



OPEN ACCESS

Volume: 5

Issue: Special 2

Month: October

Year: 2026

ISSN: 2583-7117

Published: 15.10.2026

Citation:

Kavya Ramakrishnan, Dr. Anand Achari
“A Simulation-Based Study of Daylight
Performance in School Classrooms” In-
ternational Journal of Innovations in Sci-
ence Engineering and Management,
vol.5, no.S2, 2026, pp. 26-35

DOI:

10.69968/ijisem.2026v5iS226-35



This work is licensed under a Creative
Commons Attribution-Share Alike 4.0
International License

A Simulation-Based Study of Daylight Performance in School Classrooms

Kavya Ramakrishnan¹, Dr. Anand Achari¹

¹VESCOA

Abstract

Daylight is one of the few architectural elements that operates simultaneously at physical, cognitive, and emotional levels of human experience. It especially affects children in school. For example, it can have direct effects on the visual comfort, posture, attentiveness, emotional stability, and the ability to stay engaged in learning. The classrooms often require artificial lighting due to closely packed buildings, deep corridors, and limited sky exposure. There is a gradual disengagement from learning as well as restlessness, reduced focus as a response to visual strain.

The idea of this research is to understand daylight as an active spatial and environmental condition. It is not a passive by-product. The objective is to evaluate the performance of daylight in urban school classrooms and identify how design variables influence indoor light quality. This study focuses on warm-humid climatic conditions and classroom typologies accommodating 40-60 students.

The research methodology is analytical and simulation-based. The software used is DesignBuilder v2025.1.1. Selected classrooms are documented for spatial parameters such as floor area, opening size, sill and lintel levels, visible transmittance, room height, and shading devices. Simulations are conducted using metrics such as Daylight Autonomy and Useful Daylight Illuminance. The outcome of this research is a clearer understanding of how daylight performance varies with design decisions in dense urban contexts. The findings aim to inform design strategies that improve indoor daylight quality in schools. Future scope lies in applying these insights to early design stages, expanding to different age groups, and integrating daylight with thermal comfort and energy performance.

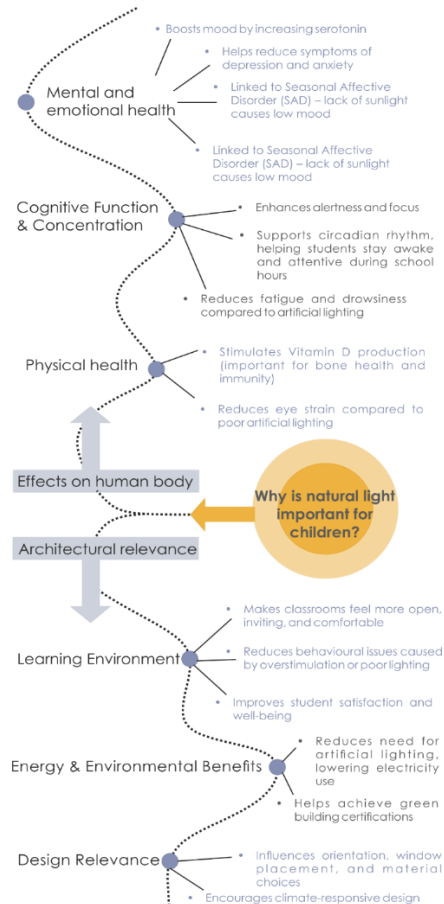
Keywords; Daylight performance, School Classrooms, Visual comfort, Daylight Autonomy

INTRODUCTION

Daylight is one of the few architectural elements which operates simultaneously at physical, cognitive, and emotional levels of a human. It determines how a child can perceive the space around it, how they sit at their desk, and how long their attention remains fixed in a task and on the blackboard. Natural daylight plays a critical role in supporting mental and emotional health among children. Exposure to daylight is associated with increased serotonin production, which contributes to improved mood and a reduction in symptoms related to anxiety and depression. As illustrated in Fig. 1, daylight enhances alertness and focus while supporting circadian rhythm regulation. This alignment of biological cycles enables students to remain attentive during academic hours and reduces fatigue and drowsiness commonly associated with prolonged exposure to artificial lighting.

The connection between daylight and children's well-being is not speculative at all. Hescong et al. (1999) found that classrooms with ample daylight correlated with drastically improved learning results which showed 20% faster progress in mathematics, 26% in reading. Studies such as WSEAS (2013) show that daylight is aligned with the body's circadian rhythm which helps in stabilizing mood, helping attentiveness, and reducing physiological tiredness.

IICBE (2016) shows that even 3 hours exposure to the of natural-light can improve emotional stability. These are not inconsequential correlations.



