Research on CO₂ Emission Reduction of a Steel Structure Prefabricated Building Considering Resource Recovery

Chunzhen Qiao, Peihao Hu, Qi Pan, Jialin Geng
School of Civil Engineering, North China University of Technology, Beijing, 100144, China
joecz1221@sina.com

Abstract. This paper constructs a carbon emission calculation model for the production, recovery and transportation of steel structure prefabricated building components. Taking a steel structure sales office in Beijing as the research object, the carbon emissions of the dismantled components under non-recycling and different recycling conditions (transport distance and recycling ratio) were calculated. From the perspective of reducing CO₂ emissions, the feasibility of recycling steel components in sales offices is analyzed.

1. Introduction
At present, the production mode of the construction industry is changing. As a core of transformation and upgrading, prefabricated buildings are an important step in the transformation and upgrading of construction. As China develops prefabricated buildings later than other countries, the research focus is not on the recycling of resources after the end of the life cycle of the building. The steel structure building system is the most suitable structural system for the prefabricated construction mode. It has been widely used in civil buildings and industrial buildings for many years. It has the characteristics of good seismic performance, energy saving and environmental protection, and can be recycled and reused. Due to the wide application and characteristics of steel structure construction in the construction industry, more scholars began to study the energy consumption and carbon emission in the stage of steel structure demolition and recycling[1-5]. The main purpose of this paper is to establish a calculation model of energy consumption and carbon emission in the stage of steel structure prefabricated building recycling in combination with the actual situation in China, and take a steel structure sales center in Beijing as an example. In addition, this paper will use the actual calculation data to study and analyze the impact of transportation distance and component recovery utilization on energy consumption and carbon emissions.

2. Calculation model for carbon emission in the recovery stage

2.1. Calculation boundary
The entire life cycle of a prefabricated building can be divided into four phases, namely the production of components, construction and assembly, use and maintenance, and demolition and recycling [6]. This paper will regard the carbon emissions generated in the stage of demolition and recycling as the research object. Look for sources of carbon emissions during this phase and determine the carbon emissions calculation boundary. In the demolition and recycling stage, carbon emissions mainly come from two parts, one is the energy consumption of the equipment when the
components of the original building are dismantled, and the other is the energy consumption when the components are transported to the stacking site.

2.2. Calculation method

2.2.1. Demolition phase. The calculation model uses the carbon emission factor method, in which the building material recovery factor is added for calculation [7]. As shown in the formula (1):

\[ Q_1 = \sum W_i \cdot T_i \cdot \alpha_i \cdot A \]  

In the equation:
- \( Q_1 \) — CO₂ emissions during the demolition phase, t;
- \( W_i \) — demolition of i-device rated power, kW;
- \( T_i \) — run time of i device during the demolition phase, h;
- \( \alpha_i \) — carbon emission factor of i-device consuming energy, kgCO₂/kW·h;
- \( A \) — recovery coefficient.

2.2.2. Transport phase. The CO₂ emissions from the transportation process of building materials refer to the CO₂ emissions converted from the fuel consumption during the transportation of the demolished building materials to the construction site. Among them, the total fuel consumption of building materials transportation [8] is calculated by the formula (2).

\[ T_d = \sum \frac{Q_{in}}{(G_i - G_{i0})} \times \frac{(P_i - P_{i0}) \cdot D_i}{100} \]  

In the equation:
- \( T_d \) — total fuel (diesel) consumed by all building materials transportation, L;
- \( Q_{in} \) — the amount of transportation of the i-th building materials, t;
- \( G_i \) — total mass of loading of truck carrying the i-th construction materials, t;
- \( G_{i0} \) — no-load quality of truck transporting i-th construction materials, t;
- \( P_i \) — fuel (diesel) consumption of truck transporting i-th construction materials, L/100km;
- \( D_i \) — distance between the production site of the i-th building material and the construction site, km.

The calculation of the total fuel consumed by building materials transportation to CO₂ [8] is shown in (3)

\[ Q_2 = \frac{0.84 \times 1.4571 \times 2.62 \times T_d}{1000} \]  

The density of diesel in the calculation is about 0.84 kg/L. The conversion of diesel and standard coal is 1.4571kgce/kg. The conversion of standard coal and CO₂ [8] is 2.62kg/kgce.

3. Case calculation analysis

3.1. General situation

Taking a sales office in Beijing as an example, the building materials are counted in table 1.

| Table 1. Engineering data of a steel structure sales center in Beijing |
|---------------------|-----------------|--------|
| material           | quantity        | unit   |
| steel              | 32.30           | t      |
This article will mainly analyze the recovery and reuse of steel materials, and other materials will not be analyzed. For the convenience of calculation, the size of each 50mm sandwich color steel plate is simulated as a plate shape of 1200*600 mm, and the core material has a thickness of 100 mm. In this case, there are about 604 steel plates. Available from Table 1, the steel is 32.30 tons.

