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A Review of Smart Building Energy Management Systems (BEMS) to Enhance Building Sustainability

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The increasing demand for energy efficiency in buildings highlights the importance of Building Energy Management Systems (BEMS) in optimizing energy consumption and greenhouse gas emissions. While several research studies have focused on BEMS, there is still a lack of understanding of various energy management strategies for overall building performance. This research aims to define what constitutes a BEMS and its key components. It identifies and describes the various applications included in BEMS that facilitate energy efficiency and environmental control. Additionally, the study assesses the significant challenges faced during implementing BEMS in the construction industry, including compatibility issues and financial constraints. Furthermore, it evaluates the benefits of adopting BEMS in construction, particularly regarding energy efficiency and occupant comfort. The research also explores future directions and innovations in BEMS to enhance building sustainability and operational efficiency. A comprehensive literature review was conducted, analyzing 17 key papers from Scopus and Google Scholar databases. The findings indicate that BEMS allows for real-time monitoring and control of energy usage, significantly improving occupant comfort due to enhanced environmental conditions. Advanced technologies, such as the Internet of Things (IoT) and renewable energy sources, can be integrated to provide added functionality to BEMS. Proper implementation of BEMS brings substantial cost benefits to building owners and contributes to achieving sustainability goals. This work informs building managers, occupants, and policymakers about best practices for managing building energy, thereby identifying gaps in current building energy modeling and control strategies.

Keywords: Building Energy Management Systems, BEMS, Smart Buildings, Sustainability, Energy Efficiency, Renewable Energy Integration.

Introduction

The BEMS originated in the 1970s when energy efficiency became of great concern and required an increased need for better control of energy consumption in buildings. In the early 1970s, these systems were initially called Building Management Systems (BMS) or Building Automation Systems (BAS) and focused on essential electrical control over lighting and heating systems. Due to technological developments, such as microprocessors and digital controls, BEMS started to be fitted with more sophisticated functionalities that allow it to monitor and manage energy consumption in real time. Further significant field development has occurred since the 2000s with technologies based on Wireless Sensor Network (WSN) approaches. This further enables energy usage data to be gathered at finer levels of granularity than possible, for instance, at levels related to specific appliances or circuits. This development gave birth to smart meters and smart plugs that combined old-fashioned metering with communication capability, thus providing comprehensive information on resource consumption and enabling the implementation of functions for remote control. From then on, BEMS evolved into complex systems that monitor energy consumption, provide feedback, and offer means for its power. As a result, they form the foundation for more efficient and sustainable operation, contributing to the development of environmentally friendly, energy-efficient, and sustainable buildings through sustainable design processes (Nguyen & Adhikari, 2024).

Buildings can significantly benefit from managing energy usage and smartly enhancing sustainability. Tracking and controlling a building's energy needs in an advanced manner is referred to as a building energy management system (BEMS). In addition to energy management, this system oversees and regulates various other components, such as HVAC (heating, ventilation, and air conditioning), lighting, and security features. Energy management forms the basis for energy conservation and cost reduction. (Levermore, 2013). Both new and existing buildings can utilize this approach. BEMS is intelligent and adaptable, handling a building's access, security, fire, and HVAC. The BEMS industry is expanding as businesses realize the utility of improving a building's energy efficiency and reaping immediate benefits. While energy managers and building owners may possess existing systems in their structures, newer technology can economically extend the advantages of these structures. BEMS can enhance productivity by creating a more comfortable work environment and saving energy. Skyrocketing gas prices and concerns about global warming are two significant global trends, both providing strong incentives for energy efficiency. The World Business Council for Sustainable Development has stated that structures are the top five electricity consumers and that substantial changes are needed to improve energy efficiency in this sector (Barnett, 2004). In most countries, buildings account for 40 percent of energy consumption, which is rising. According to projections, building energy costs will account for over half of the new energy consumption estimates by 2030 (*Buildings - Energy System*, 2023). BEMS optimization leads to improved energy management. However, continuous building assessments, renovations, and adjustments are required to manage energy. Technological strategies for reducing energy consumption while maximizing occupant comfort are crucial, and factors such as the physical plant, operator, control numbers, zoning, and the environment in which the system is deployed all contribute to BEMS optimization (Kazmi et al., 2014).

