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Analyze Differences in Carbon Emissions from Traditional and Prefabricated Buildings Combining the Life Cycle

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Abstract: Construction, as an important producer of energy, material, and waste emissions, the high energy consumption problem has not been solved. Prefabricated buildings have become more and more popular and promoted in China in recent years. This study takes prefabricated buildings and traditional cast-in-situ buildings as research objects and divides the buildings into five stages: factory building materials production, component transportation, field installation, use, and demolition. In addition, the paper presents the calculation method of carbon emissions in five stages of construction. By calculating the carbon emissions of the two buildings in five stages, the total carbon emissions of the two buildings and the differences in carbon emissions are obtained. In particular, in this case, the prefabricated buildings and traditional cast-in-situ buildings were constructed at the same time and in the same place. It is concluded that prefabricated buildings can reduce carbon emissions by about 86 kg per square meter compared with traditional cast-in-situ buildings. In all stages of carbon emissions, the field installation stage produces the most carbon emissions. Prefabricated buildings consume more concrete, steel bar, and diesel and fewer wall materials than traditional cast-in-situ buildings.

Keywords: prefabricated building; carbon emissions; traditional cast-in-situ building; life cycle assessment

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1. Introduction

In recent years, extreme weather, such as high temperatures, drought, and catastrophic precipitation, has occurred in many places around the world, and natural disasters continue. Buildings account for 32% of the world's total energy use [1,2]. More than 4 billion square meters of buildings have been built annually since 2013, with an estimated 33billion square meters to increase by 2040 and another 17billion square meters by 2060 [3]. Studies have found that building sectors take about 20% of China's total energy consumption in the buildings' operational stage, and if measured from a life cycle perspective, building sectors' consumption account for as high as 43% of total energy consumption [4,5]. The fifth assessment report of the Inter governmental Panel on Climate Change(IPCC) predicted that building-related greenhouse gas emissions would account for about 30% of global greenhouse gas emissions in 2030 [6]. Global climate problems need to be urgently alleviated, and prefabricated buildings are widely recognized by society.

Prefabricated building refers that persons manufacturing prefabricated building components in a factory and then transporting them to the construction site for assembly to achieve rapid assemble components [7,8]. Prefabricated buildings have the characteristics of a manufacturing factory, construction assembly, short construction period, low cost, and so on. In the whole life cycle of buildings, there is little impact of prefabricated buildings on environmental damage and high resource utilization rate. Compared with traditional cast-in-situ buildings, prefabricated buildings are more able to meet the needs of the current society.

Some scholars have studied the carbon emissions during the construction stage of traditional cast-in-situ buildings and prefabricated buildings. Comparing two similar apartments in Hong Kong, suggests that prefabricated exterior walls can reduce carbon emissions by 2.1kg/m^2 [9]. For the carbon emissions of two buildings in Chongqing, the on-site prefabrication model can reduce carbon emissions by 3.1% [10]. Comparing a cast-in-situ office building and a prefabricated office hotel in Chengdu, the prefabricated model can reduce carbon emissions by 8.40% compared to the cast-in-situ model [11]. Comparing two similar residential buildings in Xi'an, prefabricated buildings can reduce carbon emissions by 18% [12]. The above study is only for the construction stage, and the following research is for the full life cycle of the building. When comparing the environmental benefits of prefabricated buildings with traditional cast-in-situ buildings in terms of resource-saving and waste reduction, it is shown that compared with traditional buildings, prefabricated buildings have a clear advantage in waste with a waste reduction ranging from 24.91% to 81.25% [13]. Green buildings can minimize the impact on the environment and maximize the economic and social benefits. Non-green buildings only meet people's living needs and don't make full use of the existing conditions to do something beneficial to society. Comparing the differences between green buildings and non-green buildings in China, it is shown that for residential buildings, the carbon emissions of green buildings are10% lower than that of non-green buildings [5]. For commercial buildings, the carbon emissions of green buildings are32% lower than that of non-green buildings [5]. When comparing the carbon emissions cast on site, it is shown that prefabricated structures can reduce greenhouse gas emissions by 14.10% [14]. By comparing the carbon emissions from semi-prefabricated and cast-in-situ buildings, it is found that semi-prefabricated buildings produce slightly fewer carbon emissions than cast-in-situ buildings [15].

