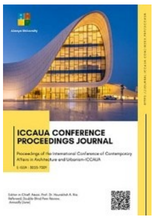

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Daylight Parameters in Hospital Wards in Hot, Arid Regions: A Simulation Analysis in The Context of Saudi Arabia

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Abstract

The healing effect of daylight cannot be underestimated or overstated because multiple studies and research have revealed that exposure to natural light accelerates the healing or recovery process of patients. This research paper investigates the optimization of daylighting in hospital wards situated in hot, arid regions with a focus on Saudi Arabia. The study employed simulation tools to evaluate different daylighting strategies, aiming to improve energy efficiency and well-being. The research determined that patients in daylight rooms tend to experience less pain; this is a testament to the therapeutic effects of daylight. Consequently, daylighting decreases hospital stays and enhances mood and productivity among staff. The evaluation of the recent situation in the case study ward in a Saudi Arabia hospital established that the daylight levels are below the recommended standards and that the daylight varies between the identical wards due to the time of the day and ward direction.

Keywords: Illuminance levels; Uniformity distribution; Helthcare Buildings;Daylight performance.

1. Introduction

Daylighting is crucial in any hospital environment since it can improve staff productivity and patient recovery. In their case study, Muhamad et al. (2022) established that daylighting involves using natural light to illuminate indoor spaces, providing physiological and psychological benefits. Recognizing Daylighting is integral when discussing sustainability and efficiency of healthcare typologies, considering the wellbeing of users such as: patients' shorter stays, one day visits by patients, and long working hours of staff (Ulrich, 1984; Choi et al., 2012). This signifies the role of daylight as a healing component, especially in medical environments like hospitals.

Optimizing daylighting in hot and arid regions like Saudi Arabia is characterized by challenges due to extreme temperatures and intense sunlight. Some of these problems include minimizing heat gain while maximizing natural lighting. Thus, architects must find the equilibrium between daylighting and thermal comfort. This issue must be dealt with through the contextual parameters of Saudi Arabia whether cultural leaning for privacy, climate, and the utilization of energy-intensive buildings.

On the bright side there is an increasing attention to sustainable design in Gulf-region hospitals. Yet, this paper spots a literature gaps addressing climate-responsive daylighting strategies considering both thermal comfort and visual performance in health-care facilities in Saudi Arabia. This study contributes to tackling such a gap through investigating a local environmental and cultural case study. Accordingly, the study explores the integration of daylighting in hospital designs, highlighting its ability to enhance energy efficiency and improve the healing environment for patients.

This research paper investigates the optimization of daylighting in hospital wards situated in hot, arid regions with a focus on Saudi Arabia. The research raises the question of How can hospital ward daylighting designs that promote healing environments be achieved in hot arid regions like Saudi Arabia? The research aims at investigate the performance of architectural features to achieve hospital daylighting designs that improve the healing of patients and develop guidelines and recommendations for the design of daylight in hospital wards appropriate to the Saudi Arabian climate and culture. The research in this context set 3 susbsequent objectives: First, to identify the impact of daylight in hospital wards on healing. Second, to evaluate different daylighting design strategies and determine useful solutions

that maximize the utilization of daylight in the hospital ward. Third, to provide hospital wards daylighting design guidelines for architects appropriate to the Saudi Arabian climate and culture.
The study employs simulation tools to evaluate different daylighting strategies, aiming to improve energy efficiency and well-being while also considering climate challenges specific to Saudi Arabia. This research applied a mixed-methods approach, combining systematic, cluster, and simple random sampling techniques, and referred through its analysis to thematic and content analysis methodologies. Quantitative data was reviewed from secondary sources, including peer-reviewed journals, academic books, and published articles, while qualitative data was collected primarily through semi-structured interviews with healthcare professionals and hospital facility managers. Furthermore, the study grounded instrumental tools through a case study of King Khalid University Hospital in Saudi Arabia.
The research focuses on the connection between light, well-being, and ward designs in Saudi Arabia, emphasizing the outlined aspects. These include evidence of daylight's impacts on health outcomes, hospital wards' past and present design, energy-efficient hospitals, and single-patient rooms. The research also focuses on social considerations that may affect hospital design in Saudi Arabia. Finally, it evaluates different passive daylighting design strategies.
Certainly, the research provides clear evidence of the relationship between daylight and health through literature and by presenting new architectural techniques for utilizing more daylight in hospital wards. It shows the impact of this method on space energy consumption. The research encourages and helps architects and policymakers to use this approach in future hospitals. This contributes to establishing climate-sensitive daylighting standards for healthcare buildings in arid regions, supporting sustainable healthcare design practices.
This research paper is structured as follows: Section 2 literature review on daylighting, healing environments, and sustainable hospital design in hot climates. Section 3 outlines the research methodology. Section 4 presents the results towards improving the daylighting strategies. Section 5 discusses the research results. At last, Section 6 concludes with a summary towards fruitful contribution to next research steps.

