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Research on Carbon Emissions of Green Buildings Based on LCA

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Abstract: In recent years, with the rapid development of China, carbon emissions have also increased year by year. China once proposed at the Paris Climate Conference that by 2030, the carbon dioxide emissions per unit of GDP will fall by 60%-65% compared with 2005, and peak as early as 2030, so China faces enormous pressure on carbon emission reduction. According to statistics, the carbon emissions of the construction industry are 40% of China's total carbon emissions. Therefore, the development of green buildings as a solution to reduce carbon emissions in the construction industry has received increasing attention in China. This paper attempts to use a full life cycle assessment (LCA) method to compare and analyze the carbon emissions of green and non-green buildings, and selected 21 construction projects in China, including 12 green buildings and 9 non-green buildings for research. This paper also divides the whole life cycle of the building into five stages, which are the production and processing of building materials, the transportation of components, the on-site assembly construction, the construction operation and the stage of building demolition, and then calculate the carbon emissions of each stage separately. In the first, second, third and fifth stages, the impact of the prefabricated buildings on the carbon emissions of green buildings is taken into account, which makes the research more accurate. The results show that the carbon emissions of green buildings are lower than the carbon emissions of non-green buildings, and in the five phases of the whole life cycle of the building, the carbon emissions in the construction operation stage account for the highest proportion, reaching about 80%. In addition, the higher the assembly rate of the building, the lower the carbon emissions of the entire life cycle. And for residential and public buildings, the impact of different building structures on their carbon emissions is different.

Keywords Whole life cycle assessment method, Green building, Prefabricated building, Carbon emissions

INTRODUCTION

As one of China's five pillar industries, the construction industry consumes huge energy while promoting the development of the national economy, and it has caused huge pollution to the environment. The carbon dioxide emissions of the construction industry throughout the life cycle are also huge, and China is a major carbon emitter, facing huge domestic and international emission reduction pressures. The Chinese government has promised to reduce carbon dioxide emissions by 40%-45% by 2020 and 60%-65% by 2030 [Allouhi, *et. al.*, 2015]. According to relevant statistics, about 40% of the world's annual energy consumption is related to construction. The carbon dioxide emissions of the construction industry account for about 36% of the total global carbon dioxide emissions[Gao, *et. al.*, 2018]. Therefore, reducing energy consumption and carbon dioxide emissions in the construction sector is very important for reducing carbon emissions in China and around the world.

The main way to reduce carbon dioxide emissions from the construction industry is to promote green buildings. China's "13th Five-Year Plan" mentions that by 2020, the proportion of green buildings in urban new buildings will exceed 50%. Therefore, the development of green building has become an important direction of China's construction industry. In the past, people's focus on building carbon emissions was mostly concentrated in the operation and maintenance stage. Few people considered the carbon emissions generated from the perspective of the whole life cycle of the building. The evaluation of green buildings from the perspective of the whole life cycle Carbon emissions make the evaluation of the whole life cycle assessment (LCA) method to evaluate the carbon emissions of green buildings throughout their life cycle. In addition, the traditional construction methods of green buildings will be changed and combined with prefabricated buildings to further reduce the carbon emissions of green buildings, so as to make green buildings more green and low-carbon and more scientific in the calculation results of carbon emissions. Finally, the carbon emission reduction of green buildings can be predicted more reasonably and accurately.

In 1996, the method of full life cycle assessment was applied for the first time in the calculation and evaluation of building energy consumption [Raymond, *et. al.*, 1996]. As the global environment continued to degradation, people are turning their attention to controlling carbon emissions. Michya used the LCA model to evaluate the carbon emissions of an office building in Japan in 1998 [Michiya, *et. al.*, 1998]. However, these studies are based on carbon emissions data for the entire life cycle of a single building, and there is no general applicability.

In 2010, Ramesh show that 80%-90% of the building's energy consumption is in the operation and maintenance phase of the building, and the rest 10%-20% energy consumption is at other stages[Ramesh, *et. al.,* 2010]. In the literature, the carbon emissions calculated and the evaluation of energy consumption in the construction industry are wide-ranging, numerous and representative. In 2011, Tianyan Wu applied a full life cycle assessment method for low-carbon buildings, and evaluated it in planning, design, construction, operation and maintenance, and demolition and recycling literature [Wu, *et. al.,* 2012]. It further explores the construction industry in carbon reduction and energy saving methods and the ways of healthy sustainable development, and uses the LCA method to study the carbon emissions of buildings. Therefore, people gradually focused their attention on details and green buildings. Zhang Xiaoling conducted a study on the carbon Evaporation of the construction process in the whole life cycle of a construction case in Hong Kong and proposed an inventory analysis method for carbon emission estimation [Xiaocun, *et. al.*, 2015]. when South Korea SeungjnnRsh evaluating the carbon emissions of green buildings, integrated the British BREEAM standard [Haapio, 2008] and the US LEED evaluation method [Srinivasan, *et. al.*, 2014], proposed a new green building carbon emission evaluation method, and through the reasonable refinement of standards reduced carbon emissions[Seung, *et. al.*, 2016]. However, Xiaoling Wu added the impact of climate on building carbon emissions to the study based on previous studies of life cycle carbon emissions. He divided China into seven climate zones and assessed the life-cycle carbon emissions of two different types of buildings, public and residential, which gave his results more authority [Xiaoying, et. al., 2017]. As the global environment degradations, the pressure on carbon emission reduction is increasing. Because the construction industry is one of the industries with the largest carbon emissions, people are constantly seeking ways to reduce carbon. Pan Wei et al. found that inconsistent system boundaries would make a difference when conducting LCA evaluations, as a breakthrough to find new ways to reduce emissions [Wei, *et. al.*, 2018]. Xiaochun Zhang proposed that when evaluating buildings with LCA method, a random comparison method could be used to seek a breakthrough in emission reduction method. Steven M used energy-efficient equipment to create a building with nearly zero life-cycle energy consumption, contributing to the global carbon reduction industry.