To sum up, there is relatively little existing works of literature on the comparison of carbon emissions between prefabricated buildings and traditional cast-in-situ buildings. Furthermore, two or more buildings in most study cases were not built at the same time, reducing their comparability. In this study case, two different ways of construction are built at the same time and in the same place, making them more comparable. The main purpose of this study is to calculate the carbon emissions produced by prefabricated buildings and traditional cast-in-situ buildings through a case, analyze the difference between the two buildings, and put forward suggestions. To this end, this study uses the life cycle assessment and defines the five stages of the building. The five stages of buildings are factory building materials production, component transportation, field installation, use, and demolition. The resulting carbon emissions are calculated by analyzing the carbon emission sources at each stage and finally by differential analyses. Finally, combined with the case, draw emission reduction recommendations.

2. Research Method

The Life Cycle Assessment(LCA) is a widely accepted method to quantify products or processes that analyze environmental impacts. The application of the LCA is the basis for understanding the real impact of the construction industry on the environment, especially for industrial architecture [16,17]. Most engineering theses are written about the life cycle of the project so as to better reflect the research situation.

Compared to traditional cast-in-situ buildings, prefabricated buildings can save costs, effectively shorten time periods, and reduce carbon emissions for the entire stage. As mentioned by Achenbach et al. [18], the transportation impacts cannot be neglected, as they can represent up to 20% of total embodied impacts. Therefore, according to ISO 14040, the paper divides the life cycle of the prefabricated building into five stages.

The five stages of the prefabricated building life cycle are as follows, as shown in Figure 1:

- Factory building materials production
- Component transportation
- Field installation
- Use
- Demolition

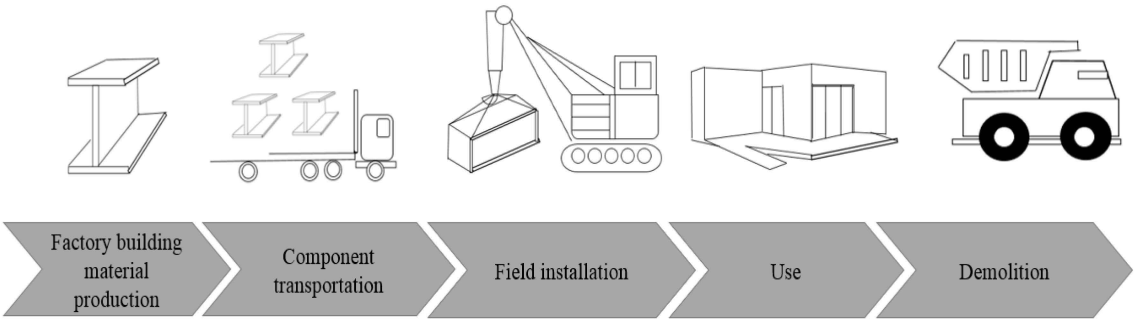

Figure 1. Division of the life cycle of prefabricated buildings.

The carbon emissions during the whole stage of prefabricated buildings mainly come from six aspects during these five stages. First, building materials consumption and the energy consumption during the factory building materials production stage. Studies have shown that building materials production produces the most carbon emissions, accounting for 96.2% [19]. Second, the energy consumption of the vehicle during the component transport stage. Third, the consumption of energy and building materials for machinery during field installation. Fourth, the consumption of building materials during the use stage. Fifth, the energy consumption of machinery during the demolition stage. Sixth, artificial carbon emissions of the whole process. During the whole stage, carbon emissions are mainly from these aspects, produced by building materials, machinery, and labor.

2.1. Carbon Emissions Model

The life cycle of prefabricated buildings is divided into five stages: factory building materials production, component transportation, field installation, use, and demolition. Carbon emissions from the life cycle of prefabricated buildings are calculated as follows:

$$Pref = Pref_1 + Pref_2 + Pref_3 + Pref_4 + Pref_5 + A \tag{1}$$

where, *Pref* denotes total carbon emissions from the life cycle of prefabricated buildings. $Pref_1$, $Pref_2$, $Pref_3$, $Pref_4$ and $Pref_5$ represent, respectively, the carbon emissions of factory building materials production, component transportation, field installation, use, and demolition. A denotes the total carbon emissions generated by workers living and consuming energy throughout the process. Since workers are involved throughout the stage, the carbon emissions generated by workers are calculated separately. The sources and impacts of carbon emissions throughout the stage are shown in Figure 2.

