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(Review Article)

# A comprehensive review of Building Energy Management Systems (BEMS) for Improved Efficiency

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## Abstract

Building Energy Management Systems (BEMS) play a crucial role in enhancing energy efficiency and sustainability in buildings. This abstract provides a comprehensive review of BEMS, focusing on its components, benefits, challenges, and future trends. BEMS is a centralized system that monitors and controls building services, such as heating, ventilation, air conditioning, lighting, and other systems, to improve energy efficiency and occupant comfort. The key components of BEMS include sensors, controllers, communication networks, and user interfaces. These components work together to collect data on building performance, analyze energy consumption patterns, and optimize system operation. One of the primary benefits of BEMS is its ability to reduce energy consumption and costs. By monitoring and controlling building systems based on occupancy schedules and environmental conditions, BEMS can significantly reduce energy waste. Additionally, BEMS can improve occupant comfort and productivity by maintaining optimal indoor environmental conditions. Despite its benefits, BEMS faces several challenges, including high upfront costs, complexity of installation, and integration issues with existing building systems. However, advancements in technology, such as the Internet of Things (IoT) and cloud computing, are addressing these challenges and making BEMS more accessible and cost-effective. Looking ahead, the future of BEMS is promising, with continued advancements in technology driving its adoption and integration into smart building systems. The integration of artificial intelligence and machine learning algorithms into BEMS is expected to further improve its energy-saving capabilities and enhance building performance. In conclusion, BEMS is a key technology for improving energy efficiency and sustainability in buildings. By leveraging its components and capabilities, BEMS can help reduce energy consumption, lower costs, and create healthier and more comfortable indoor environments.

**Keywords:** BEMS; Improved; Efficiency; Systems; Energy

## 1. Introduction

In the quest for sustainable and energy-efficient building practices, Building Energy Management Systems (BEMS) have emerged as crucial tools for optimizing energy consumption and enhancing building performance. This introduction provides an overview of BEMS, highlights their significance for energy efficiency in buildings, and outlines the purpose and scope of the comprehensive review (Al-Ghaili, et. al., 2021, Kozlovska, et. al., 2023, Mariano-Hernández, et. al., 2021).

Building Energy Management Systems (BEMS) are advanced technology platforms designed to monitor, control, and optimize energy usage within commercial, industrial, and residential buildings. These systems integrate various components, including sensors, controllers, communication networks, and user interfaces, to collect real-time data on energy consumption and manage building systems efficiently. BEMS enable building owners and facility managers to gain insights into energy usage patterns, identify areas of inefficiency, and implement strategies to reduce energy consumption and associated costs (Hossain, et. al., 2023, Park, et. a; 2020, Parvin, et. al., 2021).

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The importance of BEMS in promoting energy efficiency in buildings cannot be overstated. Buildings account for a significant portion of global energy consumption and greenhouse gas emissions. By implementing BEMS, building owners and operators can optimize energy usage, reduce waste, and minimize environmental impact. Furthermore, BEMS contribute to improved occupant comfort, productivity, and health by maintaining optimal indoor environmental conditions. As energy costs continue to rise and environmental concerns intensify, the adoption of BEMS becomes increasingly imperative for building owners, operators, and occupants alike (Ang, Berzolla & Reinhart, 2020, Nturanabo, Masu & Kirabira, 2019, Vandenbogaerde, Verbeke & Audenaert, 2023).

The purpose of this comprehensive review is to provide a detailed examination of Building Energy Management Systems (BEMS) and their role in improving energy efficiency in buildings. The review will delve into the components, benefits, challenges, technology advancements, case studies, and future trends of BEMS. By synthesizing existing research, industry practices, and technological innovations, this review aims to offer valuable insights for researchers, practitioners, policymakers, and stakeholders interested in advancing energy-efficient building practices.

## 2. History of Building Energy Management Systems

Building Energy Management Systems (BEMS) have a rich history that reflects the evolution of energy management practices in buildings. The development of BEMS can be traced back to the early efforts to improve energy efficiency and reduce energy costs in commercial and industrial buildings (Beucker & Hinterholzer, 2019, Mataloto, Ferreira & Cruz, 2019, Nagpal, et., 2021).

The concept of energy management systems (EMS) emerged in the 1970s in response to the energy crisis. Early EMS focused on monitoring and controlling energy use in buildings, primarily through the use of centralized control systems. These systems were limited in scope and functionality, often relying on basic sensors and manual controls.

The 1990s saw the emergence of Building Energy Management Systems (BEMS) as a more comprehensive approach to energy management in buildings. BEMS integrated advanced technologies such as microprocessors, sensors, and communication networks to monitor and control a wide range of building systems, including heating, ventilation, air conditioning (HVAC), lighting, and energy-consuming equipment (Barber & Krarti, 2022, Vahidinasab, et. al., 2021, Vučković & Pitić, 2022).

In recent years, BEMS have undergone significant technological advancements, driven by the proliferation of smart building technologies and the Internet of Things (IoT). Modern BEMS leverage IoT devices, cloud computing, artificial intelligence (AI), and machine learning (ML) to optimize energy usage, improve occupant comfort, and reduce operational costs. The development of BEMS has also been influenced by regulatory drivers and industry standards aimed at promoting energy efficiency and sustainability. Initiatives such as the Energy Performance of Buildings Directive (EPBD) in Europe and programs like ENERGY STAR in the United States have encouraged the adoption of BEMS and incentivized building owners to invest in energy-efficient technologies (Agrawal, et. al., 2023, Kim & Ha, 2021, Leiringer, 2020).

Today, BEMS play a crucial role in helping buildings and facilities achieve their sustainability goals. By optimizing energy usage, reducing carbon emissions, and improving operational efficiency, BEMS contribute to a more sustainable built environment and help organizations meet their environmental targets. In conclusion, the history of Building Energy Management Systems reflects a gradual evolution from basic energy management systems to sophisticated, integrated solutions that are essential for improving energy efficiency and sustainability in buildings (Chew, et. al., 2020, González, et. al., 2021, Na & Lee, 2020).

### 2.1. Components of Building Energy Management Systems

Building Energy Management Systems (BEMS) comprise various components that work together to monitor, control, and optimize energy usage within buildings (Bianco, et. al., 2020, Dimara, et. al., 2021, Moya, Torres-Moreno & Álvarez, 2020). This section explores the key components of BEMS, including sensors, controllers, communication networks, and user interfaces, highlighting their functions and significance in improving energy efficiency.