Innovating on the basis of previous studies, this study divides the whole life cycle of a building into five stages, followed by the production and processing of building materials, the transportation of components, the on-site assembly construction, the construction operation and the stage of building demolition, then calculate the carbon emissions at each stage separately, and take into account the impact of the prefabricated buildings on the carbon emissions of green buildings in phases 1, 2, 3, and 5, so that the research is more accurate. The carbon emission of green building and non-green building is calculated by LCA method respectively, and the carbon emission of the two is compared, so as to carry out sensitivity analysis and put forward policy Suggestions for carbon emission reduction of China's construction industry.

METHOD

Overview of the method

The full life cycle assessment model (LCA) is a common and mature method for estimating the total carbon emissions of a building's life cycle. In the process of conducting a green emission of fabricated green buildings, this paper uses the LCA model to the five stages include: production and processing of building materials, transportation of components, on-site assembly and construction, operation and maintenance, and demolition and recycling. Calculate the carbon emissions per square meter of assembled buildings by calculating the carbon emissions of these five stages. And use the LCA method to compare and analyze the carbon emissions of 21 green and non- Green buildings in China, and research on the main factors affecting carbon emissions. The life cycle carbon emission analysis process is as follows:

Firstly, define the boundaries of the system under study by excluding the influence of other environments. Then, collect the raw data and basic information of 21 buildings. The third step is to analyze the collected data and information and collate them. In the process of collating the data, return to the second step if any problem is found in the accuracy of the data or any omission is found. The fourth step is to calculate the collated data. In this step, the carbon emissions of the five phases of the building's life cycle are calculated and aggregated separately to arrive at the carbon emissions of the life cycle of the case building. Finally, analyze the calculated results from the perspective of lca and compare and analyze the carbon emissions of green and non-green buildings. The entire flow chart is shown in Figure 1.

Determination of the boundary of the LCA system

The carbon emissions in some stages are of little significance to this study, so it is necessary to determine the research boundary of the LCA system when performing detailed calculations. The life cycle of a building is the process from the "cradle to the grave" of the building. In this paper, the carbon emissions of buildings during their life cycle can be divided into five research stages: mining of raw materials and production and processing of components, assembly and transportation, on-site assembly and construction, building operation and maintenance, and building demolition and recycling.

These five phases are used as system boundaries for the study of carbon emissions from the entire life cycle of the building, thereby reducing the impact of other systems on the study. Figure 2 below is a schematic diagram of the study boundary.

The first phase of the extraction of raw materials and the production and processing of building components. At this stage, some green building materials are used as much as possible to reduce carbon emissions in the process. The transportation of the building components from the manufacturer to the construction site, the carbon emissions in this process is the second phase, that is the transportation phase of the components. The assembly parts arrive at the site for actual assembly and construction, and the carbon emissions generated by various mechanical equipment and on-site lighting are the third stage. The fourth stage is the operation and maintenance phase, which is the stage with the most carbon emissions. The building use time is generally 35-100 years. In this paper, the building life is considered to be 50 years. The carbon emissions in this phase are mainly derived from heating, water, air conditioning systems and maintenance related carbon emissions during the refurbishment process. After 50 years, the building will be demolished and the building enters the fifth phase, which includes carbon emissions from the mechanical equipment used in the demolition process. When recycled waste is reused, carbon emissions due to re-production of transportation and building materials are no longer calculated, so as to avoid double counting affecting the research results.

Calculate carbon emissions at each stage

The carbon emissions at each stage of the study are calculated by the equation. The calculation formulas for the production, processing, transportation and on-site assembly of the building components of the prefabricated building refer to the carbon emission analysis and calculation method of the whole process of the prefabricated building construction by Yin Shichao et al. For the determination of carbon emission factors, refer to the papers of Li Xuedong, Yan Yan, Zhao Ping, et al., and the data of the National Development and Reform Commission and IPCC formulas (1)-(8) are the life of assembled green buildings. The calculation formula for the five stages of the life cycle.

$Q = Q_m + Q_t + Q_c + Q_o + Q_d$ （1）

Q: $Totalcarbonemissionsfromtheentirelifecycleofthebuilding$

Qm: $Carbonemissionsfromtheproductionandprocessingstagesofbuildingcomponents$

Qt: $Carbonemissionsduringtransportation$

Qo: $Carbonemissionsduringoperationandmaintenance$

Qd: $Totalcarbonemissionsduringthedemolitionandrecoveryphase$

$Q_m = Q_{m1} + Q_{m2}$ （2）

Qm: $Carbonemissionsfromtheproductionandprocessingstagesofbuildingcomponents$

$Qm1$: $Totalcarbonemissionsfromrawmaterialsconsumption$

$Qm2$: $Totalcarbonemissionsduringcomponentproduction$

Calculation of carbon emissions during component production and processing:

$Q_{m1} = \sum_{i=1}^{n} q_i \times e_i$ （3）

qi: $Theamountofrawmaterialsused\ (kg)$

ei: $Carbonemissionfactorsforrawmaterialproduction$

i: $Typeofrawmaterials$

$Q_{m2} = \sum_{i=1}^{n} (F_{id} \times M_d + F_{ig} \times M_g + F_{ie} \times M_e)$ （4）

Fid、Fig、Fie: $memberiConsumptionofdiesel, gasoline, electricity$

Md、Mg、Me: $Carbonemissionfactorsfordiesel, gasolineandelectricity$

Build carbon emissions during the transportation phase:

$Q_t = \sum_{i=1}^{n} E_{ti} \times W_{ti} \times D_{ti} \times k_y$ （5）

Qt: $Carbonemissionsduringtransportation$

Eti: $TransportationvehicletransportcomponentsiCarbonemissionfactor$

Wti: $memberiTransportationquality\ (kg)$

Dti: $Transportationdistance\ (km)$

ky: $Emptyreturnfactor$ 1.67

Construction assembly stage

$Q_c = \sum_{i=1}^{n} (F_{id} \times M_d + F_{ig} \times M_g + F_{ie} \times M_e + F_{iw} \times M_w)$ （6）

Qc: $Total\ carbon\ emissions\ per\ unit\ volume\ during\ construction\ and\ installation$

Fid、Fig、Fie、Fiw: $memberiConsumption\ of\ diesel, petrol, electricity\ and\ water$

Md、Mg、Me、Mw: $Carbon\ emission\ factors\ for\ diesel, gasoline, electricity\ and\ water$Operation and maintenance phase

