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# Development Status and Trend of Building Integrated Energy System

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## Abstract

**An integrated energy system (IES) is defined as a multi-energy coupling system characterized by energy complementarity and interactive supply-demand mechanisms. It is considered effective in reducing energy supply costs and improving energy utilization efficiency. In this paper, the development models and trends of IES at both domestic and foreign levels are summarized and analyzed. The architecture and fundamental units of integrated energy intelligent buildings are examined. On this basis, the status and development trends of key technologies associated with IES are reviewed.**

## Keywords

**Integrated Energy System; Energy Storage; Interconnection Technology; Intelligent Load Forecasting; Energy Conversion.**

## 1. Introduction

Energy is regarded as the cornerstone of human survival and development and the lifeline of the national economy. Adequate energy supply is considered essential for societal progress [1]. Traditional energy systems are characterized by low efficiency, high carbon emissions, uneven distribution, and non-renewable limitations. These issues have resulted in energy waste and environmental pollution [2]. Greenhouse gas emissions can be reduced through energy conservation and efficiency improvements.

Renewable energy (RE) sources can provide energy without incurring emission costs and play a crucial role in achieving the goal of improving energy efficiency. Ensuring energy demand while reducing system operating costs and enhancing energy efficiency through the optimal scheduling of various energy resources has become a global focus [3,4]. Breaking away from the conventional practice of designing and operating energy systems independently, efforts have been made to integrate multiple energy systems and enhance their synergistic effects [5]. In this context, the concept of the "Energy Internet" has been proposed in the energy sector, which aims to achieve integrated operation through the use of combined heat and power equipment, energy conversion devices, and energy storage systems.

With the continuous advancement of the Energy Internet concept, IES, serving as the physical carriers of energy, have attracted widespread attention from researchers. To develop the next generation of power systems, it is essential to ensure energy and electricity security. The primary goal is to meet the electricity demands of economic and social development through a robust hub platform based on smart grid technologies.

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## 2. Development Status of IES

Due to global warming, the development of RE has become a widely discussed topic in China and around the world. The cascade utilization of energy in IES has increased the penetration rate of renewable energy, aiming for low costs and high efficiency while continuously improving various performance indicators of the system.

An IES refers to an energy production-supply-consumption system that is organically coordinated and optimized across all stages, including energy generation, transmission and distribution, conversion, storage, consumption, and trading, during planning, construction, and operation [6].

### 2.1 Foreign Development Status of IES

The efficiency of energy use is directly linked to the future development of global energy. With the rise and advancement of the Energy Internet, IES is being further studied in various countries. Efforts are focused on formulating development strategies tailored to national conditions. Competition and cooperation among countries have accelerated the progress of IES development.

The concept of IES was first proposed and implemented in Europe. The results have been significant, with the usage of clean energy continuously increasing. The development focus is on coordination and optimization among various energy sources, as well as the coupling of different energy systems. The early forms of this concept were addressed in the European Union's Fifth Framework Programme [7]. Research on IES was further advanced in the European Union's Sixth (FP6) and Seventh (FP7) Framework Programmes. In 2015, the UK government increased its investment in energy innovation research projects, with the Energy Innovation Programme focusing on smart grids, heating systems, and energy efficiency improvements [8].

The United States, as a major global economic power with advanced technology and high levels of urban modernization, has a massive energy demand. With long-term considerations in mind, the U.S. has been exploring energy reform and innovation. In 2001, the U.S. Department of Energy introduced the concept of IES, focusing on energy system transformation and the study of distributed energy resources (DER) and combined cooling, heating, and power (CCHP) technologies [9]. In Japan, based on national needs, research is being conducted to explore future home energy management systems (HEMS) [10].

### 2.2 Domestic Development Status of IES

Compared to foreign developments, China started research in the field of IES relatively late. However, research institutions have established IES research teams and initiated studies, while the government has actively introduced various policies to support energy transformation. With the rapid development of China's economic strength, the acceleration of energy transition, and the introduction of the "dual carbon" concept in recent years, the green and low-carbon development of energy and electricity has become imperative [11]. The demand for integrated energy services across society has increased, and the prospects for industrial development are promising.

