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Research on Green Building under the "Double-Carbon"Goal --Take Anhui Province as an Example

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Abstract

The realization of the realization of green buildings is to provide favorable guarantee for the realization of the "double carbon" goal, and then promote the sustainable economic development of my country's economy. This article uses the main component analysis. From the perspective of the full life cycle, the factors of the carbon emissions of the residential building in Anhui Province are studied; based on the data of the 2023 statistical yearbook of Anhui Province, using the fuzzy comprehensive evaluation model to study the status of residential buildings in Anhui Province. Policy recommendations for emission reduction are designed to help Anhui Province achieve the "double carbon" goal as soon as possible.

Keywords

"Double Carbon" target; green building; main component analysis; blur comprehensive evaluation.

1. Introduction

In the symposium on the New Era of Promoting the rise of the central region, General Secretary Xi Jinping emphasized the importance of scientific and technological innovation as the pioneer of industrial innovation, actively breeding new quality productive forces, and promoting new industrialization and the upgrading of traditional industries. As one of the main traditional industries, the construction industry requires its industrial transformation and green innovation. The construction activities of the construction industry have huge energy consumption and have a significant impact on the environment. However, the goal of "double carbon" and the popularization of environmental protection concept are guiding the industry to transform to sustainable development. The low-carbon development of the construction industry should comprehensively consider energy-saving measures in the construction process, reduce energy consumption, promote green development, control costs and improve economic efficiency. As a key development force in the central region, Anhui province has fully deployed the green building reform. According to the Regulations on the Development of Green Buildings in Anhui Province, new civil buildings must meet the basic green building standards by 2025, indicating that new urban buildings will fully enter the green era and enter the stage of high-quality and large-scale development.

In the academic discussion on the green and low-carbon transformation of the construction industry, Yangdong and others analyzed the carbon emission sources in various stages of the construction industry and proposed improvement plans[1]. Fan Zhi for the four major changes in the industry, in order to achieve the "double carbon" goal, suggested five strategic changes[2]. Wang Jiangbo developed a management strategy for the low-carbon process of the construction industry in Anhui province by establishing the system dynamic model and scenario analysis[3].

Zhang Kai studied the relationship between "double-carbon" goals and green building, and after analyzing the practical challenges of green building development, they put forward policy suggestions to promote their high-quality development[4]. From the perspective of the whole life cycle, Pu Yunhui and other scholars have provided a way for the low-carbon, builders and high-quality development of the construction industry[5]. Chen provided suggestions for China's construction industry from different processes and key factors[6]. Previous studies have mostly focused on carbon emission factors in the construction industry. Combined with digital technology, there are few studies on micro energy saving and carbon reduction in the whole life cycle stage of the project. Therefore, from the perspective of the whole life cycle of buildings, this paper will use the principal component analysis model to find the main factors affecting the development of green building in Anhui Province, and show the current development status of green building in Anhui Province by the method of fuzzy comprehensive evaluation.

2. Identification of Green Building

2.1. Data retrieval and index sorting

Through CNKI database and EPMAP for residential building carbon emissions calculation of related literature retrieval, reference to China carbon accounting database, the National Bureau of Statistics in 2012-2023, under the perspective of the whole life cycle, from the construction, operation and demolition of three aspects of the 18 quantifiable related factors, as shown in table 1.

Table 1. Summary table of possible related indicators of residential buildings

Class	Variable name	Influencing factor
Construction link	x_1	Transportation distance of building materials (km)
	x_2	Energy consumption of building materials production (kJ)
	x_3	Fossil energy usage (ten million tons)
	x_4	Service life of main materials (years)
	x_5	Carbon emission of building materials (ten thousand tons)
Running link	x_6	Building Orientation (Degree)
	x_7	Exterior wall heat transfer coefficient (W / m^2·K)
	x_8	Heat transfer coefficient of the outer window (W / m^2·K)
	x_9	Outer window shading coefficient (W / m^2·K)
	x_{10}	Roof heat transfer coefficient (W / m^2·K)
	x_{11}	Building window wall more than (%)
	x_{12}	The average annual temperature is (℃)
	x_{13}	Population density (person / m^2)
	x_{14}	Annual income of the residents (ten thousand yuan)
Demolition link	x_{15}	Building demolition energy consumption (kJ)
	x_{16}	Reuse rate of dismantled materials(%)
	x_{17}	Number of building floors (floors)
	x_{18}	Transport distance from the disposal site (km)

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2.2. Model operation and analysis

The annual carbon emission of residential buildings was set as, indicating 18 related influencing factors respectively, and the year was solved by principal component analysis method. Direct independent and dependent variables and the results are shown in Tables 2 and 3.