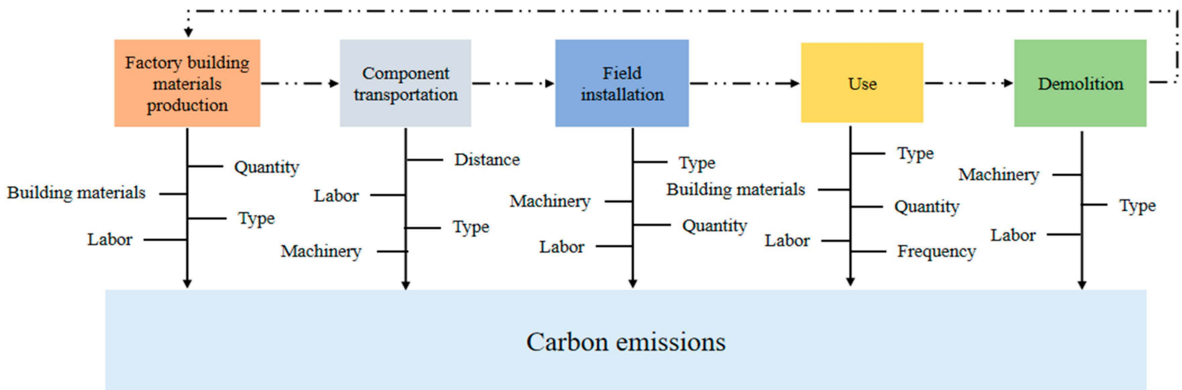

Figure 2. Source and impact of the life cycle carbon emissions.

Figure 2 shows the source of carbon emissions for the whole stage of the prefabricated building and the factors affecting the various stages.

2.2. Analysis of Carbon Emission Sources at Each Stage

Factory building materials production involves the mining of raw materials, the production of building materials in the factory, and the production of some components. The source of carbon emissions is the carbon emissions caused by energy consumption in the production process of mining raw materials and building materials, which is calculated as follows:

$$Pref_1 = \sum_{i=1}^{n} M_i \times F_{M,i} \tag{2}$$

where M_i denotes the use of class I building materials, $F_{M,i}$ demotes the carbon emission factors produced by class i building materials.

The component transportation stage refers to the transportation of the produced building materials and some prefabricated components to the construction site. The source of carbon emissions is carbon emissions from fuel consumed by the transport, calculated as follows:

$$Pref_2 = \sum_{j=1}^{n} D \times E_j \times F_{E,j} \tag{3}$$

where D denotes the distance from the origin to the construction site, E_j demotes the energy consumed by class j transport vehicles, and F_j demotes the carbon emission factors of class j energy consumed by the transport process. The shorter the distance between the factory to the construction site, the less carbon emissions are generated. Ding concluded in the study that carbon emissions during the component transport stage accounted for 5.27% of the whole stage [20]. The paper uses 5.27% as the calculation basis of the component transportation stage.

The field installation stage involves the process of building the prototype. The source of carbon emissions generated by the energy consumption of mechanical operation during hoisting connection and field installation. The calculation method is performed as follows:

$$Pref_3 = \sum_{j=1}^{n} E_j \times F_{E,j} \tag{4}$$

where E_j demotes the amount of energy consumed by class j mechanical equipment, $F_{E,j}$ demotes the carbon emission factors of energy consumed by class j mechanical equipment.

The use stage involves the maintenance of the building. The sources of carbon emissions mainly include carbon emissions generated by materials, resources, and energy used for maintenance during the use stage. The calculation method is as follows:

$$Pref_4 = \sum_{j=1}^{n} (E_j \times F_{E,j}) \times Y + \sum_{i=1}^{n} M_i \times N_i \times F_{M,i} \tag{5}$$

where E_j denotes the annual use of class j energy, $F_{E,j}$ denotes the carbon emission factors of class j energy, Y denotes the service life of buildings, M_i denotes the use of building materials to be replaced in class i, N_i denotes the replacement times of class i building materials, $F_{M,I}$ denotes the carbon emission factors produced by class i building materials.

The demolition stage involves the demolition of buildings and the recycling of building materials. Carbon emissions mainly come from the carbon emissions generated by the mechanical energy consumption used in building demolition and the energy consumption of transporting construction waste. The calculation method is as follows:

$$Pref_5 = \textstyle\sum_{j=1}^{n} E_j \times F_{E,j} \tag{6}$$

where E_j denotes the amount of energy consumed by class j construction machinery and the amount of energy consumed by transporting construction waste, $F_{E,j}$ demotes the carbon emission factors of energy consumed by class j.

