Analysis of Building Energy Saving and Carbon Reduction Measures and Future Development Trend Under the Background of Carbon Peak and Carbon Neutrality

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Abstract: Under the background of the targets of carbon peak and carbon neutrality, this paper discusses the key measures of building energy conservation and carbon reduction and its future development trend. First of all, it reviews the origin and development of capacity building, the concept evolution from zero energy building to capacity building, and elaborates the definition and characteristics of capacity building. Then, it analyzes the practical experience of Germany in the field of capacity building, as well as the development status of China 's building energy conservation and capacity building. By comparing the development of capacity buildings at home and abroad, this paper reveals the importance and urgency of building energy conservation and carbon reduction. In addition, the article also focuses on the future development trend of building envelope energy efficiency improvement technology industry and renewable energy technology industry (including solar thermal industry and heat pump industry). The study highlights that advancements in technology and industrial development will bring both new opportunities and challenges for energy conservation and carbon reduction in the building sector. The research results of this paper not only provide theoretical support for the research and practice in related fields, but also contribute new ideas and methods to promote the development of building energy conservation and carbon reduction.

Keywords: Carbon Peaking, Carbon Neutrality, Building Energy Efficiency; Capacity Building; Renewable Energy

1. Introduction

With the intensification of global climate change and resource and environmental constraints, the international community has reached a consensus on the need to decrease energy usage and lower carbon emissions. As one of the three main forces of energy consumption, building has great potential for energy conservation and carbon reduction. Under the background of carbon peak and carbon neutrality, building energy conservation and carbon reduction have become the focus of attention of governments and research institutions. This paper aims to investigate the primary strategies for energy conservation and carbon reduction in buildings, as well as to forecast their future trends, offering insights for research and practical applications in relevant domains.

2. Development History and Current Situation of Capacity Building

2.1 The Origin and Development of Productive Building

The concept of productive buildings originated from the continuous development of building energy efficiency. With the improvement of building energy efficiency, new building forms such as zero energy consumption buildings and production capacity buildings appear one after another. The concept of zero-energy buildings can be traced back to 1976, which was proposed by Torben V. Esbensen and others at the Technical University of Denmark through theoretical calculations and experimental tests. They studied the comprehensive utilization process of solar energy for winter heating in a single-storey residential building in Denmark, and realized the concept of "zero-energy building" for the first time [1]. The building has reduced winter heating energy consumption from 20,00kwh /a to 2,300kwh /a through a refined external insulation envelope, and uses active solar collectors and heat storage tanks for heating and domestic hot water supply.

In the following decades, research on zero-energy buildings gradually increased. In view of the situation that many remote buildings in Europe could not be connected with regional heat networks and power grids, Voss.K and others of the Fraunhofer Solar Energy Research Institute in Germany used solar thermal photovoltaic technology to heat and heat a building in Germany in 1992. A three-year testing study found that in parts of Europe where the climate is relatively mild, the total annual energy consumption of buildings can be reduced to less than 10 kWh/m² through careful design, and all energy consumption requirements of buildings can be provided by solar energy [2]. Voss.K therefore proposed "Energy Autonomous House" (also known as Self-sufficient Solar House), that is, it does not need to be connected to external energy infrastructure, and integrates solar photothermal photoelectric system with energy storage technology. A building that ensures a building's energy supply at all times. "Passive building" requires a building to achieve energy or emissions neutrality over a period of time measured in years.

Considering the connection between the building and the power grid, Voss.K et al. combined with the development of solar photovoltaic technology, further proposed the definition of "zero-energy building" as follows: it can generate electricity itself, and it can either generate electricity from the building or use the power grid to supply power to the building by connecting to the public grid. Primary energy generation and consumption can be balanced in buildings.

