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IoT based Smart Building Concept with Dynamic Energy Management in High-Rise Buildings

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Abstract— Consumption energy electricity in the building tiered Keep going increase along with height activity users, needs cooling, and use device electronics, so that management strategy is needed energy efficient without reduce comfort occupants. Smart buildings based on the Internet of Things (IoT) are seen as solution through real-time monitoring, control automatic, and analysis predictive for optimize consumption energy. Research This aim designing a conceptual model of an IoT- based smart building with management energy systematic, practical, and neutral dynamic device. The model was developed through approach conceptual with a narrative review of literature related to IoT, adaptive energy optimization, and management energy building. Research results produce framework three stages that include sensor data input (temperature, light, humidity, and presence), processing unit AI -based for analysis and prediction need energy, as well as output in the form of control automatic HVAC and lighting for efficiency energy without reduce comfort residents. The model also offers contribution addition in the form of potential sustainability environment, predictive maintenance, and integration ecosystem energy such as smart grid and Building Information Modeling (BIM). With thus, the framework conceptual results generated can become base more smart building implementation efficient, adaptive, and sustainable, as well as push study advanced through testing prototype and validation empirical in the field.

Keywords— Smart Building; Internet of Things; Adaptive Energy Optimization; HVAC

I. Introduction

Electrical energy consumption in multi-storey buildings tends to increase along with the intensity of space use, cooling needs, and the use of electronic devices. This condition demands an efficient energy management strategy without compromising occupant comfort. The concept of smart buildings based on the Internet of Things (IoT) offers solutions through real-time monitoring capabilities, automatic control, and analysis of energy usage patterns to optimize electricity consumption (Abid et al., 2025; Poyyamozhi et al., 2024). The integration of IoT in energy management systems allows for dynamic energy allocation to devices such as HVAC and electric vehicle charging stations using advanced algorithms to maintain network stability and reduce waiting times and processing loads (Abid et al., 2025). This shows that sensor-based automation and energy analytics are increasingly becoming basic needs not only for cost efficiency, but also for the operational sustainability of modern buildings.

Secure and efficient IoT-based smart building architectures have been shown to reduce energy consumption by up to 30% through the use of optimized communication protocols (Kumar et al., 2021). Furthermore, IoT-based predictive mechanisms and optimization strategies can maximize thermal comfort while minimizing energy use in residential buildings (Imran et al., 2022). However, the implementation of these systems still faces several obstacles, including high infrastructure investment costs, data security challenges, and the complexity of device integration. The development of secure, user-centric, interoperable solutions is expected to increase the wider adoption of smart building technology (Billanes et al., 2025). Thus, the success of smart building transformation is determined not only by technological sophistication but also by the maturity of the ecosystem and ease of implementation.

Adaptive energy optimization approaches are increasingly seen as key to addressing the dynamics of energy demand influenced by occupant activity, environmental conditions, and building operational schedules. Adaptive energy management systems that utilize IoT and optimization algorithms such as Particle Swarm Optimization (PSO), Model Predictive Control (MPC), or reinforcement learning are capable of making automatic adjustments based on real-time data, thereby increasing energy efficiency without sacrificing comfort (Li et al., 2025). Machine learning-based methods such as Deep Q-Network and hybrid algorithms such as Weighted Mean of Vectors are capable of generating more accurate energy demand predictions and supporting dynamic load management, which in turn can reduce electricity costs and load peaks (Ebeed et al., 2025). This reinforces the need for a transformation from static energy control systems to adaptive systems based on the context of space use.

The integration of IoT sensor data and Building Information Modeling (BIM) also strengthens predictive energy management models, such as in building retrofits that combine HVAC with renewable energy sources to improve efficiency and sustainability (Villani et al., 2025). In addition to

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optimizing energy consumption, adaptive systems create flexibility in energy demand, contributing to grid stability and carbon emission reduction (Salerno et al., 2021). However, the implementation of these technologies still faces challenges related to design complexity, the need for sophisticated hardware and software, as well as security and interoperability issues. Scalable and integrated solutions are being developed to overcome these obstacles and enable energy management at the building level down to the urban ecosystem level (Kulkarni et al., 2024).

Despite these advances, conceptual models that integrate IoT, energy management, and adaptive decision-making in the context of smart buildings are still rarely formulated in a comprehensive and easily applicable manner. Some studies have proposed frameworks that combine IoT, machine learning, and BIM for adaptive energy management, but the resulting models tend to be case-specific, dependent on specific device configurations, and difficult to replicate (Villani et al., 2025). Systems based on deep reinforcement learning and iterative algorithms have been developed to manage HVAC loads and energy storage, taking into account user comfort and real-time data (Gao et al., 2022). Other approaches utilize a combination of AI and IoT for rule-based and predictive dynamic power control (Ghazo & Salah, 2025), or hybrid models based on finite automata and machine learning for adaptive energy management (Rikame et al., 2025). However, none of these approaches have yet produced a conceptual framework that is simple, integrated, applicable, and easily replicable across building types (Shalaby et al., 2023).

