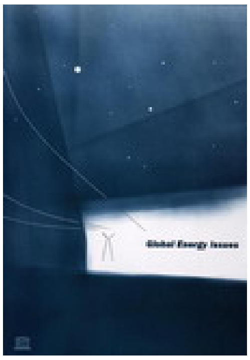

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Short-term carbon emission prediction method of green building based on IPAT model

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Abstract: In order to solve the problems of high complexity and low prediction accuracy of green building carbon emission prediction process, this paper proposes a green building short-term carbon emission prediction method based on IPAT model. The IPCC method is used to determine the influencing factors of carbon emission of green buildings, and the classification of influencing factors is completed according to the importance of influencing factors. The IPAT model is established to decompose the carbon emission into the products of different factors, and the model is used to predict the short-term carbon emission of green building construction stage and the whole stage. The experimental results show that the prediction time of this method is always less than 4 s and the prediction accuracy is always higher than 95%, which proves that this method has fast prediction process and high accuracy, and realises the design expectation.

Keywords: IPAT model; green building; short-term carbon emissions; emission factor; mutual information; impact factors.

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1 Introduction

With the continuous development of industrial economy, people's living standard and quality have been significantly improved. Comfortable living environment has become the pursuit of people. With the main advantages of energy conservation and environmental protection, green building has become an important place for people to choose to live (Li et al., 2020). Energy crisis and global warming are two major problems that threaten the existence of today's society. The growing lack of energy and environmental pollution have become the key problems to solve at present (Zhai et al., 2020). The continuous accumulation of greenhouse gases is the main cause of the current rising temperature of the Earth's regions. Global climate change is inevitable in the short term, and the scale and degree of change are deepening. In the field of construction, the amount of carbon emissions in green buildings is also an important factor affecting the ecological environment (Yogi et al., 2019). Green building is in the stage of large-scale development, and the total energy consumption is large, the efficiency of energy utilisation is low, and the carbon emission is low, has become an important development goal in the field of building. Therefore, the short-term emission prediction of green buildings has become a key research issue at present (Wu et al., 2020). For this reason, the related researchers have done a lot of research on it, and achieved some results.

In Lan et al. (2019), a carbon emission prediction method based on prediction time domain is proposed. The method firstly analyses the cycle of carbon emission and its short-term emission law, and determines the short-term carbon emission with the help of the periodic decision-making method of the periodic emission law. By calculating the optimal prediction time domain of carbon emissions in different periods, the prediction of the material emissions is completed. This method effectively analyses the law of carbon emissions, but the medium of carbon is seldom considered, and the prediction accuracy is low, which needs further improvement and optimisation. In Zhao et al. (2019), a prediction method of carbon emission peak based on lmdi-sd method is proposed. By analysing the influencing factors of carbon emissions, this method constructs the factor decomposition model of carbon emissions. With the help of the decomposed factors, the idea and contribution rate of carbon emissions are calculated. According to the contribution rate, the ranking results are applied to the research object, the peak value of carbon emissions at different times is calculated, and the periodic carbon emissions prediction is completed. The effect of this method is remarkable, but the operation process of prediction is complex, and the prediction time is long. Wu and Xu (2019) propose to design a carbon emission prediction model based on production function theory. The model mainly aims at the prediction of carbon dioxide. Based on the analysis of the basic operation principle of the production function, the ideal emission and the general model are integrated. According to the current situation and the general model, the emission intensity is determined, a new prediction model is constructed, and the error in the cause model is corrected. The driving factor of carbon emission is studied, and the construction of the prediction model is completed. The model can effectively analyse the driving factors and correct the original prediction model, but there are still many shortcomings.

It can be seen that the above methods do not analyse the influencing factors of carbon emission and emission coefficient during construction. In order to solve the problems of poor prediction accuracy and complex prediction process, this paper proposes a short-term green building carbon emission prediction method based on IPAT model. By determining the carbon emission factors and emission coefficient in construction, the importance of influencing factors is divided, and the contribution value of carbon emission results is calculated by studying the most important influencing factors. Take the contribution value as the average value of global mutual information, calculate the short-term carbon impact factor, and determine the different stages of green building. The structure of IPAT model is designed, and the model is used to predict the short-term carbon emission in the construction and completion stages of green buildings. It reflects the novelty of the design method. The specific technical route studied in this paper is as follows:

1 Combined with the relevant building materials and energy consumption data, the relevant carbon emission factors were represented in the multiple linear regression model, and then the IPCC method was used to determine the impact factors of green building short-term carbon emission, and the data set of the impact factors was established.