Table 2. Analysis of variance table

Source of variance	Free degree	Quadratic sum	Mean square	F price	Pr>F
model	5	211088	47128	5.68	0.0027
residual	11	80774	6873.31572		
sum	17	312691			

Table 3. The goodness of fit test

Root-mean-square error	79.07230	R^2	0.7302
Mean of dependent variables	1036.73254	adjust R^2	0.6327

The measure of fit to the model, F=5.68, Pr> F=0.0027, less than 0.05, adjusted R^2Was 0.6327, indicating that the overall fit of the model is considerable.

The mean and variance of 18 independent variables were calculated by Excel 2019. The resulting normalized variables are recorded, set the mean and the variance are, and the eigenvector of the correlation coefficient matrix was calculated. The calculation formula is shown in Equation 1.

$$x_i^* = \frac{x_i - E_i}{\delta_i} \tag{1}$$

Through the eigenvalue, contribution rate and cumulative contribution rate of the correlation coefficient matrix, it can be found that the cumulative contribution rate of the first two principal components has accounted for 97.68% of the combined contribution rate of the five principal components, so the first two principal components are selected to replace the original five independent variables.

Table 4. Eigenvalues and contribution rate of the correlation coefficient matrix

order number	eigenvalue	difference	Contribution rate	Cumulative contribution rate
1	4.09325	3.2345	0.8191	0.8191
2	0.73270	0.7317	0.1577	0.9768
3	0.08265	0.6720	0.0163	0.9931
4	0.02137	0.0113	0.0047	0.9978
5	0.01026	0.1547	0.0022	1.0000

Therefore, the normalized dependent variable on the principal component was obtained. The regression equation of is:

$$y^* = 0.2534\,Z_1 - 0.4219\,Z_2 \tag{2}$$

Substitutin Z_1, Z_2 back to obtain the standardized dependent variable y^*, and finally restoring it to the original variable, the regression equation between the dependent variable y and the original independent variable x can be obtained, as well as the linear relationship between the annual carbon emissions of residential buildings and 18 related indicators

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$$\begin{aligned} y &= 0.1324\,x_1 + 0.3475\,x_2 - 0.2174\,x_3 + 0.0001x_4 + 0.2384\,x_5 \\ &+ 0.0748\,x_6 + 0.2453\,x_7 + 0.0013\,x_8 + 0.0002x_9 - 0.0001x_{10} \\ &+ 0.0004x_{11} - 0.2394\,x_{12} + 0.3742\,x_{13} + 0.0998\,x_{14} - 0.2947\,x_{15} \\ &+ 0.0234\,x_{16} + 0.1293\,x_{17} - 0.0743\,x_{18} \end{aligned} \tag{3}$$

According to equation 3, it can be found that $x_4, x_8, x_9, x_{10}, x_{17}$, which includes the service life of the main materials, the heat transfer coefficient of the external windows, the shading coefficient of the external windows, the heat transfer coefficient of the roof, and the number of floors, has a relatively small impact coefficient (<0.0005) on the carbon emissions of residential buildings, and the correlation is weak. Therefore, it is excluded and the remaining 13 influencing factors are retained as comprehensive evaluation indicators for carbon emissions of residential buildings.

3. Green Building Grade Evaluation in Anhui Province

3.1. Grade division and weight determination of evaluation indicators

3.1.1. Classification of evaluation indicators

The primary index layer and the second index layer were established for the 13 influencing factors above. As shown in Table 5.