Mumbai complicates this dynamic even further. The warm-humid climate of Bombay produces overwhelming sun exposure, harsh radiance, seasonal variability, and a puzzle of micro shadows created by tight urban landscape. Classrooms facing to the east or west face low-angle sun,

making the incoming glare almost unavoidable. South light is ample in its presence but thermally loaded. North light which can perform the best is not always available due to site restrictions.

This project returns to that crucial missing bridge between climate, design, and learning. The project examines real world examples of schools operating in dense urban conditions. It studies how WWR variations, VT values, shading depth, and interior reflectance shape daylight conditions. And as we know architectural observation in itself cannot exhibit the entire pattern, the project uses DesignBuilder simulations. Using the Mumbai EnergyPlus Weather (EPW) file, orientations and configurations are tested under real conditions.

Metrics enable the analysis to be statistical. Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) are critical indicators. DA shows us how often natural light meets functional illumination. UDI tests whether the light is within a comfortable, usable range. These are not be assumed as perfect metrics, but they work best with the messy reality of warm-humid climates, better than old models like the Daylight Factor. They respond to things which children personally experience such as to sky conditions, orientation shifts, atmospheric clarity, and seasonal variability.

LITERATURE REVIEW

Li & Lam (2001) – Evaluation of lighting performance in open-plan offices

Lighting research in office environments is not new it goes back decades. For this project we are going to focus on Li & Lam (2001). It asks the harder question: what are the implications of lighting when people actually live with it?

Author	Year	Type of Study or document	Problem	Explanation/Solution/Conclusion
Yuen (2023)	2023	Research article	The effect of filtered fluorescent lighting on the emotional state of students in learning spaces.	In the study, students preferred the option of filtered lighting over fluorescent lighting because it favored their emotional state.
Indarto, (2023)	2023	Research article	Analysis Of Classroom Lighting Compatibility with Standard Parameter's Lighting	The lighting conditions in degrees Kelvin for a perception of comfort for the users of an environment are in the range of 4000 to 6500 Kelvin.
Babu (2022)	2022	Research article	Impact of window view classrooms on architecture students' performance	The results show that the classrooms holding a view of nature or landscape show significant performance in attention and cognitive skills. Hence, designers must work together to give students access to natural window views.
Lekan-Kehinde (2021)	2021	Review article	Impact of lighting on children's learning Environment	The study of lighting in learning spaces shows that there is an association between lighting conditions, such as blue-enriched light, and learning, cognitive aspects, concentration, memory, processing, and speed; an effective choice of the lighting system favors the emotional state of students in learning and cognitive skills.

Figure. 2: Summary of research papers

Source: Li, D.H.W. & Lam, T.N.T., Evaluation of lighting performance in open-plan offices, 2001.

They worked ran simulation-based tools like Radiance, Ecotect to run daylight penetration models, adjusting variables such as the glazing type, orientation, and even the geometry of the windows. The numbers they got in Daylight Factor (DF), horizontal illuminance, uniformity ratios are the usual suspects. But what made their study more than a mere technical documentation was the way it used objective data in parallel with the subjective responses.

Recent daylighting research has shifted from static metrics such as Daylight Factor toward climate-based metrics such as Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI), which better represent real daylight conditions across the year (Reinhart, Mardaljevic &

Rogers, 2006). Numbers told them one story on the other hand people told another. Glare, whether it is bouncing off of a computer screen or directly coming through a window, is something that numbers can rarely capture but your eyes cannot ignore.

This research focuses on the Spatial Daylight Autonomy (sDA 300/50%) in Leed v4 as shown in Fig: 3. sDA tells us how much of a regularly occupied space receives at least 300 lux of daylight for 50% of the annual occupied hours. In LEED v4, achieving sDA 300/50% means that 55% (Option 1) or 75% (Option 2) of the regularly occupied floor area must meet this daylight condition.

TABLE 1. Points for daylit floor area: Spatial daylight autonomy			
New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
sDA (for regularly occupied floor area)	Points	sDA (for perimeter floor area)	Points
55%	2	75%	1
75%	3	90%	2

Figure. 3: sDA Credits LEED V4. 0

Source: USGBC, LEED v4.1 BD+C Reference Guide, 2019

Buildings & Processes	Recommended Illuminance (lux)
Classrooms	300
Activity area	300
Libraries	300
Manual training	300

Fig. 4: GRIHA Standards

Source: GRIHA Council, GRIHA v2019 Rating System Manual

Impact of Daylighting on Learning Outcomes

The project uses the work by Heschong et al. (1999). The research involves over 21000 students. The children in classrooms with ample daylight showed 20% faster progress in mathematics and 26% faster progress in reading compared to their peers who were in poorly lit spaces (Heschong, 1999). Exposure to natural daylight also influences circadian rhythms, sleep quality, and psychological well-being, which indirectly affect productivity and attentiveness in indoor environments (Boubekri et al., 2014). This study marks a change in how daylighting was being understood within schools. It shifts the conversation from simple illumination levels towards an appreciation of daylight as a cognitive tool.