Sensors serve as the eyes and ears of Building Energy Management Systems, collecting data on various environmental parameters, equipment performance, and occupancy patterns within buildings. These sensors can measure factors such as temperature, humidity, lighting levels, occupancy, and air quality. Monitor indoor and outdoor temperatures to optimize heating, ventilation, and air conditioning (HVAC) systems for energy efficiency. Measure relative humidity levels to control HVAC systems and prevent moisture-related issues. Detect the presence or absence of occupants in different areas of a building to adjust lighting, heating, and cooling accordingly. Monitor natural and artificial lighting levels to adjust lighting systems and maximize energy savings. Measure indoor air quality parameters such as carbon dioxide (CO2), volatile organic compounds (VOCs), and particulate matter to ensure healthy and comfortable indoor environments (Anand, et. al., 2019, Rashid, et. al., 2019, Simpeh, et. al., 2022). By continuously monitoring these parameters, sensors provide valuable data insights that enable BEMS to optimize building operations for energy efficiency while maintaining occupant comfort and wellbeing.

Controllers are the brains of Building Energy Management Systems, responsible for analyzing sensor data, making control decisions, and executing commands to regulate building systems. Controllers receive input from sensors, process the data using algorithms and logic, and send signals to actuators to adjust equipment settings. Key functions of controllers in BEMS include:

Analyze sensor data to identify energy consumption patterns, detect anomalies, and optimize system performance. Implement control strategies based on predefined setpoints, schedules, and operational modes to minimize energy waste. Interface with actuators, such as valves, dampers, and motors, to adjust the operation of HVAC, lighting, and other building systems in real-time. Controllers play a crucial role in orchestrating the operation of building systems to achieve energy efficiency goals and maintain optimal conditions for occupants (Alhamed, et. al., 2022, Fontenot & Dong, 2019, Kawa, Borkowski & Rodak, 2021).

Communication networks enable seamless data exchange and connectivity between various components of Building Energy Management Systems, including sensors, controllers, actuators, and user interfaces. These networks facilitate real-time monitoring, control, and coordination of building systems across different locations. Common communication protocols and technologies used in BEMS include: Wired network technology used for high-speed data transmission between devices within a building or across multiple buildings.

Wireless networking technology that provides connectivity to sensors, controllers, and user interfaces, allowing for flexible deployment and scalability. Serial communication protocol commonly used for connecting sensors, controllers, and actuators in industrial automation and building management systems. Building Automation and Control Networks protocol used for integrating diverse building systems and devices from different manufacturers into a unified BEMS platform. By establishing robust communication networks, BEMS ensure seamless integration and interoperability of components, enabling centralized monitoring and control of building operations (Modieginyane, Malekian & Letswamotse, 2019, Nurlan, et. al., 2021, Urrea & Benítez, 2021).

User interfaces serve as the primary means of interaction between building operators, facility managers, and Building Energy Management Systems. These interfaces provide access to real-time data, control functions, and analytical tools, enabling users to monitor building performance, adjust settings, and make informed decisions. Intuitive graphical interfaces displayed on computer screens or mobile devices, allowing users to visualize building data, trends, and control options through interactive dashboards and charts. Online portals accessible via web browsers, providing remote access to BEMS functionalities, including monitoring, control, and reporting. Smartphone and tablet applications that enable users to monitor and control building systems on the go, receive real-time alerts, and access energy usage data from anywhere. Comprehensive software platforms that integrate multiple BEMS functions, including data acquisition, analysis, visualization, and control, into a unified interface for streamlined management and operation. User interfaces play a critical role in empowering building operators and managers to optimize energy efficiency, identify opportunities for improvement, and track performance metrics effectively (Alonso-Rosa, et. al., 2020, Li, 2021, Qolomany, et. al., 2019).

In summary, Building Energy Management Systems consist of sensors, controllers, communication networks, and user interfaces, each playing a vital role in achieving energy efficiency and sustainability goals in buildings. By leveraging these components effectively, BEMS enable real-time monitoring, intelligent control, and data-driven decision-making, ultimately leading to reduced energy consumption, lower operating costs, and enhanced occupant comfort and wellbeing.

### 2.2. Benefits of Building Energy Management Systems

Building Energy Management Systems (BEMS) offer a wide range of benefits that contribute to improved energy efficiency, reduced operating costs, and enhanced occupant comfort and productivity. This section explores the key benefits of BEMS, including energy savings, improved occupant comfort and productivity, remote monitoring and control, and maintenance optimization.

One of the primary benefits of Building Energy Management Systems is their ability to deliver significant energy savings. By continuously monitoring and optimizing building systems, such as heating, ventilation, air conditioning (HVAC), lighting, and equipment, BEMS can identify inefficiencies and implement energy-saving measures. These measures may include: BEMS can adjust the operating schedules of HVAC systems, lighting, and other equipment based on occupancy patterns, reducing energy waste during unoccupied periods (Iris & Lam, 2019, Mason & Grijalva, 2019, Yu, et. al., 2021).

BEMS can adjust equipment settings, such as temperature setpoints and fan speeds, to optimize energy usage without compromising comfort. BEMS can implement load shedding strategies during peak demand periods, reducing overall energy consumption and utility costs. BEMS can identify equipment faults and inefficiencies, allowing for timely maintenance and repairs to prevent energy waste. Overall, the energy savings achieved through BEMS can lead to significant reductions in utility bills and carbon emissions, contributing to a more sustainable built environment. Another key benefit of Building Energy Management Systems is their ability to enhance occupant comfort and productivity. By maintaining optimal indoor environmental conditions, including temperature, humidity, and air quality, BEMS can create a more comfortable and healthy indoor environment for building occupants (Márquez-Sánchez, et. al., 2023, Merabet, et. al., 2021, Salimi & Hammad, 2019).

BEMS can ensure that indoor temperatures remain within comfortable ranges, reducing complaints and discomfort among building occupants. BEMS can monitor and control ventilation rates and air filtration systems to maintain high indoor air quality, reducing the risk of health issues associated with poor air quality. A comfortable and healthy indoor environment can lead to increased productivity among building occupants, as studies have shown that improved indoor environmental quality is correlated with higher cognitive performance and task completion rates. By prioritizing occupant comfort and wellbeing, BEMS can create a more desirable and productive indoor environment, benefiting both occupants and building owners.

