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Systematic Review

The Indoor Climate of Hospitals in Tropical Countries: A Systematic Review

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Abstract: An indoor climate impacts human comfort, well-being, and safety. Therefore, it remains an important topic since, nowadays, people spend a significant amount of time indoors. Additionally, as tropical geographical zones become more populated, urbanised, and industrialised, the energy demand for air conditioning will rise significantly. In terms of the indoor climate, hospitals are particularly demanding due to the special needs of their occupants, however there is a paucity of studies about the tropics. Through a systematic analysis of accessible data and peer-reviewed articles, this study performed a quantitative and qualitative review of the scientific studies selected by the defined inclusion and exclusion parameters. A total of 65 tropics-related scientific publications, 28 on indoor thermal comfort and 37 on indoor air quality published between 2000 and 2023, were systematically reviewed. This study's findings corroborated those from the previous studies, alluding that there is a paucity of scientific studies on the indoor climate conditions of buildings in tropical countries. A total of 42 studies (65%) were conducted in Asia and 15 studies (23%) in Africa. Six studies (9%) were reported in South America and two studies (3%) were obtained from Oceania, Australia. The results indicated that tropical Africa recorded the lowest number of indoor climate studies considering the population indices. Many of the reviewed indoor climate studies employed mixed methods, whereas only very few considered a seasonal approach. Meanwhile, in the developing tropics, only one record was found regarding an indoor climate study of hospitals based on their locations (correlating the outdoor and indoor air quality). Additionally, no record was found regarding the IC studies of hospitals in sub-Saharan Africa, in which, the IC impact on the occupant's performance, productivity, and behaviour was assessed. Inferably, gaps still exist in the indoor climate of tropical hospitals. The current study highlights the need to improve the indoor climate considerations in the design, siting, awareness, regulations, and policy implementations concerning the hospitals in developing tropical countries. In conclusion, the study emphasises the need for more scientific studies on the indoor climate of tropical hospitals and highlights the relevant areas of the indoor climate studies in future works for considering the climate, environmental, socio-economic, infrastructural, and demographic peculiarities of the tropics for the betterment of hospital indoor climates in developing tropical countries.

Keywords: indoor climate; thermal comfort; indoor air quality; well-being; tropical countries; hospital

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1. Introduction

Humans continue to work relentlessly to ensure comfortable and safer indoor environments. Meanwhile, precedence should be given to human health and safety when determining the overall comfort of any indoor environment (permanent or mobile). If the built environment causes sickness or has a detrimental influence on the health of its inhabitants, for whatever reason, it is a call for concern and may suggest a design or technological fault in the building system. Buildings are generally designed to offer shelter and promote well-being, but studies have identified the negative impacts of poor indoor environmental quality (IEQ) in buildings, such as the phenomenon of sick building syndrome (SBS) [1–3]. These negative impacts have been connected to a variety of building-related illnesses (BRIs), such as those that are identifiable and caused by airborne building contaminants [4,5] or indoor air pollutants, inadequate temperature levels, noise, and infectious aerosols that affect the physiological and mental health of exposed occupants [6,7]. Buildings should be maintained within the prescribed limits of safe and acceptable boundaries to sustain the optimal human productivity and performance. The indoor climate (IC) refers mainly to the indoor air quality (IAQ) and the indoor thermal comfort (ITC) parameters of the IEQ. Since the 1960s, P.O. Fanger pioneered the thermal comfort studies, specifically, a predictive model [8,9] referred to as the predictive mean vote (PMV), which serves as an index for predicting the mean thermal sensation of an occupant's population in any indoor environment on a seven-point scale, calculated using the physical and physiological parameters as the inputs [10]. The physical parameters are the air temperature, t_a (°C), mean radiant temperature, t_r (°C), partial water vapour pressure (P_a), and relative air velocity (V_{ar}), while the physiological parameters are the metabolic rate (Met) and clothing insulation (Clo) [11]. Regarding the IAQ, the most common evaluation parameters include, but are not limited to, the concentrations of carbon dioxide (CO_2), formaldehyde (HCHO), volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM), and nitrogen dioxide (NO_2) [12–14]. Since the outdoor environmental conditions impact the indoor conditions, the influence of the climate and the outdoor environment should be taken into consideration. The unique climate conditions of tropical countries, which are typically hot and humid apart from the other climate variabilities that depend on the specific tropical region, deserve more attention regarding the IC conditions of the buildings in these regions. Furthermore, the standard EN ISO 7730 generally assumes that extended acceptable conditions may be applied to free-running buildings (naturally ventilated) in warm climate regions. In these buildings, the ITC is regulated primarily by the occupants through the opening and closing of the windows. In such cases, the thermal conditions may be designed for higher PMV values compared to those with mechanical ventilation, in which case, the adaptive comfort model seems to be more applicable [15,16]. Meanwhile, it is important to highlight the findings from a thermal comfort study in a Belgian hospital, in which no significant difference was found between the PMV and actual mean vote (AMV) in 99 patients with various illnesses in all the wards except neurology [17].

It is noteworthy to mention that nearly 80% of tropical countries are still developing countries characterised by an inadequate IEQ consideration in their building infrastructure designs and inadequate IEQ regulations and implementation, including a general awareness of the importance of good IC and the associated demerits to the building's exposed occupants. As reported by Rodriguez and D'Alessandro [18], approx. 50% of the world's population will possibly live in tropical countries by 2050. More specifically, the geometric growth of persons in many developing tropical countries suggests a potential for a higher occupancy density in built and mobile indoor spaces. Therefore, ensuring good IC conditions of indoor spaces in these regions is of paramount importance. In tropical countries, the indoor thermal environment is heavily influenced by the local outdoor temperature and an airflow through the structure is required to reduce the indoor discomfort caused by overheating [19]. Furthermore, in countries with warm and humid climates, the external air movement assists with controlling the indoor environment [20], and the importance of this influence on the IAQ for humans has been reported in some studies [21]. Indoor air pollution from outside sources can arise due to pollution infiltration from anthropogenic activities, such as vehicle emissions, industrial emissions, and agricultural activities, including other natural processes that are sources of CO_2, CO, particulate matter (PM), and nitrogen dioxide (NO_2), which can have a detrimental impact on human comfort and well-being. Indeed, numerous studies concerning human health in indoor settings, such as in homes, schools, and workplaces have lately gained increased attention in relation to the development of hospitals in tropical nations.

A hospital is one of the most crucial places since the patients are more sensitive than healthy individuals. Furthermore, as mentioned by [22], an excellent IC might influence a patient's well-being and shorten their hospitalization period. Similarly, research showed that the IC in hospitals contributes to the recovery of the patients, as well as the well-being of the medical personnel. A hospital that is recognised as a high-performance building in terms of its IEQ, on the other hand, would attract and retain its patients and enhance their recovery process, as well as its staff efficiency [23]. Researchers have discovered that the importance of preserving one's health and comfort should never be underestimated. A healthy environment has been reported to positively impact the health of the patient. According to another study, a hospital is a diagnostic human therapeutic setting where activities such as health education, training, and research may be carried out [24]. Since hospital's principal role is to provide patient care, hospitals must be constructed to provide the utmost advantages to their patients, the patient's family, and their personnel. The importance of paying close attention to the environmental conditions of healthcare facilities cannot be overstated. Numerous studies have found that the indoor temperature has an influence on both health and performance, which, in turn, has an impact on productivity [25,26]. A poor IC can cause discomfort, sickness, or worsen serious diseases in the occupants, especially in vulnerable people. The effect of the IC on patient satisfaction is measured by psychological reactions and physical complaints [27]. Therefore, the improvement of the IC in hospitals should consider the emotional needs of the patients, their families, and the staff.

Meanwhile, a poor IAQ plays a significant role in the spread of infectious diseases and bioaerosols in indoor spaces, as reported by several studies [28–30]. For hospitals, there is already a high risk of infectious disease spread since the typical occupants include persons with ill health. This highlights the need to ensure adequate ventilation, airflow, and air exchange to minimise the risk of transmission from aerosolised infections. The importance of good air conditioning, including air filtration and treatment, is essential for achieving a suitable IAQ for hospital buildings. It is noteworthy to mention that, for many developing tropical countries, the existential challenges of energy poverty and energy access [31,32], poor building infrastructure, and inefficient technologies can negatively impact several parameters in health care operations, including achieving an adequate IC and other sustainability concerns. Therefore, gaps exist in the IAQ and comfort parameters of many hospital buildings in these regions, which can negatively affect the exposed occupants' well-being, performance, productivity [3], and safety. Apart from the thermal comfort, the other comfort parameters such as the visual and acoustic comfort are critical for achieving an adequate IEQ in hospital buildings. The poor lighting in hospitals can affect a nurse's level of fatigue and performance and it can lead to errors in dispensing medication [33,34]. Moreover, the acoustic comfort can impact the performance and productivity of the doctors and nurses in hospitals, as well as the patients' well-being [35,36]. Therefore, employing energy- and cost-efficient interventions, such as the use of passive enhancements like light shelves [37,38] and reflective roof insulations, and active strategies like hybrid photovoltaic/thermal solar systems and low-energy heat pump systems [39], are suitable recommendations for developing tropical countries.

This systematic review will provide an overview of the current studies on the IC in tropical hospital buildings, focusing on the ITC and IAQ. Apart from the statistical literature analysis of the studies, the discussion and conclusion address the research gaps and potential areas of future work. The organization of the rest of the paper is as follows. Section 2 presents the review methodology, Section 3 provides the literature analysis, Section 4 presents the results and discussion, and Section 5 presents the conclusion.

2. Review Methodology

The current study performed a systematic review, which is an organised way to extract, analyse, and synthesise the information from the existing primary databases concerning a series of studies for a particular study. Research is the most efficient way to conduct the indicative investigations while identifying the potential knowledge gap of the researchers. This systematic review was carried out following PRISMA (the priority report elements for systematic review and meta-analysis) [40]. Figure 1 presents a simple schematic of the review process. The systematic review system was divided into multiple steps and began with the definition of the possible research questions and responses that were within the scope of the document. After this, the strategy and search process were described using specific keywords and search strings to select the related publications for the literature database. The integral criteria were also described to clarify the selection of the relevant literature. Next, the data extraction process was defined according to the title of the article within the scope of the document, the summary, the year of publication, and the name of the country. After these processes, the details about the associated document were combined in the results section. Finally, the restrictions and risks of the systematic review processes related to the bias were described.

