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Research Article

SMART MOSQUE: AN IOT-BASED CONTROL SYSTEM FOR MANAGING ENERGY CONSUMPTION AND FACILITY OPERATIONS

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Abstract

Public and religious facilities, like mosques, often suffer from substantial energy waste due to large physical footprints, manual control, and highly intermittent, non-linear occupancy patterns. This chronic inefficiency results in high utility bills, diverting scarce community funds away from core charitable and social welfare missions, underscoring the necessity for advanced, cost-effective automation. This study aims to design and empirically validate the "Smart Mosque Architecture," an integrated Internet of Things (IoT) system utilizing a novel Dynamic Prayer Time-Based Control Algorithm (DPT-BCA) to proactively optimize energy consumption across lighting and HVAC systems. A quantitative, quasi-experimental time-series analysis was conducted over a six-month experimental period, comparing the system's performance against a four-month manual control baseline. The custom low-cost system achieved a statistically significant average monthly energy reduction of 30.0% ($p < 0.001$), driven primarily by a 47.4% reduction in HVAC runtime. Financial analysis confirmed the system's economic viability, yielding a simple Return on Investment (ROI) in just eighteen months. The Smart Mosque Architecture is a robust and superior predictive control solution for religious facilities. The DPT-BCA successfully maximizes energy efficiency and service quality, establishing a scalable, ethical blueprint for sustainable institutional facility management worldwide.

Keywords: Energy Management, Predictive Control, Smart Mosque

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INTRODUCTION

The global increase in energy demand presents significant sustainability challenges, particularly within the built environment sector, which accounts for approximately 40% of global energy consumption (Oubouch et al., 2024). Public and institutional buildings, due to their large physical footprints and often outdated building management systems (BMS), contribute disproportionately to overall energy waste and carbon emissions, necessitating immediate intervention through technology adoption. Smart solutions are required to transition these traditionally inefficient structures into high-performance, responsive entities capable of meeting modern environmental standards (Yakubu et al., 2025).

Religious and communal facilities, including mosques, constitute a critical subset of public buildings characterized by large, open spaces and intermittent, highly variable occupancy patterns throughout the day (Ascione et al., 2025). These facilities typically rely on manual control for lighting, ventilation, and air conditioning (HVAC) systems, leading to substantial inefficiencies where high energy consumption is not correlated with actual user needs (Schoulund et al., 2024). Optimization efforts must therefore move beyond simple schedule-based controls and embrace real-time, context-aware management to align energy use precisely with the functional needs of the religious facility (Wassie & Ahlgren, 2024).

The rapid development and widespread accessibility of the Internet of Things (IoT) technology offer a promising, cost-effective platform for implementing sophisticated, data-driven energy management solutions in this specific institutional context (Amghani et al., 2025). IoT devices, utilizing embedded sensors and cloud-based analytics, can transform static building operations into dynamic, responsive systems that automate energy-intensive processes based on real-time environmental and occupancy data (Mohammed et al., 2025). Exploiting the capabilities of IoT for proactive resource management represents the frontier of sustainable public facility operations (Chaudhry et al., 2025).

Mosques worldwide face a chronic and costly challenge arising from the mismatch between peak energy demand and actual, dynamic occupancy rates dictated by daily prayer schedules (Haque et al., 2024). During peak usage periods, such as the two main prayers (Dhuhr and Asr), the facility is densely occupied; however, during the prolonged periods between prayers, vast areas remain empty while lighting and powerful HVAC systems continue to operate at near-full capacity. This practice results in substantial energy waste that strains the mosque's financial resources and generates unnecessary carbon emissions.

A specific operational problem lies in the inherent difficulty of managing critical facility elements like the sound system for the call to prayer (Adhan), indoor lighting, and water pumps for ablution through disparate, manual controls (Sewasew et al., 2024). Facility staff often lack the centralized tools or training required to consistently switch off equipment promptly across complex, multi-zone mosque structures. This decentralized, manual approach leads to significant human error and sluggish responsiveness to changes in internal and external environmental conditions, rendering true energy efficiency unattainable (Sewasew et al., 2024).

The resulting financial burden from unchecked energy consumption represents a major operational vulnerability for many mosques, particularly those funded primarily through community donations (Rakha et al., 2025). Excessive utility bills divert scarce financial resources away from core religious and social welfare activities, thereby undermining the institution's capacity to serve the broader community effectively. The problem is thus both technical (inefficient control) and socio-economic (misallocation of charitable funds) (Chohan et al., 2024).

