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From Living Room to Workstation: Daylighting Performance Optimization in the Hybrid Domestic Space of Algerian Collective Housing — A Parametric Study in Bejaia

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Abstract

Post-COVID Algeria has seen the collective housing living room emerge as the primary telework space and, simultaneously, as an informal setting for collaborative work among peers embodying a new hybrid live-work habitat typology. Yet existing housing stock was never designed for such use, generating critical visual comfort deficiencies for computer-based workers. This study examines the living room of a representative Algerian collective housing unit in Bejaïa, a coastal Mediterranean city, across eight building orientations. Using Rhinoceros and Grasshopper with a Radiance-based engine, spatial Daylight Autonomy, Useful Daylight Illuminance, Annual Sunlight Exposure, and Daylight Glare Probability are simulated at workstation level. Results show orientation and workstation placement are decisive for visual comfort, with northern orientations proving most favorable. For critical southern and western orientations, a dual-layer strategy combining exterior shading with an interior translucent blind achieves full metric compliance, providing directly actionable retrofit guidelines for Algeria's existing hybrid housing stock.

Keywords: Hybrid Live-work Space; Telework; Collective Housing; Visual Comfort; Parametric Optimization.

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1. Introduction

The COVID-19 pandemic profoundly disrupted the spatial organization of domestic life. Lockdowns imposed on billions of workers and students within days condensed decades of latent change in residential space use into a single, irreversible transition ((Megahed & Ghoneim, 2020). In Algeria, this transition found no accommodation in dedicated home offices, virtually nonexistent in multi-unit housing, but was absorbed instead by kitchens and living rooms, the primary social spaces of Algerian dwellings. The scale of this constraint is quantified: 67.1% of Algerian teleworkers lacked a dedicated workspace (Guernoub, 2023), a direct consequence of chronic spatial limitations in collective housing. The living room became a workstation not by ergonomic choice but by topological necessity, the only room large enough to accommodate both individual work and informal collaborative activity. This appropriation extended rapidly beyond the individual. Colleagues began gathering in residential living rooms to work side by side, generating a novel spatial typology: the hybrid live-work space, a private dwelling that simultaneously functions as a semi-professional shared environment. The workstation is almost exclusively digital, with 90.4% of Algerian teleworkers relying on a laptop and 65.8% on a smartphone (Guernoub, 2023), making screen-based visual comfort the operative ergonomic criterion.

The health consequences of this spatial reallocation extend beyond ergonomics. Daylight exposure is now established as a primary determinant of worker health, sleep regulation, and cognitive performance — not merely subjective comfort. Office workers with window access sleep approximately 46 minutes more per night and report significantly better sleep quality than workers in windowless environments, as measured by actigraphy (Boubekri et al., 2014). The mechanism is circadian: light exposure delivering a circadian stimulus (CS $\geq$ 0.3) reduces daytime sleepiness and increases vitality and alertness among office workers (Figueiro et al., 2019). Adequate daylighting synchronizes the body's biological clock with the external day-night cycle, directly supporting sustained cognitive work (Figueiro et al., 2020).

The transition to home-based telework disrupts this system in a specific and underappreciated way. The morning commute — previously a reliable source of early-day light exposure critical for circadian entrainment — disappears entirely (Sun et al., 2019). Residential dwellings must therefore compensate for a photobiological deficit that office environments had only partially resolved, and then only incidentally, through the commute itself.

Visual comfort at screen-based workstations is an objective determinant of cognitive performance and health, not merely of subjective well-being (Boyce, 2014; Nguyen & Tran, 2025). Sustained glare exposure, excessive luminance contrast, or insufficient illuminance each independently produce visual fatigue, headaches, and measurable cognitive decline (Boyce, 2014). Among the photometric dimensions of daylight, illuminance levels — rather than spectral quality — most strongly determine visual performance and alertness at screen-based workstations (Chen et al., 2019), establishing illuminance adequacy as the primary criterion for evaluating telework environments. Field measurements in Germany confirm this deficit in practice: home workstations frequently fall below occupational daylight standards, failing recommended exposure thresholds during working hours (Rolf et al., 2024). The deficit is structural — residential buildings were never designed to meet the visual performance requirements of prolonged computer work (Bellia et al., 2014).

Algeria's public housing stock exemplifies this mismatch. The product of centralized mass-housing programs launched in the 1970s (Bourras, 2021), this typology was designed according to strictly residential principles (Djafri & Osman, 2021): living spaces were sized, oriented, and fenestrated for domestic comfort and family socialization, not for the visual and ergonomic demands of screen-based work. The window-to-wall ratios characteristic of this standardized stock restrict daylight penetration depth, while uncontrolled solar incidence on critical orientations generates glare conditions incompatible with sustained visual tasks. This spatial mismatch between design intent and contemporary use frames the research problem.

The literature on daylight in residential telework environments converges on three interconnected findings. First, daylight availability correlates directly with teleworker concentration and satisfaction (Vicente-Salar et al., 2025); natural light also improves mood, reduces depressive symptoms, and supports circadian regulation (Woo et al., 2021). Second, residential dwellings systematically lack the functional attributes of office environments (Vicente-Salar et al., 2025): spaces repurposed for telework — kitchens, living rooms, and bedrooms — produce inadequate lighting conditions for professional tasks (Rolf et al., 2024), and the room-workspace hybrid has consequently been identified as a distinct spatial category requiring specific design responses (Acosta et al., 2023). Third, optimal interior layout scenarios can be defined for each building orientation when workstation position is evaluated against daylight and glare metrics (Ploycharoen et al., 2024)— demonstrating that furniture configuration, rather than architectural intervention, constitutes a viable adaptive strategy within existing stock.

The Mediterranean climate poses a twofold challenge: harvesting abundant natural light while controlling solar glare and thermal gain, particularly on south- and west-facing orientations (Baker & Steemers, 2000). As a primary determinant of daylight performance, building orientation is a decisive parameter for assessing whether existing dwellings adequately support hybrid live-work use (Ploycharoen et al., 2024). No study has yet systematically examined this adequacy across orientations for the Algerian collective housing typology — a gap with direct implications for a national stock shared by millions of households now undergoing an irreversible shift in spatial practice.

This study fills that gap. We analyzed the daylight performance of the living room of a representative Algerian collective dwelling in Bejaïa (36.75°N, Mediterranean coast) across eight cardinal and intercardinal building orientations, using climate-based daylight modeling (CBDM) with validated metrics (sDA, ASE, UDI, DGP). From this performance diagnosis, we derive a spatially differentiated adaptive strategy: optimal workstation positioning is prescribed for each orientation category, and a corresponding furniture typology is proposed — reversible, non-invasive, and calibrated to the social function of the Algerian living room. The central argument is that orientation determines the photometric conditions of the living room; those conditions, in turn, determine optimal workstation position; and furniture configuration reconciles visual comfort with domestic use without modifying the building envelope.

2. Materials and Methods

The methodological framework is structured in two sequential phases, as illustrated in Figure 1. Phase 1 identifies visually compliant workstation zones through climate-based daylight simulation across eight orientations, applying four complementary metrics. Phase 2 addresses the critical orientations identified in Phase 1 and resolves their constraints through multi-objective optimization (MOO).

