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Original Article

A Comparative Study of Daylighting Metrics Across Design Studio Geometries, Surface Finishes, and Window Wall Ratio - A Case Study of Chennai City

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Abstract *- In India's tropical climate, the use of daylight has very high potential as it not only reduces artificial lighting demand, but also enhances the spatial quality and user wellbeing. This is especially true in the case of educational institutions, particularly those in the field of architecture. Architecture students spend long hours in studios focused on creative and concentration-intensive activities. This requires access to well-distributed natural light as it is essential for both psychological and academic performance. This study focuses on three critical design parameters that influence indoor daylight performance: room geometry, interior surface reflectance, and Window-to-Wall Ratio (WWR). Daylighting metrics, namely static and dynamic metrics, were considered for the study using simulation software under clear sky conditions. Static metrics like Daylight Factor, Point-in-Time Illuminance, and Dynamic metrics like Spatial Daylight Autonomy, Useful Daylight Illuminance, Annual Sunlight Exposure, Daylight Glare Probability, and Continuous Daylight Autonomy were used to evaluate the daylight performance. The results revealed that the WWR at 20%, paired with matte or low-gloss finishes, delivered the most efficient and visually comfortable lighting across different room types. In contrast, larger window areas or high-gloss surfaces had unwanted glare and visual discomfort. Among all combinations, materials like white acoustic ceiling tiles, white painted gypsum walls, and white matte vitrified flooring could evenly reflect and diffuse natural light. The study thus highlights the importance of integrating form, material, and fenestration positioning in institutional design, particularly for learning environments like architecture studios that have prolonged indoor usage.*

Keywords *- Window-To-Wall Ratio, Daylight Metrics, Daylight Glare Probability, Spatial Daylight Autonomy.*

1. Introduction

Daylighting in design institutions impacts students' alertness, concentration, and affects overall creative outcome, as reflected in a study conducted by Babalola. It established the fact that students' academic output and engagement levels in a classroom well-lit by natural lighting showed significant progress [1]. Research reveals that the decreased symptoms of depression and anxiety occur in a naturally illuminated study environment [2]. Daylighting reduces stress and Seasonal Affective Disorder (SAD) and has a psychological impact, it is suggested. Further, the study identified that more than 52% of the students preferred daylighting exclusively over artificial lighting [3]. In an evaluation across multiple architecture departments in the area of Southeast Asia with the post-occupancy evaluation, students ranked daylighting as one of the top three factors affecting the learning satisfaction [4]. Study observations suggested that daylight in institutions should be made as one of the standard criteria in Architectural Accreditation evaluation, as access to natural lighting enhances collaboration and design quality [5]. An instructional building with integrated daylighting design can effectively reduce the lighting energy consumption by as much as 45% without compromising on glare.

Daylighting in a building is shaped by many factors. Though previous studies have examined these factors, most of the previous researches either take a broad view or concentrates on a specific technical aspect like glazing, fenestration, façades, bright lighting, etc. However, the present work focuses on context-specific analysis for educational studios in the Tropical climate of Chennai, India. Indian Architectural studios deal with clear skies, excessive daylight, and struggle to manage the glare, yet this unique context remains largely unrepresented in daylight research. The research gap in this paper addresses the key aspects, such as room geometry, surface reflectance, and Window Wall Ratio (WWR) as a combination, which significantly aids in controlling the glare and visual discomfort in tropical architectural studios while also ensuring adequate daylighting by quantitative analysis using static and dynamic metrics.

1.1. Role of Natural Lighting in Educational Environment

A long-term study by Aghajari and Chen (2025) found that children in the well-lit classroom advanced about 20% faster in arithmetic skills, which are much required for bridging creativity with practicality, accurate measurement, and scaling. Reading skill was increased by 26% in comparison to those with less natural light [6].

Exposure to natural daylight encourages the production of serotonin ("a feel-good hormone"), which supports a sense of comfort and connection to outdoor factors that help students feel more relaxed and ready to learn [7]. Morning daylight with higher blue wavelength suppresses melatonin, which enhances alertness and helps maintain wakefulness during early morning. This also supports better sleep quality at night, which then feeds back into improved performance the following day [8]. Educational institutions incorporating more daylight often see low absentee rates, as this environment with balanced daylight helps in reducing glare and visual strain [9].

1.1.1. Necessity of Daylighting in Tropical Institutes

In higher educational institutions focusing on creative studies, students perform highly detailed, creative tasks. Daylight enhances special perception, colour rendering, and overall students' productivity, making it a vital design consideration.

While daylighting is abundant in tropical climates, balanced daylighting is required, which can be achieved by optimization of key parameters such as room geometry, surface finishes, and window-to-wall ratio. Effective daylighting design contributes to sustainable campus design while maintaining a comfortable indoor environment [10].

1.1.2. Long-term Effects of Daylighting on Students

Recent Research highlights that natural daylight has profound, long-term benefits for students' physical and mental wellbeing. Studies show that students learning in a classroom with greater sunlight exposure supports a healthier circadian rhythm, which in turn is linked to improved cognitive performance, memory retention, emotional stability, and overall students' academic productivity [11]. A Beijing-based study (2021) found that natural light before awakening improves morning alertness, mood, and sleep depth, which reveals that consistent daylight access in an educational environment not only enhances short-term psychological balance and sleep quality but also enhances academic engagement [12].

1.1.3. Key Strategies to Improve Daylighting in Tropical Educational Institutions

Optimize Building Orientation and Layout

In tropical regions, the orientation of the building makes a huge difference. Placing the longer sides of classrooms toward the north or south reduces the harsh morning and evening sun from the east and west. Arranging windows on the north and south façades provides consistent, glare-free light. This careful planning ensures students get bright, usable daylight throughout the day without the discomfort of low-angle sun [13].

Use Shading Devices and Light Control Elements

Since the sun is intense in the tropics, Overhangs, vertical fins, louvers, and perforated screens filter out direct glare while still allowing soft, diffused light in. Innovative solutions like perforated shading screens not only improve daylight levels but also reduce heat inside. Some buildings even use their shape - sloped walls or angled façades - to provide built-in shading, reducing the need for extra devices [14].

Select Appropriate Glazing and Window Design

Windows are more than just openings; Taller windows bring light deeper into rooms, while clerestory windows high on the wall spread light more evenly. Adding windows on opposite sides of a classroom can also balance the daylight, preventing dark corners and bright spots.

Incorporate Light-Reflective and Diffusive Interior Materials

The color and texture of interior surfaces influence how light behaves. Pale, matte finishes like white paint or acoustic tiles bounce daylight deeper into a room, creating a softer, more even glow. In contrast, dark or glossy finishes absorb or reflect light harshly, causing visual discomfort. Simple material choices can make a big difference at a very low cost [15].

Use Light Redirection Devices

Devices like light shelves reflect sunlight upward toward ceilings, pushing it deeper into rooms while shading lower windows to prevent glare. Other options include prismatic panels, angled blinds, or even tubular daylight devices that channel light from roofs into rooms without windows. These solutions help distribute daylight more evenly across learning spaces [14].

Integrate Smart Controls and Adaptive Lighting

Daylight levels change constantly, so relying only on static design is not enough. Sensors that adjust artificial lighting based on available daylight keep interiors bright and energy-efficient. More advanced systems can even detect glare and automatically move blinds or louvers, ensuring students always work in comfortable lighting conditions [15].

Simulation-Based Optimization in Early Design

The best results come when daylighting is considered right from the start. Using computer simulations, architects and designers can test different layouts, window sizes, shading types, and materials before construction. This approach helps balance daylight access with comfort, avoiding issues like glare or overheating. For tropical educational spaces, this means a brighter, more sustainable, and student-friendly environment [17].

2. Key Daylight Parameters Governing Rooms' Illumination

Room orientation, surrounding obstruction, glazing type, window wall ratio, interior surface reflectance, room geometry, shading device, and climatic conditions are the key factors affecting the interior room illuminance [18]. Metrics are used to evaluate daylight performance in a building quantitatively, and there are two types of metrics, namely static and dynamic metrics. Static metric includes Daylight Factor (DF), Uniformity Ratio (UR), and Point in Time Illuminance (PTI), which analyze the performance with a fixed sky condition (usually overcast sky) without considering temporal variations. Dynamic metrics include Daylight Autonomy (DA), Spatial Daylight Autonomy (SDA), Useful Daylight Illuminance (UDI), Annual Sunlight Exposure (ASE), Daylight Glare Probability (DGP), and Continuous daylight autonomy, which analyzes daylight performance over the year based on precise real weather data, building orientation, sun movements, and occupancy schedule [19]. In a country like India, which experiences a tropical climate, most of the longer side of the building is oriented in the north-south direction, and the glazing adopted is clear glass with a visual light transmittance of 80 to 90%. The envelopes of Most of the design studios in the institution have one wall facing the external and another wall facing the corridor, and the remaining two walls are shared with the adjacent rooms. Of all the parameters, the most impactful ones to be considered are room geometry, window-to-wall ratio, and interior surface reflectance.

The novelty of this Research focuses on implementing the combination of three key parameters, namely room geometry, surface reflectance, and window-to-wall ratio, integrating static metrics and dynamic metrics for analysis. These three are the fundamental parameters for a building design and are difficult to change post-construction. These factors strongly affect the amount of daylight entering the space and how glare is managed. These parameters provide simple and cost-effective, sustainable design solutions in comparison to high-cost options such as smart glazing and automated shading systems.

Amongst static metric daylight factor, point in time illuminance is considered for this Research along with dynamic metrics, spatial daylight autonomy, useful daylight illuminance, annual sunlight exposure, daylight glare probability, and continuous daylight autonomy, which helps in achieving Balanced interior daylighting and Visual comfort by improving occupant wellbeing and performance, which is particularly crucial in educational and institutional spaces.

2.1. Room Geometry

Room geometry acts as one of the significant parameters in daylighting, as it determines how natural light penetrates and disperses to light the space evenly. Other aspects, like spatial arrangements, room proportions, and window placement, determined by the geometric design, also play a crucial role in optimizing daylighting. As per the aspect ratio for an elongated room, windows placed only on the shorter side of the room will get unevenly distributed daylight, and dark zones are created further away from the window [20]. For a room with a single-sided window, the daylight penetration into the interior space shall be 2.5 times the window height, which results in the decreased DA beyond that point [21]. Square-shaped rooms with a 1:1 ratio will have uniform daylighting, but to avoid glare in this room geometry, careful window sizing is required [22]. Higher ceiling heights of more than three meters improve daylight penetration deeper into the room [23]. Compared to a flat ceiling, a vaulted ceiling enhances light diffusion, reducing contrast between bright and dark areas [24]. Trapezoidal room layout with angled walls is more effective than rectangular rooms, improving uniformity [25]. Contrast in light, which causes dark corners, is reduced in the circular rooms but requires sky lighting or clearstory for sustained illuminance [26]. Of the many Architectural institutions in India, as per case studies, the most observed room geometries are either square, rectangular, or sector. Thus, the study touches upon the above-mentioned three shapes for the analysis.

2.2. Interior Surface Reflectance

Light diffusion is improved by the high reflectance of interior wall, ceiling, and floor surfaces, allowing daylighting to reach deeper into the interior space. A study found that daylight autonomy in the perimeter zones of the room has improved by 15 to 20 % by increasing wall reflectance from 50 % to 80% [27]. Research findings demonstrated that matte finished interior with 60 to 70% minimizes glare while maintaining sufficient illuminance with visual comfort [28]. Energy consumption is reduced by 10 to 30 % in interior spaces with highly reflecting interior finishes, as it reduces the need for artificial lighting [29]. In a comparative analysis of interior finishes for optimal daylighting, it was found that a white painted wall with 80% reflectance outperforms dark surfaces by 30 % reflectance in daylight factor by 2 to 3 times. [30] Interior surface reflectance is a critical factor in daylight design. Combining high reflectance with a window design that maximizes daylight penetration, leading to energy efficiency [31]. Of the many Architectural institutions in India, as per case studies, the most observed interior materials are concrete, light colour white vitrified tiles, matte finish acrylic paint, satin finish white paint, light color micro cement plaster, white mineral fiber acoustic ceiling tiles, white colour gypsum wall panel, high gloss white paint, and plastic emulsion paint.

2.3. Window to Wall Ratio

Window-to-wall ratio is a critical design parameter that significantly influences daylight performance in educational institutions in tropical zones where solar radiation is intense and consistent throughout the year [32]. Research probe has found that the optimal range of WWR is 30 to 40% in educational institutions while minimizing glare and solar heat gain, and WWR of more than 40%

leads to excessive daylight penetration, causing visual discomfort and increasing the cooling load. [33]. In interior spaces with windows with a higher WWR, without proper shading devices, the interior temperature of the space will increase by 2 to 3 degrees Celsius [34]. Recommended WWR for various building orientations for east and west facade-oriented windows is 30 to 35% and for windows in the north and south façades, it is 40 to 45% [35]. Optimizing the wall-to-area ratio could reduce artificial lighting usage by 35 to 45% while maintaining an acceptable illuminance level [36]. Best UDI from the range of 300 lux for 80% of the occupied hours in the classroom is achieved by having a WWR of 35 to 45% [37]. Of the many Architectural institutions in India, as per case studies, the most observed WWRs are 20%, 30%, and 40%.

3. Daylighting Metrics

Daylight metrics are quantitative measures to calculate the availability, quantity, and performance of natural daylight within an interior space. These metrics are used by the architects and lighting engineers to assess and optimize daylighting for visual comfort, energy efficiency, and sustainable building design. Daylight metrics can be classified into static metrics and dynamic metrics. Static metrics are traditional, simplified metrics based on fixed sky conditions, typically the CIE standard overcast sky, and do not account for temporal variation. It is independent of time and natural variation in the weather or sky conditions. Point daylight factor is a ratio of indoor illuminance at a specific point to outdoor illuminance under a standard sky condition; it indicates the daylight availability at a point. Average daylighting factor is the mean of the point daylight factor across multiple points in a room, representing overall daylight sufficiency [38]. These metrics are convenient for early conceptual assessment and design comparisons. Point in time illuminance is a climate-based or real-time measure that measures light in lux inside a space at a specific time and date using sun position, weather data, time, and date. Dynamic metrics are climate-based metrics that incorporate real climate data and simulate daylight availability throughout the year for a more realistic assessment, considering weather variability and the sun's movements. These dynamic metrics are computationally intensive and require more sophisticated simulation tools. Daylight metrics provide both quick. Simplified Indicators (static) for initial design evaluation and detailed dynamic measures (CBDMs) for performance over time, enabling optimized daylighting strategies to climate, building use, and occupants' needs [39].

3.1. Static Metric -Daylight Factor

DF is a static metric used to quantify the daylighting in an interior space. It assumes overcast sky conditions, which are rare in a tropical country like India, where clear skies dominate [40]. Unlike dynamic metrics, daylight factor does not account for temporary variation in daylighting. Research suggested that UDI, as a dynamic metric ranging from 100 to 2000 lux, is more reliable than the daylight factor [41]. The optimal value for daylight factor ranges from 2% to 5% higher daylight factor; more than 5% DF may lead to discomfort glare [42]. In tropical regions, daylight factor values vary significantly based on the window orientation and shading devices due to direct sunlight in the east and west directions, showing a higher daylight factor with poor daylight uniformity [43]. Greater accuracy can be achieved using Climate-Based Daylighting Modelling (CBDM), which also augments visual comfort data by predicting glare to a specific region of one climate type [44]. Research findings indicate that SDA is found to be more Representative than DF for educational buildings in tropical countries [45].