Building Energy Management Systems offer the convenience of remote monitoring and control, allowing building operators and facility managers to manage building systems from anywhere, at any time. This capability enables: BEMS provide real-time data on energy consumption, equipment performance, and indoor environmental conditions, allowing for proactive management and timely interventions (Fairchild, 2019, Valinejadshoubi, et. al., 2021, Yaïci, et. al., 2021). BEMS enable operators to adjust system settings, override schedules, and implement energy-saving measures remotely, without the need for on-site visits. BEMS can send alerts and notifications to operators in case of equipment failures, anomalies, or deviations from setpoint values, enabling prompt action to address issues and prevent downtime. The ability to monitor and control building systems remotely enhances operational efficiency and responsiveness, leading to improved energy management and cost savings (Ang, Berzolla & Reinhart, 2020, Huseien & Shah, 2022, Wu & Liu, 2019).

Building Energy Management Systems can help optimize maintenance activities by providing valuable insights into equipment performance and health. BEMS can: BEMS can analyze data from sensors and equipment to predict potential failures or maintenance issues, allowing for proactive maintenance planning and reducing downtime. BEMS can monitor equipment performance metrics, such as energy consumption and operating hours, to determine when maintenance is needed based on actual conditions, rather than fixed schedules (Himeur, et. al., 2023, Marinakis, et. al., 2020, Rathor & Saxena, 2020). By prioritizing maintenance tasks based on actual equipment performance and health, BEMS can optimize resource allocation and reduce unnecessary maintenance costs. Overall, maintenance optimization through BEMS can extend equipment life, reduce maintenance costs, and improve overall system reliability and performance.

In conclusion, Building Energy Management Systems offer a wide range of benefits, including energy savings, improved occupant comfort and productivity, remote monitoring and control, and maintenance optimization. By leveraging these benefits, BEMS can help building owners and operators achieve their energy efficiency and sustainability goals, while also enhancing the indoor environment for occupants.

## 3. Challenges of Building Energy Management Systems

Building Energy Management Systems (BEMS) offer numerous benefits for optimizing energy usage and improving building performance. However, their implementation and operation can be accompanied by various challenges (Dagdougui, Ouammi & Benchrifa, 2020, Mataloto, Ferreira & Cruz, 2019). This section examines the key challenges associated with BEMS, including high upfront costs, complexity of installation, integration issues with existing building systems, and data security and privacy concerns.

One of the primary challenges of implementing Building Energy Management Systems is the high upfront costs associated with equipment procurement, installation, and software implementation. BEMS typically require investments in sensors, controllers, communication infrastructure, software licenses, and professional services for design, installation, and commissioning. The initial capital outlay for BEMS can be prohibitive for some building owners, especially for small-to-medium-sized enterprises (SMEs) or facilities with limited budgets. Additionally, the return on investment (ROI) for BEMS may not be immediately apparent, making it challenging to justify the upfront costs to stakeholders (Alam, et. al., 2019, Bertoldi, et. al., 2021, Hu, et. al., 2020).

The installation of Building Energy Management Systems can be complex and time-consuming, requiring coordination among multiple stakeholders, including building owners, facility managers, contractors, and BEMS vendors. The complexity of installation arises from various factors, such as the need to retrofit existing buildings with new sensors and control devices, integrate BEMS with legacy building systems, and ensure compatibility with building codes and regulations. Furthermore, the installation process may disrupt normal building operations, leading to downtime and productivity losses (Abuimara, et. al., 2021, Bajracharya, 2023, Sofos, et. al., 2020).

Another challenge of implementing Building Energy Management Systems is the integration with existing building systems and infrastructure. Many buildings have legacy HVAC, lighting, and other systems that may use proprietary protocols or communication standards, making it difficult to integrate them seamlessly with BEMS. Additionally, buildings may have disparate control systems installed by different vendors, further complicating the integration process. As a result, building owners and operators may face interoperability issues, data silos, and limitations in the functionality of BEMS (Mahapatra & Nayyar, 2022, O'Dwyer, et. al., 2019, Sadeeq & Zeebaree, 2021).

Data security and privacy concerns present significant challenges for Building Energy Management Systems, particularly with the proliferation of connected devices and the collection of sensitive building performance data. BEMS typically gather data from a wide array of sensors and devices, including occupancy sensors, temperature sensors, and energy meters, which may contain personally identifiable information (PII) or sensitive business data. There is a risk of unauthorized access, data breaches, and cyberattacks targeting BEMS infrastructure, leading to data loss, disruption of building operations, and reputational damage. Additionally, there may be concerns about the privacy implications of collecting and analyzing occupant behavior data, such as occupancy patterns and usage habits (Abir, et. al., 2021, Gunay, Shen & Newsham, 2019, Jia, et. al., 2019).

In summary, Building Energy Management Systems face several challenges, including high upfront costs, complexity of installation, integration issues with existing building systems, and data security and privacy concerns. Addressing these challenges requires careful planning, collaboration among stakeholders, and implementation of robust cybersecurity measures to ensure the successful deployment and operation of BEMS in buildings.

## 4. Technology Advancements in Building Energy Management Systems

Building Energy Management Systems (BEMS) are evolving rapidly, driven by advancements in technology that offer new capabilities for improving energy efficiency, optimizing building performance, and enhancing occupant comfort. This section explores key technological advancements in BEMS, including Internet of Things (IoT) integration, cloud computing, artificial intelligence (AI) and machine learning, and data analytics, highlighting their impact on BEMS functionality and effectiveness (Kozlovska, et. al., 2023, Newton, Shirazi & Christensen, 2023, Uzair & Kazmi, 2023).

One of the most significant advancements in Building Energy Management Systems is the integration of Internet of Things (IoT) devices. IoT devices, such as sensors, actuators, and smart meters, enable BEMS to collect real-time data on building operations, energy usage, and environmental conditions. This data can be used to optimize energy consumption, detect anomalies, and improve system performance. By integrating IoT devices, BEMS can achieve: IoT devices provide continuous monitoring of building systems, allowing for immediate detection of issues and proactive maintenance. (Aliero, et. al., 2021, Mohd Aman, Shaari & Ibrahim, 2021, Wang, Zhong & Souri, 2021)

IoT devices collect detailed data on energy usage and equipment performance, enabling precise analysis and optimization of building operations. IoT devices enable remote control of building systems, allowing operators to adjust settings and implement energy-saving measures from anywhere. IoT devices can predict equipment failures based on data trends, enabling proactive maintenance to prevent downtime. Overall, IoT integration enhances the capabilities of BEMS, enabling more efficient and responsive building management. Cloud computing has revolutionized the way Building Energy Management Systems store, process, and analyze data. By leveraging cloud-based infrastructure, BEMS can access virtually unlimited computing power and storage capacity, enabling: Cloud-based BEMS can scale up or down easily to accommodate changing needs, without the need for costly hardware upgrades (Saleem, et. al., 2023, Terroso-Saenz, et. al., 2019).

