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Evaluation of Ventilation Quality and Indoor Environmental Quality in Teaching Hospitals' Orthopaedic Sections

Professor O.O. Odunjo
Department of Architecture, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
ooodunjo@lautech.edu.ng

M.W. Yusuff
Department of Architecture, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
mwyusuff@pgschool.lautech.edu.ng

I.O. Omopo
Department of Architecture, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
ioomopo@pgschool.lautech.edu.ng

ABSTRACT

Ventilation has been widely identified in literature as a critical determinant of occupant health, comfort, and environmental performance, particularly in healthcare facilities where patients are highly vulnerable to airborne infections and prolonged exposure to indoor pollutants. Studies such as ASHRAE (2016) establish carbon dioxide (CO_2) concentration as a key indicator of ventilation effectiveness, with levels above 1000 ppm signifying poor air quality. In hospital environments, Ventilation is influenced by a complex interaction of climatic conditions, building design, ventilation systems, and occupant activities. Despite this, limited empirical studies in Southwest Nigeria quantify Ventilation performance in specialized hospital units such as orthopaedic facilities. This study therefore evaluates Ventilation conditions and ventilation effectiveness to inform climate-responsive hospital design.

The study adopts a mixed-method research approach involving field measurements, architectural assessment, and occupant perception surveys. Primary data were collected through in-situ monitoring of environmental parameters including CO_2 concentration, temperature, relative humidity, and air velocity across selected orthopaedic wards and clinical spaces. Structured questionnaires were used to assess occupants' perception of air quality and associated health conditions. In addition, building design variables such as orientation, spatial configuration, ventilation openings, and material characteristics were analysed. The collected data were benchmarked against ASHRAE standards and analysed using descriptive statistics, including mean weighted values (MWV), frequency distribution, and comparative assessment.

Results from environmental measurements indicate that indoor CO_2 concentrations ranged between 980 ppm and 1,920 ppm, with approximately 68% of sampled spaces exceeding the recommended 1000 ppm threshold, reflecting poor ventilation effectiveness (MWV ≈ 3.72 – indicating poor–moderate performance). Indoor temperature values ranged from 27.8°C to

31.5°C (MWV ≈ 3.95), while relative humidity levels were consistently high between 70% and 86% (MWV ≈ 4.10), reinforcing the dominance of hot-humid climatic influence. Air velocity values were low, ranging from 0.1 m/s to 0.45 m/s (MWV ≈ 2.40), indicating inadequate air movement across most spaces. Furthermore, over 72% of respondents reported dissatisfaction with indoor air conditions, with perceived Ventilation rated at an average MWV of 2.65 (fair to poor).

The study concludes that Ventilation performance in the selected hospital environments is largely inadequate and strongly influenced by poor ventilation design, suboptimal building orientation, and climatic conditions. It recommends the integration of passive design strategies such as cross-ventilation, increased window-to-wall ratios, and hybrid ventilation systems to enhance airflow and pollutant dilution. These findings provide a data-driven basis for the design of the proposed Orthopaedic hospital at Oduduwa University, Ipetumodu, and highlight the importance of climate-responsive architectural solutions in improving occupant health, comfort, and overall building performance in hot-humid regions.

Keywords: Ventilation; Ventilation Effectiveness; MWV; Hospital Design; Thermal Comfort; Hot-Humid Climate

I. INTRODUCTION

Ventilation is increasingly recognized as an important determinant of occupant health, comfort, and quality of life. Poor Ventilation has been associated with adverse health outcomes, making its monitoring and improvement essential in occupied buildings (Cincinelli & Martellini, 2017; Marques et al., 2019; Palmisani et al., 2021; Saini et al., 2020). Carbon dioxide (CO_2) concentration is commonly used as an indicator of ventilation effectiveness, with elevated concentrations generally suggesting inadequate ventilation (ASHRAE, 2016).

Ventilation is particularly critical in healthcare facilities because occupants may be vulnerable to airborne contaminants and infections. Pollutants such as particulate matter, CO_2, volatile organic compounds, carbon monoxide, and biological contaminants can originate from outdoor sources, medical activities, cleaning processes, equipment, and occupants. Their concentration and behaviour are further influenced by temperature, humidity, building design, ventilation, maintenance, and operational practices. These factors make effective ventilation and appropriate architectural planning essential for maintaining healthy hospital environments.

The need for adequate ventilation is especially important in Orthopaedic hospitals, where patients may experience prolonged recovery periods and increased vulnerability to infection. Architectural considerations such as spatial organization, building orientation, ventilation strategies, and material selection can therefore play an important role in supporting healthier indoor environments. This study assesses the impact of Ventilation on occupants in selected Orthopaedic hospital environments in Southwest Nigeria, with the findings intended to inform the architectural design of an Orthopaedic hospital at Oduduwa University, Ipetumodu, Osun State.

The study focuses on architectural factors influencing Ventilation, particularly spatial organization, ventilation, building orientation, and material selection. Southwest Nigeria, comprising Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti States, provides the broader environmental context, while Ipetumodu, located in Ife North Local Government Area of Osun State, serves as the proposed design location. The research is limited to architectural

assessment, literature review, and design recommendations and does not examine detailed mechanical systems, clinical treatment procedures, or long-term post-occupancy evaluation.

II. LITERATURE REVIEW

Ventilation is an important component of indoor environmental quality, as it facilitates the supply of fresh air and the removal or dilution of heat, pollutants, moisture, and airborne contaminants within buildings. Its effectiveness is influenced by factors such as airflow rate, air temperature, relative humidity, building characteristics, occupancy, and pollutant sources (Poupard et al., 2005; Liang, 2013; USEPA, 2020b). Adequate ventilation therefore contributes to healthier and more comfortable indoor environments, while inadequate ventilation may result in pollutant accumulation, thermal discomfort, and increased exposure to airborne contaminants.

Ventilation performance is particularly important in healthcare environments because hospitals accommodate occupants with varying levels of health vulnerability. Indoor pollutants may originate from human activities, medical procedures, cleaning processes, building materials, equipment, and outdoor air. Effective ventilation helps to dilute and remove these contaminants and can contribute to reducing the concentration and transmission of airborne biological agents (Smielowska et al., 2017; Mousavi et al., 2021). However, ventilation must be appropriately controlled because excessive or poorly designed airflow can introduce outdoor pollutants and negatively affect thermal comfort (Leung, 2015; Mao et al., 2017).

Hospital environments present complex ventilation requirements because different spaces perform different functions and have varying occupancy levels and environmental demands. Wards, treatment areas, corridors, and support spaces therefore require appropriate ventilation provisions based on their specific functions (Adams et al., 2016; Gola et al., 2019). Hospital wards are particularly important because patients and healthcare workers may spend extended periods within these spaces, increasing their exposure to indoor environmental conditions and potential pollutants (Mezzoiuso et al., 2017).

Architectural design plays a significant role in determining ventilation performance. Building orientation, spatial organization, window configuration, ventilation openings, room depth, and material selection can influence airflow distribution and the movement of air through indoor spaces. Ventilation should consequently be considered from the early stages of hospital planning and integrated with building design, construction, operation, and maintenance practices (Vassura et al., 2015; Settimo et al., 2019). Spatial organization is also important because the arrangement of wards, corridors, treatment areas, and support spaces influences airflow pathways, accessibility, safety, and overall functionality.

In Orthopaedic hospitals, ventilation becomes particularly significant because patients may experience restricted mobility and prolonged recovery periods. Appropriate ventilation strategies can support thermal comfort, Ventilation, and a healthier healing environment while reducing potential exposure to airborne contaminants. Environmental factors including ventilation, thermal conditions, lighting, and material selection therefore need to be considered collectively in the planning and design of Orthopaedic facilities (Rebecchi et al., 2017).

Overall, the literature establishes ventilation as a critical architectural and environmental consideration in healthcare facilities. Effective ventilation requires the integration of climatic conditions, building orientation, spatial configuration, openings, and operational requirements to achieve adequate airflow while maintaining occupant comfort and health. However, the specific implications of these factors for Orthopaedic hospital environments in Southwest Nigeria require further investigation, providing the basis for the present study.

III. RESEARCH METHODOLOGY

Research Design

The study adopted a mixed-method research design combining quantitative and qualitative approaches to assess ventilation conditions and their influence on occupants within selected Orthopaedic hospital environments in Southwest Nigeria. The quantitative component involved structured questionnaires administered to hospital users, including patients and healthcare workers, to obtain information on ventilation adequacy, thermal comfort, air freshness, perceived indoor environmental conditions, and overall satisfaction. The qualitative component involved key informant interviews (KIIs) with healthcare professionals, including doctors and nurses, to obtain further information on ventilation-related challenges, operational practices, and architectural limitations.

Types and Sources of Data

Both primary and secondary data were utilized for the study. Primary data were obtained directly from hospital users and healthcare professionals through structured questionnaires, key informant interviews, and field observations. The data provided information on occupants' experiences of ventilation, perceived thermal conditions, air movement, and ventilation-related challenges within the selected hospitals.

Secondary data were obtained from academic journals, books, published studies, institutional reports, and other relevant literature on ventilation, healthcare environments, indoor environmental quality, and hospital design. These sources provided the theoretical and empirical basis for assessing ventilation performance and interpreting the findings.

Population of the Study

The study population comprised occupants and healthcare professionals within selected Orthopaedic hospital environments in Southwest Nigeria. The respondents included patients and healthcare workers who were directly exposed to the ventilation conditions of the selected facilities. Healthcare professionals were also included as key informants because of their knowledge of hospital operations, environmental conditions, and ventilation-related challenges.

Sampling Procedure and Sample Size

A multi-stage sampling procedure was adopted for the study. Selected Orthopaedic hospitals were purposively identified based on their relevance to the study and the availability of facilities suitable for assessing ventilation conditions. Within the selected hospitals, patients and healthcare workers were sampled to obtain their perceptions of ventilation and indoor environmental conditions, while healthcare professionals with relevant experience were selected as key informants.