Table 5. Carbon emission evaluation system for the whole life cycle of residential buildings

Target layer	Level 1 index layer B	Secondary index number	Secondary index layer
Comprehensive evaluation index system of carbon emission for the whole life cycle of residential buildings	Construction link B1	C11	Transportation distance of building materials (km)
		C12	Fossil energy usage (ten million tons)
		C13	Energy consumption of building materials production (kJ)
		C14	Carbon emissions of building materials (t)
	Operation link B2	C21	Building Orientation (Degree)
		C22	Annual income of the residents (ten thousand yuan)
		C23	Heat transfer coefficient of external wall ($W / m^2 \cdot K$)
		C24	Building dense wall than (%)
		C25	air temperature (℃)
		C26	Population density (person / m^2)
	Removal link B3	C31	Construction demolition energy consumption (kJ)
		C32	Building demolition and reutilization rate of (%)
		C33	Transport distance from the disposal site (km)

Using δ_k $(k=1,2,\ldots,n)$ to represent the k-th carbon emission assessment level, and specifying $\delta_1 > \delta_2 > \ldots > \delta_n$ to indicate that the k-th level is superior to the k+1th level, constitutes the carbon emission level $R = \{\delta_1, \delta_2, \ldots, \delta_n\}$ for the entire life cycle of residential buildings. This model has five evaluation levels, namely $R = \{\delta_1, \delta_2, \ldots, \delta_5\}$, where δ_1 =very good, δ_2 =good, δ_3 =good, δ_4 =fair, δ_5 =unqualified. Subsequently, the five levels were divided and defined, as shown in the table.

Table 6. Definition of carbon emission rating scores of residential buildings

grade	fine	good	preferably	same as	unqualified
value	$100 \geq \delta > 90$	$90 \geq \delta > 80$	$80 \geq \delta > 70$	$70 \geq \delta > 60$	$60 \geq \delta$

3.1.2. Determine the weight of indicators

Referring to China Carbon Accounting Database, Anhui Provincial Statistical Yearbook and related research literature, the data of carbon emission related factors of residential buildings in Anhui province and its prefecture-level cities are obtained, and the judgment matrix is constructed based on this.

When constructing the judgment matrix, the classical 1-9 and its inverse are used to compare different levels of indicators and judge the importance of indicators, as shown in the table below

Table 7. judges the matrix scaling and its meaning

scale value b_{ij}	Importance level
1	The I and j factors are equally important
3	Factor i i is slightly more important than factor i j
5	Factor i i is significantly more important than factor i j
7	The i factor is strongly more important than the j factor
9	Factor i is extremely more important than factor j
1/3	Factor i is slightly less important than factor j
1/5	Factor i i is significantly less important than factor i j
1/7	Factor i i is more strongly unimportant than factor i j
1/9	The i factor is extremely less important than the j factor

The judgment matrix is constructed based on the above scale:

Table 8. First-level index judgment matrix

Level 1 indicators	B1	B2	B3
B1	1	1/3	3
B2	3	1	1/5
B3	1/3	5	1

Table 9. Judgment matrix of the construction link

Construction	C11	C12	C13	C14
C11	1	1/3	1/7	5
C12	3	1	1	1/7
C13	7	1	1	3
C14	1/5	7	1/3	1

Table 10. Judgment matrix of operation links

In terms of operation	C21	C22	C23	C24	C25	C26
C21	1	1/3	1	5	1/3	1
C22	3	1	1/5	7	1	1/7
C23	1	5	1	9	1/3	3
C24	1/5	1/7	1/9	1	1/3	1
C25	3	1	3	3	1	1/5
C26	1	7	1/3	1	5	1

Table 11. Remove the link judgment matrix

Demolition	C31	C32	C33
C31	1	1/3	1/5
C32	3	1	1
C33	5	1	1

By solving the maximum eigenvalue of the eigenequation, and the corresponding eigenvector. The index weight vector is calculated. Due to the large number of indicators involved in this problem and the large amount of calculation, the root-finding method is used to calculate the weight vector of the indicators: in the row geometric distribution of each row of the judgment matrix, the following formula is needed:

$$W_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{n}} \tag{4}$$

The formula for calculating the weight vector is as follows:

$$W_{i0} = \frac{W_i}{\sum_{i=1}^{n} W_i} \tag{5}$$

In summary, the following index weight values are obtained:

Table 12. Summary of the weight of the carbon emission evaluation index of residential buildings in Anhui Province