3.1.1. Static Metrics - Point in Time Illuminance

PTI, as a static metric, quantifies the daylight performance by capturing the vertical light levels at specific moments. These measurements reflect the amount of daylight illuminance that reaches a particular point, such as a work surface, and offer a snapshot daylight contribution at that instant. This metric provides precise, measurable data about the existing daylight levels at a specific location for evaluation of the effectiveness of daylighting in the interior environment [48]. The recommended permissible range of point in time illuminance in interior spaces within the tropical climate aims to balance sufficient daylighting for visual comfort. For general visual task levels ranging from 300 lux to 750 lux, for daylight optimization it is common to target 300 lux to 600 lux as the practical range during the peak daylight condition, aligning with the standard for classroom and workspace lighting as per the guidelines given by the National building code 2016 Annex D and IGBC AP credits 300–500 lux on the work plane at 9 AM, 12 PM, and 3 PM under clear sky conditions [47].

3.2. Dynamic Metrics

Spatial daylight autonomy focuses on the percentage of floor area where the specific illuminance level is met for a specific percentage of the occupied hours. As a dynamic climate-based metric, DA assesses the sufficient daylight received above a certain illuminance threshold in a certain percentage of the operating hours. These metrics make the designer aware of the temporal availability of daylighting for effective sizing and positioning of the window. As per IGBC New Building Rating System, LEED v4, it is recommended that ≥ 55% of regularly occupied area achieve ≥ 300 lux for 50% of occupied hours. Useful daylight illuminance evaluates the amount of daylight within a desirable range, eliminating over-illumination that could cause glare and under-illumination that might hinder the visual tasks. These metrics influence decisions made on the shading devices and the glazing properties to maintain comfort and energy efficiency. As per the IGBC norms for an educational institutional space like a studio, it is recommended 100–2000 lux for at least 80% of the time [48]. ASE measures the potential solar glare and overheating risks by evaluating the extent of the direct sunlight exposure over the year of use of this metrics aids in window placement and selecting the type of shading device required so has to prevent excessive solar gain, ensuring visual comfort and thermal regulations as per the IGBC norms ≤ 10% of floor area receiving >1000 lux for more than 250 hours /year. [49]. Daylight glare probability as a dynamic metric evaluates the likelihood of glare experienced by the occupants under different lighting conditions. Unlike static metrics, it incorporates variation over time and different daylight scenarios. This aspect enables a more comprehensive and realistic assessment of visual comfort throughout the day. DGP is based on vertical illuminance at eye level and source luminance, making it an effective metric for monitoring daylighting quality in real-time over a specific period. The DGP value below 35% is an imperceptible acceptable glare condition of all time, between 35% 40% is perceptible but not disturbing, DGP in the range of 40 to 45% is disturbing, and above 45% is Intolerable. As per the IGBC, it is recommended via EN17037 < 0.35 preferred (imperceptible), < 0.4 acceptable. Continuous daylight autonomy is a dynamic metric that captures the temporal variability of daylighting throughout the year, reflecting how a space maintains adequate daylighting levels for the visual tasks. This metric analyses the data across all the hours of the year, calculating the percentage of time during which illuminance at a given point or zone exceeds the specific threshold (eg, 300 lux) as per the IGBC, and the LEED tis metrics should be ≥ 55% of area achieving ≥ 300 lux continuously during all occupied hours [50]. To assess the daylighting performance in an interior space, various simulation tools like Radiance, Climate Studio, and Design Builder have been used in many papers. The present study aims to evaluate the daylight metrics using three parameters: room geometry, WWR, and interior surface reflectance

4. Methodology

The Research aims to compare the three key design parameters for an optimal institutional daylighting solution using static and dynamic daylighting metrics to find the best possible combination for the room's interior illumination. The simulation has been carried out using various permutations and combinations for the three variable parameters, resulting in 21 cases using Design Builder software version 7.0.2.006. The scope of the design is limited to Chennai, which experiences a warm, humid climate with clear sky conditions. Thermal heat gain has not been considered for the study. Working hours considered for the study are between 9 am and 6 pm. The glazing considered for light penetration is clear glass, 8mm thick glass with 90% visual light transmission (VLT). The research design is indicated in Figure 1.

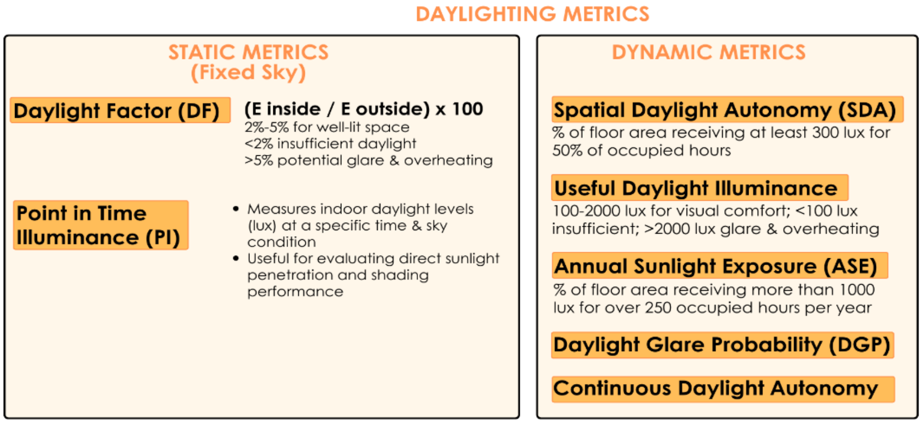
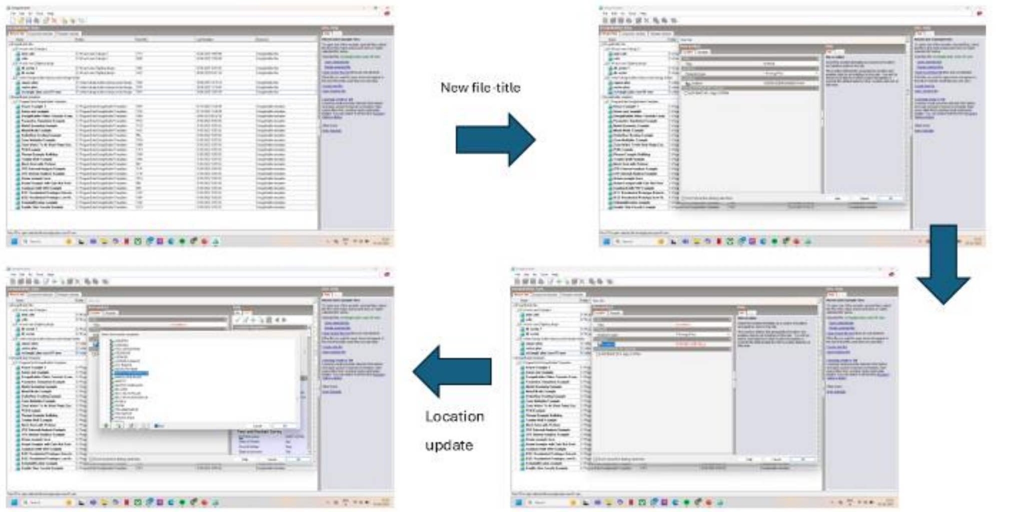
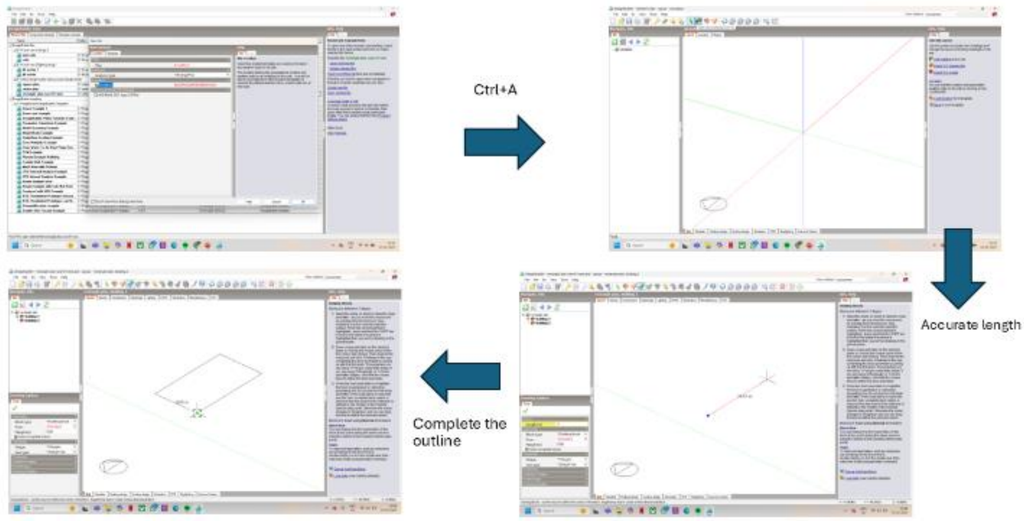


Fig. 1 Daylighting metrics

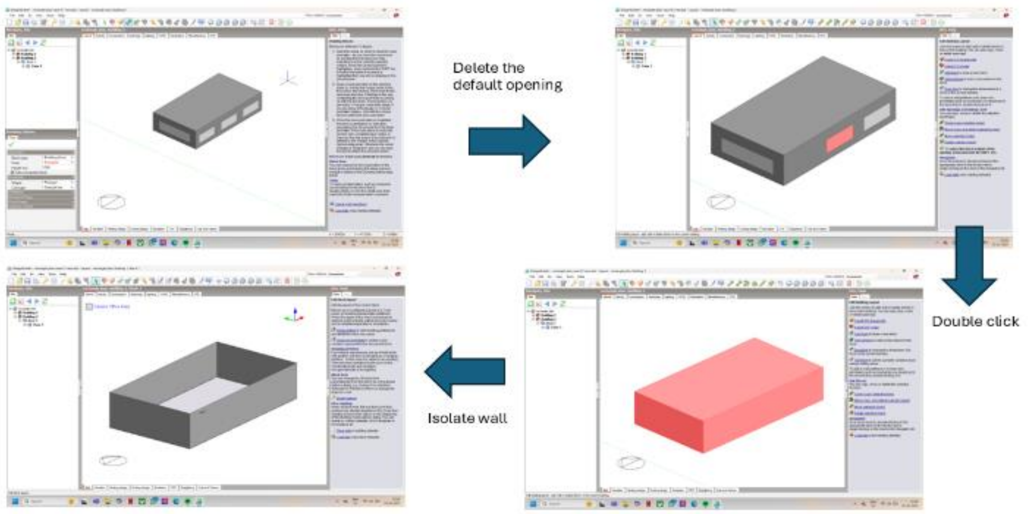
Fig. 2 Room Geometry – Methodology Diagram



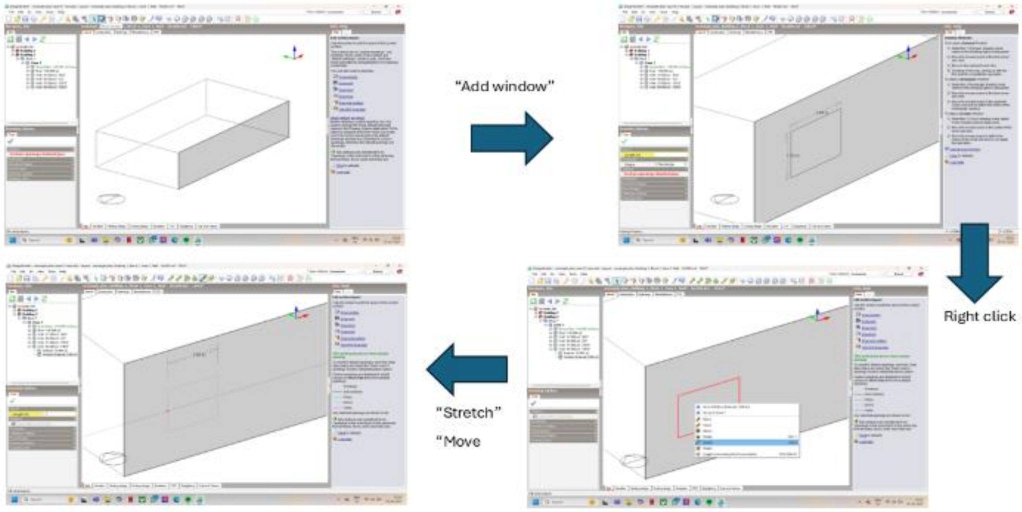
Begin by launching the DesignBuilder software. Once the application is open, create a new project file and assign it a name corresponding to the intended simulation. Proceed to define the geographic location of the building where the simulation will be conducted, ensuring accurate climate and environmental data integration.



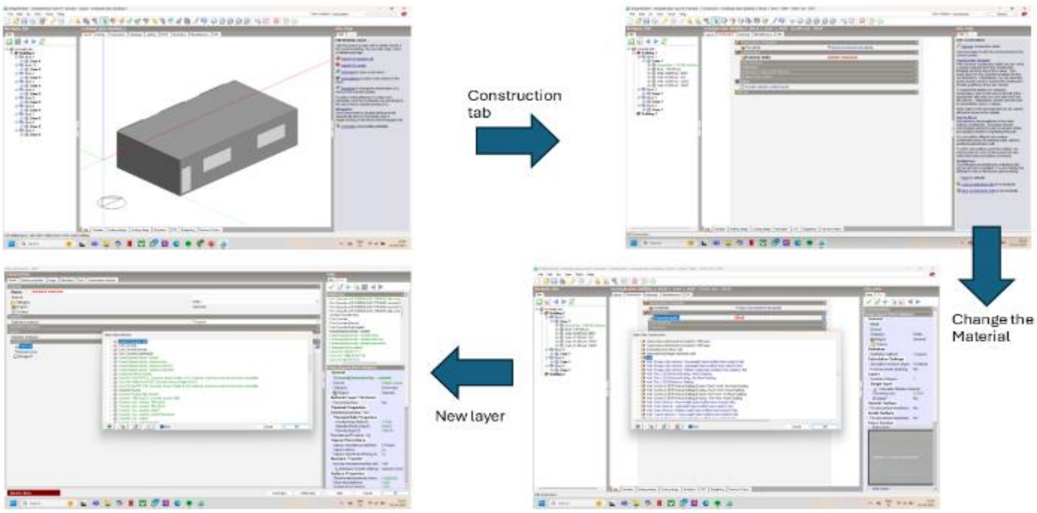
Once the building location is set, a new file is initiated for constructing the 3D model based on the architectural plan's measurements. To begin, select the 'Add New Building' icon or use the shortcut Ctrl+A to create a new building entity. Following this, delineate the building's outline, ensuring that the wall thickness and floor height are accurately specified in accordance with the design requirements.



