Ramasingha, K.S., Soorige, D. and Natasha, K.A.D.M., 2026. Temperature and humidity control in operating theatres: BMS vs. Thermostat systems. In: Waidyasekara, K.G.A.S., Jayasena, H.S., Chandanie H. and Tennakoon, G.A. (eds). *Proceedings of the 14th World Construction Symposium*, 10-11 July 2026, Sri Lanka. pp. 1637-1650. DOI: https://doi.org/10.31705/WCS.2026.119. Available from: https://ciobwcs.com/papers/

TEMPERATURE AND HUMIDITY CONTROL IN OPERATING THEATRES: BMS VS. THERMOSTAT SYSTEMS

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ABSTRACT

Maintaining proper temperature and humidity in operating theatres (OTs) is essential for infection control, patient safety, and equipment performance. This study examines the effectiveness of environmental monitoring and control practices in Sri Lankan hospitals, comparing building management system (BMS)-enabled facilities with traditional thermostatically controlled settings. Although international standards such as ASHRAE 170 recommend temperatures of 20–24°C and relative humidity of 40–60%, implementation is inconsistent. A multi-case study approach was used, involving two BMS-enabled and two non-BMS hospitals. Findings show that although BMS systems enable real-time monitoring, issues such as delayed responses, threshold deviations, and energy saving compromises impact compliance. Non-BMS setups lack centralized monitoring, rely on inconsistent manual adjustments, and offer limited transparency. Common challenges across all scenarios include technical errors, limited staff awareness, and behavioural impacts such as frequent door openings and comfort-based overlaps. The study highlights the need for targeted strategies across both system types. Key recommendations include staff training, engineering-clinical collaboration, visual compliance indicators, and adoption of IoT-based monitoring in non-BMS environments. This research addresses a gap in OT environmental management in Sri Lanka and suggests practical, system-specific solutions to improve safety and compliance.

Keywords: *ASHRAE 170; Building Management Systems; Indoor Environmental Control; Operating Theatre; Temperature and Humidity*

1. INTRODUCTION

Indoor Environmental Quality (IEQ) refers to the performance of the indoor environment (Patnaik et al., 2017) and includes factors affecting occupant well-being, such as indoor air quality, lighting, thermal comfort, acoustics, drinking water, ergonomics, and electromagnetic exposure (Mujeebu, 2019). Among these, temperature and humidity are key determinants of indoor air quality, along with ventilation, airflow, and pollutant levels (Türk, 2022). Inadequate temperature and humidity can reduce air quality and contribute to sick building syndrome (Fang et al., 2004), while maintaining proper levels is

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particularly critical in specialized environments such as healthcare, pharmaceutical, and microbiological facilities (Vijayalakshmi et al., 2022).

Proper temperature and humidity control in healthcare facilities is crucial for infection prevention, patient comfort, and equipment integrity (G & Balaji, 2023; Kumar et al., 2024). Temperature and humidity requirements in hospitals are complex, varying by medical procedure and the function of each area (G & Balaji, 2023; Sadrizadeh & Loomans, 2016). Operating theaters (OTs) are critical hospital environments requiring precise temperature and humidity control to prevent infection rather than for comfort (Mohta, 2010; Katz, 2016). Major deviations from proper environmental conditions can reduce efficiency, harm surgical outcomes, and increase morbidity and mortality risk. Moreover, there are standards for operating room air conditioning (Mohta, 2010). According to Sánchez-Barroso and Sanz-Calcedo (2019), UNE 100713:2015, ASHRAE 170-2017, and EN 16244 are common, globally recognized standards used to evaluate OT environmental performance. Heating, Ventilation, and Air Conditioning (HVAC) control temperature, humidity, and air quality, playing a crucial role in maintaining optimal conditions in hospital OT (Hussain et al., 2020). However, in complex facilities such as hospitals, HVAC systems alone are insufficient to maintain optimal temperature and humidity levels. Advanced technologies play a crucial role in continuously monitoring and regulating these environmental parameters within the desired range. Building Management System (BMS) provides an integrated platform to collect real-time data from various building systems and issue control commands to the installed technologies (Vcelak et al., 2017). Furthermore, the use of IoT sensors enhances this process by providing a cost-effective way to automatically measure and control temperature and humidity by transmitting data to a secure server, enabling continuous monitoring and precise environmental control throughout the facility (Darji, 2021). Although BMS has been popular globally for many years, its use in Sri Lanka remains limited, with only a few facilities implementing it (Kumara et al., 2016). Hospitals in Sri Lanka largely rely on standalone thermostats for HVAC control, making it essential to evaluate OT temperature and humidity practices under both BMS-integrated and independent systems to assess current effectiveness and technology performance.

