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Indoor Environmental Quality Assessment of Inpatient Wards, Case Study: Public Hospital in Jeddah, Saudi Arabia

Hussain Osama Al-Mansouri **Jamil Farid Hijazi**

Department of Architecture, College of Architecture and Planning, King Abdulaziz University, Jeddah, Saudi Arabia

hhussainalmansouri@stu.kau.edu.sa *jhijazi@kau.edu.sa.*

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Abstract: Indoor environmental quality (IEQ) is more crucial in hospitals than other building types due to its effects on the recovery of patients. In Saudi Arabia, there is a lack of hospital design guidelines prioritizing IEQ, making it difficult to design spaces that provide adequate levels of comfort. In this study, objective and subjective assessments utilizing field measurements and focus groups were conducted on inpatient wards in a public hospital in Jeddah, Saudi Arabia, to develop IEQ-focused design guidelines that provide users with more comfort and satisfaction. The objective assessment targeted the four main parameters of IEQ: thermal, acoustical, visual comfort, and indoor air quality. The subjective assessment targeted the same four parameters by gauging the satisfaction level of three hospital user groups: patients, visitors, in addition to nurses and resident doctors as one group. A correlated analysis between both assessments revealed that Thermal Comfort and Indoor Air Quality were closest to acceptability, whereas Visual and Acoustic Comfort were less satisfactory. A set of categorized IEQ-focused design guidelines was then developed based on the IEQ-related design issues concluded from the analysis

Keywords:Indoor Environmental Quality; Thermal Comfort; Acoustic Comfort; Visual Comfort; Indoor Air Quality; Inpatient Wards.

1. Introduction

It is human nature to adapt to the surrounding environment to survive. Since humans are constantly surrounded by an environment (Parsons, 2013), it is also in their nature to make the environment as safe and as comfortable as possible (Florides et al., 2002, as cited in Almeida et al., 2015). Over time, humans eventually started spending most of their time indoors, ultimately affecting their health and comfort depending on the quality of the indoor environment (Wargocki, 2009, as cited in Almeida et al., 2015).

1.1 Indoor Environmental Quality (IEQ)

Although IEQ is considered a broad concept, the National Institute for Occupational Safety and Health (2013, as cited in Awada et al., 2021) defines it as “the quality of a building’s environment in relation to the health and well-being of those who occupy space within it.” IEQ is affected by several factors which can be categorized under four main parameters (Franchimon et al., 2009; Alfano et al., 2010, as cited in Almeida et al., 2015), as follows:

1.1.1 Thermal Comfort

Thermal comfort is the thermal adaptation of building users to their surrounding environment, which depends on variables such as location, climate, and season (Quang et al., 2014, as cited in Al Horr et al., 2016). Thermal comfort is affected by environmental factors such as air temperature, relative humidity, and personal factors such as metabolic rate and clothing insulation (ASHRAE, 2010, as cited in Katafygiotou and Serghides, 2015).

1.1.2 Acoustic Comfort

Acoustic comfort refers to protecting a building's users from loud noises (Greek Legislation, 1989, as cited in Al Horr et al., 2016). Patients in spaces as sensitive as hospitals are considered more vulnerable to loud noises than healthy users such as staff members and visitors (Gabor et al., 2003; Loupa, 2020, as cited in Secchi et al., 2022).

1.1.3 Indoor Air Quality (IAQ)

The U.S. Environmental Protection Agency (2022) defines IAQ as the air quality inside and around buildings correlated with users' health and comfort. IAQ is also concerned with infection and air pollution control. Factors affecting IAQ include outdoor air, indoor occupant density, and HVAC system types and practices (Fonseca et al., 2022; U.S. Environmental Protection Agency, 2022).

1.1.4 Visual Comfort

The European standard EN 12665 (2011, as cited in Carlucci et al., 2015) defines visual comfort as "a subjective condition of visual well-being induced by the visual environment". Visual comfort is affected by several factors correlating with human needs, such as the amount of light, the uniformity of light, and the risk of glare for the building's users (Carlucci et al., 2015).

1.2 IEQ International and Local Standards

Even though some standards for health and safety in buildings are specific to certain countries, most standards are international, such as the various collaborations between ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, n.d.) and ANSI (American National Standards Institute, 2023). Even though both mentioned entities are US-based, they provide standards used globally, including Saudi Arabia (ASHRAE, 2021).

1.2.1 International Standards

These standards cover various topics but rarely provide users with architectural design guidance. For example, ANSI and ASHRAE's Standard 55 'Thermal Environmental Conditions for Human Occupancy' (2023), focuses mainly on thermal comfort and provides information such as acceptable temperature ranges for building occupants.

Some cases include detailed design guidance, such as the US Department of Veterans Affairs 'Inpatient Unit Design Guide' (2011). This guide, alongside design standards, lists important factors related to patients' physical and mental health. Most of these factors are associated with the main parameters of IEQ, such as potential stress caused by loud noises and inadequate lighting.

1.2.2 Local Standards

Local standards are limited in comparison, with local researchers resorting to international standards when conducting quality assessment studies, such as the IAQ-focused ASHRAE Standard 62-2004 (as cited in Budaiwi et al., 2022), the thermal environment-focused ISO (International Organization for Standardization) 7730 Standard (1994, as cited in Al-Sualihi et al., 2015), and the WHO (World Health Organization) Guidelines for IAQ (2010, as mentioned in Saleem et al., 2020), all of which do not provide architectural design guidelines and simply list their standards for higher levels of IEQ.

The public hospital targeted by this research utilizes both international and local standards. The international standards are the CDC (Centers for Disease Control and Prevention, 2019) 'Guidelines for Environmental Infection Control in Healthcare Facilities', which mainly focus on thermal comfort and IAQ. On the other hand, the local standards used are the CBAHI (Saudi Central Board for Accreditation of Healthcare Institutions, 2015) National Hospital Standards which focus on safety and the quality of the provided services in the hospital, much more so than IEQ from an architectural viewpoint.

1.3 Problem Statement

As of 2023, 69.94% of healthcare facilities in Saudi Arabia are part of the public sector, 52.44% of which are accredited by CBAHI (Ministry of Health, 2024). However, CBAHI's (2015) healthcare standards lack IEQ-focused design guidelines that ensure adequate levels of IEQ. Although the Facility Guidelines Institute (2024) and National Health Service (Department of Health, 2014) provide IEQ-focused design guidelines in the US and UK, respectively, their only equivalent in Saudi Arabia is CBAHI, which provides standards for healthcare services instead of IEQ-focused design guidelines for hospital spaces, indicating that there is still a lack of focus on IEQ in healthcare facility design in Saudi Arabia.

1.4 Research Objectives and Methods

Previous data suggests that the built environment of hospitals can affect the health and recovery of patients, which is especially impactful for patients spending multiple days inside inpatient rooms (Gao and Zhang, 2021). Furthermore, in an environment as sensitive as inpatient wards, a high level of IEQ is crucial to providing users with a comfortable experience that promotes their recovery (Nimlyat et al., 2022). Therefore, thisthis study aims to develop IEQ-focused design guidelines that can be integrated with CBAHI's (2015) existing standards to create comprehensive local hospital guidelines covering both design and performance. To achieve this goal, the following objectives must first be accomplished (Table 1).

After accomplishing the above objectives, a correlated analysis of both the objective and subjective assessments was conducted, based on which the development of the IEQ-focused guidelines was made possible.

2. Literature Review

This literature review targeted cases published between 2017 and 2023, both locally and internationally, in which IEQ is assessed either objectively, subjectively, or both ways. It also covered topics that study IEQ as a concept, such as studies that developed models and assessment tools that help identify factors affecting IEQ (Table 2).