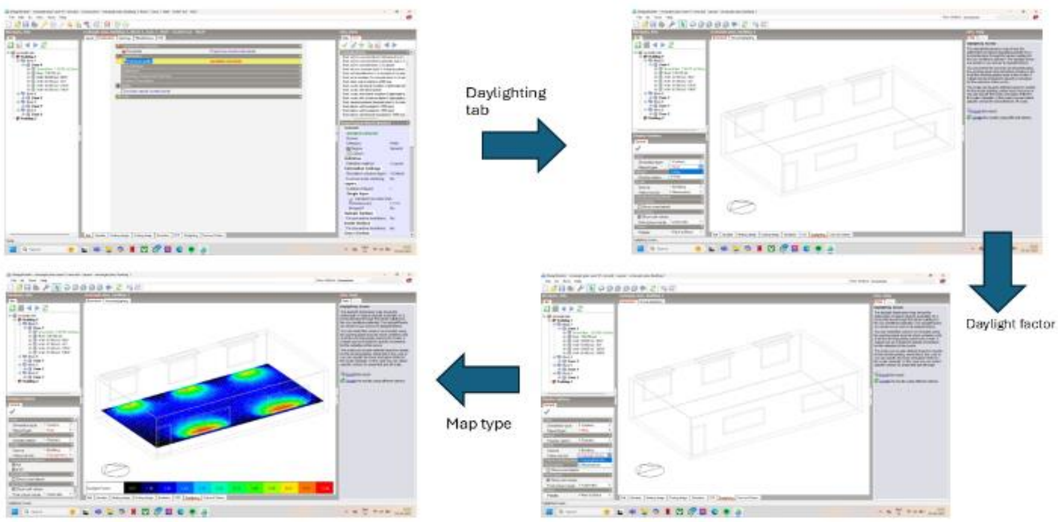
Upon generating the 3D model, default openings are automatically assigned. These must be removed and replaced with windows and doors that align with the architectural plan. To modify individual components, double-click on the building surface to isolate elements such as walls, floors, and ceilings. Each component should be individually accessed to accurately insert the required openings.



After isolating the wall component, windows can be added based on the specified measurements. An 'Opening' icon labeled 'Draw Window' will appear in the center of the icon tab. Initially, a window with approximate dimensions can be placed, which can then be resized or repositioned accurately by right-clicking on the roughly drawn window. Doors are added using a similar process by selecting the 'Add Door' icon located adjacent to the 'Add Window' icon.



Once the building block is fully constructed, proceed to modify the material specifications by selecting the 'Construction' tab located adjacent to the 'Activity' tab. To update the material, add a new layer and navigate through the designated material folders to locate and select 'Concrete'. Adjust the thickness of the selected material as required, then click 'OK' to apply the changes to the building model.



After confirming that the wall material has been correctly applied, proceed to assign appropriate materials to all other building components, such as floors, ceilings, and roofs. Once material specifications are finalized, the model is ready for simulation. Navigate to the 'Daylighting' module to evaluate illuminance levels and daylight factors, which will be displayed in both map and grid formats for detailed analysis.

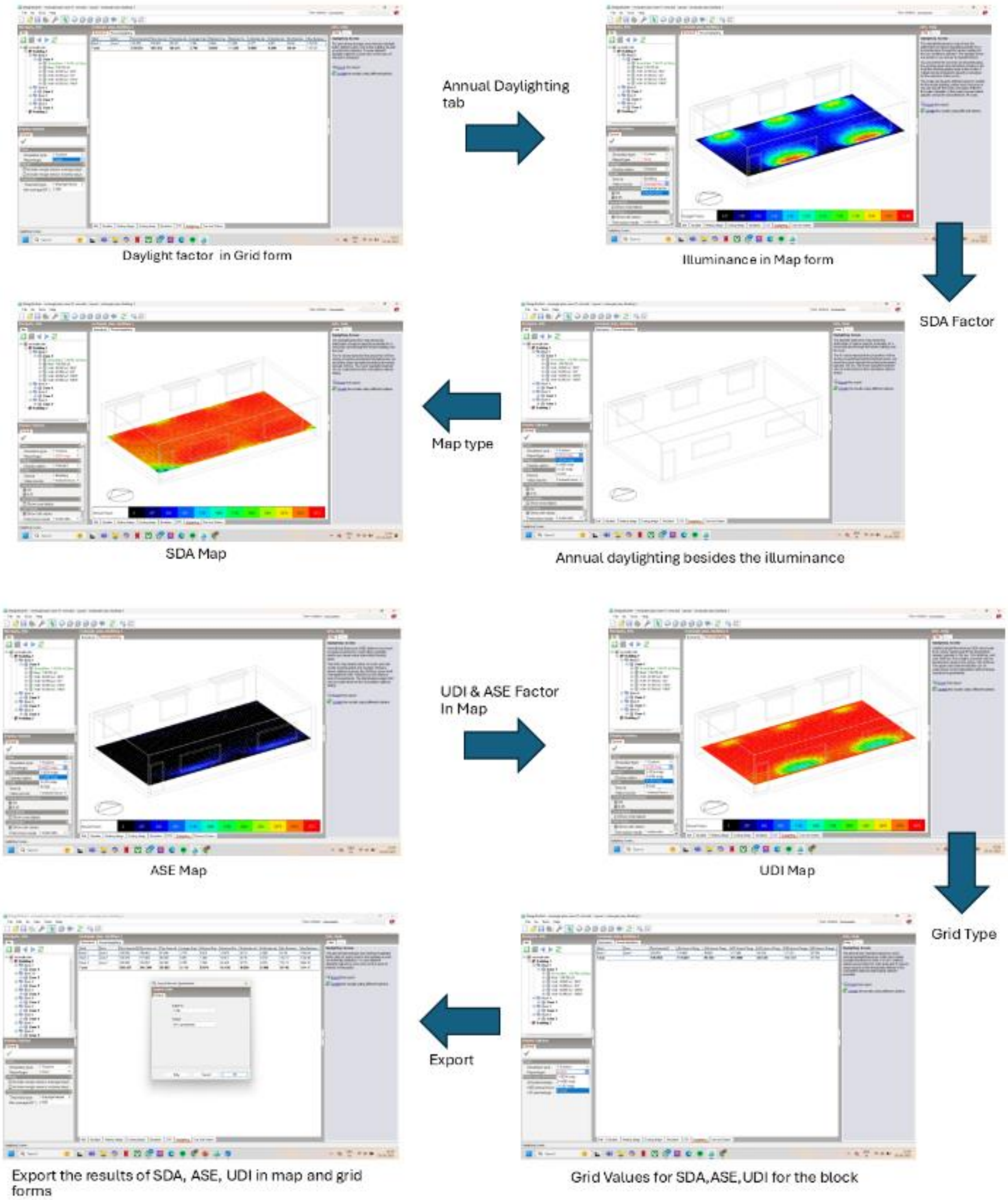


Fig. 3 Design Builder Simulation – Step-by-step representation

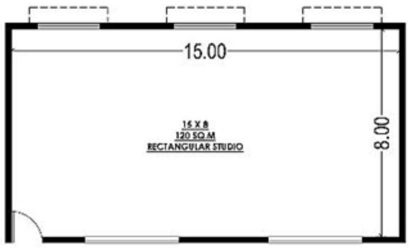
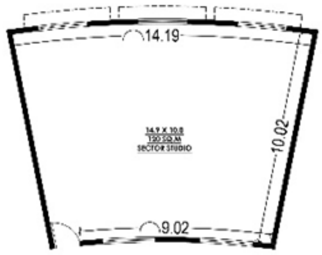
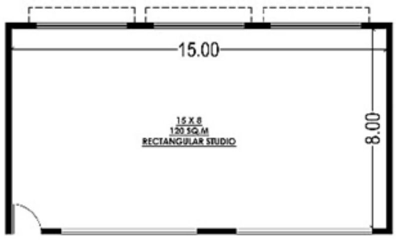
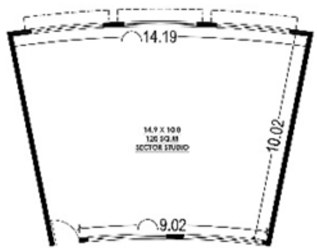
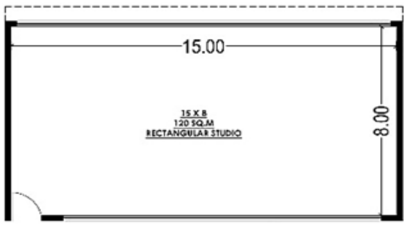
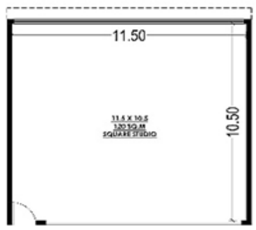
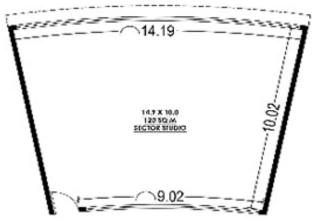
4.1. Variation of Room Geometry in Design Studio

The built-up area for a studio in a Technical Institution, as per All India Council for Technical Education (Governing body for technical institutions in India) norms, is 120 sq. meters. Based on the case studies conducted across architectural colleges in India, the commonly observed classroom geometry is a rectangle, square, or sector. This has been taken as a base model for comparison in the study.

The rectangular room considered for the design measures an area of 15m*8m and a height of 4 m. The longer side is oriented towards a north-south direction for optimal daylight performance, with north facing the external wall and the corridor facing south. The square room measures an area of 11m x 11m x 4m in height. The sector room, with a radius of 10.2m and the chord length measuring 14.19 meters on the larger side, is modelled as the third room geometry.

Below Table 3, seven material combinations have been assigned that will be used for the simulation model. It is as follows:

Table 1. Room Geometry with respective Window-to-wall ratio

S.NO	WWR	ROOM GEOMETRY RECTANGLE	ROOM GEOMETRY SQUARE	ROOM GEOMETRY SECTOR
1.	20%			
2.	30%			
3.	40%			

4.2. Variation of Material Surface Reflectance in Design Studio

Interior surface reflectance improves light distribution, enhances illumination level, lowers the need for artificial lighting, and strengthens visual comfort. The ceiling reflectance value is set at 80-90%, while the reflectance value of internal walls is 60-80% and the floor at a reflectance value of 20 – 40%. These values are set as per NBC 2016 standard part 8, section 1, SP 41 (Daylighting Design), enough to bounce the light but not cause glare. As per the data inferred from the existing case studies of institutional buildings in India, the commonly used building materials with their respective Light reflectivity value that will be used for the simulation in the base case models are as follows:

Table 2. Material with a Light reflectance value

CASE NO	PLANE	MATERIALS	LIGHT REFLECTANCE VALUE (LRV)
1	CEILING PLANE	Concrete	25% -40%
		Satin-finish white paint	85–90%
		Matte Acrylic Paint – Light Pastel or White	75–90%
		White Mineral Fiber Acoustic Ceiling Tiles	85–90%
		High-gloss white paint	90–95%
2	WALL PLANE	Concrete	25%-40%
		Matte White Acrylic paint	85–95%
		Microcement Plaster (light colored)	70–85%
		Vinyl-Coated Gypsum Wall Panels	75–90%
		Unglazed Matt-Finish Ceramic Tiles (White/Cream)	80–90%
		Plastic Emulsion Paint (White/Cream)	80–90%
3	FLOORING PLANE	Light-colored (White /Beige) Vitrified Tiles - Matte finish	60–75%

Table 3. Material combinations with the Light reflectance value

CASE NO	CEILING PLANE	LIGHT REFLECTANCE VALUE (LRV)	WALL PLANE	LIGHT REFLECTANCE VALUE (LRV)	FLOOR PLANE	LIGHT REFLECTANCE VALUE (LRV)
1	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White /Beige) Vitrified Tiles - Matte finish	60–75%
2	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-coloured Vitrified Tiles - Matte finish	60–75%
3	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-coloured Vitrified Tiles - Matte finish	60–75%
4	Matte Acrylic Paint – Light Pastel or White	75–90%	Micro cement Plaster (light coloured)	70–85%	Light-coloured Vitrified Tiles - Matte finish	60–75%
5	White Mineral Fiber Acoustic Ceiling Tiles	85–90%	Vinyl-Coated Gypsum Wall Panels	75–90%	Light-coloured Vitrified Tiles - Matte finish	60–75%
6	High-gloss white paint	90–95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	80–90%	Light-coloured Vitrified Tiles - Matte finish	60–75%
7	High-gloss white paint	90–95%	Plastic Emulsion Paint (White/Cream)	80–90%	Light-coloured Vitrified Tiles - Matte finish	60–75%

Table 4. Window area with respect to the Window-to-wall ratio

S.NO	ROOM GEOMETRY	WWR %	NO. OF WINDOWS / WALL	WINDOW HEIGHT	WIDTH	AREA PER WINDOW	TOTAL AREA
1	RECTANGULAR	20 %	3	1.7 m	2.427 m	4.126 m²	12.378 m²
2	SQUARE	20 %	2	1.7 m	2.814 m	4.784 m²	9.568 m²
3	SECTOR	20 %	3	1.7 m	2.305 m	3.918 m²	11.754 m²
4	RECTANGULAR	30%	3	1.7 m	3.64 m	6.189 m²	18.567 m²
5	SQUARE	30%	2	1.7 m	4.22 m	7.176 m²	14.352 m²
6	SECTOR	30%	3	1.7 m	3.46 m	5.877 m²	17.631 m²
7	RECTANGULAR	40%	1	1.7 m	14.56 m	24.756 m²	24.756 m²
8	SQUARE	40%	1	1.7 m	11.26 m	19.136 m²	19.136 m²
9	SECTOR	40%	1	1.7 m	13.83 m	23.508 m²	23.508 m²

4.3. Variation of WWR in Design Studio

As per previous studies performed on the WWR for institutional buildings, the moderate value ranges to 20%, 30% and 40%, which have been set up as a base case model for simulation. The calculation for WWR is shown in Table 4.

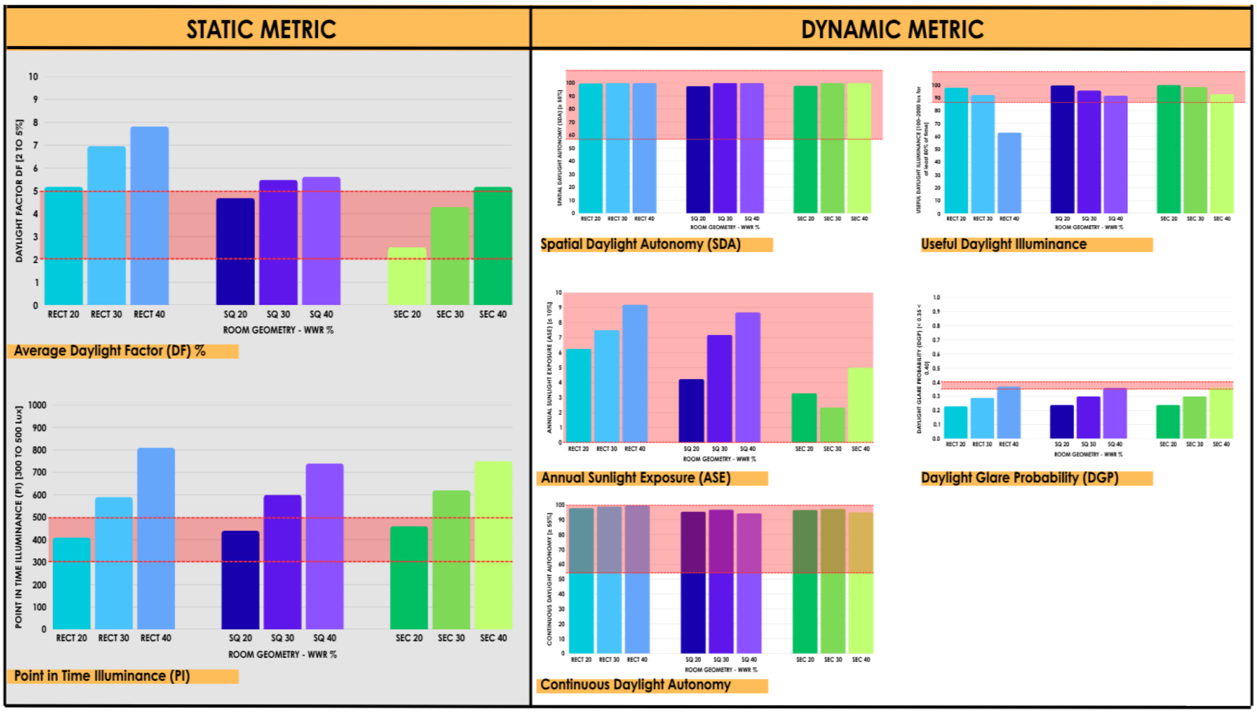
Based on the above-mentioned data, a simulation was performed for 21 cases with varied WWR, material combination, and room geometry as mentioned in the table, with a constant sill height of 1.5 meters and clear sky conditions. The static metrics considered for the simulation study are Daylight Factor (DF), Uniformity Ratio (UR), and point-in-time illuminance. Dynamic metrics are Daylight Autonomy (DA) and Spatial Daylight Autonomy (SDA). Uniform Daylight Illuminance (UDI), Annual Sunlight Exposure (ASE), Daylight Glare Probability (DGP), and continuous daylight autonomy.

