ISSN-2394-5125 VOL 11, ISSUE 02, 2024

ADVANCEMENTS IN SMART BUILDING ENERGY MANAGEMENT SYSTEMS FOR ENHANCED ENERGY EFFICIENCY

***Rushika Gupta**

*natashagaurav2004@gmail.comB-2/141 Paschim Vihar , 110063 New Delhi

Abstract:
This paper reviews innovative techniques, particularly the Building Energy Management Open Source Software (BEMOSS), to optimize energy use in commercial buildings. It introduces a Smart Building Energy Management System that dynamically regulates energy consumption based on real-time occupancy and demand. A network of sensors monitors occupancy, environmental conditions, and energy requirements, enabling intelligent adjustments to lighting, heating, and cooling. Emphasizing cybersecurity, the proposed system integrates robust measures for data security and system integrity. Compliant with standards and scalable, it promises immediate energy savings and adaptability to future advancements. This groundbreaking solution aims to revolutionize energy efficiency in various building types, fostering a more efficient and sustainable future in building energy management.

Keywords— Building Energy Management System (BEMS) , Energy efficiency, Smart buildings, Energy consumption patterns, Building automation, BEMOSS (Building Energy Management Open Source Software),
Sensor networks

I. INTRODUCTION

The global surge in energy demand, coupled with the imperative need to curtail energy consumption and reduce carbon footprints, has propelled the development and adoption of innovative solutions in the realm of building energy management. In this context, Building Energy Management Systems (BEMS) have emerged as a key technological frontier, offering intelligent, data-driven approaches to optimize energy use in commercial buildings. This introduction provides a comprehensive overview of the challenges faced in energy consumption, the significance of BEMS, and the core objectives of a proposed Smart Building Energy Management System.

Energy Consumption Challenges:

The rapid urbanization and industrialization of the modern world have led to an unprecedented increase in energy consumption, particularly in commercial buildings. According to the International Energy Agency (IEA), the energy demand from buildings is expected to rise by 50% by 2050, posing significant challenges in terms of energy sustainability and environmental impact. The increasing strain on energy resources necessitates a paradigm shift in how buildings are designed, operated, and managed.

Theoretical Framework:

To understand the theoretical underpinnings of energy management in buildings, let us consider a basic mathematical representation of energy consumption:

$$E\text{total}=E\text{lighting}+E\text{heating}+E\text{cooling} +E\text{appliances}+\ldots$$

attributed to lighting, heating, cooling, appliances, and other factors, respectively.
This equation illustrates the multifaceted nature of energy consumption in a building, emphasizing the importance of a holistic approach to energy management.

$$f(\text{Occupancy},\text{Lighting Conditions},\text{Temperature},\text{Hi storical Data},\ldots)$$

conditions, temperature, historical data, and other relevant factors.
The system's user interface provides building managers with an intuitive dashboard for control and insights, while feedback mechanisms empower occupants to make informed decisions about their energy consumption.

Facts and Figures:

a. According to the U.S. Energy Information Administration (EIA), commercial buildings in the United States accounted for about 19% of the total energy consumption in 2020.
b. A study by the American Council for an EnergyEfficient Economy (ACEEE) estimates that implementing advanced BEMS in commercial buildings could result in energy savings of up to 20%.

ISSN-2394-5125 VOL 11, ISSUE 02, 2024

c. The Environmental Protection Agency (EPA) states that buildings in the United States are responsible for nearly 40% of the country's greenhouse gas emissions, emphasizing the urgent need for energy-efficient solutions.
d. The global market for Building Energy Management Systems is projected to reach $9.64 billion by 2027, indicating a growing recognition of the importance of energy-efficient building operations.