$Q_o = \sum_{i=1}^{n} QE_i \times e_i \times \alpha / A$ （7）

Qo: $Carbonemissionsduringoperationandmaintenance\ (kg/m^2)$

QEi: $No.iEnergyemissionfactor$
ei: $No.iEnergyconsumption$
α: $Buildingage$
A: $totalareaofbuildings(m^2)$
Demolition and recycling phase
$Q_d = (0.06\varepsilon + 2.01)/A$（8）
Qd: $Totalcarbonemissionsduringthedemolitionandrecoveryphase$ (kg/m^2)
ε: $Buildinglayers$
a: $buildingarea$ (m^2)

Determination of carbon emission factors

Table 1. carbon emission factors of major transportation modes [21]

Transportation form	The railway transport	Road transport	Water route	Air transport
Carbon emission factor[kgCO_2/(t*km)]	0.0165	0.0556	0.0133	1.2922

Table 2. carbon emission factors of major building materials[22-26]

Name of building materials	Unit	Carbon emission factor t	Name of building materials	Unit	Carbon emission factort
C30 concrete	m^3	0.250	gravel	m^3	0.050
wood	t	0.200	lime	t	1.200
brick	t	0.200	Polystyrene board	t	3.130
aluminum	t	2.370	Architectural pottery	t	1.400
PVC	t	6.260	Architectural glass	t	1.400
Cast iron	t	3.080	sand	t	0.050
Rock wool	t	0.350	Large steel	t	1.722

Table 3. carbon emission factors of transportation and electric power

Type	Carbon emission factor
Gasoline（kg CO_2 eq/L）	2.26
Diesel（kg CO_2 eq/L）	2.73
Electric power（kg CO_2 eq/kwh）	0.78
Heavy duty diesel truck（30t）	0.0578

Case Study Analysis

This paper studies the carbon emissions of green building life cycle, and selects case data of 21 projects in China, including 14 residential buildings and 7 commercial buildings. In these building cases, there are 9 green residential buildings (GRB1-GRB9), 3 green public buildings (GPB1-GPB3), 5 non-green residential buildings (NGRB1-NGRB5) and 4 non-green public buildings (NGPB1-NGPB4). These projects all use shear wall or frame shear Wall infrastructure, and green building assembly rate of In the first stage of prefabricated parts production, mainly in the use of green building materials and energy consumption to reduce carbon dioxide emissions. In the prefabricated parts transportation phase, mainly used Heavy-duty diesel trucks undertaking transportation tasks. Process caused carbon emissions to be primarily generated by diesel combustion. The carbon emissions in on-site assembly construction mainly come from the electrical energy consumption of construction equipment and on-site lighting. The construction speed of fabricated buildings is faster than that of traditional buildings. a lot, thus shortening the construction period and reducing the amount of work and the amount of building formwork, while also reducing carbon emissions. Use and maintenance of the building, according to China's "national residence the building maintenance cycle specified in the act assesses the amount of consumables in the operation and maintenance cycle of the building, as well as the amount of energy consumed during use, to calculate the carbon The total emissions cycle is over. The carbon emissions at the stage are mainly from the energy consumption of the demolition equipment and the carbon emissions from the transportation of construction waste .

Calculate the carbon emissions per square meter of various buildings by using the above formula. The specific data and calculation results of the calculated cases are shown in Table 4 below.

Table 4. case specific data and calculation results

The project name	Building floor number (floor)	The basic structure	Prefabricated rate（%）	$LCCO_2(kg/m^2)$
GRB1	22	Shear wall	65	2200
GRB2	26	Shear wall	70	2235
GRB3	19	Frame shear wall	70	2345
GRB4	16	Shear wall	65	2395
GRB5	22	Frame shear wall	62	2495
GRB6	19	Frame shear wall	66	2670
GRB7	22	Frame shear wall	72.5	2691
GRB8	32	Frame shear wall	72	2755
GRB9	19	Frame shear wall	72	2795
NGRB1	16	Frame shear wall	—	3424
NGRB2	20	Frame shear wall	—	4206
NGRB3	18	Shear wall	—	4194
NGRB4	16	Frame shear wall	—	3484
NGRB5	9	Frame shear wall	—	2294
GPB1	3	Frame shear wall	67	3949
GPB2	2	Frame shear wall	62	3738
GPB3	3	Frame shear wall	65	3934
NGPB1	2	Shear wall	—	5072
NGPB2	2	Frame shear wall	—	5117
NGPB3	2	Frame shear wall	—	5562
NGPB4	3	Frame shear wall	—	7820

RESULT

The entire life cycle of residential buildings CO_2 Emission（$LCCO_2$）

Through all stages of the life cycle of 9 prefabricated green residential buildings and 5 non-green traditional buildings CO2 Emissions are calculated, and the total number of buildings isCO2Emissions, and calculate the average of two types of buildings per square meterCO2 emissions. As shown in Figure 3.

The $LCCO_2$ emissions of the nine prefabricated green residential buildings ranged from 2,200kg/m^2 to 2,795kg/m^2, with the highest CO_2 emissions of the building being approximately 1.3 times and the average carbon emissions being 2,539 kg/m^2. The average CO_2 emissions from the stage of building and building materials production to the demolition of buildings are 385kg/m^2, 23kg/m^2, 8kg/m^2, 2,055kg/m^2, 70kg/m^2, respectively, among which carbon emissions in building materials production and construction operation and maintenance. The proportion of carbon emissions in the whole life cycle is the highest, reaching 15.13% and 80.87% respectively, and the proportion of other stages is shown in Figure 4. The average carbon footprint of a non-green traditional building throughout its life cycle is 3955kg/m^2. The average carbon emissions of the building materials production and construction operation and maintenance phases are 850kg/m^2 and 2987kg/m^2, respectively, and the proportion of these two phases is as high as 21.48% and 75.51%. The proportion of carbon emissions in other stages is shown in Figure 5.