3.2. Calculation and analysis

![Relative position diagram](image)

The following two models are formulated according to the figure 1:

The first model is to use the steel components dismantled and recycled. If the quantity is not enough, transport the additional steel components from the component production factory. The program's carbon emissions are divided into four parts: production, recycling and two transportation parts. The formula (4) is as follows:

\[
Q = Q_1 + Q_{2r} + Q_{2a} + Q_{3a}
\]  (4)

where:
- \(Q\) — Total carbon emissions come from model 1, t;
- \(Q_1\) — CO2 emissions from the demolition phase of the building, t;
- \(Q_{2r}\) — CO2 emissions from transporting dismantled components, t;
- \(Q_{2a}\) — CO2 emissions from the production of additional components, t;
- \(Q_{3a}\) — CO2 emissions from transporting additional components, t.

The second model is to obtain the required steel components directly from the building material production factory. The model has only two parts of carbon emissions. Carbon emissions come from production components and transportation components. The formula (5) is as follows:

\[
Q' = Q_{2p} + Q_{3p}
\]  (5)

where:
- \(Q'\) — Total carbon emissions from model 2, t;
- \(Q_{2p}\) — CO2 emissions from production components, t;
- \(Q_{3p}\) — CO2 emissions from transportation components, t.
3.3. Simulate the carbon emissions of the two plans

3.3.1. CO₂ emissions from building materials production. Carbon dioxide produced during the production of all building materials. The formula (6) is as follows:

\[ Q_3 = \sum q_i \cdot c_i \]  

In the equation:
- \( Q_3 \) — CO₂ emissions from building materials production, t;
- \( q_i \) — production of the i-th building materials, t;
- \( c_i \) — the CO₂ intensity value of the i-th building material during the production process, t/t.

The \( c_i \) refers to the total amount of CO₂ produced by the unit quality building materials during the production process. The \( c_i \) can be converted from the \( e_i \) that production energy intensity value of the building material. The CO₂ intensity value of the steel production process is 2.79 t/t. It can be found from formula (6) that the CO₂ emissions of the steel production process in the building are \( Q_3 = 90.12 \) tons.

3.3.2. CO₂ emissions during transport. According to the tonnage and material characteristics, steel transportation vehicles choose Beijing Ford Daimler Automobile Co., Ltd. The model is BJ4259SNFKB-XJ semi-trailer traction vehicle. It is known that 32.3 tons of steel, using two BJ4259SNFKB-XJ semi-trailer traction vehicles, each weighing 16.15 tons. Total truck loading quality = curb weight + driver and assistant quality + baggage quality. Assuming a total of 150kg for the driver and assistant, the quality of the baggage is 16.15 tons for each piece of steel to be transported. According to the relevant vehicle road transport vehicle parameters, the total loading quality of the truck is 25.105 tons, and the quality of the transportation steel truck is 8.085 tons. The first stage limit is obtained according to the extreme value of the fuel consumption of the diesel semi-trailer train. When the steel is transported, the fuel consumption limit \( P_i \) of the truck is 39.0 L/100 km, and the fuel consumption limit \( P \) of the truck at no load is 39.0 L/100 km. The whole process of the simulation arrives in Ganzhou, which is available from formula (3). The carbon emission of steel transportation of 2 trucks is \( Q_2 = 0.0049X_t \) tCO₂.

3.3.3. Analysis. The above calculation can be obtained: the total CO₂ emission of the first progress is 16.31t, and that of the second progress is 90.12t, saving 82%. Based on the above calculation method and known conditions, the amount of CO₂ produced by different recovery ratios is compared. Three different construction sites are selected, which are located in Tianjin, Jinnan (\( X_1 = 177.9 \)km), Ganzhou (\( X_1 = 1754.0 \)km) in Jiangxi Province and Urumchi (\( X_1 = 2795.1 \)km) in Xinjiang Uygur Autonomous Region. According to the location of the construction site, different distance components production factors are selected, the distances are 10 km, 20 km and 30 km respectively. The calculated data is summarized in table 2.
Table 2. Calculation table for CO₂ amount of recovering materials in different proportions

| CO₂ emissions from production components (t) | New material transportation distance X₂ (km) | Recycled material transportation distance X₁ (km) | CO₂ emissions from non-recycled materials (t) | 30% recycled materials CO₂ emissions (t) | 50% recycled materials CO₂ emissions (t) | 100% recycled materials CO₂ emissions (t) |
|-------------------------------------------|------------------------------------------|-----------------------------------------------|---------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| 90.12                                     | 10.00                                    | 177.90                                        | 92.57                                       | 67.48                                    | 48.70                                    | 1.65                                    |
| 90.12                                     | 20.00                                    | 177.90                                        | 92.57                                       | 67.48                                    | 48.70                                    | 1.65                                    |
| 30.00                                     | 1754.00                                  | 92.57                                         | 71.88                                       | 56.03                                    | 25.99                                    |                                         |
| 30.00                                     | 2795.10                                  | 92.57                                         | 74.78                                       | 60.87                                    | 25.99                                    |                                         |
| 30.00                                     | 177.90                                   | 95.02                                         | 71.97                                       | 56.12                                    | 16.31                                    |                                         |
| 30.00                                     | 2795.10                                  | 95.02                                         | 74.87                                       | 60.96                                    | 16.31                                    |                                         |
| 100%                                      | 177.90                                   | 97.47                                         | 72.06                                       | 56.22                                    | 16.31                                    |                                         |
| 100%                                      | 2795.10                                  | 97.47                                         | 74.97                                       | 61.05                                    | 25.99                                    |                                         |

Diagram of the relationship between recovery and carbon emissions is shown in Figure 2.

