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Optimizing Energy Efficiency in Healthcare Facilities: The Pivotal Role of Building Management Systems

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A B S T R A C T

This paper presents the findings of a comprehensive energy audit conducted at a large healthcare facility in North America, highlighting the critical role of Building Management Systems (BMS) in optimizing energy efficiency and driving sustainability. The audit identified opportunities for energy savings through chiller and boiler system improvements, retro-commissioning of the BAS, lighting upgrades, and minor repairs. The study emphasizes the importance of real-time energy monitoring and control, predictive maintenance, and staff training and engagement to ensure a truly optimized system. The implications for BMS include enhanced operational efficiency, integration with renewable energy sources, data-driven decision-making, policy compliance, and future-proofing infrastructure. The audit provides a practical framework for improving energy consumption patterns in healthcare facilities, demonstrating the essential role of BMS in managing energy use and reducing carbon footprints in energy-intensive environments.

Keywords: Building Management Systems; Energy efficiency; Sustainability; Healthcare facilities; Energy audit; Chiller systems; Boiler systems; Retro-commissioning; Real-time energy monitoring; Predictive maintenance; Data-driven decision-making; Future-proofing infrastructure; Energy Management; Building performance optimization

1. Introduction

The escalating global demand for energy has significantly impacted resources, environments, and economies worldwide, positioning energy efficiency as a critical objective for sustainable development. Building Management Systems (BMS) have been instrumental in reducing energy consumption and ensuring operational efficiency within commercial and institutional buildings. This paper focuses on BMS as a pivotal factor in optimizing energy efficiency within healthcare environments, with a case study done on a large healthcare facility in North America, which has undergone extensive growth and transformation to meet evolving healthcare needs, with an expansion in 2013. The facility's energy consumption data from the calendar year 2020 serves as the basis for this analysis. With the energy required to maintain such a comprehensive healthcare institution being substantial, efficient management is imperative. An ASHRAE Level 2 Energy Audit provided an in-depth examination of the facility's energy consumption, using the findings to drive improvements in energy management strategies. The audit analyzed historical energy usage patterns, evaluated system performance, and identified opportunities for enhancements aligning with best practice standards. The resultant audit highlights energy consumption by major systems and necessary interventions for promoting efficiency. These initiatives involve upgrading equipment and integrating advanced control strategies to reduce energy consumption without compromising patient care and comfort. The paper aims to demonstrate the significant role of BMS in driving sustainable healthcare facility operations, illustrating the potential for BMS enhancements to contribute to energy efficiency and resilience in the healthcare sector and beyond.

2. Literature Review

Building Management Systems plays a crucial role in creating sustainable and resilient healthcare facilities by optimizing control and monitoring various mechanical and electrical systems, including heating, ventilation, air conditioning, lighting, and power systems. The application of a sophisticated BMS can significantly enhance the operation of healthcare facilities. By employing advanced control strategies like Model Predictive Control, a BMS can forecast energy demand, manage renewable energy sources effectively, and make real-time adjustments to minimize energy consumption while maintaining comfort levels. These energy management capabilities are essential for healthcare facilities striving for climate resilience and environmental sustainability as they can help to improve energy efficiency by managing HVAC systems and integrating renewable energy sources like solar or geothermal heat pumps, as pointed out in the paper, BMS helps lower energy consumption and reduce operational costs for healthcare facilities. They can also help to enhance resilience by having a robust BMS that ensures that in times of unstable energy supply or extreme weather conditions, healthcare facilities can maintain critical operations, thus enhancing their resilience against climate-related disruptions. The applicability of BMS in healthcare facilities illustrates the broader potential of these systems to contribute to sustainable practices in different sectors[1].

By providing centralized control over HVAC, lighting, and other critical systems, BMS can optimize resource use, ensuring patient comfort and safety while also reducing energy consumption and operational costs. The intelligent monitoring and control capabilities of BMS not only enhance the energy resilience of healthcare settings but also offer broader applications for sustainable operations across various building types, contributing to global efforts to curb energy use and mitigate environmental impacts[2].

The potential of BMS enhancements, particularly through the integration of IoT technologies is to tailor operations to real-time conditions and occupant preferences. This approach can be applied to healthcare facilities to optimize HVAC and lighting systems, contributing to substantial energy savings and resilience, without compromising patient care and comfort[3].

