



## ASSESSMENT OF THE FEASIBILITY AND POTENTIAL IMPACT OF IOT-BASED PREDICTIVE MAINTENANCE FOR HVAC SYSTEMS IN PUBLIC HOSPITALS IN NIGERIA

Titus A. Ilupeju<sup>1</sup>, Danjuma S. Yawas<sup>2</sup>, Malachy Sumaila<sup>3</sup>

<sup>1,2,3</sup>Department of Mechanical Engineering, Ahmadu Bello University, Zaria, 810282, Nigeria

\*Corresponding author email: [titusyemisi@yahoo.com](mailto:titusyemisi@yahoo.com); Tel: +234 703 299 7372

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**Abstract:** Effective heating, ventilation, and air-conditioning (HVAC) performance is critical to thermal comfort, operational efficiency and better performance of installed equipment in healthcare facilities. However, air-conditioning systems in many Nigerian public hospitals are managed using reactive maintenance practices, resulting in frequent breakdowns, energy waste, and service disruption. This study presents an engineering feasibility assessment of an Internet of Things (IoT)-based predictive maintenance framework for hospital HVAC systems using the National Hospital, Abuja, as a case study. A low-cost distributed monitoring architecture incorporating temperature, current, voltage, and humidity sensors interfaced with an ESP32 edge gateway was designed to enable real-time equipment condition monitoring and automated fault detection. Analytical models were developed to estimate system power consumption, sensor performance, and preventive maintenance thresholds for early fault identification. A cost-benefit analysis indicates that predictive monitoring could reduce HVAC downtime by approximately 25-35% and decrease energy consumption by 20-30%, with a projected payback period of less than two years. Stakeholder surveys (n=284) further validated operational deficiencies and confirmed institutional readiness for technology-assisted maintenance. The results demonstrate that IoT-enabled predictive maintenance is technically feasible and economically viable for improving HVAC reliability and service delivery in resource-constrained public hospitals. The proposed framework provides a scalable pathway for modernizing healthcare facility management in Nigeria and similar contexts.

**Key words:** IoT, predictive maintenance, HVAC monitoring, smart healthcare infrastructure, energy efficiency, hospital engineering

### 1 Introduction

The management of hospital air-conditioning systems is a critical yet often overlooked component of healthcare facility operations. Effective heating, ventilation, and air conditioning (HVAC) systems are vital for maintaining indoor air quality, patient comfort, and infection control within hospitals (ASHRAE, 2022; Saran *et al.*, 2020). According to ASHRAE healthcare HVAC guidelines, continuous monitoring, timely maintenance, and adherence to operational standards are essential for ensuring thermal comfort, air quality, and infection control in hospital environments (ASHRAE, 2022). Inadequate management of these systems can lead to increased operational costs, frequent equipment breakdowns,

and compromised patient care environments, particularly in critical care units (Saran *et al.*, 2020; Alassafi *et al.*, 2024). Despite the importance of HVAC systems, many hospitals face challenges related to inefficient maintenance and suboptimal monitoring procedures. Industry reports have similarly highlighted the operational and energy-related consequences of inadequate HVAC management in healthcare facilities (Cooling India, 2025). Preventive maintenance has been identified as a critical factor in sustaining HVAC system reliability and reducing life-cycle costs in hospital

environments, yet remains inadequately implemented in many public healthcare facilities (Shohet & Lavy, 2019). The transition from reactive to predictive maintenance supported by digital monitoring tools is

consistent with established maintenance engineering principles that emphasize data-driven decision-making and continuous improvement (Mobley, 2020).

Total Quality Management (TQM) principles have been widely adopted in healthcare settings globally to enhance service delivery, operational efficiency, and patient satisfaction (Abu-Daqar & Constantinovits, 2020; Akhorshaideh *et al.*, 2023; Babatunde *et al.*, 2015; Vincent *et al.* 2019; Sadikoglu and Olcay's 2014; Ibrahim, 2013). These principles emphasize continuous improvement, stakeholder involvement, process optimization, and data-driven decision-making (Brinia & Malakelli, 2017). Previous studies have demonstrated the positive impact of TQM on hospital management processes, including clinical and administrative functions (Jrad, 2024; El-Tohamy & Al Raoush, 2015). However, the application of TQM specifically to the management of hospital HVAC systems remains under-explored, especially in the context of public healthcare institutions in Nigeria.

This study aims to bridge this gap by examining the effectiveness of Total Quality Management principles in managing the air-conditioning systems at the National Hospital, Abuja. Specifically, it evaluates the existing management approaches, focusing on maintenance and monitoring practices, and analyzes how these current methods influence the performance and reliability of the hospital's air-conditioning units. By comparing these practices with established TQM principles, this paper seeks to identify areas for improvement that can lead to enhanced system reliability, cost efficiency, and overall hospital effectiveness.