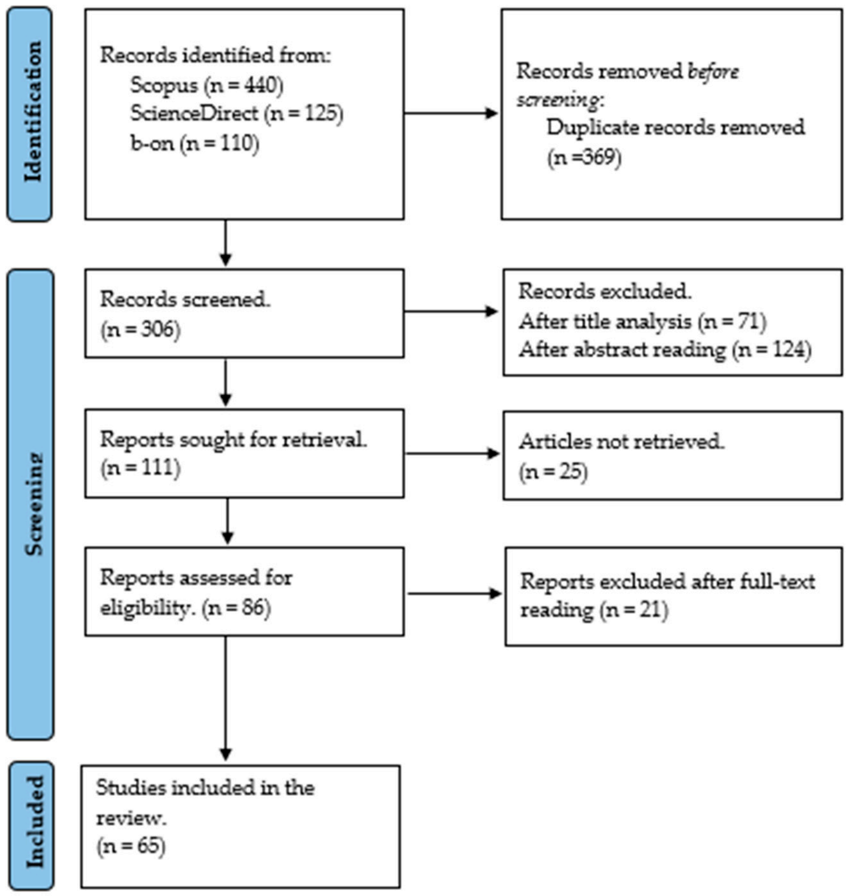

Figure 1. Number of papers at each level of the systematic review process (PRISMA diagram).

In this systematic review article, four databases were considered as the references because they covered all the relevant areas regarding the IEQ in the scientific publications. In addition, these databases included the most relevant literature on the IAQ and thermal comfort in tropical health care buildings. The four databases included Scopus, the Web of Science, ScienceDirect and PubMed. All the articles were filtered by the title, abstract, and keywords. For the tropical countries as the region of focus, the search used words such as "indoor air quality, thermal comfort, indoor air quality review, and thermal comfort review". The initial search query returned 401 publications on the IAQ and 275 publications on the ITC.

2.1. Inclusion and Exclusion Measures

The qualification criteria were used to select and review the relevant articles from the search results from the four databases. These criteria consisted of various inclusion and exclusion criteria. As shown in the first search query, this systematic review focused on the IAQ and ITC in tropical hospital buildings. Therefore, these studies related to the well-being and health of the patients and health care workers. The inclusion and exclusion principles for this systematic review are summarised in Table 1.

Table 1. Inclusion and exclusion measures.

Inclusion Criteria	Exclusion Criteria
Articles that focused on the IAQ and thermal comfort in tropical hospital building indoor environments.	Articles focused on non-tropical countries.
Only articles that were written in English.	Duplicated articles in the databases.
Publications released from 2000–2023.	Articles that were not written in English.
	Articles regarding the IC but not hospital buildings.
	Published before 2000.

2.2. Research Questions

The main objectives of the systematic review were to assess all the relevant studies regarding the ITC and IAQ that were conducted for the indoor environments of tropical hospital buildings within the aforementioned study selection parameters. The aim was to provide a valuable scientific contribution to the researchers and IEQ stakeholders through the identification of gaps and the deployment of relevant and pragmatic strategies to bridge these identified gaps for the improvement of IEQ practices in hospitals located in developing tropical countries. Moreover, the current study findings were valuable for IEQ policy and decision-makers for the development of more suitable and adapted regulations in these regions. Hence, the current study, via the discussions and critical analysis, addressed the following research questions (**RQ1** to **RQ5**):

1. What relevant scientific documentation, studies, and literature are available concerning the IC of hospitals in a tropical climate context and their main findings? (**RQ1**)
2. What aspects of the IC of hospitals in tropical regions have been studied? (**RQ2**)
3. What impacts of the IC conditions on the occupants of hospitals in tropical countries have been reported by the studies? (**RQ3**)
4. What methods were used in these scientific studies of the IC in tropical hospitals? (**RQ4**)
5. What are the areas for further studies concerning the IC of hospital buildings in tropical countries (the research gaps)? (**RQ5)**

To answer these questions, the authors analysed the available research on the hospital building indoor climates across several journal databases and all the relevant studies were subjected to an in-depth analysis of the basic specifications. The answers to these questions offered a foundation for future research on the improvement of the indoor climates in hospital buildings, especially those in tropical countries.

3. Literature Analysis

The literature analysis addresses **RQ1** and presents a summary of the relevant data, as shown in Table 2. A total of 401 IC articles arose from the first search query applied to the four databases. All the studies were transferred into the system platform and then, according to the PRISMA guidelines, the duplicate studies were identified. According to the exclusion criteria, 224 duplicate studies were removed, and 177 publications were left for the next level of selection. The 177 unduplicated collections were evaluated based on their title, abstract, keywords, article type, location, and date. In accordance with the criteria for inclusion and exclusion, 104 papers were excluded, and 73 articles were passed on to the next level of selection. At this stage, the authors screened the full text of the selected articles to consider their eligibility for the systematic review according to the specific inclusion and exclusion criteria. A total of 36 studies were found to be irrelevant for this stage. However, the same procedure was applied for the ITC papers selection. A total of 275 ITC publications in tropical countries were found and 195 duplicate studies were removed. By following the set of the inclusion and exclusion criteria, 52 articles were removed (see Table 2). All the documents were collected and analysed for their backgrounds (location and climate), building characteristics, and research features. The research articles on the IC studies in many countries were identified in Khodakarami and Nasrollahi [41], Sodha et al. [42], Chow and Yang [43], and Hwang et al. [44]. Nonetheless, the average number of citations for the overall articles on the topics in this field was much lower. Several articles contained words such as "tropical", "tropical region", or "tropical climate" in the titles, but they focused on specific countries rather than larger tropical regions. After the selection process, a total of 65 articles remained, with one previously published literature review provided in Table 2. The rest comprised 28 articles for the ITC and 37 articles for the IAQ. However, a study published in 2012 showed that, since a literature review on the hospital thermal comfort has not yet been published, the gap in the thermal comfort can be narrowed. Due to the focus on hospitals, some health-related buildings were not within their scopes, such as health and geriatric centres. At the time of the review study, the authors remarked that the available and accessible quantity of original publications was insufficient to evaluate the link between the hospital staff productivity and the thermal comfort. They also believed that comparison research should be conducted at more than one hospital [41]. Additionally, unlike its predecessors, this review is intended to cover the articles relating to the IAQ and thermal comfort in all types of hospitals to perform an up-to-date review on the topic. A total of 65 articles are presented and summarised in Table 2, which shows their title, year of publication, the country where the study was conducted, as well as their main findings.

Table 2. Sampled articles in the summary.

References	Title	Year	Country	Environment	Findings
Yi-Tun Wang et al. [9]	Investigation on indoor air quality of public sites in Tainan area	2011	Taiwan	Hospital	Hospitals need air conditioning and CO_2 control to maintain a healthy indoor environment.
Hualing Zhang [13]	Impact of Metabolism and clothing thermal resistance on inpatient thermal comfort	2021	China		The formulation of useful guidelines to facilitate the assessment and management of hospital ward thermal environments
Ramaswamy et al. [30]	IAQ in Hospitals – Better Health through Indoor Air Quality Awareness	2010	Oman	Hospital	patients in a controlled environment generally have more rapid physical improvement than do those in an uncontrolled environment
Lan et al. [39]	Thermal comfort improvement of naturally ventilated patient wards in Singapore	2017	Singapore	Hospital	A tropical warm climate medical ward might employ passive ventilation methods.
Khodakarami and Nasrollahi [41]	Thermal comfort in hospitals—A literature review	2012	Iran	Hospital	The direct impact of the thermal comfort on health has not been studied.
Chow and Yang [43]	Performance of ventilation system in a non-standard operating room	2003	Hong Kong	Hospital	The airflow and other design aspects did not meet the specifications.
Hwang et al. [44]	Patient thermal comfort requirement for hospital environments in Taiwan	2007	Taiwan	Hospital	Patients preferred warmer temperatures to neutral temperatures. This contradicts the office field studies.
Nematchoua et al. [45]	Thermal comfort and comparison of some parameters coming from hospitals and shopping centres under natural ventilation: The case of Madagascar Island	2017	Madagascar	Hospital	Hospital thermal satisfaction, preferences, and comfort may differ by gender and health.
Nematchoua, Ricciardi and Buratti [46]	Statistical analysis of indoor parameters a subjective response of building occupants in a hot region of Indian ocean: A case of Madagascar Island	2017	Madagascar	Hospital	Thermal, humidity, and air movement feelings are similar in men and women.
Alfa and Öztürk [47]	Perceived indoor environmental quality of hospital wards and patients' outcomes: A study of a general hospital, Minna, Nigeria	2019	Nigeria	Hospital	IEQ enhanced a ward's well-being. Health satisfaction most positively affected by the IEQ.
el Hamid Attia, El Helw and Teamah [48]	Three-dimensional thermal comfort analysis for hospital operating room with the effect of door gradually opened: Part (II) effect on mean age of the air and predicted mean vote distribution	2013	Egypt	Hospital	Door opening disrupts the optimal thermal impression by creating hot and humid zones.

