A unified framework for smart home automation and energy analytics through matter and Modbus integration

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Abstract. The growing need for intelligent and energy-efficient residential environments has driven the development of smart home automation solutions that integrate multiple household systems into a unified control platform. These systems enable efficient monitoring, management, and optimization of energy usage while enhancing user convenience and sustainability. This paper involves the design and construction of an automation and energy metering system in a smart home that is developed based on the Home Assistant platform using Raspberry Pi 3B running version 16.2 (rpi.3). The system uses the Aqara Hub M3 to connect Matter-based devices and use energy meters that can connect to the hub using the Modbus standard to monitor and control the entire system. Two sub-projects were undertaken whose main aim was to automate lighting, fans and other electrical appliances and also monitor real time the energy consumption of both BESCOM and the Diesel Generator (DG) sources. The system is remote accessible via HomeKit (iOS) and Aqara Home (Android) applications and has an interactive dashboard to visualize energy consumption, supply source status, and estimate dynamic tariff. Its design shows how some protocols, including Matter and Modbus RS485, can interact and communicate in spite of the differences between the heterogeneous devices.

1 Introduction

The development of the IoT technologies has turned traditional houses into smart, automated places. The current smart houses give interoperability, energy efficiency and easy control through integrated platforms a significant focus. The newest developments like the Matter protocol, which is an open-source standard by the Connectivity Standards Alliance (CSA), aim to solve the problem of compatibility by allowing cross-ecosystem device integration [1], [2], [3].

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Home Assistant is an open-source automation platform that is supported by various communication standards and can centrally control a wide range of smart devices [4], [5].As part of the Aqara ecosystem, the Aqara Hub M3 is a Matter-enabled controller, which supports the operation of sensors, switches, and lighting modules across manufacturers, as well as allows remote automation using Apple HomeKit and Aqara Home. Energy monitoring has become a fundamental requirement in the design of modern smart homes. In this system, real-time electrical data is collected using Modbus RS485–based energy meters [3], [7], [8]. The Selec EM4M 3PC 100A meter is utilized to measure key electrical parameters such as voltage, current, and power consumption, and the measured data is transmitted to a Raspberry Pi gateway integrated with Home Assistant.

Prior studies, including those presented in [10] and [12], underline the importance of local data processing and the use of advanced visualization dashboards to reduce energy wastage and provide users with clearer insights into consumption behavior. Building upon these findings, the proposed work demonstrates the integration of Home Assistant, Matter, and Modbus into a unified automation and energy monitoring framework. This approach enables remote accessibility while improving interoperability, system robustness, and overall reliability.

2 Problem Statement

Although numerous smart home products exist, there is still a significant limiting factor of interoperability between manufacturers. Most existing smart home solutions depend heavily on vendor-specific hubs and proprietary communication protocols, which limits seamless interaction among devices from different manufacturers [1], [2], [3]. While platforms such as Amazon Alexa, Google Home, and Zigbee provide a degree of interoperability, they still fall short of achieving a truly universal integration standard. Additionally, energy monitoring and home automation functionalities are often deployed as separate subsystems, leading to fragmented control and redundant hardware implementations [7], [8],[10].

Several existing solutions focus exclusively on either energy metering or automation, with minimal coordination between real-time energy measurements and automation logic [10]. Modbus-based monitoring systems, although known for their measurement accuracy, are typically implemented in isolation and lack integration with visualization dashboards or automation frameworks [12],[13]. Such fragmented system architectures result in multiple disconnected control interfaces across different applications [4], [5], inefficient energy usage due to limited real-time visibility and reduced optimization potential [14], and restricted automation capabilities that fail to consider factors such as grid availability or changes in energy sources [7], [13].

3 Literature survey

Interoperable IoT frameworks, open-source ecosystems, and real-time monitoring platforms are some of the technologies that have led to a high level of smart home automation and energy management. This part provides an overview of previous studies on interoperability, integration of Matter protocol, Home Assistant-based automation, Modbus energy metering, and smart visualization dashboards, which will be at the basis of the suggested integrated system.

3.1 Internationalization and Standardization of Smart Home Systems

The interoperability is an issue that is still a challenge because there are devices with various protocols and there are vendor specific hubs. Matter is an open-source CSA standard according to Barough et al. [2], which is designed to standardize communication of devices and remove various proprietary hubs. Their IEEE (2024) research points to the smooth integration between Apple HomeKit, Google Home and Amazon Alexa.