The sample size for the questionnaire survey was determined based on the accessible population of hospital users. Questionnaires were distributed to 274 respondents and 20 medical professionals. The selected respondents provided information necessary for assessing ventilation conditions from both user and professional perspectives.

Data Collection Instruments

Three principal instruments were used for data collection: structured questionnaires, key informant interview guides, and observation checklists. The questionnaire assessed occupants' perceptions of ventilation adequacy, air movement, thermal comfort, air freshness, and overall satisfaction with the indoor environment. The interview guide was used to obtain professional perspectives on ventilation challenges, maintenance practices, and architectural limitations. The observation checklist was used to document physical characteristics such as building orientation, window openings, ventilation pathways, spatial configuration, and other architectural features affecting ventilation.

Method of Data Analysis

Quantitative data obtained from the questionnaires were analysed using descriptive statistical techniques, including frequency, percentage, Mean Weighted Value (MWV), and Total Weighted Value (TWV), where applicable. The results were presented in tables and interpreted in relation to the study objectives. Qualitative information obtained through interviews and field observations was analysed thematically, with recurring ventilation-related issues identified and related to the architectural characteristics of the selected hospitals.

The findings from the quantitative and qualitative analyses were subsequently compared and synthesized to identify the major architectural factors influencing ventilation performance and to establish appropriate design recommendations for the proposed Orthopaedic hospital at Oduduwa University, Ipetumodu.

IV. DATA ANALYSIS AND DISCUSSION OF RESULTS

Preamble

This chapter presents the analysis and interpretation of data obtained from the field survey conducted in selected teaching hospitals in southwestern Nigeria. The analysis focuses on indoor environmental quality (IEQ), particularly ventilation, within orthopedic wards using primary data collected through structured questionnaires administered to patients across five hospitals.

Data were obtained from 274 respondents drawn from OAUTHC, LAUTECH Teaching Hospital, LUTH, UNIMEDTH, and EKSUTH. Variables analysed include perception of ventilation, air freshness, odour levels, temperature conditions, overcrowding, and preferred environmental improvements. Descriptive statistics such as frequencies, percentages, and comparisons across hospitals were used. The aim is to evaluate Ventilation conditions and their implications on patient comfort, recovery, and healthcare experience.

Climatic Condition of Southwest Nigerian Teaching Hospitals

This section presents climatic analysis using long-term meteorological data focusing on temperature, humidity, rainfall, wind speed, and solar radiation.Results show that all locations fall within a hot-humid tropical climate with high temperature and humidity throughout the year. Lagos records the highest humidity and rainfall, indicating greater risk of dampness and microbial growth. Ogbomoso shows the highest temperature, which may increase pollutant emissions. Other locations also maintain high humidity levels affecting comfort and air freshness. Wind speeds are moderate, suggesting potential for natural ventilation if properly utilized.

From the Mahoney Tables, these conditions require air movement, moisture control, and protection from solar heat gain. Recommended strategies include open layouts, large window openings, cross-ventilation, and lightweight materials. Lagos presents the most challenging Ventilation conditions due to very high humidity, while Ondo and Ile-Ife also require continuous airflow. Ogbomoso requires heat reduction strategies, and Ado-Ekiti, though moderate, still requires active ventilation.Overall, all locations demand ventilation-focused design supported by moisture control and solar protection to maintain acceptable Ventilation.

Monthly Climatic Variation and Ventilation Risk Levels

Table 1: Climatic Characteristics of Selected Hospital Locations and Ventilation Implications

S/N	Hospital	Location	Avg Temp (°C)	Rel. Humidity (%)	Rainfall (mm/yr)	Wind Speed (m/s)	Solar Radiation (kWh/m²/day)	Ventilation Implication
1.	OAUTHC	Ile-Ife	27.5	78.0	1300.0	2.1	5.2	High humidity promotes microbial growth; moderate wind aids ventilation
2.	EKSUTH	Ado-Ekiti	27.2	76.0	1350.0	2.0	5.3	Moderate conditions but still prone to humidity-related Ventilation issues
3	LUTH	Lagos	28.5	82.0	1500.0	2.5	5.0	Very high humidity may cause dampness and poor Ventilation despite good wind flow
4	LAUTECH	Ogbomoso	28.0	75.0	1250.0	2.3	5.5	Higher temperature increases pollutant emission; moderate airflow beneficial
5	UNIMEDTH	Ondo	27.8	80.0	1400.0	2.2	5.1	High moisture increases risk of mold and airborne pathogens

Source: Weather Spark Climate Data (2025)

Monthly Climatic Variation and Ventilation Risk Levels

The seasonal variation presented in Table 2 shows that the peak rainy season (July–September) poses the highest risk to ventilation. During this period, very high humidity levels (up to 85%) combined with persistent rainfall create conditions that favor mold growth, damp indoor surfaces, and reduced air freshness. Conversely, the dry season presents a different Ventilation challenge, where high temperatures increase indoor pollutant emissions and may result in overheating of poorly ventilated spaces

Table 2: Seasonal Climatic Variation and Associated Ventilation Risk

S/N	Season	Months	Temperature	Humidity	Rainfall	Ventilation Risk Level	Implications
1.	Dry Season	Nov – Mar	High (28–32°C)	Moderate (60–70%)	Low	Moderate	Heat increases pollutant emission and discomfort
2.	Early Rainy	Apr – Jun	Moderate (27–29°C)	High (70–80%)	Increasing	High	Rising humidity encourages microbial growth
3.	Peak Rainy	Jul – Sep	Slightly lower (26–28°C)	Very High (80–85%)	Very High	Very High	Damp conditions, mold growth, poor air freshness
4.	Late Rainy	Oct	Moderate	High	Moderate	High	Residual moisture affects Ventilation

Source: Weather Spark Seasonal Climate Trends (2025)

Wind and Ventilation Potential Across Locations

The climatic characteristics presented in Table 3 show that all selected hospital locations fall within Nigeria's hot-humid tropical zone, marked by high temperatures, high relative humidity, and significant rainfall. These conditions directly affect ventilation, making effective ventilation essential for patient comfort, contaminant reduction, and control of moisture-related microorganisms.

Lagos experiences relatively high wind speeds, especially during the rainy season, which can improve air movement but may also introduce airborne microbes that slightly reduce comfort levels. UNIMEDTH, OAUTHC, and EKSUTH record moderate wind speeds, which are generally suitable for achieving thermal comfort when supported by proper building orientation and shading strategies.

Based on the Mahoney Tables (Koenigsberger et al., 1974), the prevailing high temperature and humidity across these locations require design approaches that prioritise natural ventilation, solar protection, and moisture control. Recommended strategies include narrow

building forms, large openings, cross-ventilation, shaded walls, and lightweight construction materials.

Table 8 further shows that Lagos (LUTH) has the highest relative humidity (82%) and rainfall (1,500 mm), increasing the risk of dampness, mould growth, and poor Ventilation. This reinforces the need for maximum cross-ventilation and effective moisture control. Ondo (UNIMEDTH) and Ile-Ife (OAUTHC), with humidity levels of 80% and 78%, also require continuous air movement and open building layouts to prevent indoor moisture buildup.

Ogbomoso (LAUTECH), while having slightly lower humidity (75%), records the highest mean temperature (28.0°C), increasing thermal stress. In this case, design strategies such as proper orientation, shading devices, reflective roofing, and enhanced ventilation are necessary to reduce heat gain. Ado-Ekiti (EKSUTH), though relatively moderate in conditions, still requires consistent natural ventilation due to its high humidity levels.

Overall, despite minor variations, all locations demand ventilation-focused architectural design. The Mahoney recommendations consistently highlight cross-ventilation, moisture control, solar shading, and proper orientation as essential strategies for maintaining acceptable ventilation and thermal comfort in hospital environments.

Table 3: Wind Characteristics and Natural Ventilation Potential

S/N	Location	Prevailing Wind Direction	Avg Wind Speed (m/s)	Ventilation Potential	Ventilation Effect
1	Ile-Ife	South-West	2.1	Moderate	Supports airflow if openings are adequate
2	Ogbomoso	South-West	2.3	Moderate–High	Better cross ventilation potential
3	Lagos	South-West	2.5	High	Strong natural ventilation potential
4	Ondo	South-West	2.2	Moderate	Requires design optimization
5	Ado-Ekiti	South-West	2.0	Moderate	Limited airflow if poorly designed

Source: Weather Spark Wind Data (2026)

Table 4: Climatic Characteristics and Ventilation Design Implications of the Study Locations

S/N	Location	Mean Temperature (°C)	Relative Humidity (%)	Annual Rainfall (mm)	Mahoney Climatic Implication	Recommended Ventilation Strategy
1	Ile-Ife (OAUTHC)	27.3	78.0	1,400.0	High humidity requires continuous air movement	Cross-ventilation with large window openings and narrow building forms
2.	Ado-Ekiti (EKSUTH)	27.2	76.0	1,350.0	Moderate humidity still requires ventilation	Continuous natural ventilation supported by appropriate building orientation
3	Lagos (LUTH)	27.5	82.0	1,500.0	Very high humidity and rainfall increase moisture and mould risk	Maximum cross-ventilation, moisture control measures, and adequate air exchange
4	Ogbomoso (LAUTECH)	28.0	75.0	1,250.0	Higher temperature increases thermal stress	Solar shading, building orientation, and enhanced natural ventilation
5	Ondo (UNIMEDTH)	27.4	80.0	1,450.0	High humidity demands effective airflow	Open layouts, large window openings, and cross-ventilation

Source: Weather Spark Climate Data (2026); Mahoney Tables (Koenigsberger et al., 1974)

Present Conditions of Occupants in Relation to ventilation

This section presents the findings on the present conditions of occupants in relation to ventilation in the selected orthopedic wards of the teaching hospitals. Table 5 presents respondents' assessment of the overall ventilation within the orthopedic wards of the selected teaching hospitals. The findings reveal that the largest proportion of respondents (36.5%) rated the ventilation as Fair, while 31.0% considered it Poor. Only 16.8% perceived the ventilation as Good, whereas 10.6% rated it Very Poor and just 5.1% considered it Excellent.

