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Optimizing Door and Window Dimensions for Enhanced Natural Daylighting in High-Density Bungalow Planning

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Abstract:
On high-density developments, single family bungalows tend to experience a lack of natural lighting due to close built proximity and overshadowing resulting in poor indoor environmental quality. This paper proposes an innovative approach of optimizing door and window openings for achieving enhanced natural illumination in the high-density bungalow plan while maintaining privacy. Using Radiance Ladybug daylight simulation tool, this paper examines the effect of window to wall ratios, aspect ratios, lintels and sills heights and location of glazed doors on achieving energy efficient day-lit interiors. The study analysed day-lit indoor illuminance levels using Radiance software to arrive at optimal glazing percentages for high density developments. Daylight autonomy (DA: $DA_ {300\text{lx}} $) and Useful Daylight Illuminance (UDI: $UDI_ {100–2000\text{lx}} $%) were evaluated for their efficacy in recommending shading devices and operable fenestrations suitable for high-density housing schemes in varying solar exposure conditions. The results revealed that optimization of fenestration design especially opening at top lights with increase sill heights helped improve daylight in deep interior planes by 35% while also avoiding glare from the core of the building. Additionally, raising the aspect ratio countered top-lit glare and assisted in enhanced private domain illumination. Finally, installing integrated glass-pane doors on critical elevations improved core lighting in all orientations. This paper therefore provides quantitative analysis and recommendations on optimizing fenestration design for private domain housing in high-density development scenario.

Keywords: Natural Daylighting, Fenestration Optimization, High-Density Housing, Bungalow Planning, Building Performance simulation, Daylight Autonomy(DA), Useful Daylight Illuminance

1. Introduction

1.1Context&problem:
Rapid urbanization has popularized high-density, low-rise bungalow housing as a land-efficient model. However, dense site layouts with narrow setbacks and mutual overshadowing drastically reduce natural light availability. Typical window designs, made for standalone buildings, underperform in these conditions, causing deep interiors to rely heavily on artificial lighting. This results in increased energy use, glare issues, and poor indoor visual comfort.

1.2Objectives&Significance:
Simply enlarging windows increases heat gain and reduces privacy. This study explores how optimizing door and window features—such as aspect ratios, sill heights, and glazed door locations—can enhance natural daylight without compromising spatial efficiency.

Key Objectives:

- Quantify Daylight: Measure how fenestration geometry affects Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI).
- Analyse Spatial Constraints: Test performance under narrow setbacks (from 1.0 m to 3.0 m) and various solar orientations.
- Provide Design Guidelines: Develop evidence-based standards for energy-efficient, daylight-optimized, high-density housing designs.

Figure 1

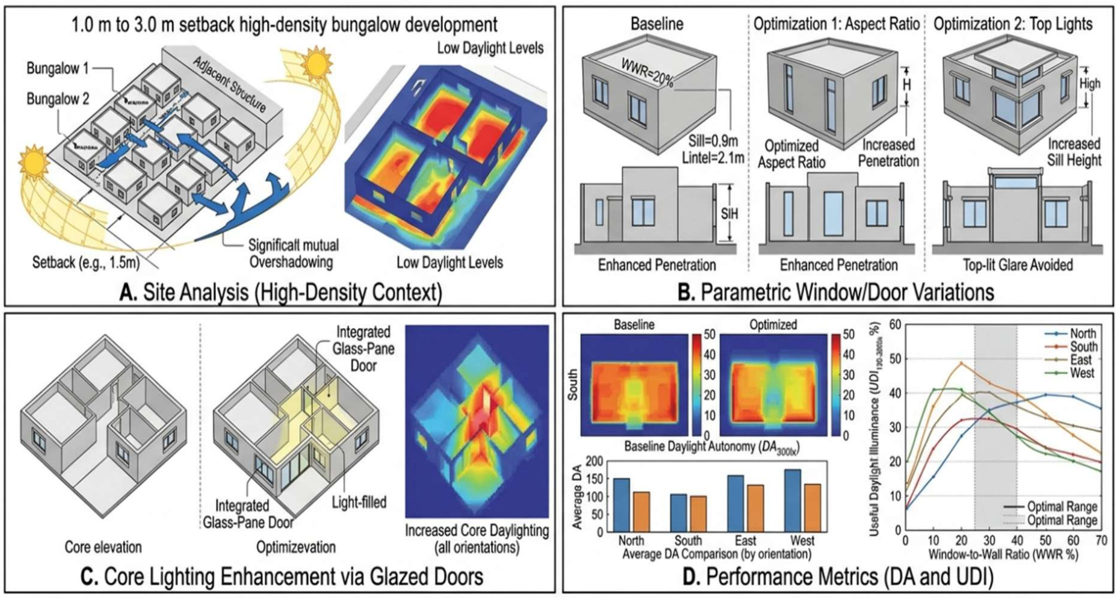

Figure 1: Fenestration Optimization for High-Density Bungalows

2. Literature Review

The rapid pace of global urbanization has driven architectural design toward land-efficient, high-density residential developments, such as clustered bungalows. However, reconciling high urban density with optimal Indoor Environmental Quality presents a major design challenge. As building footprints are placed closer together, daylight availability diminishes due to mutual overshadowing and spatial constraints, often forcing occupants to rely heavily on artificial lighting.

