Design and Planning of China's Green Building Evaluation System Integrating with Carbon Emission Assessment

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Abstract. Many countries and regions worldwide have successively developed various green building evaluation systems to promote the development of green buildings and sustainable urban ecology development, as well as protect the human living environment. China has also formulated and improved the national "Green Building Evaluation Standards" (ESGB, GB/T50378-2019). However, with the changes in green building development ideas, the evaluation system for green building has also been exposed to shortcomings. For example, carbon emissions, as a critical link in energy conservation and emission reduction of green buildings, have yet to be addressed in ESGB. This article tries to establish a green building evaluation indicator system related to carbon emissions based on the current version of ESGB in China, employing an improved AHP fuzzy comprehensive evaluation method. The proposed system includes indicator systems, indicator benchmarks, and weight systems. This work fills the gap in building carbon emissions on the current version of ESGB in China. It evaluates green buildings more comprehensively and accurately. The case study shows that the green building evaluation system based on the integrated carbon emission assessment has good applicability and feasibility, providing a reference for developing China's green building evaluation system and offering guidance for urban ecology and green building design and planning.

Keywords: green buildings design and planning; evaluation system; carbon emissions; improved analytic hierarchy process; fuzzy comprehensive evaluation; urban ecology

1 INTRODUCTION

With their multifaceted mission of combating climate change, conserving energy, fostering sustainable urban ecology development, reducing emissions, and promoting green and sustainable development [1-3], green buildings hold immense promise for our future. The concept of green building has evolved from 'four savings and one environmental protection' to a more comprehensive and environmentally friendly approach [4]. The growing attention towards green building evaluation is a testament

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to this potential [1]. China, for instance, has issued three evaluation standards for green building (ESGB) in 2006, 2014, and 2019. The 2019 version of ESGB, with its comprehensive set of control items, scoring items, and improvement and innovation items, has emerged as China's most authoritative and widely used green building evaluation system[5].

The building sector, as one of the three major sectors of energy consumption, emits more than 50% of the global total carbon emissions, which makes building carbon emission a key factor affecting climate change. Therefore, evaluating building carbon emissions and developing low-carbon and zero-carbon buildings are crucial to mitigating global climate change and promoting sustainable development [6]. Most of the standard green building evaluation systems are centered around energy, materials, water, and the indoor environment [7]. Although the 2019 version of ESGB (partial revision draft for comments) has included building carbon emissions in the improvement and innovation items, the selected green buildings must pay more attention to the carbon emission issue due to the lack of mandatory regulations. Therefore, to promote the green transformation of buildings as well as promote energy saving and emission reduction, it is necessary to incorporate building carbon emission-related indicators into the green building evaluation system.

There have been some achievements in the research on carbon emission assessment of green buildings. The current standard green building evaluation systems, such as BREEAM in the UK, LEED in the US and DGNB in Germany, have specified the scope and method of building carbon accounting and stipulated the corresponding star certification standards [8]. Meanwhile, scholars in China and South Korea researched green building carbon emissions [9-10]. Some Chinese provinces and cities have incorporated carbon emission assessment indicators into the local green building evaluation system [11-13]. In summary, the current research on carbon emission assessment of green buildings focuses on building carbon emission accounting, and further research has yet to be carried out on the assessment of carbon emission in the whole life cycle of green buildings.

Based on the 2019 version of China's ESGB, this paper integrates carbon emission assessment into the green building evaluation system, uses the improved AHP fuzzy comprehensive evaluation method to re-determine the weights of the indicators, and adds the improvement and innovation items adapted to the reality of China's green building, thus constructs China's green building evaluation system integrating with carbon emission assessment. It has become a green building evaluation tool for engineers, designers, researchers, building service departments, and other practitioners related to the construction industry. This system is tailored to advance green building practices in China, aiming to provide a more comprehensive and accurate evaluation of green buildings. It will also contribute to achieving the dual-carbon targets and promoting the sustainable development of buildings. Additionally, this system can serve as a reference for developing China's green building evaluation system and offer guidance for urban ecology and green building design and planning.

2 CHINA GREEN BUILDING EVALUATION SYSTEM INTEGRATING WITH CARBON EMISSION ASSESSMENT

2.1 Indicator Benchmark

According to the data published in the 2023 Annual Development Report of China's Building Energy Efficiency, in 2021, CO_2 emissions from urban buildings (except northern heating) will be 16.4kgCO_2/m^2, CO_2 emissions from rural dwellings will be 21.7kgCO_2/m^2, CO_2 emissions from public buildings (except northern heating) will be 48.9kgCO_2/m^2, and northern heating CO_2 emissions were 29.7kgCO_2/m^2 (see Fig. 1.). According to the calculation, the carbon emissions baseline value from the building total life cycle is 116.7 kgCO_2/m^2 in 2021.