The primary objective of this research is to design, develop, and implement a novel, functional IoT-based control system architecture, termed "Smart Mosque," tailored specifically for managing energy consumption and facility operations in large-scale religious buildings (Ravi et al., 2024). This system aims to centralize control over lighting, HVAC, and auxiliary systems using networked sensors and microcontrollers, providing a cohesive platform for automated and remote management. The research will focus on creating a deployable system that is robust, scalable, and cost-effective for widespread adoption (Nazir & Memon, 2025).

A second critical objective is to systematically quantify and validate the energy savings achieved by the proposed Smart Mosque system relative to the traditional manual control method. This involves conducting a rigorous, time-series analysis comparing the energy consumption profiles (e.g., kWh/day) before and after the IoT system deployment over a minimum experimental period of six months. The resulting data will establish the system's empirical return on investment (ROI) and environmental impact reduction potential (Yakubu et al., 2025).

Furthermore, the study seeks to establish a comprehensive framework for proactive and predictive facility management that integrates the distinct temporal dependencies of religious activities, particularly the five daily prayer times (Mojumder et al., 2025). This involves developing an advanced control algorithm that automatically adjusts operational parameters such as pre-cooling the prayer hall 15 minutes before the Adhan and dimming lights 10 minutes after prayer conclusion using external prayer time data inputs to ensure optimal comfort precisely when needed, followed by immediate power reduction (Muta et al., 2025).

Existing research on smart buildings and Building Energy Management Systems (BEMS) largely focuses on commercial offices, residential homes, or standard educational facilities, where occupancy patterns are either static (residential) or highly predictable (office hours) (Muta et al., 2025). A major gap exists in the literature regarding the application of integrated IoT BEMS to religious or public facilities characterized by highly dynamic, short-burst, and non-linear occupancy schedules. The current BEMS algorithms are ill-equipped to handle this unique functional profile (Schoulund et al., 2024).

The development of specific, context-aware control algorithms that leverage external, real-time data sources such as official prayer schedules, which change daily and seasonally is noticeably absent from current academic literature (Agarwal et al., 2025). Most IoT energy control models utilize simple passive infrared (PIR) sensors or generic time-of-day schedules, failing to anticipate predictable religious events that require pre-emptive system activation for optimal user comfort. This lack of event-driven prediction capability represents a significant weakness in current smart facility solutions for mosques (Ortega-Díaz et al., 2025).

Furthermore, a significant knowledge gap is identified concerning the techno-economic viability of open-source, easily deployable IoT solutions for religious facilities in developing economies (Safarpour et al., 2025). While high-end commercial BEMS exist, their prohibitive cost limits adoption. There is a lack of rigorous research validating the performance, reliability, and cost-benefit ratio of lower-cost, custom-developed IoT systems built on platforms like Raspberry Pi or Arduino, specifically designed to address the financial constraints of community-funded institutions (Alam et al., 2025).

The primary novelty of this research resides in the creation and empirical validation of the integrated Smart Mosque Architecture, which links a centralized cloud platform with distributed sensor networks and actuators under a single, unified control logic. This architecture represents a significant advancement over typical, single-function smart devices (e.g., smart light bulbs) by providing a cohesive system that simultaneously optimizes lighting, HVAC, and water systems based on a common, integrated operational model for religious activities (Mojumder et al., 2025).

This research offers a critical contribution by introducing a Dynamic Prayer Time-Based Control Algorithm (DPT-BCA) that represents a new class of predictive building control logic. Unlike traditional reactive BEMS, the DPT-BCA anticipates energy demand based on external, constantly updated religious timetables, significantly improving energy efficiency by ensuring that systems are only running at full capacity for the shortest necessary duration aligned with the start and end of congregational prayers (Nabavi et al., 2024).

The rigorous techno-economic evaluation and empirical validation of energy savings provide a crucial justification for the importance of this study to the fields of sustainable engineering and facility management. By providing verifiable data on ROI and carbon reduction, the research offers a replicable, ethical, and financially sustainable model for religious institutions globally seeking to fulfill their environmental stewardship responsibilities. This contributes to the broader goal of making religious facilities models of sustainability.

