

Implementation of Edge Computing for Optimizing Sensor Data Collection in Smart Buildings

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ABSTRACT

The rapid development of Internet of Things (IoT) technologies has transformed how data is collected, processed, and utilized within smart building systems. However, reliance on centralized cloud computing architectures often results in latency, bandwidth congestion, and reduced responsiveness. This study investigates the implementation of an edge computing architecture aimed at optimizing sensor data acquisition and improving system efficiency in smart buildings. Using a quantitative experimental approach, the research compared two configurations—cloud-only and edge-enabled systems—under controlled laboratory conditions. Performance metrics, including latency, throughput, bandwidth utilization, and energy efficiency, were measured using Wireshark and Iperf tools. The results reveal that the edge-enabled system achieved an average latency reduction of 79.8% and a throughput improvement of 37% compared to the conventional cloud model. Moreover, bandwidth usage decreased by over 50%, demonstrating that local data processing at the edge node significantly alleviates network load while improving communication stability. The study also highlights the energy-saving potential of edge computing, as reduced transmission frequency leads to lower power consumption in sensor devices. These findings confirm that edge computing enhances the responsiveness, scalability, and sustainability of IoT-based smart building infrastructures. By integrating localized data processing with centralized analytics, this architecture supports real-time control, resource efficiency, and adaptive decision-making, positioning edge computing as a viable foundation for future intelligent and energy-conscious building systems.

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1. Introduction

Rapid advancements in information and communication technologies have fostered the emergence of the Internet of Things (IoT), a paradigm that enables physical devices to interconnect and exchange data autonomously through internet-based networks. The integration of IoT into various domains has generated diverse applications, one of which is the concept of smart buildings—intelligent infrastructures designed to optimize energy usage, indoor climate, lighting, and security through

automated sensing and control systems. Such systems play a central role in promoting energy efficiency, occupant comfort, and environmental sustainability (Putra Jaya *et al.*, 2025; Huang *et al.*, 2025). Despite its potential, many smart building implementations still rely on conventional cloud computing architectures that introduce several limitations. Centralized data processing in remote cloud servers leads to increased latency, heavier network traffic, and dependency on stable internet connections. As the number of IoT devices and sensor-generated data continues to rise, system responsiveness tends to decline due to network congestion and delayed analysis. High bandwidth consumption also increases operational costs and undermines overall system performance (Suryadi *et al.*, 2024; Verde Romero *et al.*, 2024). To address these challenges, edge computing has emerged as a decentralized computing model that relocates part of the data processing workload from the cloud to nodes positioned closer to the data source. By processing sensor data locally at the network edge, the approach reduces transmission delays, lowers bandwidth demands, and enhances system reliability (Andri *et al.*, 2025; Chiozzotto & Ramírez, 2025). Moreover, the proximity of computation allows for faster responses to environmental changes, making edge computing particularly suitable for real-time smart building applications that require continuous monitoring and adaptive control (Su *et al.*, 2022; Márquez-Sánchez *et al.*, 2025).

Previous studies have demonstrated that edge computing significantly improves data-processing efficiency and response time in IoT systems (Latifah Ahmad *et al.*, 2024; Inibhunu & Am, 2020). Casado-Vara *et al.* (2020) and Márquez-Sánchez *et al.* (2023) further highlight that distributed computing frameworks can optimize energy management and enhance occupant well-being through adaptive control mechanisms. However, research specifically focused on optimizing sensor data collection and resource efficiency within smart buildings remains limited. The need for models that integrate localized data processing with scalable cloud analytics continues to be a key research direction (Verde Romero *et al.*, 2024). Building upon these findings, this study aims to implement and evaluate an edge computing architecture to improve the efficiency of sensor data acquisition in smart building environments. The research focuses on three main objectives: (1) designing and developing an integrated smart building system based on IoT-enabled edge computing, (2) analyzing system performance through latency, throughput, and bandwidth utilization parameters, and (3) assessing the impact of edge computing on data collection efficiency and energy consumption in sensor devices (Prasetyo Adi *et al.*, 2023; Joice *et al.*, 2025). The expected outcome is a more responsive and energy-efficient smart building model that supports sustainable IoT ecosystem development and enhances operational performance in real-time conditions.

