Measurement and analysis of carbon emissions from prefabricated buildings under the transition of new and old kinetic energy

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Abstract. The "fourteenth fiveyear plan" period is the key period for China to cross the high income threshold and tackle the key problems of reform, and it is also the key period for China to continue to transform the old and new kinetic energy. In this period, the pace of new urbanization in China is gradually accelerating, and it is becoming a powerful engine of China's economic growth and social development. The new urbanization strategy will leverage a new round of development of the construction industry and become a new growth point of the construction industry. The traditional construction industry is at the cost of consuming a lot of natural resources and causing heavy environmental burden. As a technological innovation with innovative significance in changing the mode of production, prefabricated building is an important way of energy conservation and emission reduction, and its development prospect is very broad. However, due to the relatively deep practice of prefabricated building based on the market environment has just started, the targeted research on energy conservation and emission reduction is not sufficient or even blank. Taking a project in Shenyang City of Liaoning Province as an example, this paper establishes the calculation formula of carbon emission of concrete prefabricated and cast-in-place residential buildings by using the emission factor method, calculates and compares the differences of carbon emission of the two kinds of buildings in the production stage, transportation stage and construction stage, and puts forward the corresponding carbon reduction measures of prefabricated buildings in each stage, so as to provide a powerful reference for the healthy and rapid development of other low-carbon buildings in China theoretical basis and practical guidance of the project.

Keywords: New and old kinetic energy; prefabricated building; carbon emission calculation; emission factor method

1. Research background

1.1 The key period of new and old kinetic energy conversion

Due to the historical development of our country, the industrialization process started late, and the industrial structure of our country was imperfect for a long time. With the founding of new China, China’s industrialization process has developed rapidly, and the imbalance of industry has been improved. However, due to the extensive management for a long time, industrial development consumes a lot of resources and environment. At the same time, with the transformation of modern industrial structure, the traditional and single industrial model cannot meet the needs of socialist development. At present, China is adjusting the industrial structure, and the focus of industrial transformation is the transformation of new and old kinetic energy.
The transformation of new and old kinetic energy mainly refers to reducing the old kinetic energy in the process of industrial development and increasing the application proportion of new kinetic energy in industrial development, so as to make the industrial development move towards a healthy direction. However, the conversion of new and old kinetic energy is not to replace all the old kinetic energy with new kinetic energy, but to retain the old kinetic energy to a certain extent and strengthen the use efficiency of the new kinetic energy, which can also be said to be the supplement or upgrading of the old kinetic energy.

1.2. Carbon emission status of construction industry

Construction, industry and transportation are the three major areas of energy consumption, and they are also the main sources of greenhouse gas emissions. According to the report "building and climate change" released by the United Nations Environment Programme (UNEP) in 2019, the energy consumption of the construction sector accounts for 27.83% - 39.61% of the global energy consumption, and one third of the global greenhouse gas emissions are related to it, which is one of the key areas of low-carbon energy conservation.

In China, residential building energy consumption accounts for about 27% of the total energy consumption, and carbon emissions account for about 40% of the total emissions. The energy consumption per unit residential building area in China is 2-3 times of that in developed countries. More than 70% of new residential buildings are high energy consumption buildings, and more than 85% of existing residential buildings are high energy consumption buildings. The scale of urban buildings in China continues to grow at a rate of 5% - 8% due to the urbanization process. The annual new buildings (more than 1 billion square meters) account for 40% of the world, and will last for 25-30 years. Therefore, building energy consumption and carbon emissions are the current focus of research.

2. Research status

Cang Yujie studied the accounting methods of building materials and construction structures and the corresponding accounting methods, based on the process based inventory analysis, quickly calculated and predicted the carbon emissions in the architectural design stage and construction drawing stage [1]; Liu Rui and Zhang Mingshun introduced the different concepts of carbon emissions, analyzed the role of carbon emissions calculation, and summarized the EU carbon emissions calculation and statistics methods and carbon emission status. Based on the advanced development experience of the European Union, this paper puts forward some suggestions for the development of China's carbon emission calculation and statistics [2]; Shao Shuai, Zhang Ke and Dou Jianmin take energy consumption and carbon emission as input factors and unexpected output respectively into the traditional output density model, and discuss the impact of economic agglomeration and energy intensity on carbon emission intensity. The linear influence mechanism is explained, and then the dynamic spatial panel Durbin model composed of the data of China’s 30 provincial regions from 1995 to 2016 is used to empirically test the theoretical hypothesis [3]; may think that the carbon emission of building use stage is only caused by the energy consumption of building equipment, such as heating, ventilation, air conditioning, lighting, etc, not including the energy consumption. Including energy consumption and carbon emissions due to the use of various household appliances [4]; Randolph conducted a research on energy and greenhouse gas emissions in 12 residential areas in Sydney, which included carbon emissions in the life cycle of building construction, material replacement and infrastructure [5].

