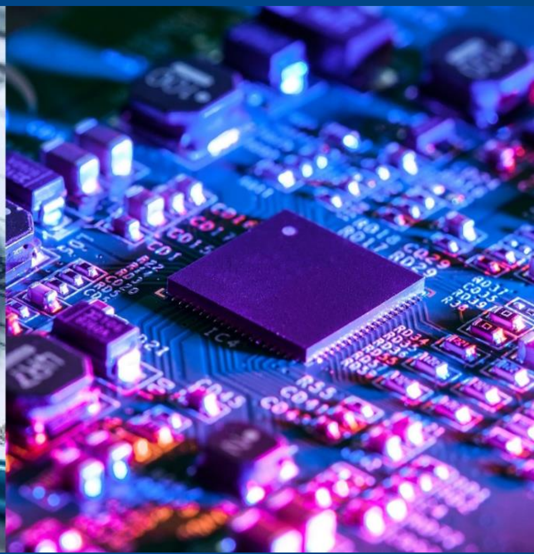
ISSN: 2582-7219

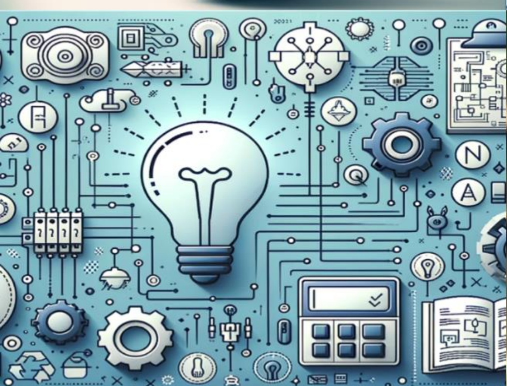




International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 6, June 2025

www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

© 2025 IJMRSET | Volume 8, Issue 6, June 2025| DOI:10.15680/IJMRSET.2025.0806102

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Energy-Efficient Smart Buildings: Integrating IoT for Sustainable Living

Shruthi

Department of Computer Applications, St Joseph Engineering (Autonomous) College, Vamanjoor, Mangalore, India

ABSTRACT: Applications of the Internet of Things (IoT) are rapidly utilized in smart buildings and smart cities to reduce energy consumption. This advancement has caused a knowledge gap in applying IoT effectively by experts in the built environment to achieve energy efficiency. The study aims to provide an extensive review of IoT applications for energy savings in buildings and cities. This study contributes to the field of IoT by guiding and supporting built environment experts to utilize IoT technologies. This paper performed a thorough study using a systematic review that covered an overview of IoT concepts, models, applications, trends and challenges that can be encountered in the built environment. The findings indicated limitations in developing IoT strategies in buildings and cities by professionals in this field due to insufficient comprehension of technologies and their applied methods. Additionally, the study found an indefinite implementation and constraints on using IoT when integrated into the built environment. Finally, the study provides critical arguments and the next steps to effectively utilize IoT in terms of energy efficiency.

KEYWORDS: Internet of Things (IoT), indoor air quality (IAQ), energy efficiency, smart buildings, learning factory

I. INTRODUCTION

The rapid digitalization of modern life has significantly increased global energy demands. Efforts like the EU's 2050 roadmap aim to reduce energy consumption and greenhouse gas emissions. The Internet of Things (IoT) presents a vital opportunity to improve energy efficiency in buildings and cities, contributing to sustainable development goals.

IoT, initially conceptualized by Kevin Ashton in 1999, involves interconnected objects using technologies like radio-frequency identification

(RFID) to enable seamless communication and data exchange. This innovation allows everyday physical objects to integrate electronics into global infrastructures, providing immense potential for monitoring and managing energy use. The term "IoT" encompasses various applications, from sensors in human health monitoring to safety systems in vehicles and GPS tracking in wildlife.

