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Engineering

Special Topic: Energy Systems of Low Carbon Buildings

Energy systems of low carbon buildings: Research advance and perspective

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Developing low-carbon buildings is of great importance because the carbon emissions from buildings (including the embodied emissions from new construction) account for about 40% of global carbon emissions, and have been growing continuously at a rate of 2% to 3% per year [1]. For sustainable global development and national energy security, the Chinese government has announced a national strategy in which China will reach its carbon emission peak and achieve carbon neutrality. These goals call for a series of novel or even revolutionary techniques. Among them, developing low-carbon energy systems and techniques are of the greatest importance. Therefore, we have organized a special topic on energy systems for low-carbon buildings. Eight excellent studies of recent research advances and perspectives on the topic have been selected [2–9].

To develop Energy Systems of Low Carbon Buildings, we need to first identify the key problems from "big pictures" related to the topic and then find solutions.

Ge *et al*. [2] from Zhejiang University present a perspective on building decarbonization based on building loads' flexibility and building clusters' collaboration. In particular, they consider low-carbon solutions that utilize renewable energy, such as wind and photovoltaic power. Given the intermittency and instability of these energy sources, they state that the building sector should adapt by developing building load flexibility and building clusters' collaboration. Research is needed to make buildings active participants in effectively matching energy needs with fluctuating renewable energy generation.

Yu *et al*. [3] from China Academy of Building Research noted that nearly zero-energy buildings (NZEBs) in China have become crucial in the building industry. The development of NZEBs in China has included fundamental and applied research as well as developing national and local standards. They give an overview of the last decade's progress in NZEBs in China, covering key technological research, policy development, engineering demonstrations, and the current industrial development status. They present prospects for the NZEB industry development.

Guo *et al*. [4] from Xi'an Jiaotong University developed a method to schedule zero-carbon building energy systems (ZCBS) both seasonally and daily. They address the complicated interactions of multi-energy hybrid

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storage with the complexities of coordinating seasonal and daily scheduling. Their results show that ZCBS can be achieved by using renewable energy sources with system flexibility provided by hydrogen, geothermal, and water storage devices. This scheduling approach can reduce operation costs by over 43.4% under the same device capacities compared with existing scheduling approaches.

Because conventional machine learning algorithms inadequately address building operational data, Fan *et al*. [5] from Shenzhen University introduce a novel machine learning paradigm that includes transfer learning, semi-supervised learning and generative learning. They analyze progress and perspectives on the effective utilization of machine learning for building energy needs, fault detection and diagnosis, and control optimization. They discuss in-depth the pros and cons of different approaches with respect to data compatibility, modeling difficulties, and possible application scenarios. Their study contributes to understanding the feasibility of data-driven technologies for building management.

New materials play an important role in developing the energy systems of low carbon buildings.

Zhong *et al*. [6] from Zhejiang University report a novel pH-sensitive tunable thermochromic hydrogel with carbon quantum dots for smart windows. The hydrogel has intriguing features of a tunable transition temperature and enhanced switching speed. The building energy simulation that they performed reveals the necessity of tunability for both transition temperatures and solar transmittance in thermochromic smart windows. Their novel design of thermochromic composite hydrogel provides insight into theoretical and experimental support for future adaptive building envelopes.

Radiative cooling coatings are promising for low-carbon buildings. However, comprehensive research on their weather resistance, long-term performance, and effects on building load is required. To fill this research gap, He *et al*. [7] from Chongqing University studied seven coatings via both experimental and simulated study. Their results show that there are noticeable differences among different coatings in anti-aging properties, cooling performance and building load reduction and that the cooling performance of all coatings gradually decreases due to natural aging. The authors suggest that such coatings be selected based on usage scenarios in different climatic zones.

The use of a hybrid energy storage system can solve the problem of low renewable energy utilization levels caused by a spatiotemporal mismatch between the energy source and load. Guo *et al*. [8] summarize the typical frameworks, current status, and advantages of a hybrid energy storage system in industrial parks. They also discuss key challenges in developing hybrid energy storage systems.

The use of phase change materials (PCMs) in buildings is prospectively a method for mitigating building energy consumption. Among the diverse PCMs, salt hydrate PCMs stand out for their superior thermal storage densities, adaptable operating temperature ranges, and cost-effectiveness. However, supercooling, phase separation, and insufficient thermal conductivity limit their efficacy in practical applications. Yang *et al*. [9] from Shenzhen University offer a comprehensive overview of the strategies to address these challenges, and also elucidate the corresponding optimization methodologies and bolstering mechanisms.

All of these studies are multidisciplinary. The corresponding authors have all contributed extensively to developing Low Carbon Energy Systems for Buildings. Given the limited space of this special topic, we could not include more studies. We will be satisfied if the special topic papers attract the interest of many readers and strengthen the studies on this topic. We also want to remind readers that low-carbon buildings should also be healthy buildings. Reducing the burden of disease from indoor air pollutants is also important for the current Chinese national strategy of “Healthy China” [10,11]. Our goal should be to balance Low

Carbon Energy Building Systems with Healthy Indoor Environments.

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