Table 2. *Cont.*

References	Title	Year	Country	Environment	Findings
el Hamid Attia, El Helw and Teamah [49]	Three-dimensional thermal comfort analysis for hospital operating room with the effect of door gradually opened part (I) effect on velocity and temperature distributions	2013	Egypt	Hospital	Door opening negatively affects the thermal comfort. Thermal comfort is enhanced by the air curtain.
Tartarini, Cooper, and Fleming [50]	Thermal perceptions, preferences, and adaptive behaviours of occupants of nursing homes	2018	Australia	Elderly Centre	This study is likely to have practical implications for all the stakeholders in the aged care sector. The residents were more tolerant of temperature variations than staff or visitors.
Pedro Filipe et al. [51]	Thermal comfort applied in hospital environments	2020	Brazil	Hospital	Professionals and patients demanded adequate temperature conditions. Hospital productivity is inadequate.
Cheong and Chong [52]	Development and application of an indoor air quality audit to an air-conditioned building in Singapore	2001	Singapore	Hospital	Building air quality assessments showed that the ACMV system decreases pollutants.
Khodakarami and Knight [53]	Required and current thermal conditions for occupants in Iranian hospitals	2008	Iran	Hospital	The measurements of the hospital thermal comfort conditions were unsatisfactory.
Yau et al. [54]	Thermal comfort study of hospital workers in Malaysia	2009	Malaysia	Hospital	The tropical hospital thermal comfort temperature range may help services engineers save HVAC energy.
Pourshaghaghy and Omidvari [55]	Examination of thermal comfort in a hospital using PMV–PPD model	2012	Iran	Hospital	Men and women's PMV values exceed the ISO's acceptable range.
Azizpour et al. [56]	A thermal comfort investigation of a facility department of a hospital in hot–humid climate: Correlation between objective and subjective measurements	2013	Malaysia	Hospital	People in hot–humid climates prefered lower temperatures to neutral temperatures.
Azizpour et al. [57]	Thermal comfort assessment of large-scale hospitals in tropical climates: A case study of University Kebangsaan Malaysia Medical Centre (UKMMC)	2013	Malaysia	Hospital	Globally, the neutral temperature is higher than the preferred temperature.
Yau and Chew [58]	Adaptive thermal comfort model for air-conditioned hospitals in Malaysia	2013	Malaysia	Hospital	Tropical hospital adaptive thermal comfort model may save HVAC energy while preserving the thermal comfort.
Khalid et al. [59]	Thermal comfort requirements for different occupants in Malaysian hospital in-patient wards	2018	Malaysia	Hospital	Patients, visitors, and staff complained about overcooled rooms and nursing stations.

Table 2. *Cont.*

References	Title	Year	Country	Environment	Findings
Khalid et al. [60]	Investigation of comfort temperature and thermal adaptation for patients and visitors in Malaysian hospitals	2019	Malaysia	Hospital	Higher temperatures improve patient comfort in the hospital.
Fujen Wang et al. [61]	Field evaluation of thermal comfort and indoor environment quality for a hospital in a hot and humid climate	2012	Taiwan	Hospital	The hospital residents prefer lower tropical temperatures.
Sattayakorn, Ichinose and Sasaki [62]	Clarifying thermal comfort of healthcare occupants in tropical region: A case of indoor environment in Thai hospitals	2017	Thailand	Hospital	Thermal sensitivity differs among the patients, visitors, and hospital personnel.
Lawrence, et al. [63]	Indoor air quality investigations in hospital patient room	2018	India	Hospital	Hospital patient room active ventilation systems provide thermal comfort indoor air.
Pirsaheb, et al. [64]	Assessment of thermal comfort in hospital wards of Kermanshah, Iran, based on the standards	2017	Iran	Hospital	None of the sites were within the acceptable temperature and humidity ranges.
Azmoon et al. [65]	The relationship between thermal comfort and light intensity with sleep quality and eye tiredness in shift work nurses	2013	India	Hospital	Defects in the thermal and light conditions and a lack of a managerial strategy for night shift work nurses are harmful to their physical and mental well-being.
Mohammadyan, et al. [66]	Indoor and ambient air concentrations of respirable particles between two hospitals in Kashan	2016	Iran	Hospital	WHO/EPA 24-h PM limits were exceeded. Air conditioning may improve the indoor air quality.
Sana et al. [67]	Evaluation of hospital wards indoor air quality: the particles concentration	2016	Iran	Hospital	Low air exchange and ventilation in hospitals can produce and spread airborne particles that cause hospital infections.
Azhar et al. [68]	Air quality assessment of some selected hospitals within Baghdad City	2019	Iraq	Hospital	Hospital IAQ is significantly affected by the surrounding environment.
Luksamijarulkul et al. [69]	Indoor air quality at different sites of a governmental hospital, Thailand	2019	Thailand	Elderly Centre	Bacteria in hospital air may affect patients and workers, particularly nurses.
Tungjai Kubaha. [70]	Indoor air quality evaluation of isolation room for hospital in Thailand	2017	Thailand	Hospital	The indoor air quality index showed moderate VOC, formaldehyde, $PM_{2.5}$, and PM_{10} levels (IAQI).
Hong-Wen et al. [71]	Indoor air distribution of nitrogen dioxide and ozone in urban hospitals	2009	Taiwan	Hospital	Nitrogen dioxide, PM_{10}, and traffic increased indoor pollution.

Table 2. *Cont.*

References	Title	Year	Country	Environment	Findings
Chin-Sheng [72]	Air quality monitoring of the post-operative recovery room and locations surrounding operating theaters in a medical centre in Taiwan	2013	Taiwan	Hospital	Patients and staff need clean air in the post-operative recovery room.
Ming et al. [73]	High total volatile organic compounds pollution in a hospital dental department	2017	Taiwan	Hospital	PM_{10}, $PM_{2.5}$, PM_1, and TVOCs were higher in hospitals. Hospital air quality needs attention.
Daniel et al. [63]	Indoor air quality investigations in hospital patient room	2018	India	Hospital	Predictions for the indoor–outdoor relationship for fresh air supply, temperature flow, and human load.
Kumar and Parijat [74]	Hospital indoor air quality in respect to transmission of infection	2020	India	Hospital	A hospital HVAC and IAQ regulating structure will enhance the IAQ.
H Yulinawati et al. [75]	Analysis of indoor and outdoor particulate (PM2.5) at a women and children's hospital in West Jakarta	2021	Indonesia	Hospital	$PM_{2.5}$ levels were higher in hospitals. Thus, a hospital must control the indoor and outdoor $PM_{2.5}$ concentrations to reduce health risks.
Khew et al. [76]	Sources of indoor air quality problem in a new hospital in Malaysia	2007	Malaysia	Hospital	Low-level air pollution affects respiratory and cardiovascular health.
Mahmoud F et al. [77]	Indoor air quality levels in a University Hospital in the Eastern Province of Saudi Arabia	2014	Saudi Arabia	Hospital	Particulate matter (PM_{10} and TSP) exceeded the air quality guidelines.
Basharia, et al. [78]	Assessment of indoor air quality in medical facilities in Sudan	2013	Sudan	Hospital	In hospitals, the window and split units don't provide adequate ventilation.
Zemichael Gizaw et al. [79]	High bacterial load of indoor air in hospital wards: the case of University of Gondar teaching hospital, Northwest Ethiopia	2016	Ethiopia	Hospital	Poor ventilation, waste management, temperature, and humidity increase the bacterial load.
K. Emuren, B. Ordinioha [80]	Physico-chemical assessment of indoor air quality of a tertiary hospital in South–South Nigeria	2017	Nigeria	Hospital	Hospital air pollutants were within the regulatory limits.
Ayodele et al. [81]	Investigation on the ambient air quality in a hospital environment	2016	Nigeria	Hospital	In the hospital airshed, human activities may degrade the air quality.
Hadir Gawili et al. [82]	Indoor air quality in Benghazi's hospitals and its impact among patients	2019	Libya	Hospital	Hospital health was most affected by the temperature, humidity, PM, other chemical pollutants, and noise.
Quadros et al. [83]	Indoor air quality in hospitals: A case study and a critical review of current standards	2009	Brazil	Hospital	Chemical pollution from cleaning can affect the air quality in hospitals.
Macedo et al. [84]	Air quality in a hospital environment	2013	Brazil	Hospital	The hallways and NICU have a wide variety of fungi.

Table 2. *Cont.*

References	Title	Year	Country	Environment	Findings
Yousef et al. [85]	Assessment of indoor air quality in neonatal intensive care units in government hospitals in Gaza Strip, Palestine	2016	Palestine	Hospital	Hospital CO_2 was higher than recommended.
Shahid Zaman et al. [86]	Indoor air quality indicators and toxicity potential at the hospitals' environment in Dhaka, Bangladesh	2021	Bangladesh	Hospital	PM levels were lower indoors than outdoors, but gaseous pollutants were higher, except for NO_2.
Božić et al. [87]	Indoor air quality in the hospital: The influence of heating, ventilating and conditioning systems	2019	Brazil	Hospital	Monitoring proves HVAC systems reduce microbiological contamination.
Cocom Martínez [88]	Empirical investigation of indoor environmental quality (IEQ) in a hospital building in Merida Yucatan, Mexico	2018	Mexico	Hospital	Hospitals needed cross ventilation in all interior rooms due to poor ventilation.
ME Osman [89]	A study on microbiological contamination on air quality in hospitals in Egypt	2017	Egypt	Hospital	Airborne germs and fungus in hospitals came from dust on air conditioning filters and floors.
Taushiba et al. [90]	Assessment of indoor air quality and their inter-association in hospitals of northern India—a cross-sectional study	2023	India	Hospital	The outdoor vehicular load, greenery, industries, etc., play a crucial role in maintaining the IAQ at an acceptable level.
Udobang and Otumo [91]	Assessment of thermal comfort in hospital rooms and health status of patients	2023	Nigeria/Ghana	Hospital	Thermal comfort can foster the healing process of the patients in hospitals.
Alghamdi et al. [92]	Distribution and the trend of airborne particles and bioaerosol concentration in pediatric intensive care units with different ventilation setting at two hospitals in Riyadh, Saudi Arabia	2023	Saudi Arabia	Hospital	Advanced filtration system and central HEPA filters play a significant role in the reduction in indoor fine particulates and TBC.
Lan et al. [39]	Thermal comfort improvement of naturally ventilated patient wards in Singapore	2017	Singapore	Hospital	Ventilation could be used effectively for a patient hospital ward, even in a tropical warm climate.