5. Analysis and Discussion

Varied design parameters with different daylighting metrics have been analysed using DesignBuilder simulation software, resulting in 21 cases with 63 simulations.

DAYLIGHTING METRICS																
	INTERIOR SURFACE REFLECTANCE OF MATERIALS - DAYLIGHT ANALYSIS - SIMULATION - TRIAL 1									STATIC METRICS		DYNAMIC METRICS				
SL. NO	CASE NO	ROOM GEOMETRY	WINDOW-TO-WALL RATIO WWR	CEILING PLANE	LIGHT REFLECTANCE VALUE (LRV)	WALL PLANE	LIGHT REFLECTANCE VALUE (LRV)	FLOOR PLANE	LIGHT REFLECTANCE VALUE (LRV)	Average Daylight Factor (DF) %	Point in Time Illuminance (PI)	Spatial Daylight Autonomy (SDA)	Useful Daylight Illuminance	Annual Sunlight Exposure (ASE)	Daylight Glare Probability (DGP)	Continuous Daylight Autonomy
										2% – 5% (minimum 2% for classrooms; up to 5%–6% for studios)	300–500 lux	≥ 55%	100–2000 lux for at least 80% of time	≤ 10%	< 0.35 < 0.40	≥ 55%
1		(a) RECTANGLE ROOM	20	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.18	410	119.683 m^2 / 99.692%	117.465 m^2 / 97.844%	7.5m^2 / 6.25%	0.23	97.80%
2	CASE 1	(b) RECTANGLE ROOM	30	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	6.96	590	120 m^2 / 100%	110.642 m^2 / 92.148%	9 m^2 / 7.5%	0.29	98.90%
3		(c) RECTANGLE ROOM	40	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	7.82	810	120 m^2 / 100%	75.711 m^2 / 63.048%	11m^2 / 9.2%	0.37	99.60%
4		(a) SQUARE ROOM	20	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.69	440	117.786 m^2 / 97.517%	120.513 m^2 / 99.774%	5.08m^2 / 4.23%	0.24	95.50%
5	CASE 2	(b) SQUARE ROOM	30	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.48	600	120 m^2 / 100%	115.713 m^2 / 95.786%	8.61 m^2 / 7.18%	0.3	96.80%
6		(c) SQUARE ROOM	40	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.618	740	120 m^2 / 100%	110.723m^2 / 91.648%	10.42m^2 / 8.68%	0.36	94.20%
7		SECTOR ROOM	20	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	2.527	460	119.671sq.m / 97.969%	120 m^2 / 100%	3.96m^2 / 3.3%	0.24	96.70%
8	CASE 3	SECTOR ROOM	30	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.289	620	120 m^2 / 100%	119.671sq.m / 98.436%	2.79m^2 / 2.33%	0.3	97.30%
9		SECTOR ROOM	40	Concrete	25% to 40%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.181	750	120 m^2 / 100%	113.391sq.m / 92.813%	6m^2 / 5%	0.36	95.00%
10		RECTANGLE ROOM	20	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.17	390	118.757 m^2 / 98.922%	117.74 m^2 / 98.075%	2.26m^2 / 1.88%	0.21	96%
11	CASE 4	RECTANGLE ROOM	30	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.85	570	120 m^2 / 100%	111.012 m^2 / 92.456%	8.988m^2 / 7.49%	0.28	98.60%
12		RECTANGLE ROOM	40	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	7.58	800	120 m^2 / 100%	79.964 m^2 / 66.59%	10.9m^2 / 9.1%	0.36	99%
13		SQUARE ROOM	20	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.67	430	116.423 m^2 / 96.388%	120 m^2 / 99.699%	3.577m^2 /2.98%	0.24	95.20%
14	CASE 5	SQUARE ROOM	30	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.35	610	120 m^2 / 99.699%	116.076 m^2 / 96.087%	5.924m^2 / 4.94%	0.3	96.50%
15		SQUARE ROOM	40	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.17	740	120 m^2 / 100%	111.541 m^2 / 92.325%	8.459m^2 / 7.05%	0.37	94.20%
16		SECTOR ROOM	20	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	2.445	440	118.908sq.m / 97.344%	120 m^2 / 100%	5.028m^2 /4.19%	0.24	96.80%
17	CASE 6	SECTOR ROOM	30	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.173	600	120 m^2 / 100%	120 m^2 / 100%	7.957m^2 / 6.63%	0.29	97.50%
18		SECTOR ROOM	40	Concrete	25% to 40%	Matte White Acrylic paint	85–95%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.053	760	120 m^2 / 100%	113.963 m^2 / 93.281%	8.412m^2 / 7.01%	0.36	95.00%
19		RECTANGLE ROOM	20	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.18	400	119.683 m^2 / 99.692%	117.465 m^2 / 97.844%	6.545m^2 /5.45%	0.21	98%
20	CASE 7	RECTANGLE ROOM	30	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.97	600	120 m^2 / 100%	110.642 m^2 / 92.148%	9.488m^2 / 7.91%	0.3	95.00%
21		RECTANGLE ROOM	40	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	7.82	850	120 m^2 / 100%	75.711 m^2 / 63.048%	11.437m^2 / 9.53%	0.42	88%
22		SQUARE ROOM	20	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.8	420	117.786 m^2 / 97.517%	120 m^2 / 99.774%	4.96m^2 /4.13%	0.24	96.00%
23	CASE 8	SQUARE ROOM	30	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.48	600	120 m^2 / 100%	115.713 m^2 / 95.786%	7.33m^2 / 6.11%	0.3	96.80%
24		SQUARE ROOM	40	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	6	740	120 m^2 / 100%	110.995 m^2 / 91.874%	8.62m^2 / 7.18%	0.38	94.50%
25		SECTOR ROOM	20	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	2.525	440	119.671sq.m / 97.969%	120 m^2 / 100%	5.4m^2 /4.5%	0.24	96.80%
26	CASE 9	SECTOR ROOM	30	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.284	610	120 m^2 / 100%	119.671sq.m / 98.436%	7.2m^2 / 6.%	0.3	97.50%
27		SECTOR ROOM	40	Satin-finish white paint	85–90%	Concrete	25% to 40%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.181	750	120 m^2 / 100%	113.391m^2 / 92.813%	9.2 m^2 / 7.67%	0.38	95.20%
28		RECTANGLE ROOM	20	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.18	420	119.683 m^2 / 99.692%	117.465 m^2 / 97.844%	2.535m^2 2.11%	0.22	97%
29	CASE 10	RECTANGLE ROOM	30	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.97	610	120 m^2 / 100%	110.642 m^2 / 92.148%	9.358m^2 / 7.8%	0.31	95.50%
30		RECTANGLE ROOM	40	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	7.82	850	120 m^2 / 100%	75.711 m^2 / 63.048%	11.437m^2 / 9.53%	0.43	89%
31		SQUARE ROOM	20	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.8	420	117.786 m^2 / 97.517%	119 m^2 / 99.774%	2.26m^2 / 1.88%	0.23	96%
32	CASE 11	SQUARE ROOM	30	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.48	610	120 m^2 / 100%	115.713 m^2 / 95.786%	4.287m^2 / 3.57%	0.3	96.20%
33		SQUARE ROOM	40	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	6.19	760	120 m^2 / 100%	110.358 m^2 / 91.347%	9.642m^2 / 8.02%	0.37	94%
34		SECTOR ROOM	20	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	2.525	440	119.671sq.m / 97.969%	120 m^2 / 100%	2.535m^2 2.11%	0.24	96.30%
35	CASE 12	SECTOR ROOM	30	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.284	600	120 m^2 / 100%	119.671sq.m / 98.436%	3.577m^2 /2.98%	0.3	97.20%
36		SECTOR ROOM	40	Matte Acrylic Paint – Light Pastel or White	75–90%	Microcement Plaster (light colored)	70–85%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.181	750	120 m^2 / 100%	113.391m^2 / 92.813%	6.609m^2 / 5.51%	0.36	95.50%
37		RECTANGLE ROOM	20	White Mineral Fiber Acoustic Ceiling Tiles	85–90%	Vinyl-Coated Gypsum Wall Panels	75–90%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.24	430	118.851 m^2 / 98.999%	117.65 m^2 / 97.998%	2.35m^2 1.96%	0.23	97%
38	CASE 13	RECTANGLE ROOM	30	White Mineral Fiber Acoustic Ceiling Tiles	85–90%	Vinyl-Coated Gypsum Wall Panels	75–90%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.85	600	120 m^2 / 100%	111.012 m^2 / 92.456%	8.99m^2 /7.49%	0.32	95.00%
39		RECTANGLE ROOM	40	White Mineral Fiber Acoustic Ceiling Tiles	85–90%	Vinyl-Coated Gypsum Wall Panels	75–90%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	7.58	880	120 m^2 / 100%	79.964 m^2 / 66.59%	9.642m^2 / 8.02%	0.45	88%
40		SQUARE ROOM	20	White Mineral Fiber Acoustic Ceiling Tiles	85–90%	Vinyl-Coated Gypsum Wall Panels	75–90%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	4.67	390	116.423 m^2 / 96.388%	119 m^2 / 99.925%	1m^2 /0.83%	0.21	95%
41	CASE 14	SQUARE ROOM	30	White Mineral Fiber Acoustic Ceiling Tiles	85–90%	Vinyl-Coated Gypsum Wall Panels	75–90%	Light-colored (White) Vitrified Tiles - Matte finish	60–75%	5.35	590	120 m^2 / 100%	116.076 m^2 / 96.087%	3.924m^2 /3.27%	0.3	95.80%

42		SQUARE ROOM	40	White Mineral Fiber Acoustic Ceiling Tiles	85-90%	Vinyl-Coated Gypsum Wall Panels	75-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	6.07	770	120 m² / 100%	111.086 m² / 91.949%	8.914m² / 7.43%	0.37	94%
43		SECTOR ROOM	20	White Mineral Fiber Acoustic Ceiling Tiles	85-90%	Vinyl-Coated Gypsum Wall Panels	75-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	2.445	430	118.908sq.m / 97.344%	120 m² / 100%	1.092m² /0.91%	0.23	95%
44	CASE 15	SECTOR ROOM	30	White Mineral Fiber Acoustic Ceiling Tiles	85-90%	Vinyl-Coated Gypsum Wall Panels	75-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	4.173	600	120 m² / 100%	119.671sq.m / 99.14%	4.96m² /4.13%	0.29	96.80%
45		SECTOR ROOM	40	White Mineral Fiber Acoustic Ceiling Tiles	85-90%	Vinyl-Coated Gypsum Wall Panels	75-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.053	750	120 m² / 100%	113.963 m² / 93.281%	6.037m² / 5.03%	0.36	95%
46		RECTANGLE ROOM	20	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.46	370	119m² / 99.923%	116.818m² / 97.306%	3.182m² /2.65%	0.32	91%
47	CASE 16	RECTANGLE ROOM	30	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	6.27	515	120 m² / 100%	108.794 m² / 90.608%	11.206m² /9.34%	0.36	96.00%
48		RECTANGLE ROOM	40	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	8.16	610	120 m² / 100%	68.039 m² / 56.659%	12.5m² / 10.2%	0.39	98%
49		SQUARE ROOM	20	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	4.94	410	119m² / 99.549%	119m² / 99.473%	1m² /0.83%	0.22	97%
50	CASE 17	SQUARE ROOM	30	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.74	620	120 m² / 100%	114.258 m² / 94.582%	5.742m² /4.79%	0.31	96.30%
51		SQUARE ROOM	40	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	6.37	800	120 m² / 100%	108.631 m² / 89.917%	11.369m² / 9.47%	0.39	95%
52		SECTOR ROOM	20	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	2.692	420	119.671sq.m / 99.609%	120 m² / 100%	1.092m² /0.91%	0.23	97%
53	CASE 18	SECTOR ROOM	30	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	4.559	610	120 m² / 100%	118.523 m² / 97.029%	1.477m² /1.23%	0.31	96.70%
54		SECTOR ROOM	40	High-gloss white paint	90-95%	Unglazed Matt-Finish Ceramic Tiles (White/Cream)	70-85%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.454	780	120 m² / 100%	112.15 m² / 91.797%	7.85m² / 6.54%	0.38	95%
55		RECTANGLE ROOM	20	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	3.774	378	119.406 m² / 99.461%	117.65 m² / 97.998%	2.35m² / 1.96%	0.58	98%
56	CASE 19	RECTANGLE ROOM	30	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.801	580	120 m² / 100%	110.92 m² / 92.379%	9.08m² / 7.57%	0.79	92%
57		RECTANGLE ROOM	40	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	8.755	870	120 m² / 100%	75.619 m² / 62.972%	12.5m² / 10.2%	0.93	90%
58		SQUARE ROOM	20	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	2.531	253	119.385 m² / 97.734%	120 m² / 100%	0.615m² / 0.5125%	0.49	98%
59	CASE 20	SQUARE ROOM	30	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	4.29	429	120 m² / 100%	119.955 m² / 98.2029%	0.045m² / 0.0375%	0.83	98%
60		SQUARE ROOM	40	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.186	518	120 m² / 100%	113.295 m² / 92.734%	6.705m² / 5.5875%	0.87	92%
61		SECTOR ROOM	20	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	2.933	293	117.786 m² / 97.517%	120 m² / 100%	2.214m² / 1.845%	0.4	97%
62	CASE 21	SECTOR ROOM	30	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	4.471	447	120 m² / 100%	115.622 m² / 95.711%	4.378m² / 3.648%	0.61	95%
63		SECTOR ROOM	40	High-gloss white paint	90-95%	Plastic emulsion paint (white/ cream)	80-90%	Light-colored (White | Vitrified Tiles - Matte finish	60-75%	5.617	561	120 m² / 100%	110.631 m² / 91.573%	9.369m² / 7.808%	0.68	91%



DAYLIGHTING METRICS - CASE 1,2,3

MATERIAL COBINATION 1 - Concrete [CEILING PLANE]- Concrete [WALL PLANE]- Light-colored (White /Beige) Vitrified Tiles -Matte finish [FLOOR PLANE]

