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ORIGINAL ARTICLE

Energy savings from the shading performance of devices in highly glazed multi-story office buildings in the tropical climates of China and India

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Abstract

Rapid urbanization in China and India has led to the widespread development of high-rise office buildings with highly glazed façades in tropical climates, increasing the need for energy-efficient design strategies. Exterior shading systems can significantly enhance building energy performance by regulating solar heat gain in cooling-dominated climates. However, a systematic strategy is required to evaluate the energy-saving potential of such systems during the design phase. This study investigates the impact of shading fraction (SF) on space cooling load through simulation-based methods in two major tropical climate zones of Asia. Two Köppen climate types are examined: humid subtropical (Cwa), represented by Hong Kong (China) and New Delhi (India); and tropical wet and dry (Aw), represented by Haikou (China) and Chennai (India). The tools employed include Revit for geometry modeling, Dynamo for shaded area calculation, and E-Quest for energy simulation. A custom Dynamo script was developed to calculate the hourly shaded area of horizontal and vertical fins by varying fin depth. These were categorized into five SF levels (45–95%) at 10% intervals for four orientations and four representative seasonal days. Hourly cooling energy demand for each SF case was compared to a base model without shading. Results show cooling load savings ranging from 6% to 14% across locations: Chennai (9–14%), New Delhi (7–13%), Hong Kong (6–13%), and Haikou (8–14%). Despite identical climate classifications, Indian cities showed higher savings due to higher mean monthly temperatures. These findings offer valuable guidance for climate-responsive shading design in highly glazed tropical buildings.

Keywords: Shading fraction; Exterior shading device; Energy-saving shading system; Fully glazed buildings; Tropical climatic zones

1. Introduction

Highly glazed buildings have emerged as a prominent trend in contemporary architectural design worldwide and are increasingly applied across diverse climatic conditions (Chown *et al.*, 2010). In Asia, numerous highly glazed office structures are designed to offer abundant natural daylight and aesthetically pleasing external views, regardless of local climate. In tropical regions, however, air-conditioned office buildings with extensive glazing can have space cooling loads (SCLs) exceeding 50% of total energy use (Bano & Kamal, 2016). To mitigate unwanted heat gains—particularly during peak seasons—glazed areas must be shaded during daylight hours, which significantly reduces a building's cooling load (Hien & Istiadji, 2003). Moreover, shading devices can minimize glare, provide privacy, and preserve outdoor views (Kent *et al*., 2017). Fixed shading devices, however, have limited adaptability to the changing solar position (Al-Masrania *et al*., 2018), whereas dynamic shading devices are capable of maintaining a relatively constant shading fraction (SF) throughout the year (Johnsen & Winther, 2015).

Several methods have been proposed for calculating shaded areas. Hiller *et al*. (2000) developed an algorithm to calculate shaded area and solar radiation by determining the sunlit fraction of fixed shading devices. Gronbeck's (2016) online shading tool, "Sustainable by Design," offers a simple annual shading analysis for rectangular fixed overhangs. Pongpattana & Rakkwamsuk (2006) introduced a time-based shading area algorithm for fixed shading devices. For dynamic shading devices with complex geometries and motion, polygon-based methods are used to calculate hourly shading. Choi *et al*. (2017) proposed the Projection and Clipping (P&C) method, which calculates intersections of solar rays with projected polygonal shapes. In the present study, the P&C method proposed by Maestre *et al*. (2015), validated against experiments and European standards, was adopted to calculate hourly shaded areas.

Kim *et al*. (2015) introduced a methodology to analyze the energy performance of dynamic shading systems. In their methodology, they simplified the intricate panel design while keeping the opening ratio constant, and the energy outcomes were calculated based on the ratio of window to wall or the areas that were shaded versus those that were not.

In the present study, a more straightforward method was adopted. The hourly SF was first determined using simple shading fins, followed by the estimation of equivalent hourly space cooling energy savings for specific locations.

While numerous building energy standards advocate for the implementation of external shading or low-transmittance glazing to reduce heat gains in climates dominated by cooling needs, a more sophisticated design strategy involves assessing the necessary extent of shading and determining the most appropriate type of shading for various locations. The SF range serves as a key design parameter for selecting and optimizing any type of shading device, whether fixed, dynamic, or in the form of solar screens, based on the building's location, orientation, and analysis period. Although substantial research has focused on shading calculations using fixed window devices, further investigation is required to evaluate the performance of complex and dynamic shading systems, especially for highly glazed buildings. Moreover, the percentage of shaded area and its impact on space cooling energy savings are often overlooked in design decisions. This study aims to address these gaps by analyzing the relationship between SF and space cooling energy savings in two distinct tropical climatic zones in India and China.

2. Materials and tools

The key components of the present study included the climatic context, simulation tools, and SF calculation method, analysis period, analysis plane, five SF ranges, base-case model, and overall methodology.

2.1. Two climate zones in India and China

Asia exhibits substantial climatic diversity due to its vast geographical scale and varied topography. For this study, two Köppen climate types were selected: the humid subtropical climate (Cwa) and tropical wet and dry climate (Aw). The representative cities selected are Chennai (India) and Haikou (China) for Aw, and New Delhi (India) and Hong Kong (China) for Cwa (Figure 1). The monthly mean temperatures for the selected cities are shown in Figure 2, with Chennai exhibiting the highest values and Hong Kong the lowest.

The percentage of diffused horizontal solar radiation relative to peak global radiation for each city is shown in Figure 3. On the typical peak solar day of each month, Haikou exhibits the highest diffuse radiation ratio at 45%, followed by Hong Kong at 30%, Chennai at 28%, and New Delhi at 21%. The lower value for New Delhi is attributed to its inland location, unlike the other three coastal cities. Notably, within the Aw classification, Haikou receives nearly twice the diffuse radiation of Chennai.

This study focuses solely on the climatic context relevant to international-style highly glazed office buildings. Cultural and building code differences between India and China were not considered.

2.2. Simulation tools and SF calculation methods

The present research employed the following tools: Revit for creating shading geometries, the P&C method for SF calculation, a Dynamo script to implement the P&C method, and E-Quest as the energy simulation software to obtain hourly energy use data.