IES are research systems that focus on the overall coordinated operation and planning of "generation, grid, load, and storage" (sources, grids, storage, and loads) [12]. In line with China's commitment to developing clean, low-carbon, safe, and efficient energy, IES represents an important energy development strategy and is currently the most effective method for addressing energy challenges.

## 3. The Concept of IES in Buildings

Combined cooling, heating, and power (CCHP) systems are one of the most important forms of IES. Currently, the integration of CCHP systems with renewable energy sources can achieve cost minimization while efficiently utilizing clean energy. Wang et al. [13] integrated a CCHP system with biomass energy, assisted by solar energy, and analyzed the complementarity of these systems in improving system efficiency. Chen et al. [14] introduced a distributed solar-assisted CCHP gas turbine system and conducted an analysis of its energy, exergy, economic, and environmental performance.

IES in buildings are relatively small-scale, user-oriented multi-energy systems. One of the key research directions is to achieve flexible coordination and interaction among internal energy sources and loads. The operation scheduling and energy management strategies of IES in buildings are formulated based on the configuration of multi-energy supply and multi-use energy units within the building. These systems can reduce energy costs while effectively promoting the utilization of distributed energy on the user side [15]. The structural diagram of IES in buildings is shown in Fig.1.

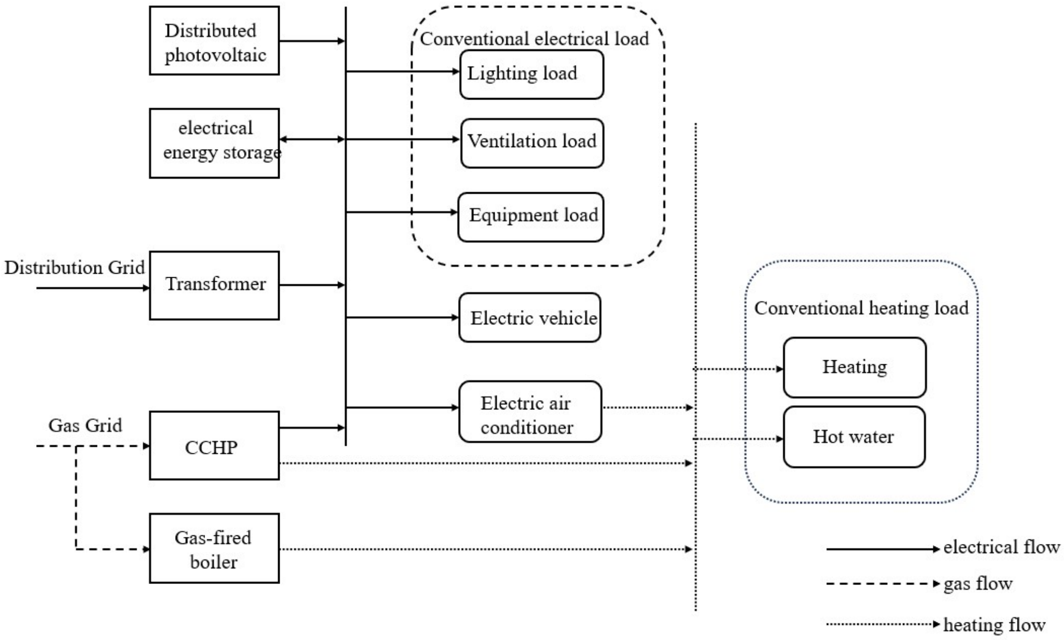


**Fig. 1** The structural diagram of IES in buildings

As shown in Fig.1, IES in buildings consists of two main parts: the energy supply side and the load side. The energy supply side includes systems such as CCHP, photovoltaic, and energy storage, providing multiple energy types, including electricity, gas, and cooling (heating). Through internal energy conversion devices, multi-energy cascade utilization is achieved to meet the demands of various energy loads. The energy supply side and the user-side load together form the integrated energy intelligent building system.