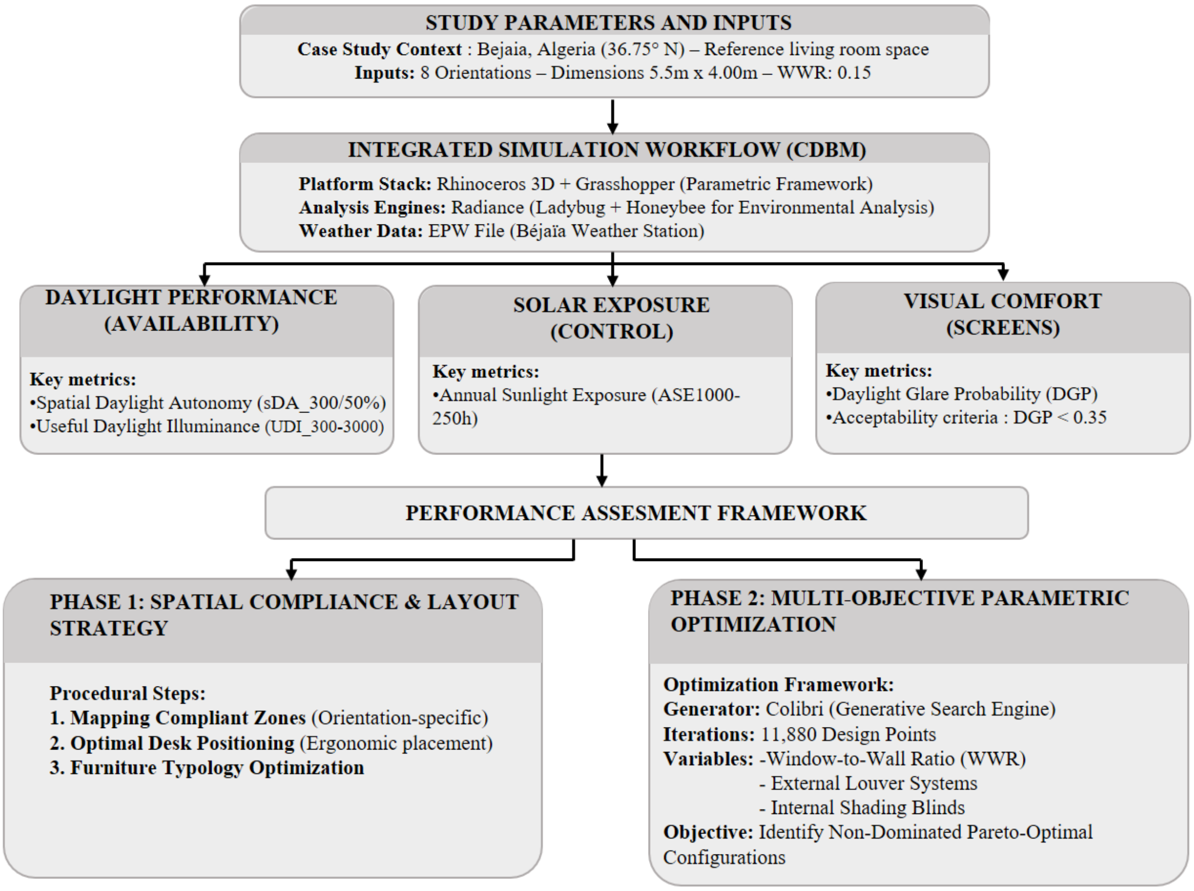

Figure 1. Methodological framework of the study (Developed by the Authors).

2.1 Representative Living Room of Algerian Collective Housing: A Case Study

Algeria's collective housing stock, produced through centralized programs (AADL, LSP, and LPP) across five decades, is characterized by a high degree of constructive standardization: building systems, structural grids, floor-to-ceiling heights, and fenestration practices were defined at the program level and applied uniformly across contractors and regions (Bourras, 2021; Djafri & Osman, 2021). Within this stock, the living room configuration retained here recurs as the dominant typological unit across the LSP and AADL programs. This typological frequency does not imply geometric invariance across the full national stock; minor variations in window position, room proportions, and WWR (0.15–0.20) exist across contractors and construction periods. Therefore, the case study functions as a representative instance of the dominant constructive type rather than a geometric proxy for the entire national stock. Simulation results are directly applicable to dwellings sharing these parameters and transferable by analogy with configurations within the observed range of variation; extrapolation beyond this range requires verification.

The reference model is located in Bejaïa (36.75°N, 5.08°E), a Mediterranean coastal city in northeastern Algeria. Within the Algerian collective housing typology, two living room configurations recur: one incorporating a balcony accessed via a full-height glazed door and one without, served by a standard window. The balcony slab acts as an uncontrolled horizontal shading device that systematically attenuates daylight penetration regardless of orientation. The windowless-balcony configuration was retained as the reference case to isolate the effect of building orientation on daylight performance without this confounding variable. The geometric and optical parameters were calibrated to local construction standards:

- Spatial configuration: a standard rectangular living room (5.50 m × 4.00 m), with a single façade opening on the short side.
- WWR: 0.15, reflecting the conservative fenestration practice of the Algerian collective housing typology.
- Surface reflectance: ceiling 0.80, walls 0.50, and floor 0.20.

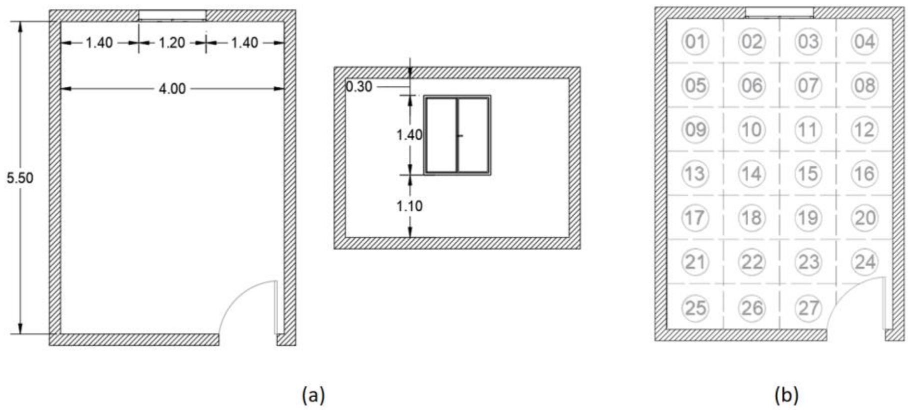

Figure 2. Floor plan and cross-section of the reference room, showing the dimensions, window location **(a)**, and grid of the 27 sampling points **(b)** (Developed by the Authors).

2.2 Simulation Framework

Simulations were conducted using a parametric workflow integrating Rhinoceros 3D and Grasshopper, with the Radiance engine accessed through the Ladybug Tools ecosystem (Ladybug + Honeybee). This approach enables CBDM grounded in the Bejaïa EPW weather file (EnergyPlus, 2025).