2.2.1. The P&C method

This study adopts the polygon intersection method proposed by Murta (2015). The method calculates the shaded area on a glass surface by subtracting the

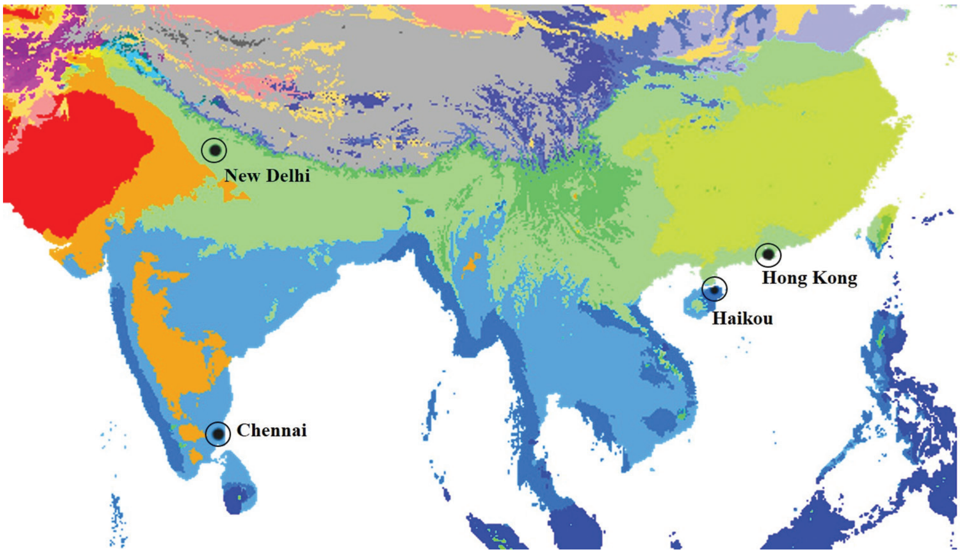

Figure 1. Köppen climate classification map of Asia, highlighting the selected cities
Aw: Tropical wet and dry climate Cwa: Humid subtropical climate
Source: Map adopted from https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification

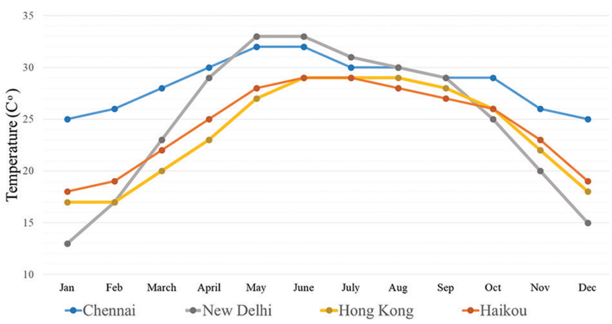

Figure 2. Monthly mean temperatures for Chennai, New Delhi, Hong Kong, and Haikou
Source: Graph adopted from https://clima.cbe.berkeley.edu

overlapping shadow area from the total projected shaded area. In the Dynamo environment, the analysis plane is defined as a panel with dimensions 4 m × 2 m. For each hour, the Sun Vector (Sv) node defines the solar direction, projecting a polygonal shadow onto the analysis plane using the "Surface Projection Input Onto" node. The resulting shaded area is referred to as Sa. The intersected or overlapping shaded area (Oa) is calculated using the "Geometry Intersect All" node. The hourly SF is calculated using Equation I (Figure 4). The corresponding Dynamo script used to calculate SF is shown in Figure 5.

$$SF = (\frac{sa - Oa}{Ap}) \times 100 \quad \text{(I)}$$

Where:
- SF = SF or percentage of shading for a given hour or Sv
- Sa = Shaded area
- Oa = Overlap area
- Ap = Area of the analysis plane.

2.2.2. Dynamo 2.0.2

Dynamo is a visual programming tool that works in conjunction with Revit, extending its capabilities by providing access to the Revit API in a more accessible manner (Darwin, 2019). In Dynamo, programs are created by manipulating graphic elements called "nodes," which form a computational workflow. Each step, defined by specific parameters, becomes a series of instructions that can be evaluated, revised, and improved.

In this study, Dynamo was used to import the shading device geometry from Revit and to calculate the SF for specified times and orientations. The key nodes used in the process are as follows:
- Sun path: Part of the Ladybug package for Dynamo, the Sun Path node retrieves climatic data from an EnergyPlus weather file for the selected location. It generates the Sv, representing the direction of sunlight, and defines the analysis plane for a given hour (Figure 6).
- Surface projection input: Projects the input geometry of the shading device onto the analysis surface in the direction of the Sv (Figure 7).
- Geometry intersects: Identifies the intersection of the input object. This node calculates overlapping shadow areas generated by multiple elements. Geometry intersected areas are subtracted from the total shaded area to determine the SF (Figure 8).

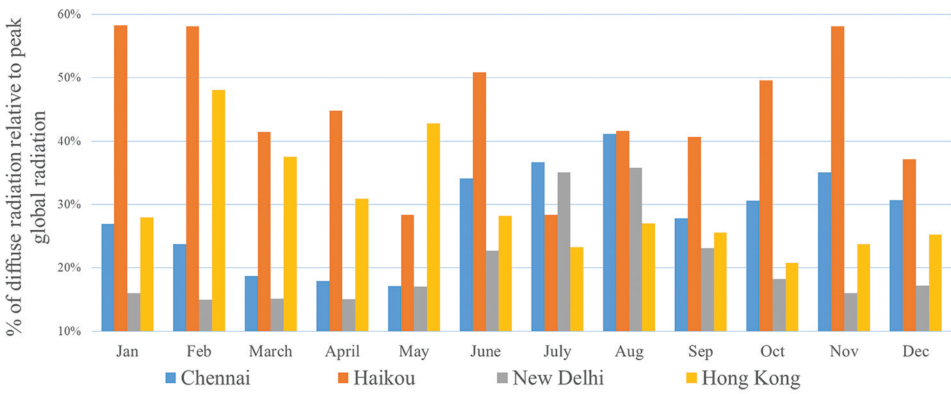

Figure 3. Percentage of diffuse horizontal radiation relative to peak global radiation on a typical day of each month for Chennai, New Delhi, Hong Kong, and Haikou
Source: Graph adopted from https://clima.cbe.berkeley.edu