Currently, billions of devices are connected via IoT, a number expected to grow substantially in the coming years. This growth is driven by IoT's capability to sense, measure, and process data, opening vast opportunities for enhancing energy efficiency. IoT applications range from individual In the context of smart buildings and cities, IoT enables the efficient management, utilization, and storage of energy resources. "Smart" refers to the use of interconnected electronic systems and sensors to gather and analyze data, facilitating network connectivity and information exchange. This connectivity allows for the optimization of energy use, reducing waste and environmental impact.

Recent studies highlight the increasing interest in IoT applications for improving energy efficiency in buildings. Effective communication between building systems can significantly lower energy consumption. However, there are gaps between traditional building design and the integration of advanced IoT technologies, as well as between building design and automation solutions.

Challenges remain in understanding IoT from the perspective of built environment professionals. There is often a lack of comprehensive knowledge about developing and implementing IoT strategies for energy efficiency. This gap is critical as cities and buildings strive to achieve net-zero energy goals.

Therefore, this study aims to review IoT applications to explore energy-efficient solutions in buildings and cities. Specific objectives include reviewing IoT applications and trends, exploring IoT directions toward net-zero buildings and cities, and identifying challenges in using IoT in the built environment. The novelty of this study lies in its extensive review of IoT's role in energy efficiency, providing a conceptual guide for professionals in the built environment to effectively utilize IoT technologies for sustainable living.

II. LITERATURE SURVEY

The integration of IoT into smart buildings and cities is a rapidly evolving field that holds the promise of significantly enhancing energy efficiency. This literature review examines the key themes, trends, and challenges associated with the application of IoT in the built environment.

IoT and Energy Management:
IoT technologies facilitate real-time monitoring and control of energy consumption in buildings, enabling more efficient energy use. Various studies have demonstrated how IoT- enabled systems can optimize HVAC (heating, ventilation, and air conditioning) operations, lighting, and other energy- intensive systems. For instance, a study by GhaffarianHoseini et al. (2013) highlighted the potential of IoT to reduce energy consumption in office buildings through intelligent control systems that adjust based on occupancy and environmental conditions [1]

Smart Buildings and IoT Applications:
Smart buildings integrate IoT to create environments that are adaptive and responsive to the needs of occupants. According to Xu et al. (2014), smart buildings utilize sensors, actuators, and data analytics to manage energy use, enhancing both efficiency and occupant comfort. These systems can predict and respond to energy demands, thereby reducing wastage and improving overall energy performance [2].

IoT in Smart Cities:
The application of IoT extends beyond individual buildings to entire cities. Smart cities leverage IoT to manage urban resources efficiently, including energy, water, and waste. Studies such as those by Zanella et al. (2014) have shown that IoT can support urban sustainability through smart grids, smart meters, and other technologies that enable more effective energy distribution and consumption management [3].

IoT and Building Design:
The integration of IoT into building design requires a shift from traditional methods to more holistic approaches that consider the entire lifecycle of the building. Pan et al. (2012) emphasized the need for integrated design processes that incorporate IoT from the planning stages through to operation. This approach can ensure that IoT technologies are effectively utilized to achieve energy efficiency goals [4].

Technological Advancements and Trends:
The field of IoT is continuously evolving, with advancements in sensor technology, data analytics, and machine learning driving new applications. Recent trends include the development of edge computing, which allows data processing closer to the source, reducing latency and improving the responsiveness of IoT systems (Shi et al., 2016). Additionally, the rise of blockchain technology offers potential solutions for enhancing data security and integrity in IoT applications (Christidis and Devetsikiotis, 2016) [5].

Case Studies and Real-World Applications:
Several real-world implementations of IoT in smart buildings and cities provide valuable insights. For example, the SmartSantander project in Spain demonstrates how IoT can support urban sustainability through extensive sensor networks that monitor environmental conditions and energy use (Sanchez et al., 2014). Similarly, the Amsterdam Smart City initiative showcases how IoT can enhance energy efficiency through smart grids and sustainable energy solutions (Barbosa et al., 2013) [7].

