

# Analyzing the effects of orientation, window size and position on solar heat gain for four Indian cities

Amalan Sigmund Kaushik S<sup>1\*</sup> and Sheetal Amraotkar<sup>2</sup>

<sup>1</sup> National Institute of Technology Tiruchirappalli, Tiruchirappalli 620015, India

<sup>2</sup> Chembur Trombay Education Society's College of Architecture, Mumbai 400088, India

## ABSTRACT

**\*Corresponding author:**  
Amalan Sigmund Kaushik S  
[kaushik@nitt.edu](mailto:kaushik@nitt.edu)

**Received:** 23 June 2023  
**Revised:** 22 January 2025  
**Accepted:** 8 March 2025  
**Published:** 4 February 2026

**Citation:**  
Kaushik S, A. S., &  
Amraotkar, S. (2026).  
*Analyzing the effects of  
orientation, window size and  
position on solar heat gain for  
four Indian cities. Science,  
Engineering and Health  
Studies, 20, 26040001.*

The orientation of a building is the most important passive design strategy to achieve an energy-efficient design. Solar insolation studies help identify orientations that minimize solar heat gain. However, existing literature often overlooks the challenges posed by site constraints that prevent implementing the optimal orientation. India, covering just 2.4% of the world's land area but accommodating 18% of the global population, faces a significant land scarcity issue. Consequently, the available development sites may not allow for the ideal orientation. In this research, in order to address this issue, Trichy, Chennai, and Mumbai, Kolkata across India were chosen and a solar insolation study was conducted for four different possible orientations of buildings in each of the cities and the best orientations were identified. Subsequently, the empirical calculation method outlined in GRIHA was used to calculate the ideal window design (size and position) for all orientations. The findings reveal that a north-south-oriented building module (M1) minimizes solar heat gain in Trichy, Chennai, and Mumbai, while a northeast-southwest orientation (M4) is optimal for Kolkata; moreover, orientation-responsive window redistribution reduces annual solar heat gain by up to 11.55% even in non-optimal orientations. The findings provide a transferable reference framework for designers to apply the methodology across other cities.

**Keywords:** passive design; orientation; window design; GRIHA

## 1. INTRODUCTION

As Indian urban centers contend with the persistent challenge of soaring temperatures, the implementation of passive design strategies has become increasingly critical. Passive design is predicated on the judicious utilization of natural elements, including, but not limited to, the sun, wind, and surrounding environment, with the goal of curbing the energy consumption required to maintain indoor thermal comfort in buildings. Such measures encompass a wide range of techniques, such as the strategic orientation of buildings relative to the sun, integration of optimized window design, and inclusion of features such as sun shades and appropriate building envelope materials for walls and

roofs. In this exposition, we evaluated the passive design strategies deployed to optimize solar heat gain (SHG) in Indian urban centers (Varghese & Kaushik, 2022). The successful execution of climate-responsive architecture entails the astute amalgamation of various building design parameters, judiciously calibrated to realize a comfortable living environment within built-up areas. Orientation always constitutes the foremost criterion governing the placement of a building on a site, as it plays a pivotal role in ameliorating the undesirable impact of natural climatic factors such as solar heat, illumination, ventilation, and ambient noise (Sinha, 2020).

Attaining an appropriate orientation for any building during the initial stages of design represents a highly

efficacious strategy for achieving passive cooling, obviating the need for implementing such measures in later phases. This pertains to the spatial relationship between the elevation of a building and the cardinal geographic direction. A well-conceived orientation can markedly reduce the requirement for mechanical systems to maintain desired heating, cooling, and ventilation levels. It governs the manner in which solar radiation impinges on the building façade, modulating its thermal load and thereby impacting the thermal comfort of the interior space. A judicious building solution requires the seamless integration of site-oriented and climate-responsive design, both of which are predicated on the building orientation (Li et al., 2022).

Optimizing SHG represents a vital consideration for architects and building designers as it assumes a pivotal role in determining the energy efficiency of the building. The orientation of the building, the positioning of the windows, the window-to-wall ratio (WWR), and the latitude of the location all represent factors that can influence SHG within a building.

India, comprising merely 2.4% of the total land area of the world, sustains a staggering 18% of the global population (Department of Land Resources, 2019). Owing to this incongruous distribution of land versus population, there exists an incessantly high demand for land. As a result, available development sites may not necessarily accommodate the most optimal orientation with respect to SHG. The extant literature largely highlights the importance of determining the optimal building orientation; however, it inadequately addresses the challenges posed by site constraints that hinder the implementation of this ideal orientation, which include irregular plot shapes, unfavorable site orientations, proximity to neighboring buildings, and compliance with regulatory setback requirements. This research aims to resolve this problem by optimizing window design in all non-performing orientations, thereby proposing the best possible control of annual SHG for all orientations.

The goal of this research was to exert a degree of control over the annual heat gain in buildings in four designated warm and humid cities across India through

the precise control of orientation, design, and placement of windows, accounting for varying WWRs. Specifically, the objective of this study was to identify the most optimal orientation for a prototypical residential unit, featuring dimensions of 15 (L) × 10 (W) × 4 (H) m, via an exhaustive solar insolation analysis. The research aimed to achieve maximal solar radiation absorption during the colder winter months, while concurrently minimizing such radiation in the sweltering summer months, thereby leading to a significant curtailment in overall building energy consumption. Furthermore, this study strived to provide novel recommendations for ideal window design and placement not only for the best orientation but also for the non-performing orientations, given a diverse range of WWRs.

## 2. MATERIALS AND METHODS

The most fundamental and commonly employed passive design strategy is to orient buildings in a climate-responsive manner. This initial step is crucial as it lays the foundation for harnessing the natural elements to achieve thermal comfort and energy efficiency. Following this, the design and strategic placement of windows play an equally significant role. Windows not only facilitate natural ventilation but also regulate solar heat gain and daylight ingress, contributing to a comfortable indoor environment.