The spatial resolution is a 0.5 m × 0.5 m calculation grid positioned at the work plane (0.75 m above floor level), covering the entire room area. Eight orientations, four cardinal (N, E, S, and W) and four intercardinal (NE, SE, SW, and NW), were simulated as the sole independent variable, while room geometry and material properties remained constant across all runs to ensure comparability.

2.3 Daylight Performance Metrics

Four climate-based daylight metrics (CBDM) were used, collectively covering both daylight availability and risk of visual discomfort. The compliance thresholds follow IES LM-83-12 standards and are summarized in Table 1.

- Spatial Daylight Autonomy - sDA$_{300/50}$%: quantifies daylight self-sufficiency: a zone is compliant when at least 50% of its area receives ≥ 300 lux for ≥ 50% of annual occupied hours (08:00–18:00). The 300 lux threshold adopted for sDA compliance follows the residential daylight standard established by IES LM-83-12 and is consistent with the threshold applied in the emerging literature on home-based telework environments (Acosta et al., 2023; Ploycharoen et al., 2024; Rolf et al., 2024). Although EN 12464-1 prescribes 500 lux for permanent office workplaces, its scope is explicitly limited to professional work premises and does not extend to residential dwellings, which retain their residential regulatory status regardless of their de facto telework use. Applying the 500 lux threshold to this context would impose an occupational standard for which the building typology was neither designed nor regulated. The 300 lux criterion therefore functions as a conservative diagnostic threshold: any zone that fails at 300 lux fails a fortiori at 500 lux, and any zone identified as compliant at 300 lux should be interpreted as a minimum acceptable condition for screen-based work rather than an optimum. This framing is consistent with recent field studies confirming that residential telework spaces systematically fall below occupational illuminance standards (Rolf et al., 2024), reinforcing the diagnostic rather than prescriptive intent of the sDA metric as applied here.
- Annual Sunlight Exposure - ASE$_{1000,250h}$: Identifies direct solar overexposure risk: a zone is critical when more than 10% of the regularly occupied area exceeds 1,000 lux for more than 250 h per year.
- Useful Daylight Illuminance - UDI$_{300–3000}$: determines the fraction of occupied hours during which illuminance falls within the visually comfortable and task-appropriate range, avoiding both deficiency (< 300 lux) and excess (> 3,000 lux) (Chi et al., 2018).
- DGP: evaluates visual comfort at eye level (1.20 m). The analysis targets exceedance of the perceptibility threshold, DGP = 0.35, above which glare becomes noticeable. (Wienold & Christoffersen, 2006)

Full compliance requires all three spatial metrics (sDA, ASE, and UDI) to be simultaneously satisfied across the workstation zone. The DGP criterion then determines the workstation orientation within that zone

Table 1: Computer simulation, daylight performance, and daylight glare indexes.

Indicator	Threshold/Condition	Explanation
sDA (Spatial Daylight Autonomy)	$sDA_{300/50\%}$	50% of the regularly occupied space must receive at least 300 lux for 50% of the annual occupied hours (simulation from 8 a.m. to 6 p.m., IES LM-83, 2012).
ASE (Annual sunlight exposure)	$ASE_{1000/250} \leq 10\%$	Less than 10% of the regularly occupied space receives more than 1,000 lux for at least 250 h per year.
UDI (Useful Daylight Illuminance)	3 ranges: (UDI_{low}) < 300 lux (UDI): 300–3000 (high UDI) (UDI_{up}) > 3000 lux	UDIlow: insufficient illuminance - UDI: adequate illuminance - UDIup: excessive illuminance

2.4 Phase 1: Workstation Positioning and Typologies of Adaptive Furniture

Phase 1 identifies visually compliant zones within the existing building envelope, integrating daylight performance with domestic ergonomics through a three-step sequential workflow.

1. **Spatial Overlay:** Compliance zones are first identified by overlaying sDA, UDI, and ASE results. These are rendered as false-color spatial maps to isolate areas where all three criteria are simultaneously satisfied.
2. **Glare Assessment:** A 27-point sampling grid simulates potential workstation locations across the floor plan. At each node, the Daylight Glare Probability (DGP) is evaluated at eye level (1.20 m) to determine admissible desk orientations.
3. **Visual Synthesis**: Results are visualized as a positional grid superimposed on the room plan. Each node features a circular marker divided into four quadrants representing principal desk orientations. Orientations are color-coded red where the annual percentage of occupied hours (08:00–18:00) with a DGP > 0.35 indicates glare-critical conditions, and green where levels remain within comfort thresholds.

Finally, an adaptive furniture typology is assigned to each viable zone. Rooted in the "loose-fit" design framework (Brand, 1994; Schneider & Till, 2007), this approach resolves the functional conflict between the room's social role (reception and family life) and its emerging productive role as a telework environment, achieving this without permanent spatial reconfiguration.

2.5 Phase 2 - **Shading Optimization of Critical Orientations**

Phase 2 targets the three orientations in which direct solar penetration systematically violates ASE and DGP thresholds (South, South-East, and South-West) identified in Phase 1 as the most constraining configurations. Among these, the SW orientation is selected as the optimization case, representing the most adverse daylight and glare conditions of the three. Phase 2 addresses the three orientations in which direct solar penetration systematically violates ASE and DGP thresholds — S, SE, and SW — identified in Phase 1 as Category 3 configurations. Among these, SW is selected as the optimisation case on the basis of four convergent quantitative criteria (Table 3): it records the highest ASE exceedance within the sDA-compliant zone (27.00% vs. 22.22% for SE and 20.18% for S), the lowest sDA compliant area (55.55%), the lowest UDI-useful fraction in the proximal zone (45.63%), and the highest annual DGP exceedance at the window-facing workstation position (15.68%). The SW orientation also presents the geometrically most demanding shading problem within Category 3: dominant solar penetration occurs at low solar altitude combined with high azimuthal angle in the late afternoon, rendering conventional horizontal shading geometry ineffective. A solution validated against this worst case is directly transferable to S and SE, whose solar penetration geometry is less extreme; this transferability is verified in Section 4.5.

Table 2: Design space parameters and variables for MOO.

Category	Parameter	Values/variation range	Number of States of Origin
Opening geometry	Window-to-Wall Ratio	0.15; 0.20; 0.25	3
External shading	Number of slats (H and V)	0–10	11
	Slat depth	10–40 cm	4
	Setback from the façade	0–40 cm	5
	Tilt angle	15°, 30°, and 45°	3
Internal protection	Shading transmittance	0.40–0.90 (step of 0.10)	6
Total simulations	Solution space	11,880 iterations (via Colibri)	

3. Results

3.1 Spatial Distribution of Useful Daylight Illumination

UDI mapping across the eight orientations revealed a structural spatial dichotomy that persisted independently of the building orientation. The proximal half of the room, adjacent to the glazing, consistently receives illuminance within the useful range (300–3,000 lux) for a sufficient proportion of the annual occupied hours. The distal half remains chronically underlit, with UDI-low values exceeding 60% of occupied hours regardless of orientation.

Three distinct UDI regimes emerge across orientations (Figure 3):

- **Daylight deficiency** (UDI low **< 300 lux).** Chronic underexposure affects approximately 50% of the room depth across all orientations. The phenomenon is most severe for the N, NE, and NW orientations, where the insufficiency threshold is reached during 100% of occupied hours in the distal zone. This shadow zone is confined to the rear half of the room with south-facing orientations (S, SE, SW), with relative compliance rates of 20–30% immediately adjacent to the opening.