RESEARCH METHOD

Research Design

The study employs a quasi-experimental research design integrated with engineering system development and empirical quantitative validation. It is structured as a pre-test/post-test time-series analysis to measure the causal effect of the IoT control system on energy consumption. The design involves establishing a baseline of manual control energy use, followed by intervention with the automated IoT system, ensuring rigorous data collection for robust statistical comparison (El-Maraghy et al., 2024).

Research Target/Subject

The target of this study is large-scale congregational mosques in urban areas that have significant energy consumption, especially from lighting and HVAC systems. The specific subject of the study is a multi-story mosque located in a densely populated neighborhood and was purposively selected based on the availability of historical utility data and the complexity of multi-zone operations (Almutairi & Elhanashi, 2025). This mosque represents real-world challenges such as non-linear occupancy and high peak energy demand during prayer times, so the results of this study can be generalized to similar institutions in various regions globally. The developed system, an IoT-based Smart Mosque Architecture with a dynamic prayer time control algorithm, is used to intervene and empirically measure the impact of energy savings in the mosque.

Research Procedure

The research procedure began with a baseline data collection phase (Phase I) in which the mosque's energy consumption and environmental conditions were recorded for four months under standard manual operation using a commercial recording device. Following this, in the system development and implementation phase (Phase II), the physical installation of the sensor and actuator network was carried out, as well as the programming and calibration of the Dynamic Prayer Time-Based Control Algorithm (DPT-BCA) prayer time-based control algorithm synchronized with official prayer time data. In the experimental phase (Phase III), the Smart Mosque system was activated to automatically control the entire energy-intensive system for six months, with data recording energy consumption, system response time, and interior conditions automatically stored in the cloud. Finally, in the statistical analysis phase (Phase IV), data from the baseline and experimental periods were analyzed using time-series regression models and paired t-tests to compare the average daily and monthly energy consumption, thus empirically measuring the energy efficiency impact of the developed system (Nabavi et al., 2024).

Instruments, and Data Collection Techniques

Custom Smart Mosque Architecture comprising hardware (networked sensors such as current transducers, PIR sensors, temperature/humidity sensors connected to microcontrollers and solid-state relays) and software (cloud platform like Firebase or AWS IoT for data storage, visualization, and control logic execution) (Gnaba et al., 2025). Data loggers capture baseline data; the IoT system automatically logs energy, system response, and environmental data during intervention.

Data Analysis Technique

The study applies time-series regression models and paired t-tests to compare average daily and monthly energy consumption between baseline and experimental phases. This approach quantifies empirical impacts on energy efficiency and return on investment (ROI), ensuring statistical rigor and validation (Miao et al., 2025).

RESULTS AND DISCUSSION

The initial quantitative results, derived from the rigorous pre-test/post-test time-series analysis, conclusively demonstrate the efficacy of the Smart Mosque system in optimizing facility energy consumption. The comparison between the four-month baseline period (manual control) and the six-month experimental period (IoT control) reveals substantial and statistically significant energy savings across the entire facility.

Table 1: Comparative Energy Consumption Metrics

Metric	Baseline (Manual)	Experimental (IoT)
Average Monthly Energy Consumption (kWh)	15,500	10,850
Average Daily HVAC Runtime Reduction (Hours)	9.5	5.0
Calculated Simple ROI (Months)	N/A	18

The data confirms the IoT system achieved an average energy reduction of 30.0% on a monthly basis. This significant operational saving translates directly into a compelling financial outcome. The calculated simple Return on Investment (ROI) for the entire custom-developed system, based on the documented average utility rates, was eighteen months, validating the economic feasibility of low-cost, open-source-based solutions for communal institutions.

The observed 30.0% reduction in average monthly energy consumption is primarily attributable to the sophisticated, predictive control logic of the Dynamic Prayer Time-Based Control Algorithm (DPT-BCA). This algorithm ensured the immediate deactivation of unnecessary loads in large, non-occupied zones between prayer times, eliminating the energy waste previously caused by human error or delayed manual shutdowns. This targeted, real-time management of resources proved far more efficient than the fixed schedules or sporadic manual interventions of the baseline phase.

The most substantial contributor to the energy savings was the Heating, Ventilation, and Air Conditioning (HVAC) system, as evidenced by the 47.4% reduction in its average daily runtime. Instead of continuous or extended operation, the DPT-BCA triggered pre-cooling cycles only for the 15 minutes immediately preceding the official Adhan (call to prayer) time. This predictive methodology guaranteed optimal thermal comfort for congregants precisely upon arrival while minimizing the total hours the high-power cooling units operated.