Studies have shown that if the reusability of the materials is considered, the concrete structures of prefabricated buildings can reduce carbon emissions by32.3% [21]. In addition, reusable prefabricated modules can reduce material consumption by 75% [22]. Because of the material reuse, carbon emissions in the demolition stage have great uncertainty. Therefore, the carbon emissions in the demolition stage of this paper are calculated as a proportion of the life cycle. In the He Wang study, the demolition stage accounted for 1% of the life cycle [23]. Therefore, this paper takes 1% as the calculation basis for the demolition stage.

Finally, the resources needed for the lives of prefabricated buildings and the carbon emissions from the energy they consume.

$$A = \sum_{q=1}^{n} (R_q \times F_{R,q} + T \times F_b) \tag{7}$$

where R_q denotes the amount of energy consumed when workers live, $F_{R,q}$ denotes the carbon emission factors that consume energy, F_b denotes the carbon emission factors consumed by hourly artificial respiration, and T denotes the duration of manual labor work.

This chapter focuses on a focus on the process of quantifying carbon emissions from the life cycle of prefabricated buildings. The factors generating carbon emissions at each stage are analyzed and producing carbon emissions at each stage is expressed by the formula. In the following chapter, this paper will combine the cases to calculate the carbon emissions at each stage and analyze the data.

3. Differences in Carbon Emissions

Prefabricated buildings and traditional cast-in-situ buildings are different in carbon emissions. This paper will compare the carbon emissions generated from prefabricated buildings and traditional cast-in-situ buildings and, thus, the differences in carbon emissions between prefabricated and traditional cast-in-situ buildings. As mentioned above, 5.27% and 1% were used as calculations for carbon emissions in the component transportation and demolition stages. Therefore, the factory building materials production stage, field installation stage, use stage, and artificial carbon emissions account for 93.73% of the life cycle. Thus, the total carbon emissions of the life cycle can be represented as factory building materials production stage, field installation stage, use stage, and artificial carbon emissions divided by 93.73%. The same is true for calculating carbon emission differences. This paper mainly analyzes the differences in carbon emissions in the life cycle of prefabricated buildings and traditional cast-situ buildings. The differences in carbon emissions from the life cycle of prefabricated and traditional cast-in-situ buildings are expressed by the formula:

$$\Delta C = \sum_{i=2}^{6} C_i \tag{8}$$

where ΔC denotes the differences between carbon emissions in the life cycle of prefabricated buildings and traditional cast-in-situ buildings, namely the sum of the six partial carbon emissions. The variable C_i denotes the differences between the carbon emissions from each stage of prefabricated buildings and traditional cast-in-situ buildings. If $\Delta C > 0$, it means that prefabricated buildings produce more carbon emissions. In other words, prefabricated buildings have poor environmental benefits. If $\Delta C < 0$, it means that prefabricated buildings produce fewer carbon emissions. In other words, the environmental benefits of prefabricated buildings are better. If $\Delta C = 0$, it means that the carbon emissions from prefabricated buildings and cast-in-situ buildings are equal.

4. Case Analysis

4.1. Project Background

This case explores the differences in carbon emissions between prefabricated buildings with traditional cast-in-situ buildings in the same project to ensure comparability. Distinguishingly, prefabricated buildings and traditional cast-in-situ buildings are constructed simultaneously. The study takes the relocation and renovation project of a company in Dalian, China. The project includes two public buildings, four small high-rise buildings and six foreign-style houses, cultural activities sites, property management sites, and many other life service facilities. All the construction facilities of the project meet the living needs of 4004 households. The planning diagram of the relocation project of a company is shown in Figure 3.

Figure 3. Planning diagram of the relocation project of a company.

The project adopts prefabricated on the 3~13th floors of 1# floors (13th floors), 3~14th floors of 4# floors (14th floors), 2# floors, and 1~8th floors of 3# floors (9th floors). The design of prefabricated buildings includes using prefabricated stairs, balcony board, prefabricated inner wallboard, combined forming steel products, and so on. In this study, buildings 1to 4# of the project were used for the calculation and analysis of carbon emissions in the life cycle. The project has a total of 20,316 square meters, with a prefabricated assembly rate ranging from 20.2 to 20.8%. In contrast to the other cases, the case outperforms other cases in that prefabricated and traditional cast-in-situ buildings are built in a project and are constructed simultaneously. Therefore, this case analysis is comparable and persuasive.

