



PREDICTIVE MAINTENANCE AND ITS ROLE IN ENERGY EFFICIENCY IN THE HOSPITALITY INDUSTRY

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Abstract

Energy efficiency has emerged as a critical priority in the hospitality industry, driven by the need for sustainable operations and long-term cost optimization. Predictive Maintenance (PdM), an innovative strategy that integrates advanced analytics, machine learning, and real-time monitoring, offers a proactive approach to equipment management. Despite its potential, many hospitality establishments remain reliant on reactive maintenance models, resulting in frequent equipment failures, excessive energy consumption, and shortened asset lifespans. This study examines the application of PdM in enhancing energy efficiency across hospitality facilities and seeks to establish a framework for anticipating equipment failure, reducing operational disruptions, and promoting sustainable resource use. Using a desk research approach, the study draws insights from a comprehensive review of contemporary literature on smart sensor technologies, machine learning applications, and energy-efficient practices in facility management in Nigeria. The findings underscore PdM's capacity to extend equipment lifespan, curtail energy waste, and reduce operating costs. However, barriers such as high implementation expenses, insufficient technical expertise, and algorithmic biases continue to impede widespread adoption. Small- and medium-sized enterprises (SMEs), in particular, face significant challenges due to limited financial and human capital, often defaulting to reactive or minimal preventive maintenance approaches. To overcome these constraints, the study advocates for a strategic blend of ethical AI deployment and workforce upskilling. By addressing structural and skill-related gaps, the hospitality sector can unlock the full potential of predictive maintenance, positioning it as a transformative pathway toward greater operational resilience, energy efficiency, and sustainable growth.

Keywords: Predictive maintenance (L23), Energy efficiency (Q41:Q48), Equipment reliability (L60:L23), Machine learning (C63:C45: O33), Smart sensors (O33:L63), Assets performance (O33:L63), Sustainability.

INTRODUCTION

Energy efficiency has become a central concern in global sustainability discourse, especially as nations confront the dual challenges of rising energy demand and the ongoing global energy crisis. As highlighted by Gajdzik et al. (2024), the energy crisis has exposed systemic weaknesses in global energy systems, prompting a shift toward efficiency as a critical strategy for ensuring energy security and economic resilience. Their analysis reveals that energy efficiency is not only a cost-saving measure but also a necessary adaptation to safeguard industrial and societal stability in times of energy volatility. Similarly, Popkova and Sergi (2021) underscore the importance of energy efficiency as a common priority for both developed and emerging economies. Their

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findings indicate that countries that proactively invest in energy-efficient technologies and policies are better positioned to achieve sustainable development, reduce emissions, and enhance long-term competitiveness. These perspectives collectively reinforce the notion that energy efficiency is not just an environmental necessity but a strategic lever for global stability and growth.

Hamdan et al. (2024) review the role of AI in renewable energy, emphasizing its effectiveness in predictive maintenance and energy optimization across large-scale systems like wind and solar power. However, the study does not address how these AI applications translate to the hotel sector, where energy loads are building-specific and operational contexts differ significantly. Key gaps include the lack of focus on hotel-specific systems (e.g., HVAC and lighting), integration challenges with existing hotel technologies, high implementation costs for SMEs, and the need for staff training. These limitations highlight the necessity for sector-specific research to adapt AI-driven predictive maintenance for meaningful energy reduction in hospitality environments

This study responds to how predictive maintenance can be effectively deployed in hotel environments which explores the impact of PdM on reducing downtime, enhancing productivity, and minimizing environmental footprints, offering insights into how the hospitality industry can become more resilient, efficient, and sustainable through technology-driven strategies. Hotels face mounting challenges related to energy inefficiency, equipment breakdowns, and rising operational costs. Conventional maintenance approaches particularly reactive and time-based strategies are proving inadequate in today's energy-conscious world. These outdated methods often lead to unplanned downtime, excessive energy use, shortened equipment lifespan, and inflated maintenance costs (Lu et al., 2009). In many cases, hotels end up performing unnecessary maintenance or responding too late to system failures, both of which result in wasted resources and guest dissatisfaction.

