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LITERATURE REVIEW OF THERMAL COMFORT FOR HOSPITAL DESIGN

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Abstract - Creating indoor environments in hospitals that meet the varied needs of patients and staff is essential, with thermal comfort being a critical factor affecting patient healing and the welfare of medical personnel. While numerous studies explore thermal comfort and related contexts, there is a shortage of review articles on this vital subject. This paper aims to address this gap by conducting a thorough and evaluative review of existing research, analyzing 160 articles to identify key themes and provide insights into future research directions. Additionally, it is observed that achieving satisfactory thermal comfort is influenced by various factors, including the patient's health status and the nature and intensity of staff activities, underscoring the context-specific nature of this phenomenon. The review also explores measures aimed at reducing energy consumption in hospital settings. Important issues such as the limitations of predicted mean vote (PMV) and the influence of demographic factors such as gender and age on thermal comfort are addressed. Ultimately, this review provides valuable insights into designing and evaluating thermal environments in hospitals, highlighting the need for tailored approaches to ensure optimal conditions for both patients and staff.

***Key Words*:** Thermal comfort; Hospital buildings; Improvement measures; Energy efficiency.

1. INTRODUCTION

Thermal comfort, essentially feeling good about the temperature of your surroundings, is a critical aspect of our indoor experience. It's about ensuring that people are comfortable and content with the temperature indoors. This is especially important in places like hospitals, where people are already dealing with health issues and need all the comfort they can get to aid in their recovery.

Hospitals are unique buildings designed to provide care for patients with various health conditions. Because of this, they have to meet specific indoor environmental standards to ensure the well-being of patients. But it's not just about the patients; hospitals also need to be safe and comfortable for the staff working there. After all, they spend long hours caring for patients and need a conducive environment to perform their duties effectively.

Due to the nature of their operations, hospitals use a lot of energy to maintain their indoor environments. This is because they need to regulate the temperature, humidity, and air quality to meet the diverse needs of patients and staff. Whether it's keeping surgery rooms cool or ensuring comfortable conditions in patient wards, hospitals have to constantly monitor and adjust their indoor environments to provide the best care possible.

To help manage these complex requirements, organizations like the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have developed guidelines and standards for designing hospital buildings. These guidelines divide hospital indoor spaces into different functional areas, each with its own unique environmental needs. For example, surgery rooms require precise temperature and humidity control to create a sterile environment, while patient wards need to be kept comfortable and cosy for recovery.

This division into functional zones highlights the complexity of hospital buildings. Each area serves a specific purpose and caters to different groups of people, whether it's patients, doctors, nurses, or administrative staff. As a result, hospitals have to juggle multiple requirements to ensure that everyone inside is comfortable and safe.

But why is indoor comfort so important in hospitals? For one, it plays a significant role in patient recovery. When patients feel comfortable in their surroundings, it can have a positive impact on their emotional well-being, which in turn can aid in their healing process. Similarly, a comfortable working environment is essential for hospital staff to perform their duties effectively. Whether it's administering medication, performing surgeries, or attending to patients' needs, having a comfortable indoor environment can make a big difference in staff morale and productivity.

Moreover, maintaining a comfortable indoor environment in hospitals can also have broader benefits.

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Studies have shown that improved indoor conditions can help reduce the spread of airborne illnesses, such as the flu or respiratory infections. By ensuring proper ventilation and air quality, hospitals can create a healthier environment for patients and staff, ultimately reducing the risk of infection and associated healthcare costs.

In conclusion, thermal comfort is a crucial aspect of hospital design and operation. It's not just about keeping patients and staff comfortable; it's also about creating an environment that supports healing and promotes well-being. By following guidelines and standards set by organizations like ASHRAE, hospitals can ensure that their indoor environments meet the diverse needs of patients and staff. And in doing so, they can create spaces that are not only comfortable but also safe and conducive to healing.

2. METHOD

To initiate the literature review, we commenced by compiling lists of academic articles sourced from databases that explored individuals' perceptions of temperature within hospital settings. Following this, we applied specialized tools for analysis, aiding in the examination of this information. These tools, such as CiteSpace, facilitate the identification of key themes and connections among various articles.

