

Study on the life cycle model of residential building carbon emission based on principal component analysis method

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Abstract. The aim of this paper is to establish a carbon emission model for residential buildings and comprehensively analyze the carbon emissions during their whole life cycle. According to the indexes of construction stage, operation stage and demolition stage, the model is established, and the influencing factors such as building materials, production and transportation mode, decoration style and climate factors are considered respectively. In the construction stage, the comprehensive carbon emission model is established to consider the influence of transport index and material carbon emission factors. In the operation stage, the carbon emission of different room types is analyzed by simulating, and the influence of design standard factor, decoration style factor and climate factor is considered. In the demolition stage, the influence of the carbon content of the demolition construction waste on the carbon emission is considered. The principal component evaluation model was established through principal component analysis to comprehensively evaluate the carbon emissions of different types of houses. Finally, the total carbon emission of the whole life cycle is calculated, which provides an important reference for the carbon emission management of residential buildings.

Keywords: Principal component analysis, residential buildings, carbon emissions, full life cycle model

1. Introduction

In recent years, with the increasing prominence of global climate change and the deepening of the concept of sustainable development, the carbon emission problem of the construction industry has gradually become one of the focuses of social attention. Green low-carbon buildings comply with the needs of The Times to save energy and reuse energy, and provide a more comfortable living environment[1]. According to statistics, the carbon emissions of the global construction industry account for the proportion of total emissions that cannot be ignored, especially in the life cycle of buildings, including construction, operation and demolition stages, which have an important impact on the environment[2]. The prominence of this problem makes it urgent for people to explore effective ways to reduce building carbon emissions and promote the development of the construction industry in a more environmentally friendly and sustainable direction[3].

The purpose of this paper is to deeply analyze and study the carbon emission of buildings by establishing a comprehensive carbon emission model. Specifically, this paper will focus on the contribution of the various stages of a building's life cycle to carbon emissions and explore the key factors that influence carbon emissions. Through this research, we aim to provide scientific basis and effective strategies for reducing carbon emissions in the construction industry, and contribute to promoting the construction industry towards a low-carbon and environmentally friendly direction.

In this context, this paper will focus on the following questions: how to establish the carbon emission index in the construction stage? How to determine the carbon emission index during the operation phase? How to build the carbon emission model in the demolition stage? How to build a comprehensive assessment model of carbon emissions in the whole life cycle? By discussing and answering these questions, we hope to fully understand the essence of the building carbon emission problem, and put forward effective measures and suggestions to promote the construction industry towards the goal of sustainable development.

2. Empirical research design

In the whole life cycle of residential buildings, the factors that affect carbon emissions can include architectural design standards, climate, production and transportation of building materials, regional differences, construction and demolition energy consumption, decoration style, energy consumption, and building type. The objective of this paper is to establish the expression of carbon emission through the model, so the total carbon emission is calculated from three stages. For the construction phase, the relevant indicators are the building materials and the mode of production and transportation. Through data reference [4], it can be found that production and transportation indexes and building materials are related to carbon emission factors. According to the carbon emission factor coefficient, a comprehensive carbon emission model can be established:

$$W = C_1 * M * l + C_2 * V \quad (1)$$

C_1 C_2 Where, is the transport index carbon emission factor, is the material carbon emission factor, M is the material weight, l is the transport distance. After consulting, the distance between the material and the construction site is generally 50km, and the above model can be transformed into:

$$W = 50C_1 * M + C_2 * V \quad (2)$$

For all kinds of houses, there are many different types of differences, such as material, house type and climate. In order to better reflect the influence of various factors under the same restrictive conditions, this paper establishes a number of simulated houses to model and analyze the carbon emissions in the operation stage.

Now assume a single-storey flat-roofed single building of 8 m long, 6 m wide and 6 m high, with brick-concrete walls and a thickness of 30 cm, reinforced concrete roof and a thickness of 30 cm, concrete ground, located in a temperate monsoon climate. At the same time, through consulting the energy-saving design standards for residential buildings in mild areas [5], based on the body type coefficient of this house type being 0.5625, the wall-window ratio of 0.35 was selected in this paper, and the corresponding heat transfer coefficient was 2.8. Heat transfer coefficient is shown in table 1.