Components of the Smart Building Energy Management System:

The proposed Smart Building Energy Management System comprises several integral components working in harmony to achieve optimal energy efficiency:

a. Sensor Networks:

The system relies on a network of sensors strategically placed throughout the building. Occupancy sensors detect human presence, enabling the system to adjust lighting and environmental conditions based on realtime occupancy patterns. Light sensors assess natural light availability, contributing to optimized artificial lighting adjustments. Temperature and humidity sensors provide crucial data for Heating, Ventilation, and Air Conditioning (HVAC) systems, ensuring efficient management of the building's thermal conditions.

b. Data Analytics Engine:

At the heart of the system is a sophisticated data analytics engine. This engine processes the data collected by sensors in real time, employing advanced algorithms to interpret patterns, trends, and correlations. The mathematical models within this engine enable the system to make predictions about future energy demand, allowing for proactive adjustments to optimize energy consumption.

c. Machine Learning Models:

Machine learning algorithms play a pivotal role in enhancing the system's intelligence. By continuously learning from historical data and adapting to changing conditions, these models contribute to more accurate predictions and efficient energy management. The system becomes capable of recognizing patterns that may not be apparent through conventional programming, enabling a higher degree of adaptability.

d. User Interface:

A user-friendly interface serves as the bridge between the Smart BEMS and building managers or occupants. The dashboard provides real-time insights into energy consumption patterns, system performance, and environmental conditions. Building managers can use the interface to make manual adjustments or set preferences, while occupants gain visibility into their individual energy consumption behaviors.

Advanced Mathematical Models for Energy Forecasting:

The energy forecasting aspect of the proposed system relies on advanced mathematical models that consider a multitude of variables. One such model is a regressionbased formula that incorporates factors like occupancy, lighting conditions, temperature, historical data, and even external factors like weather forecasts:

$$E\text{forecast}=\beta 0+\beta 1\times\text{Occupancy}+\beta 2\times\text{Lighting Conditions}+\beta_3\times\text{Temperature}+\beta_4\times\text{Historical Data}+\ldots$$

,… are coefficients determined through statistical analysis. This formula represents a dynamic approach to energy forecasting, acknowledging the interconnectedness of various factors influencing energy consumption.

Benefits of the Smart Building Energy Management System:

The proposed system offers a myriad of benefits, including:

a. Energy Savings:

Real-time adjustments and proactive energy optimization strategies contribute to substantial energy savings. Studies suggest that advanced BEMS implementations can lead to energy savings ranging from 10% to 30%.

b. Environmental Impact:

By curbing energy consumption and reducing greenhouse gas emissions, the system aligns with global efforts to combat climate change. The EPA estimates that a 10% reduction in commercial building energy consumption could mitigate approximately 22 million metric tons of carbon dioxide emissions annually.

c. Cost-Effectiveness:

The upfront investment in implementing the Smart BEMS is offset by long-term cost savings resulting from reduced energy bills. The system's adaptability ensures continued effectiveness, even as technology evolves.

d. Occupant Comfort and Productivity:

The system's ability to maintain optimal environmental conditions enhances occupant comfort and productivity. By tailoring lighting and climate control to individual preferences, it creates a conducive and pleasant workspace.

ISSN-2394-5125 VOL 11, ISSUE 02, 2024

Fig. 1. BEMOSS system architecture for commercial buildings

BUILDING ENERGY MANAGEMENT SOFTWARE: EMPOWERING EFFICIENCY IN THE BUILT ENVIRONMENT

Building Energy Management Software (BEMS) has emerged as a pivotal tool in the pursuit of enhanced energy efficiency and sustainability within the built environment. As energy consumption in buildings continues to be a significant contributor to global energy demand, the need for sophisticated software solutions has become paramount. This article explores the landscape of BEMS, highlighting key functionalities, notable software platforms, and the transformative impact these technologies have on optimizing building energy use.

Overview of Building Energy Management Software:

BEMS is a comprehensive platform designed to monitor, control, and optimize energy usage within buildings. It encompasses a range of functionalities, including real-time monitoring, data analytics, and automation, allowing building operators to make informed decisions for efficient energy management. The software serves as a bridge between various building systems, such as HVAC, lighting, and security, ensuring a holistic approach to energy optimization.

Key Functionalities of BEMS:

a. Real-time Monitoring:

BEMS provides real-time visibility into a building's energy consumption patterns. Through the integration of sensors and meters, operators can monitor electricity, gas, and water usage, enabling a granular understanding of where and how energy is being utilized.