Research on the effects of the built environment on users' health dates back a few decades, and although there is an abundance of IEQ assessments in hospital buildings both locally and internationally, most of these assessments simply presented their data without building guidelines based on the results. Additionally, local literature and guidelines regarding hospital design in Saudi Arabia are still lacking, specifically in ways that ensure higher levels of IEQ. Therefore, this study aims to fill this gap by developing design guidelines focusing on increasing the level of IEQ in inpatient wards to provide the occupants with a more comfortable and satisfactory experience.

Table (1). Research objectives and their respective methods (Author, 2024).

Objective	Method
1. Objective IEQ Assessment of a public hospital's inpatient wards.	1. Field measurements of various IEQ factors via physical measurement instruments.
2. Identifying the IEQ parameters that fall short of standards.	2. Comparing measured IEQ factors with international standards.
3. Subjective IEQ Assessment of a public hospital's inpatient wards.	3. Conducting focus groups targeting three types of inpatient ward users: (a) Inpatients, (b) visitors, (c) nursing staff and resident doctors (as one group).
4. Identifying the least satisfactory IEQ parameters from the users' point of view.	4. Analysis of the focus groups' data.

Table (2). Literature Review (Author, 2024).

Author/ Year	Title	Methods	Findings
Garnawat et al. 2017	Assessment of indoor environmental quality in Australian healthcare facilities: a review of standards and guidelines	A literature review was conducted on IEQ evaluation studies of healthcare and non-healthcare facilities in Australia, IEQ assessment methods in practice, and Australian guidelines and standards for managing and maintaining IEQ.	Even though Australian healthcare facility guidelines concerned with IEQ focused more on infection control over occupant satisfaction, IEQ assessments were found to include both subjective and objective data collection methods, with no universal standards for either type, as each study would develop its scale to gauge occupant satisfaction, producing different results.
Wu et al. 2019	Interaction between Sound and Thermal Influences on Patient Comfort in the Hospitals of China's Northern Heating Region	This study focuses on the sound–thermal influence on comfort in hospitals. The combined effects of the acoustic and thermal environment were objectively evaluated through field measurements of temperature, humidity, and sound pressure and then subjectively evaluated through surveys.	Both thermal and acoustic influences revealed that they are almost equally influential, meaning that a higher level of thermal comfort results in a higher level of acoustic comfort and vice versa.
Al-Atawi 2020	Efficiency evaluation of public hospitals in Saudi Arabia: an application of data envelopment analysis	A data envelopment analysis, which estimates the efficiency of comparative samples that use similar inputs to produce similar outputs, referred to as decision-making units, was utilized to gauge the technical efficiency of public hospitals in Saudi Arabia. The input used for the analysis includes the quantities of variables such as hospital beds, and full-time physicians and nurses. The output variables include yearly quantities such as outpatient visits, discharged inpatients, and surgical operations.	The study's findings indicate that 75.8% of public hospitals are considered inefficient in their performance, with small hospitals being relatively more efficient than medium-sized hospitals. The analysis also reveals that the major causes of inefficiency are the overabundance of health workers compared to the shortage of health services, indicating that a reallocation of health workers should occur to increase their efficiency.
Hassanain et al. 2020	Quality assessment of a campus medical facility: a users' perspective approach	Surveys, walkthroughs, and focus groups were conducted to assess the quality of the medical facility based on a set of quality indicators, which focused on: All four IEQ parameters, space planning and layout Building site, safety, support facilities, operation and maintenance.	The study revealed three key design issues: Accessibility from the outside and wayfinding from the inside, colder temperatures at night, and old furniture in need of renewal. The focus groups were revealed to be an effective way to enhance the quality and usability of the medical facility from a user-centric point of view.
Khan et al. 2020	Thermal Comfort and Ventilation Conditions in Healthcare Facilities - Part 1: An Assessment of IEQ	In this study, RH, temperature, and CO_2 were measured using physical measurement instruments at specific hospital locations based on three parameters: Occupancy, HVAC systems, and current comfort conditions. The selected locations are emergency rooms, operation theaters, intensive care units, and medical wards	The results reveal that IEQ in naturally ventilated areas appears to be closer to standard levels during nighttime, however, it is still affected by occupancy level. On the contrary, areas with central air conditioning have the same level of controlled IEQ, and areas with split air conditioning perform better in standardizing concentrations of CO_2. Thus, the authors recommend designing healthcare facilities' HVAC systems based on the maximum possible occupancy, to avoid uncomfortable conditions.
Tang et al. 2020	Post-occupancy evaluation of indoor environmental quality in ten nonresidential buildings in Chongqing, China	The study utilized surveys and physical measurements to evaluate all four IEQ parameters in four types of nonresidential buildings in the Chongqing region of China: hospitals, schools, office buildings, and shopping malls.	Glare from artificial lighting was the most repeated complaint across all building types. Furthermore, a strong relationship was identified between CO_2 concentration and IAQ satisfaction. For hospitals, the findings indicate relatively higher IEQ satisfaction rates in all parameters except for acoustic comfort.
Al-Ghamdi 2021	Experience Design Modelling of the Relationship between Patient Recovery and Hospital Design in the Kingdom of Saudi Arabia	This study focused on developing a hospital design framework that promotes the safety and recovery of public hospital patients in Saudi Arabia. To achieve this goal, case studies, surveys, interviews, and building user observations were employed to collect data on local design processes, adverse incidents caused by design defects in hospitals, and how these incidents affect patient health and recovery.	The results indicate that most of the issues in local hospital design and operation occur during the early design stages, caused by the design teams' lack of experience and the lack of local data and guidelines for hospital design. The developed framework was based on principles that focus on improving local hospital design processes: prioritizing patient health and recovery through design, implementing multi-stage design processes to ensure quality, and evaluating newly built hospitals using the same framework to measure their success.

Table (2). Literature Review (Author, 2024).

Gao and Zhang 2021	Inpatient perceptions of design characteristics related to ward environments' restorative quality	Research on hospital environments indicates that patients' mental and physical wellbeing relates to the restorative quality of inpatient ward environments, which in turn is affected by design. This study utilized surveys targeting inpatients to identify the exact design factors influencing restorative quality in inpatient ward environments.	The results indicate that the most prominent design characteristics that influence the restorative quality of ward environments include nature, artwork, furniture layout, room size, and wall color. These were categorized under four main design dimensions: object, connection, spatiality, and ambiance. Object and connection had the most significant effects on restorative quality.
Budaiwi et al. 2022	IEQ-based space categorization framework: the case of healthcare facilities	A subjective assessment was conducted through interviews and surveys targeting healthcare experts to classify healthcare space types by the importance of certain IEQ parameters in said vicinities. The interviews collected qualitative information, whereas the surveys rated the importance of each IEQ parameter in each space type.	Although the experts rated all IEQ parameters as important in all spaces, certain IEQ factors were revealed to be more significant in some spaces than others. The most critical IEQ parameter influencing healthcare facilities was revealed to be IAQ, as the participants rated it 'Highly Important'.
Nimlyat et al. 2022	The impact of IEQ on patients' health and comfort in Nigeria	Both longitudinal surveys, which target the same people over a long period, and transverse surveys, which target different people in a short period, were targeted toward patients in two hospitals to understand how IEQ affects patient health and satisfaction and to utilize this knowledge in the development of healthier hospital environments. The collected data was then analyzed using structural equation modeling, a statistical tool that analyzes the structural relationship between latent variables, such as happiness, that cannot be directly measured and measured variables. This allowed us to simultaneously investigate the parameters of IEQ and patient health and satisfaction.	The study's results revealed that patients' perceptions of their wards' IEQ affect their overall satisfaction and health outcomes, depending on the IEQ parameter. For example, the thermal and visual environments affected patient satisfaction more than health. However, all four IEQ parameters must be integrated to create a hospital environment that promotes both recovery and satisfaction.
Ismaeil and Sobaih 2022	Enhancing Healing Environment and Sustainable Finishing Materials in Healthcare Buildings	This study attempted to enhance the IEQ of an under-construction public educational hospital building while focusing on sustainability. An assessment framework based on international standards such as LEED was developed as a checklist that focuses on IEQ, energy, and interior design materials. The data for the framework was collected by interviewing green building design experts.	The assessment tool's application to the building produced positive results in all four IEQ parameters, gained high acceptance from stakeholders and decision-makers, and even promoted the building to receive a LEED Gold certification.
Zhang et al. 2023	Ten Questions Concerning Indoor Environmental Quality (IEQ) Models: The Development and Application	This study summarizes IEQ assessment methods and analysis frameworks through a review of the literature between the years 2001 and 2022. It includes 10 questions that cover the most important aspects of IEQ assessment, such as IEQ assessment models and their different applications, IEQ parameters and their relationship with satisfaction, and data collection methods.	To increase the applicability of IEQ assessment methods, a standardized database must be built covering various building types. Answering the 10 questions in this study should help promote IEQ model development and eventually lead to developing a universal IEQ model covering most building types.

