Daylight and Energy Performance Assessment of Passive Design Strategies in a Subtropical Commercial Building Using Honeybee–Radiance in Bhutan

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Abstract

The increasing reliance on artificial lighting and mechanical cooling in warm-humid climates highlights the need for climate-responsive passive design in commercial buildings. This study evaluates a prototype commercial building in Gelephu, Bhutan using Honeybee–Radiance and a parametric assessment of building orientation, window-to-wall ratio (WWR), glazing type, and interior surface reflectance. The base case, representing a conventional commercial building configuration, recorded sDA 0.49, ASE 0.24, UDI 0.61 and DGP 0.25, indicating insufficient daylight distribution, excessive solar exposure and perceptible glare. The optimized configuration (45° orientation, 40% WWR, Low-E glazing and wall/floor/ceiling reflectance of 0.70/0.40/0.90) improved performance to sDA 0.78, ASE 0.09, UDI 0.84, DGP 0.11 and average illuminance of 560 lux. These results represent a 59% increase in sDA, a 63% reduction in ASE and a 56% reduction in glare probability. The findings demonstrate that integrated passive design strategies can substantially improve daylight quality and visual comfort while supporting more energy-efficient commercial building design in Bhutan's subtropical climate.

Keywords: *Daylight Performance1, Passive Design Strategies2, Energy Efficiency3, Honeybee–Radiance4, Subtropical Climate5*

1. INTRODUCTION

Commercial buildings are one of the world's biggest energy consumers and consume a large percentage of energy in both developed and developing nations, especially electricity (Pérez-Lombard et al., 2008). In warm humid and subtropical climates, architects and building engineers must deal with the dual problem of managing solar heat gain and ensure adequate natural light while at the same time avoiding unnecessary design interventions, which are hard to accomplish without deliberate design action (Ruck et al., 2000). Traditional commercial buildings in these areas have traditionally heavily depended on mechanical cooling and artificial lighting, resulting in high operational energy costs and high carbon emissions (IEA, 2023).

Passive design strategies are an attractive alternative, because they rely on the natural features of a building shape, orientation, envelope, and materials for the purpose of reducing the thermal and visual impact inside the building, provided no energy is being used to achieve this effect (Givoni, 1992). Optimized building orientation, optimized window-to-wall ratio (WWR), external shading devices and appropriate spatial configuration have been proven to reduce cooling loads and enhance daylight quality at the same time, for instance, for various building projects (Mardaljevic et al., 2012; Tzempelikos & Athienitis, 2007). The effectiveness of the passive strategies, however, is climate specific and in the subtropical context of Bhutan (warm–humid summer with high solar radiation) has not been fully explored in the academic literature (Dorji & Tshering, 2022).

Daylighting is a fundamental passive design feature that can be used for both positive and negative building performance. With good management, natural daylight can help to lower artificial-lighting energy consumption, as well as improve health and visual comfort for occupants (Reinhart & Voss, 2003). Since then, climate-based metrics like Spatial Daylight Autonomy (sDA), Useful Daylight Illuminance (UDI) and Annual Sunlight Exposure (ASE) have been identified as strong annual metrics for quantifying daylight performance under real sky conditions (Nabil & Mardaljevic, 2005; IES, 2012). These metrics can also more accurately capture the light levels experienced during fluctuating daylight conditions as opposed to static or overcast-sky calculations, and thus are well suited to the evaluation of the integrated light performance of passive design interventions (Mardaljevic et al., 2012).

With improvements in computer simulation, it is now more possible than ever to understand the linkage between daylighting and energy performance at an early stage in the design. The Honeybee–Radiance framework is a highly validated parametric simulation environment that allows for high fidelity, climate-based daylight modelling and can be used in conjunction with a parametric workflow (Ladybug Tools, 2023; Ward & Shakespeare, 1998). This platform can provide a complete passive design evaluation of their impact on visual comfort and whole-building energy use specifically the savings gained in artificial lighting and mechanical cooling loads (Reinhart & DesRoches, 2011).

The current study is aimed at filling the gap in the knowledge of climate responsive design of commercial buildings in Bhutan's sub-tropical climate. A generic prototype commercial building is developed and compared to a baseline building, which represents an average of traditional, non-optimized building design, and an optimized building with a complete set of passive design methods. The study in this investigation is conducted systematically to explore the effect of building orientation, WWR, different types of glazing and surface reflectivity of the interior on daylight performance and energy efficiency. The results can offer evidence-based design guidance for sustainable commercial buildings in subtropical climates, and can be translated to other South and Southeast Asian climate zones, similar to the subtropical climate (Do et al., 2025; Escobar et al., 2024).