2 In order to reduce the complexity of green building carbon emission prediction process, improve the accuracy of prediction, and divide the importance of impact factors, the contribution value of green building carbon emission prediction results is calculated according to the classification results, and the calculated average value is taken as the global mutual information, so as to complete the classification of impact factors.

3 Establish IPAT model structure. IPAT model decomposes carbon emissions into the product of different factors, simplifies the linear relationship between consumption and emissions, and can effectively improve the prediction speed of building carbon emissions. The model can be used to predict the short-term carbon emission of green building during construction and completion.

2 Research on short-term carbon emission prediction methods of green buildings

In view of the energy consumption of cement, steel, glass, wood, aluminium and other materials and equipment in green buildings, this study firstly uses IPCC method to determine the carbon emission coefficient of green buildings and determine the influencing factors of green buildings' short-term carbon emission. In order to reduce the complexity of the green building carbon emission prediction process and improve the prediction accuracy, the importance of impact factors was divided and the classification of impact factors was completed. Based on this, the IPAT model structure is constructed, and the carbon emissions are decomposed into the product of different factors. The model is used to predict the short-term carbon emissions in the construction and complete stages of green buildings.

2.1 Determine the short-term carbon emission impact factors of green buildings

In a broad sense, carbon emission refers to the general term of unified emissions of various greenhouse gases, not only including carbon dioxide emissions. The gas emission system mainly includes: carbon dioxide, methane, nitrous oxide and sulphur hexafluoride and other gases (Wang and Chao, 2021). So it's not just carbon dioxide that matters. Among them, carbon dioxide is the most discharged gas in the system, so this gas is used as the standard to measure carbon emissions.

In the prediction of green building short-term carbon emission, this paper defines the carbon dioxide emission in green building to realise the prediction of green building short-term carbon emission. There are many factors affecting carbon emissions such as carbon dioxide emitted by green buildings. Therefore, the influencing factors of short and medium term carbon emissions of green buildings are determined. Carbon emission factor is a kind of nonlinear data, and its convergence is difficult to be stable in the process of determination. Therefore, in this paper, carbon emission factors in buildings are firstly expressed by means of multiple linear regression model (Han et al., 2019), namely:

$$a(t) = a_1 + a_2 x_2(t) + a_3 x_3(t) + \dots a_n x_n(t) + b(t) + \gamma \tag{1}$$

In the formula, $a(t)$ represents the carbon emission factor determined at the early stage, $a_2x_2(t)$ represents the interference factors affecting its emission, $b(t)$ represents the multiple linear regression coefficient, and γ represents the random variable constant.

Among the green building carbon emission factors extracted from the multiple linear regression model, the carbon emission factors initially determined in this paper are unstable due to their nonlinear characteristics (Zhou et al., 2020). Therefore, on this basis, the carbon emission factors in green buildings are further determined more accurately with the help of IPCC carbon emission calculation method, and the constructed carbon emission impact factors are extracted by Formula (2) as follows:

$$V = V_{dir} + V_{ind} = \frac{1}{2} \sum c_i \times {}^{\circ}F + \sum m_j \times \delta \tag{2}$$

In the formula, V represents the direct carbon emissions in green buildings, V_{dir} represents the indirect carbon emissions in green buildings, V_{ind} represents the number of energy consumption, c_i represents the proportion coefficient of carbon emission factor, ${}^{\circ}F$ represents the carbon content in building materials, and m_j represents the carbon emission coefficient.

According to the above determined carbon emission factors in green buildings, the emission coefficients of the major components of carbon emission in green materials are determined, and the specific contents are shown in Table 1.

Table 1 Carbon emission coefficient of related materials in green building carbon

Project	*Cement*	*Steel*	*Glass*	*Wood*	*Aluminium*
Discharge coefficient	0.88 kg/kg	1.75 kg/kg	0.95 kg/kg	–842.1 kg/m^3	2.5 kg/kg

The carbon emission coefficient in green buildings is represented by the actual material emission coefficient and the corresponding operation mode, which can be calculated according to the different properties of each material in the building, namely:

$$\mathrm{V} = \sum a(t) \times QK \tag{3}$$

Where, Q and K represent the emission coefficient and operation data of green building materials respectively.