3. Methodology

To achieve the research's objectives, the methodology listed below was followed (Figure 1):

This research targeted the inpatient wards of a public hospital in Jeddah, Saudi Arabia. The current hospital building was established in 1996 and houses 1067 beds across all its departments. The hospital is also one of the largest and most frequented public hospitals in Jeddah (H. Jalal, Personal Communication, November 16, 2023), hence its choice as a case study.

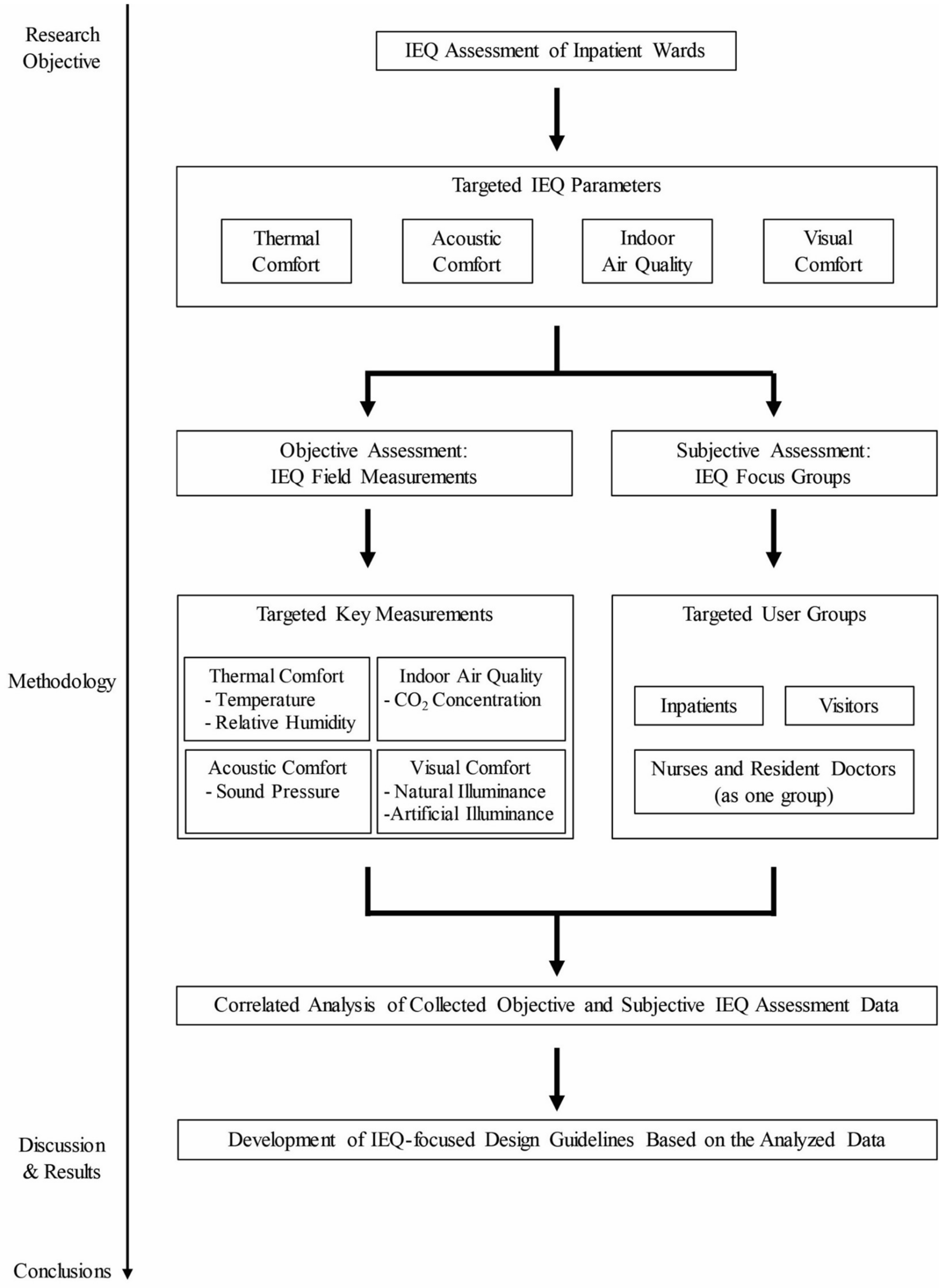

Figure (1). Summary of the research's methodology (Author, 2024).

2.1 Objective Assessment

Since each of the four primary IEQ parameters has its factors, the factors most suitable for this research's objective assessment must be determined. In previous studies that share a similar setting (Nimlyat et al., 2015; Wu et al., 2019; Khan et al., 2020; Tang et al., 2020), the following IEQ factors were the most commonly measured ones:

- Temperature and relative humidity under Thermal Comfort
- Sound pressure, under Acoustic Comfort
- CO2 concentration in air, under IAQ
- Natural and artificial illuminance under Visual Comfort

The field measurements for this research targeted the hospital's inpatient wards, specifically the first three floors, since they share the same air-handling unit (H. Jalal, Personal Communication, November 16, 2023). The details of the instruments used to measure the above IEQ factors are listed in Table 3.

The measurements were taken between November 17th and 24th, 2023, at different intervals in multiple rooms between 9 AM and 9 PM, with the data grouped into four equal parts of the day (Table 4).

The short measurement period is due to the hospital's highly controlled environment, which is generally not affected by seasons since it exclusively uses mechanical ventilation. On the other hand, changes that could potentially affect the hospital's environment have been taken into account, such as the elevation a room is facing or the time of day. The measurements were also taken in vacant rooms to minimize thermal and acoustic interference from inside the rooms.

After taking the measurements, the next step was to compare their results with the CDC (2019) standards that the hospital follows, in addition to international standards, to conclude whether they fall within the acceptable range.

2.2 Subjective Assessment

After completing the objective assessment phase, the subjective assessment phase can start. The first step was deciding on the subjective assessment tool, which was chosen as focus groups since they allow for direct conversation with the targeted user groups. The second step was determining the targeted user groups, followed by the spaces covered by the assessment.

The focus groups targeted three inpatient ward user groups due to the time they spend inside the rooms: inpatients, visitors, nursing staff, and resident doctors (as one group). The assessment's targeted spaces were the inpatient rooms since they are the only spaces accessible and most frequented by all three user groups (Table 5).

The targeted number of users per group was determined by assessing the maximum possible occupancy of the inpatient wards. There are three different inpatient wards: two public wards and a private ward. According to the inpatient unit layout (Figure 2), the maximum possible occupancy across all three wards is 155 occupants (Table 6).

It is worth noting, however, that there has been

Table (3). Field measurement instrument specifications (Author, 2024).