III. METHODOLOGY

3.1 Data Collection:
This stage focuses on gathering comprehensive data on IoT applications in energy-efficient smart buildings and cities. Primary data sources include surveys and interviews with industry experts, building managers, and occupants to gain insights into current practices, challenges, and perceptions related to IoT implementation. Additionally, real-time sensor

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

data is collected from IoT sensors installed in various smart buildings, capturing information on energy consumption, temperature, occupancy, lighting, and HVAC system performance. Secondary data sources encompass an extensive review of existing literature, such as academic papers, industry reports, and case studies, to collate information on IoT applications, trends, and energy efficiency measures. Publicly available databases and datasets providing information on building energy consumption and IoT deployment are also utilized.

3.2 Algorithm Analysis:

This section investigates the specific algorithms and models used in IoT-based energy management systems. It involves identifying and selecting relevant algorithms for energy management, including machine learning models, optimization algorithms, and control strategies like neural networks, decision trees, and genetic algorithms. Performance metrics such as energy savings, computational efficiency, and prediction accuracy are defined to evaluate the effectiveness of different algorithms. The selected algorithms are implemented on the collected sensor data to analyze their performance in real-world scenarios, and simulation tools are used to model and predict energy consumption under various conditions and control strategies.

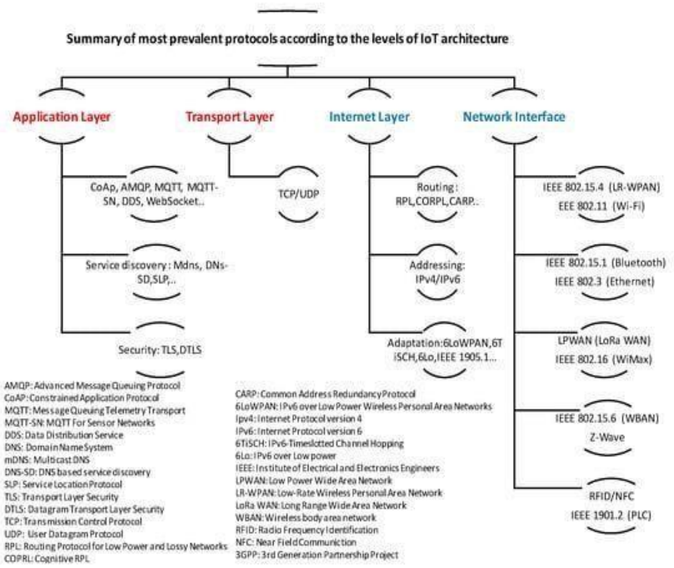


Figure 1: Summary of most prevalent protocols according to the levels of IoT architecture

3.3 Qualitative Evaluation: The qualitative evaluation involves expert interviews and questionnaires to assess the reception and perceived value of IoT-enabled energy management systems. In-depth interviews with IoT and energy management experts provide qualitative data on the benefits, challenges, and future trends of IoT in smart buildings. Thematic analysis of interview transcripts helps identify common themes, insights, and patterns related to IoT integration for energy efficiency.

Additionally, feedback from building occupants and managers is gathered to understand the usability, effectiveness, and satisfaction with IoT-based systems. This qualitative evaluation aims to reveal a complex picture of the social and cultural reception of IoT in energy-efficient smart buildings.

3.4 Comparative study:

The comparative study entails a side-by-side comparison of IoT-enabled energy management systems with conventional systems. This involves assessing the visual, auditory, and functional qualities of IoT-generated data and outcomes according to criteria such as originality, complexity, and the ability to evoke an emotional or practical response. Quantitative metrics measure viewer or user ratings, engagement levels, and the market performance of IoT-enabled versus traditional systems. Blind review sessions are organized where experts and laypersons assess these systems without knowledge of their origin to avoid bias and derive objective assessments. This rigorous comparison aims to identify the relative strengths and weaknesses of IoT systems compared to traditional approaches.