Background

The primary motivation for increasing energy efficiency is to save costs; however, new structures have the added advantage of serving as involuntary surveillance and directing mechanisms, tracking, evaluating, and calculating usage to help with carbon reportage and dealing productivity. To track energy usage, detect waste, highlight opportunities for improvement, and compare consumption to similar buildings or organizations, users can gather, analyze, and translate these data into usable information (Sayed & A.Gabbar, 2018). Automatic surveillance and filtering are beneficial when monitoring many sites since they allow managers to drill down into individual locations and get a complete report of the overall business's energy utilization.

Some BEMS must have reporting capabilities to comply with ever-growing environmental regulations like the CRC energy conservation plan. The finest systems often reduce usage by 25 percent to quickly recoup investment costs and lower carbon emission fees. A conventional system can generate a return on investment within one to five years. An efficiency improvement calculator was used to estimate the power conservation from mounting a BEMS based on recent deployments for stove automation using BMS, which resulted in 28–54 percent reductions. Innovative finance models have been developed to broaden the availability of new technologies due to the rising focus on energy efficiency and the hesitation of enterprises to make any capital investments. An energy performance contract program called the Guaranteed Savings Contract offers the choice of purchasing energy monitoring systems you pay for while saving. Businesses can then enjoy instant energy savings without making capital investments or paying for setting up and contracting (Sayed & A. Gabbar, 2018). Energy and operating cost reductions under energy formation and management terms repay the investment.

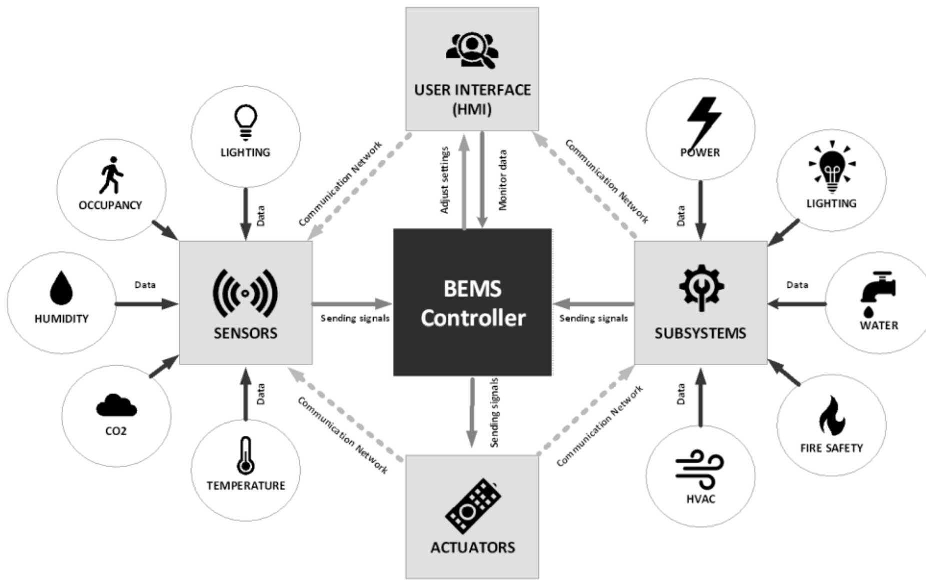

Figure 1. BEMS Components Concept Diagram

Figure 1 presents a conceptual overview of a BEMS, illustrating the relationships between its key components. The BEMS Main Controller is at the core, which serves as the processing hub. Data flows into the controller from various sensors that measure parameters such as temperature, humidity, and energy usage throughout the building. After processing this data with energy-saving algorithms, the controller sends control signals to actuators and subsystems like HVAC, lighting, and pumps, optimizing their operation. The actuators adjust the physical settings of these systems, such as modifying temperature or turning off lights. Building operators interact with the BEMS through a User Interface (HMI), which displays real-time data and allows adjustments to system settings. Finally, a Communication Network links all components as sensors, controllers, actuators, subsystems, and the user interface, enabling seamless data flow and control across the system. The interconnected structure ensures optimal energy efficiency and updated building management.

