

Research Maturity of IOT-Based Energy Efficiency in Hospitality: A PRISMA Systematic Review [†]

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Abstract

Energy consumption in hotels is strongly influenced by HVAC operation, lighting systems, and highly variable occupancy patterns. Internet of Things (IOT) technologies have been widely proposed to improve energy efficiency in building interiors; however, the maturity and practical applicability of this research remain unclear. This study presents a PRISMA-based systematic literature review of IOT-driven energy efficiency research in hospitality environments. A total of 1709 records were initially identified across Web of Science, Scopus, and Google Scholar, from which 60 peer-reviewed articles were selected for detailed analysis. Each study was evaluated using a three-dimensional research maturity assessment framework and a four-level ordinal scoring scale. The results indicated a moderate research maturity (average score 2.65/4), limited real-world implementation, and insufficient reporting of technological architectures and operational details required for replicability. These findings highlight the need for more rigorous empirical validation and clearer reporting standards to enable scalable adoption of IOT-based energy management in hospitality.

Keywords: internet of things; maturity process; smart rooms; building automation; implementation strategies; tourism; occupancy-based

1. Introduction

The hospitality sector is characterized by a high dependence on nonstop, continuous energy consumption, especially in guest rooms, where HVAC and lighting systems must respond to dynamic thermal comfort requirements and highly variable occupancy patterns [1–3].

This concentration of energy demand creates a structural challenge for hotels striving to reduce operational expenditure while simultaneously meeting increasingly stringent global expectations for sustainability and decarbonization goals [4–6].

Among the technological responses emerging in this context, the Internet of Things (IOT) has gained significant attention. IOT enables granular sensing, real-time data analytics, adaptive automation, and machine-driven decision-making. In hospitality settings, smart devices such as occupancy sensors, thermostats, HVAC controllers, light-control modules, and centralized management platforms can improve energy performance while preserving or even enhancing the guest experience [2,3].

However, despite the rapid expansion of IOT-related literature on energy-saving in buildings, significant variability persists in methodological rigor, experimental designs,



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analytical indicators, system architecture, and real-world validation. Much of the existing research relies on small-scale pilots, simulations, or laboratory experiments that do not reflect the complexity of an operational hotel environment [2,4].

This study systematically reviews the scientific literature on IOT-driven energy efficiency in hospitality environments and evaluates the maturity of existing research using a structured assessment framework composed of three analytical dimensions and seven evaluation questions. The objective is to determine the extent to which current studies provide sufficient conceptual, technological, and methodological detail to support real-world implementation and replicability.

Several critical gaps continue to hinder scientific consolidation and do not reflect the complexity of an operational hotel environment, causing several issues:

First, the lack of a standardized set of indicators for evaluating energy efficiency across IOT-enabled hotel interventions limits the comparability of findings. It reduces the potential for cumulative knowledge development [1,7].

Second, evidence from operational hotels remains limited; many studies do not measure actual HVAC loads, occupancy-driven variations, or system stability [7–9].

Third, the role of user behavior, often one of the strongest determinants of energy demand, remains insufficiently studied, particularly in the context of hotels where guests display unpredictable thermal preferences and override tendencies [2,10,11].

Fourth, research on interoperability, cybersecurity, and platform integration is scarce, although these components are essential for real-world deployment [3,11,12].

Finally, despite numerous empirical contributions, no comprehensive maturity assessment of the field exists. Without such an evaluation, it is difficult to determine the extent to which current research is ready for scalable, replicable hotel application and where exactly, in which part of the implementation process, further investigation is needed.

The central research question guiding this review was:

- What measurable impacts and research-maturity levels characterize IOT-driven energy efficiency systems in real-world hotel operations?

The design sought not only to extract findings but also to classify the field along maturity dimensions relevant to real-world deployment.

2. Method

2.1. Research Design

This study follows the PRISMA methodology for systematic literature reviews to ensure transparency and replicability. The review focuses on empirical and analytical studies that examine IOT-driven solutions to improve energy efficiency in hospitality settings, particularly hotel rooms and similar indoor operational spaces. The review process included structured stages of identification, screening, eligibility, and inclusion, following a predefined protocol for article selection and data extraction.

2.2. Search Strategy and Databases

Following PRISMA guidelines, a structured search was conducted in the major academic databases Web of Science, Scopus, and Google Scholar. The search combined keywords related to “Internet of Things”, “Industry 4.0”, “smart systems”, “hospitality”, “hotel rooms”, and “energy efficiency” in both English and Spanish. The search covered publications with available data up to June 2025, and initially identified 1709 records. After screening and applying the inclusion and exclusion criteria, 60 articles were selected for the final analysis (Figure 1).