In healthcare facilities, where system reliability and efficiency are critical, BMS informed by machine learning can enable predictive maintenance, ensuring uninterrupted service, while also optimizing energy use to reduce waste. These BMS capabilities, when enhanced with cutting-edge data analytics and IoT technologies, not only bolster healthcare facilities' operational resilience but also have the potential to significantly cut energy costs and contribute to broader energy efficiency goals across various sectors[4].

Building Management Systems integrate various building services such as HVAC, lighting, and security, optimizing operations based on actual use. With predictive HVAC control adapted to occupancy patterns, healthcare facilities can significantly improve energy efficiency and ensure patient comfort. These enhancements not only contribute to energy savings but also bolster the resilience of healthcare operations, crucial for emergency scenarios[5,6].

The relevance of BMS to healthcare settings is there when it comes to infection risks. A numerical model using sensor data to assess indoor COVID-19 infection risks can be developed. By integrating such models, a BMS can not only improve energy efficiency and reduce costs but also ensure patient safety by maintaining air quality and mitigating airborne infection risks, illustrating how advancements in BMS technology can significantly contribute to public health and operational excellence in healthcare[7].

Building Management Systems enhanced with advanced control strategies, such as Reinforcement Learning, can significantly improve the energy efficiency and resilience of healthcare facilities. The application of intelligent HVAC automation using Reinforcement Learning shows how systems can adapt and optimize energy use in real time, leading to reduced energy consumption and operational costs, without the need for extensive prior modeling. This approach aligns with sustainable healthcare practices by maintaining patient comfort while minimizing the environmental impact, showcasing a powerful method of achieving energy efficiency and sustainability in the healthcare sector and beyond[8].

The "Intelligent OPC Building Information Management System based on IoT" emphasizes the importance of advanced Building Management Systems for healthcare facilities through optimized energy usage, improved interoperability among diverse systems, and bolstered operational resilience. OPC, originally named "OLE for Process Control," evolved from the earlier Microsoft technology OLE, which allowed for embedding and linking to documents and other objects. In the context of BMS, OPC acts as a standard interface that allows different control devices and systems, regardless of manufacturer, to communicate with each other, providing centralized, real-time monitoring and control—particularly important for HVAC and other critical systems in healthcare settings. By utilizing a combination of OPC and Internet of Things technologies, this intelligent BMS offers a cohesive and unified method for managing essential systems, contributing to enhanced energy efficiency, cost reduction, and a sustainable operating environment that meets stringent healthcare facility standards. The OPC standard enables diverse systems to share data and functionality efficiently, leading to a smoother and more responsive management of building operations. This technical synergy between OPC and IoT underpins the potential for broader implementation of intelligent BMS across different sectors. By applying the principles contained within the "Intelligent OPC Building Information Management System based on IoT," there is a clear path to improve energy management and conservation at a larger scale, optimizing the operation of not only healthcare facilities but potentially all types of buildings that seek to enhance their efficiency and operational effectiveness through advanced BMS technology[9].

3. Methodology

The research methodology used for the comprehensive analysis of a large healthcare facility's energy utilization employs a Level 2 Energy Audit, a standardized process that involves several critical stages:

- Site Inspection and Data Collection: Gathering data on the building envelope, existing equipment, operational patterns, and system configurations through a thorough physical walkthrough. A summary of utility data is provided in Table

1. The pattern of electricity and gas consumption is shown in **Figure 1 and Figure 2**.

- System Performance Evaluation: Assessing the performance of existing systems against recognized standards and best practices, identifying areas for improvement.
- 3. Identification of Energy Conservation Measures (ECMs): Identifying potential energy-saving opportunities and system upgrades based on collected data. A summary of ECMs is provided in **Table 2**.
- Engineering Analysis: If needed, use engineering principles and energy simulation software to model the impact of potential retrofits and replacements.
- Stakeholder Consultation: Engaging with facility managers, staff, and maintenance personnel to gather input on current system usability and problems.
- Report Generation: Compiling all findings into a comprehensive energy audit report, including an overview, detailed descriptions of energy conservation measures, projected costs, potential savings, and a prioritized action plan.