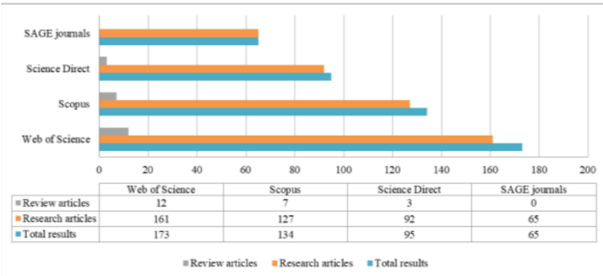
Upon completion of the analysis, we undertook a thorough review of the articles to discern significant patterns and glean insights. This process enabled us to gain a comprehensive understanding of the research landscape surrounding thermal comfort in hospitals. By identifying common themes and emerging trends, we were able to organize our findings into distinct sections.

Through this systematic approach, we were able to synthesize the information gathered from the reviewed articles. We categorized our findings according to different levels of hospital comfort or sensation, allowing us to present a comprehensive overview of the research conducted in this area. This organized presentation of information enabled us to highlight key insights and trends observed across the literature.

3. DATA COLLECTION

The initial literature search targeted articles containing the keywords "hospital thermal comfort" or "hospital thermal sensation" within titles, abstracts, and keywords across four prominent academic databases: Web of Science, Scopus, Science Direct, and SAGE journals. The search spanned all available years up to the present date. Specifically, the search criteria were narrowed down to include research and review articles written in English. The findings of this search are illustrated in Figure 1.

Among the databases surveyed, Web of Science yielded the highest number of publications, with a total of 73 articles meeting the specified criteria related to hospital thermal comfort.



	Web of Science	Scopus	Science Direct	SAGE journals
Review articles	12	7	3	0
Research articles	161	127	92	65
Total results	173	134	95	65

Fig.1: Result from the general literature search on hospital thermal comfort in four database.

4. ANALYSIS AND DISCUSSION

4.1INFLUENCING FACTOR RELATED TO THERMAL COMFORT: Ensuring health and comfort in hospital buildings is of utmost importance, with factors such as thermal comfort, acoustics, lighting, electromagnetic frequency levels, potable water surveillance, and indoor air quality (IAQ) collectively constituting the Indoor Environmental Quality (IEQ) of a building. Typically, studies examining indoor building environments prioritize IAQ, lighting, thermal comfort, and acoustics as key parameters to gauge indoor comfort levels.

Human perception of comfort results from the interplay of various sensory stimuli in different environments. The interplay between indoor environmental conditions, human occupancy, and building operational characteristics significantly influences thermal comfort and indoor environmental quality. Enhancing environmental comfort has the potential to improve the health and performance of healthcare providers and patients alike.

A comfortable thermal environment in hospitals plays a crucial role in maintaining patients' mood and aiding in their recovery process. Several environmental factors, including temperature, humidity, illumination, and ventilation systems, impact patients' comfort levels. Additionally, there is growing evidence highlighting the influence of the working environment on healthcare providers' efficiency, productivity, and satisfaction, ultimately affecting patient outcomes.

For healthcare providers, factors such as indoor air quality, noise level, and thermal comfort rank among the top considerations in healthcare settings. Temperature,

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specifically, is a critical factor for frontline practitioners. In operating rooms, the choice of ventilation type significantly affects the thermal comfort of medical personnel. Research suggests that factors such as noise, lighting, and ventilation can lead to stress, anxiety, and distractions among staff.

Studies measuring long-term environmental and operational parameters in hospital buildings have shown that most measured temperatures, humidity values, and luminance levels fall within acceptable comfort ranges. However, there are weak correlations between indoor temperature, luminance, and human occupancy/activity across rooms, while factors like relative humidity and outdoor air fractions exhibit strong seasonal patterns and spatial correlations.

Moreover, research indicates that thermal comfort and acoustic comfort may mutually influence each other, as evidenced by studies investigating the interaction between sound and thermal comfort in hospital wards.