3. Research significance and purpose

3.1. Prefabricated building: an important way to reduce carbon emission

In China, from the 1950s, people began to gradually understand and understand the prefabricated building. In the early 1960s, people began to study the construction method of prefabricated building, and formed a new building system. Through the continuous development of science and technology. In 2016, the general office of the State Council issued the document "guidance on vigorously developing prefabricated buildings". In response to the call of the State Council, various regions have
issued policies. In the next decade, the proportion of prefabricated buildings in new buildings in China will reach 30%.

Although there will be a lot of resistance in the early stage of building industrialization, as long as the scale application degree reaches the threshold of diluting the increase cost brought by technological innovation, the speed of scale promotion will be further accelerated, and the effect of energy conservation and emission reduction will be more prominent. Compared with the difference of carbon emission between the traditional construction method and the industrialized method, the energy consumption alone is reduced by 20% - 30%, the material loss is reduced by 60%, the construction waste is reduced by 83%, and the recyclable materials are increased by 66%, all of which can reduce the carbon emission.

3.2. Research objective
The research content of this paper reflects the requirements and trends of the construction industry, and has great and far-reaching significance for the development of prefabricated carbon buildings in China. By building a comprehensive carbon emission accounting model of prefabricated buildings, the quantification, visualization and intellectualization of carbon emission of prefabricated houses are realized, so as to assist architects to calculate and count the carbon emission of buildings, find out the direct and main causes of carbon emission impact, and find the most effective way to improve and design the best building scheme. It will provide a strong theoretical basis and practical guidance for the healthy and rapid development of other low-carbon buildings in China.

4. Carbon emission calculation of prefabricated and cast-in-place buildings

4.1. Project overview
This paper takes a project in Shenyang City of Liaoning Province as an example. The project includes three prefabricated concrete buildings and three cast-in-place residential buildings, and one of them is selected for carbon emission analysis. The building area of the two buildings is the same, which is 15685.19m2. The prefabrication rate of prefabricated buildings is 23.17%. The main prefabricated components are decorative columns, interior walls, exterior walls, slabs, stairs and balcony slabs.

4.2. Selection of carbon emission factors
At present, there are three main methods to calculate carbon emissions from buildings: measurement method, material balance algorithm and emission factor method. As the first carbon emission estimation method proposed by IPCC, emission factor method is the most widely used method at present. Its basic calculation idea is to construct the activity data and carbon emission factor of all emission sources that can produce carbon emission in the construction process, and take the product of the two as the carbon emission estimation value of the emission source.

In this paper, the emission factor method is used to establish the calculation formula of carbon emission of concrete prefabricated and cast-in-place buildings. The selection of the most important carbon emission factor in the calculation formula of emission factor method is the basis and key to the calculation of building carbon emission. The list of carbon emission factors in this paper is shown in Table 4-1.

| type                      | Carbon emission factors | data sources                                      |
|---------------------------|-------------------------|--------------------------------------------------|
| diesel oil                | 3.0959kg CO₂/kg         | China carbon trading network (www.tanjiao.com)    |
| gasoline                  | 2.9251kg CO₂/kg         |                                                  |
| power (national average)  | 0.6101kg CO₂/kWh        |                                                  |
| tap water                 | 0.194kg CO₂/t           |                                                  |
| Medium diesel truck (8t)  | 0.179kg CO₂/(t·km)      | Calculation standard of building carbon emission |
4.3. Carbon emission calculation