Many studies worldwide examine thermal comfort, indoor air quality, and temperature-humidity control systems, highlighting the role of HVAC systems, indoor environmental conditions, and advanced technologies such as BMS (Bearg, 2019; Mazzei et al., 2005; Zeng et al., 2026). Limited research exists on process-cooling environments like hospital OT. However, while areas such as indoor environmental control parameters, HVAC system performance, and energy efficiency have been extensively studied in the global literature, comparatively less attention has been given to the application and performance of BMS in OTs (Ahmadzadehtalatapeh, 2014; Balaras et al., 2007; Hussain et al., 2020;).

OTs require strict standards for sterilization, air exchange, filtration, and pressure to minimize infection risk and ensure safe surgery (Fredrick & Kumaran, 2018). Despite the importance of these parameters, there is a lack of focused studies assessing the efficiency of temperature and humidity control mechanisms in operating rooms, especially in the Sri Lankan context. This research gap becomes more pronounced when considering the performance differences between facilities that use integrated BMS for environmental monitoring and those that rely solely on standalone thermostat-based HVAC controls. Furthermore, there is a lack of empirical studies that evaluate and compare the ability of these control approaches to maintain compliance with prescribed temperature and relative humidity requirements under actual operating conditions. This gap is particularly evident in healthcare facilities within developing and tropical regions, where environmental control demands are high, and building automation adoption varies considerably. Even though BMS have become widely adopted globally, their adoption remains limited in the Sri Lankan context (Kumara et al., 2016). Most hospitals still rely on standalone thermostats, highlighting the need to assess their effectiveness in maintaining standard OT conditions.

Accordingly, this study will have 3 objectives: 1. To study the current regulations related to maintaining temperature and humidity requirements for OTs. 2. Understand the current situation of compliance to identified standards and investigate the potential causes of deviations in BMS and traditional thermostat-controlled environments. 3. Propose expert strategies for enhancing compliance with established standards in OTs in Sri Lankan healthcare facilities. The findings of this study explain how various IEQ controls, such as thermostat control and BMS, affect the effectiveness of compliance in OTs. It also highlights implications for healthcare facility managers, engineers, decision-makers, and users of healthcare facilities in selecting and implementing appropriate environmental control strategies to enhance compliance, operational performance, and environmental management in critical healthcare spaces. Ultimately, the study contributes to the limited body of knowledge on OT environmental control in Sri Lanka, addressing a research area that has received relatively little attention in the existing literature.

2. LITERATURE REVIEW

2.1 TEMPERATURE AND HUMIDITY MONITORING AND CONTROLLING IN OTs

The air conditioning system of OTs should provide high comfort for patients and the surgical team by avoiding patient hypothermia, medical team discomfort, and anaesthetic gas pollution, controlling microclimatic parameters such as temperature, humidity, and air velocity (Cannistraro & Cannistraro, 2016). Key areas like ICUs, pharmacies, and OTs need an integrated monitoring system for temperature and humidity (Guo et al., 2016). Carefully controlled temperature and humidity are required to balance the needs of the surgical team and the patient (Katz, 2016).