Understanding the interplay between TQM and HVAC management within healthcare facilities is essential for promoting sustainable infrastructure maintenance and ensuring the delivery of quality patient care (Hu *et al.*, 2024). Recent studies have demonstrated that IoT-enabled HVAC monitoring systems can significantly improve fault detection, energy efficiency, and maintenance responsiveness in large building facilities (Kim *et al.*, 2021; Shaikh *et al.*, 2020). The findings of this study have the potential to inform policymakers and hospital administrators in Nigeria and similar contexts on best practices for HVAC system management, ultimately

contributing to safer and more efficient healthcare environments.

National Hospital Abuja is a 350-bed tertiary healthcare facility serving as a major referral center in Nigeria. The hospital operates continuously and relies heavily on centralized and split-unit HVAC systems

to maintain infection control, thermal comfort, and equipment safety. However, frequent power instability, aging infrastructure, and reactive maintenance practices contribute to recurring HVAC failures, increased energy consumption, and service interruptions. These challenges make the facility an appropriate real-world case study for evaluating the feasibility of IoT-based predictive maintenance in resource-constrained healthcare environments.

## 2 Methodology

### 2.1 Hypotheses

This study is guided by two null hypotheses formulated based on the research questions:

**H<sub>01</sub>:** Existing air-conditioning management practices at the National Hospital, Abuja do not significantly align with key Total Quality Management principles.

**H<sub>02</sub>:** Stakeholders do not perceive that adopting TQM-aligned and IoT-supported management approaches would significantly improve air-conditioning system performance.

### 2.2 Research Design

A quantitative research design was adopted to empirically assess the effectiveness of TQM principles in the management of hospital air-conditioning systems. Quantitative methods provide empirical rigour and enable actionable insights through statistical analysis of structured data (Lim *et al.*, 2024). The primary data collection instrument was a structured questionnaire, which was administered to three distinct stakeholder groups at the National Hospital: admitted patients, clinical staff (including medical doctors and nurses), and maintenance technicians/engineers responsible for air-conditioning system upkeep.

### 2.3 Sample Size and Sampling Technique

The total population for the study was 1,450 individuals, encompassing patients, clinical staff, and maintenance personnel. Using a confidence level of 95% and a precision level of 5%, the sample size was calculated via the standard formula (Equation 1):

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Where ‘N’ is the population size (1,450) and ‘e’ is the level of precision (0.05).

Stratified sampling was employed to ensure proportional representation across the three groups, as per the stratified sampling formula (Equation 2):

$$ni = \frac{Ni}{N} \times n \tag{2}$$

Where *ni* is the sample size for group ‘i’, *Ni* is the population size of group ‘I’, *N* is the total population size, and ‘n’ is the total sample size.

Using eligibility and response rates tailored to the population characteristics (eligibility rate = 0.75; response rate = 0.5), the calculated patient sample size was 61. For clinical staff (population 1,033) and maintenance staff (population 134), sample sizes were 223 and 29 respectively. The total sample size was 313 respondents, who were selected and surveyed over a period of 50 days.

## 2.4 Data Collection

Quantitative data were collected through three variations of a structured questionnaire, each tailored to one of the stakeholder groups:

**Clinical staff and maintenance personnel:** The questionnaires contained three sections which were personal biodata, questions addressing research objectives related to maintenance and monitoring practices, and items related to knowledge and application of Internet of Things (IoT) technologies.

**Patients:** The questionnaire had two sections namely personal information and experiential ratings of hospital services, specifically focusing on air-conditioning system performance.

The questionnaires targeted key performance measures including equipment availability, service quality, maintenance responsiveness, funding adequacy, adherence to manufacturers’ guidelines, and overall user satisfaction. Respondents evaluated these measures relative to TQM principles such as leadership, customer focus, knowledge, involvement, continual improvement, and conducive working conditions.

A 5-point Likert scale was used to capture respondents’ attitudes and perceptions, where 1 = Strongly Disagree and 5 = Strongly Agree. This scale was chosen for its ease of understanding, reliability, and ability to quantify subjective measures.

## 2.5 Data Presentation and Analysis

Reliability of the questionnaire constructs was evaluated using Cronbach’s alpha. The computed coefficient of 0.82 indicates good internal consistency of the survey instrument, confirming the reliability of the measured variables. Descriptive statistics, including frequencies and percentages, were used to summarize respondent perceptions. Chi-square tests of association were employed to examine differences between observed management practices and TQM-aligned benchmarks, as well as stakeholders’ perceptions regarding the adoption of IoT-based monitoring systems. Statistical significance was assessed at the 5% level ( $p < 0.05$ ).

Descriptive statistics and chi-square tests were used to evaluate differences between observed management practices and TQM-aligned benchmarks. Statistical significance was assessed at the 5% level ( $p < 0.05$ ).