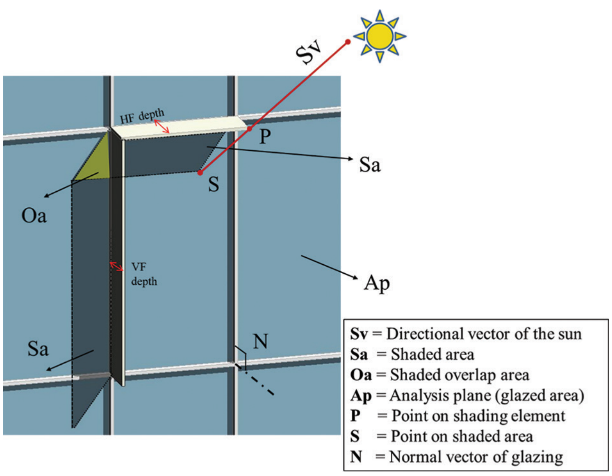

Figure 4. Shading calculation using the projection and clipping methods
Source: Illustration by the author

- Element. Set Parameter By Name: This node allows modification of a Revit family element's parameter. Inputs include the element and a number slider that assigns values to the parameter name. In this study, various fin depths were assigned to a Revit family element using this node (Figure 9). The complete Dynamo script used for the shaded area calculation is illustrated in Figure 5.

2.2.3. E-Quest

Among various energy simulation software, E-Quest is notable for providing dynamic thermal characteristics on an hourly basis, making it suitable for analyzing heat transfer through building envelopes. E-Quest, derived from DOE-2, features a simulation "engine" and a graphical interface that facilitates both schematic and detailed modelling workflows.

E-Quest is recognized as a sophisticated yet user-friendly tool that delivers professional-level building energy analysis results with relatively minimal effort (Ying *et al*., 2014). However, E-Quest has certain limitations. It does not allow for adjustments to fin angles, cannot simulate solar heat transfer through shading devices, and does not account for the thermal properties of those devices—factors that were not considered in this research.

To assess the impact of exterior shading devices, two primary outputs from E-Quest were employed: energy efficiency measures (EEM) and SCL, which are described as follows:

- EEMs are sub-simulations based on variations from the base-case model. They are essential tools for improving energy efficiency by changing components such as the building envelope, internal loads, heating, ventilation, and air conditioning systems, or other mechanical elements. In this research, EEM simulations were used to evaluate the impact of adding exterior window shades to the building envelope.
- SCL refers to the amount of energy required to remove heat at the cooling coil to maintain indoor thermal comfort. In E-Quest, SCL values are provided on both an hourly and annual basis, expressed in kWh.

2.3. Analysis period

To capture representative solar conditions for shading evaluation, the analysis was conducted based on selected days and hours with the greatest relevance to solar impact:

- Four seasonal days: The simulation was conducted on four key days of the year that represent seasonal extremes: the spring and fall equinoxes (March 21 and September 21), and the summer and winter solstices (June 21 and December 21). These days

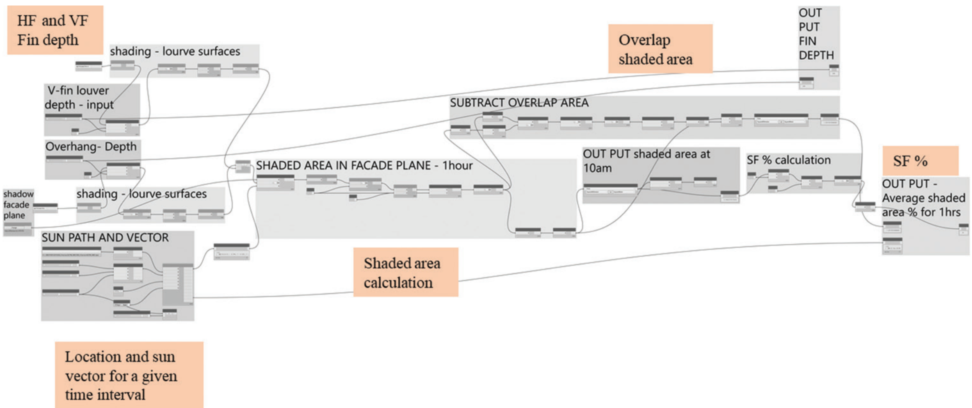

Figure 5. Dynamo script for shaded area calculation
Source: Screenshot from Dynamo
Abbreviation: SF: Shading fraction

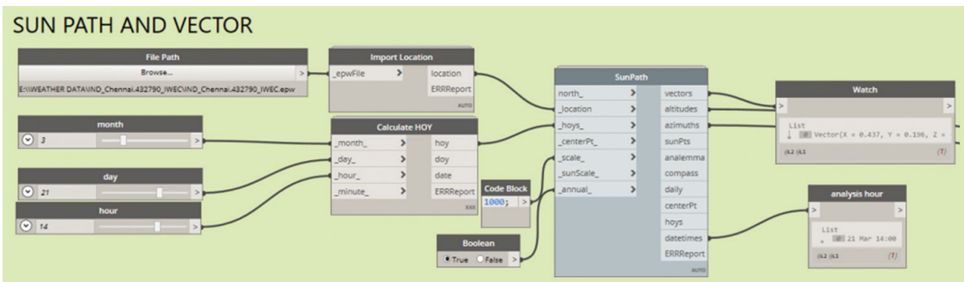

Figure 6. Sun Vector node
Source: Screenshot from Dynamo

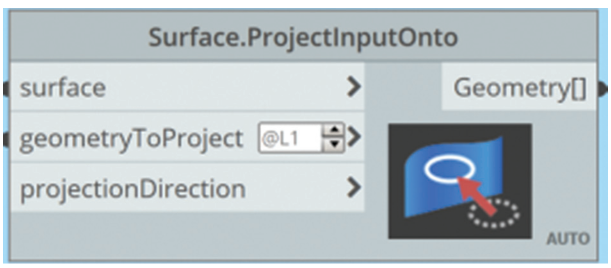

Figure 7. Surface projection input node
Source: Screenshot from Dynamo

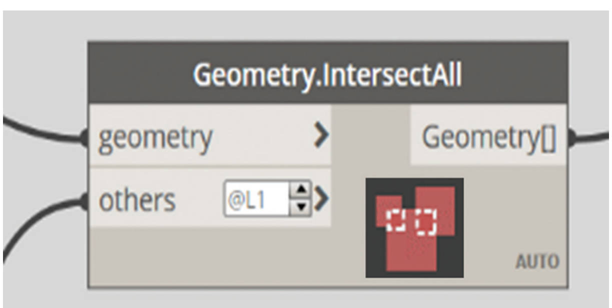

Figure 8. Geometry intersects nodes
Source: Screenshot from Dynamo

were selected based on solar position and day length, which significantly impact shading performance. Using these representative dates is a widely acceptable method in shading device analysis (Bazazzadeh *et al*., 2021).

