Journal of Advances in Developmental Research (IJAIDR)

E-ISSN: 0976-4844 ● Website: www.ijaidr.com ● Email: editor@ijaidr.com

Building Management System (BMS) an In-Depth Overview (Understanding BMS, Its Operation, Necessity, and the Role of IoT)

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Abstract

Building management systems have now become a vital tool for enhancing the energy efficiency, comfort, and automatic operation of buildings. Through the integration of all kinds of technologies, BMS controls and monitors such critical systems as HVAC, lighting, and security, reducing manual intervention and operation costs. The introduction of IoT significantly raised the bar in BMS functionality, allowing real-time acquisition of data, analytics, and predictive maintenance. IoT-connected sensors and devices, such as temperature, humidity, motion, and occupancy sensors, deliver real-time information to help in enhancing the performance and sustainability of a building. Niagara or horizontal M2M frameworks can ensure smooth communication among devices and thus provide scalable solutions for energy and building management. Integration of IoT in BMS provides operational efficiency besides helping the technicians to take proactive actions over impending issues, ensuring continuity of operation with minimum downtime. The paper examines the working, need, and benefits of BMS, the role of IoT in bringing a change in basic assumptions, and the types of sensors/devices available in the market.

Keywords: Building Management System, IoT, Energy Efficiency, Smart Buildings, HVAC Systems, Sensors, Predictive Maintenance, Automation, Niagara Framework, and Building Automation.

I. INTRODUCTION

A building management system, often referred to as a building automation system, is an intelligent control system that is applied in monitoring and controlling the mechanical, electrical, and environmental systems within a building. The HVAC system, lighting, security, and fire safety all make up this structure. BMS ensures the best performance and energy efficiency, as well as the comfort of the occupants, through the integration of several subsystems into one framework [1][4].The operation of a BMS is based on a network of devices and sensors interlinked together to provide real-time data from building systems. Central controllers process these data points to make automated adjustments, such as regulating temperature, turning off unused lights, or enhancing air circulation in occupied spaces. The system operates on a combination of hardware (PLCs) and software platforms, including but not limited to visualization and analytics provided by Niagara and similar technologies [5][7] [14]. The primary need for a BMS is to optimize energy efficiency, reduce operation costs, and enhance safety. Traditional building management approaches are resource-intensive and bound to have human errors. A BMS allows automation with remote monitoring, which reduces most of the manual interventions while keeping the building environment green. In commercial, industrial, and residential areas, a BMS helps in energy conservation by finding out the inefficiency and making the equipment operate within a predefined parameter [2] [6]. The introduction of the Internet of Things into BMS has transformed it by allowing communication between devices, sensors, and controllers in an easier way. The use of IoT devices such as temperature sensors, motion detectors, and smart thermostats helps to increase the precision with which the system performs the monitoring and controlling of building functions. Scalable IoT-based advanced BMS platforms ensure real-time responsiveness with data storage and analytics on cloud-based architectures [3] [11] [14]. A BMS employs numerous devices and sensors for performing certain tasks. For instance,

Devices: Niagara Framework, Honeywell's Tridium, and Johnson Controls' Metasys are some of the most used BMS platforms that provide device connectivity and analytics.

Sensors: Temperature, humidity, CO_2, light, and occupancy sensors are some of the general sensors. These devices provide detailed data that forms the basis for automation and optimization [5] [15].

Connectivity and Usefulness. The BMS makes use of IoT-enabled devices to communicate using protocols such as BACnet, Modbus, and Zigbee. These protocols allow for effective data exchange and ensure the integrated systems work smoothly. BMS has extensive applications in commercial buildings, hospitals, airports, and industrial plants for improving the efficiency of operations, maintaining safety, and meeting environmental standards [6] [12]. One of the key advantages of a BMS is that it reduces manual intervention to a minimum. Predictive analytics and remote diagnostics allow technicians to trace system faults before they turn into critical issues. The proactive approach minimizes downtime, reduces maintenance costs, and generally enhances the reliability of building systems [14][9].In conclusion, a BMS, empowered by IoT technologies, is one of the most important enablers of modern building management; it not only enhances the operational efficiency of building systems but also contributes to the global move toward sustainability and smart infrastructure[1][3][7][15].