- **Useful daylight range ($UDI_{300–3000\ lux}$).** The compliant zone is systematically confined to the proximal area. For north-sector orientations (N, NE, and NW), useful illuminance reaches 70–80% of annual hours but remains strictly concentrated at the window zone. The south and east orientations exhibit marginally deeper lateral penetration toward the opposite wall, though the useful contribution remains geometrically constrained and does not extend into the room core.
- **Daylight excess (UDI_{up} > 3000 lux).** The overexposure risk is concentrated in S, SE, and SW orientations, with exceedance rates reaching 20% of occupied homes at the window zone. North orientations yield near-zero exceedance. East and west façades exhibit moderate incidence (~ and are exclusively localized within the proximal half.

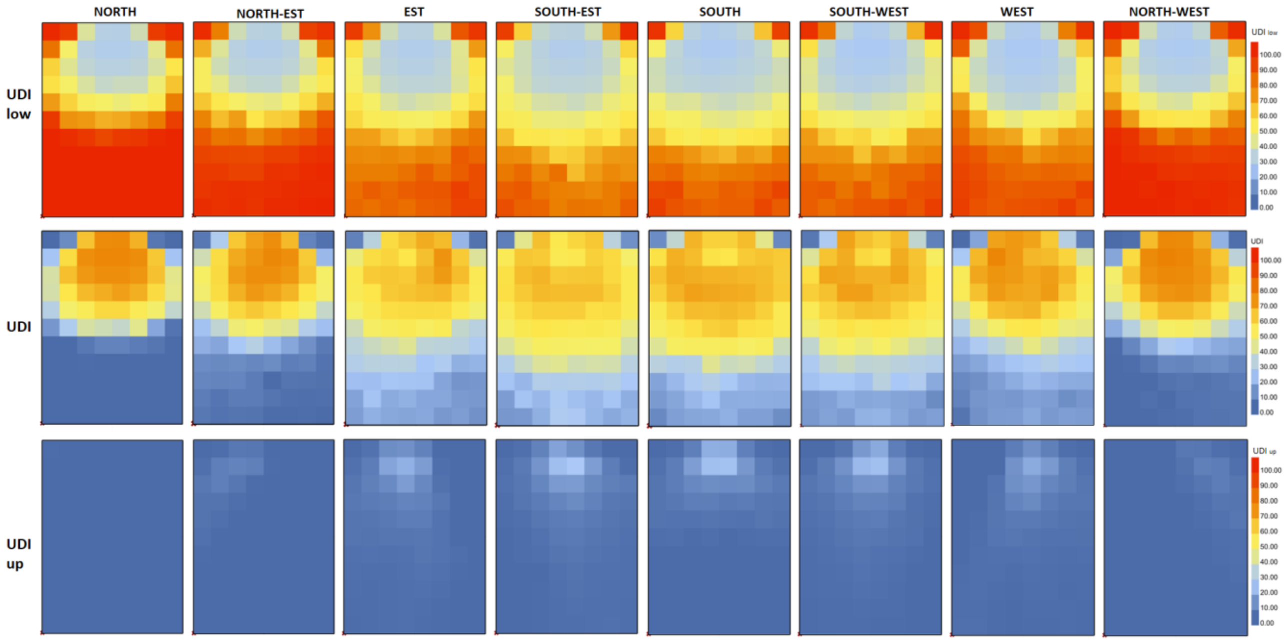

Figure 3. Spatial distribution of Useful Daylight Illuminance (UDI)across eight orientations: UDI-low (<300 lux), UDI useful(300–3,000 lux), and UDI-up (>3,000 lux) at work plane level (Developed by the Authors).

3.2 Spatial Daylight Autonomy and Annual Sunlight Exposure: Definition of Workstation Zone

While UDI delineates the viable half of the room, the composite sDA–ASE mapping introduces the critical discriminating variable between orientations: direct solar exposure. The sDA maps confirm that the window-adjacent zone satisfies the minimum illuminance criterion (≥ 300 lux for ≥ 50% of occupied hours) across all eight orientations, with compliant areas covering approximately 40 – 60% of the total floor area. However, ASE analysis reveals a fundamental divergence between orientation groups that sDA alone cannot capture.

Three orientation categories emerge from the composite analysis (Figure 4):

- **Category 1: Favorable orientations (N, NE, NW).** ASE exceedance within the sDA-compliant zone is negligible, affecting less than 5% of the window-proximal area. The workstation zone freely extends across the proximal area adjacent to glazing, offering maximum spatial flexibility.
- **Category 2: Intermediate orientations (E and W)** ASE exceedance is asymmetrically distributed, confined to one lateral half of the proximal zone, and reflecting the unidirectional nature of direct solar penetration for these orientations.
- **Category 3: Critical orientations (S, SE, and SW).** A dominant central ASE-exceedance zone systematically eliminates the sDA-compliant area near the window due to south-facing glazing and high-altitude summer solar penetration.

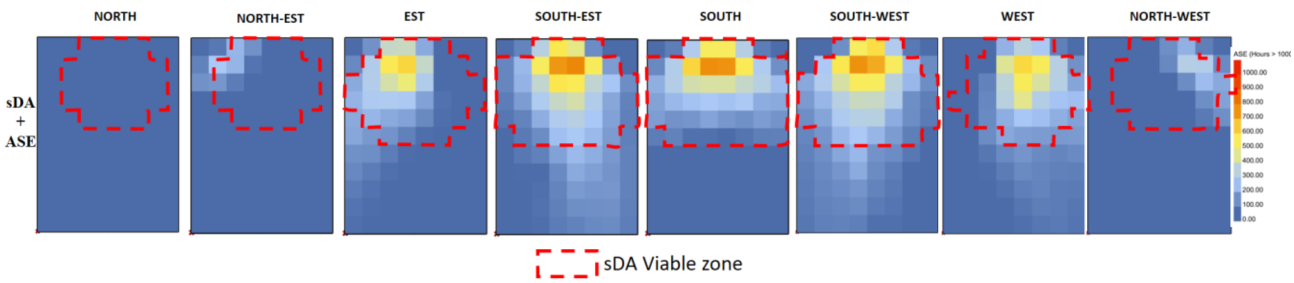

Figure 4. Composite sDA–ASE maps for eight orientations: sDA-compliantzones (dashed boundary) overlaid with annual sunlight exposure(ASE, false-colour scale) at work plane level (Developed by the Authors).

Table 3 quantifies the four performance indicators for the three Category 3 orientations at the sDA-compliant zone boundary. The SW orientation records the highest ASE exceedance (27.00%), the lowest sDA compliant area (55.55%), and the lowest UDI-useful fraction (45.63%) among the three critical configurations, while its annual DGP exceedance at the window-facing position (15.68%) is the highest. This four-metric convergence confirms SW as the most photometrically adverse orientation within Category 3 and motivates its selection as the Phase 2 optimisation case.

Table 3. Daylight performance indicators for Category 3 critical orientations (S, SE, SW) at the sDA-compliant zone boundary.