- Shading analysis hours: Since shading effectiveness varies throughout the day, the analysis focused on peak solar heat gain hours—from 10:00 a.m. to 4:00 p.m. Noon was excluded from the calculation because, at the time, the sun's rays are nearly perpendicular to the façade, resulting in minimal direct shadow projection. Therefore, 6 h/day were analyzed.

2.4. Analysis plane

The analysis plane comprised a fully glazed façade grid measuring 4 m × 2 m, corresponding to the dimensions of the shading device. The entire façade was treated as a continuous window with no opaque wall elements. As illustrated in Figure 10, shadows cast outside the grid were considered to have the same impact as those within it. In this context, the shadow cast by the end curtain panel may not fall directly on the analysis plane; therefore, a small fraction of the cropped shadow area was neglected.

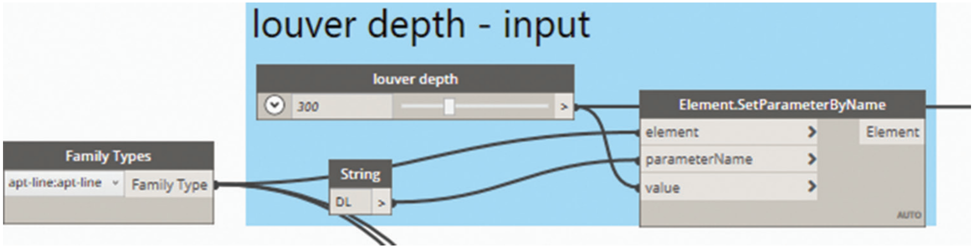

Figure 9. Element. Set Parameter By Name node
Source: Screenshot from Dynamo

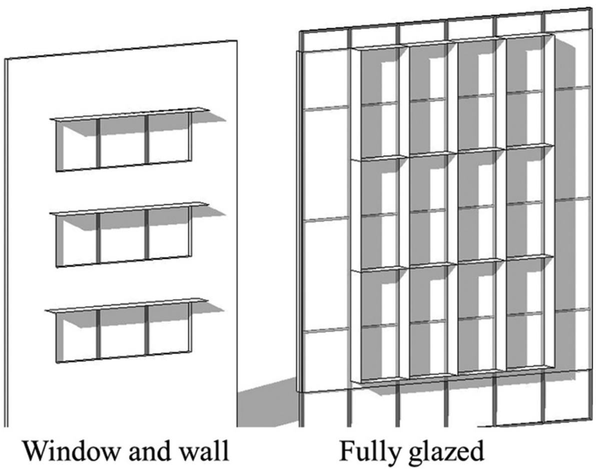

Figure 10. Shadow area on windows versus a highly glazed façade
Source: Drawings by the authors

2.5. Five shading ranges

To facilitate the estimation of shaded areas and their corresponding energy savings, the SF results were grouped into five ranges. This classification allows for a simplified correlation between shading performance and energy savings using a proportional relationship. The minimum SF required to achieve noticeable energy savings was 45%, with a maximum of 95%. The five defined ranges—SF1, SF2, SF3, SF4, and SF5—are shown in Figure 11 and span intervals of 10% each, as follows:

- SF1: 45–55%
- SF2: 55–65%
- SF3: 65–75%
- SF4: 75–85%
- SF5: 85–95%.

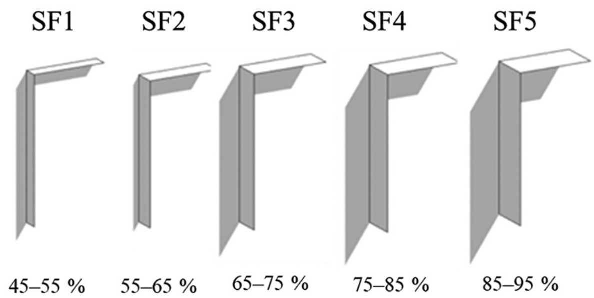

Figure 11. Shading fraction (SF) ranges from SF1 to SF5
Source: Drawings by the authors

2.6. Base case energy model

Based on previous research for the Chennai climate, a shading device is recommended when the façade glazing area exceeds 25% of the total office floor area (Chandrasekaran, 2020). Accordingly, a base-case energy model was developed in E-Quest, incorporating a glazing area exceeding this threshold. The modeled office building was a rectangular block measuring 30 m × 45 m, with the longer side oriented east–west and a total height of 80 m. The building was configured as a fully glazed multi-storied structure with 20 floors using the mid-floor multiplier approach (excluding ground and top floors). The total built-up area was 27,000 sqm, of which 21,600 sqm was a fully air-conditioned office area. Each typical floor had an area of 1,350 sqm, including 1,080 sqm of air-conditioned office space. Each floor was divided into four perimeter zones (one per orientation) and a central core zone, which was non-air-conditioned, as illustrated in Figure 12. The assumptions and thermal properties used for the energy analysis, based on default values and case studies (Chandrasekaran, 2020), are summarized in Table 1.

The base-case model was created using the detailed design wizard in E-Quest to obtain hourly results for SCL and energy use intensity hourly results. Among the four cities, the highest SCL was recorded in Chennai at 74.51 W/sqm/year, while the lowest was in Hong Kong at 50.4 W/sqm/year. Table 2 presents the average SCL across 2,910 annual analysis hours and the daily average SCL for four seasonal days (24 h each). Interestingly, the annual average SCL in Chennai and New Delhi was lower than their corresponding four-seasonal-day averages, whereas the opposite was observed in Hong Kong and Haikou.