II.LITERATURE REVIEW

Alessandra De Paola et al. (2014): Give a critical overview of intelligent management for energy efficiency improvement in buildings. The authors discuss various methodologies and technologies in the realm, underlining how these systems could be used to optimize energy use and contribute toward sustainable building operations. The study also covers the integration of various data-driven technologies, including IoT, which will play a crucial role in the advancement of energy management strategies. Authors express detailed analysis underlining the central function of an intelligent system at building management nowadays. [1]

Ovidiu Noran et al (2019): Discuss the evolution of building management systems and propose next-generation approaches required to mitigate modern infrastructure management challenges. Their research highlights how different technology platforms-IoT and advanced software-can meet and bring about further adaptive and efficient management solutions. The authors underscore increasing integration between the systems as necessary to enhance building performance and operational efficiency. [2]

Shu Tang et al. (2019): Reviewed the development of BIM and IoT devices; both current developments and future trends are shown. This paper identifies that integration will thus enable real-time monitoring and better analytics for building management. The authors underline that these technologies taken together foster smarter and more sustainable built environments. This paper highlights how this integration can bring a revolution to the management and maintenance of a building. [3]

Iveta Puķīte and Ineta Geipele (2017): Investigate different methodologies of building management and maintenance. The authors discuss various approaches that contribute to maintaining and optimizing buildings in operation, with simultaneous assurance of resource use in a sustainable manner. This study provides insight into the definition and practical implications of building management and thus offers useful considerations for future development. The findings are useful in understanding the contextual diversity in managing different building systems. [4]

Elena Malakhatka and Per Lundqvist (2019): Introduce an end-user activity context information management framework for sustainable building operation. This framework aims to improve how user data is processed and utilized to ensure optimal building performance. Their research emphasizes that understanding and incorporating user behavior is essential for designing systems that cater to real-world needs and promote sustainability in building management. The study provides a forward-looking perspective on adaptive building operations. [5]

Wan et al. in (2019): Develop a BIM-based bridge management system. The work identifies the capabilities of BIM in enhancing structural monitoring, scheduling of maintenance, and decision-making processes towards infrastructure management. Such findings are relevant for integrating building management practices with general civil engineering applications and thus focus on cross-domain approaches toward technology utilization. [6]

M. Floeck et al (2014): Investigate how horizontal M2M platforms can enable vertical industries by using a case study from the building energy management system area. They present an effectiveness study demonstrating how these platforms can foster better coordination and efficiency in energy management practices. In fact, the authors outline how this M2M technology might thus serve the aim of real-time data sharing to provide better operational outcomes. [7]

A. Aagaard et al. (2019): Discuss the role of IoT in driving business model innovation and digital transformation. Their work highlights how IoT can act as a catalyst for developing innovative solutions in various industries, including building management. The authors focus on how leveraging IoT can lead to improved business strategies, enhanced data analytics, and optimized operations. This exploration is crucial for understanding the strategic integration of IoT in enhancing building management capabilities. [9]

III.OBJECTIVES

- BMS Definition and Scope: BMS stands for centralized control systems that monitor and manage various building operations like heating, ventilation, air conditioning, lighting, and security systems with the aim of improving energy efficiency and enhancing occupants' comfort [1][3].
- Energy Efficiency in Buildings: Intelligent management systems apply IoT and building automation to gain energy efficiency. Techniques to optimize energy consumption include real-time monitoring, predictive analysis, and adaptive control [1], [15]. IoT-enabled smart buildings

address the challenges of energy efficiency through sensors and automated controls to operate the building in a sustainable manner [5], [15].

