SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V11I9P104

Volume 11 Issue 9, 39-53, September 2024

Orinal Article

Variations in Wall Fenestrations for Institutional Buildings to Achieve Optimal Daylighting - A Simulation-Based Approach, Case of Chennai, India

A. Harinya Meenu[1*], Swetha Madhusudhanan[1], Radhakrishnan Shanthi Priya[2], S. Nallusamy[3]

[1]*Faculty of Architecture, Dr. M.G.R. Education and Research Institute, Tamilnadu, India.*
[2] *School of Architecture and Interior Design, SRM Institute of Science and Technology, Taminadu, India.*
[3]*Department of Adult, Continuing Education and Extension, Jadavpur University, Kolkata, India.*

**Corresponding Author : harinyameenu.arch@drmgrdu.ac.in*

Received: 10 July 2024 Revised: 09 August 2024 Accepted: 12 September 2024 Published: 02 October 2024

Abstract *- Effective daylighting in institutional classrooms often results in lesser usage of artificial lighting, thereby reducing electrical consumption and additionally enhancing the visual comfort for the user. This study explores how to manipulate Window to Wall Ratios (WWR) strategically and include different forms of fenestration to optimize natural lighting in an academic studio environment. The process includes computer simulations using design builder software with varying cases. With the baseline conditions, cases are tested from minimum to maximum window area coverage, with several WWR layouts and increased sill levels to find the best ratio for optimizing daylight penetration. In addition to adjusting WWR, the research investigates various fenestration styles, such as light shelves and clerestories, which demonstrate their better performance. A thorough examination of daylight distribution patterns under different setups is made possible using the metrics Spatial Daylight Autonomy (SDA), Annual Sunlight Exposure (ASE), and Uniform Daylight Illuminance (UDI) by computational simulation. From the results, it may be noted that maximum illuminance inside the classroom can be achieved with respect to UDI, SDA AND ASE by having a 30% window wall ratio with the sill height of 1.5m without the addition of clerestory and light shelves.*

Keywords *- Daylighting, Higher education, Institutional building, Lighting quality, Useful Daylight Illuminance (UDI), Window wall ratio.*

1. Introduction

Daylighting is a demanding aspect of Architectural interior planning in any educational setting that fundamentally affects the overall comfort of the students and the educators. Educational Institutions, which operate only during the day, between 8.00 am to 6.00 pm, awareness is needed to promote good daylighting, highlighting the efficiency of students' performance [1]. In a tropical region like Chennai, Tamil Nadu, India, which experiences sunny days for almost 350 days a year, achieving daylight illumination as per the recommended standard requirement presents unique challenges all through the year [2]. As an integral part of the educational setting, Architectural design studios should promote innovation, creativity and efficiency. To support a wide range of activities that engage students in technical drawings, three-dimensional physical modelling, group discussion, and sheet presentation, these spaces must provide enough daylight with visual comfort to augment these activities [3]. Inadequate lighting design may cause eyestrain, weariness, and decreased cognitive function, all of which can impair learning.

2. Literature Study

2.1. Importance of Daylighting in Building

Daylighting in a building can accentuate human performance and improve productivity as it utilizes the natural light source to illuminate the building interior. It also enhances the occupant's mood and overall health [4]. An effective architectural design of the building should aim to maximize natural light, especially when the sun is above the horizon, which involves careful consideration of orientations, shapes, size, window placement and materials to optimize the effect of daylighting [4, 5]. For tropical climates experiencing hot summers and moderate winters, north facing windows provide good quality natural light throughout the day without glare. It avoids overheating in summer and excessive heat loss in winter by providing a stable and comfortable indoors [6].

Additionally, window orientation can reduce dependence on artificial lighting. Designers, Architects and consultants integrate the lighting code and standards while orienting the window direction, size and sill height in their design for better illumination during the greater period of the day [5, 7]. Among most building typologies, Institutional daylighting is considered more important as student learning in Institutions happens most of the time during the day between 8.00 am and 5.00 pm [8].

2.2. Institutional Daylighting and its Benefits on Students

Daylighting with proper illumination is an important aspect of the institutional design to enhance the visual comfort for students in creative studies [9]. Natural lighting plays a major role in maintaining circadian rhythm and regulating the biological clock for various physiological wellness. Daylighting is an important factor in improving cognitive functions and emotional wellbeing as it can improve academic productivity in students. Better visualization of spaces improves design skills, increases creativity and innovation, and enhances practical learning for the students, as well as how a well-lit space augments their learning process [10].

In three districts in the United States of America- Washington, California, and Colorado-Heschong examined the academic performance and accomplishments of 21,000 pupils. In comparison to pupils in the least illuminated rooms, the results indicated that students in naturally lit classrooms advanced 20% quicker on math tests and 26% faster on reading tests, with 7–18% higher scores. Mabdeh, in his research, identified various retrofit measures to achieve effective passive daylighting in institutions through radiance software simulation [10, 11]. Study after study on daylighting in classrooms revealed improved student performance and achieved 55% energy savings through daylighting when compared to artificially illuminated schools [11].

2.2.1. Physiological Benefits of Daylighting on Students and Staff

Daylighting exposure is associated with the production of the hormone serotonin, which promotes well-being. Studies indicate that students and staff exposed to adequate natural light have lower occurrences of sleep disorders as daylighting synchronizes the sleep-wake cycle by modulating circadian rhythm. Daylighting offers better visual comfort than artificial lighting, which creates eye strain and fatigue caused by prolonged reading and screen activities. It also regulates vitamin D production, which is required for bone health and immune function, by lowering blood pressure and heart rate, creating a calmer and healthier environment. The natural variation in the light intensity throughout the day can keep students less lethargic [12, 13].

2.3. Building Components that Promote Daylighting

Building components like fenestrations, windows, and clerestory play a major role in resolving the quality of light entering the space. Furthermore, the fenestration light shelves, which reflect daylight indoors, can also help to provide glare free visual environment [14]. Sill height determines the point at which the window begins and determines the quantity of light falling on a work plane. In institutions catering to creative design studies, the work plane is 0.8m from the finished floor level. A study conducted by Maleki in 2021 reveals that varying sill height for different orientations leads to different daylighting outcomes with an increase in energy efficiency, especially in office buildings [15].

2.3.1. Importance of Fenestrations

Fenestration plays a critical role in enhancing daylighting performance within the building, and it also augments pleasing vista through visual connection to the outdoors by natural views, which in turn creates a conducive learning atmosphere. Fenestration, such as window clerestory, is designed in various sizes, shapes, and orientations to optimize daylighting. The window to wall ratio plays a major role in resolving the quality of light entering indoors [16].

Fixed windows allow daylighting where ventilation is not a priority, operable windows provide natural ventilation and daylighting, and clerestory windows allow light to enter while maintaining privacy and reducing glare, making it ideal for large spaces [17]. Light shelves, which are horizontal surfaces, reflect daylight deeper into the interior space and provide shade to the lowest window from direct sunlight, thus reducing the glare and illumination of daylighting [18].

The placement and size of windows should be designed to maximize daylight penetration into larger areas. Optimal daylighting should be achieved on a work plane at 0.8m height where the actual lighting falls on the working table. Windows or clerestory can bring more illumination deeper into interior spaces, which is governed by an important factor known as the Window Wall Ratio (WWR) [19].

2.3.2. Use of Clerestory Window in Educational Institutions

A clerestory window is found in the upper part of the wall above the eye level near the roofline, which effectively paves the way to bring in glare free daylighting with good illumination. This can be continuous or segmented, adapting to fit the architectural style of the building [20]. Orienting north-facing clearstories in the northern hemisphere provides consistent and diffused light. They can be either fixed or operable [21].

Clearstories allow for natural light and outdoor views without compromising the privacy of the interior spaces. It also gives a sense of special volume in large institutional buildings. These windows bridge the gap as a biophilic design element between the indoor built spaces and the outdoor environment through a visual connection. In a multifunctional space, attributing to the flexibility in space, clearstories can provide adaptable lighting conditions based on the time of day [22].

2.3.3. Use of Light Shelves in Educational Institutions

Light shelves are designed to spread uniform light indoors, reaching even the spaces furthest away from the space; the need for artificial light reduces and hence increases the energy efficiency of the element. The light distribution of the light shelves is done through reflectance, thereby reducing the glare effect from direct sunlight, which is an important factor required for classroom visual comfort [23]. Parameters like SDA, UDI, and ASE are very important in quantifying the required amount of daylight entering the built space.

2.4. WWR in Institutional Fenestrations

WWR plays a major role in indoor daylighting, which stipulates the proportion of a building wall area that is covered by a window. It is expressed in percentage and is calculated by dividing the total area of the window by the total wall area (excluding the door and other openings) and then multiplying by 100 [23].

$$\text{WWR}= (\text{Total window area}/ \text{Total wall area}) \times 100$$

The optimal WWR should balance these factors to achieve a comfortable and sustainable indoor environment [23]. According to Ayoosu et al., the research suggests that a minimum WWR of 12- 14% is necessary for adequate daylighting in a school building. A higher window to wall ratio can increase daylight penetration, improving the overall illumination [18]. As per the research conducted by Alwetaishi, a WWR of around 30% is optimal for daylight performance in lecture theatres. Different WWRs can be implemented in institutional buildings as each space has a distinct impact on daylighting [19].