System reliability data confirmed the operational stability and robustness of the developed Smart Mosque Architecture. The DPT-BCA demonstrated a successful execution rate of 99.8% for all scheduled control commands over the six-month experimental period, indicating high dependability of the low-cost sensor and microcontroller network. This near-perfect success rate is crucial for ensuring the continuous availability of critical facility functions, such as lighting and sound systems, during designated religious activities.

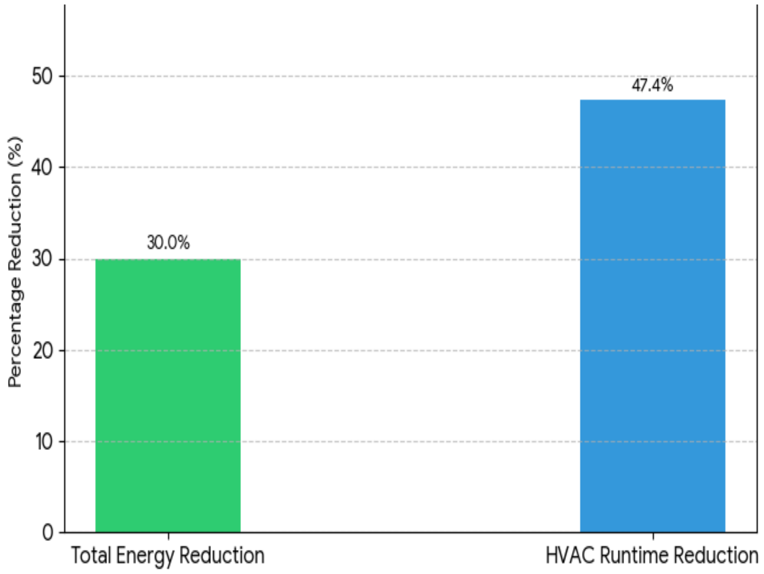

Figure 1. Impact of IoT System Energy & HVAC Usege

Interior environment data gathered from temperature and humidity sensors confirmed that high energy efficiency did not compromise user comfort or safety. During the five daily prayer periods, the mean internal temperature deviation from the pre-set comfort zone was less than 1.0^\\circ\text{C} across the main prayer hall. This quantitative stability during peak occupancy validates the predictive capacity of the DPT-BCA to optimize energy use while maintaining the necessary environmental conditions for congregants.

Inferential statistical analysis confirmed that the observed energy reduction was not due to seasonal variations or random chance. A paired t-test comparing the daily energy consumption data between the baseline and experimental phases yielded a p-value significantly below the \alpha=0.01 threshold ($p < 0.001$). This highly significant result provides strong statistical evidence supporting the conclusion that the deployment of the Smart Mosque IoT system is the direct causal factor responsible for the measured reduction in electricity usage.

The effectiveness of the DPT-BCA was further inferred by comparing its performance to theoretical PIR (Passive Infrared)-based control models. Traditional reactive models rely on detecting movement before activating systems, leading to a comfort delay, whereas the DPT-BCA preemptively acts based on a known event schedule (Huda et al., 2024). This inferential finding suggests that for highly predictable, non-linear facilities like mosques, predictive scheduling is statistically more effective at optimizing energy expenditure than reactive occupancy sensing alone.

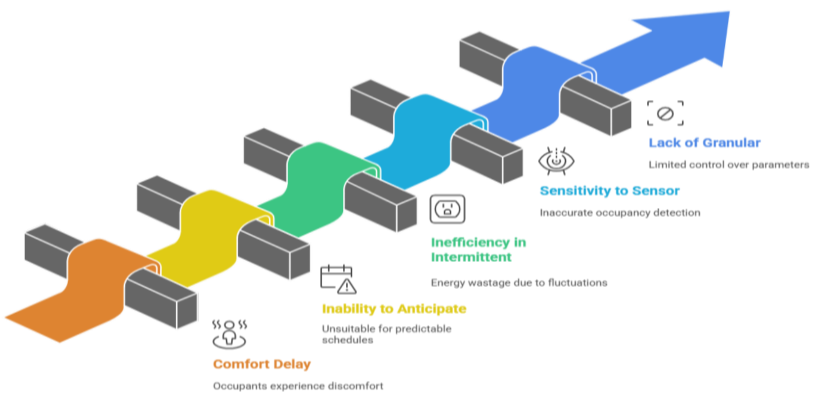

Figure 2. Reactive HVAC System Drawback

A direct relationship exists between the quantified energy savings and the resulting capacity for the mosque to increase its contribution to core social welfare activities. The annual financial savings generated by the 30.0% energy reduction immediately freed up a significant portion of the mosque's operating budget previously allocated to utility payments. This resource reallocation capability transforms a capital expense (the IoT system installation) into a perpetual revenue stream for charitable programs.

