To Study the Variation of Daylight Illuminance Using VELUX Daylight Visualizer Under Overcast and Actual Sky Models

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Abstract— **Accurate daylight prediction is critical for designing energy-efficient and visually comfortable indoor environments. Traditionally, daylight simulations rely on the CIE overcast sky model, which serves as a standardized but idealized representation of sky conditions. However, this model does not reflect the dynamic and location-specific nature of real skies, particularly in diverse climatic regions like India. This study investigates the variation in daylight illuminance using the VELUX Daylight Visualizer by comparing results under the overcast sky model and a measured sky model developed from luminance data collected in Gurugram using a sky scanner as per ISO 15469:2004 (CIE Standard General Sky) methodology. A simplified box model with varying Window-to-Wall Ratios (WWRs) (10%, 20%, 30%, 40%) was analyzed. The results show that the overcast model consistently overestimates daylight availability. For instance, in March, 100% of the floor area exceeded 100 lux under overcast conditions for 10% WWR, while only 77% met the same threshold under the measured sky model. This discrepancy demonstrates that relying solely on the overcast model can lead to inflated predictions of daylight performance.**

Keywords – Illuminance; Daylight; Overcast Sky; CIE sky type

I. INTRODUCTION

Daylighting plays a fundamental role in sustainable building design, offering substantial energy savings, improved indoor environmental quality, and enhanced occupant comfort. In commercial office buildings, where lighting can account for 20% to 30% of total energy consumption, the strategic use of daylight has proven to reduce artificial lighting energy demand by 30% to 60% annually [1] [2] [3] [4]. Daylight also supports visual and psychological health, making it a desirable design element in high-performance buildings [5] [6]. The effectiveness of daylighting design, however, hinges on accurate simulation and prediction of indoor daylight illuminance under varying sky conditions. Traditionally, the Daylight Factor (DF) method has been employed as a simple, static metric for evaluating daylight performance. This approach, based on the CIE Standard Overcast Sky model, assumes a uniform sky luminance distribution with symmetric about the zenith. While widely used due to its simplicity, the DF method is inherently limited in dynamic accuracy and fails to account for direct solar irradiance, diurnal variations, seasonal changes, and local atmospheric effects [7] [8] [9]. To address these limitations, the Commission Internationale de l'Éclairage (CIE) introduced a set of 15 Standard General Sky models in 2003, which represent diverse atmospheric and luminance conditions ranging from fully overcast to cloudless skies with circumsolar brightening. These models are now included in daylighting simulation software to improve the realism of indoor illuminance predictions [10] [11]. Despite their availability, the conventional overcast model continues to dominate design assessments in many regions, including India. This modeling assumption is particularly inadequate in rapidly urbanizing Indian cities like Gurugram which is situated in the National Capital Region. As a key financial and commercial hub, Gurugram has witnessed significant vertical development characterized by high-rise, fully glazed office buildings. The region experiences a subtropical climate with clear skies prevailing for most of the year, rendering overcast-based simulations both inaccurate and insufficient for performance-based design [12] [13] [14]. To capture actual sky conditions, a sky scanner was installed in Gurugram in 2020 to record sky luminance distributions across diverse sky types. The resulting dataset (2020–2024) offers a valuable basis for accurate climate-based daylight simulation. [15] demonstrated that simulations using actual measured skies specific to Gurugram can improve daylight prediction accuracy by 24%, compared to overcast-based models. Nevertheless, such empirical datasets remain underutilized in both research and practice, with measured sky data available only for Gurugram and Chennai. Considering this, the present study aims to assess the variation in daylight illuminance in an interior space when simulated under the CIE Standard Overcast Sky and the actual measured sky models derived from the Gurugram dataset. The simulations are conducted using the VELUX Daylight Visualizer, a Radiance-based daylight simulation tool designed for architects and lighting designers. VELUX Daylight Visualizer allows for precise calculation of luminance and illuminance in 3D geometry under various sky conditions. It supports point-in-time and annual daylighting metrics, facilitating performance-based analysis for façade design, room depth, and glare control. The software integrates validated Radiance algorithms and can simulate both CIE skies and user-imported climate-based sky data, making it particularly useful in this context [16].