### 2.1 Methodology

The initial phase of this research focused on analyzing SHG through the use of weather files for designated cities (Figure 1). To conduct this analysis, ISHRAE “Typical Year” weather files were assessed using the commonly utilized climate analysis software, Climate Consultant. The software calculates the total annual solar radiation (direct plus diffused) incident on various vertical surfaces of buildings, in Watt hours per square meter (Wh/m<sup>2</sup>). The outcomes of this assessment were used to determine the SHG patterns for each cardinal orientation within the four cities.

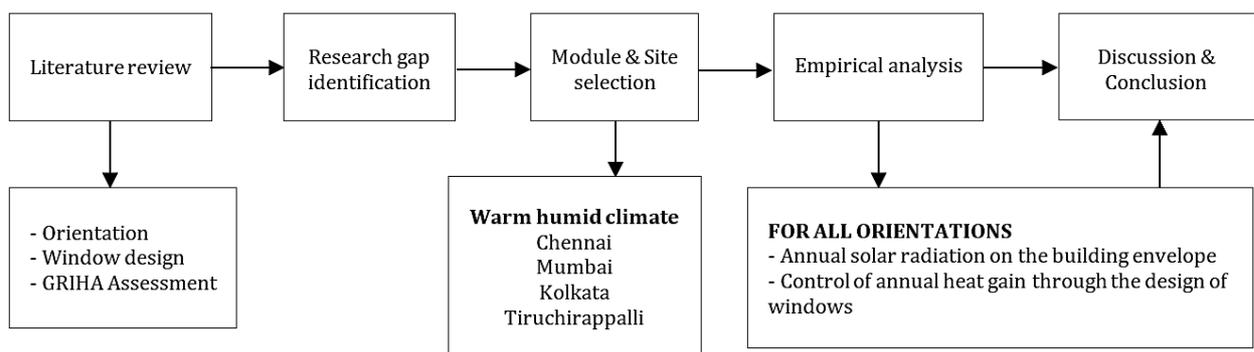


Figure 1. Methodology

The second part of this research involves a study on solar insolation across the building envelope for four different orientations of a designated building type, aiming to identify the optimal building orientation for each city. The building is a middle-income group residential structure with a flat roof, measuring 10 m × 15 m, with a height of 4 m. This base module has no shading devices or verandah, and its external wall surfaces remain unshaded except when the sun is not directly shining on them. The total annual solar radiation (TASR) on a surface can be obtained by multiplying the total load per unit area by the surface area. TASR for building envelopes of a rectangular form can be calculated using Equation 1.

$$TASR_{BE} = O_1A \times ASR_1 + O_2A \times ASR_2 + O_3A \times ASR_3 + O_4A \times ASR_4 \quad (1)$$

where  $TASR_{BE}$  = TASR of the building envelope in kWh;  $O_{1,2,3,4}A$  = area of specific orientation in m<sup>2</sup>;  $ASR_{1,2,3,4}$  = annual solar radiation of the respective vertical surface in Wh/m<sup>2</sup>.

The next phase of this research focuses on regulating annual heat gain through window orientation and design in accordance with GRIHA 2019. Window design to control SHG is determined not only for the best-performing orientation but also for those with higher SHG. The Bureau of Energy Efficiency design standards recommend that the WWR for residential buildings in warm-humid and hot-dry climates should ideally range between 20% and 30%. Therefore, to regulate annual heat gain through window orientation and design, all four modules in this study are evaluated for WWR values of 20% and 30% in each of the four cities. An assessment is conducted to demonstrate that heat gain from windows in the design scenario is lower than that in the GRIHA baseline case. In the baseline case, the total window area is uniformly distributed across all orientations.

$$SHGW = \text{Insolation} \times \text{Window area of specific orientation} \quad (2)$$

where SHGW = solar heat gain on windows

$$SHGW_{BE} = SHGW_1 + SHGW_2 + SHGW_3 + SHGW_4 \quad (3)$$

where  $SHGW_{BE}$  = SHG on windows for the building envelope in kWh,  $SHGW_{1,2,3,4}$  = SHGW of the respective orientation.

SHG on windows for the entire building envelope can be calculated using Equations 2 and 3. To optimize efficiency, windows were designed with the highest window area in the orientation with the least solar radiation, followed by orientations with progressively higher solar radiation. Conversely, the orientation with the highest solar radiation was assigned the least window area. This design approach enables windows to achieve optimal efficiency in controlling heat gain, reducing glare, and improving visual comfort.

## 2.2 Site selection

Warm-humid climate zones are regions located within tropical belts where excessive heat poses a primary challenge. Four cities in India with warm-humid climates were selected for this study (Figure 2), based on the National Building Code 2016. These cities were Chennai (13.0827° N, 80.2707° E), Mumbai (19.0760° N, 72.8777° E), Kolkata (22.5726° N, 88.3639° E), and Tiruchirappalli, referred to as Trichy (10.7905° N, 78.7047° E). To

determine SHG on a typical building envelope measuring 10 m × 15 m × 4 m, four modules were assessed. Module 1 (M1) has its long axis oriented in the north-south (N-S) direction (Figure 3), Module 2 (M2) in the east-west (E-W) direction, Module 3 (M3) in the northwest-southeast (NW-SE) direction, and Module 4 (M4) in the northeast-southwest (NE-SW) direction.