Building a life cycle of carbon reduction is a crucial aspect of our sustainability efforts. It involves minimizing CO2 emissions during building construction, operation, and demolition. To this end, the "building carbon emission reduction rate within life cycle" is introduced as a benchmark parameter for assessment, and its calculation is shown in equation (1):

$$\alpha = \left(1 - \frac{\beta}{\gamma}\right) \times 100\% \tag{1}$$

Where, the whole life cycle of the building α is the carbon emission reduction rate, β is the carbon emission, γ is the carbon emission benchmark.

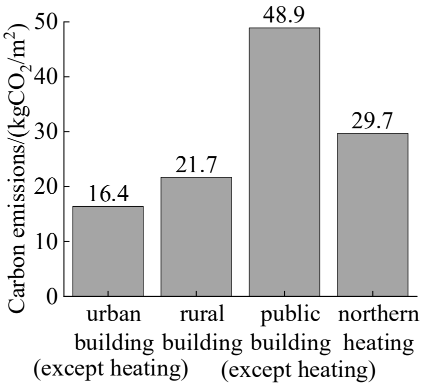

Fig. 1. Carbon emission data per unit area of buildings in China in 2021.

2.2 Indicator System

Comparative analysis of representative green building evaluation indicators in countries around the world through Table 1. shows that, compared with the US, the UK, and Germany, China's current 2019 version of the ESGB achieves complete coverage of green building evaluation indicators. However, it does not incorporate building carbon emission indicators into the evaluation system.

Table 1. Comparison of green evaluation indicators around the world.

	US	UK	Germany	2019 ESGB
Management		√		√
Comfort		√		√
Energy	√	√		√
Transport	√	√		√
Location	√		√	√
Water	√	√		√
Material	√	√		√
Save land		√		√
Atmosphere	√		√	√
Environment			√	√
Culture			√	
Service				√

Therefore, this paper applies the flexibility and expandability of the framework of the weight evaluation system. According to the provisions of the "Chinese 14th Five-Year Plan" of the modern energy system plan about strengthening the ecologically friendly construction, we will add the ecologically friendly primary indicators based on five primary indicators of the 2019 version of the ESGB, and set the building carbon emission, green construction management technology secondary indicators under the indicator. Other primary indicators within the secondary indicators remain unchanged. In addition to setting up the improvement and innovation items of ecological protection and restoration, building power interaction is needed to complete the construction of the green building evaluation indicator system for the evaluation of comprehensive carbon emissions. On this basis, the hierarchical analysis model of China green building evaluation system based on the target layer, guideline layer and programme layer of the comprehensive carbon emission assessment is established, and the specific model is shown in Fig. 2.

The secondary indicator of green construction management technology is based on the "Green Construction Evaluation Standard for Construction Projects", which aims to achieve green in the construction process and personnel management regarding carbon emission, and fits the primary indicator of ecologically friendly. The improvement and innovation items of ecological protection, restoration, and building power interaction are proposed based on experts' opinions and national policy documents. Ecological protection and restoration are to implement the national "Opinions on Accelerating the Construction of Ecological Civilisation", to protect and restore the natural ecosystem after the building is completed, so that the green building can be further developed. Building power interaction refers to the interactive regulation of the power grid by combining renewable energy into buildings so that the building side can flexibly regulate the power load. In contrast, the grid side can suppress the peak of power consumption, and the orderly integration of renewable energy can reduce carbon emissions.