This study investigates the variation in daylight illuminance using VELUX Daylight Visualizer under both standardized overcast and measured sky models, focusing on commercial office spaces in Gurugram. By maintaining consistent geometry and material settings across simulations, the study highlights the limitations of static sky assumptions and emphasizes the importance of climate-specific data for daylight-responsive design. Section 2 reviews relevant literature on daylight modeling and sky classification. Section 3 outlines the methodology, including simulation setup and sky data processing. Section 4 presents the simulation protocol and illuminance band classification. Section 5 discusses the results and comparative analysis. Finally, Section 6 concludes with key findings and design recommendations.

II. Literature Review

Daylighting is recognized as a low-cost and high-impact strategy for improving building energy performance and enhancing indoor environmental quality. However, accurate daylight modeling depends fundamentally on the choice of sky luminance model used in simulations. While overcast models are convenient, they do not represent the full spectrum of sky conditions encountered in practice. The CIE Overcast Sky, developed in 1955, assumes diffuse skylight distributed symmetrically around the zenith, leading to the simplification that all directions contribute equally to indoor illumination. This method excludes direct sunlight and thus severely underrepresents peak daylight availability [7]. The CIE Standard General Skies, formalized in CIE S 011:2003/ISO 15469:2004, classify skies into 15 distinct types based on empirical measurements. These models offer a more realistic alternative to the overcast assumption, accounting for turbidity, circumsolar brightening, and horizon brightening effects [10]. [14] further demonstrated that accurate prediction of indoor daylighting levels requires the selection of appropriate CIE sky types based on local atmospheric conditions. Several researchers have validated these models against field measurements. [10] used sky scanners to record overcast sky luminance in Southern England and found that the CIE overcast model performed well under fully overcast conditions but failed under transitional skies. [17] obtained similar results in Hong Kong, showing that CIE models performed better when calibrated with measured data. [8] used actual sky measurements in Bangkok and highlighted that intermediate and clear skies dominated, contradicting the assumptions of static overcast modeling. In India, empirical daylight data remains scarce. The measured sky luminance distribution database is only available for Gurugram and Chennai, and this has been a major obstacle in the adoption of realistic daylight simulation practices. [15] analyzed the performance of Gurugram-based CIE sky simulations and concluded that actual sky models produced more reliable results, with higher agreement to observed daylight behavior. Additionally, several studies highlight that sky luminance distribution is the most influential parameter in daylight prediction [18] [12]. These findings support the view that accurate prediction of indoor daylight illuminance must begin with accurate modeling of the outdoor luminous environment. [19] compared non-overcast luminance models against recorded data in Hong Kong and observed significant variations depending on sky clarity, solar angle, and pollution content. While the Daylight Factor (DF) remains the dominant metric in many countries due to its simplicity, it cannot account for real-time changes in solar geometry or sky condition. DF assumes a constant ratio of indoor to outdoor illuminance, which may vary substantially across seasons, times of day, and climatic contexts [19] [8]. Furthermore, DF-based assessments cannot predict overexposure or insufficient illumination near windows or in room corners. Modern dynamic daylight metrics, such as Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), are increasingly recognized as more informative for performance-based design [20]. Despite advancements in metrics, the simulation accuracy still depends on the validity of sky condition assumptions. Numerous researchers [5] [7][21] emphasized the necessity of using location-specific solar and sky data to improve performance predictions. The VELUX Daylight Visualizer, by supporting both CIE and real-sky inputs, facilitates this transition toward climate-responsive simulation. It uses Radiance-based backward ray tracing to simulate light transport with high precision and can be used to produce both illuminance maps and luminance visuals. This makes it suitable for comparing predicted daylight distributions under various sky models.

In conclusion, the reviewed literature converges on the need to replace static overcast-based modeling with measured or climate-specific sky conditions. This need is particularly pressing in Indian commercial contexts like Gurugram, where actual daylight availability is heavily influenced by atmospheric and seasonal factors. The current study builds on this body of work by applying measured sky data within a validated simulation framework and quantifying the discrepancies in daylight prediction to support evidence-based daylighting design.

III. Methodology

This section outlines the research framework, simulation setup, and analytical procedures used to evaluate daylight performance under different sky conditions.

