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Building a greener future—Progress of the green building technology in the "13th Five-Year Plan" of China

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The building sector plays an important role in energy conservation and carbon neutrality in China. According to the Building Energy Research Center of Tsinghua University, carbon dioxide (CO_2) emissions account for 38% of the total emissions, of which 16% and 22% are contributed by building construction and operation, respectively (Hu et al. 2022). Hence, promoting green buildings is proposed as an effective solution to the key problems of building industry development, including low labor productivity, high consumption of building materials, and high CO_2 emissions in construction and operation. Green buildings are environmentally responsible and resource-efficient throughout their life cycle from siting, design, and construction to operation, maintenance, renovation, and deconstruction. They aim to use energy, water, and other resources efficiently, while protecting occupant health and improving productivity, adopting eco-friendly materials, and reducing the production of waste and pollution.

Green building development can contribute to transforming the building industry and construction. In the "13th Five-Year Plan" of China, various green building technologies have been developed rapidly, mainly aiming at five practical aspects such as planning and design, energy efficiency, indoor air quality, high-performance structure and material, and green construction and industrialized building systems (Figure 1). These technologies have achieved desired results and have provided practical support for the development of low-carbon, energy-efficient, comfortable, and healthy green buildings. A brief overview of the aspects has been given below.

- Planning and design: Methodologies for planning and design were proposed at different spatial scales. For instance, at the building microscale, an optimized design method was proposed to adapt to different climate characteristics and building use and user behavior patterns. The climate adaptation mechanism of green public buildings was studied, and the coupling law between form and space in architecture and climate parameters was quantitatively analyzed. At the macroscopic level, a theoretical method and optimization technology related to the planning and design of new urban areas in China were established, and an intelligent planning platform integrating policy decision optimization was developed. The above achievements were demonstrated in regions such as the Xiong'an New Area and Pudong New Area.
- Energy efficiency: A new calculation method for indoor and outdoor design parameters such as heating, ventilation, and air conditioning systems was proposed based on thermal comfort and energy-saving requirements. An

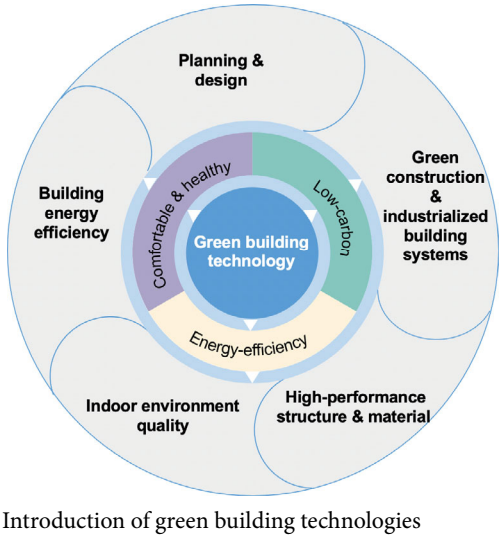

Fig. 1 Introduction of green building technologies

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open-source joint simulation platform kernel with fully independent intellectual property rights was developed to integrate lighting, thermal processes, airflow, indoor air quality, dynamic coupling between heat and humidity transfer, novel types of building envelopes, and renewable energy systems with building energy consumption. The technologies of nearly zero-energy buildings based on active and passive approaches were developed, and the standards related to design, construction, and evaluation were released. Aiming at the part-time-part-space characteristics of cooling and heating use patterns in the Yangtze River Basin area, a solution for the indoor thermal environment was proposed, and high-efficiency cooling and heating equipment was developed. For the spatial layout and functional characteristics of high-rise spaces and underground transportation buildings, energy-saving and indoor-environment control technologies have been established and implemented in practical projects.

- Indoor environment quality: Online monitoring and rapid air microbial detection technologies have been developed, reducing the air microbial concentration detection time from the traditional 24–48 h to 5–6 min. The technologies in terms of operating room air supply and negative pressure devices were proposed based on the theory of non-uniform environment cleanroom air supply. For industrial buildings with high pollutant emissions, the transportation mechanism and distribution characteristics of gas and airborne pollutants were revealed based on strong heat source and pollution conditions. Control technologies and devices were then developed for typical pollutants.
- High-performance structures and materials: High-performance steel structure systems involved the novel shear wall, novel frame, assembly of plate column, and assembly of the staggered truss were developed. A novel seismic design method of high-strength steel box-column–beam-column connections and frames was proposed, thus decreasing the size of members. New products and preparation technologies have been developed for high-performance fiber-reinforced composites such as meshes and large-tonnage polymers. The achievements have been applied to major projects such as the World Expo Pavilion, Shenzhen–Zhongshan Corridor, Nairobi–Malaba Railway, China–Maldives Friendship Bridge.
- Green construction and industrialized building systems: A design platform that is fully independent of intellectual property rights was developed to realize collaboration and integration between green building technologies and data interaction. An optimized performance design methodology was proposed for seismic isolation and energy dissipation, and corresponding products were developed. A building information model collaborative work application platform (PKPM-BIM) with independent intellectual property rights was developed for 3D visualization, real-time data acquisition, and intelligent manipulation.

In summary, during the "13th Five-Year Plan" period of China, green building technologies have made achievements in various aspects such as planning and design, energy efficiency, indoor air quality, high-performance structures and materials, green construction, and industrialized building systems, providing technological and practical support to the green and low-carbon development of the building industry. With the improvement in the green building industry in China, its "14th Five-Year Plan" is a key period for achieving the goal of carbon peak by 2030 and carbon neutrality by 2060 (State Council of the People's Republic of China 2021). The following points are considered important for the future development of green buildings:

(1) Improve the quality of green building development by advocating the concept of green and low-carbon design of buildings, making full use of natural ventilation, natural lighting, and other passive ways to reduce residential energy usage intensity and improve residential health performance. The planning, design, construction, and operational management of green buildings should be strengthened. Guides should be provided for the development of local policies to promote the large-scale development of green buildings.
(2) Improve energy efficiency in new buildings by building and improving energy-saving standards for new buildings and promoting the implementation of green building standards. The construction of high-performance green buildings should be encouraged, large-scale construction of ultra-low energy consumption buildings should be carried out, and pilot projects of zero-carbon buildings and communities should be promoted.
(3) Promote renewable energy applications by promoting the applications of photovoltaic and solar thermal systems in buildings and carrying out distributed demonstrations at the regional level, integrating new technologies, including intelligent photovoltaic and energy storage systems, and building demand response. The application of geothermal energy, air-source heat pumps, biomass, and other solutions to domestic heating, cooking, and other energy needs in buildings should be promoted.
(4) Conduct building electrification programs by encouraging the implementation of a new type of building power system such as PSDF (photovoltaic, storage, direct current, and flexible) to achieve flexible power demand and demonstrate sustainable electrification designs for

new public buildings. The application of air-source heat pumps and other electric heating products should be encouraged to satisfy the heating demand in hot summer and cold winter areas.

(5) Promote innovative green construction technologies by improving the standardized design and production systems of assembly buildings and promoting the standardization of components. The structural systems of assembly buildings for different building types should be improved, and the integrated application of high-performance concrete, high-strength steel, energy dissipation and vibration reduction, and prestressing technology should be increased.

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