Fig. 4 Daylighting Metrics Chart- Case 1, 2, 3

5.1. Analysis of Daylight Metrics Case 1, 2, 3

In the case of 1,2,3, with the material combination of ceiling and wall plane as concrete, and the floor plane of light colour white vitrified tiles has been considered for a simulation study with a window-to-wall ratio of 20,30,40% and the room geometry as Square, Rectangle, and Sector has been considered. It has been observed from Table 1 concerning the static metrics square room case 2, with a 20% of WWR reaching the permissible average daylight factor of 4.69%. The point in time illuminance in case 1 for a rectangular room with 20% WWR is found to be 410 lux, with the permissible range of 300 to 500 lux. Concerning dynamic to dynamic metrics, SDA, ASE, and CDA are found to be optimum for all three cases. The DGP is found to be satisfactory for all three cases with a WWR OF 20 and 30 %. UDI of the rectangular room with 40% of WWR is found to be much below the permissible value of 63%

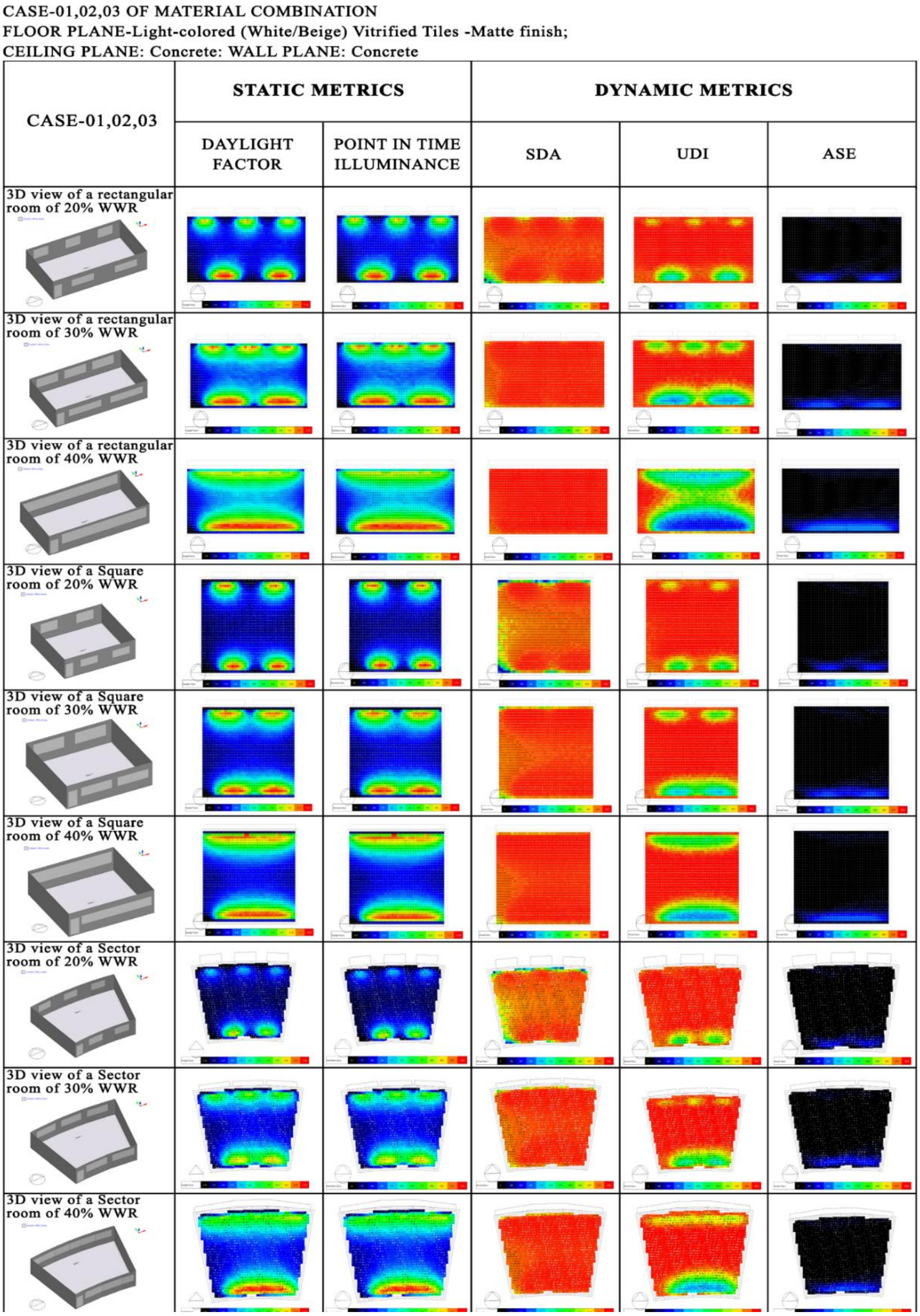
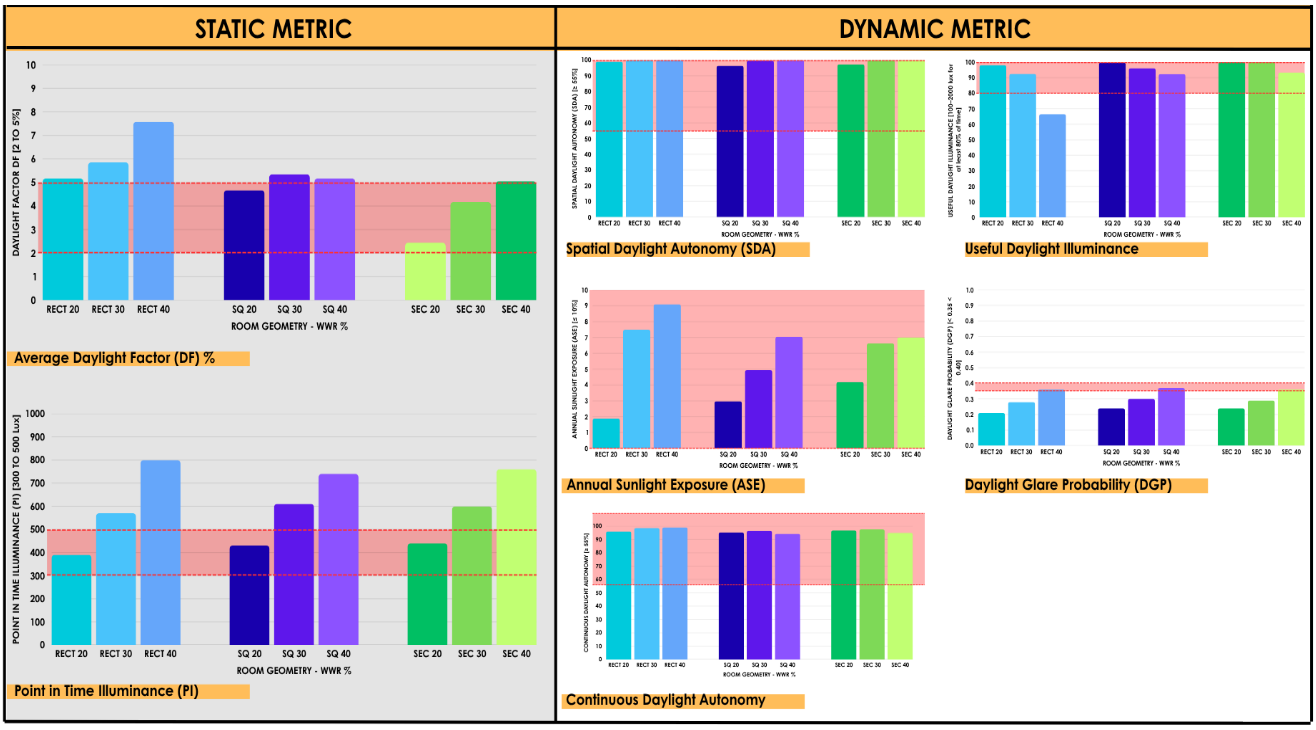


Fig. 5 Daylighting metrics simulations output- Case 1, 2, 3



DAYLIGHTING METRICS - CASE 4,5,6

Concrete [CEILING PLANE]- Matte White Acrylic paint [WALL PLANE]- Light-colored (White/Beige) Vitrified Tiles - Matte finish [FLOOR PLANE]

Fig. 6 Daylighting Metrics Chart- Cases 4, 5, 6

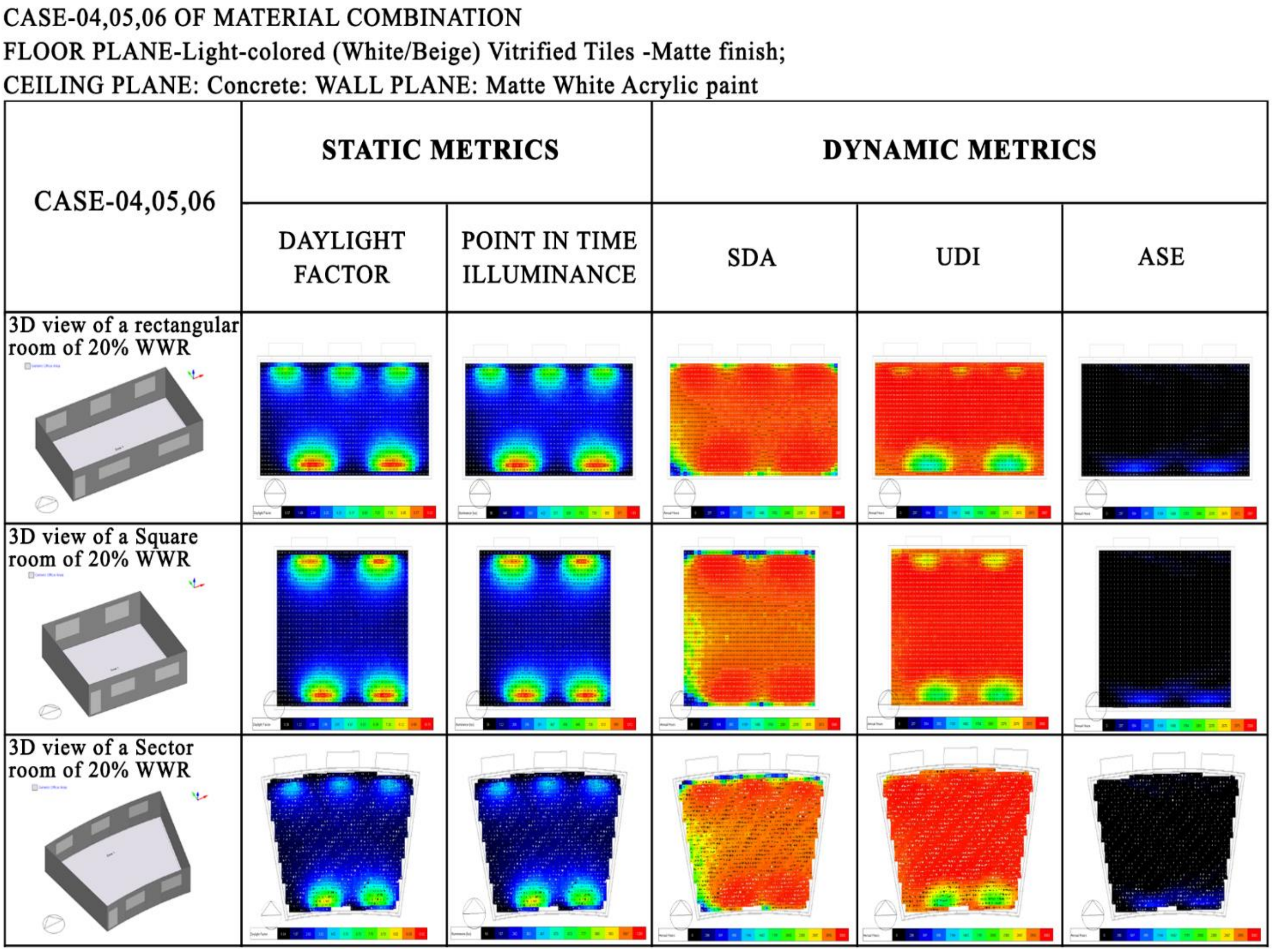


Fig. 7 Daylighting metrics simulations output- Case 4,5,6 [wwr=20%]

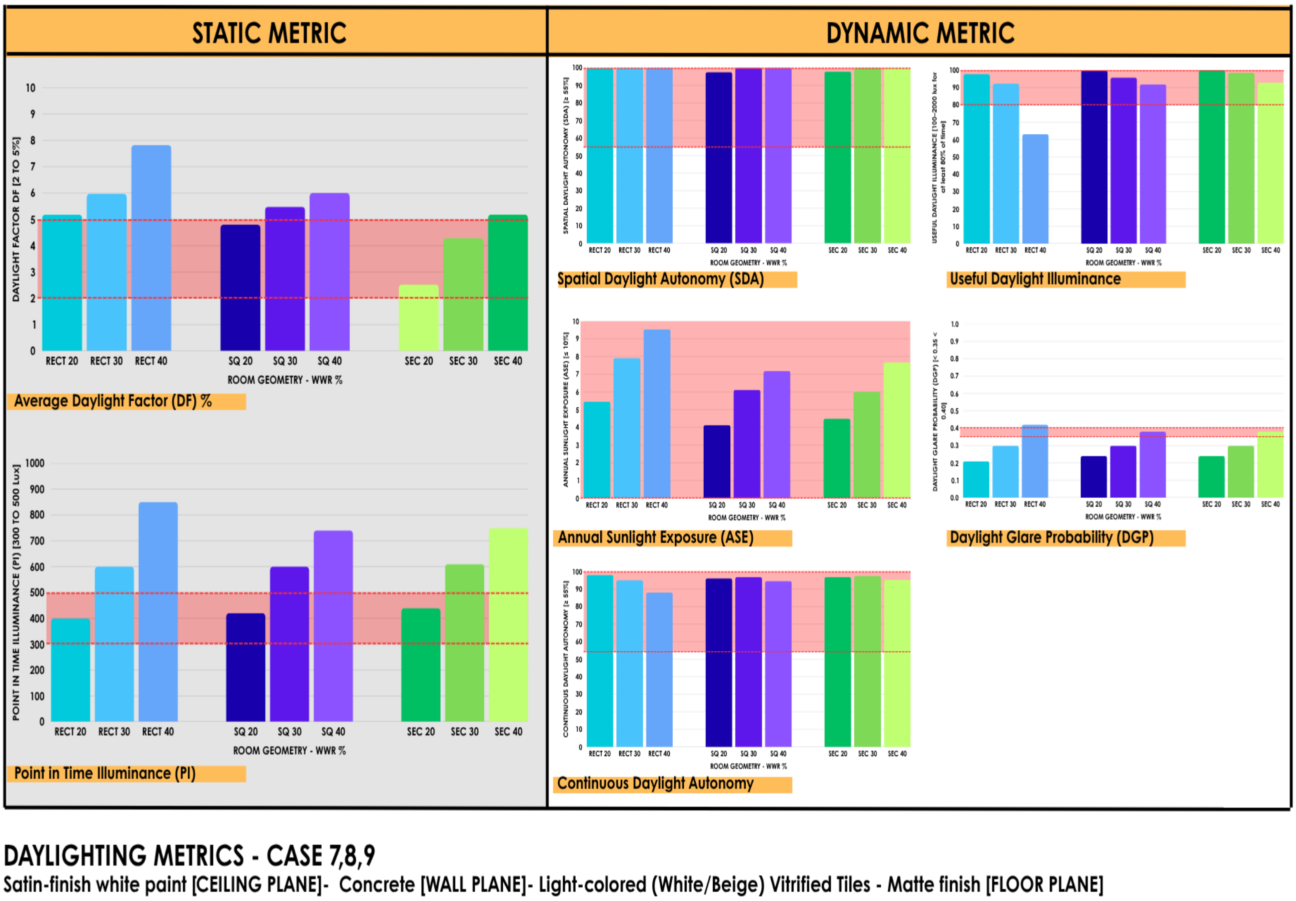


Fig. 8 Daylighting Metrics Chart- Case 7, 8, 9

5.2. Analysis of Daylight Metrics Case 4, 5, 6

Graph Set II, representing cases 4, 5, and 6, investigates daylighting performance with a material combination of concrete for the ceiling, matte white acrylic paint for the walls, and matte finish vitrified tiles for the floor. In terms of static metrics, optimal Average DF values are observed for the square room with 20% WWR (4.67%), the sector room with 20% WWR (2.445%), and the sector room with 30% WWR (4.173%), indicating satisfactory daylight penetration. In comparison, PTI is adequate in the rectangular room with 20% WWR (390 lux), the square room with 20% WWR (430 lux), and the sector room with 20% WWR (440 lux). Regarding dynamic metrics, SDA and CDA are high across all room geometries and WWRs (20%, 30%, 40%), confirming consistent and ample proper daylight supply. UDI values are generally within or close to the desirable range (above 80%) for all configurations, except the rectangular room with 40% WWR, which shows a lower 66.59%. ASE values remain consistently low across all scenarios, which is beneficial for minimizing excessive direct sunlight. Furthermore, DGP is found to be satisfactory for all room geometries with 20% and 30% WWR. The material combination, featuring matte surfaces and light colors, effectively contributes to these positive outcomes by diffusing light for more even illumination, reducing harsh reflections, and utilizing high reflectance values to bounce daylight deeper into the rooms, thereby uniformly increasing overall illuminance levels.