4.2. Project Analysis

For prefabricated buildings, component transportation is much more step than for traditional cast-in-situ buildings. The calculation of the component transportation stage will be explained above, using the total carbon emissions multiplied by 5.27% as the component transportation stage. Therefore, it can be calculated that the carbon emissions of prefabricated buildings are 484,857.8kg, and that of traditional cast-in-situ buildings is 577,171.3kg. Therefore, the differences between carbon emissions from prefabricated buildings and traditional cast-in-situ buildings in the component transportation stage are:

$$C_2 = 484,857.8 - 577,171.3 = -92,313.5 \text{ kg}$$

The following article will calculate the carbon emissions from the project field installation stage. For prefabricated buildings, the carbon emissions generated by factory building materials production are calculated for the field installation stage. In this way, it can be compared with the carbon emissions generated by traditional cast-in-situ buildings, and it will be more comparable. That is to say, when counting the concrete consumption in the field installation stage, the prefabricated component concrete consumption of prefabricated buildings is taken into account. Therefore, the consumption of prefabricated building concrete is far more than that of the consumption of traditional cast-in-situ buildings. The same is true of the consumption of prefabricated steel bars in prefabricated buildings. The formwork is mainly made of wood, but the steel template recycling situation is not considered in this paper. Thus, the formwork consumption is used as the wood consumption to analyze. Table 1 lists differences in carbon emission during the field installation stage.

Table 1. Differences in carbon emissions during the field installation stage of the project.

Type	Carbon Emission Factor	Prefabricated Building Project	Carbon Emissions from Prefabricated Building Project (kg)	Traditional Cast-in-Situ Building Project	Carbon Emissions from Traditional Cast-in-Situ Building Project (kg)
concrete	321.3 $kgCO_2eq/m^3$	7837.3982	2,518,156.052	6949.3405	2,232,823.103
steel bar	2617 kg CO_2eq/t	922.8561014	2,415,114.417	836.506101	2,189,136.466
block	0.4826 $kgCO_2q/m^3$	946.5242	456.7925789	8130.4023	3923.73215
wood	33.1 $kgCO_2eq/m^3$	64,831.04143	2,145,907.471	67,783.9406	2,243,648.434
wall	334.8 $kgCO_2eq/m^3$	2911.34	974,716.632	8228.3	2,754,834.84
water	0.1891 $kgCO_2eq/m^3$	1422.12	268.922892	3047.4	576.26334
diesel	3.67 $kgCO_2q/kg$	5688.48	20,876.7216	11,783.28	43,244.6376
electricity	0.97 $kgCO_2eq/kw{\cdot}h$	257,810.04	250,075.7388	414,446.4	402,013.008
coal	2.89 $kgCO_2eq/kg$	25,395	73,391.55	0	0
Total			8,398,964.299		9,870,200.484

In order to see the data gap more clearly, this paper made bar charts according to the data in Table 1, as shown in Figure 4.

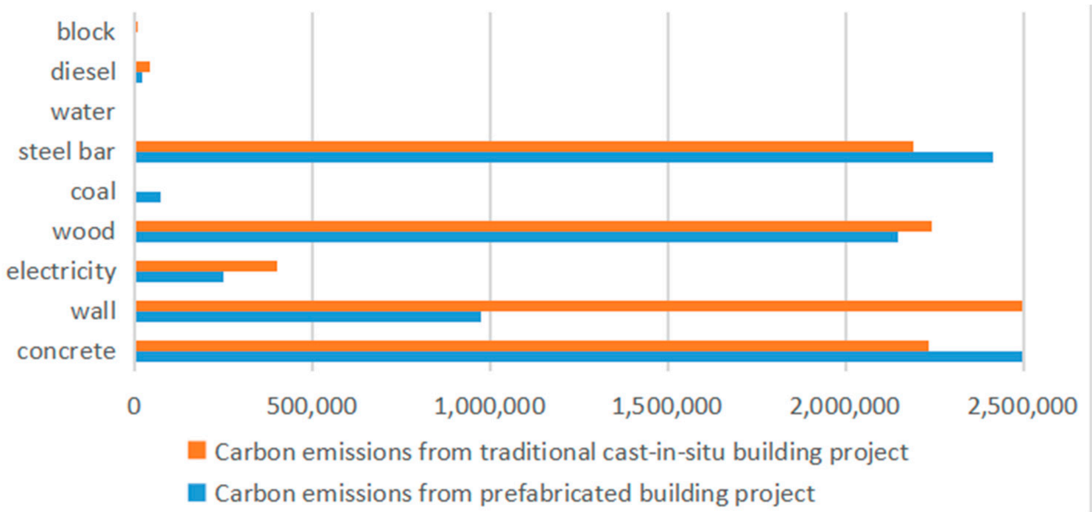

Figure 4. Bar chart of carbon emissions differences in the field installation stage.