BEMS offers a computer-based platform that aims to bring together various building functions. These services can incorporate building automation and monitoring for HVAC, safety mechanisms, mechanical and electrical equipment, lights, transmission networks, and fire processes. BEMS are often designed to provide integrated, entirely computerized monitoring and control systems for power machinery, such as HVAC and lights. Nevertheless, they frequently exclude integrating systems for fire and security that are not considered electrical systems. Important components of the BEMS system requirements may depreciate without routine servicing or maintenance. For instance, temperature sensors may deteriorate and lose precision in their calibration or break or get broken; control dampers and valves may stop working correctly as they age or wear out. Thermal dead bands and solar cooling alternatives are the other two most frequent sources of issues (Harish & Kumar, 2016). The control software may also become outdated. Figure 2 has a word cloud generated from relevant papers, which presents the top 100 words constructed by collecting the different definitions available in the existing literature of 17 selected papers. It notes that the top words are *"Building," "Energy," "System," "Control," and "Management,"* among others, all representing that the technological and operational aspects of building management inspire the definition. Therefore, the data and building focus are the significant shortcomings of the current BEMS literature, indicating a need for more integrated approaches that include real-time data analysis, predictive maintenance, and enhanced system interoperability for more efficient and sustainable energy management.

Figure 2. Word Cloud of the BEMS in Literature (Retrieved data from Nvivo)

Methodology

The methodology for this research on BEMS involved a comprehensive literature review to identify and analyze existing studies on energy management in buildings. Initially, a systematic search was conducted using academic databases such as Scopus and Google Scholar, employing targeted keywords like *"BEMS"* and *"Building Energy Management Systems."* This search resulted in over 1,357 relevant articles. From this large pool, 17 key papers were selected based on the journal ranking and the paper's contribution to understanding BEMS, explicitly focusing on definitions, applications, challenges, benefits, and future directions. This approach facilitated a detailed understanding of the various applications of BEMS, the challenges encountered during implementation, and the benefits realized in terms of energy efficiency and occupant comfort. The literature review also aimed to identify gaps in current BEMS research and propose future directions for research and practice in the construction industry. Synthesizing the findings from the selected studies, this research provides a comprehensive overview of the state of BEMS, ensuring alignment with the research questions and objectives outlined in the Abstract and Results and Discussions section.

Literature Review of BEMS in Construction

The current body of literature on BEMS is vast, with numerous studies exploring technologies and strategies to enhance energy efficiency and reduce waste in building operations. A critical theme across the literature is using WSN and Smart Building Systems (SBS) to monitor and optimize energy usage. For example, Kazmi et al. (2014) discuss the deployment of WSNs as a central component of BEMS, enabling real-time data collection and energy management strategies that minimize waste and improve efficiency. Similarly, Dong et al. (2019) state how smart building sensing systems leverage indoor sensors to monitor thermal output, lighting, and air quality, optimizing these parameters to enhance energy efficiency and occupant comfort.

Another important trend is the integration of BEMS with smart grids and Distributed Energy Resources (DERs). According to Park et al. (2011), smart grids ensure real-time energy management and distribution, thus providing sustainable growth through optimization of energy generation and consumption. While this integration enhances reliability in energy supply, it affords better management of power fluctuations, as discussed by Rocha et al., 2015. In this study, Rocha and co-authors suggest incorporating DERs and other advanced models, such as the Custom Adoption Model (CAM), to improve grid resilience with reduced carbon emissions. The other focus point relating to the literature involves Automated Control Systems (ACS). Manic et al. (2016) explain that Building Automated Systems (BAS) and Building Control Systems (BCS) operate and supervise different building segments, such as electrical, mechanical, and plumbing systems. A BEMS focused on energy efficiency, utilities interface, and security would significantly lessen energy usage. This work was extended by Yonezawa (2000) to include comfort air conditioning control systems, which use data relating to the presence of occupants and usage in buildings, in general, to dynamically adjust heating and cooling to optimize energy use without sacrificing occupant comfort.

