E3S Web of Conferences **356**, 01012 (2022) https://doi.org/10.1051/e3sconf/202235601012
ROOMVENT 2022

The future development path of low carbon building design

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Abstract. Excessive carbon emissions are causing the problems of global warming and greenhouse effect. It is urgent to control carbon emissions worldwide. As one of the main sources, it is crucial to reduce the carbon emits of construction industry. Carbon is generated at all phases of the building life cycle. Notably, building design has various extent of influence on carbon emissions at each phase, which is urgently to explore a low carbon method. This paper is to summarize the current status of building design by literature review. The challenges of building design are analysed as the lack of 1) a comprehensive standard system by considering different factors; 2) the carbon emission calculation method; 3) real-time optimization model aiming at carbon reduction. Therefore, the path of "standard-calculation-prediction-optimization" (SCPO) for building design is proposed. This paper can provide theoretical guidance for low carbon building design.

1 Introduction

Increased fossil fuel combustion and exploitation of finite resources are causing excessive carbon emissions, further resulting in global warming and greenhouse effect. For a doubling of CO_2 in atmospheric, the global average temperature rises by about 3 °C [1]. Reducing carbon emissions has become an urgent issue worldwide. Globally, the building sector accounts for 40 % of total carbon emissions. Reducing carbon emissions from the building sector is the key to achieving carbon neutrality. It is a major challenge to reduce carbon emission in building sector to achieve the goal of carbon neutrality.

The main principles to achieve the goal of zero carbon are: 1) making full use of renewable energy to reduce the embedded carbon emissions from the production of building materials, building construction to the completion phase; 2) using renewable energy and advanced energy-saving technologies to reduce the carbon emissions in the operation phase; 3) the remaining carbon can be neutralized by means of carbon sinks or compensated carbon, to finally achieve the goal of low carbon building. To this end, the carbon emission process of the life cycle of the building should be fully comprehended. There are seven phases in whole life cycle: including building materials production, building transportation, building design, construction, building operation and maintenance [2], building renewal and building demolition. Each phase of the building life cycle has a diverse impact on carbon emissions.

It is important to note that building design affects carbon emissions in various phases of the building life cycle in variable extents levels [3]. Building design phase can determine the form of the building envelope, material selection, etc., which directly affects the embedded carbon emissions in the phases of building materials production and building transportation, etc. [4]. The design of air conditioning and ventilation systems in the building operation and maintenance and building renewal phases are based on the finalized building morphology [5]. More seriously, if the building performance is optimized by active technology or retrofitting. However, the embedded carbon emission of the building could be increased [6]. Thus, low carbon building design is crucial to reduce carbon emissions throughout the building life cycle.

At present, scholars from all over the world have fully recognized and conducted in-depth research about the impact of building design on carbon emissions [7]. However, for the complex building environment, how to achieve low carbon and zero carbon through building design is facing many challenges in the actual application. This paper is to summarize the current status of low carbon building design through literature analysis, to discuss the challenges and possible development in the future. This paper will have a guiding effect on low carbon building design.

2 The status and challenges of low carbon building design

2.1 The status of low carbon building design

This paper describes the status of low carbon building design from three aspects, which are 1) the standard system of low carbon building design, 2) The calculation methods of carbon emissions, and 3) The optimal building design.

2.1.1 Low carbon building design standard system

Aiming to achieve the goal of "carbon peak and carbon neutral", China's Ministry of Housing and Urban-Rural

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Development released the national standard "General Specification for Building Energy Efficiency and Renewable Energy Utilization" to make the calculation of building carbon emissions a mandatory demand. "The announcement on the issuance of the implementation plan for the in-depth development of green low-carbon leading action for public institutions to promote carbon peaking" states that the promotion of ultra-low energy buildings and low-carbon buildings should be accelerated and green buildings should be developed. Solar photovoltaic photothermic systems should be vigorously promoted. The photoelectric high-efficiency photovoltaic power generation facilities should be installed by making full use of suitable site space such as building roofs and facades.

Currently, there are timely development requirements for low carbon building design in all regions. The building design is a complex issue influenced by climate, humanities, economy, culture and other factors [8]. Therefore, the standard system of low-carbon building design should be improved.