4. Results and Discussion

4.1. Aspects of IC in Tropical Hospitals

RQ2 was addressed by the results and a summary of the relevant data, which are presented in Table 3 and Figures 2 and 3. This study found 37 IAQ records and 28 ITC documents, of which several tropical countries had zero IAQ and ITC records. Particularly, the records showed that 67% and 61% of the IAQ and ITC studies were in Asia in countries, such as Malaysia, Taiwan, India, Thailand, Indonesia, and Singapore. These were followed by Africa with 19% for the IAQ and 28.5% for the ITC, tropical American countries with 11% for the IAQ and 7% for the ITC in, and finally tropical Oceania countries with 3% for the IAQ and 3.5% for the ITC in tropical Oceania countries. These statistics are visually presented in a map of the world in the Appendix A. Table 3 shows the most and least studied countries on the continent, including the different aspects of the data for each country that were directly or indirectly related to the IAQ and ITC research and might have affected the development of this topic. For example, in theory, the countries with large populations and high carbon dioxide emissions may need more research on the IAQ and ITC or IEQ interventions studies. The highest level in each category was highlighted to determine the key for the IAQ and ITC research.

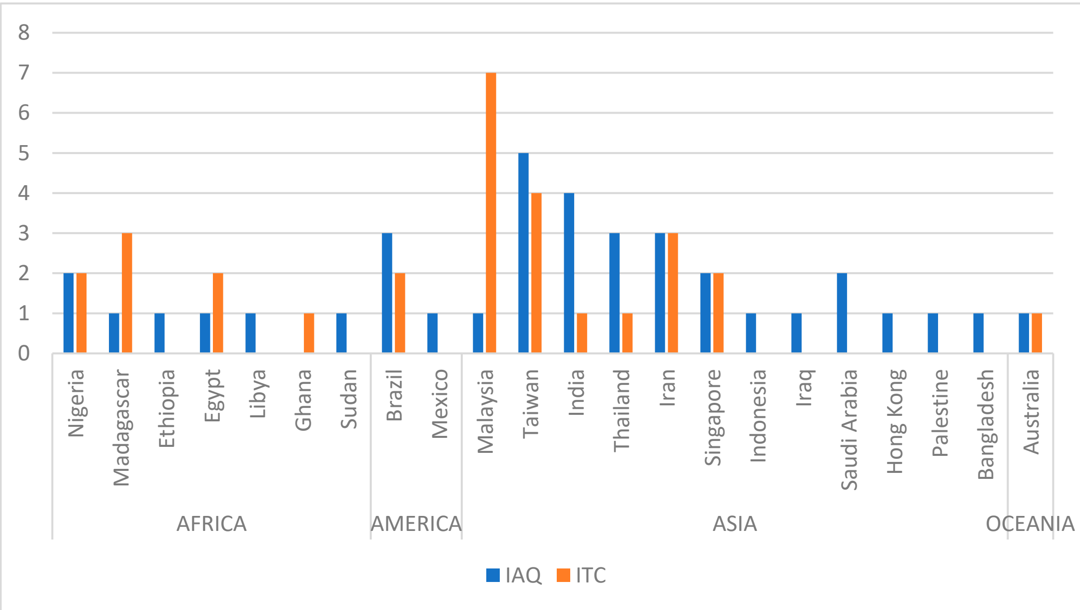

Figure 2. Distribution of the countries by the amount of the available and accessible studies on the IC parameters of the hospital environments.

Moreover, a distribution of the countries by the amount of the available and accessible studies on the IC parameters of the hospital environments is shown in Figure 2.

Tropical America was the region with the least research on the IAQ and general thermal comfort of hospital buildings, followed by tropical Africa (Figure 3). Furthermore, considering the 54 African countries, eight ITC and seven IAQ documents were found. Of these, five countries studied the IAQ, only three countries studied the ITC while 47 of these countries had zero IAQ and ITC records. Among them, Ethiopia, the Democratic Republic of the Congo (DRC), Sudan, Mozambique, and Angola had the least research on the size and population of their country, with the first two countries identified as the key countries. Nigeria was the country with the most records in the region. However, considering the combination of the country size and population, Nigeria and Madagascar were the most studied countries, while the DRC and Angola had no records regarding IC research.

Regarding **RQ2**, twenty-three countries were researched in tropical America, and three ITC and five IAQ documents were found in the region. Of these, 21 countries had zero IAQ and ITC records. Peru, Guatemala, Bolivia, Haiti, and the Dominican Republic had the least research. Brazil was the most registered country in the region, with four ITC documents and one IAQ document. However, Mexico and Brazil were the most researched countries, while Peru and Bolivia had the least research considering their population and size. The tropical Asian countries were examined, and 16 ITC documents and 21 IAQ documents were found for the region. There were fewer studies in 11 countries, such as the Philippines, Vietnam, and Cambodia, which had zero ITC or IAQ registrations. Malaysia was the most registered country in the region, with six ITC documents, while Taiwan had four IAQ documents. Therefore, this was considered a key figure, together with Vietnam. The most registered countries were Taiwan and Malaysia. The Philippines and Cambodia had the least research regarding the country and population. Two IAQs were considered in 13 countries in Oceania, and one ITC document was found for the region.

Table 3. The most and least studied hospital indoor climates in tropical countries.

Continent	Country	No. Documents		Population (Millions)		CO_2 Emissions (Metric Tons/Capita)	Average Annual Temp.
		IAQ	ITC	2015	2022	2019	(°C)
AFRICA	Nigeria	2	2	181.1	218.5	0.70	27.2 °C
	Madagascar	1	3	24.2	27.6	0.15	23 °C
	Ethiopia	1	0	100.8	123.3	0.14	22.6 °C
	Egypt	1	2	92.4	110.9	2.46	22.5 °C
	Libya	1	0	6.4	6.8	6.85	22.6 °C
	Sudan	1	0	38.9	46.8	0.54	27 °C
	Congo, DR.	0	0	76.2	99.5	0.03	26.6 °C
	South Africa	0	0	55.3	59.8	8.17	18.3 °C
	Chad	0	0	14.1	17.7	0.06	27.4 °C
	Ghana	0	1	28.8	32.8	13.9	27.2 °C
	Angola	0	0	27.8	35.5	1.19	27 °C
	Mozambique	0	0	27.0	32.9	0.29	24.3 °C
AMERICA	Brazil	3	2	204.4	215.3	2.21	25 °C
	Mexico	1	0	121.8	127.5	3.44	20.6 °C
	Venezuela	0	0	28.3	30.3	4.09	24 °C
	Peru	0	0	30.3	32.9	1.68	23.5 °C
	Colombia	0	0	47.5	50.8	2.03	24 °C
	Bolivia	0	0	10.8	11.6	1.96	20 °C
	Cuba	0	0	8.3	11.3	2.29	25.2 °C
ASIA	Malaysia	1	6	31.5	33,9	7.83	25.4 °C
	Taiwan	5	4	23.4	27.5	11.05	22 °C
	India	4	1	1.310	1.417	1.91	25 °C
	Thailand	3	1	68.7	69.7	4.14	26.3 °C
	Iran	3	3	78.4	83.9	9.40	22 °C
	Singapore	2	2	5.5	5.8	6.71	26.7 °C
	Indonesia	1	0	258.3	275.5	2.28	26.5 °C
	Iraq	1	0	35.5	40.2	5.63	22.6 °C
	Saudi Arabia	2	0	31.7	34.8	16.99	26.2 °C
	Hong Kong	1	0	7.2	7.5	7.5	22.6 °C
	Philippines	0	0	102.1	109.5	1.33	26 °C
	Palestine	1	0	4.2	5.1	0.66	19.6 °C
	Bangladesh	1	0	156.2	164.6	0.63	26.1° C
OCEANIA	Australia	1	1	23.8	26.1	16.31	22.1° C
	Solomon Islands	0	0	0.6	0.7	7.64	25.65 °C
	Papua New Guinea	0	0	8.1	8.9	0.81	25 °C
	Fiji	0	0	0.9	0.9	2.54	24.4 °C
	New Caledonia	0	0	0.3	0.3	8.53	27.0 °C
	French Polynesia	0	0	0.3	0.3	2.98	26.1 °C

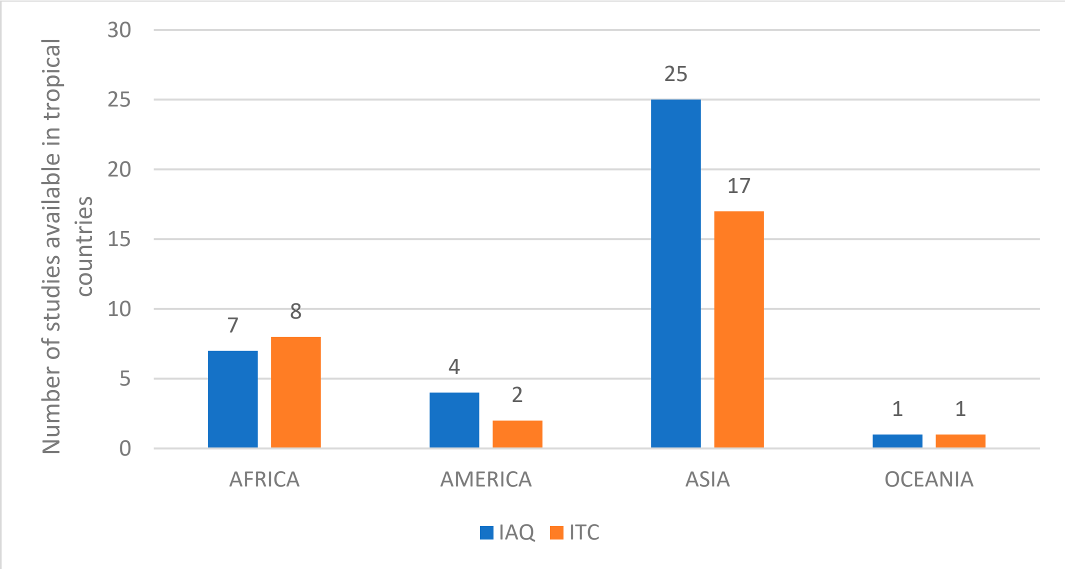

Figure 3. Number of studies available in the different tropical countries on different continents.

4.2. Implications of Poor IC in Tropical Hospitals

In the following discussion, some impacts of the IC conditions highlighted by the identified and selected studies of the IC in hospital buildings in tropical countries are presented (**RQ3**). The increase in poor indoor climates may decrease the productivity, recovery, and well-being of the inhabitants, and this has prompted the scientific community to create a slew of technologically inspired remedies for this problem. This systematic review studied 65 articles on the IC in tropical hospitals by focusing on the IAQ and thermal comfort. However, a total of 42 studies (65%) were conducted in Asia and 15 studies (23%) in Africa. Six studies (9%) were reported in South America and two studies (3%) were obtained from Oceania, Australia.