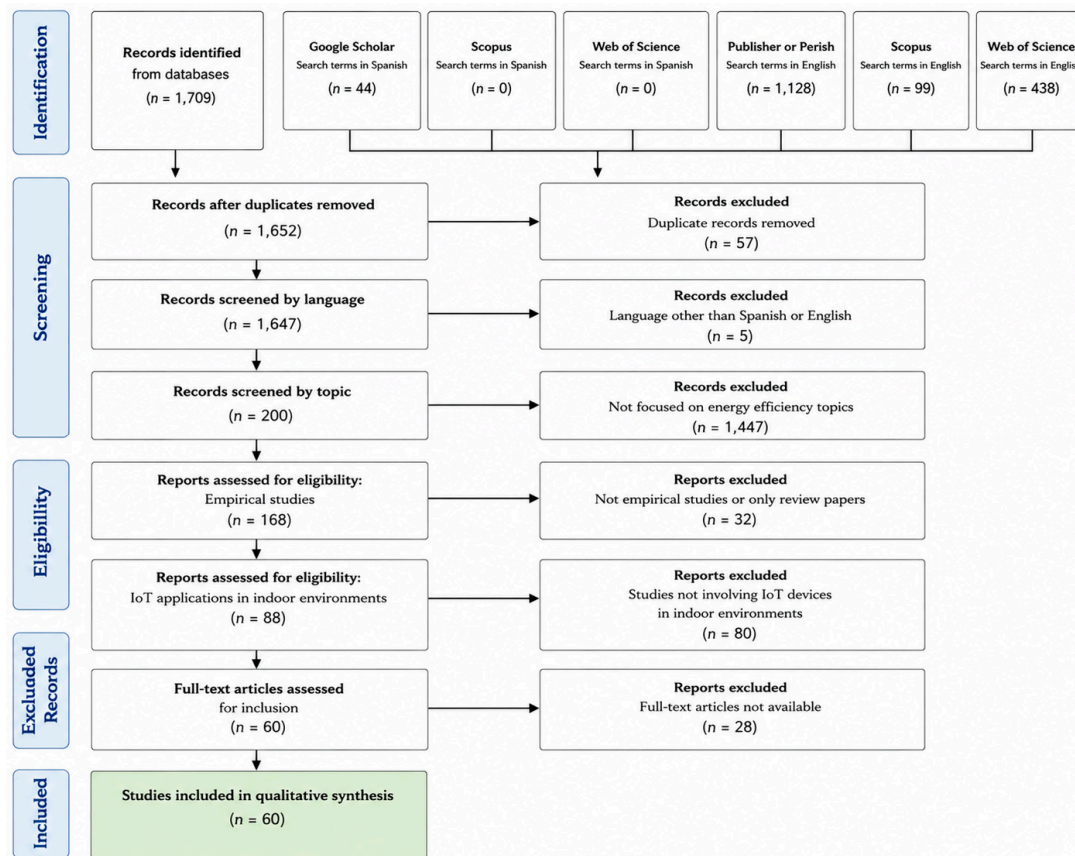


Figure 1. PRISMA guidelines for article selection. Source: Authors' elaboration.

Inclusion criteria were:

- Peer-reviewed and open-access articles.
- Focus on indoor hotel rooms or comparable building spaces.
- Evaluation of IOT or intelligent control systems.
- Quantitative reporting of energy, HVAC-related metrics.
- Evidence-based analysis (experiment, simulation, etc.)

Exclusion criteria were:

- Duplicates or incomplete manuscripts.
- Non-English and non-Spanish languages.
- Articles lacking measurable indicators.
- Outdoor or non-comparable building contexts.

2.3. Research Maturity Assessment Framework

To evaluate the maturity of the research field, each article was assessed using a structured analytical framework composed of three dimensions and seven evaluation-specific questions. The framework evaluates key aspects that underpin the scientific robustness and practical applicability of IOT-based energy-efficiency research in hospitality environments. These dimensions capture conceptual clarity, technological specification, methodological rigor, and operational applicability.

(A) Conceptual Foundations

- Does the article clearly define the concepts of automation, Internet of Things (IOT), Industry 4.0, and energy efficiency?

(B) IOT Technological Components

- Does the article clearly specify the IOT devices used in the study?
- Does the article identify the technological platform used to control or manage the IOT system?
- Does the article describe the algorithms, commands, or smart control scenarios enabling energy efficiency?