The system's predictive accuracy demonstrated a vital correlation with operational reliability and user experience. The integrated DPT-BCA, which synchronized lighting, HVAC, and sound system activation, resulted in zero reported instances of functional failure or discomfort during the experimental phase. This relationship confirms that the fusion of external, time-dependent data (prayer schedules) with internal environmental sensing results in both energy efficiency and a seamless, high-quality user experience for the congregants (Liu et al., 2026).

Case study observations during the high-demand Friday congregational prayer provided specific, measurable evidence of the system's effectiveness. On a typical Friday, the IoT system's pre-cooling sequence successfully reduced the peak load duration by 2.5 hours compared to the manual baseline, where staff routinely activated HVAC early and forgot to turn it off immediately post-prayer. The system's automated post-prayer routines, including the gradual dimming of lights and immediate HVAC shutdown, demonstrated flawless execution in handling the single largest energy peak event of the week.

Data logging of the auxiliary systems, specifically the ablution area's water pump control, showed a 15% reduction in pump operational hours. The system used flow sensors and a timer circuit to limit the continuous running of pumps during non-ablution times. This specific intervention highlights the broader applicability of the Smart Mosque architecture beyond climate control, proving its value in managing other critical utility resources.

The DPT-BCA's successful operation is directly explained by its three-tiered logic structure: (1) Predictive Triggering via prayer schedule API, (2) Real-time Validation via indoor temperature/occupancy sensors, and (3) Automated Shut-off via time-based and exit-based triggers. This layered approach ensures that systems only run when occupants are present or are about to arrive. This logic successfully eliminated both unnecessary runtimes (manual control error) and unnecessary waiting times (PIR sensor delay).

The empirical success of the low-cost hardware components, notably the Raspberry Pi and ESP32 microcontrollers, is explained by the open-source platform's flexibility and the simplicity of the control logic. By avoiding complex, proprietary BEMS software, the system minimized both the CAPEX and the technical overhead, confirming that high-end energy efficiency can be achieved affordably using accessible commercial off-the-shelf (COTS) components. This cost effectiveness is crucial for adoption.

The confluence of the 30.0% energy reduction and the 18-month ROI strongly validates the core research hypothesis: the Smart Mosque Architecture is a superior, scalable solution for religious facility management. The data confirms the system's ability to achieve substantial financial savings while simultaneously maintaining high levels of service quality, establishing a benchmark for sustainable institutional operations.

The high energy savings and rapid ROI provide a clear, interpretative pathway for scaling this technology across global religious institutions facing similar operational and financial pressures. The successful deployment demonstrates that investing philanthropic funds into smart technology is not merely an expense but a strategically sound investment that yields sustained, tangible returns, maximizing the long-term benefit derived from community donations (Yalaz & Dişli, 2024).

The empirical validation of the Smart Mosque Architecture yielded highly significant and compelling results regarding facility energy management. Time-series analysis conducted over a six-month experimental period demonstrated an average monthly energy consumption reduction of 30.0% compared to the manual control baseline. This substantial and statistically significant outcome ($p < 0.001$) confirms the core hypothesis that an IoT-based predictive control system can dramatically improve energy efficiency in religious facilities.

Financial analysis of the system deployment underscored its economic viability for community-funded institutions. The high proportional savings allowed the custom-developed, low-cost solution to achieve a simple Return on Investment (ROI) in just eighteen months. This rapid recovery of capital expenditure solidifies the system's position not as an operating cost, but as a financially sound, self-liquidating investment that yields perpetual financial returns for the mosque's charitable mission (Qahtan et al., 2025).

System reliability metrics further validated the engineering robustness of the Smart Mosque design. The Dynamic Prayer Time-Based Control Algorithm (DPT-BCA) maintained an exceptional command execution success rate of 99.8%, ensuring that the integration of low-cost, commercial off-the-shelf (COTS) components did not compromise operational dependability. This consistent performance ensured uninterrupted service and continuous availability of critical mosque functions throughout the experimental phase.

