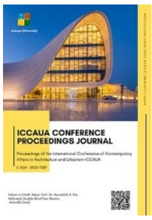

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Architectural Strategies for Circadian Health: Evidence-Based Design Recommendations for Rhythmic Daylight in Healthcare Spaces

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Abstract

The design of built environments significantly influences rhythmic daylight exposure, impacting circadian health and well-being in healthcare settings. Despite increasing awareness of the role of daylight in healthcare architecture, patient rooms often fail to provide sufficient exposure to dynamic daylight cycles, potentially disturbing circadian regulation. This study employs an iterative analytical approach and a comprehensive review of daylighting strategies to develop 38 evidence-based design recommendations tailored to patients' circadian biological needs. These recommendations focus on factors such as opening size, geometry, orientation, shading devices, and high-performance glazing, aiming to enhance daylight conditions in healthcare spaces. Additionally, the study identifies critical gaps in existing research regarding architectural features and their effects on circadian health, highlighting the need for more focused guidance on design interventions. Ultimately, this research offers insights into architectural design and circadian biology, recommending future research directions for developing comprehensive guidelines to enhance recovery and performance in healing environments.

Keywords: Rhythmic daylight; Circadian health; Design; Simulation; Healthcare settings; Light cycle; Design recommendations.

1. Introduction

1.1 Background and Context

Daylight is a fundamental natural element that is essential for human health; it is characterized by its dynamic nature and rhythmic pattern, which creates variations in intensity, color temperature, brightness, and distribution throughout the day (Heschong, L, 2021; Cristina Caramelo, 2015). These variations are crucial for physiological and psychological well-being (Mathias Adamsson, 2019), since they help to synchronize internal biological clocks and regulate essential functions like sleep-wake cycles and hormone secretion (Roenneberg et al., 2019).

Within built environments, daylight has a profound impact on health, particularly in healing environments, where studies show that well-designed daylight access in rooms improves physical and psychological well-being (Alzoubi & Al_Rqaibat, 2014; Jafarifiroozabadi et al., 2022; Ferrante & Villani, 2022). Several studies emphasize the positive impact of daylight on patient recovery rates and staff productivity, highlighting the significance of daylight and its consequences in healthcare environments.

Windows and daylight are highly valued in indoor spaces and are vital for promoting well-being (Knoop et al., 2019). The impact of natural daylight is linked to its connection to the environment, including light from windows and the views they provide (Jafarifiroozabadi et al., 2022). Healthcare facilities incorporating natural daylight achieve better health outcomes for patients (ibid), making lighting a key element of a 'healthy healing environment' (Amleh et al., 2022), especially with concepts like rhythmic daylight design and circadian health. Continuous exposure to natural light is crucial in such environments (Morales-Bravo & Navarrete-Hernandez, 2022), as it is tied to the human circadian rhythm, which influences vital physiological functions like sleep patterns, hormone secretion, and metabolism (Lockley, 2010). Furthermore, daylight has been shown to reduce pain, stress, and depression, shorten hospital stays, accelerate the healing process, and enhance visual activities for patients (Alzoubi & Al-Rqaibat, 2014; Salonen et al., 2013; Ferrante & Villani, 2022).

Emerging fields like Neuroarchitecture and Chronobiology examine the effects of circadian rhythms on health (Ezzat, 2023; Hala, 2023; Kim et al., 2023). The focus is on designing built environments that consider light's biological effects (Wirz-Justice, 2010). Neuroarchitecture investigates beneficial architectural elements, emphasizing human-centered designs (Djebbara et al., 2022; Gepshtein & Snider, 2019). Chronobiology studies biological rhythms, emphasizing the 24-hour light-dark cycle's impact on physiology (Buchanan, 2014; Wirz-Justice, 2010).

1.2 Problem Statement and Research Gap

Despite increasing awareness of the role of daylight in healthcare architecture, many traditional healthcare facilities fail to harness its full potential. Specifically, patient rooms often lack exposure to dynamic rhythmic daylight, characterized by variations in illuminance levels, intensity, direction, and color temperatures, which is essential to support healthy circadian rhythms. Insufficient exposure to dynamic, rhythmic daylight can lead to adverse health effects and disrupt natural physiological rhythms (Wirz-Justice et al., 2021; Nagare et al., 2021).

While the importance of daylight in healthcare settings is increasingly acknowledged, current architectural practices often neglect insights from fields such as Neuroarchitecture and Chronobiology, resulting in inadequate lighting conditions (Heschong, 2021). There are critical gaps in the understanding of how specific architectural elements affect circadian effective lighting.

Furthermore, there is a lack of evidence-based architectural design strategies specifically focused on the optimization of rhythmic daylight exposure in patient rooms. This highlights the need for an interdisciplinary collaboration in design research that brings together architects, neuroscientists, and healthcare professionals to develop integrated design guidelines that aim to enhance circadian health in healthcare environments.

1.3 Research Aim, Objectives, and Hypotheses

This study aims to develop evidence-based design recommendations to enhance rhythmic daylight exposure in healthcare environments, with a focus on supporting circadian health. The research is rooted in a thorough exploration of how various architectural designs influence the quality and rhythmic pattern of natural light within the patient rooms.

To effectively pursue this aim, the study pursues the following objectives: Firstly, investigate the relationships between various architectural design parameters – such as window-to-wall ratio (WWR), opening geometry, size, orientation, shading devices, and glazing type- and the quality of dynamic daylight exposure in patient rooms. Secondly, examine the potential impact of these dynamic daylight patterns, shaped by design parameters, on indicators relevant to human circadian health. And finally, translate these findings into actionable design strategies aimed at optimizing the pattern, timing, and intensity of daylight to enhance circadian alignment in healthcare settings.

The design recommendations developed through this research will specifically address deficiencies in current daylighting practices by proposing refined strategies for the positioning, sizing, and orientation of window openings to better replicate natural light rhythms.

To effectively address these objectives, this research employs a multifaceted methodology that synthesizes findings drawn from extensive scientific literature, simulation-based analyses, and in-depth iterative data evaluation. Through this triangulated approach, the research seeks to identify and validate architectural interventions that enhance rhythmic daylight quality in patient spaces.

Grounded in the identified research gap and informed by the existing literature, this research hypothesizes that careful considerations of architectural design parameters related to openings can significantly influence the pattern and quality of dynamic daylight exposure, which in turn, are positively associated with improved circadian health outcomes for occupants of healthcare facilities.

1.4 Significance and Structure of the Paper

This study carries significant implications for both architectural practice and the specialized field of healthcare design. By investigating the intersection of architectural daylighting strategies and circadian biology, this research offers valuable insights that can inform future design guidelines, tailored to enhance recovery and performance within healing environments. Moving beyond the scope of general guidelines, this research is intended to contribute to a more nuanced and sophisticated understanding of how to intentionally design healing environments grounded in humanistic, nature-inspired, and biologically focused principles.

At its core, this research aims to support the development of design strategies that harness the therapeutic potential of natural light cycles, achieved through the careful and considered design of opening characteristics. The anticipated impact includes improved patient recovery rates, reduced fatigue among healthcare staff, and an overall enhancement in occupant health and well-being.

Following the introduction, section 2 reviews existing literature on dynamic daylight exposure and its physiological and psychological impacts. It also explores recent developments in neuroscience and chronobiology that inform effective daylighting strategies. The section concludes with a critical analysis of how architectural parameters can be used to shape rhythmic light patterns. Section 3 presents the research methodology, outlining the literature synthesis and simulation-based approach employed, with the analytical techniques used for evaluating the generated data. Section 4 delivers the key findings, critically discussing the simulation results in relation to the study's objectives. Finally, Section 5 concludes the paper with a summary of key findings, acknowledges the limitations of the research, and outlines directions for future investigations.