A. *Research Objective and Context*

The primary aim of this study is to analyze the variation in indoor daylight illuminance within a commercial office environment using simulation-based methods under both standardized and actual sky conditions. The research is conducted in the urban context of Gurugram, India (28.4595° N, 77.0266° E), a core economic zone in the National Capital Region (NCR), known for its composite climate and high concentration of commercial developments. Gurugram's rapid urban growth, dominated by high-rise office architecture, underscores the need to evaluate daylight availability as a sustainable design strategy. This study investigates the impact of Window-to-Wall Ratio (WWR) on indoor daylight levels under varying sky models, specifically comparing the standardized CIE Type 1 Standard Overcast

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Sky with sky conditions classified from measured luminance data.

B. Simulation Model Development

1) Geometric and Material Configuration

A simplified geometric model representing a typical single-floor office layout was developed using the VELUX Daylight Visualizer software, a raytracing based daylight simulation tool. The model consists of a cuboidal floor plate with dimensions 50 m × 50 m × 4.2 m, totaling a floor area of 2500 m². To investigate the role of façade transparency, the model was configured with four distinct Window-to-Wall Ratios (WWRs): 10%, 20%, 30%, and 40%, with fenestrations distributed uniformly across all façades. Surface reflectance values were assigned in accordance with the National Building Code (NBC) of India: 0.21 for the floor, 0.74 for the ceiling, and 0.51 for interior walls. All façade configurations were modeled with a 12 mm thick low-emissivity (low-e) Single Glazed Unit (SGU) having a Visible Light Transmittance (VLT) of 51%. This specification reflects commonly adopted commercial façade systems in the region, providing an appropriate balance between daylight admission and solar control.

2) Sensor Grid and Measurement Plane

To capture spatial daylight distribution, an analysis grid comprising 49 evenly spaced sensor points was laid out across the interior floor plate at 6.25 m intervals. The measurement plane was positioned at a height of 0.8 m above finished floor level, corresponding to the standard working plane in office environments. Each sensor point represented an analysis zone of 51.02 m² for spatial mapping.

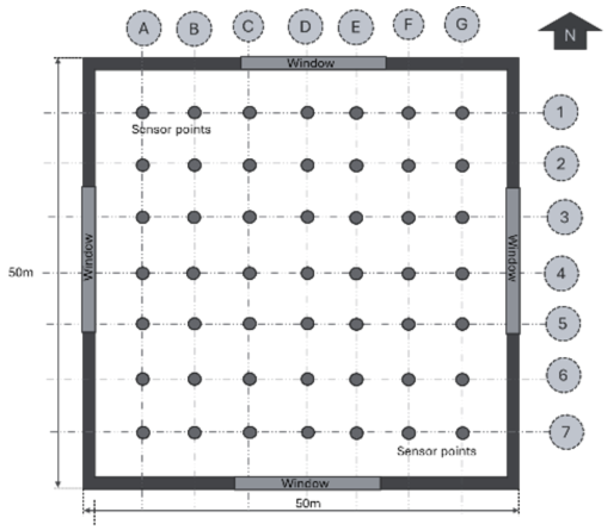

Figure 1: Box model plan with placement of 49 sensor Points on the analyses grid with placement of fenestration in all the orientations equally.

C. Sky Models and Luminance Data Classification

1) Baseline Sky Condition: CIE Standard Overcast

As a baseline for comparison, simulations were first performed using the CIE Type 1 Standard Overcast Sky, as defined by the International Commission on Illumination (CIE). This sky model assumes uniform luminance distribution with the highest intensity at the zenith and decreasing intensity toward the horizon. The model is invariant to solar azimuth and represents a conservative or worst-case scenario, commonly used for benchmarking daylight performance in architectural daylighting studies.

2) Measured Sky Conditions: CIE Sky Type 14 and Sky Type 9

To assess daylight performance under realistic local conditions, the study incorporated measured sky luminance data collected using a MS-321LR Sky Scanner installed at the Mahindra-TERI Centre of Excellence (MTCoE) in Gurugram. Operational since October 2021, the scanner captures 145 angular luminance points of the sky dome at 10-minute intervals between 09:00 and 18:00 hours, aligning with office operational hours. Measured sky data were classified according to the CIE General Sky Model defined under ISO 15469:2004. The classification methodology applies two mathematical descriptors:

- Gradation Function (Φ): characterizing luminance from zenith to horizon
- Indicatrix Function (f): describing luminance distribution relative to the sun's position