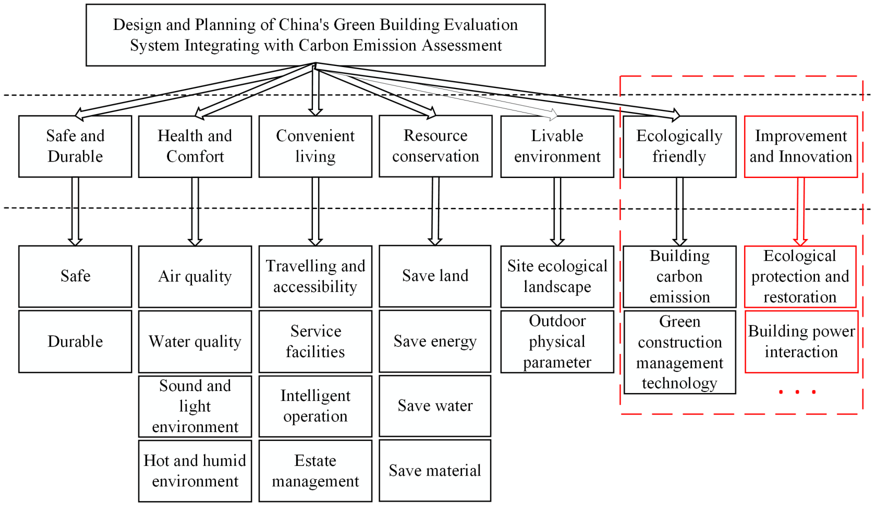

Fig. 2. Hierarchical analysis model of the indicator system.

2.3 Weight system

Based on the green building evaluation indicator system of China based on integrated carbon emission assessment, this paper adopts a two-by-two judgment of each indicator based on the Delphi method by inviting 100 stakeholders in the construction industry, including architectural engineers, designers, researchers, building services departments, and other practitioners related to the construction industry, to combine with the green building evaluation indicator system of the integrated carbon emission assessment to reconstruct the weight distribution scheme. The distribution of the number of stakeholders in the construction industry is shown in Fig. 3., and the calculation results of the weights of the green building evaluation system with integrated carbon emission assessment are shown in Table 2.

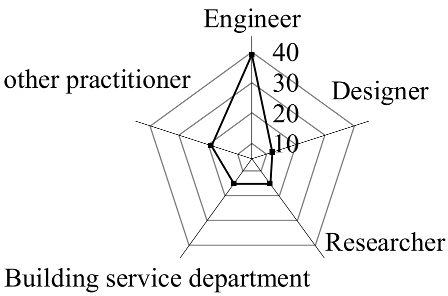

Fig. 3. Distribution of the number of stakeholders in the construction industry.

Table 2. Weight results.

Guideline layer (Primary indicator)	Weight	Programme layer (Secondary indicator)	Weight	Weight
Safe and durable	0.29	Safe	0.73	0.21
		Durable	0.27	0.08
Health and comfort	0.20	Air quality	0.36	0.07
		Water quality	0.31	0.06
		Sound and light environment	0.15	0.03
		Hot and humid environment	0.18	0.04
Convenient living	0.11	Travelling and accessibility	0.40	0.04
		Service Facilities	0.26	0.03
		Intelligent operation	0.15	0.02
		Estate management	0.19	0.02
Resource conservation	0.13	Save land	0.13	0.02
		Save energy	0.44	0.06
		Save water	0.27	0.04
		Save material	0.16	0.02
Livable environment	0.10	Site ecological landscape	0.55	0.06
		Outdoor physical parameter	0.45	0.05
Ecologically friendly	0.17	Building carbon emission	0.54	0.09
		Green construction management technology	0.46	0.08

Analyzing the results of the weights of the primary indicators, ecologically friendly (17%) ranks third after safe and durable (29%) and health and comfort (20%) among all the primary indicators. This result shows that the ecologically friendly evaluation indicator is essential in the green building evaluation system. Stakeholders in the construction industry have an urgent demand for an ecologically friendly society and ecologically friendly green buildings.

By analysing the results of the weights of the secondary indicators, among all the secondary indicators, building carbon emission (9%) ranks second after safe (21%), and green construction management technology (8%) and durable (8%) are tied for the third place. Stakeholders in the construction industry are beginning to pay attention to building carbon emissions and green construction management technology on top of green building safety. The public's urgent demand for green buildings, while further confirming the rationality of the green building evaluation system constructed in this paper with integrated carbon emission assessment.

The results of weighting the improvement and innovation items are ecological protection and restoration (52%) and building power interaction (48%). This result will be used to calculate the plus points of the green building evaluation system integrating with carbon emission assessment.

3 FUZZY COMPREHENSIVE EVALUATION METHOD BASED ON IMPROVED AHP

3.1 Improved AHP Method

In this paper, the analysis is based on the traditional hierarchy process (AHP), and the three-scaled method is used instead of the nine-scaled method, making the judging, and scoring easier and improving the system consistency [14-17]. The main steps to improve AHP to determine the weights of indicators are as follows:

(1) Construct judgement matrix

Invite experts to use the three-scaled method (0-0.5-1, the closer to 1 the more important) to judge the indicators at the guideline layer and the programme layer of the green building evaluation system Integrating with carbon emission assessment, and then obtain the judgement matrices of the indicators at all layers $\boldsymbol{A}=\left\{a_{ij}\right\}_{n\times n}$.