2.1.2 Carbon emission calculation methods

Life cycle assessment (LCA) is an internationally and nationally acknowledged method for calculating carbon emissions [9]. Based on LCA, input-output analysis (IO-LCA) method is widely used around the world [10]. This method uses economic input and output data to calculate industry-wide carbon emissions, without the ability to perform specific calculations and analyses during the detailed building processes. The process analysis method [11] can overcome the limitations of IO-LCA, which can calculate carbon emissions from the materials production, transportation, construction, operation, disassembly and recycling of building. The process analysis method calculates carbon emissions by means of carbon emission factors for each phase, which requires a detailed process inventory for each phase.

The carbon emission factor is the key of the calculation method. The IPCC provided the basic database of carbon emission factors. Owing to the complex and diverse building types, the traditional carbon emission factors cannot be fully suitable for the carbon emission calculation for all building types [12]. Besides, regarding the carbon emission calculation, the sources of carbon emission factors are not uniform, including basic data-bases, literature, and standards [13,14]. It is an urgent issue to be solved for the establishment of a standardized and comprehensive carbon emission factor database.

In addition to the carbon emission factor database, the detailed building inventory is also crucial for the life cycle carbon emission calculation. Since the building inventory in-formation can be commonly obtained from engineering drawings, less detailed information is available in the conceptual and preliminary design phases of building design [15]. Therefore, the carbon emission calculation method should also be towards the life cycle process with less inventory information.

2.1.3 The optimal building design

Three types of the optimization of low carbon building design are shown as following. The first one is to investigate the impact of different factors in building design on carbon emission or energy saving (univariate optimization). Compared with active means, passive design can effectively reduce energy consumption and carbon emissions. Studies have been carried out on passive design factors for energy saving or low carbon emission. These include green roofs [16], window-to-wall ratios [17] and building orientation [18], etc., which can provide sufficient theoretical support for low carbon and low energy consumption building design. However, there are strong interactions between different design factors. It is limited to investigate effect of single design factor on carbon emissions.

The second one is the multi-objective optimization of building design factors. The commonly used objective functions are construction cost, energy consumption, etc. [19], to achieve low energy consumption and low carbon building design by finding the optimal objective [20]. However, it refers more to the carbon emissions of operational energy consumption. The energy consumption in the operation phase is not enough to indicate the actual carbon emission reduction. The life cycle carbon emissions should be considered in low carbon building design. Many scholars have conducted research on the whole life cycle carbon emission calculation model of buildings, which is the research content of the third one.

Generally, in the research of life-cycle carbon emission model of buildings, carbon emission database should be firstly established. Secondly, the model can be constructed by the advanced methods such as machine learning and regression fitting, etc. [21]. However, the current database construction mainly includes: research statistics and energy consumption simulation [22]. Research statistics requires continuous statistical data for several years or months, which costs more time to build a database of carbon emissions. Therefore, the existing building design optimization is both time-consuming and heavy investment. It is necessary to explore a fast and convenient optimization method for low carbon building design.

2.2 Low carbon building design challenges

The first challenge is the lack of a global perspective design system. China's building stock is relatively high. Different cities have different climate characteristics, population density, economic level, and human characteristics. There is an urgent need for low-carbon buildings to consider multiple factors and develop novel design approaches that accommodate different characteristics. Based on the different characteristics, the building design system should take spatial form of buildings and low carbon as the common optimization objective.

The second challenge is the lack of carbon emission calculation methods applicable to the design phase. The existing calculation methods require a comprehensive data-base of carbon emission factors and detailed process inventories. The current database of carbon emission factors needs to be improved to be applicable to more building types. The detailed process inventory cannot be available in time in the building design phase, which may affect the accuracy of the calculation of building carbon emissions. Hence, exploring a calculation method applicable to the design phase remains a great challenge.

The third challenge is the lack of real-time optimization methods in the design process with the goal of reducing carbon emissions. Low carbon building design should take into account the building morphology constructed by circulation space, open space and aesthetics, floor area, floor layout, floor height, building volume, building orientation and fenestration, as well as windows, doors, shading and exterior walls, etc. Each factor can affect the carbon emission, and even the subsequent carbon emission of the active design (i.e., the utilization of renewable energy, air condition system). Moreover, the method of optimizing design factors in the design process by simulation has the problem of time-consuming. Low carbon building design needs to use convenient and fast optimization method, i.e., drawing-prediction-design, which can provide accurate guidance for building design.