2. BACKGROUND

Daylighting plays an important role in the building performance and has significant impact on the visual comfort, energy consumption, indoor environmental quality and wellbeing of the user. The goal of daylighting in building design is to create adequate daylighting for the activities that are conducted inside the building while minimizing unwanted glare, thermal discomfort, and amount of unwanted direct daylight. With the prevalence of climate-based methods and metrics in current daylighting assessment practice, methods based on annual metrics are increasingly replacing methods based on single-point or static sky evaluations. The IES LM-83 method is often employed for this purpose, such as measured by the metric of Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), which together measure daylight sufficiency and risk of excessive direct sun exposure. These are generally simulated by using EPW climate data and hourly sky conditions, typically with a honeybee radiance-based workflow.

The design of daylighting in buildings is given particular importance in Gelephu due to the climatic conditions which may pose a challenge between providing acceptable natural lighting and managing solar gain. In such contexts, orientation, window size, window type, and internal surface reflectance are key design considerations. A poorly balanced solution can produce underlit interior zones in deeper plan areas while also causing glare and overheating near the facade. Hence, daylighting optimization is not only on quantity, but on quality of daylighting with regard to distribution and value in occupied spaces. With multiple design options readily compared, within a given set of local weather conditions, climate-based simulation is well suited for this purpose.

3. METHODOLOGY

This daylighting analysis was performed with the software Rhinoceros 3D/Grasshopper with the tools Ladybug Tools and Honeybee-Radiance with the climate-based annual simulation software, using the weather file Gelephu. The first evaluation of the then base case model was conducted with five daylight metrics: sDA, ASE, Useful Daylight Illuminance (UDI 100-2000 lux), daylight factor and average illuminance. The above-mentioned variables were then used in a three-stage parametric study to test the building orientation, window-to-wall ratio, internal surface reflectance and type of glazing, which are known to have a significant effect on daylight quality and visual comfort (Do et al., 2025; Escobar et al., 2024). Those that performed best were then combined into an optimized design, and compared to the base case. The results were then displayed via tables and charts for reference in the final design recommendations (Honeybee-Radiance Primer, 2023; Honeybee-Radiance Primer, 2025a)

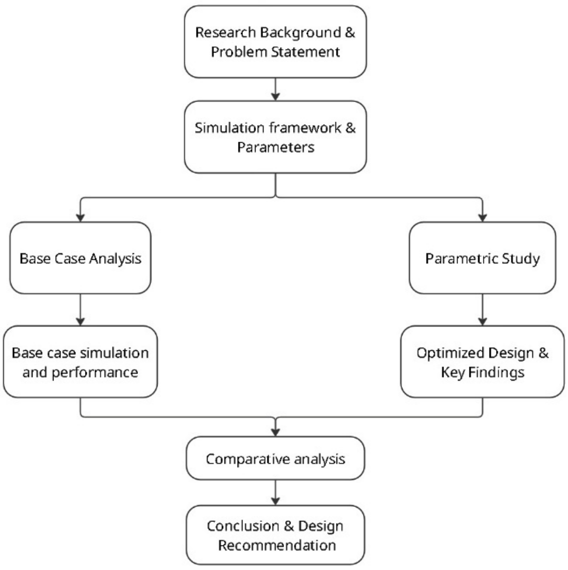

Fig.1: Methodology chart

4. SIMULATION FRAMEWORK AND RESEARCH DESIGN

4.1. Simulation Framework

A climate-based daylight simulation method is employed to evaluate the passive design strategies in subtropical environment. Daylighting performance is evaluated using a parametric modelling model within Honeybee–Radiance, which is a combination of the accuracy of the ray-tracing model Radiance and the modeling parametric tool developed by Honeybee. The parametric modelling tool Honeybee is combined with the accuracy of the ray-tracing model Radiance to analyze daylighting performance within the building, such as daylight distribution, illuminance levels, and visual comfort.