Level 1 index layer	weight	Secondary index layer	weight
Construction link	0.2254	Building materials transportation distance	0.3796
		The use of fossil energy	0.2683
		Building materials production energy consumption	0.1182
		Building materials carbon emissions	0.2369
Running link	0.5355	building orientation	0.1852
		Annual income of the resident population	0.1562
		External wall heat transfer coefficient	0.2367

		Construction wall to wall ratio	0.0987
		air temperature	0.2156
		density of population	0.1076
Demolition link	0.2391	Build and dismantle energy consumption	0.1692
		Reuse rate of dismantled materials	0.3874
		Transportation distance from the disposal site	0.4434

3.2. Agreement evaluation

The consistency test method of judgment matrix is mature. Generally, the maximum eigenvalue Y of judgment matrix is calculated first. Solve the consistency index C by using equation (6), to solve the ratio of the stochastic consistency index by Equation (7).

$$C.I. = \frac{Y_{\max} - n}{n-1} \tag{6}$$

$$C.R. = \frac{C.I.}{R.I.} \tag{7}$$

Table 13. The average random agreement index table

Order	3	4	5	6	7	8	9
R.I.	0.58	0.96	1.12	1.24	1.32	1.41	1.45

When, $C.R. < 0.1$, it is considered that the consistency test of the carbon emission evaluation indicators for the entire life cycle of residential buildings is acceptable, that is, the logic of the weight of the evaluation indicators is acceptable; On the contrary, it is necessary to make corrections. By substituting the data into the above formula, the study found that the $C.R.$ values of 13 secondary indicators were all less than 0.1, so further exploration and application can be carried out.

3.3. Model construction and operation

3.3.1. Determine the membership function

For the qualitative index, the following membership functions are selected:

$$\mu_{ijk} = \begin{cases} 1, & \text{when the eigenvalues are met} \\ 0, & \text{when the eigenbalues are not met} \end{cases} \quad (k=1,2,3,4,5) \tag{8}$$

Based on the study of the above indicators, the benchmark values of the five grades are all different, so the level membership functions are selected as follows:

$$\mu_{ij1} = \begin{cases} 1, & y_{ij} \geq a_{ij1} \\ \frac{y_{ij}}{a_{ij1}}, & 0 \leq y_{ij} \leq a_{ij1} \end{cases} \tag{9}$$

$$\mu_{ij1} \begin{cases} \frac{a_{ij(k-1)}}{y_{ij}}, & y_{ij} \geq a_{ij1} \\ 1, & a_{ij1} \leq y_{ij} \leq a_{ij(k-1)} \quad (k=1,2,3,4,5) \\ \frac{y_{ij}}{a_{ij1}}, & 0 \leq y_{ij} \leq a_{ij(k-1)} \end{cases} \tag{10}$$

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By combining various indicators with membership functions, the ranking evaluation matrix a_i of the single factor subset R_i （$i = 1,2,3$）was obtained. After calculation, the following results were obtained.

3.3.2. 3.3.3. Fuzzy comprehensive evaluation of secondary indicators

Combining the membership function, the rating matrix of the factor subset is obtained, and the following results are obtained:

$$R_1 = \begin{pmatrix} 0.84 & 1.00 & 0.75 & 0.86 & 0.86 \\ 0.82 & 0.98 & 0.77 & 0.99 & 0.88 \\ 0.86 & 0.92 & 0.81 & 0.95 & 0.91 \\ 0.90 & 0.83 & 0.86 & 0.91 & 1.00 \end{pmatrix} \tag{11}$$

$$R_2 = \begin{pmatrix} 0.63 & 0.91 & 0.76 & 0.86 & 0.98 \\ 0.76 & 0.93 & 0.87 & 0.88 & 0.99 \\ 0.77 & 0.87 & 0.85 & 0.87 & 0.87 \\ 0.75 & 0.85 & 0.76 & 0.93 & 0.89 \\ 0.81 & 0.96 & 0.87 & 0.91 & 0.74 \\ 0.86 & 0.94 & 0.89 & 0.85 & 0.89 \end{pmatrix} \tag{12}$$

$$R_3 = \begin{pmatrix} 0.96 & 0.89 & 0.96 & 0.86 & 0.87 \\ 0.98 & 0.96 & 0.97 & 0.95 & 0.89 \\ 0.79 & 0.78 & 0.76 & 0.81 & 0.76 \end{pmatrix} \tag{13}$$

Based on this, the scores of the carbon emission secondary evaluation index of residential buildings in Anhui Province in 2022 can be summarized, as shown in the table below.