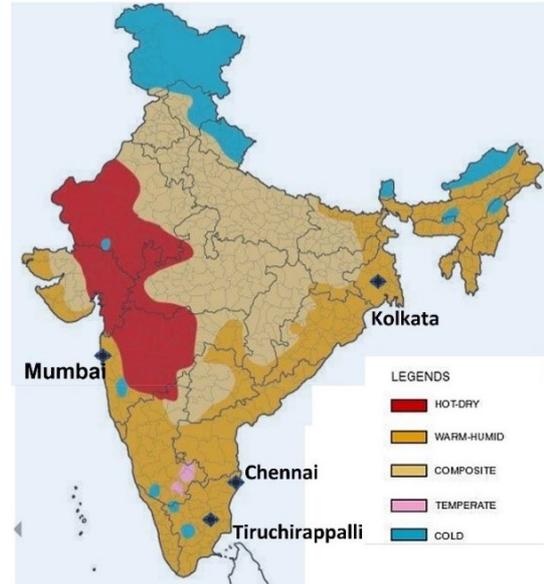


Figure 2. Climate zones in India and selected cities for this study

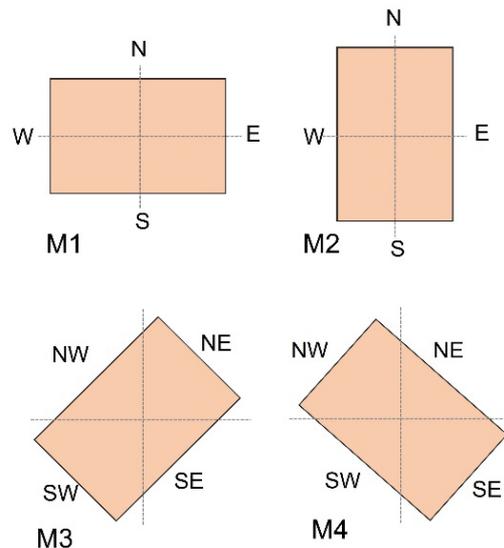


Figure 3. Identified modules M1, M2, M3, M4

## 2.3 Climate analysis

Climate analysis for the selected cities was conducted using Climate Consultant software. In Chennai (Figure 4), overheating occurs between 11 AM and 5 PM throughout the year, with full-day overheating from April to June. December has the highest comfort period, while July has the least. Other months offer comfort in the mornings and nights. In Kolkata (Figure 5), 26% of the year is classified as comfortable, while overheating

occurs throughout the day from May to August and between 11 AM and 5 PM from February to November. Underheating occurs during early mornings and midnight from December to February, accounting for 16% of the year.

In Mumbai (Figure 6), only 2% of the year experiences underheating, occurring in the early mornings from December to February. Overheating is prevalent from May

to July throughout the day and consistently between 10 AM and 6 PM year-round, with just 25% of the year considered comfortable. Tiruchirappalli (Figure 7) experiences comfortable conditions for 29% of the year, while the remaining 71% is classified as overheated. Overheating persists throughout the day from April to August and from 10 AM to 6 PM year-round, regardless of the season (Varghese & Kaushik, 2022).