According to Brock (1975), most surgeons prefer 18.5–21 °C, some 21–22 °C, with 21 °C being the optimal ambient temperature, though universally acceptable conditions are difficult to achieve. ASHRAE 170 recommends 20–24 °C, a range supported by multiple studies, though surgical teams often favour lower temperatures in practice (Ufat et al., 2017). Moreover, several studies demonstrated that RH often exceeds the acceptable range given by the ASHRAE 170 (Accelix, 2022; Mustafa et al., 2019). Therefore, proper monitoring and control are significant in OTs' temperature and humidity control. Katz (2016) notes that OTs have strict environmental needs, where small changes can affect safety and comfort. AC systems must meet NABH and government standards to prevent risks like hypothermia and anesthetic gas exposure (Mishra et al., 2021), though global guidelines vary, making review of local and international standards essential. The table below summarizes recommended temperature and humidity ranges.

Table 1: Standard requirements for OTs

Standard	Temperature	Humidity
ASHRAE 170	20°C -24 °C	20% -60%
Centers for Disease Control and Prevention (CDC)	20°C -23°C	30% -60%
Joint Commission International (JCI)	20°C -24 °C	20% -60%
Hospital Infection Prevention Control Manual-Sri Lanka	20°C -24 °C	40% -60%

2.2 TEMPERATURE AND HUMIDITY MONITORING AND CONTROL TECHNOLOGIES

There are various monitoring and controlling techniques used for temperature and humidity control, such as IoT-enabled monitoring systems, BMSs, control algorithms, and smart systems.

IoT-enabled HVAC monitoring systems significantly improve operating room environmental control by enabling real-time monitoring of key parameters such as temperature, humidity, and pressure (Yojana, 2021). These systems issue automatic alerts when values exceed safe limits, ensuring timely interventions. Advanced IoT frameworks combine optimization and demand response strategies, achieving 20%-40% energy savings, while maintaining comfort (Giron et al., 2023). In addition, they support cloud-based data processing and remote monitoring, which is particularly beneficial in critical areas such as intensive care units (Rajith et al., 2018).

Building Management Systems (BMS) are an essential tool for enhancing energy efficiency and promoting sustainability in healthcare settings (Sharma & Alshtshati, 2024). They enable centralized oversight of building operations by utilizing sensor-based technologies to monitor critical environmental factors such as temperature and humidity in real time (Valinejadshoubi et al., 2020). BMS helps ensure adherence to standards like ASHRAE 170 by maintaining accurate environmental control within healthcare facilities (Setyonugroho et al., 2021). BMS effectively monitor and manage energy use, making them suitable for both small- and large-scale buildings (Harris & Madomercandy, 2007).

Recent studies have focused on smart HVAC control in operating rooms to improve air quality, comfort, and energy efficiency. Fuzzy logic controllers (FLC) effectively manage inputs such as temperature and humidity, improving system reliability and comfort (Saritas et al., 2007). CFD simulations help optimize performance while maintaining pollution standards (Wang et al., 2021). IoT-based systems enable real-time air quality monitoring and mobile alerts, improving environmental control and reducing energy use (Yojana, 2021).

3. METHODOLOGY

This study focused on examining the reality of the established concept that building management systems (BMS) are more effective than independent thermostat controls. Hence, this research was conducted across four hospitals that operate general surgery rooms, as defined by the ASHRAE 170 operating room classification. This study consisted of 3 phases, including a literature survey, 4 hospital case study evaluations, and expert interviews to validate the findings of case studies. The literature survey helped in realizing the current standards and regulations related to maintaining temperature and humidity requirements for OTs. The four case studies helped to understand the current situation of compliance with identified standards and investigating the potential causes of deviations in BMS and traditional thermostat-controlled environments. Finally, interviews with experts helped to propose strategies for enhancing compliance with established standards in OTs in Sri Lankan healthcare facilities. The four hospitals studied had centralized air-conditioning systems with modulating controls. Cases A and B were equipped with BMS-enabled real-time monitoring and maintained historical temperature and humidity records, while Cases C and D relied on basic thermostat controls without BMS and lacked historical data. In each case, one member of the technical staff and one member of the medical staff were interviewed to obtain case-specific insights. Table 3 summarises the profile of case-study respondents.