Table 1. Heat transfer coefficient

unit	Window wall area ratio	Heat transfer coefficient K[W/(m ² *K)]
Body shape coefficient ≤0.45	Window wall area ratio ≤0.30	3.8
	0.30< window wall area ratio ≤0.40	3.2
	0.40< window wall area ratio ≤0.45	2.8
	0.45< window wall area ratio ≤0.60	2.5
	Window wall area ratio ≤0.20	3.8
Body shape coefficient >0.45	0.20< window wall area ratio ≤0.30	3.2
	0.30< window wall area ratio ≤0.40	2.8
	0.40< window wall area ratio ≤0.45	2.5
	0.45< window wall area ratio ≤0.60	2.3
	horizontal	3.5

In this paper, 18 degrees Celsius is selected as the adjustment value [6], which can be determined by the heat loss index. The heat required to increase 1 degree Celsius in the unit volume is 12.9J[7], the time is 1s, and the heat loss per second is 2464W based on the house thermal conductivity 2.8. To maintain this part of the heat balance, according to the unit volume of 1 degree Celsius increase in the need to provide 1297.74J of heat, can be obtained per second carbon emissions of 0.689kg.

Decoration style factors can be determined by the wall-window ratio index, taking the time of 1s, according to the 0.35 wall-window ratio, it can be obtained that there are 58.8 square meters of window area, the heat loss per second of the window is 188.16J, the part of the heat loss through the air conditioning adjustment, the carbon emissions generated per second is 0.0526kg.

Climate factors can be determined by the monthly average temperature index. The average monthly temperature for the temperate monsoon climate is shown in Table 2.

Table 2. Average monthly temperature of temperate monsoon

month	1	2	3	4	5	6	7	8	9	10	11	12
Mean air temperature	2.5	3.5	11.5	17	22	28.5	28	29	23	15	11.5	1.5

Human body comfortable room temperature range 18-26 degrees Celsius. For the monthly average temperature that exceeds the comfortable temperature of human body, this paper believes that it is necessary to adjust the air conditioner and calculate the minimum carbon emission generated by reaching the comfortable temperature range by selecting months that are not in the comfortable temperature range. It can be seen from the above table and the following figure that air conditioners are required to adjust the temperature in June, July and August (when the temperature is higher than the upper limit) and January, February, March, April, October, November and December (when the temperature is lower than the upper limit). Average monthly temperature of temperate monsoon is shown in figure 1.

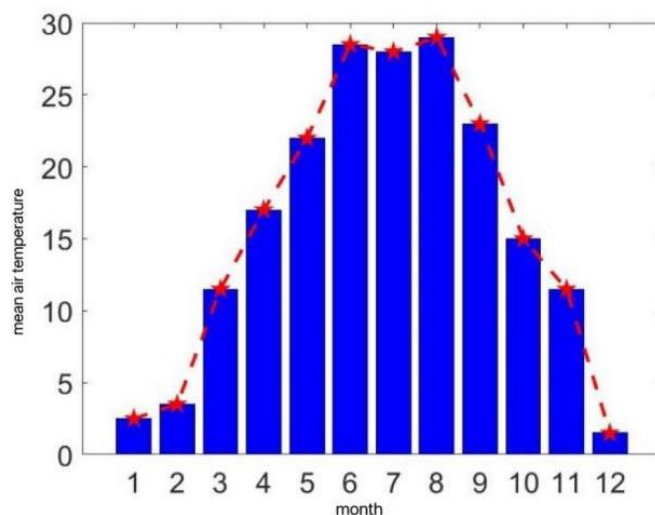


Figure 1. Average monthly temperature of temperate monsoon

The monthly average temperature plus the indoor and outdoor temperature difference was added to analyze the processed data. The months to be excluded were May and September, and the data of the remaining months were substituted into the formula. The parameters were calculated according to the thermal conductivity coefficient and the heating performance coefficient of the air conditioner , and the annual emission was 1279.37kg.

Similarly, this paper selects a subtropical monsoon climate, and assumes that there is a single-storey flat-roofed single building with a length of 10 meters, a width of 5 meters and a height of 5 meters. The wall is a brick-concrete structure with a thickness of 30 centimeters. The roof is reinforced concrete with a thickness of 30 centimeters and the ground is concrete. The body type coefficient is 0.8, the wall-window ratio of 0.43 is selected in this paper, and the heat transfer coefficient is 2.5.

