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Daylighting Performance in Hospital Patient Rooms: Effects of Orientation and Evaluation of an Internal Light-Shelf Using DIALux Evo

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ABSTRACT

Daylighting performance in hospital patient rooms is strongly influenced by façade orientation, seasonal conditions, and spatial light distribution, requiring orientation-sensitive assessment of daylight-control strategies. This study evaluates daylight-only and combined daylight–artificial lighting performance in comparable north- and south-facing single-patient rooms at Fırat University Hospital, Türkiye, and investigates the effect of a fixed internal light shelf. The novelty of the study lies in evaluating the same light-shelf configuration across contrasting room orientations and examining not only its effect on daylight availability and spatial uniformity but also its influence on artificial-lighting requirements under combined lighting conditions. Simulations were conducted using DIALux Evo 13 for 21 June and 21 December under clear and overcast skies at 09:00, 12:00, and 18:00. Performance was assessed using illuminance and uniformity at the work plane and visual task area, together with daylight factor and luminaire operation. The north-facing room was primarily daylight-limited, whereas the south-facing room received substantially higher but more spatially variable daylight. The investigated light shelf did not increase overall daylight availability. Under daylight-only conditions, mean work-plane illuminance decreased by 22.1% and 21.7% in the north- and south-facing rooms, respectively, while daylight factor decreased by 29.9% and 28.1%. Under combined conditions, artificial lighting partially compensated for these reductions, while mean work-plane uniformity improved by ΔU_0 = +0.015 in the north-facing room and +0.065 in the south-facing room. However, the shelf did not provide a systematic reduction in luminaire use. Overall, the investigated shelf functioned primarily as a daylight-modulation element rather than a daylight-enhancement strategy, with its practical effectiveness dependent on orientation, baseline daylight availability, and interaction with artificial lighting.

1. Introduction

Daylight is an important environmental component in healthcare buildings, where indoor conditions are expected to support patient comfort, clinical activities, and recovery-oriented spaces [1, 2]. In hospital patient rooms, lighting is not only required for visual tasks but also contributes to the overall quality of the healing environment. Previous studies have shown that light, colour, daylight access, and window-related environmental qualities can influence visual comfort, psychological responses, and user satisfaction in healthcare interiors [2-7]. Therefore, patient-room lighting should be evaluated as both a functional and environmental design issue.

Unlike artificial lighting, daylight is a dynamic source of illumination that changes according to time of day, season, sky condition, façade orientation, and room geometry [8, 9]. This dynamic character makes daylight valuable for indoor environmental quality, but it also makes its performance difficult to predict without detailed evaluation. Daylight can reduce dependence on artificial lighting during daytime hours and support energy-conscious design when it is properly combined with artificial lighting systems [10, 11]. However, daylight alone does not necessarily provide sufficient or balanced lighting conditions in all parts of a patient room.

The distribution of daylight inside a room is strongly affected by architectural and environmental parameters. Façade orientation, window size, window position, interior surface properties, external obstructions, and sky conditions can all influence the amount and spatial distribution of daylight [12, 13]. As a result, two patient rooms located in the same hospital building may perform differently if they face different directions. North-facing rooms may receive lower but more diffuse daylight, while south-facing rooms may receive higher daylight levels with stronger spatial variation during certain periods [8, 12]. For this reason, room orientation should be considered a key variable in the assessment of patient-room lighting performance.

In hospital patient rooms, lighting adequacy cannot be judged only by average illuminance values. A room may receive high daylight levels near the window while deeper zones remain less illuminated, creating an uneven luminous environment. Similarly, excessive daylight can increase spatial contrast and reduce visual balance, even when average illuminance appears sufficient. Therefore, both illuminance and lighting uniformity should be assessed together when evaluating daylighting performance and its interaction with artificial lighting. In this study, the evaluation criteria were based on EN 12464-1 for indoor workplace lighting and EN 17037 for daylight in buildings [14, 15].

Artificial lighting remains necessary in healthcare buildings because hospitals operate continuously and patient rooms must support different activities throughout the day and night. Combined daylight–artificial lighting strategies aim to use daylight when available and provide artificial lighting support when daylight is insufficient [11]. This integration is particularly important in existing hospital buildings, where architectural constraints may limit the ability to redesign windows, façades, or room layouts. However, combined lighting does not automatically ensure spatial balance; its effectiveness depends on the existing daylight distribution, room orientation, and the way artificial lighting compensates for insufficient daylight. Previous research has also shown that lighting strategies in hospital buildings are closely related to energy efficiency and lighting-control decisions [16, 17].

Previous research on hospital patient rooms has demonstrated the importance of daylight availability, window configuration, room orientation, and the relationship between the patient and the window in determining indoor lighting conditions [18-22]. Simulation-based and parametric investigations have further shown that daylight performance is sensitive to room and façade characteristics, supporting the need for context-specific assessment rather than relying on daylight quantity alone [19-21, 23]. Collectively, these studies establish the importance of evaluating both the availability and spatial distribution of daylight in healthcare environments.

Light shelves represent one passive approach for controlling and redistributing daylight in side-lit spaces. By intercepting incident daylight and redirecting part of it toward the ceiling, they can modify both daylight penetration and its spatial distribution. However, previous research has demonstrated that their effectiveness depends strongly on shelf geometry and reflectance, façade orientation, solar position, sky condition, room dimensions, and ceiling characteristics [24-26]. Reviews of light-shelf research therefore emphasize that their performance cannot be generalized independently of the building and environmental conditions in which they are applied.

This dependence is particularly relevant for internal light shelves. Experimental and simulation studies have shown that internal shelves may improve daylight uniformity without necessarily increasing illuminance deeper within a room, and that improved spatial distribution can occur together with reductions in average illuminance. Their effectiveness has also been shown to vary with season, shelf configuration, and ceiling height [27, 28]. These findings indicate that internal light-shelf performance should be evaluated in terms of both daylight quantity and spatial distribution rather than assuming that increased daylight penetration is an inherent outcome of shelf installation.

Healthcare-specific applications remain comparatively limited. Light-shelf investigations in hospital rooms have examined their use in combination with other daylight-control elements, such as blinds, demonstrating that daylight performance varies according to the investigated device configuration [29]. Parametric research in hospital patient rooms has also investigated combined internal and external light-shelf configurations under clear-sky conditions, demonstrating the sensitivity of daylight performance to shelf configuration and inclination [30]. However, comparatively limited evidence is available on how the same fixed internal-only light-shelf configuration affects both daylight quantity and spatial distribution across existing patient rooms with contrasting façade orientations, particularly when the resulting artificial-lighting requirements are also considered.

Based on this context, the present study evaluates daylight-only and combined daylight–artificial lighting performance in existing north- and south-facing single-patient rooms at Fırat University Hospital in Elazığ, Türkiye, and investigates the effect of a fixed internal light shelf. A simulation-based assessment was conducted using DIALux Evo 13 for 21 June and 21 December under clear- and overcast-sky conditions at 09:00, 12:00, and 18:00. Lighting performance was assessed using average illuminance and spatial uniformity at the work plane and visual task area, together with daylight factor and luminaire operation where applicable.

The novelty of the study lies in evaluating the same fixed internal light-shelf configuration across two existing patient-room configurations with contrasting façade orientations and examining its performance not only in terms of daylight availability but also spatial uniformity and its interaction with artificial-lighting requirements under combined conditions. Rather than assuming that a light shelf provides a universally beneficial daylighting solution, the study investigates whether its practical effect changes according to the baseline daylight characteristics of the investigated rooms. Accordingly, the study addresses three research questions:

(1) How do daylight availability and spatial distribution differ between the investigated north- and south-facing patient-room configurations under the selected seasonal, temporal, and sky conditions?

(2) How does artificial lighting supplement daylight under conditions in which daylight alone is insufficient?

(3) How does the investigated fixed internal light shelf affect illuminance, spatial uniformity, daylight factor, and luminaire operation in the two room configurations?

2. Materials and Methods

2.1. Research Design and Case Study Selection

This study was designed as a simulation-based lighting performance assessment focusing on the influence of room orientation and the application of a light-shelf strategy in hospital patient rooms. The research was not intended to redesign the entire lighting system or to replace the existing architectural configuration. Instead, it examined how daylight behaves in north- and south-facing patient rooms, how the existing artificial lighting system supports daylight under insufficient conditions, and how a light shelf modifies illuminance distribution and lighting uniformity.

The study was conducted at Fırat University Hospital, located in Elazığ, eastern Türkiye, at approximately 38°41' N latitude and 39°13' E longitude. The project location was defined as Elazığ in DIALux Evo using the UTC+03:00 (Istanbul) time zone, and the geographical coordinates were used to establish the solar position and associated daylight conditions for the simulations. The building model was aligned with geographic north, with the north alignment set to 0.00°. Accordingly, the investigated façades of Block B were represented at azimuths of 0° for the north-facing room and 180° for the south-facing room, measured clockwise from geographic north. The hospital was selected because it represents an existing healthcare building in which patient rooms are exposed to contrasting façade orientations under the same local climatic and operational context, making it suitable for examining orientation-related daylight behaviour and the potential role of passive daylight-control strategies.

Two single-bed patient rooms located on the fifth floor of Block B were selected as representative case-study spaces. Room selection was based on three criteria: consistency of clinical function and occupancy pattern, comparable room geometry and interior finishes, and contrasting façade orientations that produce distinctly different daylight exposure conditions. The selected rooms belong to the same hospital block and operate under the same local climatic context, while representing north- and south-facing patient-room conditions within the building. Their nearly equivalent floor dimensions also reduce the influence of room size on the comparison. Nevertheless, the rooms are existing spaces rather than geometrically identical experimental models; differences in window width, façade exposure, and installed lighting configuration were retained in the simulations to represent the actual conditions. Accordingly, the comparison is interpreted as a case-based assessment of two comparable existing patient rooms with contrasting orientations rather than as a controlled experiment in which orientation is the only independent variable. The location of the case-study building and the selected patient rooms are shown in Fig. (**1**).