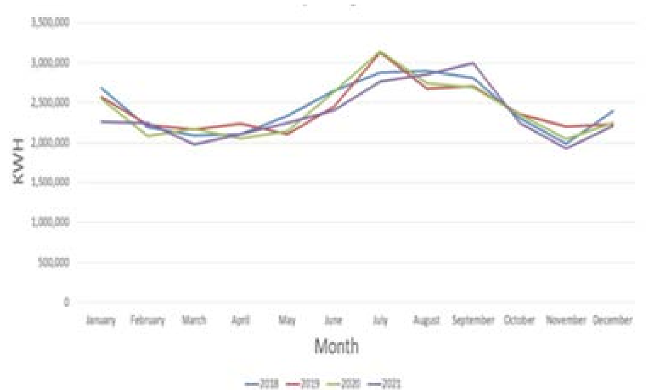

Figure 1: Electricity consumption pattern.

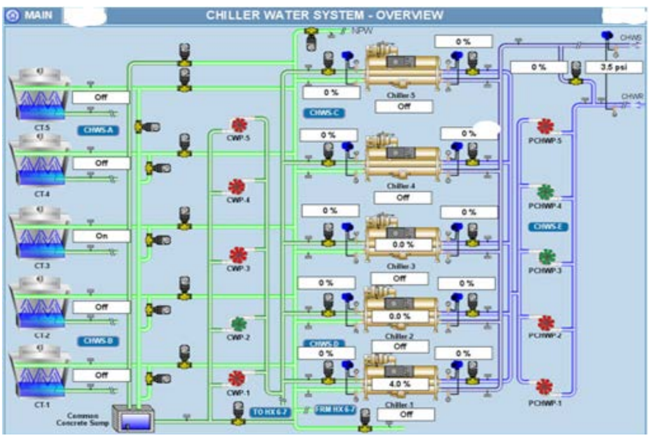

Figure 2: Gas consumption pattern.

Figure 3: Primary Cooling System BMS Screenshot.

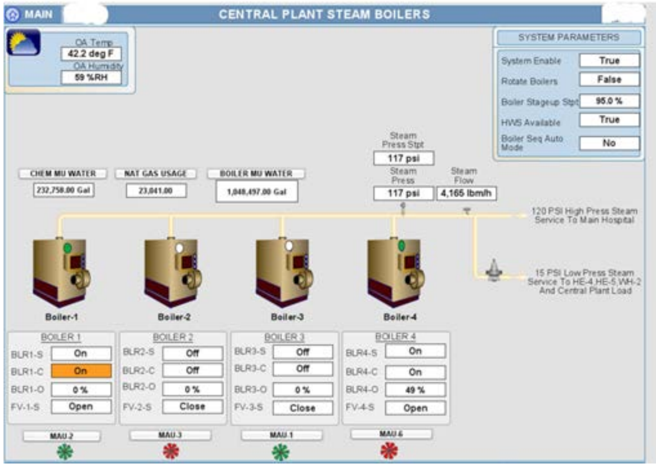

Figure 4: Primary Heating System BMS Screenshot.

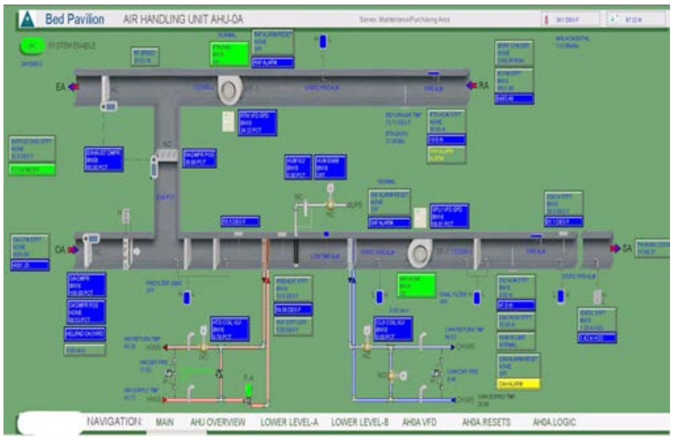

Figure 5: Air System BMS 1 Screenshot.

Figure 6: Air System BMS 2 Screenshot.