2. Literature Review

Past and present studies demonstrate that natural light substantially enhances both the patient recovery process and staff performance. In hot, arid regions, the key challenge lies in maximizing daylight along with minimizing heat gain, which requires careful consideration of factors such as the orientation of building, selection of materials, and design of openings and window sizes. Muhamad et al. (2022) highlighted techniques such as advanced glazing technologies, and advanced shading installations, whereas varying levels of success were revealed and further investigated towards achieving effective daylighting.
The body of research also postulated that natural light has a critical role in decreasing the duration of patients' stays as well as enhancing staff efficiency. Eisazadeh, Troyer, and Allacker (2022) noted that electricity is the main energy source in healthcare buildings, with artificial lighting accounting for around 25% to 40% of total energy consumption. Daylight is thus an essential factor in hospital design, exerting substantial influence on the perceived quality of spaces, as well as users' health and well-being. Akinbami (2024) found that daylight adds economic value to design solutions, making it a vital asset in architecture and urban design. However, daylight is inherently variable, fluctuating seasonally and throughout the day, which underlines the need to examine how different architectural features affect daylight quality in hospital settings.

2.1. Hospital Ward Design: Past and Present Insights

Studies indicate that hospitals located in densely populated cities may experience higher patient mortality rates compared to those in less urban areas. Florence Nightingale, a pioneer in modern healthcare and hospital design, advocated for constructing hospitals ideally near gardens, attempting to enhance the process of patient recovery and reduce disease spread. Her principles focused on natural light, ventilation, and integration with nature. However, gender segregation existed, with imbalanced spatial allocations for male and female patients.
The Nightingale ward influenced modern hospital design by incorporating key elements such as windows, natural light, greenery, acoustic control, and color schemes. McDonald (2020) noted that Nightingale hospitals featured large, open wards with high ceilings, enhancing visibility and supervision by nurses. In contrast, Victorian-era hospital wards were labelled as large, vast spaces, without aligning its spatial design to users' health needs, reflecting a departure from Nightingale's evident design concepts.
Looking forward to the 20th century, building occupancy emerged as a major driver of energy use, especially in hospitals. Akinbami (2024) noted that many hospitals during this period neglected the integration of daylight and natural ventilation. Thus, contemporary design movements have highlighted the importance of daylighting. Subsequent research ever since attempted to investigate effective strategies for implementing daylighting, while reducing energy consumption in hospitals.
The paper emphasizes that achieving optimal indoor daylighting requires the effective use of shading devices, window openings, spatial planning, and daylighting systems. These should be the primary approach to improving lighting efficiency and promoting energy conservation in healthcare facilities.