(2) Calculate indicator weight

The judgement matrix is normalized and calculated to obtain the guideline layer weights $\boldsymbol{W}=(W_1,W_2,\cdots W_i\cdots W_m)$, the programme layer weights $\boldsymbol{W}_i\left\{\boldsymbol{W}_i=\left(W_{i1},W_{i2},\cdots,W_{ij},\cdots,W_{iN_i}\right)\right\}$, m is the number of primary indicators. N_i is the number of secondary indicators included under the i primary indicator.

(3) Consistency test

The consistency test of the judgement matrix is carried out through equations (2) and (3). In the case of consistency ratio CR =0, it is completely consistent; in the case of CR <0.1, it satisfies the consistency; in the case of CR >0.1, it does not meet the requirements.

$$CI=\frac{\lambda-n}{n-1} \tag{2}$$

$$CR=\frac{CI}{RI} \tag{3}$$

Where, CI , RI , CR are the consistency indicator, stochastic consistency indicator and consistency ratio, n and λ are the judgement matrix order and eigenvalue, respectively.

3.2 Fuzzy Comprehensive Evaluation

The fuzzy comprehensive evaluation method, a comprehensive evaluation method based on fuzzy mathematics, is employed in this study. It provides a comprehensive evaluation of the entire system by determining the weight scores of multiple evaluation indicators [18-20]. The primary steps of this method, which is crucial for our research, are as follows:

(1) Establishment of a comprehensive evaluation indicator set

The fuzzy comprehensive evaluation indicator set includes two layers of indicators, corresponding to the guideline layer and programme layer of the AHP method. The comprehensive evaluation indicator set is expressed as equation (4).

$$\boldsymbol{X}=\left(\boldsymbol{X}_1,\boldsymbol{X}_2,\cdots,\boldsymbol{X}_i,\cdots,\boldsymbol{X}_m\right) \tag{4}$$

Where, $\boldsymbol{X}_i(i=1,2,\cdots m)$ is the i primary indicator.

$$\boldsymbol{X}_i\left\{X_i=\left(X_{i1},X_{i2},\cdots,X_{ij},\cdots,X_{iN_i}\right)\right\} \tag{5}$$

Where, $X_{ij}(i=1,2,\cdots m)$ is the j secondary indicator under the i primary indicator.

(2) Establishment of a comprehensive evaluation level

Establishment of K level evaluation grades $\boldsymbol{V}=\left(V_1,V_2,\cdots,V_k,\cdots,V_K\right)$, V_k denotes different evaluation levels.

(3) Determination of the comprehensive evaluation matrix

The comprehensive evaluation matrix $\boldsymbol{P}=\left[\boldsymbol{P}_1,\boldsymbol{P}_2,\ldots,\boldsymbol{P}_i,\cdots,\boldsymbol{P}_m\right]^T=\left\{p_{ijk}\right\}$ based on the comprehensive evaluation level is expressed as equation (6).

$$p_{ijk}=\frac{V_{ijk}}{z} \tag{6}$$

Where, V_{ijk} is the number of people with a rating of V_k for evaluation X_{ij} and z is the total number of people evaluated.

(4) Determine the comprehensive evaluation indicator weight vector

In this work, the weight vector of the integrated evaluation indicators adopts the weight results $\boldsymbol{W}$, $\boldsymbol{W}_i$ of the improved AHP method.

(5) Determine the comprehensive evaluation vector

The comprehensive evaluation vector $\boldsymbol{B}_i$ is obtained by multiplying the programme layer comprehensive evaluation matrix $\boldsymbol{P}_i$ and the comprehensive evaluation indicator weight vector $\boldsymbol{W}_i$.

The comprehensive evaluation vector $\boldsymbol{B}$ is obtained by multiplying the guideline layer comprehensive evaluation matrix $\boldsymbol{P}_A=\left[\boldsymbol{B}_1,\boldsymbol{B}_2,\ldots,\boldsymbol{B}_i,\cdots,\boldsymbol{B}_m\right]^T$ and the comprehensive evaluation indicator weight vector $\boldsymbol{W}$.