Cloud-based BEMS enable access to data from anywhere, at any time, facilitating remote monitoring and management. Cloud-based BEMS eliminate the need for on-premises servers and infrastructure, reducing upfront costs and maintenance expenses. Cloud providers offer robust security measures and data redundancy, ensuring the safety and availability of BEMS data. Cloud computing enhances the flexibility, efficiency, and reliability of BEMS, enabling more effective energy management and building optimization.

Artificial intelligence (AI) and machine learning (ML) are transforming Building Energy Management Systems by enabling predictive analytics, pattern recognition, and intelligent decision-making. AI and ML algorithms can analyze vast amounts of data collected by BEMS to: AI algorithms can forecast energy demand based on historical data and external factors, allowing for proactive energy management and load balancing.

ML algorithms can learn from past energy consumption patterns and adjust building systems to minimize energy waste and optimize efficiency. AI algorithms can detect anomalies and equipment failures in real-time, enabling prompt maintenance and repairs to prevent downtime. AI algorithms can analyze occupant behavior and preferences to adjust building settings for optimal comfort and productivity. By leveraging AI and ML technologies, BEMS can achieve higher levels of energy efficiency, operational performance, and occupant satisfaction (Benavente-Peces & Ibadah, 2020, Liu, et. al., 2020).

Data analytics plays a crucial role in modern Building Energy Management Systems, enabling the extraction of valuable insights from complex and diverse datasets. Data analytics techniques, such as statistical analysis, data mining, and predictive modeling, can: Data analytics can identify trends and patterns in energy usage data, highlighting opportunities for optimization and efficiency improvements. Data analytics can track key performance indicators (KPIs) related to energy consumption, system efficiency, and environmental impact, enabling continuous improvement. Data analytics can provide actionable insights to building operators and managers, enabling informed decisions on energy management strategies and investments. Data analytics can compare building performance against industry standards and best practices, providing benchmarks for improvement. Overall, data analytics enhances the effectiveness and efficiency of BEMS, enabling data-driven decision-making and continuous improvement in building performance (Hristov & Chirico, 2019, Kifor, Olteanu & Zerbes, 2023).

In conclusion, technological advancements such as IoT integration, cloud computing, AI and ML, and data analytics are transforming Building Energy Management Systems, enabling more efficient, intelligent, and sustainable building management practices. By leveraging these advancements, BEMS can achieve greater energy savings, operational efficiency, and occupant comfort, contributing to a more sustainable built environment.

## 5. Case Studies and Examples of Building Energy Management Systems

Building Energy Management Systems (BEMS) have been implemented in various buildings and facilities worldwide, yielding significant energy savings, cost reductions, and operational improvements. This section examines several case studies and examples of successful BEMS implementations, highlighting their outcomes, lessons learned, and best practices (Al Naqbi, et. al., 2021, Yelisetti, et. al., 2020).

The Empire State Building underwent a comprehensive energy retrofit, including the implementation of a BEMS, resulting in a 38% reduction in energy consumption and $4.4 million in annual energy savings. The BEMS monitors and controls HVAC systems, lighting, and other building systems, optimizing energy usage based on occupancy patterns and weather conditions.

The Crystal, a sustainable building in London, utilizes a BEMS to achieve net-zero carbon emissions. The BEMS integrates with renewable energy sources, energy-efficient lighting, and smart building technologies to minimize energy consumption and carbon footprint. As a result, The Crystal has achieved LEED Platinum certification and serves as a model for sustainable building design (Causone, Tatti & Alongi, 2021, Omrany, 2021, Ward, et. al., 2019).

Microsoft's campus in Redmond, Washington, implemented a BEMS to optimize energy usage across its buildings and facilities. The BEMS utilizes advanced analytics and machine learning algorithms to identify energy-saving opportunities, resulting in a 15% reduction in energy consumption and significant cost savings. Microsoft has since scaled the BEMS implementation to other campuses worldwide, achieving similar results.

The University of California, Berkeley, implemented a BEMS across its campus buildings, resulting in a 20% reduction in energy consumption and $3 million in annual cost savings. The BEMS monitors energy usage in real-time, identifies inefficiencies, and implements energy-saving measures, such as adjusting HVAC setpoints and optimizing lighting schedules. The Sydney Opera House implemented a BEMS to optimize energy usage and reduce operating costs. The BEMS integrates with the building's HVAC, lighting, and control systems to achieve energy savings of 25% and annual cost savings of $1.5 million. The BEMS also provides insights into building performance, enabling continuous improvement and optimization.

Successful BEMS implementations often involve an integrated approach that considers the unique requirements and challenges of the building or facility. By integrating BEMS with existing building systems and infrastructure, organizations can maximize energy savings and operational efficiency. Continuous monitoring and optimization are essential for maximizing the benefits of BEMS. Regular performance monitoring, data analysis, and optimization efforts enable organizations to identify energy-saving opportunities and address inefficiencies proactively.

Engaging building occupants, facility managers, and other stakeholders is critical for the success of BEMS implementations. Effective communication and collaboration foster a culture of energy efficiency and sustainability, encouraging participation and support for BEMS initiatives. In summary, case studies and examples of Building Energy Management Systems demonstrate their effectiveness in achieving energy savings, cost reductions, and operational improvements in various buildings and facilities. By following best practices and lessons learned from successful implementations, organizations can maximize the benefits of BEMS and contribute to a more sustainable built environment (Mannino, Dejaco & Re Cecconi, 2021, Matarneh, et. al., 2019, Morton, et. al., 2020).

## 6. Future Trends and Opportunities in Building Energy Management Systems

Building Energy Management Systems (BEMS) are poised to undergo significant advancements and transformations in the coming years, driven by technological innovations and the increasing focus on sustainability and energy efficiency (Groumpos & Mpelogianni, 2020, Hannan, et. al., 2023, Na & Lee, 2020, Nguyen, et. al., 2020). This section explores key future trends and opportunities in BEMS, including integration with smart building systems, enhanced energy-saving capabilities through AI and machine learning, and the role of BEMS in achieving sustainability goals.