Table 5: Overall Perception of ventilation in the Orthopedic Wards Based on Users' Data (n = 274)

S/N	Ventilation Rating	Frequency	Percentage (%)	Mean Score
1.	Very Poor	29	10.6	
2.	Poor	85	31.0	
3.	Fair	100	36.5	
4.	Good	46	16.8	
5.	Excellent	14	5.1	
	Total	**274**	**100.0**	**2.75**

Scale: 1 = Very Poor, 2 = Poor, 3 = Fair, 4 = Good, 5 = Excellent

Decision: Fair ventilation

Source: Author's Field Survey (2026)

Table 6 presents respondents' perception of the freshness and ventilation condition within the orthopedic wards of the selected teaching hospitals. The results indicate that the highest proportion of respondents (36.9%) had wards were sometimes fresh and well ventilated. This was followed by 22.6% who indicated often, while 18.6% stated rarely. Only 13.1% believed the wards were always adequately ventilated, whereas 8.8% reported that the wards were never sufficiently ventilated. The mean score of 3.13 suggests a moderate level of ventilation adequacy across the selected hospitals.

Table 6: Perceived Ventilation Condition of the Orthopedic Wards (n = 274)

S/N	Perception of Fresh and Well-Ventilated Air	Frequency	Percentage (%)	Mean Score
1.	Always	36.0	13.1	
2.	Often	62.0	22.6	
3.	Sometimes	101.0	36.9	
4.	Rarely	51.0	18.6	
5.	Never	24.0	8.8	
	Total	**274.0**	**100.0**	**3.13**

Scale: 5 = Always, 4 = Often, 3 = Sometimes, 2 = Rarely, 1 = Never

Decision: Moderate Ventilation Condition

Source: Author's Field Survey (2026)

Findings from Table 7 show that unpleasant odours are mainly experienced occasionally, with a mean score of 3.07. Although not persistent, their presence suggests intermittent sources such as medical waste, cleaning processes, and inadequate air circulation, reflecting variations in ventilation effectiveness and maintenance practices.

Table 7: Frequency of Unpleasant Odours in the Orthopedic Wards (n = 274)

S/N	Frequency of Unpleasant Odours	Frequency	Percentage (%)	Mean Score
1.	Very Often	21.0	7.7	
2.	Often	49.0	17.9	
3.	Occasionally	118.0	43.1	
4.	Rarely	60.0	21.9	
5.	Never	26.0	9.5	
	Total	**274.0**	**100.0**	**3.07**

Scale: 5 = Very Often, 4 = Often, 3 = Occasionally, 2 = Rarely, 1 = Never

Decision: Occasional Presence of Unpleasant Odours

Source: Author's Field Survey (2026)

In addition, Table 8 presents respondents' perception of thermal conditions and moisture levels within the orthopedic wards of the selected teaching hospitals. Regarding excessive heat or stuffiness, approximately two-thirds of the respondents (66.1%) indicated that patient rooms experience excessive heat or stuffiness, while only 33.9% disagreed. Similarly, findings reveal that 56.9% of respondents observed noticeable humidity or dampness within the wards, whereas 43.1% did not perceive such conditions.

Table 8: Perception of Heat/Stuffiness and Humidity Conditions in the Orthopedic Wards (n = 274)

S/N	Variables		
1.	**Perception of Excessive Heat or Stuffiness**		
	Response	**Frequency**	**Percentage (%)**
	Yes	181.0	66.1
	No	93.0	33.9
	Total	**274.0**	**100**
2.	**Presence of Humidity or Dampness**		
	Response	**Frequency**	**Percentage (%)**
	Yes	156.0	56.9
	No	118.0	43.1
	Total	**274.0**	**100.0**

Source: Author's Field Survey (2026)

The predominance of affirmative responses indicates that thermal discomfort and moisture-related issues are major concerns within the orthopedic wards. Excessive heat and high humidity can reduce comfort, affect staff efficiency, and create conditions that may hinder patient recovery while encouraging microbial growth. These findings suggest that although basic indoor conditions are provided, improvements in ventilation, thermal control, and moisture management are necessary to enhance ventilation and comfort.

Present Condition of Patients

This section examines patients' experiences of health and comfort in relation to ventilation within the orthopedic wards. Table 9 shows that cough (60.7%) was the most reported symptom, followed by headaches (56.5%), sneezing (52.3%), and eye irritation (42.8%), while 36.5% experienced breathing difficulty.

The high occurrence of these symptoms suggests that the indoor environment may contribute to discomfort and health challenges, as such conditions are commonly linked to poor ventilation, airborne pollutants, humidity, and thermal stress, even though patients' medical conditions may also play a role.

Table 9: Health Conditions Experienced by Patients Since Admission (n = 274)

Health Condition*	Frequency	Percentage (%)	Rank
Cough	173	60.7	1st
Headache	161	56.5	2nd
Sneezing	149	52.3	3rd
Eye irritation	122	42.8	4th
Breathing difficulty	104	36.5	5th
Others	38	13.3	6th

Multiple responses were allowed; therefore, percentages exceed 100%.

Source: Author's Field Survey (2026)

However, Table 10 presents patients' opinions regarding the influence of ventilation on their recovery process. Findings indicate that the majority of respondents (66.0%) believed that ventilation affects their recovery, while 18.9% did not share this opinion. Meanwhile, 15.1% were uncertain about whether ventilation had any influence on their recovery.

Table 10: Patients' Perception of the Effect of ventilation on Recovery (n = 274)

Response	Frequency	Percentage (%)
Yes	188	66.0
No	54	18.9
Not Sure	43	15.1
Total	**274**	**100.0**

Source: Author's Field Survey (2026)

Table 11 presents patients' assessment of their breathing comfort while admitted in the orthopedic wards. The largest proportion of respondents (32.6%) indicated that they sometimes felt comfortable breathing within the wards. This was followed by 24.9% who reported often, while 17.2% stated rarely. Furthermore, 16.5% indicated always, whereas only 8.8% reported never feeling comfortable breathing in the ward environment.

The calculated mean score of 3.23 indicates a moderate level of breathing comfort among patients. Although many respondents experienced acceptable breathing conditions on several occasions, findings suggest that breathing comfort is not consistently maintained across the selected hospitals.

Table 12: Patients' Breathing Comfort within the Orthopedic Wards (n = 274)

Breathing Comfort	Frequency	Percentage (%)	Mean Score
Always	47	16.5	
Often	71	24.9	
Sometimes	93	32.6	
Rarely	49	17.2	
Never	25	8.8	
Total	**274**	**100.0**	**3.23**

Scale: 5 = Always, 4 = Often, 3 = Sometimes, 2 = Rarely, 1 = Never

Decision: Moderate Breathing Comfort

Source: Author's Field Survey (2026)

Breathing comfort is influenced by several environmental factors including adequate ventilation, indoor temperature, relative humidity, airborne particulates and odour control. The predominance of responses within the "sometimes" category indicates fluctuations in indoor environmental quality, suggesting that patients' comfort may vary according to occupancy level, weather conditions and ventilation performance. Findings imply that improvements in indoor air management could enhance patients' respiratory comfort and contribute positively to the hospital experience.

Furthermore, Table 13 presents patients' perceptions of overcrowding and humidity conditions within the orthopedic wards. The findings reveal that 68.8% of respondents considered the wards to be overcrowded, while only 31.2% believed otherwise. Similarly, 63.5% reported that overcrowding negatively affected their comfort during hospitalization, whereas 36.5% indicated that it did not. With respect to moisture conditions, 59.3% of respondents perceived the wards as humid or damp, while 40.7% did not observe such conditions.

Table 13: Patients' Perception of Overcrowding and Humidity within the Orthopedic Wards (n = 274)

(a) Perception of Overcrowding		
Response	**Frequency**	**Percentage (%)**
Yes	196	68.8
No	89	31.2
Total	**274**	**100**
(b) Does Overcrowding Affect Your Comfort?		
Response	**Frequency**	**Percentage (%)**
Yes	181	63.5
No	104	36.5
Total	**274**	**100**
(c) Does the Ward Feel Humid or Damp?		
Response	**Frequency**	**Percentage (%)**
Yes	169	59.3
No	116	40.7
Total	**274**	**100**

Source: Authors' Field Survey (2026)

These findings show that overcrowding is a major issue within the orthopedic wards, reducing ventilation effectiveness, increasing heat and pollutant levels, and potentially raising the risk of cross-infection. The widespread perception of high humidity further indicates moisture-related discomfort and possible microbial growth.

Overall, overcrowding, humidity, and weak environmental control significantly affect occupants' comfort, highlighting the need for better space planning, ventilation, and occupancy management.

Relationship Between ventilation and the Present Conditions of Occupants

A correlation analysis using Spearman's rank coefficient was conducted to examine the relationship between ventilation and occupants' health and comfort, with results showing statistically significant associations.

The findings indicate a strong positive relationship between Ventilation and breathing comfort ($r = 0.682$), and a moderate relationship with perceived recovery ($r = 0.594$). Ventilation showed the strongest link with breathing comfort ($r = 0.718$) and was also positively related to recovery ($r = 0.608$).

In contrast, heat, humidity, overcrowding, and unpleasant odours were negatively associated with comfort and Ventilation. Unpleasant odours, in particular, were linked to poorer breathing comfort and recovery, and were more common in poorly ventilated, high-temperature, and crowded conditions. Overall, the results confirm that better ventilation and improved ventilation enhance occupant wellbeing, while adverse environmental conditions reduce comfort and recovery outcomes.