5.3. Analysis of Daylight Metrics Case 7, 8, 9

Graph Set III, representing cases 7, 8, and 9, investigates daylighting performance with a material combination of satin white paint for the ceiling, concrete for the walls, and matte finish vitrified tiles for the floor. Regarding static metrics, the ideal Average Daylight Factor (DF) values are found in the square room with 20% WWR (4.8%), the sector room with 20% WWR (2.525%), and the sector room with 30% WWR (4.284%), suggesting good daylight access, whereas PTI is sufficient in the rectangular room with 20% WWR (400 lux), square room with 20% WWR (420 lux), and sector room with 20% WWR (440 lux).

Concerning dynamic metrics, SDA and CDA are elevated for all room shapes and WWRs (20%, 30%, 40%), verifying a steady and abundant availability of beneficial daylight. UDI values typically fall within or near the preferred range (above 80%) for all setups, except for the rectangular room with a 40% WWR, which displays a reduced value of 63.048%. ASE levels stay uniformly low in all scenarios, which is advantageous for reducing excessive direct sunlight. Moreover, DGP is deemed acceptable for all room configurations with 20% and 30% WWR. The material blend focuses on enhancing total light through the ceiling while efficiently controlling glare through the diffuse characteristics of the walls and floor, resulting in a harmonious and pleasant daylighting atmosphere.

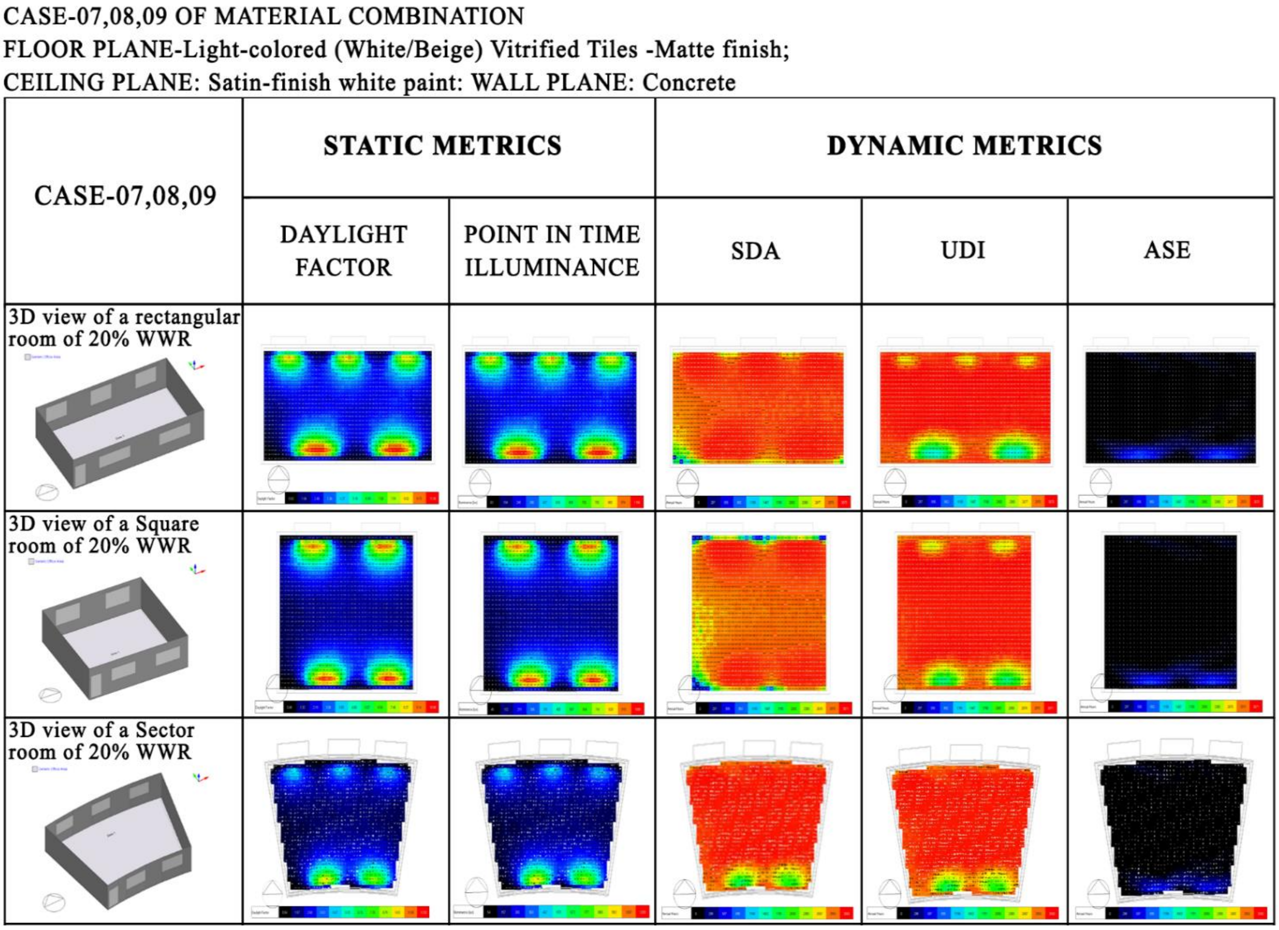


Fig. 9 Daylighting metrics simulations output- Case 7,8,9 [wwr=20%]

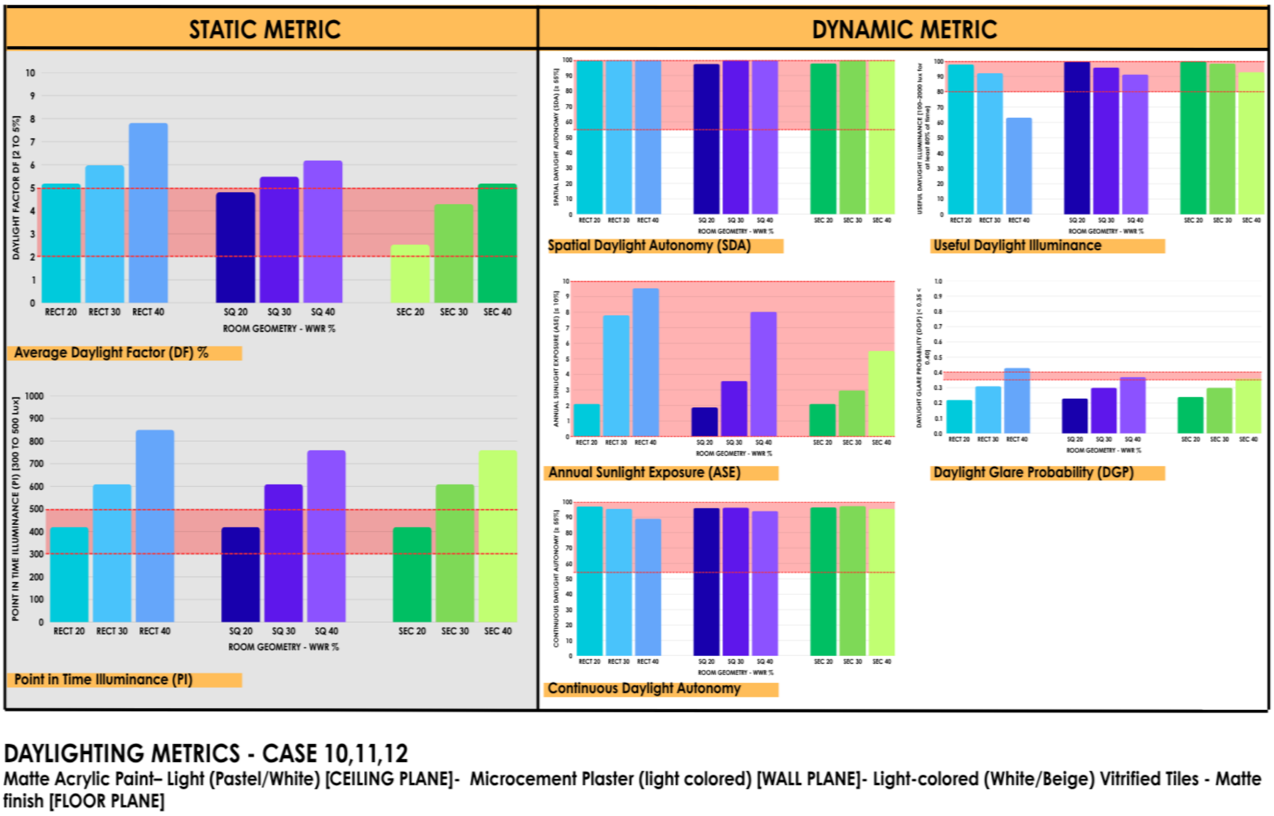


Fig. 10 Daylighting Metrics Chart- Cases 10, 11, 12

5.4. Analysis of Daylight Metrics Case 10, 11, 12

Graph Set IV, representing cases 10, 11, and 12, investigates daylighting performance with a material combination of Matte Acrylic Paint– Light Pastel or White for the ceiling, Micro cement Plaster (light colored) for the walls, and matte finish vitrified tiles for the floor. Static metrics show excellent daylight penetration, with Average DF reaching optimal levels in the square 20% WWR room (4.8%) and sector rooms at 20% (2.525%) and 30% (4.284%) WWR. PTI is also consistently adequate (420 lux) across 20% WWR rectangular, square, and sector rooms. Dynamically, SDA and CDA are robust across all tested room geometries and WWR (20%, 30%, 40%), ensuring continuous useful daylight. Furthermore, low ASE values minimize unwanted solar heat gain and glare, and DGP is satisfactory for all 20% and 30% WWR configurations. While UDI is generally strong (above 80%), the rectangular room with a 40% WWR is a notable outlier at 63.048%. This material combination effectively balances light reflection and glare control. The matte white ceiling paint maximizes light distribution, and the light-colored micro cement plaster walls also contribute to ambient light, which is instrumental in achieving this balanced and comfortable daylighting environment.

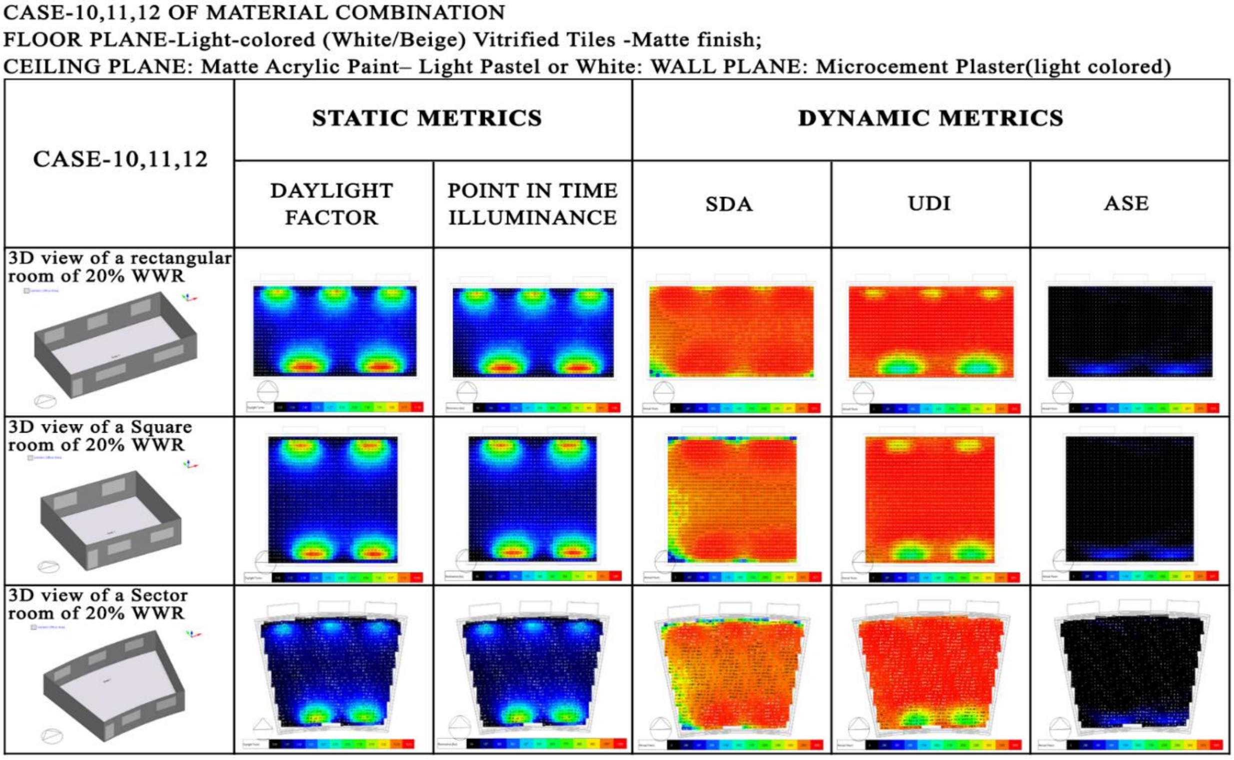


Fig. 11 Daylighting Metrics Simulations Output- Case 10, 11, 12 [wwr=20%]

