Al-Farouk journal of sciences
Volume (2), Issue (3) (JUNE, 2026)
ISSN: 3135-2359

مجلة الفاروق للعلوم
المجلد (2) ملحق العدد 3 يونيو 2026
ردمد: 3135-2359

Evaluating the HVAC System Design for Operating Rooms in Nalut Central Hospital According to International Standards

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Received: 30/05/2026 Revised: 20/06/2026 Accepted: 28/06/2026 Publication: 29/07/2026

Abstract

This research aims to evaluate the Heating, Ventilation, and Air Conditioning (HVAC) system in the operating theaters of Nalut Central Hospital and analyze its compliance with approved international standards such as ASHRAE Standard 170 and WHO Guidelines for Surgery. The study adopted a comprehensive analytical approach, combining field visits, technical records review, and direct interviews with staff to assess the system's performance and adherence to modern operating room requirements. The findings revealed that the previously used non-centralized HVAC system had significantly exceeded its recommended operational lifespan. It failed to achieve essential requirements, including positive pressure, standard Air Change Rates (ACH), or precise temperature/humidity control. Currently, the hospital relies on household air conditioners (Split Units) and natural ventilation, which are entirely incompatible with surgical requirements, posing a significant risk of Surgical Site Infections (SSI). The study concluded that the current system is unable to meet standard specifications, necessitating immediate corrective actions, including the installation of a compliant centralized HVAC system.

Keywords : HVAC System, Operating Rooms, Positive Pressure, Air Change Rate, Healthcare-Associated Infection .

1. Introduction :

The indoor environment of surgical operating theaters represents the most critical ecological unit within a healthcare facility. The quality of air in these spaces is directly correlated with the rates of Healthcare-Associated Infections (HAIs), particularly Surgical Site Infections (SSIs) [1]. Consequently, the Heating, Ventilation, and Air Conditioning (HVAC) system in these spaces transcends its traditional role of providing thermal comfort, functioning primarily as a vital

biological risk control system. It is the primary defense mechanism responsible for filtering and removing microbial particles and fine particulate matter from the air [2].

To ensure patient safety and the success of surgical procedures, the design of an HVAC system must meet stringent technical requirements. These include continuous control of positive differential pressure to prevent the ingress of contamination, providing the minimum required Air Changes per Hour (ACH) to ensure clean air circulation, and utilizing High-Efficiency Particulate Air (HEPA) filtration. These requirements have been documented and internationally standardized under ANSI/ASHRAE/ASHE Standard 170 (Ventilation of Health Care Facilities), which is considered the academic and professional benchmark for designing such systems [3].

1.1 Problem Statement : Nalut Central Hospital currently faces a critical structural and technical challenge due to the complete breakdown of the dedicated HVAC system for its operating rooms since 2016. This situation represents an explicit violation of the necessary design requirements for surgical environments, significantly multiplying the risk of exposing patients to SSIs. Such complications bear high health and economic costs [4]. Presently, the hospital relies on household split-unit air conditioners, which entirely fail to meet infection control standards.

1.2 Study Objectives : The general objective of this study is to conduct a comprehensive engineering and analytical evaluation of the HVAC system in the operating rooms of Nalut Central Hospital according to international standards. The specific objectives include:

- Analyzing and evaluating the efficiency of the current HVAC system and determining its compliance with approved global health and engineering standards.
- Proposing and designing an upgraded HVAC system aimed at improving the efficiency of the rooms and ensuring a safe, sterile environment.
- Verifying the proposed system's compliance with technical specifications for infection control (e.g., positive pressure, HEPA filtration).

Literature Review HVAC systems are an essential part of hospital infrastructure, particularly in operating rooms that require the highest degrees of environmental control. This system contributes to providing stable thermal conditions, improving indoor air quality, and ensuring a safe surgical environment that limits the transmission of airborne contaminants [1].

Importance of HVAC in Operating Rooms The HVAC system guarantees a sterile environment by minimizing suspended particles and bacterial pollutants using HEPA or Ultra-Low

Penetration Air (ULPA) filters. Studies have proven that using these filters reduces environmental bacterial contamination in the surgical site by up to 90% [5]. Furthermore, providing a unidirectional (laminar) airflow over the surgical area at a constant velocity (0.2 - 0.5 m/s) reduces air stagnation and prevents the redistribution of contaminants [6]. To prevent polluted air from entering, the system must maintain a positive differential pressure (minimum +2.5 Pa) compared to adjacent corridors [2]. Temperature and humidity are also critical factors; ASHRAE recommends maintaining a temperature between 18-24°C and a relative humidity between 40-60% [3].