Table 14: Spearman Correlation between ventilation Variables and Occupants' Conditions (n = 274)

S/N	Variables	Breathing Comfort	Perceived Recovery	Heat/Stuffiness	Humidity	Overcrowding
1.	Overall Ventilation Rating	0.682	0.594	−0.521	−0.473	−0.436
2.	Ventilation Condition	0.718	0.608	−0.557	−0.481	−0.452
3.	Frequency of Unpleasant Odours	−0.566	−0.488	0.534	0.502	0.391

Source: Author's Field Survey (2026)

NB: Correlation is significant at the 0.01 level (2-tailed); $p < 0.01$

Factors Influencing ventilation in the Selected Orthopedic Hospital Environments

This section examines the environmental and building-related factors influencing ventilation within the selected orthopedic wards. Analysis considers respondents' perceptions of ventilation systems, adequacy of air circulation, operating theatre ventilation, thermal conditions, overcrowding, natural ventilation practices and other environmental conditions capable of affecting ventilation.

Table 15 presents respondents' opinions regarding the predominant ventilation systems used within the orthopedic wards. The findings reveal that natural ventilation is the most commonly used system, as indicated by 45.3% of respondents. Also, 25.9% reported that their hospitals employ a hybrid ventilation system, while 21.2% identified the use of mechanical ventilation (HVAC). A relatively small proportion (7.6%) were uncertain about the type of ventilation system available.

Table 15: Predominant Ventilation Systems Used in the Orthopedic Wards (n = 274)

S/N	Ventilation System	Frequency	Percentage (%)
1.	Natural Ventilation	124	45.3
2.	Mechanical (HVAC)	58	21.2
3.	Hybrid System	71	25.9
4.	Not Sure	21	7.6
	Total	**274**	**100.0**

Source: Author's Field Survey (2026)

The predominance of natural ventilation suggests that many of the selected hospitals rely primarily on windows, doors and other passive ventilation strategies for indoor air movement. Though natural ventilation provides an economical means of improving air circulation under favourable climatic conditions, its effectiveness is largely dependent on outdoor weather conditions, building orientation and window operation. Consequently, inconsistent ventilation performance may occur during periods of low wind movement or high outdoor temperatures. The findings therefore indicate that while natural ventilation remains the principal means of

air exchange within the selected orthopedic wards, integrating mechanical systems could improve ventilation reliability and overall indoor environmental quality.

Table 19 presents respondents' assessment of the ability of existing ventilation systems to remove airborne contaminants from the orthopedic wards. Findings indicate that 30.7% of respondents remained neutral, while 28.8% agreed that the ventilation systems adequately removed airborne contaminants. Furthermore, 15.3% strongly agreed, whereas 18.6% disagreed while6.6% strongly disagreed. The calculated mean score of 3.28 indicates that respondents generally perceived the ventilation systems as moderately adequate.

Table 16: Perceived Adequacy of the Ventilation System in Removing Airborne Contaminants (n = 274)

S/N	Response	Frequency	Percentage (%)	Mean Score
1.	Strongly Disagree	18	6.6	
2.	Disagree	51	28.8	
3.	Neutral	84	30.7	
4.	Agree	79	18.6	
5.	Strongly Agree	42	15.3	
	Total	**274**	**100.0**	**3.28**

Scale: 5 = Strongly Agree, 4=Agree, 3=Neutral, 2=Disagree, 1 = Strongly Disagree

Decision: Moderately Adequate

Source: Author's Field Survey (2026)

Table 17 indicates that 64.2% of respondents believed the operating theatres were adequately ventilated to minimize the spread of airborne infections. However, 19.0% disagreed, while 16.8% were uncertain. Although the majority expressed confidence in theatre ventilation, the presence of negative responses suggests that ventilation effectiveness may not be consistent across all hospitals or theatre spaces. Continuous monitoring and periodic maintenance of ventilation systems are therefore necessary to maintain acceptable indoor environmental conditions within critical clinical areas.

Table 17: Perception of Operating Theatre Ventilation Adequacy (n = 274)

Response	Frequency	Percentage (%)
Yes	176	64.2
No	52	19.0
Not Sure	46	16.8
Total	**274**	**100.0**

Source: Author's Field Survey (2026)

Table 18 examines two important environmental factors that influence ventilation within the orthopedic wards: thermal discomfort arising from temperature fluctuations and the effect of overcrowding on airflow. Results reveal that 42.7% of respondents occasionally experienced discomfort due to temperature variations, while 29.9% indicated that such discomfort

occurred frequently. In contrast, only 19.3% reported rarely experiencing thermal discomfort, and a relatively small proportion (8.1%) stated that they never experienced such conditions.

Table 18: Perceived Temperature Variations and the Effect of Overcrowding on ventilation (n = 274)

S/N	Variables		
1.	**Experience of Discomfort Due to Temperature Variations**		
	Response	**Frequency**	**Percentage (%)**
	Frequently	82	29.9
	Occasionally	117	42.7
	Rarely	53	19.3
	Never	22	8.1
	Total	**274**	**100**
2.	**Does Overcrowding Affect Airflow and ventilation?**		
	Response	**Frequency**	**Percentage (%)**
	Yes	206	75.2
	No	68	24.8
	Total	**274**	**100**

Source: Author's Field Survey (2026)

More than three-quarters of respondents (75.2%) also agreed that overcrowding adversely affects airflow and ventilation within their units, while only 24.8% disagreed. This overwhelming response suggests that occupancy levels play a critical role in determining indoor environmental conditions within the selected hospitals.

Factors Influencing ventilation

The environmental conditions influencing ventilation within the orthopedic wards were analysed. The analysis focuses on respondents' experiences regarding ventilation, thermal comfort, odours, natural ventilation practices and other physical conditions capable of affecting indoor environmental quality.

Table 19 identifies the environmental conditions that patients perceive as having the greatest influence on ventilation within the orthopedic wards. Findings reveal that poor ventilation was the most frequently identified factor, reported by 74.0% of respondents. This was followed by overcrowding (69.1%), excessive heat (65.3%), humidity or dampness (57.9%), and unpleasant odours (52.3%). Relatively fewer respondents (44.6%) identified dust or airborne particles (44.6%) and inadequate cleaning practices (37.9%) as major contributors. This aligns with empirical fieldwork across Nigerian public healthcare facilities by Eze and Onwuka (2022), which revealed that carbon dioxide levels and indoor air temperatures consistently exceed international regulatory comfort zones due to lack of passive cooling design.

Table 19: Occupants' Perception of Factors Influencing ventilation in the Orthopedic Wards (n = 274)

S/N	Environmental Factor	Frequency	Percentage (%)	Rank
1.	Poor Ventilation	211	74.0	1st
2.	Overcrowding	197	69.1	2nd
3.	Excessive Heat	186	65.3	3rd
4.	Humidity/Dampness	165	57.9	4th
5.	Unpleasant Odours	149	52.3	5th
6.	Dust/Airborne Particles	127	44.6	6th
7.	Inadequate Cleaning	108	37.9	7th

Multiple responses were permitted.

Source: Author's Field Survey (2026)

The dominance of poor ventilation as the highest-ranked factor reinforces the observations made by healthcare personnel in the preceding section. Adequate ventilation is widely recognized as the primary mechanism through which indoor contaminants, excess moisture, odours and airborne pathogens are diluted and removed from occupied spaces. Where ventilation is inadequate, pollutants accumulate more rapidly, leading to reduced indoor environmental quality and increased discomfort among occupants.

Table 20 presents the weighted analysis of the major environmental factors influencing ventilation within the orthopedic wards. An Average Weighted Value (AWV) of 3.79 was obtained and used as the reference point for evaluating the relative significance of each factor. The results reveal that poor ventilation recorded the highest Mean Weighted Value (MWV = 4.09) and ranked first, demonstrating that respondents regarded inadequate ventilation as the most significant factor affecting ventilation. This finding aligns with the earlier descriptive analysis and reinforces the central role of ventilation in controlling indoor pollutants, regulating temperature and maintaining acceptable concentrations of airborne contaminants.

Table 20: Environmental Factors Affecting ventilation in the Orthopedic Wards by Medical Practitioners and Users (n = 274)

S/N	Environmental Factor	SD (1)	D (2)	N (3)	A (4)	SA (5)	TWV	MWV	Rank
1	Poor ventilation influences Ventilation	8.0	19.0	34.0	103.0	121.0	1165.0	4.09	1st
2	Overcrowding affects airflow	11.0	26.0	28.0	94.0	126.0	1153.0	4.05	2nd
3	Excessive indoor heat influences Ventilation	16.0	31.0	41.0	97.0	100.0	1089.0	3.82	3rd
4	Humidity contributes to poor Ventilation	19.0	36.0	46.0	96.0	88.0	1053.0	3.69	4th
5	Unpleasant odours affect indoor comfort	22.0	42.0	49.0	88.0	84.0	1025.0	3.60	5th
6	Dust and airborne particles reduce Ventilation	27.0	45;0	58.0	81.0	74.0	985.0	3.46	6th
	Average Weighted Value (AWV)							**3.79**	

Scale: Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly Agree = 5

Source: Author's Field Survey (2026)

Overcrowding ranked second with an MWV of 4.05, further emphasizing the influence of occupant density on indoor environmental conditions. High occupancy increases carbon dioxide concentrations, metabolic heat production and moisture generation while simultaneously reducing the effectiveness of existing ventilation systems. The close proximity of the MWVs for poor ventilation and overcrowding indicates that respondents perceive these two factors as closely interconnected. Excessive indoor heat (MWV = 3.82) also exceeded the Average Weighted Value, indicating that thermal discomfort remains a significant environmental issue within the selected hospitals. Elevated temperatures may arise from inadequate air movement, solar heat gain, medical equipment and high occupancy levels, all of which contribute to reduced occupant comfort and perceived air quality.

Occupants' Satisfaction with ventilation in the Selected Hospitals

Table 21 presents the satisfaction evaluation of ventilation variables within the selected orthopedic wards. The findings reveal that air freshness recorded the highest satisfaction level with a Mean Weighted Value (MWV) of 3.55 and a Satisfaction Index (SI) of 0.55, ranking first among the evaluated variables. This indicates that patients generally perceived the availability of fresh air within the wards positively. The result may be attributed to the presence of natural ventilation features such as windows and open circulation areas observed in some of the selected hospitals. Similar findings were reported by Adeleke and Balogun (2024), who noted that effective ventilation strategies significantly influence occupants' perception of indoor environmental quality in healthcare buildings.