Figure 1: Case study building and selected patient rooms.

2.2. Room Geometry, Window Configuration, Calculation Areas, and Surface Properties

The selected patient rooms were modelled according to their existing architectural characteristics. The model included room geometry, ceiling height, window dimensions, furniture arrangement, internal surface properties, and the existing artificial lighting layout. These elements were included because they directly influence daylight penetration, secondary reflections, and the spatial distribution of both daylight and artificial light.

The two investigated rooms had closely comparable overall dimensions. The north-facing room measured 3.40 × 6.80 m, corresponding to an approximate floor area of 23.1 m², whereas the south-facing room measured 3.40 × 6.85 m, with an approximate floor area of 23.3 m². Both rooms had a clear height of approximately 3.00 m. Despite their similar room proportions, the existing window configurations, however, were not identical. The north-facing room had a window width of 2.60 m, whereas the south-facing room had a wider 3.20 m opening. In both rooms, the clear glazing height was 1.10 m, the sill height was 0.80 m, and the frame width was approximately 0.12 m. For daylight calculations, the glazing was assigned a degree of transmittance of 90%, a reflection factor of 10%, and a refractive index of 1.50 in the DIALux Evo model. These optical properties were retained consistently across all corresponding simulation scenarios. The existing geometric and window-related differences between the two rooms were retained in the simulations because the objective was to reproduce and compare the actual patient-room conditions rather than to construct geometrically normalized theoretical models. The room configurations and the corresponding window dimensions are illustrated in Fig. (**2**).

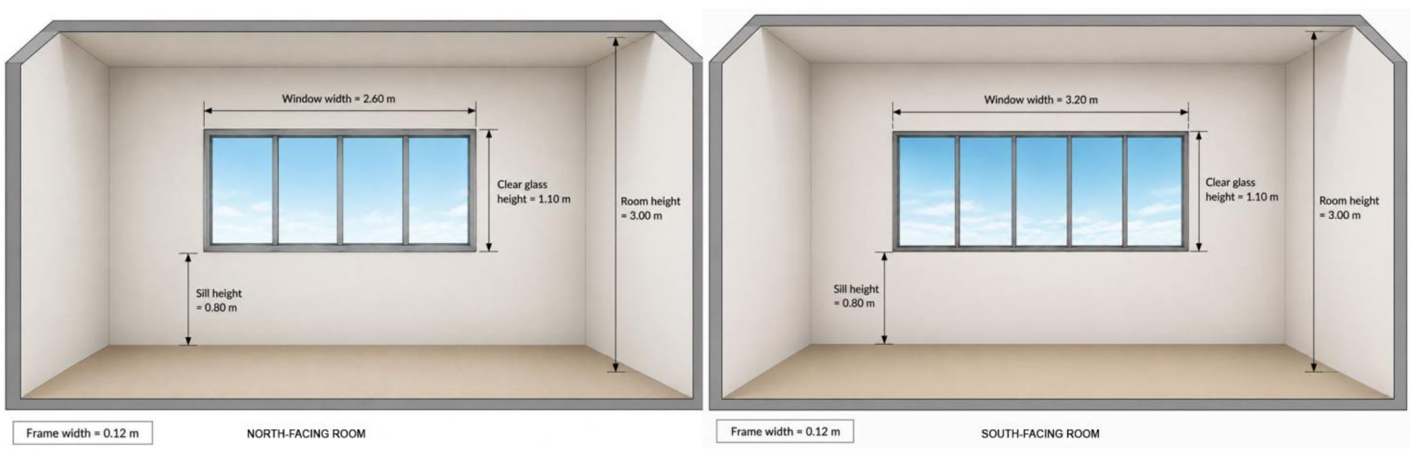

Figure 2: Window configuration and dimensions of the selected patient rooms.

Existing exterior façade shading elements were explicitly incorporated into the daylight model. Their geometry, dimensions, positions, and projections were reproduced according to the available architectural drawings and were retained unchanged throughout the corresponding simulation scenarios. Thus, daylight calculations accounted for the existing façade obstructions rather than assuming unobstructed window openings.

Lighting simulations were performed using DIALux Evo 13, a professional lighting simulation software used for daylight and artificial lighting calculations [31, 32]. The calculation areas were defined to represent both general room lighting and task-related lighting conditions. A horizontal work plane was positioned 0.80 m above the finished-floor level with a 0.20 m offset from the surrounding walls to avoid boundary effects. The vertical position of the work plane and its offset from the window wall are illustrated in Fig. (**3**). Its evaluation grid was generated in DIALux Evo using the calculation-grid setting according to EN 12464-1 and EN 12464-2. A separate horizontal visual task area was defined within the patient-bed zone to assess lighting conditions relevant to reading, examination, and patient-care activities. Daylight factor (DF) was evaluated separately from the date- and time-specific illuminance calculations using the DIALux Evo daylight-factor calculation procedure, with the DF calculation area defined using a 1.0 m boundary offset from the surrounding walls. As a static relative indicator of daylight availability under the reference sky condition, DF was evaluated independently of the date- and time-specific illuminance calculations. The calculation-plane definitions and corresponding grid settings were maintained consistently across comparable simulation scenarios to enable direct comparison of illuminance and spatial uniformity.

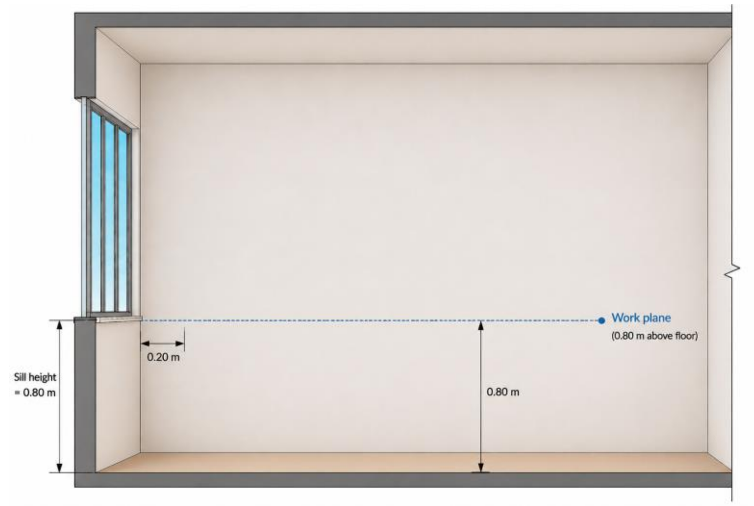

Figure 3: Vertical section illustrating the work-plane definition at 0.80 m above the finished-floor level and the 0.20 m offset from the surrounding walls.

Interior surface reflectance values were assigned according to the existing material characteristics of the patient rooms. Since the investigated rooms had similar interior finishes, the same reflectance values were used in the baseline simulations for both orientations. The ceiling was modelled as light-coloured ceiling paint with a reflectance value of 0.50, the walls as light-coloured interior paint with a reflectance value of 0.70, and the floor as light-toned PVC/vinyl flooring with a reflectance value of 0.40. These values were included because surface reflectance affects inter-reflections within the room and therefore influences both daylight distribution and artificial lighting performance.

2.3. Existing Artificial Lighting Arrangement

The existing artificial lighting system was reproduced in DIALux Evo because the study evaluates combined daylight–artificial lighting conditions in addition to daylight-only conditions. The installed luminaires were therefore included in the simulation model to assess how artificial lighting supports daylight when daylight alone is insufficient.

Both investigated rooms included three functional lighting layers: general ceiling lighting, bedhead lighting, and low-level night/orientation lighting. However, the ceiling-lighting composition differed between the north- and south-facing rooms, and this difference was reflected in the model.

In the north-facing patient room, general artificial lighting was provided by the existing ceiling luminaire group. The ceiling luminaires had powers ranging between approximately 12–24 W, luminous flux values between approximately 1180–2160 lm, and colour temperatures between 4000–5000 K. The room also included bedhead lighting units of approximately 22 W and 960 lm at 5000 K, intended to support reading, examination, and patient-bed-related visual tasks. A low-wall night luminaire of approximately 11 W and 480 lm at 4000 K was also included as part of the existing lighting arrangement.

In the south-facing patient room, the ceiling lighting system consisted of one LED ceiling luminaire and two fluorescent ceiling luminaires. The LED ceiling luminaire had a power of approximately 24 W and a luminous flux of about 2160 lm, while each fluorescent ceiling luminaire had a power of approximately 22 W and a luminous flux of about 960 lm. The colour temperatures of the ceiling lighting components were 4000 K and 5000 K. Similar to the north-facing room, the south-facing room also included bedhead lighting units of approximately 22 W and 960 lm at 5000 K, together with a low-wall night luminaire of approximately 11 W and 480 lm at 4000 K. The existing artificial lighting layout used in the simulation model is shown in Fig. (**4**).

Figure 4: Existing artificial lighting arrangement in the north- and south-facing patient rooms: ceiling luminaires, bedhead lighting units, and low-level night lighting.

The existing luminaires were represented in DIALux Evo using the photometric data associated with the corresponding luminaire entries in the software. These data included the luminaire light-distribution characteristics together with the rated luminous flux, connected load, and other available technical parameters.

For calculations involving electric lighting, the global maintenance-factor method based on DIN 5035 was applied in DIALux Evo, with the maintenance factor fixed at 0.80. This value was retained consistently across the corresponding electric-lighting scenarios.