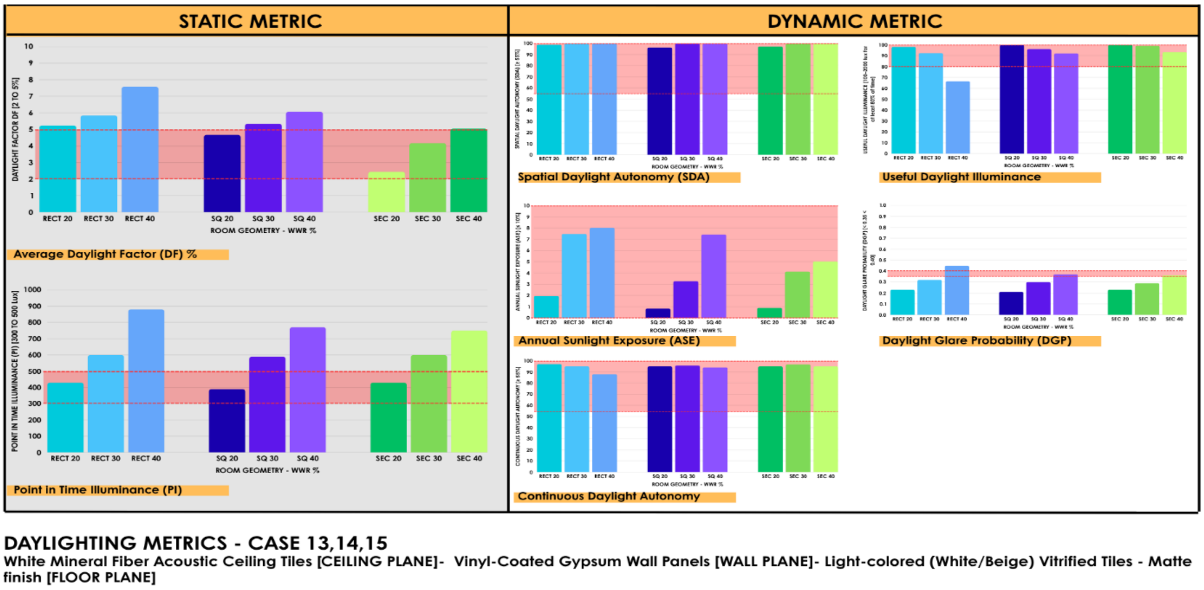


Fig. 12 Daylighting Metrics Chart- Case 13, 14, 15

5.5. Analysis of Daylight Metrics Case 13, 14, 15

Graph Set V, representing cases 13, 14, and 15, investigates daylighting performance with a material combination of White Mineral Fiber Acoustic Ceiling Tiles for the ceiling, Vinyl-Coated Gypsum Wall Panels for the walls, and matte finish vitrified tiles for the floor. Static metrics show excellent daylight penetration, with Average DF reaching optimal levels in the square 20% WWR room (4.67%) and sector rooms at 20% (2.445%) and 30% (4.173%) WWR. PTI is sufficient in the rectangular room with 20% WWR (430 lux), the square room with 20% WWR (390 lux), and the sector room with 20% WWR (430 lux). Dynamic metrics, SDA, and CDA are robust across all tested room geometries and WWR (20%, 30%, 40%), ensuring continuous useful daylight. Furthermore, low ASE values minimize unwanted solar heat gain and glare, and DGP is satisfactory for all 20% and 30% WWR configurations. While UDI is generally strong (above 80%), the rectangular room with a 40% WWR is a notable outlier at 66.59%. White Mineral Fiber Acoustic Ceiling Tiles provide high diffuse reflectance, efficiently spreading daylight and boosting overall illuminance. Vinyl-Coated Gypsum Wall Panels with a light color further enhance light distribution. Coupled with matte finish vitrified floor tiles, which effectively control glare, this combination optimizes daylight penetration, visual comfort, and acoustic performance.

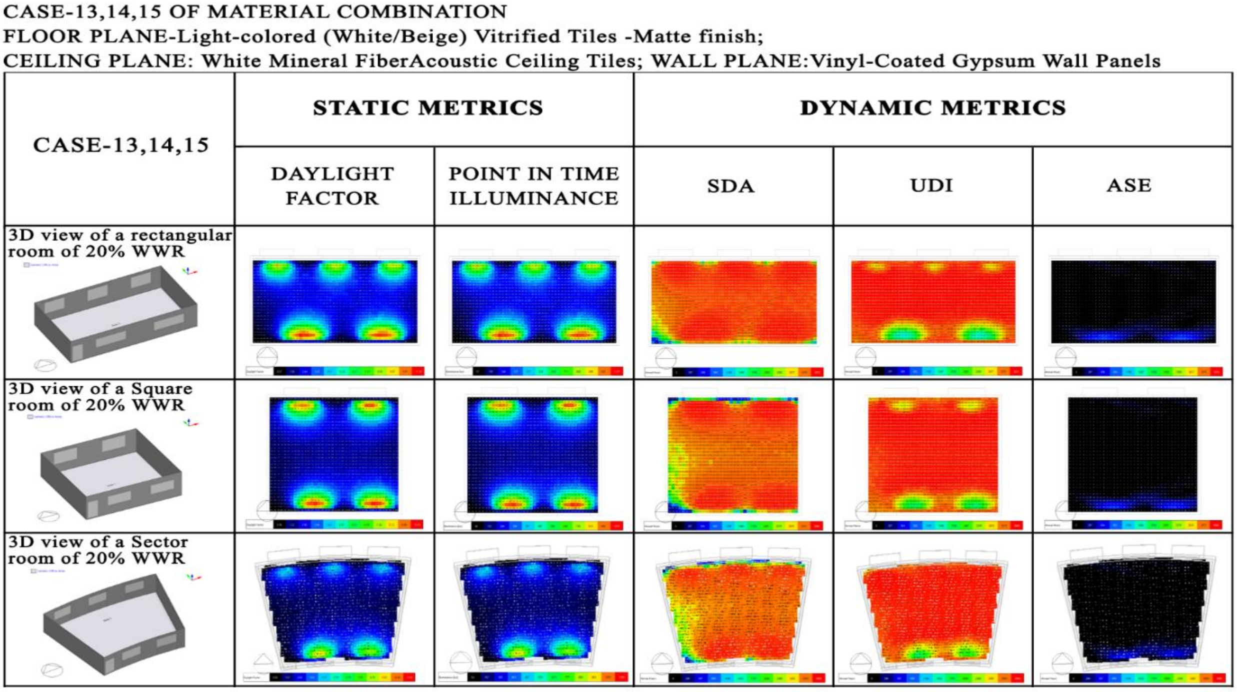


Fig. 13 Daylighting Metrics Simulations Output- Case 13, 14, 15 [wwr=20%]

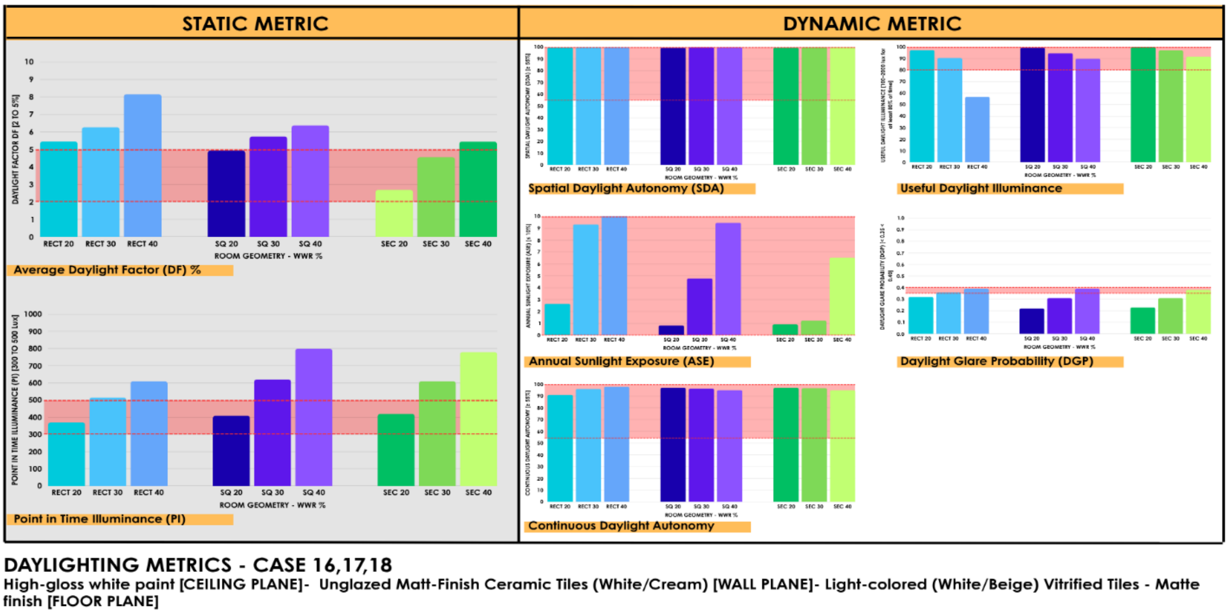


Fig. 14 Daylighting Metrics Chart- Case 16, 17, 18

5.6. Analysis of Daylight Metrics Case 16, 17, 18

Graph Set VI, representing cases 16, 17, and 18, investigates daylighting performance with a material combination of High-gloss white paint for the ceiling, Unglazed matte-finish ceramic Tiles (White/Cream) for the walls, and matte-finish vitrified tiles for the floor. Static metrics show excellent daylight penetration, with Average DF reaching optimal levels in the square 20% WWR room (4.94%) and sector rooms at 20% (2.692%) and 30% (4.559%) WWR. PTI is sufficient in the rectangular room with 20% WWR (370 lux), the square room with 20% WWR (410 lux), and the sector room with 20% WWR (420 lux). Dynamic metrics, SDA, and CDA are consistently high across all room geometries and WWRs (20-40%), ensuring continuous useful daylight. Low ASE values effectively minimize solar heat gain, and DGP is satisfactory for 20% and 30% WWR configurations. While UDI is generally strong (>80%), the rectangular room with 40% WWR is a notable exception at 56.659%. This positive outcome is supported by the high-gloss white ceiling paint, which maximizes light reflection and boosts overall illuminance and autonomy, complemented by the good diffuse light reflection from the unglazed matte-finish white/cream ceramic wall tiles.

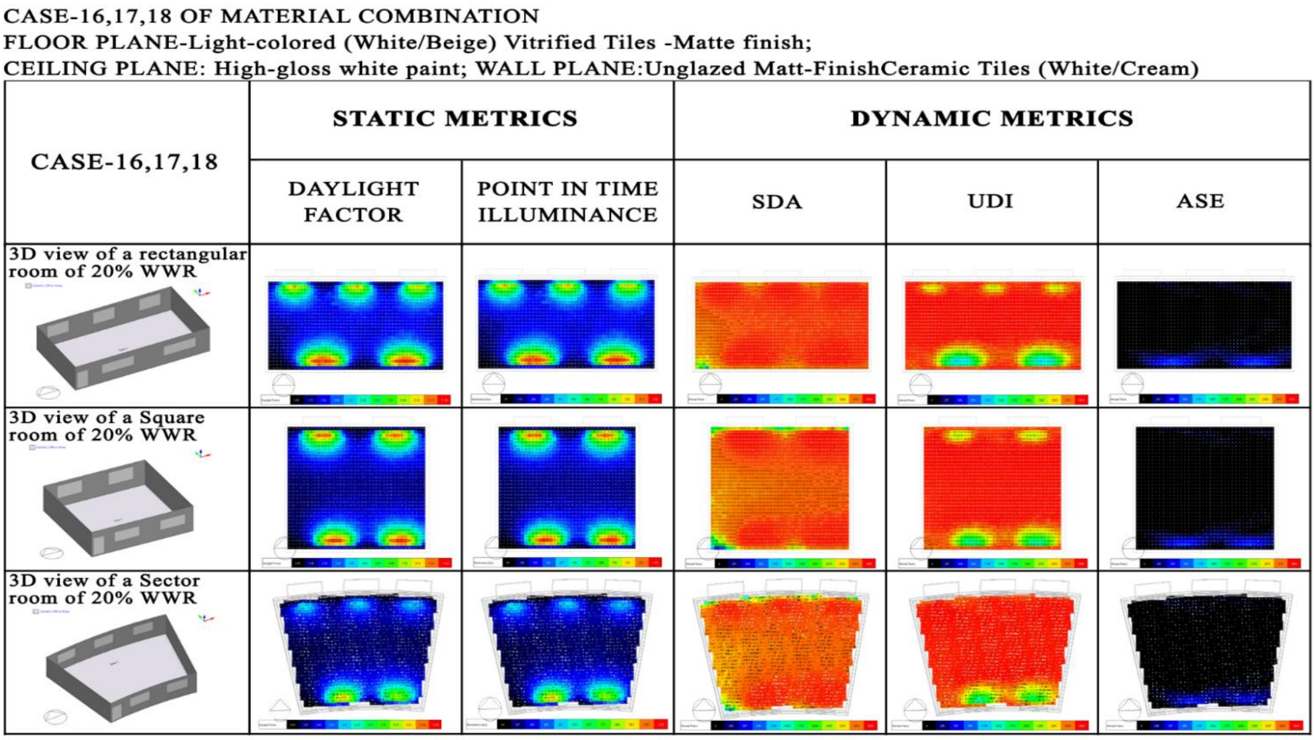


Fig. 15 Daylighting metrics simulations output- Case 16,17,18 [wwr=20%]

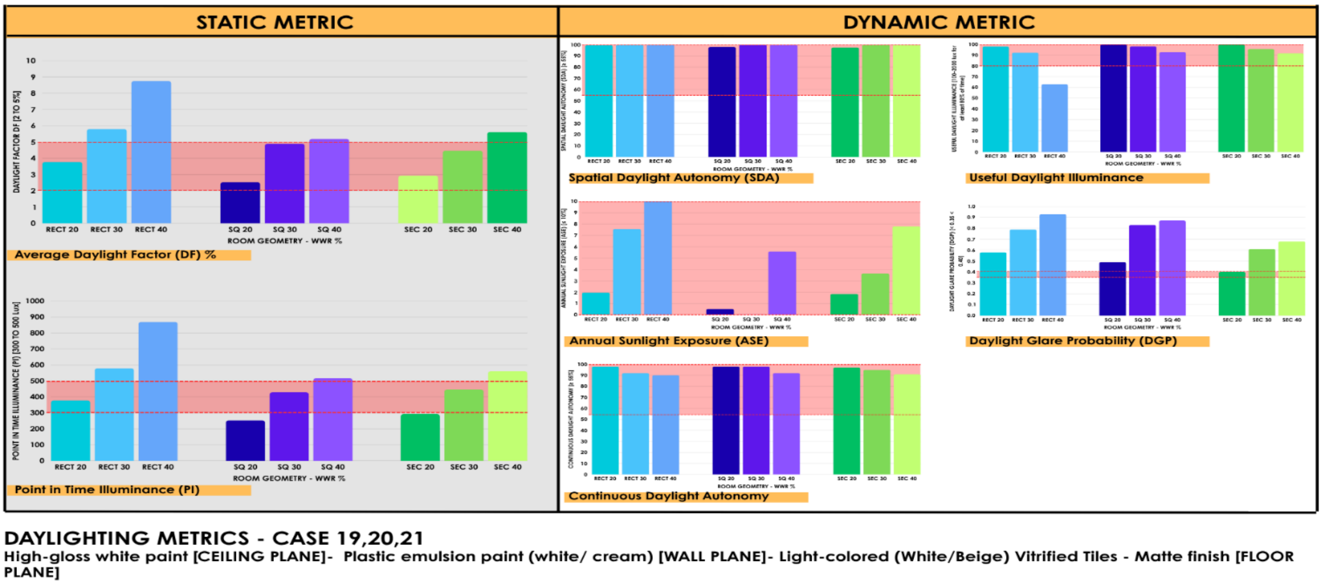


Fig. 16 Daylighting Metrics Chart- Case 19, 20, 21

5.7. Analysis of Daylight Metrics Case 19, 20, 21

Graph Set VII, representing cases 19, 20, and 21, investigates daylighting performance with a material combination of High-gloss white paint for the ceiling, Plastic emulsion paint (white/ cream) for the walls, and matte finish vitrified tiles for the floor. Static metrics indicate outstanding daylight access, with Average Daylight Factor (DF) achieving ideal levels in the Rectangle 20% WWR room (3.774%), square 20% WWR room (2.531%), and sector rooms at 20% (2.933%) and 30% (4.471%) WWR. The illuminance at a specific moment PTI is adequate in a rectangular room with a 20% window-to-wall ratio (378 lux), a square room with a 30% window-to-wall ratio (429 lux), and a sector room with a 30% window-to-wall ratio (447 lux). Dynamic metrics, SDA, and CDA remain consistently elevated across all room shapes and WWR (20-40%), guaranteeing ongoing beneficial daylight. ASE values vary when compared to different material combinations, yet remain within the ideal range. This mixture leads to elevated DGP, except for the Sector room with a 20% WWR, which remains within acceptable limits. High-gloss white ceiling paint greatly enhances daylight measurements by optimizing reflection. Plastic emulsion paint (white/cream) applied to walls offers superb diffuse reflection, improving light distribution and leading to elevated DF, PI, SDA, and CDA. The matte finish vitrified floor tiles play a vital role in controlling glare, successfully reducing reflections, and enhancing visual comfort by maintaining a low DGP. The following points are the key findings of the simulation study.