A classroom with insufficient natural light is dull and reduces a child's capacity to concentrate. In the long term, this affects learning pace, retention, and even classroom behaviour. Heschong et al. (1999) they confirm the need to examine the daylight in Mumbai's schools, where issues such as but not limiting to overcrowding, dense neighbourhoods, and small plot sizes create a challenge to the daylight in these classrooms. In tropical climates, daylight design must balance adequate illumination with the control of glare and excessive solar radiation (Nugroho, Triyadi & Wonorahardjo, 2022).

Educational research indicates that classroom layout, spatial openness, and access to environmental stimuli directly influence student engagement and collaboration (Oblinger, 2006). Flexible and well-lit spaces encourage

movement, peer learning, and active participation, thereby aligning spatial conditions with contemporary pedagogical models.

Architectural Parameters Affecting Daylighting

Architectural design decisions changes not only the visual performance but also alter how students may feel, interact, and behave within their lightened-up classrooms.

In Mumbai's climate, glare and heat gain are unavoidable. Overhangs and fins need to be adjusted to the sun's angle and position on the respective facades. The literature highlights this tension, between optimizing daylight and decreasing glare.

The reviewed literature puts forth a clear conceptual foundation:

- daylighting is a multidimensional architectural problem,
- it has a direct effect on learning, health, psychology, and, behaviour, and its workability in warm-humid cities require an integrated approach that simultaneously handles illumination, glare

Pedagogical intent often determines spatial configuration. Constructivist learning models, which emphasize exploration and interaction, require open, adaptable environments rather than rigid classroom layouts (Piaget, 1970; Vygotsky, 1978). Thus, architectural space becomes a direct physical manifestation of teaching philosophy.

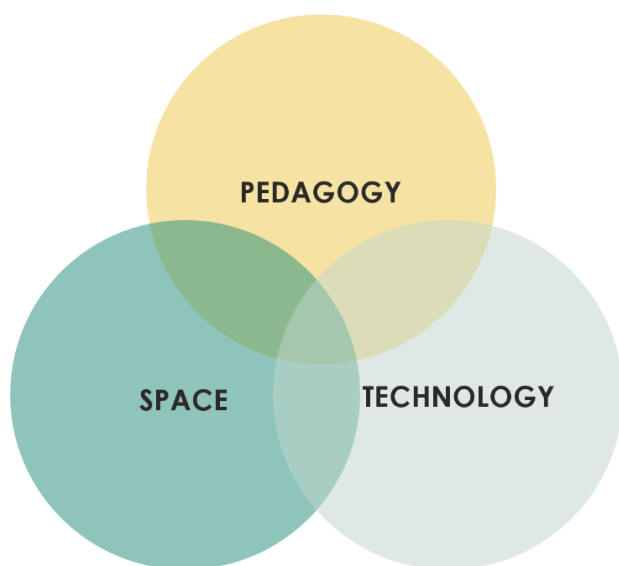


Figure. 5: Space-pedagogy-technology

Spatial design (the physical environment) supports and enables pedagogical approaches, while technology enhances both teaching methods and spatial use. The overlap of all three represents an integrated learning ecosystem where built form, teaching practices, and digital tools work together to improve learning outcomes and student engagement. Fig. 5 illustrates the interrelationship between space, pedagogy, and technology in shaping effective learning environments.

METHODOLOGY

The methodology blends case study analysis, digital simulations, and comparative modelling. But not in a neat, perfect line. It moved, shifted, circled back. Numbers had to meet feelings, and design intent had to meet lived reality.

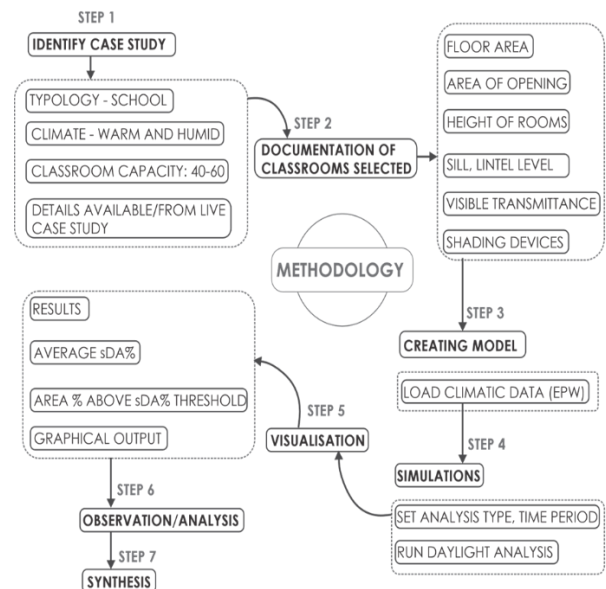


Figure. 6: Methodology

Table 1: Chosen Case studies

No	Location	Dimensions	Window geometry & orientation	Visible transmittance
1	MPS, Shivshrushti	9m X 7m X 3m	South wall, no glaze.	VT 0.9.
2	Apeejay School, Nerul	8.6m × 6.2m × 3.3m	North wall, no glaze	VT 0.7
3	Ryan International School, Sanpada	7.5m x 6.5m x 3.3m	North – West wall, no glaze	VT 0.6