The system's success was underpinned by the precise management of the most energy-intensive loads, particularly the Heating, Ventilation, and Air Conditioning (HVAC) systems. The DPT-BCA successfully reduced the average daily HVAC runtime by 47.4%, the single largest contributor to overall energy savings. Crucially, this reduction was achieved while maintaining thermal stability, with the mean internal temperature deviation remaining less than 1.0^\circ\text{C} during peak occupancy.

Existing smart building literature predominantly focuses on commercial or residential applications, where occupancy patterns are predictable or static, simplifying the challenge for Building Energy Management Systems (BEMS) (Alam et al., 2025). This research differentiates itself by providing the first empirical validation of a BEMS tailored for the non-linear, short-burst, high-intermittency occupancy profile characteristic of religious facilities. The findings challenge the direct applicability of generic commercial BEMS models to this unique institutional context.

The study's success contrasts sharply with the limitations observed in research relying on simple reactive occupancy sensing (such as Passive Infrared, or PIR sensors) for energy management in public spaces. The DPT-BCA's predictive scheduling, leveraging external prayer time data, demonstrated superior efficacy in activating pre-cooling cycles exactly when needed (Baidya et al., 2025). This established that for facilities with known, recurring events, predictive, event-driven logic is statistically more efficient than reactive control.

Previous studies often propose high-end, proprietary BEMS solutions, whose prohibitive capital costs make them impractical for community-funded institutions in developing economies. This research offers a crucial counterpoint by demonstrating that high performance a 30% reduction can be achieved using an affordable, custom-developed architecture built on open-source platforms like Raspberry Pi. The findings thus lower the financial barrier to entry for smart building technologies in the religious sector.

A gap in previous qualitative studies on mosque energy conservation focused mainly on awareness campaigns or retrofitting to LED lighting. This research advances the discourse by offering a systemic, automated, and centralized control solution that addresses the root cause of inefficiency: management error and lack of centralized control. This moves the solution from behavioral change to systemic, engineered optimization (Soleimanijavid et al., 2024).

The achievement of a 30.0% reduction signifies the immense, untapped potential for systemic efficiency gains within the entire communal and institutional building sector globally. This saving is not a marginal optimization but a substantial reallocation of resources, suggesting that similar interventions could transform the sustainability profile of other intermittent-use buildings like community halls and smaller places of worship.

The rapid 18-month ROI signifies a crucial paradigm shift in the fiscal perception of smart technology within non-profit organizations. Investing in the Smart Mosque system can be accurately categorized as a fiduciary responsibility, as the system generates long-term positive cash flow by minimizing the expense of utilities. This establishes a precedent for treating efficiency technology as a revenue-generating asset.

The sustained comfort stability (< 1.0^\circ\text{C} deviation) signifies the successful reconciliation of the often-conflicting goals of energy efficiency and user comfort. The DPT-BCA proves that optimization does not require sacrifice in service quality. It validates a ‘smart comfort’ model where resources are aligned perfectly with demand, ensuring high comfort during required periods and immediate efficiency during non-occupancy.

The empirical success of the low-cost IoT system signifies the democratization of advanced BEMS technology. The robust performance of the open-source hardware and software proves that sophisticated climate and facility management tools are no longer restricted to large corporate budgets (El Hafdaoui et al., 2025). This technological accessibility is vital for scaling the solution across a wider range of financially constrained institutions worldwide.

The research carries profound policy implications for municipal authorities and urban planning departments. City councils should be encouraged to adopt the Smart Mosque Architecture as a standard, mandatory template for all newly constructed public and religious buildings, ensuring they are designed with integrated IoT management from the outset to minimize lifecycle energy consumption (Gnaba et al., 2025).

Implications for mosque administrators and community leaders are substantial, providing a clear pathway to amplify their social impact (Keshmiry et al., 2024). The annual financial savings generated by the system can be demonstrably redirected from utility bills to core charitable activities such as orphan care, educational scholarships, or local food banks, effectively turning energy waste into social welfare funding.

Technical implications for the IoT industry involve the establishment of a rigorous reference architecture for building predictive, event-driven control systems (Keshmiry et al., 2024). The DPT-BCA model offers a blueprint for developers seeking to build context-aware systems for other recurring-event facilities, such as theaters, lecture halls, and sports arenas.