The emergence of predictive maintenance technologies offers a promising alternative. By using AI and machine learning algorithms to predict when maintenance is actually needed, hotels can shift from a reactive to a proactive maintenance culture. Studies by Hamdan et al. (2024) and Cruz and Garcia (2024) demonstrate how such approaches enhance energy efficiency, reduce unnecessary interventions, and contribute to smarter resource use. However, in the hospitality industry, the adoption of PdM remains limited, and there is a lack of practical frameworks guiding its implementation in hotel operations. Without addressing this gap, hotels risk continued inefficiencies, higher emissions, and missed opportunities to align with sustainability goals.

The aim of this study is to evaluate the role of predictive maintenance in enhancing energy efficiency within hotel operations providing a comprehensive synthesis of the existing literatures, industry reports, and practical case studies by identifying early equipment failure risks, minimizing downtime, and developing a practical framework to extend equipment lifespan, improve productivity, and support sustainable practices. The specific objectives of the study centers around Predictive maintenance role in Energy efficiency in Hospitality Industry in Nigeria and how this technology can be leveraged to improve operational efficiency, reduce costs, and enhance guest experiences. To identify and address how predictive maintenance reduce equipment failures before they occur and what framework can be developed to extend the lifespan of hotel equipment while enhancing energy efficiency and overall productivity.

LITERATURE REVIEW

Predictive Maintenance

Predictive maintenance (PdM) has been widely studied within the framework of Industry 4.0, primarily focusing on industrial and manufacturing contexts, but with limited application to the hospitality industry. Zonta et al. (2020) conducted a systematic literature review, emphasizing the integration of machine learning, IoT, and big data analytics in enabling early fault detection and optimized maintenance. However, the review does not extend its analysis to service-based industries such as hospitality, where energy consumption dynamics and maintenance requirements differ significantly. Similarly, Achouch et al. (2022) provided a comprehensive overview of predictive models and real-time analytics for PdM, but their discussion remains confined to industrial use cases. The unique operational patterns and infrastructural limitations of hotels especially small and medium-sized enterprises are not addressed, thereby leaving a contextual gap.

Nunes et al. (2023) reviewed practical implementation challenges of PdM, such as data sparsity, system heterogeneity, and the difficulty of generalizing models across environments. While these concerns are highly relevant to hotels, where multiple energy-dependent systems (like HVAC, lighting, and kitchen equipment) operate independently, the hospitality context is notably absent from their review. Ucar et al. (2024) discussed trustworthiness in AI-based PdM, stressing the importance of algorithmic transparency, reliability, and human-AI interaction. These issues are particularly important in hotels, where facility managers and non-technical personnel must interpret AI-generated maintenance recommendations. Yet, their review does not offer strategies for implementing trust-enhancing mechanisms in service environments with limited digital infrastructure.

Babayaju et al. (2024) explored PdM for aging infrastructure in the oil and gas sector, showing how AI and IoT extend equipment lifespan and reduce system failure. Although this study confirms the effectiveness of PdM in asset-intensive sectors, its relevance to hospitality remains unexplored, especially in relation to energy-intensive hotel systems. Collectively, these studies reveal significant empirical gaps, as none provide evidence or case studies from the hospitality sector. Methodologically, there is a lack of models adapted to service environments where human interaction, guest comfort, and operational continuity are critical. Additionally, few studies incorporate real-world hospitality datasets, and most neglect the role of workforce skills and management systems in successful PdM adoption.

Theoretically, there is limited articulation of how PdM contributes to energy efficiency within service industries or how existing Industry 4.0 frameworks can be adapted to hospitality contexts. The concept of AI trustworthiness, while developed for industrial applications, lacks theoretical grounding in service-sector literature, particularly for small hotels with limited technical expertise. These gaps highlight the need for hospitality-specific research that empirically validates PdM's effectiveness, develops contextualized methodologies, and advances theory at the intersection of maintenance, energy management, and service operations.

Energy Efficiency

Energy efficiency remains a cornerstone of sustainable development policies worldwide, with mounting interest in how technological interventions like predictive maintenance (PdM) can optimize energy consumption across sectors. Román-Collado and Economidou (2021) examined

the progress of energy efficiency targets across EU productive sectors and concluded that sector-specific strategies and technological innovations were critical to closing performance gaps. While their study provided macro-level insights into efficiency trends, it did not explore the contribution of PdM as a targeted energy-saving strategy, nor did it address service industries such as hospitality. Economidou et al. (2020), in a review of 50 years of EU policies on building energy performance, emphasized the evolution of regulatory frameworks and retrofit strategies. Although relevant to hospitality facilities, this body of work largely omits operational interventions like PdM that address inefficiencies in real-time energy usage and equipment reliability.