2.2. Impacts of Daylight on Health and Wellbeing

According to a study conducted by Karlin and Zeiss (2006), daylight has been proved to positively impact patient health outcomes by increasing satisfaction, accelerating recovery process, improving staff performance towards limiting medical errors. Also, the role of daylighting is inevitable to alleviating stress and depression and regulating circadian rhythms and sleep cycles. Buijs et al. (2021) emphasized the role of the hypothalamus—the body's biological clock—

which relies on daylight signals to regulate sleep patterns. Lack of daylight, conversely, may disrupt hypothalamic function, leading to circadian rhythm disorders. As well, daylight facilitates the production of vitamin D, which is vital for bone health, cardiovascular protection, and lowering the risk of colon cancer. Additionally, natural light has been found to benefit critically ill patients, including those undergoing spine surgery and individuals with bipolar disorder.
In a landmark study, Choi et al. (2012) demonstrated a significant relationship between patient duration of stay and daylight exposure. Patients in southeast-facing rooms experienced 16% to 40% shorter stays compared to those in other hospital zones. Furthermore, daylight has been linked to better outcomes for infants in neonatal intensive care units (NICUs). As such, the strategic positioning of windows in ICUs is critical. However, excessive sunlight penetration must be controlled using curtains and blinds to avoid visual discomfort and overheating.
Another point is the impact on staff, for instance, access to windows with views of nature that can reduce stress levels, enhance productivity, and increase job satisfaction among staff. In short, multiple studies have consistently correlated natural lighting and improved mood, reduced depression, and overall positive attitudes among staff members (Park et al., 2018).

2.3. Minimizing Medical Errors and Accelarating Patient Recovery
Numerous studies associate poor hospital lighting with increased medical errors. Evidence shows that adequate daylighting can reduce such errors. For example, pharmacists working under three different lighting conditions (1500 lux, 1000 lux, and 450 lux) had error rates that decreased from 3.8% under the lowest light level to 2% under the highest. In certain clinical scenarios, the ability to accurately assess a patient's skin color is critical—for example, a bluish hue may signal respiratory distress. Artificial lighting, especially with warm tones, may compromise color perception, making daylight preferable in such contexts.
Karlin and Zeiss (2006) found that daylight promotes recovery in depressed patients, while windowless environments are associated with feelings of isolation and emotional distress. Harshalatha, Patil, and Kini (2024) stressed that hospital lighting systems must adhere to guidelines established by the Society of Light and Lighting, ensuring that illumination is adequate and consistent for clinical care.

2.4. Socio-Cultural Considerations in Ward Design in Saudi Arabia
Saudi Arabia's hospital design must account for cultural norms and gender-related healthcare practices, which differ markedly from Western models. Traditionally, female patients could only be treated by female healthcare professionals, a policy complicated by the historical unavailability of medical education for women (Ahmad et al., 2023). In the absence of female practitioners, male healthcare providers are permitted to treat women only in the presence of male guardians.
Creating a healing environment in Saudi hospitals necessitates a human-centered design that respects local customs while promoting health and dignity. Al-Qahtani et al. (2021) argued that single-patient rooms provide more privacy and enable greater support from family and friends. Visiting the sick is a highly encouraged social practice, often involving large gatherings of relatives, which places unique demands on patient room design and spatial configuration.

3. Material and Methods
The research employed a cross-sectional study design, which is widely used in research to measure the prevalence of outcomes associated with specific determinants. This approach is not necessarily tracing subjects over time, which allows for a snapshot of the variables under investigation. Wang and Cheng (2020) highlighted that the cross-sectional design is often preferred because it is cost-effective, convenient to implement, and useful for establishing preliminary evidence, to guide future advanced studies. In this paper, the cross-sectional design explored health outcomes associated with daylighting and climate determinants in Saudi Arabia, providing an insightful understanding of the persistent key issues.

3.1. Sampling Strategy
The study used a combination of systematic, cluster, and simple random sampling techniques. The sampling intended to ensure the data collected represented a broad spectrum of participants, with sufficient knowledge and expertise to answer the research questions. Thus, the researchers engaged with both typical target users and clustered participant groups with relevant characteristics to validate or challenge the study's assumptions, while also employing random selection to ensure a diversity of perspectives.

3.2. Data Collection
The research involved both quantitative and qualitative data collection methods, and implied an empirical study.

- Quantitative data was reviewed from published books, journals, and articles discussing daylighting and its impacts in hospital wards.
- Field Data was also collected through the direct measurement of light levels in one of Saudi Hospital wards. Consequently, the research utilized computer-based building simulation tools to assess daylighting and energy saving. The case study focused on King Khalid University Hospital, where data was collected from two specific words (Ward A and Ward B) to assess effectiveness of daylighting strategies and gather views directly from participants.