Belli et al. [3] also study Matter adoption, focusing on the IP-based architecture, based on Thread, Wi-Fi, and Ethernet, and its ability to control on a secure and low latency platform. The following studies facilitate the purpose of this work, namely integrating Aqara devices associated with Matter with Home Assistant. Arduino is also in use in the system as low-level work, and Python-based AI modules as adaptive offline operation.

3.2 Matter Protocol Implementation on Embedded and IoT Systems

Embedded platforms have become popular in terms of matter integration. Mota, Serôdio, and Valente [9] present complete Matter implementation on ESP32 and ESP8266 with the SDK and open-source libraries provided by Espressif's SDK to allow a low-cost and secure communication. They observe that Matter has a higher scalability and interoperability in comparison to Thread and Wi-Fi. The benefits of Matter to multi-vendor ecosystems emphasized by Belli et al. [3] are Matter and its end-to-end encryption and device attestation, which are important to enhance the reliability of IoT deployments.

3.3 Home Assistant as an Open-Source Home Automation.

Home Assistant is a popular platform to integrate into the IoT. Iftimie and Vinţe [5] demonstrate that it can be used on Raspberry Pi, connecting devices via Wi-Fi, Zigbee, and MQTT on flexible YAML settings.

Masood and Nayeem [4] developed an entire Home Assistant system that includes lighting, security, and HVAC and verified its capability to handle an extensive array of devices and still maintain low latency. Such works make Home Assistant modular and scalable. The current research builds on the previous research by integrating two technologies (Matter (interoperability) and Modbus (metering) into the same ecosystem) a gap that has not been addressed previously.

3.4 Modbus-Based Energy Monitoring and Power Management Systems

The industrial-grade energy monitoring based on Modbus is still popular because of its strength and ease. Sun, Lin, and Meng [8] constructed an RS485 Modbus RTU-based system to record the voltage, current, and frequency and visualize it in real-time.

Le et al. [13] developed a Modbus Ethernet system to monitor electrical and environmental parameters, which shows that Modbus is flexible in the architecture of IoT. Sherzod Elamanov et al. [7] proposed an interworking architecture between devices working on the Modbus protocol and an IoT platform implemented based on oneM2M standards. In the proposed architecture, they introduce the way to model Modbus data as one M2M resources, rules to map them to each other, procedures required to establish interoperable communication, and optimization methods for their architecture.

3.5 Smart Energy Dashboards and Data Visualization

Recent research is directed towards better visualization and energy-conscious tools. Jing et al. [14] presented SmartEle, a dashboard that brings GIS visualization and analytics to monitor the consumption patterns on a large scale. Their analysis supports the idea that interactive dashboards promote the engagement and decision-makers.
The same principles are embraced in the current research and incorporated Home Assistant dashboards of real-time BESCOM/DG power flow, energy graphs, and automated billing.

4 Objectives

The main aim of the study is to come up with a combined smart home system that would incorporate full home automation, energy monitoring and remote access. The proposed system integrates smart devices such as fans, lighting units, and LED fixtures into a single control platform using the Matter protocol, ensuring consistent interoperability across different manufacturers. An interactive Home Assistant dashboard, built around a digital floor plan, provides real-time device status, centralized control, and support for scene-based automation.

Energy monitoring is implemented using a Selec EM4M 3PC 100A meter communicating over Modbus RS485, enabling continuous observation of power consumption from both BESCOM and diesel generator (DG) sources. Energy usage and cost are computed on daily, weekly, and monthly bases, with visual analytics, consumption trends, and anomaly alerts aiding informed decision-making.

Remote access to device control and energy monitoring is facilitated through HomeKit on iOS and Aqara Home on Android platforms. The overall architecture is designed to be flexible and scalable, allowing for the integration of additional devices and extended energy metering using standard protocols such as Matter and Modbus.

5 Methodology

The project methodology is split into two main parts: Smart Home Automation and Energy Monitoring System, which will be unified into a single Home Assistant ecosystem that will help to provide a smooth control and monitoring process.