4.3.1 Production stage of prefabricated components

No matter in the field construction or in the component factory production, there is no shortage of concrete, steel, cement and other building raw materials. Therefore, in the process of calculating the carbon emissions of prefabricated buildings, this paper ignores the carbon emissions of building materials consumption. The production stage of prefabricated components is a unique stage of prefabricated buildings. The carbon emission of this part comes from the carbon emission generated by the operation of machines on the production line. The calculation formula is shown in Formula 1. Table 4-2 shows the carbon emissions generated by the operation of the machine during the production stage of unit cubic prefabricated components. Table 4-3 shows the carbon emissions generated during the production stage of prefabricated building components.

\[ C_i = \sum_{i=1}^{n} (F_{ic} \times M_c + F_{is} \times M_s + F_{id} \times M_d) \]

where: \( C_i \) -- carbon emission in the production stage of prefabricated components;

- \( n \) -- type of prefabricated components;

- \( F_{ic} \), \( F_{is} \) and \( F_{id} \) -- are diesel, water and electricity consumed by class \( i \) components respectively;

- \( M_c \), \( M_s \) and \( M_d \) -- are the carbon emission factors of diesel, water and electricity respectively.

| Unit cube component | column | Composite beam | Integral plate | a partiti on | She ar wall | wallbo ard | Lamina ted plate | balco ny | sta irs | Small compon ents |
|---------------------|--------|----------------|---------------|-------------|------------|-----------|-----------------|----------|--------|------------------|
| Diesel quantity (kg / m³) | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 |
| Water consumption (m³) | 0.134 | 0.134 | 0.134 | 0.134 | 0.134 | 0.134 | 0.134 | 0.134 | 0.134 |
| Electricit y consumption (kWh / m³) | 9.17 | 9.17 | 9.17 | 9.17 | 9.17 | 9.17 | 9.17 | 9.17 | 9.17 |
| Carbon emission (kg / t) | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 |
Table 4-3. Carbon emissions of prefabricated building components in production stage

| prefabricated component | column | Flat | Balcony board / air conditioning board | stairs | exterior wall | interior wall | Other components | total |
|-------------------------|--------|------|--------------------------------------|--------|--------------|--------------|----------------|-------|
| Carbon emission per cubic meter (kg / m³) | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | 7.565 | —   |
| Quantity (m³) | 73.31 | 146.6 | 2 | 67.99 | 73.31 | 704.44 | 234.81 | 59.37 | —   |
| Total carbon emissions (kg) | 554.5 | 1109.18 | 700.05 | 514.34 | 5329.08 | 1776.3 | 449.168 | 1043.2759 |

4.3.2 Transportation phase
Prefabricated buildings all include transportation stage. The calculation of carbon emission in transportation stage needs statistics of transportation volume, transportation distance and other data, as well as the return no-load coefficient of transportation vehicles. The calculation assumes full load transportation and no-load return. Therefore, the actual transport distance $D_t = \text{one-way transport distance} \times K_y$, according to the existing research, the environmental load of no-load is 0.67 times of full load, then the empty car return coefficient $K_y = 1.67$. The specific calculation formula is shown in formula 2.

$$C_2 = \sum_{i=1}^{n} E_{ti} \times W_{ti} \times D_{ti} \times K_y$$

where: $C_2$ -- carbon emission in transportation stage; $E_{ti}$ -- carbon emission factor of transport component I of transport vehicle; $W_{ti}$ -- transportation quality of component i; $D_{ti}$ -- transportation distance of component i

Table 4-4. Carbon emission calculation of prefabricated buildings in transportation stage

| Transportation volume (T) | Load (T) | Number of vehicles | Transport carbon emission factor kgCO₂ / (T·km) | One way transportation distance (km) | Return coefficient of empty vehicle | Carbon emission (kg) |
|---------------------------|----------|--------------------|-----------------------------------------------|-----------------------------------|-----------------------------------|--------------------|
| 1631.82                   | 18       | 91                 | 0.129                                         | 100                               | 1.67                              | 35154.298          |

4.3.3 Construction stage
Both cast-in-place and prefabricated buildings include the on-site construction stage. The carbon emission in this stage is mainly the carbon emission generated by the energy consumption of the construction machinery during the on-site installation. The specific calculation formula is shown in Formula 3.

$$C_3 = \sum_{i=1}^{n} a_i \times m_i \times g_i$$

where: $C_3$ -- carbon emission in construction stage; $a_i$ -- energy consumption per shift of the I construction machinery;
\( m_i \) -- the number of construction machinery shift \( i \);
\( g_i \) -- the \( i \)-th carbon emission factor of construction machinery.