Metric	S	SE	SW
$sDA_{300/50}$% — compliant area (%)	57.40	56.23	55.55
$ASE_{1000,250}$ — exceedance within sDA zone (%)	20.18	22.22	27
$UDI_{300–3000}$ — proximal zone (%)	47.13	46.32	45.63
Annual DGP > 0.35 — window-facing position (%)	14.64	13.21	15.68

3.3 Daylight Glare Probability: Determination of Workstation Orientation

The composite sDA–ASE analysis identifies where the workstation can be positioned, and the DGP analysis determines how it must be oriented. The DGP was evaluated at eye level (1.20 m) for candidate workstation positions identified within each orientation category.

The results are consistent across all eight orientations (Figure 5): perpendicular positioning relative to the primary glazing is the only DGP-compliant configuration, with values remaining below the imperceptible threshold (DGP < 0.35) for this viewing direction. Two alternative orientations systematically fail compliance:

- Facing the window generates disturbing to intolerable glare (DGP > 0.35), driven by the luminance contrast between the bright aperture and the surrounding wall.
- Backlighting the window produces screen reflection artifacts that compromise visual task performance despite acceptable DGP values.
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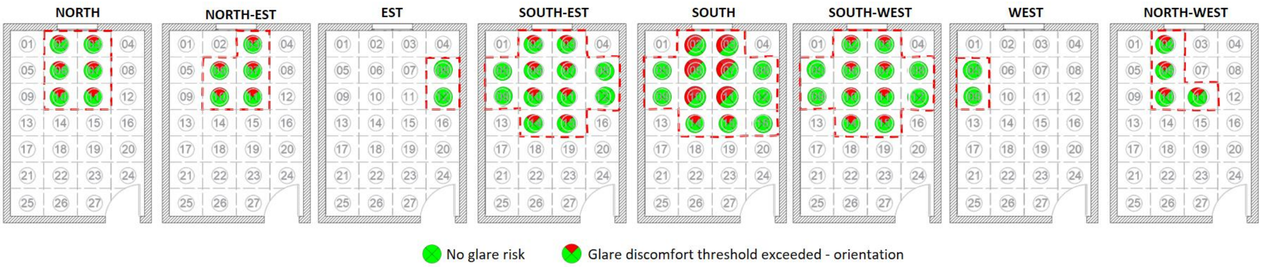


Figure 5. Ideal office location and spatial comparison of the risk of glare (risk 0.35) for the occupant under different scenarios Developed by the Authors).

3.4 Phase 1 Synthesis: Compliant Workstation Zones per Orientation Category

Integrating the UDI, sDA, ASE, and DGP results yields a complete positional specification for each orientation category. Approximately 60% of the living room floor area is non-compliant across all orientations, primarily attributable to the WWR constraint. The viable workstation zone is invariably confined to the proximal area, with boundaries determined by orientation category: Category 1 (N, NE, NW) offers full lateral flexibility, with the workstation positioned perpendicular to the façade wall, either flush against it or slightly set back; Category 2 (E, W) restricts the proximal zone to the non-solar side, with the workstation flush against the lateral wall and perpendicular to it; Category 3 (S, SE, SW) yields no annually fixed compliant position, ASE exceedance covers the entire sDA-compliant surface, making compliance temporal rather than spatial and demanding an adaptive rather than a fixed furniture strategy. This condition defines the phase 2 boundary.

3.5 Phase 2: Shading Optimization for Critical Orientations

Multi-objective optimization over 11,880 design iterations identifies the Pareto-optimal envelope configuration for the SW orientation, simultaneously maximizing sDA and UDI-useful while constraining ASE ≤ 10% and DGP < 0.35. The retained solution combines a WWR of 0.25, eight vertical blades inclined at 30° relative to the façade normal (depth: 20 cm; façade offset: 20 cm), an interior blind transmittance of 0.80, and a near-transparent screen that preserves daylight admission while providing marginal diffusion of direct radiation. No horizontal blades are included in the optimal configuration.

The before/after performance comparison (Figure 6) quantifies the effect of this envelope intervention across three complementary metrics. The UDI maps (Figure 6a) show that useful daylight penetrates significantly deeper into the room, with the compliant range extending toward the distal zone. sDA–ASE maps (Figure 6b) show that the compliant area is increasing by approximately 22.5%, while ASE exceedance, previously dominating the proximal zone at ~70%, drops to approximately 20% near the window, restoring a viable workstation zone previously eliminated by direct solar penetration. The workstation grid (Figure 7c) confirms that compliant positions now occupy the majority of the proximal half, with non-compliant positions (DGP > 0.35) confined to points directly facing the glazing, consistent with the perpendicular orientation requirement established in Phase 1.

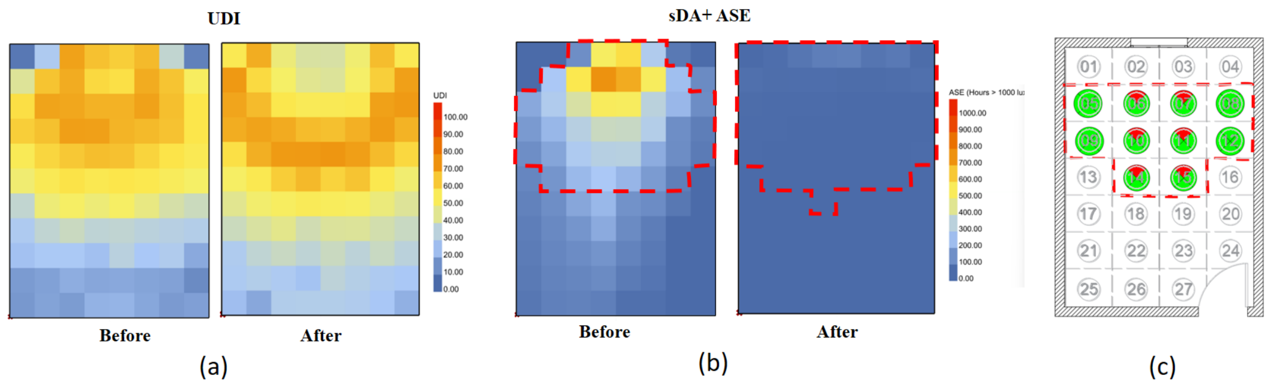


Figure 6. Before/after comparison of the Pareto-optimal shading configuration (SW orientation): **(a)** UDI maps, **(b)** sDA–ASE overlay,**(c)** DGP workstation compliance grid, showing the recovered proximal workstation zone after envelope optimization (Developed by the Authors).

4. Discussion

4.1 The WWR as a Universal Limiting Factor

The primary finding of this study concerns a constraint independent of orientation: 60% of the living room floor area is photometrically unsuitable for telework regardless of the building's cardinal alignment. This result identifies the window-to-wall ratio (WWR) of 0.15—not the local climate and not the façade orientation—as the principal structural determinant of daylighting inadequacy. The chronic underperformance of the distal zone (UDI-low exceeding 60% of occupied hours) follows directly from insufficient daylight penetration at this fenestration ratio. Field measurements in comparable residential contexts confirm that home workstations consistently fall below recommended occupational illuminance thresholds regardless of façade orientation (Rolf et al., 2024), and melanopic equivalent daylight illuminance frequently fails to reach the levels required for healthy circadian entrainment. In a rectangular living room with a single opening on the short wall, daylight remains confined to the proximal zone—consistent with the geometric analysis reported by Do et al. (2025). Workstation placement must, therefore, be restricted to the proximal zone as a geometric constraint imposed by the building itself, not a design preference.