This study assessed stakeholders’ perceptions of current air-conditioning management practices and the perceived feasibility of IoT-based monitoring systems alongside the design and selection of the IoT materials. No experimental deployment or physical installation of IoT devices was conducted

## 3 IOT ARCHTECHTURE

### 3.1 Proposed IoT-Based Predictive Maintenance Architecture

To address the limitations of reactive maintenance practices identified at the National Hospital, Abuja, an Internet of Things (IoT)-based predictive maintenance framework was designed to enable continuous monitoring, early fault detection, and data-driven decision-making for HVAC systems. The architecture adopts a distributed edge–cloud design to ensure low cost, scalability, and resilience under the infrastructural constraints typical of Nigerian public hospitals.

The design comprises three principal layers which are: sensing, edge processing, and cloud analytics.

#### 3.1.1 Sensing Layer

Each air-conditioning unit is instrumented with low-cost sensors to capture critical operational parameters associated with system health. Temperature sensors (DS18B20) monitor evaporator and ambient conditions, current sensors (ACS712) measure compressor electrical load, voltage sensors (ZMPT101B) detect supply instability, while humidity sensors provide indoor

environmental indicators. These variables were selected because compressor over-current, abnormal temperature rise, and voltage fluctuations are well-established precursors of HVAC failure.

### 3.1.2 Edge Processing Layer

Sensor data are acquired by an ESP32 micro-controller-based gateway which performs local pre-processing, filtering, and threshold evaluation. Edge processing reduces communication overhead and ensures continued operation during temporary network outages. The gateway samples data at one-minute intervals and transmits aggregated measurements via Wi-Fi or GSM using MQTT protocol. Local storage enables buffering when connectivity is unavailable.

3.2 Table 1: Sensor and Hardware Components of the Monitoring Node

Component	Measured Variable	Purpose	Typical Accuracy
ACS712	Current	Compressor load monitoring	±1.5%
ZMPT101B	Voltage	Power stability detection	±1%
DHT22	Humidity	Indoor air quality	±2%
ESP32	Processing/Communication	Edge gateway	—

### 3.1.3 Cloud and Analytics Layer

A cloud server receives and stores operational data in real time for visualization and analysis. Dashboards provide maintenance personnel with system status, historical trends, and automated alerts. Predictive rules based on threshold violations and runtime accumulation trigger early maintenance requests, enabling transition from reactive to preventive strategies.

This architecture emphasizes affordability and deployability. Each node is modular, consumes less than 2W, and can be retrofitted to existing HVAC units without major modification. The framework supports scalable expansion across multiple hospital wards or buildings.

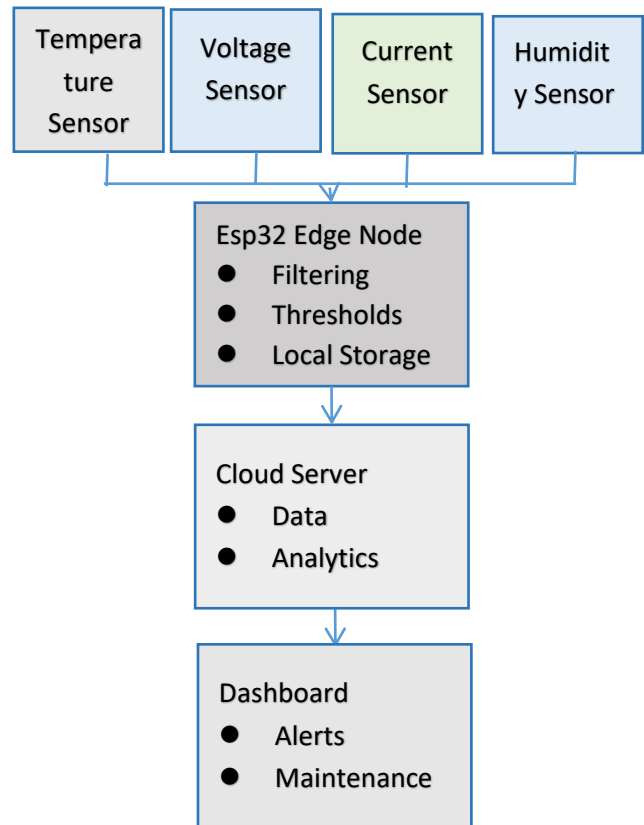


Figure 1: Proposed IoT-Based Predictive Maintenance Architecture

## 4 MODELING & ANALYTICAL

### 4.1 System Modelling

Analytical models were developed to quantify HVAC electrical demand, sensor operation, and fault-detection thresholds, enabling engineering evaluation and sizing of the proposed IoT monitoring architecture. The electrical power requirement of each air-conditioning unit was first estimated using compressor horsepower as shown in equation 3

$$P = 746 \times HP \tag{3}$$

For a typical 2 hp compressor, the calculated demand is approximately 1.5 kW. The coefficient of performance (COP) was further applied to relate cooling output to electrical input and support estimation of energy efficiency and potential savings.