2.4.1. Types of WWR in Institutions and their Impact on Daylighting

A low WWR of 0-20% configuration has minimal glazing compared to the wall area and is suitable for spaces where daylighting is less critical. A moderate WWR of 20-40% range has a balance between the glazing and the wall area. It allows for an effective strategy, such as light shelves or reflective surfaces, to distribute light evenly indoors and is the most recommended for classrooms and other learning environments. A high WWR of above 40% leads to excessive solar heat gain, glare and potential overheating and is not recommended for hot tropical climates. If the usage is unavoidable, proper shading devices must be used to mitigate this issue [24].

2.5. Role of DF, SDA, UDI and ASE in Quantifying the Spatial Illumination Indoors

DF, SDA, UDI, and ASE are important quantifying metrics for analyzing building daylight design. Each of these parameters is unique to find the different aspects of daylighting

2.5.1. Daylight Factor

The percentage of the ratio of internal illumination at a given location within a room to exterior daylight illumination under a cloudy sky is known as the daylight factor. DF= (Ei x Eo) x 100 %. One of the three components of illumination, the Sky component, plays a vital role in increasing the daylight factor, for example, placing a window.

Hence, it “sees” more of the sky rather than the adjacent building. As per the international standard in the UK CIBSE lighting guide, which broadly bands average daylight factor into the following categories under 2% DF, it is taken as no adequate lit space and artificial lighting is required all the time. For over 5% of DF, artificial lighting is generally not required except at dawn and dusk but may be subjected to glare and solar gain. Architects and designers, for effective window size, placement, and the type of glazing to be used to enhance daylight performance in the interiors [25], use daylight factor as the optimization metric.

As per Liang et al.'s study for educational spaces, a DF greater than 2% is considered a prerequisite for most activities in a well-lit environment for healthcare spaces. The values ranging between 2% to 5% are considered optimal for visual comfort and productivity as per design guidelines prescribed by setting the Standard for Environmental and Energy Design Leadership for finding Window to Floor Ratio (WFR). For occupancy in institutional settings for creative studies where students may spend long hours of more than 10 hours, DF has been linked to enhanced mood, increased alertness and support circadian rhythm for general wellbeing [26].

2.5.2. Spatial Daylight Autonomy

Sufficient daylighting for a given space is measured using SDA for a specific occupied hour, 55% of the time spent during institutional working hours of 8 am to 6 pm, which receives a minimum of 300lux above 0.8 meters above the finished floor level (standards). This metric helps to understand how well a space is naturally lit throughout the day in a year by daylight illumination [27]. An increase in SDA indicates better illumination by daylighting, enhancing the visual comfort of the occupants [28].

2.5.3. Useful Daylight Illuminance

This metric helps in evaluating the beneficial quantity of daylighting that falls within a “useful range” for the occupants for activities such as reading and working. The three bands of UDI “Fell short” (<100 lx), “Useful” (100- 500 lx), and “Exceeded” (>2000 lx). Quantifying the amount of time spaces receive useful daylight helps the designer plan the window orientation and placement of shading devices to maximize daylight illumination and minimize glare. To ensure daylighting positively contributes to the indoor habitat, it is divided into two categories [29, 30], namely, UDI – a (for acceptable daylighting level), UDI – e (for excess daylighting level).

2.5.4. Annual Sunlight Exposure

This measures for one year the amount of direct sunlight that an indoor space receives above a certain threshold required (eg.1000 lx). This metric is important in the analysis of glare and overheating. By properly analyzing this data, designers can plan the fenestration mindfully without compromising the occupant's visual comfort (or) leading to excessive heat gain [31].

These metrics provide a complete sense of how daylighting interrelates with building interior spaces for assessing daylight performance, allowing architects and engineers to develop a fenestration design for occupants' comfort while minimizing potential drawbacks. The change from the conventional metrics like the daylight factor to these distinct measures implicates the evolving specific consideration of how daylighting in different aspects impacts human acquaintance in a built habitat [32].

Table 1. ECBC suggested WWR percentage for education institution

Structure Type	**percentage of above-grade floor space that satisfies the UDI criteria**		
	ECBC	**ECBC +**	**Super ECBC**
Business, Educational	40%	50%	60%

2.6. Environmental Impact Potential Saving in Carbon Emission

This would provide a holistic view of the benefits of optimal daylighting, effective passive daylighting strategies such as building orientation, fenestration design such as light shelves, reflective louvers, and prismatic glazing can reduce energy usage by up to 50% in institutional buildings .passive daylighting improves indoor environment quality by lowering the operational energy use and reducing environmental footprint with lower Greenhouse gas emission as per the study [33].

2.7. Recommended International and National Standards for Daylighting in Institutional Building

2.7.1. Illumination Engineering Society Standards for Spatial Daylight Autonomy (SDA) and Annual Sunlight Exposure (ASE)

The term "ASE" refers to the proportion of an analysis area that is above a direct sunshine illuminance level (e.g., 1000 lux) for more than 250 hours annually. As a supplement to SDA, ASE helps designers limit excessive sunlight. ASE may denote glare risk. SDA evaluates whether an area gets enough daylight on a work plane at 0.8m height during normal operation hours on a yearly basis.

The aim is to provide 300 lux for 50% of the time spent on an institutional building [12]. In India, the Bureau of Energy Efficiency recommends minimum standards for effective daylighting with the help of the Energy Conservation Building Code 2017, as indicated in (Table 1), which indicates the standards to be followed for manual measurements and computer simulations. Computer simulation is done through BEE-approved daylighting simulation software.

2.7.2. ECBC Standards for Calculation of UDI, WWR and for Modelling Simulation

For at least 90% of the potential daylight period, buildings must reach 100 lux to 2,000 lux for the minimum floor area as in (Table 1). All places enclosed by opaque, translucent, or transparent interior partitions over 2 m from the finished floor must be measured for illumination. Normal Measurements will be taken 0.8 m above the finished floor on top of the work plane. All institutional buildings imparting design-related courses will be analyzed for 8 hours per day from 8:00 am to 5:00 pm IST, totaling 2,920 hours.

Useable daylight throughout a space is measured using point-by-point grid values. A minimum of one point is considered per square meter of floor area for measuring Uniform Daylight Illuminance (UDI). Material specification sheets, as prescribed by the manufacturer, specify actual Visible Light Transmission (VLT) for fenestration modelling. All surrounding natural or artificial daylight obstructions must be modelled if the distance between the façade and the obstructions is less than or equal to twice their height. Default reflectance of 30% and 0% will be applied when it is unknown for all vertical surfaces of obstructers, both natural and artificial.

Simulation models are developed with values of interior surface reflectance using material specifications as prescribed by the manufacturer. In the absence of material specification, the default values, as mentioned in Table 2, are to be used.

Table 1. Default values for surface reflectance as prescribed in ECBC 2017

Surface Type	**Reflectance**
Wall or Vertical Internal Surface	50%
Ceiling	70%
Floor	20%
Furniture (Permanent)	50%

All climate zones must have vertical fenestration standards that satisfy the following requirements for compliance with the three incremental energy efficiency levels: ECB, ECBC+, and Super ECBC.

a) The maximum permitted Window Wall Ratio (WWR), which is 40%, is applicable to structures that demonstrate conformity with the Prescriptive Method, which includes the Building Envelope Trade-off Method.
b) The minimum permitted Visual Light Transmittance (VLT) is 0.27 [34].

2.7.3. NBC Standards for Illumination Levels as per National Building Code, 2016 [35]

Table 2. NBC standards for illumination

Type of Interior in Education Building	Range of Service Illumination	Quality class of Direct glare limitation
Assembly Hall	200-300-500	3
Teaching / Lecture Space	200-300-500	1
Demonstration Benches	300-500-750	1
Seminar Rooms	300-500-750	1
Art Room	300-500-750	1
Libraries	200-300-500	1
Laboratories	300-500-750	1
Workshop	200-300-500	1

2.7.4. NLC standards for Illumination Levels [36]

Table 3. Recommendations for the various locations of an educational institution about lighting levels and glare index

Area	Illumination (Lux)	Glare Index
Classrooms	300	16
Lecture Rooms	300	16
Reading Rooms	150-300	19
Laboratories	300	16
Corridors	70	-
Libraries	300	16
Auditorium	70 (Stage Area- 300)	-
Cafe	100	-
Staff Room	150	-

Thus, a comfortable indoor environment for occupants can be ensured by using a simulation tool like Design builder. The percentage of above-grade floor space that satisfies the UDI criteria creates a table tag for this content to derive metrics such as spatial daylight autonomy, annual sunlight exposure, and useful daylight illuminance to optimize different lighting scenarios and validate design fenestrations [37].

