# Development of Standards for Building Energy Efficiency Using AI

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***Abstract*— This paper investigates the emerging role of artificial intelligence (AI) in enhancing building energy efficiency through autonomous control technologies and integrated data-driven management frameworks. As buildings increasingly incorporate distributed energy resources, high-efficiency equipment, and real-time monitoring infrastructures, the need for intelligent and interoperable control systems has become critical. AI-based predictive models, reinforcement learning–driven HVAC optimization, and advanced data analytics enable buildings to improve operational efficiency, reduce peak loads, and enhance indoor environmental quality (IEQ). However, the stable and scalable deployment of such technologies requires well-defined standards that ensure interoperability, data reliability, security, and explainability of AI algorithms. Through an examination of international standardization initiatives—including frameworks from the United States, Europe, China, and Korea—this study identifies key gaps and opportunities in the current landscape. It further proposes a standardized reference model for a Building Energy Integrated Management Platform that supports heterogeneous data collection, microservices-based control, digital twin visualization, and AI-enabled optimization. The findings highlight the importance of establishing a comprehensive standardization ecosystem to accelerate the adoption of AI-driven energy management and to support future smart building and smart grid integration.**

***Keywords*— AI-based control, building energy efficiency, autonomous control, smart building standards, BEMS, interoperability, data integration**

## I. INTRODUCTION

Buildings account for approximately 30–40% of total electricity consumption in urban areas, making them a critical sector and a primary target of national and municipal energy demand management strategies.[1] With the increasing deployment of Building Energy Management Systems (BEMS), high-efficiency equipment, energy storage systems (ESS), and distributed energy resources such as photovoltaic (PV) and geothermal systems, building owners and operators are placing growing emphasis not only on energy savings but also on demand response (DR), carbon emission reduction, and electricity cost optimization. This trend has amplified the demand for intelligent control technologies capable of achieving these multiple objectives.

In particular, the rapid advancement of AI-based autonomous control technologies—including deep learning–based predictive models, reinforcement learning–based HVAC control, and various optimization algorithms—has stimulated efforts to achieve real-time energy demand management, equipment operation optimization, and improvements in indoor environmental quality (IEQ) simultaneously[2]. However, for such AI technologies to be applied in commercial buildings in a stable and economically viable manner, it is essential to establish well-defined standards that ensure interoperability of data interfaces, reliability of control algorithms, security and privacy safeguards, and verifiability and explainability of AI models. Accordingly, the development of a comprehensive standardization ecosystem is indispensable.

This paper examines AI-based autonomous control technologies that focus on indoor spatial environments to enhance building energy efficiency. It then reviews current international standardization trends and proposes future directions for standard development.

## II. AI-BASED AUTONOMOUS BUILDING ENERGY CONTROL TECHNOLOGY

### *A. Concept*

AI-based autonomous building energy control technology is defined as an advanced control approach that integrates and analyzes diverse information—such as distributed energy resources (DER), user preferences, indoor environmental conditions, and energy prices—to automatically optimize energy use at the spatial level.

This technology collects and shares heterogeneous data from multiple objects, including sensors and building systems, and employs AI algorithms to learn correlations within the data and accurately predict energy demand. The prediction results are then used to optimize the real-time operation of key building systems such as HVAC, lighting, and ventilation. Through this process, buildings can autonomously achieve multiple operational goals, including reducing energy costs, lowering peak loads, and maintaining indoor environmental quality (IEQ).

To enable autonomous energy control, it is necessary to develop an energy data hub device and implement functionalities for deploying and operating artificial intelligence analytics modules that can analyze, predict, and process heterogeneous data locally.