The existing patient rooms were not equipped with an automatic lighting-control or dimming system. Accordingly, electric-lighting operation was represented by discrete switching, consistent with the existing hospital lighting arrangement. In the combined daylight–artificial lighting scenarios, luminaires were switched on when daylight alone was insufficient to provide the required illuminance for the evaluated area. Consequently, the number of operating luminaires varied among the investigated conditions according to daylight availability and the illuminance requirement to be supported. No continuous dimming was applied to the existing lighting system. Thus, the reported numbers of operating luminaires represent different switching states rather than different luminaire-output levels.

2.4. Simulation Conditions and Investigated Scenarios

Lighting simulations were conducted for 21 June and 21 December at 09:00, 12:00, and 18:00 to examine contrasting seasonal and temporal daylight conditions. Clear-sky and overcast-sky conditions were evaluated separately using the corresponding reference-sky selections in DIALux Evo. For clear-sky calculations, direct sunlight was enabled so that direct solar penetration was included in the calculated illuminance. Solar conditions were determined according to the project location, simulation date and time, and the geographic orientation assigned to the model.

Four groups of simulation scenarios were investigated in this study. First, daylight-only simulations were performed for the existing north- and south-facing patient rooms without the light shelf and with all electric lighting switched off. These simulations established the baseline daylight performance of the two rooms under the investigated seasonal, temporal, orientation, and sky conditions.

Second, daylight-only simulations were performed after introducing the internal light shelf, while all electric lighting remained switched off. The corresponding baseline and light-shelf configurations were evaluated under otherwise identical room geometry, window properties, exterior shading, surface properties, date, time, sky condition, and calculation settings. This paired analysis was used to isolate the daylighting effect of the light shelf independently of electric-lighting operation. Average work-plane illuminance and illuminance uniformity were compared to determine how the shelf affected daylight quantity and its spatial distribution.

Third, combined daylight–artificial lighting simulations were conducted for the existing condition without the light shelf, using the installed artificial-lighting system to evaluate whether the combined contribution of daylight and electric lighting could support the required illuminance and uniformity levels.

Fourth, combined daylight–artificial lighting simulations were evaluated after introducing the internal light shelf to examine the combined performance of the passive daylighting intervention and the existing artificial-lighting system under the investigated orientation and sky conditions. Comparison with the corresponding combined baseline condition was used to assess changes in illuminance and spatial uniformity when artificial-lighting support was also considered.

2.5. Light-Shelf Strategy

An internal light shelf was introduced into the simulation model to investigate its effect on daylight distribution and lighting uniformity in the north- and south-facing patient rooms. Light shelves are passive daylighting elements that redirect a portion of incoming daylight toward the ceiling and deeper parts of interior spaces, thereby modifying daylight penetration and spatial distribution [24, 27].

In the present study, the light shelf was positioned entirely inside the patient room at the existing window opening; therefore, no modification to the external façade or existing window dimensions was required. The shelf geometry was adapted to the existing window width of each room. In the north-facing room, the shelf extended 2.60 m across the window, whereas a width of 3.20 m was used in the south-facing room. In both rooms, the shelf projected 0.30 m into the interior and was positioned 1.50 m above the finished floor level. The modelled shelf had a thickness of 0.013 m and an upward inclination of 15°. The geometric and optical characteristics of the investigated configuration are summarised in Table **1**.

Table 1: Geometric and optical characteristics of the investigated internal light-shelf configuration.

Parameter	North-facing Room	South-facing Room
Shelf type	Internal	Internal
Width (m)	2.60	3.20
Interior projection (m)	0.30	0.30
Installation height above finished floor (m)	1.50	1.50
Upward inclination (°)	15	15
Modelled thickness (m)	0.013	0.013
Material representation in DIALux Evo	Metallic	Metallic
Reflection factor (%)	85	85
Reflective-coating parameter (%)	5	5

In DIALux Evo, the shelf was represented as a metallic surface with a reflection factor of 85% and a reflective-coating parameter of 5%. A highly reflective upper surface is generally desirable for light shelves because surface reflectance influences the amount of incident daylight available for redirection toward the ceiling and the deeper interior [27]. The 85% reflection factor used in the present model was therefore selected to represent a highly reflective shelf surface.

The shelf was inclined upward by 15°. Shelf inclination influences the direction of reflected daylight, and previous investigations have shown that inclined configurations can modify daylight penetration and distribution; however, their performance varies with orientation, solar position, shelf geometry, and other design parameters [26]. Accordingly, the 15° inclination adopted in this study is treated as a tested case-study configuration rather than as a universally optimal angle.

A projection depth of 0.30 m was adopted for the internal light shelf. The selected depth provides a compact reflective surface within the existing window zone while limiting its extension into the occupied patient-room space. This was particularly relevant because the intervention was conceived as an internal addition to the existing room rather than as a modification of the façade or window system. The same 0.30 m projection was maintained in both rooms to provide a consistent shelf-depth parameter despite the difference in window width. Since light-shelf performance is influenced by shelf dimensions in combination with mounting position, room geometry, façade orientation, and solar conditions, the selected depth is reported as a case-specific design parameter rather than as a universally optimal dimension [26].

The performance of the light shelf was evaluated through changes in both average illuminance and lighting uniformity. This approach was adopted because the effectiveness of a light shelf is not necessarily represented by an increase in total illuminance alone; redistribution of daylight and changes in spatial uniformity are also relevant indicators of its performance [27]. Fig. (**5**) illustrates the internal light-shelf configuration applied to the north-facing patient room. The same modelling approach and optical properties were applied to the south-facing room, with the shelf width adjusted to 3.20 m to correspond to the existing window opening.

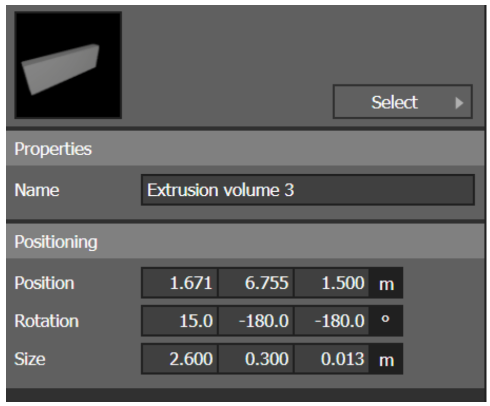

Figure 5: Internal light-shelf configuration modelled in the north-facing patient room in DIALux Evo, showing its position relative to the existing window opening.

2.6. Field Measurements and Model Validation

The baseline DIALux Evo model adopted in the present study was verified using field illuminance measurements previously obtained in the same patient-room environment [33]. The verification was conducted in the existing south-facing patient room on 20 July 2026 between 21:00 and 23:00. Measurements were deliberately performed after sunset under artificial-lighting-only conditions to exclude daylight contribution and enable direct comparison between the measured indoor illuminance and the corresponding DIALux Evo predictions.

During the measurement period, the room door and curtains were kept closed to minimise the influence of external light sources. The existing luminaires were operated at full output and were switched on approximately 15 min before data collection to allow their light output to stabilise. Horizontal illuminance was measured using an institution-owned, unbranded data-logging digital lux meter (serial no. 2019011167). The instrument had a measurement range of 0.1–200,000 lx, a resolution of 1 lx, and a sampling interval of 0.5 s. According to the specifications stated on the instrument, its measurement accuracy was ±4% within the 0.1–10,000 lx range and ±10% at illuminance levels above 10,000 lx.

Twelve measurement positions were distributed across the patient room and matched with corresponding calculation locations in the DIALux Evo model, as illustrated in Fig. (**6**). Measurements were taken on a horizontal plane positioned 0.80 m above finished floor level, with a 0.20 m offset from the surrounding walls. For the numerical comparison, the simulation reproduced the room geometry, luminaire arrangement, surface-reflectance assumptions, and operating condition corresponding to those present during field measurements.

Agreement between measured and simulated illuminance was examined on a point-by-point basis and quantified using the mean absolute percentage error (MAPE), root mean square error (RMSE), and coefficient of determination (R^2). In addition to illuminance magnitude, spatial uniformity was evaluated for both datasets. Overall illuminance uniformity (U_o) was calculated as the ratio of minimum illuminance (E_{min}) to average illuminance (E_m) over the evaluated plane, as expressed in Equation (1):

$$U_O = E_{min}/E_m \tag{1}$$

where E_{min} is the minimum horizontal illuminance and E_m is the average horizontal illuminance, both expressed in lux (lx). The same calculation procedure was applied to the field-measurement and simulation datasets to allow a consistent comparison of their spatial illuminance distributions. The point-by-point measured and simulated values and the resulting validation indicators are presented in Section 3.1.

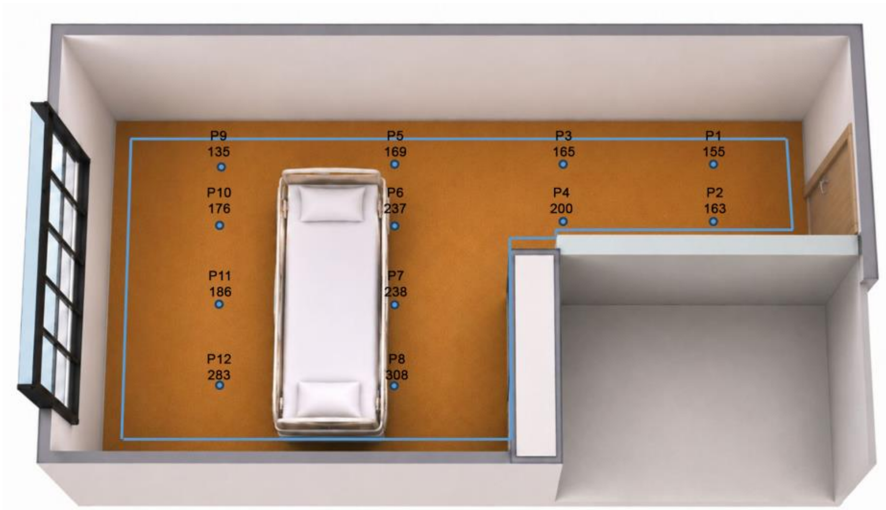

Figure 6: Spatial distribution of the 12 measurement positions and corresponding calculation points used for validation in the south-facing patient room.