3. Methodology

The methodology used to evaluate SCL energy savings based on the shaded area involves the following steps. The overall process flow is illustrated in Figure 13.

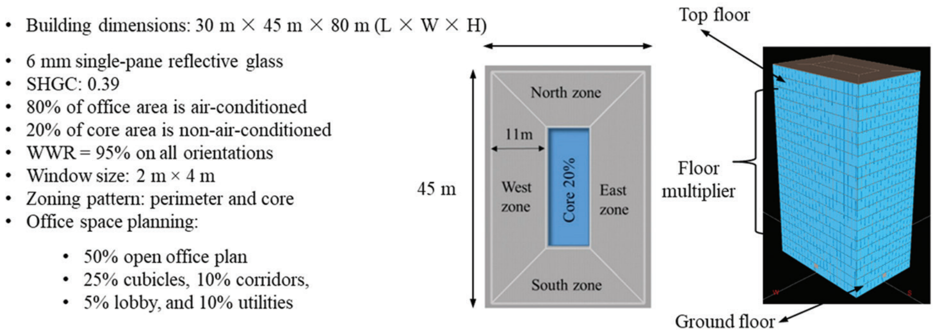

Figure 12. Base-case model in E-Quest
Source: Drawings by the authors
Abbreviations: SHGC: Solar heat gain coefficient; WWR: Window-to-wall ratio

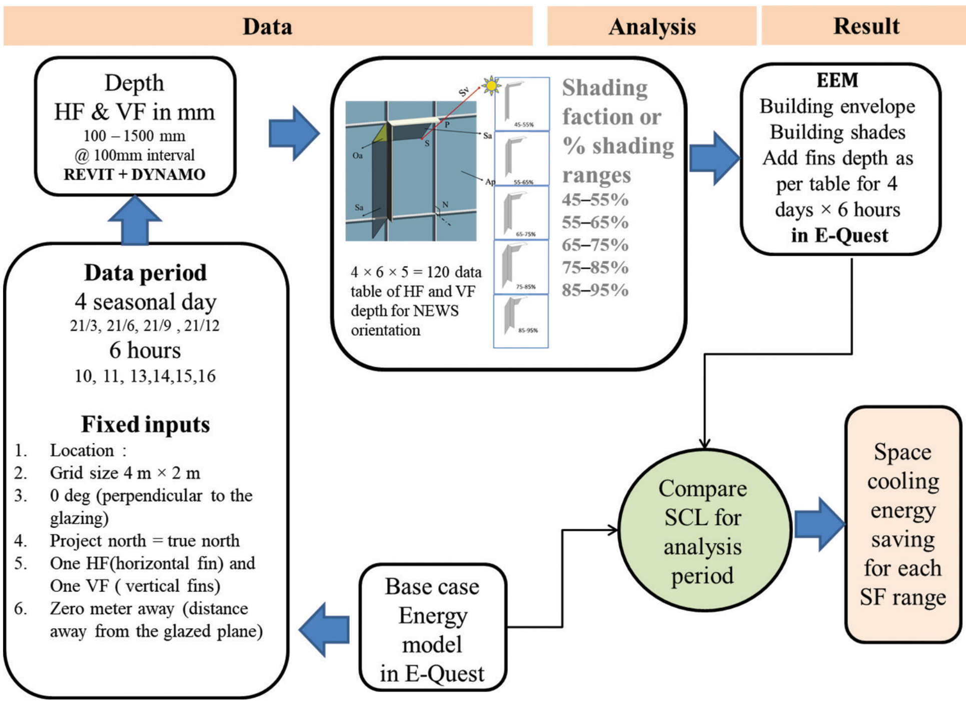

Figure 13. Methodology flow chart
Source: Diagram by the authors
Abbreviations: HF: Horizontal fin; SCL: Space cooling load; SF: Shading fraction; VF: Vertical fin

(i) Geometry was created in Revit for one horizontal fin (HF) and one vertical fin (VF) on a 4 m × 2 m grid. The SF was calculated for a given hour, orientation, and location using the P&C method through a visual programming script in Dynamo (Figures 4 and 10).
(ii) To simplify the results, the fin depth data were categorized into five SF ranges and tabulated for 6 h across four seasonal days for each selected location.
(iii) A base-case model was created in E-Quest for each selected location (Figure 12 and Table 2).
(iv) In E-Quest, the tabulated fin depths were assigned as window shades for all orientations in the base-case model to determine the hourly space cooling energy associated with each SF range.
(v) Energy savings for each SF range were compiled from 24 simulation runs (6 h × 4 days).
(vi) The energy use results for each SF range were then compared to the base-case model without shading devices for the same analysis period and locations (Table 3).
(vii) Finally, energy savings for all five SF ranges were compared across the four tropical cities (Figure 14).

This methodology enables the evaluation of shading device designs for energy efficiency based on the shaded

Table 1. Assumptions and thermal properties used in the base-case energy model

Parameter	Specification
Location and climate	Weather data in *.EPW and *.BIN files
Project north	True north
Office space planning/ activity zones	50% open office, 25% cubicles, 10% corridors, 5% lobby, and 10% utilities
Floor-to-floor height	4 m
Floor-to-false ceiling height	3 m
Zoning pattern	Perimeter and core
Air-conditioning zones	80% air-conditioned (office), 20% non-air-conditioned (core area)
Occupancy rate	12.5 persons per sqm
Occupancy schedule	9:00 a.m. to 6:00 p.m., 6 days a week
Walls	150 mm autoclaved aerated concrete block with no insulation
U-value of walls	0.65 W/sqm•K
Glazing material	6 mm single reflective clear glass in an aluminum frame
Glazing type	No. 1407 (per DOE Glass Library)
Solar heat gain coefficient	0.39
Solar coefficient	0.45
Solar transmittance	0.24
Solar reflectance	0.16
Visual transmittance	0.78
Visual reflectance	0.16
Window-to-wall ratio	95% in all orientations
Glazed panel size	2 m×4 m
Lighting load	14 W/sqm
Power load	20 W/sqm
Cooling set point	23.3°C
Heating, ventilation, and air conditioning type	Variable air volume with chilled water system per floor
Supply air temperature	12°C
Relative humidity	50%
Latent heat gain per person	58 W
Sensible heat gain per person	73 W

Abbreviation: EPW: Energy plus weather.

area created during the analysis period. The simulation model represents a typical multi-story office building across the four selected cities. To estimate the SCL energy savings associated with each SF range, the geometry was first generated with adjustable fin depth inputs to calculate the shaded area. These fins were then applied to windows on all orientations in the base-case energy model, followed by hourly simulations in E-Quest to assess energy savings for each EEM scenario.