3.3. Data Analysis
The data analysis relied on Content and thematic analysis to compare and overlay the qualitative data from the semi-structured interviews. Thematic analysis helped pinpointing the recurring topics related to both: daylighting and its

effects on patient recovery and staff performance. Concurrently, the research team utilized Microsoft Excel and SPSS to analyze secondary data, helping to feed in the interpretation of the empirical investigation.

3.4. Inclusion and Exclusion Criteria

The study included articles, journals, and books about the effect of daylight on patients in wards. Nonetheless, the study excluded any information on patients' personal data. The site visit to the hospital rooms excluded any privacy abuse for a patient.

3.5. Ethical Considerations

Ethical practices were strictly followed throughout the study. Ethical approval was officially obtained from the university before the initiation of any empirical data collection. All participants provided with a clear consent form before their involvement, ensuring their awareness of the study's purpose and their rights. The data collected through this research was only used for academic purposes. Confidentiality was maintained by using identifiers to protect participant identities, and all records were securely destroyed after the study's completion.

4. Results

This section aligns with the scope of the research, which investigates the optimization of daylighting in hospital wards located in hot, arid regions, with a specific focus on Saudi Arabia. It presents the results of the empirical study conducted in two hospital wards within King Khalid University Hospital—Ward A and Ward B—selected as base cases to evaluate the effectiveness of natural light in these settings. The study involved on-site light measurements and computer-based simulations, followed by an analysis of spatial daylight distribution across different months of the year. Particular attention was given to illumination levels, daylight uniformity, and building orientation. Additionally, the case study examined the role of artificial lighting in addressing daylight deficits, as well as design strategies such as window-to-wall ratio, light shelves, and anidolic lighting systems.

4.1. Base Case 1- Ward A: Assessment Results

This susbsection presents Indoor Daylight Assessment in Base case 1- Ward A. Ward A recorded adequate illumination levels in areas near the windows; nonetheless, the daylight levels significantly decreased with distance from the window. The maximum illumination level reached 285 lux, which dropped to 14 lux, while the average daylight level in March was measured at 240 lux in March. However, daylight levels recorded a decline in June, with the highest illumination level of 1337 lux has dropped to 6.4 lux. Although daylight levels in September were higher than in June, March remained the highest overall daylight levels. In December, illumination levels close to the windows were higher, but this was accompanied by poor daylight uniformity. While illumination near the windows remains high, it declines considerably in the deeper sections of the ward. Furthermore, daylight uniformity across space is weak, with a maximum recoded ratio of only 0.07, as shown in Table 1 below.

Table 1. Monthly means of daylight level in lux and uniformity of daylight in ward A.

Date and Time 12:00 PM	Average EV (Lux)	Lowest EV (Lux)	Uniformity (Lowest/ Average)	Glare
21 December	285	19	0.07	No
21 March	240	14	0.06	No
21 June	160	6.4	0.04	No
21 September	194	9	0.05	No

4.2. Base Case 2- Ward B: Assessment Results

This susbsection presents Indoor Daylight Assessment in Base case 2- Ward b. Ward B is oriented in a direction that receives minimal solar radiation and, as a result, experiencing inadequate daylight levels. In March, Ward B recorded poor illumination levels across most areas, except for zones near the windows. The highest recorded illumination was 1151 lux, which dropped sharply to 4.7 lux, with an average illumination of 121 lux. A similar trend was noted in June, although overall daylighting was higher than in March, given that summer months offer better daylight exposure. In September, the ward experienced a significant drop in daylighting, with almost no coverage into the deeper parts of the ward.

In December, daylight levels were at their lowest, as the ward faces north and receives minimal exposure during winter. Only areas closer to the windows received daylight. During peak winter, daylight levels had the poorest records, with the maximum illumination reaching 812 lux and an average of 108 lux across space.