2.7. Evaluation Criteria

Lighting performance was evaluated using average illuminance, lighting uniformity, and daylight factor. Average illuminance was used to assess the quantity of light available on the work plane and visual task area, while lighting uniformity was used to evaluate the spatial distribution of light. Daylight factor was used as a static indicator of daylight availability under the same room geometry, window configuration, and surface-reflectance conditions. Although daylight factor was reported in the results to compare daylight availability between orientations and light-shelf conditions, it was not used as an independent pass/fail criterion. The final interpretation was based mainly on whether illuminance and uniformity requirements were satisfied on the work plane and visual task area.

The evaluation was carried out separately for the work plane and the visual task area because these two zones represent different functional requirements in patient rooms. The general work plane was evaluated with reference to a recommended illuminance level of 100 lx and a minimum uniformity value of Uo ≥ 0.40. The visual task area around the patient bed was evaluated with reference to a higher recommended illuminance level of 300 lx and a minimum uniformity value of Uo ≥ 0.60. These criteria were interpreted in relation to the lighting requirements of patient rooms and indoor workplace lighting standards, particularly EN 12464-1 and daylight-related assessment principles in EN 17037 [14, 15].

Illuminance and uniformity were interpreted together rather than separately. This was necessary because a room may achieve sufficient average illuminance while still showing poor spatial distribution, especially when daylight is concentrated near the window or when deeper parts of the room remain underlit. For this reason, the analysis focused not only on whether the light shelf increased or decreased illuminance, but also on whether it improved the balance of light distribution across the room and around the patient-bed area.

Compliance was determined separately for illuminance and uniformity. A condition was classified as fully compliant only when both the corresponding illuminance and uniformity requirements were satisfied. This distinction was maintained throughout the results to avoid interpreting increased illuminance alone as evidence of satisfactory lighting performance.

3. Results and Discussion

Lighting performance was evaluated by considering average illuminance and lighting uniformity together. The numerical results are presented in the tables, while the discussion interprets their meaning in relation to daylight availability, room orientation, combined lighting behaviour, and the light-shelf strategy. This approach is important because hospital patient rooms require both sufficient light levels and balanced spatial distribution to support patient comfort, care-related activities, reading, circulation, and visual tasks.

3.1. Agreement between Field Measurements and Simulation

The point-by-point comparison between field measurements and DIALux Evo predictions is presented in Table **2**. Across the twelve validation locations, the measured horizontal illuminance ranged from 140 to 314 lx, whereas the corresponding simulated values ranged from 135 to 308 lx. The average illuminance obtained from the measurements was 206.83 lx, compared with 201.25 lx predicted by the simulation. Thus, the model showed a small overall tendency to underestimate the measured illuminance while preserving a closely comparable spatial pattern.

Table 2: Point-level comparison between field-measured and DIALux Evo-predicted horizontal illuminance under the baseline artificial-lighting condition.

Dataset / Location	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	Mean
Field measurement (lx)	161	168	172	207	175	242	241	314	140	182	191	289	206.83
DIALux Evo (lx)	155	163	165	200	169	237	238	308	135	176	186	283	201.25
Absolute difference, |ΔE| (lx)	6	5	7	7	6	5	3	6	5	6	5	6	5.58
Absolute percentage error, APE (%)	3.73	2.98	4.07	3.38	3.43	2.07	1.24	1.91	3.57	3.30	2.62	2.08	2.86

Note: E_m and E_s denote the measured and simulated illuminance values, respectively. The absolute illuminance difference was calculated as $|\Delta E| = |E_m - E_s|$, while the absolute percentage error (APE) was calculated as $APE = (|E_m - E_s| / E_m) \times 100$.

Quantitative error analysis further confirmed the close correspondence between the two datasets. The mean absolute percentage error across the twelve validation locations was 2.86%, while the RMSE was 5.68 lx. Moreover, the relationship between measured and simulated illuminance produced a coefficient of determination of R^2 = 0.9996, indicating that the model closely reproduced the spatial variation observed in the field measurements. A similarly close agreement was observed for spatial illuminance uniformity. Based on Equation (1), the measured condition yielded U_0 = 0.677, while the corresponding DIALux Evo simulation produced U_0 = 0.671. The absolute difference between the two uniformity values was therefore only 0.006. This correspondence indicates that the agreement between measurement and simulation was not limited to average illuminance but also extended to the spatial distribution of illuminance over the evaluated plane.

Although the field measurements were slightly higher than the corresponding simulated values, the magnitude of the discrepancy remained small. The residual differences may be associated with unavoidable uncertainties in representing actual surface reflectance, luminaire photometric characteristics, exact sensor positioning, and the measurement accuracy of the lux meter. Overall, the low prediction errors, high coefficient of determination, and close correspondence in uniformity support the use of the baseline DIALux Evo model for the subsequent comparative analyses.

3.2. Existing Daylight-Only Performance

Table **3** presents the existing daylight-only work-plane performance of the north- and south-facing patient rooms. The results show that room orientation had a clear influence on daylight availability and spatial distribution. The north-facing room generally produced lower work-plane illuminance values than the south-facing room, indicating a daylight-limited condition. This was especially evident under winter clear-sky conditions, where the south-facing room received substantially higher daylight levels than the north-facing room.

However, higher daylight availability in the south-facing room did not necessarily result in better lighting quality. For example, under winter clear-sky midday conditions, the south-facing room reached a very high work-plane illuminance value, but its uniformity remained very low. This indicates that daylight was not evenly distributed across the room. In contrast, the north-facing room showed lower illuminance values, but the main issue was insufficient daylight rather than excessive or uneven daylight concentration. Therefore, the two orientations presented different daylighting problems: the north-facing room required daylight support, while the south-facing room required daylight control and redistribution.

The exceptionally high value observed in the south-facing room at 12:00 under the winter clear-sky condition was verified against the original simulation output. The average work-plane illuminance reached 6283 lx, accompanied by a very low uniformity of $U_o = 0.054$. This result was associated with direct solar penetration through the south-facing window under the relatively low winter solar altitude, which allowed sunlight to extend deeper into the room. Consequently, the high average illuminance should not be interpreted as uniformly improved daylight performance; rather, it reflects a strongly uneven daylight distribution with substantial local differences in illuminance.

From a visual-comfort perspective, the exceptionally high illuminance should be interpreted cautiously. Daylight discomfort glare is influenced by several photometric and visual-field parameters, including source luminance, luminance contrast, adaptation level, source size, and position [34]. Accordingly, the combination of intense direct solar penetration and strongly non-uniform daylight distribution observed in this case indicates a potential for visual discomfort and highlights the possible need for occupant-operated shading to control excessive solar exposure. However, glare was not quantified in the present study using a view-dependent metric such as Daylight Glare Probability (DGP), which considers vertical eye illuminance together with the luminance, size, and position of glare sources [35]. Therefore, the reported 6283 lx should be interpreted as an indicator of potentially problematic daylight exposure rather than as direct evidence of discomfort glare.

Table 3: Existing daylight-only work-plane performance of the north- and south-facing patient rooms.

Season	Sky Condition	Time	North-facing Room		South-facing Room	
			Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane	Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane
Winter	Clear	09:00	122	0.20	814	0.12
Winter	Clear	12:00	219	0.21	6283	0.054
Winter	Clear	18:00	0	–	0	–
Winter	Overcast	09:00	74.5	0.10	86.5	0.097
Winter	Overcast	12:00	166	0.10	192	0.097
Winter	Overcast	18:00	0	–	0	–
Summer	Clear	09:00	283	0.17	381	0.15
Summer	Clear	12:00	260	0.18	597	0.15
Summer	Clear	18:00	281	0.17	203	0.18
Summer	Overcast	09:00	249	0.10	288	0.097
Summer	Overcast	12:00	342	0.10	397	0.096
Summer	Overcast	18:00	123	0.10	143	0.097
Daylight factor	Daylight factor for north-facing room is 1.435%					
	Daylight factor for south-facing room is 1.5%					

Table **4** presents the daylight-only performance in the visual task area. Compared with the work plane, the visual task area generally showed more favourable uniformity values in both orientations. This indicates that the patient-bed zone received a more stable lighting contribution than the wider room area. Nevertheless, daylight-only performance in the visual task area was not consistently sufficient under all conditions, particularly under overcast sky conditions and at 18:00 in winter. This confirms that daylight alone cannot reliably satisfy the lighting requirements of patient rooms throughout the evaluated periods.

The daylight factor values also supported the orientation-based comparison. The south-facing room had a slightly higher daylight factor than the north-facing room, indicating greater daylight availability. However, the results show that daylight factor alone is not sufficient to describe lighting quality, because it does not explain whether daylight is evenly distributed across the room. Therefore, daylight factor was interpreted together with illuminance and uniformity rather than as an independent performance criterion.

Table 4: Existing daylight-only visual-task-area performance of the north- and south-facing patient rooms.