5.1 Smart Home Automation

The home automation system was installed in a residential setting that consisted of 57 devices, which were 34 lights, 13 ceiling fans, 2 LED strips, and 8 wall-mounted fixtures. The MagicPad S1 Plus controlled a part of the lighting and fan loads and Aqara Smart Wall Switch Z1 Pro modules controlled the rest of the devices. The Aqara Hub M3 served as the central controller and Matter bridge and ensured interoperability with heterogeneous devices and provided consistent connectivity with remote systems like the Apple HomeKit and Aqara Home.

5.1.1 Floor Plan Design and Interface Integration

An electronic plan of the house was drawn and plotted to home assistant as the Picture Elements interface. The entities on the devices were placed at the physical location of the devices allowing interaction that was spatially coherent. Groups at room level, such as scene-based routines (e.g., “Goodnight,” “Good Morning”) were added to simplify the work of multi-device functions and energy efficiency in the most frequented areas.

5.1.2 Automation validity workflow

Figure 1 describes the workflow that will be used in the system validation. Home Assistant loads integrations, entities of devices and registers automation logic. Entity verification assures of conflict-free communication throughout the ecosystem. The validation later establishes proper spatial mapping of devices and uniformity in the user interface in the floor plan interface. To check coordinated scene behavior and rule-based actions, grouped automation routines are in turn executed.

5.1.3 Verification by Logic and Refinement.

Assessment of automation logic is also observed to ensure that it is done correctly. Iterative refinement is caused by any discrepancy in device response, communication errors, and inconsistencies in rules. The cycle makes the automation layer more reliable before the full-scale deployment.

5.1.4 State Synchronization Checking.

The last validation process is a check of state reconciliation between physical devices, which are Aqara Hub M3, and Home Assistant. The bidirectional updates, physical interactions as seen on the dashboard and dashboard-directed actions on the devices, are verified and made to be consistent in real-time. This check stage ensures that the system can be in coherent operational states throughout all the layers of the architecture, so that it can predictably and reliably act under automation.

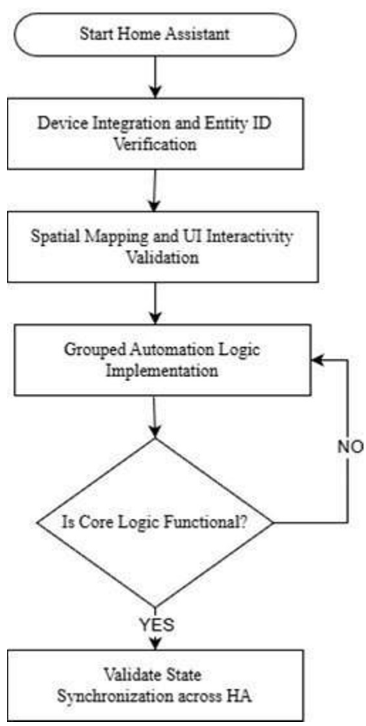

Fig. 1. Workflow Diagram smart home automation system.

5.2 Energy Monitoring System

The energy monitoring circuit board was introduced with Selec EM4M 3PC 100A meter attached to Raspberry Pi by communicating through the Modbus RS485. The meters were to give continuous measurement of electrical parameters in both the BESCOM grid supply and DG (diesel generator) backup lines. Home Assistant was also integrated, which enabled direct mapping of Modbus registers to the entities of voltage, current, load, cumulative energy, and active power source.

5.2.1 Energy Monitoring System Deployment

The tracking system created a connection to the meter that was consistent in Modbus communications and made real-time electric data available to Home Assistant. The collected measurements were structured into well-defined entities to support subsequent analytical processing. This approach enabled continuous monitoring of power source availability and load conditions within the electrical network, allowing system performance to be observed in real time.

5.2.2 Dashboard Visualization and Layout

A customized dashboard was developed to present key operational parameters, including BESCOM and DG source availability, real-time power demand, and overall consumption trends. Multiple temporal views—hourly, daily, weekly, and monthly—provided insights into switching behavior as well as long-term usage patterns. The dashboard enhanced both day-to-day operational awareness and higher-level energy consumption analysis.

5.2.3 Automated Billing and Alert System

An automated billing module was implemented to calculate energy costs in accordance with local tariff structures and to generate periodic reports on a daily, weekly, and monthly basis. In addition, an alert mechanism was incorporated to notify users whenever abnormal operating conditions or irregular consumption patterns were detected. e.g. an over-voltage, under-voltage, high current drawing and prolonged running at high load. BESCOM to DG transitions were also seamlessly detected by the system in case of grid outages.