IEQ Parameters	IEQ Factors	Measurement Instrument	Measurement Range	Measurement Accuracy
Thermal Comfort	Temperature	Nightingale Air Quality Monitor	0 to 50˚C	±1 ˚C
	Relative Humidity		0 to 99% RH	±5%
IAQ	CO_2 Concentration		400 to 5000 ppm	5% ±50 ppm
Acoustic Comfort	Sound Pressure	Mengshen Digital Sound Meter	30 to 130 dB (A-weighted)	±1.5 dBA
Visual Comfort	Natural Illuminance	Wintact Digital Illuminance Light Meter	0 to 200,000 lx	±3% (below 10,000 lx)
	Artificial Illuminance			

Table (4). Field measurement time of day details (Author, 2024).

Time of Day	Starting Hour	Ending Hour
Morning	9:00 AM	11:59 AM
Early Afternoon	12:00 PM	2:59 PM
Late Afternoon	3:00 PM	5:59 PM
Evening	6:00 PM	9:00 PM

Table (5). Occupied hospital spaces per user group (Author, 2024).

Occupied Spaces / User Groups	Inpatient Rooms	Inpatient Ward Corridors/ Nurse Stations	Nursing Staff Offices/ Break Rooms
Inpatients	✓		
Visitors	✓	✓	
Nursing Staff & Resident Doctors	✓	✓	✓

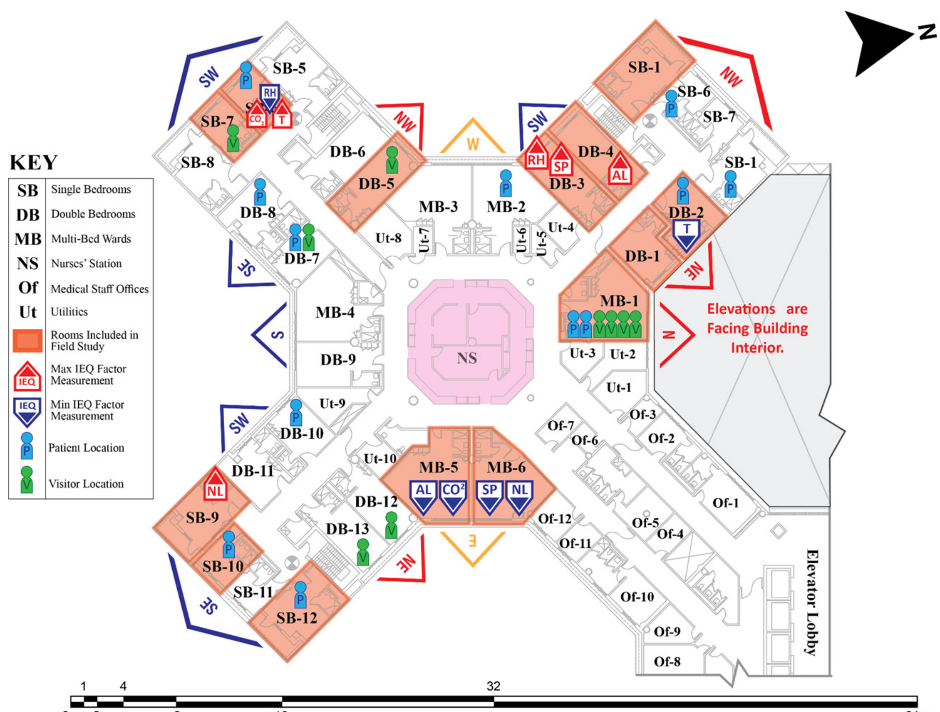

Figure (2).Typical non-intensive ward floor layout with added key information (Author, 2024).
T= Temperature; RH = Relative Humidity; SP = Sound Pressure; NL = Natural Light; AL = Artificial Light

Table (6). Maximum possible inpatient ward occupancy (Author, 2024).

	Room Type			Total per Ward	No. of Wards	Grand Total
	Single Bedroom	Double Bedroom	Multi-bed Ward			
Average Area	21.4 m²	23.4 m²	37.5 m²	-		
No. of Rooms per Ward	12	13	6	31 Rooms	-	-
Public Wards						
No. of Occupants per Room Type	1	2	4	-		-
No. of Occupants Across all Rooms	12	26	24	62 Occupants	2	124 Occupants
Private Ward						
No. of Occupants per Room Type	1	1	1	-		-
No. of Occupants Across all Rooms	12	13	6	31 Occupants	1	31 Occupants

a shortage of staff members recently in the inpatient department (S. Ekram, Personal Communication, November 18, 2023), with a total of 31 nurses across all three wards, which led to vacating half of the inpatient rooms to accommodate for this shortage. Judging by this, the calculations in Table 6 for occupants are halved, resulting in 78 potential occupants across all three wards.

Taking this shortage of nursing staff into account, in addition to the low probability of having all 78 beds occupied by inpatients during the assessment period, along with the recommended focus group size ranging from 3 to 12 users (Graham & Bryan, 2022), 12 people were initially planned as the targeted group size per user group, for a total of 36 users across all 3 groups. However, during the assessment, the actual group sizes were 12 patients, 9 visitors, 12 nurses, and 3 resident doctors, with the nurses and resident doctors grouped for 15 members.

As part of the focus group, the targeted users were asked to subjectively rate their satisfaction with IEQ factors such as temperature and noise. However, factors such as humidity and air freshness were omitted from the subjective assessment due to the difficulty in subjectively assessing them. The rating questions utilized 0-5 Likert-scale questions, which were used to quantify the subjective answers for comparison with the field measurements. Additionally, more qualitative questions were included to help specify sources of discomfort related to the four IEQ parameters, such as sources of noise, to minimize their impact on the users' comfort through the research.

After conducting the focus groups and collecting the required data, the next step in the subjective assessment phase was analyzing the results to identify the order in which the building users rated the four IEQ parameters from most satisfactory to least satisfactory. This ended the subjective assessment phase.

After analysing both the objective and subjective collected data individually, the next step was to find the correlation between both sets of data. Since qualitative data is not as scientifically accurate and objective as quantitative data, correlating the users' satisfaction rate from the focus groups with the physically measured IEQ factors can result in reaching unbiased judgments when developing the design guidelines this research aims for.

4. Results and Discussion

This section presents the results of each IEQ parameter's field measurements and the focus groups in correlation. Although the inpatient unit is divided into four wings (Figure 2), the results consider the different rooms' types, elevations, and time of day in some cases, rather than the wing they are located in. Key information regarding the field visit can be seen in Figure 2. In the case of patients and visitors, they are always assigned to specific rooms during their stays. Whereas nurses and resident doctors move around different rooms to check on the different patients. For this reason, nurses and resident doctors were considered one user party during the subjective data analysis, and patients and visitors were the second user party. The assessment results are as follows:

4.1 Thermal Comfort

The IEQ factors measured for thermal comfort's objective assessment are temperature and relative humidity (RH), the results of which are as follows:

4.1.1 Temperature

Across all four elevations, the average temperature is 24.03±1°C, whereas the minimum and maximum are 22.30±1°C and 28.10±1°C, respectively. According to the CDC (2019) Standards that the hospital follows, in addition to ASHRAE Standard 170 (2019), the acceptable range for temperature inside patient rooms is 21 to 24 °C. While considering the measurement tool's error rate, the temperature in the northeast and northwest elevations mainly falls within the acceptable range, whereas in the southeast and southwest elevations temperature reaches higher levels (Figure 3).

As for the subjective assessment, except for the northeast elevation, the subjective temperature ratings seem to have an inverse relationship with both the average and median field measurements, with the southwest elevation having the highest recorded measurement and the lowest user rating. Although the rating was relatively positive ($R \geq 3.25$), it was rated more positively by the patients and visitors than by the nurses and resident doctors. Furthermore, some of the users vocally complained that the room temperature was sometimes too cold.