2FIELD SURVEY OF THERMAL: Thermal comfort is a crucial aspect of maintaining a healthy indoor environment, and the literature on this topic has been organized by country. The summarized information is presented in Tables 1. Objective and subjective data collection methods are commonly utilized in these studies.

The focus of research often centers on two main groups: patients and medical staff, although some studies also consider visitors. Interestingly, these groups exhibit varying thermal perceptions within the same indoor area. Patients generally express higher satisfaction with indoor conditions compared to medical staff, who typically prefer cooler temperatures over neutral ones. Additionally, visitors have been found to have distinct temperature preferences from both staff and patients.

Studies have explored the thermal comfort of different functional areas within hospitals, with wards and operating rooms being the most frequently examined. Specialized areas such as ultrasound suites have also garnered attention. Notably, much of the research has been confined to single hospital settings, with only a small portion involving multiple hospitals.

Two primary types of studies emerge, focusing either on specific functional areas or specific populations. Intriguing issues such as gender and age differences in thermal perception have been uncovered and will be further discussed. These findings shed light on the complexities of achieving optimal thermal comfort within hospital environments and highlight the need for tailored approaches to meet the diverse needs of patients, staff, and visitors alike.

Country	Year	Subject	Methods	Functional Areas	Main Conclusion
Sweden	2005	Patient and Staff	Objective and Subjective data collection	Orthopaedic Ward	The difference between staff and patient perception of the indoor air temperature differed more during winter than summer.
Japan	2005, 2008	Patient and Staff	Objective and Subjective data collection	20 sickrooms, nurse stations and corridors.	Introducing humidifiers into a hospital during winter is an effective method of improving low relative humidity environments in sickrooms and of relieving the discomfort of staff members.
	2013	Patient and Staff	Objective and Subjective data collection	Orthopaedics, Paediatrics and Internal Medicine wards.	Patients were more satisfied with building-related aspects and indoor conditions than medical staff.
Italy	2015	Patient and Staff	Objective and Subjective data collection	8 Wards of Public hospital.	PMV Model does not seem to prove suitable for the patient population gender and age are factors that must be taken into account in the assessment of thermal comfort in the hospital.
	2019	Pregnant Women	Objective and Subjective data collection	Obstetrical Ward.	For Pregnant women in a typical sedentary condition when hosted in the impatient room, the **met (Metabolic rate)**value corresponds to 2.17.
	2013	Staff	Objective and Subjective data collection	Facility departments (lobby, office, prayer room, kindergarten, and catering area).	The neutral operative temperature based TSV and PMV regression models are 26.8° C and 25°C, respectively
	2013	Non-Patient respondents	Objective and Subjective data collection	Three offices, pharmacy, radiology, prayer room, kitchen, nursery, lobby, and corridor.	The effective neutral temperatures based on TSV and PMV are 23.4°C and 21.3°C, respectively; preferred operative and effective temperatures (OT, ET*) are 23.6° and 20.3°C, respectively.
Malaysia	2014	Staff	Objective and Subjective data collection	9 hospitals with 41 departments (the staff rooms, nurse counters, and the working space of the hospital personal.	The adaptive model is $T_n = 0.3314T_{out}$ +14.858 and the most comfortable or neutral temperature Found from the field study in hospital was26.4°C.
	2019	Patient and Visitors	Objective and Subjective data collection	Medical surgical maternity and paediatric Wards in three private hospitals.	The operative temperature range of 22.0-28.0*C is thermally acceptable to more than 86% of subjects. Mean comfort, temperatures for patients and visitors were 25.3*C and 25.5*C respectively.
Poland	2015	Surgical staff (surgeons nurses and surgeons assist anthetistist)	Thermal environment measurements.	37 Ors in 7 Warsaw hospitals.	The thermal environment in most of measured ORs was assessed as warm or slightly warm for nurses, surgeons assistance and surgeons while quite comfortable For anaesthetists
Madagascar	2017	Patients	Questionaries interviews, and physical parameter measurements	5 Big Hospitals.	The acceptable temperature ranges for the patient, visitor, and medical staff are at 21.8-27.9, 22-27.1 and 24.1-25.6°C, respectively.
Thailand	2017	Patients, Visitors, and Staff	Objective and Subjective data collection	Public waiting areas, nurse stations, and clinical examination room in five OPD clinics (medicine(med);car, nose, and throat(ENT); and Dentistry (Dent).	The acceptable temperature ranges for the patient, visitor, and medical staff are at 21.8-27.9, 22-27.1 and 24.1-25.6°C, respectively
Netherlands	2018	Nursing Staff	Objective and Subjective data collection	Two words of a hospital, (patient rooms, reception, meeting, room, break, room, and medicine room)	The optimal thermal sensation for the nurses would be closer to slightly cool than neutral.