2.8. Use of the Simulation Tool - Design Builder for Adequate Illumination

Design Builder software version 6 gives an extensive analysis of building performance by integrative daylight simulation with modelling. This aids in the perception of how daylighting and energy influence one another. A simple graphical interface for the modelling process makes this software for both experienced professionals and newcomers.

This software uses an energy-plus engine as it assists in accurate simulation for complex design systems. This proficiency allows this software version 6 to study how daylighting correlates with other building elements for quantitative optimization of daylighting. This software uses various metrics such as DF, SDA, UDI, and ASE. The flexibility in modelling design is allowed in this software for exploration of various design options as it helps in finding the optimal solution [38].

This software avails a two-module approach: one is an energy plus module based on solar irradiation data, and another one is a radiance-based module which uses outdoor illuminance characteristics from selected sky models. This result is more accurate depending on the needs of the project. Comprehensive data input options that include geometrical and optical properties of the room, as well as various weather conditions, enhance the accuracy of simulation for different scenarios. This software is more reliable for professionals as it has been validated against the empirical data for the demonstration of satisfactory accuracy in daylight calculation [39]. Thus, the present research focuses on conducting a pilot study for an institutional classroom addressing three main parameters, namely window to wall ratio, addition of clerestory and light shelves to achieve effective illumination using the metrics Annual Sunlight Exposure (ASE), Spatial Daylight Autonomy (SDA), Uniform Daylight Illuminance (UDI) by computational simulation.

2.9. Innovative Daylighting Technologies for Institutional Building in Tropical Climate

The dynamic shading system is most preferred in the tropical region as there are notable shifts in the sun angles throughout the day. This system plays an efficient role in sustaining a plush indoor temperature with optimal lighting for study purposes. The use of optical components that both refract and disperse light prismatic glazing creates a consistent distribution of daylighting. Contrarily, smart windows utilize electrochromic or photochromic material to alter their transparency about the outdoor environment. These are more appropriate for tropical climates as they are crucial to managing solar heat gain.

In tropical settings, controlling glare is a crucial aspect. Reflective louvers are a good solution as they reflect light into deeper portions of the room with dispersed light, reducing the effect of direct sunlight. Light courts, like a smaller courtyard, can allow daylight penetration on multiple levels. These passive strategies will create a well-lit interior with good ventilation. Areas like hallways and inner classrooms that lack outside windows can be fitted with light tubes as they block UV Radiation and prevent heat transfer. These are very effective for tropical climates [40].

3. Materials and Methods

3.1. Study Area

The pilot study considered for the research is a Design studio of an Institutional building located in Chennai, Tamil Nadu, India. The studio measures 1469 sq.m and is located on the first floor, as shown in Figures 1, 2 and 3. Four windows of size measuring 1.8mx1.2m face west on the roadside, and the remaining four windows of similar size face east towards the internal courtyard, as shown in Figure 4(a).

Fig. 1 Geographical location of the site

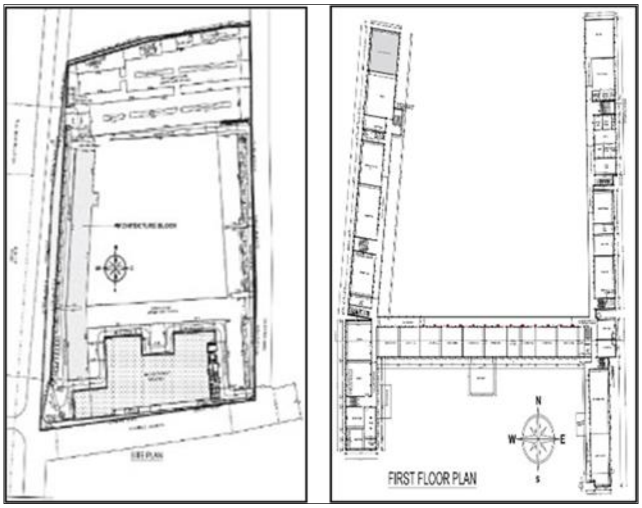

Fig. 2 Plan of the studio under study

The existing sill height of the classroom subjected to study is 0.9m from the finished first floor level with a ceiling height of 3.5m and has a window to wall ratio of 17% on both the west and east sides, as indicated in Figure 4(b). During the simulation process, in all cases, the painted white walls on the north, west and eastern sides, the pin-up boards on the southern wall, the rough white textured paint finish on the ceiling and the half-white matt ceramic tile for flooring are considered as constants in design. Basic furniture required in the studio and external factors, namely, temperature, humidity, wind speed, and adjacent built forms, are not considered for the study.

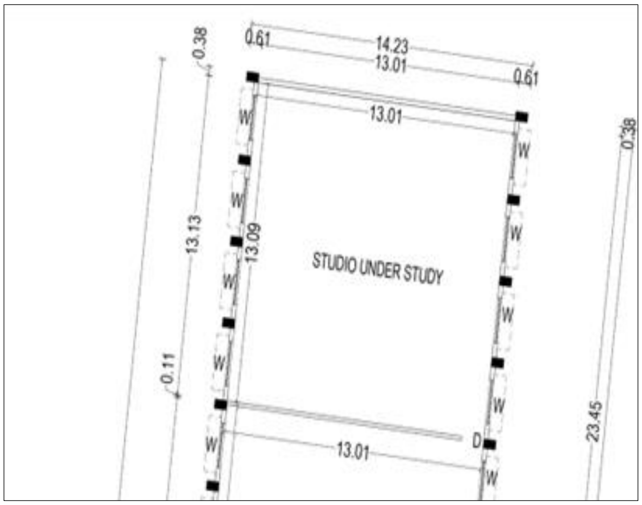

Fig. 3 Plan of the studio under study

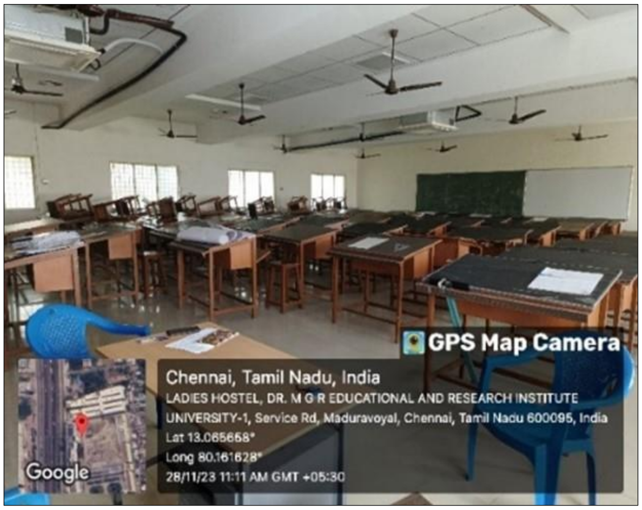

Fig. 4(a) Plan of the studio under study

The simulation is calculated for the Institutional building operating from 8-5. For this simulation, the sky model of clear sky is used with the work plane height at 0.8m from the floor level on which the simulations are calculated. The climate data inputs of the study location are used from ASHRAE standard climate data. The window glazing used has the properties of

Total Solar transmission – 0.691, Direct Solar transmission- 0.624, Light transmission – 0.744, U value (ISO10292/ EN673) (W/sq.m- K)- 1.924. The final output is taken in a daylighting map/grid of 0.3m x 0.3m. Simulation Output Parameters Daylight Illuminance Levels: Specify the desired daylight illuminance metrics, such as Daylight Autonomy (DA), Spatial Daylight Autonomy (SDA), and Annual Sunlight Exposure (ASE).

These are some of the main parameters you would set when using DesignBuilder for daylighting analysis. The specific values and settings would depend on the particular requirements of your project, the local climate, and building design considerations.

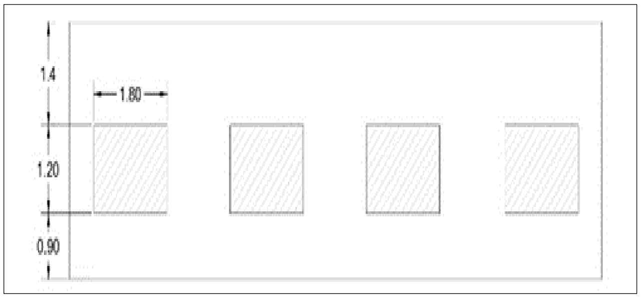

Fig. 4(b) Existing fenestration with 17 % of WWR

3.2. Performance of Simulation with Varied Sill Levels and Window Wall Ratio

3.2.1. Existing Sill Level of 0.9m with Varied WWR

The window wall ratio has been varied to 20%, 30% and 40% for the existing sill height of .9 m from the finished first floor level. The simulation was performed to find the values of SDA, ASE, and UDI for illumination on a work plane at 0.8m from the finished floor level, as shown in Figure 6. For a WWR of 20%, the lintel is maintained at .9 m from the finished first level, and the width of the windows is 1.8m, as shown in Figure 6(a). For WWR of 30%, the lintel is maintained at 0.9m from the finished first floor level, and the width of the windows is 1.95m, as indicated in Figure 6(b). Similarly, for WWR of 40%, the lintel is maintained at 0.9m from the finished first floor level, and the width of the windows is 2.7m, as seen in Figure 6(c).