The overall satisfaction score recorded an MWV of 3.35 and SI of 0.35, indicating that patients were generally satisfied with ventilation conditions within the selected orthopedic wards. However, the relatively low positive margin above the neutral benchmark (3.00) suggests that satisfaction remains moderate rather than optimal. This implies that while existing hospital environments provide acceptable conditions, there are still opportunities for improvement, particularly in ventilation efficiency, humidity management, odour control, and environmental maintenance.

Table 22 further summarizes the ranking of ventilation components based on occupants' satisfaction levels. The results show that air freshness and temperature comfort were the strongest contributors to positive indoor environmental perceptions, while humidity control, odour management, and overall ventilation require greater attention. The findings demonstrate that occupants evaluate ventilation based on multiple interacting environmental factors rather than a single condition.

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Table 21: Occupants' Satisfaction with ventilation Variables within Orthopedic Wards (n = 274)

S/N	Satisfaction Variables	VS (5)	S (4)	I (3)	DS (2)	VDS (1)	TWV	MWV	SI (MWV−3.00)	Rank	Satisfaction Level
1	Air freshness within the ward	58	101	63	37	15	972	3.55	0.55	1st	Satisfied
2	Temperature comfort	51	94	71	42	16	944	3.45	0.45	2nd	Satisfied
3	Humidity comfort	42	88	76	48	20	906	3.31	0.31	3rd	Slightly Satisfied
4	Control of unpleasant odours	38	86	81	50	19	896	3.27	0.27	4th	Slightly Satisfied
5	Overall ventilation	33	79	87	55	20	872	3.18	0.18	5th	Slightly Satisfied
	Overall Mean Satisfaction							**3.35**	**0.35**		**Satisfied**

SI > 1.00 = Very Satisfied, SI = 0.01–1.00 = Satisfied, SI = 0.00 = Indifferent, SI = -0.01 to -1.00 = Not Satisfied, SI < -1.00 = Not Satisfied at All

Source: Author's Field Survey (2026)

Evaluation of Architectural Strategies for Improving ventilation in Orthopedic Hospitals

The evaluation of architectural strategies for improving ventilation in the selected orthopedic hospitals was conducted to identify design interventions capable of enhancing occupants' comfort, health, and overall environmental performance. The findings presented in Table 25 reveal that 68.5% of healthcare workers believed that building materials and interior finishes contribute to unpleasant smells or irritation within orthopedic wards, while 18.5% disagreed and 13.0% were uncertain. This finding supports Adeleke and Balogun (2024), who emphasized that material selection, ventilation performance, and maintenance practices must be considered together when designing healthy indoor environments.

Similarly, only 57.4% of healthcare workers agreed that ward layouts adequately support airflow, while 31.5% disagreed. This suggests that spatial arrangement remains a challenge affecting ventilation efficiency. In orthopedic wards where patient beds, medical equipment, and circulation routes occupy significant space, poor arrangement may restrict air movement and reduce ventilation effectiveness. According to Allen et al. (2020), indoor environmental quality is strongly influenced by the interaction between building layout, ventilation systems, occupancy density, and pollutant sources. Therefore, spatial planning should be considered an important architectural strategy for improving Ventilation.

The strongest agreement among healthcare workers was observed regarding future hospital design considerations. About 92.6% recommended improvements to natural ventilation strategies, while 98.1% agreed that Ventilation principles should be incorporated into future hospital designs. These findings demonstrate a strong recognition among healthcare professionals that architectural decisions influence indoor environmental performance. This aligns with evidence-based healthcare design approaches, which emphasise that hospital buildings should integrate environmental quality considerations from the initial design stage rather than relying mainly on operational adjustments after construction.

Table 22: Healthcare Workers' Assessment of Architectural Design Factors Influencing ventilation (n = 54)

S/N	Architectural Design Factors	Yes	No	Not Sure	Total
1	Building materials and interior finishes contribute to unpleasant smells or irritation within wards	37 (68.5%)	10 (18.5%)	7 (13.0%)	54 (100%)
2	Existing window positions support effective cross-ventilation within wards	34 (63.0%)	14 (25.9%)	6 (11.1%)	54 (100%)
3	Ward layout supports proper airflow and movement of fresh air	31 (57.4%)	17 (31.5%)	6 (11.1%)	54 (100%)
4	Natural ventilation strategies should be improved in orthopedic hospitals	50 (92.6%)	4 (7.4%)	–	54 (100%)
5	Future hospital designs should integrate ventilation-focused design principles	53 (98.1%)	1 (1.9%)	–	54 (100%)

Source: Author's Field Survey (2026)

Table 23 presents the preferred architectural strategies identified by healthcare workers for improving ventilation. The results show that better ventilation systems ranked first (40.7%), followed by reduced overcrowding (24.1%) and improved maintenance practices (14.8%). The dominance of ventilation-related responses reflects earlier findings in this study, where airflow,

humidity, and air freshness emerged as important determinants of occupants' satisfaction. The finding agrees with ASHRAE Standard 170 (2021), which identifies ventilation effectiveness as a fundamental requirement for maintaining acceptable indoor conditions within healthcare facilities.

Improved maintenance practices ranked third, demonstrating that occupants recognise the importance of maintaining existing environmental systems. Poor maintenance of windows, ventilation openings, and mechanical systems may reduce their effectiveness and contribute to deterioration of indoor conditions. The finding reinforces the argument by Rashid and Zimring (2021) that healthcare environments require continuous management and maintenance to sustain their intended performance throughout the building lifecycle.

Table 23: Preferred Architectural Strategies for Improving ventilation among Healthcare Workers (n = 54)

S/N	Architectural Strategy	Frequency	Percentage (%)	Rank
1	Better ventilation systems	22	40.7	1st
2	Reduced overcrowding	13	24.1	2nd
3	Improved maintenance practices	8	14.8	3rd
4	Use of low-VOC building materials	7	13.0	4th
5	Improved building orientation	4	7.4	5th
	Total	**54**	**100**	

Source: Author's Field Survey (2026)

From the patients' perspective, Table 24 shows that respondents recorded an overall indoor environment satisfaction MWV of 3.39 and SI of 0.39, indicating general satisfaction with the ward environment. However, the moderate satisfaction level suggests that existing conditions are acceptable but require further improvement. This corresponds with earlier findings where patients expressed lower satisfaction regarding humidity comfort, odour control, and overall ventilation. Therefore, patient satisfaction should not be interpreted as evidence of optimal environmental performance but rather as an indication that the existing conditions meet basic expectations.

Table 24: Patients' Satisfaction with Indoor Environmental Conditions of Orthopedic Wards (n = 274)

S/N	Indoor Environmental Variables	Very Dissatisfied (1)	Dissatisfied (2)	Neutral (3)	Satisfied (4)	Very Satisfied (5)	TWV	MWV	SI	Rank	Satisfaction Level
1	Availability of fresh air within the ward	15	37	63	101	58	972	3.55	0.55	1st	Satisfied
2	Thermal comfort within the ward	16	42	71	94	51	944	3.45	0.45	2nd	Satisfied
3	Control of indoor humidity	20	48	76	88	42	906	3.31	0.31	3rd	Satisfied
4	Control of unpleasant odours	19	50	81	86	38	896	3.27	0.27	4th	Satisfied
5	Cleanliness and maintenance of ward environment	22	55	74	82	41	887	3.24	0.24	5th	Slightly Satisfied
6	Adequacy of natural lighting	17	39	70	103	45	940	3.43	0.43	3rd	Satisfied
7	Adequacy of space between patient beds	26	61	79	72	36	853	3.11	0.11	7th	Slightly Satisfied
8	Overall indoor environmental quality	18	43	72	97	43	926	3.38	0.38	6th	Satisfied
	Overall Mean Satisfaction							**3.34**	**0.34**		**Satisfied**

SI > 1.00 = Very Satisfied, SI = 0.01–1.00 = Satisfied, SI = 0.00 = Indifferent, SI = -0.01 to -1.00 = Not Satisfied, SI < -1.00 = Not Satisfied at All

Source: Author's Field Survey (2026)

Table 25 presents patients' preferred architectural improvements for better ventilation. The results indicate that increasing the number of windows for natural ventilation ranked first (31.9%), followed by reducing the number of patients per room (25.6%) and improving cleaning practices (18.2%). The preference for additional windows demonstrates that patients associate fresh air availability with improved comfort and healthier ward conditions. This finding supports recent healthcare design studies, which highlight natural ventilation as an important passive strategy for improving occupant experience and reducing dependence on mechanical systems.

Interestingly, patients ranked ceiling fans (13.3%) and air conditioning (10.9%) lower than passive design improvements. This suggests that occupants may prefer architectural solutions that improve the building's environmental performance rather than relying solely on energy-intensive mechanical interventions. The finding reinforces sustainable healthcare design principles, where orientation, ventilation openings, shading, and spatial planning are prioritised as long-term strategies for maintaining indoor environmental quality.

Overall, the evaluation demonstrates that both healthcare workers and patients identify ventilation improvement, effective spatial planning, reduced overcrowding, appropriate material

selection, and improved maintenance as critical strategies for enhancing ventilation within orthopedic hospitals. The agreement between professional assessments and patient experiences indicates that Ventilation improvement requires a combination of architectural design interventions and effective facility management practices. Therefore, future orthopedic hospital designs should adopt occupant-centred approaches that integrate natural ventilation, healthy material selection, flexible ward layouts, and continuous environmental monitoring.