Table: 1

4.3THERMAL COMFORT RESEARCH IN DIFFERENT FUNCTIONAL AREAS: The focus on thermal comfort extends to various functional areas within hospitals, with ward rooms and operating rooms (ORs) garnering the most attention, followed by some examination of hospital streets and ultrasound areas. Ward rooms, in particular, are the subject of numerous studies. De Guile et al. employed innovative statistical techniques to compare the perspectives of patients and staff within these spaces. Their findings highlighted staff concerns regarding privacy, room size, air quality, and noise levels, while patients generally reported satisfaction with building-related aspects. Notably, Orthopaedic wards emerged with the highest staff satisfaction, whereas Internal Medicine witnessed the lowest frequency of discomfort.

Within the intricate environment of ORs, maintaining thermal comfort is paramount, balancing patient safety and staff well-being. Studies have underscored the effectiveness of the Predicted Mean Vote (PMV) model in evaluating thermal conditions within surgical wards, demonstrating minimal variance between survey outcomes and PMV measurements. Furthermore, discernible differences in thermal sensation among OR personnel have been observed, with nurses typically experiencing slight coldness near air diffusers, while surgeons tend to prefer areas of air stagnation.

Exploration extends beyond ward rooms and ORs to encompass other crucial hospital areas, including sickrooms, nurse stations, corridors, and ultrasound suites. Concerns over low humidity levels during winter in sickrooms have been raised due to their potential to exacerbate the spread of influenza viruses, prompting suggestions for the introduction of humidifiers to enhance staff comfort. An illuminating case study conducted in an ultrasound suite unveiled significant overheating issues, prompting recommendations for remedial actions such as improved signage and patient scheduling strategies.

Moreover, investigations into thermal comfort have ventured into physiotherapy centres, shedding light on patient preferences for specific temperature ranges during treatments. These studies also highlighted therapists' adeptness at adjusting their clothing levels to adapt to varying environmental conditions.

Overall, the quest for optimal thermal comfort in hospital settings underscores its pivotal role in fostering both patient well-being and staff efficiency. Through meticulous research and innovative approaches, scholars continue to unravel the complexities of thermal comfort dynamics across diverse functional areas within hospitals, ultimately striving to create environments that promote healing, comfort, and productivity for all stakeholders involved.

4.4 THERMAL COMFORT RESEARCH ON DIFFERENT PEOPLE: Hospital thermal comfort research predominantly centers on two key demographics: patients and hospital staff. Numerous investigations have probed into the thermal preferences of medical staff within Malaysian hospitals, consistently revealing a preference for temperatures below the neutral range. Effective neutral temperatures, as determined by methods like Thermal Sensation Votes (TSV) and Predicted Mean Vote (PMV), have been found to fall between 21.3°C and 23.4°C. Similarly, preferred operative and effective temperatures typically range from 20.3°C to 23.6°C. Moreover, through regression analysis, researchers successfully developed an adaptive thermal comfort model that correlates outdoor temperatures with indoor comfort levels across various hospital settings.

Studies focusing on patient thermal comfort have also been undertaken. For instance, a case study evaluating thermal comfort in naturally ventilated hospital buildings in Madagascar highlighted gender differences in mean neutral temperatures, with approximately 90% of patients reporting a comfortable temperature range between 22.4°C and 25.3°C. Additionally, research conducted by Alotaibi et al. underscored the diverse preferences among patients for indoor environments, showcasing a wide spectrum of neutral temperature preferences. Moreover, specific patient groups, such as pregnant women, have been the subject of study, revealing metabolic rates corresponding to sedentary conditions in inpatient rooms.