Observations

Case study 1 – Mumbai Public school, Shivshrushti
Classroom dimensions – 9m X 7m X 3m
Location – Nehru Nagar, Kurla



Fig. 7: MPS, Shivshrushti
Source: Google Maps

Simulation Results –

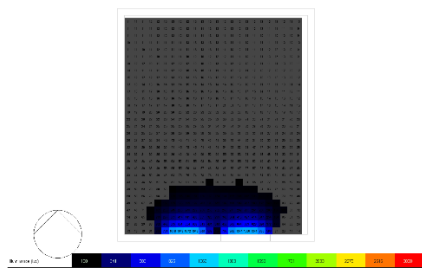


Fig. 8: Illuminance - MPS

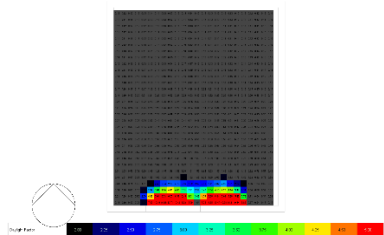


Fig. 9: Daylight Factor - MPS

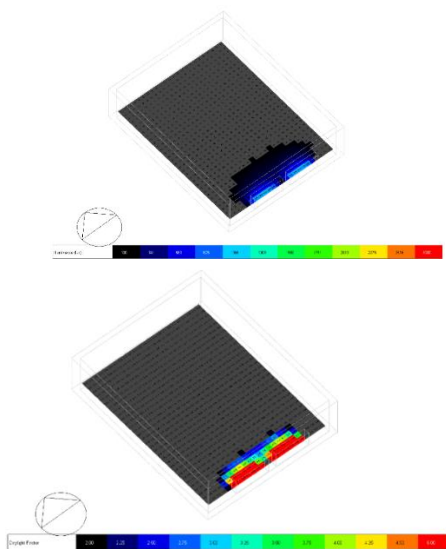


Figure. 10: Axonometric views of illuminance and DF
– MPS

Table 2: Results of Daylight factor and illuminance simulation

MPS	Floor Area (m2)	Floor Area above Threshold (m2)	Floor Area above Threshold (%)	Average Daylight Factor (%)	Minimum Daylight Factor (%)
Classroom	69.812	3.847	5.511	0.764	0.096

MPS	Maximum Daylight Factor (%)	Uniformity ratio (Min / Avg)	Uniformity ratio (Min / Max)	Min Illuminance (lux)
Classroom	10.715	0.126	0.009	9.61

Average Daylight Factor - 0.764%

The recommended daylight factor for classrooms are 2%. Hence the space is poorly lit in the deeper parts of the room.

Uniformity Ratios (Min/Average = 0.126, Min/Max = 0.009)

The uniformity ratio comes out to be 0.126% which is very less than the desirable 0.3 or above. This means that there is uneven lighting which creates visual discomfort, glare near windows and dark zones in the deeper parts of the classrooms.

Illuminance (Min 9.61 lux, max 1072 lux)

The minimum illuminance level of 9.61 lux is below the educational standards (typically 300–500 lux). The maximum illuminance of 1072.59 lux indicates very high daylight intensity near openings.

Summary -

- Avg DF (0.764%) → Very low daylight; space not “daylit” by standards.
- Uniformity (0.126 / 0.009) → Highly uneven daylight distribution.
- Min Illum (9.61 lux) → Extremely underlit zones.
- Max Illum (1072.59 lux) → Intense daylight near openings; risk of glare.

Improved case

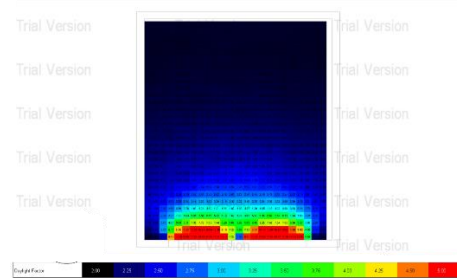
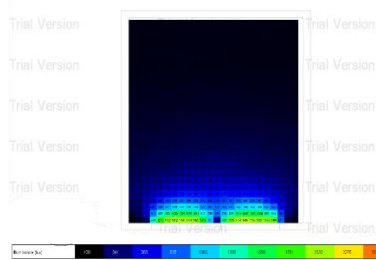