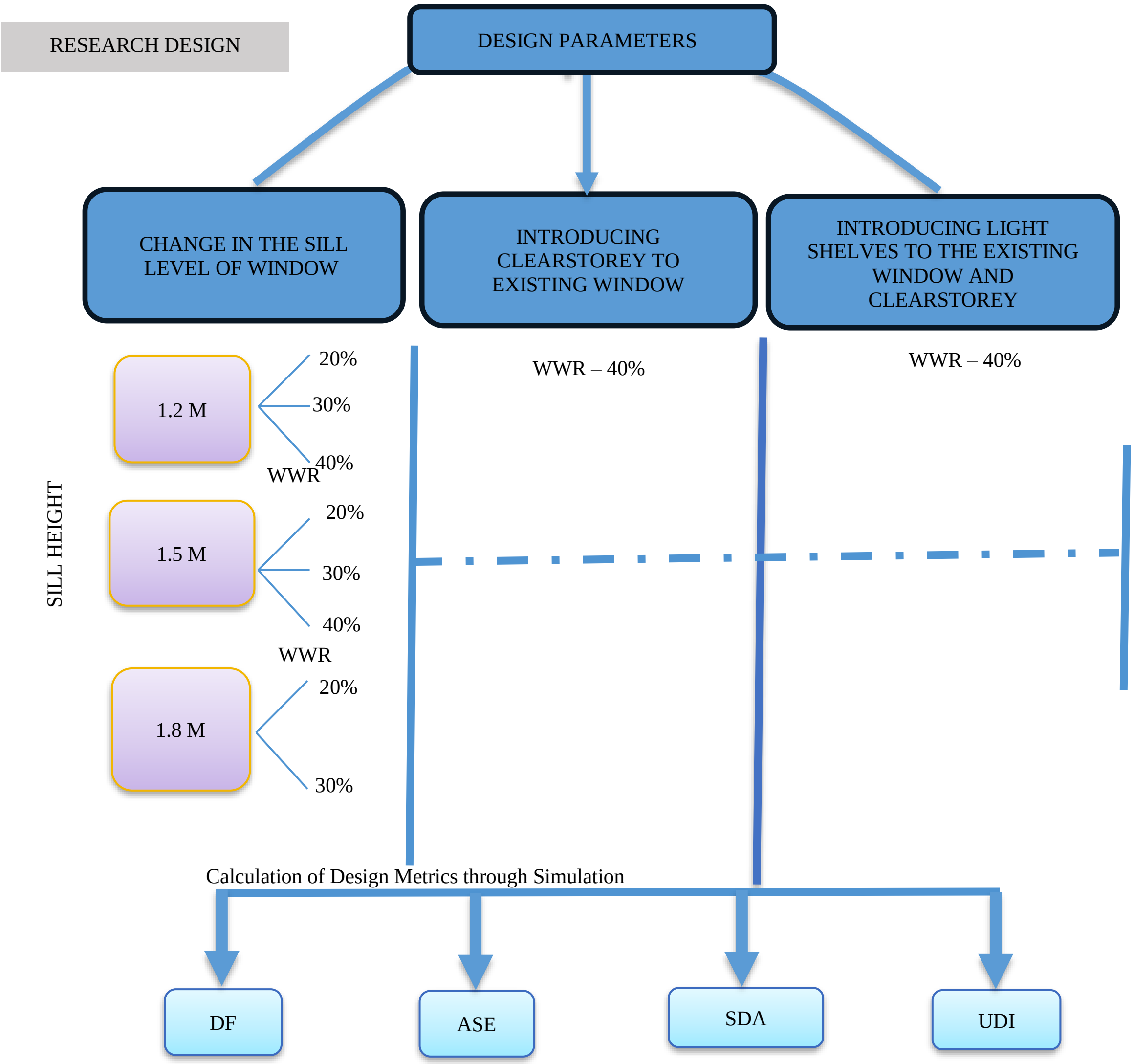

Fig. 5 Simulation Design Diagram

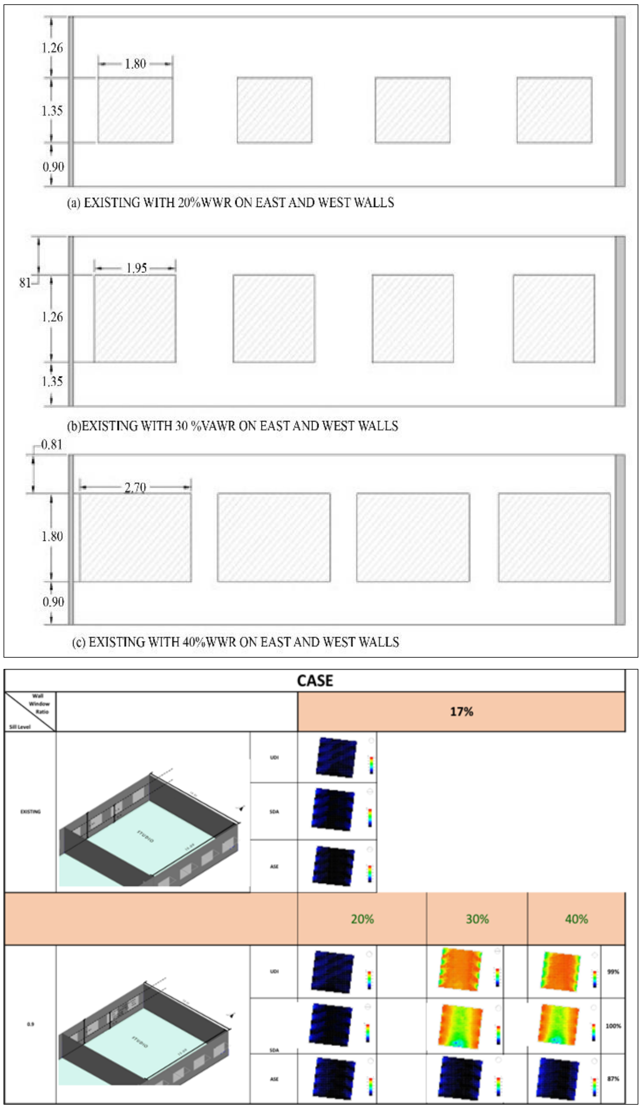

Fig. 6 0.9m sill with (a) 20%, (b) 30, and (c) 40% WWR – both east and west walls.

3.2.2. Change of Sill Level to 1.2m with Varied WWR

The window wall ratio has been varied to 20%, 30% and 40% for a sill height of 1.2m from the finished first floor level. Simulation has been performed to find the values of SDA, ASE, and UDI for illumination on a work plane at 0.8m from the finished floor level. For a WWR of 20%, the lintel is maintained at 2.55m from the finished first level, and the width of the windows is 1.8m, as shown in Figure 7 (a). For WWR of 30%, the lintel is maintained at 3.0m from the finished first floor level, and the width of the windows is 1.95m, as indicated in Figure 7(b). Similarly, for WWR of 40%, the lintel is maintained at 3.0m from the finished first floor level, and the width of the windows is 2.7m, as seen in Figure 7(c).

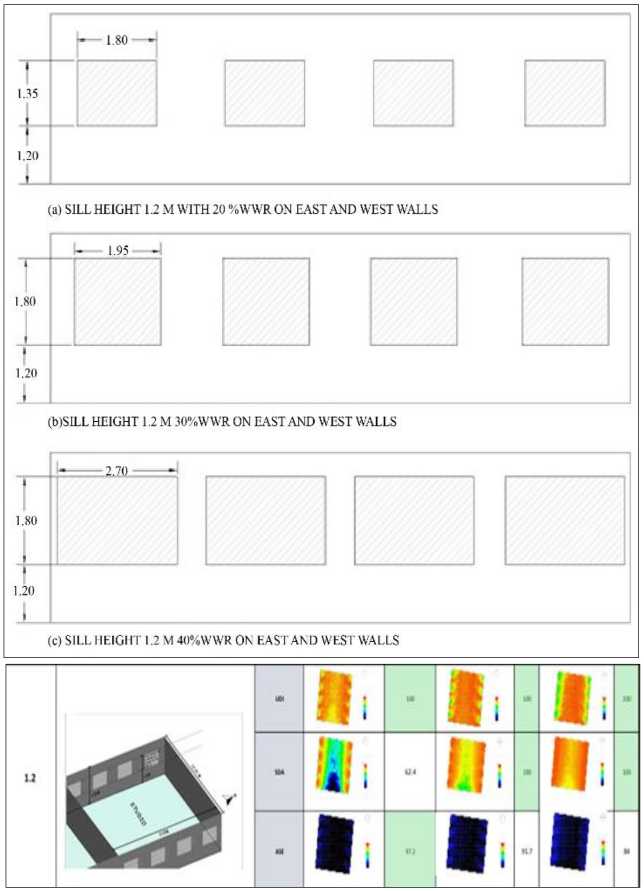

Fig. 7 1.2m sill with (a) 20 %, (b) 30, and (c) 40% WWR – both east and west walls.