Comparative analyses examining thermal preferences among various groups have also been conducted. Despite similar physical measurements of indoor temperatures, disparities in perceptions of indoor air temperature between staff and patients were more pronounced during winter months. Another survey conducted in Bangkok concluded that acceptable temperature ranges for patients, visitors, and medical staff varied, ranging from 21.8°C to 27.9°C, 22.0°C to 27.1°C, and 24.1°C to 25.6°C, respectively.

These comprehensive investigations contribute significantly to our understanding of thermal comfort dynamics within hospital environments, shedding light on the diverse preferences and requirements of both patients and medical staff. Such insights are crucial for designing and maintaining indoor environments that foster comfort, well-being, and optimal performance for all occupants.

5. MEASURES TO IMPROVE THERMAL COMFORT:

5.1 MEASURES TO ADDRESS INADVERTENT PERIOPERATIVE HYPOTHERMIA

Inadvertent perioperative hypothermia (IPH) occurs when a patient's core temperature drops below 36°C. The incidence of postoperative hypothermia during elective surgeries varies widely, ranging from 26% to 90%. This condition can have adverse effects on patient outcomes and increase hospital treatment costs. However, IPH is preventable through various warming techniques.

Preventing IPH involves several strategies, including preoperative skin warming, adjusting the operating room temperature, intraoperative temperature monitoring, and the use of warming devices such as heated anesthesia circuits, forced-air warming blankets, and warmed intravenous fluids. Prewarming, which involves warming the patient's skin before surgery, helps minimize heat loss during anesthesia induction. Using real-scale operating room models can help determine the optimal climatic conditions to prevent patient hypothermia while ensuring the comfort of both patients and surgical teams.

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Warming methods can be categorized as active or passive. Active heating devices, such as forced-air warming and conduction mattress warming, are commonly used. Forced-air warming is particularly effective in reducing heat loss from the skin. However, studies have shown that even actively warmed patients are at risk of hypothermia, especially during the initial stages of anesthesia.

Research has explored various warming devices to prevent IPH. One study compared different warming methods during elective cesarean sections and found that intravenous fluid warming alone was sufficient to prevent maternal hypothermia. However, intraoperative forced-air warming did not effectively prevent IPH, highlighting the need for alternative warming devices.

A prototype thermal compression device, designed to warm specific areas like the popliteal fossa and soles of the feet, has shown promise in increasing perioperative temperatures and reducing hypothermia risk. Additionally, new self-warming blankets, such as the BARRIER EasyWarm blanket, have demonstrated improved perioperative temperature control and reduced instances of postoperative shivering compared to standard hospital blankets. These advancements in warming technology offer more efficient and effective means of preventing IPH in surgical patients.

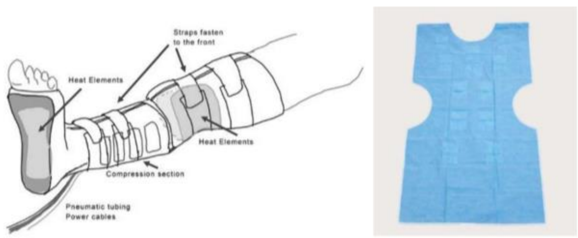

Fig 2: New device for the prevention of inadvertent perioperative hypothermia

5.2 PROPER VENTILATION SYSTEMS:

Proper ventilation systems play a crucial role in enhancing indoor air quality and occupant satisfaction, especially in hospital settings. In operating rooms (ORs), designing an appropriate air conditioning system is paramount to prevent the spread of infections while ensuring a comfortable environment for all occupants. Two commonly used airflow distribution methods in ORs are laminar (or unidirectional) airflow and mixing (or conventional ventilation) systems. Recent studies indicate that the number and location of exhaust diffusers in ORs with mixing ventilation can significantly affect air quality near surgical patients.