Continuous current monitoring was adopted as the primary indicator of compressor health. Abnormal operating conditions were detected using percentage deviation (see equation 4),

$$\Delta I(\%) = \left( \frac{I_{rated} - I_{measured}}{I_{rated}} \right) \times 100 \quad (4)$$

where deviations greater than 20% were considered symptomatic of mechanical wear, refrigerant leakage, or overload conditions. Preventive alerts were generated using rule-based thresholds including under/over-voltage protection, over-current detection, excessive temperature, and accumulated runtime limits. These criteria approximate remaining useful life and enable maintenance actions prior to catastrophic failure.

To ensure stable micro-controller operation, the node power supply was designed by limiting ripple voltage according to equation 5, which guided capacitor selection and ensued reliable data acquisition.

$$C = I / (2fVr) \quad (5)$$

The consolidated electrical characteristics of a representative hospital HVAC unit used in the modelling are summarized in Table 2 the analytical framework provides quantifiable criteria for system sizing, threshold selection, and operational reliability.

4.2 **Table 2:** Electrical Characteristics of Typical Hospital AC Unit

Parameter	Value
Rated power	1.5 kW
Rated current	7–9 A
Voltage range	220–240 V
Operating hours/day	18–24 h
Estimated annual energy	13,000–15,000 kWh

## 5 COST–BENEFIT / FEASIBILITY

### 5.1 Feasibility and Cost–Benefit Analysis

The technical and economic feasibility of deploying the proposed IoT-based predictive maintenance framework was evaluated using downtime reduction and energy-consumption models. From the maintenance records and stakeholder reports, an average of four HVAC failures per month, with approximately six hours of service interruption per event, corresponding to 24 hours of downtime

monthly. Literature on predictive maintenance suggests failure reductions of 25–35% (Mobley, 2020; Kim et al., 2021). Applying a conservative 30% reduction yields an estimated 7.2 hours of downtime saved per month, improving operational continuity in critical hospital areas.

Energy optimization provides additional benefits. IoT-enabled building management systems have been reported to reduce HVAC electricity consumption by 20–30% through real-time monitoring and adaptive control (Kim et al., 2021; Shaikh et al., 2020; Al-Obaidi et al., 2022). For a facility with approximately 1,000 split air-conditioning units rated at 1.5 kW operating 18 hours per day, the estimated annual energy consumption is:

$$E_{\text{annual}} = 1,000 \times 1.5 \text{ kW} \times 18 \text{ h/day} \times 365 \text{ days} \approx 9,855,000 \text{ kWh} (\approx 9.86 \text{ GWh}).$$

A conservative 25% reduction from IoT-enabled predictive maintenance corresponds to ~2.46 GWh saved annually, representing substantial cost savings and reduced environmental impact.

Hardware deployment costs were estimated at approximately USD 80 per monitoring node (per unit of a complete monitoring unit installed on one HVAC), comprising sensors, an ESP32 edge controller, power supply, and enclosure. For 1,000 monitored units, the total capital investment is USD 80,000. Given the projected energy savings, the payback period is expected to be less than two years, demonstrating clear economic viability for large-scale deployment.

Tables 3 and 4 summarize the estimated per-unit costs and projected improvements in energy use and downtime.

5.2 **Table 3:** Estimated Deployment Cost per HVAC Unit

Item	Cost (USD)
Sensors set	35
ESP32 board	12
Power supply & enclosure	18
Installation	15
<b>Total per unit</b>	<b>80</b>

5.3 Table 4: Projected Energy and Downtime Savings

Metric	Current	With IoT	Improvement
Downtime/month	24 h	16.8 h	30% reduction
Annual energy use	9,855,000 kWh	7,391,000 kWh	25% saving
Annual cost saving	—	2,464,000 kWh	
Payback period			< 2 year

## 6 Result and Discussion

### 6.1 Stakeholder Assessment Result

A total of 284 valid questionnaires were returned from the 313 distributed, representing a 90.7% response rate, which is considered excellent for survey-based studies and indicative of reliable data quality. Respondents comprised clinical staff (73.2%), patients (16.9%), and maintenance personnel (9.8%), ensuring balanced stakeholder representation (Figure 1).