- Role of IoT in BMS: IoT technologies are improving BMS by integrating devices and systems to effortlessly exchange data that enables real-time monitoring and control [3], [11]. IoT applications involve predictive maintenance, energy management, and operational efficiency with advanced analytics and edge computing [9], [14].
- BIM and IoT Integration: Building Information Modeling integrated with IoT supports enhanced decision-making, lifecycle management, and operation efficiency in building systems [3], [6].
- It allows for advanced visualization, monitoring, and maintenance scheduling [6].
- Horizontal M2M Platforms in Building Energy Management: Horizontal machine-to-machine platforms are a scalable solution for the implementation of IoT in energy management systems, enhancing cross-domain data sharing and analytics [7]. Such platforms can enable automation, interoperability, and better energy-saving measures [7].
- End-User Activities and Context Management: Frameworks focusing on end-user activities and contextual information enhance BMS for sustainable building operations by aligning system functionalities with user behavior [5].
- IoT as a Driver for Business Model Innovation: IoT technologies in BMS lead to business model innovations by enabling digital transformation, supporting new revenue streams, and fostering service-centric approaches [9], [13].
- Challenges and Future Trends: Challenges in IoT-enabled BMS include data privacy, interoperability issues, and cybersecurity risks [11], [14]. Future trends include integration of AI and machine learning for predictive analytics, autonomous operations, and real-time adaptive systems [11], [12], [14].
- Supply Chain Implications: IoT-driven BMS systems affect supply chains by offering predictive maintenance, reducing downtime, and optimizing resources [13].
- Case Studies and Applications: Some case studies present how IoT-based architectures enhance building automation and management. For instance, cloud-based systems are adopted for secure and efficient operations [11].

IV.RESEARCH METHODOLOGY

The objective of this research is to find out how BMS will integrate with the IoT for enhancing operational efficiency, energy management, and sustainability. A systematic literature review of state-of-the-art advancements about BMS and IoT applications is conducted. The methodology applied identified the studies from reputed journals, conference proceedings, and technical reports. The literature reviewed discusses intelligent energy management systems, IoT-enabled BMS frameworks, and horizontal M2M platforms for the optimization of energy consumption in buildings [1][7][9][14]. This analysis focused on how the integration of IoT devices with BIM technologies could improve the interoperability of systems and enhance decision-making capabilities [3][6]. Case studies dealing with cloud-based IoT architectures were examined to determine how scalable and secure solutions could be found for the automation of smart buildings [11]. Further, the review of edge analytics for BMS was done to understand its role in decreasing latency and improving real-time decision making [14]. Energy efficiency strategies in IoT-based smart buildings were studied to give an overview of sustainability challenges and their solutions [15]. The paper thus considers interdisciplinary approaches, including works on sustainability frameworks, business model innovation driven by IoT [9] [13] how digital transformation in building management could leverage enabling adaptive and context-aware functionalities [2][5]. Synthesis involved the use of advanced data analytical methods and statistical tools to enable evidence-based conclusions from the literature review. The methodology will ensure holistic understanding of the role of IoT in BMS, fill the gaps in the existing literature, and provide a base for future studies on sustainable and intelligent building management systems.

V.DATA ANALYSIS

The building management system forms the backbone of energy efficiency improvement and optimization of building operations. Integrating IoT devices with BMS will, therefore, provide advanced data collection and real-time monitoring to assist in sustainable building practices and operational efficiencies [1][3]. Modern works highlight IoT for smart building solutions, proving how data-driven insights from IoT-based BMS can be used to develop improved energy usage, reduced operation costs, and better management of resources [2][5]. The implementation of such technologies also often exploits building information modeling (BIM) to ensure seamless data integration in enhancing the maintenance of a building during its lifecycle management [3][6]. Furthermore, edge analytics have been recognized as crucial to process data locally for immediate decisions and thereby ensuring system responsiveness [7] [14]. Challenges are that robust cloud-based IoT architectures must be designed to manage complex streams of data to provide resilience and security to the system [11] [15]. Innovative business models enabled by IoT and edge computing are changing the landscape of BMS, enabling digital transformation and operation excellence [9] [12]. The given approach has pointed out a change in basic assumptions toward Industry 4.0-based data-centric solutions and contributed to achieving sustainable cities in [4] [13].