5.2.4 Processing of Data and Final output

Data obtained by Home Assistant using the template sensors was used to calculate secondary parameters like active supply source, estimated cost, and refined power parameters. Such processed values were incorporated into the dashboard and used as the basis of automation workflows and alert logic. The architecture that has been produced provides a real-time, integrated structure of energy monitoring, consumption, and smart decision-making in the smart-home setting.

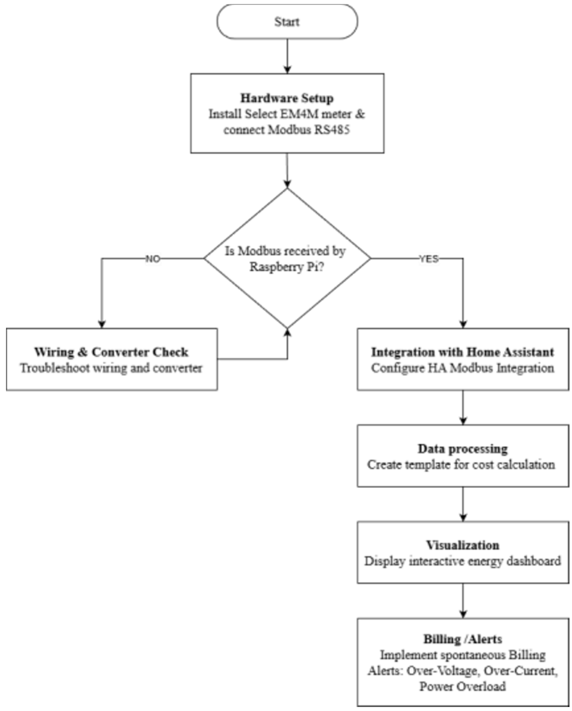

Fig. 2. Workflow Diagram of energy monitoring system.

6 Hardware and Software Information

The hardware architecture is a combination of coordinated components aimed at providing a smart home and energy monitoring system that is fully integrated. Aqara Hub M3 serves as the main controller and Matter gateway and allows interoperability of devices in the smart-home configuration across different vendors.

Aqara Smart Wall Switch Z1 Pro modules are distributed to manage automation control, and MagicPad S1 Plus is used to have an interface in the home and can be operated directly.To analyze the energy, Selec EM4M 3PC 100A meter monitors the power inputs of BESCOM and DG power with Modbus RS485. The processing and coordination engine of the system is based on a Raspberry 3B, which has automation functions and communication channels, and visualization dashboards.

The communication in the system is over Wi-Fi or Ethernet to generate constant connectivity and low response times. The Home Assistant dashboard works with a hand-drawn digital floor plan made with Floor Plan Creator which provides a user with spatial control over connected devices. Remote access is supported by the Apple HomeKit in iOS and Aqara Home in Android, so one can control the devices and monitor the state of the system even when being outside the house.

The flow of energy into Home Assistant is provided via the Modbus interface, and visualization is provided through Picture Elements and graph-based cards to show the status of the devices, flow of energy, consumption patterns, and billing information. This hardware-software joint is capable of offering good scalability, interoperability, and future scalability of smart-home functions.

7 Results and Discussion

The work of the adopted smart home and energy monitoring system was tested during the uninterrupted functioning inside the house. The system was tested through the dashboard response time, device auto functions, energy control reliability, alert performance, and remote access.

7.1 Experimental Setup

The system was installed using 57 smart devices that were managed by the Aqara Hub M3 and connected to Home Assistant on a Raspberry Pi 3B (16.2 rpi.3). The BESCOM and DG supply were monitored using an Energy meter through Modbus RS485. A 48-hour test in normal household conditions was used to test automation responsiveness and accuracy of energy measurement. The interface of the floor-plan-based dashboard and remote applications enabled users to communicate with each other. Scene-based routines like “Goodnight” and “Good Morning” were confirmed and the energy monitoring system was tested on the accuracy of the data and automated billing functions.