ECO STRUXURE BUILDING:

EcoStruxure Building Expert, formerly known as SmartStruxure Lite solution, represents a cutting-edge approach to monitoring and controlling small to medium-sized buildings. It distinguishes itself by offering a web interface without license fees, coupled with wireless technologies for seamless integration [2]. This solution is part of the broader EcoStruxure system architecture, meticulously designed to supervise, control, and manage overall enterprise performance [3].

At the core of the EcoStruxure Building Expert lies the Multi-Purpose Management devices (MPM). These devices seamlessly integrate programmable controller, gateway, and web server functionalities into a single unit. The MPM serves as the host for EcoStruxure Building Expert, eliminating the need for specialized gateways or servers. This innovative design results in a cost-effective solution for small and medium-sized buildings, making it an economically viable choice [2].

Beam radiation (I_{bc}) + Sky diffuse radiation (I_{dc}) + Ground reflected radiation (I_{rc}) $S_T = I_{bc} + I_{dc} + I_{rc}$	
$I_{bc} = C_n I e^{-k/\sin\alpha} * \cos i$	C_n = clearness number (assuming the value of 1) I = extraterrestrial solar radiation k = atmospheric optical depth α = solar altitude angle i = angle of incidence
$I_{dc} = C(C_n I e^{-k/\sin\alpha})\cos^2(\beta/2)$	C = sky diffuse factor β = wall angle
$I_{rc} = \rho C_n I e^{-k/\sin\alpha}(\sin\alpha + C)\sin^2(\beta/2)$	ρ = ground reflection factor (0.2)

ISSN-2394-5125 VOL 11, ISSUE 02, 2024

ECOSTRUXURE BUILDING EXPERT: A REVOLUTIONARY BUILDING MANAGEMENT SYSTEM

EcoStruxure Building Expert, formerly recognized as the SmartStruxure Lite solution, signifies a transformative leap in the realm of buildingmanagement systems (BMS). By offering a license-freeweb interface and incorporating wireless technologies, this solution has become a go-to choice for efficiently monitoring and controlling small to medium-sized buildings. Part of the broader EcoStruxure system architecture, it is meticulously designed to provide a holistic approach to managing enterprise performance [22].

Eco Struxure Methodology:

The EcoStruxure Methodology, proposed by researchers D. Mora, M. Taisch, and A.W. Colombo [23], introduces a structured four-step life cycleprocess. This process serves as the foundation for the seamless integration and operation of the EcoStruxure system. With a focus on efficiency, this methodology underscores the importance of controlling three major loads – HVAC, lighting, and metering – collectively responsible for a substantial portion of a building'senergy consumption.

Multi-Purpose Management Devices (MPM):

At the heart of the EcoStruxure Building Expert lies the Multi-Purpose Management devices (MPM). These devices are revolutionary in their integration of programmable controller, gateway, and web server functionalities into a single, cohesive unit. By hosting EcoStruxure Building Expert, the MPM eliminates the need for specialized gateways or servers, providing an In conclusion, EcoStruxure Building Expert stands as a revolutionary solution in the field of building energy management. Its innovative design, featuring MultiPurpose Management devices and a license-free web interface, sets it apart in terms of cost-effectiveness and versatility. With an emphasis on scalability, open access, and the integration of cutting-edge technologies, EcoStruxure represents a forward-thinking approach to building management systems. As the building management landscape continues to evolve, EcoStruxure's prominence is likely to grow, making it a cornerstone in the pursuit of energy-efficient and smart building solutions.