Table.1. Illustrates Energy Management, Sustainability, Iot Integration, User Experience, Operational Efficiency, And Predictive Maintenance, Derived From Case Studies

Element	Description	Example	Technology Used	IoT Integration	Benefits
Energy Management	Optimizing energy consumption through real-time monitoring and control.	Smart thermostats in commercial buildings [2].	IoT sensors, M2M platforms [7].	IoT-enabled energy meters and analytics platforms [2].	Reduced energy consumption by up to 30% [11].
Sustainability	Incorporating sustainable practices like renewable energy integration.	Solar energy systems in modern offices [5].	Renewable energy IoT solutions [14].	IoT monitoring of renewable energy sources [14].	Improved carbon footprint; reduced operational costs by 20% [11].
IoT Integratio	Using IoT to connect and	Intelligent HVAC	IoT-enabled	Cloud-based IoT systems	Enhanced energy

n	automate HVAC, lighting, and security systems.	automation in hospitals [9].	actuators and cloud platforms [7].	for remote management [13].	efficiency and user comfort [9].
User Experience	Enhancing user interaction with BMS through mobile and web applications.	Mobile app to control smart lighting in residential buildings [4].	Mobile IoT applications [15].	Real-time user feedback and customization [3].	Increased occupant satisfaction and control [3].
Operational Efficiency	Reducing downtime and streamlining building operations using IoT data analytics.	Automated maintenance scheduling in commercial complexes [14].	Edge analytics, predictive analytics [6].	Predictive analytics to identify system faults before failure [7].	Reduction in operational costs by 15% [11].
Predictive Maintenance	Identifying and addressing equipment issues proactively using IoT-enabled predictive algorithms.	Fault detection in HVAC systems using IoT in malls [9].	IoT predictive analytics models [6].	Sensor data aggregation for machine learning algorithms [14].	Avoidance of unplanned downtimes and reduced repair costs by 25% [11].

The above table-1 gives an overview of six key elements that may explain the integration of IoT with BMS: energy management, sustainability, integration of IoT, user experience, operational efficiency, and predictive maintenance. Energy management involves real-time monitoring and controlling systems that are utilized to optimize energy use, such as smart thermostats in commercial buildings powered by IoT sensors and M2M platforms. This approach has been demonstrated to reduce energy consumption by as much as 30%. Sustainability is stressed through the integration of renewable energy solutions, such as solar energy systems in modern office spaces, using IoT to monitor the flow of energy and further contributing toward a lower carbon footprint and reduced operational costs by 20%. IoT integration connects various building subsystems, such as HVAC, lighting, and security, to a network that can be monitored and controlled remotely. This maximizes energy efficiency and comfort for the occupants. For instance, in a hospital, intelligent HVAC automation will be enhanced by IoT-enabled actuators and cloud platforms through the provision of real-time data. It adds to the user experience by letting them control their environments with mobile applications, such as smart lighting systems within residential buildings. Such interaction increases satisfaction and personalization for occupants. Operational efficiency means smoothing all the building operations and reducing downtime, hence making better decisions based on IoT data analytics. This includes automated scheduling of maintenance in commercial buildings, applying edge and predictive analytics to predict such issues in advance and handle them beforehand. Finally, predictive maintenance applies IoT in the detection of problems within equipment before they happen, as seen in fault detection systems for HVAC units in malls. By aggregating data from sensors and applying machine learning models, BMS can avoid unplanned downtime and reduce repair costs by as much as 25%. All these factors together point toward the transformative impact of IoT-enhanced BMS, offering benefits that range from huge energy savings and improved sustainability to increased user satisfaction and reduced operational costs.