Yang et al. (2020) approached energy efficiency from a technological angle, proposing energy-efficient federated learning techniques for wireless networks. Their focus on computational optimization suggests promising potential for applying distributed AI models in PdM systems to enhance real-time monitoring without overburdening energy systems. However, the study remains anchored in ICT infrastructure and fails to extend its implications to hospitality environments, where predictive analytics must also consider non-technical variables such as guest comfort and service continuity. Boltianska et al. (2020) focused on improving energy efficiency in agricultural production, highlighting measures like equipment modernization and process automation. While these interventions are structurally analogous to hospitality, the absence of empirical models linking PdM with energy performance indicators in hotels reveals a sector-specific research gap.

Collectively, these studies expose a number of gaps in the literature. Empirically, there is limited application of PdM models in the hospitality sector, particularly concerning their role in achieving energy efficiency goals. The service-based nature of hospitality—with its reliance on uninterrupted operations, diverse energy-dependent systems, and user-centered performance metrics—demands empirical validation of PdM strategies tailored to such environments. Theoretically, much of the existing research frames energy efficiency within policy, regulatory, or technological silos, with insufficient integration of predictive maintenance as a unifying operational and strategic tool. Moreover, frameworks for linking PdM to energy performance in buildings are still underdeveloped in hospitality contexts.

Methodologically, most studies rely on large-scale econometric analyses, simulation models, or technical performance reviews without incorporating qualitative or mixed-method approaches that capture organizational behavior, human capital readiness, or management system integration—all critical in hotel operations. There is also a noticeable lack of longitudinal or real-time case studies applying PdM in hospitality settings to monitor energy outcomes. This calls for further research grounded in the operational realities of hospitality management, utilizing industry-specific datasets and human-centered evaluation metrics to bridge this growing knowledge gap.

METHODOLOGY

This study uses desk research and through review of literatures to explore the role of predictive maintenance in improving energy efficiency in hotel buildings. Rather than collecting primary data, the research relies on existing literature, technical reports, and real-world case studies to build a solid understanding of current practices. Relevant sources were drawn from peer-reviewed journals, professional industry publications, and global energy and hospitality organizations. Particular attention was paid to studies published in the past decade to ensure that the findings reflect recent technological advances and operational realities in the hospitality sector.

The literature was carefully selected based on its relevance to predictive maintenance, energy use in hotels, cost management, and sustainability. By analyzing a range of documents—including empirical studies, case reports, and strategic frameworks—this review identifies key trends, challenges, and benefits linked to the use of predictive maintenance systems. Case studies from both high- and low-resource hospitality settings were included to show how predictive maintenance varies depending on location, scale, and access to technology. The review also considers how emerging tools such as (Internet of Things) IoT sensors and AI-based monitoring are influencing energy-saving practices.

FINDINGS AND DISCUSSION

The review shows that predictive maintenance plays a meaningful role in improving energy efficiency in hotels. Instead of waiting for equipment to break down or relying on rigid maintenance schedules, many hotels are now using data to predict when systems need attention. Li et al. (2022) show that when guest behavior is factored into these systems—such as recognizing patterns in lighting or HVAC use—it becomes easier to save energy without affecting guest comfort. Similarly, Gunduz Songur et al. (2023) highlight that hotels using smart technology to monitor energy use in real-time have seen tangible savings, especially when these systems are used to guide timely maintenance. These tools help avoid overuse or inefficient operation of major systems like air conditioning, which can be one of the biggest energy drains in a hotel. Karvounidi et al. (2024) point out that early detection of issues allows hotel managers to fix problems before they escalate, saving both time and money. This kind of proactive approach also helps equipment last longer, which reduces the need for replacements and lowers environmental impact. However, the literature also makes it clear that smaller hotels may struggle to access or afford these technologies. As Gunduz Songur and colleagues note, many properties know the benefits but lack the tools or budget to make the switch. So while predictive maintenance offers real promise, there's still a need for simpler, more affordable systems that work for hotels of all sizes.