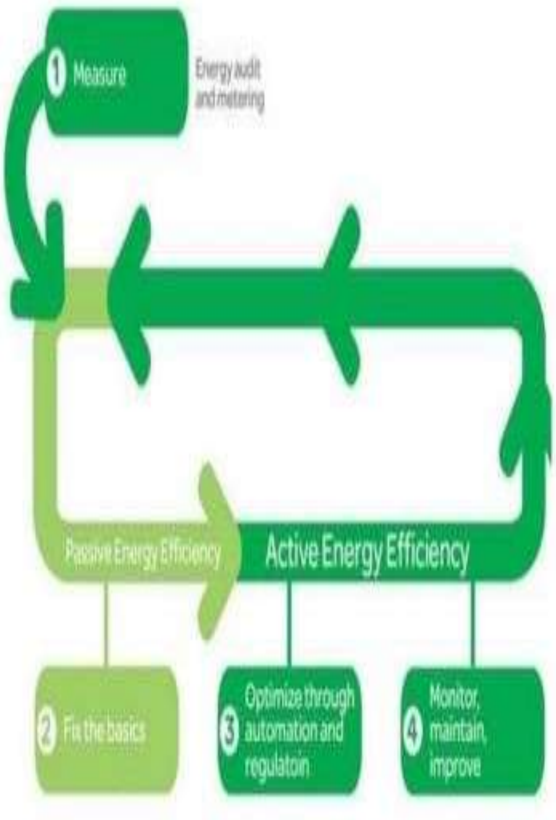

Fig. 2. Four Step Life Cycle Process

ISSN-2394-5125 VOL 11, ISSUE 02, 2024

METHODOLOGY

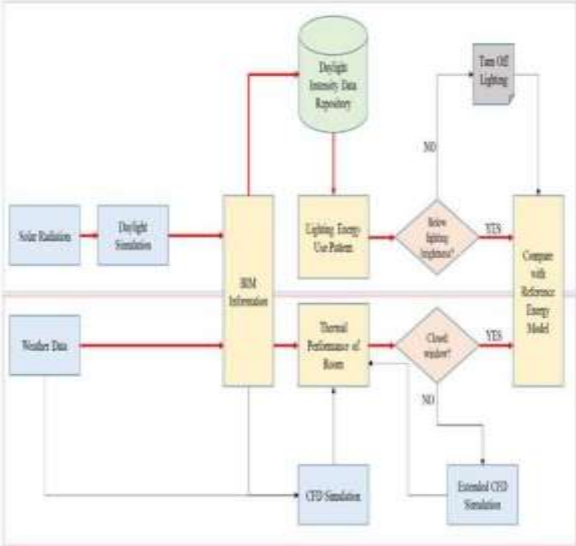

Fig. 3 Smart BEMS Conceptual Framework.

Hourly daylighting simulation was conducted for a typical office building schedule from 8 am to 5 pm on December 3rd, 2015. Results, depicted in visual images and a spreadsheet (Figure 3), showcase daylighting intensity at 1-hour intervals. Daylighting images are averaged over each hour, highlighting the proposed office space's illumination levels. The spreadsheet provides transient daylighting intensity at the simulation's start and end times. Figure 3 specifically illustrates daylighting levels at key times (9 am, 1 pm, 3 pm, and 5 pm) to identify instances of excessive lighting in the analyzed space.

Heating and Cooling Controlled BEMS:

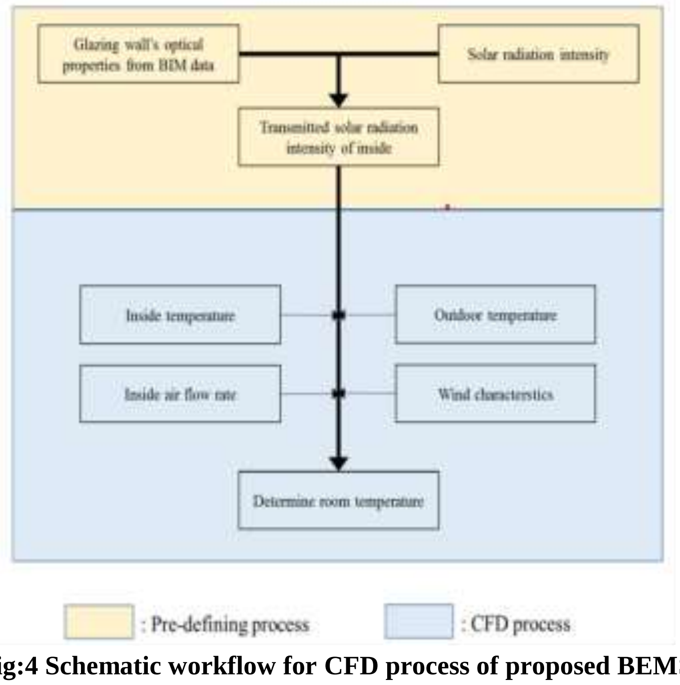

Fig:4 Schematic workflow for CFD process of proposed BEMS.