Season	Sky Condition	Time	North-facing Room		South-facing Room	
			Illuminance (lx) – Visual Task Area	Uniformity (Uo) – Visual Task Area	Illuminance (lx) – Visual Task Area	Uniformity (Uo) – Visual Task Area
Winter	Clear	09:00	135	0.65	399	0.61
Winter	Clear	12:00	252	0.66	1240	0.62
Winter	Clear	18:00	0	–	0	–
Winter	Overcast	09:00	67.2	0.54	47.6	0.58
Winter	Overcast	12:00	149	0.54	106	0.58
Winter	Overcast	18:00	0	–	0	–
Summer	Clear	09:00	316	0.59	256	0.63
Summer	Clear	12:00	277	0.64	425	0.64
Summer	Clear	18:00	265	0.60	156	0.64
Summer	Overcast	09:00	224	0.54	159	0.58
Summer	Overcast	12:00	308	0.54	218	0.58
Summer	Overcast	18:00	111	0.54	78.7	0.58
Daylight factor	Daylight factor for north-facing room is 1.435%					
	Daylight factor for south-facing room is 1.5%					

Overall, the existing daylight-only results demonstrate that patient-room lighting performance should not be evaluated only according to the amount of daylight entering the room. A higher illuminance level may still be associated with poor spatial balance, while a lower illuminance level may indicate the need for artificial lighting support. This confirms the importance of evaluating both illuminance and uniformity in hospital patient rooms.

3.3. Daylight-Only Performance with the Internal Light Shelf

Table **5** presents the daylight-only work-plane performance of the north- and south-facing patient rooms after introducing the internal light shelf. As in the baseline daylight-only analysis, all electric lighting was switched off, allowing the daylighting effect of the shelf to be evaluated independently of artificial-lighting operation. The results show that the response to the light shelf varied according to room orientation, season, time, and sky condition.

In the north-facing room, daylight availability generally remained limited after the introduction of the light shelf, particularly during winter and under overcast conditions. In the south-facing room, considerably higher illuminance levels continued to occur under clear-sky conditions, especially at winter midday, although the magnitude of the very high illuminance observed in the baseline condition was reduced. These results indicate that the light shelf did not produce a uniform increase in daylight availability; rather, its effect depended on the incident daylight conditions associated with façade orientation and sky condition.

Table 5: Daylight-only work-plane performance of the north- and south-facing patient rooms with the internal light shelf.

Season	Sky Condition	Time	North-facing Room		South-facing Room	
			Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane	Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane
Winter	Clear	09:00	99.5	0.20	721	0.12
Winter	Clear	12:00	180	0.21	4690	0.058
Winter	Clear	18:00	0	–	0	–
Winter	Overcast	09:00	55.8	0.11	64.7	0.10
Winter	Overcast	12:00	124	0.11	144	0.10
Winter	Overcast	18:00	0	–	0	–
Summer	Clear	09:00	227	0.18	303	0.15
Summer	Clear	12:00	207	0.19	506	0.15
Summer	Clear	18:00	229	0.18	165	0.18
Summer	Overcast	09:00	186	0.11	216	0.10
Summer	Overcast	12:00	256	0.11	297	0.10
Summer	Overcast	18:00	92.3	0.11	107	0.10
Daylight factor	Daylight factor for north-facing room is 1.006%					
	Daylight factor for south-facing room is 1.078%					

Comparison with the corresponding baseline daylight-only condition shows that the light shelf predominantly reduced average work-plane illuminance rather than increasing daylight availability. For example, under winter clear-sky conditions at 12:00, average illuminance in the north-facing room decreased from 219 to 180 lx, corresponding to a reduction of approximately 17.8%, while work-plane uniformity remained unchanged at 0.21. The effect was more pronounced in the south-facing room, where average illuminance decreased from 6283 to 4690 lx under the same condition, representing a reduction of approximately 25.4%. The corresponding uniformity changed only slightly from 0.054 to 0.058. Thus, although the shelf reduced the exceptionally high daylight level associated with direct winter solar penetration in the south-facing room, it did not substantially improve the highly non-uniform spatial distribution.

Table **6** presents the corresponding daylight-only performance within the visual task area after introducing the internal light shelf. As observed in the baseline condition, the visual task area generally maintained substantially higher uniformity than the wider work plane. However, the effect of the light shelf on task-area illuminance varied according to orientation and daylight condition, and adequate daylight was not consistently maintained throughout the investigated periods.

Table 6: Daylight-only visual-task-area performance of the north- and south-facing patient rooms with the internal light shelf.

Season	Sky Condition	Time	North-facing Room		South-facing Room	
			Illuminance (lx) – Visual Task Area	Uo – Visual Task Area	Illuminance (lx) – Visual Task Area	Uo – Visual Task Area
Winter	Clear	09:00	105	0.67	348	0.64
Winter	Clear	12:00	197	0.68	1112	0.62
Winter	Clear	18:00	0	–	0	–
Winter	Overcast	09:00	48.2	0.60	37.7	0.62
Winter	Overcast	12:00	107	0.60	83.7	0.62
Winter	Overcast	18:00	0	–	0	–
Summer	Clear	09:00	241	0.63	209	0.62
Summer	Clear	12:00	213	0.67	361	0.67
Summer	Clear	18:00	208	0.63	126	0.66
Summer	Overcast	09:00	161	0.59	126	0.61
Summer	Overcast	12:00	221	0.60	173	0.61
Summer	Overcast	18:00	79.7	0.59	62.3	0.61
Daylight factor	Daylight factor for north-facing room is 1.006%					
	Daylight factor for south-facing room is 1.078%					

Overall, the daylight-only results with the internal light shelf demonstrate that its performance was strongly dependent on the existing daylight condition. The shelf generally reduced daylight availability in both orientations, as also reflected by the lower daylight-factor values. This reduction was potentially beneficial in conditions characterized by excessive direct solar penetration, particularly in the south-facing room during clear winter midday conditions, but was less advantageous in the daylight-limited north-facing room. Moreover, reductions in average illuminance were not consistently accompanied by substantial improvements in work-plane uniformity. Therefore, the effectiveness of the investigated light-shelf configuration should be interpreted primarily in terms of its ability to modify and control daylight distribution rather than as a strategy that universally increases indoor daylight levels.

3.4. Existing Combined Daylight–Artificial Lighting Performance

Table **7** presents the existing combined daylight–artificial lighting work-plane performance of the north- and south-facing patient rooms. Compared with the daylight-only condition, the combined daylight–artificial lighting condition improved work-plane illuminance in both rooms. In the north-facing room, artificial lighting played a compensatory role by supporting the limited daylight contribution. This is reflected in the consistent use of five luminaires under all evaluated conditions.

In the south-facing room, the role of artificial lighting was more variable. Under strong daylight conditions, such as winter clear-sky periods, fewer or no luminaires were required. This indicates that daylight became the dominant source of illumination during these periods. However, the work-plane uniformity values show that combined lighting did not fully solve the problem of uneven distribution. In some cases, the south-facing room achieved high illuminance values, but the spatial distribution remained weak, especially when daylight was concentrated near the window zone.

Table **8** presents the existing daylight and artificial lighting performance in the visual task area. The results show that the visual task area generally performed better than the work plane in both orientations. In the north-facing room, the combined condition provided sufficient support around the patient-bed zone, with relatively stable uniformity values. In the south-facing room, the visual task area also showed strong performance in many conditions, particularly when daylight contribution was high.

Table 7: Existing daylight and artificial lighting work-plane performance of the north- and south-facing patient rooms.

Season	Sky Condition	Time	North-facing Room			South-facing Room		
			Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane	Number of Luminaires Used	Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane	Number of Luminaires Used
Winter	Clear	09:00	354	0.32	5	814	0.12	0
Winter	Clear	12:00	451	0.30	5	6283	0.054	0
Winter	Clear	18:00	232	0.36	5	199	0.46	5
Winter	Overcast	09:00	306	0.30	5	285	0.44	5
Winter	Overcast	12:00	397	0.26	5	391	0.35	5
Winter	Overcast	18:00	232	0.36	5	199	0.46	5
Summer	Clear	09:00	515	0.27	5	581	0.31	5
Summer	Clear	12:00	492	0.28	5	796	0.27	5
Summer	Clear	18:00	513	0.27	5	355	0.44	3
Summer	Overcast	09:00	480	0.23	5	487	0.30	5
Summer	Overcast	12:00	574	0.21	5	596	0.27	5
Summer	Overcast	18:00	355	0.27	5	342	0.38	5
Daylight factor	Daylight factor for north-facing room is 1.435%							
	Daylight factor for south-facing room is 1.5%							

Table 8: Existing daylight and artificial lighting visual-task-area performance of the north- and south-facing patient rooms.

Season	Sky Condition	Time	North-facing Room			South-facing Room		
			Illuminance (lx) – Visual Task Area	Uniformity (Uo) – Visual Task Area	Number of Luminaires Used	Illuminance (lx) – Visual Task Area	Uniformity (Uo) – Visual Task Area	Number of Luminaires Used
Winter	Clear	09:00	473	0.66	5	399	0.61	0
Winter	Clear	12:00	590	0.66	5	1240	0.62	0
Winter	Clear	18:00	338	0.64	5	266	0.76	5
Winter	Overcast	09:00	405	0.64	5	314	0.83	5
Winter	Overcast	12:00	487	0.63	5	372	0.83	5
Winter	Overcast	18:00	338	0.64	5	266	0.76	5
Summer	Clear	09:00	654	0.62	5	523	0.85	5
Summer	Clear	12:00	615	0.65	5	691	0.84	5
Summer	Clear	18:00	603	0.69	5	318	0.59	3
Summer	Overcast	09:00	562	0.63	5	425	0.82	5
Summer	Overcast	12:00	647	0.62	5	484	0.81	5
Summer	Overcast	18:00	449	0.64	5	345	0.83	5
Daylight factor	Daylight factor for north-facing room is 1.435%							
	Daylight factor for south-facing room is 1.5%							

Fig. (**7**) and (**8**) illustrate the spatial illuminance distribution in the north- and south-facing rooms under the existing combined daylight–artificial lighting condition for the summer overcast-sky condition at 12:00. Fig. (**7**) shows the north-facing room, where illumination is strengthened around the luminaire and patient-bed zones, while the wider room area remains less evenly illuminated. Fig. (**8**) shows the south-facing room, where daylight contribution is stronger near the window and patient-bed area, while the deeper part of the room shows a less balanced distribution. These false-colour maps complement the quantitative illuminance and uniformity results by illustrating the spatial differences between the two room configurations under the same investigated condition.