© 2025 IJMRSET | Volume 8, Issue 6, June 2025| DOI:10.15680/IJMRSET.2025.0806102

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

3.5 Case Studies:

The case studies involve an in-depth analysis of selected IoT- enabled smart buildings and cities to demonstrate the creative possibilities and limitations of IoT. Typical examples of buildings that have implemented IoT for significant energy efficiency improvements are selected. Contextual analysis describes the objectives of these IoT implementations and the target users. The creative process, including the IoT system itself and any human collaboration or intervention, is elaborated upon. Impact assessments cover cultural, commercial, and critical aspects, focusing on public reception and critical acclaim. Limitations are noted and discussed, addressing challenges such as originality, ethical concerns, and technological constraints. These case studies highlight the opportunities and challenges of integrating IoT in energy-efficient smart buildings and cities.

IV. IMPLEMENTATION

Nowadays, smart devices with the capacity for computation and communication are ubiquitous, ranging from simple sensors to household appliances and smartphones. The integration of such smart elements helps to develop heterogeneous networks, leading to the consolidation of an IoT basis .

The integration of IoT technologies in smart buildings demonstrates effective solutions to lower energy consumption, reduce environmental impacts, assist in utilizing renewable energy resources and offer flexibility to users that all help in establishing smart and sustainable cities.

The advancement in networking infrastructure, wireless technologies and smart algorithms open new opportunities for intelligent buildings to achieve efficient communication and proper control between multiple systems and spatial spaces to reach optimal integration. Lê et al. described smart buildings via five essential features: Interactivity, Adaptability, Multi-functionality, Automation and Efficiency. Al Dakheel et al. conducted a review on smart buildings to identify features and indicators, the study provided key aspects in designing smart buildings using four aspects: grid response, climate response, monitoring and supervision and user response. In Europe, the Energy Performance of Buildings Directive (EPBD) stated that smart buildings are defined as nearly Zero Energy Buildings (nZEB) that are equipped with sensing systems for smart monitoring, automated control, diagnostics, fault detection and supervision that respond to external conditions and user needs.

Generally, the utilization of IoT by building experts is limited and requires further studies to understand its application. Therefore, this section aims to clarify these limitations by demonstrating the gaps for specialists in building design. This section focuses on two research directions: studies of IoT in computer science and engineering that are mostly presented for demonstration and explanation, and studies of IoT by experts in the built environment to highlight the gaps from this perspective.

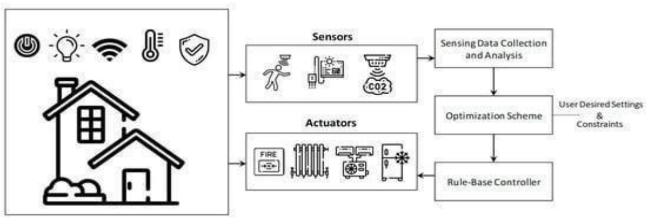


Figure 2: Model of optimization mechanism to achieve energy efficiency in a smart building [

Users represent the main entity that utilizes energy to attain comfort, safety and satisfaction.
Generally, IoT offers a wide range of options that benefit occupancy detection and activity recognition . Many studies indicated the impo building components and the physical layer of IoT technologies, building occupants, or in other words, users, play an important role to determine energy consumption in any building. rtance of occupant energy behavior in reducing electricity consumption . Zhang et al.stated that 30% of energy use in commercial buildings could be saved by adopting energy-aware behaviors among building users. Rafsanjani et al. studied user energy behavior using IoT. The study demonstrated useful results by employing data in the form of static and dynamic factors in a building

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

V. RESULTS

The research on the integration of IoT for energyefficient smart buildings and cities reveals several critical outcomes. Firstly, it identifies significant knowledge gaps among built environment professionals regarding IoT technologies and their effective application methods. This lack of understanding poses a substantial barrier to developing and implementing robust IoT strategies aimed at enhancing energy efficiency. The study underscores the challenges and constraints faced in the practical deployment of IoT solutions, highlighting issues such as the complexity of IoT systems, interoperability concerns, data privacy, and security risks. Moreover, the research points out the indefinite nature of IoT implementation in the built environment, where the absence of standardized protocols and clear methodologies further complicates effective adoption.

