EDITORIAL

Call for innovative theory and technologies for healthy and low-carbon buildings

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Buildings are very important to both human health and reducing global carbon emission. People spend over 80% of their lives in buildings. For adults, breathing contributes over 75% of their total mass intake (air, water and food). It follows that indoor air quality (IAQ) greatly influences human health, comfort, productivity, creativity, and well-being.[1] Indoor air pollution is severe in China and India and other developing countries, whose people are over half of the global population. Liu et al. found that in 2017 the burden of disease attributable to the top ten indoor air pollutants expressed as disability-adjusted life years (DALYs) in China was 3700 per 100,000 people. In mainland China, indoor air pollution ranked third among all recognized and reported risk factors. The equivalent financial loss was 3·45% of the gross domestic product (GDP) for 2017.[2] In addition, buildings and construction consumed about 36% of global final energy and emitted about 37% of global energy-related CO_2 in 2020,[3] as well as producing ambient pollution such as $PM_{2.5}$, PM_{10}, SO_x , NO_x especially in countries such as China, where coal combustion is the main source of electricity. Therefore, researchers in building science and related fields are challenged to create buildings that are both healthy and low-carbon emitting. In China, there is presently a great opportunity to fix the problems because the government has launched two national strategies, "Healthy China" and "Carbon Peak and Carbon Neutrality".

To create healthy and low-carbon buildings, we should keep in mind: (1) Healthy and low-carbon should be addressed together, and never in opposition to each other; (2) innovative methods to create healthy buildings with good air quality should be developed; (3) innovative techniques to reduce building energy consumption and carbon emissions should be developed and applied properly; (4) innovative theory and models for healthy, low-carbon emitting buildings are urgently needed; and (5) various intelligent technologies should be used properly and multi-disciplinary researchers should cooperate. See Figure 1.

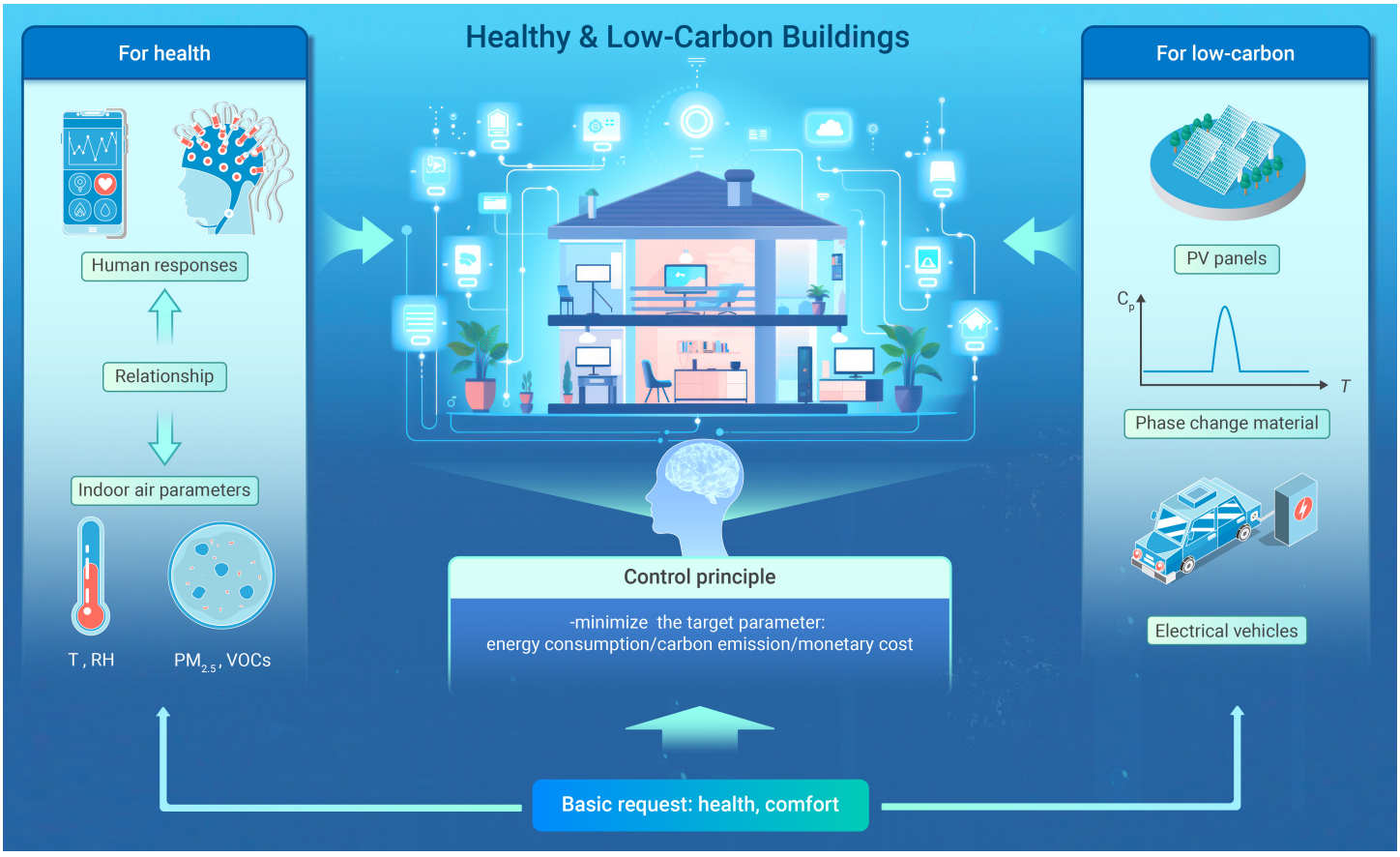

Figure 1. Healthy and low-carbon buildings call for innovative techniques and theory.