and Powerful Analytics and Reporting functionalities. Notably, the suite incorporates alerting capabilities to ensure timely responses to energy-related events. The Cisco Energy Management Suite [7] revolves around four key functions:

Discovery and Measurement:
Through automated processes, this function identifies and measures all network-connected devices and systems, laying the groundwork for a comprehensive understanding of the energy landscape.

ISSN-2394-5125 VOL 11, ISSUE 02, 2024

Assessment and Simulation:
The suite delves into a thorough analysis of energy usage, carbon emissions, as well as environmental factors like temperature and humidity. This critical evaluation enables users to make informed decisions about energy conservation.

Policy and Control:
Following a detailed analysis of energy consumption patterns, the suite executes various policies and control commands. This ensures that energy usage aligns with predefined parameters and guidelines, contributing to efficient energy management.

Reporting and Decision Support:
The final function involves the delivery of comprehensive reports. These reports consolidate data from the discovery, assessment, and policy enforcement phases, providing users with actionable insights and decision support for ongoing energy optimization efforts.

In essence, the Cisco EnergyWise Management Suite acts as a holistic solution, combining continuous monitoring, analytical capabilities, and proactive control features. By addressing the entire spectrum of energy management, from initial discovery to policy enforcement and reporting, the suite empowers users to make informed decisions, reduce energy costs, and enhance overall energy efficiency in their respective environments.

Fig. 3. Four Major Functions of Cisco Energy Management Suite

BENEFITS

Environmental Sustainability:
In the face of escalating concerns about climate change and the rising emission of greenhouse gases globally, the concept of 'Green Home' or 'Green Building' gains significance. This entails the practice of creating environmentally responsible and resource-efficient structures and processes. The incorporation of a Building Energy Management System aids in monitoring energy usage, offering suggestions to reduce CO_2 emissions—a significant contributor to global warming.

Peaceful Operation:
Beyond energy savings, the BEMS provides a sense of peace. Users are relieved from the constant need to manually turn electrical appliances on and off. The system automatically adjusts based on requirements, tracking energy consumption patterns around the clock and sending alerts to users when they are away from the building.

Demand Response Solutions for Renewable Energy:
With an increasing global shift towards renewable energy sources due to cost-effectiveness and the depletion of non-renewable resources, BEMS plays a pivotal role. It facilitates the implementation of Demand Response Programs, simplifying the interaction for software companies in smart buildings [29].

ISSN-2394-5125 VOL 11, ISSUE 02, 2024

Cost Reduction:
Continuous monitoring and control of energy usage by the BEMS result in automatic reductions in electricity bills, contributing to cost savings.

Enhanced Comfort:
BEMS, by regulating conditions like temperature, lighting, air quality, ventilation, and humidity, creates a more comfortable and relaxing environment for employees. This focus on comfort extends beyond energy savings, contributing to a conducive working atmosphere.

. CONCLUSION

In this paper, we extensively reviewed diverse technologies and software solutions for enhancing energy efficiency in buildings. Technologies like BEMOSS and various software applications have shown the potential for significant energy savings, ranging from 10-35%. Building Energy Management Systems (BEMS) emerged as crucial for optimizing energy usage, aiming not only for efficiency but also healthier environments and a shift in user behavior.

REFERNECES

[1] The International Energy Outlook 2016, [Online].Available:https://www.eia.gov/outlooks/ieo/pdf/buildings.pdf.

[2] IEEE Spectrum–Magazine [Online]. Available: http://spectrum.ieee.org/energywise/energy/thesmarter-grid/a-postmortem-on-india-blackout.