4.2.1. Thermal Comfort Studies

In a study at a university hospital in Taiwan, 927 datasets were collected to show that physical strength had a highly significant influence on the thermal feeling, while gender, age, and acclimatization did not [29]. According to a field research study on the thermal comfort conducted in Malaysia, the neutral temperature during the day was approximately 26 °C, the comfort range was between 25 °C and 27 °C, and the acceptable range was 23.8 °C to 29 °C [43]. Similar studies found that patients with certain chronic conditions, such as cardiovascular and cerebrovascular disease, diabetes, respiratory and renal disease, Parkinson's disease, Alzheimer's disease, and epilepsy, were more sensitive to heat [11]. Research also found that patients preferred a slightly warm indoor temperature than a neutral temperature [26]. In Taiwan, Hwang et al. discovered that only 40% of all the assessed thermal conditions were within the ASHRAE-recommended comfort zone [29]. A researcher addressed not only the thermal comfort of the patients but also of the hospital employees. Comparable research on the thermal comfort of 114 medical personnel in Malaysian hospitals identified a neutral temperature of 26.4 °C. The preferred temperature range for 90% of the space's inhabitants was 25.3 °C to 28.2 °C [76]. A thermal comfort study in four Iranian hospitals showed that, while the air temperature ranged from 20 °C to 28 °C and the relative humidity ranged from 30% to 60%, healthcare workers experienced uncomfortably hot thermal conditions [77]. According to research on the hospital thermal comfort in Nigeria, the maximum recorded values of the outside and indoor temperatures varied from 34.1 °C to 36.9 °C and from 32.5 °C to 35 °C, respectively. This temperature fluctuation among the residential densities was shown to negatively impact the ITC (Yousef et al. 2013). A similar study on the thermal comfort revealed that, in two hospital wards in Nigeria, the relative humidity exceeded the maximum limit. Equally, the indoor air temperature in both buildings exceeded the range of 23 °C to 26 °C as recommended by the ASHRAE Standard(Gizaw, Gebrehiwot, and Yenew 2016). According to the research in Madagascar, the traditional structures were more pleasant than the other types of buildings, with more than 80% of the occupants satisfied when the indoor air temperature ranged between 24.5 °C and 27.5 °C [80]. Concerning the effects of the thermal comfort on patients, a study [91] conducted in Ghana evaluated the effects of the thermal comfort on patients in the hospital rooms. The findings suggested that good thermal comfort conditions can help the patients heal in hospital, although their reports indicated that this effect was highly case-dependent and varied greatly when considering other influences, such as the patient's health and the type and level of the hospital staff.

4.2.2. Indoor Air Quality Studies

A study on the air quality in three hospitals in urban and suburban environments in Pakistan showed that the particulate matter concentrations were very high and exceeded the WHO guidelines, and a strong positive correlation was found between the indoor and outdoor $PM_{1.0}$, $PM_{2.5}$, and PM_{10} during the winter season [93] The outdoor air significantly impacted a hospital's IAQ [72]. According to the research conducted in a Taiwanese hospital, the indoor nitrogen dioxide concentration was strongly correlated with the outdoor nitrogen dioxide concentration, PM_{10} concentration, and traffic flow (r = 0.91, r = 0.65 and r = 0.72, correspondingly) [58]. A similar study showed that the CO_2 concentrations, TVOC, and bacteria in hospitals and schools exceeded the threshold recommended by the WHO guidelines and were commonly caused by outdoor air pollution [9]. A similar study revealed that the outdoor air pollution from vehicle traffic and other chemical pollutants was the main pollution source in ten different Libya hospitals [68]. The research carried out in Saudi Arabia discovered that the IAQ inside healthcare facilities was strongly influenced by external sources, particularly traffic, where the levels of the particles and fungus species, such as Cladosporium and Penicillium, were higher than the recommended levels in the air quality guidelines [63]. Similarly, the IAQ investigation for another Saudi Arabian hospital found that the fine particles concentration in the hospital were higher than the outdoor pollution levels, while the airborne pollutants and microbial counts in the ICUs were greatly impacted by the ventilation system [92]. A study in eight Ethiopian hospital wards and the Gondar University teaching hospital indicated a high bacterial concentration in the indoor air that was found to be between 480 CFU/m^3 and 1468 CFU/m^3. The temperature (26.5 °C to 29.5 °C), humidity (64.5–85%), and poor ventilation were favourable conditions for the growth and multiplication of the bacteria [65]. Another study on the IAQ in an Egyptian hospital revealed that high concentrations of microbes, fungi, and PM were found in the hospital's indoor environment, which was caused by poor hygiene and the infiltration of polluted air that contained dust through natural ventilation. However, they also stated that several patients and hospital staff had a risk of infection from the bacterial and indoor air pollutants [89]. Similarly, a Sudanese dental hospital study revealed that the indoor air and volatile organic compound (VOC) concentrations exceeded the ASHRAE Standard due to insufficient air provided by the mechanical ventilation. Moreover, using natural ventilation as a source of air infiltration significantly impacts the outdoor air pollution entering the hospital, such as dust and bacteria, which increase the risk of disease for patients in the clinic [78]. A study of the IAQ at different locations in a Nigerian hospital showed a greater variability in the VOC levels, ranging from 236.57 mg/m^3 in the HIV clinic to 530.77 mg/m^3 in the men's surgical ward. However, the levels of the tested pollutants were within the regulatory levels, despite the evidence of poor ventilation in some of the study sites [80]. However, the common thread in these findings suggested that effective mechanical ventilation systems, coupled with adequate operation and maintenance, are necessary to achieve a better IAQ in hospitals to mitigate the potential risks to health, recovery, and well-being of the exposed occupants.

4.3. Main Methods and Approaches Used in the Reviewed Studies

With respect to **RQ4**, we highlighted the methods and approaches used in these reported studies reported. The findings indicated that most of the reviewed studies employed mixed methods, using both experimental measurements and subjective assessments, while in some studies, a combination of all the methods, including simulation method or either of the methods, was used. Significantly, many of these studies did not assess the IC of the hospital buildings considering a seasonal approach or report the peculiarities in the IC for the different seasons in these tropics. Furthermore, most of the hospitals evaluated in the developing tropical countries paid minimal attention to the hospital location, although a study in India assessed the levels of heavy metals, particles, and microbial pollutants for the outdoor and indoor environments of three hospitals based on their locations. Their findings reported the highest indoor level of the particle concentrations in hospital A, situated in an industrial area, while hospitals B and C had higher levels of microbial and fungi pollutants, respectively [90]. Therefore, it is important that a consideration for the environmental influences due to the hospital location and the surrounding activities of the indoor and outdoor areas are evaluated in the IC studies of the hospitals. There can be also potential risk to the IC of the indoor spaces in such areas besides air pollution, such noise and vibrational impacts. Specifically, only a few of the reviewed studies considered the potential risks to the IC from industries, such as mineral processing and mining operations. Furthermore, it is important to note that, the impact of poor waste management systems, pollution, poor environment awareness, and poor regulation and policy vastly contribute to the risk of a poor IAQ and other comfort parameters in hospitals located in the industrial areas of many developing tropical countries. These studies [94–96] revealed that the occupants of the buildings located near mining operations were exposed to metals, nitrogen oxides, $PM_{2.5,}$ and PM_{10} and were at risk of negative health impacts. Likewise, the studies [97,98] in the developing sub-Saharan countries of Zambia and the DRC showed that the mining operations in the Copperbelt regions of Kitwe and Lubumbashi resulted in high environmental pollution, such that the residents of these towns were susceptible to unsafe levels of ultra-fine particulate matter, $PM_{2.5}$ and PM_{10}.

Moreover, concerning the risks of occupant exposure to a poor IC, in sub-Saharan countries, the IAQ reviewed studies mainly investigated the fungi and bacteriological concentrations. Only a few studies assessed the VOCs and $PM_{2.5}$ in the hospital buildings of the developing tropical countries compared to other tropical regions. Apart from these findings, the discussions, conclusions, and recommendations of many studies that were reviewed suggested that gaps exist in the IC due to the poor hospital building infrastructure and inadequate or complete absence of mechanical ventilation. In many developing tropical countries, there is still a significant dependence on natural ventilation with little or an inadequate use of mechanical ventilation systems. The realities of energy poverty, inefficient air-conditioning systems, absence of IEQ regulations, or inadequate implementation pose a great risk to health, well-being, comfort, and safety, especially for hospitals. Therefore, the responsibility of addressing the current gaps should be shared, which is important for the advancement of the IC knowledge and the possible interventions for the identified gaps in these tropics, especially for the sub-Saharan African countries.

It is important to note that there were some limitations to the current study. The current systematic review study considered only the scientific papers on the IC of tropical hospitals, excluding other health care facilities which might have included geriatric centres, fitness and well-being centres, maternity centres, nursing homes, medical labs, clinics, and pharmacies. Additionally, the scientific studies regarding the other IEQ parameters in hospital buildings, such as the acoustic comfort, visual comfort, and ergonomics, were not reviewed according to the current study's inclusion and exclusion parameters. Finally, the studies on the outdoor air quality and pollution impacts on a hospital building environment were not considered in the current study. Meanwhile, several studies on the IEQ correlated the ambient outdoor conditions to the indoor climate of the buildings.

The results and discussions of the current study show that gaps exist in the IC scientific data and the studies on the tropics, leading to veritable conclusions and an emphasis on the viability of the potential areas of the IEQ that can be researched in future studies, as presented in the final remarks.

5. Conclusions

The study systematically reviewed 65 accessible scientific articles on the indoor climate across four relevant databases for the subject matter within the premise of the defined inclusion and exclusion parameters. For the studies on the IC of the hospital buildings in tropical regions, the main selection constraints were that they were published in English within the period of 2000 to 2023. In this context, the following research gaps (**RQ1**, **RQ2**, **RQ3**, **RQ4**, and **RQ5**) were underlined as follows.

The available data on the IC in the tropical regions was concentrated in only a few countries. The data was considerably limited or non-existent in the studies in many tropical countries. Meanwhile, the records indicated that 65% of the studies were in Asia, 23% in Africa, 9% in South America, and 3% in tropical Oceania countries. Additionally, the research was essentially concentrated in Asia rather than Africa, which was a concern, given that the population growth will rise geometrically in the tropics and predominantly in Africa by 2030 (**RQ1**).