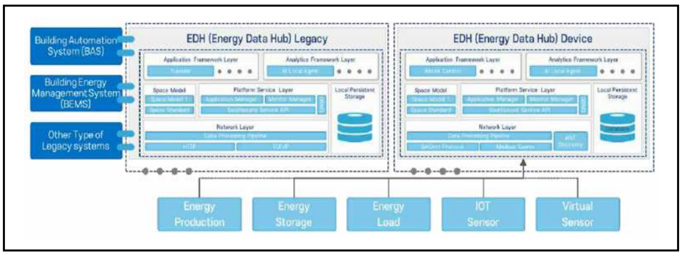

Figure 1. Conceptual Diagram of a Data Hub Device for Autonomous Building Energy Control

## B. Scope

To effectively reduce energy demand in buildings, it is essential to integrate enabling technologies that enhance consumer energy cost savings and support the coordinated use of distributed energy resources. This requires optimizing the production, storage, and consumption of energy by analyzing large-scale data related to time-dependent user behavior patterns, electricity generation costs, weather conditions, and the specific characteristics of each space within the building.

Currently, remote building control systems primarily rely on ICT technologies that collect data via IoT devices and enable remote monitoring and control. However, these systems still depend heavily on manual intervention for final decision-making, which limits their operational efficiency. To address these limitations, AI models capable of learning data patterns and providing guidance on key control variables must be introduced, thereby minimizing human involvement. The adoption of AI-based prediction and optimization models enables advanced control strategies that can respond dynamically to real-time conditions, positioning AI-driven autonomous control as a critical approach for significantly improving the operational efficiency of building energy systems.

Furthermore, to ensure interoperability in the processing of heterogeneous data, it is necessary to apply IoT standard technologies based on the W3C international standard Web of Things, and to enhance security by adopting Decentralized Identifier (DID)–based authentication technologies for objects to enable the application of diverse services and AI technologies.

## C. Cases

Research, development, demonstration, and testing efforts aimed at applying AI technologies to building energy management are being actively pursued across many countries. In particular, the United States has established a national-level Grid-Interactive Efficient Building (GEB) roadmap as a representative initiative[3].

The GEB concept seeks to optimize building energy consumption by enhancing energy efficiency, enabling demand flexibility, and integrating renewable energy resources, thereby allowing buildings to function as intelligent platforms that interact dynamically with the power grid. Since its launch in 2018, the program has evolved from an initial focus on high-efficiency equipment and control optimization toward an expanded agenda that, beginning in 2025, emphasizes AI- and big-data–driven predictive control, real-time optimization models, and strengthened cybersecurity capabilities.

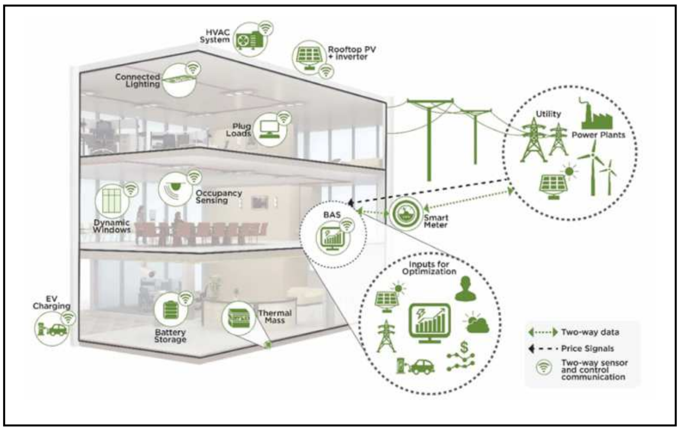

Figure 2. GEB Architecture (US DOE)

In Europe, the Smart Readiness Indicator (SRI) framework has been developed and implemented as a comprehensive initiative aimed at assessing and enhancing the level of smart technology adoption in buildings. The SRI serves as a quantitative tool for evaluating building smartness and focuses on demonstrating core technologies for flexible energy demand management by integrating major energy-consuming systems—such as heating and cooling equipment, ventilation systems, and lighting—with renewable energy resources[4]. Within this context, AI technologies can further extend the functional scope of the SRI by enabling buildings to evolve from mere physical structures into intelligent and sustainable environments that actively respond to occupant needs and external conditions.