Figure. 11: Improved Daylight Factor - MPS


Figure. 12: Improved Illuminance - MPS
Table 3: Improved case results

MPS	Floor Area (m2)	Floor Area above Threshold (m2)	Floor Area above Threshold (%)	Average Daylight Factor (%)	Minimum Daylight Factor (%)
Classroom	69.812	42.50	60.88%	2.86%	0.78

MPS	Maximum Daylight Factor (%)	Uniformity ratio (Min / Avg)	Uniformity ratio (Min / Max)	Min Illuminance (lux)
Classroom	12.94	0.34	0.12	328

Strategies used –

- Window-to-Wall Ratio (WWR): increased to 40% (from 15%)
- Window height (head): 1.8 m above finished floor
- Clerestory band: added above window — 0.60 m tall continuous band above the main window head (runs full façade)

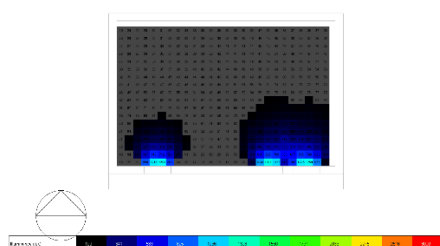
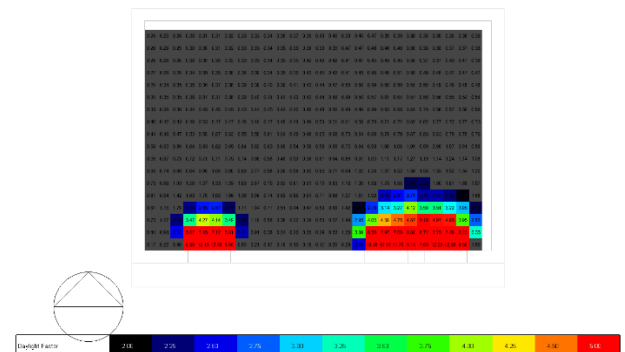
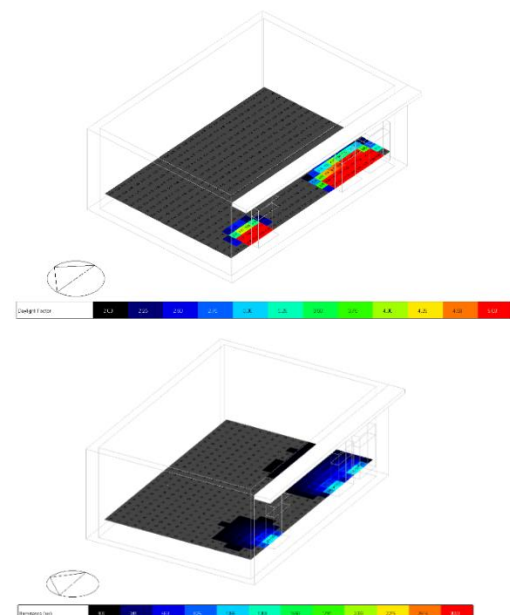
Case study 2 – Apeejay school, Nerul

Classroom dimensions – 8.6m X 6.2m X 3.3M

Location – Nerul, Navi Mumbai


Figure. 13: APJ School

Simulation Results –


Figure. 14: Illuminance - APJ

Figure. 15: Daylight Factor - MPS

Figure 16: Axonometric views of illuminance and DF – MPS
Table 4: Results

MPS	Floor Area (m2)	Floor Area above Threshold (m2)	Floor Area above Threshold (%)	Average Daylight Factor (%)	Minimum Daylight Factor (%)
Classroom	45.004	4.327	9.615	1.29	0.158

MPS	Maximum Daylight Factor (%)	Uniformity ratio (Min / Avg)	Uniformity ratio (Min / Max)	Min Illuminance (lux)
Classroom	13.16	0.122	0.012	15.78

Average Daylight Factor – 1.29%

This value shows sub-optimal daylight levels but is still below the recommended 2%.

Uniformity Ratios (Min/Average = 0.122, Min/Max = 0.012)

The uniformity ratio comes out to be 0.122 which is very less than the desirable 0.3 or above. This means that there is uneven lighting which creates visual discomfort, glare near windows and dark zones in the deeper parts of the classrooms.

Illuminance (Min 15.78 lux, max 1317.18 lux)

The minimum illuminance level of 9.61 lux is below the educational standards (typically 300–500 lux). The maximum illuminance of 1072.59 lux indicates very high daylight intensity near openings.

Summary -

- Avg DF (1.29%) → Moderate but still below recommended daylight levels.
- Uniformity (0.122 / 0.012) → Highly uneven daylight; steep contrast across the room.
- Min Illum (15.78 lux) → Severely underlit zones.
- Max Illum (1317 lux) → Very bright hotspots; risk of glare.