The simulation is done using location specific climatic data for Bhutan which include variations of the sun radiation, sky condition and atmospheric parameters in the country on an annual basis to ensure climatic reliability. This enables the daylight performance to be tested all year round allowing for a more realistic picture of building performance.

The study also investigates the effect of significant design parameters, such as building orientation, window to wall ratio, window properties and surface reflectance, by employing a parametric modelling approach. This method can be used to compare several scenarios to determine the best design configuration and make data-driven decisions for daylight and energy optimization.

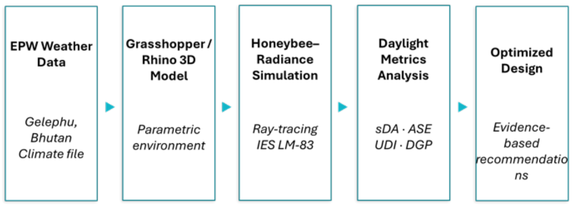

Fig 2: Simulation Framework

4.2. Performance Metrics and Benchmarks

Daylighting performance is evaluated against important daylighting metrics derived from climate and their respective reference values. Spatial Daylight Autonomy ($sDA_{300,50\%}$) is the percentage of the floor area that receives illuminance of 300 lux or more for 50% of the hours of the year in which the area. A value of sDA 0.55 or higher is classified as Nominally Daylit and sDA 0.75 or higher as Preferred Daylit (IES LM-83-12).

Annual Sunlight Exposure ($ASE_{1000,250h}$) refers to the percent of floor area receiving more than 1000 lux of direct sunlight for more than 250 hours annually when the space is occupied. Avoid values greater than 0.10 whereby they may suggest glare and overheating problems, according to LEED v4.

Useful Daylight Illuminance ($UDI_{100–2000}$ lux) is the percentage of the hours of the day which have daylight levels between 100 and 2,000 lux. Values that fall below this range are indicative of insufficient daylight while values above this range may indicate excessive daylight and glare.

Daylight Glare Probability (DGP) is a measure of the probability of glare, based on the brightness of the glare source and the illuminance received at the eye level. The values of DGP below 0.20 represent imperceptible glare, 0.20 to 0.35 perceptible glare, 0.35 to 0.45 disturbing glare, and above 0.45 intolerable glare (Wienold & Christoffersen, 2006).

These can be combined to understand the total picture of daylight availability, visual comfort, glare risk and IEQ in subtropical conditions.

5. STUDY AREA

The present study looks at a prototype single-storey commercial building located in Gelephu, Bhutan, a tropical region with high solar radiation, high humidity with high temperatures. This geographic context has been chosen on purpose since it is a key climatic region where the solar orientation, daylight hours and cooling needs have a significant impact on building performance.

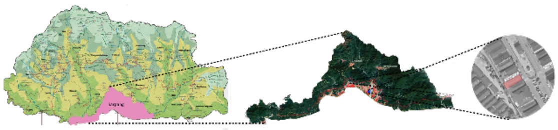

Fig.3: *Study Area of Gelephu*

It includes traditional building materials which are commonly used in Bhutanese construction practice, to make a realistic representation of the building performance. Furthermore, a standardized spatial configuration has been used corresponding to the typical spatial planning configurations that are found throughout the country. This assumption enables a controlled comparative analysis of the building.

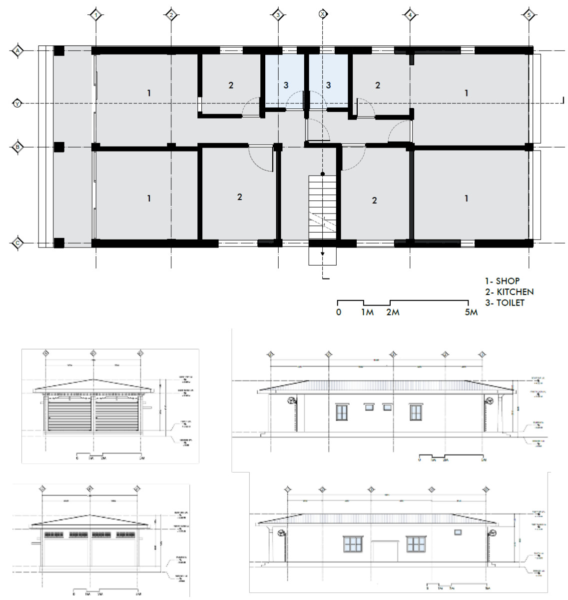

Fig 4: *Plan and Elevations*

Fig 5: *3D View of Base Case*

5.1. Parameters Studied

a. Building Orientation

A total of five orientations from true north (0°, 45°, 90°, 135°, 180°) were tested as part of the building orientation. The orientation of the building determines the quantity, time and direction of light entering the interior and so has a significant impact on daylighting and solar exposure. The intent was to determine the orientation that would get sufficient daylight without glare and heat gain.