This finding also has implications for the design of new Algerian housing. Increasing WWR beyond the current 0.15 standard would structurally expand the compliant workstation zone and partially recover the distal area lost to daylight deficiency, provided that any aperture enlargement is paired with appropriate shading to control glare and solar overexposure—a coupling directly demonstrated by the Phase 2 optimization.

4.2 Orientation as a Distinguishing Variable

While the WWR defines the universal outer boundary of the viable zone, orientation determines its internal structure — specifically, the spatial relationship between daylight availability and direct solar exposure. The composite sDA–ASE analysis yielded three qualitatively distinct regimes.

Category 1 orientations (N, NE, and NW) offer the most favorable configuration: diffuse, glare-free illumination across the full proximal zone and maximum workstation flexibility. This result clarifies an obvious contradiction—that orientations conventionally penalized for low total solar gain are the most suitable for screen-based work. When the evaluation criterion shifts from thermal gain to glare-free visual performance, the contradiction dissolves. Baker & Steemers (2000) established that north-facing glazing in the Mediterranean climate delivers diffuse illumination suited to prolonged visual tasks. Ahmad et al. (2025) and Mirrahimi et al. (2022) independently confirmed that north-facing orientations produce stable, uniform light while avoiding direct solar radiation and uncomfortable glare.

Category 2 orientations (E, W) impose an asymmetric constraint: direct sunlight penetrates only one lateral half of the proximal zone, leaving the opposite half photometrically viable. Relocating the workstation toward the non-solar lateral wall resolves the conflict without envelope modification. Non-compliance in these orientations is also temporally concentrated—confined to specific hours rather than distributed across the occupied year—a dimension that annually integrated climate-based daylight metrics (CBDM) capture only partially.

Category 3 orientations (S, SE, and SW) present the most severe configuration. High-altitude summer solar radiation penetrating south-facing glazing generates ASE exceedance across the entire sDA-compliant proximal surface, eliminating any annually fixed compliant workstation zone. The spatial tension between glare prevention and adequate illuminance cannot be resolved by furniture positioning alone—a direct motivation for the envelope optimization conducted in Phase 2. Tzempelikos & Athienitis (2007) report analogous constraints for south-facing office façades in temperate latitudes, concluding that integrated aperture and shading co-design is essential for maintaining acceptable visual conditions at perimeter workstations.

4.3 Workstation Orientation: Rotational Constraint

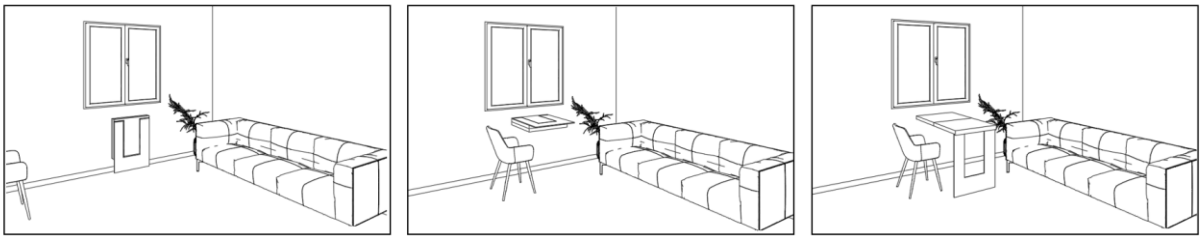
Spatial positioning determines where a workstation may be placed; DGP analysis determines how it must be oriented. Only one desk configuration consistently satisfies the DGP threshold of 0.35 across all eight orientations and all three categories: perpendicular alignment relative to the primary glazing wall.

Both alternative orientations fail systematically. Facing the window generates luminance contrasts that exceed the perceptible glare threshold, reaching bothersome levels at DGP > 0.40—a mechanism documented by Wienold & Christoffersen (2006). Positioning with back to the window introduces specular screen reflections that compromise visual task performance even at nominally acceptable DGP values, an effect described by Boyce (2014) in the context of computer workstation lighting. Rotational orientation is therefore an ergonomic constraint of equal weight to spatial position and must be treated as a primary parameter in any adaptive furniture strategy.

4.4 Furniture Strategy: From Positional Specification to Adaptive Typology

Integrating the three performance metrics (sDA, ASE, and DGP) yields a complete positional specification for each orientation category, which is directly actionable as a furniture strategy. The photometrically optimal workstation zones coincide with the conventional furniture arrangements already found in Algerian living rooms. This convergence is not incidental: both the photometric optimum and the customary layout are governed by the same geometric variables—room depth, single opening position, and usable floor area. The implication is architecturally significant: adapting the living room for telework does not require correcting the environment around the workstation but reinterpreting existing furniture archetypes as hybrid live-work elements.

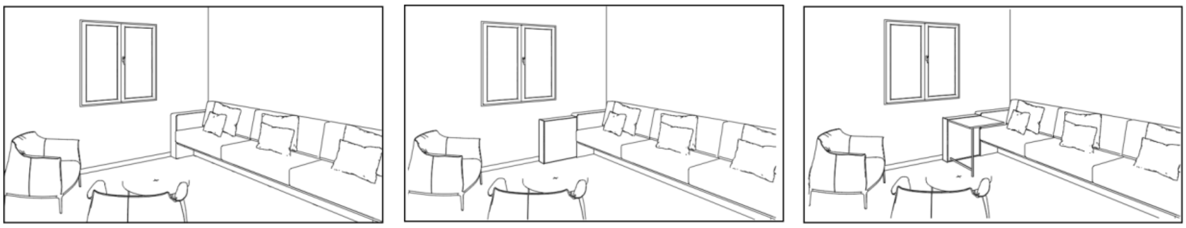
For Category 1 orientations (N, NE, and NW), the viable zone extends across the full proximal area adjacent to the glazing. A fold-down work surface mounted below the window opening is an appropriate response (Figure 7): fully retracted, it functions as a domestic wall element; deployed, it accommodates a laptop workstation or a shared two-person surface. Its defining characteristic is reversibility—the productive function disappears entirely when not in use. Equally valid alternatives include a lightweight console table, a fixed shelf at desk height, or a modular storage-and-work unit, provided the user maintains a perpendicular orientation to the glazing.



(a) (b) (c)

Figure 7. Design of a Wall-Mounted, Fold-Down Workstation Below a Window: Sequential Deployment. **(a)** Retracted state showing the rotation mechanism, **(b)** intermediate deployment with user, and **(c)** fully deployed workstation configuration. (Developed by the Authors).

A second possibility for the same zone integrates the work surface within an existing seating element (Figure 8)—a tablet arm or swing-out tray extending from a lounge chair—suited to individual light tasks (reading, note-taking, laptop use) without adding floor footprint.