Table 2: Profile of respondents

Respondent Identity	Hospital Name	Department or professional background
R1	Case A	Engineering Staff Person-HVAC Controlling
R2	Case A	Medical Staff –OT User
R3	Case B	Engineering Staff Person-HVAC Controlling
R4	Case B	Medical Staff – OT User
R5	Case C	Engineering Staff Person-HVAC Controlling
R6	Case C	Medical Staff – OT User
R7	Case D	Engineering Staff Person-HVAC Controlling
R8	Case D	Medical Staff – OT User

The five semi-structured interviews with subject experts, who had extensive experience in hospital indoor environmental quality management and building automation systems, were conducted to validate the case study findings. Each interview lasted approximately 30 minutes. A purposive sampling approach was followed in the selection of experts. The expert interviews were limited to five due to the recurrence of the same opinions and responses, detecting data saturation in the validation process. Table 3 summarises the profile of experts involved in the study.

Table 3: Profile of experts

Respondent Identity	Years of Experience	Profile descriptions
E1	10 +	Engineering Manager of the leading Pvt sector hospital.
E2	3+	Assistant maintenance engineer of a Pvt sector hospital with experience in the automation industry.
E3	15+	Director of the leading automation company.
E4	3+	HVAC commissioning engineer with experience in the automation industry.
E5	20+	HVAC consultant.

The data collected in both phases was analysed using manual content analysis as it is a qualitative study that and required systematically reviewing interview transcripts. The authors believed that human interpretation would achieve the most appropriate contextually relevant results. Hence, the responses were manually reviewed, coded, and grouped into categories based on common themes and patterns.

4. FINDINGS

Findings are divided into two areas as case study findings and findings of the expert interviews.

4.1 CASE-WISE ANALYSIS

4.1.1 Case A

Case A is a private hospital where OT environmental conditions are controlled through a centralized BMS with a dedicated AHU, modulating controls, and duct sensors, enabling real-time 24/7 monitoring. A knowledge gap between technical and clinical staff was observed, which may affect communication and decision-making. However, both R1 and R2 emphasized that the HVAC system must operate continuously (24/7) to maintain the required temperature and humidity levels. As per respondents, temperature and humidity deviations were minimal, though R1 noted slight fluctuations during hot, humid months when the setpoint is set at the upper margin. BMS readings show stable temperature but frequent humidity fluctuations, though overall conditions meet standards. R1 and R2 confirmed that BMS supports effective environmental control, with R1 noting its multi-sensor, automatic adjustments outperform conventional thermostats, even amid budget and operational constraints. While BMS, limited sensors, and actuators restrict its full potential. R1 recommended expanding to IoT-based BMS, particularly in critical areas, to enhance environmental control, safety, and efficiency.

4.1.2 Case B

Case B is a private hospital that has a centralized BMS to control the environment. The OT has its own AHU with adjustable controls, and the hospital can monitor environmental conditions continuously (24/7). However, temperature and humidity data are only recorded three times a day manually by the BMS operator. R3 showed general awareness of temperature and humidity standards, referencing ASHRAE and national guidelines, indicating efforts to align with accepted practices. In contrast, R4 demonstrated limited awareness, relying on the BMS operator and past practices rather than defined standards. Medical staff also reported discomfort with temperature settings. Respondents noted recent temperature and humidity deviations due to technical issues. While continuous HVAC operation is required for a sterile environment, R3 highlighted challenges such as staff preferences (often requesting ~18°C), frequent door openings, and balancing energy demand, all of which affect maintaining standard conditions. As a result, the HVAC system tends to maintain lower temperatures to suit surgical preferences rather than standards. While significant fluctuations and instability were observed in both temperature and humidity, the humidity frequently exceeded limits, indicating poor dehumidification. Despite having a BMS, poor sensor accuracy and system programming, staff behavior, and operational practices limited its ability to maintain required environmental conditions.