In the process of determining the influencing factors of green buildings' short-term carbon emissions, the carbon emission factors in buildings are represented by multiple linear regression model (Holmes et al., 2019). Then with the help of IPCC calculation method to determine the relevant emission coefficient of green building materials, complete the determination of the impact factors of green building short - and medium-term carbon emissions.

2.2 Classification of short-term carbon emission impact factors of green buildings

Since there are many short-term carbon emission influencing factors of green buildings identified above, in order to reduce the complexity of calculation of green building carbon emission prediction and improve the prediction accuracy of short-term emissions, the impact factors are classified in this stage. The impact factors are divided into different categories to calculate the contribution of different factors to the forecast of carbon emissions (Sinha and Chaturvedi, 2019).

Assume that the data set of short-term carbon emission impact factors of green buildings is expressed as:

$$I = (X, Y) = \log \frac{P(X, Y)}{P(X)} \tag{4}$$

In the formula, $P(X, Y)$ represents the composition data of green building short-term carbon emission impact factors.

The information data in the short-term carbon emission impact factors of green buildings are divided into one kind of importance degree and expressed through mutual information, that is:

$$I = (X, Y) = \log \frac{P(X, Y)}{P(X)} = \vartheta \frac{P(X, Y)}{P(X) P(Y)} sd \tag{5}$$

In the formula, ϑ represents the importance of the characteristic factor of the impact factor, s represents the probability of the predicted occurrence in carbon emissions, and d represents the category of the current impact factor of carbon emissions.

When $I = (X, Y) = 0$, it means that the importance degree in the impact factors is general; $I = (X, Y) > 0$ means that the importance degree in the impact factors is high. According to the impact degree of information data in the short-term carbon emission impact factors of green buildings, the average value of various impact factors is further taken as the global mutual information through mutual information to complete the classification study of impact factors, namely:

$$EI(X, Y) = \sum P(X) EI = (X, Y) \tag{6}$$

Green building short-term carbon impact factor classification, set up green building short-term carbon impact factor of data collection, with its impact factors in the calculation of carbon emissions to the importance of the division, said by mutual information, and will be calculated as the average of global mutual information, complete the green building short-term carbon emissions influence factor to the classification of different stages.

3 Construction of IPAT model for short-term carbon emission of green buildings

According to the classification results of the above-mentioned short-term green building carbon emission impact factors at different stages, in order to realise the prediction of short-term green building carbon emission, this paper constructs the IPAT model to realise the prediction research (Nabernegg et al., 2019).

3.1 Expression of IPAT model

In the IPAT model, we represent environmental impact, P represents population, A represents affluence, and T represents technology. The model has a certain systematicness in the prediction, which can realise the research purpose through the prediction of the research object in different stages. In this model, we include data related to environmental pollution sources such as resources and pollutants (Gu et al., 2020). Applying it to the prediction of green building short-term carbon emissions, the prediction process is simple and the result is good. The calculation expression of IPAT model is as follows:

$$C = L \times Z_A \sum_{i=1}^{n} r f_P t_i \tag{7}$$

In the formula, C represents the granularity of green building short-term carbon emissions, L represents the total amount of emissions, Z_A represents the total amount of GDP, r represents the amount of energy needed, f_P represents the population, and t_i represents the per capita GDP.

The model is applied to the short-term carbon emission prediction of green buildings, and it is predicted according to the carbon emission of green buildings in different stages. The total predicted model can be expressed as:

$$C = \frac{Z}{(GPD / Z)} \tag{8}$$

3.2 Calculation of carbon emissions from green buildings in different historical stages

On the basis of the above determination of the IPAT model, in order to achieve the prediction of the short-term carbon emissions of green buildings, it is necessary to calculate the carbon emissions of green buildings in different historical stages to achieve the prediction of the short-term carbon emissions of green buildings.