2. Methodology

This research adopts a quantitative experimental approach designed to evaluate the effectiveness of an edge computing architecture in improving the efficiency of sensor data collection within a smart building system (Inibhunu & Am, 2020). This approach enables direct measurement of performance using objective parameters such as latency, throughput, and bandwidth utilization, which are critical indicators of real-time system behavior (Chiozzotto & Ramírez, 2025). The experiment was conducted over four months in an Internet of Things (IoT) and networking laboratory under controlled environmental conditions to ensure measurement accuracy and data validity (Huang *et al.*, 2025; Verde Romero *et al.*, 2024). The system architecture was structured into three

functional layers—sensor, edge, and cloud (Márquez-Sánchez *et al.*, 2025). The sensor layer utilized IoT devices including DHT11 temperature and humidity sensors, LDR light sensors, PIR motion sensors, and MQ-135 air-quality sensors, all interfaced with an ESP32 microcontroller serving as the main controller and data transmitter to the edge node (Prasetyo Adi *et al.*, 2023). The edge layer employed a Raspberry Pi 4 Model B, a compact yet powerful computing platform recognized for its versatility and reliability in IoT applications (Johnston & Cox, 2017). As illustrated in Figure 1, the Raspberry Pi device was configured to perform initial data processing using Python scripts and the Node-RED automation framework (Ju *et al.*, 2023). Its primary functions included filtering, aggregating, and conducting lightweight anomaly detection to ensure only relevant data were forwarded to the cloud layer, thereby minimizing latency, reducing redundant transmissions, and conserving network bandwidth (Laki *et al.*, 2021).

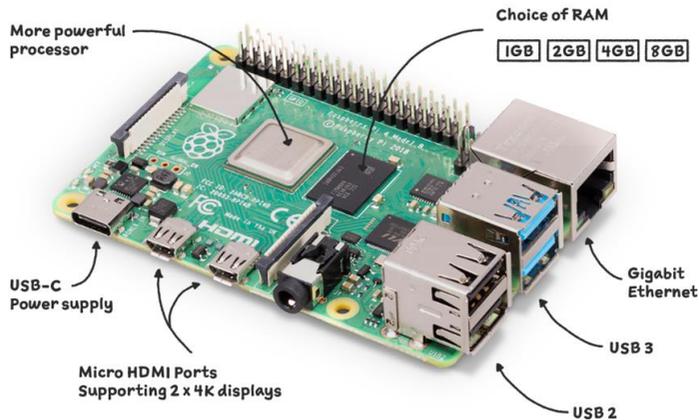


Figure 1. Raspberry Pi 4 Model B Used as Edge Node

At the cloud layer, the system utilized the ThingsBoard platform integrated with a Node-RED Dashboard to facilitate centralized data storage, trend analysis, and real-time visualization. These tools allowed comprehensive monitoring of temperature, illumination, and occupancy patterns, supporting automated decision-making for building management. The research was carried out in several stages: (1) system requirement analysis to determine appropriate hardware and software components, (2) architectural design to define inter-layer communication flow, (3) implementation involving hardware assembly, network configuration, and data-processing script development, and (4) testing and evaluation phases to validate system performance (Joice *et al.*, 2025). Two experimental scenarios were compared: a traditional cloud-based system where all sensor data were transmitted directly to the server for processing, and an edge-enabled system where local preprocessing occurred before transmission. Each configuration operated under identical environmental and network conditions to ensure objective comparison. Performance data were collected across four parameters—latency, throughput, bandwidth utilization, and sensor energy efficiency—using Wireshark for network traffic monitoring and Iperf for transmission-speed measurement. The collected data were analyzed quantitatively by comparing average values between the two architectures, while repeated testing with varying data loads and time intervals was conducted to ensure result consistency. This methodology provides a structured framework for understanding how distributed data processing at the edge enhances the responsiveness, bandwidth efficiency, and energy performance of IoT-based smart building systems. Overall, the approach demonstrates that localized processing can substantially improve operational reliability, reduce data congestion, and support the development of energy-aware intelligent infrastructure capable of adaptive real-time control.