Zhao & Kumar (2022), Revealed that AI integration in hotel operations reduces costs by 20% and improves efficiency. Underlines the operational benefits of predictive analytics in hotel management while Johnson & Lee (2021), found out that dynamic pricing increases revenue by 15% on average compared to static pricing and the efficacy of predictive analytics in optimizing pricing strategies. Patel & Nguyen (2021), demonstrated a 25% reduction in energy costs by using predictive analytics for energy management by highlighting sustainability and cost saving aspects of predictive analytics in resource management. Singh et al. (2020), revealed that targeted marketing campaigns based on predictive analytics have a 40% higher conversion rate by emphasizing the use of predictive analytics in creating more effective marketing strategies.

The primary benefit of application of energy-efficient technologies (EET) is a reduction in energy cost. Generally, energy efficiency is usually related to the environment. To support this, Pons pointed out that energy efficiency had a strong relationship with environmental performance. But these are not the only benefits. The application of EET also contributes to an increase in productivity that may lead to lower the production cost. Other research found out that energy intensity was proportional to productivity that 1% rise in productivity may lead to more than 1% increase in energy efficiency. To make an energy efficiency program much more cost-effective, one needs to combine energy efficient technology application with energy management practices. An effective maintenance program will play a very important role in energy management practices

CONCLUSION AND RECOMMENDATIONS

Predictive maintenance represents a transformative approach to improving energy efficiency in industrial systems. By leveraging real-time monitoring, advanced analytics, and machine learning, organizations can optimize equipment performance, reduce energy consumption, and achieve significant cost savings. While challenges such as high implementation costs and the need for skilled personnel persist, the benefits of predictive maintenance far outweigh its drawbacks. The findings underscore the potential of predictive maintenance to drive sustainability and operational excellence across industries. The future of hospitality, shaped by predictive analytics, promises enhanced energy efficiency, improved guest satisfaction, and stronger business performance. As hotels continue to embrace these technologies, they will likely find new and innovative ways to differentiate themselves in the market, offering unique and memorable experiences to their guests.

From a policy perspective, the study highlights the need for guidelines and standards that support the effective implementation of machine learning technologies in manufacturing. Policymakers should consider developing frameworks that facilitate the adoption of predictive maintenance solutions while addressing potential barriers such as data privacy, cybersecurity, and interoperability. Additionally, policies that promote research and development in machine learning and its applications in manufacturing can drive innovation and competitiveness in the industry. Support for educational and training programs to build expertise in machine learning and predictive maintenance is also recommended to ensure that the workforce is equipped to leverage these technologies effectively.

The integration of machine learning algorithms with other advanced technologies, such as IoT and cloud computing, is recommended to maximize the benefits of predictive maintenance. The study suggests that seamless integration of these technologies can enhance data collection, real-time analysis, and overall predictive accuracy. Organizations should consider organizational factors such as change management and stakeholder engagement when implementing machine learning-based predictive maintenance solutions. Effective change management practices, including training and support for employees, can facilitate the successful adoption and integration of predictive maintenance technologies. By addressing organizational challenges, manufacturers can achieve smoother transitions and better outcomes with their predictive maintenance initiatives.

Limitations of Study and Areas of Future Research

While this study sheds light on the benefits of predictive maintenance for energy efficiency in hotels, it is important to keep in mind some limitations. Since this was mainly a desk-based review of existing research and reports, it did not include direct interviews or hands-on data from hotels themselves. Because of that, some real-world challenges—like how different hotels actually implement these systems or deal with unexpected issues—might not be fully reflected here. Also, a lot of the research focuses on bigger hotels or those in more developed countries, so smaller hotels or those in less tech-savvy regions might face different realities that this study could not fully capture.

Looking ahead, there is a lot of value in digging deeper with on-the-ground research. Talking directly to hotel managers, maintenance staff, and tech providers could reveal practical hurdles and successes that do not always show up in academic papers. It would also be helpful to see how predictive maintenance works in smaller hotels or in places with fewer resources, to find solutions

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that are affordable and easy to adopt. Lastly, exploring how newer technologies like AI and smart sensors can be combined to make these systems even smarter could open up exciting possibilities for the future of sustainable hotel operations.

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