Therefore, in Ward B, daylight availability in the base was especially poor during mid-winter, with high illumination only near the windows, and declines significantly toward the deeper into space.

Additionally, daylight uniformity in the ward is weak, with a maximum recorded uniformity ratio of 0.04, which is lower than the recommended standard value of 0.5, as shown in Table 2 below.

Table 2. Monthly means of daylight level in lux and uniformity of daylight in ward B.

Date and Time 12:00 PM	Average EV (Lux)	Lowest EV (Lux)	Uniformity (Lowest/ Average)	Glare
21 December	108	4.5	0.04	No
21 March	121	4.7	0.04	No
21 June	159	5.3	0.03	No
21 September	119	4.5	0.04	No

4.3. Comparing On-site Daylight Measurements and Computer-based Simulations

On-site measurements recorded a high illumination level of 2,379 lux in areas closer to the window, while computer-based simulations revealed a lower value of 1,620 lux. However, the overall distribution patterns—particularly in the patient bed areas—were the same across both methods, indicating that the simulation results are reliable.

Both wards represented cases of insufficient daylight levels, with inadequate uniformity ratios compared to recommended standards. During the peak winter season, Ward A presented relatively better illumination levels compared to Ward B receiving poorer daylight availability.

4.4. The Use of Artificial Lighting in Wards A and B

To adapt to the insufficient daylight levels, engineers and architects applied artificial lighting as a viable solution. Three lighting cassettes were installed to enhance illumination, significantly enhancing brightness levels in Ward A during the month of June, despite the persistence of some darker areas. This improvement trend was consistent for both June and December. In Ward B, visual performance in the test rooms improved notably in mid-winter and summer after the integration of artificial lighting. These findings denote that the south-facing orientation of supports better lighting outcomes compared to Ward B.

4.5. Strategies to Improve Daylight Availability in Wards A and B

To improve daylight availability, increasing the window-to-wall ratio (WWR) from 30% to 50% and subsequently to 80% significantly enhances natural light penetration and affects overall energy consumption. In Ward A, increasing the WWR resulted in notably better daylight conditions within the test rooms (see Table 3).

Table 3. Monthly mean of daylight level in lux and the uniformity of daylight in ward A window-to-wall ratio WWR.

Date and Time 12:00 PM	Average EV (Lux)	Lowest EV (Lux)	Uniformity (Lowest/ Average)	Glare
21 December	1600	438	0.27	Yes
21 March	662	252	0.38	No
21 June	260	80	0.31	No
21 September	603	229	0.38	No

Similarly, Ward B demonstrated improved illumination following the same settings (see Table 4), in which . Overall, both wards showed increased daylight levels and improved daylight uniformity following the higher WWR.

Table 4. Monthly mean of daylight level in lux and the uniformity of daylight in ward B window-to-wall ratio WWR.

Date and Time 12:00 PM	Average EV (Lux)	Lowest EV (Lux)	Uniformity (Lowest/ Average)	Glare
21 December	186	56	0.30	No
21 March	200	59	0.30	No
21 June	247	71	0.29	No
21 September	203	60	0.30	No

To further address issues such as glare and inaadequate uniformity, implementing architectural light shelves is recommended. Light shelves not only reduce reliance on artificial lighting but also help distribute daylight more evenly across the interior. The inclusion of light shelves proved to reduce illumination levels, enhance uniformity, and mitigate glare in the wards, as shown in Tables 5 and 6. These systems reflect daylight deeper into spaces, towards improving quality of lighting and visual comfort.

Table 5. Monthly mean of daylight level in lux and the uniformity of daylight in ward A.

Date and Time 12:00 PM	Average EV (Lux)	Lowest EV (Lux)	Uniformity (Lowest/ Average)	Glare
21 December	215	70	0.33	No
21 March	170	60	0.35	No
21 June	95.7	29	0.30	No
21 September	131	39	0.30	No

Table 6. Monthly mean of daylight level in lux and the uniformity of daylight in ward B.