Improved case

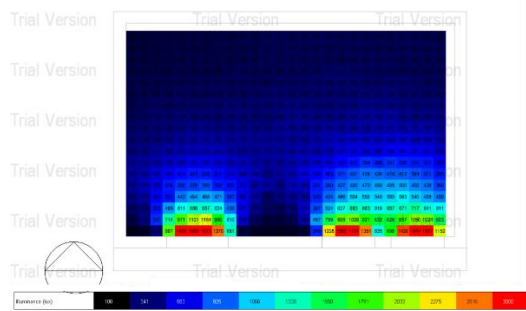


Figure. 17: Improved Illuminance - MPS

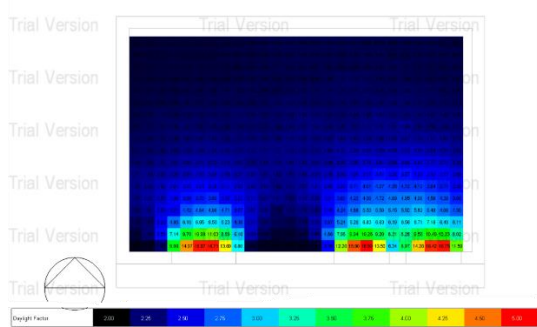


Figure. 18: Improved Daylight Factor

Table 5: Improved case results

MPS	Floor Area (m2)	Floor Area above Threshold (m2)	Floor Area above Threshold (%)	Average Daylight Factor (%)	Minimum Daylight Factor (%)
Classroom	69.812	42.50	60.88%	2.86%	0.78

MPS	Maximum Daylight Factor (%)	Uniformity ratio (Min / Avg)	Uniformity ratio (Min / Max)	Min Illuminance (lux)
Classroom	12.94	0.34	0.12	328

Strategies used –

- Window-to-Wall Ratio (WWR): increased to 45%
- Window height (head): 1.9 m above finished floor
- A continuous Clerestory band: added above window — 0.50 m tall continuous band above the main window head (runs full façade)
- High reflectance ceiling, white plaster finish
- Diffusing glazing: VLT ≈ 70–75%, low-e coating — increases transmitted light while softening glare.

Ryan International School, Vashi

Classroom dimensions – 12.2m x 8.1m x 3.5

Location – Sanpada, Navi Mumbai



Figure. 19: Ryan International school

Simulation results –

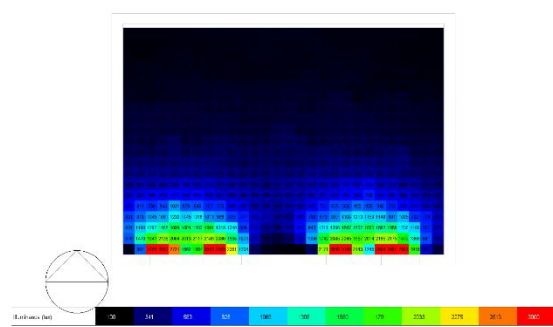


Figure. 20: Illuminance

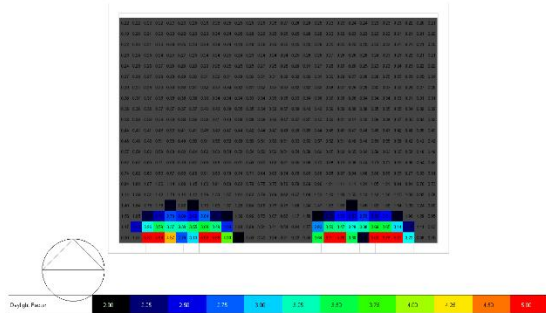


Figure. 21: Daylight Factor

Table 6: Improved case results

MPS	Floor Area (m2)	Floor Area above Threshold (m2)	Floor Area above Threshold (%)	Average Daylight Factor (%)	Minimum Daylight Factor (%)
Classroom	53.982	20.289	37.585	0.683	0.174

MPS	Maximum Daylight Factor (%)	Uniformity ratio (Min / Avg)	Uniformity ratio (Min / Max)	Min Illuminance (lux)
Classroom	5.299	0.255	0.033	103.74

Average Daylight Factor (0.683%)

This value shows sub-optimal daylight levels but is still below the recommended 2%.

Uniformity Ratios (Min/Average = 0.255, Min/Max = 0.033)

The uniformity ratio comes out to be 0.255 which is very close to 0.3. This means that there is better distribution of light in this classroom, as compared to the other 2.

Illuminance (Min 103.74 lux, max 3155.7)

The minimum illuminance level of 103.74 lux is below the educational standards (typically 300–500 lux). The maximum illuminance of 3155.7 lux indicates very high daylight intensity near openings.

Summary -

- Avg DF (0.683%) → Very low daylight; not sufficient for learning.
- Uniformity (0.255 / 0.033) → Moderate distribution but high contrast; uneven lighting.
- Min Illum (103 lux) → Below standards; underlit zones persist.
- Max Illum (3155 lux) → Very high hotspots; risk of glare and discomfort.