1 *Calculate the carbon emission during the construction phase of green building*

In the green building construction stage, carbon emission is an important index that affects the short-term carbon emission prediction. Therefore, firstly, the carbon emissions of green building construction stage are calculated. Wherein, the energy consumption of material components in the construction stage of green building can be expressed as (An et al., 2021):

$$U_y = \sum_{y=1}^{n} \frac{G}{ZG} \times W \times O \tag{9}$$

In the formula, U_y represents the total energy consumption of green building material components, G represents the usage amount of components, W represents the average mass of materials, and O represents the carbon emissions of materials.

The carbon emissions generated in the application of vehicles and construction equipment in the construction stage of green building can also be added to the actual calculation of green building carbon emission, and the following can be obtained:

$$SS_i = \sum_{i=1}^{m} D_i \times T_i \times M_i \tag{10}$$

In the formula, SS_i represents the total oil consumption in the construction stage, D_i represents the average oil consumption of equipment, T_i represents the number of tools, and M_i represents the actual emissions.

2 *Calculate the carbon emission in the complete stage of green building*

After the construction of green buildings is complete, a variety of energy consumption is also the key to carbon emissions. After the construction of green buildings, electricity consumption in the complete process is the main source of carbon emissions. Therefore, the calculation formula of power consumption in this stage is as follows:

$$g_y = l \times \sum_{y=1}^{n} v_i \times k_i \times u_i \tag{11}$$

In the formula, g_y represents the total power consumption of the green building at this stage, l represents the total power consumption, and v_i represents the operating time.

In this stage of green building, the consumption of fuel and gas required by the equipment in green building is also the main source of carbon emissions. Therefore, it can be calculated as follows:

$$H_i = l \times \sum_{i=1}^{m} \left(k_i \times u_i \times e_i\right) \sigma \tag{12}$$

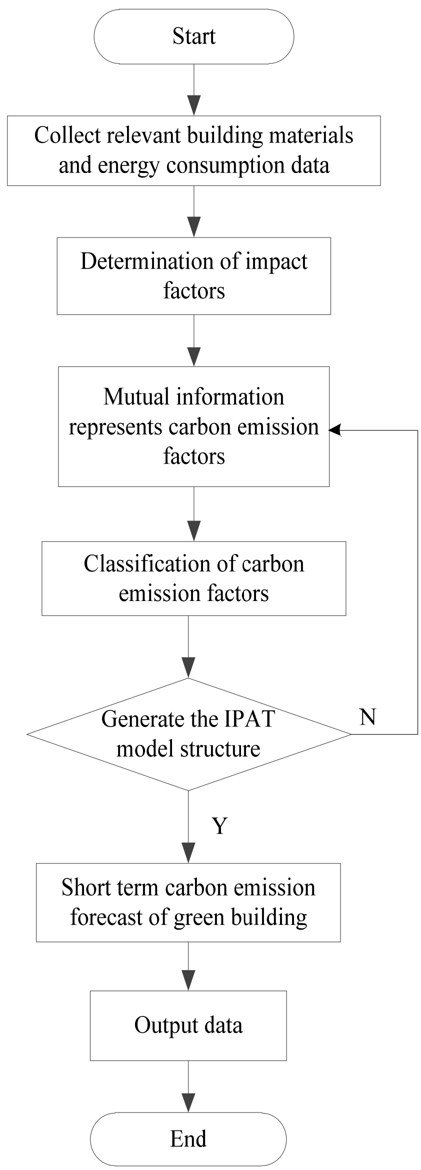
In the formula, H_i represents the gas consumption, l represents the average gas consumption, k_i represents the running time of equipment, u_i represents the gas consumption equipment in construction equipment, e_i represents the running time of construction equipment, σ represents the serial number of equipment.

3.3 Short term carbon emission prediction of green building based on IPAT model

Through the construction of IPAT model, this model is used to predict the short-term carbon emissions of green buildings in the construction stage and complete stage, and the short-term carbon emissions prediction of green buildings based on IPAT model is completed.

To sum up, in view of the material use and energy consumption of green buildings, this study determined the influencing factors of green building short-term carbon emissions after determining the carbon emission coefficient of green building materials by using IPCC method. In order to reduce the complexity of the green building carbon emission prediction process and improve the prediction accuracy, the importance of impact factors was divided and the classification of impact factors was completed. Then, the IPAT model structure is established to decompose carbon emissions into the product of different factors, and the model is used to predict the short-term carbon emissions in the green building construction stage and complete stage. The specific prediction process is shown in Figure 1.

