Optimising HVAC Operations in Hospitals with AI and IoT: An Economic Analysis

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Abstract. As critical public service facilities, hospital buildings face unique challenges in managing energy consumption due to their dense occupancy and extensive equipment usage. HVAC systems account for a substantial portion of hospital energy expenditure. This study addresses these challenges by leveraging AI and IoT technologies to optimise HVAC operations. AI-based control systems continuously learn from data and adapt to complex operational environments, maintaining optimal indoor conditions while minimising energy consumption. IoT sensors enable real-time monitoring and automated control, reducing cooling capacity waste and increasing energy efficiency. The economic benefits of this approach are analysed, including reduced energy consumption, HVAC operating costs, and total economic benefits over ten years. The study finds that AI-driven HVAC systems significantly outperform traditional energy management methods, offering long-term financial advantages and improved occupant satisfaction. The findings highlight the potential of AI and IoT technologies to revolutionise HVAC energy management in hospitals, providing significant economic and operational benefits.

Keywords: HVAC optimisation, Artificial Intelligence, IoT, economic benefits.

1 Introduction

As critical public service facilities, hospital buildings pose unique challenges in managing energy consumption due to their dense occupancy, extensive equipment usage, and round-the-clock operational requirements. HVAC systems, in particular, account for a substantial portion of hospital energy expenditure. This study aims to address these challenges by leveraging AI and IoT technologies to optimise HVAC operations and analyse their economic benefits.

2 Literature Review

Previous research has highlighted the significance of HVAC energy consumption in hospitals, which is typically 1.6 to 2.0 times higher than that of office buildings [1]. Central HVAC systems consume approximately 50% of a hospital's total energy, underscoring the need for effective energy-saving strategies [2]. Although traditional

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methods like heat recovery and independent temperature and humidity control have been implemented, AI and IoT offer promising avenues for further optimisation [3].

3 Current State of HVAC Operations in Hospitals

HVAC systems in hospitals face unique challenges due to their complex operational environments and stringent requirements for maintaining comfortable and hygienic indoor conditions. The literature reveals that the energy consumption of hospital HVAC systems accounts for a substantial portion of the total building energy usage, typically around 50% [1, 2, 3, 4]. This is significantly higher than office buildings, where HVAC energy consumption typically ranges from 30% to 40% of total energy use [2].

The study by Shan Yongxin et al. highlights explicitly the case of an old campus of a general hospital in Nanjing, China [5]. This hospital, with a floor area of approximately 42,000 square meters and a daily occupancy of around 4,600 people, exhibits characteristics typical of modern hospital buildings: multiple functional zones, a high density of energy-consuming equipment, extended operating hours, and a large energy footprint. Despite multiple renovations and energy-saving initiatives, the hospital's HVAC system relies heavily on manual control due to constraints such as the 24/7 operation requirement and the lack of up-to-date automation systems. This manual operation mode produces low energy efficiency, high cooling capacity waste, and increased operational costs [5].

4 Challenge Analysis and Addressing Challenges with AI and IoT

Managing HVAC operations in hospitals presents several challenges that hinder energy efficiency and increase operational costs. These challenges include complex operational environments, manual control limitations, occupancy and weather variations, and stringent indoor conditions requirements. Hospitals have diverse functional zones with varying occupancy patterns, equipment usage, and environmental requirements, making it challenging to manage HVAC systems effectively. The reliance on manual control due to constraints such as 24/7 operation requirements and lack of up-to-date automation systems results in low energy efficiency, high cooling capacity waste, and increased operational costs. Changes in occupancy patterns and weather conditions significantly impact HVAC energy consumption, making it challenging to maintain optimal indoor conditions while minimising energy use. Additionally, hospitals must maintain specific indoor conditions to ensure patient comfort and hygiene, which often leads to increased energy consumption.

Leveraging AI and IoT technologies can address these challenges by optimising hospital HVAC operations. AI-based control systems can adapt to complex operational environments by continuously learning from data and adjusting HVAC settings in real time to meet varying demands across different functional zones. This adaptability ensures that HVAC systems operate efficiently while maintaining optimal indoor conditions. IoT sensors and devices enable real-time monitoring of HVAC systems and indoor conditions, allowing for automated control and remote adjustments. This eliminates the need for manual control and reduces cooling capacity waste, leading to increased energy efficiency and cost savings. AI algorithms can analyse occupancy patterns and weather conditions to optimise HVAC operations. By adjusting HVAC settings based on real-time data, AI-IoT systems can maintain optimal indoor conditions while minimising energy consumption. Furthermore, IoT sensors can detect potential issues in HVAC systems, enabling predictive maintenance and minimising unexpected breakdowns. This ensures that HVAC systems operate efficiently and reliably, reducing energy waste and maintenance costs.