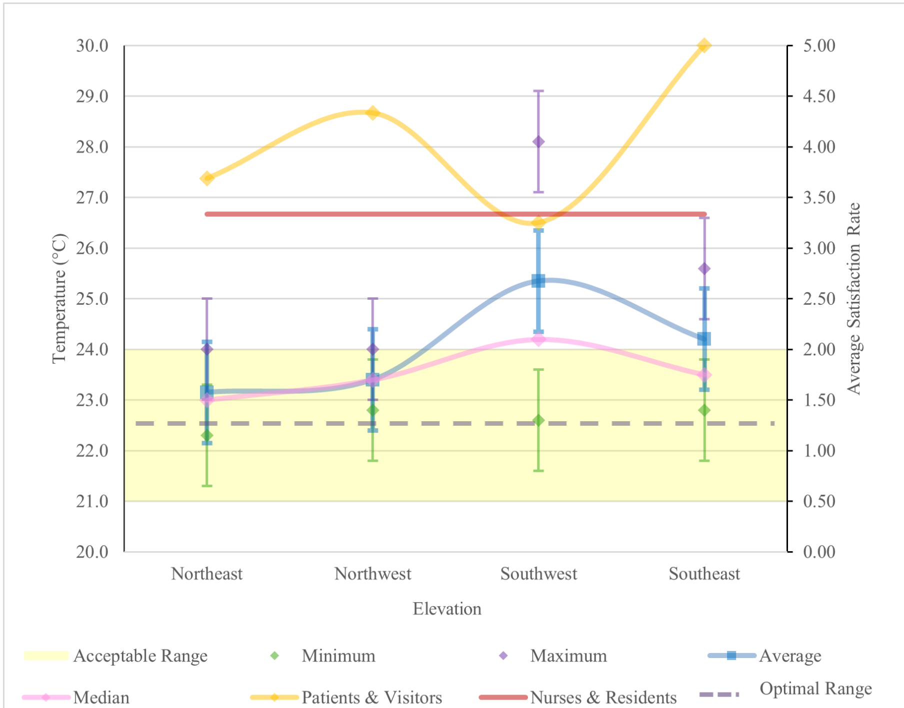

Figure (3).Temperature measurements by elevation (Author, 2024).

4.1.2 Relative Humidity

As for RH's average across all room types is 52.52±5%, whereas the minimum and maximum are 40.80±5% and 58.50±5%, respectively. The CDC (2019) Standards do not list a specific RH range for patient rooms, whereas in most other rooms it lists the acceptable range as 30 – 60%. ASHRAE Standard 170 (2019) also lists the acceptable range as having a maximum of 60% without specifying a minimum. RH levels across all room types fall within the acceptable range without including the error rate (Figure 4).

The subjective assessment of RH considers the stuffiness of air, which is also a factor of IAQ. In the subjective assessment, RH was rated slightly above average by both user parties (3.0≤R<4). Like temperature, the users' ratings share an inverse relationship with both the median and average measurements, with smaller rooms receiving higher user ratings due to their lower RH levels.

While temperature levels affect the spreading of bacteria, RH affects the potential for germs and viruses to grow and survive. RH also affects the dryness of the skin, which itself can lead to further problems for all hospital building users (Vijaykrishna & Balaji, 2023).

4.2 Acoustic Comfort

In the case of acoustic comfort, sound pressure was the only IEQ factor assessed. According to the U.S. Environmental Protection Agency (1974, as cited in Nyembwe et al., 2023), the standard for A-weighted sound pressure differs between daytime and nighttime. The daytime maximum is 45 dBA, whereas the nighttime maximum is 35 dBA. According to the measurements, the overall average across all three-room types is 60.33±1.5 dBA, whereas the minimum and maximum are 85.20±1.5 dBA and 37.60±1.5 dBA, respectively (Figure 5).

Across all room types, the averages exceed the standards, while the medians partly fall within acceptable daytime ranges. Surprisingly, rooms with higher recorded measurements received higher ratings by patients and visitors (3.5<R<4.25), with user satisfaction and average measurement sharing a direct relationship. On the other hand, the median measurement shares an inverse relationship with the user satisfaction ratings.

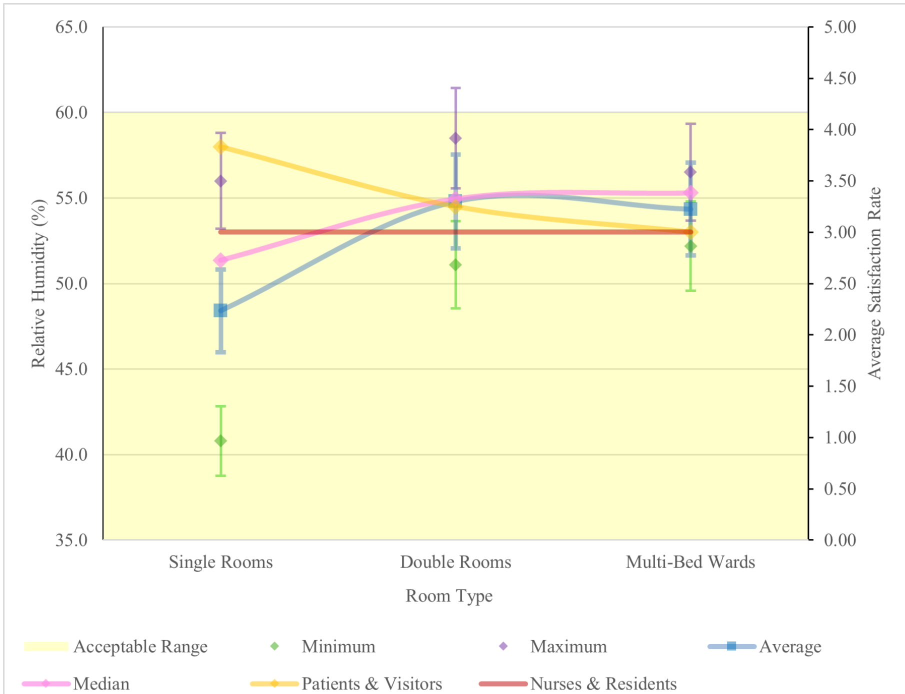

Figure (4). Relative Humidity measurements by room type (Author, 2024).

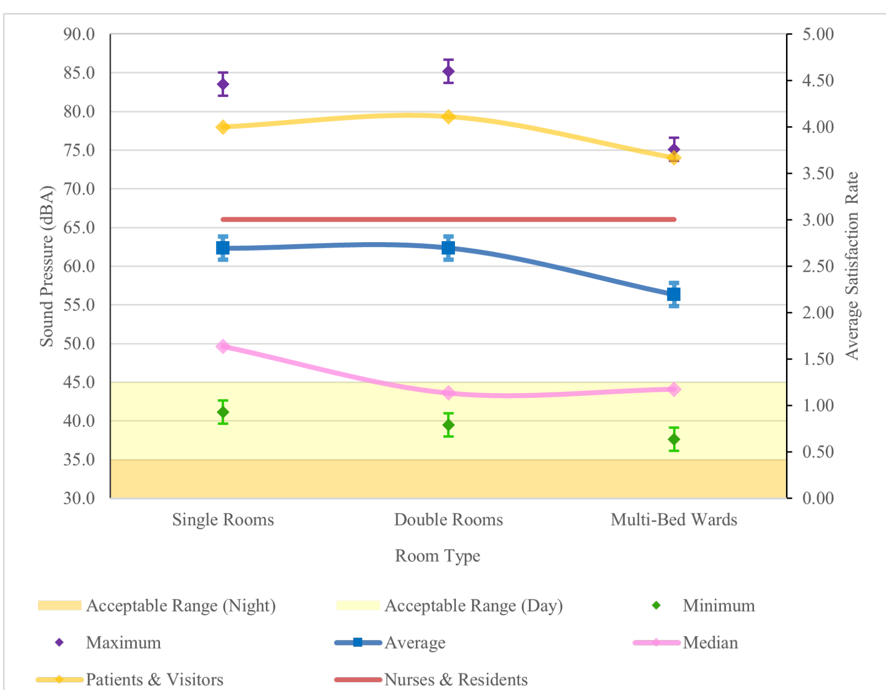

Figure (5). Sound pressure measurements by room type (Author, 2024).