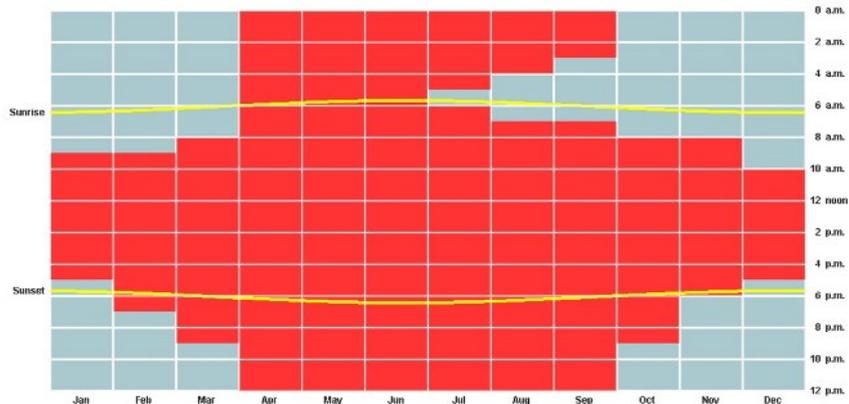


Figure 4. Annual comfort plot for Chennai

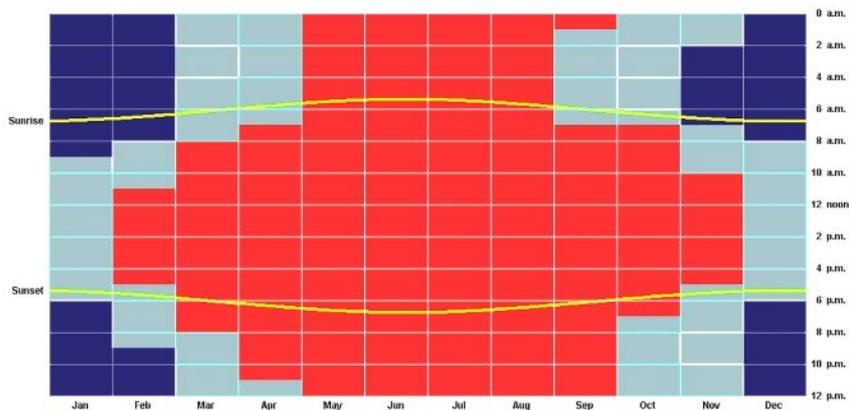


Figure 5. Annual comfort plot for Kolkata

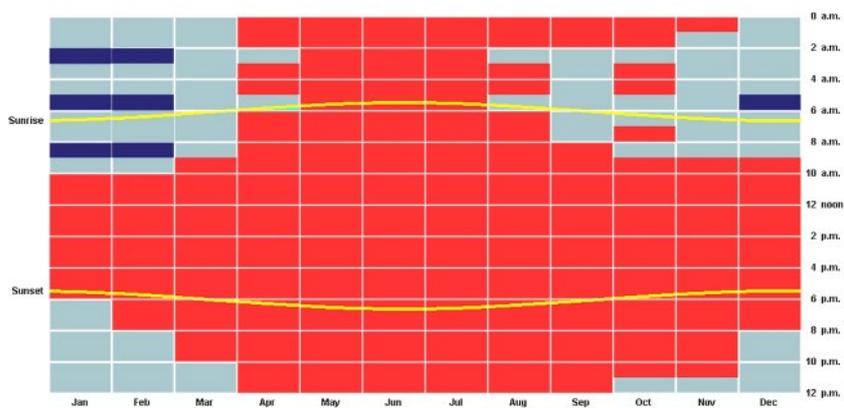
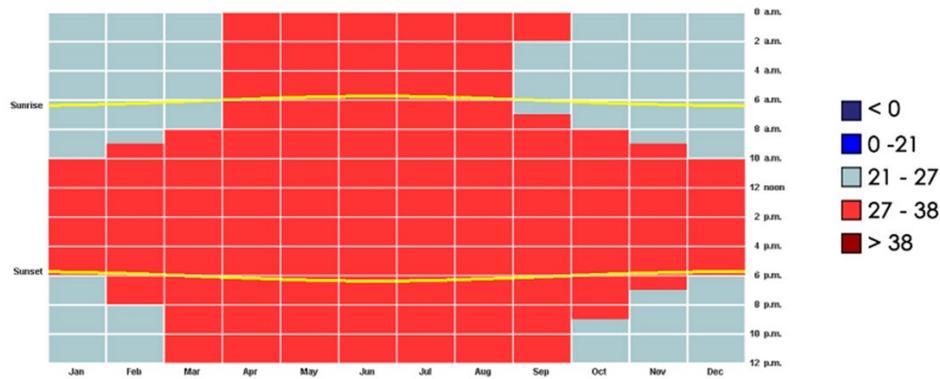


Figure 6. Annual comfort plot for Mumbai



**Figure 7.** Annual comfort plot for Tiruchirappalli

### 3. RESULTS

#### 3.1 Annual surface radiations

SHG refers to the heat energy absorbed by a building from the sun, influencing indoor temperature, comfort, and energy efficiency. Figure 8 presents a radar chart from Climate Consultant, comparing surface radiation ( $\text{Wh}/\text{m}^2$ ) across eight cardinal directions for the four Indian cities. Trichy and Chennai receive higher radiation on their western surfaces and lower radiation on their northern surfaces, whereas Mumbai and Kolkata experience elevated radiation on their southern and southwestern surfaces, respectively, with lower levels on their northern sides.

#### 3.2 Total annual solar radiation on the building envelope

Four cities were studied to understand which orientation will result in the least SHG. Figure 9 illustrates the total annual solar radiation absorbed by a building, measured in kWh, with higher values indicating greater absorption. Upon scrutinizing the M1 module, Mumbai exhibited the least SHG at 33.71, followed sequentially by Kolkata at 33.70, Chennai at 35.51, and Trichy at 35.71. Furthermore, examining the M2 module reveals that Trichy had the highest SHG, recording 37.91, followed closely by Chennai at 37.57, while Mumbai displayed the lowest SHG among the mentioned cities, clocking in at 35.79. In the M3 and M4 modules, Mumbai boasted the maximum SHG, followed by Trichy, while Kolkata ranked last in terms of SHG within the same modules. Thus, it may be inferred that, for Mumbai, the M3 and M4 modules represent the least favorable orientations due to the substantial difference in SHG levels. Conversely, Kolkata's equivalent modules exhibited lower SHG values.

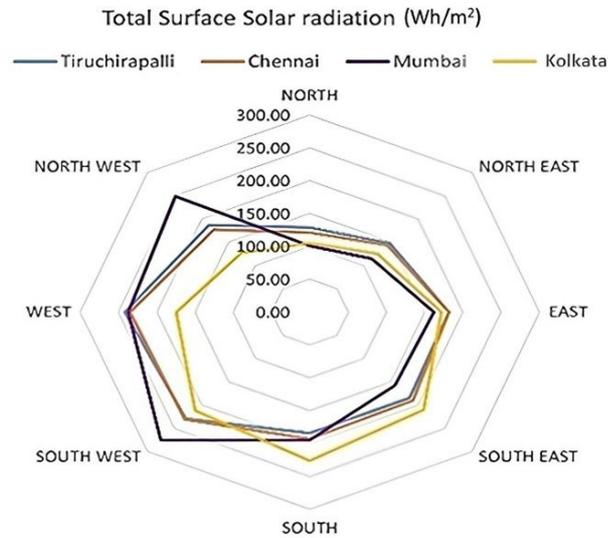
It has been found that the M1 module oriented in the north-south direction exhibited the lowest SHG for the cities of Trichy, Chennai, and Mumbai, while M4 oriented in the northeast-southwest direction had the lowest SHG for Kolkata. The necessity of the lowest SHG for the identified cities is paramount as it helps reduce heat gain and enhance thermal comfort. Notably, for Trichy, the subsequent superior module was M3, with a 4.72% elevation in SHG in comparison to M1. Similarly, the subsequent superior module for Chennai was M3, with a 4.26% increase in SHG when compared to M1; for Mumbai it was M2, with a 6.19% increase in SHG when compared to M1, and for Kolkata, it was M3, with a 0.04% increase in SHG when compared to M4. This observation clearly

suggests that M4 and M3 offer nearly identical performance concerning SHG in Kolkata, allowing the longer axis of the building to be oriented as in M4 or M3 with regard to SHG. However, in Mumbai, Trichy, and Chennai—three cities in proximity to the Equator in comparison to Kolkata—the divergence between the minimum SHG orientation and the second-lowest SHG orientation is within the 4.26% to 6.19% range. This indicates that if buildings are not oriented optimally with regard to SHG, it will result in amplified SHG, leading to increased thermal discomfort and escalated energy consumption.