Public building life cycle CO_2 emission

The calculation results of the average carbon emissions of the three green public buildings and four non-green public buildings at various stages of the whole life cycle are shown in Figure 6.The average carbon emissions of the three green public buildings are 3,778 kg/m2.In the building materials production and construction operation and maintenance stage, the carbon emissions are the highest, respectively 391kg/m2 and 3281kg/m2, and its proportion is also as high as 10.34% and 86.84%, the proportion of other stages as shown in Figure 7.The average carbon emission of non-green public buildings during the whole life cycle is 5,776kg/m2, and its carbon emissions are much higher than that of green buildings. The average carbon emissions of non-green buildings throughout life cycle are almost the entire life cycle carbon emissions of fabricated green buildings. 1.53 times. The average carbon emissions of non-green public buildings during the production and operation and maintenance phases of building materials are 818kg/m2 and 4817kg/m2, respectively. These two phases account for 14.17% and 83.39% of the total life cycle carbon emissions, respectively. The proportion of emissions is shown in Figure 8.

DISCUSSION

Analysis of carbon emissions from green and non-green traditional buildings

Calculate the average carbon emissions at each stage of the two types of buildings (The average carbon emissions for each life cycle of each building case are shown in Figure 9. The average carbon emissions for each stage of each type of building are shown in Figure 10.). It is found that in green buildings and non-green traditional buildings, the proportion of carbon emissions in the operation and maintenance phase accounts for 80.87% and 75.51%, respectively, and the average carbon emissions in the building materials production phase account for about 15.13% and 21.48% respectively. It is not difficult to find that the carbon emission of the building operation and maintenance stage and the building materials production stage account for the highest proportion. Therefore, the carbon emission reduction for the construction industry is mainly carried out from these two stages.

This study conducts carbon emission reduction research on fabricated green buildings and public buildings. From the data, it can be concluded that the average carbon emissions in the stages of building building materials production, component transportation, construction, operation and maintenance, and building demolition are lower than ordinary traditional houses. The average carbon emissions at each stage of the public building are about 465 kg/m2, 0 kg/m2, 8 kg/m2, 932 kg/m2, 10 kg/m2 and 427 kg/m2, 3 kg/m2, 22 kg/ m2, 1536kg/m2, 10kg/m2.Because the use of green building materials and large-scale production in the production of building components in the fabricated green building in this paper will greatly reduce CO2 emissions. However, traditional buildings in the building materials will waste a lot of water and electricity, and will generate a lot of dust and pollute the environment, so the assembled green building is compared with the traditional non-green building in the production stage of residential and public building components and building materials. The relative reduction in carbon emissions is about 54% and 52%. In the transportation phase of building materials, since the transportation weight is roughly the same, the carbon emissions of the two types of buildings are also roughly equal at this stage, so that the carbon emissions of the difference are 0 kg/m2 and 3 kg/m2, and this difference is almost negligible. In the construction and construction stage, due to the prefabricated construction method of the assembled green building, the construction period is greatly shortened compared with the traditional building, thereby reducing the energy consumption such as water and electricity, and in terms of the number of construction personnel, compared with the traditional building. Carbon emissions have also been reduced, resulting in a reduction of approximately 8 kg/m2 and 22 kg/m2 per square metre for green buildings and public buildings. Therefore, the use of prefabricated construction methods can reduce the carbon emissions of the construction industry throughout the life cycle. CO2 emissions in the construction operation and maintenance phase accounted for the largest proportion in the 50-year operating cycle. Although green buildings account for a relatively large proportion of non-green buildings throughout the life cycle at this stage, the average carbon emissions of green houses and public buildings at this stage are 932 kg/m2 and 1536 kg /m2lower than non-green houses and public buildings, respectively. Since green buildings use water-saving and electricity-saving systems and new ventilation systems at this stage, as well as thermal insulation and good peripheral maintenance materials, large amounts of CO2 emissions are reduced relative to non-green buildings at this stage.

Residential and public buildings in CO2 differences in emissions

Compare the two types of architectural cases CO_2 according to the calculation results of emissions, the total carbon emissions of residential buildings in the whole life cycle ranged from 2,200kg/m^2 to 4,206kg/m^2, and the average carbon emissions were 3,248 kg/m^2. Residential buildings with the highest carbon emissions are nearly 1.9 times the lowest carbon-emitting residential buildings.The total life cycle carbon emission of public buildings ranges from 3,506 kg/m^2 to 7,820 kg/m^2, and the average carbon emission is 4,777 kg/m^2, of which the highest value of public buildings is nearly 2.2 times the lowest.

As can be seen from the above chart, the difference in carbon emissions of different types of buildings is still very large. From a macro perspective, the total carbon emissions of public buildings throughout the life cycle is significant higher than residential buildings, and the average Carbon emissions of public buildings is nearly 1.5 times that of residential buildings. In terms of the total amount, the main reason for this difference is the difference in carbon emissions during the operation and maintenance phase.Because public buildings consume far more electricity and water than Residential buildings, the total carbon emissions of public buildings throughout their life cycle are much higher than residential buildings. Therefore, reducing carbon emissions from public buildings is an effective measure to reduce carbon emissions in the construction industry.

Influence of building structure on carbon emissions

For buildings, different building structures can affect the consumption of building materials and the consumption ratio of different types of building materials, thus affecting building carbon emissions.

This case only includes the shear wall and Frame shear wall structure. The carbon emission distribution of residential buildings and public buildings under different structural systems is shown in Figure 11 and Figure 12.

It can be clearly seen that the average carbon emission of the frame shear wall structure and the shear wall structure is basically the same for residential buildings, so for residential buildings, the building structure has little effect on its carbon emissions.For public buildings, the average carbon emission of the shear wall structure is significantly higher than that of the frame shear wall structure, so for public buildings, the frame shear wall structure can reduce the carbon emissions of public buildings.

Layer and assembly rate impact on building carbon emissions

The number of building layers in this study ranges from 2 to 32 layers, and the assembly rate ranges from 60% to 72%. For different building layers, different layers of building materials and scale benefits are different, and the building's carbon emissions are also different. For buildings with different assembly rates, the carbon emissions are also different. Different assembly rates and different types of building carbon emissions under different layers are shown in Figure 13 and Figure 14.

It is not difficult to see from the figure that the carbon emissions of both public and residential buildings will increase as the assembly rate decreases, and the number of building layers has no obvious effect on the carbon emission of the building. Therefore, the number of building layers is different for the two types of buildings. Carbon emissions have little impact.