Figure 2. CO₂ amount at different recovery ratios

Figure 2 can be seen: When the distance between the steel component factory and the construction site is constant, it can be clearly seen that the amount of carbon dioxide generated during transportation decreases as the proportion of recycled materials increases.

At the same recycling rate, there is little difference in CO₂ emissions from transporting recycled materials. In other words, the proportion of CO₂ emissions generated during the production phase of the component to the total emissions far exceeds the CO₂ emissions during the material transport phase.

3.3.4. Limit calculation. The following article calculates the limit value of the distance from the component production factory to the construction site according to different recovery ratios. Use this limit to determine how to choose a solution to reduce carbon emissions.
30% recycled materials: Let Q=Q', calculated as X2=2606-X1. If the recycled materials are shipped from Beijing to Zhangzhou City, Jiangxi Province, then X1=1754. Therefore, as long as the component production factory is within 852km of the construction site, all the steel components transported from the nearby component production factory will produce fewer carbon emissions.

50% recycled materials: X2=5963-X1 is calculated in the same way. If the recycled materials are shipped from Beijing to Zhangzhou City, Jiangxi Province, X1=1754. Therefore, the transportation of steel components from factories within 4,209 km produces less carbon emissions.

4. Conclusion
The model selected in this paper is the sales office as a temporary building. The reason for the selection is the timeliness of the functional building. As the commercial housing transaction ends, the timeliness of the sales office is over. When a building performs its function locally and does not have any other function, the building needs to be demolished. However, may be able to let it play other functions. After investigation, it was found that steel structural components were used in the sales offices of temporary buildings in Beijing, and the recycling of building materials after demolition was considered. This shows that it is possible to recycle the resources of the sales office. Carbon dioxide emissions from production, transportation, demolition and recycling are discussed primarily in this paper. The following conclusions were drawn:

(1) Production components produce far more CO2 than CO2 produced by dismantling and transport of components of the same quality. Priority is given to the use of recycled steel components to save up to 80% in carbon emissions.

(2) During the transportation of materials, the CO2 emissions are roughly linear with the transport distance of recycled materials.

(3) When the distance of the transport steel components is constant, the CO2 emissions during transportation decrease as the proportion of recycled materials increases.

(4) Establish a limit value calculation model. When determining the starting point and construction site of the recovery component, the limit distance between the factory and the construction site can be calculated to reduce CO2 emissions.

(5) From the above analysis, it can be seen that recycling certain materials to build new buildings will help reducing carbon emissions.

Acknowledgments
This work was financially supported by National Key R&D Plan(2016YFC0701807), the Great Wall scholars reserve project, North China University of Technology (18XN012-071) and General items of science and technology plan of Beijing Education Committee.

References
[1] Wang, J., Zhao, JD., Hu, Z. (2016) Development status and thinking of building industrialization in China. Journal of Engineering, 49(05):1–8.
[2] Xu, YM. (2015) Research on the Sustainable Development of Prefabricated Buildings in China. Wuhan Institute of Technology, Wuhan. 1-9
[3] Chen, S., Cui, DG., Zhang, HJ. (2016) Calculation method and case study of building carbon emissions. Journal of Beijing University of Technology, 42(04):594–600.
[4] Zhao, P., Jiu, M., Liao, L., Han, JH. (2018) Current situation and development of carbon emissions in green hotel buildings. Construction of science and technology, 2018(04):35–38.
[5] Yin, SC. (2012) Accounting analysis of carbon emissions in the whole life cycle of buildings. Harbin Institute of Technology, Harbin. 44-46
[6] Fan, S. (2014) Research on the design and sustainability of sales offices. Beijing Architecture University, Beijing. 33-51
[7] Duan, XP., Wei, LP. (2018) Research on Carbon Emission Calculation of Reconstruction and
Expansion Project Based on Raw Material Recycling—Taking Central College as an Example. Scientific and technological wind, 2018(25):133–134.

[8] Shao, GF., Zhao, XL., Gao, YJ., Zhang, MX., Huo, SX. (2012) Study on Calculation Method of Carbon Emission of Building Materials in Buildings. New building materials, 39(02):75–77.

[9] Transport Services Division, 2018. Road transport vehicle fuel consumption standard vehicle model(47th batch) publicity. http://zizhan.mot.gov.cn/zfxxgk/bnssj/dlyss/201804/t20180427_3014844.html.

[10] Ministry of Communications, Department of Energy Management Office. Operating truck fuel consumption limit and measurement method. 2010(05):25-29