4.1.3 Case C

Case C is a private hospital without a BMS to control the OT environment. The OT has a dedicated AHU with modulating controls. However, temperature is managed using a basic thermostat system. Respondents showed a clear knowledge gap: R5 had strong awareness of ASHRAE 170 and CDC guidelines, emphasizing maintaining 20–24 °C and humidity below 60%, while R6 had limited knowledge and relied on the traditional practice of 18 °C. Current practices followed relied on historical norms rather than formal standards, highlighting the need for better communication and training to ensure operating room safety and compliance. Interviews and observations revealed critical deficiencies in operational practices related to environmental controls in OT. Both R5 and R6 acknowledge that there was a lack of systematic monitoring, particularly regarding the accuracy and reliability of environmental data. R5 noted that temperature and humidity are logged only by surgical staff, with no historical records for the engineering team, highlighting a disconnect between clinical and engineering teams and a lack of monitoring transparency. In Case C, OT temperature is logged manually twice daily, risking inaccuracy, while HVAC systems are turned off when unused, violating ASHRAE 170 standards. Lack of real-time monitoring and stable conditions compromises infection control and patient safety. Staff noted the need for a BMS, though budget constraints hinder implementation.

4.1.4 Case D

Case D is a semi-government hospital where a there is no BMS available to control the thermal comfort in the OT. The OT has a dedicated AHU with modulating controls; however, temperature is managed using a basic thermostat, and a centralized BMS is not in operation. Respondents showed limited understanding of ASHRAE standards for operating rooms. R7 and R8 highlighted a significant knowledge gap in both technical and medical staff, with R7 showing low-confidence estimates (18–20 °C) and R8 unaware of formal standards, relying on 18 °C, indicating risks to environmental control and patient safety. The current practice for monitoring temperature and humidity in the selected OT appears to be informal and lacks a structured protocol. R7 noted that engineering teams are not proactive; OT staff check thermostats and request maintenance only when issues arise, causing potential delays in resolving environmental problems. R8 noted that temperatures are logged daily in a general book without a formal monitoring system, limiting trend analysis, standards compliance, and preventive maintenance. Limited engineering oversight and lack of routine humidity monitoring in Case D reveal high risks of temperature and humidity deviations, with low staff awareness posing threats to efficiency, patient safety, and infection control.

5. ANALYSIS

5.1 CROSS-CASE ANALYSIS

This section presents a cross-case analysis of Cases A, B, C, and D, comparing similar cases to identify common practices and contrasting cases to highlight gaps and context-specific challenges, providing insights into the effectiveness of temperature and humidity monitoring in OTs.

5.1.1 Cross-Case Analysis of Case A and Case B

The cross-case analysis of case A and case B revealed that the availability of BMS supports centralized control of OT conditions and real-time monitoring and control of temperature and humidity due to historical trend logs providing better decision-making by allowing analysis of temperature and humidity behaviour trends and patterns, while manual recording limited responsiveness and data accuracy. When proper data recording is lacking, medical officers appear to influence temperature controls based on personal preferences, affecting indoor environmental quality. Also, the presence of BMS, system design limitations, sensor placement, number of sensors used, and programming errors can limit the effectiveness of the BMS system in maintaining temperature and humidity within acceptable ranges. User behaviour, training, and awareness of temperature and humidity control are among the technical factors that affect maintaining effective temperature and humidity.

5.1.2 Cross-Case Analysis of Case C and Case D

Cross-case analysis of cases C and D revealed that when BMS was not available, and manual thermostat control was available, the medical staff relied on routine and past practices rather than formal standards. The hospital lacks structured OT training and protocols, increasing risks to patient safety and limiting compliance with ASHRAE 170. It was also observed that when a BMS was absent, the engineering team was less involved in temperature and humidity control. Case C maintains manual temperature logs, though their accuracy is questionable, while Case D has no records. The lack of record-keeping prevents predictions, making engineering interventions mostly reactive. Case C also risks sterile conditions by shutting down HVAC during non-surgical hours. User behaviour, lack of training and awareness of regulatory standards (especially among clinical staff), and minimal involvement of engineering personnel contribute to poor environmental control. In both cases, staff prioritize personal or patient comfort over required environmental standards due to low awareness. Both also lack real-time monitoring, alerts, and trend analysis, allowing temperature and humidity deviations to go undetected and increasing risks to patient safety and operational efficiency.

5.2 Cross-Case Analysis of BMS and Thermostat Control in OT for Temperature and Humidity Control

Table 4 is a summary of the characteristics of four cases.