## 4. IES Interconnection Technology in Buildings

### 4.1 Multi-energy Collaborative and Complementary Technology

Multi-energy collaborative and complementary technology is an optimization process involving multiple objectives and fields. By coordinating the allocation of resources within IES, energy efficiency can be improved. Energy complementary technology primarily includes the cascade utilization of energy. Cascade utilization refers to the sequential use of energy and resources according to their energy grade, from high to low, enabling multiple uses of energy. With each use, the energy grade decreases until it is no longer usable [16].

### 4.2 Energy Storage Technology

Thermal energy storage technology uses heat transfer materials to store thermal energy from sources such as industrial waste heat, natural gas waste heat, solar thermal energy, and geothermal energy, which can be released when needed. Currently, three forms of thermal energy storage are employed: sensible heat storage, latent heat storage, and thermochemical heat storage. Sensible heat storage is the simplest and most mature technology among these. Heat storage devices using water as the storage

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medium are the most widely applied in practice due to the significant advantages of water in cost and availability compared to other materials [17].

The development of energy storage technology in IES faces three main challenges. First, core technological issues. From a technical perspective, problems such as the high cost of key materials, incomplete mastery of critical technologies, and low energy conversion efficiency remain unresolved. Second, reliability issues. The successful integration of large-scale energy storage technologies into the system alters its operating characteristics, which requires careful consideration. Finally, joint planning and innovation issues. The development of energy storage technology involves multiple disciplines and complex systems. Collaborative efforts among researchers from various fields are essential to overcome these challenges.

### 4.3 Intelligent Load Forecasting Technology of Microgrid

Accurate load forecasting of integrated energy demand plays a critical role in constraining the development and transformation processes of energy networks [18]. Therefore, precise and reasonable load forecasting is required for the energy demand of building IES. Considering the main characteristics of smart devices under complex operating conditions, including reliability, high efficiency, and energy-saving operation, research and application of digital intelligence technologies for power equipment are carried out. These technologies are enabled by the Internet of things, big data, artificial intelligence, and the digital twin of power equipment [19].

### 4.4 Energy Conversion Technology

Energy conversion technology refers to the process of converting primary energy into secondary energy [20]. Primary energy includes renewable sources such as wind energy, solar energy, and biomass energy, as well as non-renewable sources like natural gas, all of which are considered clean energy. Among secondary energy forms, electrical energy is the most widely used, clean, and convenient option.

Common energy conversion processes include electrothermal conversion, wind-to-electricity conversion, photovoltaic conversion, and biomass gasification [21]. Electrothermal conversion typically involves internal combustion engines using electricity supplied by the grid to convert natural gas into thermal energy. The electricity generated by the internal combustion engine meets user electrical loads, while the waste heat produced is used to satisfy thermal loads on the user side.

Wind-to-electricity conversion is accomplished through wind turbines, which convert wind energy into mechanical energy to drive the turbines, subsequently generating electricity to meet electrical loads on the user side. Photovoltaic conversion utilizes solar cells as photovoltaic components to directly convert solar radiation into direct current electricity through the photoelectric effect of semiconductors [22]. Biomass gasification technology is a thermochemical process that converts solid biomass materials, such as straw, into gaseous fuels. The generated gaseous fuels can be used to power internal combustion engines [23].

## 5. Conclusion

In the context of energy resource shortages and ecological environmental stress, resource conservation and the development of clean energy have become priorities in energy development and principles for sustainable social progress. IES play a crucial role in energy conservation and the utilization of renewable energy. The development of IES is urgently needed, and integrated energy technology is expected to be a core technology in the future energy sector.

This study, based on the characteristics and development models of building IES, elaborates on the current development status of IES at home and abroad. The main associated technologies and their trends are analyzed in detail.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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