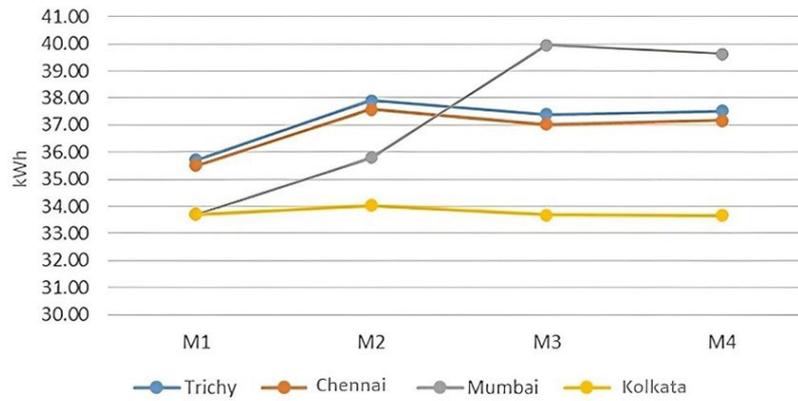
#### 3.3 Control of annual heat gain through the design of windows

In accordance with the recommendations set forth in GRIHA 2019, an approach was taken to regulate the annual heat gain through the windows of a building. This approach involves a meticulous calculation of the SHG metric for all vertical surfaces of the building, using a fixed sill level of 0.9 meters and a lintel level of 2.1 m, thereby fixing the window height at 1.2 m. Additionally, the effect of clear story windows, having a height of 0.45, was also taken into consideration, only for 30 WWR. To optimize efficiency, the windows were designed such that the orientation with the lowest solar radiation was assigned the highest window area, while the window area was progressively decreased for orientations with higher radiation.

Table 1 provides a detailed calculation of the distribution of window areas for all vertical surfaces of the building envelope across different modules. SHG on windows was then computed empirically for both the base and design cases, considering different WWRs and orientations. The results indicate that the design case outperforms the base case in all cities examined (Figure 10). When considering a 20% WWR, a substantial increase in performance was observed in the design case across all cities compared to the 30% WWR. Specifically, for a 20% WWR, the design case demonstrated a performance improvement ranging from 3.65% to 11.55% over the base case, while for a 30% WWR, the improvement ranged from 1.49% to 9.6% (Figure 11). Notably, Chennai and Trichy exhibited a marked enhancement in the design case when the M1 orientation was employed for both WWRs. In Mumbai, the M3 and M4 orientations exhibited the lowest performance; however, even in these orientations, the design case achieved an improvement of 9.03% and 10.11%, respectively.



**Figure 8.** Radar chart showing surface radiation across different orientations for selected cities



**Figure 9.** Total annual solar radiation on the building envelope (kWh)

**Table 1.** Base & design case window areas

Building modules	Module 1 (M1)				Module 2 (M2)				Module 3 (M3)				Module 4 (M4)			
	LS1 N	LS2 S	SS1 E	SS2 W	LS1 E	LS2 W	SS1 N	SS2 S	LS1 NW	LS2 SE	SS1 SW	SS2 NE	LS1 NE	LS2 SW	SS1 NW	SS2 SE
<b>Base case window area for all cities (m<sup>2</sup>)</b>																
20 WWR	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
30 WWR	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
<b>Design case window area for all cities (m<sup>2</sup>)</b>																
Chennai 20 WWR	15	15	10	0	15	5	10	10	15	15	0	10	15	5	10	10
Chennai 30 WWR	21	21	14	4	21	11	14	14	21	21	4	14	21	11	14	14
Mumbai 20 WWR	15	10	10	5	15	0	10	15	15	15	0	10	15	5	10	10
Mumbai 30 WWR	21	21	14	4	21	11	14	14	21	21	4	14	21	11	14	14
Trichy 20 WWR	15	15	10	0	15	5	10	10	15	15	0	10	15	5	10	10
Trichy 30 WWR	21	21	14	4	21	11	14	14	21	21	4	14	21	11	14	14
Kolkata 20 WWR	15	5	10	10	15	15	10	0	15	15	0	10	15	5	10	10
Kolkata 30 WWR	21	11	14	14	21	21	14	4	21	21	4	14	21	11	14	14

Note: LS - Long side of the building form (15M), SS - Short side of the building form (10M), N - North, S - South, E - East, W - West, NE - North East, SE - South East, NW - North West, SW - South West