3.2.3. Change of Sill Level to 1.5m with Varied WWR

The sill height is changed to 1.5m from the finished first floor level. The WWR is changed from 18% to 20% sill at 1.5m with lintel at 3m and width of the window at 1.8m as in Figure 8 (a), 30% (sill at 1.5m with lintel at 3m and width of 2.4m) as in Figure 8 (b), 40% sill at 1.5m with lintel at 3m and width of 3m on both east and west sides of the classroom as in Figure 8 (c). Simulation has been performed to find the values of SDA, ASE, and UDI with varied WWR on a work plane at 0.8m from the finished floor level.

3.2.4. Change of Sill Level to 1.8m with Varied WWR

Sill height is changed to 1.8m from the finished first floor level, and the WWR is changed from 18% to 20% (Sill at 1.8m with lintel at 3m and 2.1m window width) as in Figure 9 (a), 30% (sill at 1.8m with lintel at 3m and 3m window width), on both the sides of east and west as in Figure 9 (b). 40% of WWR has not been considered due to the constraint in the window surface area. Simulation has been performed to find the values of SDA, ASE, and UDI with varied WWR on a work plane at 0.8m from the finished floor level.

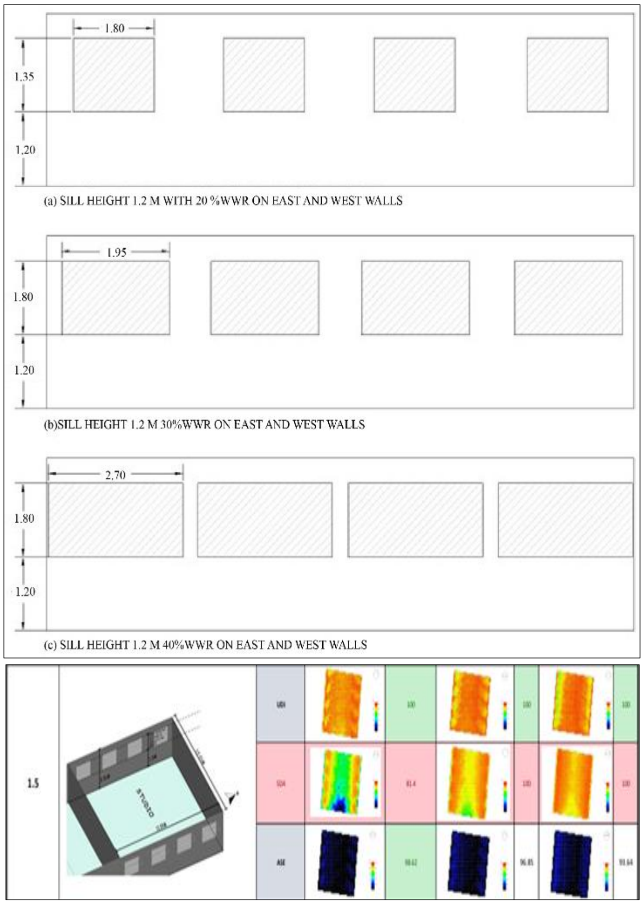

Fig. 8 1.5 m sill with (a) 20%, (b) 30, and (c) 40% WWR – both east and west walls.

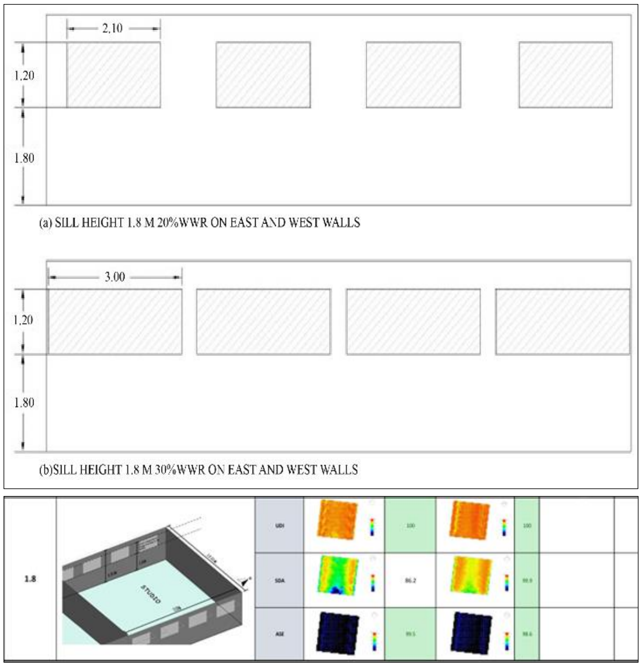

Fig. 9 1.8m sill with (a) 20%, and (b) 30% – both east and west walls.

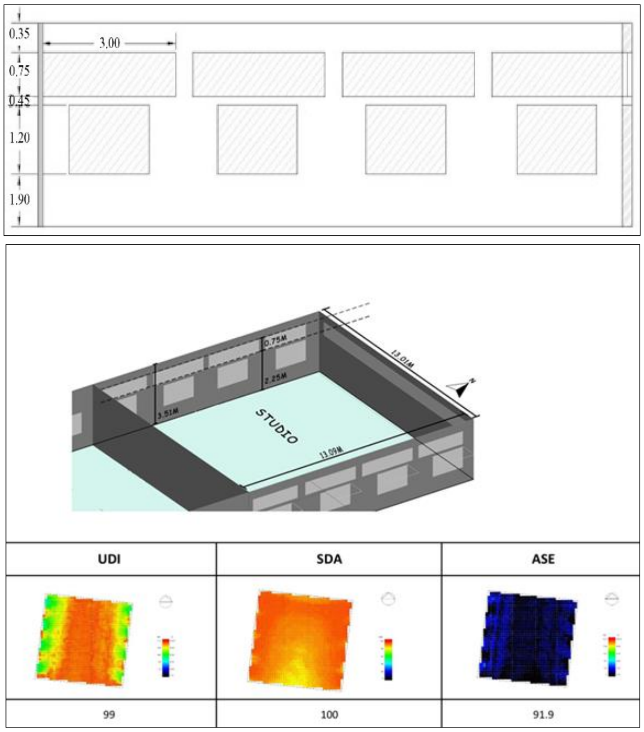

Fig. 10 Addition clerestory above the existing windows

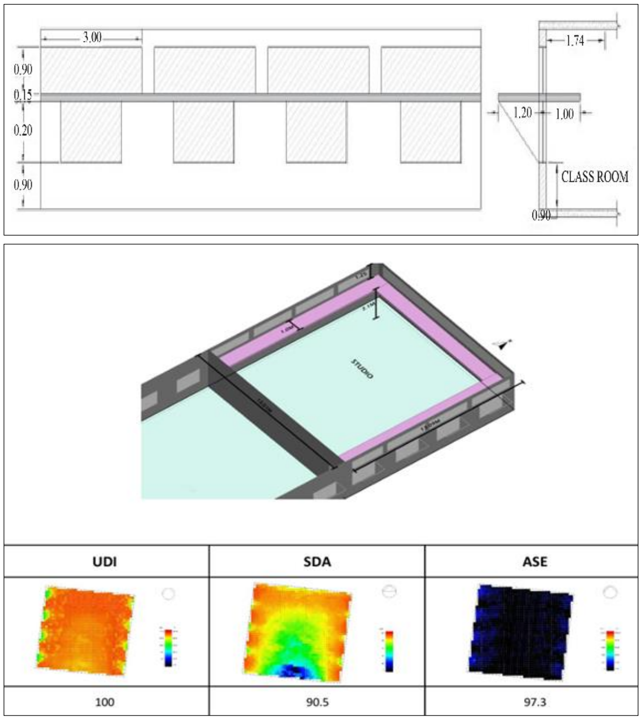

Fig. 11 Addition of light shelf to the existing

3.3. Performance of Simulation with Addition of Clerestory

Clerestory has been added above the existing east and west facing windows with dimensions of 3 m x 0.75 m, as shown in Figure 10. Additional clerestory has been provided on the northern wall owing to the glare free light. Simulation has been performed to find the values of SDA, ASE, and UDI with a 40% window wall ratio on a work plane at 0.8m from the finished floor level.

3.4. Performance of Simulation with Addition of Light Shelves

In addition to clerestory, light shelves are placed on North, West and Eastern side walls measuring 1m length internally inside the classroom and 1.2m extended outside, as shown in Figure 11. Simulation has been performed to find the values of SDA, ASE, and UDI with a 40% window wall ratio on a work plane at 0.8m from the finished floor level.

4. Results and Discussion

Simulation has been performed under three different conditions, namely, varied window wall ratio addition of clerestory and light shelves to analyze the values of the design metrics - UDA, SDA and ASE for achieving better illumination for the work plane height of 0.8m.