Each measured sky scan was compared against all 15 standard CIE sky types using a Root Mean Square Error (RMSE) minimization technique. The sky type with the lowest RMSE was assigned as the best fit for that scan. From the two-year dataset, CIE Sky Type 14 emerged as the most representative sky model across the majority of months. Sky Type 14 is defined as a cloudless turbid sky with a broad solar corona, typically observed in urban settings with moderate to high atmospheric pollution. For the month of July, characterized by monsoon-related cloud cover and diffused sunlight, CIE Sky Type 9 was identified as dominant. Sky Type 9 represents a partly cloudy sky with an obscured sun, resulting in a more diffused luminance distribution.

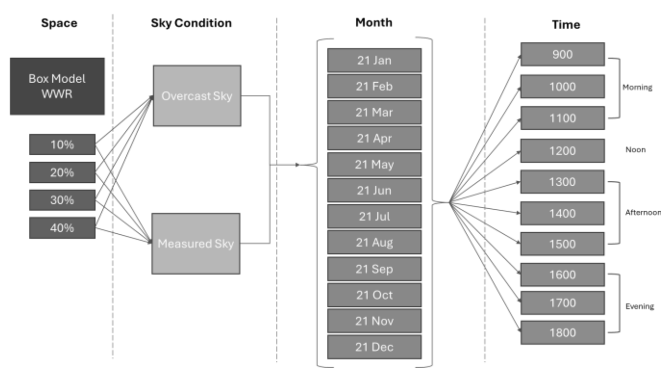

Figure 2: Simulation workflow diagram

D. Simulation Protocol

Simulations were performed using the VELUX Daylight Visualizer software for all WWR configurations (10%, 20%, 30%, and 40%) under two sky conditions:

- CIE Type 1 Standard Overcast Sky (reference case)

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- Measured Sky Conditions: CIE Sky Type 14 for all months, and Sky Type 9 specifically for July

The analysis was carried out for the 21st day of each month, representing a typical solar condition for each month of the year. For each sky condition and WWR combination, hourly simulations were conducted from 09:00 to 18:00, matching standard office operational hours. This resulted in 9 hourly data points per day, capturing daylight variation throughout the working period. At each time step, horizontal illuminance values (in lux) were recorded at all 49 sensor points on the work plane. These values formed the basis for further classification and spatial performance analysis.

E. Illuminance Band Classification and Spatial Analysis

To enable detailed interpretation of daylight sufficiency and distribution, the simulated illuminance values were categorized into six defined bands

TABLE 1: DAYLIGHT ILLUMINANCE BANDS AND THEIR INTERPRETATION.

Illuminance Band	*Interpretation*
< 100 lux	Very Poor – Artificial lighting required
100 – 300 lux	Moderate – Minimum acceptable threshold
300 – 500 lux	Good – Functionally sufficient daylight
500 – 750 lux	Very Good – High daylight sufficiency
750 – 1000 lux	Excellent – Daylight surplus
> 1000 lux	Poor – Too high visual discomfort

The illuminance thresholds used in this study are informed by both international guidelines (EN 12464-1, ISO 8995, IES LM-83) and Indian standards, including the Energy Conservation Building Code (ECBC 2017), the National Building Code of India (NBC 2016), and IS:3646 (Part 1 & 2). According to the ECBC, Useful Daylight Illuminance (UDI) falls within the range of 100–2000 lux, which ensures adequate daylight availability while minimizing visual discomfort. The NBC and IS:3646 specify that 300–500 lux should be considered the minimum acceptable maintained illuminance for office spaces, with levels of 500 lux and above being preferable for typical office tasks. However, illuminance exceeding 1000 lux is frequently linked to glare and thermal discomfort, highlighting the need for shading or control strategies.

For each hourly simulation, the area covered by each illuminance band was calculated by summing the respective zones (sensor points) falling within each range and multiplying by the area represented by each sensor (51.02 m²). This enabled a quantitative evaluation of the spatial extent of daylight sufficiency under different façade designs and sky conditions. By mapping daylight levels against these predefined illuminance categories, the study provides a robust basis for assessing design compliance with daylighting performance benchmarks and understanding the spatial distribution of natural light throughout the year.