Previous studies have established that IoT is a crucial technology for modern BEMS, enabling remote monitoring and controlling building energy systems. Verma et al. (2019) illustrate through their analysis how IoT infrastructures allow for the off-site management of HVAC, lighting, and security through web-based platforms and mobile devices. This capability allows facility managers to maintain optimal energy efficiency and respond swiftly to changes or issues. Building on this foundation, the Internet of Energy (IoE) significantly enhances BEMS by offering a more integrated and responsive approach to energy management. This integration allows BEMS to benefit from IoE's robust architecture, which includes dependable data collection and analysis, scalability for future expansions, and adaptability to varying meteorological conditions (Verma et al., 2019; Zhang et al., 2018). For instance, IoE allows BEMS to dynamically adapt to the energy fluctuations within it and make informed decisions with real-time data to enhance its performance, thereby improving its energy efficiency and reducing operational costs. In this respect, the IoE-based BEMS integrates renewable energy sources and ensures adequate power quality and scalability. Such systems have also been able to answer current and future energy needs (Kazmi et al., 2014); Zhang et al., 2018). However, challenges such as high costs and environmental conditions must be managed to realize the potential of this technology fully (Hurtado et al., 2013; Sayed & A.Gabbar, 2018). Thus, IoE-BEMS can contribute effectively to bringing forth sustainable and effective energy management solutions.

Furthermore, several studies focus on Simulation and Real-Time Adaptation Frameworks. For instance, Ock et al. (2016) discuss a conceptual framework for BEMS that adapts to external conditions such as weather changes and daylight fluctuations in real time. By developing sophisticated control algorithms and simulation models, this approach allows buildings to maintain energy efficiency dynamically. Similarly, Chen et al. (2009) provide insights into integrating BEMS into the architectural design phase, demonstrating how real-world data can be used to validate the effectiveness of energy management strategies in reducing costs and enhancing occupant comfort.

Table 1. Summary of Selected BEMS Studies

#	Authors & Year	Methodologies	Key Contributions
1	Harish & Kumar (2016)	Literature Review	A comprehensive review of modeling methodologies for building energy systems.
2	Dong et al. (2019)	Systematic Literature Review	Advancements in smart building sensing systems for indoor quality improvement.
3	Zhang et al. (2018)	Critical Review	Energy systems integration at cluster levels, renewable energy optimization.
4	Kazmi et al. (2014)	Analytical Review	WSN for real-time building energy monitoring.
5	Barnett (2004)	Thematic Analysis	Globalization and sustainability debate with environmental focus.
6	Sayed & Gabbar (2016)	Case Study	Insights into energy management in smart buildings.
7	Park et al. (2011)	Experimental Study	Development of smart grid-based energy management systems.
8	Hurtado et al. (2013)	Optimization Study	Balancing comfort and energy use in building systems.
9	Manic et al. (2016)	Analytical Framework	Explores intelligent and adaptive approaches in energy management.
10	IEA (2020)	Policy Review	Discusses energy system policies and implications for buildings.
11	Yonezawa et al. (2000)	Experimental Simulation	Air conditioning control strategies for energy savings.
12	Jia et al. (2018)	Design Framework	Automation design for smarter building system operations.
13	Rocha et al. (2015)	Comparative Study	Policy impacts on energy efficiency improvements in smart buildings.
14	Verma et al. (2019)	Review Article	IoT infrastructure development for sensing and controlling in buildings.
15	Ock et al. (2016)	Simulation Study	Conceptual framework for energy management systems simulation.
16	Chen et al. (2009)	Case Study	Design and implementation of control systems for smart buildings.
17	Buckman et al. (2014)	Conceptual Review	Defines the concept of smart buildings and their components.