UDI: Irrespective of the change in sill levels from 0.9m to 1.8m and the WWR from 20 – 40%, the useful daylight illuminance remains constant throughout the day. However, it has been observed from Figure 12 that with WWR less than 20%, the value of illumination nearer to the windows ranges from 130 to 230 lux, with the minimum permissible value being 300 lux. The values diminish rapidly to 7 lux towards the center of the intuitional space, indicating the “Fell short” band.

SDA: The value of SDA increases with an increase in WWR and sill height. The values are reduced to 10% - 20% in the case of clearstory, but it is well within the permissible level of 55% of the time spent in the classroom during working hours of 8 am to 6 pm. In the case of light shelves with a projection of one meter inside the classroom, the values are well within the permissible limits throughout the classroom except towards the central part of the southern side of the wall, as shown in Figure 13. This may be encountered due to the presence of the diffused light rather than the direct light, as in the case of the clerestory. With reference to the earlier studies, it may be observed that the presence of light shelves ensures uniform lighting throughout the class interiors, but in this case, that is not true. Uniform illumination can be observed only using clerestory.

ASE: Even though with the increase of 40% of WWR, the annual sunlight exposure is comparatively lesser than in classrooms with 2sssss0% and 30% WWR, which clearly indicates the presence of excessive glare and heat inside. From Figure 13, it may be noted that maximum efficiency with respect to three metrics, namely, SDA, ASE and UDI, can be achieved with 30% WWR with a sill height of 1.5m-1.8m.

DF: The average daylight factor in all the cases of the study during simulation, for WWR OF 20%, is observed as inadequate. In the case of 40% WWR, the daylight factor is found to be greater than five (as recommended by the National Lighting Code India), which may result in glare and solar heat gain. From Figure 14, it may be observed that for the window having a 1.5m sill height with a window wall ratio of 30%, optimum daylight is achieved with an illumination range of 150 to 400 lux.