F. Assumptions and Limitations

The simulation assumes that the 21st day of each month represents the monthly median condition for solar geometry and daylight potential. This aligns with standard practices in climate-based daylight modeling. While the VELUX Daylight Visualizer software restricts simulations to a fixed date per month, the incorporation of locally measured and classified sky types enhances the contextual relevance of the analysis. The simplified box model excludes internal furniture, partitions, or dynamic shading systems to isolate the influence of fenestration and sky type. While this assumption limits architectural realism, it strengthens the clarity of daylighting insights derived from the façade and external sky influences alone.

IV. OBSERVATIONS

The comparative analysis of daylight performance under the CIE Standard Overcast Sky (Type 1) and the measured sky conditions derived using CIE Sky Type 14 and Sky Type 9 offers clear insights into the divergence between generalized daylight modeling assumptions and real-world sky behavior. Across all months and WWR configurations, the use of measured sky conditions consistently demonstrated greater sensitivity to local climatic variability, resulting in more realistic spatial daylight distribution patterns. These results highlight the limitations of relying solely on the CIE overcast model for daylight simulation, particularly in the context of a composite climate such as that of Gurugram, where atmospheric transparency, solar intensity, and seasonal transitions significantly influence daylight availability. Under the overcast sky condition, illuminance distribution across the interior space was largely uniform, with most zones falling within the 100–300 lux range, regardless of WWR. For instance, in the month of March, at WWR 10%, nearly 100% of the interior area received illuminance within this 100–300 lux band, with no zones exceeding 300 lux. Even at WWR 40%, the overcast sky simulation yielded only 11% of the space reaching into the 300–500 lux band, while the remaining 89% remained confined to 100–300 lux. Notably, no areas at any WWR under the overcast scenario exceeded 500 lux, which significantly underrepresents the potential for high daylight availability and ignores possible risks associated with glare or overexposure.

In contrast, simulations performed using the measured sky type—classified predominantly as CIE Sky Type 14, representing a cloudless turbid sky with broad solar corona—exhibited a greater range and diversity of illuminance levels. For March, WWR 10% under measured sky conditions resulted in 11% of the space falling below 100 lux, 45% within the 100–300 lux band, and 17% in the 300–500 lux band. With WWR increased to 20%, the percentage of space receiving illuminance in the optimal 300–500 lux range rose to 22%, and 13% of the space shifted into the 500–750 lux range. At WWR 30%, the simulation recorded 17% of the area in the 300–500 lux band and 13% in the 500–750 lux band, with an additional 9% of the space reaching 750–1000 lux. Even more pronounced, WWR 40%

under the measured sky condition produced 15% of the interior area above 1000 lux, a level considered excessive and likely to result in visual discomfort. These results underscore a critical distinction: while the overcast sky model effectively predicts conservative and uniform lighting, it fails to capture the spatial and temporal complexity that defines actual daylight performance in practice. The overcast sky model significantly underrepresents zones of low illuminance—where artificial lighting would be essential and simultaneously masks zones of excessive illuminance that may require glare mitigation. In contrast, the measured sky conditions expose the nuanced interplay between solar angle, atmospheric clarity, and building orientation. For example, the appearance of illuminance levels exceeding 750 lux under WWR 30% and 40% was exclusive to measured sky simulations and absent under overcast assumptions. Such variations are crucial for accurate daylight modeling in modern, glazed office buildings. The influence of sky type becomes even more evident in the month of July, when the measured data classified the prevailing sky condition as CIE Sky Type 9, representing a partly cloudy sky with the sun obscured. This sky model resulted in a more diffuse and balanced luminance profile, particularly suitable for analysis during monsoon-influenced months. At WWR 20%, under measured July skies, 23% of the interior area received daylight in the optimal 300–500 lux range, while only 6% fell below 100 lux. At WWR 30%, the simulation showed a steady shift into the 500–750 lux band, accounting for 17% of the floor area, while excessive illuminance beyond 1000 lux was effectively negligible. These results contrast sharply with those under the overcast sky for the same month, which again showed a uniform dominance of the 100–300 lux band, regardless of window size. Beyond absolute values, the spatial daylight dynamics revealed through measured sky types enable design decisions to be made with significantly greater clarity. Under measured sky conditions, the zones of underlit and over lit areas shifted distinctly across the day and across seasons patterns that the overcast sky model, with its static luminance field, simply cannot represent. This variability is crucial for informing the placement of workstations, dynamic shading devices, and daylight sensors. For instance, the perimeter zones of the floor plate near windows experienced daylight levels well above 750 lux in months like April and October under WWR 40%, highlighting the potential for glare without appropriate daylight-responsive control systems. These extremes are not reflected in the overcast model, which remains largely indifferent to orientation, solar altitude, or glazing performance.