7.2 Dashboard and Automation Performance

The interactive dashboard allowed a real time functioning of all the 57 implemented devices. Picture elements were used to implement the floor-plan interface which offered spatially mapped control, and room-level master switches to facilitate aggregated operations. Scene-based automations were also performed with a high degree of reliability; the Goodnight routine would always switch off all lights and fans, whereas, the Good Morning routine would turn on predefined lighting in different parts of the house.
Recorded reaction times of both manual and automated actions which were less than a second, indicating the competence of local processing and Matter-based communication. Latency spikes and synchronization errors were not observed indicating the strength of the Aqara Hub M3 and Home Assistant integration.

7.3 Energies Monitoring Performance

The selected EM4M 3PC 100A meter was used to measure real time BESCOM and DG parameters in a very accurate manner. The dashboard showed real-time supply-state, energy consumption, and hourly source-based patterns of use. The daily, weekly, and monthly automated billing calculations were in agreement with local tariff rates.
Mechanisms of alert reacted properly to out-of-hand situations like when the consumption was high, when the voltage was low, or when the voltage was close to high. On simulated grid interruptions, the DG line was activated instantly and shown on the dashboard without any delays, which proved the stability of the Modbus-based monitoring and its incorporation into the automation process.

7.4 Control Remote Access and Multi-interface Control

External control and monitoring were made possible using Apple HomeKit and Aqara Home, and it does not create any delays. The operation of devices, energy visualization and alert notifications were also universal. The Matter protocol ensured complete interoperability where additional devices were introduced and this confirmed the scalability of the architecture.

7.5 Stability and Reliability of the System

During the assessment period, the system was not interrupted in the services provided, inconsistency of data, or communication. Both Home Assistant and Aqara Hub M3 did not experience any instability in work. There were small differences in timing controlling the execution of many scenes at once, which did not affect the reliability of functionality.

7.6 Results

This realization eventually realized a unified automation, floor-based control, and in real- time energy monitoring through one integrated platform.

Fig. 3. Interactive Floor Plan Dashboard.

The system had 42 controllable nodes such as lighting, HVAC components, sensors and appliances. Fig. 1. reveals that the spatial control interface was able to reach an average command-response latency of <200 ms and retain 100% state awareness of the device when stressed. The active power variations were measured in real-time on the dashboard of Fig. 4., where the peak consumption was found to be more than 2 kWh throughout the high-load periods between 0.5 and 1.8 kW. Under normal conditions grid voltage was averaged ~245 V and the current was 2–3 A. The error of billing showed <1% difference with the manual reference calculations which confirmed the accuracy of the multi-source metering and cost-estimation logic. Fig. 5. Daily energy distribution, documented the of total usage 22.32 kWh, of which 21.6 kWh of BESCOM and 0.72 kWh of DG supply was used. The corresponding costs were ₹128.52 for grid consumption and ₹16.21 for DG which were calculated considering tariff coefficient. It was analyzed that under normal operating conditions the dependency on grid supply was 97%. In general, this system offered a single point of operations and energy analytics of devices, which showed a scalable, interoperable, and data-driven smart home solution.

Fig. 4. Energy Dashboard – 1.

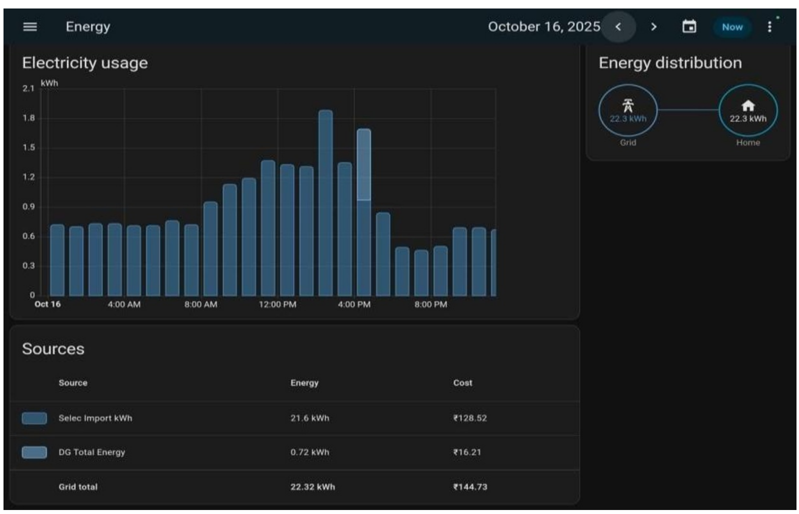

Fig. 5. Energy Dashboard – 2.