CONCLUSION

This paper uses the method of full life cycle assessment, combined with the actual engineering cases of 21 green and non-green buildings, to compare and analyze its carbon emissions. Through the research of this paper, the following conclusions are drawn:

(1) For residential buildings, the structure of the building has little impact on the carbon emissions of the building; for public buildings, the carbon emissions of the frame shear wall structure are lower than those of the shear wall structure.

(2) The number of building layers in this study has little effect on the carbon emissions of the two types of buildings, but the assembly rate of the building has a great impact on the carbon emissions of the building. The higher the assembly rate, the lower the carbon emissions of the building.

(3) For residential buildings, the average carbon emissions of non-green buildings are about 1.6 times higher than that of green buildings, and the average carbon emissions of non-green public buildings is about 1.5 times higher than that of green public buildings.

(4) Whether it is residential or public buildings, its carbon emissions are mainly concentrated in the construction operation stage, and its carbon emissions account for about 80% of the total carbon emissions of the building's life cycle.

(5) The average carbon emission of public buildings is nearly 1.5 times that of residential buildings. It can also be seen that the carbon emissions of the construction industry mainly come from public buildings.

Therefore, in terms of reducing the carbon emissions of buildings, we can consider the two aspects of building structure and building assembly rate, and vigorously develop green buildings to reduce building carbon emissions.However, this paper does not consider the impact of the surrounding environment on the carbon emissions of buildings.For example, the impact of green plants on carbon emissions, taking these factors into account will make the building life cycle carbon emissions assessment more accurate.In addition, the case studied in this paper selects historical data of demolition buildings in the calculation of carbon emissions in the fifth stage, and there may be data shortage in this aspect.These factors should be taken into account in future research to make the research more precise.

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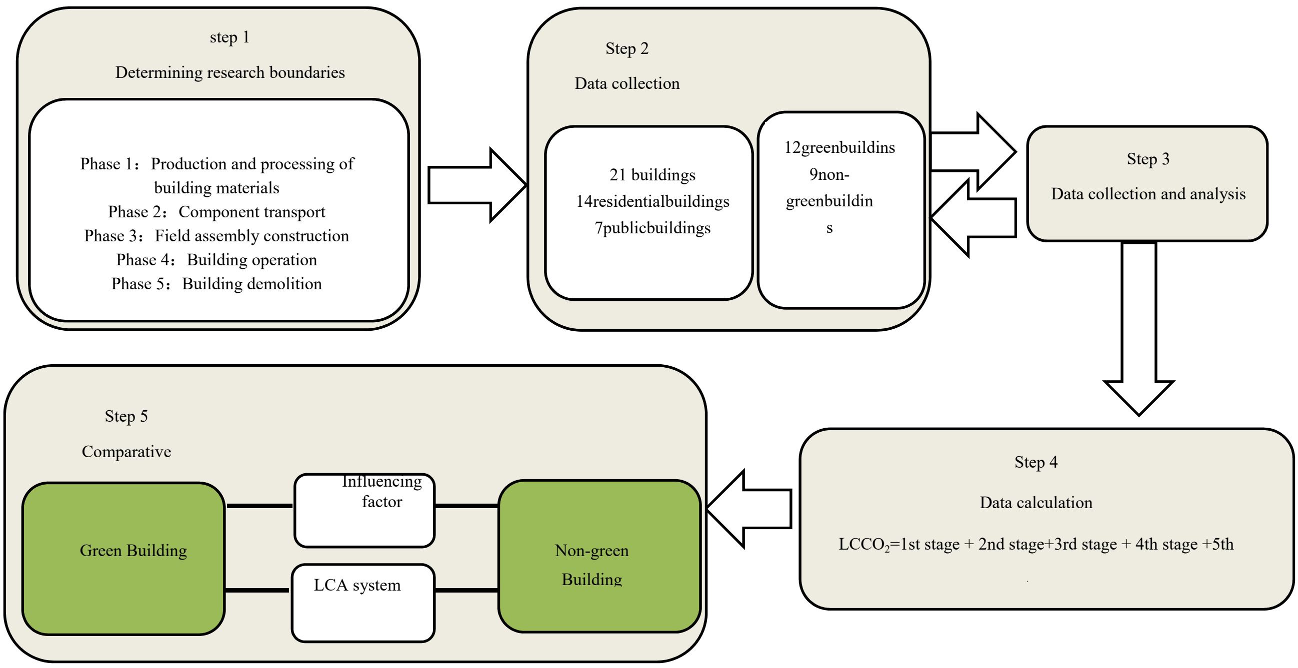