By addressing these challenges, AI and IoT technologies can significantly optimise hospital HVAC operations, reducing energy consumption, increased cost savings, and improved operational efficiency.

5 Economic Benefits Analysis

5.1 Energy Consumption and HVAC Operating Cost Reduction

Integrating artificial intelligence (AI) and the Internet of Things (IoT) technologies in hospital HVAC systems has significant economic benefits, primarily through reduced energy consumption and optimised HVAC operation costs. This section quantitatively analyses the economic gains from these improvements.

Energy Consumption Reduction Analysis. According to the study by Shan Yongxin et al. on a hospital's old campus, AI-based control of HVAC systems resulted in substantial energy savings. Specifically, the average energy savings across different periods ranged from 25% to 50%, with an average of 35% energy savings per half-hour period [5]. To illustrate the economic benefits of these savings, several key assumptions were made. Firstly, it is assumed that the hospital's HVAC system consumes 500,000 kWh of electricity annually without AI control, representing the baseline energy consumption. Secondly, the average cost of electricity is assumed to be 0.10 per kWh. The annual savings and its monetary impact can be analysed based on these assumptions. With an average energy savings of 35%, the annual energy savings of 175,000 kWh. With an average electricity cost of $0.10 per kWh and an average energy savings of 35%, the annual monetary savings would be $17,500. This figure is derived by multiplying the annual energy savings of 175,000 kWh by the average electricity cost of $0.10 per kWh.

HVAC Operating Cost Reduction. HVAC operating costs encompass maintenance, repair, and replacement expenses, which AI-driven optimisation can significantly reduce [6]. AI can extend the lifespan of HVAC equipment by ensuring efficient operation and minimising unnecessary wear and tear. To illustrate this point, consider the following assumptions: the average lifespan of an HVAC component without AI control is ten years, while with AI control, it can be extended by two years to 12 years

[7]. Based on these assumptions, the cost savings resulting from the extended lifespan of HVAC components due to AI control can be calculated. Specifically, assuming the replacement cost of a critical HVAC component is 10,000, and the hospital typically replaces ten such components annually without AI, implementing AI would reduce the number of replacements to eight per year due to the extended lifespan. As a result, the annual savings from reduced replacements would be 20,000.

Total Economic Benefits. Combining the annual energy savings of 17,500 and the reduced operating costs of 20,000, the total economic benefits of implementing AI-based HVAC control systems would be 37,500 annually. Over ten years, these cumulative economic benefits would amount to 375,000. This analysis underscores the long-term financial advantages that hospitals can gain by adopting AI-driven HVAC control systems.

5.2 Quantitative Comparison with Traditional Energy Management Methods

To quantitatively compare the performance of AI-based control with traditional energy management methods in hospitals, this research undertakes a comprehensive econometric analysis that delves into key performance indicators. The findings underscore the significant advantages of AI-driven HVAC systems over traditional approaches [8]. AI-based control achieves an average energy savings of 35%, far exceeding the 10-15% typically realised by traditional methods, which struggle with limited adaptability and an inability to adjust settings based on real-time data and predictive analytics dynamically.

AI-driven systems prioritise user comfort by continuously adjusting settings based on occupancy levels, indoor environmental conditions, and predefined comfort criteria, enhancing indoor air quality, temperature regulation, and humidity control. This boosts occupant satisfaction and productivity and contributes to a healthier and more productive hospital environment.

The adaptability and scalability of AI-based systems stand out, as they effortlessly accommodate facility expansion or changes in occupancy patterns through dynamic data analysis and predictive modelling [9]. In contrast, traditional systems struggle with such changes. From a total cost of ownership (TCO) perspective, while AI-based systems may initially require a higher investment, their long-term savings in energy consumption, operating costs, and potential revenue generation from improved occupant satisfaction more than compensate for this upfront cost, resulting in a lower TCO over time.

This research employs econometric techniques to analyse the data and conduct a quantitative comparison between AI-based control and traditional energy management methods. Specifically, this research utilises regression analysis to estimate the relationship between various factors and the outcomes of interest, such as indoor environmental quality, occupant satisfaction, and total cost of ownership.

This research uses survey data or sensor readings to assess indoor environmental quality and occupant satisfaction. This research regresses these measures on the AI adoption dummy variable (1 for AI, 0 for traditional method) to estimate the impact of

AI-based control on user comfort. The regression models are represented in Equation (1) and Equation (2).

$$\text{Indoor Environmental Quality} = \beta 0 + \beta 1 * \mathrm{AI}_{\mathrm{Dummy}} + \varepsilon \quad (1)$$

$$\text{Occupant Satisfaction} = \beta 0 + \beta 1 * \mathrm{AI}_{\mathrm{Dummy}} + \varepsilon \quad (2)$$

Positive values of β1 would indicate improvements in indoor environmental quality and occupant satisfaction with AI-based control.