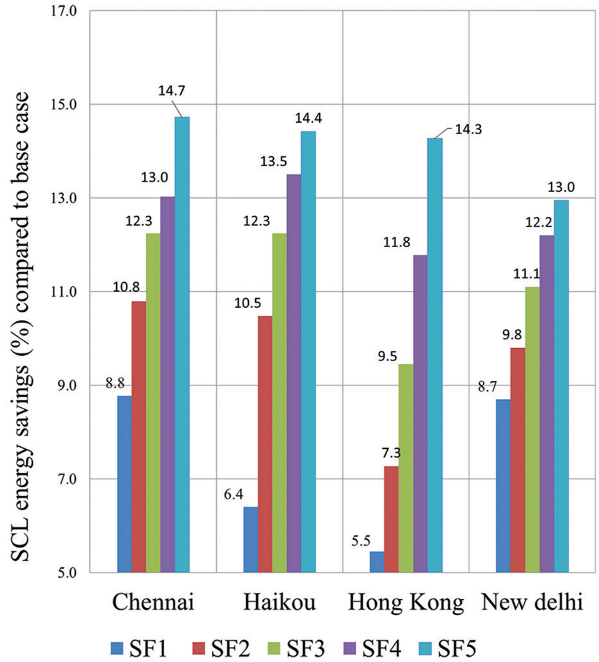

Figure 14. Space cooling load energy savings (%) relative to the base case for different shading fraction ranges across four selected cities
Source: Graph by the authors

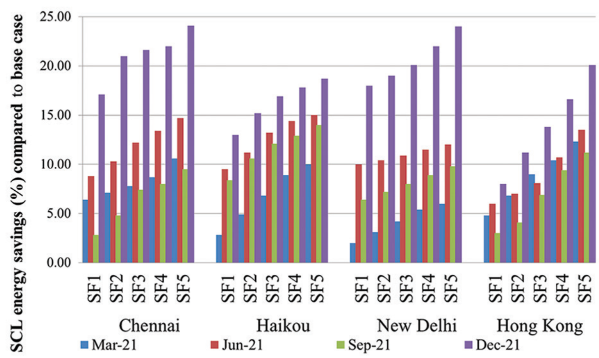

Figure 15. Space cooling load energy savings relative to the base case for five shading fraction ranges across four seasonal days in four selected cities
Source: Graph by the authors

3.1. Hourly fin depth for five SF ranges

Hourly energy savings based on SF were analyzed for different fin depths on the façade. One HF and one VF were modelled for six analysis hours per day across four seasonal days. The geometry of the HF and VF was created in Revit as family elements for a sample glazed panel measuring 4 m × 2 m, with fin parameters corresponding to the window shade input used in E-Quest. The shaded area was calculated using the polygon clipping method in Dynamo, as shown in Figures 9 and 10. Fin depth values were tabulated for a given hour, day, orientation, and

Table 2. Geographic, climatic, and cooling load characteristics of the four selected cities

City	Latitude	Longitude	Köppen climate zone	Daytime temperature (9:00 a.m. to 6:00 p.m.; °C)		Space cooling load (kWh/sqm/year)	Average space cooling load over 2,910 h (kWh/sqm)	Space cooling load over 4-day analysis (kWh/sqm)	Diffuse radiation (% of peak global)
				Max	Min				
Chennai	13.083	80.327	Aw	38	24	74.51	510	536	28
Haikou	20.033	110.350	Aw	33.7	13.7	56.37	428	387	45
New Delhi	28.614	77.209	Cwa	42	13	69.5	471	497	21
Hong Kong	22.302	114.174	Cwa	32	13	50.4	383	318	30

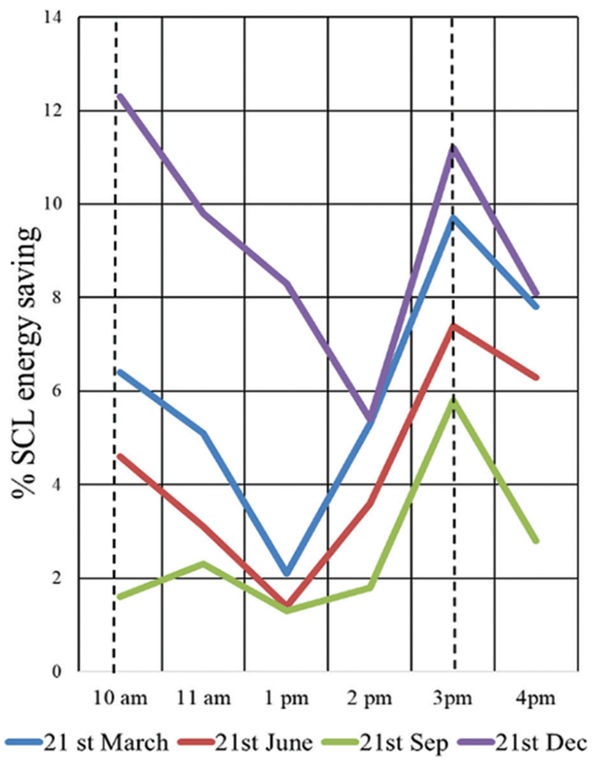

Figure 16. Hourly space cooling load energy saving (%) for SF1 in Hong Kong (Cwa: humid sub-tropical climate)
Source: Graph by the authors