Since this study only included vacant rooms, this discrepancy is most likely due to sharp noises occurring from outside the rooms during measurement, which may skew the average to higher levels. In this case, the median may represent the data more accurately than the average. As for user complaints, both user parties focused mainly on people talking outside the rooms as the most prevalent source of noise, followed by equipment, such as trolleys, and finally HVAC systems.

Although loud noises can affect patients' quality of rest and healing process (WHO, 1995, as cited in Secchi et al., 2022), they can also affect staff members' stress levels and work performance (Bayo et al., 1995, Montes-Gonzalez et al., 2019, as cited in Secchi et al., 2022), which may in turn affect patients as the staff members attend to them.

4.3 Indoor Air Quality

The objective assessment of IAQ focused only on CO2 concentration and is presented for each available room type (Figure 6). The average across all 3 room types is 421.83±5% ppm, whereas the minimum and maximum are 400±5% ppm and 465±5% ppm, respectively. According to the Pan American Health Association and WHO (2017), CO2 levels less than 600 ppm are acceptable. Whereas the Federation of European Heating, Ventilation, and Air Conditioning Associations list the standard as less than 550 ppm (2022, as cited in Smyth, 2022).

All measurements of CO2 fall within the range of the standards. Furthermore, the user satisfaction rates of patients and visitors (4.0≤R<4.25) directly correlate with the average measurements, decreasing with room size. On the other hand, the median shares an irregular relationship with the satisfaction rates, where it increases with room size and then decreases to its lowest recorded point. The nurses and resident doctors gave above-average ratings (R=3.64). According to the focus groups, a few users were not satisfied with the air inside the rooms, stating that it was stuffy and held unpleasant odors.

IAQ and thermal comfort are connected based on the previously mentioned relationship between temperature, RH, bacteria, and viruses, where the bacteria and viruses can travel through the air between all hospital building users. However, increased CO2 levels in closed spaces such as inpatient rooms can cause drowsiness, headaches, and other health risks that can affect patients' recovery processes (Wisconsin Department of Health, 2023).

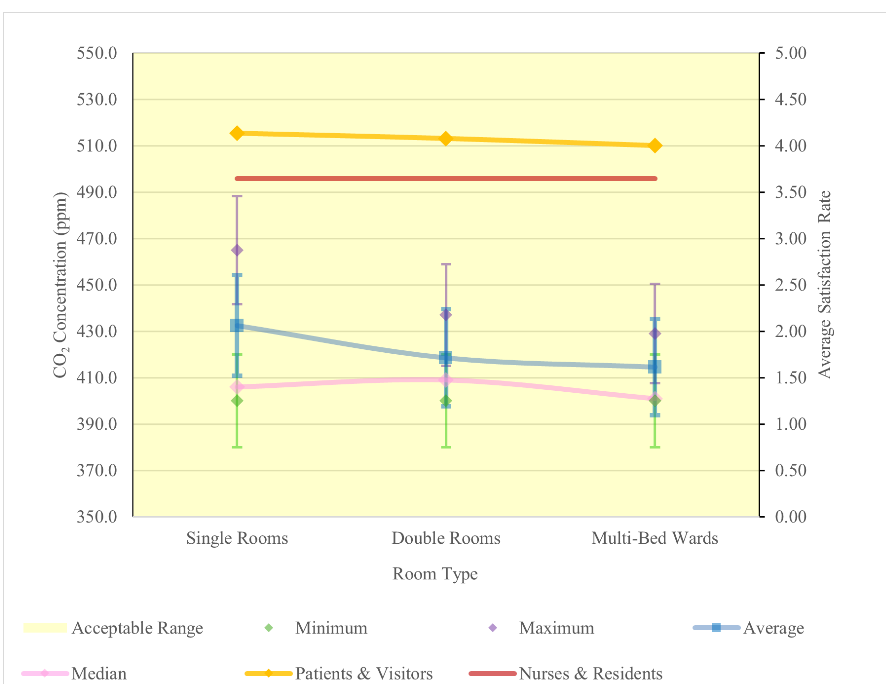

Figure (6). CO2 concentration measurements by room type (Author, 2024).

4.4 Visual Comfort

In the case of visual comfort's objective assessment, two IEQ factors were chosen: natural and artificial illuminance.

4.4.1 Natural Illuminance

The overall average across all four elevations for natural illuminance is 75.13±3% lx, whereas the minimum and maximum are 1.70±3% lx and 241.00±3% lx, respectively (Figure 7). The acceptable range of ambient lighting as per ANSI and Illuminating Engineering Society Standard 29-22 is 100 lx (2022, as cited in US Department of Veteran Affairs, 2022). The averages of the northwestern and southwestern elevations barely fall within the acceptable range, whereas the other two elevations have lower averages.

The satisfaction rates for natural illuminance share an inverse relationship with the median measurements and a mostly inverse relationship with the average that starts as a direct relationship in the northeastern elevation. The southwestern elevation was rated the lowest (R=2.33). Otherwise, ratings by the patients and visitors are positive (4.0<R≤4.75). Nurses and resident doctors, however, gave below-average ratings (R=2.87).

Finally, shading devices were inconsistent. Some rooms had louvers, some even had broken controls, and others had semi-transparent curtains. Despite this, user complaints about direct sunlight and sun glare were minimal.

4.4.2 Artificial Illuminance

As for artificial illuminance, the overall average across all room types for artificial illuminance is 481.98±3% lx, while the minimum and maximum are 13.40±3% lx and 1098.00±3% lx respectively (Figure 8). Although the acceptable range for ambient lighting is the same as natural illuminance, multiple acceptable ranges are depending on the task as per ANSI and Illuminating Engineering Society Standard 29-22 (2022, as cited in US Department of Veteran Affairs, 2022). The general range is between 100 and 400 lx, the recommended light for reading is 400 lx, and the examination light nurses must be around 1000 lx.

Only rooms with fully functional artificial lighting were included in this assessment, and the measurements were taken at the center of each assessed room. Artificial illuminance is much closer to the standards than natural illuminance. However, the multi-bed rooms seem to fall behind.

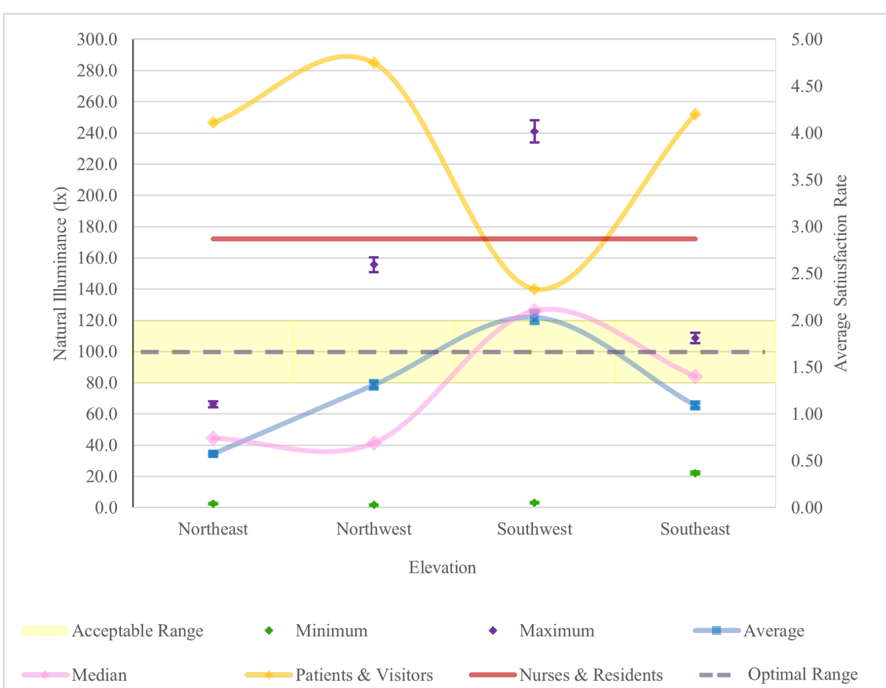

Figure (7). Natural illuminance measurements by elevation (Author, 2024).