HEALTH AND LOW-CARBON ISSUES IN BUILDINGS MUST BE CONSIDERED TOGETHER

Health and comfort are the basic human requests that must be met as we strive for energy-saving and low-carbon emission. How to balance and optimize the control approaches? We first need to quantify the cost of balancing indoor air climate comfort with indoor air quality. This requires evaluating the indoor air pollution burden of disease and the benefit of controlling the pollu-

tion to equivalent economic loss and benefit. Similarly, reducing energy consumption and carbon emission by using various approaches must also be balanced with human health and comfort. Only then can the overall net economic benefit of controlling indoor air climate and indoor air quality be quantitatively estimated. This is the basis of optimizing the control approach for indoor air climate and indoor air quality.

CALL FOR INNOVATIVE TECHNIQUES TO IMPROVE INDOOR AIR QUALITY AND TO CREATE HEALTHY BUILDINGS

In the past decades, many techniques have been developed to improve indoor air quality. Indoor air pollutants can now be identified and their concentrations measured precisely; various online sensors for monitoring the concentrations of air pollutants such as $PM_{2.5}$, PM_{10}, CO2 outdoors and indoors and can be used on a large scale; source identification and source controlling techniques for typical pollutants from indoor materials have been developed and are being applied; new air cleaning materials and techniques have been invented and are being applied in a variety of indoor environments. In addition, biomarker evaluation of human health responses are also being developed rapidly. However, online monitoring techniques with acceptable precision and costs for formaldehyde, benzene, toluene, and TVOC are inadequate. Wearable devices for monitoring human physiological and health responses need further development. Therefore, although the relationships between indoor air environments and human health responses are being understood better and better, they are still far away from to be completely characterized.

CALL FOR INNOVATIVE TECHNIQUES TO REDUCE BUILDING ENERGY CONSUMPTION AND CARBON EMISSIONS

In the past decades, many building energy efficient and low-carbon techniques have been developed. For example, the overall heat transfer coefficient for building walls has been greatly reduced. Low emittance glass, also called heat mirror glass, has been developed and applied in energy efficient buildings. Photo voltaic panels with solar cells have become cheaper and are being used widely in buildings. The coefficients of performance (COP) of devices/systems of heating, ventilating, and air-conditioning (HVAC) are approaching their limits. Although climate responsive materials such as phase change materials in building envelopes can minimize the HVAC energy consumption by adjusting to changing ambient temperatures, they are still too expensive to be used on a large scale. Also, the number of buildings with proper electricity and/or renewable energy storage systems as well as plug-in electric vehicles are far from being sufficient. Therefore, the electricity load of current buildings cannot match the electricity and/or renewable energy supply. Many innovative techniques to fix these problems are urgently needed.

CALL FOR INNOVATIVE THEORY FOR HEALTHY AND LOW-CARBON BUILDINGS

Engineering thermodynamics provides a theory of optimizing equilibrium heat-work conversion processes. However, it cannot optimize various non-equilibrium heat and mass transfer processes involving temperature, humidity and multi-species pollutants. Heat and mass transfer theory can analyze the process characteristics but cannot obtain the optimized values. In order to overcome these limitations, Guo et al. put forward a new concept, entransy, defined as half of the product of the internal energy and the temperature of the object.[4] However, for a system including both heat-work conversion, and heat and mass transfer processes, it is still impossible to optimize the output by using engineering thermodynamics and/or by using entransy theory. Therefore, an innovative theory is strongly needed. As a preliminary effort, a theory called analytical heat and mass transfer for the built environment was put forward.[5] Similarly to analytical mechanics, it is based upon the inverse problem and variation method. The key differences between the new theory and the traditional engineering thermodynamics and Guo et al.'s entransy theory are: (1) it is not solely applicable to heat-work conversion processes or to heat and mass transfer processes; (2) it is not based on the second law of thermodynamics but is rather based on the principle of minimizing the target parameter of greatest interest, such as energy consumption, carbon emission, or monetary cost under given constraints. The salient feature of this new theory is that it is suitable for complicated, nonlinear systems. However, much future work is needed to develop the preliminary theory to mature theory such that it can solve the challenging problems of creating healthy, low-carbon buildings. Certainly, more innovative theories will also be needed in the future.

CALL FOR INTELLIGENT TECHNOLOGIES AND MULTI-DISCIPLINARY CO-OPERATION

Last but not least, considering that the Internet, Wi-Fi, the Internet of Things, and electric vehicles have become part of our lives, and that artificial intelligence (AI) and robots are being developed rapidly, all building components and control systems can become smarter and smarter. Materials science, design and engineering of the built environment, and the AI research communities should co-operate thoroughly at this beginning stage of creating healthy and low-carbon buildings. I think such co-operation can bring about a series of real breakthroughs for the healthy and low-carbon buildings in the future.

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DECLARATION OF INTERESTS

Yinping Zhang is an Editorial Board member of The Innovation Energy and was blinded from reviewing or making final decisions on the manuscript. Peer review was handled independently of this member and their research group.