Table 4: Summary of case studies

Case	System Type	Monitoring Method	Temp Control Approach	RH Control Approach	Key Feature
Case A	BMS	Continuous (5-sec data)	Automated control	Automated control	High-level monitoring
Case B	BMS	Continuous monitoring	Advanced BMS control	Integrated RH control	Optimised system settings
Case C	Thermostat	Manual/3 readings/day)	Local thermostat-based	Limited RH control	Low-frequency monitoring
Case D	Thermostat	Manual/spot checks	Manual adjustment	Basic RH control	Reactive control system

Cross-case analysis shows BMS-enabled OTs comply better with ASHRAE 170 than those using decentralized thermostatic controls. The findings are presented in Table 5.

Table 5: Cross-case analysis summary

Criteria	BMS-enabled OTs	Thermostat enabled OTs
Compliance status to ASHRAE 170	Partial and Full compliance	Failure to comply
Infrastructure and Monitoring Capability	Real-time monitoring, precise control, and alerts, ensuring compliance and safety.	Rely on manual adjustments and periodic logging, risking efficiency and patient safety.
Standard temperature and humidity requirements	Considerably acceptable temperature and humidity conditions	Low compliance, frequent deviations
Monitoring Accuracy & Responsiveness	Improved monitoring accuracy and responsiveness	Very low, manual, infrequent, and often inaccurate recording
Operational Practices Impact	Predictive control	Reactive control

According to these analyses, the superior performance in Case A reflects the benefits of real-time data and automated trend analysis. However, in places like Case B, even within BMS-enabled hospitals, human factors, technical factors , and underutilization of system capabilities can neglect the technological advantages. On the other hand, the thermostat-operated OTs showed poor performance and compliance, increasing risks to patient safety and infection control.

5.3 VALIDATION AND RESPONSES OF EXPERTS

The findings from the case study analysis were validated through expert review, and strategies were developed to address the identified issues.

E1, E2, and E3 experts acknowledged that BMSs offer significant advantages in maintaining environmental conditions in OTs. They highlighted that BMS enables real-time monitoring, automatic alerts, and early detection, which are crucial for maintaining temperature and humidity within surgical standards. As E1 noted, “BMS provides continuous data that helps take action before conditions go far beyond acceptable ranges.” Similarly, E2 and E3 pointed out that BMS platforms allow for remote diagnostics and data logging, making them very effective for preventive maintenance. However, E4 and E5 raised a warning about the practical limitations and risks associated with over-reliance on BMS for critical environments such as OTs. E4 emphasized that full override control by the BMS during technical malfunctions can become a liability due to the inability to make manual adjustments. E5 reinforced this concern by stating that, regardless of the benefits, many hospitals in SL still preferred basic thermostat controls in operating rooms because of their simplicity and direct manual control. According to E5, “*Most operating rooms are not connected to a BMS, as basic thermostat control is preferred for its reliability and ability to allow immediate adjustments without relying on engineering teams or software”*. This confirmed the situation in cases B, C, and D, where surgical needs were prioritized over standard temperature and humidity. E1 noted that OT temperature and humidity deviations, even with real-time monitoring, are often intentional due to surgical needs or energy-saving measures, but when setpoints are configured correctly, the BMS automatically modulates the chilled water valve and dampers to maintain desired conditions. This automatic adjustment mechanism works equally well in both BMS-enabled systems and thermostatically controlled systems, E1 explained. However, the main limitation of thermostatically controlled environments is the lack of centralized monitoring, as only OT staff can view or change setpoints, making it invisible to the engineering team, limiting proactive response, which would make compliance difficult. E3 highlighted that humidification and dehumidification systems often require reheating after lowering the temperature, causing long-term deviations. E4 added that even with correct setpoints, system response delays, especially during load or occupancy changes leading to temporary deviations. All respondents agreed that medical staff behaviour can hugely impact temperature and humidity control. A summary of the reasons for non-compliance within OTs highlighted by the experts, is presented in Table 6.