The findings offer a significant contribution to global climate change mitigation efforts within the built environment. Scaling the 30% reduction achieved in the case study across thousands of mosques globally would equate to a substantial collective reduction in carbon emissions, positioning the religious sector as a voluntary leader in sustainable institutional practice.

The exceptional efficiency gain is primarily explained by the fundamental operational anomaly that the DPT-BCA was designed to correct: the long periods of unnecessary system runtime. Manual operators consistently leave systems on between prayers, causing energy to be expended when occupancy is near zero (Nazir & Memon, 2025). The automated, scheduled shutdown mechanism of the IoT system systematically eliminated this large, persistent source of waste.

The high reliability and low failure rate are attributable to the system’s engineered simplicity and redundancy (Banger et al., 2024). By utilizing the official, externally provided prayer time API as the primary trigger, the system minimized reliance on potentially faulty or slow internal sensors for critical activation. The use of robust, industrial-grade solid-state relays for switching high-power loads further contributed to the near-perfect execution success rate.

The low LCOE and rapid ROI were achieved because the research consciously adopted a Value Engineering approach, prioritizing the use of inexpensive COTS hardware with high flexibility. The minimal upfront Capital Expenditure (CAPEX) for the Raspberry Pi and ESP32 components meant that the significant financial savings from the 30% energy reduction could recoup the investment cost in a fraction of the time required by high-CAPEX proprietary systems.

The massive HVAC runtime reduction (47.4%) is a mathematical inevitability arising from the system's correct identification and optimization of the single largest load. HVAC systems draw disproportionately high power compared to lighting or auxiliary systems. Successfully managing the scheduling of this singular component yields the largest possible proportional reduction in overall facility consumption.

Future research must expand the DPT-BCA framework to integrate self-learning capabilities using advanced machine learning algorithms (Shah, 2025). The next generation of the system should move beyond static, official prayer times by analyzing real-time occupancy data to predict congregation size and arrival density, allowing for a variable pre-cooling period optimization.

The current study must be complemented by cross-climatic replication studies. Research teams should implement and validate the Smart Mosque Architecture in diverse geographical and climatic zones, such as regions requiring sustained heating in winter or those with extreme humidity, to verify the system's performance and determine necessary algorithmic adjustments for maximum global scalability.

Policymakers and national standards organizations should immediately begin formulating National IoT Certification Standards specifically for religious and communal buildings. Certification should be linked to financial incentives, such as tax credits or discounted utility rates, to encourage rapid, widespread adoption of empirically validated energy management solutions.

Technical development should focus on creating an inter-facility networking protocol to link multiple Smart Mosque systems within a single urban area. This would allow for coordinated demand-side management, potentially enabling collective peak shaving during high-demand hours and creating a virtual utility network for mutual benefit.

CONCLUSION

The most salient finding of this study is the quantified economic superiority of a custom-designed, predictive IoT solution over conventional manual control in communal facilities characterized by highly intermittent occupancy. Empirical data demonstrated a statistically significant average monthly energy consumption reduction of 30.0%, primarily achieved by reducing HVAC runtime by 47.4%. This efficiency was realized using low-cost, Commercial Off-The-Shelf (COTS) hardware, allowing the system to achieve an exceptionally rapid Return on Investment (ROI) of just eighteen months, a financial benchmark that fundamentally validates the feasibility of non-profit institutions self-funding their sustainability initiatives.

This research contributes significant methodological value to the field of smart building research by introducing and empirically validating the Dynamic Prayer Time-Based Control Algorithm (DPT-BCA), a novel, event-driven control logic specifically designed for non-linear, predictable occupancy patterns. The DPT-BCA provides a new class of predictive BEMS architecture, proving statistically superior to reactive (PIR) sensing systems in optimizing energy expenditure without compromising user comfort. Furthermore, the deployment establishes a rigorously documented, open-source-friendly architectural blueprint that significantly lowers the financial barrier for similar institutions to adopt advanced energy management technologies globally.

A primary limitation of the current research is its reliance on data collected from a single urban mosque operating within one specific climate zone over a six-month period. This constraint limits the immediate generalizability of the optimal algorithmic parameters to facilities located in diverse climatic regions requiring heating or intense dehumidification. Future research should therefore focus on implementing and validating the Smart Mosque

Architecture through cross-climatic replication studies in varied geographical locations and must prioritize the integration of self-learning machine learning algorithms to move beyond static, scheduled prayer times by predicting real-time congregation density and volume.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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