The decoration style factor is determined by the wall-window ratio index, taking the time of 1s, according to the wall-window ratio of 0.43, it can be obtained that there are 64.5 square meters of Windows, and the heat loss of the window is 206.4W per hour, and the heat loss of the part is adjusted by the air conditioning, and the carbon emissions generated by the hour is 0.0577kg.

The design standard factor can be determined by the heat loss index, taking the indoor rise of 1 degree Celsius as the heat loss calculation, taking the time as 1s, according to the thermal conductivity of the house 2.5, the heat loss per hour can be 2083.3W. To maintain this partial heat equilibrium, it can be calculated that the carbon emission per hour is 0.58kg.

Climate factors are determined by the monthly average temperature index. After searching the data, the average monthly temperature of the subtropical monsoon climate is shown in Table 3:

Table 3. Average monthly temperature of subtropical monsoon

month	1	2	3	4	5	6	7	8	9	10	11	12
Mean air temperature	2	4	8	12	17	30	32	31	27	20	9	3

As can be seen from the above table, the average monthly temperature of the subtropical monsoon climate is above 0 degrees Celsius, and the temperature is higher in June, July and August throughout the year.

According to the data in Table 3, the monthly mean temperature of the subtropical monsoon climate is plotted, as shown in figure 2.

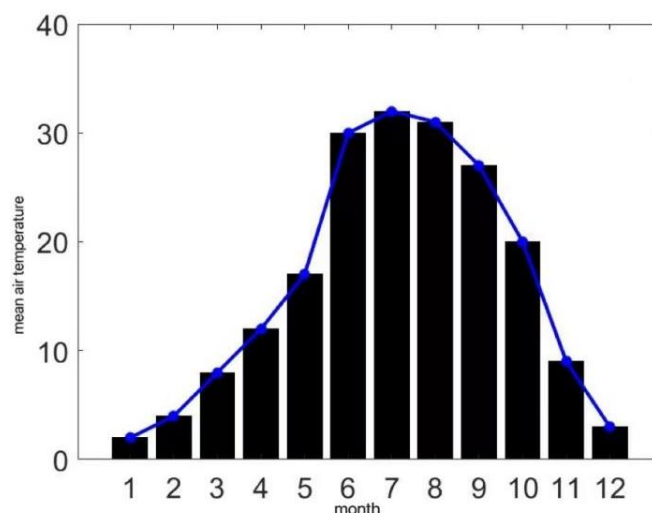


Figure 2. Average monthly temperature of subtropical monsoon

According to the comfortable room temperature range of the human body, considering the indoor and outdoor temperature difference, excluding the data in May and October, substituting the processed data into the formula, According to the known parameters, the annual carbon emission is 1357.012kg.

In tropical monsoon climate and temperate continental climate, the model houses were built again with the same method, which were a single-storey flat-roofed single building with a length of 15 meters, a width of 13 meters and a height of 8 meters, and a single-storey flat-roofed single building with a length of 12 meters, a width of 7 meters and a height of 4 meters. The walls were brick-concrete structure with a thickness of 30 centimeters, and the roof was reinforced concrete with a thickness of 30 centimeters and the ground was concrete. Body shape coefficients were 0.534, 0.952, wall-window ratios were 0.35, 0.43, and corresponding heat transfer coefficients were 2.8 and 2.5, respectively.

The design standard factor can be determined by the heat loss index, taking the indoor rise of 1 degree Celsius as the heat loss calculation, taking the time as 1s, and according to the house thermal conductivity 2.8, the heat loss per hour can be obtained as 7821W and 2666W. To maintain this part of the heat balance, it can be obtained that the carbon emissions per hour are 2.19kg and 0.746kg, respectively.

The factors of decoration style can be determined by the wall-window ratio index. Taking the time as 1s, the window area of 209.3 square meters and 96.32 square meters can be obtained according to the wall-window ratio of 0.35, and the heat loss of the window per hour is 1172.08W and 481.6W. The heat loss of this part is adjusted by the air conditioner. Carbon emissions per hour are 0.328kg and 0.135kg.

Climate factors can be determined by the monthly average temperature index. The monthly average temperature at the comfortable temperature of the human body is eliminated, and the minimum carbon emission generated by reaching the comfortable temperature range is calculated by selecting months that are not in the comfortable temperature range.