*Note: IEA - The International Energy Agency

The table provides a critical synthesis of 17 research papers that examine advancements and challenges in energy management, smart building systems, and sustainability within the built environment. These studies underscore a growing emphasis on leveraging innovative technologies such as IoT (e.g., Verma et al., 2019) and WSN (Kazmi et al., 2014) to enhance real-time monitoring and optimize building energy systems. Methodologies span literature reviews, simulation frameworks, experimental studies, and comparative analyses, each uncovering unique perspectives on energy modeling and system design complexities. For example, Harish & Kumar (2016) present a foundational review of energy modeling methodologies, while Rocha et al., (2015) critically examine the intersection of policy measures and smart energy management systems. Despite these advancements, notable gaps persist in addressing scalability and integrating emerging technologies into existing infrastructures, as Dong et al. (2019) highlighted in their smart building sensing systems analysis. While the contributions signal a paradigm shift toward intelligent, adaptive, and sustainable building solutions, many remain conceptual, lacking robust empirical validation and practical implementation strategies. The compilation highlights the need for interdisciplinary approaches to bridge theoretical innovations with real-world applications, particularly in achieving resilient and sustainable buildings. Moreover, the studies collectively support a multifaceted approach incorporating advanced sensor networks, smart grid integration, automated controls, IoT technologies, and adaptive simulation models. This approach is important for optimizing energy use, reducing costs, and enhancing occupant comfort in modern BEMS, aligning these technologies as a key in shaping the future of sustainable construction.

Results and Discussion

A variety of definitions of BEMS are employed across industry and academia. This lack of consistency has led to a breadth of illustrations and a misunderstanding of the concept of BEMS. To answer research questions, BEMS definitions have been analyzed for detailed review from relevant selected papers. The literature review compares different definitions of the term *"Smart Building Energy Management System"* to answer the following research questions:

Question #1: What is a Smart Building Energy Management System?

A Smart BEMS focuses on the methodology of integrating various technologies and systems for better energy efficiency in a building. According to Kazmi et al. (2014), the definition also elaborates that BEMS encompasses wide-ranging solutions in building energy management, covering applications of sensor and actuator networks, energy management and control, system modeling, and simulation tools. Manic et al. (2016) further explain that BEMS would normally execute control functions of HVAC and systems of lighting, amongst other building systems such as physical security, fire safety, and access control. These systems connect state-of-the-art software to monitor energy use, track real-time energy consumption patterns as well as point out abnormal usage to maintain the best indoor environmental quality in association with minimum costs, as indicated by Ock et al. (2016). Again, BEMS will also be able to interface with smart grids through demand response, where the amount of energy used would vary automatically depending on grid conditions, improving the overall energy usage efficiency. According to Park et al. (2011), a Smart BEMS takes full advantage of data from various building operations to achieve optimum energy consumption and sustainability.

Question #2: What applications are included in the BEMS?

BEMS incorporates multiple applications to facilitate energy efficiency and environmental control for different settings. Among the primary computer-assisted applications are online monitoring systems for businesses and smart buildings that use specialized software to manage energy consumption in real time (Kazmi et al., 2014). Thermal control is another crucial application involving indoor air and environmental control systems to regulate building HVAC systems (Dong et al., 2019). BEMS are also widely implemented in the utility sector, where they integrate with electrical grids and metering systems to optimize energy distribution and usage across cities, states, and countries (Park et al., 2011). Applications from BEMS concern residential and commercial automation, whereby specific systems manage HVAC, lighting, and electrical systems to enable energy efficiency and occupational comfort (Manic et al., 2016; Yonezawa, 2000). The integration of Internet-based applications further allows for remote management of the security, electrical, and HVAC systems, thus further increasing flexibility and control over building operations (Verma et al., 2019). Additionally, BEMS manages the control of thermostats and lighting systems within the premises for the best environmental conditions with a minimum energy cost (Ock et al., 2016). Together, these applications show how versatile BEMS is in pursuing energy efficiency and sustainability for differently constituted constructions.

Question #3: What are the significant challenges when implementing a BEMS?