Based on the current relevant studies on capacity buildings [2-6], the capacity buildings are defined as a type of zero-energy structure that integrates renewable energy generation and heating systems. These buildings, along with the renewable energy sources within a 100-meter radius, produce more than 110% of the energy required for heating, air conditioning, ventilation, lighting, and other equipment within the building. Not only do these productive buildings meet their own energy needs through renewable sources, but they also have the capability to supply energy to external systems. Furthermore, excluding renewable energy contributions, the annual electricity consumption of such buildings should not exceed 50kWh per square meter.

2.2 Capacity Building Practices in Germany

Germany is the world leader in the field of production capacity construction, and its development history and practical experience provide valuable reference for countries around the world. In 2000, the Solar Community in Freiburg, Germany, built the world's first productive residential community. The buildings, which were 2-3 storeys high, were the first to combine the then advanced passive building energy efficiency technology with solar photovoltaic power generation. Photovoltaic panels generate more electricity than residents need, and the excess electricity is incorporated into the national grid [6].

In 2007, the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) proposed the "Production capacity Building" - Future building research program, which aims to study the technology of different functional production capacity buildings, the transformation of results and the construction standards of residential and public buildings. The program also specifically examines the integration of capacity buildings with electric vehicles. With the support of the government, the capacity building launched by the Technical University of Darmstadt was selected in the "Solar Ten Competition" held in Washington State in 2007 [7]. In addition, a number of capacity building demonstration projects have been built in Berlin, Frankfurt and other places, demonstrating capacity building solutions under different technologies and application scenarios.

Germany is at the forefront of the world in terms of productive communities, and its local governments are responsible for elaborating such long-term strategies, providing a framework for specific policy and investment decisions [8]. Ideally, local stakeholders and residents should be involved in strategy development, at least in surveys aimed at understanding critical views and aspirations. Active participation of local stakeholders and users has been shown to be an important part of local development planning, helping to improve the quality and acceptability of planning results and implementation processes.

2.3 Building Energy Efficiency and Capacity Building in China

China's building energy efficiency work began in the early 1980s, after decades of efforts, has achieved remarkable results. Recently, in response to the goals of carbon peaking and neutrality, the Chinese government has prioritized efforts in energy conservation and carbon reduction within the building sector. Consequently, research and implementation of energy-efficient buildings have increasingly gained attention [9].

From the building type, the first from the residential building, followed by public buildings, and then industrial buildings; Start with new buildings, then less energy-efficient buildings, and then other poorly insulated buildings. After a long period of preparation, we will gradually promote the energy-saving transformation of existing large public buildings. Gradually expand geographically, starting from the northern heating area (cold and cold areas), then developing to the central hot summer and cold winter areas, and expanding to the southern hot areas; Starting from cities with a good foundation, it will develop into general cities and regions, and then gradually expand to the vast rural areas.

In 2019, China introduced the "Technical Standards for Near Zero Energy Buildings," marking the nation's inaugural framework for defining ultra-low energy, near zero energy, and zero energy buildings. This regulation outlined mandatory control indices encompassing indoor environmental quality and building energy consumption benchmarks. Additionally, it presented pertinent technical performance metrics, strategies, and assessment methodologies, along with the advancement of calculation and evaluation tools tailored for near-zero energy buildings. Notably, this represents a global precedent in formally delineating zero-energy building concepts through national standards, establishing a technically feasible system tailored to China's unique circumstances, and proposing standardized Chinese solutions [10].

3. Future Development Trend

3.1 Building Envelope Energy Efficiency Improvement Technology Industry

Since 2016, the "Passive Low Energy Building Industry Technology Innovation Alliance," established by the Science and Technology and Industrialization Development Center of the Ministry of Housing and Urban-Rural Development, has been publishing the "Passive Low Energy Building Product Selection Catalog." This catalog has witnessed a significant surge in the number of high-performance energy-saving technology providers for near-zero energy buildings, rising from 51 enterprises in the inaugural batch in 2016 to 136 in 2019. This represents a more than twofold increase in the number of businesses over a span of four years, as illustrated in Figure 1.