Perhaps most importantly, the optimal WWR for daylight performance appears to vary between the two sky types. Under the overcast model, increasing the WWR from 10% to 40% offered marginal gains in daylight sufficiency without meaningful risk of overexposure. However, under measured sky conditions, WWR 30% consistently produced the best performance in terms of maximizing space in the 300–750 lux range while limiting zones that fell below 100 lux or exceeded 1000 lux. At this configuration, the daylighting potential is sufficiently high to reduce reliance on artificial lighting during working hours across most months, without exposing users to excessive glare. In contrast, WWR 40%, while increasing daylight autonomy, also introduced risk zones of visual discomfort that must be managed through architectural or technological interventions.

TABLE 2: PERCENTAGE OF AREA WITH RESPECTIVE TO WWR CATEGORIZED UNDER SIX ILLUMINANCE BANDS

		Percentage of Area																							
		below 100 lux				100-300				300-500				500-750				750-1000				above 1000			
	WWR	10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40	10	20	30	40
Month																									
Jan	Measured Sky	83	45	32	23	17	45	52	51	0	9	13	19	0	1	2	5	0	0	0	2	0	0	0	0
	Overcast Sky	100	100	98	89	0	0	2	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	Measured Sky	88	48	34	24	12	43	52	52	0	6	9	15	0	1	3	3	0	1	2	3	0	0	0	1
	Overcast Sky	100	100	93	86	0	0	7	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	Measured Sky	89	48	34	27	11	45	52	50	0	6	11	16	0	0	3	5	0	0	0	2	0	0	0	0
	Overcast Sky	100	98	89	79	0	2	11	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	Measured Sky	77	40	27	20	23	45	49	47	0	13	17	15	0	2	6	12	0	0	2	3	0	0	0	3
	Overcast Sky	100	96	82	73	0	4	18	26	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
May	Measured Sky	77	40	27	17	23	49	49	51	0	10	17	17	0	1	5	10	0	0	1	3	0	0	0	2
	Overcast Sky	100	94	83	70	0	6	17	28	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Jun	Measured Sky	80	33	20	10	20	54	53	56	0	12	19	17	0	1	6	12	0	0	2	3	0	0	0	3
	Overcast Sky	100	94	77	68	0	6	21	30	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0
Jul	Measured Sky	77	36	14	10	23	50	47	51	0	12	20	18	0	2	13	14	0	0	4	3	0	0	1	4
	Overcast Sky	100	94	77	68	0	6	23	30	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Aug	Measured Sky	65	26	14	9	35	47	47	43	0	24	20	20	0	3	13	16	0	0	4	5	0	0	1	7
	Overcast Sky	100	94	79	70	0	6	21	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sep	Measured Sky	68	26	17	10	32	48	48	43	0	23	20	22	0	3	12	14	0	0	2	6	0	0	1	5
	Overcast Sky	100	96	83	73	0	4	17	25	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Oct	Measured Sky	88	49	36	22	12	44	51	53	0	5	9	18	0	0	2	4	0	1	1	2	0	0	0	0
	Overcast Sky	100	98	89	79	0	2	11	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	Measured Sky	87	50	40	29	13	43	48	51	0	7	9	14	0	0	3	5	0	0	0	2	0	0	0	0
	Overcast Sky	100	100	94	87	0	0	6	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec	Measured Sky	77	48	36	25	23	44	52	54	0	8	10	14	0	0	2	6	0	0	0	1	0	0	0	0
	Overcast Sky	100	100	98	89	0	0	2	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