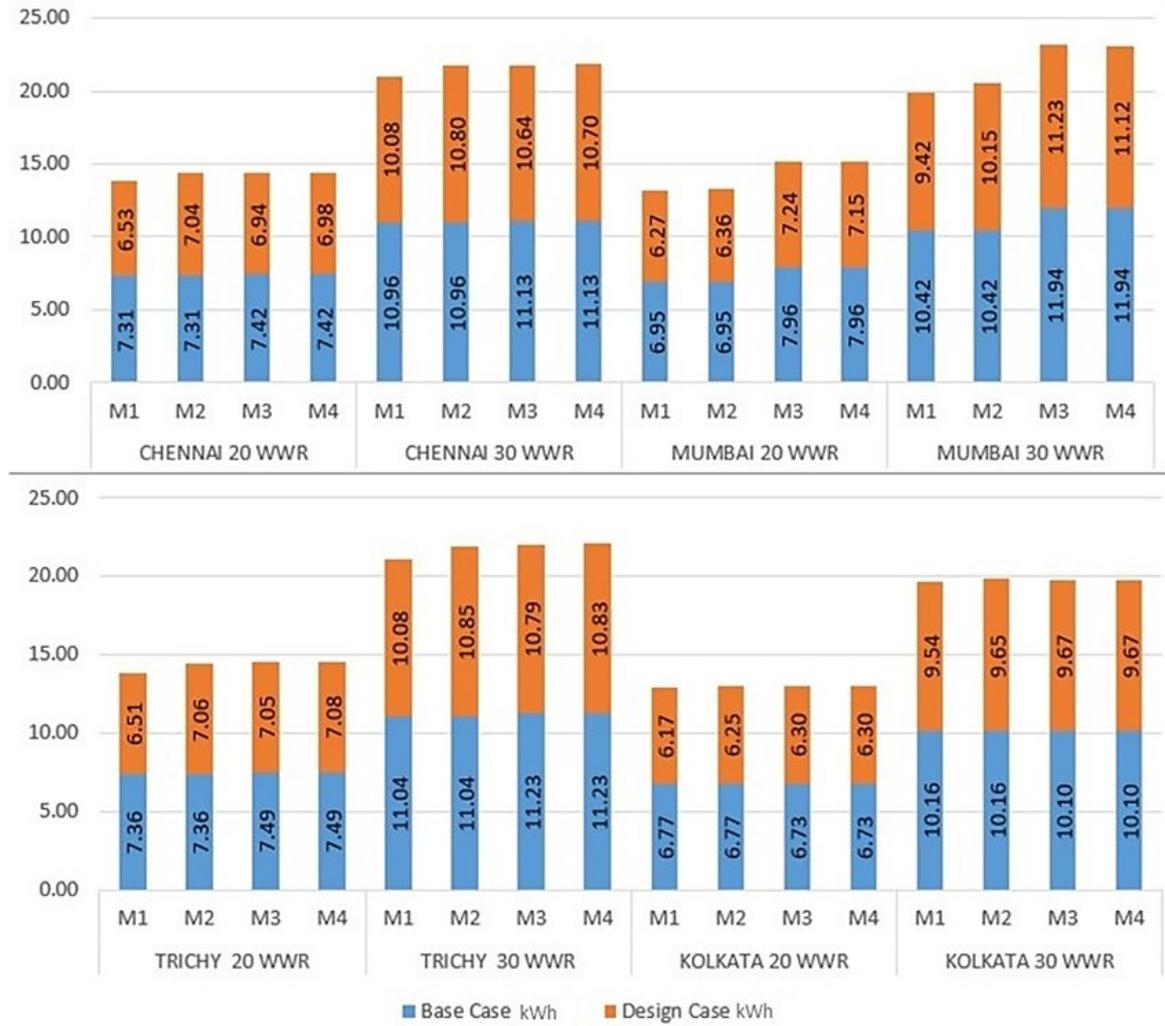


Figure 10. SHG of base and design case

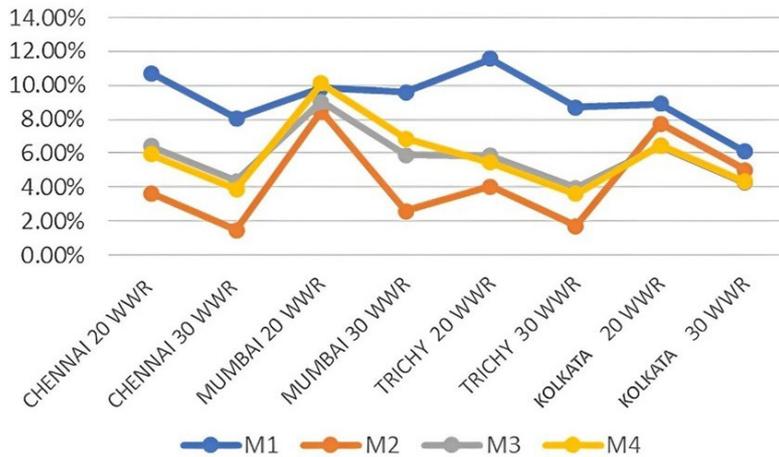


Figure 11. Efficiency of design case against base case

In Kolkata, although the base case for M4 performs better than M1, the design case for 20% WWR is observed to show superior performance for the M1 orientation.

Elaborate plans and elevations of all vertical surfaces for the design cases of Kolkata and Trichy for both 20% and 30% WWR are illustrated in Figures 12, 13, 14, 15.

Analyzing the effects of orientation, window size and position on solar heat gain for four Indian cities