Table-2 Real-Time Examples Related To Building Management Systems (Bms)

Example	Energy Efficiency	IoT Integration	Automation	Sustainability	Operational Efficiency	Business Model Innovation	Reference
1	High energy savings in smart buildings	Sensors and connected devices monitor usage	Automated HVAC and lighting systems	Reduced carbon emissions through better energy management	Remote monitoring and predictive maintenance	Enhanced service models for facilities management	[1]
2	Energy management via data analytics	Smart meters and environmental sensors	Centralized control of building systems	Use of renewable energy sources	Optimized energy consumption schedules	New revenue streams through service-oriented models	[2]
3	Real-time energy data analysis	Integration with cloud-based platforms	Automated fault detection in systems	Adoption of eco-friendly construction methods	Efficient task allocation for facilities staff	Leveraging data-driven insights for cost savings	[3]
4	Energy-saving algorithms applied in BMS	IoT-enabled smart thermostats	Robotic process automation for building management	Green certifications and sustainable building practices	Workflow automation reducing manual tasks	Strategic partnerships leveraging IoT capabilities	[4]
5	Smart window and shading systems for	IoT connectivity for sensor data	Automated response to	Environmental impact reduction through	Increased building responsiveness to	Creating ecosystems for energy-	[5]

	natural light	collection	occupancy changes	resource management	real-time data	efficient technology	
6	Energy reduction through predictive analytics	IoT-driven lighting control systems	AI-powered management systems	Minimizing power wastage	Performance optimization via automated insights	Using AI for more adaptive management practices	[6]
7	Adaptive climate control for energy efficiency	Sensors linked to data processing hubs	Smart access systems integrated with building controls	Comprehensive recycling programs and waste management	Streamlined data management and reporting	IoT-based modular solutions for scalability	[7]
8	Consumption profiling for reduced peak load	Smart grid integration	Automated HVAC system adjustments	Climate-conscious facility operations	Reduced operational delays through automation	Introduction of IoT as a service for buildings	[7]
9	Energy-efficient building envelope monitoring	Networked devices for real-time feedback	Automated security systems linked to IoT	Advanced use of thermal insulation materials	Intelligent maintenance scheduling	Enhanced operational strategies for diverse building types	[9]
10	Smart energy dashboards showing consumption trends	Comprehensive IoT ecosystem for building data	System alerts for energy inefficiencies	Sustainability-focused upgrades in existing infrastructure	Consolidated data access for better decision-making	Optimizing building services through new tech models	[10]
11	Power factor correction techniques implemented	Device-to-device communication for synchronized systems	Automation of window blinds for temperature control	Building design focusing on sustainability and energy use	Reduced workload for facilities managers	Integration of cloud-based analytics for new	[11]

						solutions	
12	Dynamic energy storage solutions	Real-time remote sensing capabilities	AI-driven smart irrigation systems	Programs supporting urban green spaces	Monitoring system health for efficiency	Creating consumer-centric service platforms	[12]
13	Smart energy meters for billing and analysis	IoT devices ensuring comprehensive coverage	Seamless indoor climate management	Solar panel integrations for clean energy	Streamlined usage data for effective management	Innovative cross-sector collaborations	[13]
14	Green technology implementations	High-speed data transmission for building systems	Smart elevators using demand-based operations	Long-term eco-friendly construction strategies	Enhancing building occupancy comfort levels	Leveraging partnerships with tech start-ups	[14]
15	AI tools predicting energy needs	Cloud-integrated sensor networks	Automated building safety checks	Practices to minimize waste and promote reuse	Energy audit simplification	Expansion of the building-as-a-service concept	[15]