Table 4. Average monthly temperature of tropical monsoon

month	1	2	3	4	5	6	7	8	9	10	11	12
mean temperature of air	16	19	23.5	27	24	24.5	26.5	26.5	25	22.5	20	17

According to the data of meteorological Bureau, the average monthly temperature of temperate continental climate is as follows:

Table 5 Monthly average temperature of temperate continents

month	1	2	3	4	5	6	7	8	9	10	11	12
Mean air temperature	-7	-7	4.5	11.5	16	23	24	22	17	8	0.5	-11

According to the data, table 4 and Table 5 can be seen that the average monthly temperature of tropical monsoon climate is generally higher than the average monthly temperature of temperate continental climate, and the lowest average temperature is also over 15 degrees Celsius, and the maximum temperature will reach in April due to the tropical cyclone. In the temperate continental climate, the maximum temperature is not over 25 degrees Celsius, and the average monthly average temperature is below zero.

According to Table 4 and Table 5, draw the monthly mean temperature map of tropical monsoon climate and temperate continental climate, respectively, as shown in figure 3.

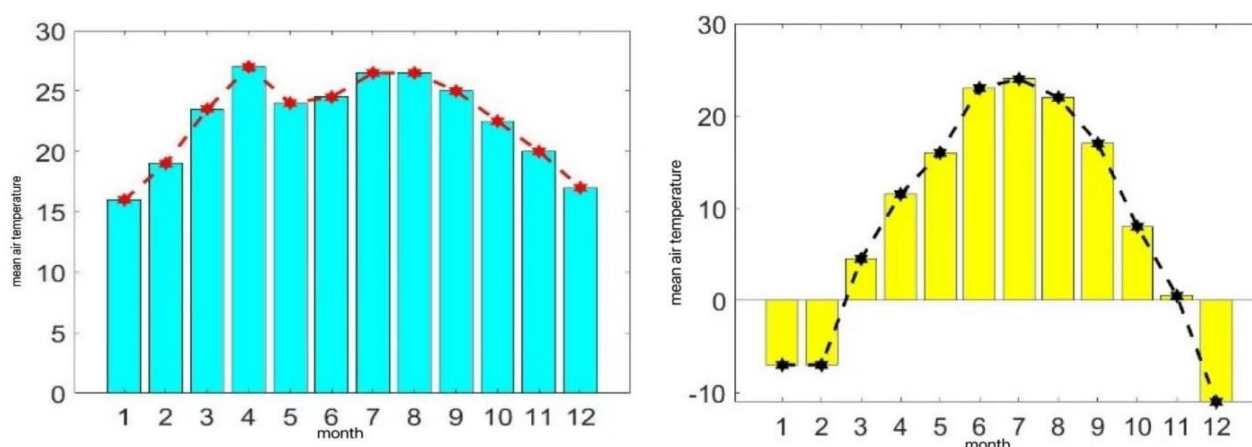


Figure 3. Average monthly temperature of tropical monsoon

After analysis, the simulated house of temperate continental climate type needs to subtract the data of 5,6,8 and September to calculate the annual carbon emission of 1368.688kg. For tropical monsoon climate type, the simulated house needs to subtract 2,3,11, December data, annual carbon emissions 4259.223kg.

According to the calculation results of the simulation rooms of temperate monsoon climate, subtropical monsoon climate, temperate continental climate and tropical monsoon climate, the design standard factors, decoration style factors and climate factors are analyzed, and the following table 6 is drawn:

Table 6. Ftype of factors

type	Design criterion factor	Decoration style factors	climatic factor
1	6035.64	460.776	1279.37
2	5080.8	505.452	1357.012
3	19184.4	2873.28	4259.223
4	6534.96	1182.6	1368.688

The data is then imported into SPSS for z-score normalization with the following formula:

$$x' = \frac{x - u}{\delta} \quad (3)$$

In order to better carry out the principal component analysis, this paper needs to carry out the internal test of the model, and KMO and Bartlett spherical test are used to do the correlation analysis of the original variables, observe whether there is a strong correlation of the original variables, and then get the feasibility of principal component analysis. The following table 7 is the SPSS:

Table 7. KMO and Bartlett tests

KMO sample appropriateness measure	0.691
Bartlett sphericity test	Approximate chi square 8.918
	free degree 3
	conspicuousness 0.03

The closer the KMO value is to 1, the stronger the correlation. The KMO value is 0.691, the correlation is good, and the significance of batlite spherical gradient test is 0.03, less than 0.05, so it is considered that each original variable has a strong correlation, which can be established and the model accuracy is high.