This methodology provides a structured approach to assessing the facility's energy efficiency and forms the basis for the subsequent analysis presented in this paper. Through this rigorous approach, our study demonstrates the significant role of Building Management Systems (BMS) in driving sustainable healthcare facility operation, illustrating the potential for BMS enhancements to contribute to energy efficiency and resilience in the healthcare sector and beyond. **Figure 3, Figure 4, Figure 5, and Figure 6** demonstrate the BMS operation at the facility. The improvements to the BMS system are done in retro-commissioning work.

4. Energy Audit Findings

Table1: Utility Usage Summary.

AREA	ANNUAL ENERGY CONSUMPTION	ANNUAL ENERGY CONSUMPTION (MMBTU/YR)	ANNUAL COST	AVERAGE COST
Electricity	28,855,907 kwh	98,460	$2,713,796	$0.094/kWh
Natural Gas	1,546,001 Therms	154,563	$459,719	$0.297/therm
Total		253,023	$3,173,515	$12.54/MMBTU

Table 2: List of ECMS Recommended.

OPPORTUNITY	PROJECT NET COST	TOTAL PROJECT SAVINGS	SPB	REDUCED EMISSIONS (CO2-LBS.)
Replace CH-4	$700,000	$39,000	17.9	330,109
Replace CH-5	$700,000	$33,000	21.0	264,088
Retro-commissioning	$50,000	$184,000	0.3	2,555,977
LED retrofit	$2,000,000	$280,000	7.1	1,450,440
Boiler burnerretrofit	$422,700	$50,250	8.4	297,629
TOTALS	$3,872,700	$586,250	5.8	4,898,243

The comprehensive ASHRAE Level 2 Energy Audit of the healthcare facility assessed the building's major systems to identify potential inefficiencies and optimize energy use. This section outlines the primary findings from the audit and considers the implications for the facility's energy management strategy.

Chiller Efficiency and Replacement Opportunities: The audit identified the chillers as both an energy efficiency opportunity and a crucial infrastructural element. While the chillers currently installed were of high efficiency, the audit recommended replacements to achieve better performance and leverage technological advancements.

Retro-Commissioning of Building Automation Systems: Retro-commissioning of the BAS to realign and tune it with the prevailing needs of the facility. Ensuring the BAS operates in harmony with current facility requirements is vital for minimizing energy waste and applying precise controls to energy-consuming systems.

Boiler and Burner Retrofits: Another key recommendation involved boiler burner retrofits aimed at improving energy efficiency through lower turndown ratios and tighter control parameters. The boilers, already equipped with oxygen trim capabilities, suggested that they could benefit from further fine-tuning to improve efficiency.

Lighting System Upgrades: The facility's lighting systems, comprising high-efficiency electronic ballasts and T8 lamps, were found to be relatively energy-efficient. Despite this, the audit flagged the potential for LED retrofits in the following decade to further enhance lighting efficiency and reduce energy consumption.

Implemented Energy Efficiency Features: The audit also provided insights into the previously implemented energy efficiency features, which included temperature and pressure resets for air handling units, chilled water resets, and the implementation of free cooling strategies. The use of variable air volume handling units and control retrofits had already improved the facility's energy footprint significantly.

Identification of Minor Repairs: Additionally, the audit helped in identifying minor repairs and small-scale interventions that could lead to incremental energy savings, emphasizing the importance of regular maintenance and attention to system integrity.

Observation: The retro-commissioning measure recommended in Table 2 saves 2,555,977 lbs of CO_2, which is 52% of all CO_2 savings combined.

5. Discussion

The extensive energy audit of the healthcare facility has yielded insightful observations about current energy management practices and potential areas for further optimization. This discussion delves into the key findings, interprets their implications, and connects them with broader trends and knowledge in the field of energy management in healthcare settings.

Chiller and Boiler System Improvements: The audit's recommendation for chiller replacements and boiler burner retrofits represents a dual opportunity to enhance energy efficiency and update infrastructure. Such upgrades are not strictly about immediate gains in energy conservation but are also about the long-term sustainability and reliability of the facility's essential services.

Significance of Retro-Commissioning: The suggested retro-commissioning of the BAS has emerged as a critical intervention. It shows a lot of promise. It emphasizes the dynamic nature of energy management, where systems must evolve in line with changing building usage and occupancy patterns. Retro-commissioning ensures that the energy consumption is finely tuned to current operational necessities, avoiding the common pitfalls of overconsumption due to outdated control parameters.