(C) Methodology and Experimental Implementation

- Does the article clearly define the energy efficiency indicators used in the study?
- Was the research implemented in a real-world environment rather than only simulated or theoretically described?
- Does the article discuss operational or human limitations and propose directions for future research?

Each study was evaluated on a 1–4 ordinal scale for robustness and applicability. A 60×7 matrix was generated, enabling frequency analysis, depth evaluation, cross-comparison, and maturity profiling.

The scoring criteria were defined as follows:

- 1—Not addressed or only indirectly mentioned.
- 2—Mentioned but insufficiently explained.
- 3—Clearly reported but lacking methodological or operational detail.
- 4—Clearly documented, methodologically detailed, and potentially replicable.

3. Results and Discussion

3.1. Indicators and Methodological Gaps in Literature

The review revealed substantial inconsistencies in how variables and analytical indicators are defined across the literature. Many studies report environmental variables such as temperature, humidity, HVAC operation time, and energy consumption, but do not clearly explain how these variables are translated into analytical indicators for evaluating energy efficiency outcomes.

In many cases, the justification for selecting specific indicators is not sufficiently explained, and their relevance to the reported results remains unclear. Only a small number of variables and indicators appear consistently across the literature. Sensors and control platforms are among the most frequently mentioned technological components, while energy consumption (kWh) and smart control commands are the most common indicators, reported in approximately 65% of the reviewed articles. However, the remaining indicators are used inconsistently, and no clear analytical baseline can be identified. Additionally, several studies describe proposed solutions as “low cost”, but only two articles provide information regarding return on investment (ROI) or implementation costs [2,11].

Humidity also emerges as a critical variable that cannot be neglected, as it directly influences indoor thermal conditions, HVAC operation, and occupant comfort. Nevertheless, humidity is not consistently incorporated in the analytical frameworks of many studies, which tend to focus primarily on temperature measurements. Similarly, operational variables such as system failures or downtime are rarely reported, even though they are essential for evaluating the long-term reliability of smart energy systems [11,13].

Indoor environmental variables such as temperature and humidity play a central role in many of the reviewed studies because they directly influence HVAC operation and indoor comfort conditions [1,9,14,15]. Several studies also report monitoring variables related to system operation, including air-conditioning runtime [3,8], occupancy detected through presence sensors [3,16], and the execution of automated control scenarios designed to regulate HVAC performance [2,11].

These variables are often used as inputs for intelligent control strategies that combine occupancy patterns, environmental conditions, and predefined automation rules to optimize energy use while maintaining acceptable thermal comfort levels for hotel guests [17,18]. In addition to environmental and operational variables, several studies also report energy-related indicators such as electricity consumption (kWh) and, in some cases, estimated carbon emissions associated with HVAC operation [7,8,17]. Other aspects occasionally considered include regional electricity costs, system connectivity reliability, and user satisfaction indicators such as guest feedback or complaint records when smart control systems are implemented [7–9].

3.2. Research Maturity Assessment Results (RMA)

The overall research maturity of the field was moderate, with an average score of 2.65 out of 4 across the studies reviewed. This result indicates that although the literature shows growing interest in IOT-based energy-efficiency solutions for hospitality environments, many studies lack the methodological detail and operational clarity required for real-world replication and large-scale deployment.

The RMA framework reveals that the field remains in an emerging stage and has not yet reached full scientific consolidation. Key weaknesses identified in the reviewed studies include:

- Limited real-world validation;
- Inconsistent use of analytical indicators;
- Insufficient replicability of technological implementations;
- Limited reporting of methodological uncertainty;
- Minimal evaluation of long-term platform stability.

The areas with the greatest scarcity of research, as presented in the RMA figure (Figure 2), are platform architecture, automation instructions that enable interaction between devices and control platforms, and device specification. The vast number of articles mention that it is possible to achieve 20% to 50% energy savings, or they claim the achievement but without explaining which devices, platform, or smart scenarios were used, making it impossible to replicate the research and confirm the values, as the gap between 20% and 50% is relevant.