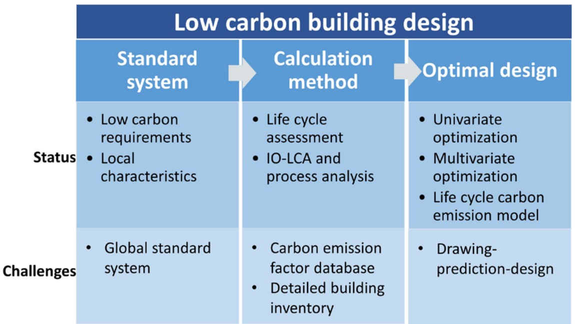

Fig. 1. Statues and challenges of low carbon building design.

3 Possible future work

In accordance with the characteristics of building design under different climatic characteristics in China, the design standard system of "spatial regulation" and "performance regulation" for low carbon green buildings will be established in the future work. Specifically, it includes: building morphology design, envelope design, low carbon material selection, balancing control between light and heat, passive-active and air conditioning coupling design, indoor humidity independent control, etc.

Based on the low carbon building design standard system, future work will explore carbon emission calculation methods applicable to the design phase. Through research and evaluation methods, a comprehensive database of carbon emission factors will be built to meet the needs of different climatic conditions, building types, and building heights, etc. In addition, the carbon emission calculation in the design phase needs to meet the reality demand of incomplete content of inventory information in future research. It is proposed to explore the influence of detailed contents of each process in the building life cycle on carbon emission and construct a database of process inventory factors. Based on the carbon emission factor and the process inventory database, a convenient and fast carbon emission calculation method should be formed to facilitate the rapid assessment of carbon emission in the design phase.

Based on the low carbon building design standard system and carbon emission calculation method, the building design in the future will be optimized through the design model. Firstly, different climate zones and building types are used as the first boundary conditions. Site area, floor area ratio and building height limits are used as the second boundary conditions. The building orientation, and window-to-wall ratio are used as the third boundary conditions. The influence of each factor of building design on carbon emission, to construct a comprehensive database of design factors. Secondly, based on the above boundary conditions, a low-carbon design prediction model will be constructed through big data analysis and machine learning methods. Finally, the building design drawing software including Computer Aided Design (CAD), Building Information Modelling (BIM) will be coupled with the low carbon design prediction model to form a design pattern that buildings can be optimized immediately after drawing.

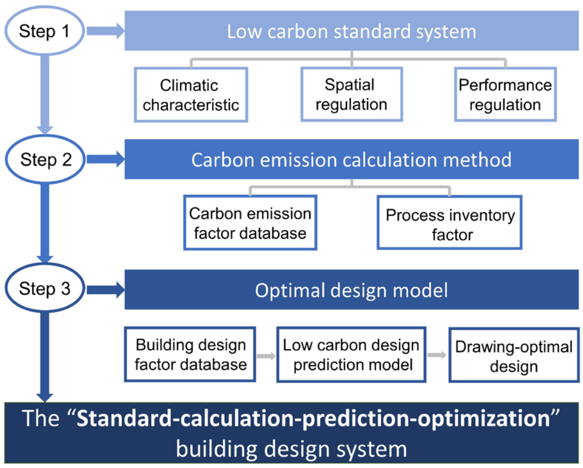

Fig. 2. Possible future work of low carbon building design.

4 Conclusions

This paper is to summarize the current status of building standard system, carbon emission calculation methods and building design optimization. The main challenges are concluded as: 1) the lack of a comprehensive standard system for different climate zones, space and performance requirements in the building design phase; 2) the existing carbon emission calculation methods lack a comprehensive database of carbon emission factors, which are not applicable to the design phase without a detailed process inventory; 3) the ability to optimize building design factors based on real-time carbon emissions during the drawing process in the design phase is also an urgent problem to be solved.

Based on the above mentioned challenges, this paper aims to sum up the possible future work in building design. The future work on building design will form a standard design system integrating spatial building information and low carbon performance. It is significant to explore a convenient carbon calculation method based on a comprehensive carbon emission factor database and a process inventory factor database, construct a database of the impact of different building design factors on carbon emissions, and propose a prediction model for building design using machine learning methods. Specifically, the spatial-low carbon standard system, the carbon calculation method, the prediction model of building design and the optimal design of low carbon will be the framework, the foundation, the theoretical, and the objective, respectively. The system of "standard-calculation-prediction-optimization (SCPO)" will provide precise guidance for future building design.

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