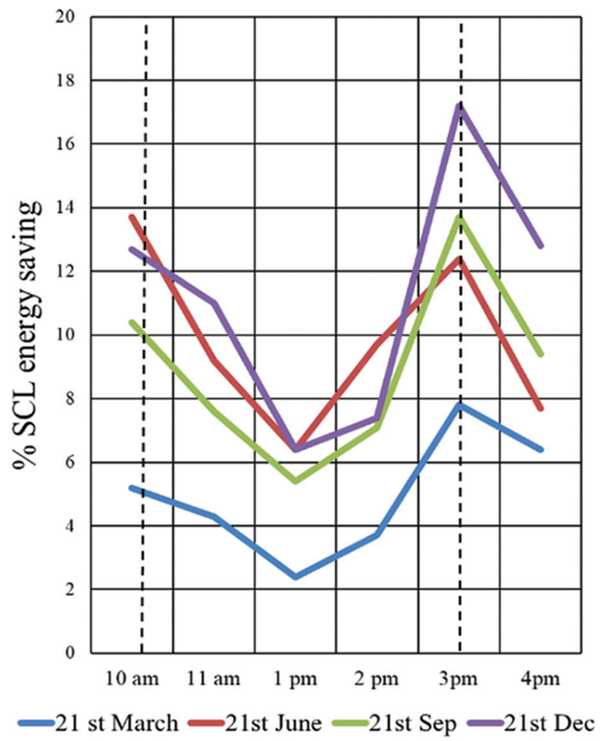

Figure 17. Hourly space cooling load energy savings (%) for SF 1 in Chennai (Aw: Tropical wet and dry climate)
Source: Graph by the authors

location corresponding to the five SF ranges. The analysis hours included 10:00 a.m. and 11:00 a.m. for the east-facing façade, 1:00 p.m. to 4:00 p.m. for the west, and all 6 h for the south. Data were collected for three seasonal days (excluding the summer solstice) and for the north façade only on the summer solstice, across three cities: Chennai, Hong Kong, and Haikou. For example, Table 3 presents the fin depths corresponding to SF3 (65–75%) for each analysis hour, day, and orientation in Chennai.

3.2. Hourly SCLs for five SF ranges

In the EEM of the base-case model, window shading was applied using the tabulated fin depths for each SF range. The SCL results for each SF range were compiled from 24 runs (6 h × 4 days) and compared with the base-case data for the same 24 analysis hours. Figure 14 shows the percentage of SCL savings across all four cities and five SF ranges. Figure 15 illustrates SCL savings for the five SF ranges in each of the four cities across the four seasonal days. The peak saving hours for SCL were observed at 10:00 a.m. and 3:00 p.m. across all 4 days, as shown in Figures 16 and 17 for the SF5 range. Similar peak-hour saving patterns were observed across all SF ranges.

4. Results

The EEM simulations were performed for each city by inputting the corresponding tabulated fin depths for all

Table 3. Horizontal fin (HF) and vertical fin (VF) depths (in mm) for SF3 (65–75%) for Chennai on the four seasonal days

Orientation	March 21						June 21						September 21						December 21					
	10:00 a.m.	11:00 a.m.	1:00 p.m.	2:00 p.m.	3:00 p.m.	4:00 p.m.	10:00 a.m.	11:00 a.m.	1:00 p.m.	2:00 p.m.	3:00 p.m.	4:00 p.m.	10:00 a.m.	11:00 a.m.	1:00 p.m.	2:00 p.m.	3:00 p.m.	4:00 p.m.	10:00 a.m.	11:00 a.m.	1:00 p.m.	2:00 p.m.	3:00 p.m.	4:00 p.m.
East/West																								
HF	800	450	250	550	750	1,000	550	300	200	550	750	1,100	600	250	250	700	1,000	1,250	500	200	200	500	700	1,300
VF	800	450	250	600	900	1,200	750	400	300	550	900	1,200	700	350	400	750	1,150	1,350	600	350	300	600	900	1,300
South/North																								
VF	200	250	250	250	150	100	400	350	400	400	450	550	250	200	200	200	100	100	700	750	750	700	600	550
HF	250	250	250	300	250	200	300	300	350	350	400	450	200	300	250	250	200	200	800	900	850	800	700	650

analysis hours (6/day), over four seasonal days. The energy savings, compared with the unshaded base case, varied across the four cities located in two distinct climatic zones, as shown in Figures 14 and 15. For SF1, SCL savings ranged from 5.5% to 8.8%, with the lowest in Hong Kong and the highest in Chennai. The highest observed SCL energy saving was 14.7% for Chennai under SF5, while the lowest under SF5 was 13% for New Delhi. According to Figure 15, SCL savings were greater during the winter solstice for all cities, coinciding with the maximum fin depth on December 21. Conversely, lower savings were observed during the spring and fall equinoxes. As illustrated in Figures 16 and 17, the peak energy-saving hours for a given SF range consistently occurred at 10:00 a.m. and 3:00 p.m.

The fin depths for a given SF range during these hours were at their maximum, and the solar angle was shallow enough to allow sunlight to penetrate indoor spaces. The SCL savings were similar for Chennai, Haikou, and New Delhi. In contrast, savings were lower for Hong Kong, likely due to its lower mean temperature. Across all cities, the SF ranges had a direct impact on the SCL—energy savings increased as the SF range increased. Haikou experienced the highest percentage of diffuse radiation from January to April, resulting in the lowest energy savings on March 21 compared to other seasonal days.

Both Haikou and Hong Kong exhibited lower energy savings on March 21, likely because the ratio of diffuse to peak global radiation was higher on that day. Despite having the same climatic classifications (Aw and Cwa), the percentage of SCL savings relative to the base case differed among the cities. Haikou and Hong Kong showed lower savings compared to the Indian cities, which have higher mean monthly temperatures. Additionally, the percentage of space cooling energy savings compared to the base case (without shades) was greater for SF1, SF2, and SF3 than for SF4 and SF5.

5. Conclusion

The use of shading devices in office buildings with fully glazed façades in tropical regions, such as those in China and India, can significantly improve energy efficiency by reducing cooling demand. The present study demonstrated the effectiveness of simple shading designs, achieving up to 75% shading coverage on fully glazed façades. Nonetheless, several limitations were identified. The analysis focused exclusively on horizontal and vertical shading factors (HF and VF), omitting angular or non-orthogonal configurations, as well as the thermal properties of shading materials. The simulations primarily assessed the impact of direct solar radiation, which may underestimate the influence of diffuse radiation—particularly relevant in tropical regions with frequent cloud cover during peak seasons (Bhattacharya *et al*., 1996). In addition, the analysis was restricted to a 4-day period and considered only one type of reflective glazing. Consequently, the findings may not fully represent year-round performance or account for variability in façade materials.