As can be seen in Figure 4, compared to the traditional cast-in-situ building, carbon emissions from concrete and steel bars increase. Therefore, prefabricated buildings need to be improved in the future inthe optimization of concrete, steel bar, and other raw materials. The total carbon emissions in the field installation stage have been reduced, among which the carbon emissions of blocks, wood, and walls all have an obvious saving effect. During the field installation stage, differences in carbon emissions are water, diesel, electricity, and coal, especially the consumption of coal used from mechanical equipment. As can be seen in Figure 4, the differences between carbon emissions from prefabricated and traditional cast-in-situ building during field installation is:

$$C_3 = 8,398,964.299 - 9,870,200.484 = -1,471,236.185 \text{ kg}$$

According to the maintenance records of the use stage of the project, compared prefabricated buildings with traditional cast-in-situ buildings, the main projects with carbon emission differences may have the concrete base plastering layer empty drum, internal wall brick wall, cracks, external wall crack maintenance projects, external wall insulation maintenance projects, plastering layer surface cracks maintenance projects and so on. The materials mainly involved in the use stage of the project include concrete block (brick wall), plain cement slurry, polymer mortar, cement mortar, putty, insulation bonding adhesive, protective layer rubber slurry, alkali-resistant grid cloth, tap water PPR pipe, wire PVC pipe, plastic wire groove and so on. Relevant materials are shown in Table 2.

Table 2. Differences in carbon emissions during the use stage of the project.

Material	Carbon Emission Factor	Prefabricated Building Project	Carbon Emissions from Prefabricated Building Project (kg)	Traditional Cast-in-Situ Building Project	Carbon Emissions from Traditional Cast-in-Situ Building Project (kg)
concrete block	0.4826 $kgCO_2eq/m^3$	40	19.304	70	33.782
Fine aggregate concrete	298.7 $kgCO_2eq/m^3$	40	11,948	60	17,922
Structural concrete pouring	321.3 $kgCO_2eq/m^3$	100	32,130	200	64,260
plain cement slurry	321.3 $kgCO_2eq/m^2$	110	35,343	250	80,325
polymer mortar	2.556 $kgCO_2eq/m^2$	60	153.36	180	460.08
cement mortar	469.4 $kgCO_2eq/m^3$	110	51,634	250	117,350
putty	5.394 $kgCO_2eq/m^2$	110	593.34	250	1348.5
Insulation bonding adhesive, protective layer rubber slurry, alkali-resistant grid cloth	3 $kgCO_2eq/m^2$	50	150	180	540
tap water PPR pipe	0.5 $kgCO_2eq/m$	160	80	320	160
wire PVC pipe	1 $kgCO_2eq/m$	170	170	360	360
plastic wire groove	0.7 $kgCO_2eq/m$	160	112	320	224
coal	2.89 $kgCO_2eq/kg$	31,896.12	92,179.7868	38,803.56	112,142.2884
Total			224,512.7908		395,125.6504

The materials in Table 2 include annual fixed consumption and maintenance and irregular non-fixed consumption, such as overhaul. In terms of energy, because the thermal insulation performance of prefabricated buildings varies greatly compared with the traditional cast-in-situ buildings, it directly affects energy consumption. Judging from the data of coal consumption, the coal consumption is still relatively large, which is where the prefabricated building needs to be optimized in the future. It can be seen from the data in Table 2 that the more carbon emissions are from coal, cement mortar, plain cement slurry, and structural concrete pouring. The differences in carbon emissions are mainly derived from concrete pouring, plain cement slurry, cement mortar, and so on. They are all prefabricated buildings that produce fewer carbon emissions. As shown in Table 2, the differences in carbon emissions between prefabricated building and traditional cast-in-situ building is:

$$C_4 = 224,512.7908 - 395,125.6504 = -170,612.8596 \text{ kg}$$

The demolition stage is mainly used with excavator buildings for demolition. Removed construction wastes are transported to the landfill for landfill treatment, and recyclable materials are transported to the designated locations for recycling treatment. The calculation of the demolition stage will be explained above, using the total carbon emissions multiplied by 1% as the demolition stage. The demolition stage of traditional cast-in-situ building also accounts for 1% of the life cycle. Therefore, it can be calculated that the demolition stage of a prefabricated building is 92,003.4 kg, and that of a traditional cast-in-situ building is 109,520.2kg. So, the differences in carbon emission between prefabricated building and traditional cast-in-situ building during the demolition stage is:

$$C_5 = 92,003.4 - 109,520.2 = -17,516.8 \text{ kg}$$

On artificial carbon emissions, this paper starts with labor. The worker salary in this paper is calculated by each work quantity, and the total salary of workers is the amount of each project multiplied by the worker salary corresponding to each work quantity. Workers in prefabricated buildings pay 3,649,809CNY, and workers in traditional cast-in-situ buildings pay 3,673,376CNY. Because the percentage differences between both workers 'wages are close to 1, this paper treats the carbon emission differences produced by workers as 0; in other words, $C_6 = 0$.

In conclusion, the differences in carbon emissions in the life cycle of prefabricated buildings and traditional cast-in-situ buildings are:

$$\Delta C = C_2 + C_3 + C_4 + C_5 + C_6 = -1,751,679.3446 \text{ kg}$$

Because $\Delta C < 0$, prefabricated buildings produce fewer carbon emissions, in other words, the environmental benefits of prefabricated buildings are better. In this project, prefabricated buildings reduced about 86 kg per 1 m^2 in carbon emissions compared with the project under traditiona lcast-in-situ buildings.

5. Discussion

5.1. Analyze the Carbon Emissions Produced at Each Stage

This study presented the carbon emissions from each stage of prefabricated buildings and traditional cast-in-situ buildings, as shown in Figure 4. As mentioned earlier, since traditional cast-in-situ buildings do not have a link to the component production process, the carbon emissions generated by materials production are attributed to the field installation stage. So, the carbon emissions of the building in Figure 5 are in four parts.

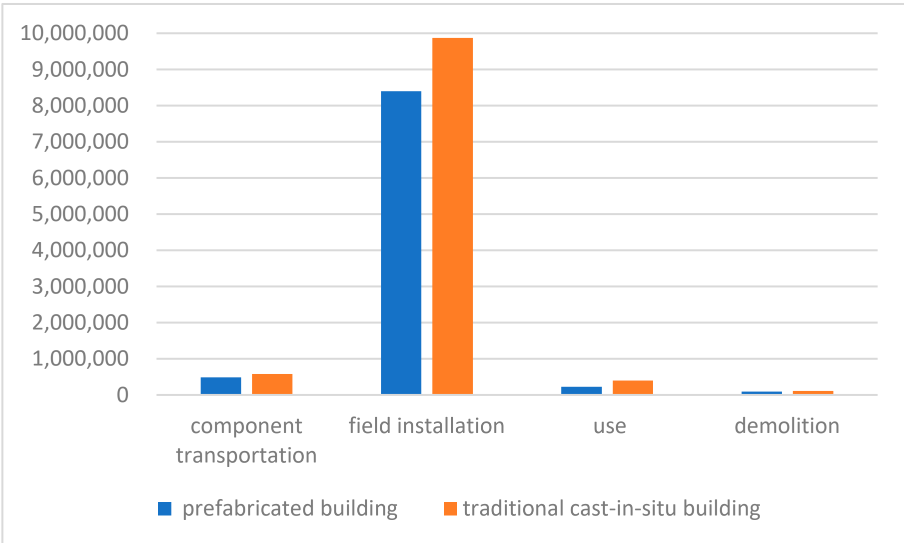

Figure 5. Carbon emissions of each stage in prefabricated buildings and traditional cast-in-situ buildings.

According to Figure 5, traditional cast-in-situ buildings produce more carbon emissions than prefabricated buildings. In addition, the most carbon emissions from buildings are during the field installation stage.

5.2. Analysis of the Influence of Building Materials on Carbon Emissions

This study presented the sources of carbon emissions at this stage separately, as shown in Figure 6. Originally, there were nine differences in carbon emissions at this stage, such as concrete, steel bar, block, wood, wall, water, diesel, electricity, and coal. However, blocks, diesel, and water produce fewer carbon emissions, so in Figure 6, there are only six prefabricated buildings and five in traditional cast-in-situ buildings.