Considering its population and size, tropical Africa was the region with less research on the IC in hospitals which requires more attention. It was followed by South America, Central America, and the Caribbean. Tropical Asia was the most studied region. It was also the most populated with IAQ and ITC research, however it was concentrated only in a few countries, such as Taiwan, Singapore, Malaysia, India, and Iran. Very little research was available in highly populated countries, such as Ethiopia, Nigeria, Sudan, and Egypt. Additionally, no records on the IAQ and ITC in hospitals were found for many populous countries, such as the Democratic Republic of Congo, Pakistan, Tanzania, and Myanmar. This is a concern since most of these countries have an increased risk of high temperatures due to climate change and industrial air pollution, which will potentially increase the demand for heating, ventilation, and air conditioning (HVAC) in the near future (**RQ2**).

Most studies on the IAQ in African hospitals focused on infectious substances (fungi and bacteriological concentrations) than other pollutants, such as CO_2, VOCs, ultra-fine particles, and PM. If the latter are present in hospital indoor spaces, they can have significant effects on the patients and staff, especially in the countries where the outdoor air is already polluted from industry, traffic, and other environmental pollution sources. No study records were found in tropical Africa for assessing the impact of the hospital IC on an occupant's performance, productivity, and behaviour. Furthermore, only one study in India evaluated the hospital IC by considering the location's impact on the IC in regard to the outdoor and indoor air quality (**RQ3**).

Many of the reviewed studies used mixed methods for the objective and subjective assessments, including simulation methods. A few studies used a combination of these methods or either of the methods. Only very few studies performed a seasonal assessment and the influences the seasons have on the hospital IC in the tropics. However, it is important to consider the seasonal peculiarities, hospital location, ventilation types, and the potential effects of these factors on the IC parameters of hospital buildings in tropical countries (**RQ4**).

Hence, to address (**RQ5**), the following future lines of research are recommended as per the current findings of this work.

- More studies are required to assess the IC of hospitals with consideration for the outdoor factors, such as the location in industrial zones (exposure to heavy industry operations, mines, mineral processing etc.), commercial zones, and residential zones (ambient traffic and city noise, religious activities). Particular attention should be given to the IC of hospitals in sub-Saharan Africa, such as in the Copperbelt regions.

- Future studies should consider the use of a seasonal assessment in their methodology to evaluate the IEQ parameters by considering the peculiarities of the seasonal differences and effects on the IC. Meanwhile, a seasonal approach for assessing the thermal comfort may be important for considering the peculiarities of occupant's activities, behaviour, and cultural nuances in developing tropical countries.
- Future studies should pay special attention to the IAQ and comfort parameters, such as the thermal, visual, and acoustic comfort and their impacts on an occupant's productivity, performance, and behaviour, as well as any behaviour change in the healthcare and schools in tropical countries.
- Future studies should evaluate the gaps and challenges of the IEQ policies, regulations, implementation challenges, and building design practices in developing tropical African countries, with particular attention on the IC of hospitals and schools.
- Future studies should evaluate the IEQ gaps and requirements for the development of well-adapted standards and regulations by considering the climatic, environmental, and infrastructural peculiarities of the tropical countries for the betterment of the IEQ conditions in built and mobile indoor spaces.

In conclusion, the current study findings are recommended to the researchers in future works for the improvement of the IC in tropical hospital buildings. Additionally, they offer the possibility of a plausible move away from of the current IEQ standards (which are still universal in approach) towards more well-adapted standards (which can be more region specific) for tropical countries, especially for developing tropical countries. Furthermore, obtaining local information on the IC in hospitals is essential not only for the specific locations where studies are lacking, but also for humans in general. Since tropical nations rank significantly in the global population density, pollution, and climatical variability, the management of the IC in hospitals will have long-term global consequences on sustainable development, energy use, climate change, CO_2 emissions, and the associated pollutants.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

In this appendix, the tropical countries and sample locations are indicated and presented in a map of the world, as shown in Figure A1.

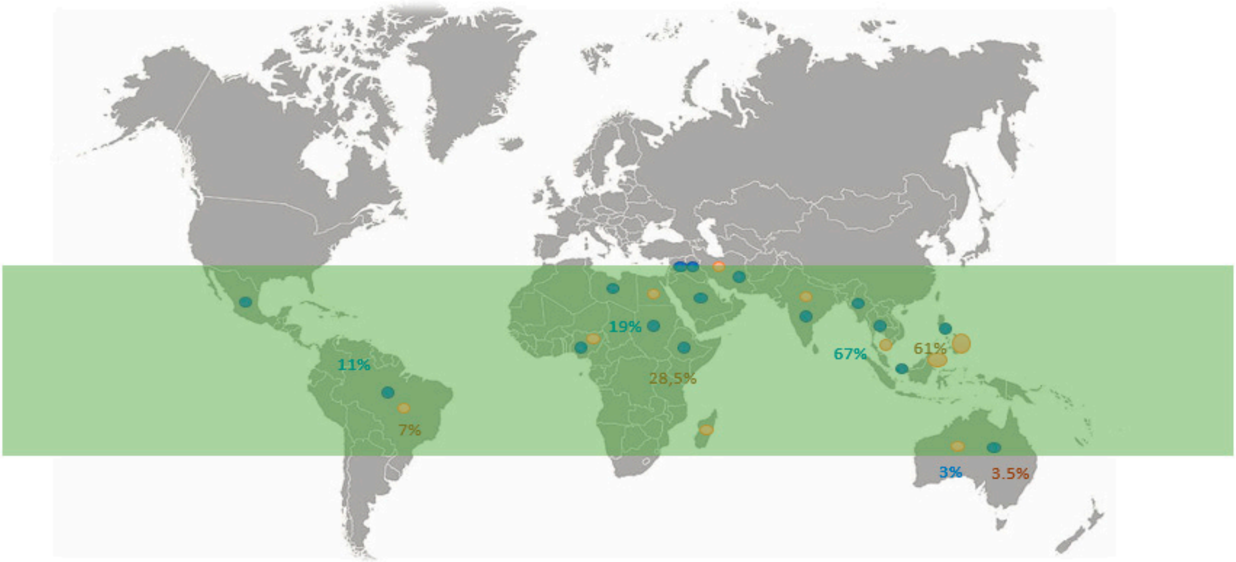

Figure A1. Map of the world indicating the tropical countries and sample locations where the blue circle are indoor air quality and the yellow for the thermal comfort studies.

References

1. Gómez-Acebo, I.; Llorca, J.; Ortiz-Revuelta, C.; Angulo, B.; Gómez-Álvarez, S.; Dierssen-Sotos, T. Sick building syndrome in a general hospital and the risks for pregnant workers. *Int. J. Gynecol. Obstet.* **2011**, *113*, 241–242. [CrossRef]
2. Akova, I.; Kiliç, E.; Sümer, H.; Keklikçi, T. Prevalence of sick building syndrome in hospital staff and its relationship with indoor environmental quality. *Int. J. Environ. Health Res.* **2020**, *32*, 1204–1219. [CrossRef]
3. Babaoglu, U.T.; Sezgin, F.M.; Yag, F. Sick building symptoms among hospital workers associated with indoor air quality and personal factors. *Indoor Built Environ.* **2019**, *29*, 645–655. [CrossRef]
4. Norbäck, D. An update on sick building syndrome. *Curr. Opin. Allergy Clin. Immunol.* **2009**, *9*, 55–59. [CrossRef]
5. U.S. Environmental Protection Agency and I. Environments Division. Indoor Air Facts No. 4 Sick Building Syndrome. EPA - Air & Radiation (6609J), Research and Development (MD-56). 1991; pp. 1–4. Available online: https://www.epa.gov/sites/production/files/2014-08/documents/sick_building_factsheet.pdf (accessed on 10 April 2023).
6. McMichael, A.J. *Climate Change and Health: Policy Priorities and Perspectives*; Centre on Global Health Security: Washington, DC, USA, 2011; p. 15.
7. Haines, A.; Smith, K.R.; Anderson, D.; Epstein, P.R.; McMichael, A.J.; Roberts, I.; Wilkinson, P.; Woodcock, J.; Woods, J. Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. *Lancet* **2007**, *370*, 1264–1281. [CrossRef]
8. Fanger, P.O. *Analysis and Applications in Environmental Engineering*; Danish Technical Press: Copenhagen, Denmark, 1970.
9. Wang, Y.T.; Chiu, J.C.; Hsu, Y.C.; Wu, T.N.; Shen, Y.H.; Wen, S.B. Investigation on Indoor Air Quality of Public Sites in Tainan Area. *Adv. Mater. Res.* **2011**, *255–260*, 1413–1417. [CrossRef]
10. Van Hoof, J.; Kort, H.; Duijnstee, M.; Rutten, P.; Hensen, J. The indoor environment and the integrated design of homes for older people with dementia. *Build. Environ.* **2010**, *45*, 1244–1261. [CrossRef]
11. Dahlia, Y. Physical and Physiological Thermal Comfort on Indoor Studio. 2018, pp. 19–23. Available online: https://www.thefreelibrary.com/_/print/PrintArticle.aspx?id=601551025 (accessed on 10 April 2023).
12. Szczurek, A.; Maciejewska, M.; Połoczański, R.; Teuerle, M.; Wyłomańska, A. Dynamics of carbon dioxide concentration in indoor air. *Stoch. Environ. Res. Risk Assess.* **2014**, *29*, 2193–2199. [CrossRef]
13. Zhang, H.; Xie, X.; Hong, S.; Lv, H. Impact of metabolism and the clothing thermal resistance on inpatient thermal comfort. *Energy Built Environ.* **2020**, *2*, 223–232. [CrossRef]
14. Watkins, E. VOCs and Indoor Air Quality. September 2014. Available online: https://blog.cashins.com/blog-0/bid/194114/VOCs-and-Indoor-Air-Quality (accessed on 10 April 2023).
15. Corgnati, S.P.; da Silva, M.G.; Ansaldi, R.I.; Asasi, E.; Costa, J.J.; Filipi, M.; Kaczmarczyk, J.; Melikov, A.K.; Olesen, B.W.; Popiolek, Z. *Indoor Climate Quality Assessment*; REHVA, Federation of European Heating, Ventilation and Air-conditioning Associations: Brussels, Belgium, 2011.
16. Fanger, P.O.; Toftum, J. Extension of the PMV model to non-air-conditioned buildings in warm climates. *Energy Build.* **2002**, *34*, 533–536. [CrossRef]

