ$ | $61^\circ$ |

### 3.3. Selection of shading devices for analysis

Six types of facade systems are designed and selected for analysis. The strategies for selection are:

- Types of shading devices, and their combinations for a facade system.
- Depth of horizontal and vertical devices (towards exterior).
- Fenestration size.

Several types of shading devices were studied. A combination of horizontal and vertical shading devices give better shading solutions from solar radiations, and also support diffused lighting. The depth of shading devices increases with an increase in the size of fenestration on it. More will be the depth for lower values of HSA and VSA.

### 3.4. Simulation

The simulation was carried out using BIM software: Autodesk Revit 2019 (Student’s Version). The limitations of simulation are:

- The building is considered clear glazed on all sides.
- All materials in white colour with reflective values above 85%.
- The thickness of all shading devices is 50mm.
- The uppermost floor (third floor) is considered for simulation, at 75cm above floor level.
- External obstructions are considered NIL.
- No partitions exist in indoor spaces, except the existing 18 concrete columns.
- The simulation date (of BIM analysis) is 29th August at 12:30 PM taking into consideration of the altitude angle of $88^\circ$; the most shaded time for indoors in an entire year, specific to the location.

#### 3.4.1. Facade System 01

This facade system is a combination of horizontal and vertical shading devices (Figure 11, a). Horizontal devices dominate in depth than vertical devices at a ratio of 1:1.5. Thus, vertical devices have
a depth of 50cm and horizontal devices have a depth of 75cm. The only variation is in the spacing between devices on all sides, regarding the HSA and VSA.

3.4.2. Facade System 02
This facade system is twice the size of System 01 in proportion. Horizontal devices dominate in depth over vertical devices at a ratio of 1:1.5 (Figure 12. a). Thus, vertical devices have a depth of 100cm and horizontal devices have a depth of 150cm. This system has larger fenestrations than the previous type.
3.4.3. Facade System 03
This facade system resembles a second skin, enveloped at 125cm outside the floor edge. It has horizontal louvres of 10cm width running along full length on all sides with support systems (Figure 1.a). All horizontal louvres are closely arranged to satisfy VSA. The facade system ends at 240cm above floor level and has a cavity till roof level. The roof overhangs to all sides like a parasol, shading the cavity below as a horizontal shading device.
3.4.4. Facade System 04

This facade system is similar to system 03, enveloped at 125cm outside the floor edge. It also has horizontal louvres of 10cm width running along full length on all sides with support systems (Figure 14. a). All horizontal louvres are closely arranged to satisfy VSA. The facade system ends at 240cm above floor level and has an opaque wall till roof level.
3.4.5. Facade System 05
This facade system is an egg-crate type with smaller fenestrations in round shape running full height (Figure 15. a). The fenestrations have an inner radius of 30cm and depths based on HSA and VSA on all sides.
3.4.6. Facade System 06
This facade system is an egg-crate type with larger fenestrations in regular shapes running full height. All devices have equal depths of 200cm but vary in spacing based on HSA and VSA (Figure 16. a).
4. Results and Discussion
Facade systems 02, 03 and 06 lit up 100% of carpet area above 500 lux. System 01 covered 99.66% above 500 lux, 0.34% of the area is near the lift lobby. Facade system 05 could cover only 9.9% of carpet area above 500 lux (Table 4). Daylight levels of 500 to 750 lux reached up to a depth of 163cm on the southern side and remained below 500 lux on all other sides. The base range of service illuminance for the General category of retail is 350-500-750 lux [13].
Table 04. Percentage of area lit up above 500 lux, along with the depth of daylighting for different façade systems.

| Facade System  | Area lit up above 500 lux (sq. ft.) | % of carpet-area lit up above 500 lux | Natural lighting depth above 500 lux in 04 directions. |
|----------------|-------------------------------------|--------------------------------------|--------------------------------------------------------|
| 01             | 1479                                | 99.66                                | North: full length, East: full length, South: full length, West: full length |
| 02             | 1484                                | 100                                  | North: full length, East: full length, South: full length, West: full length |
| 03             | 1484                                | 100                                  | North: full length, East: full length, South: full length, West: full length |
| 04             | 1484                                | 100                                  | North: full length, East: full length, South: full length, West: full length |
| 05             | 146.5                               | 9.9                                  | North: full length, East: NIL, South: 163 cm, West: NIL |
| 06             | 1484                                | 100                                  | North: full length, East: full length, South: full length, West: full length |

5. Conclusions
This paper reviewed the indoor daylighting impact of façade control systems specific to a commercial building in Changanassery, Kerala, belonging to warm-humid climate. Six different types of façade systems including horizontal shading devices, vertical shading devices, thin horizontal louvres, parasol roof (in combination), and two different types of egg-crate devices were discussed. The design, application and performance of each type were explored. Conclusions inferred from the study states that: Regular horizontal and vertical combinations of shading devices gave optimum daylighting inside the building. Facade systems with larger fenestrations gave better daylighting than smaller fenestrations respective of shade depths. Northern and Southern sides penetrate more daylight inside the building due to larger spacing and lesser depths of systems compared to the ones in East and West directions. Facade Systems 03 and 04 could be considered as the better solution for any building due to their efficiency, lighter massing, aesthetic appeal, and similarities with the vernacular architectural features of Kerala [22]. All types of shading devices except smaller size (fenestration) egg-crate type (Facade System 05) are optimum for daylighting inside a commercial building in Kerala [13]. The results also satisfy the standards as per the National Building Code and National Lighting Code of India. However, out of the many indoor environmental qualities, only visual comfort has been looked at in this paper. Visual comfort is defined in the European standard EN 12665 as “a subjective condition of visual well-being induced by the visual environment”. It depends- (i) on the physiology of the human eye, (ii) on the physical quantities describing the amount of light and its distribution in space, and (iii) on the spectral emission of the light source [17],[20]. Thermal comfort is equally important to maintain a healthy environment in a building. Therefore, further studies will be done to achieve both visual and thermal comfort inside the building along with maintaining energy savings.