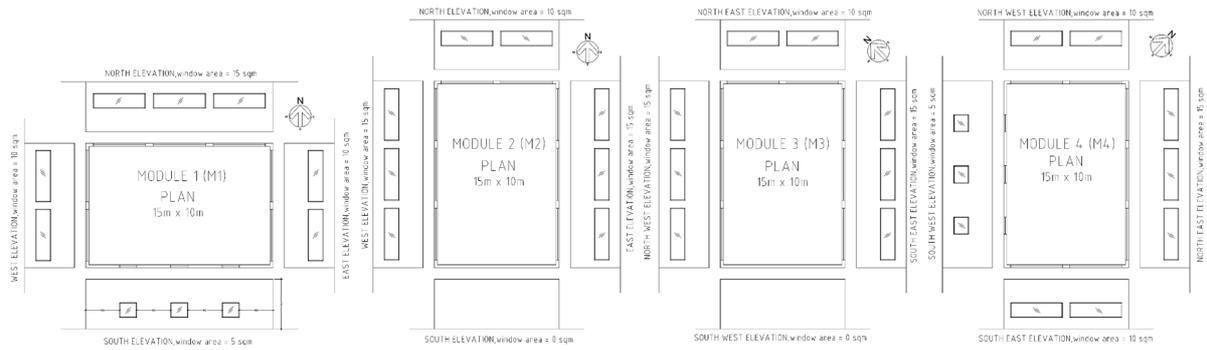


Figure 12. Plan & elevations of design cases for Kolkata 20 WWR

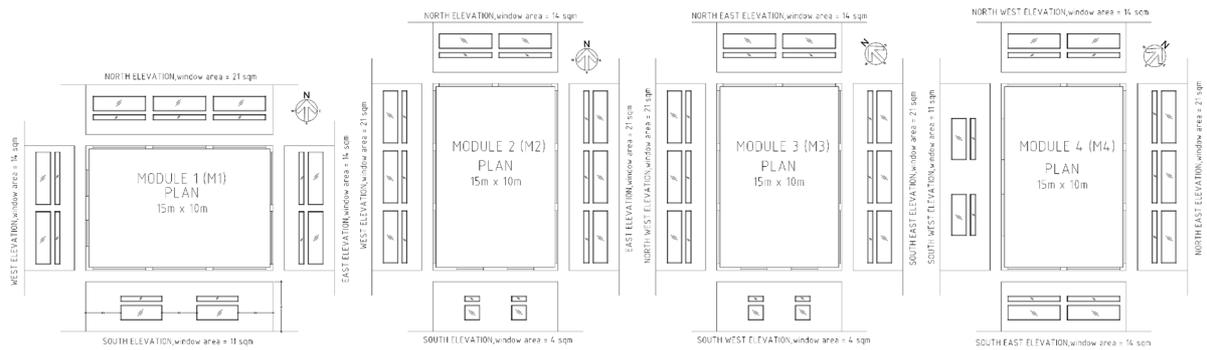


Figure 13. Plan & elevations of design cases for Kolkata 30 WWR

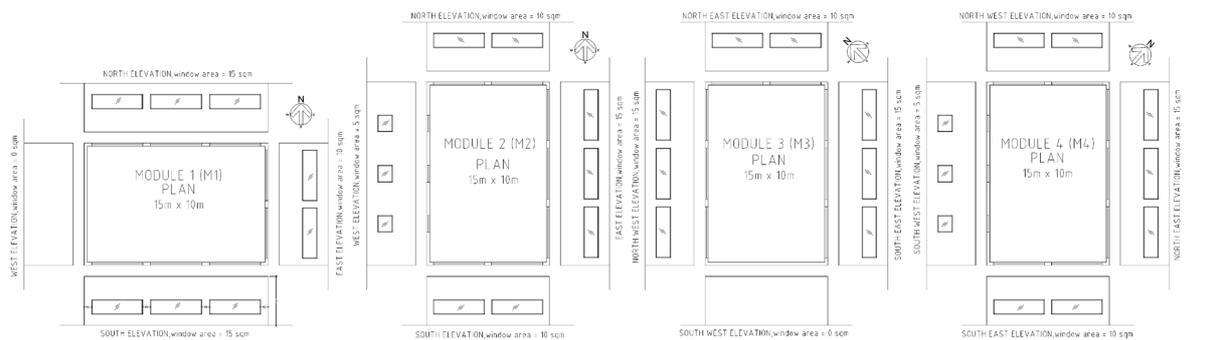


Figure 14. Plan & elevations of design cases for Trichy 20 WWR

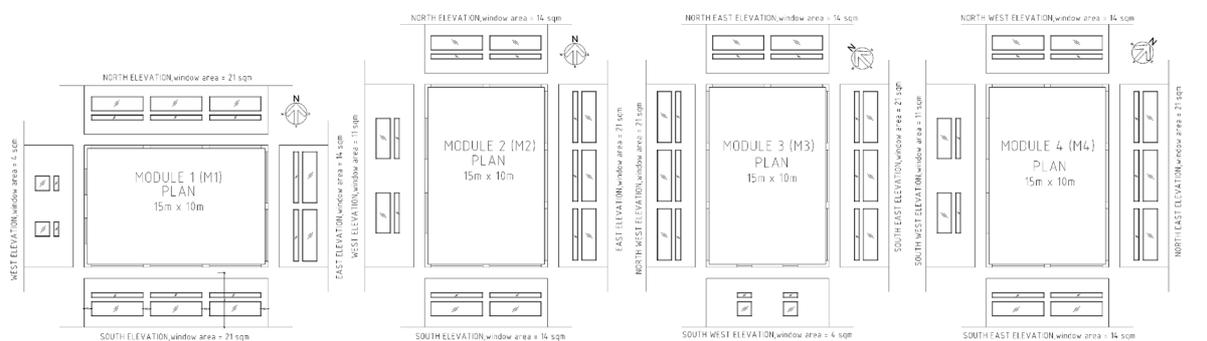


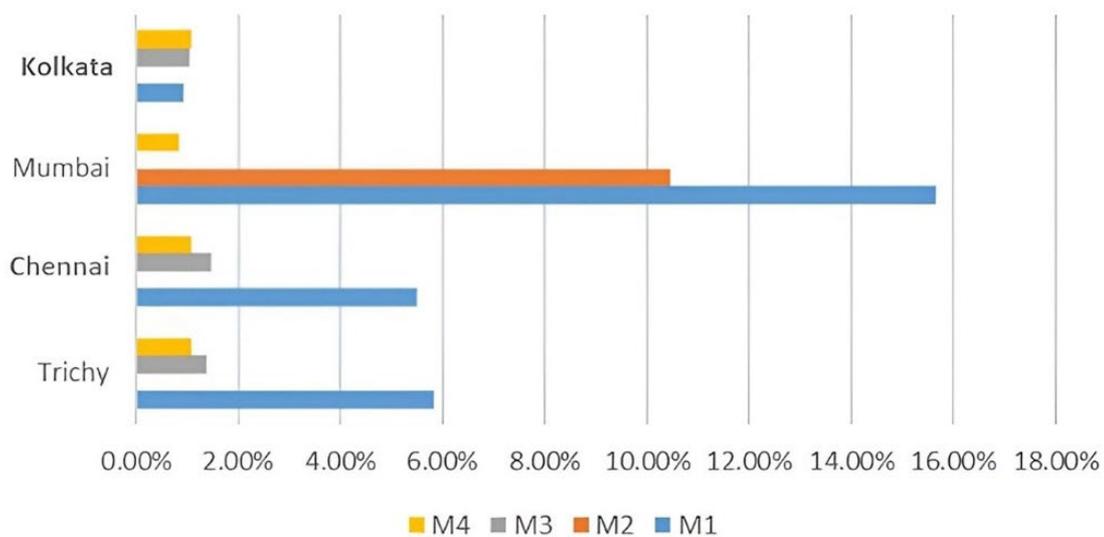
Figure 15. Plan & elevations of design cases for Trichy 30 WWR

#### 4. DISCUSSION

Upon analyzing surface radiation across different orientations, it is evident that radiation patterns vary significantly with latitude. For example, surface radiation on the north-facing orientation decreases with increasing latitude, as seen in Trichy (10.79° N) with 128.39 Wh/m<sup>2</sup> compared to Kolkata (22.57° N) with 104.96 Wh/m<sup>2</sup>. Conversely, surface radiation on the south-facing orientation increased with latitude, while the west-facing orientation showed a decreasing trend. The percentage difference between the lowest and peak surface radiation across orientations highlights significant variations: Trichy (46.83%), Chennai (48.45%), Mumbai (63.39%), and Kolkata (53.52%). The highest variation across cities was observed in the north-west-facing orientation, emphasizing the importance of designing buildings with orientation in mind to minimize heat gain.