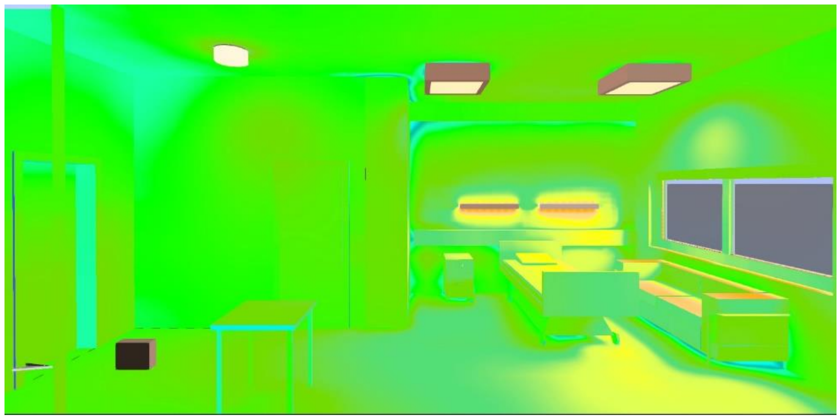

Figure 7: False-colour illuminance map of the north-facing room under summer overcast sky at 12:00 for the existing daylight and artificial lighting condition.

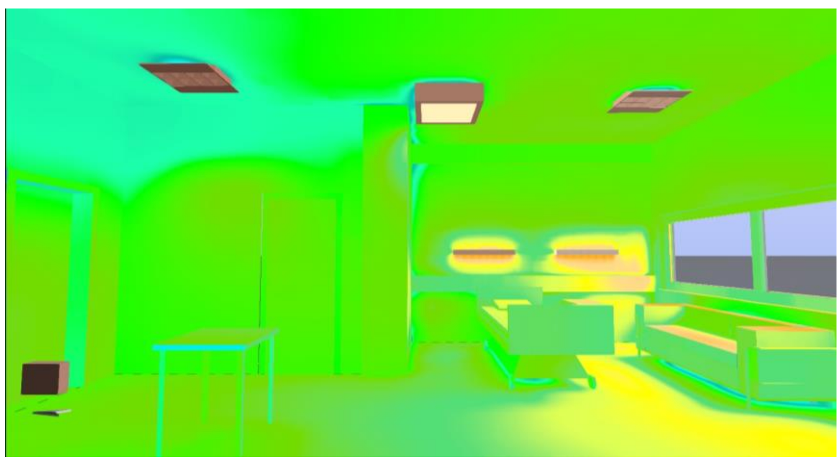

Figure 8: False-colour illuminance map of the south-facing room under summer overcast sky at 12:00 for the existing daylight and artificial lighting condition.

Overall, the existing daylight–artificial lighting results show that combining daylight and artificial lighting improves functional adequacy, especially around the visual task area. However, combining daylight and artificial lighting does not automatically create a fully balanced luminous environment. The north-facing room mainly requires artificial lighting support, while the south-facing room requires better daylight control and redistribution.

3.5. Combined Daylight–Artificial Lighting Performance with the Internal Light Shelf

Table **9** presents the work-plane performance of the north- and south-facing patient rooms after the application of the light-shelf strategy. The results show that the effect of the light shelf was strongly orientation-dependent. In the north-facing room, the light shelf did not produce a substantial improvement in work-plane performance. In several conditions, illuminance decreased compared with the existing combined condition. This suggests that, because the north-facing room already had limited daylight availability, the shelf reduced part of the useful daylight contribution rather than acting as an effective daylight-enhancement element.

Table 9: Daylight and artificial lighting work-plane performance of the north- and south-facing patient rooms with the internal light shelf.

Season	Sky Condition	Time	North-facing Room			South-facing Room		
			Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane	Number of Luminaires Used	Illuminance (lx) – Work Plane	Uniformity (Uo) – Work Plane	Number of Luminaires Used
Winter	Clear	09:00	332	0.33	5	721	0.12	0
Winter	Clear	12:00	412	0.31	5	4690	0.058	0
Winter	Clear	18:00	232	0.36	5	199	0.45	5
Winter	Overcast	09:00	288	0.31	5	275	0.47	5
Winter	Overcast	12:00	356	0.28	5	342	0.40	5
Winter	Overcast	18:00	232	0.36	5	199	0.45	5
Summer	Clear	09:00	459	0.28	5	489	0.36	5
Summer	Clear	12:00	439	0.30	5	656	0.31	5
Summer	Clear	18:00	461	0.28	5	338	0.56	5
Summer	Overcast	09:00	418	0.25	5	400	0.37	5
Summer	Overcast	12:00	488	0.23	5	475	0.33	5
Summer	Overcast	18:00	325	0.29	5	299	0.48	5
Daylight factor	Daylight factor for north-facing room is 1.006%							
	Daylight factor for south-facing room is 1.078%							

In the south-facing room, the light shelf had a different role. Since this room already received higher daylight levels, the shelf functioned more as a daylight-control and redistribution element. Although work-plane illuminance decreased in some cases, this reduction should not necessarily be interpreted as a negative outcome. In daylight-rich rooms, reducing excessive illuminance may be beneficial if it contributes to a more balanced distribution of light. However, the results also show that the shelf did not improve all conditions equally, which means that its performance cannot be assumed to be universally positive.

Table **10** presents the visual-task-area performance after applying the light shelf. The results show that the patient-bed zone remained relatively well supported in both rooms. In the north-facing room, the visual task area maintained acceptable lighting performance in many combined conditions, but the shelf did not provide a major additional benefit. In the south-facing room, the shelf was more meaningful because it helped modify the daylight pattern in a room with stronger daylight availability. Nevertheless, its effect remained dependent on season, sky condition, and time of day.

Fig. (**9**) and (**10**) illustrate the spatial illuminance distribution after introducing the internal light shelf in both orientations under summer overcast-sky conditions at 12:00. Because the same number of luminaires was operating in the corresponding baseline and light-shelf conditions, these figures provide a consistent visual comparison of the resulting lighting distribution. Fig. (**9**) shows relatively limited changes in the north-facing room after the shelf was introduced, consistent with its limited effectiveness under daylight-limited conditions. In contrast, Fig. (**10**) shows more noticeable changes in the spatial illuminance pattern of the south-facing room, particularly in relation to the window and patient-bed zones. This observation supports the interpretation that the investigated shelf was more relevant for modifying and controlling daylight distribution in the south-facing room than for enhancing daylight availability in the north-facing room. These visual observations are interpreted together with the quantitative illuminance and uniformity results and should not be considered independent evidence of increased daylight penetration.

Table 10: Daylight and artificial lighting visual-task-area performance of the north- and south-facing patient rooms with the internal light shelf.

Season	Sky Condition	Time	North-facing Room			South-facing Room		
			Illuminance (lx) – Visual Task Area	Uniformity (Uo) – Visual Task Area	Number of Luminaires Used	Illuminance (lx) – Visual Task Area	Uniformity (Uo) – Visual Task Area	Number of Luminaires Used
Winter	Clear	09:00	444	0.66	5	348	0.64	0
Winter	Clear	12:00	536	0.66	5	1112	0.62	0
Winter	Clear	18:00	339	0.64	5	266	0.76	5
Winter	Overcast	09:00	387	0.65	5	310	0.81	5
Winter	Overcast	12:00	446	0.65	5	358	0.83	5
Winter	Overcast	18:00	339	0.64	5	266	0.76	5
Summer	Clear	09:00	580	0.64	5	494	0.86	5
Summer	Clear	12:00	552	0.66	5	628	0.86	5
Summer	Clear	18:00	548	0.70	5	280	0.59	5
Summer	Overcast	09:00	500	0.65	5	404	0.84	5
Summer	Overcast	12:00	560	0.65	5	450	0.84	5
Summer	Overcast	18:00	419	0.65	5	333	0.83	5
Daylight factor	Daylight factor for north-facing room is 1.006%							
	Daylight factor for south-facing room is 1.078%							

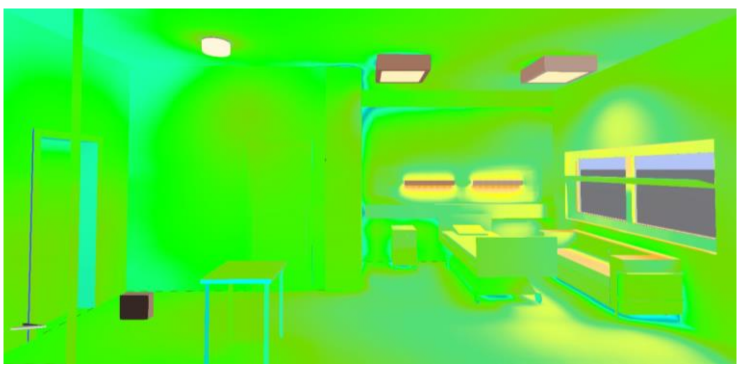

Figure 9: False-colour illuminance map of the north-facing room under summer overcast sky at 12:00 for the daylight and artificial lighting condition with the internal light shelf.