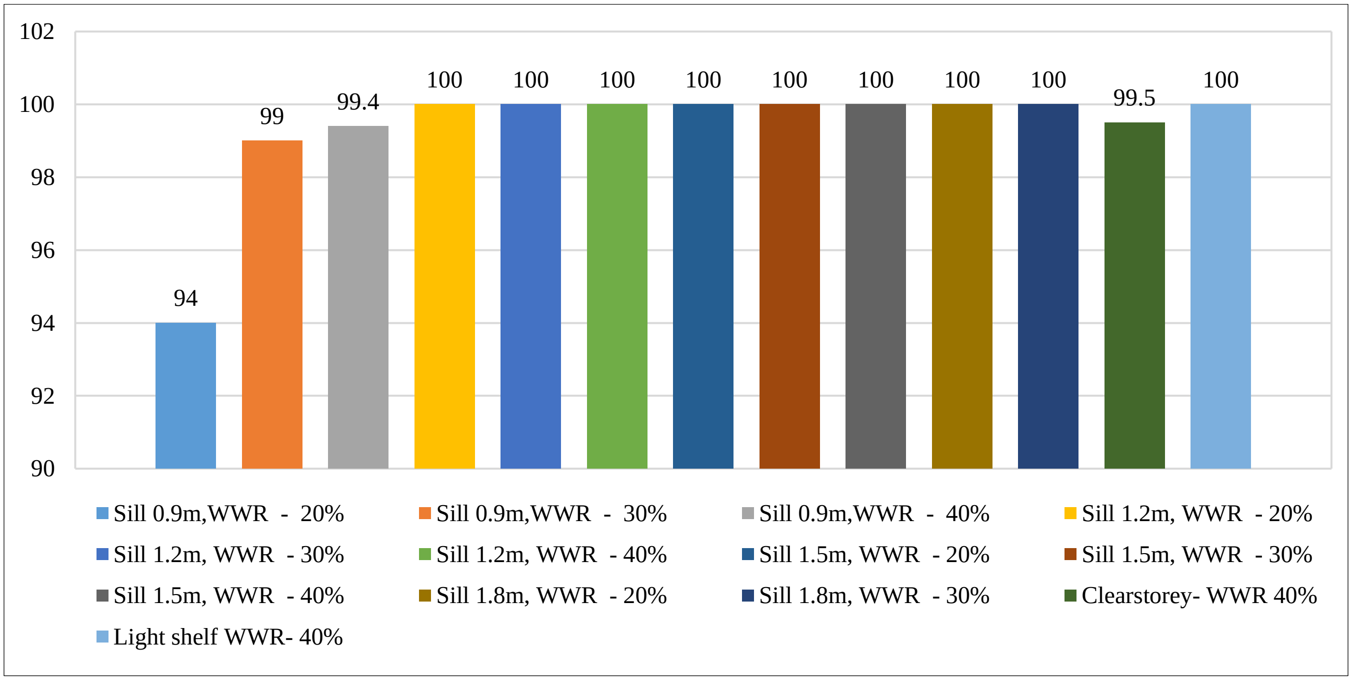

Fig. 12 Uniform daylight illuminance

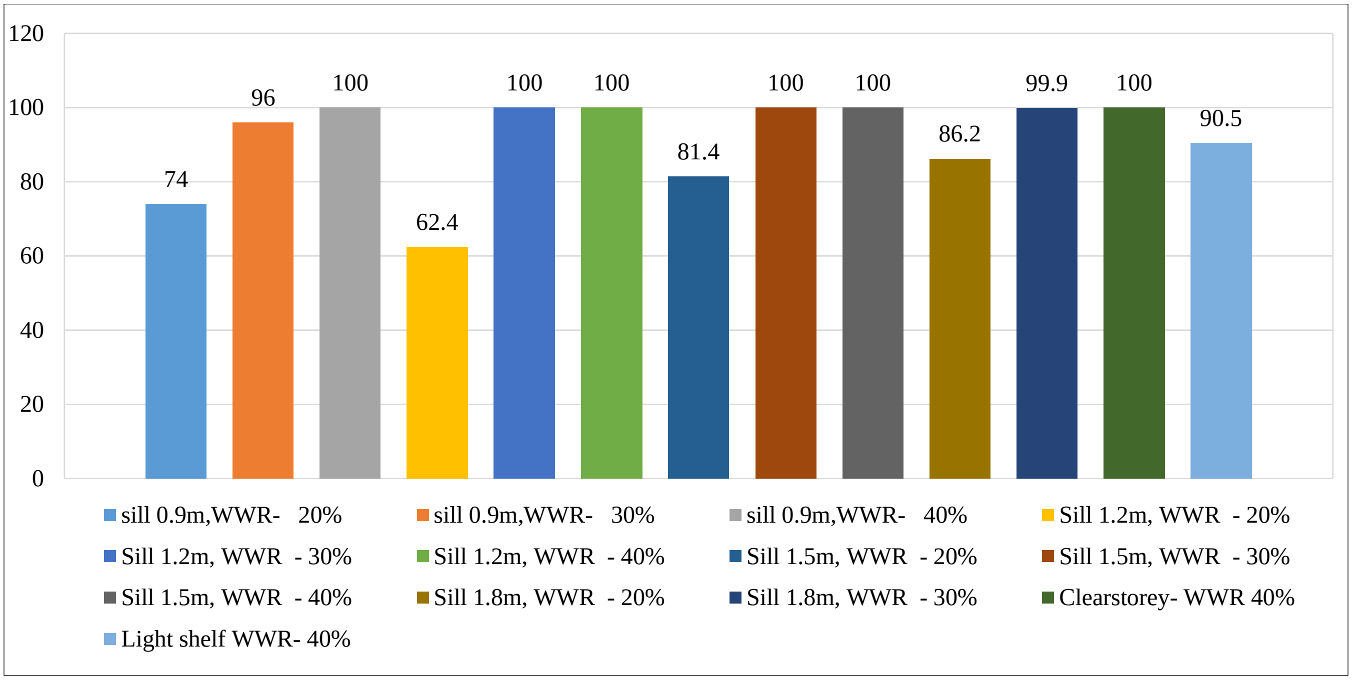

Fig. 13 Spatial daylight autonomy

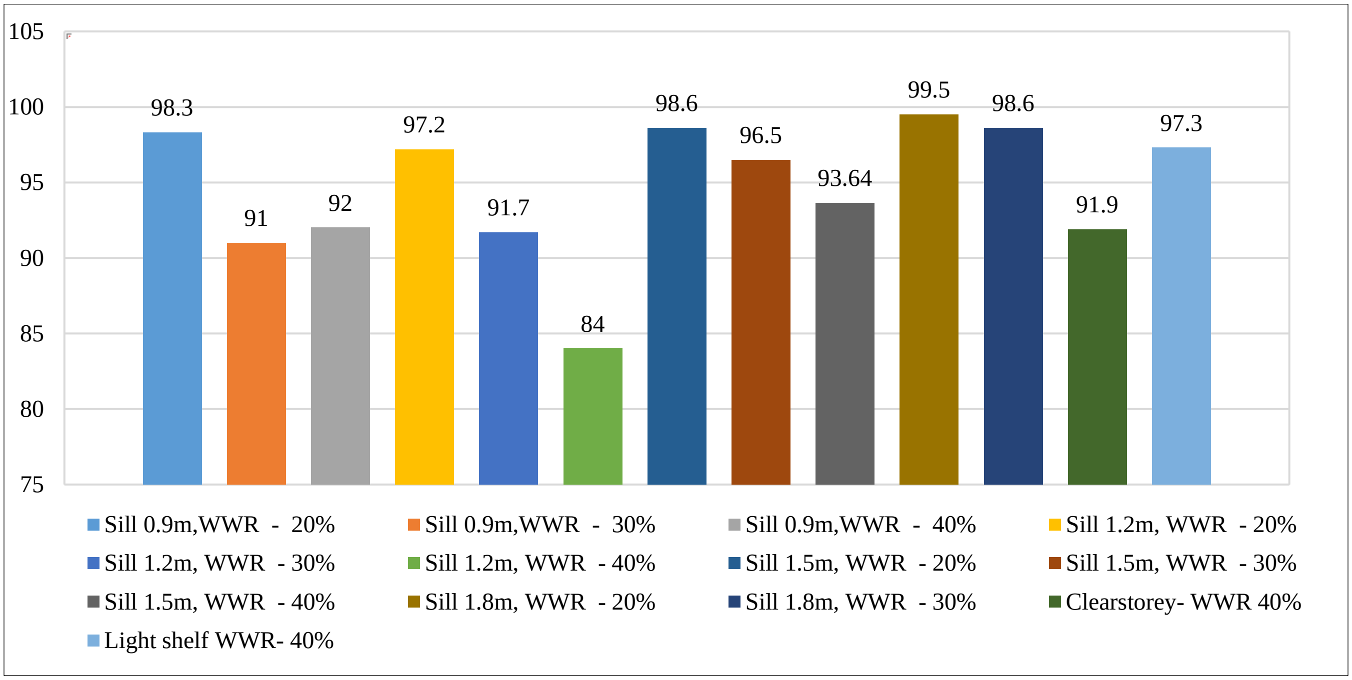

Fig. 14 Annual sunlight exposure

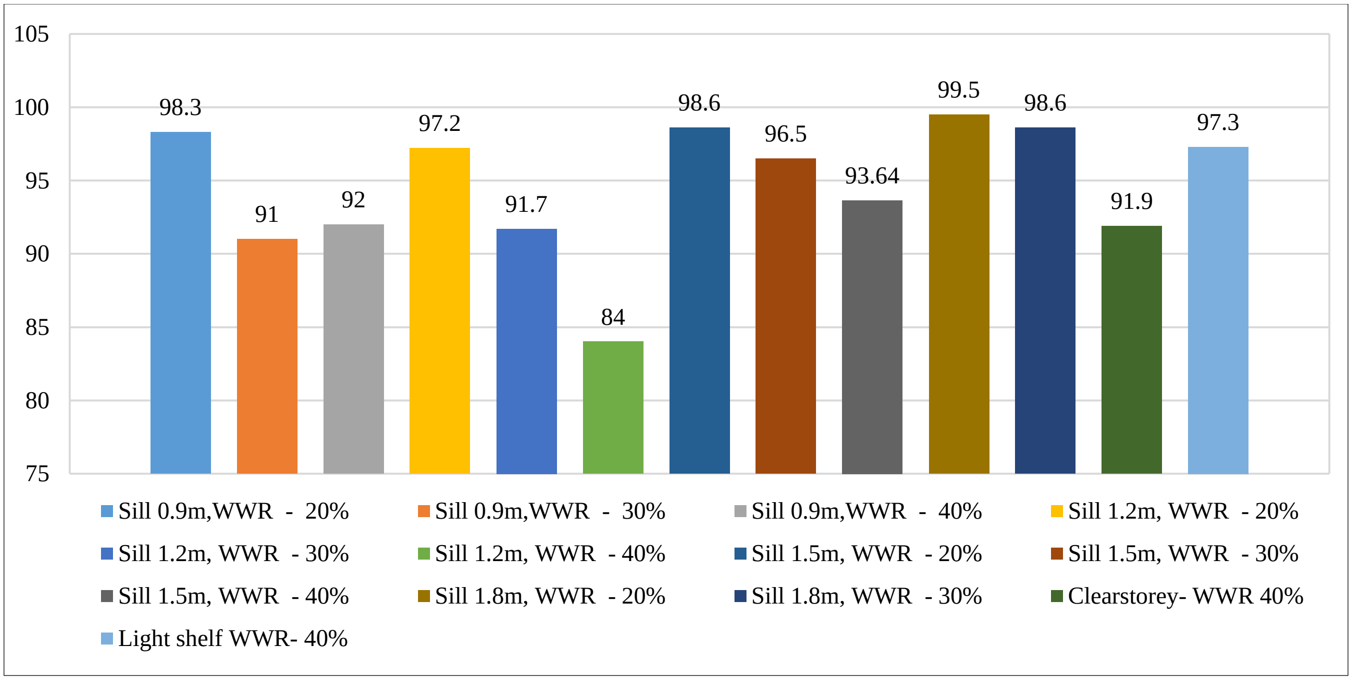

Fig. 15 Daylight factor

Table 5. Comparative analysis of metrics with differed sill height and WWR ratio

Sill Height	**Sill .9 M for Window Existing Window**				**1.2 M Sill Height**			**1.5 M Sill Height**			**1.8 M Sill Height**		**Introducing Clearstory for Existing Window**	**Introducing Light Shelves for Existing Window**
WWR	17%	20%	30%	40%	20%	30%	40%	20%	30%	40%	20%	30%	40%	40%
SDA	0	74.1	96	100	62.4	100	100	81.4	100	100	81.2	99.9	100	90.5
ASE	94.4	98.3	91	92.5	97.2	91.7	84.9	98.6	99.7	93.6	99.5	98.6	91.9	97.3
UDI	0%	100	99.4%	99	100	100	100	100	100	100	100	100	99.5	100

5. Conclusion

In conclusion, this research highlights how important daylighting is to the design of educational buildings, particularly for those located in tropical regions, by educating more about what kind of design strategies could be used to enhance daylighting in the interior space.

Narrowing down the observation and the analysis, it has been observed in all the cases that a sill height of 1.5m and WWR of optimum daylighting can be achieved even though for residential buildings, as per the government norms, the recommended sill height of 0.75m where work plan is not taken in to account but for an institutional space where 0.8m is the work plane light from the window accounts for the lighting where institution have larger volume floor plate, it is observed from the piolet study that 30% of WWR and 1.5m of sill height the three metrics SDA, UDI, ASE. In the case of 40% of WWR with the addition of clerestory UDI and SDA, it has been achieved but fails with ASE, which analyses glare and overheating. Thus, the study highlights the importance of balancing design elements to optimize daylight performance in educational spaces. Increasing the WWR leads to better performance across all daylight metrics, including daylight illuminance and spatial daylight autonomy, resulting in energy savings and improved indoor environmental quality.

The research's conclusion also provides a glimpse to the architects and designers with helpful guidance, adding that in higher education buildings located in tropical climates, daylighting solutions may be carefully included in the architectural design process to improve sustainability, energy efficiency, and occupant well-being. Future studies should examine how these daylighting techniques affect students' academic performance and well-being over the long run, as well as the financial advantages they provide in the form of lower operating expenses and energy savings.

5.1. Limitation of the Study

The pilot study considered for the research focuses only on daylighting for institutional classrooms with external walls oriented towards the west for a tropical climate, Chennai. During the simulation process, daylight pertaining to the Chennai weather profile with latitude and longitude coordinates of the institutional site is taken into account, and artificial light is not considered for the study.

External factors such as trees and abutting buildings are not considered for the study. The metrics pertaining to illumination for a work plane at 0.8m from the finished floor level alone have been taken for study. Other factors, such as glare, uniform lighting, and daylight factor, were not considered in the study.

Acknowledgement

The research was conducted at Dr. M.G.R Educational and Research Institute, Chennai, Tamil Nadu, India, for which the authors are grateful to the institution. We express our gratitude to every reviewer and writer who helped make this special issue a reality.