To address these challenges, the study provides comprehensive guidance and support for built environment experts, offering critical insights into the potential and limitations of IoT applications. It emphasizes the importance of interdisciplinary collaboration and continuous education for professionals to bridge the knowledge gap. Additionally, the research suggests practical steps and strategies for overcoming the identified challenges, such as developing standardized frameworks, enhancing cybersecurity measures, and fostering innovation through pilot projects and real-world applications.

Furthermore, the study highlights the necessity of creating a supportive regulatory environment and incentivizing the adoption of IoT technologies through policy measures and financial incentives. By doing so, it aims to encourage more widespread and effective use of IoT in achieving energy efficiency. The findings of the research also suggest that future studies should focus on exploring advanced IoT models and applications, evaluating their performance in real-time scenarios, and assessing their longterm impact on energy consumption and sustainability. Ultimately, the research provides a roadmap for the next steps, advocating for a strategic and informed approach to leveraging IoT for sustainable living in smart buildings and cities.

VI. CONCLUSION

The integration of IoT technologies in smart buildings and cities presents a significant opportunity for enhancing energy efficiency and promoting sustainable living. However, this research highlights substantial knowledge gaps among built environment professionals, which impede the effective application of IoT solutions. The complexities of IoT systems, coupled with interoperability issues, data privacy concerns, and security risks, pose considerable challenges to their implementation.

To overcome these obstacles, it is crucial to provide comprehensive education and training for professionals, develop standardized frameworks, and ensure robust cybersecurity measures. The research emphasizes the importance of interdisciplinary collaboration and continuous innovation through pilot projects and real-world applications.

Additionally, creating a supportive regulatory environment and offering financial incentives can accelerate the adoption of IoT technologies.

Future research should focus on exploring advanced IoT models, evaluating their real-time performance, and assessing their long-term impact on energy consumption and sustainability. By addressing these challenges and leveraging the potential of IoT, built environment experts can significantly contribute to the development of energy-efficient smart buildings and cities, ultimately leading to a more sustainable future.

REFERENCES

[1] CHRYSI K. METALLIDOU, KOSTAS E. PSANNIS, AND EUGENIA ALEXANDROPOULOU EGYPTIADOU, (Member, IEEE) Department of Applied Informatics, University of Macedonia, 546 36 Thessaloniki.
[2] Olsthoorn M, Schleich J, Faure C. Exploring the diffusion of low-energy houses: An empirical study in the European Union. Energy Policy.
2019;129:1382–93.
[3] Oguntuase OJ, Windapo A. Green bonds and green buildings: new options for achieving sustainable development in Nigeria. Housing and SDGs in Urban Africa. 2021:193–218.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

[4] Smith P, Keesstra SD, Silver WL, Adhya TK, De Deyn GB, Carvalheiro LG, et al. Soil-derived Nature's Contributions to People and their contribution to the UN Sustainable Development Goals. Philosophical Transactions of the Royal Society B. 2021;376(1834):20200185. [5]Lyu J, Li J, Zhao Z, Miao X, Du H, Lai D, et al. How do people set air conditioning temperature setpoint in urban domestic–Behavior model in Chinese three climate zones based on historical usage data. Energy and Buildings. 2023;284:112856.

[6] Bajaj K, Sharma B, Singh R. Implementation analysis of IoT-based offloading frameworks on cloud/edge computing for sensor generated big data. Complex & Intelligent Systems. 2022;8(5):3641–58.

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

SJIF Scientific Journal Impact Factor

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com