2. Literature Review

2.1 The Importance of Exposure to Dynamic Daylight in Healthcare Settings

Numerous studies highlight the significant impact that the amount, form, and quality of daily light exposure have on both human emotional and physical well-being (Konis, 2018). In healthcare settings, providing patients with sufficient exposure to daylight at appropriate times of day and aligned with a natural rhythmic cycle is crucial for fostering recovery and maintaining a healthy environment (Riva et al., 2022). Thus, prioritizing the integration of healthy rhythmic daylight is essential for creating healing environments, rather than merely ensuring the presence of daylight (Münch et al., 2020). Additionally, the design of daylight in architecture influences how light enters and interacts within spaces, affecting mood and productivity while enhancing therapeutic qualities (Madsen, 2006). Strategic design approaches, including large windows, skylights, and thoughtful spatial arrangements, optimize daylight penetration and positively impact occupant health and well-being (Morales-Bravo & Navarrete-Hernandez, 2022; Aguilar-Carrasco et al., 2023; Alkhatatbeh & Asadi, 2021; Rockcastle & Andersen, 2014). Therefore, understanding the relationship between architectural design and natural light patterns is essential in the development of healthcare settings that truly support health and healing.

Aligned with the expanding principles of biophilic design, which emphasize the importance of human nature connections in built environments, daylighting emerges as a critical design factor in healthcare environments (Al-azzawi et al., 2024; Almusaed, 2010). Research has shown that access to natural light not only accelerates patient recovery but also significantly enhances cognitive function (Yin et al, 2023). Furthermore, the presence of both ample natural light and well-designed green spaces in healthcare settings has been consistently linked to improved attention restoration and heightened concentration, thus highlighting the numerous benefits of incorporating such elements (Richardson et al., 2013).

From an architectural perspective, incorporating naturalistic elements into design increases place attachment and contributes to a more positive experience for occupants (Cole et al., 2021) while also improving subjective well-being (Krols et al., 2022; Yasminingrat et al., 2023). These findings collectively highlight the importance of achieving a harmonious connection between architcture and nature to support health, well-being, and therapeutic efficacy in healthcare settings (Al-azzawi et al., 2024).

2.2 Advancements in Neuroscience and Chronobiology for Daylight Design

Emerging fields like Neuroarchitecture and Chronobiology examine the effects of circadian rhythms on health (Ezzat, 2023; Hala, 2023; Kim et al., 2023). The focus is on designing built environments that consider light's biological effects (Wirz-Justice, 2010). Neuroarchitecture investigates beneficial architectural elements, emphasizing human-centered designs (Djebbara et al., 2022; Gepshtein & Snider, 2019). Chronobiology studies biological rhythms, emphasizing the 24-hour light-dark cycle's impact on physiology (Buchanan, 2014; Wirz-Justice, 2010). However, current indoor environments often overlook these findings, resulting in inadequate lighting conditions (Heschong, 2021). This highlights the need for interdisciplinary integration in design research to create comprehensive design guidelines (Wirz-Justice, 2010).

2.3 Designing Lighting Openings to Create Rhythmic Daylight Patterns

Recent research emphasizes the importance of integrating scientific principles, such as circadian and rhythmic daylight design, into architectural practice to promote healthier indoor environments (Heschong, 2021; Caramelo et al., 2015). Designing daylight openings requires a shift in mindset to mimic the sun's natural cycle through thoughtfully positioned openings (Farivar & Teimourtash, 2023; Lockley, 2010). Designers must consider variables such as opening position, orientation, and size to create dynamic daylight (Farivar & Teimourtash, 2023).

A range of architectural design parameters significantly affect daylight quality, including orientation, number, distribution, shape, and dimensions of window openings (Farivar & Teimourtash, 2023; ERDEM et al., 2023). Properly distributed windows, skylights, and clerestory designs enhance lighting and visibility (William et al., 1986; Stamps & Krishnan, 2006). High clerestory windows allow deeper light penetration and views (Heschong, 2021), while multiple openings enhance vitality and perceived spaciousness (Veitch & Galasiu, 2012). However, window area restrictions in building codes often limit daylight access (Eleanor et al., 2021). The orientation and window-to-wall ratios are important for mitigating overheating (LOFTNESS, 2008). Square windows have the best dynamic daylight performance, while vertical shapes are less effective (Farivar & Teimourtash, 2023). Opening positions also influence daylight penetration patterns (Farivar & Teimourtash, 2023).

In recent years, there has been increasing recognition of the need for rhythmic daylight that mimics natural light, in addition to the concept of 'naturalistic design' (Al-azzawi et al., 2024), especially in healing environments. Research indicates that direct experiences of nature in built environments enhance health outcomes, promoting physical activity and healing (Sari et al., 2023), while indirect nature experiences, such as simulated natural environments, are linked to psychological benefits like reduced anxiety (Chang & Chen, 2005).

Additionally, incorporating side-lighting with top-lighting ensures light penetrates from multiple directions (Heschong, 2021). This multi-directional approach reduces shadows and enhances uniform illumination (Heschong, 2021). Skylights provide controlled lighting and uniform illumination, but many spaces lack adequate skylighting (Heschong, 2021). Understanding the sun's position relative to openings is also crucial for optimal daylighting performance (Heschong, 2021). Effective opening orientations can maximize natural light patterns, positively influencing health

(Browning et al., 2014; Morales-Bravo & Navarrete-Hernandez, 2022), while well-oriented openings create beneficial changes in daylight throughout the day (Salland et al., 2020; Whitsett & Fajkus, 2018).
Aligning with the principles of this research on healthy rhythmic daylight design in healthcare environments, Akande (2021) posits that for optimal health outcomes, building design must integrate key elements such as strategic orientation for natural daylight capture, thoughtful fenestration placement, effective shading to prevent overheating, and the incorporation of landscaping.
Overall, the literature review highlights the necessity of integrating opening-related parameters into architectural designs to enhance lighting quality and human well-being in healthcare spaces. These findings reinforce the need for novel, evidence-based design strategies focused on enhancing rhythmic daylight through architectural openings.

3. Research Method

This study adopts a multi-step methodological approach grounded in iterative analysis, combining insights from an in-depth literature review and simulation-based assessments. The objective is to identify and evaluate the relationships between architectural design parameters and the quality of daylight exposure, with particular attention to their impact on circadian health. Through this integrated approach, the study aims to develop evidence-based design recommendations that enhance rhythmic daylight in healthcare environments. The methodological progression ensures that these recommendations are rooted in established principles of circadian, dynamic, and healthy daylighting aligned with natural light cycles.

3.1 In-depth Literature Review and Iterative Analysis

The first step involved an extensive review of studies exploring the relationship between design parameters, daylight quality, and circadian health outcomes. With a focus on literature addressing opening-related design parameters such as window orientation, shape, and size, and their impact on daylight quality in healthcare spaces.
The review was supported by an iterative analysis of empirical findings to assess the effectiveness of existing design strategies. As a result, 38 evidence-based design recommendations were identified as potentially impactful in promoting rhythmic daylight exposure. These findings highlight the importance of dynamic daylight patterns in synchronizing human circadian rhythms and advocate for adaptive architectural strategies responsive to both seasonal and daily light variations.

3.2 Simulation-Based Analysis of Daylight Quality

The second step involves conducting a simulation-based assessment of daylight performance in three patient rooms-single, double, and quadruple at King Abdullah University Hospital (KAUH). The simulations were conducted for key seasonal days —March 21, June 21, and December 2— at 7 hour intervals across the day to capture variability in daylight patterns. Key daylight-related issues were identified for each room based on assessed daylight metrics, including daylight availability, melanopic-photopic ratios, and overall illuminance patterns.
The analyzed data indicated discrepancies in daylight quality across the three room types and configurations. revealing that certain opening configurations hindered effective rhythmic daylight exposure. This synthesis informs the subsequent design recommendations by pinpointing specific shortcomings and establishing performance benchmarks tailored to enhance daylight quality in healthcare settings.