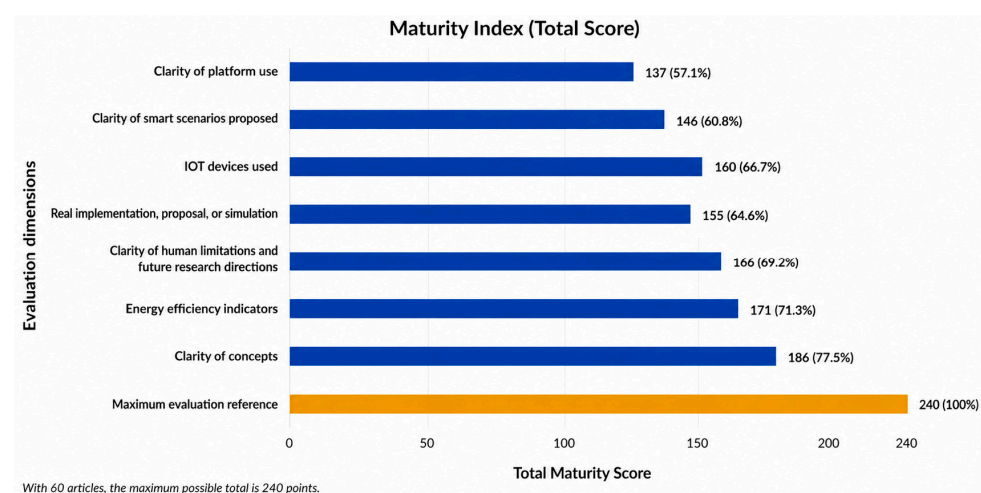


Figure 2. RMA evaluation. Source: Authors' elaboration.

The geographic distribution of publications indicates growing global interest in the topic, with research contributions from all five continents. Countries with strong tourism sectors, such as Spain, China, and Greece, appear frequently among the leading contributors. However, the publication landscape remains highly fragmented, with studies distributed

across multiple journals and publishers, and no single journal currently emerging as a dominant outlet for this research area.

3.3. *Technological Landscape of IOT in Hospitality*

According to the literature, IOT implementations for hotel energy management rely extensively on networks of wireless sensors such as humidity and temperature sensors, motion sensors (PIR, microwave, ultrasonic), HVAC controllers, and lighting-control systems [3,11,13]. These devices enable adaptive thermal control, automatic lighting management, and real-time monitoring of environmental conditions. Centralized platforms that aggregate sensor data, perform rule-based control, and communicate with HVAC units are increasingly common. However, interoperability challenges persist due to heterogeneity in communication protocols, gateway architectures, and vendor ecosystems [2,19]. This fragmentation is one of the most frequently reported barriers to large-scale adoption.

3.4. *Hospitality-Focused Research*

Only 11.66% of the studies included in this review reported field experiments conducted in operational hotels, while the remainder relied on simulations, conceptual proposals, or model-based approaches. Although these methods provide insight into system behavior, they do not capture:

- Unpredictable guest behavior;
- Spatial variability;
- Issues of maintenance and long-term degradation;
- Actual occupancy fluctuations.

The lack of long-term empirical studies is one of the strongest indicators of limited research maturity.

3.5. *Operational Implications for Hotels*

The findings of this review highlight several operational conditions that should be considered before large-scale adoption of IOT-based energy management systems in hospitality environments. The moderate research maturity identified in the literature suggests that many proposed technological solutions have not yet been fully validated in real operational hotel settings.

Real-world adoption requires attention to several key factors, including:

- Understanding guest behavior patterns [10,12].
- Cybersecurity and privacy safeguards [4,6,20].
- Integration with existing BMS/HMS systems and data standardization [1,3,12].

In addition, hotels must ensure adequate readiness conditions, such as appropriate sensor placement, network reliability, and long-term maintenance planning, before attempting large-scale or AI-driven automation deployments [8,11,18].

4. **Conclusions and Future Research**

IOT systems represent a strategic opportunity to improve energy efficiency and reduce carbon emissions in the hotel industry, particularly in guest rooms where the highest levels of energy consumption are concentrated. The literature reveals significant progress in this field; however, important limitations remain, including insufficient empirical evidence, a lack of methodological standardization, and a limited number of real-world implementations.

This study provides a systematic assessment of the maturity of existing research using a structured analytical framework. The results indicate that the field remains in a moderate stage of development, with many studies lacking the operational detail and technological

specification required for real-world replication. The findings also highlight the need for future research to develop standardized indicators and reporting frameworks that enable energy-efficiency outcomes to be compared and replicated across hospitality contexts.

Future research should therefore prioritize the following directions to strengthen the scientific and practical foundations of IOT-based energy management in hospitality:

- Standardization of energy and environmental indicators.
- Long-term empirical studies conducted in operational hotels.
- In-depth analysis of guest behavior.
- Predictive models based on real operational data.
- Comparative studies between technologies and architectures.

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Abbreviations

IOT	Internet of Things
HVAC	Heating, Ventilation, and Air Conditioning
RMA	Research maturity assessment
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses

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