Improved case

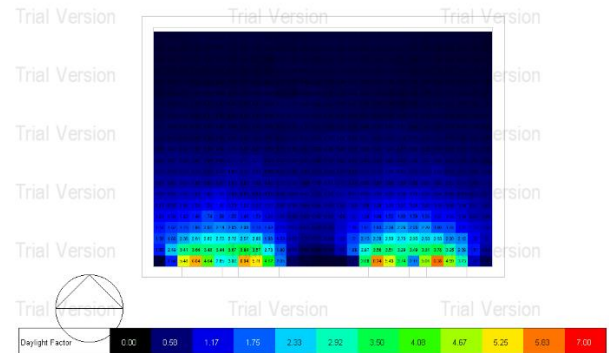


Figure. 22: Improved Daylight Factor - MPS

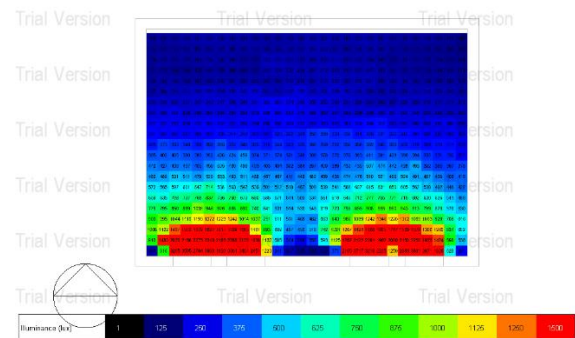


Figure. 23: Improved Illuminance – MPS

Table 7: Improved case results

MPS	Floor Area (m2)	Floor Area above Threshold (m2)	Floor Area above Threshold (%)	Average Daylight Factor (%)	Minimum Daylight Factor (%)
Classroom	53.982	36.00	66.7	2.95	0.82

MPS	Maximum Daylight Factor (%)	Uniformity ratio (Min / Avg)	Uniformity ratio (Min / Max)	Min Illuminance (lux)
Classroom	13.50	0.42	0.12	320

Strategies used –

- Window-to-Wall Ratio (WWR): increased to 38%
- Window height (head): 2.1 m above finished floor
- A continuous Clerestory band: added above window — 0.30 m tall continuous band above the main window head (runs full façade)
- Horizontal overhang projection $\approx 0.6 \times$ window head (~ 1.3 m) plus vertical fins at 1.2 m spacing where sun exposure is high.
- Glazing: VLT $\approx 60\%$, low-e coating

RESULTS AND DISCUSSIONS

Table 8: Base case comparative matrix

Parameter	MPS	Apeejay	Ryan
Floor Area (m ²)	69.812	45.004	53.982
Floor Area Above Threshold (m ²)	3.847	4.327	20.289
Floor Area Above Threshold (%)	5.511%	9.615%	37.585%
Average Daylight Factor (%)	0.764%	1.29%	0.683%
Minimum DF (%)	0.096	0.158	0.174
Maximum DF (%)	10.715	13.16	5.299
Uniformity Ratio (Min/Average)	0.126	0.122	0.255
Uniformity Ratio (Min/Max)	0.009	0.012	0.033
Minimum Illuminance (lux)	9.61	15.78	103.74
Maximum Illuminance (lux)	1072.59	1317.18	3155.7

Table 9: Improved case comparative matrix

Parameter	MPS	Apeejay	Ryan
Floor Area (m ²)	69.812	45.004	53.982
Floor Area Above Threshold (m ²)	42.50	28.00	36.00
Floor Area Above Threshold (%)	60.88%	62.22%	66.70%
Average Daylight Factor (%)	2.86%	2.60%	2.95%
Minimum DF (%)	0.78%	0.72%	0.82%
Maximum DF (%)	12.94%	12.10%	13.50%
Uniformity Ratio (Min/Average)	0.34	0.38	0.42
Uniformity Ratio (Min/Max)	0.12	0.12	0.12

Table 10: Final summary table

Category	MPS – Strategies Applied	Apeejay – Strategies Applied	Ryan – Strategies Applied
Glazing & Openings	- Increased WWR to 40% - Window head height raised to 2.10 m	- Increased WWR to 45% - Continuous horizontal glazing band - Window head fixed at 1.90 m, sill at 0.80 m	- Increased WWR to 38% - Window head at 2.10 m
Clerestory Integration	Introduced clerestory band 0.60 m tall above main façade	Added clerestory of 0.60 m height at 2.40 m	Installed clerestory band 0.50 m tall at 2.60 m
Light-Redirecting Devices	Exterior light shelf 0.60 m	- Exterior light shelf 0.75 m depth - Light-redirection through upper roofing treatment	

Minimum Illuminance (lux)	328 lux	300 lux	320 lux
Maximum Illuminance (lux)	1458 lux	1400 lux	1420 lux

CONCLUSIONS

The improved daylighting interventions applied across the three schools demonstrate a clear advancement toward meeting accepted performance criteria for educational interiors. The increase in window-to-wall ratios (38–45%), introduction of clerestory bands (0.50–0.60 m height), significantly enhanced daylight penetration into the classrooms. These measures, combined with high-reflectance finishes (ceilings at ~85%, walls at ~75%, floors at ~30%), resulted in uniform distribution of light and an observable reduction in low-illuminance zones.