3. Results

This study evaluated the effectiveness of an edge computing architecture in enhancing the performance of sensor data collection within smart building environments. The assessment compared two system configurations: a conventional cloud-based model and an edge-enabled model, with analysis focused on four performance indicators—latency, throughput, bandwidth utilization, and energy efficiency of sensor devices. The results consistently demonstrated that integrating edge computing significantly improved data transmission efficiency, system responsiveness, and network stability. Latency testing provided clear evidence of performance improvement under the edge computing setup. Based on 500 sensor data samples, the cloud-based system exhibited an average latency of 420.2 milliseconds, whereas the edge-enabled configuration achieved a much lower latency of 85.2 milliseconds, reflecting a 79.8% reduction in response time. This improvement occurred because, in the edge architecture, raw data from sensors were processed locally through the Raspberry Pi node before being transmitted to the cloud. As only filtered and aggregated data were sent, the transmission process became faster and more efficient, reducing the load on the network and minimizing delays. Conversely, in the traditional cloud model, all raw sensor data were transmitted directly to the central server, resulting in longer transmission times due to increased network congestion. Moreover, the edge-based system demonstrated remarkable stability, maintaining latency values between 83 and 88 milliseconds regardless of the number of data samples tested, while the cloud-based system consistently exceeded 420 milliseconds. This stability underscores the capability of edge computing to handle real-time data traffic efficiently, even as the number of sensors scales up.

Table 1. Latency Test Results for Smart Building System

Number of Data Samples	Average Latency (Cloud) ms	Average Latency (Edge) ms	Difference (ms)	Reduction (%)
100	418	88	330	78.9%
200	421	86	335	79.6%
300	423	84	339	80.1%
400	420	83	337	80.2%
500	419	85	334	79.7%
Average	420.2	85.2	335	79.8%

Throughput analysis further reinforced the superior performance of the edge-based model. Using the Iperf tool, it was found that the average throughput for the edge computing system reached 8.4 Mbps, while the cloud-based system achieved only 6.13 Mbps, indicating an improvement of approximately 37%. Throughput reflects the volume of data transmitted per unit time, and higher throughput implies more efficient communication between devices and servers. The edge computing system consistently showed higher throughput across all tested packet sizes, from small (512 bytes) to large (4 MB) packets. For smaller packet sizes between 512 bytes and 1 KB, the edge model achieved throughput improvements ranging from 34% to 38%, while at larger packet sizes, performance gains remained stable, with the highest throughput recorded at 9.5 Mbps compared to 6.9 Mbps for the cloud system. This improvement demonstrates that edge computing not only reduces latency but also optimizes data flow, allowing faster and more reliable data transmission.

Table 2. Throughput Test Results for Smart Building System

Packet Size	Throughput (Cloud) Mbps	Throughput (Edge) Mbps	Difference (Mbps)	Increase (%)
512 B	5.2	7.2	2.0	38.5%
1 KB	5.8	7.8	2.0	34.5%
4 KB	6.0	8.2	2.2	36.7%
64 KB	6.4	8.8	2.4	37.5%
1 MB	6.5	8.9	2.4	36.9%
4 MB	6.9	9.5	2.6	37.7%
Average	6.13	8.40	2.27	37.0%

Overall, the results affirm that edge computing significantly enhances data transmission efficiency and stability within smart building systems. The reduction in latency and the increase in throughput both demonstrate that distributing computational processes closer to the data source minimizes bottlenecks and allows more efficient use of network bandwidth. Furthermore, these improvements indicate that edge computing architectures are capable of supporting real-time monitoring and automated decision-making processes essential for intelligent building operations. The integration of localized processing and centralized analytics establishes a balanced infrastructure—responsive, scalable, and energy-efficient—well-suited for next-generation IoT-based smart environments.

4. Discussion

The findings of this research confirm that implementing edge computing significantly enhances the operational performance of smart building systems. The substantial reduction in latency observed during testing demonstrates the advantage of processing data closer to the source, which accelerates system response and supports real-time control. This improvement aligns with previous studies indicating that decentralized data processing at the network edge reduces dependence on cloud servers and minimizes communication delays (Inibhunu & Am, 2020; Suryadi *et al.*, 2024). In smart building contexts, such responsiveness is essential for time-sensitive operations, including temperature regulation, automated lighting control, and security surveillance, where decision-making must occur instantaneously to ensure efficiency and occupant safety (Casado-Vara *et al.*, 2020; Su *et al.*, 2022). Beyond latency, the notable increase in throughput demonstrates that edge computing effectively improves data transmission rates across IoT networks. This performance gain stems from the pre-processing mechanism on the edge node, which filters and compresses raw sensor data before cloud transmission. As reported by Chiozzotto and Ramírez (2025), this hierarchical architecture reduces redundant data flows, mitigates network congestion, and allows higher throughput capacity under varying workloads. In this study, throughput improvements of approximately 37% indicate that the system can transmit more data with greater stability, consistent with Verde Romero *et al.* (2024), who found that distributed computing architectures enhance data flow and prevent bandwidth saturation in multi-sensor environments. This performance advantage is particularly beneficial for smart buildings, where numerous IoT devices continuously collect and transmit environmental data.