Table 6: Reasons for non-compliance as per experts

Potential causes	E1	E2	E3	E4	E5
Surgical procedure requirements outside the standard range	✓	✓	✓		✓
Energy-saving practices	✓	✓			
Delay in system response (dehumidification/reheating)			✓	✓	
Manual override limitations in BMS				✓	✓
Lack of centralized monitoring in thermostat-controlled systems	✓	✓	✓		✓
Technical faults/system lag				✓	✓
Staff behaviour (door opening, comfort prioritization)	✓	✓	✓	✓	✓
Faulty or delayed humidification/dehumidification design			✓		

Based on these findings, experts proposed strategies to address temperature and humidity control challenges. Table 7 summarises the recommended strategies for both BMS-enabled and thermostat-controlled operating theatre environments.

Table 7: Strategies by experts

Strategies for BMS-Enabled Environments	Strategies for Thermostat-Controlled Environments
Enhance real-time centralized monitoring with automated alerts and fault detection.	Implement accurate digital thermostats for improved manual control.
Improve responsiveness using modulating valves, dampers, and reheating loops.	Conduct regular manual monitoring and data logging protocols.
Establish scheduled preventive maintenance and automated sensor calibration alerts.	Use standalone humidifiers/dehumidifiers to control humidity independently.
Enable fail-safe manual override options to maintain control during BMS faults.	Train clinical and support staff on manual thermostat operation and proper usage.
Provide training for staff on BMS interface, alert handling, and collaborative protocols.	Establish clear communication between clinical staff and engineers for quick response.
Leverage AI and data analytics for predictive trend analysis and HVAC optimization.	Maintain backup sensors and manual alarm systems for early fault detection.

The findings of the analysis are presented in Figure 1.