3.3 The Formulation of New Design Recommendations

In the final step, design recommendations were formulated based on the combined findings of the literature review and simulation analysis. These design recommendations propose strategies for integrating rhythmic daylight into healthcare environments by optimizing design parameters such as opening patterns and dimensions, shape and orientation, window-to-wall ratio WWR, positioning and glazing material. The resulting guidelines are intended to support architects and healthcare planners in implementing practical and performance-based solutions for improving daylight quality and supporting circadian health in healthcare environments.

4. Results

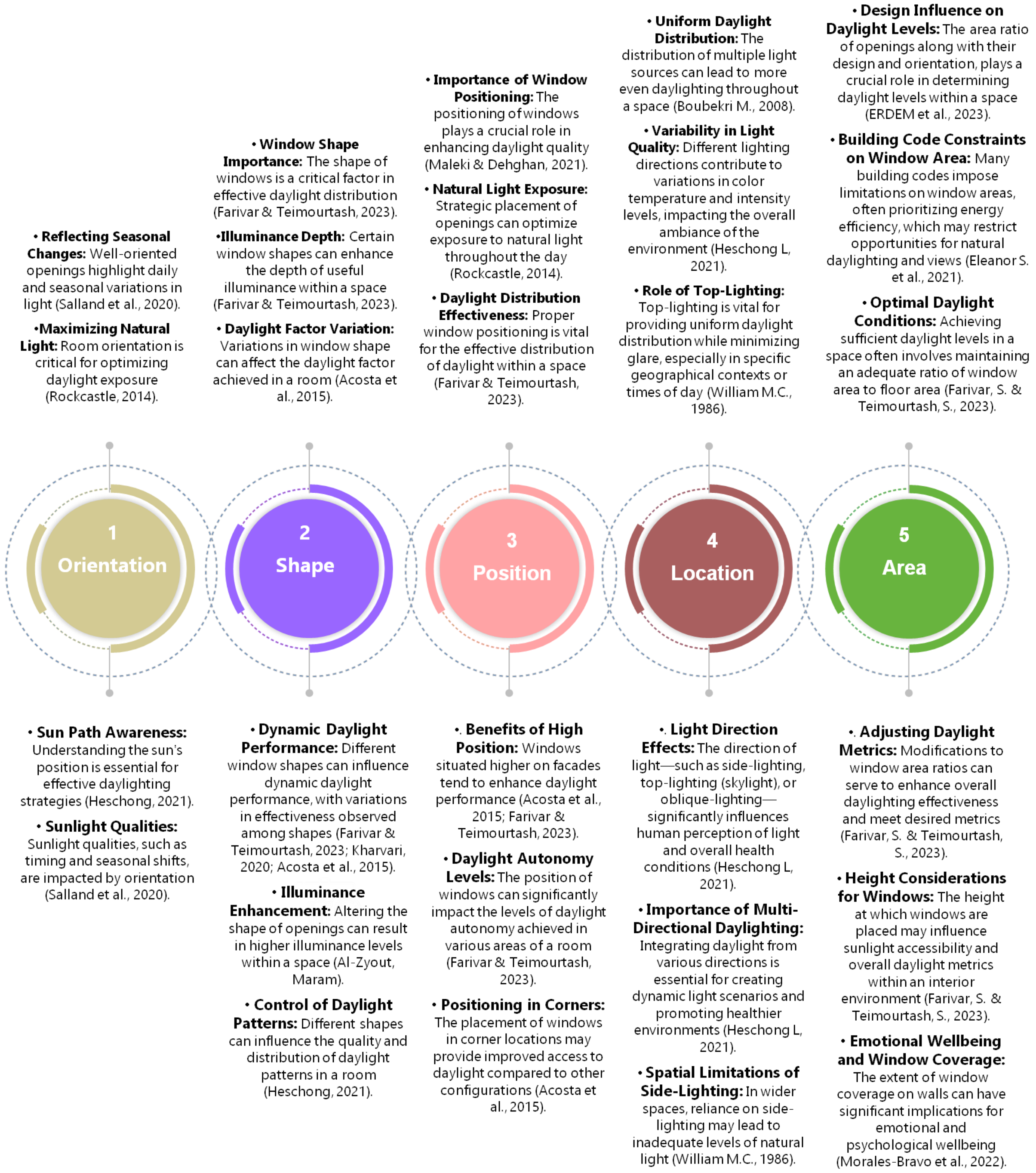
4.1 In-depth Literature Review.

This section presents findings from an extensive literature review aimed at exploring the correlations between design parameters and their effects on daylight quality, circadian health, and overall well-being. The goal is to identify how specific design strategies can be reformulated to support dynamic daylight scenarios in healthcare settings and optimize environmental outcomes for patient health.

4.1.1 Extracting Design Parameters

The first step of the review identified a set of opening-related design parameters that significantly affect daylight quality and occupant circadian health, see Figure 1. These include opening orientation, number, pattern, distribution, shape, window-to-wall ratio, position, height, dimensions, and proportions (Farivar & Teimourtash, 2023; ERDEM. et al., 2023; Morales-Bravo et al., 2022; Heschong, 2021; Eleanor. et al., 2021; Vetter. et al, 2021; Maleki & Dehghan, 2021; Kharvari, 2020; Elbiz, 2020; Salland et. al., 2020; Ko, et. al., 2020; Heschong, 2003).
The identified design parameters are related to the physical characteristics of the opening design, affecting how daylight enters interior spaces and creates visual and physiological effects. Numerous studies confirm that these design variables have both direct and indirect impacts on illuminance, daylight factor, thermal comfort, and emotional well-being.

Importantly, spatial arrangement and orientation significantly affect the distribution of light over time, supporting the creation of rhythmic light patterns. For example, square and horizontal windows enable deeper light penetration and improve visual comfort (Acosta et al., 2015). Additionally, high clerestories and multi-directional openings reduce glare and promote uniform lighting (Heschong, 2021). Studies also link window area and light variability to enhance emotional states and reduce stress, reinforcing the importance of strategic design in healing environments.