(a) (b) (c)

Figure 8. Integrated retractable work surface within seating furniture: domestic state **(a)**, partially deployed **(b)**, and working configuration **(c)** (Developed by the Authors).

When the workstation is set back from the window wall, its optimal location coincides with the position conventionally occupied by the dining table in the Algerian living room. No structural modification is required: the dining table becomes a dual-function element (Figure 9), serving family meals in its domestic register and a functional laptop workstation in its productive register through a purely behavioral transition—*repositioning* a chair and opening a laptop. More elaborate responses (a reversible double-faced table, integrated cable management, a height-adjustable surface) extend this logic toward greater functional differentiation without departing from the Algerian interior's cultural vocabulary.

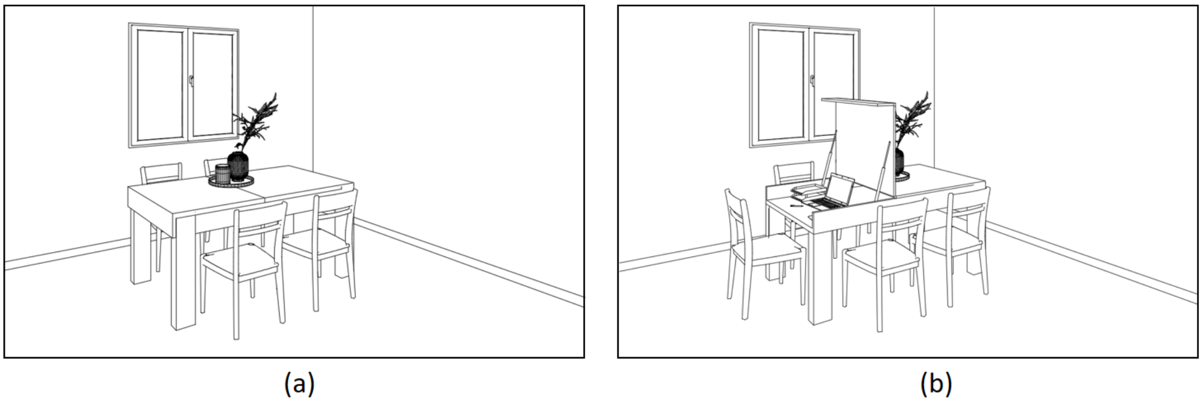


Figure 9. Dining table as a dual-function live-work element: domestic configuration **(a)** and workstation configuration **(b)** (Developed by the Authors).

For Category 2 orientations (E, W), the viable zone shifted laterally toward the non-solar side of the proximal area, with the optimal position flush against the lateral wall and perpendicular to the window. A wall-mounted fold-down unit on this lateral wall (Figure 10)—*read* as closed storage in its domestic state and deploying a work surface in its productive state—*preserves* the lateral daylight incidence ergonomically favorable for screen work by minimizing direct glare and display reflections.

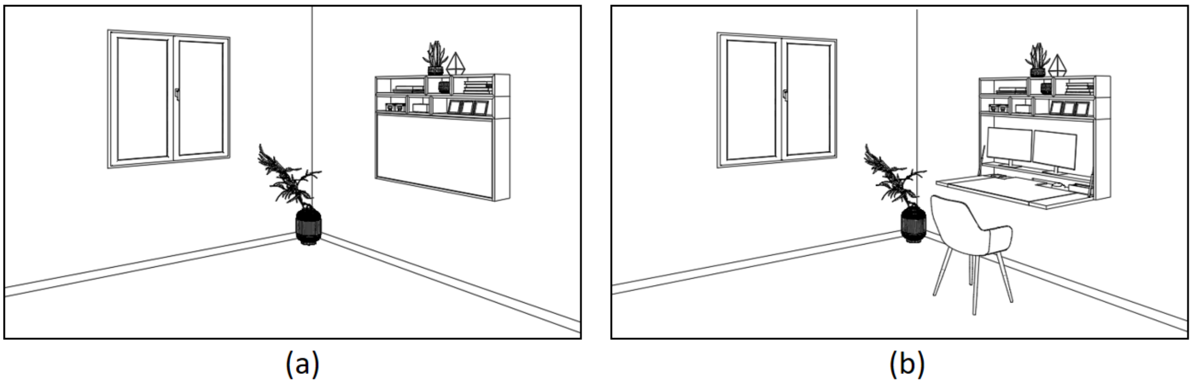


Figure 10. Wall-mounted fold-down desk on the lateral wall: (a) closed storage state and (b) deployed workstation state (Developed by the Authors).

A sideboard, chest of drawers, or display cabinet already characteristic of the Algerian living room offers an alternative vehicle: a hinged or sliding panel conceals a work surface (Figure 11) that deploys to form a conventional desk configuration. This typology operates entirely within the room's existing furniture vocabulary, preserving spatial and cultural continuity without introducing a visually foreign productive element.

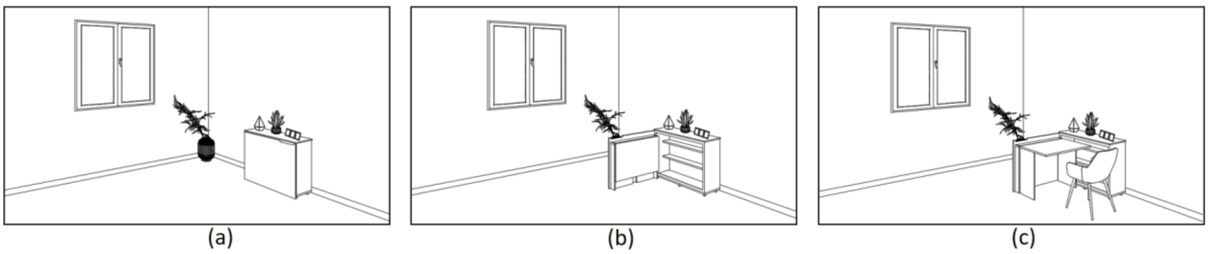


Figure 11. Decorative furniture with concealed integrated workstation: **(a)** closed domestic state **(b)**, panel opening to reveal the work surface **(c)** (Developed by the Authors).

For Category 3 orientations (S, SE, and SW), no annually fixed compliant workstation zone exists before envelope intervention. In these configurations, compliance is temporally conditioned rather than spatially fixed: adjustable-blade blinds or semi-transparent interior screens must be operated dynamically to create periods of adequate visual conditions within which the workstation can function. Phase 2 envelope optimization is the necessary precondition — only once the optimized shading configuration (vertical fins, WWR 0.25, blind transmittance 0.80) is in place does a stable proximal workstation zone re-emerge, to which the furniture typologies described for Categories 1 and 2 apply directly.

These typological proposals share a common principle: a spatially fixed structure absorbs multiple and evolving uses through the reversibility of its contents, not of its form — what Estaji (2017) defines as adaptability, the capacity of a space to accommodate different social uses without major physical modification. This principle is operationalized at the dwelling scale by multifunctional furniture, enabling functional reconfiguration according to the time of day and evolving household demands (Daglio et al., 2023). Recent evidence suggests that an ergonomic layout combined with transformable furniture can increase usable floor area by 25%–40% (Elmurodov & Mametova, 2026), improving functional comfort while mitigating the psychological burden of spatial constraint — a finding directly relevant to Algerian collective housing, where floor areas are among the most constrained in the public stock.