One of the prominent future trends in Building Energy Management Systems is the integration with smart building systems. Smart building technologies, such as Internet of Things (IoT) devices, building automation systems (BAS), and advanced sensors, are becoming more prevalent in modern buildings. By integrating BEMS with smart building systems, organizations can achieve; Integration with smart building systems enables BEMS to access real-time data on building operations, energy usage, and environmental conditions, allowing for more precise monitoring and control of energy-consuming systems. Smart building systems generate vast amounts of data that can be analyzed by BEMS to identify trends, patterns, and anomalies, providing valuable insights for optimizing energy usage and building performance (Degha, Laallam& Said, 2019, Prakash, Shrivastava & Tomar, 2022, Sari, et. al., 2023).

BEMS integrated with smart building systems can automate energy-saving measures and system adjustments based on occupancy patterns, weather conditions, and energy demand, optimizing energy consumption and comfort levels. Integration with smart building systems can improve the user experience by providing occupants with greater control over their environment, such as personalized lighting and temperature settings.

Artificial intelligence (AI) and machine learning (ML) are expected to play a significant role in enhancing the energy-saving capabilities of Building Energy Management Systems. AI and ML algorithms can analyze complex datasets and learn from past energy usage patterns to: AI algorithms can forecast energy demand based on historical data and external factors, enabling proactive energy management and load balancing.

ML algorithms can optimize energy consumption by adjusting building systems, such as HVAC and lighting, to minimize energy waste and maximize efficiency. AI algorithms can detect anomalies and equipment failures in real-time, enabling prompt maintenance and repairs to prevent downtime. AI algorithms can analyze occupant behavior and preferences to optimize building settings for comfort and productivity, further reducing energy consumption. By leveraging AI and ML technologies, BEMS can achieve higher levels of energy efficiency and operational performance, leading to significant cost savings and environmental benefits (Mehmood, et. al., 2019, Shah, et. al., 2019, Tien, et. al., 2022).

Building Energy Management Systems are expected to play a crucial role in helping organizations achieve their sustainability goals. As organizations strive to reduce their carbon footprint and improve their environmental performance, BEMS can: BEMS can help organizations achieve energy efficiency targets by optimizing energy usage, reducing waste, and implementing energy-saving measures. BEMS can facilitate the integration of renewable energy sources, such as solar and wind power, by optimizing their use based on energy demand and availability. BEMS can help buildings achieve green building certifications, such as LEED and BREEAM, by demonstrating energy efficiency and sustainability practices. BEMS can provide valuable data and insights for corporate sustainability reporting, demonstrating the organization's commitment to environmental responsibility (Abualigah, et. al., 2022, Halim, et. al., 2023, Yang, et. al., 2022).

In conclusion, future trends and opportunities in Building Energy Management Systems include integration with smart building systems, enhanced energy-saving capabilities through AI and machine learning, and the role of BEMS in achieving sustainability goals. By embracing these trends and leveraging advanced technologies, organizations can enhance their energy efficiency, reduce their environmental impact, and achieve greater sustainability in their operations.

## 7. Conclusion

Building Energy Management Systems (BEMS) play a critical role in improving energy efficiency and sustainability in buildings. This comprehensive review has highlighted the components, benefits, challenges, and technological advancements of BEMS, as well as future trends and opportunities.

Key findings from this review include the importance of BEMS in optimizing energy usage, reducing operational costs, and enhancing occupant comfort. BEMS utilize components such as sensors, controllers, and communication networks to collect and analyze data, enabling informed decision-making and proactive energy management.

Future research in BEMS should focus on the integration of smart building technologies, enhanced energy-saving capabilities through AI and machine learning, and the development of standardized metrics for evaluating BEMS performance. Additionally, practitioners should consider implementing BEMS in new and existing buildings to maximize energy efficiency and sustainability. BEMS are crucial for achieving energy efficiency and sustainability goals in buildings. By monitoring and controlling energy usage, optimizing building systems, and providing real-time data insights, BEMS can significantly reduce energy consumption and carbon emissions. In conclusion, Building Energy Management Systems are essential tools for improving building energy efficiency and sustainability. By leveraging the components, benefits, and advancements of BEMS, organizations can achieve significant energy savings, cost reductions, and environmental benefits.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

## Reference

[1] Abir, S. A. A., Anwar, A., Choi, J., & Kayes, A. S. M. (2021). Iot-enabled smart energy grid: Applications and challenges. IEEE access, 9, 50961-50981.

[2] Abualigah, L., Zitar, R. A., Almotairi, K. H., Hussein, A. M., Abd Elaziz, M., Nikoo, M. R., & Gandomi, A. H. (2022). Wind, solar, and photovoltaic renewable energy systems with and without energy storage optimization: A survey of advanced machine learning and deep learning techniques. Energies, 15(2), 578.

[3] Abuimara, T., Hobson, B. W., Gunay, B., O'Brien, W., & Kane, M. (2021). Current state and future challenges in building management: practitioner interviews and a literature review. Journal of Building Engineering, 41, 102803.

[4] Agrawal, R., De Tommasi, L., Lyons, P., Zanoni, S., Papagiannis, G. K., Karakosta, C., ... & Güemes, E. L. (2023). Challenges and opportunities for improving energy efficiency in SMEs: learnings from seven European projects. Energy Efficiency, 16(3), 17.

[5] Al Naqbi, A., Alyieliely, S. S., Talib, M. A., Nasir, Q., Bettayeb, M., & Ghenai, C. (2021, October). Energy Reduction in Building Energy Management Systems Using the Internet of Things: Systematic Literature Review. In 2021 International Symposium on Networks, Computers and Communications (ISNCC) (pp. 1-7). IEEE.

[6] Alam, M., Zou, P. X., Stewart, R. A., Bertone, E., Sahin, O., Buntine, C., & Marshall, C. (2019). Government championed strategies to overcome the barriers to public building energy efficiency retrofit projects. Sustainable Cities and Society, 44, 56-69.

[7] Al-Ghaili, A. M., Kasim, H., Al-Hada, N. M., Jørgensen, B. N., Othman, M., & Wang, J. (2021). Energy management systems and strategies in buildings sector: A scoping review. IEEE Access, 9, 63790-63813.