b. Window-to-Wall Ratio

Window to wall ratios of between 20% and 60% were tested to gain an understanding of the impact of varying window areas on daylight performance. Increase in WWR may result in better daylighting, but may also contribute to glare, overheating, and excessive solar gain. The aim was to determine the most balanced WWR that provides sufficient daylight without causing overexposure.

c. Surface Reflectance and Glazing Type

Surface reflectance and glazing type were investigated together to gain an understanding of the combined effects of surface reflectance and glazing type on daylight performance. The reflectance of the walls, ceiling and floor was changed to determine the redistribution of light into the interior space. Concurrently, various types of glazing were evaluated using visible transmittance and solar heat gain coefficient. The goal was to determine the optimal combination which would achieve an optimum balance between useful daylight and unwanted glare and unwanted heat gain.

6. BASE CASE DAYLIGHTING PERFORMANCE RESULTS

6.1 Annual Performance Summary

The sDA value of 0.49 is lower than the recommended sDA value of 0.55 for a nominally daylit space in IES LM-83-12. This is primarily because of the shallowness of light penetration in the core of the zones. Concurrently, the LEED v4 limit of 0.10 is exceeded with the ASE value of 0.24, indicating that 24% of the floor area is receiving excessive direct sunlight. This suggests a high risk of glare and heat gain, especially near the perimeter.

The UDI value of 0.61 means that 61% of the time spent indoors is spent in the useful daylight range of 100-2000 lux. However, there is spatial variation in this value, in the perimeter zones too much daylight but in the deeper zones too little. The Daylight Factor of 1.9% is just under the minimum recommended Daylight Factor for general commercial interiors (2%). The average illuminance of 400 lux is within the average office target range but the uneven distribution and DGP of 0.25 suggest that, under peak conditions, there is perceptible glare.

Table 1: *Base Case Annual Daylighting Performance Summary with Benchmark Comparisons*

Metric	Value	LEED/IES Benchmark Commentary
($sDA_{300,50}$%)	0.49	Below the sDA ≥ 0.55 threshold recommended (IES LM-83-12)
($ASE_{1000,250}$h)	0.24	Exceeds the ASE ≤ 0.10 ceiling; 24% of floor area receives excessive direct sun
($UDI_{100–2000}$)	0.61	Moderate; roughly 61% of occupied hours fall within the useful 100–2000 lux band
Daylight Factor (DF)	1.9%	Below the 2% minimum for general commercial use (CIBSE LG10)
Average Glare Probability	0.25	Exceeds the DGP < 0.20 comfort threshold; perceptible glare under peak conditions

The overall result of the base case indicates a typical daylighting problem: less daylight in the interior and more daylight on the façade. This reinforces the necessity of passive design elements like optimum orientation, window to wall ratio, shading, window and wall glazing and enhanced surface reflectivity.

6.2 Seasonal and Diurnal Illuminance Distribution

During the summer solstice, the building shows the highest daylight levels, with average illuminance reaching 520 lux at solar noon, which is acceptable for general commercial use under ISO 8995-1. However, perimeter areas receive up to 1,820 lux, creating a high risk of glare, with a DGP of 0.35, which falls near the disturbing glare range (Wienold & Christoffersen, 2006). In contrast, the core zones receive only 95 lux, showing a strong imbalance between bright perimeter areas and underlit interior spaces.

During the equinox, daylight conditions become slightly more balanced, with average illuminance between360 and 445 lux and maximum values below 1,340 lux. Glare levels are lower than in summer, with DGP values of 0.23 to 0.29, but they still remain above the imperceptible glare threshold of 0.20. The continued difference between perimeter and core daylight levels indicates the lack of light-redirecting strategies in the base model.