V. CONCLUSION

This study demonstrates that simulations conducted under the CIE Standard Overcast Sky significantly underestimate indoor daylight availability when compared to those based on measured sky conditions, specifically CIE Sky Types 14 and 9. The overcast model was found to underpredict daylight in critical illuminance bands by as much as 40–60%, particularly in areas exceeding 300 lux, which are essential for visual comfort and daylight autonomy. In contrast, simulations using measured sky data more accurately captured seasonal and spatial daylight variability, providing a realistic basis for performance assessment. Among the façade configurations analyzed, a Window-to-Wall Ratio (WWR) of 30% consistently delivered the most favorable daylighting outcomes—achieving up to 45% of the interior area within the 300–750 lux range, while keeping underlit zones (<100 lux) below 5% and areas prone to glare (>1000 lux) under 6% across most months. These findings underscore that relying solely on overcast sky simulations may lead to overdesign, particularly in glazing specifications, and mask opportunities for cost optimization. Incorporating measured sky conditions in early-stage simulation enables more accurate predictions of daylight performance, facilitating the selection of glazing with appropriate Visible Light Transmittance (VLT) and supporting energy-efficient, comfort-driven façade design. Therefore, a WWR of 30% is recommended for commercial office buildings in composite climates to ensure balanced daylight sufficiency, glare control, and informed material selection.

It is important to acknowledge that the present study was conducted under simplified conditions, excluding internal furniture layouts, interior partitions, and dynamic elements such as blinds, louvers, or automated shading systems. Similarly, occupancy patterns and their associated behavioral responses to daylight were not incorporated. These factors are known to significantly influence daylight distribution and visual comfort in real-world office environments. While their exclusion was intentional to isolate the effect of sky conditions and façade geometry, future research incorporating such variables would enhance the robustness and practical applicability of the findings.

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REFERENCES

[1] L. Pérez-Lombard and C. P. José Ortiz, "A review on buildings energy consumption information," Energy and Buildings, pp. 394-398, 2008

[2] B. Roisin, M. Bodart, A. Deneyer and P. D'herdt, "Lighting energy savings in offices using different control systems and their real consumption.," *Energy Build.,* pp. 514–523, 2008,

[3] I. Acosta, M. Campano, S. Domínguez-Amarillo and C. Muñoz, "Dynamic Daylight Metrics for Electricity Savings in Offices: Window Size and Climate Smart Lighting Management.," *Energies ,* p. 3143, 2018.

[4] C. De Bakker, T. van de Voort and A. Rosemann, "The energy saving potential of occupancy–based lighting control strategies in open–plan offices: the influence of occupancy patterns.," Energies , p. 2, 2017.

[5] A. D. Galasiu and Jennifer A. Veitch, "Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review," *Energy and Buildings,* pp. 728-742, 2006.

[6] T. C. H.D. Cheung, "A study on subjective preference to daylit residential indoor environment using conjoint analysis," Building and Environment, pp. 2101-2111, 2008.

[7] D. H. Li and J. C. Lam, "Evaluation of lighting performance in office buildings with daylighting controls,," *Energy and Buildings,* pp. 793-803, 2001.

[8] M. T. Z. S. Z. Nastaran Seyed Shafavi, "Investigation of illuminance-based metrics in predicting occupants' visual comfort (case study: Architecture design studios)," *Solar Energy,* pp. 111-125, 2020.

[9] M. Á. C. J. F. M. Ignacio Acosta, "Window design in architecture: Analysis of energy savings for lighting and visual comfort in residential spaces," Applied Energy, pp. 493-506, 2016

[10] S. Darula and R. Kittler, "CIE general sky standard defining luminance distributions.," in In Proceedings of the 2002 IBPSA Conference (Proceedings eSim) , Montreal, QC, Canada, , 12 September 2002.

[11] "Commission Internationale de l'Eclairage," 16 September 2025. [Online]. Available: www.cie.co.at/publications/spatial-distribution-daylight-cie-standard-general-sky.

[12] D. Li, S. Lou, A. Ghaffarianhoseini, K. Alshaibani and J. Lam, "A review of calculating procedures on daylight factor based metrics under various CIE Standard Skies and obstructed environments.," Building and Environment, pp. 29–44, 2017.

[13] K. Alshaibani, "Average daylight factor for the ISO/CIE Standard General Sky.," Lighting Research & Technology, p. 742–754, 2016.

[14] R. Kittler and S. Darula, "Scattered sunlight determining sky luminance patterns.," Renewable and Sustainable Energy Reviews, p. 575–584, 2016.