Many hospitals employ laminar airflow systems (LAF) in their ORs to reduce rates of surgical site infections (SSIs). Modern vertical LAF designs have evolved to eliminate the need for panels or curtains by introducing exponential laminar flow systems. These systems fall into three categories: air curtain systems, multi-diffuser arrays, or a single large diffuser. Studies have shown that integrating an air curtain into the air conditioning system can greatly reduce air contamination and create desired conditions, contributing to a decrease in OR bacterial counts. However, evidence regarding the effectiveness of laminar flow ventilation systems in reducing SSIs remains limited or even contradictory. Furthermore, the thermal comfort level varies with different ventilation methods, with studies suggesting that ORs with mixing ventilation (MV) may experience a higher percentage of dissatisfaction with the thermal environment compared to those with LAF ventilation.

In hospital wardrooms, indoor conditions differ significantly from other environments like office spaces. Two common ventilation systems used in hospital wards are mixing type and displacement type. Computational fluid dynamics (CFD) analysis has revealed that displacement ventilation can result in larger particles remaining suspended in the air for longer periods, while smaller particles may escape more easily. Additionally, experiments conducted in multiple-bed patient rooms have shown that during displacement ventilation, exhaled nuclei droplets from infected patients penetrate greater distances and take longer to dissipate compared to air-mixing ventilation strategies. Innovative ventilation strategies, such as bedside personalized ventilation (PV) systems, have been proposed for hospital wards. These systems have been shown to improve thermal comfort levels and subjective sleep quality in experiments involving children, adults, and the elderly. Moreover, natural ventilation is encouraged in some regions due to its ability to provide high airflow rates with low energy consumption, particularly in tropical countries.

In addition to ventilation system characteristics, human behavior can significantly affect ventilation efficiency. Models have been developed to predict window opening/closing behaviors based on indoor and outdoor variables, with indoor air temperature and relative humidity identified as dominant factors influencing window-opening behaviors across seasons. These findings underscore the importance of considering both ventilation system design and occupant behavior in optimizing indoor air quality and thermal comfort in hospital environments

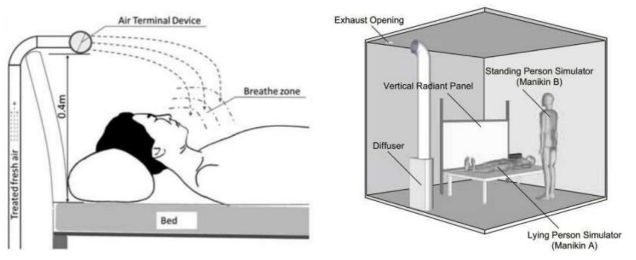

Fig: 3: New ventilation systems

Fig. 4: Novel PV-PE System

5.3 OTHER MEASURES: Implementing low carbon adaptive and refurbishment measures can significantly enhance thermal comfort in hospital buildings. Light-touch low-carbon strategies, such as reducing internal heat gains, installing horizontal shading above windows, and incorporating user-controlled fans, have demonstrated positive impacts on indoor comfort conditions in hospital wards, particularly in regions like the UK Midlands and Bradford .An innovative low-energy (Low Ex) system has been developed and tested to control physical hazards effectively. This system allows for individual control of thermal comfort parameters, catering to the specific needs of burn patients within the same room. Compared to conventional systems, the Low Ex system has shown remarkable energy savings, with measured reductions of 11-27% for heating and 32-73% for cooling.

Ensuring the safety and well-being of hospital staff is paramount. A new optimized working gown for dentists has been proposed, receiving high praise during fitting tests. Additionally, selecting appropriate personal protective equipment is crucial for mitigating the spread of infectious germs from patients' saliva and blood. Furthermore, promoting a culture of noise reduction as part of high-quality healthcare delivery is essential. Nurse-led interventions have been shown to enhance the patient experience and improve outcomes, emphasizing the importance of proactive measures in healthcare settings.

These innovative approaches and interventions not only contribute to improving thermal comfort and safety in hospital environments but also demonstrate the potential for sustainable and efficient practices in healthcare facilities. By prioritizing occupant comfort, energy efficiency, and safety measures, hospitals can create environments conducive to healing and well-being for both patients and healthcare professionals.