Table 3: *Seasonal Daylighting Characteristics and Primary Performance Limitations*

Season	AvgLux (range)	Peak Max Lux	Min Lux	Primary Limitation
Summer Solstice	410–520	1,820	85	Overheating & glare at perimeter
Equinox	360–445	1,340	78	Non-uniform distribution; under illumination
Winter Solstice	300–380	1,020	66	Severe under illumination at depth; lowest sDA

During the winter solstice, daylight availability is the weakest. Average illuminance drops to 300 to 380 lux, while interior sensor values fall as low as 66 to 75 lux, below the 100 lux lower UDI limit. This indicates under-illumination in the core areas and the need for artificial lighting support. Although glare risk is lower, with DGP values of 0.17 to 0.21, low sun angles still allow deeper solar penetration and may create localized glare.

Overall, the base case shows an uneven daylight pattern: summer causes excessive glare, while winter results in insufficient daylight. This confirms that the base design is not well optimized for the subtropical climate and requires passive design improvements.

6.3. Spatial Distribution and Daylight Zoning

The base model has a clearly visible perimeter to core daylight imbalance under all simulated sky conditions. Zones located within 1.5 m to 2.5 m of the glazed façade may reach levels higher than 500 lux, which are too high for general office work at levels indicated between 300–500 lux.

However, spaces more than 4 m away from the façade often measure less than 200 lux, which means that the interior spaces are not well lit.

The difference in illuminance levels is more pronounced in the peak summer season, with a difference of more than 1,820 lux near the façade to 85 lux in the core. This means that this is a poor level of daylight uniformity which is less than the recommended level of daylight uniformity for an office.

The base model has even more of a problem, due to the low surface reflectivity of the walls (50%), floor (20%), and ceiling (70%). These finishes restrict daylight from spreading throughout the room, particularly towards the central spaces. This results in an excessive brightness level for people who are close to the façade and insufficient daylight for people who are further from the façade. This implies that there would still be a substantial amount of light required during the majority of the time this building is in use, negating the energy saving potential of daylighting

6.4. Diagnostic Interpretation and Design Deficiencies

Based on the base case analysis, the following major design flaws are identified that can be addressed by the passive design strategies:

a. Poor orientation

In the subtropical climate of Gelephu, the strong afternoon sun is directed towards the south and west glazed facades of the building. This adds to the high ASE value of 0.24 from direct solar penetration, and increases the risk of glare.

b. No external shade.

No overhangs, vertical fins or other shading devices are included in the base model. This has created direct gain by the building to direct sunlight, particularly during the summer solstice, causing too much solar exposure.

c. Unoptimized glazing

A large quantity of daylight enters due to the use of standard single clear glass that has a high visible transmittance. But it is not effective in controlling solar heat gain and solar glare.

d. Low surface reflectance.

Interior finishes, particularly the floor reflectance, have low reflectivity, which reduces daylight redistribution by reflection. This leads to less penetration of daylight into the core spaces and under-illumination, requiring more artificial lighting.

7. PARAMETRIC STUDY

7.1. Building orientation

a. Parametric Results

Table 4 summarizes the daylighting performance metrics across five discrete orientations evaluated at 45° intervals from 0° to 180°.

Table 4: *Daylighting performance metrics by building orientation (0°–180°)*

Rotation	sDA	ASE	UDI	DGP	Overheating Risk
0°	0.58	0.18	0.69	0.21	Medium
45°	0.63	0.15	0.73	0.18	Low-Medium
90°	0.55	0.21	0.66	0.24	Medium-High
135°	0.60	0.17	0.71	0.20	Medium
180°	0.52	0.16	0.64	0.19	Low-Medium

b. Analysis and Optimal Selection

The 45° orientation works best out of all the rotations tested. It also has the highest sDA value of 0.63, and the highest UDI value of 0.73; the lowest ASE value is 0.15 and the lowest DGP value is 0.18. It has an average illuminance of 520 lux and a Daylight Factor of 2.4%, which are in line with the daylighting requirements, and suggest good daylight availability and reduced glare potential. The lower solar penetration depth of 4.6 m is also indicative of a better control of direct sunlight in the occupied floor area.

The 90° orientation has the highest ASE of 0.21 and DGP of 0.24, primarily because of exposure to the sun for a longer duration in the east-west direction, compared to the other practical options. The 0° orientation option yields moderate results with an sDA of 0.58 and ASE of 0.18, but performs better than the 45° option. The orientation of 180° has a slight decrease in solar exposure, but also a lower daylight availability, in terms of sDA and UDI, of 0.52 and 0.64 respectively.