[15] R. M. R. T. S. S. Ankit Bhalla, "A Validation Study of Simulated Illuminance Levels of an Office Space in Gurgaon, India under actual CIE Sky Conditions," in The Fourteenth International Conference on Advances in System Simulation, Lisbon, Portugal, 2022.

[16] K. W. S. Y. L. Wenxin Li, "Effects of electrochromic glass window on energy efficiency, thermal and visual performances under tropical climate," Energy for Sustainable Development, pp. 1-11, 2023.

[17] Danny H.W Li and Joseph C. Lam, "An investigation of daylighting performance and energy saving in a daylit corridor," *Energy and Buildings,* pp. 365-373, 2003

[18] N. Igawa, "Improving the All Sky Model for the luminance and radiance distributions of the sky.," *Solar Energy,* p. 354–372, 2014

[19] Danny H.W Li and Joseph C. Lam, "An investigation of daylighting performance and energy saving in a daylit corridor," *Energy and Buildings,* pp. 365-373, 2003

[20] C. F. Reinhart and J. Wienold, "The daylighting dashboard – A simulation-based design analysis for daylit spaces," Building and Environment, pp. 386-396, 2011

[21] T. Muneer, "Evaluation of the CIE overcast sky model against Japanese data," *Energy and Buildings,* pp. 175-177, 1998

Figure 3: Percentage of area under 10% WWR for overcast and measured sky type.

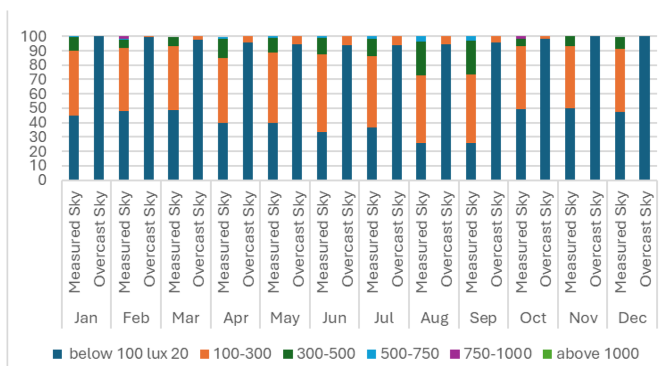

Figure 4: Percentage of area under 20% WWR for overcast and measured sky type.

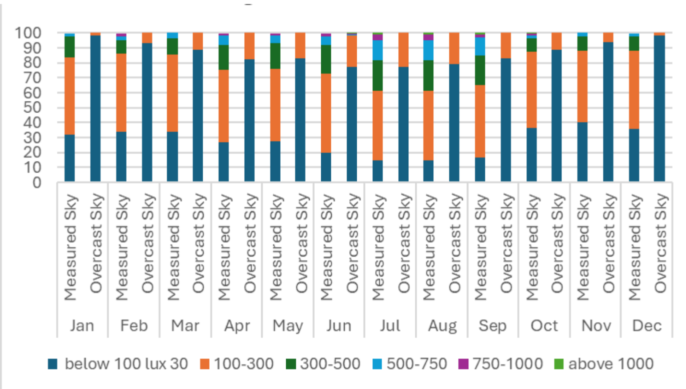

Figure 5: Percentage of area under 30% WWR for overcast and measured sky type

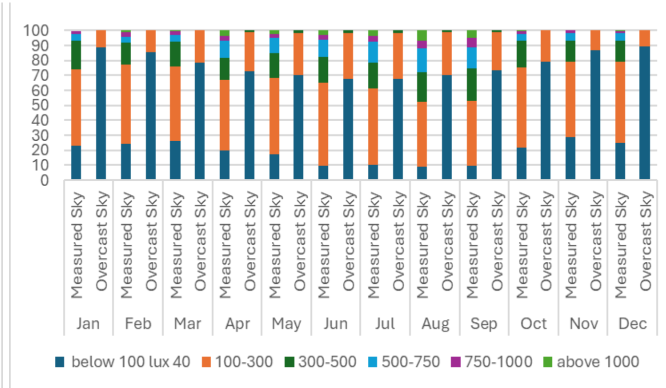

Figure 6: Percentage of area under 40% WWR for overcast and measured sky type.