Figure 1. Comparative analysis flow chart

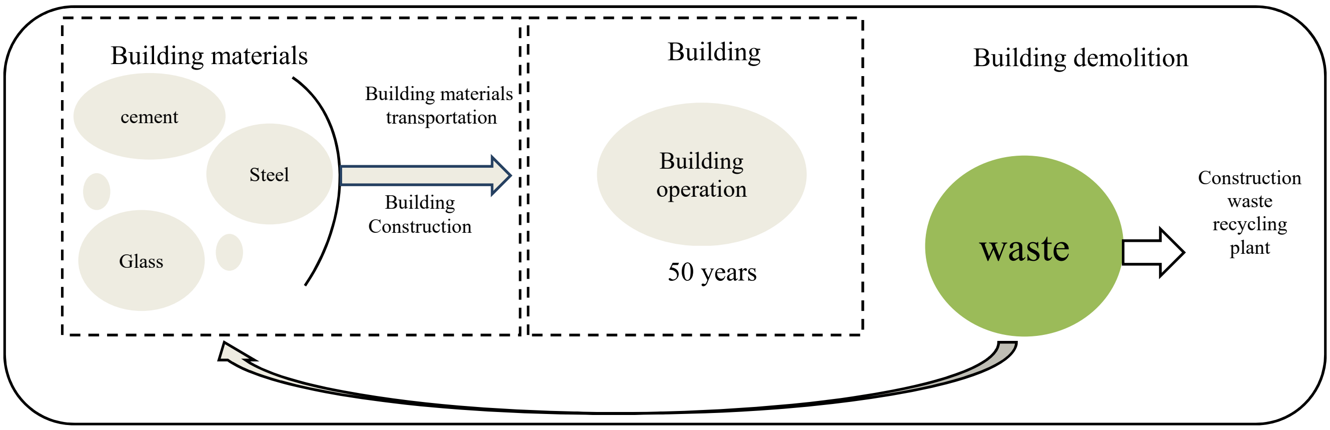


Figure 2 . Study system boundary diagram

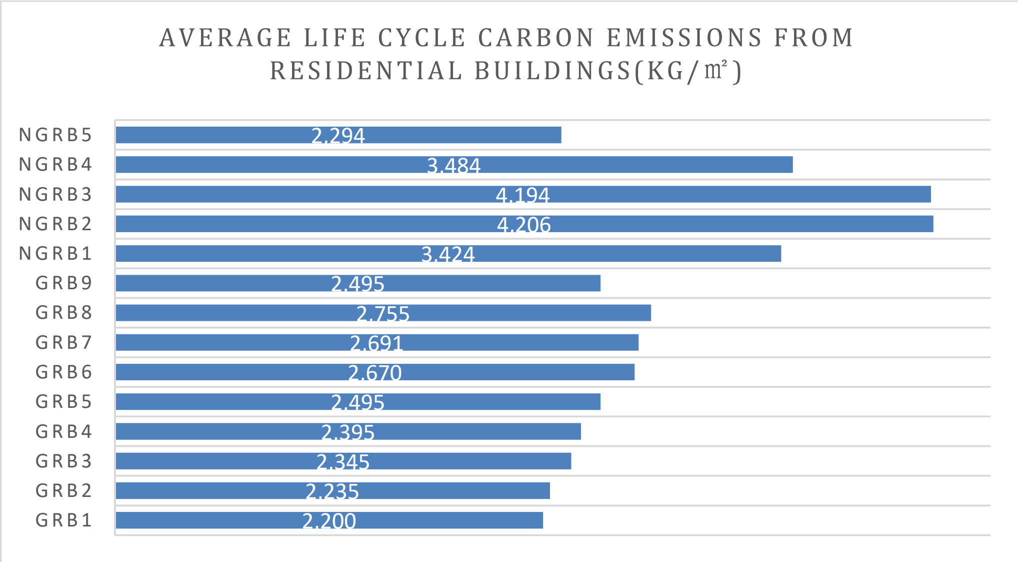


Figure 3. Average carbon emissions of residential buildings over the whole life cycle

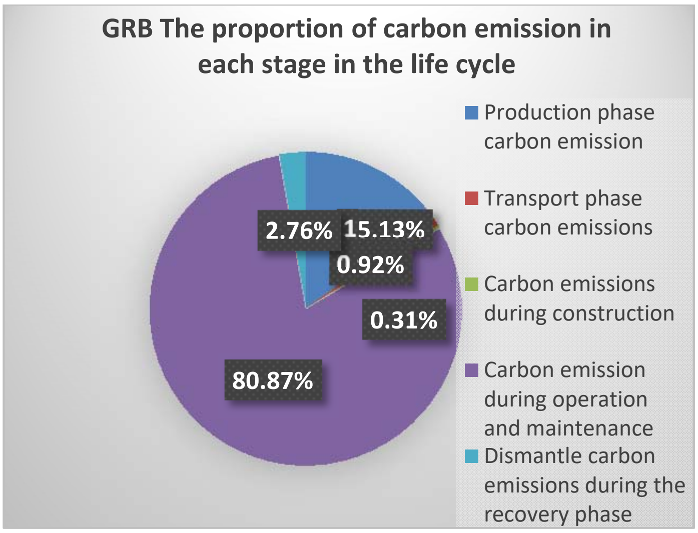


Figure 4. GRBThe proportion of carbon emission in each stage in the life cycle

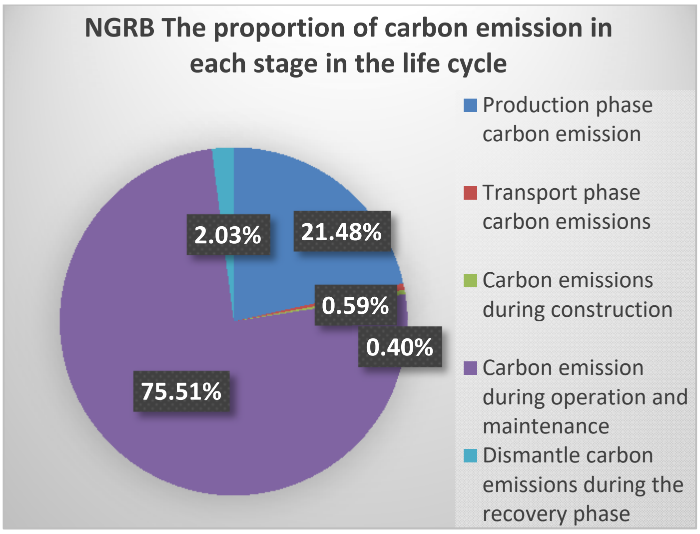


Figure 5.NGRBThe proportion of carbon emission in each stage in the life cycle

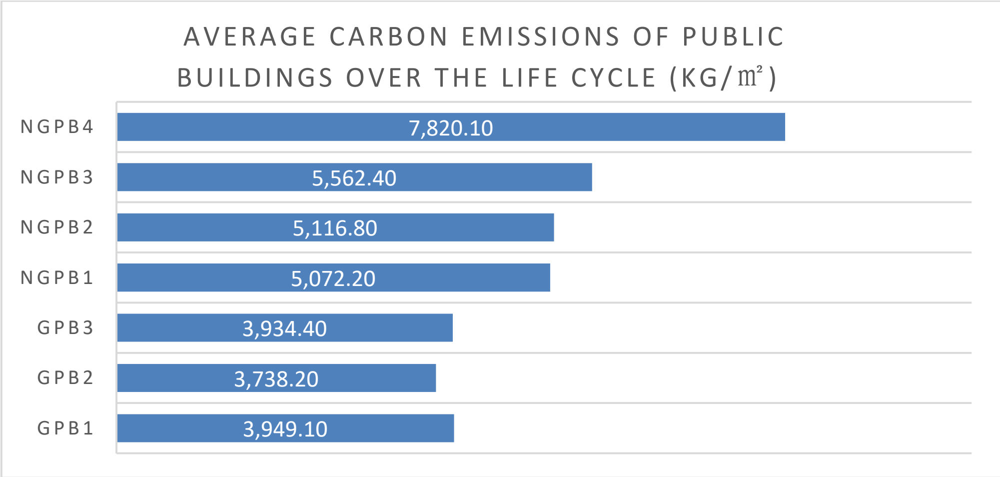


Figure 6 .Average carbon emissions of public buildings over the life cycle (kg/m^2)