Overall, the 45° diagonal orientation is considered the best option to provide an even distribution of sunlight across the façades, to minimize excessive solar gain on a single façade, and to balance daylight availability and glare control.

7.2. Window-to-Wall Ratio

a. Parametric Results

Table 5 presents the performance response to WWR variation from 20% to 60%.

Table 5: *Daylighting performance metrics by window-to-wall ratio (WWR)*

WWR	sDA	ASE	UDI	Pen. Depth (m)	DGP	Overheating Risk
20%	0.46	0.05	0.58	3.2	0.08	Low
30%	0.61	0.08	0.76	4.1	0.11	Low–Medium
40%	0.68	0.10	0.81	4.8	0.14	Medium
50%	0.72	0.16	0.79	5.2	0.22	Medium–High
60%	0.75	0.24	0.71	5.7	0.31	High

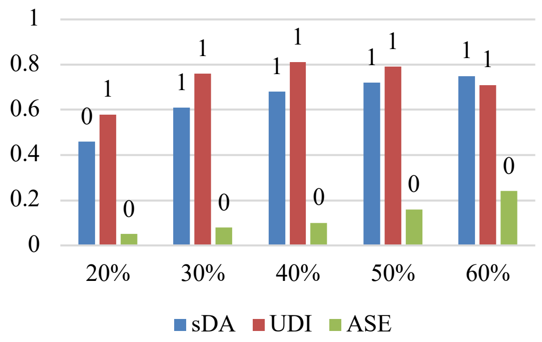

Fig 6: *Daylighting performance metrics by window-to-wall ratio (WWR)*

b. Analysis and Optimal Selection

WWR is not a linear relationship with daylight performance, with 40% being the better option. The sDA at 20% WWR is only 0.46 and is less than the IES LM-83-12 threshold of 0.55 for a nominally daylit space. The solar penetration depth of 3.2 m further indicates that the dark zones in the interior are not well lit during the day. Performance is enhanced with 30% WWR, sDA 0.61, UDI 0.76 and low glare risk (DGP 0.11). But the mean illuminance of 470 lux could be restrictive for applications that need more intense task lighting.

The best performance is obtained by the 40% WWR, whose UDI is equal to 0.81, which corresponds to 81% of the occupied hours being in the useful daylight range (100 to 2,000 lux). It also has a sDA of 0.68, an average illuminance of 555 lux, and a low glare risk (DGP 0.14). Achieves good daylighting with a LEED v4 ASE limit.

Performance starts to drop after 40%. The AWW values are 0.16 and 0.22 for ASE and DGP at 50% WWR, respectively, which are the values corresponding to an easily noticed glare. The results at 60% WWR are worst, with the results of ASE 0.24, DGP 0.31, and reduced UDI 0.71, caused by too much daylight. Thus, the optimum configuration is chosen to be 40% WWR for optimum balance between daylight available, useful illuminance and glare control.

7.3. Interior Surface Reflectance

a. Parametric Results

Table 6 details the performance response of wall, floor, and ceiling surfaces across tested reflectance values.

Table 6: *Daylighting performance metrics by surface type and reflectance value*

Surf-ace	Refle-ctance	sDA	UDI	Avg Lux	DGP	Assessment
Wall	0.30	0.60	0.73	505	0.15	Acceptable
Wall	0.50	0.64	0.78	535	0.14	Good
Wall	0.70	0.68	0.81	555	0.14	Optimal
Wall	0.90	0.71	0.80	570	0.18	Over-reflective
Floor	0.20	0.65	0.77	530	0.13	Good
Floor	0.40	0.68	0.81	555	0.14	Optimal
Floor	0.60	0.69	0.80	565	0.17	Reflected glare
Ceiling	0.50	0.63	0.75	515	0.15	Acceptable
Ceiling	0.70	0.66	0.79	540	0.14	Good
Ceiling	0.90	0.68	0.81	555	0.14	Optimal