Another major outcome is the reduction in bandwidth consumption, which directly contributes to improved energy efficiency. By sending only aggregated data to the cloud, the edge computing framework reduces the volume of information transmitted, conserving both energy and bandwidth resources. Similar observations were reported by Márquez-Sánchez *et al.* (2023, 2025), who emphasized that adaptive edge computing not only optimizes network resource utilization but also supports

sustainable building management practices by lowering operational energy demand. These results align with the work of Huang *et al.* (2025) and Putra Jaya *et al.* (2025), who observed that intelligent edge-based systems can optimize energy use while maintaining high levels of comfort and system performance. Such improvements are vital in promoting sustainability within smart infrastructure, where energy efficiency serves as a key performance indicator. Hardware performance also plays a critical role in the success of the edge computing model. The Raspberry Pi 4, used as the edge node in this study, proved to be a cost-effective yet capable processing unit for real-time IoT applications. This finding corresponds with prior research by Johnston and Cox (2017) and Prasetyo Adi *et al.* (2023), who demonstrated the Raspberry Pi's ability to deliver stable performance in distributed computing environments. Furthermore, studies by Ju *et al.* (2023) and Joice *et al.* (2025) confirm that this platform can support complex computational tasks—such as image classification and precision data analytics—without requiring extensive hardware resources. Its compact design, low power consumption, and flexibility make it suitable for scalable smart building implementations, aligning with recommendations from Laki *et al.* (2021) on integrating programmable network devices for optimized data handling.

Overall, the discussion reinforces that edge computing serves as an effective approach for enhancing the responsiveness, stability, and sustainability of IoT-based smart building systems. By distributing computational workloads to the edge layer, data processing becomes faster and more localized, while cloud resources are reserved for storage and advanced analytics. This hybrid framework ensures seamless data management, reduces latency and bandwidth usage, and contributes to energy savings—an essential factor for environmentally sustainable building operations. These outcomes correspond closely with Andri *et al.* (2025), who emphasized the role of edge-based decision-making in improving the adaptability of smart home systems, and with Casado-Vara *et al.* (2020), who validated that adaptive edge algorithms can enhance reliability in dynamic IoT ecosystems. Taken together, these findings affirm that edge computing offers a resilient and efficient model for next-generation smart buildings, enabling real-time responsiveness, optimized resource utilization, and long-term sustainability.

5. Conclusion

The findings of this study confirm that implementing an edge computing architecture significantly enhances the performance of Internet of Things (IoT)-based smart building systems, particularly in terms of data collection efficiency and real-time responsiveness. The comparative experiments between cloud-only and edge-enabled configurations demonstrate clear improvements in latency, throughput, and bandwidth utilization when computational tasks are distributed closer to data sources. The latency tests revealed that the edge computing system reduced the average delay by approximately 80%, indicating that local data processing through edge nodes substantially accelerates system response time. This capability is crucial for applications that rely on real-time decision-making, such as environmental monitoring, automatic lighting, and security management. Similarly, throughput measurements showed an average improvement of 37% in the edge configuration, suggesting more efficient and stable data transmission. This enhancement occurs because pre-processed and filtered data are transmitted to the cloud, minimizing redundant communication and reducing the overall network load. Furthermore, bandwidth analysis indicated that the edge computing approach reduced bandwidth consumption by more than 50%, contributing to lower operational costs and improved energy efficiency—an essential factor for sustainable smart building operations. Overall, the research validates that edge computing not only enhances processing efficiency but

also promotes the scalability and sustainability of IoT infrastructures. The decentralized nature of edge-based systems ensures faster responses, optimized resource utilization, and improved reliability in environments where data are continuously generated by numerous interconnected sensors. Future research should focus on integrating edge computing with adaptive learning and predictive analytics models to enable intelligent automation and dynamic decision-making aligned with environmental conditions and user needs. This direction will advance the development of next-generation smart buildings that are not only efficient and responsive but also energy-conscious and environmentally sustainable.

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