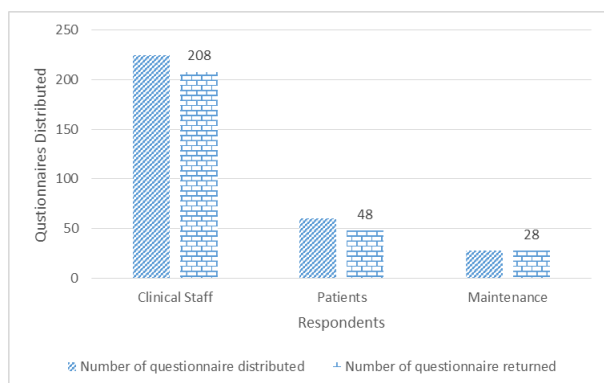


Figure 1: Distribution of survey respondents across stakeholder groups at the National Hospital, Abuja.

Survey responses revealed widespread dissatisfaction with the reliability and performance of the hospital’s air-conditioning systems. Only 12.5% of respondents strongly agreed that units were consistently functional, while more than half expressed dissatisfaction with temperature regulation and indoor air quality. Maintenance responsiveness was similarly poor; 43.7% disagreed that faults were addressed promptly and 58.3% reported prolonged repair times (Figure 2).

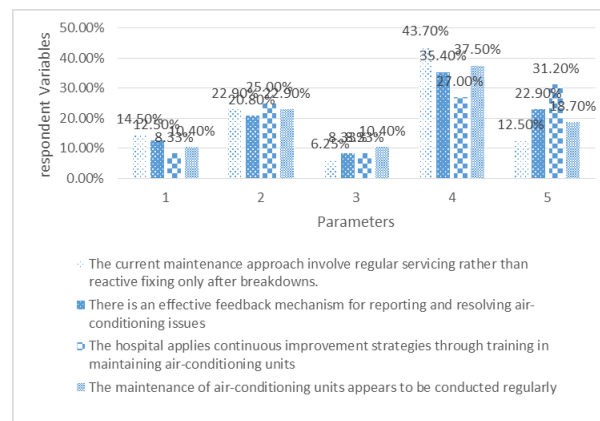


Figure 2: Evaluation of maintenance responsiveness and monitoring efficiency of air-conditioning systems.

These findings indicate a predominantly reactive maintenance culture inconsistent with preventive maintenance practices.

The operational consequences were substantial. Approximately 90% of respondents agreed that HVAC performance directly affects staff productivity and patient care, yet 72.1% rated the system as unreliable and 67.7% reported ineffective repairs (Figure 3).

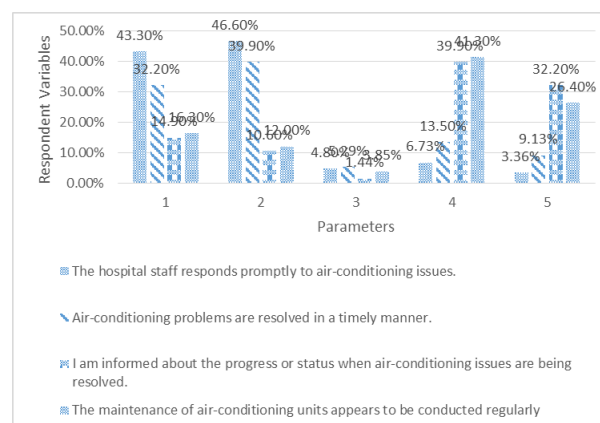


Figure 3: Impact of air-conditioning system performance on staff efficiency and patient care.

Comparison with Total Quality Management (TQM) principles further showed limited implementation of preventive maintenance, continuous monitoring, and structured training (Figure 4).

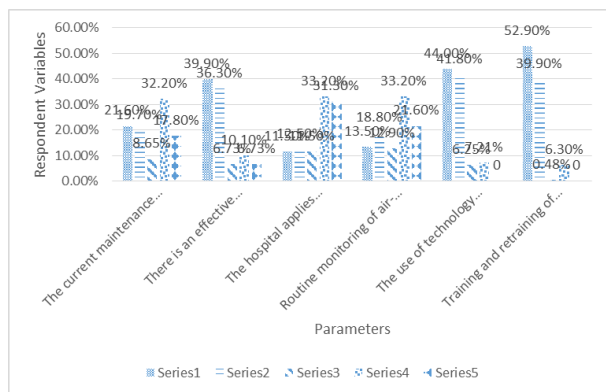


Figure 4: Comparison of existing air-conditioning management practices with Total Quality Management principles

Despite these shortcomings, strong support for technology-driven solutions was observed. Most respondents endorsed IoT-based real-time monitoring (89.9%) and automated maintenance alerts (96.1%), while maintenance staff identified cost, training, and infrastructure limitations as the primary barriers to implementation (Figures 5–6).