6. FUTURE PRESPECTIVES

Various factors influence thermal comfort and indoor environmental quality in hospital buildings, and understanding their correlations is crucial for effective design and operation. While some factors are well-known, others, like overcrowding in Chinese hospitals and lighting conditions, also play significant roles and warrant further investigation. Considering these additional factors, such as lighting and indoor air quality, as variables in thermal comfort studies can provide valuable insights into patient satisfaction.Different types of employees and functional areas within hospitals have distinct thermal comfort requirements, with ward rooms and operating rooms receiving the most attention. However, there's a pressing need for further research in other functional areas. Strategic decisions in design, operation, and maintenance should align with the workforce's needs and priorities.

Individual differences, influenced by factors like gender, age, and health status, are also important considerations often overlooked in conventional comfort assessments. Future studies require larger samples and longer investigation periods to comprehensively understand these factors' effects on thermal comfort. The type of personnel in hospitals is another crucial factor, and personalized comfort systems (PCS) offer promising solutions. Innovations like low-energy (Lowe) systems and personalized ventilation-perfusion (PV-PE) systems have shown potential but require further exploration.

Considering metabolic values for different populations, such as pregnant women, children, and the elderly, is essential to define comfort standards for diverse patient groups in various environments. While the Predicted Mean Vote (PMV) index is widely used in controlled environments, its suitability varies, particularly in places like operating rooms where individuals experience different thermal sensations. Surgeons and nurses, constrained in their thermal adaptation, require adequate clothing insulation for a neutral thermal sensation zone based on their metabolic values. However, PMV may not always accurately reflect actual thermal sensations, leading to the development of adaptive models, as observed in Malaysia where hospital staff prefer warmer indoor environments due to adaptation. Further research in practical situations is necessary to refine comfort evaluation methods and ensure optimal thermal conditions in hospital settings.

7. CONCLUSIONS

This literature review summarizes the factors that affect thermal comfort and indoor environmental quality based on the comprehensive analysis of the existing studies on the topic of hospital thermal comfort and the improvement measures for thermal comfort and energy consumption. Based on the overview of reviewed publications, the findings, and the future research direction are as follows:

1. It is important to identify the factors that affect thermal comfort inside and outside the buildings. The layout of the various functional areas, including the hospital street, contributes to the overall thermal comfort in hospital buildings. A properly designed layout can improve a hospital's operational efficiency and staff and patient satisfaction. Gender, age, health conditions, and other related factors may have an impact on thermal comfort. In the future, larger samples and longer investigation periods are required to study the effect of these factors on thermal comfort.

2. Thermal comfort, as one of the important components of IEQ, is often influenced by other related IEQ factors. A comprehensive assessment considering the interactive impact of factors such as the thermal, lighting, and acoustic environments in a hospital is encouraged.

3. PMV and TSV are the two most commonly used indices in field studies. There are significant (or slight) discrepancies between PMV and TSV. Using PMV for hospital rooms cannot give a reasonable reflection of patients' diverse requirements. The accurate evaluation of the thermal comfort of the patients and surgical staff will be an important requirement. Individualized thermal comfort provision for different types of personnel is also important. Classifying patients by illness and giving proper temperature set-points is needed. Zonal indoor environment solutions and personalized microenvironment control with personalized IEQ control may be a future research direction. New research focusing on an individual's thermal sensation in different function areas, like different zones in ORs, should be encouraged.

4. The self-warming blankets, prototype thermal compression devices, and in-line intravenous fluid warming are effective measures to provide satisfactory body temperature control and reduce discomfort for perioperative patients.

5. A proper ventilation system can improve indoor air quality and potentially increase occupant satisfaction. A personalized ventilation system could deliver fresh air to multiple patients and minimize airborne contaminants. However, the improvement of thermal comfort must also be accompanied by energy considerations.

6. Energy-efficient design, especially for operation rooms, is an important research topic. The retrofitting of windows and walls and the adjustment of ventilation strategies are significant for the energy efficiency of hospital buildings. Beyond the thermal comfort topic, the elimination of infection transmission is paramount.

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