References

[1] Paola Ricciardi, and Cinzia Buratti, "Environmental Quality of University Classrooms: Subjective and Objective Evaluation of the Thermal, Acoustic and Lighting Comfort Conditions," *Building and Environment*, vol. 127, pp. 23-36, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] G.S.N.V.K.S.N. Swamy, S.M. Nagendra, and Uwe Schlink, "Impact of Urban Heat Island on Meteorology and Air Quality at Microenvironments," *Journal of the Air & Waste Management Association*, vol. 70, no. 9, pp. 876-891, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] Hernan Casakin, and Andrew Wodehouse, "A Systematic Review of Design Creativity in the Architectural Design Studio," *Buildings*, vol. 11, no. 1, pp. 1-19, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Eleanor S. Lee et al., "Advocating for View and Daylight in Buildings: Next Steps," *Energy and Buildings*, vol. 265, pp. 1-18, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Lambros T. Doulos et al., "Examining the Impact of Daylighting and the Corresponding Lighting Controls to the Users of Office Buildings," *Energies*, vol. 13, no. 15, pp. 1-25, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Yingjie Jia et al., "Effect of Interior Space and Window Geometry on Daylighting Performance for Terrace Classrooms of Universities in Severe Cold Regions: A Case Study of Shenyang, China," *Buildings*, vol. 13, no. 3, pp. 1-23, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] Kiel Moe, *Integrated Design in Contemporary Architecture*, Princeton Architectural Press, pp. 1-203, 2008. [Google Scholar] [Publisher Link]

[8] Vincenzo Costanzo, Gianpiero Evola, and Luigi Marletta, "A Review of Daylighting Strategies in Schools: State of the Art and Expected Future Trends," *Buildings*, vol. 7, no. 2, pp. 1-21, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[9] Kurnia Widiastuti, Mohamad Joko Susilo, and Hanifah Sausan Nurfinaputri, "How Classroom Design Impacts for Student Learning Comfort: Architect Perspective on Designing Classrooms," *International Journal of Evaluation and Research in Education*, vol. 9, no. 3, pp. 469-477, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[10] Shouib Ma'bdeh, and Baraa Al-Khatatbeh, "Daylighting Retrofit Methods as a Tool for Enhancing Daylight Provision in Existing Educational Spaces —A Case Study," *Buildings*, vol. 9, no. 7, pp. 1-18, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Ahmed A.Y. Freewan, and Jackline A. Al Dalala, "Assessment of Daylight Performance of Advanced Daylighting Strategies in Large University Classrooms; Case Study Classrooms at Just," *Alexandria Engineering Journal*, vol. 59, no. 2, pp. 791-802, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Yin Zhang et al., "Solar Radiation Reflective Coating Material on Building Envelopes: Heat Transfer Analysis and Cooling Energy Saving," *Energy Exploration & Exploitation*, vol. 35, no. 6, pp. 748-766, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[13] Christina Giarma, Katerina Tsikaloudaki, and Dimitris Aravantinos, "Daylighting and Visual Comfort in Buildings' Environmental Performance Assessment Tools: A Critical Review," *Procedia Environmental Sciences*, vol. 38, pp. 522-529, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[14] Umberto Berardi, and Hamid Khademi Anaraki, "The Benefits of Light Shelves over the Daylight Illuminance in Office Buildings in Toronto," *Indoor and Built Environment*, vol. 27, no. 2, pp. 244-262, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[15] Abbas Maleki, and Narges Dehghan, "Optimum Characteristics of Windows in an Office Building in Isfahan for Save Energy and Preserve Visual Comfort," *Journal of Daylighting*, vol. 8, no. 2, pp. 222-238, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[16] Yuan Fang, and Soolyeon Cho, "Design Optimization of Building Geometry and Fenestration for Daylighting and Energy Performance," *Solar Energy*, vol. 191, pp. 7-18, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[17] Khaled Alhagla, Alaa Mansour, and Rana Elbassuoni, "Optimizing Windows for Enhancing Daylighting Performance and Energy Saving," *Alexandria Engineering Journal*, vol. 58, no. 1, pp. 283-290, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[18] Mamdooh Alwetaishi, and Ahmad Taki, "Investigation into Energy Performance of a School Building in a Hot Climate: Optimum of Window-to-Wall Ratio," *Indoor and Built Environment*, vol. 29, no. 1, pp. 24-39, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[19] Moses Iorakaa Ayoosu et al., "Daylighting Evaluation and Optimisation of Window to Wall Ratio for Lecture Theatre in the Tropical Climate," *Journal of Daylighting*, vol. 8, no. 1, pp. 20-35, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[20] Ranald Lawrence, Mohamed Elsayed, and Charlotte Keime, "Evaluation of Environmental Design Strategies for University Buildings," *Building Research & Information*, vol. 47, no. 8, pp. 883-900, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[21] Kratika Rajeev Piparsania, Prasad Vaidya, and Pratul Chandra Kalita, "Evaluation of Daylight Performance of Classroom Spaces in Ahmedabad," *DS 101: Proceedings of NordDesign 2020*, Lyngby, Denmark, pp. 1-12, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[22] Narein Perera, and Nirma Swaris, "Good Reading Light: Visual Comfort Perception and Daylight Integration in Library Spaces," *Proceedings of the 10th International Conference of Faculty of Architecture Research Unit (FARU)*, Colombo, Sri Lanka, pp. 336-348, 2017. [Google Scholar]

[23] Merve Öner, and Tuğçe Kazanasmaz, "Illuminance and Luminance-Based Ratios in the Scope of Performance Testing of a Light Shelf-Reflective Louver System in a Library Reading Room," *Light & Engineering*, vol. 27, no. 3, pp. 39-46, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[24] Mamdooh Alwetaishi, and Omrane Benjeddou, "Impact of Window to Wall Ratio on Energy Loads in Hot Regions: A Study of Building Energy Performance," *Energies*, vol. 14, no. 4, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Apoorva Dubey, and Nawab Ahmad, "Preliminary Critique by GRIHA Criteria Energy with Respect to Window Wall Ratio," *International Research Journal of Engineering and Technology*, vol. 7, no. 8, pp. 5101-5106, 2020. [Google Scholar] [Publisher Link]

[26] Jaewook Lee, Mohamed Boubekri, and Feng Liang, "Impact of Building Design Parameters on Daylighting Metrics using an Analysis, Prediction, and Optimization Approach Based on Statistical Learning Technique," *Sustainability*, vol. 11, no. 5, pp. 1-21, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[27] Juan Liang et al., "Maternal Mortality Ratios in 2852 Chinese Counties, 1996-2015, and Achievement of Millennium Development Goal 5 in China: A Subnational Analysis of the Global Burden of Disease Study 2016," *The Lancet*, vol. 393, no. 10168, pp. 241-252, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[28] Jin Ma, and Qingxin Yang, "Optimizing Annual Daylighting Performance for Atrium-Based Classrooms of Primary and Secondary Schools in Nanjing, China," *Buildings*, vol. 13, no. 1, pp. 1-17, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[29] Iara Gonçalves dos Santos, "*Indoor Daylight Performance and Outdoor Daylight Parameters: Characterizing Different Cities as a Basis for Urban Design*," Technical University of Munich, pp. 1-234, 2022. [Google Scholar] [Publisher Link]

[30] Longyu Guan, "*An Investigation of Alternative Daylight Metrics*," PhD Thesis, Institute for Environmental Design and Engineering University College London, pp. 1-215, 2020. [Google Scholar] [Publisher Link]

[31] Liang Yu, and Jianwen Lu, "Analysis of the Influence of Peripheral Light Shelves on Building Lighting," *Journal of Physics: Conference Series*, vol. 2755, pp. 1-8, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[32] Sergey Ershov et al., "Effective Simulation of Spatial Daylight Autonomy and Annual Sunlight Exposure," *Graphicon-Conference on Computer Graphics and Vision*, vol. 32, pp. 64-72, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[33] Randy Frans Fela et al., "The Effects of Orientation, Window Size, and Lighting Control to Climate-Based Daylight Performance and Lighting Energy Demand on Buildings in Tropical Area," *Proceedings of Building Simulation 2019: 16th Conference of IBPSA*, Rome, Italy, vol. 16, pp. 1075-1082, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[34] M.S.M. Effendi et al., "Sustainability Assessment of Torchlight Design: Identification of New Design Structure and Material Selection," *AIP Conference Proceedings*, vol. 2339, no. 1, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[35] "*Energy Conservation Building Code*," Bureau of Energy Efficiency, pp. 1-200, 2017. [Google Scholar] [Publisher Link]

[36] National Building Code, Bureau of Indian Standards, 2016. [Online]. Available: https://www.bis.gov.in/standards/technical-department/national-building-code/#:~:text=SP%207%20%3A%202016&text=Code%20has%20been%20brought%20out,and%20contemporary%20applicable%20international%20practices.

[37] National Lighting Code 2010, (SP 72: 2010), Bureau of Indian Standards, pp. 1-333, 2010. [Online]. Available: https://law.resource.org/pub/in/bis/S05/is.sp.72.2010.pdf

[38] Migael Moelich "*Thermal Performance of Cavities in 3DPC Building Facades using DesignBuilder*," Master's thesis, Stellenbosch University, pp. 1-97, 2022. [Google Scholar] [Publisher Link]

[39] Pil Brix Purup, and Steffen Petersen, “Research Framework for Development of Building Performance Simulation Tools for Early Design Stages,” *Automation in Construction*, vol. 109, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[40] Godfried Augenbroe, *The Role of Simulation in Performance-Based Building*, 2nd ed., Building Performance Simulation for Design and Operation, pp. 1-31, 2019. [Google Scholar] [Publisher Link]

[41] Chahrazed Mebarki et al., “Improvement of Daylight Factor Model for Window Size Optimization and Energy Efficient Building Envelope Design,” *Journal of Daylighting*, vol. 8, no. 2, pp. 204-221, 2021. [CrossRef] [Google Scholar] [Publisher Link]