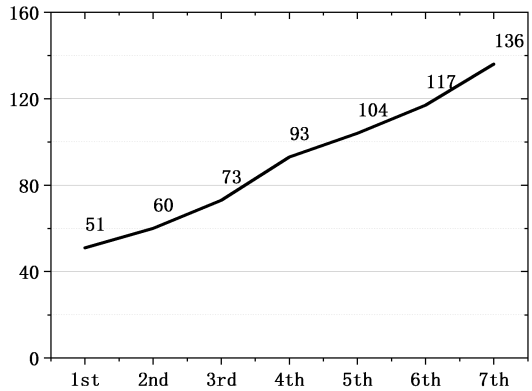

Figure 1. Product Catalog Number of Manufacturers

The published supplier directory predominantly features state-owned enterprises, representing over 90% of the listings. Notably, external doors, windows, and auxiliary materials companies, as well as external insulation system providers and fresh air/HVAC equipment suppliers, have experienced rapid growth. Specifically, the count of external door and window systems, profiles, and auxiliary materials enterprises in 2019 saw a two-fold increase from 2016 levels [11-12]. The reason is that China's original such industries have a good foundation, a large number of product suppliers, and the strong demand for these energy-saving technologies in near-zero energy buildings has spawned the replacement of products and the rapid development of the industry.

3.2 Renewable Energy Technology Industry

(1) Solar thermal industry

Since 2006, with the introduction of mandatory measures for the construction application of solar water heaters in China, the sales volume of solar water heaters has continued to grow, reaching a peak in 2012, reaching nearly 100 billion yuan of market share, but with the low quality problems caused by low-price competition in the industry, user satisfaction has decreased. The solar water heater market has been in decline since 2014. Production enterprises from the peak of more than 5,000 reduced to less than 1,000, of which there are only more than 100 solar water heater enterprises with a certain scale, sales revenue of more than 50 million yuan of solar water heaters only about 20. Domestic application demand is weak, air source heat pump water heaters gradually occupy market share, and solar domestic hot water applications mainly come from new rural + urban renewal demand. At present, although the number of enterprises in the solar thermal industry is decreasing, the concentration is constantly increasing. Domestic production enterprises reaching 100 million yuan and above scale mainly include: Sunrise Oriental solar energy, Shandong Linuo New energy, Tempu new energy, Beijing Tsinghua Sunshine, Shandong Muyang Solar energy and so on.

(2) The Heat Pump Sector

Driven by the demand for eco-friendly heating solutions in northern regions, air-source heat pump systems have experienced sustained growth over the past three years. As technology continues to advance, these products are becoming more versatile, capable of operating efficiently even in temperatures as low as -30°C. Consequently, within the northern "coal-to-electricity" transition market, low-temperature air-source heat pumps are rapidly gaining traction, with some models incorporating variable-frequency technology for enhanced performance. Nevertheless, the diverse climatic conditions across the north and the varying technical capabilities of these products mean that some low-temperature modular units from certain manufacturers struggle to provide adequate heating [13].