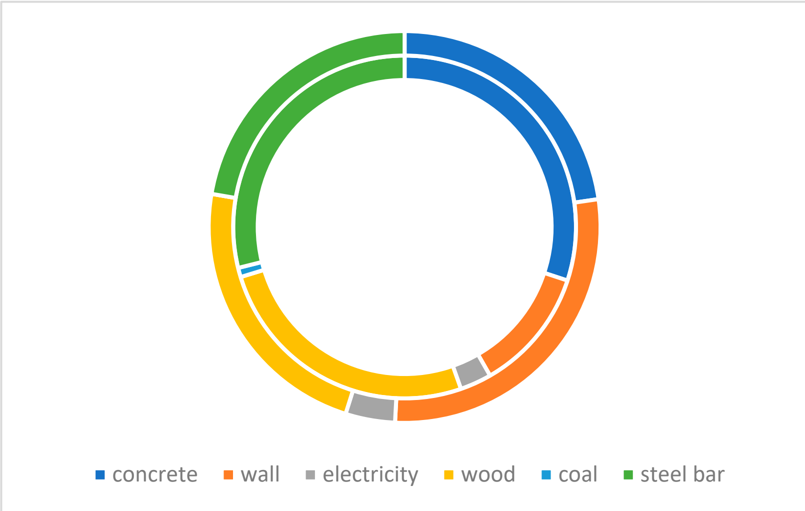

Figure 6. Carbon emissions of field installation in this project.

In Figure 6, the inner circle is a prefabricated building, and the outer circle is a traditional cast-in-situ building. As can be seen from Figure 6, concrete, steel bar, and wood consumption account for more consumption in these two construction methods. Prefabricated buildings consume more concrete and steel bars than traditional cast-in-situ buildings, while traditional cast-in-situ buildings consume more wall materials than prefabricated buildings.

5.3. Emissions Reduction Recommendations

The case shows that prefabricated buildings, which produce fewer carbon emissions, consume more fossil fuels. Furthermore, the Chinese government mandated that 30% (by building floor area) of the nation's annual new construction will be built in a prefabricated manner by 2025 [24]. So, in order to better promote prefabricated buildings, cleaner energy sources should be developed and used to reduce the environmental footprint of prefabricated buildings. For example, the Chinese government should continue to promote the transformation of green electricity, using natural gas instead of coal to provide steam for curing concrete products help lower their air pollution emissions. Diesel is used during both the transportation and field installation stages, and diesel use can cause air pollution. So, replacing diesel with biodiesel and liquefied natural gas can make buildings more environmentally friendly [25]. Furthermore, to realize the effective construction of prefabricated buildings, contemporary departments promote vigorously autoclaved aerated concrete block prefabricated multistorey building technology, which can improve the economic benefits and social benefits [26]. According to research, China's coal replacement policy during the 13th Five-Year Plan period will reduce carbon emissions from the construction industry by 20–29% [27]. Using wood floors instead of ceramic tiles, buildings can reduce 0.16–2.85 t of carbon emissions per unit [28]. These studies suggest that building carbon emissions can be reduced by changing materials. Prefabricated buildings will be widely popularized in the future, so it is necessary to improve the relevant measures of prefabricated buildings.

6. Conclusions

Global climate affects people's lives, so energy consumption and environmental pollution have attracted widespread social attention. As one of the high-energy consumption industries, it is urgent to achieve sustainable development. This study explored an analytical framework to quantify differences in carbon emissions between prefabricated buildings and traditional cast-in-situ buildings. Specifically, this study identified the five phases of building, and the carbon emission sources in each phase. The five stages are factory building materials production, component transportation, field installation, use, and demolition phase. In addition, this study used a quantitative process-based model to calculate and analyze the carbon emissions of the project. By analyzing prefabricated buildings and cast-in-situ buildings constructed at the same time and in the same place, the differences and characteristics of carbon emissions are illustrated by comparing the prefabricated buildings and traditional cast-in-situ buildings.

Results indicate that prefabricated buildings reduced about 86 kg per 1 m^2 in carbon emissions compared with traditional cast-in-situ buildings in this project. In the life cycle of buildings, it is common that the field installation stage produces more carbon emissions. In this case, both prefabricated and traditional cast-in-situ buildings consume more concrete, steel, and wood. Compared with traditional cast-in-situ buildings, prefabricated buildings consume more concrete, steel bar, and diesel and fewer wall materials. Prefabricated buildings can reduce carbon emissions by changing the type of materials. Hopefully, in the future, the above suggestions can be improved, and prefabricated buildings will be widely popularized.

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Acronyms

IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
ISO	International Standardization Organization
PPR	Polypropylene-Random
PVC	Polyvinylchlorid
CNY	Renminbi Chinese Yuan

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