User satisfaction rates (3.50<R<4.75) for the patients and visitors are directly related to the average and median. The ratings by patients are highest in double rooms(R=4.56), which is most likely due to them being well distributed inside the rooms, whereas in most single bedrooms (R=4.33) the lights are too close to the beds. On the other hand, the lights in multi-bed rooms (R=3.67) are spread out to make the wards feel darker than other rooms.

Unlike natural illuminance, there were more user complaints regarding artificial illuminance as a source of discomfort. However, most users who complained were nurses and resident doctors, who gave below-average ratings (R=2.87).

The subjective assessment of visual comfort also covered interior design and outside views, both of which received surprisingly acceptable ratings from the users, although there were some issues, such as:

- The nurses vocally complained about the interior design and decorations, stating that it requires a revamp.
- Some patients and visitors also complained about the cleanliness of the walls, floors, and curtains (in multi-bed rooms).
- Some rooms had beds facing walls instead of TVs or windows.
- Most rooms were severely lacking in interior design elements.
- Some rooms had shading devices with broken controls, meaning they were stuck and could not be opened or closed to allow or prevent daylight inside the rooms.

The different IEQ factors of visual comfort enhance the users' experience inside the building. For example, natural views from within an inpatient room can ease patients patients stay and help them discharged faster from a hospital than other patients whose rooms lack views (Ulrich, 1983, as cited in Mahmood and Tayib, 2021).

4.5 Research Limitations

Before concluding the research's findings in the form of design guidelines and recommendations, the following are the most notable restrictions that had a significant impact on the study:

The hospital's administration has a rule against leaving measurement devices unattended inside hospital spaces, meaning that devices that take measurements automatically at set time intervals could not be used in the study, as explained in Section 3: Methodology.

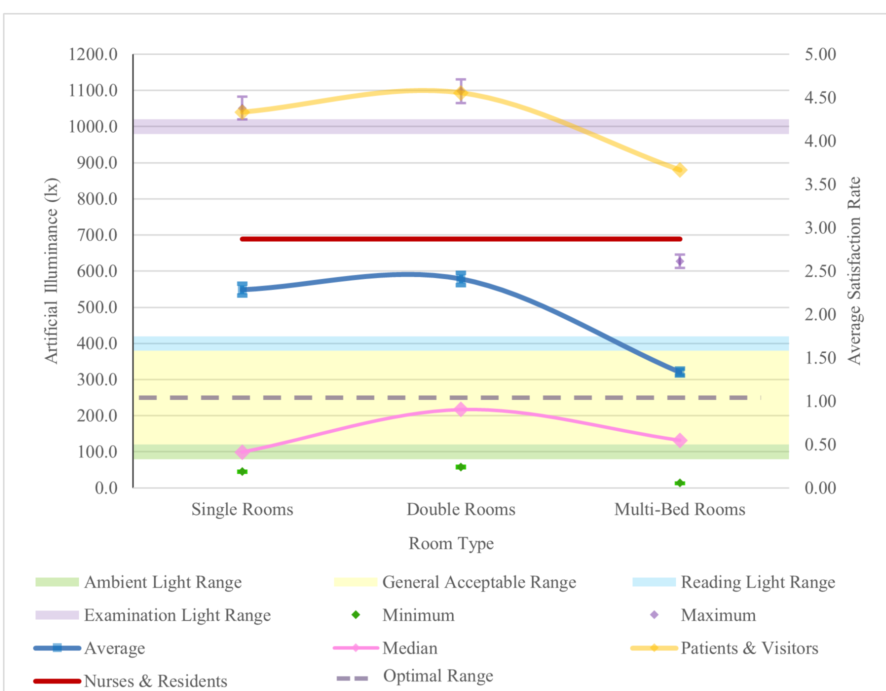

Figure (8). Artificial illuminance measurements by elevation (Author, 2024).

Table (7). Objective and subjective assessments correlation matrix (Author, 2024).

Subjective Assessment: Focus Group Questions		Code[*]	Objective Assessment: IEQ Field Measurements — Thermal: Temperature (T)	Thermal: Relative Humidity (RH)	IAQ: CO_2 Concentration (CO_2)	Acoustic: Sound Pressure (SP)	Visual: Natural Illuminance (NL)	Visual: Artificial Illuminance (AL)	Correlation Type (Direct/ Inverse)	Correlation
Thermal	Temperature	T.1		T.1-RH					DIR	The capacity of air to hold moisture increases as temperature increases (University of Kentucky, 2024).
IAQ	Airflow	I.1				I.1-SP			DIR	Increased airflow from HVAC units increases sound pressure (Fausti et al., 2019).
			I.1-T						INV	Airflow and temperature share an inverse relationship (Zhang et al, 2015; Stanmech Technologies, 2016).
				I.1-RH	I.1-CO_2				INV	Increased airflow decreases the amount of moisture and pollutants in an indoor environment (WHO, 2009).
	Air Stuffiness	I.2		I.2-RH	I.2-CO_2				DIR	Both air stuffiness and unpleasant smells are variables affected by increased RH (Wisconsin Department of Health, 2023) and CO_2 (Reinikainen et al., 1997, Reinikainen and Jaakkola, 2003, as cited in Wolkoff, 2018).
	Unpleasant Smells	I.3		I.3-RH	I.3-CO_2					
Acoustic Comfort	Comfort in Sleep	A.1				A.1-SP			INV	Increased noise sources, such as people talking and airflow, can cause users to feel less comfortable in sleep (Dubose and Hadi, 2016).
							A.1-NL		DIR	Increased exposure to direct sunlight can allow patients to sleep more comfortably at night due to it positively affecting the circadian rhythm (Roenneberg et al., 2003, as cited in Blume et al., 2019; DuBose and Hadi, 2016).
								A.1-AL	INV	Artificial light can affect the circadian rhythm in different ways (Wright et al., 2013, as cited in Blume et al., 2019; Vethe et al., 2020).
Visual Comfort	Natural Lighting	V.1	V.1-T						DIR	Exposure to direct sunlight increases temperature and affects thermal comfort (Arens et al., 2018).
				V.1-RH					DIR	Direct sunlight increases temperature, which in turn increases relative humidity.
	Artificial Lighting	V.2	V.2.T						DIR	Non-dimmable artificial lighting can generate indoor heat (Ahn et al., 2014).
	Interior Design	V.3					V.3-NL	V.3-AL	DIR	Using lighting when designing a hospital's environment can positively impact patients' wellbeing (Dijkstra et al., 2006, Oberlin, 2008, as cited in Aljunid et al., 2020).
	Outside Views	V.4					V.4-NL		DIR	Outside views of nature can aid patients' recovery (Ulrich, 1983, as cited in Mahmood and Tayib, 2021).

[*] The codes shown in gray highlights are combinations of the individual codes given to each objective and subjective assessment element found under the 'Code' row and column. For example, 'T.1-RH' is a combination of the codes 'T.1' representing 'Temperature' as a subjective assessment element, and 'RH' representing 'Relative Humidity' as an objective assessment element. The explanation of the correlation between these two elements is found in the 'Correlation' column.