This research encompassed diverse climatic zones across India and China, introducing both geographic and climatic variability into the analysis. However, the results are based solely on simulations and have not yet been validated with field data, which is essential for improving reliability and real-world applicability. Accurate calculation of shaded areas is critical for minimizing direct solar heat gain and reducing thermal loads on building façades. A more comprehensive understanding of shading factors, especially in complex or dynamic systems, could provide valuable insights for future design strategies. While this study examined energy performance, it did not address the effects of shading devices on daylight quality, external views, or occupant satisfaction. Nevertheless, well-designed shading systems can simultaneously reduce cooling needs, improve indoor thermal comfort, mitigate urban heat island effects, and lower overall environmental impacts.

Beyond its immediate technical contributions, the study's findings have important implications for sustainable urban development in Asia. Rapid urbanization in Asian cities—particularly in tropical regions—has intensified energy demand, much of it driven by air conditioning in buildings with poorly designed envelopes. Integrating shading factor (SF) systems into both new construction and retrofit projects can reduce dependence on mechanical cooling, thereby lowering operational energy consumption and greenhouse gas emissions. Aligning SF design with regional climatic conditions and local building codes can also promote context-sensitive architecture that balances energy efficiency with occupant well-being. As Asian cities face mounting challenges related to urban heat islands, grid reliability, and climate resilience, the deployment of adaptive, solar-responsive façades represents a scalable and cost-effective solution. To encourage widespread adoption, architects, urban planners, and policymakers should integrate SF strategies into green building certification schemes, urban heat mitigation initiatives, and climate action frameworks. Continued research—including field validation and life-cycle cost analysis—will be essential to bridge simulation-based insights with real-world applications, ultimately supporting the transition toward low-carbon, climate-adaptive cities across Asia.

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Conflict of interest

The authors declare that they have no competing interests.

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References

Al-Masrania, S. M., Al-Obaidi, K. M., Zalina, N. A., & Aida Isma, M. I. (2018). Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends. *Energy, 170*:849-872.

https://doi.org/10.1016/j.solener.2018.04.047

Bano, F., & Kamal, M. A. (2016). Examining the role of building envelope for energy efficiency in office buildings in India. *Architecture Research*, *6*(5):107-115.

https://doi.org/10.5923/j.arch.20160605.01

Bazazzadeh, H., Świt-Jankowska, B., Fazeli, N., Nadolny, A., Safar Ali Najar, B., Hashemi Safaei, S. S., *et al*. (2021). Efficient Shading device as an important part of daylightophil architecture; a designerly framework of high-performance architecture for an office building in tehran. *Energies*, *14*(24):8272.

https://doi.org/10.3390/en14248272

Bhattacharya, A., Kar, S., & Bhattacharya, R. (1996). Diffuse solar radiation and associated meteorological parameters in India. *Annales Geophysicae*, *14*(10):1051-1059.

https://doi.org/10.1007/s005850050366

Chandrasekaran, C. (2020). *Envelope Performance Analysis of Office Buildings in Warm and Humid Climate: From Case Studies of Multi-storied Office Buildings in Chennai*. Singapore: Sustainable Urban Architecture Springer.

https://doi.org/10.1007/978-981-15-9585-1

Choi, S. J., Lee, D. S., & Jo, J. H. (2017). Method of deriving shaded fraction according to shading movements of kinetic façade. *Sustainability, 9*(8):1449.

https://doi.org/10.3390/su9081449

Chown, S. L., Hoffmann, A. A., Kristensen, T. N., Angilletta, M. J. Jr., Stenseth, N. C., & Pertoldi, C. (2010). Adapting to climate change: A perspective from evolutionary physiology. *Climate Research, 43*:3-15.

https://doi.org/10.3354/cr00879

Darwin, N. (2019). *Parametric Design with Visual Programming in Dynamo with Revit The Conversion from CAD Models to BIM and the Design of Analytical Applications.* [Master Thesis]. Brinellvägen, Sweden Stockholm: KTH Royal Institute of Technology.

Gronbeck, C. (2016). *Sustainable by Design*. Available from: https://www.susdesign.com/overhang_annual/index.php [Last accessed on 2025 Mar 10].

Hien, W. N., & Istiadji, A. D. (2003). Effects of External Shading Devices on Daylighting and Natural Ventilation. In: *Proceedings of the 8th International IBPSA Conference, Eindhoven, The Netherlands*, p. 475-482.

Hiller, M. D. E., Beckman, W. A., & Mitchell J. W., (2000). TRNSHD - a shading and isolation calculations program. *Building and Environment*, *35*:633-644.

Johnsen, K., & Winther, F. V. (2015). Dynamic façades, the smart way of meeting the energy requirements, *Energy Procedia*, *78*:1568-1573.

https://doi.org/10.1016/j.egypro.2015.11.210

Kent, M. G., Altomonte, S., Wilson, R., & Tregenza, P. R. (2017). Temporal effects on glare response from daylight. *Building and Environment*, *113*:49-64.

https://doi.org/10.1016/j.buildenv.2016.09.002

Kim, H., Asl, M. R., & Yan,W. (2015). *Parametric BIM-Based Energy Simulation for Buildings with Complex Kinetic Façades*. In: 33rd eCAADe Conference. Vol. 1. Vienna, Austria: Vienna University of Technology.

Maestre, I. R., Pérez-Lombard, L., Foncubierta, J. L., & Cubillas, P. R. (2013). Improving direct solar shading calculations within building energy simulation tools. *Build. Perform. Simulation*, *6*:437-448.

Murta, A. (2015). *GPC: General Polygon Clipper Library. Astrophysics Source Code Library*, p. 1512.

Pongpattana, C., & Rakkwamsuk P. (2006). Efficient algorithm and computing tool for shading calculation. *Songklanakarin Journal of Science and Technology*, *28*(2):375-386.

Ying, H., Liu, X., & Chang, L. (2014). Comparison of software for building energy simulation. *Journal of Chemical and Pharmaceutical Research*, *6*(3):467-471.