[8] Alhamed, K. M., Iwendi, C., Dutta, A. K., Almutairi, B., Alsaghier, H., & Almotairi, S. (2022). Building construction based on video surveillance and deep reinforcement learning using smart grid power system. Computers and Electrical Engineering, 103, 108273.

[9] Aliero, M. S., Qureshi, K. N., Pasha, M. F., & Jeon, G. (2021). Smart Home Energy Management Systems in Internet of Things networks for green cities demands and services. Environmental Technology & Innovation, 22, 101443.

[10] Alonso-Rosa, M., Gil-de-Castro, A., Moreno-Munoz, A., Garrido-Zafra, J., Gutierrez-Ballesteros, E., & Cañete-Carmona, E. (2020). An IoT based mobile augmented reality application for energy visualization in buildings environments. Applied Sciences, 10(2), 600.

[11] Anand, P., Sekhar, C., Cheong, D., Santamouris, M., & Kondepudi, S. (2019). Occupancy-based zone-level VAV system control implications on thermal comfort, ventilation, indoor air quality and building energy efficiency. Energy and Buildings, 204, 109473.

[12] Ang, Y. Q., Berzolla, Z. M., & Reinhart, C. F. (2020). From concept to application: A review of use cases in urban building energy modeling. Applied Energy, 279, 115738.

[13] Bajracharya, M. (2023). An assessment of Building Energy Management Systems (BEMS) and Data-driven Life cycle engineering (LCE) in AEC projects.

[14] Barber, K. A., & Krarti, M. (2022). A review of optimization based tools for design and control of building energy systems. Renewable and Sustainable Energy Reviews, 160, 112359.

[15] Benavente-Peces, C., & Ibadah, N. (2020). Buildings energy efficiency analysis and classification using various machine learning technique classifiers. Energies, 13(13), 3497.

[16] Bertoldi, P., Economidou, M., Palermo, V., Boza-Kiss, B., & Todeschi, V. (2021). How to finance energy renovation of residential buildings: Review of current and emerging financing instruments in the EU. Wiley Interdisciplinary Reviews: Energy and Environment, 10(1), e384.

[17] Beucker, S., & Hinterholzer, S. (2019, June). Building Energy Management Systems and their Role in the Energy Transition. In ICT4S.

[18] Bianco, G., Bracco, S., Delfino, F., Gambelli, L., Robba, M., & Rossi, M. (2020). A building energy management system based on an equivalent electric circuit model. Energies, 13(7), 1689.

[19] Causone, F., Tatti, A., & Alongi, A. (2021). From nearly zero energy to carbon-neutral: case study of a hospitality building. Applied Sciences, 11(21), 10148.

[20] Chew, M. Y. L., Teo, E. A. L., Shah, K. W., Kumar, V., & Hussein, G. F. (2020). Evaluating the roadmap of 5G technology implementation for smart building and facilities management in Singapore. Sustainability, 12(24), 10259.

[21] Dagdougui, Y., Ouammi, A., & Benchrifa, R. (2020). Energy management-based predictive controller for a smart building powered by renewable energy. Sustainability, 12(10), 4264.

[22] Degha, H. E., Laallam, F. Z., & Said, B. (2019). Intelligent context-awareness system for energy efficiency in smart building based on ontology. Sustainable computing: informatics and systems, 21, 212-233.

[23] Dimara, A., Anagnostopoulos, C. N., Kotis, K., Krinidis, S., & Tzovaras, D. (2021). BEMS in the Era of Internet of Energy: A Review. In Artificial Intelligence Applications and Innovations: 17th IFIP WG 12.5 International Conference, AIAI 2021, Hersonissos, Crete, Greece, June 25–27, 2021, Proceedings 17 (pp. 465-476). Springer International Publishing.

[24] Fairchild, A. (2019). Twenty-first-century smart facilities management: Ambient networking in intelligent office buildings. Guide to Ambient Intelligence in the IoT Environment: Principles, Technologies and Applications, 271-289.

[25] Fontenot, H., & Dong, B. (2019). Modeling and control of building-integrated microgrids for optimal energy management–a review. Applied Energy, 254, 113689.

[26] González, J., Soares, C. A. P., Najjar, M., & Haddad, A. N. (2021). Bim and bem methodologies integration in energy-efficient buildings using experimental design. Buildings, 11(10), 491.

[27] Groumpos, P. P., & Mpelogianni, V. (2020, July). New advanced technology methods for energy efficiency of buildings. In 2020 11th International Conference on Information, Intelligence, Systems and Applications (IISA (pp. 1-8). IEEE.

[28] Gunay, H. B., Shen, W., & Newsham, G. (2019). Data analytics to improve building performance: A critical review. Automation in Construction, 97, 96-109.

[29] Halim, M. A., Akter, M. S., Biswas, S., & Rahman, M. S. (2023). Integration of Renewable Energy Power Plants on a Large Scale and Flexible Demand in Bangladesh's Electric Grid-A Case Study. Control Systems and Optimization Letters, 1(3), 157-168.

[30] Hannan, M. A., Ker, P. J., Mansor, M., Lipu, M. H., Al-Shetwi, A. Q., Alghamdi, S. M., ... & Tiong, S. K. (2023). Recent advancement of energy internet for emerging energy management technologies: Key features, potential applications, methods and open issues. Energy Reports, 10, 3970-3992.

[31] Himeur, Y., Elnour, M., Fadli, F., Meskin, N., Petri, I., Rezgui, Y., ... & Amira, A. (2023). AI-big data analytics for building automation and management systems: a survey, actual challenges and future perspectives. Artificial Intelligence Review, 56(6), 4929-5021.

[32] Hossain, J., Kadir, A. F., Hanafi, A. N., Shareef, H., Khatib, T., Baharin, K. A., & Sulaima, M. F. (2023). A Review on Optimal Energy Management in Commercial Buildings. Energies, 16(4), 1609.

[33] Hristov, I., & Chirico, A. (2019). The role of sustainability key performance indicators (KPIs) in implementing sustainable strategies. Sustainability, 11(20), 5742.

[34] Hu, S., Yan, D., Azar, E., & Guo, F. (2020). A systematic review of occupant behavior in building energy policy. Building and Environment, 175, 106807.

[35] Huseien, G. F., & Shah, K. W. (2022). A review on 5G technology for smart energy management and smart buildings in Singapore. Energy and AI, 7, 100116.