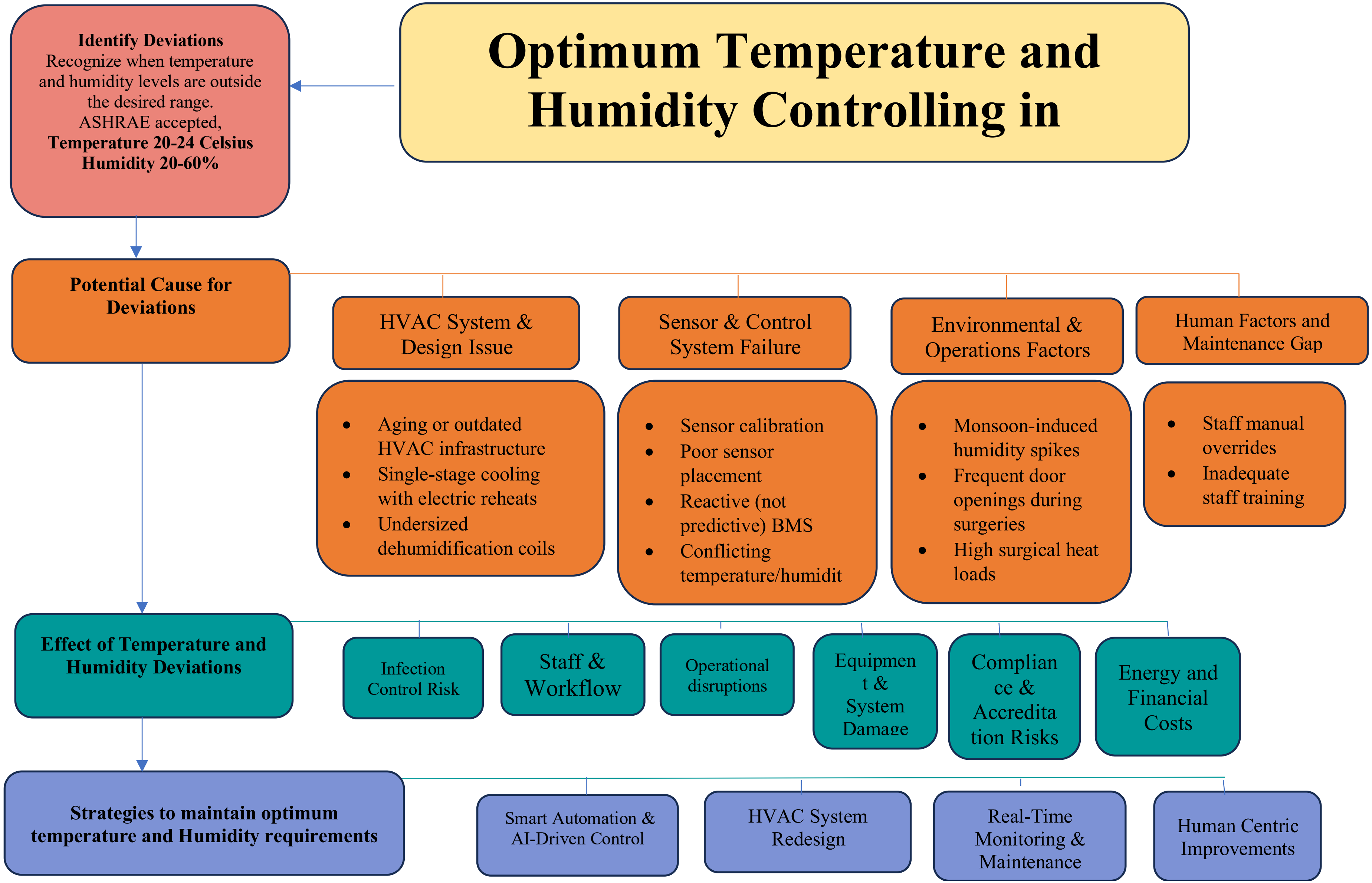

Figure 1: Summary of study

6. CONCLUSIONS

The literature revealed that many international standards, including ASHRAE, CDC, and JCI, recommend maintaining operating room temperature between 20°C and 24°C and relative humidity between 20% and 60% to ensure infection control, thermal comfort, and optimal equipment performance. Sri Lankan guidelines align with JCI, ASHRAE, CDC standards and the Hospital Infection Prevention and Control Manual, but implementation varies across hospitals. All guidelines align with ASHRAE standards, identifying temperature (20–24°C) and humidity (40–60%) as the benchmark ranges.

Two BMS-controlled hospitals were assessed, revealing that despite sensor-based systems, there are instances where temperature and humidity standards were unmet due to multiple factors. Furthermore, despite mandatory requirements for monitoring temperature and humidity, non-BMS facilities that relied on thermostat control showed a similar situation. It was further revealed that deviations from recommended temperature and humidity levels in operating rooms are caused by multiple interrelated causes. In BMS-enabled environments, factors such as delayed system response times, technical errors, energy-saving configurations, and limited flexibility in manual overrides were identified as major contributing factors to non-compliance. In contrast, thermostatically controlled systems faced challenges mainly due to a lack of centralized monitoring, being reactive rather than preventive in maintenance work, and poorly designed humidity/humidity reduction settings. In addition, in both system types, human factors such as frequent door openings, personal comfort adjustments, and lack of awareness among staff were significant behavioural contributors to environmental instability. These findings emphasize the importance of both technical robustness and disciplined operational practices in achieving consistent temperature and humidity compliance in operating rooms.

The proposed strategies by the experts were focused on both technical improvements and operational improvements that were tailored to the Sri Lankan healthcare context. For BMS-enabled environments, the experts recommended system-level improvements such as improved fault detection, integration of AI for predictive control, responsive dehumidification loops, and improved user interface training for clinical and engineering staff. In thermostatically controlled settings, the strategies emphasized the need for semi-automated control improvements, centralized data logging, and strict protocols for manual adjustments. In both systems, common recommendations included strengthening staff awareness, implementing maintenance schedules, and minimizing behavioural disruptions such as door openings. The practical implications of this study highlight that maintaining temperature and humidity compliance in OTs depends not only on the control system used but also on system operation, maintenance, and user behaviour. Relevant hospital managers should assess BMS and thermostat systems based on actual performance, as both may show similar compliance levels in practice. The findings also emphasize the need for continuous monitoring, proper maintenance, and staff awareness to ensure stable environmental conditions. The future research could examine staff collaboration on HVAC compliance, indoor air quality compliance in Sri Lankan healthcare facilities, and the role of AI-enabled BMS in improving temperature and humidity control in operating theatres.

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