Table 14. Score of carbon emission secondary evaluation index of residential buildings in Anhui Province in 2022

Level 1 index layer	Secondary index layer	score
formation	Transportation distance of building materials (km)	89
	Fossil energy usage (t)	78
	Energy consumption of Building materials production (J)	86
	Carbon emissions of building materials (t)	88
formation	Building Orientation (Degree)	93
	Annual income of the resident population (RMB)	95
	Heat transfer coefficient of external wall (W / $m^2 \cdot K$)	95
	Building with a window-to-wall ratio	89
	air temperature (°C)	80
	Population density (person / m^2)	77
demolish	Construction and Demolition Energy Consumption (J)	92
	Building demolition and reutilization rate	90
	Transport distance from the disposal site (km)	85

By assigning values based on the weights of the secondary indicators mentioned above, the evaluation indicator weights of the single factor subset a_i can be obtained, namely the allocation of secondary indicator weights $A_i = (b_{i1}, b_{i2}, \ldots, b_{in})$. Subsequently, a second fuzzy comprehensive evaluation was conducted on the single factor subset a_i. After calculation, the evaluation results for $B_i = A_i \times R_i$ are as follows:

$$B_1 = (0.756 \quad 0.852 \quad 0.945 \quad 0.983 \quad 0.885) \tag{14}$$

$$B_2 = (0.727 \quad 0.818 \quad 0.933 \quad 0.999 \quad 0.919) \tag{15}$$

$$B_3 = (0.756 \quad 0.845 \quad 0.964 \quad 0.784 \quad 0.845) \tag{16}$$

3.3.3. Fuzzy comprehensive evaluation of first-level indicators

The second level fuzzy comprehensive evaluation is the evaluation of the single factor subset of the second level indicators separately. In order to obtain the 2022 Anhui Province residential building carbon emission level assessment results, the comprehensive influence of the first level indicators must also be considered, that is, the first level fuzzy comprehensive evaluation. Using each a_i as an element and B_i as its single factor evaluation can also form an evaluation matrix..

$$R = \begin{pmatrix} B_1 \\ B_2 \\ B_3 \end{pmatrix} = \begin{pmatrix} 0.756 & 0.852 & 0.945 & 0.983 & 0.885 \\ 0.727 & 0.818 & 0.933 & 0.999 & 0.919 \\ 0.756 & 0.845 & 0.964 & 0.784 & 0.845 \end{pmatrix} \tag{17}$$

Similarly, according to the weight of the evaluation index obtained above, the assigned weight of each factor subset is:

$$A = (0.2254, 0.5355, 0.2391) \tag{18}$$

According to formula $B = A \times R$, the fuzzy comprehensive evaluation result of carbon emissions from residential buildings in Anhui Province in 2021 is obtained, $B = (0.752, 0.845, 0.947, 0.985, 0.891)$ which means that the comprehensive membership vector of the carbon emission evaluation level δ_k $(k = 1,2,3,4,5)$ for residential buildings in Anhui Province in 2021 is:

$$U = (0.752, 0.845, 0.947, 0.985, 0.891) \tag{19}$$

3.4. Confirmation of the evaluation grade

Normizing the integrated membership vector by dividing each component of the vector by the module length of the vector:

$$U = (0.17, 0.19, 0.21, 0.22, 0.20) \tag{20}$$

The most commonly used maximum membership principle is used to evaluate, and the carbon emission rating of the overall residential buildings in Anhui Province in 2022 is better. At the same time, this paper evaluates the 16 prefecture-level cities in Anhui province respectively, Each prefecture-level city is indicated separately, and the detailed scores are shown in Table 15.