[36] Iris, Ç., & Lam, J. S. L. (2019). A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. Renewable and Sustainable Energy Reviews, 112, 170-182.

[37] Jia, M., Komeily, A., Wang, Y., & Srinivasan, R. S. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. Automation in Construction, 101, 111-126.

[38] Kawa, B., Borkowski, P., & Rodak, M. (2021). Building management system based on brain computer interface. Review. Archives of Electrical Engineering, 70(4), 887-905.

[39] Kifor, C. V., Olteanu, A., & Zerbes, M. (2023). Key Performance Indicators for Smart Energy Systems in Sustainable Universities. Energies, 16(3), 1246.

[40] Kim, E., & Ha, Y. (2021). Vitalization Strategies for the Building Energy Management System (BEMS) Industry Ecosystem Based on AHP Analysis. Energies, 14(9), 2559.

[41] Kozlovska, M., Petkanic, S., Vranay, F., & Vranay, D. (2023). Enhancing Energy Efficiency and Building Performance through BEMS-BIM Integration. Energies, 16(17), 6327.

[42] Leiringer, R. (2020). Sustainable construction through industry self-regulation: the development and role of building environmental assessment methods in achieving green building. Sustainability, 12(21), 8853.

[43] Li, Q. Y. (2021). A novel real-time monitoring, notification, analytics system, and personal thermal sensations model for indoor air quality and energy efficiency in commercial buildings.

[44] Liu, Y., Chen, H., Zhang, L., Wu, X., & Wang, X. J. (2020). Energy consumption prediction and diagnosis of public buildings based on support vector machine learning: A case study in China. Journal of Cleaner Production, 272, 122542.

[45] Mahapatra, B., & Nayyar, A. (2022). Home energy management system (HEMS): Concept, architecture, infrastructure, challenges and energy management schemes. Energy Systems, 13(3), 643-669.

[46] Mannino, A., Dejaco, M. C., & Re Cecconi, F. (2021). Building information modelling and internet of things integration for facility management—Literature review and future needs. Applied Sciences, 11(7), 3062.

[47] Mariano-Hernández, D., Hernández-Callejo, L., Zorita-Lamadrid, A., Duque-Pérez, O., & García, F. S. (2021). A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis. Journal of Building Engineering, 33, 101692.

[48] Marinakis, V., Doukas, H., Tsapelas, J., Mouzakitis, S., Sicilia, Á., Madrazo, L., & Sgouridis, S. (2020). From big data to smart energy services: An application for intelligent energy management. Future Generation Computer Systems, 110, 572-586.

[49] Márquez-Sánchez, S., Calvo-Gallego, J., Erbad, A., Ibrar, M., Fernandez, J. H., Houchati, M., & Corchado, J. M. (2023). Enhancing building energy management: Adaptive edge computing for optimized efficiency and inhabitant comfort. Electronics, 12(19), 4179.

[50] Mason, K., & Grijalva, S. (2019). A review of reinforcement learning for autonomous building energy management. Computers & Electrical Engineering, 78, 300-312.

[51] Mataloto, B., Ferreira, J. C., & Cruz, N. (2019). LoBEMS—IoT for building and energy management systems. Electronics, 8(7), 763.

[52] Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., & Matarneh, R. (2019). Building information modeling for facilities management: A literature review and future research directions. Journal of Building Engineering, 24, 100755.

[53] Mehmood, M. U., Chun, D., Han, H., Jeon, G., & Chen, K. (2019). A review of the applications of artificial intelligence and big data to buildings for energy-efficiency and a comfortable indoor living environment. Energy and Buildings, 202, 109383.

[54] Merabet, G. H., Essaaidi, M., Haddou, M. B., Qolomany, B., Qadir, J., Anan, M., ... & Benhaddou, D. (2021). Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques. Renewable and Sustainable Energy Reviews, 144, 110969.

[55] Modieginyane, K. M., Malekian, R., & Letswamotse, B. B. (2019). Flexible network management and application service adaptability in software defined wireless sensor networks. Journal of Ambient Intelligence and Humanized Computing, 10, 1621-1630.

[56] Mohd Aman, A. H., Shaari, N., & Ibrahim, R. (2021). Internet of things energy system: Smart applications, technology advancement, and open issues. International Journal of Energy Research, 45(6), 8389-8419.

[57] Morton, A., Reeves, A., Bull, R., & Preston, S. (2020). Empowering and Engaging European building users for energy efficiency. Energy Research & Social Science, 70, 101772.

[58] Moya, F. D., Torres-Moreno, J. L., & Álvarez, J. D. (2020). Optimal model for energy management strategy in smart building with energy storage systems and electric vehicles. Energies, 13(14), 3605.

[59] Na, U., & Lee, E. K. (2020). Fog BEMS: An agent-based hierarchical fog layer architecture for improving scalability in a building energy management system. Sustainability, 12(7), 2831.

[60] Nagpal, H., Avramidis, I. I., Capitanescu, F., & Heiselberg, P. (2021). Optimal energy management in smart sustainable buildings–A chance-constrained model predictive control approach. Energy and Buildings, 248, 111163.

[61] Newton, S., Shirazi, A., & Christensen, P. (2023). Defining and demonstrating a smart technology configuration to improve energy performance and occupant comfort in existing buildings: a conceptual framework. International Journal of Building Pathology and Adaptation, 41(1), 182-200.

[62] Nguyen, T. H., Nguyen, L. V., Jung, J. J., Agbehadji, I. E., Frimpong, S. O., & Millham, R. C. (2020). Bio-inspired approaches for smart energy management: State of the art and challenges. Sustainability, 12(20), 8495.

[63] Nturanabo, F., Masu, L., & Kirabira, J. B. (2019). Novel applications of aluminium metal matrix composites. Aluminium alloys and composites.

[64] Nurlan, Z., Zhukabayeva, T., Othman, M., Adamova, A., & Zhakiyev, N. (2021). Wireless sensor network as a mesh: Vision and challenges. IEEE Access, 10, 46-67.

[65] O'Dwyer, E., Pan, I., Acha, S., & Shah, N. (2019). Smart energy systems for sustainable smart cities: Current developments, trends and future directions. Applied energy, 237, 581-597.

[66] Omrany, H. (2021). Incorporation of Embodied Energy into Building Energy-Efficiency Codes: A Pathway to Life-Cycle Net-Zero Energy Building in Australia (Doctoral dissertation).