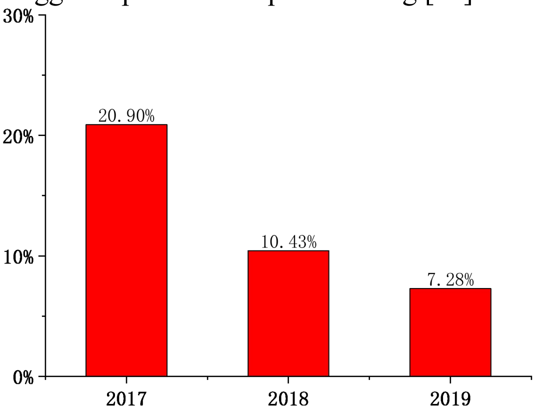

Figure 2. Market Share Growth of Air Source Heat Pump Units in 2017-2019

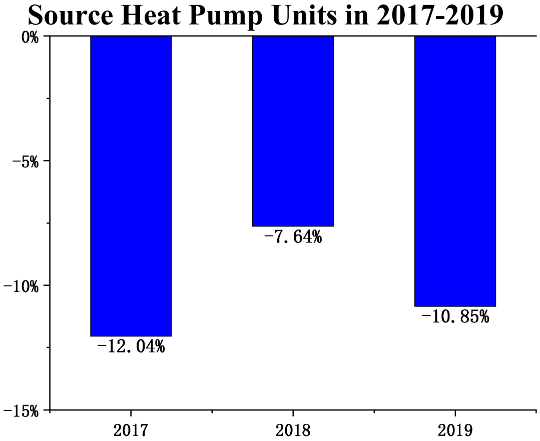

Figure 3. Market Share Growth of Water-Ground Source Heat Pump Units in 2017-2019

Furthermore, there has been a notable increase in the adoption and market penetration of air-source heat pump water heaters. The domestic manufacturing landscape is characterized by a mix of players, including traditional air conditioning companies, specialized air-source heat pump water heater firms, electric water heater manufacturers, solar water heater enterprises, and gas water heater producers. Among them, the United States and Gree are the most important production enterprises, the combined output value of the two accounts for more than 30% of the whole industry. Enterprises with a scale of more than 100 million yuan also include Zhongguang Otes, Guangdong Nuentai, Huatiancheng, AO Smith, Changling, Haier, Finney Technology and so on. Air source heat pump cold and hot water units, the number of enterprises is increasing, but the concentration is not high, as shown in Figure 2.

Following several years of robust growth, the market for ground source heat pump systems has experienced a notable contraction, with a clear downward trajectory. In comparison to 2018 figures, the market for water source heat pump units witnessed a decline of 10.85% in 2019. Market demand has changed, and miniaturization has become a faster growing direction. The capillary system used in small units of water-ground source heat pump has developed rapidly in recent years. Relying on the small temperature difference of radiation air conditioning uniform heat dissipation, its body feeling, comfort and energy saving are relatively high, will also be a trend of future market development, as shown in Figure 3.

4. Conclusion

After a thorough examination of the aforementioned energy-saving and carbon-reduction measures for buildings, along with future trends, this paper presents three key findings.

(1) Building energy saving and carbon reduction technology has developed rapidly, and capacity buildings have become an important trend. As the global emphasis on energy conservation and emission reduction continues to increase, building energy conservation technology has made significant progress, especially as a high-level form of zero-energy buildings, through the integrated application of renewable energy generation and heating systems, to achieve energy self-sufficiency and even external energy supply. The practice of production capacity building in Germany and other developed countries has provided valuable experience for China, and China's building energy efficiency work has gradually developed from a single measure to a systematic and standardized development, and the research and application of production capacity buildings are gradually promoted.

(2) Enhancing the energy efficiency of building envelopes and fostering the growth of the renewable energy technology sector. Building envelope energy efficiency improvement technology is the basis of building energy conservation, in recent years, the rapid expansion of related industries, the number of technology suppliers doubled, product replacement accelerated. Renewable energy technologies, particularly solar thermal and heat pump systems, are experiencing favorable growth due to policy backing and technological advancements. Despite market volatility and increasing competition, their overall progress is promising, offering substantial technical assistance for enhancing building energy efficiency and reducing carbon emissions. In the foreseeable future, the combined advancement of these two technologies will play a crucial role in achieving highly efficient and low-carbon buildings.

(3) The advancement of building energy conservation and carbon reduction hinges on policy direction and technological innovation. Government policies play an essential role in fostering these initiatives through guidance and financial backing. The successful case of Germany, among others, illustrates that well-defined policy goals, financial assistance, and incentives for technological R&D can significantly propel the advancement and adoption of energy-efficient building technologies. Additionally, technological advancements, such as innovations in envelope materials, renewable energy utilization, and smart control systems, are pivotal in enhancing building energy efficiency and reducing carbon emissions. Consequently, bolstering policy guidance and fostering technological innovation are vital for sustaining and deepening the progress in building energy conservation and carbon reduction efforts.

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