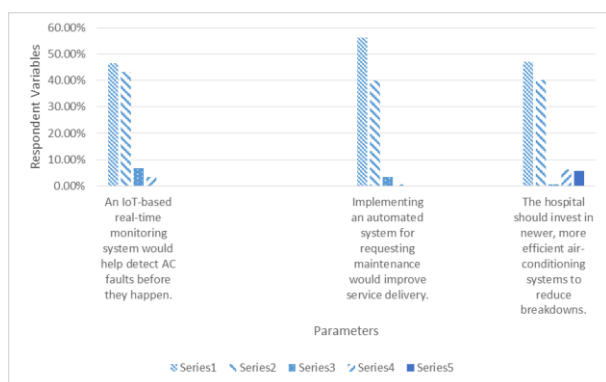


Figure 5: Stakeholders' support for TQM-aligned and IoT-based improvement strategies.

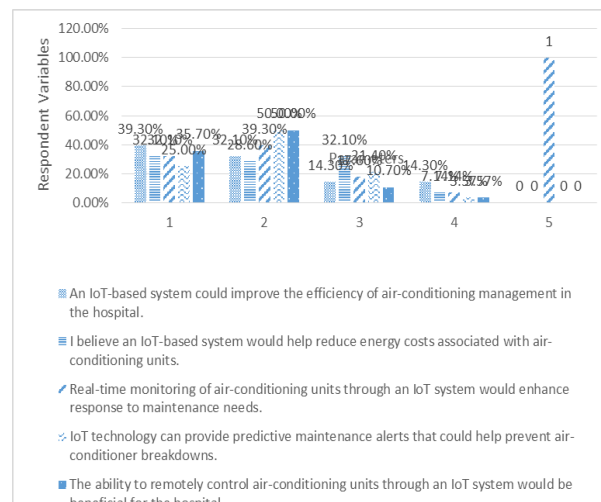


Figure 6: Perceived challenges to IoT-based air-conditioning management implementation (maintenance staff, n = 28).

Overall, these results indicate both the necessity and institutional readiness for predictive, data-driven maintenance strategies.

## 6.2 Discussion and Implications

The results demonstrate that the predominant challenge facing HVAC management at the National Hospital is not merely organizational but technical in nature. Reactive maintenance practices allow minor electrical and mechanical faults to propagate into major failures, resulting in avoidable downtime and energy waste. Continuous condition monitoring, as enabled by the proposed IoT framework, directly addresses this limitation by transforming maintenance from time-based to condition-based decision-making.

The engineering analysis indicates that monitoring compressor current, voltage stability, and temperature provides sufficient indicators for early detection of most HVAC faults. Edge-based processing ensures reliable operation even under unstable network conditions common in Nigerian public infrastructure. Furthermore, the low hardware cost and minimal power consumption make the system suitable for large-scale deployment.

The projected energy savings (20–30%) and downtime reductions (25–35%) align with prior smart-building studies and confirm that predictive maintenance can produce measurable operational benefits. The stakeholder survey further reinforces implementation feasibility by demonstrating strong institutional acceptance. Consequently, integrating IoT-enabled monitoring within a Total Quality Management framework offers both technical and managerial advantages.

## 7 Limitations

This study is limited to a single hospital site and relies partly on stakeholder perception data, which may introduce response bias. The predictive maintenance model was analytically validated but not yet deployed in a live pilot environment. Consequently, projected energy savings and downtime reductions are based on modeling and literature benchmarks rather than measured field performance. Future work will implement pilot installation and real-time validation to quantify prediction accuracy and long-term operational benefits.

## 8 Conclusion

This study presented an engineering feasibility assessment of an IoT-based predictive maintenance framework for hospital HVAC systems using the National Hospital, Abuja, as a case study. A low-cost sensing architecture, edge gateway, and cloud analytic platform were designed to enable real-time monitoring and automated fault detection. Analytical modeling and cost-benefit evaluation showed that the system could reduce downtime by approximately 25–35% and decrease energy consumption by up to 30%, with a payback period of less than two years. Stakeholder assessments confirmed operational deficiencies and readiness for digital transformation.

The findings demonstrate that predictive, data-driven maintenance is both technically viable and economically justified for resource-constrained healthcare facilities. Future work should involve pilot deployment and long-term performance validation. The proposed framework provides a scalable pathway toward smart, reliable, and energy-efficient hospital infrastructure management in Nigeria and similar contexts.