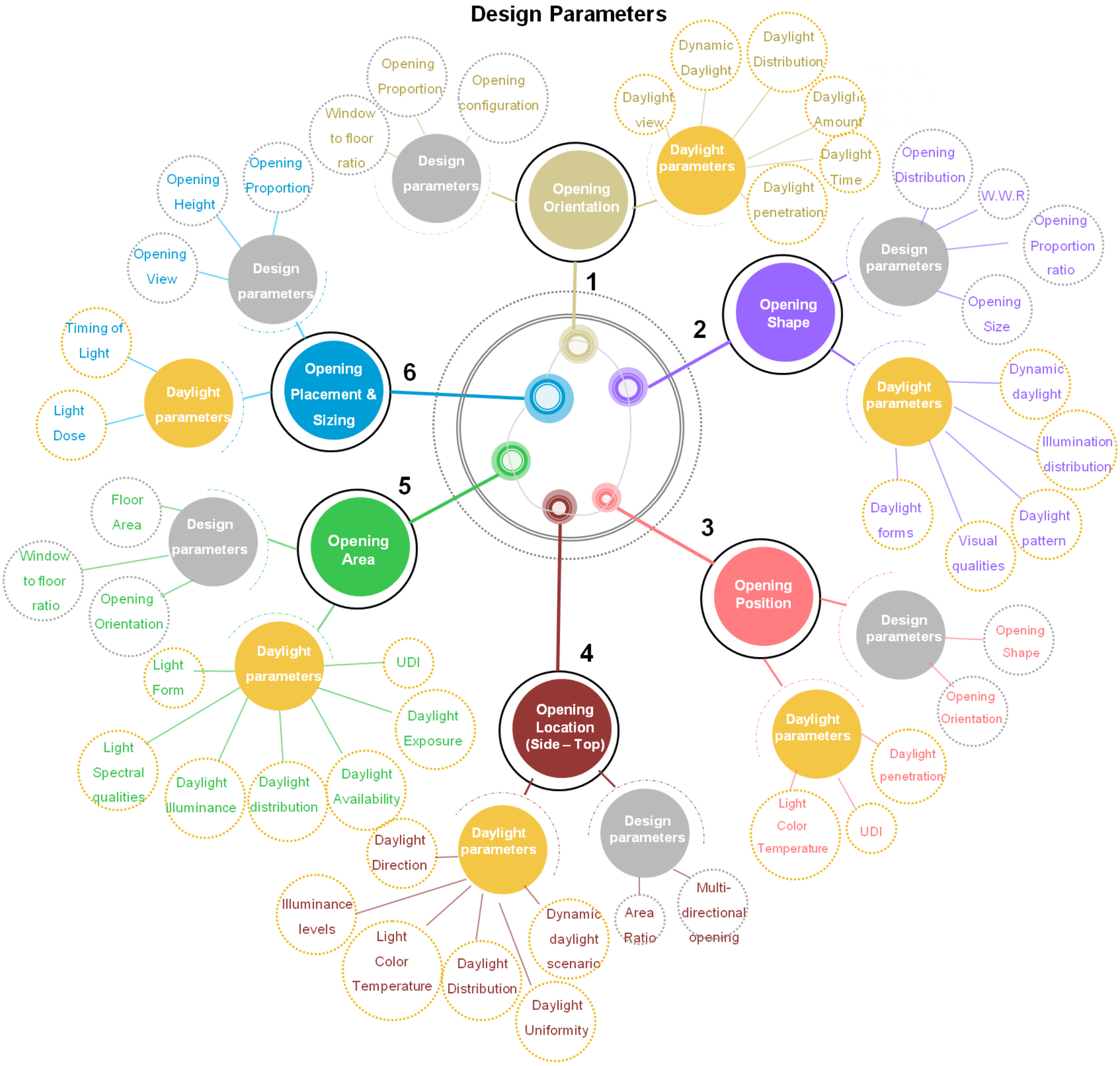
Error! Reference source not found.. Opening-related design parameters influencing daylight quality and health.

4.1.2 Correlations among design parameters.

The second step of the review examined interdependencies among the design parameters. A comprehensive analysis revealed a complex network of relationships that collectively shape daylight performance in healthcare spaces.

Error! Reference source not found. Shows six design parameters, each linked to multiple correlated variables related to design and daylight. For instance, opening orientation directly affects dynamic daylight metrics and visual comfort through optimal arrangement and proportion, while opening placement and sizing influence multi-directional daylight exposure and daylight uniformity.

Notably, the most frequently affected parameter across the other five is opening orientation, which consistently dictates the daylighting and aesthetic attributes of the space. Among these parameters, opening location presents the greatest variability; its multifaceted nature allows it to encompass a wide array of associated factors, such as multi-directional daylight, light color temperature, and daylight uniformity (Heschong, 2021). In the context of rhythmic or dynamic lighting design, both opening orientation and location stand out, as their strategic deployments facilitate diverse lighting scenarios throughout the day cycle, enhancing emotional responses and circadian regulation (Heschong, 2021). Furthermore, health is intrinsically linked to opening placement and sizing, which significantly influence circadian health through effective daylight exposure and improved visual environments (Ulrich et al., 2008; Hubalek et al., 2010).



Error! Reference source not found.. Correlations between opening-related parameters and associated performance outcomes.

4.1.3 Recommended Design Strategies.

The final step involved identifying 38 evidence-based design strategies aimed at enhancing rhythmic daylight and supporting circadian health in healthcare environments. These strategies are distributed across six main design parameters: orientation, location, position, shape, area, and sizing/placement of openings. Table 1 presents these strategies, their objectives, and sources.

Based on the assessment, approximately 25% of the strategies center around the orientation of openings, emphasizing their alignment with natural light sources; 20% focus on location and placement, ensuring optimal daylight penetration; 15% relate to shape; 20% emphasize the area of openings, stressing the necessity of adequate window sizes for effective daylighting; the remaining 20% cover various considerations related to sizing and spacing to create harmonious lighting experiences within spaces.

The objectives of these strategies can be summarized into several key points:

- Enhancing daylight entry and pattern
- Supporting occupant health through circadian alignment
- Facilitating dynamic lighting experiences
- Optimizing visual comfort by creating healthy daylit environments
- Enhancing functionality and productivity for occupants through daylight exposure

Table 1. The 38 evidence-based design strategies for enhancing rhythmic daylight and circadian health.

Design Strategy		Objective	References
1	Design spaces with windows on two or three sides.	To maximize daylight entry and provide diverse views, enhancing occupants' well-being.	Heschong L, 2021
2	Ensure window areas meet a 60% floor area ratio.	To optimize light exposure, improving overall indoor health conditions.	Farivar and Teimourtash , 2023
3	Maintain a minimum window-to-wall ratio (WWR) of 30%.	To ensure adequate daylighting and reduce reliance on artificial lighting.	A. Maleki & N. Dehghan, 2021
4	Understand UDI variation based on window orientation.	To inform design choices that enhance daylight quality and performance.	Costa et al., 2024
5	Design windows in higher positions.	To increase Useful Daylight Illuminance (UDI) and ambient light levels.	Farivar and Teimourtash, 2023
6	Increase window-to-floor area ratio while managing UDI levels.	To balance day lighting against visual comfort and glare issues.	Farivar and Teimourtash, 2023
7	Optimize daylight performance using square and high-angled windows.	To enhance natural light penetration and reduce reliance on artificial lighting.	Acosta et al., 2015 ; Phillips 2004
8	Aim for horizontal window orientations.	To improve Annual Sunlight Exposure (ASE) and ensure visual comfort in occupied spaces.	F. Kharvari, 2020
9	Design west-facing windows with a low PR value.	To create visually appealing daylight conditions while minimizing glare.	F. Kharvari, 2020
10	Ensure northern façades have a higher WFR.	To capture consistent daylight, ensuring efficient use in interior spaces.	F. Kharvari, 2020
11	Incorporate well north-east oriented openings.	To enhance morning light penetration, positively influencing occupant health.	Salland et al., 2020
12	Use well west-oriented openings.	To create engaging light transitions which contribute to aesthetic quality.	Dubois et al., 2019
13	Design openings that mimic natural light changes.	To improve physical and psychological health through enhanced daylight exposure.	Salland et al., 2020; Whitsett & Fajkus, 2018
14	Incorporate light shelves and top-lighting in classrooms.	To achieve uniform daylight distribution throughout the learning environment.	Z.S. Zomorodian et al., 2016
15	Design openings to capture sunlight at specific times.	To maximize health benefits by utilizing optimal solar exposure throughout the day.	Browning W. et al., 2014; Phillips, D., 2004
16	Use shaded south-facing windows.	To improve daylight access without compromising thermal comfort or view.	Heschong. L., 2003
17	Incorporate daylighting through roof skylights and sloped ceilings.	To enhance the quality of indirect lighting and reduce glare.	Koti. R., 2014
18	Use light shelves to reflect light toward the ceiling.	To maximize daylight distribution, enhancing room brightness and comfort.	Phillips, D., 2004