(6) Determination of comprehensive evaluation results

The comprehensive evaluation results can be determined according to the principle of maximum affiliation. At the same time, the indicators are quantified through the formula (7) to obtain the comprehensive evaluation score.

$$S=\boldsymbol{B}\times\boldsymbol{G} \tag{7}$$

where $\boldsymbol{G}=\left(G_1,G_2,\cdots,G_k,\cdots,G_K\right)$ is the median of the corresponding values in evaluation level $\boldsymbol{V}$.

3.3 Fuzzy comprehensive evaluation based on improved AHP

In this article, based on the 5 primary indicators and 16 secondary indicators of the current version of ESGB in China, the carbon emission indicators are integrated into the guideline layer and program layer (add the ecologically friendly primary indicators based on five primary indicators of the 2019 version of the ESGB, and set the building carbon emission, green construction management technology secondary indicators under the indicator) to reconstruct the hierarchical analysis model of the AHP method in order to establish china green building evaluation indicator system integrating with carbon emission assessment.

The improved AHP method based on the three-scalar method is used to determine the weights of the indicators in the guideline layer and programme layer by constructing the judgement matrix, calculating the weight of the indicators, and consistency test, and obtaining the comprehensive evaluation vector. The comprehensive evaluation indicator set is established based on the evaluation indicator system with the fuzzy comprehensive evaluation method, the evaluation level is determined, the comprehensive evaluation matrix is constructed at the guideline layer and program layer, and the comprehensive evaluation score is obtained through the multiplication of the comprehensive evaluation vector and the matrix, thus realizing the comprehensive carbon emission evaluation of green buildings in China.

4 CASE STUDY

The building, spanning an impressive area of 54,268m^2, with a floor area of 84,254m^2 and 17 buildings, boasts a commendable greening rate of 41.1 percent. Its construction process was guided by a commitment to sustainability, with the selection of low-carbon materials, the adoption of energy-efficient equipment, and thoughtful planning of building sites and landscaping to minimize damage to the natural ecosystem.

Two experts from each of the five stakeholders in the construction industry have been carefully selected to evaluate the building. Based on the green building evaluation system with integrated carbon emission assessment, their insights will be invaluable. They will assess the building across four grades: excellent, good, qualified, and unqualified, considering the indicator baseline, the indicator system, and the weighting system. Their opinions and suggestions will be crucial in identifying areas for improvement and innovation.

The weights of the green building evaluation system are obtained from the results of the weights of the green building evaluation system with integrated carbon emission assessment, and the weights of the guideline layer (primary indicators) are obtained:

$$\boldsymbol{W} = [0.29, 0.20, 0.11, 0.13, 0.10, 0.17]$$

Programme layer (secondary indicators) weights:

$$\boldsymbol{W}_1 = [0.73, 0.27]$$

$$W_2 = [0.36, 0.31, 0.15, 0.18]$$

$$W_3 = [0.40, 0.26, 0.15, 0.19]$$

$$W_4 = [0.13, 0.44, 0.27, 0.16]$$

$$W_5 = [0.55, 0.45]$$

$$W_6 = [0.54, 0.46]$$

According to the evaluation results of the 10 experts and based on the ratings corresponding to each evaluation level:

$$\begin{aligned} V &= \{\text{Fail, Pass, Good, Excellent}\} \\ &= \{(0 \sim 3], (3 \sim 5], (5 \sim 7], (7 \sim 9]\} \end{aligned}$$

Calculation of equation (6) is collated to obtain a comprehensive evaluation matrix:

$$P_1 = \begin{bmatrix} 0 & 0.1 & 0.1 & 0.8 \\ 0.1 & 0.2 & 0.3 & 0.4 \end{bmatrix}$$

$$P_2 = \begin{bmatrix} 0.1 & 0.1 & 0.3 & 0.5 \\ 0.1 & 0.1 & 0.3 & 0.5 \\ 0.3 & 0.2 & 0.1 & 0.4 \\ 0.4 & 0.2 & 0.2 & 0.2 \end{bmatrix}$$

$$P_3 = \begin{bmatrix} 0.1 & 0.1 & 0.3 & 0.5 \\ 0.2 & 0.1 & 0.3 & 0.4 \\ 0.2 & 0.2 & 0.3 & 0.3 \\ 0.5 & 0.3 & 0.1 & 0.1 \end{bmatrix}$$

$$P_4 = \begin{bmatrix} 0.1 & 0.1 & 0.3 & 0.5 \\ 0 & 0.1 & 0.2 & 0.7 \\ 0 & 0 & 0.5 & 0.5 \\ 0.1 & 0.1 & 0.3 & 0.5 \end{bmatrix}$$

$$P_5 = \begin{bmatrix} 0.3 & 0.3 & 0.2 & 0.3 \\ 0.4 & 0.2 & 0.2 & 0.2 \end{bmatrix}$$

$$P_6 = \begin{bmatrix} 0.1 & 0.2 & 0.3 & 0.4 \\ 0.3 & 0.3 & 0.2 & 0.3 \end{bmatrix}$$