Date and Time 12:00 PM	Average EV (Lux)	Lowest EV (Lux)	Uniformity (Lowest/ Average)	Glare
21 December	62.3	19	0.30	No
21 March	65.7	20	0.30	No
21 June	79.2	24	0.30	No
21 September	65.4	20	0.31	No

Additionally, Anidolic lighting systems were found to be vital factor in enhancing daylight performance. These systems contributed to higher illumination levels and enhanced uniformity, further optimizing the daylighting conditions in both wards.

5. Discussions

This paper emphasizes the importance of daylighting in healthcare facilities and should be utilized especially in hot and arid climates such as Saudi Arabia. Through this study, researchers examined the case of daylight availability in two wards A and B Ward at King Khalid University Hospital, viewing the results variation due to differences in orientation and spatial configuration. Ward A exhibited higher illumination levels than B, still was challenged in terms of poor uniformity, with light levels dropping sharply in deeper areas and specific months. Similarly, Ward B recorded inadequate daylight exposure, even recorded lower figures compared to ward A, also, with light distribution highly localized near the windows and overall low uniformity.

The implementation of daylight-enhancing strategies, such as increasing the window-to-wall ratio WWR and integrating architectural light shelves, demonstrated better illumination and uniformity results in both wards. These measures postulate practical design solutions to improve indoor environmental quality and reduce the excessive reliance on artificial lighting.

These results can provide an opportunity for further research to be connotated with reviewed studies, for instance those by Ulrich (1984), Choi et al. (2012), and Karlin and Zeiss (2006), which emphasize the therapeutic and psychological benefits of natural light in healthcare environment. Hence, this paper attempts to corroborate the argument that further studies and retrofitting should be conducted to increase daylight and positively influence recovery.

Certainly, the noted daylight deficiencies in deep zones of the wards are consistent with challenges highlighted by Muhamad et al. (2022) and McDonald (2020), particularly in adapting historical hospital layouts or poorly oriented buildings to modern lighting needs. The study confirms that daylighting should be contextually adapted, especially in climates with intense solar radiation like Saudi Arabia, where both thermal comfort and privacy must be balanced.

5.1. Limitations

This study focused on only one hospital and two wards A and B, which cannot be fully generalized. On another note, the research focus overlooked the real-time energy consumption related to artificial lighting use.

5.2. Recommendations

To enhance daylighting in Saudi hospitals and similar geographic contexts:

- Architectural design should prioritize south or southeast-facing wards, as much as possible, towards maximizing uniformed daylight exposure.
- Window-to-wall ratios WWR should be increased to optimize light penetration and still considering the use of shading devices to control heat gain.
- Daylight systems, such as light shelves and anidolic lighting, are recommended to improve uniformity and reduce glare.
- Cultural and privacy considerations should be embedded in design of spaces versus windows, ensuring user comfort and privacy, particularly in gender-sensitive settings.

Future research should expand the sample size to include multiple hospitals with different orientations, designs, and patients. strategic studies comparing recovery rates, staff performance, and actual energy savings would also enrich the body of literature.

6. Conclusions

The outcomes of this research offer valuable insights for hospital designers, medical managers, and administrators both locally and internationally. A review of the literature confirms that maximizing daylight in hospital wards significantly contributes to patient recovery and enhances hospital performance by reducing the length of patient stays. Consequently, the literature indicated that there is a greater shift to single patient rooms, and this affects patient well-being, enhances privacy, and improves noise management. The case study conducted in a Saudi Arabian hospital revealed that existing daylight levels in the wards fall below recommended international standards. Notably, daylight availability varied between the two identical wards, primarily due to differences in orientation and the time of day.

The study also revealed that improving the window-to-wall ratio WWR enhanced illumination levels, but the wards still scored values below the accepted value of 300 lux and 0.5 daylight uniformity level.To address these shortcomings, the study recommends incorporating anidolic lighting systems and architectural light shelves, enhancing daylight exposure and penetration as well as reducing dependency on artificial lighting. Finally, this study concludes that daylight exposure in healthcare facilities is vital towards creating a more convenient and sustainable recovery environment.

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Conflict of Interests

The authors report there are no competing interests to declare.

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