Design Strategy		Objective	References
19	Ensure optimum window sizes (height of at least 60 cm).	To create effective daylight conditions that support occupant activities.	F. Kharvari, 2020
20	Aim for a PR value between 0.1 and 0.5.	To facilitate effective daylight entry while managing visual thermal performance.	F. Kharvari, 2020
21	Utilize multiple openings for illumination.	To create a sense of spatial spaciousness and improve occupant comfort.	Veitch J. & Galasiu A., 2012
22	Employ high clerestory windows.	To bring daylight deeper into spaces, improving overall illumination.	Heschong L, 2021
23	Align window orientations with the natural light cycle.	To support circadian rhythms, enhancing overall health and wellness.	Hubalek et al., 2010; Gillette & Tischkau, 1999; Heschong. L., 2003
24	Prioritize the opening shape for daylight performance.	To influence occupant well-being and comfort through effective daylight design.	Farivar, S. & Teimourtash, S., 2023
25	Ensure the WWR of square and horizontal windows is at least 30%.	To create environments with better visual comfort and lower energy use.	A. Maleki & N. Dehghan, 2021
26	Improve visual and thermal comfort through efficient window design.	To foster occupant productivity and satisfaction within spaces.	F. Kharvari, 2020
27	Incorporate a mixed pattern of daylight forms.	To achieve uniform lighting conditions and diverse visual experiences.	Lam, William M. C., 1977
28	Avoid fully shaded south clerestory windows.	To maintain optimal daylight distribution characteristics within spaces.	Heschong. L., 2003
29	Position square and horizontal windows in the upper and central facades.	To enhance daylight access and improve overall space functionality.	A. Maleki & N. Dehghan, 2021
30	Use corner-positioned openings.	To maximize daylight autonomy and improve illumination consistency.	I. Acosta. et al., 2015
31	Maximize daylight levels by increasing skylight size.	To enhance mental health outcomes through improved sunlight exposure.	ERDEM. et al., 2023
32	Ensure a 4/3 height/width ratio for skylights.	To optimize light transmission and distribution, ensuring adequate sunlight.	Elbiz G., 2020
33	Distribute windows across multiple external walls and roofs.	To ensure a high-quality luminous environment that supports non-visual effects.	VELUX, 2013
34	Incorporate top-lighting with side-lighting openings.	To enhance daylight visibility and prevent glare while supporting activities.	VEITCH. J., 2012; Heschong L, 2021
35	Aim for direct sunlight to cover about 10% of the floor area.	To facilitate balanced daylight distribution while maintaining health benefits.	Heschong (2021)

Design Strategy		Objective	References
36	Merge different opening orientations for rhythmic daylight performance.	To create dynamic daylight characteristics throughout various times of the day.	Phillips (2004)
37	Use diffusing glass for skylights.	To produce even sunlight distribution, enhancing comfort and visual quality.	Heschong L, 2021
38	Incorporate reflective materials in skylight design.	To maximize daylight effectiveness and support occupant well-being.	ERDEM. et al., 2023

From a comprehensive perspective, these strategies reflect a growing awareness of the pivotal role that daylighting plays in enhancing healthy built environments. The insights suggest that effective daylighting not only boosts productivity and mood but also positively influences physiological health through its impact on circadian rhythms. Despite their promise, the literature reveals gaps in current research that emerge, particularly regarding the nuanced integration of design parameters that specifically cater to circadian health. Future research should explore innovative approaches to rhythmic lighting that focus mainly on natural light sources. Investigating the technology-driven design of adaptive openings that adjust in real-time based on sunlight conditions could offer a pathway to optimize circadian health. Furthermore, assessing the long-term impacts of such design strategies on occupant health outcomes would be essential for validating their effectiveness and informing best practices in the design of several environments, including homes, schools, workplaces, and healthcare facilities. By addressing these gaps, future research can significantly contribute to advancing healthy built environments that prioritize the rhythmic connection between humans and their natural surroundings.

4.2 Daylight Quality in Patients' Rooms: Simulation Results

This section presents results from simulation-based analysis of daylight performance in three patient room typologies: single, double, and quadruple occupancy at King Abdullah University Hospital (KAUH) in Irbid, Jordan. The analysis focused on the key daylight metrics, including illuminance levels, illuminance variability (rhythmicity), daylight factor (DF), daylight availability, and both melanopic and photopic light values. Analyzing these metrics reveals the overall daylight quality and specific issues in each room. The goal is to align these issues with design recommendations that create a rhythmic daylit environment that is vital for patient recovery, circadian health, and comfort.
Table 2 Summarizes the comparative performance of each prototype based on key daylight quality indicators.
Error! Reference source not found.. Overall daylight quality in the three room prototypes.

Room Type	Daylight Illuminance			Daylight Factor			Daylight Availability	M / P ratio			Overall Daylight quality – in terms of Rhythmicity and Healthiness (A comparison between the 3 Prototypes)
	21/march	21/June	21/December	21/march	21/June	21/December	Average value	21/march	21/June	21/December	
Prototype 1: *Single Room – South*	16.7 %	9.6 %	10.9 %	3.8	4.7	3.7	14.18 %	0.95	1.01	0.99	36.8 / 100
Prototype 2: *Double Room - North*	3 %	4.7 %	47.3 %	3.9	3.5	6.5	14.16 %	1.05	0.95	1.07	40.3 / 100
Prototype 3: *Quadruple Room- South*	16.2 %	39 %	67%	5.4	6.6	8.8	23.10 %	0.94	1.004	0.91	46.1 / 100

Findings indicate clear disparities in daylight quality among the prototypes. Prototype 3 (Quadruple Room - South, W.W.R: 0.71) demonstrated the best daylight conditions, achieving 46.1% quality with fewer health implications. In contrast, Prototype 1 (Single Room - South, W.W.R: 0.75) exhibited the poorest quality at 36.8%, correlating with serious health issues. Such issues include disrupted circadian rhythms, sleep disturbances, compromised immune function, delayed healing, and cognitive impairments, particularly in vulnerable populations like children. Prototype 2 (Double Room - North, W.W.R: 0.70) provided moderate daylight quality at 40.3% but indicates the need for further improvement and thoughtful design. Consequently, patients in Prototype 3 face fewer health implications than those in Prototypes 1 and 2, with Prototype 1 showing the most unfavorable conditions.
The disparities in daylight quality necessitate tailored design interventions for each room.

Table 2 Highlights significant daylight challenges, underscoring the urgent need for comprehensive design improvements for each scenario. Prototype 1's deficiencies in daylight illuminance and variability hinder a healthy lighting environment. Despite a favorable window-to-wall ratio (0.75), its illuminance levels significantly lag behind natural levels, showing insufficient exposure variability. In Prototype 2, inconsistent daylight availability limits its ability to foster a rhythmic atmosphere for patient well-being, with its north-facing orientation compromising light quality. Conversely, Prototype 3 exhibits higher illuminance values but still struggles to maintain optimal Melanopic/Photopic ratios necessary for circadian health. This suggests that even well-designed rooms may face challenges in supporting optimal circadian health due to opening designs and orientations.

Table 2. Key daylight issues observed across the room prototypes.

Room	Key Daylight Issues	Findings & Results
Room 1 (Single Room - South, W.W.R: 0.75)	**Inadequate Daylight Illuminance**	Illuminance levels range from 14 to 2101 lux in spring and 44 to 1528 lux in summer, showing significant disparities compared to natural levels—particularly low in winter.
	Low Daylight Factor (DF)	DF values predominantly fall below 4, peaking at 4 only at 9:00 a.m. on June 21, while dropping to as low as 0.5 during midday on March 21, indicating insufficient natural light levels.
	Lack of Variability in Illuminance	Illuminance variability hinders the creation of a healthy rhythmic pattern; minimal variations observed during winter highlight a stable yet inadequate lighting environment.
	Suboptimal M/P Ratio	M/P ratios from 0.95 to 1.01 across all days suggest insufficient Melanopic and Photopic light levels, negatively impacting circadian health.
Room 2 (Double Room, - North, W.W.R: 0.70)	**Limited Daylight Availability**	Daylight availability on June 21 ranged from 14% to 23%, recording the lowest percentage during afternoon. This restricts natural light exposure crucial for a rhythmic atmosphere.
	Moderate Daylight Factor (DF)	Maximum DF of 10.0 on December 21, which drops to 0.8 on June 21, indicating fluctuations in daylight conditions but lack of consistent performance overall.
	Unstable M/P Ratio	M/P ratios fluctuated between 0.69 and 1.25, with Room 2 achieving optimal 1.05 only on March 21, suggesting inconsistent daylight effects on circadian health.
Room 3 (Quadruple Room, -South, W.W.R: 0.71)	**Inconsistent Daylight Illuminance**	Although Room 3 shows higher variances (43 to 2234 lux in spring), it still experiences periods of low illuminance, particularly in winter (32 to 724 lux).
	Low Daylight Factor (DF)	DF averages 6.9, with some periods falling below recommended values, indicating that the daylight distribution is not fully meeting patient needs.
	Suboptimal M/P Ratio	M/P ratios varied but generally fell below the ideal range, with values showing potential issues in maintaining the balance necessary for optimal circadian health (averaging around 1.004).