Lighting As a Continuous Opportunity: Lighting upgrades to LED technology reveal an ongoing opportunity for energy reductions. The audit acknowledged the existing system's efficiency while also projecting future benefits from emerging lighting technologies. This forward-thinking stance is aligned with global trends towards LED lighting for its superior energy efficiency and longer lifespan.

Minor Repairs and Regular Maintenance: The importance of regular maintenance and addressing minor repairs cannot be understated. These actions often provide cost-effective energy savings, improve equipment longevity, and prevent more significant issues in the future.

Energy Efficiency in Healthcare Context: Discussion of these findings within the larger context of healthcare facility management sheds light on the unique challenges such facilities face. They must strike a balance between stringent health and safety requirements and the goal of reducing energy consumption. The role of BMS becomes even more pronounced in this setting, as it allows for the customization and control necessary to meet varied and precise environmental stipulations.

Implications for Future Research and Practice: The study prompts a reevaluation of common practices and encourages continuous improvements in technology integration and management strategies.

6. Implications for Building Management Systems

The implications for Building Management Systems based on the findings of the energy audit are multifaceted and have the potential to greatly impact the operational performance and energy management strategies of buildings, especially in energy-intensive environments like healthcare facilities.

Enhanced Operational Efficiency: The audit's emphasis on updating and retrofitting components like chillers and boilers highlights the need for BMS to support advanced efficiency measures. Newer technologies in these areas can offer improved integration with the BMS, leading to smarter, more responsive operations and better management of peak demand periods.

Real-Time Energy Monitoring and Control: The identification of retro-commissioning needs points towards an opportunity to enhance real-time monitoring and control capabilities within BMS. Accurate, real-time data can facilitate more informed decision-making and allow operators to adjust energy consumption based on actual conditions and needs, rather than relying on schedules or setpoints that may no longer be appropriate.

Predictive Maintenance and Fault Detection: The detection of minor repairs and the maintenance opportunities identified suggest a need for BMS to integrate predictive maintenance and fault detection capabilities. This could lead to proactive management of building systems, preventing downtime, and ensuring the efficiency and longevity of critical equipment.

Integration of Renewable Energy Sources: Modern BMS systems should have the capability to integrate with renewable energy sources and other sustainable technologies. By efficiently managing the interplay between traditional energy systems and renewables, BMS can support a building's transition to a more sustainable energy profile.

Data-Driven Decision-Making: As more sophisticated analytical tools become available, the role of BMS in data-driven decision-making becomes increasingly significant. The insights gained from energy audits can inform the development of more advanced BMS algorithms that optimize building performance through machine learning and artificial intelligence.

User Training and Engagement: The success of any BMS depends on the people who operate it. The implications underscore the necessity for ongoing training and engagement programs for facility operators to ensure they can utilize the full capabilities of the BMS.

Policy and Regulatory Compliance: Regulatory frameworks and building codes are continually evolving, and BMS must be adaptable to meet new standards for energy efficiency. A BMS that is flexible and updatable can help a building remain compliant with changing regulations and practices.

Future-Proofing Infrastructure: Lastly, the energy audit findings suggest an overarching implication for BMS to be designed with the future in mind. This involves considering the long-term scale of upgrades, integration of next-generation technologies, and scalability to adapt to future operational changes.

7. Conclusion

The comprehensive energy audit highlights the critical role of Building Management Systems (BMS) in realizing energy efficiency potential in healthcare facilities. Key findings emphasize the importance of BMS in managing energy consumption, optimizing building performance, and ensuring continuous improvement. Retrofitting and future-proofing building systems with the latest technologies, regular retro-commissioning and monitoring, and staff training and engagement are crucial for a truly optimized system. The audit's broader implications for sustainability in the built environment demonstrate the instrumental role of BMS in reducing carbon footprints and managing energy consumption in energy-intensive facilities. The energy audit provides a practical framework for improving energy consumption patterns, underscoring the essential nature of BMS in monitoring, managing, and mitigating energy use in complex environments, and ensuring they keep pace with technological advancements and changing facility needs.

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