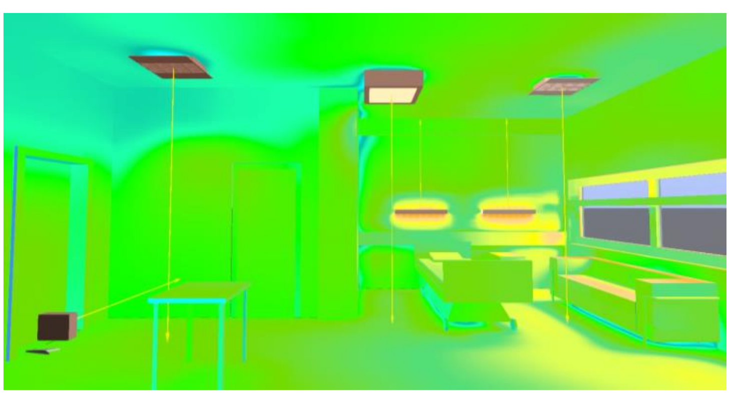

Figure 10: False-colour illuminance map of the south-facing room under summer overcast sky at 12:00 for the daylight and artificial lighting condition with the internal light shelf.

The daylight factor values after applying the light shelf also decreased in both orientations. This indicates that the shelf reduced part of the direct daylight contribution. However, this reduction should not be evaluated only as a loss of daylight quantity. The purpose of the light shelf was not only to increase illuminance, but also to influence daylight distribution and support spatial balance. Therefore, the effectiveness of the light shelf should be judged through the combined interpretation of illuminance and uniformity rather than daylight factor or illuminance alone.

3.6. Overall Comparative Assessment

The comparative assessment demonstrates that the daylight-only and combined daylight–artificial lighting analyses provide complementary information on the performance of the investigated internal light shelf. The daylight-only comparison isolates the optical effect of the shelf on daylight availability and spatial uniformity, whereas the combined comparison shows how the modified daylight contribution affects the resulting lighting service when artificial lighting is introduced where required. Accordingly, the shelf was evaluated in terms of changes in average illuminance, spatial uniformity, daylight factor, and, under combined conditions, the number of operating luminaires.

To quantify the magnitude of the light-shelf effect, each shelf condition was compared with its corresponding baseline condition without the shelf under the same orientation, season, sky condition, time, lighting mode, and evaluation area. Because a reduction in illuminance may represent either beneficial moderation of excessive daylight or undesirable loss of useful daylight depending on the baseline condition, the results are expressed as percentage changes rather than percentage improvements. The relative change in average illuminance was calculated using Equation (2):

$$\Delta E_{\mathrm{m}}\,(\%) = [(\mathrm{E_m,shelf} - \mathrm{E_m,base}) \,/\, \mathrm{E_m,base}] \times 100 \quad (2)$$

where E_m,shelf and E_m,base represent the average illuminance values with and without the internal light shelf, respectively. Conditions with zero baseline daylight illuminance were excluded from percentage-change calculations. Changes in uniformity were expressed as absolute differences using Equation (3):

$$\Delta \mathrm{U_o} = \mathrm{U_o,shelf} - \mathrm{U_o,base} \quad (3)$$

Positive values indicate improved spatial uniformity and negative values indicate reduced uniformity. Absolute rather than relative changes were emphasized for U_o, because percentage changes can appear disproportionately large when the baseline uniformity is very low.

As shown in Table **11**, the internal light shelf consistently reduced daylight availability in both orientations. In the north-facing room, average work-plane illuminance decreased by approximately 22.1% and visual-task-area illuminance by approximately 25.3%. The daylight factor also decreased by 29.9%, from 1.435% to 1.006%. Although some improvement in spatial uniformity was observed, particularly within the visual task area, this improvement occurred at the expense of useful daylight in a room that was already daylight limited. Consequently, the investigated fixed shelf provided limited practical benefit for the north-facing configuration.

In the south-facing room, average work-plane illuminance decreased by approximately 21.7% and visual-task-area illuminance by approximately 18.0%, while daylight factor decreased by 28.1%, from 1.500% to 1.078%. Unlike the north-facing room, however, this reduction occurred in a space with substantially greater and more variable daylight availability. Under winter clear-sky conditions at 12:00, work-plane illuminance decreased from 6283 to 4690 lx (−25.4%), while task-area illuminance decreased from 1240 to 1112 lx (−10.3%). The shelf therefore substantially moderated excessive daylight while preserving a high daylight contribution at the patient-bed zone. However, work-plane uniformity improved only from 0.054 to 0.058, indicating that the pronounced spatial imbalance was not resolved. The practical significance of the work-plane illuminance reduction, however, depended on its relation to the adopted 100 lx general-lighting criterion. In the daylight-limited north-facing room, further reductions represented a loss of useful daylight when illuminance was already close to or below this criterion, whereas under high-daylight south-facing conditions, illuminance could remain well above 100 lx after shelf introduction, indicating moderation of excessive daylight rather than loss of basic general-lighting adequacy.

Table 11: Quantified effect of the internal light shelf on daylight-only performance relative to the corresponding baseline conditions.

Evaluation Area	Orientation	Mean Illuminance Change	Range of Illuminance Change	Mean ΔUo	Daylight Factor Change
Work plane	North-facing	−22.1%	−25.3% to −17.8%	+0.008	1.435% → 1.006% (−29.9%)
Visual task area	North-facing	−25.3%	−28.3% to −21.5%	+0.042	
Work plane	South-facing	−21.7%	−25.4% to −11.4%	+0.002	1.500% → 1.078% (−28.1%)
Visual task area	South-facing	−18.0%	−21.0% to −10.3%	+0.024	

As shown in Table **12**, the effect of the internal light shelf remained evident under daylight and artificial lighting conditions, although its influence on total illuminance was smaller than that observed under daylight-only conditions because electric lighting compensated for part of the daylight reduction. In the north-facing room, mean combined work-plane illuminance decreased by approximately 9.9%, with individual reductions ranging from 5.9% to 15.0%. The corresponding visual-task-area illuminance decreased by an average of approximately 9.0%, with reductions ranging from 4.4% to 13.4%. These reductions were considerably smaller than the daylight-only reductions of 22.1% at the work plane and 25.3% within the visual task area, demonstrating the compensating contribution of the electric-lighting system. Importantly, work-plane illuminance under the combined conditions generally remained above the adopted 100 lx criterion, indicating that these percentage reductions did not necessarily represent a loss of basic general-lighting adequacy.

Despite the reduction in combined illuminance, spatial uniformity showed a small but consistent improvement. Mean work-plane uniformity increased by ΔU_0 = +0.015, while the visual task area showed a mean increase of ΔU_0 = +0.013. Because five luminaires remained in operation in the compared north-facing conditions both before and after introduction of the shelf, these changes primarily reflect the interaction between the modified daylight distribution and the unchanged electric-lighting contribution. Thus, for the north-facing room, the shelf did not reduce electric-lighting demand and its modest uniformity benefit was accompanied by a measurable reduction in available illuminance.

A different response was observed in the south-facing room. For the combined conditions included in the comparison, mean work-plane illuminance decreased by approximately 13.1%, with individual changes ranging from −20.3% to −3.5%. The mean reduction within the visual task area was smaller, approximately 5.9%, with a range from −11.9% to −1.3%. The smaller reduction within the patient-bed task area indicates that the shelf moderated the overall luminous contribution while retaining a comparatively larger proportion of useful illuminance in this localized zone.

Table 12: Quantified effect of the internal light shelf under daylight and artificial lighting conditions.

Evaluation Area	Orientation	Mean Illuminance Change	Range of Illuminance Change	Mean ΔU_0	Typical Number of Luminaires
Work plane	North-facing	−9.9%	−15.0% to −5.9%	+0.015	5 → 5
Visual task area	North-facing	−9.0%	−13.4% to −4.4%	+0.013	5 → 5
Work plane	South-facing	−13.1%	−20.3% to −3.5%	+0.065	Generally 5 → 5*
Visual task area	South-facing	−5.9%	−11.9% to −1.3%	+0.008	Generally 5 → 5*

Note: The summary includes only combined conditions in which electric luminaires were operating and a non-zero daylight contribution was present. Conditions with zero operating luminaires were excluded because they represent daylight-only performance. Conditions with zero daylight contribution were also excluded from the percentage-change summary because the internal light shelf has no daylight component to modify. In the south-facing room under summer clear-sky conditions at 18:00, the number of operating luminaires increased from three in the baseline condition to five after introduction of the light shelf; this case is discussed separately below.

The principal benefit in the south-facing room was observed in work-plane uniformity. Mean ΔU_0 reached +0.065, substantially greater than the corresponding improvement in the north-facing room (+0.015). The visual task area, which already exhibited relatively high uniformity under the combined baseline condition, showed only a small mean change of approximately +0.008. These findings indicate that the internal shelf was more effective in modifying the spatial distribution of the stronger south-facing daylight contribution across the wider work plane than in further improving the already favourable distribution within the localized patient-bed zone.

One condition requires separate consideration because introduction of the shelf altered the required electric-lighting operation. Under summer clear-sky conditions at 18:00 in the south-facing room, daylight-only visual-task-area illuminance decreased from 156 lx without the shelf to 126 lx with the shelf. In the baseline combined condition, three luminaires were sufficient to provide 318 lx within the visual task area. After introduction of the shelf, however, the reduced daylight contribution meant that this operating condition no longer provided the adopted 300 lx task-area criterion, and all five luminaires were therefore required. With five luminaires operating, the resulting combined task-area illuminance was 280 lx in the simulated condition. This case demonstrates that the shelf can increase dependence on electric lighting when the available daylight is already close to the lower threshold required to support the visual task.