Table 25: Patients' Preferred Architectural Improvements for Better ventilation (n = 274)

S/N	Preferred Improvement	Frequency	Percentage (%)	Rank
1	Increase number of windows for natural ventilation	91	31.9	1st
2	Reduce number of patients per room	73	25.6	2nd
3	Improve cleaning practices	52	18.2	3rd
4	Provide ceiling fans	38	13.3	4th
5	Provide air conditioning	20	10.9	5th
	Total	**274**	**100**	

Source: Author's Field Survey (2026)

V. CONCLUSION

This study assessed ventilation conditions and their implications for occupants in selected Orthopaedic sections of teaching hospitals in Southwest Nigeria. The findings revealed that ventilation performance within the assessed hospitals is generally inadequate, with poor ventilation, overcrowding, excessive heat, high humidity, and unpleasant odours identified as major factors influencing indoor environmental conditions. Environmental measurements further indicated elevated indoor temperatures, high relative humidity, low air velocity, and elevated CO_2 concentrations in several of the assessed spaces, confirming the ventilation challenges reported by occupants.

Despite these challenges, occupants recorded moderate levels of satisfaction with air freshness, temperature comfort, and overall ventilation. However, dissatisfaction with humidity control, odour management, and general ventilation indicates that existing conditions remain below optimal levels. The findings further demonstrate that architectural characteristics, including window provision, spatial organization, building orientation, material selection, and ward occupancy, play important roles in determining ventilation effectiveness.

The study therefore concludes that improving ventilation in Orthopaedic hospitals requires an integrated approach combining climate-responsive architectural design, adequate natural ventilation, appropriate spatial organization, controlled occupancy, suitable material selection, effective maintenance, and supplementary mechanical ventilation where necessary. Incorporating these strategies at the early design stage will enhance indoor environmental quality, occupant comfort, and the overall health performance of Orthopaedic healthcare facilities.

Recommendations

i. Ventilation-focused design principles should be integrated into the planning and design of Orthopaedic hospitals, with emphasis on adequate airflow, air exchange, and thermal comfort.

ii. Natural cross-ventilation should be prioritized through appropriate building orientation, strategically positioned windows, adequate ventilation openings, and unobstructed airflow pathways.

iii. Ward layouts should be carefully organized to support effective airflow by avoiding excessive obstruction from beds, medical equipment, partitions, and other functional elements.

iv. Overcrowding should be minimized through appropriate patient-to-space ratios and adequate ward sizes, considering the significant influence of occupancy levels on airflow and ventilation.

v. Building orientation and façade design should respond to the prevailing climatic conditions of Southwest Nigeria to maximize natural airflow while reducing excessive solar heat gain.

vi. Low-emission, hygienic, and suitable interior materials should be specified to minimize unpleasant odours, irritation, and the accumulation of indoor pollutants.

vii. Regular maintenance and cleaning of windows, ventilation openings, fans, and mechanical ventilation systems should be implemented to sustain effective ventilation performance.

viii. Future Orthopaedic hospitals should adopt hybrid ventilation strategies where natural ventilation alone cannot adequately control temperature, humidity, and indoor air quality.

ix. Periodic monitoring of indoor temperature, relative humidity, air velocity, and CO_2 concentration should be incorporated into hospital facility management to identify and address ventilation deficiencies.

x. Further studies should evaluate ventilation performance in other healthcare facility types and climatic regions of Nigeria using long-term environmental monitoring and building performance simulation.

REFERENCES

Abbakyari, M., Abubakar, I. R., Usman, A., and Abdullahi, S. (2023). User-centred approaches in healthcare architecture: Towards sustainable healing environments. *International Journal of Architecture and Planning, 11*(2), 45–59.

Abdul Hamid, M., Abdullah, A. M., and Ismail, M. R. (2020). Energy recovery in mechanical ventilation systems for sustainable buildings. *Energy Reports, 6*, 123–135. https://doi.org/10.1016/j.egyr.2019.11.012

Ackley, J., Williams, J., and Amato, M. (2017). The effects of envelope design on indoor environmental quality. *Journal of Building Performance, 8*(2),45–58.

Ackley, S. F., Rhew, I. C., Horn, E. E., and McCauley, E. (2017). Indoor environmental quality and adolescent well-being. *Journal of Environmental Psychology, 50*, 24–32. https://doi.org/10.1016/j.jenvp.2017.01.004

Adams, R. I., Bateman, A. C., Bik, H. M., and Meadow, J. F. (2016). Microbiota of the indoor environment: A meta-analysis. *Microbiome, 3*(1), 49. https://doi.org/10.1186/s40168-

015-0108-3

Adeleke, A. O., & Balogun, T. A. (2024). The role of sustainable building materials in improving ventilation in hospital buildings within Ikorodu, Lagos. *International Journal of Scientific Research Journal*, *2*(2), 45–56. https://www.ijsrjournal.com/api/download/ijsr-105230/vol-2-issue-2.pdf

Adeleke, A. O., & Balogun, T. A. (2024). The role of sustainable building materials in improving ventilation in hospital buildings within Ikorodu, Lagos. International Journal of Scientific Research Journal, 2(2), 45–56. https://www.ijsrjournal.com/api/download/ijsr-105230/vol-2-issue-2.pdf

Ajayi, O., Thwala, W. D., Okanlawon, S. A., & Odunjo, O. O. (2015). Assessment of the impact of musculoskeletal disorders on Nigerian construction workers. *International Journal of Civil Engineering, Construction and Estate Management*, *3*(3), 69-84.

Alghoul, M. A., Sopian, K., Al-Turki, Y. A., and Sulaiman, M. Y. (2017). Review of transparent and translucent building envelope materials for daylighting applications. *Renewable and Sustainable Energy Reviews, 73*,736–744.https://doi.org/10.1016/j.rser.2017.01.154

AlHorr,Y.,Arif,M.,Katafygiotou,M.,Mazroei, A.,Kaushik,A., andElsarrag,E. (2016). Impact of indoor environmental quality on occupant well-being and comfort: Areview of the literature. *International Journal of Sustainable Built Environment, 5*(1),1–11. https://doi.org/10.1016/j.ijsbe.2016.03.006

Allen, J. G., Spengler, J. D., Vallarino, J., MacNaughton, P., & Satish, U. (2020). Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers. Environmental Health Perspectives.

Altomonte, S., Allen, J., Bluyssen, P., Brager, G., Heschong, L., Loder, A., … Veitch, J.(2020). Ten questions concerning well-being in the built environment. *Building andEnvironment, 180*, 106949. https://doi.org/10.1016/j.buildenv.2020.106949

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2022). ASHRAE Standard 170: Ventilation of Health Care Facilities. Atlanta: ASHRAE.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).(2016). *ASHRAE Standard 62.1-2016: Ventilation for acceptable ventilation*.ASHRAE. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2021).*ASHRAEhandbook: Fundamentals*. ASHRAE.

Ankita, B., Shilpa, J., and Pooja, J. (2021). Indoor air pollution: Sources, effects, andmitigation. *Environmental Claims Journal, 33*(1), 1–18. https://doi.org/10.1080/10406026.2020.1840618

Ardoino, L., Azara, A., Dettori, M., Fadda, A., and Castiglia, P. (2016). ventilation in healthcare environments: A review. *Annali di Igiene: Medicina Preventiva e diComunità, 28*(5), 366–376. https://doi.org/10.7416/ai.2016.2126

ASHRAE. (2019). *Ventilation for acceptable ventilation*(ANSI/ASHRAE Standard62.1- 2019).

ASHRAE. (2020a). *ASHRAE history*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ASHRAE. (2020b). *Ventilation andventilation standards*.

ASHRAE. (2021). *Standard 62.1–2021: Ventilation for acceptable ventilation*.Atkinson, J., Chartier, Y., Pessoa-Silva, C.L., Jensen, P.,Li,Y. *Natural ventilation for infection control in health-care settings*. World Health Organization.

ASHRAE. (2021). ANSI/ASHRAE/ASHE Standard 170-2021: Ventilation of Health Care Facilities.

Aversa, F., Petronio, M. G., Angelini, E., and Barbieri, P. (2019). Monitoring indoor pollutants in hospital environments. *International Journal of Environmental Research and Public Health, 16*(10), 1752. https://doi.org/10.3390/ijerph16101752

Awbi, H.B. (2003). *Ventilation of buildings* (2nd ed.). Spon Press.

Bassi,G.,Ottone, F., and Dell'Ovo, M.(2019).The role of hospital planning inVentilation control. *Techne, 17*, 124–131. https://doi.org/10.13128/techne-25269

Baudet, A., Bordet, F., Locatelli, A., and Gosselin, S. (2021). Ventilation in healthcare establishments: Pollutants, sources, and regulations. *International Journal of Environmental Research and Public Health, 18*(5), 2382. https://doi.org/10.3390/ijerph18052382

Baudet, A., Bordet, F., Locatelli, A., and Gosselin, S. (2022). Airborne pollutants in hospital environments: Implications for occupational and patient health. *Atmosphere, 13*(6),912. https://doi.org/10.3390/atmos13060912

Bjelić, D., Ilić, P., and Stojanović, B. (2020). ventilation in healthcare facilities: Areview. *International Journal of Environmental Research and Public Health, 17*(23),1–19. https://doi.org/10.3390/ijerph17238878

Bluyssen, P. M. (2013). *The healthy indoor environment: How to assess occupants' wellbeing in buildings*. Routledge.

Bonadonna, L., Briancesco, R., and Coccia, A. M. (2021). Airborne biological risk inhealthcare facilities. *Annali dell'Istituto Superiore di Sanità, 57*(1), 72–80. https://doi.org/10.4415/ANN_21_01_12

Bousiotis, D., Harrison, R. M., and Tzanis, C. (2023). The impact of indoor air pollution on health in Europe. *Science of the Total Environment, 858*, 160054. https://doi.org/10.1016/j.scitotenv.2022.160054

Brambilla, A., Rebecchi, A., and Capolongo, S. (2019). Evidence-based hospital design: Indoor air quality and healing spaces. *Annali di Igiene: Medicina Preventiva e di Comunità, 31*(1),53–63. https://doi.org/10.7416/ai.2019.2261

Capolongo, S., Settimo, G., Gola, M., Rebecchi, A., Buffoli, M., and Signorelli, C. (2014). ventilation in healthcare facilities: The Italian experience. *Epidemiologia and Prevenzione,38*(6), 46–51.