Based on these research gaps, this study aims to design a conceptual model of an IoT-based smart building with dynamic energy management that is systematic, practical, and implementable without dependence on specific device configurations. This study offers a three-stage conceptual framework that directly links IoT sensor inputs, AI-based adaptive processing units, and HVAC–lighting automatic control outputs as a single integrated system for energy efficiency without compromising occupant comfort. This model is also modular and device-neutral, making it applicable at different scales and developed in line with future energy technology trends.

II. Method Research

This study uses a conceptual approach to develop a theoretical framework related to IoT-based smart buildings and dynamic energy management in high-rise buildings. This approach was chosen because the study does not rely on empirical field data, but rather constructs concepts based on relevant theories and previous research findings. As a basis for developing the concept, this study applies a narrative review as a technique for collecting and analyzing information. Narrative reviews provide researchers with the flexibility to examine, interpret, and synthesize various scientific literature in depth without strict quantitative procedures. This technique facilitates the identification of patterns, technological developments, important findings, and research gaps related to IoT, smart buildings, and adaptive energy optimization.

The synthesis process was conducted through a literature search relevant to the research topic, then selected based on their thematic suitability and theoretical contribution to the model formulation. The obtained literature was analyzed to identify system components, working mechanisms, and inter-concept relationships that form the basis of the conceptual model. From the results of this analysis, this study developed a conceptual framework for smart buildings that integrates IoT sensors, adaptive data analysis, and automatic energy control.

III. Result And Discussion

The development of a conceptual model for an IoT-based smart building with dynamic energy management results in a three-stage system consisting of sensor input, an AI-based processing unit, and output in the form of automatic control of energy devices. This system positions the energy management process as a sequential cycle that starts from collecting environmental data and occupant activities, then intelligently analyzing it, and then translating it into efficient operational decisions at the multi-story building level. The architecture shown in Figure 1 shows the interrelationships between components functionally, not symbolically, so it can be flexibly replicated in various modern buildings.

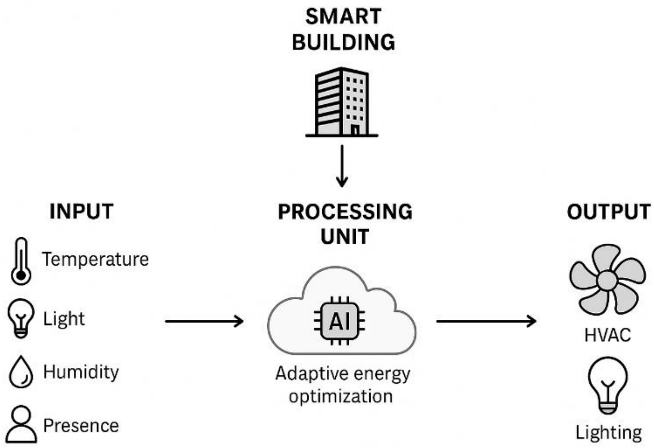

Figure 1 Conceptual model of IoT-based Smart Building with Adaptive Energy Optimization

The first stage of the system is sensor data input, which in this model includes temperature, light, humidity, and presence. Temperature monitors thermal conditions, while light measures natural and artificial lighting levels. Humidity detects air humidity as a variable that can affect cooling load, while presence identifies the presence of occupants in a room. These four input categories represent key dimensions of HVAC and lighting energy demand, so the quality of the sensor data determines the accuracy of overall energy management. The role of each sensor is different in influence optimization strategies energy.

Presence sensors play a crucial role in determining whether a space is occupied. By detecting occupant activity, the system can automatically turn off or dim lighting and adjust cooling setpoints to prevent unnecessary operation (Rikame et al., 2025). Sensor placement and number also impact system performance, as demonstrated by variations in accuracy between 35–76% based on sensor location and density (Bucarelli & El-Gohary, 2024). Furthermore, ensemble learning helps identify abnormal energy consumption patterns, allowing the system to improve HVAC operational strategies in real time (Goyal & Pandey, 2021), while environmental data such as humidity improves the precision of cooling load calculations (Amangeldy et al., 2025).

The next stage in the model is the processing unit, which serves as the system's intelligence center. This unit processes all sensor data through filtering, pattern recognition, and predictive analysis to automatically determine energy regulation strategies. An AI-based approach allows the system to learn from historical energy usage patterns and user preferences, allowing energy regulation decisions to be made not only based on current conditions but also taking into account future energy needs with a higher degree of accuracy (Singh et al., 2025).