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Appendix

**Table 4.1: Patient responses on comfort and AC service (n = 48)**

<b>General Air-Conditioning Management Approach</b>								
A	Variables	5	4	3	2	1	Mean	Rank
1	The air-conditioning units in my ward/room are consistently functional.	12.5 % 6	33.3 %16	6.25 %3	33.3 %16	14.5 %7	2.96	1
2	The air-conditioning system provides a comfortable room temperature.	10.4 %5	22.9 %11	16.7 %8	33.3 %16	16.7 %8	2.77	7
3	I rarely experience air-conditioning failures during my hospital stay.	10.4 %5	25.0 %12	8.33 %4	35.4 %17	20.8 %10	2.69	9
4	The air quality in my room is satisfactory due to proper air-conditioning.	16.7 %8	20.8 %10	10.4 %5	33.3 %16	18.7 %9	2.83	5
<b>Maintenance and Monitoring Efficiency</b>								
5	The hospital staff responds promptly to air-conditioning issues.	14.5 %7	22.9 %11	6.25 %3	43.7 %21	12.5 %6	2.83	5
6	Air-conditioning problems are resolved in a timely manner.	12.5 %6	20.8 %10	8.33 %4	35.4 %17	22.9 %11	2.65	11
7	I am informed about the progress or status when air-conditioning issues are being resolved.	8.33 %4	25.0 %12	8.33 %4	27.0 %13	31.2 %15	2.52	12
8	The maintenance of air-conditioning units appears to be conducted regularly.	10.4 %5	22.9 %11	10.4 %5	37.5 %18	18.7 %9	2.69	9
<b>Management and Overall System Performance</b>								

9	The hospital management has an efficient system for handling air-conditioning-related complaints.	8.33 %4	20.8 %10	16.7 %8	43.7 %21	10.4 %5	2.73	8
10	There are sufficient personnel assigned to handle air-conditioning maintenance issues.	16.7 %8	20.8 %10	14.5 %7	27.0 %13	20.8 %10	2.85	4
11	The management effectively monitors the performance of air-conditioning units.	22.9 %1 1	20.8 %10	6.25 %3	27.0 %13	22.9 %11	2.94	3
12	Overall, I am satisfied with the management approach for air-conditioning units in the hospital.	20.8 %1 0	25.0 %12	4.16 %2	29.2 %14	20.8 %10	2.96	1

Table 4.2: Impact of the current management practices on the performance in comparison them with Total Quality Management (TQM) principles. Clinical staff responses (n = 208)

B The Impact of Total Quality Management on The Current Management								
Variables	5	4	3	2	1	Mean	Rank	
1 The functionality of air-conditioning units in my department directly affects my work efficiency.	43.3% 90	46.6% 97	4.80% 10	6.73% 4	3.36% 7	4.25	4	
2 Frequent air-conditioning failures negatively impact patient care and staff comfort.	32.2% 67	39.9% 83	5.29% 11	13.5% 28	9.13% 19	3.73	8	
3 The hospital's air-conditioning system is reliable and rarely breaks down.	14.9% 31	10.6% 22	1.44% 3	39.9% 83	32.2% 69	2.34	17	
4 When air-conditioning units fail, repairs are completed quickly and efficiently	16.3% 34	12.0% 25	3.85% 8	41.3% 86	26.4% 55	2.50	15	
Evaluation of Current Management Practices								

5	There is a clear and well-structured maintenance schedule for air-conditioning units.	12.0% 25	19.7% 41	2.40% 5	39.0% 79	29.0% 58	2.50	15
6	The response time for fixing faulty air-conditioning units is satisfactory.	16.2% 35	19.7% 41	3.80% 8	38.5% 80	21.2% 44	2.73	13
7	The hospital's maintenance team has the necessary tools and resources to fix AC faults promptly.	18.3% 38	21.6% 45	8.17% 17	32.7% 68	19.2% 40	2.87	12
8	The hospital management promptly releases funds for routine air-conditioning repairs.	20.7% 43	26.0% 54	9.13% 19	31.2% 65	12.9% 27	3.1	10
9	There is an adequate stock of spare parts to reduce delays in AC repairs.	24.5% 51	22.6% 47	15.4% 32	23.0% 47	14.9% 31	3.19	9
Comparison with Total Quality Management (TQM) Principles								
10	The current maintenance approach involve regular servicing rather than reactive fixing only after breakdowns.	21.6% 45	19.7% 41	8.65% 18	32.2% 67	17.8% 37	2.95	11
11	There is an effective feedback mechanism for reporting and resolving air-conditioning issues.	39.9% 83	36.3% 76	6.73% 14	10.1% 21	6.73% 14	3.93	7
12	The hospital applies continuous improvement strategies through training in maintaining air-conditioning units	11.5% 24	12.5% 26	11.5% 24	33.2% 69	31.3% 65	2.40	16
13	Routine monitoring of air-conditioning units is conducted to prevent unexpected failures	13.5% 28	18.8% 39	12.9% 27	33.2% 69	21.6% 45	2.69	14
14	The use of technology improved technology such as IoT monitoring systems would improve air-conditioning management.	44.0% 93	41.8% 87	6.25% 13	7.21% 15	0	4.24	5
15	Training and retraining of maintenance staff on modern AC systems would improve service quality.	52.9% 110	39.9% 83	0.481% %1	6.3% 4	1 0	4.39	2
Future Improvements								