Carducci, A., Donzelli, G., Cioni, L., Federigi, I., Lombardi, R., and Verani, M. (2019). Air quality in healthcare settings: Implications for infection control. *Pathogens, 8*(2), 85. https://doi.org/10.3390/pathogens8020085

Carrilho da Graça, G., and Linden, P. F. (2016). Ten questions about natural ventilation of non-domestic buildings. *Building and Environment, 107*, 263–279. https://doi.org/10.1016/j.buildenv.2016.08.007

Channon, A. (2023). Indoor environmental quality and human well-being: A psychological perspective. *Building Research and Information, 51*(2), 131–147. https://doi.org/10.1080/09613218.2021.2009314

Chartered Institution of Building Services Engineers (CIBSE). (2020). Guide B: Heating, Ventilating, Air Conditioning and Refrigeration. London: CIBSE.

Chaturvedi, A., and Yadav, S.(2022). Effectof temperature and relative humidity on airborne bioaerosols. *Aerosol Science and Engineering, 6*(3), 301–310. https://doi.org/10.1007/s41810-022-00147-y

Chauhan, A., Saini, P., and Singh, R. (2023). IEQ parameters and human performance: A systematic review. *Journal of Building Performance, 14*(1), 23–38.

Chen, C., Zhao, B., and Zhang, Y. (2018). Performance of hybrid ventilation in healthcare buildings: A review. *Building and Environment, 141*, 196–214. https://doi.org/10.1016/j.buildenv.2018.05.040

Chen, W., Liu, C., and Wang, H. (2022). ventilation in hospitals: A review of influencing factors and ventilation strategies. *Building and Environment, 223*,109416. https://doi.org/10.1016/j.buildenv.2022.109416

Chenari, B., Carrilho da Graça, G., and Almeida, R. M. S. F. (2016). Towards sustainable, energy-efficient, and healthy ventilation strategies in buildings: A review. *Renewable and Sustainable Energy Reviews, 59*, 1426–1447.https://doi.org/10.1016/j.rser.2016.01.074

Cheng, S., Gao, T., and Zhang, X. (2022). Energy-efficient mechanical ventilation strategies in hospitals. *Energy and Buildings, 260*, 111895. https://doi.org/10.1016/j.enbuild.2022.111895

Cincinelli, A., and Martellini, T. (2017). ventilation and health. *International Journal of Environmental Research and Public Health, 14*(11), 1286. https://doi.org/10.3390/ijerph14111286

Correia, G., Rodrigues, L., Gameiro da Silva, M., and Gonçalves, T. (2020). Airborne routeand bad use of ventilation systems as non-negligible factors in SARS-CoV-2transmission. *Medical Hypotheses, 141*, 109781.https://doi.org/10.1016/j.mehy.2020.109781

Daouas, N. (2011). A study on optimum insulation thickness in walls and energy savings in

Tunisian buildings. *Applied Energy*, *88*(1), 156–164. https://doi.org/10.1016/j.apenergy.2010.07.030

Diaz de Garayo, S., García, L. A., and Martínez, A. (2022). Heat recovery ventilation in hospitals: Efficiency and Ventilation considerations. *Sustainable Cities and Society*, *81*,103785. https://doi.org/10.1016/j.scs.2022.103785

Du, B., Fan, X., et al. (2020). Indoor environmental quality and occupant satisfaction in healthcare facilities. Building and Environment.

Etheridge, D. (2011). *Natural ventilation of buildings: Theory, measurement and design*. John Wiley and Sons.

Etheridge, D., and Sandberg, M. (1996). *Building ventilation: Theory and measurement*. John Wiley and Sons.

European Union. (2020). *The 2021 ageing report: Economic and budgetary projections for the EU Member States (2019–2070)*. European Commission. https://ec.europa.eu/info/publications/2021-ageing-report

Eze, C. I., & Onwuka, E. N. (2022). Empirical investigation of indoor environmental quality (IEQ) performance in hospital buildings in Nigeria. *Journal of Sustainable Architectural Technology*, *14*(2), 89–101.

Eze, O. C., & Onwuka, S. U. (2022). Assessment of indoor environmental quality and ventilation performance in Nigerian public healthcare facilities. Journal of Building Engineering, 45, 103456.

Fabiyi, O. C., & Ana, G. R. (2026). ventilation, hygiene practices and the antimicrobial resistance profiles of airborne bacteria in selected areas of a tertiary health facility in Ibadan, Nigeria. *Antimicrobial Resistance & Infection Control*, *15*(1), Article 34. doi.org

Facility Guidelines Institute (FGI). (2018a). *Guidelines for design and construction of hospitals*. Facility Guidelines Institute.

Facility Guidelines Institute (FGI). (2018b). *Guidelines for design and construction of outpatient facilities*. Facility Guidelines Institute.

Fennelly, K. P., Jones-López, E. C., and Ellner, J. J. (2022). Infection control through ventilation in hospitals. *Clinical Infectious Diseases, 75*(2), 1–8.https://doi.org/10.1093/cid/ciac140

Gao, X., and Zhang, Y. (2021). Ventilation and exposure duration as dominant factors for airborne infection risk. *Indoor Air, 31*(6), 1741–1753.https://doi.org/10.1111/ina.12849

Garnawat, P. (2024). *Management of indoor environmental quality in healthcare facilities: a multi-stakeholder approach* (Doctoral dissertation, RMIT University).

Givoni, B.(1994). *Passive and low energy cooling of buildings*. Van Nostrand Reinhold.

Gola, M., Settimo, G., and Capolongo, S. (2019). Ventilation in inpatient environments: A systematic review on factors that influence chemical pollution in inpatient wards. *Journal*

of Healthcare Engineering, 2019, 8358306.https://doi.org/10.1155/2019/8358306

Gola, M., Settimo, G., and Capolongo, S. (2019). Ventilation in inpatient environments:A multidimensional approach. *Annali di Igiene: Medicina Preventiva e di Comunità,31*(5), 436–448. https://doi.org/10.7416/ai.2019.2317

Gola, M., Settimo, G., and Capolongo, S. (2020). Architecture and health: The importance of the architectural design for the well-being. *Annali dell'Istituto Superiore di Sanità,56*(1), 48–57. https://doi.org/10.4415/ANN_20_01_10

González-Martín, J., Kraakman, N. J. R., Pérez, C., Lebrero, R., and Muñoz, R. (2021). Astate-of-the-art review on indoor air pollution and strategies for indoor air pollution control. *Chemosphere, 262*, 128376.https://doi.org/10.1016/j.chemosphere.2020.128376

Harb, R., et al. (2018). Emissions from surface materials in indoor environments. *Indoor Air, 28*(2),185–197.

Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Katafygiotou, M., and Elsarrag, E. (2016). Occupant productivity and office indoor environment quality: A review of the literature. *Building and Environment, 105*, 369–389.https://doi.org/10.1016/j.buildenv.2016.06

Huo, X., et al. (2020). Health effects of indoor air pollution in hospitals. *International Journal of Environmental Research and Public Health, 17*(23), 8740. https://doi.org/10.3390/ijerph17238740

Huang, Y., Chen, C., and Wang, X. (2019). Daylighting and energy performance in healthcare buildings: Influence of envelope design. *Energy and Buildings, 199*, 350–362. https://doi.org/10.1016/j.enbuild.2019.06.045

Ibrahim, S. H., Ismail, A. H., and Ali, M. A. (2022). ventilation research: A review of recenttrends. *Environmental Challenges, 7*, 100499. https://doi.org/10.1016/j.envc.2022.100499

Ilić, P., Stojanović, B., and Bjelić, D. (2021). Indoor air pollution in hospitals: Challenges and solutions. *Environmental Research, 196*, 110973. https://doi.org/10.1016/j.envres.2021.110973

Ingrid, K. (2017). Ventilation and the well-being of healthcare workers: A systematic literaturereview.*Work, 57*(3),399–407.https://doi.org/10.3233/WOR-172574

Jiang, Z., Zhou, Y., and Chen, M. (2022). Emissions of volatile organic compounds from hospital cleaning and disinfection activities. *Building and Environment, 223*, 109443. https://doi.org/10.1016/j.buildenv.2022.109443

Jung, H., Kim, J., and Park, J. (2015). Seasonal effects on ventilationin hospitals. *Science of the Total Environment*, 524–525, 453–460. https://doi.org/10.1016/j.scitotenv.2015.04.018

Kameni Nematchoua, M., Orosa, J. A., and Reiter, S. (2017). Impact of orientation and envelope design on building energy in Cameroon. *Energy, 141*, 106–118. https://doi.org/10.1016/j.energy.2017.09.070

Korsavi, S. S., Montazami, A., and Mumovic, D. (2020). Ventilation in UK primary schools: The challenges of defining healthy environments. *Building and Environment, 171*,106623. https://doi.org/10.1016/j.buildenv.2019.106623

Kozicki, M., et al. (2018). VOC emissions from cement-based construction materials. *Construction and Building Materials,172*, 570–579.

Krarti, M. (2018). *Energy-efficient building systems: Green strategies for operation and maintenance* (4th ed.). CRC Press.

LEED. (n.d.). *Leadership in Energy and Environmental Design (LEED) rating system*. U.S. Green Building Council.

Li, Y., Cheng, P., Jia, W., et al. (2022). ventilation and ventilation strategies in healthcare buildings: A review. Building and Environment.

Lee, J., Kim, H., and Park, J. (2022). Hospital-related indoor air pollutants: Sources, health impacts, and control strategies. *International Journal of Environmental Research and Public Health, 19*(8), 4736. https://doi.org/10.3390/ijerph19084736

Leung, D. Y. C. (2015). Outdoor–indoor air pollution in urban environment: Challenges and opportunity. *Frontiers in Environmental Science,2*, 69. https://doi.org/10.3389/fenvs.2014.00069

Lewkowska, P., et al. (2017). Review of indoor air emissions from building materials. *Atmospheric Environment, 150*, 1–9.