Based on the weighting results, the results of multiplying each comprehensive evaluation matrix $\boldsymbol{P}_i$ and the programme layer comprehensive evaluation indicator weight vector $\boldsymbol{W}_i$ are calculated to obtain the programme layer comprehensive evaluation vector $\boldsymbol{B}_i$.

$$\boldsymbol{B}_1 = \begin{bmatrix} 0.027 & 0.127 & 0.154 & 0.692 \end{bmatrix}$$

$$\boldsymbol{B}_2 = \begin{bmatrix} 0.184 & 0.133 & 0.252 & 0.431 \end{bmatrix}$$

$$\boldsymbol{B}_3 = \begin{bmatrix} 0.217 & 0.153 & 0.262 & 0.368 \end{bmatrix}$$

$$\boldsymbol{B}_4 = \begin{bmatrix} 0.029 & 0.073 & 0.310 & 0.588 \end{bmatrix}$$

$$\boldsymbol{B}_5 = \begin{bmatrix} 0.345 & 0.255 & 0.200 & 0.255 \end{bmatrix}$$

$$\boldsymbol{B}_6 = \begin{bmatrix} 0.192 & 0.246 & 0.254 & 0.354 \end{bmatrix}$$

Calculate the result of multiplying the guideline level comprehensive evaluation matrix $\boldsymbol{P}_A$ and the target layer comprehensive evaluation indicator weight vector $\boldsymbol{W}$ to get the comprehensive evaluation vector $\boldsymbol{B}$ of the target layer.

$$\boldsymbol{B} = \begin{bmatrix} 0.139 & 0.157 & 0.191 & 0.489 \end{bmatrix}$$

According to the principle of maximum affiliation, using equation (7), the China green building evaluation score for the building's comprehensive carbon emission assessment is determined to be 5.859, and by the same token, the addition of the improvement and innovation item is calculated to be 0.561. The building's comprehensive carbon emission assessment is good without considering the improvement and innovation items. Considering the improvement and innovation item, the comprehensive evaluation score of the building is calculated, corresponding to the excellent evaluation result. Combining the two evaluation results, the green building evaluation result of this building is good.

5 CONCLUSION

This article incorporates building carbon emission evaluation indicators into the green building evaluation system as a critical factor affecting climate change. It proposes a perfect green building evaluation system for green buildings, which makes the green building evaluation more comprehensive and accurate. A set of green building evaluation indicator systems for carbon emission is formulated, consisting of 6 first-level indicators, 18 second-level indicators, and two improvement and innovation items. The improved AHP fuzzy comprehensive evaluation method is used to construct a set of green building evaluation systems, including indicator systems, indicator benchmarks, and weighting systems for comprehensive carbon emission assessments. The proposal of this system fills the gap in the current version of ESGB in China in terms of building carbon emission, which helps to promote the development of the green building industry in a more sustainable direction and offer guidance for urban ecology and green building design and planning. In addition, it will also promote the planning and design of urban architecture and infrastructure to conform to the principles of environmental friendliness, resource conservation, and ecological balance to reduce the impact on the natural environment and improve residents' quality of life. The case study shows that the green building evaluation system with integrated carbon emission assessment can give a comprehensive and reasonable green building score by considering the building's carbon emissions and that it has good applicability and feasibility.

The newly released Green Building Evaluation Standard (partial revision draft for comments) enriches the indicators of improvement and innovation items and adds a series of indicators, such as energy consumption of building heating and air-conditioning systems, which indicates to a certain extent that the green building evaluation system should be constantly innovated and improved based on the development of green building. This paper will follow up on the new improvement and innovation items in the draft, as well as the rooftop photovoltaic, photovoltaic storage, renewable energy, and building integration that have entered the demonstration stage mentioned in the experts' comments and suggestions, and incorporate them into the improvement and innovation items, to further enrich the green building evaluation system, and to provide references for the optimization and improvement of the evaluation system of green building in China.

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