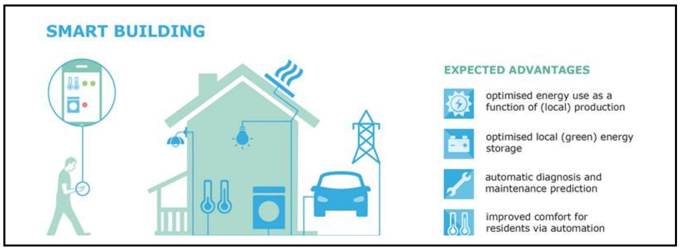

Figure 3. Smart-Readiness Building Indicators

# III. International Standardization Trends

A wide range of international standards related to improving building energy efficiency has been established or is under development worldwide; however, the incorporation of artificial intelligence (AI) technologies within these standards remains at a relatively early stage. Current standards primarily focus on providing technical guidelines for practical implementation, including the optimization of energy use within buildings, automated control based on energy data collection and analysis, smart meter–driven demand response (DR), integrated operation of energy storage systems (ESS) and distributed energy resources (DER), evaluation of energy performance contributions from building automation and control systems (BACS), and ensuring interoperability with smart grid infrastructures.

In particular, the **IEEE 2030 NIST Smart Grid Framework 1.0** in the United States and the National Institute of Standards and Technology (NIST) Smart Grid Framework are widely recognized as foundational standard frameworks that provide reference models and technical guidelines to secure interoperability among power systems, information technology (IT), and communication technology (CT). By establishing fundamental architectures for intelligent power systems, these standards offer a structural basis upon which future standardization efforts for AI-enabled building energy management technologies can be further expanded[5].

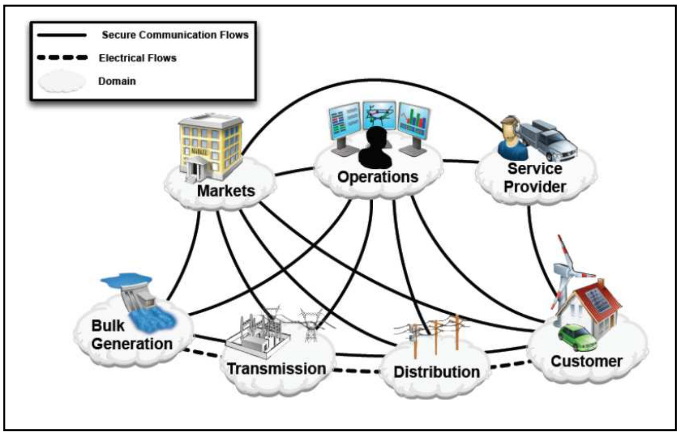


Figure 4. NIST Smart Grid Framework 1.0 January 2010

China has established a multi-layered regulatory framework to standardize building energy management systems, with the **GB/T 23331-2020** standard serving as a core specification that defines the requirements for establishing, implementing, maintaining, and continuously improving an Energy Management System (EnMS). This standard is significant in that it provides a structured management framework that enables organizations to enhance energy performance through systematic and periodic management processes[6]. In addition, the **GB/T 29456-2017** standard, building on the systematic approach outlined in **GB/T 23331-2020**, offers detailed procedures, methodologies, and implementation guidelines to support the practical deployment of EnMS, thereby strengthening the overall effectiveness and applicability of the standard. Collectively, these standards provide a technical and managerial foundation that supports China's energy-efficiency policies and the modernization of building operations.

In Europe, the **EN ISO 52120-1:2022** standard functions as an international reference for optimizing building energy performance by defining functional requirements for Building Automation and Control Systems (BACS)[7]. This standard aligns closely with the policy objectives of the EU's Smart Readiness Indicator (SRI) and Energy Performance of Buildings Directive (EPBD), providing a foundational framework for enhancing building energy efficiency, integrating smart technologies, and improving operational adaptability. Through this approach, Europe aims to strengthen technical interoperability and establish a performance-oriented management structure that supports the transition toward smart buildings.