The above table-2 provides a detailed insight into real-time examples that show how BMS integrates energy efficiency, IoT technology, automation, sustainability, operational efficiency, and innovation in business models. These examples suggest that the modern solution for BMS is more dependent on IoT connectivity to track energy use via sensors, smart meters, and cloud-based data processing platforms to provide real-time feedback and predictive analytics for energy management. Automation manifests in centralized control over the HVAC systems, automatic detection of faults, and robotic process automation for building operations that help speed and accuracy of response to any change in condition. Other features put in the sustainability focus are smart window and shading systems, integration with renewable energy sources, and upgrading building features per eco-friendly standards. It enables operational efficiency through remote monitoring, predictive maintenance, and optimized resource allocation, thus making the approach seamless and adaptive toward building management. The shift in direction toward innovative business models involves leveraging data-driven insights to capture cost savings, offering IoT as a service, and developing ecosystems that foster energy-efficient solutions. Examples are smart climate control, whereby comfort is raised by effective use of energy, and maintenance scheduling, which simplifies building management. These examples further illustrate how technology and sustainability come together in state-of-the-art BMS, how the development of IoT, AI, and smart automation is changing building operations, enabling green practices, and creating new business opportunities. The references used to detail these examples provide an authoritative basis for understanding how BMS can be leveraged for better energy efficiency, user experience, and overall building performance.

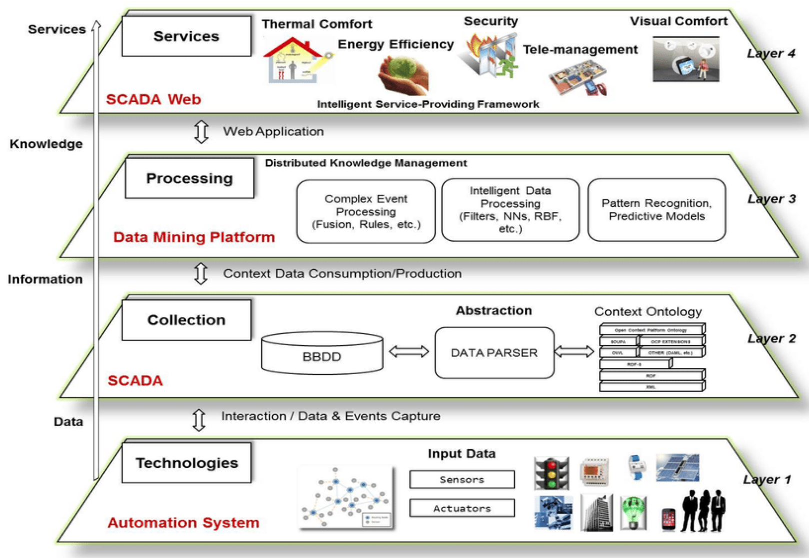

Fig.1. Layers of the base architecture of our smart building management system [15]

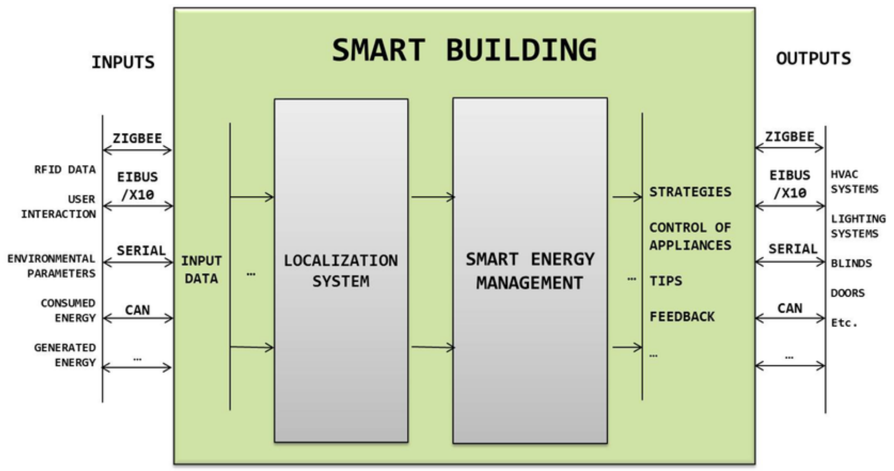

Fig.2. Our Energy Management Platform for buildings [15]