Table 15. Summary of carbon emission evaluation grade of residential buildings in Anhui Province and its prefecture-level cities in 2021

number	area	order of evaluation	grade
U	Anhui Province	preferably	78
U_1	Hefei City	fine	95
U_2	Wuhu City	preferably	76
U_3	Chuzhou	good	81

U_4	Fuyang city	preferably	74
U_5	Anqing City	preferably	78
U_6	Ma'anshan City	same as	69
U_7	the City of Suzhou	preferably	73
U_8	Bozhou city	preferably	74
U_9	Bengbu City	same as	67
U_{10}	Lu'an City	same as	68
U_{11}	Xuancheng City	preferably	72
U_{12}	Huainan City	preferably	75
U_{13}	Huaibei City	same as	63
U_{14}	Tongling city	same as	61
U_{15}	Chizhou city	same as	64
U_{16}	Huangshan city	preferably	71

From the table, as a whole, At present, the development situation of green buildings in Anhui province is relatively good, However, there are considerable regional differences and they are highly concentrated, At the same time, the degree of economic development has had a relatively positive impact on the development of green buildings, Hefei city, as the "unique branch" of economic development in Anhui Province, Its urban construction attaches great importance to environmental protection and low-carbon protection, Despite a large population, More residential buildings, But the overall level of development is good; on the contrary, The economic volume of Ma'Anshan city and Tongling City is very far behind that of Hefei city, And the population is also relatively small, But since both are industrial, At the same time, there is insufficient attention to green buildings, This gives us the "average" rating.

4. Suggestions

This paper deeply explores the carbon emission of the whole life cycle of residential buildings in Anhui province, and puts forward the following countermeasures and suggestions.

4.1. Implement building carbon reduction throughout the whole life cycle

This paper analyzes the main factors affecting the carbon emission of residential buildings in China from the perspective of the whole life cycle. Therefore, the increase of carbon emission can be actively avoided by adjusting the related factors. For example, it is recommended that developers should build buildings facing south, and arrange the buildings in the north and low, increase the light as much as possible, reduce the heat loss; in addition, the building wall should increase the construction of green building supporting infrastructure, shorten the transportation distance between building materials and waste materials, increase the reuse utilization rate of building materials, and reduce the carbon emission as much as possible.

4.2. Implement green buildings according to the current situation of various places

This paper studies the emission status of residential buildings in Anhui Province and its prefecture-level cities based on the fuzzy comprehensive evaluation model. According to the evaluation results, it can be seen that the overall carbon emission level of residential buildings in Anhui province is in a good grade, but for each prefecture-level city, the gap is still large. Therefore, only by adapting measures to local conditions can we effectively promote the development of green buildings in Anhui Province. For areas with low comprehensive scores, such as Maanshan, Bengbu and Huaibei, the introduction of green buildings is slow, and the innovation system between green technology and industrial base construction are still in the initial stage, relevant incentive policies should be improved to improve the willingness of enterprises to follow up, and improve the support of the industry; cities with relatively high scores, such as Hefei, already have certain supporting facilities, but the energy-saving design standards cannot quickly meet the realization of the "double-carbon" goal[7]Therefore, it is necessary to further improve the relevant infrastructure construction, and the implementation standards should keep pace with The Times.

4.3. Create a green building industry chain

In the long run, it is imperative to achieve the "double-carbon" goal of the construction industry in Anhui Province, so it is necessary to achieve the purpose of energy conservation and emission reduction through the establishment of a green industrial chain on the premise of ensuring the quality, safety and stability. In the production process, green building materials and high-performance concrete are used to promote energy conservation and environmental protection in the downstream construction process; in the procurement process through electronic bidding means; in the energy saving transportation; in the construction process, the accurate matching of supply and demand of raw materials, accurate cutting, and lean production; in the recovery process, the rational utilization of raw materials, energy and waste, and reduce the resource and environmental pressure caused by the production of new products. In this way, a benign and green circulation system of each link is formed, which provides an effective channel for the transformation of high-quality products with clear waters and green mountains.

5. Conclusion

From the perspective of the whole life cycle, this paper sorts out the factors affecting the development of green building in Anhui Province, screens out the factors with high correlation through the principal component analysis, and forms the evaluation index system of green building in Anhui Province to study the current development status of green building in Anhui Province. The results show that the development of green buildings in Anhui province is good, but there are great differences between regions. The research results can provide reference for the transformation and upgrading of the construction industry in Anhui province and green innovation in Anhui Province, and help to cultivate the new quality productivity of the green building industry, aiming to promote the large-scale development of green building in Anhui Province and achieve the "double-carbon" goal as soon as possible.

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