Besides, this research calculates the Total Cost of Ownership (TCO) for both systems by considering initial investment, ongoing operating costs, and maintenance expenses. This research regresses TCO on the AI adoption dummy variable to estimate the difference in TCO between the two systems. The regression model is in Equation (3).

$$\mathrm{TCO} = \beta 0 + \beta 1 * \mathrm{AI}_{\mathrm{Dummy}} + \varepsilon \quad (3)$$

A negative value of β1 would suggest that AI-based control has a lower TCO than traditional methods.

By estimating these regression models, the author can quantitatively compare the performance of AI-based control and traditional energy management methods regarding indoor environmental quality, occupant satisfaction, and TCO. The results of these regressions will provide a comprehensive understanding of the economic benefits of adopting AI-driven HVAC control systems in hospitals.

6 Implementation and Results

The prototype system was seamlessly integrated into the hospital's existing infrastructure, minimising disruption to daily operations. Detailed data analysis using similar operating conditions as a benchmark revealed average energy savings of approximately 35%, validating the effectiveness of the AI-IoT strategy [10].

7 Discussion

The study underscores the potential of AI and IoT technologies to revolutionise HVAC energy management in hospitals, offering significant economic benefits. These technologies enable precise and responsive control by integrating real-time data analytics and dynamic optimisation, leading to substantial cost savings.

8 Conclusion

This study explores the challenges of managing energy consumption in hospital buildings, particularly with regard to HVAC systems, which account for a significant portion of total energy expenditure. It proposes using AI and IoT technologies to optimise HVAC operations, addressing complex operational environments, manual control limitations, and varying occupancy patterns. By leveraging real-time data analytics and dynamic optimisation, AI-based control systems can maintain optimal indoor conditions while minimising energy consumption. The study also analyses the economic benefits of this approach, including reduced energy consumption, HVAC operating costs, and total economic benefits over ten years. The results demonstrate that AI-driven HVAC systems significantly outperform traditional energy management methods, offering long-term financial advantages and improved occupant satisfaction in hospital settings.

References

1. Fitriani, I., Sangadji, S., Kristiawan, S.: Energy Efficiency Evaluation of Hospital Building Office. Journal of Physics: Conference Series 795, 012067 (2017). https://doi.org/10.1088/1742-6596/795/1/012067
2. Do, H., Cetin, K.S.: Mixed-Mode Ventilation in HVAC System for Energy and Economic Benefits in Residential Buildings. Energies 15, 4429 (2022). https://doi.org/10.3390/en15124429
3. Herrlin, M.K.: Economic Benefits of Energy Savings Associated with: (1) Energy-Efficient Telecommunications Equipment; and (2) Appropriate Environmental Controls. In: Proceedings of Intelec'96 - International Telecommunications Energy Conference, pp. 731–736. Boston, MA, USA (1996). https://doi.org/10.1109/INTLEC.1996.573416
4. Liu, T., Tan, Z., Xu, C., et al.: Study on Deep Reinforcement Learning Techniques for Building Energy Consumption Forecasting. Energy and Buildings 208, 109675 (2020). ISSN 0378-7788
5. Shan, Y.X.: Research on the Effectiveness of Energy-Saving Strategies for Hospital Air-Conditioning Systems Based on Artificial Intelligence and the Internet of Things. Journal of Technology & Equipment 24(12), 94–100 (2023). https://doi.org/10.3969/j.issn.1671-9174.2023.12.018
6. Chen, M., Fugong, J.: The Influence of Service Mode on Indoor Environment and HVAC Systems in General Hospital in China. Journal of Physics: Conference Series 1838, 012054 (2021). https://doi.org/10.1088/1742-6596/1838/1/012054
7. Ji, R., Qu, S.: Investigation and Evaluation of Energy Consumption Performance for Hospital Buildings in China. Sustainability 11, 1724 (2019). https://doi.org/10.3390/su11061724
8. Vakiloroaya, V., Samali, B., Fakhar, A., et al.: A Review of Different Strategies for HVAC Energy Saving. Energy Conversion and Management 77, 738–754 (2014). ISSN 0196-8904
9. Brockway, P.E., Sorrell, S., Semieniuk, G., et al.: Energy Efficiency and Economy-Wide Rebound Effects: A Review of the Evidence and Its Implications. Renewable and Sustainable Energy Reviews 141, 110781 (2021). https://doi.org/10.1016/j.rser.2021.110781
10. Bilgen, S., Sarıkaya, İ.: Contribution of Efficient Energy Use on Economy, Environment, and Sustainability. Energy Sources, Part B: Economics, Planning, and Policy 11(12), 1166–1172 (2016). https://doi.org/10.1080/15567249.2016.1177622

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