TABLE I. KEY COMPONENTS OF THE EN ISO 52120-1 FRAMEWORK

| Key Components | Description |
|---|---|
| Categorized Funtions | A comprehensive list of BACS/TBM functions (like HVAC, lighting control, etc.) organized by building discipline, detailing how they contribute to energy efficiency |
| Requirement Definitions | Methods for public authorities and designers to specify minimum control function requirements for new builds and renovations |
| Factor-Based Estimation | A simplified method to estimate the energy impact (e.g., energy savings) of these functions on typical building types |
| Detailed Assessment | Techniques for in-depth analysis of BACS/TBM impact on specific buildings, crucial for auditors and managers |

The Korean standard **TTAK.KO-10.1504** defines the reference model and essential requirements for a building energy management platform that integrates building energy data with non-energy data—such as structural and environmental information—and analyzes the interrelationships among these datasets[8]. Through this integrated analytical framework, the standard supports high-quality energy supply–demand forecasting and anomaly detection, while enabling the provision of user-customized energy application services. By establishing these functional and architectural foundations, the standard contributes to enhancing the effectiveness of intelligent building energy management systems.

A summary of the major related standards, including those discussed above, is presented in the following table.

TABLE II. STANDARDS RELATED TO IMPROVING BUILDING ENERGY EFFICIENCY

| Country | Standards Organization | Standard No. | Description |
|---|---|---|---|
| China | SAC | GB/T 23331-2020 | Requirements for organizational energy management systems. |
| | | GB/T 29456-2017 | Implementation guidance for energy management systems. |
| | NEA | NBT 10001-2010 | Technical guidelines for demand-side management in the power sector. |
| Japan | JISC | JIS B 8201 | Criteria for building energy performance assessment. |
| | | JIS C 61000-4-30 | Methods for measuring power quality parameters. |
| USA | ANSI | ANSI C12 Series | Requirements for electricity and smart meter performance. |
| | | ANSI/ASHRAE/IES 90.1-2022 | Minimum efficiency criteria for non-residential buildings. |
| | FERC | FERC Order 745, 2222 | Rules for DR compensation and DER aggregation in wholesale markets. |

| | | | |
|---|---|---|---|
| | SGIP | IEEE 2030, NIST Smart Grid Framework | Reference framework for smart grid interoperability. |
| | NARUC | Demand Response & Smart Grid Policies | State-level guidance on DR and smart grid regulation. |
| | NEMA | NEMA SG-AMI 1-2009, NEMA MG 1 | Requirements for AMI systems and motor/generator performance. |
| Europe | ISO, CEN | EN ISO 52120:2022 | Use of building automation and controls to improve energy performance. |
| | CEN | EN 15232 | Classification of energy impact of building automation and controls. |
| | CENELEC | EN 50438 | Connection requirements for micro-generators on low-voltage networks. |

## IV. STANDARD DEVELOPMENT METHOD

As previously discussed, various components within buildings—such as mechanical systems, electrical systems, and information and communication equipment—exhibit significant disparities in technological advancement and limited interoperability, making integrated management challenging. These limitations hinder real-time monitoring and optimal remote control of building systems and, consequently, reinforce reliance on manual, labor-intensive control methods. To address these issues, it is essential to establish and operate a "Building Energy Data Integration and Management Platform" capable of comprehensively managing data collected, stored, and analyzed from IoT devices and systems within the building. From a standardization perspective, it is therefore necessary to define the concept of such a platform, specify the data acquisition framework, and delineate its core components and functional requirements. The following sections present detailed considerations regarding these standardization elements[9].

### *A. Concept*

The Building Energy Integrated Management Platform can be defined as a core infrastructure designed to enhance the efficiency of energy demand management and facility maintenance by enabling automated control of various building systems.