Liang, W., and Xu, Y. (2014). Emissions from flooring materials. *Building and Environment,80*, 35–42.

Li, J., Sun, Y., and Zhang, Y. (2022). Effects of temperature and humidity on indoor bioaerosols in hospital environments. *Science of the Total Environment, 832*, 154910. https://doi.org/10.1016/j.scitotenv.2022.154910

Liu, J., Zhou, J., Yao, J., Zhang, X., Li, L., Xu, X., He, M., Wang, Y., Fu, S., Niu, T., Yan, J., Shi, Y., Ren, X., Niu, J., Zhu, W., Li, S., Luo, B., Zhang, K., Yu, Y., … Zhang, Y.(2020). Impact of indoor air pollution on respiratory health in children: A meta-analysis. *Science of the Total Environment, 739,* 139845.https://doi.org/10.1016/j.scitotenv.2020.139845

Longman, J., Passey, M., Singer, J., and Morgan, G. (2019). The role of social isolation in frequent and/or avoidable hospitalisation: Rural community-based service providers' perspectives. *Australian Health Review, 43*(2), 157–162. https://doi.org/10.1071/AH17078

Lu, C. Y., Ma, Y. C., Lin, J. M., Chen, Y. Y., Sung, F. C., and Huang, P. C. (2016). Oxidative stress associated with indoor air pollution and sick building syndrome-related symptoms among office workers in Taiwan. *Inhalation Toxicology, 28*(1), 59–65. https://doi.org/10.3109/08958378.2015.1129538

Ma, X., et al. (2021). Factors influencing ventilation and comfort in healthcare facilities. *Sustainable Cities and Society, 67*, 102719.

Madureira, J., Paciência, I., and Rufo, J. (2016). ventilation in Portuguese schools:Levels and sources of pollutants. *Indoor Air*,*26*(4), 526–537.https://doi.org/10.1111/ina.12232

Manca, M., Dettori, M., Deriu, M. G., and Castiglia, P. (2022). Healing environments: The impact of architectural design on patient well-being. *Sustainability*, 14(4), 2387. https://doi.org/10.3390/su14042387

Mandin, C., Trantallidi, M., Cattaneo, A., Canha, N., Mihucz, V. G., Szigeti, T., and deOliveira Fernandes, E. (2017). Assessment of ventilation in office buildings across Europe – The OFFICAIR study. *Science of the Total Environment, 579*, 169–178. https://doi.org/10.1016/j.scitotenv.2016.10.238

Mansor, N., and Sheau-Ting, L. (2022). Indoor environmental quality and building occupants' well-being: A systematic review. *Journal of Building Engineering*, 46, 103769. https://doi.org/10.1016/j.jobe.2021.103769

Mao, P., Qi, H., Tan, W., and Li, H. (2017). Influence of ventilation on indoor thermal environment and air quality. *Energy Procedia, 142*, 1821–1826. https://doi.org/10.1016/j.egypro.2017.12.616

Marć, M. (2017). Emerging trends in indoor air pollution research. *TrAC Trends in AnalyticalChemistry*,*97*, 136–144.

Maung, T. Z., Naing, C., Ban, D. W., and Mak, J. W. (2022). Impact of poor ventilationon sick building syndrome and productivity loss among hospital workers. *Environmental Science and Pollution Research, 29*(16), 24340–24351. https://doi.org/10.1007/s11356-021-17441-0

Montagna, M.T., Caggiano,G., Lovero, G., Coretti, C., Cuna, T., Triggiano, F., and Diella, G. (2016). Evaluation of air quality in healthcare settings. *International Journal of Environmental Health Research*, 26(2), 129–138. https://doi.org/10.1080/09603123.2015.1104363

Moscato, U., Borghini, A., and Teleman, A. (2017). Hospital safety and cognitive psychology in healthcare design. *Annali di Igiene*, 29(2), 141–150.https://doi.org/10.7416/ai.2017.2135

Menegbo, A. (2017). Hospital spatial organization and patient-centered care delivery. *International Journal of Architecture and Urban Development*, 7(4),53–62.

Meng, Q., Zhang, L., and Liu, Y. (2020). Mixed-mode ventilation strategies for sustainable hospital design. *Energy and Buildings, 215*, 109908. https://doi.org/10.1016/j.enbuild.2020.109908

Mentese, S., et al. (2020). Effects of indoor plants on sick building syndrome symptoms. *Building and Environment, 169*, 106590

Mezzoiuso, G., Bonomo, M., and Ricciardi, W. (2017). Biological contaminants in hospital wards: Implications for Ventilation. *Annalidi Igiene*, 29(3), 185–196. https://doi.org/10.7416/ai.2017.2145

Mokammel, A., et al. (2022). Nanomaterials for improving ventilation in healthcare facilities.

Journal of Hazardous Materials, 424, 127310.

Morawska, L., Ayoko, G. A., Bae, G. N., Buonanno, G., Chao, C. Y. H., Clifford, S., Fu, S.C., Hänninen, O., He, C., Isaxon, C., Mazaheri, M., Salthammer, T., Waring, M., and Wierzbicka, A. (2017). Airborne particles in indoor environment of homes, schools, offices and aged care facilities: The main routes of exposure. *Environment International, 108*, 75–83. https://doi.org/10.1016/j.envint.2017.07.025

Nazaroff, W.W. (2013). Exploring the consequences of climate change for ventilation. *Environmental Research Letters, 8*(1), 015022. https://doi.org/10.1088/1748-9326/8/1/015022

Nemery, B., Hoet, P. H., and Nemmar, A. (2001). The Meuse Valley fog of 1930: An air pollution disaster. *The Lancet, 357*(9257), 704–708. https://doi.org/10.1016/S0140-6736(00)04135-0

Norbäck, D., Hashim, J. H., Hashim, Z., Ali, F., Bloom, E., Larsson, L., and Wieslander, G. (2017). Respiratory symptoms and fractional exhaled nitric oxide (FeNO) among students in schools with and without ventilation problems: Associations with fungal DNA and mycotoxins in settled dust. *Environmental Health Perspectives, 125*(9), 097020. https://doi.org/10.1289/EHP669

Okafor, K. C. (2024). Influence of indoor environmental quality (IEQ) performance of hospital wards on recovery process of patients in Enugu city. Sadi Journal of Engineering Science and Technology, 6(2), 204–218. https://sadijournals.org/index.php/SIJSET/article/view/748

Passe, U., and Battaglia, F. (2015). *Designing spaces for natural ventilation: An architect's guide*. Routledge.

Persily, A. (2016). Field measurement of ventilation rates. *Indoor Air, 26*(1), 97–111. https://doi.org/10.1111/ina.12173

Raji, B., Tenpierik, M. J., and van den Dobbelsteen, A. (2020). Mixed-mode ventilation strategies in sustainable building design. *Journal of Building Engineering, 32*,101466. https://doi.org/10.1016/j.jobe.2020.101466

Ramin, K., Farshad, S., and Ali, T. (2016). Orientation impact on energy efficiency in Iranian residential buildings. *Applied Energy, 178*, 290–301. https://doi.org/10.1016/j.apenergy.2016.06.050

Rashid, M., & Zimring, C. (2021). Healthcare environmental design and patient outcomes: Evidence-based approaches for improving healing environments. HERD: Health Environments Research & Design Journal.

Rebecchi, A., Buffoli, M., Dettori, M., Appolloni, L., Azara, A., Castiglia, P., D'Alessandro, D., and Capolongo, S. (2017). Indoor environmental quality and healthcare performance. *AnnalidiIgiene,* 29(5),415–427.https://doi.org/10.7416/ai.2017.2176

Rysanek, A. (n.d.). Climate adaptability of mixed-mode ventilation systems. *IEA Technical Report*.

Rysanek, A., Choudhary, R., and Heo, Y. (2021). Resilience of natural ventilation strategies ina warming climate. *Energy and Buildings, 252*, 111396. https://doi.org/10.1016/j.enbuild.2021.111396

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., and Fisk, W. J. (2012). Is CO_2 an indoor pollutant? Direct effects of low-to-moderate CO_2 concentrations on human decision-making performance. *Environmental Health Perspectives, 120*(12), 1671–1677.https://doi.org/10.1289/ehp.1104789

Tian, Y. (2023). A review on factors related to patient comfort experience in hospitals. *Journal of Health, Population and Nutrition*, *42*(1), 125.

US EPA. (2021). *Formaldehyde hazard assessment*. United States Environmental Protection Agency.

Wang, Z., et al. (2020). VOC emissions in real-world hospital settings. *Indoor Air*, *30*(6),1165–1176.

Wolkoff, P. (2018). Indoor air humidity, air quality, and health – An overview. *International Journal of Hygiene and Environmental Health, 221*(3), 376–390. https://doi.org/10.1016/j.ijheh.2018.01.015

World Health Organization. (2021). Roadmap to improve and ensure good indoor ventilation in the context of COVID-19.

Yuan, J., Liu, C., and Wang, Y. (2017a). Performance of multilayer envelopes with air cavities. *Applied Thermal Engineering, 110*, 1575–1585. https://doi.org/10.1016/j.applthermaleng.2016.09.071

Zhang, Y., et al. (2015). Indoor sulfur dioxide and respiratory health. *Environmental Science and Technology*, *49*(1), 537–544.

Zhang, Y., et al. (2018). VOC emissions from new building materials: Effects of temperature and humidity. *Building and Environment, 134*, 84–93.

Zhang, Y., Wang, Z., et al. (2021). Evaluation of indoor environmental quality and occupant satisfaction in healthcare buildings. Journal of Building Engineering.

Zhou, J., et al. (2017). Environmental effects on VOC release. *Atmospheric Environment, 152*, 530–538.