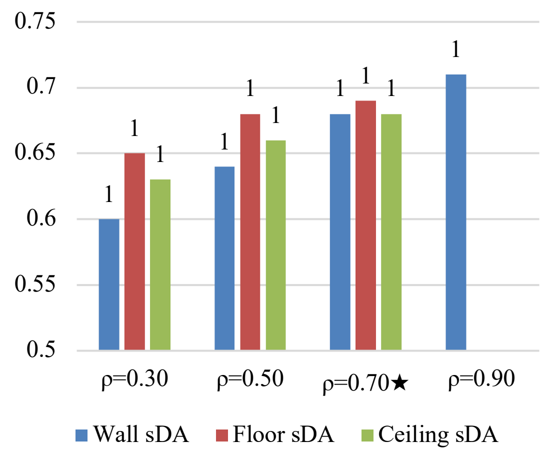

Fig 7: *Daylight performance metrics by surface types and reflectance values*

b. Analysis and Optimal Selection

The surface reflectance has a significant impact on the distribution of daylight in internal reflection in deep-plan spaces where the daylight from the windows does not reach the full floor area. In general, higher reflectance leads to higher daylight uniformity, at least up to an optimal point, but very high reflectance can lead to an increase in glare risk.

It is found that the optimal wall reflectance of 0.70, gives sDA of 0.68, UDI of 0.81, uniformity ratio of 0.58, and DGP of 0.14. A higher wall reflectance of 0.90 does incur some uniformity benefit at the expense of increasing the glare risk, and a value of 0.30 is too low to be effective in daylighting an office.

Floor reflectance of 0.40 performs best, with sDA 0.68, UDI 0.81, uniformity ratio 0.58, and DGP 0.14. The higher the value of 0.60, the more reflected glare, particularly in open-plan areas increase, and the value of 0.20 is the base case value, which reduces the amount of daylight reflection to the core areas.

The best ceiling reflectance is 0.90, which provides optimal daylight uniformity and UDI without adding glare. This indicates that the ceiling is the most critical surface for re-distribution of daylight deeper into the building, and is a low cost, passive method of enhancing the daylight performance.

7.4. Glazing Type

a. Parametric Results

Table 7 compares four glazing specifications across the full metric set.

Table 7: *Daylighting performance metrics by glazing type*

Glazing Type	VT	sDA	ASE	UDI	DGP	Assessment
Single Clear	0.82	0.71	0.20	0.77	0.24	Bright but risky
Double Glazing	0.72	0.67	0.14	0.80	0.16	Balanced
Low-E	0.68	0.66	0.10	0.82	0.12	Best overall
Tinted	0.48	0.54	0.06	0.69	0.08	Too dim at depth

b. Analysis and Optimal Selection

A combination of visible light transmittance, solar heat gain and control of glare are considered in glazing selection.

Single clear glazing offers the highest daylight availability (sDA 0.71) and average illuminance (605 lux). It also has an extremely high LEED v4 limit for ASE with a rating of 0.20, twice the LEED v4 limit, and a DGP of 0.24, which means that the lighting is perceptible as glare. It has a high overheating and glare potential, unsuitable for warm-humid climate of Gelephu.

Tinted glazing VT 0.48, ASE 0.06, DGP 0.08 is excellent in blocking solar glare and heat. It has, however, been found to reduce the daylighting by too much resulting in the sDA of 0.54 that falls below the recommended daylight threshold in IES LM-83-12. It is also not as appropriate for commercial interiors as the higher illuminance brightness might suggest due to possible colour distortion.

Those with an VT rating of 0.68 are designated as the best option in the form of low-E glazing. It provides good daylighting and solar control performance (sDA 0.66) and a high UDI (0.82), low glare risk (DGP 0.12) and ASE 0.10. Low-E glazing can transmit a portion of the light while minimizing the amount of unwanted solar heat, making it the optimal performance for subtropical commercial buildings.

8. COMPARATIVE ANALYSIS

The analysis determines the most optimal passive design as a 45° orientation, 40% WWR, wall/floor/ceiling reflectance of 0.70/0.40/0.90, and Low-E glazing. This configuration yields an annual sDA of 0.78, an annual average of 560 lux and an annual ASE of 0.09, and a DGP of 0.11. These values are clearly better than the base case in terms of daylight availability, useful daylight range, glare reduction and overall visual comfort.

The optimized model is able to achieve the following: It meets IES LM-83-12 Preferred Daylit standard, adheres to the LEED v4 ASE limit and satisfies CIBSE LG10 daylight factor and uniformity requirements. On facades that have a high solar exposure, external shades like horizontal overhangs and vertical fins are suggested for further reducing the amount of sunlight and seasonal glare, particularly on bright summer afternoons.