Implementing a BEMS in the construction industry establishes several significant challenges. A primary challenge is the integration of BEMS into existing systems and buildings, which often face compatibility issues with mechanical, electrical, and plumbing (MEP) systems and existing software infrastructure, leading to potential software conflicts and the need for server maintenance (Kazmi et al., 2014). Moreover, the financial involvement and convincing building owners to invest in upgrading their buildings to include smart management systems continues to be another financial problem; this is especially true with current difficulties in finding compatible software solutions (Dong et al., 2019; Verma et al., 2019). The design and management of software that can manage large-scale energy grid systems, for instance, at country levels, is also quite a challenge, requiring specialized training or hiring of personnel to manage and analyze the energy data efficiently (Park et al., 2011). Installation of sensory systems for energy consumption monitoring and subsequent requirements for compatible mechanical equipment, together with new security systems, make things quite complicated, often requiring additional staff or hiring independent firms that could monitor and maintain such systems (Manic et al., 2016; Jia et al., 2018). Furthermore, implementing new and untested procedures to manage energy consumption efficiently requires comprehensive training, which can be resource-intensive and challenging to implement (Rocha et al., 2015; Ock et al., 2016). Apparently, due to the competitive nature of tenders in the construction industry, the increased costs associated with BEMS could mean lost tenders where a competitor does not offer such a superior type of system (Chen et al., 2009).These challenges present a combination of technological, financial, and operational problems that hide the use of BEMS in the construction industry.

Question #4: What are the benefits of adopting a BEMS in Construction?

Adopting BEMS in construction has several beneficial factors that enhance the elements of energy efficiency and building management. A primary advantage is the ability to remotely monitor and control various energy systems through the Internet, such as HVAC, lighting, and electrical systems. This capability not only ensures optimal energy use but also enables advanced security measures like controlling doors and CCTV systems from a centralized platform (Kazmi et al., 2014; Manic et al., 2016; Verma et al., 2019). Besides, BEMS enhances HVAC system management, maintaining a comfortable environment for the occupants and conserving energy when a space is empty, thus providing considerable cost savings and enhanced energy efficiency (Dong et al., 2019; Jia et al., 2018). On a larger scale, BEMS may contribute to controlling energy consumption at higher levels, such as for whole countries, thanks to interfacing with other systems, including Distributed Energy Resources (DER) and Microgrid Customer Engineering Economic Models (MCEEM), to stabilize power fluctuations, meet demand, and reduce CO_2 emissions (Rocha et al., 2015)The adoption of BEMS contributes to smarter and more sustainable building operations, improving comfort, security, and energy management at multiple scales.

Question #5: What are the future directions of BEMS?

The future directions of BEMS will go toward better energy efficiency, further integration, and market access. Major technological advancements in readiness will make way for new systems in the market for better energy consumption globally through improved digital monitoring and control (Kazmi et al., 2014; Verma et al., 2019). There is also a growing emphasis on meeting occupant needs and comfort, supported by government programs that promote integration and lower upfront costs for adoption (Dong et al., 2019). As these systems get further standardized and permeated, one can expect an increased focus on cybersecurity to protect the digital infrastructure of BEMS and provide stability in building ecosystems (Manic et al., 2016; Jia et al., 2018). It will also enable the use of new software and equipment that comply with it to easily integrate and bring more flexibility to building management, which may result in high energy savings and jobs in energy management (Rocha et al., 2015). Furthermore, future BEMS might also be able to incorporate advanced smart sensors and climate control systems that optimize indoor environmental quality and indoor occupants' satisfaction (Chen et al., 2009)With increased awareness of building owners of the benefits of Smart Building Systems (SBS), more investments in these technologies would drive innovation and adoption.

Conclusions

This study underscores the critical role of Building Energy Management Systems (BEMS) in enhancing energy efficiency and promoting sustainability within the construction industry. A comprehensive literature review identified significant gaps in the current understanding of various energy management strategies and their impact on overall building performance. The findings reveal that BEMS facilitates real-time monitoring and control of energy usage, significantly improves occupant comfort, and leads to substantial cost savings for building owners. Moreover, integrating advanced technologies, such as the IoT and renewable energy sources, is essential for maximizing the functionality of BEMS and achieving sustainability objectives. Our research contributes to the body of knowledge by providing an in-depth understanding of how BEMS can optimize energy consumption, reduce greenhouse gas emissions, and enhance the overall operational efficiency of buildings. As we navigate increasingly complex energy landscapes, it is imperative that stakeholders, including building managers, occupants, and policymakers, leverage the insights gained from this study to implement best practices in energy management. Future studies shall fill these knowledge gaps by studying the interactions of different measures, such as radiant heat construction, lighting adjustments, and HVAC optimizations toward further BEMS and energy management strategy enhancements. By doing so, we can pave the way for more energy-efficient buildings that contribute to a sustainable future

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