These disparities illustrate how window orientation, size, and placement critically influence daylight quality and, by extension, occupant well-being. Design interventions are essential to overcome these limitations and create more circadian-aligned environments.

4.3 Aligning the design strategies with the daylight issues for the patients.

This section connects the literature-derived design strategies with the specific daylight issues in the three patients' rooms.

Table 3 aligns appropriate recommendations with each daylight metric and prototype, aiming to guide effective interventions for enhancing daylight performance related to circadian health. Each design recommendation presented in the table aims to address a specific issue related to a key daylight metric, ensuring holistic enhancement for the daylight scenario.

The design implications outlined in

Table 3 can be categorized to provide targeted strategies for each patient room based on their unique daylight challenges. For Prototype 1, with its south-facing orientation, the emphasis is on increasing the opening size and exploring operable windows with adjustable shading systems to improve the illuminance range and variance throughout different seasons. Prototype 2, which faces north, benefits from proposals that focus on enhancing the existing openings through the addition of sidelights or transom windows and integrating top skylights to optimize daylight availability. This room's unique orientation suggests that variable glazing techniques could also enhance daylight quality. Lastly, for Prototype 3, similar to Prototype 1, suggestions revolve around expanding the size of operable windows but also incorporate the idea of utilizing clerestory windows to capture sunlight strategically and increase the overall daylight factor.

Table 3. Recommended design strategies for each room types and daylight metrics.

Daylight Metric	**Design Recommendations**		
	Room 1 (South-facing, WWR 0.75)	**Room 2** (North-facing,WWR 0.7)	**Room 3** (South-facing, WWR 0.75)
Illuminance (Lux)	Increase the opening size to maximize the illuminance range, especially during winter when the sunlight is less intense.	Consider adding sidelights or transom windows to the existing openings to enhance the illuminance range throughout the year.	Introduce larger operable windows to enhance daylight ingress and maximize illuminance, particularly in spring and summer.
Illuminance Variance	Utilize operable windows with adjustable shading systems to allow for control over light entering the space, thereby increasing illuminance variance.	Integrate larger openings combined with variable glazing techniques (e.g., fritted glass) that can adjust light levels throughout different seasons.	Implement a series of smaller windows or clerestory windows in varying heights to create more light variability and enhance the overall daylight experience.
Daylight Factor (DF)	Consider increasing the window-to-wall ratio (WWR) by adding additional vertical openings to improve the overall DF.	Modify the existing opening by enlarging them or adding higher clerestory windows to increase the DF, particularly during low light seasons.	Optimize the orientation of the existing windows to capture more direct sunlight throughout the day, improving DF values.
Daylight Availability	Reassess the placement of the openings to ensure they are not blocked by external obstructions; potentially relocate them higher on the wall or add sidelights.	Implement top-hung skylights or roof monitors that can improve availability by directing light deeper into the room, especially during cloudy days.	Design ribbed or patterned openings that allow for diffuse daylight to be introduced into the space more evenly, enhancing daylight availability.
M/P Ratio	Increase the height of the openings or introduce a combination of vertical and horizontal openings to optimize the daylight-to-pedestrian count, thus enhancing the M/P ratio.	Experiment with rectangular or circular window shapes in combination with varying sizes to achieve a better balance in the M/P ratio throughout the day.	Distribute smaller windows evenly along the wall to ensure balanced light entry, thus maximizing the M/P ratio and reducing glare.

Collectively, these design implications provide a comprehensive approach tailored to each room's specific needs while promoting a harmonious integration of rhythmic daylight into the patient environment, thereby fostering improved circadian health, well-being, and comfort for occupants.

5. Discussion

The findings of this study establish a significant relationship between daylight quality and circadian health within patient rooms, with clear performance disparities among the three evaluated prototypes. Prototype 3 achieved the highest daylight quality at 46.1%, indicating that intentional design can effectively mitigate health risks associated with insufficient light exposure, such as disruptions in circadian rhythms and cognitive functioning. In contrast, Prototype 1, despite its favorable window-to-wall ratio (WWR) of .75, recorded the lowest quality at 36.8%. This highlights the critical role of opening design and orientation in achieving optimal daylight conditions.
Furthermore, the study reveals how various design parameters—specifically orientation, size, and distribution of windows—affect daylight performance and, consequently, patient well-being. The enhanced daylight metrics observed in south-facing rooms support prior research from Farivar and Teimourtash's (2023), which emphasizes the importance of larger window areas for optimal natural light penetration. Similarly, A. Maleki & N. Dehghan (2021) argue that optimal WWR values—particularly for square and horizontal windows—should exceed 30% to support effective daylighting. The performance of Prototype 3 (WWR = 0.75) aligns with this threshold, validating the role of large, well-oriented openings in maximizing Useful Daylight Illuminance (UDI) and overall light quality.
Seasonal variation in daylight performance further highlighted the importance of dynamic design. The study aligns with Costa et al. (2024), who noted that daylight metrics fluctuate throughout the year, requiring architectural responses that accommodate seasonal shifts in sun position and intensity. In this context, window orientation and design adaptability emerge as key factors in maintaining consistent light exposure and supporting circadian stability.
This study also confirms that window shape and height influence Daylight Factor (DF), as suggested by Acosta et al. (2015) and Phillips (2004), with square and high-positioned openings outperforming vertical designs. The high DF recorded in Prototype 3—featuring south-facing square windows and a high window-to-floor ratio—illustrates this connection, reinforcing best practices in daylight design.
Additionally, the alignment of specific design strategies with the identified daylight challenges illustrates the potential for targeted improvements in patient environments. Strategies such as increasing operable opening sizes in Prototype 1 and incorporating clerestory windows in Prototype 3 are direct responses to unique daylight deficits, therefore promoting circadian health. This approach advocates for a systematic integration of evidence-based design principles that prioritize rhythmic daylighting as a fundamental component of healthcare architecture.
The implications of this study extend to future research; The study supports the need for innovative strategies that incorporate adaptive design technologies capable of responding to changing natural light conditions. Exploring the long-term health outcomes associated with rhythmic daylight exposure will further validate the effectiveness of these design interventions in enhancing patient well-being.
Overall, the integrated findings illustrate the complex interplay between architectural design, daylight quality, and occupant circadian health. By optimizing window characteristics and spatial configurations, healthcare environments can be transformed into healing-oriented spaces that align with human biological rhythms. These insights support a shift toward evidence-based, human-centered design in healthcare architecture.

6. Conclusion

This research presents a comprehensive set of design recommendations aimed at enhancing the integration of rhythmic daylight in healthcare spaces, particularly within patient rooms. Building upon simulation-based analyses and prior research, this study provides a foundation for the practical implementation of rhythmic daylighting principles in healthcare architecture.
The proposed design strategies address both the quantitative and qualitative dimensions of natural light, targeting not only the optimization of natural light entry but also the creation of dynamic, health-promoting environments that enhance patient circadian health, comfort, and recovery. These strategies address the urgent need for healthier spaces conducive to healing, particularly within modern healthcare facilities. A detailed analysis of such facilities underscores the sensitivity of human circadian and alerting responses to natural cyclic light, offering a framework to inform lighting design and the application of light cycles. The challenge of optimizing light exposure stemmed from the lack of a universally accepted scientific framework to evaluate light's efficacy in eliciting physiological responses. However, decades of scientific research provide a basis for research-based recommendations and expert consensus on appropriate light exposure throughout the day and night.
For future research, it is highly needed to explore the beneficial and adverse effects of the natural rhythmic daylight cycle on human physiology, cognition, behavior, and health. Subsequent studies should aim to establish practical guidelines and design recommendations tailored to architects, designers, and researchers. This work will deepen our understanding of creating and assessing optimal rhythmic daylight design in real architectural contexts, ultimately enhancing both the design process and the environments intended to support human health and performance.
In conclusion, integrating rhythmic daylight principles into architectural design is imperative for creating healthier, more responsive and human centered environments. This research contributes to the growing body of evidence supporting the reconnection of built environments with natural light cycles, reinforcing the critical synergy between design innovation and circadian health. .