Figure 1 Short-term carbon emission prediction process of green buildings based on IPAT model



4 Experimental analysis

4.1 Experimental scheme

In order to verify the feasibility of the proposed prediction method and improve the prediction accuracy, a simulation experiment was conducted. In the experiment, a new green building in a certain place is taken as the research object. The building has 6 floors, each floor is 3.5 m high, and each household has an area of about 100 square meters. There are 16 households in total, and the occupancy rate has reached more than 95%. This green building is taken as the research object, and its carbon emission is predicted. Since the building was completed by construction, the experiment in this paper only predicted the short-term carbon emissions in the complete stage. Relevant experimental parameters are shown in Table 2.

Table 2 Test parameters

Parameter	*Value*
Carbon emission coefficient	[0,1]
Electrical power/w	1500
Sampling period/month	3
Sampling interval/day	7

According to the design of the above experimental scheme, Method of this paper, the prediction Method of carbon emission peak based on LMDI-SD Method (method of Zhao et al., 2019) and the prediction Method of carbon emission based on production function theory (method of Wu and Xu, 2019) Forecast the short-term carbon emissions of the sample buildings. In order to ensure the accuracy of the experiment, several experimental analyses were conducted in the experiment, and SPSS13.0 was used for statistical analysis of each obtained result.

4.2 Design of experimental indicators

1 Prediction accuracy. This metric is a functional indicator that directly reflects the effectiveness of different approaches. The higher the prediction accuracy is, the stronger the reliability of the prediction results is, and the more effective the prediction method is.

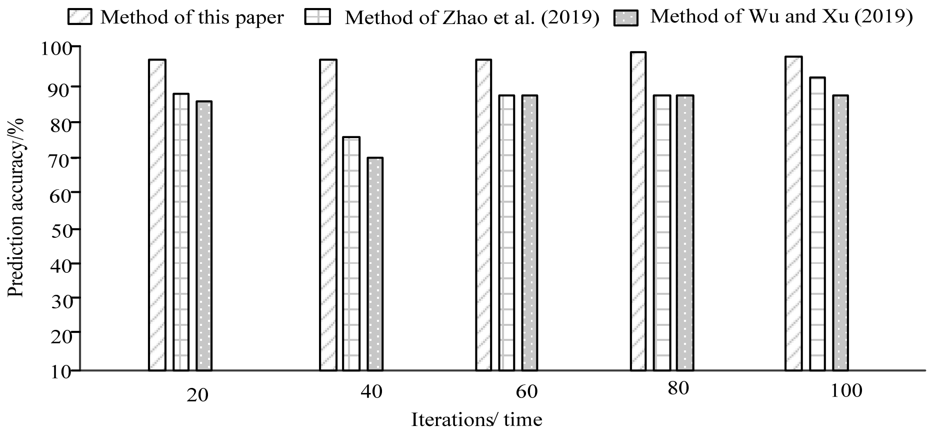
2 Forecast the computation speed. This index can intuitively reflect the timeliness of different forecasting methods. In this study, the prediction speed of different methods was represented by the time of the prediction process. The less time it takes for the prediction process, the faster the prediction calculation speed is.

4.3 Analysis of experimental results

4.3.1 Accuracy analysis of carbon emission prediction by different methods

In the experiment, the accuracy of prediction of short-term carbon emissions by Method of this paper, method of Zhao et al. (2019) and method of Wu and Xu (2019) was analysed, and 100 iterations were carried out, and the results were in line with the experimental standards. The results are shown in Figure 2.

Figure 2 Accuracy comparison of different methods for predicting carbon emissions