16	An IoT-based real-time monitoring system would help detect AC faults before they happen.	46.6% 97	43.3% 90	6.73% 14	3.36% 7	0	4.33	3
17	Implementing an automated system for requesting maintenance would improve service delivery.	56.2% 117	39.9% 83	3.36% 7	0.481 %1	0	4.52	1
18	The hospital should invest in newer, more efficient air-conditioning systems to reduce breakdowns.	47.1% 98	40.3% 84	0.481 %1	6.25% 13	5.77% 12	4.16	6

**Table 4.3: Evaluate the feasibility of implementation of IoT based system. Maintenance staff / IoT readiness (n = 28)**

C Need for Advanced Technology Package in National Hospital								
Variables		5	4	3	2	1	Me an	Rank
Awareness & Understanding of IoT								
1	I am familiar with the concept of the Internet of Things (IoT).	32.1 %9	60.7 %17	7.15 %2	0	0	4.25	6
2	I believe IoT can be beneficial in managing equipment like air-conditioners in a hospital setting.	39.3 %11	50.0 %14	10.7 %3	0	0	4.29	4
3	I understand how IoT systems work for monitoring and controlling equipment remotely	39.3 %11	39.3 %11	14.3 %4	3.57 %1	3.57 %1	4.07	9
Current Air-Conditioning Management Practices								
4	The current air-conditioning management system in the hospital meets our needs effectively	10.7 %3	50.0 %14	3.57 %1	28.6 %8	7.14 %2	3.29	22
5	Air-conditioning units in the hospital often require maintenance due to breakdowns or performance issues	57.1 %16	39.3 %11	3.57 %1	0	0	4.54	1

6	Energy consumption by air-conditioning units is a major concern in the hospital	53.6 %15	35.7 %10	3.57 %1	7.14 %2	0	4.36	3
7	There is a need for better monitoring and management of the hospital's air-conditioning units.	42.9 %12	50.0 %14	0	7.14 %2	0	4.29	4
Perceived Benefits of an IoT-Based System								
8	An IoT-based system could improve the efficiency of air-conditioning management in the hospital.	39.3 %11	32.1 %9	14.3 %4	14.3 %4	0	3.96	13
9	I believe an IoT-based system would help reduce energy costs associated with air-conditioning units.	32.1 %9	28.6 %8	32.1 %9	7.14 %2	0	3.86	18
10	Real-time monitoring of air-conditioning units through an IoT system would enhance response to maintenance needs.	32.1 %9	39.3 %11	17.6 %5	7.14 %2	1	3.89	17
11	IoT technology can provide predictive maintenance alerts that could help prevent air-conditioner breakdowns.	25.0 %7	50.0 %14	21.4 %6	3.57 %1	0	3.96	13
12	The ability to remotely control air-conditioning units through an IoT system would be beneficial for the hospital.	35.7 %10	50.0 %14	10.7 %3	3.57 %1	0	4.18	7
Feasibility & Challenges of IoT Implementation								
13	I am concerned about the cost of implementing an IoT system for managing air-conditioners	39.3 %11	35.7 %10	17.6 %5	7.14 %2	0	4.07	9
14	The hospital currently has the resources and infrastructure needed to support an IoT-based system	14.3 %4	32.1 %9	35.7 %1 0	14.3 %4	3.57 %1	3.39	21
15	Data security and privacy are concerns that could impact the adoption of IoT in the hospital.	21.4 %6	60.7 %17	14.3 %4	3.57 %1	0	4	12
16	The complexity of using and maintaining an IoT-based system might be challenging for staff.	25.0 %7	50.0 %14	17.9 %5	7.14 %2	0	3.93	16

17	Implementing an IoT system would require significant staff training.	53.6 %15	39.3 %11	7.14 %2	0	0	3.93	16	
Adoption & Alignment with Hospital Goals									
18	I would support the adoption of an IoT-based system for managing air-conditioning units in the hospital	25.0 %7	60.7 %17	10.7 %3	3.57 %1	0	4.07	9	
19	I believe that an IoT-based system for air-conditioning management would be reliable and effective.	17.6 %5	67.8 %19	10.7 %3	0	3.57 %1		3.96	13
20	Using IoT technology to manage air-conditioning units aligns with the hospital's Total Quality Management (TQM) goals.	14.3 %4	39.3 %11	46.2 %1 2	3.57 %1	0		3.64	20
21	If implemented, I believe an IoT-based system would significantly improve the hospital's air-conditioning management.	17.6 %5	50.0 %14	17.6 %5	10.7 %3	3.57 %1		3.68	19
22	I am confident that an IoT-based system would improve overall patient and staff comfort by optimizing air-conditioning performance.	32.1 %9	57.1 %16	3.57 %1	3.57 %1	3.57 %1		4.11	8
23	Air-conditioning failures often disrupt hospital operations.	21.4 %6	21.4 %6	7.14 %2	28.6 %8	21.4 %6		2.93	23