The study further analyzed module orientations for SHG across cities. Module M2 (E-W) showed the highest SHG for Trichy, Chennai, and Kolkata, while M3 was the least efficient for Mumbai. Performance efficiency comparisons (Figure 16) reveal notable differences between the best and worst orientations: Trichy (5.82%), Chennai (5.49%), Mumbai (15.66%), and Kolkata (1.08%). Kolkata's minimal variation suggests similar SHG values across orientations, whereas Mumbai's substantial variation indicates the critical impact of poor orientation on thermal loads and energy consumption.

Despite the cities sharing a climatic zone, latitude rather than climate zone appears to dictate SHG patterns. Trichy, Chennai, and Kolkata share similar optimal orientations, but Kolkata's distinct variation underscores the need for latitude-specific design strategies. SHG levels in Indian cities are generally high, which negatively impacts indoor comfort and energy efficiency, highlighting the necessity of tailored orientation and window design.



**Figure 16.** Performance efficiency of modules with respect to peak SHG for each city

The GRIHA-based study demonstrated that design cases with optimized WWR consistently outperformed base cases. For instance, M1 at 20% WWR showed improvements of 11.55% in Trichy and 10.71% in Chennai, while M4 in Mumbai improved by 10.11%. Conversely, the worst-performing modules, M2 and M3, displayed lower efficiencies, with M2 averaging 5.15% for 20% WWR, and M3 achieving 9.03% in Mumbai. Optimizing window design for poorly performing orientations resulted in moderate improvements (6.12% for 20% WWR), while best-performing orientations achieved higher efficiency gains (9.63% for 20% WWR). Notably, higher WWR percentages offered less potential for optimization compared to lower WWR percentages.

Buildings oriented north-south generally received less solar insolation than those aligned east-west, leading to cooler indoor temperatures and reduced energy demand. A lower WWR further mitigated SHG, enhancing indoor comfort. The findings emphasize that, while site constraints may dictate less favorable orientations, strategic WWR distribution and window design can optimize performance.

This study provides practical recommendations for energy-efficient building design. Optimal orientation is essential to leverage local climatic conditions for natural light and ventilation while minimizing heat gain. For window design, maximizing the window area on façades with minimal solar radiation and reducing it on sun-exposed façades improves heat control, glare reduction, and visual comfort. A 20% WWR outperforms a 30% WWR, enhancing energy efficiency across various cities. Additionally, latitude significantly impacts SHG, suggesting that building orientation and window placement should be tailored to the location's latitude for optimal performance.

#### 5. CONCLUSION

This article has presented the outcomes of SHG calculations for four cities in India with warm and humid climates, namely Chennai, Trichy, Mumbai, and Kolkata, for 20% and 30% WWRs. Despite their similar climatic

categorization, these cities are situated at different latitudes.

The study highlights the significance of building orientation, WWR, and window design in the energy efficiency and indoor comfort of residential buildings in warm and humid climates in India. The findings indicate that residential buildings with a north-south orientation and a 20% WWR can reduce solar insolation and enhance energy efficiency to the greatest extent in most cases, improving comfort in the selected cities. Notably, SHG is primarily dependent on latitude or distance from the Equator rather than climate zones. Additionally, the optimization of window design for the best-suited orientations results in a higher percentage improvement than for the worst-suited orientations. Furthermore, higher WWR percentages have less potential for optimization than lower WWR percentages. These results imply that orientations with high SHG on their envelope could still be considered, provided that site constraints exist and the design is optimized through appropriate WWR and window placement. Overall, optimal WWR and proper window positioning can lead to favorable outcomes for any orientation. Future research could focus on the impact of orientation, WWR, and other parameters on residential buildings in different climatic regions of India and at various latitudes. Further studies should also consider expanding the research to different climatic regions and conducting long-term performance analyses. These directions will help refine strategies for reducing SHG and improving energy efficiency in buildings, contributing to more sustainable and comfortable living environments.

## AUTHOR CONTRIBUTIONS

A.S. and S.A. contributed to the study conception and design. Material preparation, data collection, and analysis were performed by A.S. The first draft of the manuscript was written by A.S. and S.A. commented on previous versions of the manuscript. All authors read and approved the final manuscript.

## REFERENCES

- Department of Land Resources. (2019). *Wastelands atlas of India*. Ministry of Rural Development, National Remote Sensing Centre (NRSC). <https://www.drishtiiias.com/pdf/1599166604-wasteland-atlas-2019.pdf>
- Li, Z., Tian, M., Zhu, X., Xie, S., & He, X. (2022). A review of integrated design process for building climate responsiveness. *Energies*, 15(19), Article 7133. <https://doi.org/10.3390/en15197133>
- Sinha, A. (2020). Building orientation as the primary design consideration for climate responsive architecture in urban areas. *Architecture and Urban Planning*, 16(1), 32–40. <https://doi.org/10.2478/aup-2020-0006>
- Varghese, R. M., & Kaushik, S. A. S. (2022). Thermal performance of green roof and conventional roof in the warm humid climate of India. In D. Chakrabarti, S. Karmakar, & U. R. Salve (Eds.), *Ergonomics for design and innovation* (pp. 689–703). Springer. [https://doi.org/10.1007/978-3-030-94277-9\\_59](https://doi.org/10.1007/978-3-030-94277-9_59)