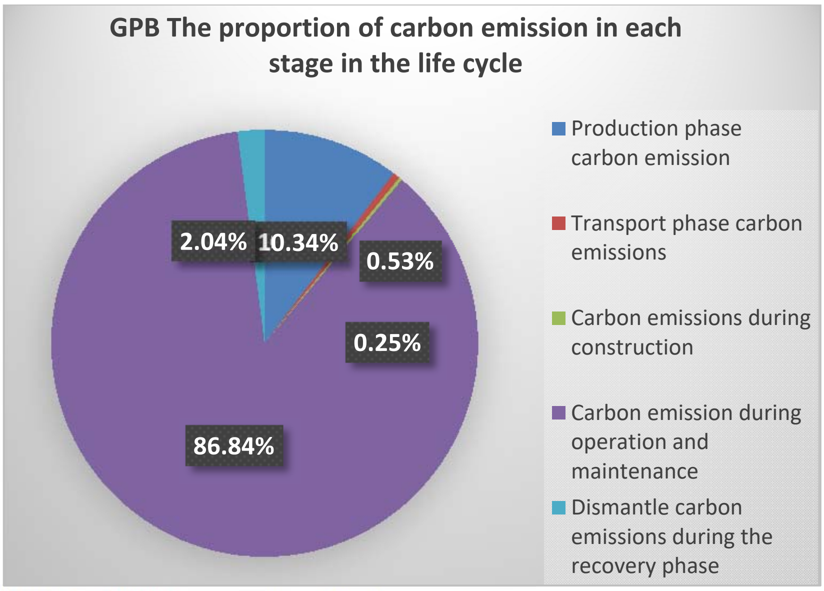


Figure7. GPB The proportion of carbon emission in each stage in the life cycle

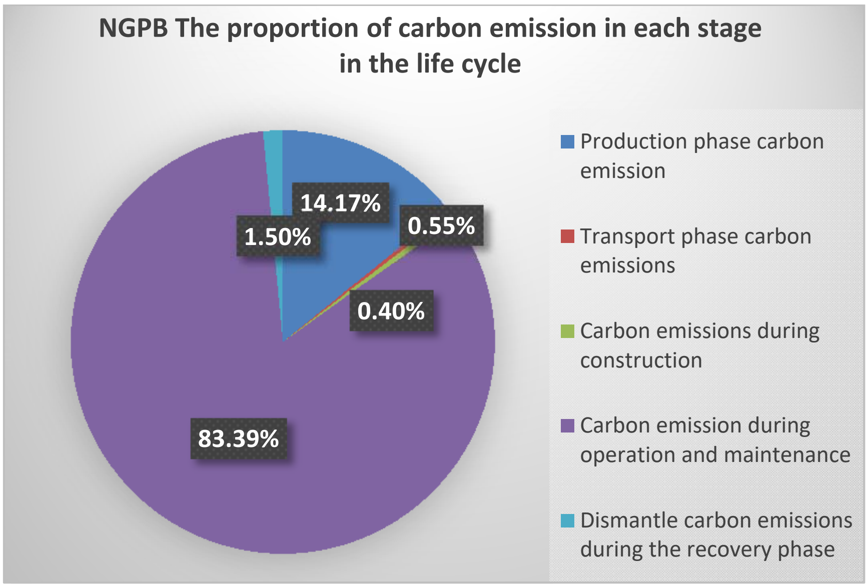


Figure8. NGPB The proportion of carbon emission in each stage in the life cycle

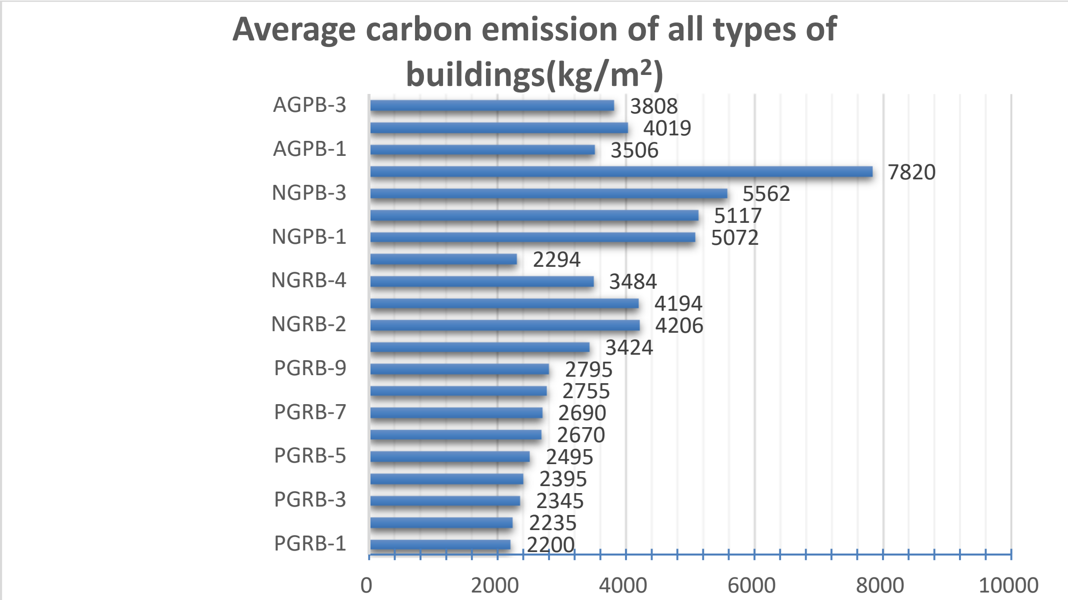


Figure 9. Average carbon emission of all types of buildings

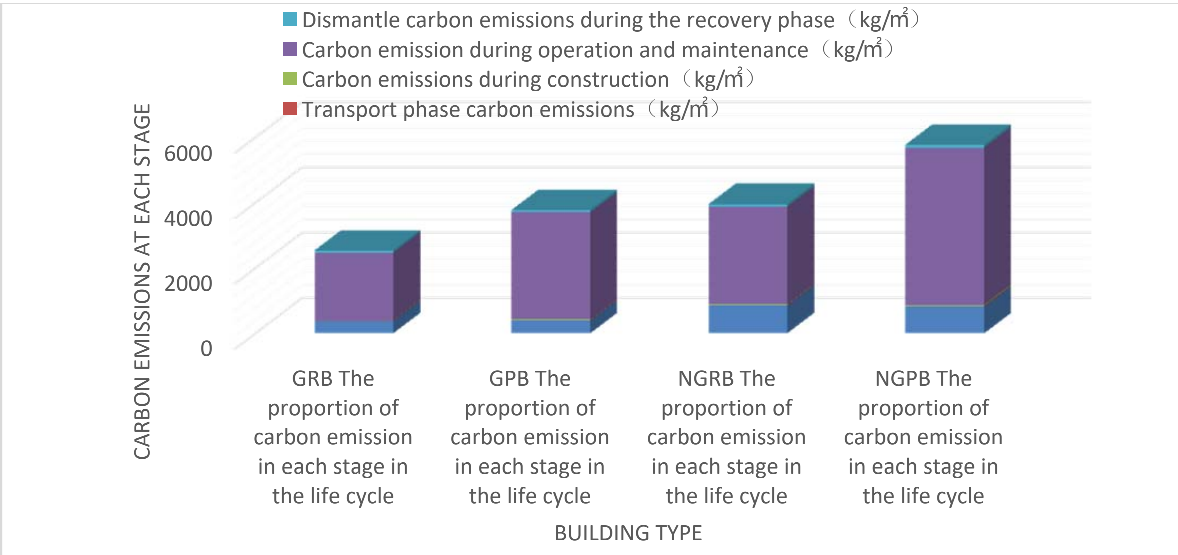
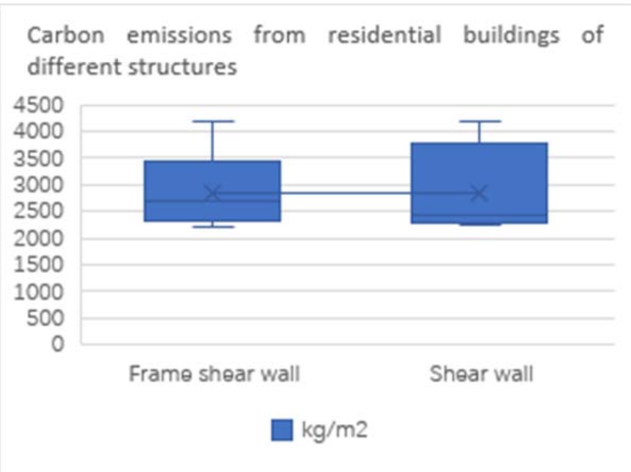