Previous Studies Several studies have investigated the efficacy of different ventilation strategies. A study by Sadrizadeh (2016) utilized Computational Fluid Dynamics (CFD) to evaluate OR ventilation, concluding that horizontal laminar airflow is a viable alternative to vertical airflow and is less susceptible to thermal plumes from medical equipment [7]. Alsved et al. (2018) compared Temperature-Controlled Airflow (TCAF) with Laminar Airflow (LAF) and Turbulent Mixed Airflow (TMA), finding that TCAF provides similar air purity to LAF but with greater staff comfort and lower energy consumption [8]. Wagner et al. (2018) highlighted that increasing the ACH to 25 does not always improve cleanliness compared to 20 ACH if the airflow distribution is poorly designed [9]. Furthermore, research has repeatedly shown that natural ventilation or mixed airflow systems fail to provide the ultra-clean air necessary for critical surgical zones [10], [11].

2. **Methodology** : This research adopted a descriptive-analytical approach to evaluate the ventilation system in the operating rooms at Nalut Central Hospital.

2.1 Study Population and Sample : The study population comprises the operating theaters at Nalut Central Hospital. The sample consisted of two actively functioning operating rooms. These rooms were selected because they represent the actual surgical environment and the real-world operational conditions of the hospital's ventilation setup.

2.2 Data Collection : Tools Data was collected through :

1. Direct field visits and observations.
2. Direct measurements of vital parameters (Temperature, Humidity).
3. A structured interview/questionnaire directed at the hospital's maintenance and engineering department. The tool contained five main sections: General System

Information, Operation and Maintenance, Quality and Safety Standards, Monitoring and Data, and Challenges and Development (See Appendix A).

2.3 Ethical Considerations : Official approval was obtained from the hospital administration to access the operating rooms and review the HVAC components. Data collected was strictly used for scientific research purposes, ensuring institutional privacy.

3. Results : The data collected from the field visits, measurements, and interviews were tabulated to assess the current state of the HVAC system against operational requirements and international standards.

- **Table I : System Information (Current State vs. Historical Setup) :**

Interview Question	Response/Observation
Type of HVAC system previously used ?	Carrier HVAC System.
Is the system centralized or independent ?	Non-Centralized Units (Independent for each room).
When was it installed and last updated ?	Installed in 1996. Cooling failed in 2008; Heating failed in 2016.
Expected operational lifespan ?	15 years (System has exceeded this lifespan).
Standard Temperature and Humidity set ?	Temp: 24-26 °C / Humidity: 60%-80%.
Automatic monitoring system exists ?	Yes (historically), but highly degraded.
Current alternative in use ?	Household Split-Unit Air Conditioners.
Filter types used ?	HEPA filters in ORs (roller system in handling units).
Filter replacement frequency ?	Monthly.

- **Table II : Ventilation System Efficiency and Indoor Air Quality :**

Evaluation Parameter	Response / Observation
Reliance on one-sided natural ventilation?	Yes (Currently relying on windows/doors).
Existence of hot air exhaust?	No.
Does opening doors transfer air between wards?	Yes.
Are there pressure differences maintained?	No (All spaces share similar pressure).
Patient privacy maintained during ventilation?	No (Doors are left open for air circulation).
Existence of upper ventilation ducts?	Yes, but non-functional.
Plan for monitoring Indoor Air Quality (IAQ)?	No.
Adherence to WHO natural ventilation guidelines?	No.

Table III: Adopted Standard Specifications vs. Current Measurements :

Standard Element	International Requirement (ASHRAE)	Current Measurements in Nalut (Hospital)
Temperature	18 - 24 °C	24 - 26 °C (Unstable)
Relative Humidity	40% - 60%	60% - 80%
Differential Pressure	Positive pressure ≥ +2.5 Pa	Not maintained / No continuous documentation
Filtration (HEPA)	Efficiency ≥ 99.97% (0.3 micron)	HEPA used, but system framework is failing
Airflow Pattern	Unidirectional (Laminar Flow)	Partially present historically, absent with split units
Environmental Monitoring	Continuous (Temp, Humidity, IAQ)	Unstable temps with human movement
Alarm System	Instant alarm upon limit breach	None

4. **Discussion** : The findings reveal a significant disparity between the current state of the operating rooms at Nalut Central Hospital and international standards .

As shown in Table I, the originally installed Carrier system was non-centralized, which theoretically aligns with the requirement for independent control to prevent cross-contamination. However, the system was installed in 1996 and has vastly exceeded its 15-year life expectancy, suffering complete heating and cooling failures between 2008 and 2016. Currently, the reliance on household split-unit air conditioners is alarming. Split units merely recirculate existing room air without introducing fresh filtered air, lacking the capacity to provide positive pressure or standard ACH. This directly contradicts the findings of Alsved et al. (2018) [8], who emphasized the necessity of dedicated medical ventilation systems capable of maintaining stable, ultra-clean environments.

Table II highlights a critical breakdown in infection control: the reliance on natural ventilation and opening doors. The absence of pressure differentials allows contaminated air from adjacent corridors to enter the sterile surgical field. This contradicts standard protocols [3], [4] which strictly mandate positive pressure inside the OR. Furthermore, Sadrizadeh and Aganovic (2016) demonstrated that uncontrolled airflows and natural ventilation in surgical environments drastically increase the concentration of airborne bacteria [7].