17. Verheyen, J.; Theys, N.; Allonsius, L.; Descamps, F. Thermal comfort of patients: Objective and subjective measurements in patient rooms of a Belgian healthcare facility. *Build. Environ.* **2011**, *46*, 1195–1204. [CrossRef]
18. Rodriguez, C.M.; D'Alessandro, M. Indoor thermal comfort review: The tropics as the next frontier. *Urban Clim.* **2019**, *29*, 100488. [CrossRef]
19. Rajapaksha, I.; Nagai, H.; Okumiya, M. Indoor Thermal Modification of a Ventilated Courtyard House in the Tropics. *J. Asian Arch. Build. Eng.* **2002**, *1*, 87–94. [CrossRef]
20. Kubota, T.; Ahmad, S. Wind Environment Evaluation of Neighborhood Areas in Major Towns of Malaysia. *J. Asian Arch. Build. Eng.* **2006**, *5*, 199–206. [CrossRef]
21. Taylor, J.; Shrubsole, C.; Davies, M.; Biddulph, P.; Das, P.; Hamilton, I.; Vardoulakis, S.; Mavrogianni, A.; Jones, B.; Oikonomou, E. The modifying effect of the building envelope on population exposure to $PM_{2.5}$ from outdoor sources. *Indoor Air* **2014**, *24*, 639–651. [CrossRef]
22. Van den Berg, A.E. *Health Impacts of Healing Environments, a Review of Evidence for Benefits of Nature, Daylight, Fresh Air, and Quiet in Healthcare Settings*; UMCG: Hanzeplein, The Netherlands, 2005.
23. Zborowsky, T.; Kreitzer, M.J. Creating optimal healing environments in a health care setting—PubMed. *Minn. Med.* **2008**, *91*, 35–38. Available online: https://pubmed.ncbi.nlm.nih.gov/18438085/ (accessed on 15 September 2021).
24. Mayssara, A. Abo Hassanin Supervised, Affiifi. IAQ in Hospitals—Better Health through Indoor Air Quality Awareness. In *Paper Knowledge. Toward a Media History of Documents*; Duke University Press: Durham, NC, USA, 2014.
25. Mahbob, N.S.; Kamaruzzaman, S.N.; Salleh, N.; Sulaiman, R. A Correlation Studies of Indoor Environmental Quality (IEQ) Towards Productive Workplace. In Proceedings of the 2nd International Conference on Environmental Science and Technology (ICEST 2011), Singapore, 26–28 February 2011; Volume 6, pp. 434–438.
26. Sadek, A.H.; Nofal, E.M. Effects of Indoor Environmental Quality on Occupant Satisfaction in Healing Environments. 2013. Available online: https://www.researchgate.net/publication/258510534 (accessed on 10 April 2023).
27. Pejtersen, J.; Allermann, L.; Kristensen, T.S.; Poulsen, O.M. Indoor climate, psychosocial work environment and symptoms in open-plan offices. *Indoor Air* **2006**, *16*, 392–401. [CrossRef]
28. Antunes, F.; Safdar, S.; Monteiro, A.; Samsudin, E.Z. Hospital indoor air quality and its relationships with building design, building operation, and occupant-related factors: A mini-review. *Front. Public Health* **2022**, *10*, 1067764.
29. Fonseca, A.; Abreu, I.; Guerreiro, M.J.; Barros, N. Indoor Air Quality in Healthcare Units—A Systematic Literature Review Focusing Recent Research. *Sustainability* **2022**, *14*, 967. [CrossRef]
30. Ramaswamy, M.; Al-Jahwari, F.; Al-Rajhi, S.M.M. IAQ in Hospitals-Better Health through Indoor Air Quality Awareness. 2010. Available online: https://oaktrust.library.tamu.edu/handle/1969.1/94139 (accessed on 10 April 2023).
31. Thiam, D.R. Structures of energy resources consumption in Senegal in 2006. *J. Energy South. Afr.* **2011**, *22*, 23–34. [CrossRef]
32. WHO. *Energizing Health: Accelerating Electricity Access in Health-Care Facilities*; WHO: Geneva, Switzerland, 2023.
33. Buchanan, T.L.; Barker, K.N.; Tyrone Gibson, J.; Jiang, B.C.; Pearson, R.E. Illumination and Errors in Dispensing. 1991. Available online: https://academic.oup.com/ajhp/article-abstract/48/10/2137/5183010 (accessed on 10 April 2023).
34. Davis, R.G.; McCunn, L.J.; Wilkerson, A.; Safranek, S. Nurses' Satisfaction with Patient Room Lighting Conditions: A Study of Nurses in Four Hospitals With Differences in the Environment of Care. *HERD Health Environ. Res. Des. J.* **2020**, *13*, 110–124. [CrossRef]
35. Juang, D.F.; Lee, C.H.; Yang, T.; Chang, M.C. ABSTRACT: Noise pollution and its effects on medical care workers and patients in hospitals. *Int. J. Environ. Sci. Tech.* **2010**, *7*, 705–716. [CrossRef]
36. Nyembwe, J.-P.K.B.; Ogundiran, J.O.; da Silva, M.G.; Simões, N.A.V. Evaluation of Noise Level in Intensive Care Units of Hospitals and Noise Mitigation Strategies, Case Study: Democratic Republic of Congo. *Buildings* **2023**, *13*, 278. [CrossRef]
37. Ebrahimi-Moghadam, A.; Ildarabadi, P.; Aliakbari, K.; Fadaee, F. Sensitivity analysis and multi-objective optimization of energy consumption and thermal comfort by using interior light shelves in residential buildings. *Renew. Energy* **2020**, *159*, 736–755. [CrossRef]
38. Ebrahimi-Moghadam, A.; Ildarabadi, P.; Aliakbari, K.; Arabkoohsar, A.; Fadaee, F. Performance analysis of light shelves in providing visual and thermal comfort and energy savings in residential buildings. *J. Braz. Soc. Mech. Sci. Eng.* **2020**, *42*, 484. [CrossRef]
39. Lan, L.; Tushar, W.; Otto, K.; Yuen, C.; Wood, K.L. Thermal comfort improvement of naturally ventilated patient wards in Singapore. *Energy Build.* **2017**, *154*, 499–512. [CrossRef]
40. Page, M.J.; Moher, D.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ* **2021**, *372*, n160. [CrossRef]
41. Khodakarami, J.; Nasrollahi, N. Thermal comfort in hospitals—A literature review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 4071–4077. [CrossRef]
42. Sodha, M.; Sharma, A.; Singh, S.; Bansal, N.; Kumar, A. Evaluation of an earth—Air tunnel system for cooling/heating of a hospital complex. *Build. Environ.* **1985**, *20*, 115–122. [CrossRef]

43. Chow, T.-T.; Yang, X.-Y. Performance of ventilation system in a non-standard operating room. *Build. Environ.* **2003**, *38*, 1401–1411. [CrossRef]
44. Hwang, R.-L.; Lin, T.-P.; Cheng, M.-J.; Chien, J.-H. Patient thermal comfort requirement for hospital environments in Taiwan. *Build. Environ.* **2007**, *42*, 2980–2987. [CrossRef]
45. Nematchoua, M.K.; Ricciardi, P.; Reiter, S.; Asadi, S.; Demers, C.M. Thermal comfort and comparison of some parameters coming from hospitals and shopping centers under natural ventilation: The case of Madagascar Island. *J. Build. Eng.* **2017**, *13*, 196–206. [CrossRef]
46. Nematchoua, M.K.; Ricciardi, P.; Buratti, C. Statistical analysis of indoor parameters an subjective responses of building occupants in a hot region of Indian ocean; a case of Madagascar island. *Appl. Energy* **2017**, *208*, 1562–1575. [CrossRef]
47. Alfa, M.T. Perceived indoor environmental quality of hospital wards and patients outcomes: A study of a general hospital, minna, Nigeria. *Appl. Ecol. Environ. Res.* **2019**, *17*, 8235–8259. [CrossRef]
48. El Hamid, A.A.; El Helw, M.; Teamah, H.A.M. Three-Dimensional Thermal Comfort Analysis for Hospital Operating Room with the Effect of Door Gradually Opened Part (II) Effect on mean age of the air and predicted mean vote distribution. *CFD Lett.* **2013**, *5*, 20–31.
49. El Hamid, A.A.; El Helw, M.; Teamah, H.A.M. Three-dimensional thermal comfort analysis for hospital operating room with the effect of door gradually opened part (I) effect on velocity and temperature distributions. *CFD Lett.* **2013**, *5*, 6–19.
50. Tartarini, F.; Cooper, P.; Fleming, R. Thermal perceptions, preferences and adaptive behaviours of occupants of nursing homes. *Build. Environ.* **2018**, *132*, 57–69. [CrossRef]
51. Pereira, P.F.D.C.; Broday, E.E.; Xavier, A.A.D.P. Thermal Comfort Applied in Hospital Environments: A Literature Review. *Appl. Sci.* **2020**, *10*, 7030. [CrossRef]
52. Cheong, K.; Chong, K. Development and application of an indoor air quality audit to an air-conditioned building in Singapore. *Build. Environ.* **2001**, *36*, 181–188. [CrossRef]
53. Khodakarami, J.; Knight, I. Required and Current Thermal Conditions for Occupants in Iranian Hospitals. *HVAC&R Res.* **2008**, *14*, 175–193. [CrossRef]
54. Yau, Y.H.; Chew, B.T. Thermal comfort study of hospital workers in Malaysia. *Indoor Air* **2009**, *19*, 500–510. [CrossRef]
55. Pourshaghaghy, A.; Omidvari, M. Examination of thermal comfort in a hospital using PMV–PPD model. *Appl. Ergon.* **2012**, *43*, 1089–1095. [CrossRef]
56. Azizpour, F.; Moghimi, S.; Lim, C.H.; Mat, S.; Salleh, E.; Sopian, K. A Thermal Comfort Investigation of a Facility Department of a Hospital in Hot-Humid Climate: Correlation between Objective and Subjective Measurements. *Indoor Built Environ.* **2012**, *22*, 836–845. [CrossRef]
57. Azizpour, F.; Moghimi, F.S.; Lim, C.; Mat, S.; Zaharim, A.; Sopian, K. Thermal comfort assessment of large-scale hospitals in tropical climates: A case study of University Kebangsaan Malaysia Medical Centre (UKMMC). *Energy Build.* **2013**, *64*, 317–322. [CrossRef]
58. Yau, Y.; Chew, B. Adaptive thermal comfort model for air-conditioned hospitals in Malaysia. *Build. Serv. Eng. Res. Technol.* **2013**, *35*, 117–138. [CrossRef]
59. Khalid, W.; Zaki, S.A.; Rijal, H.B.; Yakub, F. Thermal comfort requirements for different occupants in Malaysian hospital in-patient wards. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2018**, *43*, 128–140.
60. Khalid, W.; Zaki, S.A.; Rijal, H.B.; Yakub, F. Investigation of comfort temperature and thermal adaptation for patients and visitors in Malaysian hospitals. *Energy Build.* **2018**, *183*, 484–499. [CrossRef]
61. Wang, F.; Lee, M.; Cheng, T.; Law, Y. Field evaluation of thermal comfort and indoor environment quality for a hospital in a hot and humid climate. *HVAC R Res.* **2012**, *18*, 671–680.
62. Sattayakorn, S.; Ichinose, M.; Sasaki, R. Clarifying thermal comfort of healthcare occupants in tropical region: A case of indoor environment in Thai hospitals. *Energy Build.* **2017**, *149*, 45–57. [CrossRef]
63. Lawrernce, I.D.; Jayabal, S.; Thirumal, P. Indoor air quality investigations in hospital patient room. *Int. J. Biomed. Eng. Technol.* **2018**, *27*, 124. [CrossRef]
64. Pirsaheb, M.; Sohrabi, Y.; Yarmohammadi, H. Assessment of Thermal Comfort in Hospital Wards of Kermanshah, Iran, based on the Standards. *Indian, J. Public Health Res. Dev.* **2017**, *8*, 357. [CrossRef]
65. Azmoon, H.; Dehghan, H.; Akbari, J.; Souri, S. The Relationship between Thermal Comfort and Light Intensity with Sleep Quality and Eye Tiredness in Shift Work Nurses. *J. Environ. Public Health* **2013**, *2013*, 639184. [CrossRef]
66. Mohammadyan, M.; Keyvani, S.; Bahrami, A.; Charati-Yazdani, J.; Nejad-Yousefi, R. Indoor and ambient air concentrations of respirable particles between two hospitals in Kashan (2014–2015). *KAUMAS J.* **2017**, *21*, 66–73.
67. Shokri, S.; Nikpey, A.; Varyani, A.S. Evaluation of Hospital Wards Indoor Air Quality. *J. Air Pollut. Health* **2016**, *1*, 205–214.
68. Haleem, A.M.; Al-Obaidy, A.H.M.; Haleem, S.M. Air Quality Assessment of Some Selected Hospitals within Baghdad City. *Eng. Technol. J.* **2019**, *37*, 59–63. [CrossRef]
69. Luksamijarulkul, P.; Somjai, N.; Nankongnap, N.; Pataitiemthong, A.; Kongtip, P.; Woskie, S. Indoor air quality at different sites of a governmental hospital, Thailand. *Nurs. Palliat. Care* **2019**, *4*, 1–5. [CrossRef]
70. Tungjai, A.; Kubaha, K. Indoor Air Quality Evaluation of Isolation Room for Hospital in Thailand. *Energy Procedia* **2017**, *138*, 858–863. [CrossRef]