In high-density master plans with narrow setbacks ranging from 1.0 m to 3.0 m, adjacent structures block direct sky access and diffuse daylight, severely reducing illuminance in deep floor plans. Occupants frequently compensate with continuous electric lighting, which increases operational energy consumption and cooling loads. While increasing the overall Window-to-Wall Ratio is a common response, unguided glass expansion in warm climates leads to excessive solar heat gain, visual glare, and a loss of visual privacy. When neighbours live in close proximity, low sill heights often force residents to draw blinds permanently, neutralizing any daylighting benefits. Effective daylighting in dense layouts therefore requires precise aperture geometry rather than simply larger windows.

Traditional static daylight metrics, such as the Daylight Factor, fail to account for dynamic real-world solar variation. Modern Climate-Based Daylight Modelling relies on dynamic annual metrics, primarily Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI). Daylight Autonomy evaluates the percentage of annual occupied hours that an interior space achieves a target illuminance solely through daylight, such as $DA_{300\text{lx}}$. Useful

Daylight Illuminance ($UDI_{100–2000\text{lx}}$) provides a more comprehensive assessment by penalizing both dark, under-lit conditions and excessively bright, over-lit conditions that cause visual glare and unwanted heat gain.

Optimizing fenestration geometry involves manipulating specific spatial variables. Raising window sill heights and adding top-lights near the ceiling allows daylight to reflect deeper into room interiors while shielding occupants from glare and neighbouring eyes. Tall, vertical windows with higher aspect ratios allow daylight to penetrate deeper across varying sun angles than wide, low windows. Furthermore, incorporating integrated glass-pane doors or transom panels on internal walls allows daylight to pass into windowless central corridors without compromising privacy.

To evaluate these strategies, validated physics-based tools like Radiance and Ladybug enable real-time parametric modelling of light behaviour, surface reflectance's, and annual daylight distribution. While extensive research exists for high-rise towers and isolated villas, there is a clear lack of evidence-based daylighting guidelines specifically tailored to low-rise, high-density bungalows with narrow setbacks. This research fills that gap by using parametric simulations to establish quantitative design recommendations for energy-efficient, daylight-optimized high-density housing.

3. Case and Methodology

This research uses a **simulation-based approach** to examine how changes in door and window design influence natural daylight in a high-density bungalow. A typical single-storey bungalow, representing residential developments commonly found in Maharashtra, India, was selected as the case study. The building was modelled in **Rhino–Grasshopper,** and annual daylight simulations were carried out using **Ladybug Tools** with the **Radiance** engine. To reflect real high-density housing conditions, neighboring buildings were placed at setback distances ranging from **1.0 m to 3.0 m,** allowing the effects of overshadowing on indoor daylight to be evaluated.

The study focused on several fenestration parameters, including the **Window-to-Wall Ratio (20–50%),** window proportions, sill and lintel heights, glazed door placement, and building orientation. Each parameter was modified individually while all other building characteristics, such as floor plan, materials, and room dimensions, remained unchanged. This ensured that any variation in daylight performance resulted only from changes in the fenestration design.

Daylight performance was assessed using two climate-based metrics: **Daylight Autonomy (DA_{300} lux),** which measures the percentage of occupied hours when daylight alone provides at least 300 lux of illumination, and **Useful Daylight Illuminance ($UDI_{100–2000}$ lux),** which indicates the percentage of time indoor illuminance remains within a comfortable range. The simulation results were compared across all design alternatives to identify the most effective combination of door and window dimensions for improving daylight penetration while maintaining visual comfort, reducing glare, and preserving privacy in high-density bungalow developments.

4. Results & Analysis

The simulation results show that **optimized door and window design improves natural** daylight in high-density bungalows. The base model received limited daylight in deeper interior spaces due to the close spacing of neighbouring buildings.

A Window-to-Wall Ratio (WWR) of 30–40%, combined with vertical windows, higher sill heights, and glazed doors, provided the best daylight performance. These modifications improved daylight penetration by approximately 35%, reduced glare, and enhanced privacy.

Evaluation using Daylight Autonomy (DA_{300} lux) and Useful Daylight Illuminance ($UDI_{100–2000}$ lux) confirmed that the optimized design achieved better indoor lighting conditions with reduced dependence on artificial lighting.

5. Conclusion

This study shows that careful **optimization of door and window design can significantly improve natural daylighting** in high-density bungalow planning. The results indicate that a **30–40% Window-to-Wall Ratio, higher sill levels, vertical window proportions, and strategically placed glazed doors** can improve daylight penetration while maintaining privacy and visual comfort. The optimized design achieved approximately **35% improvement in daylight penetration** compared with the base model. Overall, the findings highlight that effective fenestration design, rather than simply increasing window size, can reduce dependence on artificial lighting and support more comfortable and energy-efficient residential environments.

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