Table 8: *Summary of Optimal Parameter Selection and Projected Performance Improvement*

Parameter	Base Case	Optimised	Improvement	Benchmark
sDA (Spatial DA)	0.49	0.78	+59%	>=0.75 Preferred (IES)
ASE (Sun Exposure)	0.24	0.09	-63%	<=0.10 LEED v4
UDI (Useful DI)	0.61	0.84	+38%	Maximize 100-2000 lux
Avg Illuminance	400 lx	560 lx	+40%	300-500 lx (ISO 8995)
DGP (Glare Risk)	0.25	0.11	-56%	<0.20 Imperceptible

The optimized model is able to achieve the following: It meets IES LM-83-12 Preferred Daylit standard, adheres to the LEED v4 ASE limit and satisfies CIBSE LG10 daylight factor and uniformity requirements. On facades that have a high solar exposure, external shades like horizontal overhangs and vertical fins are suggested for further reducing the amount of sunlight and seasonal glare, particularly on bright summer afternoons.

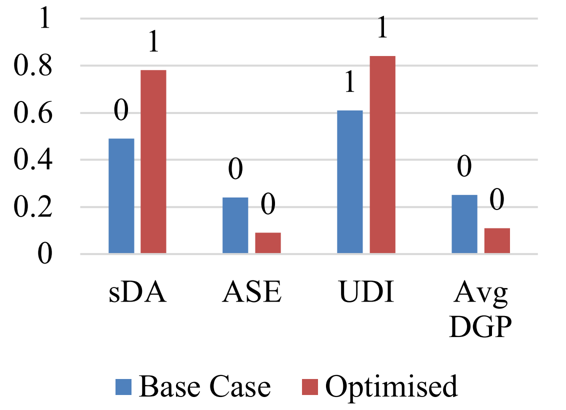

Fig 8*: Summary of Optimal Parameter Selection and Projected Performance Improvement*

9. DESIGN IMPLICATIONS

The optimized strategy, using a 45° orientation, 40% WWR, Low-E glazing, and surface reflectance of 0.70/0.40/0.90, shows that passive design can greatly improve daylight performance and visual comfort in subtropical commercial buildings.

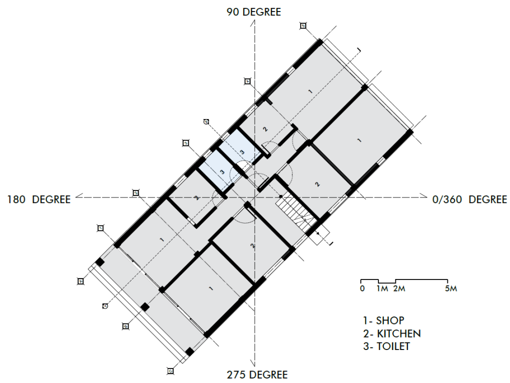

Fig 9*: Optimal orientation*

Fig 10: *3D view of optimized building*

A 45° orientation helps distribute solar exposure evenly and reduces glare and ASE. A 40% WWR provides sufficient daylight while limiting excessive solar gain. Low-E glazing controls heat gain without reducing useful daylight, while high-reflectance finishes, especially the 0.90 ceiling reflectance, improve daylight distribution into deeper zones.

10. CONCLUSION

This study confirms that integrated passive design strategies can significantly improve daylight performance and reduce energy dependence in subtropical commercial buildings. Using Honeybee–Radiance simulation, a prototype commercial building in Gelephu, Bhutan, was assessed based on orientation, window-to-wall ratio, surface reflectance, and glazing type.

The base case showed poor performance, with sDA 0.49, ASE 0.24, and DGP 0.25, failing to meet key daylighting benchmarks. The optimized configuration, consisting of a 45° orientation, 40% WWR, wall/floor/ceiling reflectance of 0.70/0.40/0.90, and Low-E glazing, improved sDA by 59%, reduced ASE by 63%, and lowered glare probability by 56%, achieving compliance with relevant standards.

The findings show that passive strategies must work together: orientation controls solar exposure, WWR manages daylight entry, reflectance improves light distribution, and glazing balances daylight with heat control. Overall, the study provides practical design guidance for creating energy-efficient and visually comfortable commercial buildings in Bhutan and similar subtropical climates.

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