Declaration of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[Huisman, E. R. C. M., Morales, E., Hoof, J., &Kort, H. (2012). Healing environment: A review of the impact of physical environmental factors on users. *Building and Environment, 58*, 70-80. https://doi.org/10.1016/j.buildenv.2012.06.016

Acosta, I., Munoz, C., Campano, M. A., & Navarro, J. (2015). Analysis of daylight factors and energy savings allowed by windows under overcast sky conditions. *Renewable Energy, 77*, 194-207.

Adamsson, Mathias & Petersson, Mikael & Aries, Myriam. . (2019). A holistic approach for a natural light variation experience: a pilot study of a practical application for office lighting. Journal of Physics: *Conference Series*. 1343. https://doi.org/012163. 10.1088/1742-6596/1343/1/012163

Aguilar-Carrasco, M., Acosta, I., & Domínguez-Amarillo, S. (2023). CircaLight, a new circadian light assessment tool for Grasshopper environment: Development and reliability testing. *Journal of Building Engineering, 71*, 106527. https://doi.org/10.1016/j.jobe.2023.106527

Akande, O. (2021). Urbanization, Housing Quality and Health: Towards a Redirection for Housing Provision in Nigeria. *Journal of Contemporary Urban Affairs*, *5*(1), 35–46. https://doi.org/10.25034/ijcua.2021.v5n1-3

Al-azzawi, S., İnalhan, G., & Al-azzawi, N. (2024). The Relationship Between Sense of Place and Nature-based Architectural Beauty: A Comparative Case Study. Journal of Contemporary Urban Affairs, 8(1), 102-119. https://doi.org/10.25034/ijcua.2024.v8n1-6

Alkhatatbeh, B. J., & Asadi, S. (2021). Role of architectural design in creating circadian-effective interior settings. *Energies, 14*, 6731. https://doi.org/10.3390/en14206731

Almusaed, A. (2010). Biophilic and bioclimatic architecture: Analytical therapy for the next generation of passive sustainable architecture. Springer Science & Business Media

Al-Rqaibat, Sana'a and Alzyout, Maram, (2024). Capturing the Essence of Rhythmic Daylight to Benefit Students' Circadian Health: A Simulation-Based Approach in Educational Spaces. Available at SSRN: https://ssrn.com/abstract=5041726 or http://dx.doi.org/10.2139/ssrn.5041726

Alzoubi, H., & Al_Rqaibat, S. (2014). The effect of hospital design on indoor daylight quality in children's section in King Abdullah University Hospital, Jordan. *Sustainable Cities and Society, 14*, 10.1016/j.scs.2014.08.008

Al-Zyout, Maram. (2024). Introducing New Design Strategies for Daylight to Create Healthier Educational Environments: Merging Neuro-Architecture and Rhythmic Light Pattern[master's thesis]. Jordan University of Science and Technology.

Amen, Mustafa Aziz. 2024. "AI-Driven Sustainable Habitat Design: Key Policy Frameworks and Ethical Safeguards." Smart Design Policies 1(1):23–32. doi:10.38027/SMART-V1N1-4.

Amleh, D., Halawani, A., & Haj Hussein, M. (2022). Simulation-based study for healing environment in intensive care units: Enhancing daylight and access to view, optimizing an ICU room in temperate climate, the case study of Palestine. *Ain Shams Engineering Journal, 14*, 101868. https://doi.org/10.1016/j.asej.2022.101868

Aristizabal, S., Byun, K., Porter, P., Clements, N., Campanella, C., Li, L., Mullan, A., Ly, S., Senerat, A., Nenadic, I., Browning, W., Loftness, V., & Bauer, B. (2021). Biophilic office design: Exploring the impact of a multisensory approach on human well-being. *Journal of Environmental Psychology, 77*, 101682. https://doi.org/10.1016/j.jenvp.2021.101682

Ashdown, Ian & Eng, P. (2015). The Kruithof Curve: A Pleasing Solution. *Wordpress blog.*

Beemer, C. J., Stearns-Yoder, K. A., Schuldt, S. J., Kinney, K. A., Lowry, C. A., Postolache, T. T., Brenner, L. A., & Hoisington, A. J. (2021). A brief review on the mental health for select elements of the built environment. *Indoor Built Environment, 30*, 152–165.

Caramelo Gomes, Cristina & Preto, Sandra. . (2015). Should the Light be Static or Dynamic?. *Procedia Manufacturing. 3.* 4635-4642. 10.1016/j.promfg.2015.07.550

Chang, C.-Y., & Chen, P.-K. (2005). Human Response to Window Views and Indoor Plants in the Workplace. HORTSCIENCE, 40(5), 1354–1359. https://doi.org/10.21273/hortsci.40.5.1354

Cole, L. B., Coleman, S., & Scannell, L. (2021). Place attachment in green buildings: Making the connections. Journal of Environmental Psychology, 74, https://doi.org/10.1016/j.jenvp.2021.101558

Costa, J., Amorim, C., &Cronemberger, J. (2024). Electrochromic glazing and evaluation of visual and non-visual effects of daylight: Simulation studies for Brasilia – Brazil. *Journal of Daylighting, 11*, 1-22. https://doi.org/10.15627/jd.2024.1

Dai, Q., Huang, Y., Hao, L., Lin, Y., & Chen, K. (2018). Spatial and spectral illumination design for energy-efficient circadian lighting. *Building and Environment*. https://doi.org/10.1016/j.buildenv.2018.10.004

Ezpeleta, S., Orduna-Hospital, E., Aporta, J., Luesma, M. J., & Sánchez-Cano, A. (2021). Evaluation of visual and non-visual levels of daylight from spectral power distributions considering orientation and seasonality. *Applied Sciences, 11*, 5996. https://doi.org/10.3390/app11135996

Ezpeleta, S., Orduna-Hospital, E., Solana, T., Aporta, J., Pinilla, I., & Sánchez-Cano, A. (2021). Analysis of photopic and melanopic lighting in teaching environments. *Buildings, 11*, 439.

Farivar, S., &Teimourtash, S. , (2023). Impact of window design on dynamic daylight performance in an office building in Iran. *Journal of Daylighting, 10*, 31-44.