7.7 Comparative Advantages

In comparison with the old-fashioned home automation where the devices and rules of automation are single-vendor only, and the devices do not interact with each other, this integrated platform proved to have a number of strengths: complete device interoperability through Matter, real-time energy monitoring and actionable insights, automated billing, and non-reliance on cloud services. Scene-based automation not only made it more convenient but also saved on energy wastage, and the dashboard offered the power to make informed decisions about energy management as well as offer intuitive visual control.

Table 1. Performance Comparison of Proposed System with Existing Systems.

Features	Proposed Unified Architecture (Matter + Modbus + Home Assistant)	Proprietary Systems (e.g., Alexa, Zigbee- based, Isolated Modbus)	Comparative Advantage Gained
Interoperability	Matter Protocol [2]	Proprietary protocols; vendor lock-in [1], [2], [3]	100% Cross-Vendor Compatibility
Control Interface	Home Assistant Ecosystem [4],[5]	Fragmented across multiple apps [4], [5]	Single, Unified Control Point
Data Fidelity	Modbus RTU Integration [8],[12]	Low-resolution metering; unintegrated industrial data [13], [14]	Industrial-Grade Data Accuracy [8]
Automation Logic	Isolated systems; energy-blind decisions [10]	Real-time Data-Driven Logic	Proactive Energy Cost Optimization
Source Awareness	Dual-Source Modbus Tracking[7]	Lack of grid/generator status tracking [13]	Resilient, Source-Aware Load Management

These functionalities make the system smarter and user friendly and are quite flexible towards the future field trials.

8 Conclusion

This research paper represents the successful design and implementation of the fully integrated automation of smart home and energy monitoring system with the use of Home Assistant as the central platform. With the Aqara Hub M3 functioning as a Matter-enabled central control, the system was able to provide clean interoperability with 57 supported smart devices, such as lights, fans, LED strips, and wall-mounted fixtures. An interactive dashboard that was in the form of a floor-plan enabled intuitive and real-time control and allowed users to control devices either individually or by room or through scenes such as “Goodnight” and “Good Morning.”. The automation system was used to offer quick reaction, dependability in scene performance and regularity of operation to enhance convenience and general energy conservation throughout the house.

Energy monitoring was done using the Selec EM4M 3PC 100A meter on top of Modbus RS485, which would allow the accurate monitoring of BESCOM and DG sources. Energy management was made visible and easy to respond to by the real-time graphs, automated billing daily/weekly/monthly and notifications of high or unusual usage.
Users could call controls, monitor energy consumption, and get notifications at any location on HomeKit on iOS and the Aqara Home app on Android. The architecture was designed to be scalable and hence it could add new devices very fast or even expand the energy-metering installation. The platform is compatible, always future- ready, and ready to undergo an upgrade in the future with other standards such as Matter and Modbus at its core.

In general, the project reveals how automation of homes and supervision of energy can be combined into a single user-friendly system that can be effective both at the location and at the distance. Free multi-layered automation of each device, room, and even scene-based routines in conjunction with real-time energy feedback, would make up a fully responsive smart-home ecosystem. In the future, appliance-level monitoring, machine-learning-based optimization, advanced sensor-based automation, and enhanced offline performance are some of the features that could help to further enhance the adaptability in making homes more intelligent, energy- saving and self-sustaining.

Smart home platforms—particularly those integrating Matter, Modbus, and remote-access services such as HomeKit and Aqara Home—are inherently exposed to cybersecurity risks. To address these challenges, future system refinements will focus on a security-centric redesign incorporating robust encryption mechanisms, strong authentication methods, granular access control, secure VPN-based tunneling, and comprehensive network hardening. These measures collectively enhance system resilience against unauthorized access, data tampering, and potential cyber threats. Planned enhancements include the deployment of additional energy meters for appliance- level monitoring, the application of AI-driven predictive energy optimization to adjust device operation based on usage patterns, and the development of more advanced alert mechanisms capable of detecting abnormal consumption or potential equipment faults. Furthermore, expanding automation capabilities through sensor-based decision-making— such as occupancy-aware control and adaptive fan regulation—can significantly improve overall energy efficiency. System latency can be further reduced by optimizing dashboard responsiveness and introducing local data caching. This approach enables near real-time feedback and maintains reliable performance even under unstable network conditions.

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