To distinguish changes in illuminance and spatial uniformity from actual compliance with the adopted lighting criteria, the combined daylight–artificial lighting conditions were additionally classified on a pass/fail basis. A condition was considered compliant only when both the required illuminance and the corresponding uniformity criterion were simultaneously satisfied. Table **13** summarizes compliance for the general work plane and visual task area under the baseline and internal light-shelf configurations.

Table 13: Compliance summary for the combined daylight–artificial lighting scenarios.

Evaluation Area	Orientation	Baseline Condition	With Internal Light Shelf	Compliance Criteria
Work plane	North-facing	0/12 Pass	0/12 Pass	$E \geq 100$ lx and $U_0 \geq 0.40$
Work plane	South-facing	4/12 Pass	6/12 Pass	$E \geq 100$ lx and $U_0 \geq 0.40$
Visual task area	North-facing	12/12 Pass	12/12 Pass	$E \geq 300$ lx and $U_0 \geq 0.60$
Visual task area	South-facing	9/12 Pass	9/12 Pass	$E \geq 300$ lx and $U_0 \geq 0.60$

Note: A condition was classified as Pass only when both the illuminance and corresponding uniformity requirements were simultaneously satisfied. The summary includes all 12 evaluated seasonal, sky, and time conditions for each configuration.

The compliance summary demonstrates that changes in illuminance or uniformity did not necessarily translate into full compliance. In the north-facing room, none of the 12 combined work-plane conditions satisfied both criteria, either before or after introduction of the light shelf, because work-plane uniformity remained below $U_0 = 0.40$ despite adequate illuminance. In contrast, all 12 north-facing visual-task-area conditions satisfied both task-area criteria in both configurations. In the south-facing room, work-plane compliance increased from 4/12 baseline conditions to 6/12 conditions with the light shelf, whereas visual-task-area compliance remained unchanged at 9/12 conditions.

Taken together, the daylight-only and combined analyses show that the investigated shelf functioned primarily as a daylight-modulation element rather than as a daylight-enhancement strategy. It reduced daylight availability in both orientations, as also reflected by the decrease in daylight factor from 1.435% to 1.006% (−29.9%) in the north-facing room and from 1.500% to 1.078% (−28.1%) in the south-facing room. Electric lighting partially compensated for these reductions under combined conditions; however, the introduction of the shelf did not reduce the number of operating luminaires. The practical consequence nevertheless differed by orientation: in the north-facing room, the shelf reduced already limited daylight with only modest uniformity gains, whereas in the south-facing room its more relevant contribution was improved work-plane uniformity under the stronger daylight conditions.

From a design perspective, these findings indicate that a fixed internal light shelf should not be considered universally beneficial for hospital patient rooms. In daylight-limited north-facing rooms, preserving available daylight and improving artificial-lighting performance may be more appropriate. In south-facing rooms with stronger and more variable daylight exposure, a light shelf may help modify the spatial daylight distribution, although its geometry should be systematically evaluated to avoid excessive loss of useful daylight and increased electric-lighting demand during lower-daylight periods. Therefore, the suitability of a light shelf should be evaluated according to orientation, baseline daylight availability, spatial uniformity, and its interaction with the electric-lighting system.

4. Conclusion

This study evaluated daylighting performance in north- and south-facing single-patient rooms at Fırat University Hospital and examined the effect of a fixed internal light shelf under daylight-only and combined daylight–artificial lighting conditions. The results demonstrate that lighting performance in the investigated patient rooms was strongly influenced by façade orientation, daylight availability, and spatial light distribution, and that the effectiveness of the examined passive daylight-control strategy cannot be assessed solely by changes in average illuminance.

The north-facing room was characterized by limited daylight availability and greater dependence on artificial lighting, whereas the south-facing room received substantially higher daylight levels but exhibited greater spatial variation under several seasonal and sky conditions. These differences indicate different lighting-design priorities for the two investigated room configurations: preservation and supplementation of available daylight were particularly important in the north-facing room, while control and redistribution of stronger daylight were more relevant in the south-facing room.

The investigated fixed internal light shelf did not enhance overall daylight availability. Under daylight-only conditions, mean work-plane illuminance decreased by 22.1% in the north-facing room and 21.7% in the south-facing room, while daylight factor decreased from 1.435% to 1.006% (−29.9%) and from 1.500% to 1.078% (−28.1%), respectively. Nevertheless, these reductions should be interpreted together with spatial uniformity and baseline daylight conditions rather than as isolated indicators of lighting performance. In the daylight-limited north-facing room, the shelf provided limited practical benefit, as the reduction in available daylight was accompanied by only modest improvement in spatial uniformity.

A different response was observed in the south-facing room. Although the shelf also reduced daylight availability, changes in spatial uniformity were more evident in the south-facing room, particularly across the work plane. Under combined daylight–artificial lighting conditions, mean work-plane uniformity increased by ΔU_0 = +0.015 in the north-facing room and by +0.065 in the south-facing room. However, these improvements in mean uniformity should not be interpreted as equivalent to compliance. In the north-facing room, none of the evaluated combined work-plane conditions satisfied the adopted room-wide criterion because U_0 remained below 0.40, despite adequate illuminance. By contrast, all north-facing visual-task-area conditions satisfied both the illuminance and uniformity requirements. In the south-facing room, work-plane compliance increased from 4/12 to 6/12 conditions after introduction of the shelf, while visual-task-area compliance remained unchanged at 9/12 conditions.

Artificial lighting partially compensated for the reductions in daylight contribution, but the shelf did not provide a systematic reduction in luminaire use. In one lower-daylight condition in the south-facing room, introduction of the shelf increased the number of operating luminaires from three to five. This result demonstrates that the investigated light shelf could increase reliance on artificial lighting when available daylight approached the required task-lighting level.

Overall, the investigated light shelf functioned primarily as a daylight-modulation strategy rather than a daylight-enhancement strategy. Its practical value was configuration- and condition-dependent: it was limited in the investigated north-facing room but more relevant for modifying the spatial distribution of the stronger daylight contribution in the south-facing room. These findings indicate that the suitability of fixed internal light shelves should be evaluated in relation to room configuration, façade orientation, baseline daylight availability, spatial uniformity, and interaction with artificial lighting rather than assuming a uniform benefit from their application. For existing hospital patient rooms with characteristics comparable to those investigated in this study, the results further emphasize the importance of considering illuminance, spatial uniformity, and artificial-lighting requirements together when evaluating daylight-control strategies.

5. Limitations

This study has several limitations that should be considered when interpreting the findings. First, the comparison between the north- and south-facing patient rooms represents a case-based assessment of two existing rooms rather than a controlled experiment in which orientation was varied while all other parameters were held constant. Although the rooms had comparable overall dimensions, they differed in window width and existing lighting configuration. Consequently, the observed differences between the two rooms should not be attributed exclusively to façade orientation, but rather to the combined influence of orientation and the existing room characteristics.

Second, the daylight simulations were conducted for two representative seasonal dates, 21 June and 21 December, at three selected times (09:00, 12:00, and 18:00) under clear- and overcast-sky conditions. These scenarios were selected to examine contrasting seasonal, temporal, and sky conditions, but they do not constitute an annual climate-based daylight assessment. Accordingly, the results characterize the investigated conditions rather than the full range of daylight performance that may occur throughout the year.

Third, only one fixed internal light-shelf configuration was investigated. The shelf was modelled with a 0.30 m interior projection, an installation height of 1.50 m above finished floor level, an upward inclination of 15°, and a reflection factor of 85%. Because light-shelf performance depends on parameters such as shelf depth, inclination, mounting position, surface reflectance, room geometry, façade orientation, and solar conditions, the investigated configuration should not be interpreted as an optimized or universally applicable solution. Further studies could evaluate alternative shelf geometries and optical properties to identify configurations better suited to different orientations and daylight conditions.

Fourth, the assessment focused primarily on horizontal illuminance, spatial uniformity, daylight factor, and the interaction between daylight and the existing artificial-lighting system. Although exceptionally high and spatially non-uniform daylight levels were identified under some conditions, particularly in the south-facing room, visual discomfort was not quantified using a view-dependent glare metric such as Daylight Glare Probability (DGP). Therefore, the reported illuminance values can indicate potentially problematic daylight exposure but cannot be interpreted as direct evidence of discomfort glare. In addition, patient comfort, circadian lighting performance, and energy consumption were not directly assessed in this study. Although the number of operating luminaires was reported under the investigated conditions, this parameter alone does not constitute an energy-performance assessment. Accordingly, no direct conclusions regarding circadian effects, patient comfort, or energy efficiency are drawn from the present results.

Finally, field verification of the baseline DIALux Evo model was performed under artificial-lighting-only conditions. This procedure supported the reliability of the baseline room geometry, surface assumptions, luminaire representation, and artificial-lighting calculations, but it did not provide direct experimental validation of the simulated daylight distribution or the proposed internal light-shelf configuration. Future work could therefore combine daylight measurements with annual climate-based simulations, glare assessment, additional room orientations and climatic conditions, and systematic testing of alternative light-shelf dimensions and configurations to provide a more comprehensive evaluation of daylight-control strategies in hospital patient rooms.

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The authors declare no conflicts of interest.

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Contributions

A.O.A.A: Conceptualization, Writing- Reviewing and Editing, Visualization, Data curation, Software A.G: Supervision, Conceptualization, Methodology, Writing- Original draft preparation.

Availability of Data and Materials

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Declaration of Generative AI Use

The authors used ChatGPT (OpenAI) for language editing and improvement of textual clarity during manuscript revision. All scientific content, simulation data, analyses, interpretations, references, and final manuscript content were reviewed and verified by the authors.

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