4.5 Phase 2

The multi-objective optimization of the southwest orientation yields two results that require interpretation beyond their numerical value.

First, the optimizer exclusively selects vertical shading geometry—eight fins, no horizontal elements—inverting the conventional Mediterranean heuristic that favors horizontal overhangs for south-facing façades (Baker & Steemers, 2000). The physical mechanism is straightforward: in the SW orientation, dominant solar penetration occurs in the late afternoon, when a low solar altitude combined with a high azimuthal angle renders horizontal blades geometrically ineffective. Vertical fins inclined at 30° precisely intercept this low-angle, high-azimuth radiation while preserving diffuse sky access—the Pareto-optimal trade-off identified by the optimizer.

Second, the optimized configuration increases WWR from 0.15 to 0.25, which is viable only because the fin system simultaneously constrains ASE within the admissible threshold. This confirms that aperture size and shading geometry must be co-optimized rather than treated sequentially (Berkouk, 2025; Lakhdari et al., 2021; Tzempelikos & Athienitis, 2007): the shading system does not merely mitigate the risks of a fixed aperture — it enables a larger aperture that a fixed system would otherwise render inadmissibly overexposed. The resulting 22.5% sDA gain directly recovers the proximal workstation zone eliminated in Phase 1 by direct solar penetration.

A residual ASE strip (~20%) persists adjacent to the glazing—the irreducible Pareto boundary of any static shading solution. Beyond this threshold, full compliance requires dynamic shading control, which falls outside the scope of this study. The workstation positioning and orientation rules established in Phase 1 remain operative after optimization: the envelope intervention expands the viable zone; the furniture strategy determines how it is occupied.

The transferability of the SW-optimised configuration to the S and SE orientations follows directly from the performance ranking established in Table 2. Since SW records the highest ASE exceedance and the lowest UDI-useful and sDA values among the three Category 3 orientations, a shading system that brings SW within full metric compliance constitutes an upper-bound intervention: applied without modification to S (ASE 20.18%, sDA 57.40%) and SE (ASE 22.22%, sDA 56.23%), the same configuration yields a more favourable starting point and therefore satisfies all four metrics a fortiori. Orientation-specific re-optimisation for S and SE is not required; the SW Pareto-optimal solution covers the full Category 3 range.

4.6 Limitations

Several constraints bound the scope of these findings. First, the analysis models a single geometric configuration selected as the dominant constructive type within the LSP and AADL programmes; the case study does not claim to represent the full geometric variability of the national stock. Minor variations in window position, room proportions, and WWR (0.15–0.20) across contractors and construction periods may alter daylight distributions beyond what the prototype captures. A morphological survey of the actual stock variability would strengthen the transferability of these results and constitutes a natural extension of this work. Second, the sDA threshold of 300 lux follows the residential norm (IES LM-83-12) and the consensus of the home-office daylighting literature (Acosta et al., 2023; Ploycharoen et al., 2024; Rolf et al., 2024), rather than the 500 lux prescribed by EN 12464-1 for professional workplaces. This choice reflects both the regulatory status of the building type — which remains residential irrespective of its telework use — and the conservative diagnostic function of the metric: zones identified as non-compliant at 300 lux are non-compliant a fortiori at 500 lux, and the comparative structure of results across orientations is independent of the absolute threshold. Adopting 500 lux would reduce the spatial extent of compliant zones without altering the orientation hierarchy or the positional prescriptions derived from it. Third, simulations assume an unobstructed sky, while the dense block morphology of Algerian collective housing generates inter-building shading that reduces compliant areas beyond the modelled values. Fourth, Phase 2 optimises the SW orientation as the Category 3 worst case; the transferability argument rests on the performance ranking in Table 2 and on geometric reasoning, but orientation-specific optimisation of S and SE would provide direct quantitative confirmation that falls outside the scope of this study. Fifth, the EPW file is specific to Bejaïa; extrapolation to Algeria's semi-arid and Saharan climatic zones requires verification with locally representative weather data. Sixth, Phase 2 proposes a static shading solution; without dynamic control, the residual ASE strip adjacent to the glazing remains irreducible. Seventh, all conclusions rest on simulation: no in situ measurements or post-occupancy surveys were conducted to validate the predicted zones against actual occupant experience.

5. Conclusion

This study demonstrates that the daylight performance of the Algerian collective housing living room, evaluated against the demands of screen-based telework, is determined not by climate but by geometry. A WWR of 0.15 imposes a universal constraint that renders 60% of the floor area non-compliant regardless of orientation. Orientation, however, determines the internal structure of the remaining viable zone, stratifying it into three qualitatively distinct categories: favorable diffuse conditions (N, NE, NW); asymmetric direct exposure (E, W); and critically overexposed configurations (S, SE, SW). Each category demands a specific workstation position and, by extension, a specific furniture typology.

DGP analysis provides the rotational constraint that spatial positioning alone cannot resolve: perpendicular orientation to the glazing is an ergonomic requirement across all eight orientations. For south-sector orientations where no fixed compliant zone exists, multi-objective envelope optimization recovers a viable proximal workstation area through co-optimized aperture enlargement and vertical shading geometry — confirming that aperture size and shading geometry must be designed jointly, not sequentially.

The convergence between photometrically optimal workstation zones and conventional Algerian living room furniture layouts reflects shared geometric logic. This correspondence substantiates the central argument: adaptive, reversible furniture, correctly positioned, constitutes a non-invasive architectural act capable of reconciling visual comfort with domestic use within an existing, unmodified building envelope. The result is a scalable, culturally calibrated response applicable to the dominant constructive type of Algerian collective housing — a typology shared by a substantial fraction of the national stock — and transferable by analogy to configurations within the observed range of geometric variation.

Nomenclature

N: North
S: South
E: East
W: West
NE: North-East
NW: North-West
SE: South-East
SW: South-West
sDA: Spatial Daylight Autonomy
ASE: Annual Sunlight Exposure
UDI: Useful Daylight Illuminance
DGP: Daylight Glare Probability
CBDM: Climate-Based Daylight Modelling
CS: Circadian Stimulus
WWR: Window-to-Wall Ratio
EPW: EnergyPlus Weather file
MOO: Multi-Objective Optimisation
IES: Illuminating Engineering Society
LM-83: IES Lighting Measurement standard (daylight)
EN 12464-1: European standard — lighting of work places
AADL: National Agency for the Improvement and Development of Housing
LSP: Promotional Social Housing (Social-Participative)
LPP: Public Promotional Housing

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Conflicts of Interest

The authors report no conflicts of interest.

Data Availability Statement

The authors confirm that all relevant data supporting the findings of this study, including the simulation parameters and performance metrics, are entirely contained within the manuscript.

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Not applicable.

CRediT Author Statement

Rayane Bitout: Conceptualization; Methodology; Software (Rhino/Grasshopper, Ladybug, Honeybee); Validation; Formal analysis; Investigation; Data Curation; Writing – original draft; Visualization.
Selma Saraoui: Supervision; Writing – review & editing.
All authors have read and approved the final manuscript.

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