71. Chen, H.-W.; Chuang, C.-Y.; Lin, H.-T. Indoor Air Distribution of Nitrogen Dioxide and Ozone in Urban Hospitals. *Bull. Environ. Contam. Toxicol.* **2009**, *83*, 147–150. [CrossRef]
72. Tang, C.-S.; Wan, G.-H. Air Quality Monitoring of the Post-Operative Recovery Room and Locations Surrounding Operating Theaters in a Medical Center in Taiwan. *PLoS ONE* **2013**, *8*, e61093. [CrossRef]
73. Liu, M.-H.; Tung, T.-H.; Chung, F.-F.; Chuang, L.-C.; Wan, G.-H. High total volatile organic compounds pollution in a hospital dental department. *Environ. Monit. Assess.* **2017**, *189*, 571. [CrossRef]
74. Sen, P.K.; Sen, P. Hospital Indoor Air Quality in Respect to Transmission of Infection. In *Indoor Environmental Quality*; Springer: Singapore, 2020; pp. 53–66. [CrossRef]
75. Yulinawati, H.; Khairani, T.; Siami, L. Analysis of indoor and outdoor particulate (PM2.5) at a women and children's hospital in West Jakarta. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *737*, 012067. [CrossRef]
76. Lian, K.S.; Inangda, P.S.N.; Ramly, A. Sources of indoor air quality problem in a new hospital in Malaysia. In Proceedings of the IAQVEC 2007 Proceedings–6th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings: Sustainable Built Environment, Sendai, Japan, 28–31 October 2007; Volume 2, pp. 367–370.
77. El-Sharkawy, M.F.; Noweir, M.E.H. Indoor air quality levels in a University Hospital in the Eastern Province of Saudi Arabia. *J. Fam. Community Med.* **2014**, *21*, 39–47. [CrossRef]
78. Yousef, B.A.A.; Elshareef, A.A.D.; Ibraheem, M.A.K.; Alsayed, S.S. Assessment of Indoor Air Quality In Medical Facilities In Sudan. *Int. J. Sci. Technol. Res.* **2013**, *2*, 92–95.
79. Gizaw, Z.; Gebrehiwot, M.; Yenew, C. High bacterial load of indoor air in hospital wards: The case of University of Gondar teaching hospital, Northwest Ethiopia. *Multidiscip. Respir. Med.* **2016**, *11*, 24. [CrossRef]
80. Ordinioha, B.; Emuren, K. Physico-chemical assessment of indoor air quality of a tertiary hospital in South–South Nigeria. *Port Harcourt Med. J.* **2017**, *11*, 21. [CrossRef]
81. Ayodele, C.; Fakinle, B.; Jimoda, L.; Sonibare, J. Investigation on the ambient air quality in a hospital environment. *Cogent Environ. Sci.* **2016**, *2*, 1215281. [CrossRef]
82. Gawili, H.; Bodabos, H.A.; Al-Awami, W.A.; Al-Gargouri, A.O.; Alhegazi, Y.F. Indoor Air Quality in Benghazi's Hospitals and Its Impact among Patients. *Asian J. Med. Health* **2021**, 39–52. [CrossRef]
83. Quadros, M.E.; Lisboa, H.D.M.; De Oliveira, V.L.; Schirmer, W.N. Qualidade do ar em ambientes internos hospitalares: Estudo de caso e análise crítica dos padrões atuais. *Eng. Sanit. Ambient.* **2009**, *14*, 431–438. [CrossRef]
84. Macedo, J.I.; Kubota, T.H.; Matsumoto, L.S.; Giordani, A.T.; Takayanagui, A.M.M.; Mendes, A.A.; Bertolini, D.A. Air quality in a hospital environment. *WIT Trans. Built Environ.* **2013**, *134*, 737–747. [CrossRef]
85. Aljeesh, Y.; Al Madhoun, W.; Shamh, I.A.; Arcaya, M. Assessment of Indoor Air Quality in Neonatal Intensive Care Units in Government Hospitals in Gaza Strip. *Palestine* **2016**, *6*, 24–30.
86. Zaman, S.U.; Yesmin, M.; Pavel, R.S.; Jeba, F.; Salam, A. Indoor air quality indicators and toxicity potential at the hospitals' environment in Dhaka, Bangladesh. *Environ. Sci. Pollut. Res.* **2021**, *28*, 37727–37740. [CrossRef]
87. Božić, J.; Ilić, P.; Ilić, S. Indoor Air Quality in the Hospital: The Influence of Heating, Ventilating and Conditioning Systems. *Braz. Arch. Biol. Technol.* **2019**, *62*. [CrossRef]
88. Martínez, F.C.C. Empirical investigation of indoor environmental quality (IEQ) in a hospital building in Merida Yucatan, Mexico. *Int. J. Eng. Technol.* **2018**, *7*, 245–249. [CrossRef]
89. Osman, M.; Ibrahim, H.; Yousef, F.; Elnasr, A.A.; Saeed, Y.; Hameed, A.A. A study on microbiological contamination on air quality in hospitals in Egypt. *Indoor Built Environ.* **2017**, *27*, 953–968. [CrossRef]
90. Taushiba, A.; Dwivedi, S.; Zehra, F.; Shukla, P.N.; Lawrence, A.J. Assessment of indoor air quality and their inter-association in hospitals of northern India—A cross-sectional study. *Air Qual. Atmos. Health* **2023**. [CrossRef]
91. Udobang, P.C.; Aniekan Otumo, E. Texas Journal of Medical Science Assessment of Thermal Comfort in Hospital Rooms and Health Status of Patients. *Peer Rev. Int. J.* **2023**. Available online: https://zienjournals.com (accessed on 10 April 2023).
92. Alghamdi, W.; Neamatallah, A.A.; Alshamrani, M.M.; Al Mehmadi, F.; El-Saed, A. Distribution and the trend of airborne particles and bio-aerosol concentration in pediatric intensive care units with different ventilation setting at two hospitals in Riyadh, Saudi Arabia. *J. Infect. Public Health* **2023**, *16*, 588–595. [CrossRef]
93. Asghar, K.; Ali, A.; Tabassum, A.; Nadeem, S.; Hakim, S.; Amin, M.; Raza, G.; Bashir, S.; Afshan, N.; Usman, N.; et al. Assessment of particulate matter (PM) in ambient air of different settings and its associated health risk in Haripur city, Pakistan. *Braz. J. Biol.* **2022**, *84*, e256190. [CrossRef]
94. Banza, C.L.N.; Nawrot, T.S.; Haufroid, V.; Decrée, S.; De Putter, T.; Smolders, E.; Kabyla, B.I.; Luboya, O.N.; Ilunga, A.N.; Mutombo, A.M.; et al. High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo. *Environ. Res.* **2009**, *109*, 745–752. [CrossRef]
95. Kurth, L.; Kolker, A.; Engle, M.; Geboy, N.; Hendryx, M.; Orem, W.; McCAWLEY, M.; Crosby, L.; Tatu, C.; Varonka, M.; et al. Atmospheric particulate matter in proximity to mountaintop coal mines: Sources and potential environmental and human health impacts. *Environ. Geochem. Health* **2014**, *37*, 529–544. [CrossRef]
96. Hendryx, M.; Islam, M.S.; Dong, G.-H.; Paul, G. Air Pollution Emissions 2008–2018 from Australian Coal Mining: Implications for Public and Occupational Health. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1570. [CrossRef]

97. Mwaanga, P.; Silondwa, M.; Kasali, G.; Banda, P.M. Preliminary review of mine air pollution in Zambia. *Heliyon* **2019**, *5*, e02485. [CrossRef]
98. Muimba-Kankolongo, A.; Nkulu, C.B.L.; Mwitwa, J.; Kampemba, F.M.; Nabuyanda, M.M. Impacts of Trace Metals Pollution of Water, Food Crops, and Ambient Air on Population Health in Zambia and the DR Congo. *J. Environ. Public Health* **2022**, *2022*, 4515115. [CrossRef]