Ferrante, T., & Villani, T. (2022). Pre-occupancy evaluation in hospital rooms for efficient use of natural light—Improved proposals. *Buildings, 12*, 2145. https://doi.org/10.3390/buildings12122145
Haruna, P. B., Zubairu, S., Olagunju, R. E., & Akande, O. K. (2023). Liveability Considerations: Towards Designing Sustainable Public Housing in Niger State, Nigeria. Journal of Contemporary Urban Affairs, 7(2), 262–278. https://doi.org/10.25034/ijcua.2023.v7n2-16
Heschong, L. Visual Delight in Architecture: Daylight, Vision, and View (1st ed.). (2021). *Routledge*. https://doi.org/10.4324/9781003097594
Hoof, J., Aarts, M., Rense, C. G., &Schoutens, A. (2009). Ambient bright light in dementia: Effects on behaviour and circadian rhythmicity. *Building and Environment, 44*, 146-155. https://doi.org/10.1016/j.buildenv.2008.02.005
Jafarifiroozabadi, R., Joseph, A., Bridges, W., & Franks, A. (2022). The impact of daylight and window views on length of stay among patients with heart disease: A retrospective study in a cardiac intensive care unit. *Journal of Intensive Medicine, 3*. https://doi.org/10.1016/j.jointm.2022.11.002
Knoop, M., Stefani, O., Bueno, B., Matusiak, B., Hobday, R., Wirz-Justice, A., Martiny, K., Kantermann, T., Aarts, M. P. J., Zemmouri, N., Appelt, S., & Norton, B. (2019). Daylight: What makes the difference? *Lighting Research & Technology, 52*, 147715351986975. https://doi.org/10.1177/1477153519869758
Konis, Kyle. (2018). Field evaluation of the circadian stimulus potential of daylit and non-daylit spaces in dementia care facilities. *Building and Environment. 135.* https://doi.org/10.1016/j.buildenv.2018.03.007
Krols, J., Aerts, R., Vanlessen, N., Dewaelheyns, V., Dujardin, S., & Somers, B. (2022). Residential green space, gardening, and subjective well-being: A cross-sectional study of garden owners in northern Belgium. Landscape and Urban Planning, 223, 104414. https://doi.org/10.1016/j.landurbplan.2022.104414
Lockley, S. W. (2008). Influence of light on circadian rhythmicity in humans. In L. R. Squire (Ed.), *Encyclopedia of Neuroscience*. Oxford, UK.
Lockley, S. W. (2010). Circadian rhythms: Influence of light in humans. *Encyclopedia of Neuroscience, 2*, 971-988. https://doi.org/10.1016/B978-008045046-9.01619-3
Madsen, M. (2006). Light-zone(s): as concept and tool: an architectural approach to the assessment of spatial and form-giving characteristics of daylight. *ARCC/EAAE*.
Maleki, A., & Dehghan, N. (2021). Optimum characteristics of windows in an office building in Isfahan for saving energy and preserving visual comfort. *Journal of Daylighting, 8*, 222-238.
Mardaljevic, J., Andersen, M., Roy, N., & Christoffersen, J. (2013). A framework for predicting the non-visual effects of daylight - Part II: The simulation model. *Lighting Research and Technology, 46*, 388-406. https://doi.org/10.1177/1477153513491873
Morales-Bravo, J., & Navarrete-Hernandez, P. (2022). Enlightening well-being in the home: The impact of natural light design on perceived happiness and sadness in residential spaces. *Building and Environment, 223*, 109317. https://doi.org/10.1016/j.buildenv.2022.109317
Münch, M., Wirz-Justice, A., Brown, S., Kantermann, T., Martiny, K., Stefani, O., Vetter, C., Wright, K., Wulff, K., & Skene, D. (2020). The role of daylight for humans: Gaps in current knowledge. *Clocks & Sleep, 2*, 61-85.
Nagare, R.; Woo, M.; Macnaughton, P.; Plitnick, B.; Tinianov, B.; Figueiro, M. (2021). Access to daylight at home improves circadian alignment, sleep, and mental health in healthy adults: A crossover study. *J. Environ. Res. Public Health18.* https://doi.org/189980./2021
Nilsson, D.-E., & Smolka, J. (2021). Quantifying biologically essential aspects of environmental light. *Journal of the Royal Society Interface, 18*, 20210184. https://doi.org/10.1098/rsif.2021.0184
Nwachukwu, L., Rodrigues, L., &Kiamba, L. (2023). Enabling Private Investment in Affordable Housing in Nigeria: Lessons from the Experience of the Millard Fuller Foundation Projects in Nasarawa State. Journal of Risk and Financial Management, 16(9), 411. https://doi.org/10.3390/jrfm16090411
Phillips, D. (2004). *Daylighting: Natural light in architecture*. Elsevier. ISBN 0 7506 6323 5.
Richardson, E., Pearce, J., Mitchell, R., & Kingham, S. (2013). Role of physical activity in the relationship between urban green space and health. Public Health, 127(4), 318–324. https://doi.org/10.1016/j.puhe.2013.01.004
Riva, A., Rebecchi, A., Capolongo, S., & Gola, M. (2022). Can homes affect well-being? A scoping review among housing conditions, indoor environmental quality, and mental health outcomes. *International Journal of Environmental Research and Public Health, 19*(23), 15975. https://doi.org/10.3390/ijerph192315975
Rockcastle, S., & Andersen, M. (2014). Measuring the dynamics of contrast and daylight variability in architecture: A proof of concept methodology. *Building and Environment, 81*, 320-333. https://doi.org/10.1016/j.buildenv.2014.06.012
Roenneberg T, Winnebeck EC and Klerman EB. (2019). Daylight Saving Time and Artificial Time Zones – A Battle Between Biological and Social Times. *Front. Physiol*.10:944. doi: https://doi.org/10.3389/fphys.2019.00944
Salland, I., Pajuste, M., & Hansen, E. (2020). Sunlight qualities in dwellings - A new computational analysis tool. In *Proceedings of the eCAADe Conference* (pp. 333-342).
Salonen, H., Lahtinen, M., Lappalainen, S., Nevala, N., Knibbs, L. D., Morawska, L., &Reijula, K. (2013). Physical characteristics of the indoor environment that affect health and well-being in healthcare facilities: A review. *Intelligent Building International, 5*(1), 3-25. https://doi.org/10.1080/17508975.2013.764838
Sari, M., Fatimah, I. S., Pratiwi, P. I., & Sulistyantara, B. (2023). Psychological Effects of Walking and Relaxed Sitting in Urban Greenspaces During Post-pandemic: A Case Study in Bogor City, Indonesia. Journal of Contemporary Urban Affairs, 7(1), 1–17. https://doi.org/10.25034/ijcua.2023.v7n1-1
Schreuder, D. (2008). Outdoor lighting: Physics, vision and perception. Springer, Dordrecht. ISBN: 978-1-4020-8601-4. https://doi.org/10.1007/978-1-4020-8602-1

Solemma. (2020). *Adaptive lighting for alertness (ALFA)* [Software]. Solemma, LLC. https://www.solemma.com/Alfa.html

Song, H., Jiang, W., & Cui, P. (2022). A study on nonvisual effects of natural light environment in a maternity ward of a hospital in a cold area. *BioMed Research International,* Article 8608892. https://doi.org/10.1155/2022/8608892

Van Bommel, Wout. (2016). Kruithof curve. *10.1007/978-3-642-27851-8_135-11.*

Van Creveld, K., & Mansfield, K. (2020). Lit environments that promote health and well-being. *Building Services Engineering Research and Technology,41*(1), 14-23. https://doi.org/10.1177/0143624419896250

VELUX. (2022). *Daylight Visualizer 3.0.89* [Software]. VELUX Group. http://www.velux.com

Wirz-Justice, A.; Skene, D.J.; M□nch, M. (2021). The relevance of daylight for humans. *Biochem. Pharmacol. 191.* https://doi.org/114304./2018

Yasminingrat, R. A. B., Sulistyantara, B., & Nasrullah, N. (2023). The Impact of Urban Home Gardens on The Mental Well-Being of Women in The Greater Jakarta Area. Journal of Contemporary Urban Affairs, 7(1), 39-50. https://doi.org/10.25034/ijcua.2023.v7n1-3

Yin, R., Leung, M., & Li, Y. (2023). A Preliminary Study of the Relationship Between Built Environment of Open Space and Cognitive Health of Older People. Journal of Contemporary Urban Affairs, 7(2), 144–155. https://doi.org/10.25034/ijcua.2023.v7n2-9

Zhong, W., Schröder, T., & Bekkering, J. (2022). Biophilic design in architecture and its contributions to health, well-being, and sustainability: A critical review. Frontiers of Architectural Research, 11(1), 114–141. https://doi.org/10.1016/j.foar.2021.07.006