Across the three improved cases, the average daylight factor values now consistently fall between 2.60% and 2.95%, representing a substantial improvement over the base cases, where values were below 1.3%. Values within the 2–5% range are recognised as adequate for classroom tasks and are associated with lower dependence on artificial lighting during daytime hours. Similarly, the minimum illuminance levels now lie between 300–328 lux, meeting the lower threshold required for general classroom activities and addressing the previously recorded deficiencies where the minimum fell below 20 lux.

Shading & Glare Control	• Horizontal overhang 1.05 m • Vertical solar fins for façade	• Overhang sized at 0.5 × window height • Vertical fins at 1.2 m spacing	• Overhang at ~1.3 m • Vertical fins at 1.2 m spacing
Glazing Specification	• High VLT ~70% diffusing glazing • Low-e coating	• Diffusing glazing with 70–75% VLT	• Fritted/diffusing glazing, ~60% VLT, low-e coating
Internal Reflectance	• Ceiling reflectance 85% • Wall reflectance 75% • Floor reflectance 30%	• Ceiling reflectance 85% • Wall reflectance 75% • Floor reflectance 30%	• Ceiling 85% • Walls 75% • Floor 30%

The uniformity ratios (Min/Avg) improved to values between 0.34 and 0.42, indicating reduced contrast gradients across the classrooms. Improved Min/Max ratios (~0.12) further suggest that no area of the room experiences disproportionate brightness relative to the darkest areas. These metrics together indicate a balanced luminous environment conducive to sustained attention and stable visual performance during instructional activities.

Daylighting is not about how much light is on a desk. It's about how children get to sit, how they lookup and interact with the blackboards, how they feel when learning a new topic that requires attention. In Mumbai's dense, humid and almost restless environment, the challenge of daylight is much harder to navigate. Too much of it and you get glare, squinting, and heat. Too little and focus gets the short end of the stick. Balance this act becomes everything. And this project is suggesting us back to that idea of moderation.

So the conclusion presses in, again and again: daylight cannot be treated as optional. Not in dense cities. Not in schools. It is not decoration. It is structured. It is pedagogy. It is well-being. And for architects, that means responsibility. Every window detail. Every shade. Every reflection. They all shape how a child learns, how a child lives.

REFERENCES

- [1] GRIHA Council (2019) GRIHA v2019 rating system manual New Delhi: GRIHA Council.
- [2] Heschong Mahone Group (1999) Daylighting in schools: An investigation into the relationship between daylighting and human performance Fair Oaks, CA: Pacific Gas and Electric Company.
- [3] Tregenza, P. & Wilson, M. (2011) Daylighting: Architecture and lighting design London: Routledge.
- [4] U.S. Green Building Council (2019) LEED v4.1 building design and construction reference guide Washington, DC: U.S. Green Building Council.
- [5] Boubekri, M., Cheung, I. N., Reid, K. J., Wang, C. H. & Zee, P. C. (2014) Impact of windows and daylight exposure on overall health and sleep quality of office workers. *Journal of Clinical Sleep Medicine*, 10(6), pp. 603–611. Available at: <https://doi.org/10.5664/jcsm.3780>
- [6] Heschong, L., Wright, R. L. & Okura, S. (2002) Daylighting impacts on human performance in school buildings. *Journal of the Illuminating Engineering Society*, 31(2), pp. 101–114. Available at: <https://doi.org/10.1080/00994480.2002.10748396>
- [7] Li, D. H. W. & Lam, T. N. T. (2001) Evaluation of lighting performance in open-plan offices. *Lighting Research & Technology*, 33(4), pp. 235–250.
- [8] Nugroho, A. M., Triyadi, S. & Wonorahardjo, S. (2022) Daylighting performance in educational buildings under tropical climate conditions. *Journal of Building Engineering*, 45, pp. 103–115.
- [9] Reinhart, C. F., Mardaljevic, J. & Rogers, Z. (2006) Dynamic daylight performance metrics for sustainable building design. *LEUKOS*, 3(1), pp. 7–31.
- [10] Oblinger, D. G. (2006) Learning spaces. EDUCAUSE. Available at: <https://www.educause.edu/research-and-publications/books/learning-spaces>
- [11] Piaget, J. (1970). *The Science of Education and the Psychology of The Child*. New York: Grossman
- [12] Vygotsky, L. S. (1978) *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press. Available at: <https://home.fau.edu/musgrove/web/vygotsky1978.pdf>