Table III quantifies the compliance failure. The recorded temperature (24-26°C) and humidity (60-80%) exceed the ASHRAE limits (18-24°C and 40-60%). High humidity promotes fungal and bacterial growth, while elevated temperatures compromise surgical staff comfort and focus. While HEPA filters are reportedly replaced monthly, their effectiveness is rendered obsolete without a functional Air Handling Unit (AHU) to drive pressurized air through them in a laminar pattern. The absence of an active alarm system and continuous environmental monitoring further exacerbates the risks, preventing immediate responses to IAQ deterioration.

5. **Conclusion** : The study concludes that the HVAC system currently operating in the surgical theaters of Nalut Central Hospital is fundamentally deficient and non-compliant with international standards (ASHRAE 170, WHO). The reliance on outdated infrastructure and household split-unit air conditioners compromises indoor air quality, fails to establish positive pressure, and creates an environment highly susceptible to surgical site infections. There is an urgent, undeniable need to halt reliance on natural and unspecialized ventilation and implement a comprehensive, modern mechanical HVAC system to safeguard patient and staff health.

6. **Recommendations** : Based on the analytical evaluation, the study recommends the following:

1- Redesign and install a comprehensive, centralized HVAC system exclusively for the operating rooms, fully compliant with ASHRAE Standard 170 and ISO 14644.

2- Implement strict HEPA filtration in the final stages of air delivery, accompanied by certified filter integrity testing.

3- Adopt a unidirectional (Laminar) airflow pattern above the surgical table to minimize suspended particles.

4- Install accurate environmental monitoring devices (temperature, humidity, differential pressure) linked to a central Building Management System (BMS).

5- Establish an electronic archiving system for operational data and logs.

6- Develop a rigorous periodic maintenance plan for AHUs, filter replacement, and pressure testing.

7- Assign and continuously train a specialized technical team (biomedical/mechanical engineers) to manage medical ventilation systems.

8- Implement energy-efficiency strategies (such as Variable Air Volume during unoccupied hours) without compromising sterile requirements.

9- Provide an emergency backup HVAC system and a redundant power supply to ensure continuous operation during power outages.

10- Enforce strict protocols for particle monitoring and limit personnel movement and door openings during surgical procedures.

- Appendix A : Data Collection Tool (Questionnaire) :

Questions Directed to the Responsible Department (Maintenance/HVAC Department at Nalut Hospital)

Section 1: General System Information

1. What type of HVAC system is used in the operating room?
2. Is the system centralized serving multiple rooms, or independent for each OR?
3. When was the system last installed, renewed, or upgraded?
4. What is the expected operational lifespan of the current system? Has it reached its limit?

Section 2: Operation and Maintenance 5. What are the standard temperature and humidity settings inside the OR? 6. Is there an automatic control and monitoring system for temp,

humidity, and pressure? 7. How many times a year is periodic maintenance performed? 8. What are the most common technical issues faced, and how are they handled? 9. Is the system equipped with automatic alarms when values exceed allowed limits? 10. Is there a backup system in case of failure during a surgical procedure?

Section 3: Quality and Safety Standards 11. Does the system meet ASHRAE or WHO standards for operating rooms? 12. What is the Air Changes per Hour (ACH) rate? 13. What type of filters are used? Are HEPA or ULPA filters utilized? 14. What is the frequency of filter inspection and replacement? 15. Is differential pressure measured regularly to maintain positive pressure? 16. Are periodic Indoor Air Quality (IAQ) tests conducted?

Section 4: Monitoring and Data 17. Is operational data (temp, humidity, pressure) logged regularly? 18. What types of sensors or devices are used to monitor performance? 19. Can operational data be shared with the academic research team?

Section 5: Challenges and Development 20. What are the main technical or operational challenges? 21. Are there future plans to upgrade or replace the current system? 22. What are the most important suggested improvements to achieve optimal efficiency? 23. What is the system's energy consumption? Are there measures to rationalize it without affecting performance?

Additional Medical Staff Questions: 24. Do Nalut Hospital facilities rely on one-sided ventilation? 25. Are there hot air exhaust outlets, or does ventilation rely only on windows? 26. Does opening doors during ventilation transfer air between hospital wards? 27. Are there pressure differences between patient rooms and corridors? 28. Have there been documented cases of cross-infection due to ventilation issues? 29. Does the current system prevent airborne infections, or is air mixing possible? 30. Is patient privacy maintained without needing to open doors for ventilation? 31. Are there upper ventilation ducts that can be upgraded? 32. Are temperature differences across facades measured to assess airflow impact? 33. Are patients distributed based on disease type and required ventilation rates? 34. Is there an IAQ monitoring plan (CO2, humidity, air velocity)? 35. Does the hospital follow WHO guidelines regarding natural ventilation for infection control ?

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