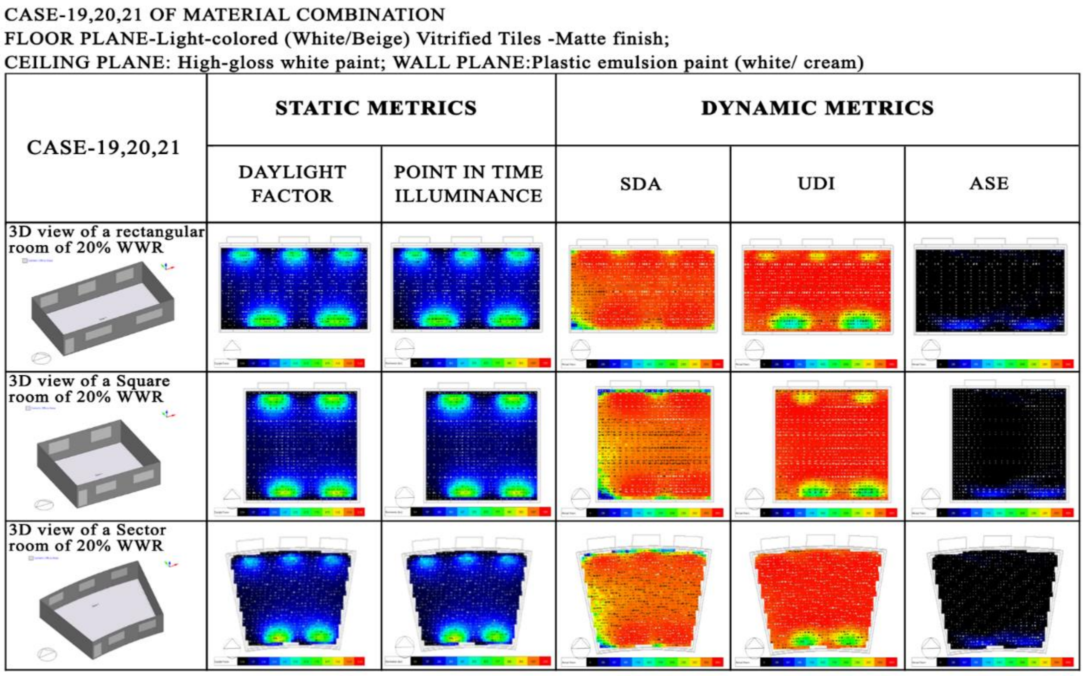


Fig. 17 Daylighting Metrics Simulations Output- Case 19, 20, 21 [WWR=20%]

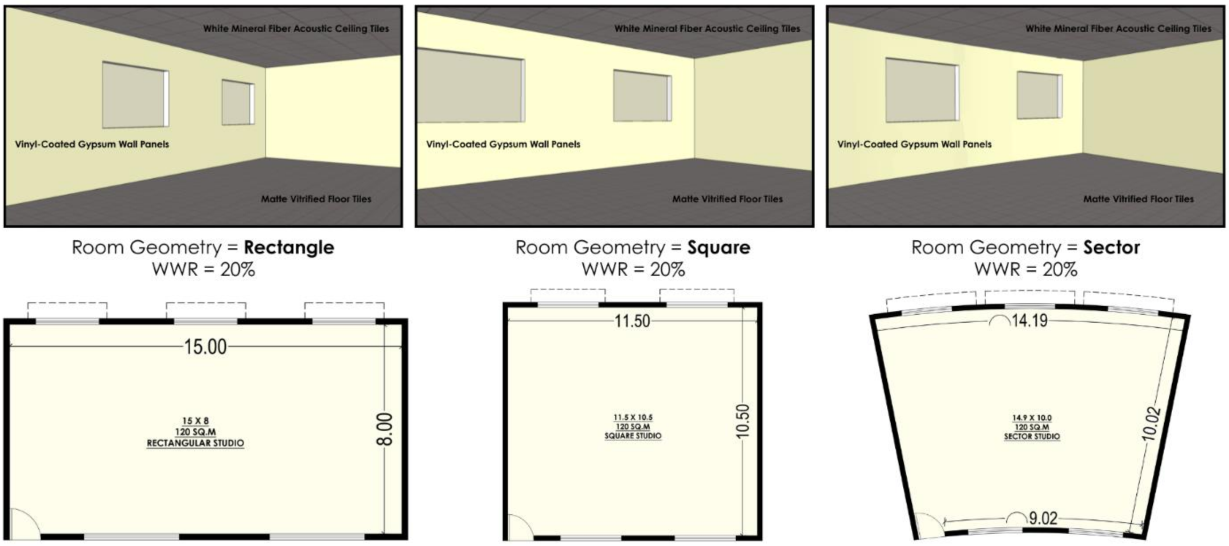
6. Results

1. Considering the daylighting parameters across all cases and three different room geometries, WWR of 20% in response to 7 different material combinations results in metrics within the recommended range, balancing daylight penetration and glare control in the classroom interiors.
2. Case 19, 20, and 21, investigates daylighting performance with a material combination of High-gloss white paint for the ceiling, Plastic emulsion paint (white/ cream) for the walls, and matte finish vitrified tiles for the floor, show elevated values of DGP above the acceptable value of <0.4 due to high gloss paint in the ceiling in combination with plastic emulsion paint on the wall which scatter light in all directions, the main factor contributing to high DGP.
3. Irrespective of the room geometry, PTL exceeds the optimal range with WWRs of 30% and 40% due to an excessive amount of daylight entering the interiors. The highly reflective interior surfaces bounce and redistribute the light throughout the classroom, exceeding the optimal range, leading to visual discomfort.
4. A Total of 21 cases with 7 material combinations resulting in 63 outcomes highlights, cases 1A, 2A, 3A, 4A, 5A, 6A, 7A, 8A, 9A, 10A, 11A, 12A, 13A, 14A, 15A, 16A, 17A, 18A have permissible values of both static and dynamic metrics.
5. The “best” material combination for daylighting in India classrooms with an ideal daylight metric values and no glare, specifically for a WWR = 20%, prioritizing a balance of good illuminance, low glare, and minimal excessive solar gain, given the hot and humid climate, Case 13,14,15: White Mineral Fiber Acoustic Ceiling Tiles- Vinyl-Coated Gypsum Wall Panels- Matte Vitrified Tiles combination shows excellent DF/PI, robust SDA/CDA, low ASE, and *satisfactory DGP* for WWR 20%. Cases 4,5, 6: Concrete for the ceiling, matte white acrylic paint for

the walls, matte finish vitrified tiles for the floor. Case 10,11,12: Matte Acrylic Paint - Micro Cement Plaster (light coloured) - Matte Vitrified Tiles are also an excellent choice due to the matte finish, which emphasizes diffuse reflection.

6. Rectangle room geometry with a window-to-wall ratio WWR 40% does not match the required Useful Daylight Illuminance value of 100–2000 lux for at least 80% of the time in cases 1, 4, 7, 10, 13, and 16, most likely due to having illuminance levels exceeding the upper limit of 2000 lux because of the direct and reflected daylight.
7. WWR = 20% Across all room geometries and under different material combination results in ideal recommended daylight metric values, as 20% WWR is typically large enough to allow a good amount of daylight into the classroom, particularly when paired with highly reflective interior surfaces. Also, 20% WWR has a less intense source of potential direct glare compared to larger windows.
8. The combinations with high-gloss ceilings (Cases 16, 17, 18, and Cases 19, 20, 21) are generally less desirable for classrooms in a tropical climate - India due to the risk of glare, even if simulations show “satisfactory” DGP for lower WWRs. The risk of visual discomfort is high due to direct or reflected glare, which can cause eye strain and reduce visual performance.

Case 13,14,15
White Mineral Fiber Acoustic Ceiling Tiles- Vinyl-Coated Gypsum Wall Panels- Matte Vitrified Floor Tiles



Case 4,5,6
Concrete Ceiling - Matte white acrylic paint walls - Matte finish vitrified floor tiles.

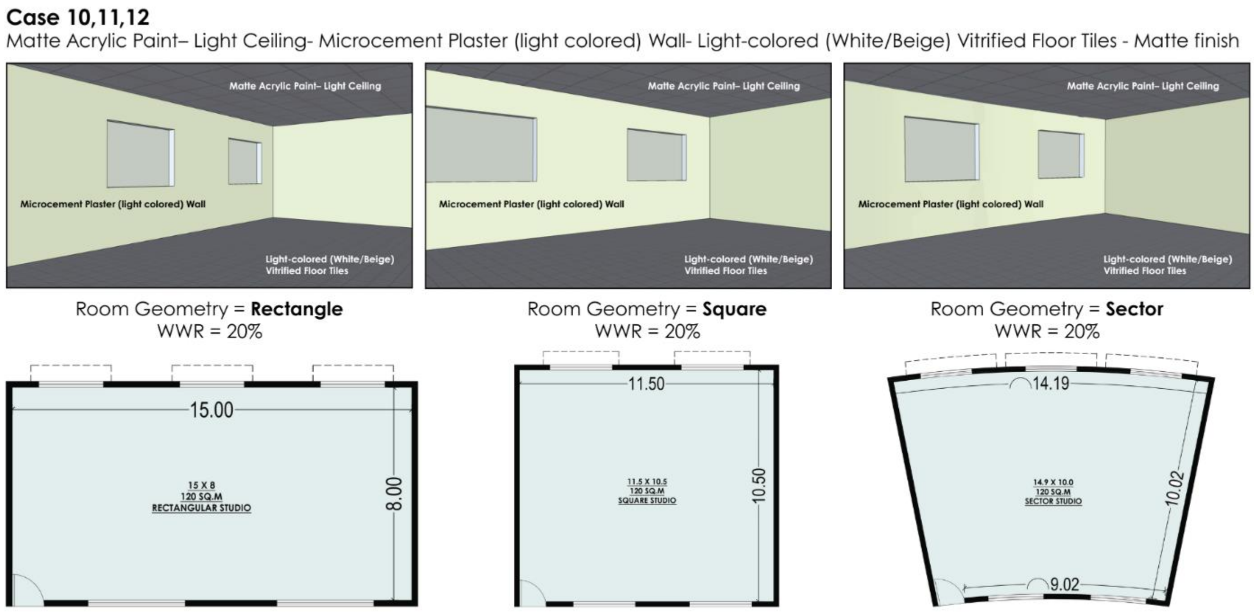


Fig. 18 Best Material Combination for Daylighting across all room geometries [WWR=20%]

7. Conclusion

Students, especially architectural students, spend much time indoors working on tasks that need good visual performance, so effective daylighting is crucial. This Research draws from a detailed analysis of daylight metrics in different material combinations and room shapes with various WWRs in tropical classrooms. It highlights key insights for improving student wellbeing and productivity.

The simulation study looked at square, rectangular, and sector room shapes with WWRs of 20%, 30%, and 40%. It also examined different interior surface reflectance properties with 7 different sets of material combinations. The findings show that a WWR of 20% consistently provides the ideal daylight metric values for all room types and material combinations while reducing glare. This 20% WWR balances enough light with reasonable control, especially in tropical climates, to avoid too much light and heat. While a high-gloss white ceiling generally increases light levels, the best overall combination for minimizing glare and achieving ideal metrics is White Mineral Fiber Acoustic Ceiling Tiles, Vinyl-Coated Gypsum Wall Panels, and matte finish vitrified tiles. This combination works well by promoting diffuse reflection from all surfaces, leading to even lighting and effective glare control.

The study confirms that the ceiling material plays a significant role in providing uniform lighting, while walls and floors contribute less but are still important for overall light distribution and glare management. Future Research should look into new building materials with higher Light Reflectance Values (LRV), explore various climate types aside from the specific one studied, and assess cost-effective, locally sourced materials to improve sustainable daylighting design in Indian schools further.

7.1. Advancements - Smart Glazing

Further Research should look into new building materials, such as smart glazing, that dynamically control the amount of light and heat entering a space. Electrochromic glass is one of the most advanced types. When the light becomes too strong, the glass darkens to reduce the glare and heat, and then clears when the light level drops. This kind of glazing can cut energy by 20% as per the studies conducted by the University of Washington Health Sciences (2019). In regions with intense sun exposure, aerogel glazing has emerged as another innovation. This material allows natural light to enter while preventing heat gain. Recent systems also integrate hybrid glazing and automated shading technologies, blending passive and active control. Roof-based innovative glazing systems, such as 3D louvers between the glass panels, allow diffused daylighting to enter evenly, perfect for large studios without visual discomfort [51].

7.2. Daylight Improvement Approaches in Different Countries

- Australia adapts to local sun pathways, which are all emphasized in Australian school design guidelines. In addition to strong daylight controls and occupant-adjustable shade, state education facility standards and energy/lighting specifications propose daylighting that minimizes summer heat and glare while permitting beneficial winter daylight [52].
- The Middle East achieves indoor comfort through spectrally selective coatings, deep external shade, fritted or reflective glass, and roof daylighting that blocks direct sunlight (light-diffusing domes, louvers). These methods preserve useful daylight for learning areas [53].
- Japanese passive daylighting with thermal balance: Sloped roofs, north lights, and carefully regulated overhangs are standard features in Japanese school

constructions that allow diffuse daylighting. Research indicates that these passive designs can drastically reduce energy use when envelope thermal performance and daylighting are combined [54].

- The United Kingdom building design practice focuses on façade geometry, high-performance glazing, light-shelves, adequately sized and placed windows, atria and clerestories, and daylight simulation early in the project. Guidance is driven by best-practice documents (CIBSE LG10) that link daylight performance to occupant comfort and energy outcomes, so projects routinely test SDA/UDI and glare during design [55].

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