The carbon emission of prefabricated buildings during construction is calculated, as shown in table 4-5. According to the analysis of table 4-5, the carbon emissions of prefabricated buildings in construction stage are 155300.6kg and 9.901kg/m\(^2\) respectively.

**Table 4-5.** Calculation of carbon emission during construction of prefabricated buildings

| Type of energy used          | Energy consumption | Energy carbon emission factors | Carbon emission (kg) |
|-----------------------------|--------------------|--------------------------------|----------------------|
| Gasoline for machinery (kg) | 4160.3             | 2.9251                         | 12169.29             |
| Diesel oil for machinery (kg)| 6095.6            | 3.0959                         | 18871.37             |
| Electrical power for machinery (kWh) | 203670.8849 | 0.6101                         | 124259.61            |
| total                        | —                  | —                              | 155300.6             |

4.3.4 **Analysis of carbon emission calculation results**

Figure 4-1 are obtained by counting the carbon emission calculation results of prefabricated buildings in different stages. It can be seen from Figure 4-1 that the component production stage is a unique stage of prefabricated buildings. The carbon emission of prefabricated buildings in the transportation stage is larger than that in the construction stage. The carbon emission of prefabricated buildings in the production, transportation and construction stages is 0.665kg/m\(^2\), 2.24kg/m\(^2\) and 9.901kg/m\(^2\) respectively.

![Carbon emission per unit area of prefabricated buildings (kg/m\(^2\))](image)

**Figure 4-1.** Carbon emissions per unit area of prefabricated buildings in different stages

5. **Carbon reduction measures for prefabricated buildings**

5.1 **Production stage of prefabricated components**

Prefabricated component production stage is a unique stage of prefabricated building, which needs reasonable control of carbon emissions. By reasonably improving the production process of prefabricated components, optimizing the product performance and minimizing the waste in the production process, the CO\(_2\) emission in the production process can be effectively reduced and the production cost of prefabricated components can be reduced. At the same time, the prefabricated components are independent of each other, which provides convenience for assembly and disassembly, as well as for the recycling of construction waste. The waste classification and recycling technology for prefabricated construction plants can effectively improve the recycling efficiency of building materials,
and the improvement of the recycling efficiency of building materials also has important significance for carbon emission reduction.

5.2 Transportation phase
Reasonable optimization of logistics transportation scheme needs to consider transportation operation time, transportation mode, transportation path, component loading scheme, etc. Based on the comprehensive analysis of the above factors, we can better organize logistics transportation and reduce unnecessary secondary transportation.

5.3 Construction stage
In the construction process, low-carbon construction management can be implemented, and the goal of saving water, electricity, materials and other resources and energy can be achieved through advanced construction machinery. The construction site can be closed construction, so as to effectively protect the noise in the construction stage of the surrounding residents’ life interference, and also can effectively control the dust problem in the construction site.

6. Conclusion
In this paper, taking the actual project as an example, the carbon emission factor method is applied to calculate the carbon emission of concrete prefabricated and cast-in-place buildings in different stages, and the measures to reduce the carbon emission of prefabricated buildings are put forward.

The carbon emissions of prefabricated buildings in the production, transportation and construction stages are 0.665kg/m², 2.24kg/m² and 9.901kg/m² respectively. Compared with the traditional cast-in-place building, the carbon emission of prefabricated building is greatly reduced.

In the production stage of prefabricated components, by improving the production process, optimizing the product performance and minimizing the waste in the production process, the CO₂ emission in the production process can be effectively reduced. Reasonable optimization of logistics transportation scheme, better organization of logistics transportation and reduction of unnecessary secondary transportation can reduce CO₂ emission of prefabricated buildings in transportation stage.

In the key period of energy conversion between the old and the new, it is an inevitable choice to vigorously develop prefabricated buildings. Through advanced construction machinery, we can achieve the goal of saving water, electricity, materials and other resources and energy, reduce the damage of new buildings to the environment, and provide a feasible strategy for the construction industry in the key period of energy conversion in China.

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