Using SPSS, the total variance interpretation table 8:

Table 8. Total variance interpretation

ingredient	amount to	Percent variance of the initial eigenvalues	accumulate%	total	The percentage of square sum of load variance was extracted	accumulate
1	2.952	98.398	98.398	2.952	98.398	98.398
2	0.044	1.48	99.878			
3	0.004	0.122	100			

Except for the first in the total variance interpretation table, the characteristic roots of the other two principal components are less than 1,0.04 and 0.004, respectively. Therefore, only one principal component is selected in SPSS, and the cumulative variance contribution of the first principal component reaches 98.398%, indicating that the first principal component can explain the information of multiple variables well.

According to the composition matrix table, the loads of design standard factors, decoration style and climate factors are 0.997,0.985 and 0.994, respectively, to obtain the expression of principal components:

$$F_1 = 0.997x_1 + 0.985x_2 + 0.994x_3 \quad (4)$$

The comprehensive evaluation model of the design standard component as the weight:

$$(5)$$

$$F = \frac{98.398}{98.398} F_1 +$$

As easily known by Equation 5, $F = F_1$

Table 9. Ranking of scores by type

type	F	ranking
1	7743.09	3
2	6912.30	4
3	26190.70	1
4	9040.69	2

Ranking of scores by type is shown in table 9, after ranking the four simulated houses, it can be obtained that the total annual carbon emission of simulated house 3 is the highest, and simulated house 2 is the lowest. For the calculation of carbon emission of a single house, the formula is shown in the above 4.

For the demolition stage, this paper chooses the demolition of construction waste as the relevant index. Through the data review, a ton of construction waste has about 15-20% carbon content. Therefore, for the index model of the demolition stage, please obtain:

$$W = c * M \quad (6)$$

Among them, c is the carbon content, and M is the total mass of the dismantled waste.

Based on the building carbon emissions of the three phases, the total carbon emissions for the entire life cycle is:

$$W = 50C_1 * M + C_2 * V + 0.997x_1 + 0.985x_2 + 0.994x_3 + c * M \quad (7)$$

This section uses the principal component comprehensive evaluation model to compare the three factors, namely, the design standard factors, decoration style factors, and climate factors on the four simulated rooms. This model can also easily solve problems in other fields, such as constructing the comprehensive evaluation model of mixed polysaccharide gel quality based on principal component analysis, so as to objectively reflect the quality of mixed polysaccharide gel, [8]. Principal component analysis was used to conduct statistical analysis of data parameters to form a comprehensive evaluation model, and then determine the dimension[9] of the nursing complexity of hospitalized elderly stroke patients. For another example, the factors closely related to the reservoir quality are selected to build the index system, the principal component analysis method is used to process the relevant data of these evaluation indexes, the weight of each evaluation index is determined, the reservoir quality evaluation model is established, and the quality of clastic rock reservoir is evaluated [10]. The comprehensive evaluation model based on principal component analysis can objectively evaluate the quality of the target and has strong credibility and feasibility.

3. Conclusion

In this paper, through the establishment of comprehensive carbon emissions model, studied the construction industry in the life cycle of carbon emissions, and obtained the following main results: in the construction stage, we successfully established the relevant indicators, including building materials and production mode of carbon emission factor, and through the model calculated the construction stage of carbon emissions. In the operation phase, we determined the carbon emission index of the operation phase based on different climate and building design standards, and carried out the model analysis through the establishment of the simulation room. During the demolition phase, we established a carbon content model of demolition construction waste and calculated the carbon emissions during the demolition phase. Considering the carbon emissions of each stage, a

comprehensive evaluation model of carbon emissions for the whole life cycle is established, and the ranking evaluation of different types of buildings is conducted.

However, this study has several limitations, such as the possible uncertainty during data acquisition and model building, and the applicability to building types and climatic conditions in specific situations requiring further validation. Future research directions could include expanding the sample size and data sources to improve the accuracy and applicability of the model; exploring more carbon emission reduction strategies, such as using renewable energy and green building materials; further studying the impact of carbon emissions in the construction industry on the environment and climate change, and the research and implementation of relevant policies and management measures.

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