Furthermore, the targeted spaces in the assessed building received cuts in the number of staff members, which reduced the study's targeted population further, which was also explained in Section 3: Methodology.

Additionally, the objective assessment in this study measured six primary IEQ factors under the four main parameters of IEQ. In order to develop more generalized IEQ-focused design guidelines, additional, less tested IEQ factors, such as volatile organic compounds and Carbon Monoxide, should also be assessed through field measurements and compared with the standards, which requires additional time and resources.

Finally, this study assessed inpatient spaces in a single building and used the assessment data to improve the same building via developed design guidelines. However, in order to produce even more generalized IEQ-focused design guidelines that can be applied to various hospital buildings, assessments of multiple buildings are necessary, which require an extensive amount of time and resources.

4.6 Development of IEQ-Focused Design Guidelines and Recommendations

After discussing the research's findings, the guidelines and recommendations were concluded in the form of a matrix showcasing the different correlations between the measured IEQ factors and the elements included in the focus group questions (Table 7). Each correlation is given a code based on its corresponding IEQ factors and subjective elements. The type of correlation is then specified as 'Direct' or 'Inverse'. Finally, the correlation is then further explained through literature.

After understanding where exactly the correlations between the various IEQ factors lie, design guidelines and recommendations that consider these correlations can be concluded (Table 8) utilizing the same codes as Table 7.

Table (8). Concluded guidelines based on the correlation matrix (Author, 2024).

Code	IEQ- Focused Design Guidelines and Recommendations
T.1-RH I.1-SP I.1-T I.1-RH I.1-CO_2 I.2-RH I.2-CO_2 I.3-RH I.3-CO_2	1) Providing individual control over HVAC within acceptable standard limits while allowing nursing staff to monitor the controls remotely should allow users to adjust the AC unit's temperature and airflow strength without negatively affecting the indoor environment. This allows users to gain more control over their environment inside the rooms, which affects their psychological comfort and satisfaction (Mahmoud and Tayib, 2021).
A.1-SP	2) In addition to HVAC control to limit airflow noise, acoustic insulation, such as absorptive ceilings and carpets, has been proven to increase user satisfaction (Deng et al., 2023).
A.1-NL	3) In the case of rooms that lack direct sunlight, simulated daylight can be implemented to positively affect users' circadian rhythm and improve their sleep and general mood (Giménez et al., 2011, as cited in DuBose and Hadi, 2019; Vethe et al., 2020).
A.1-AL	4) Distributing artificial lighting throughout the rooms, instead of being focused above beds, can increase the satisfaction level of users (DuBose et al., 2022).
V.1-T V.1-RH	5) Implementing different types of controllable shading devices, such as louvers and curtains, can allow users to control the amount of sunlight entering their rooms (Tabasi and Banihashemi, 2022, as cited in Toodekharman et al., 2023).
V.2.T	6) Implementing dimmable artificial lighting to control the increase in temperature (Ahn et al., 2014).
V.3-AL V.3-NL	7) Utilizing a combination of guidelines 3-6, in addition to allowing users to personalize their rooms by adding furniture items such as cupboards can make users feel more at home, which improves their general mood and recovery process (De Vos, 2004, as cited in Pinhão, 2016).
V.4-NL	8) Planting gardens in single-bedroom terraces and the roofs of other buildings to create natural views (Wang and Tzortzi, 2023) or (9) Utilizing virtual images of nature as distractions for the users (Vincent et al., 2010).

5. Conclusions

This research was conducted to address the lack of focus on IEQ in Saudi Arabia's hospital design guidelines, where IEQ is not considered alongside the quality and safety of provided services. By conducting objective and subjective assessments on a relatively old hospital building's inpatient department, the research's findings show that the current level of IEQ in the inpatient wards is inconsistent between the various assessed IEQ factors, whether objectively compared with international standards or subjectively when occupant satisfaction is measured. The main goal this research set out to achieve was accomplished in the form of IEQ-focused design guidelines that can help increase the level of occupant satisfaction. Furthermore, this research can serve as a starting point for CBAHI to advance the development of local hospital design guidelines by integrating this study's results with their already existing quality and safety standards.

Finally, this research also highlights the importance of occupant comfort and its relationship with design and IEQ in hospitals and all other building types. This can ultimately encourage CBAHI, the Saudi Building Code National Committee, and the Ministry of Health to consider IEQ in their future hospital standards.

6. Future Studies

In terms of applications of this study, one way the concluded guidelines can be utilized is through implementation on part of the inpatient wards as a trial, followed by reassessment using similar methods after enough time has passed. Another way is to design a virtual model that applies these guidelines and then simulate it through software to test the guidelines' effectiveness.

As for further research, on a local scale, IEQ assessments that include varying IEQ factors, a larger number of participants and user groups, and even multiple buildings are recommended to produce design guidelines that can be standardized and applied to various hospital buildings.

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تقييـــم جـــودة البيئـــة الداخليـــة لأجنحـــة التمريـــض بمستشـــفى عـــام في جـــدة، المملكـــة العربيـــة الســـعودية

حسين أسامة المنصوري **جميل فريد حجازي**

قسم العمارة، كلية العمارة والتخطيط، جامعة الملك عبد العزيز، جدة، المملكة العربية السعودية

hhussainalmansouri@stu.kau.edu.sa *jhijazi@kau.edu.sa*

قدم للنشر في ١٥/ ١١/ ١٤٤٥ هـ؛ وقبل للنشر في ١٠/ ٤/ ١٤٤٦ هـ

ملخص البحث. تعد جودة البيئة الداخلية أكثر أهمية في المستشفيات من المباني الأخرى نظراً لتأثيرها على سرعة تعافي المرضى. وهناك نقص في الضوابط التصميمية للمستشفيات في المملكة العربية السعودية من حيث التركيز على جودة البيئة الداخلية، وهو ما يجعل من الصعب تصميم الفراغات التي توفر مستويات كافية من الراحة للمستخدمين. بناءً على ذلك، تم في هذه الدراسة إجراء تقييمات موضوعية باستخدام قياسات لبعض عناصر جودة البيئة الداخلية، وتقييمات غير موضوعية عن طريق مجموعات النقاش المركزة، على أجنحة التمريض بمستشفى عام في مدينة جدة، المملكة العربية السعودية؛ بهدف تطوير ضوابط تصميمية تركز على جودة البيئة الداخلية وتوفر للمستخدمين نسبة أعلى من الراحة. استهدف التقييم الموضوعي المعايير الأربعة الرئيسة لجودة البيئة الداخلية، وهي: الراحة الحرارية، والصوتية، والبصرية، وجودة الهواء الداخلي. في المقابل، استهدف التقييم غير الموضوعي المعايير الأربعة ذاتها من خلال قياس مستوى الرضا لثلاث مجموعات من مستخدمي المستشفى: المرضى والزوار كمجموعتين مستقلتين، وطاقم التمريض والأطباء المقيمين كمجموعة واحدة. وبعد تحليل نتائج التقييمين بشكل مترابط، تم استنتاج أن الراحة الحرارية وجودة الهواء الداخلي كانت الأكثر قبولاً، بينما حازت الراحة البصرية والصوتية على نسبة رضا أقل. تم بعد ذلك تطوير ضوابط تصميمية مستهدفة مبنى المستشفى الذي تم تقييمه بناءً على المشاكل التصميمية المتعلقة بجودة البيئة الداخلية، والتي تم التوصل إليها بعد تحليل النتائج.

الكلمات المفتاحية: جودة البيئة الداخلية، الراحة الحرارية، الراحة الصوتية، الراحة البصرية، جودة الهواء الداخلي، أجنحة التمريض.