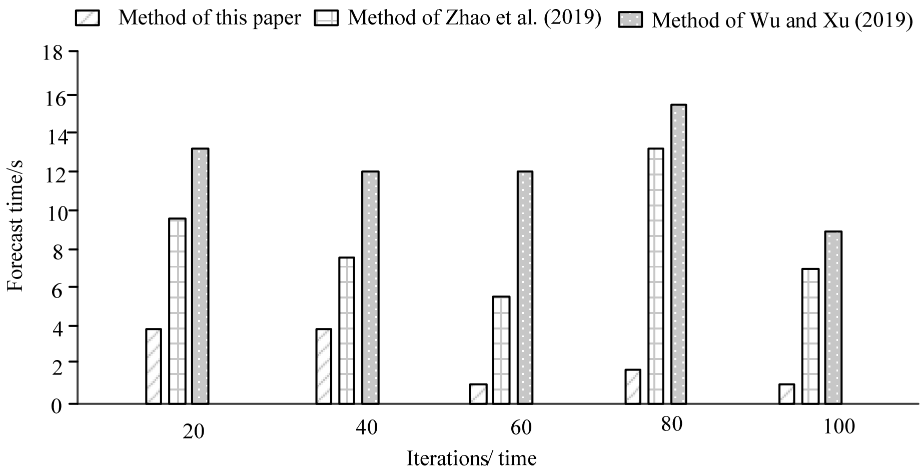
By analysing the data in Figure 2, it can be seen that the accuracy of short-term carbon emission prediction by Method of this paper, method of Zhao et al. (2019) and method of Wu and Xu (2019) is different to some extent. Among them, the prediction accuracy of reference method 6 fluctuates between 76% ~ 92%, and the prediction accuracy of reference method fluctuates between 70% ~ 88%; The prediction accuracy of this method is always higher than that of the other two methods, and its prediction accuracy is always maintained at more than 95%, and the highest value is about 98%. Although the accuracy of the other two methods is within a reasonable range, the method in this paper is higher and better in practical application.

This is because in this paper, carbon emission factors in buildings are expressed through multiple linear regression model, and relevant emission coefficients in green building materials are determined with the help of IPCC calculation method, so as to complete the determination of impact factors of green building carbon emission in the short and medium term. In addition, the data set of green building's short-term carbon emission impact factors is set, and the prediction of short-term load in different stages is completed according to the importance degree of the impact factors in the calculation of carbon emission, thus improving the accuracy of the prediction.

4.3.2 Different methods of prediction calculation speed analysis

On the basis of ensuring the accuracy of the experiment, the prediction calculation speed of Method of this paper, method of Zhao et al. (2019) and method of Wu and Xu (2019) is analysed in the experiment, which is reflected by the time spent in the prediction process. The results are shown in Figure 3.

Figure 3 Different methods of prediction calculation speed analysis



By analysing the data in Figure 3, it can be seen that the predicted calculation speeds of Method of this paper, method of Zhao et al. (2019) and method of Wu and Xu (2019) are different to some extent. Among them, the prediction calculation speed of reference method 6 is at least 5.5 s and at most more than 13 s; The lowest prediction speed of reference method 7 is 8.8 s, and the highest is more than 15 s; The prediction speed of this method is always lower than that of the other two methods, which is always less than 4 s, and the fastest prediction can be completed in 1 s. Although the other two existing methods can also complete the prediction calculation, the time is too long due to the complexity of the algorithm. It can be seen that this method is the fastest and feasible in practical application.

This is because the method in this paper designs the structure of the IPAT model after determining the factors of short-term emissions, and uses the model to predict the short-term carbon emissions of green buildings in the construction stage and the complete stage, so as to complete the prediction of the short-term carbon emissions of green buildings based on the IPAT model, and realise the rapid prediction through the prediction model.

In conclusion, the prediction accuracy of the method in this paper for the short-term carbon emissions of green buildings is always higher than 90%, and it takes less time to predict the short-term carbon emissions of green buildings and has the advantage of fast speed.

5 Conclusion

1 In order to reduce the complexity of the green building carbon emission prediction process and improve the prediction accuracy, this paper divided the importance of impact factors and completed the classification of impact factors. Then the IPAT model structure is established to decompose the carbon emissions into the product of

different factors, and the model is used to predict the short-term carbon emissions in the construction stage and the complete stage of green building.

2 The experiment results show that the prediction accuracy of green building short-term carbon emissions by this method is always higher than 90%, which has a certain credibility. Using this method to forecast the short-term carbon emissions of green buildings is shorter. Therefore, the novelty of this method lies in its ability to improve the prediction accuracy and shorten the prediction time of short-term green building carbon emissions.

3 Although the method designed in this paper can be applied to the prediction of green building carbon emissions to some extent at the present stage, there are still many deficiencies. Future research will divide the short-term carbon emissions of green buildings into different stages in detail, so as to obtain more accurate data.

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