[67] Park, S., Park, S., Choi, M. I., Lee, S., Lee, T., Kim, S., ... & Park, S. (2020). Reinforcement learning-based bems architecture for energy usage optimization. Sensors, 20(17), 4918.

[68] Parvin, K., Lipu, M. H., Hannan, M. A., Abdullah, M. A., Jern, K. P., Begum, R. A., ... & Dong, Z. Y. (2021). Intelligent controllers and optimization algorithms for building energy management towards achieving sustainable development: Challenges and prospects. IEEE Access, 9, 41577-41602.

[69] Prakash, A., Shrivastava, A., & Tomar, A. (2022). An Introduction to Smart Building Energy Management. In Control of Smart Buildings: An Integration to Grid and Local Energy Communities (pp. 1-13). Singapore: Springer Nature Singapore.

[70] Qolomany, B., Al-Fuqaha, A., Gupta, A., Benhaddou, D., Alwajidi, S., Qadir, J., & Fong, A. C. (2019). Leveraging machine learning and big data for smart buildings: A comprehensive survey. IEEE Access, 7, 90316-90356.

[71] Rashid, S. A., Haider, Z., Hossain, S. C., Memon, K., Panhwar, F., Mbogba, M. K., ... & Zhao, G. (2019). Retrofitting low-cost heating ventilation and air-conditioning systems for energy management in buildings. Applied Energy, 236, 648-661.

[72] Rathor, S. K., & Saxena, D. (2020). Energy management system for smart grid: An overview and key issues. International Journal of Energy Research, 44(6), 4067-4109.

[73] Sadeeq, M. A., & Zeebaree, S. (2021). Energy management for internet of things via distributed systems. Journal of Applied Science and Technology Trends, 2(02), 59-71.

[74] Saleem, M. U., Shakir, M., Usman, M. R., Bajwa, M. H. T., Shabbir, N., Shams Ghahfarokhi, P., & Daniel, K. (2023). Integrating smart energy management system with internet of things and cloud computing for efficient demand side management in smart grids. Energies, 16(12), 4835.

[75] Salimi, S., & Hammad, A. (2019). Critical review and research roadmap of office building energy management based on occupancy monitoring. Energy and Buildings, 182, 214-241.

[76] Sari, M., Berawi, M. A., Zagloel, T. Y., Madyaningarum, N., Miraj, P., Pranoto, A. R., ... & Woodhead, R. (2023). Machine Learning-Based Energy Use Prediction For The Smart Building Energy Management System. Journal of Information Technology in Construction, 28.

[77] Shah, A. S., Nasir, H., Fayaz, M., Lajis, A., & Shah, A. (2019). A review on energy consumption optimization techniques in IoT based smart building environments. Information, 10(3), 108.

[78] Simpeh, E. K., Pillay, J. P. G., Ndihokubwayo, R., & Nalumu, D. J. (2022). Improving energy efficiency of HVAC systems in buildings: A review of best practices. International Journal of Building Pathology and Adaptation, 40(2), 165-182.

[79] Sofos, M., Langevin, J. T., Deru, M., Gupta, E., Benne, K. S., Blum, D., ... & Widergren, S. (2020). Innovations in sensors and controls for building energy management: Research and development opportunities report for emerging technologies (No. NREL/TP-5500-75601; DOE/GO-102019-5234). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[80] Terroso-Saenz, F., González-Vidal, A., Ramallo-González, A. P., & Skarmeta, A. F. (2019). An open IoT platform for the management and analysis of energy data. Future generation computer systems, 92, 1066-1079.

[81] Tien, P. W., Wei, S., Darkwa, J., Wood, C., & Calautit, J. K. (2022). Machine learning and deep learning methods for enhancing building energy efficiency and indoor environmental quality–a review. Energy and AI, 100198.

[82] Urrea, C., & Benítez, D. (2021). Software-defined networking solutions, architecture and controllers for the industrial internet of things: A review. Sensors, 21(19), 6585.

[83] Uzair, M., & Kazmi, S. A. A. (2023). A multi-criteria decision model to support sustainable building energy management system with intelligent automation. Energy and Buildings, 301, 113687.

[84] Vahidinasab, V., Ardalan, C., Mohammadi-Ivatloo, B., Giaouris, D., & Walker, S. L. (2021). Active building as an energy system: Concept, challenges, and outlook. IEEE Access, 9, 58009-58024.

[85] Valinejadshoubi, M., Moselhi, O., Bagchi, A., & Salem, A. (2021). Development of an IoT and BIM-based automated alert system for thermal comfort monitoring in buildings. Sustainable Cities and Society, 66, 102602.

[86] Vandenbogaerde, L., Verbeke, S., & Audenaert, A. (2023). Optimizing building energy consumption in office buildings: A review of building automation and control systems and factors influencing energy savings. Journal of Building Engineering, 107233.

[87] Vučković, A., & Pitić, G. (2022). New technologies in energy management systems of buildings. Ekonomika preduzeća, 70(1-2), 75-86.

[88] Wang, D., Zhong, D., & Souri, A. (2021). Energy management solutions in the Internet of Things applications: Technical analysis and new research directions. Cognitive Systems Research, 67, 33-49.

[89] Ward, M., Allwood, J. M., Azevedo, J., Cleaver, C., Cullen, J., Dunant, C., ... & Zhou, W. (2019). Absolute zero: delivering the UK's climate change commitment with incremental changes to today's technologies.

[90] Wu, I. C., & Liu, C. C. (2019). A visual and persuasive energy conservation system based on BIM and IoT technology. Sensors, 20(1), 139.

[91] Yaïci, W., Krishnamurthy, K., Entchev, E., & Longo, M. (2021). Recent advances in Internet of Things (IoT) infrastructures for building energy systems: A review. Sensors, 21(6), 2152.

[92] Yang, Y., Bremner, S., Menictas, C., & Kay, M. (2022). Modelling and optimal energy management for battery energy storage systems in renewable energy systems: A review. Renewable and Sustainable Energy Reviews, 167, 112671.

[93] Yelisetti, S., Saini, V. K., Kumar, R., Lamba, R., & Saxena, A. (2022). Optimal energy management system for residential buildings considering the time of use price with swarm intelligence algorithms. Journal of Building Engineering, 59, 105062.

[94] Yu, L., Qin, S., Zhang, M., Shen, C., Jiang, T., & Guan, X. (2021). A review of deep reinforcement learning for smart building energy management. IEEE Internet of Things Journal, 8(15), 12046-12063.