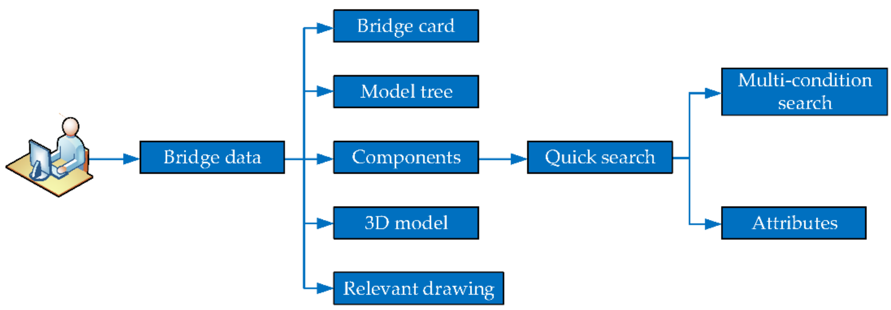

Fig.3.Brige Management System [6]

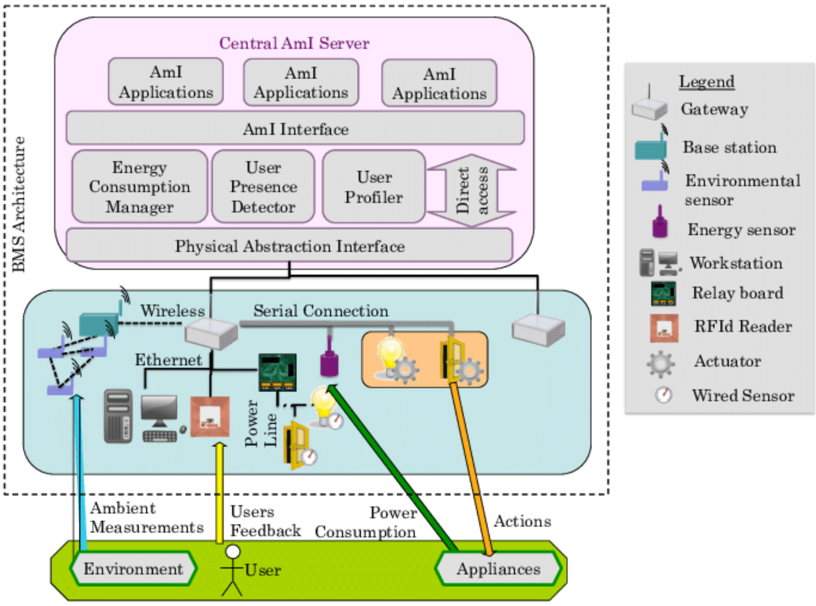

Fig.4.BMS With Sensor9k Architecture [1]

VI. CONCLUSION

This paper provides insight into how Building Management Systems have evolved through technological integration to enhance the efficiency, sustainability, and experience of a building. The inclusion of IoT in BMS has been key in driving smarter energy management, predictive maintenance, and real-time monitoring. Research underlines how IoT and related technologies will transform BMS from simple cloud-based systems to frameworks involving edge analytics, making operations of buildings flexible and scalable. The studies also emphasize that the horizontal M2M platform needs to be adopted to give proper connectivity and communication among systems, which will surely enhance energy efficiency and operational effectiveness. BIM integrated with IoT enhances the capability of the system to integrate and analyze data seamlessly. Despite the challenges with data security and interoperability, the trends of continuing developments point toward a future in which intelligent BMS, enabled by IoT and advanced data analytics, will play an essential role in fostering energy efficiency and the creation of smarter, more responsive environments. These systems contribute not only to operational savings but also to broader sustainable development goals and improved occupant comfort. As the field advances, new developments are foreseen to employ AI, machine learning, and sophisticated data management so that BMS will adequately match the challenges of today's urban landscapes and provide valuable inputs toward global goals of energy efficiency.

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