Furthermore, researches will be done on the actual material finishes (specific to building design), the indirect thermal radiation incident on façade systems, and indirect radiation incident inside the building. Research could also be done on the application of integrated photovoltaic (PV) configurations on these façade systems for generating renewable energy [21]. Finally, the thinner façade systems (Figure 13. a and Figure 14. a) are an efficient system that needs further exploration in terms of performance and aesthetics.

6. References
[1] “Natural Lighting | Green Home Technology Center.” https://greenhome.osu.edu/natural-lighting (accessed Jun. 30, 2021).
[2] S. Lorente, M. Petit, and R. Javelas, “Energy and Building,” vol. 28, pp. 237–240, 1998.
[3] Quadrennial Technology Review, “Increasing Efficiency of Building Systems and Technologies,” An Assess. Energy Technol. Res. Oppor., no. September, pp. 143–181, 2015.
[4] UN-Habitat, “Sun shading catalogue Adequate shading: Sizing overhangs and fins,” Promot. Energy Effic. Build. East Africa, 2018.
[5] A. Kirimtat, B. K. Koyunbaba, I. Chatzikonstantinou, and S. Sariyildiz, “Review of simulation modeling for shading devices in buildings,” *Renew. Sustain. Energy Rev.*, vol. 53, pp. 23–49, 2016, DOI: 10.1016/j.rser.2015.08.020.

[6] “Shading devices - Architetto Paolo Renieri.” https://www.renieriarchitetto.com/riqualificazione-en/riqualificazione-energetica/en/services/buildings-physics/shading-devices.html (accessed Jun. 30, 2021).

[7] S. R. Hastings and M. Wall, “Sustainable solar housing: Volume 2 – exemplary buildings and technologies,” *Sustain. Sol. Hous. Vol. 2 - Ex. Build. Technol.*, vol. 9781849772, pp. 1–270, 2012, DOI: 10.4324/9781849772808.

[8] “BDP | major international practice of architects, designers, engineers and urbanists.” https://www.bdp.com/ (accessed Jun. 30, 2021).

[9] “Umoja House - BDP.com.” https://www.bdp.com/en/projects/p-z/umoja-house/ (accessed Jun. 30, 2021).

[10] “Leo and Dottie Kolligian Library | Planning, Design, & Construction Management.” https://dc.ucmerced.edu/projects/auxiliary-buildings/leo-and-dottie-kolligian-library (accessed Jun. 30, 2021).

[11] “Uganda National Theatre | Architectuul.” http://architectuul.com/architecture/uganda-national-theatre (accessed Jun. 30, 2021).

[12] “Building and Architecture: High Court of Punjab and Haryana.” https://highcourtchd.gov.in/?trs=building (accessed Jun. 30, 2021).

[13] NBC, *National Building Code 2016, Volume 2*, vol. 2. Bureau Of Indian Standards, 2016.

[14] “CLIMATE | Kottayam District, Government of Kerala | India.” https://kottayam.nic.in/climate/ (accessed Jun. 30, 2021).

[15] “IMD | Home.” https://mausam.imd.gov.in/ (accessed Jun. 30, 2021).

[16] “PD: 2D Sun-Path.” http://andrewmarsh.com/apps/staging/sunpath2d.html (accessed Jun. 30, 2021).

[17] S. Carlucci, F. Causone, F. De Rosa, and L. Pagliano, “A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design,” *Renew. Sustain. Energy Rev.*, vol. 47, pp. 1016–1033, 2015, DOI: 10.1016/j.rser.2015.03.062.

[18] Koenigsberger, Ingersoll, Mayhew, Szokolay, “Manual of Tropical Housing-Climatic Design”, Universities Press (India) Private Limited, Hyderabad, India, 2010.

[19] Joud Al Dakheel and Kheira Tabet Aoul, “Building Applications, Opportunities and Challenges of Active Shading Systems: A State-Of-The-Art Review”, p. 1, 2017, *Architectural Engineering Department, UAE University, Al Ain, UAE*.

[20] EN 12665, Light and lighting - Basic terms and criteria for specifying lighting requirements. 2011, *European Committee for Standardization: Brussels, Belgium*.

[21] Francesco Fiorito and Michele Sauchelli, Diego Arroyo, Marco Pesenti, Marco Imperadori, Gabriele Masera and Gianluca Ranzi, “Shape Morphing Solar Shadings: a review”, p. 12, *Renewable and Sustainable Energy Reviews*, 2016, DOI: 10.1016/j.rser.2015.10.086.

[22] Boris Karamata, Luigi Giovannini, Valerio Lo Verso and Marilyne Andersen, “Concept, Design and Performance of a Shape Variable Mashrabiya as a Shading and Daylighting System for Arid Climates”, p. 2, 2014, DOI: 10.1016/j.egypro.2015.11.675.