[3] N. Mohamed, S. Lazarova-Molnar, and J. AlJaroodi, "CE-BEMS: A cloud-enabled building energy management system," 2016 3rd MEC Int. Conf. Big Data Smart City, ICBDSC 2016, pp. 351–356, 2016.

[4] C. Kaiwen, A. Kumar, N. Xavier, and S. K. Panda, "An intelligent home appliance control-based on WSN for smart buildings," IEEE Int. Conf. Sustain. Energy Technol. ICSET, pp. 282–287, 2017.

[5] Y. Ozturk, D. Senthilkumar, S. Kumar, and G. Lee,"An intelligent home energy management system to improve demand response," IEEE Trans. Smart Grid, vol. 4, no. 2, pp. 694–701, 2013.

[6] M. Erol-Kantarci and H. T. Mouftah, "Wireless Sensor Networks for Cost-Efficient Residential Energy Management in the Smart Grid," IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 314–325, 2011.

[7] S. R. Griful, U. Welling, and R. H. Jacobsen, "Multimodal Building Energy Management System for Residential Demand Response," 2016 Euromicro Conf. Digit. Syst. Des., pp. 252–259, 2016.

[8] M. Louvel, F. Pacull, and M. I. Vergara-Gallego,"Coordination Scheme Editor for building management systems," IECON Proc. (Industrial Electron. Conf., pp. 7052–7057, 2016.

[9] M. Kuzlu, M.Pipattanasomporn, and S.Rehman, "Hardware Demonstration of a Home Energy Management System for Demand ResponseApplications," IEEE Trans. Smart Grid, vol. 3, no. February 2016, pp. 2012–2015, 2012.

[10] M. Pipattanasomporn, M. Kuzlu, S. Rahman, S. Member, M. Kuzlu, and S. Rahman, "An Algorithm for Intelligent Home Energy Management and Demand Response Analysis," IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 1–8, 2012.

[11] P. Zhao, M. G. Simoes, and S. Suryanarayanan, "A conceptual scheme for cyber-physical systems based energy management in building structures," 2010 9th IEEE/IAS Int. Conf. Ind. Appl. - INDUSCON 2010, pp.1–6, 2010.

[12] Freedomotic Open Source Building Automation [Online]. Available: http://freedomotic.com/.

[13] OpenRemote Open Source Automation Platform [Online]. Available: http://www.openremote.org/.

[14] OpenHAB empowering the smart home [Online].Available: http://www.openhab.org/

[15] X. Zhang, R. Adhikari, M. Pipattanasomporn, M. Kuzlu, and S. R. Bradley, "Deploying IoT devices to make buildings smart: Performance evaluation and deployment experience," 2016 IEEE 3rd World Forum Internet Things, WF-IoT 2016, pp. 530–535, 2017.

[16] M. Pipattanasomporn, M. Kuzlu, W. Khamphanchai, A. Saha, K. Rathinavel, and S.Rahman, "BEMOSS: An agent platform to facilitate grid-interactive building operation with IoT devices," Proc. 2015 IEEE Innov. Smart Grid Technol. - Asia, ISGT ASIA 2015, pp. 1–6, 2016.

[17] W. Khamphanchai, M. Pipattanasomporn, M. Kuzlu, and S. Rahman, "An agent-based open source platform for building energy management," Proc. 2015 IEEE Innov. Smart Grid Technol. - Asia, ISGT ASIA 2015, 2016.

[18] Cisco, the Internet of Things, 2015[Online].Available: http://share.cisco.com/internetofthings.html

[19] W. Khamphanchai et al., "Conceptual architecture of building energy management open source software (BEMOSS)," IEEE PES Innov. Smart Grid Technol. Eur. Istanbul, pp. 1–6, 2014.

[20] BEMOSS: An open source platform for building energy management, [Online]. Available: www.bemoss.org/bemosssoftware-architecture/.

[21] BEMOSS: An open source platform for building energy management, [Online]. Available: www.bemoss.org/features/.

[22] EcoStruxure Building Expert, [Online]. Available: http://www.schneiderelectric.com/b2b/en/campaign/innovation/buildings.jsp