Based on a heterogeneous energy data hub, the platform provides integrated monitoring of building operational conditions and control states, while employing digital twin technology to establish visualization capabilities and support optimal control.

Furthermore, the reference architecture of the platform offers a systematic representation of component interactions, data flows, and control logic, thereby serving as a foundation for implementation and standardization. The following figure illustrates the reference architecture of the Building Energy Integrated Management Platform in greater detail.

### *B. Data Acquisition Systems*

To support advanced monitoring and optimal control, the Building Energy Integrated Management Platform must collect data from various building-based systems, including IoT devices, the Building Energy Management System (BEMS), and the Building Automation System (BAS). The definitions and functions of these systems are as follows[10].

First, IoT devices refer to sensing units and systems that generate raw data by directly measuring various parameters within the building, such as electricity consumption, indoor and outdoor environmental conditions, equipment operating status, and renewable energy generation.

Second, BEMS is an energy management system that continuously monitors and analyzes a building's energy consumption and supports operational strategies aimed at improving energy efficiency.

Third, BAS is a system that ensures the stable and efficient operation of building facilities by providing real-time monitoring and automatic control of major mechanical and electrical equipment, including HVAC, lighting, and power systems.

In addition to these systems, the stable operation and predictive accuracy of the Building Energy Integrated Management Platform require the integration of data from external systems, such as meteorological observation services and geographical or environmental information sources. Such external data serve as essential supplementary inputs for enhanced applications, including energy demand forecasting, optimal equipment control, and risk management.

### *C. Functional Components*

To efficiently process heterogeneous data in real time, the platform should adopt a micro services architecture in which internal software processes operate as independent, modular services that communicate through standardized APIs. Moreover, to enable AI-based optimal control, the platform must support an integrated workflow that encompasses data preprocessing, model training, and inference within the system[11]

In addition, to enhance monitoring capabilities, the platform should incorporate a responsive compositional framework that manages and supervises various elements—including data visualization, data types, metadata, and final data outputs. A robust data service layer is also required to support data analytics and a wide range of application services.

Furthermore, the platform must satisfy security requirements that account for diverse stakeholders, including data users and administrators, and must systematically incorporate legal and technical measures related to the protection of personal information.

## V. CONCLUSION

This study analyzed AI-based autonomous building energy control technologies and examined global standardization trends that support their implementation. The rapid expansion of distributed energy resources, intelligent sensing infrastructures, and digital building platforms has created strong demand for advanced control methods capable of simultaneously achieving energy efficiency, demand flexibility, and improved indoor environmental quality. While AI technologies—such as predictive analytics, optimization algorithms, and reinforcement learning—provide significant potential to address these challenges, their practical deployment requires a consistent and interoperable framework that ensures reliability, security, and transparent functionality across diverse building environments.

International efforts by the United States (IEEE 2030 series, NIST Smart Grid Framework), Europe (EN ISO 52120-1, SRI), China (GB/T 23331 and related EnMS standards), and Korea (TTAK.KO-10.1504) demonstrate increasing momentum toward establishing foundational architectures for smart and energy-efficient buildings. However, AI integration within these standards remains at an early stage. To accelerate adoption, this paper emphasizes the need for developing a unified standard for a Building Energy Integrated Management Platform that supports heterogeneous data acquisition, micro services-based system architecture, digital-twin-enabled monitoring, and AI-driven prediction and optimization.

By providing a structured approach to data governance, system interoperability, security management, and functional requirements, such a standard will serve as a critical enabler for next-generation smart buildings. Ultimately, the advancement of AI-based autonomous control technologies—underpinned by robust and forward-looking standards—will be essential for achieving sustainable, intelligent, and resilient building energy systems in the future.

## ACKNOWLEDGMENT

This work was supported by Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government(MCEE)(RS-2024-00441420, Development and demonstration of building energy efficiency improvement technology through AI-based spatial energy prediction and autonomous control).

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