Figure 10. average carbon emission of various buildings at various stages



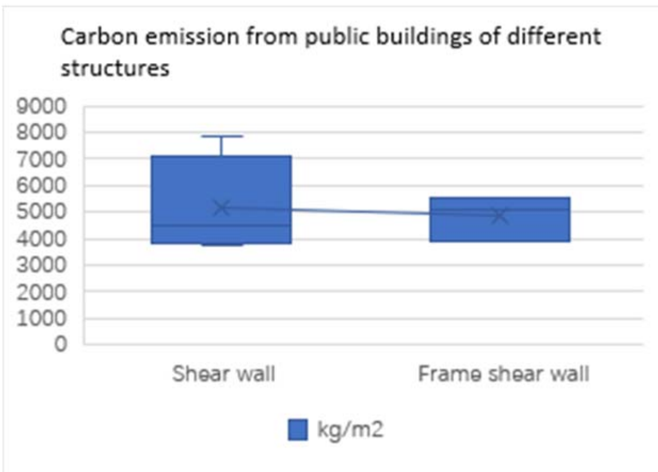


Figure 11. Carbon emissions from different   Figure 12. Carbon emissions from public

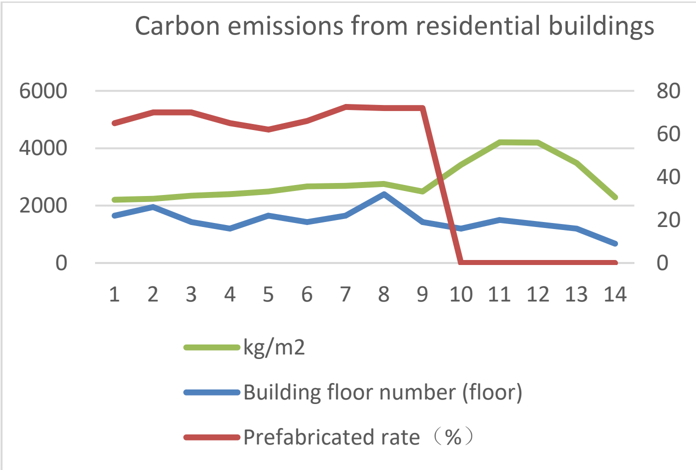


Figure 13. carbon emission of residential buildings with different floors and assembly rates

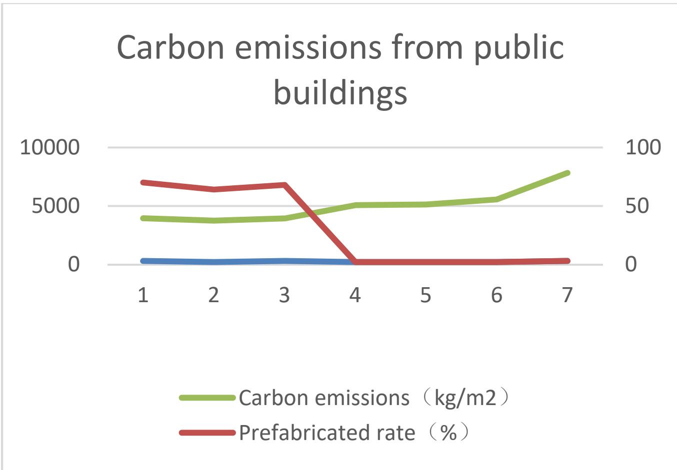


Figure 14. carbon emission of public buildings with different floors and assembly rates