The performance of the processing unit is further enhanced through the integration of deep neural networks, reinforcement learning, and distributed optimization techniques. These techniques enable adaptive energy control adjustments despite large-scale energy load changes and unpredictable variations in occupant behavior (Nene & Thankachan, 2025). To support operational efficiency, the use of edge computing and federated learning allows processing to occur locally, resulting in low latency and maintaining user data privacy (Toderean et al., 2025). In this context, the processing unit functions as an automated decision-maker in the energy management system.

The final stage of the model is the system output, which is adaptive control of HVAC and lighting. The system dynamically adjusts based on analysis and predicted energy needs, ranging from changing temperature setpoints, adjusting air volume, reducing illumination, to scheduling energy use to reduce peak electrical loads (Sha et al., 2025). AI- and machine learning-based predictive models ensure energy efficiency remains effective without compromising thermal comfort and indoor air quality (Waheed et al., 2025).

IoT-based dynamic energy management in smart buildings contributes significantly to environmental sustainability by adjusting HVAC and lighting operations based on occupancy patterns and environmental conditions, thereby reducing carbon emissions and the overall energy footprint. Reducing peak electricity loads also supports the stability of the building's internal power grid and reduces pressure on the energy infrastructure at the regional level, which aligns with achieving green building standards and long-term sustainability targets (Mishra & Singh, 2023). In addition to energy efficiency, this system enables predictive maintenance by leveraging historical data from sensors and AI algorithms to predict potential disruptions and device performance degradation, thereby reducing repair costs, extending device lifespan, and reducing the risk of downtime (Abid et al., 2025).

The integration of energy management with asset management makes smart buildings not only efficient in energy consumption but also proactive in maintaining the reliability of internal infrastructure (Krishnan et al., 2023). This system can also be connected to a broader ecosystem such as smart grids, renewable energy, and Building Information Modeling (BIM), supporting urban-scale energy management and sustainable smart cities (Mishra & Singh, 2023). Thus, the IoT and AI approach in smart buildings offers a holistic solution that simultaneously combines energy efficiency, environmental sustainability, and operational reliability.

Adaptive system control not only impacts energy savings but also reduces building operating costs. By intelligently managing energy consumption and shifting loads to low-price or off-peak periods, the stability of the internal electricity grid improves and energy use becomes more manageable (Woo-Shem et al., 2023). The system's output also has the potential to be extended to manage other devices such as electric vehicle charging stations and energy storage systems connected to renewable energy sources, making the model more holistic and futuristic (Ghazo & Salah, 2025).

The system also prioritizes user comfort. Presence data is combined with override patterns and historical preferences to generate a comfort profile that can be repeatedly learned. This approach prevents the discomfort that often arises when energy savings are implemented without considering human needs (Ngoc et al., 2021). By adapting to user preferences, automation becomes more acceptable to building occupants and aligns with the growing concept of human-centered energy automation (Paudler et al., 2022).

While the model offers high efficiency, implementation challenges remain, particularly regarding interoperability between IoT devices, infrastructure costs, and data security and privacy. The system's success is largely determined by a combination of technical solutions such as encryption, device authentication, and network segmentation, along with operational management readiness for long-term maintenance (Ngoc et al., 2021). More broadly, integration with BIM, smart grids, and renewable energy systems extends the model's benefits to the urban energy ecosystem (Agostinelli et al., 2021).

As a scientific contribution, this study simplifies the concept of adaptive energy optimization into a three-stage architecture that is modular, applicable, and device-neutral. This model bridges previous research that tends to be complex and case-specific, making it difficult to implement in buildings with different characteristics. Therefore, the next step needs to be directed at the prototype stage and field testing using performance indicators such as energy efficiency, network stability, occupant comfort, override frequency, and cost-benefit ratio to empirically verify the model's effectiveness as a future smart building solution.

IV. Conclusion

This study presents a conceptual model of an IoT-based smart building with dynamic energy management in a multi-story building designed to optimize energy consumption without compromising occupant comfort. The developed model consists of three sequential stages: sensor input (temperature, light, humidity, and presence), an AI-based processing unit as the decision-making center, and output in the form of automatic control of the HVAC and lighting systems. The integration of these three stages results in an energy management approach that is adaptive, predictive, and responsive to real-time room conditions and user activities.

The main contribution of this research lies in simplifying the adaptive energy optimization architecture into a modular, applicable, and device-neutral framework that can be applied to various types of high-rise buildings without any specific platform dependency. This model also positions occupant comfort as a fundamental component in designing energy-efficient technologies, in line with the concept of human-centered energy automation that emphasizes the balance between energy savings and human comfort. However, this research has limitations because it is still conceptual and has not been validated through prototype testing or field implementation. Therefore, future research needs to be directed at empirical testing by measuring performance indicators including energy efficiency, occupant comfort, internal power grid stability, user override frequency, and cost-benefit analysis to determine the feasibility of large-scale implementation. This empirical validation will be an important basis for developing standards for implementing efficient, adaptive, and sustainable IoT-based smart buildings.

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