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Research on Carbon Emissions of Construction Workers in the Full-cycle Environmental Assessment of Construction Projects

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Abstract: *The construction industry emits a large amount of greenhouse gases every year, which significantly impacts the world's environment. Therefore, more and more researches focus on energy saving and emission reduction in building projects. The life cycle assessment method has occupied a dominant position in the environmental assessment of construction projects in recent years. This method can measure the environmental impact of any stage or the entire life cycle of a construction project. However, in the calculation process, researchers often do not pay attention to the calculation of carbon emissions of construction workers. Some studies directly ignore this factor, while more studies use per capita carbon emission values based on national data, which do not reflect the daily habits of construction workers. This study is based on the consumer lifestyle method, combined with the personal or household carbon emission calculator developed by the Hong Kong Environment and Ecology Bureau, and conducted field visits to investigate the actual habits and related data of construction workers in the four aspects of necessities of life in actual projects. After getting the per capita data of each item, bring it into the carbon emission calculator to get the per capita carbon emission considering the characteristics of construction workers. Finally, the data obtained in this study are brought into the previous related research, and it is found that the carbon emissions and proportion of workers have increased.*

Keywords: *Life cycle assessment; Building carbon emission; Construction worker*

1. Introduction

The construction industry consumes two-fifths of the world's energy and emits over one-third of greenhouse gases (GHG) [1]. Therefore, carbon emission reduction in the construction industry is imperative and has an extensive prospect. For a building, from the beginning of construction to the completion of the building's mission and its dismantling and recycling, its entire life cycle will generate greenhouse gas emissions. Currently, environmental assessments of buildings typically use the Life Cycle Assessment (LCA) approach, which provides decision-makers with comprehensive data on the environmental impact of products and processes throughout their life cycle, from raw material extraction to end-of-life disposal [2].

However, the considerations included in buildings' current environmental assessment framework are not uniform. Generally speaking, researchers are accustomed to using the carbon emission factor method for LCA, but some studies have questioned this customary method. A study conducted a practical verification of carbon emissions during the transportation phase of fabricated components, and the results showed that based on the carbon emission factor method, the effects of load, temperature, and average speed should also be considered [3]. Another study questioned the carbon emissions of workers in prefabricated building construction, arguing that the widely used per capita data is not enough to express the real situation of prefabricated construction workers [4]. Therefore, no unified research model exists for the environmental assessment of prefabricated buildings.

Construction workers have played a pivotal role in developing the construction industry. Large-scale construction workers consume a large amount of food and energy daily, and the related expenses will directly affect the cost of construction projects [5]. Compared with light physical workers and administrative staff, construction workers consume much physical energy every day and need more food

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to supplement energy. And because higher physical exertion can lead to physiological phenomena such as sweating and dehydration, construction workers often need to consume more daily energy, such as water and electricity, to ensure everyday life. Therefore, it is biased to use the per capita carbon emissions of a specific country or region to calculate the carbon emissions of construction workers. Therefore, this research plans to start with the daily consumption of construction workers and calculate the actual average daily carbon emissions of construction workers on the project through the accurate data of an existing construction project in Chongqing to provide more accurate data for the follow-up LCA work. In the second chapter, this research will review the calculation of construction workers' carbon emissions in the current construction project LCA research. The third chapter introduces the calculation method and data source of construction workers' carbon emissions in this study. The fourth chapter gives the calculation results, and the fifth summarizes the full text.

2. Related work

2.1 LCA on construction stage

LCA can fully assess the environmental impact of buildings throughout their life cycle. This assessment includes the various phases of the building, namely the production construction phase (A), building use and maintenance (B), building demolition (C), and reuse (D) [6]. Among them, the construction stages of cast-in-place and prefabricated buildings are still different. Prefabricated buildings need to consider the steps of processing raw materials in component factories and transporting components to the construction site. For construction workers, their carbon emissions are mainly reflected in the production and construction stage, which is also called from the cradle to the end of construction, the materialization stage, or the simplified LCA process. In short, it describes the complete construction process of a building from scratch.

Wang et al. [7] expressed interest in measuring the environmental impact of prefabricated components during the use and recycling phases. Still, they did not consider worker carbon emissions in their calculation framework. Du et al. [8] calculated the carbon emissions of prefabricated construction and traditional construction from cradle to site based on LCA. However, this study focuses on the consumption of raw materials and energy and does not reflect the workers' carbon emissions calculation. Ding et al. [9] developed a carbon emission measurement system for prefabricated houses during the production and construction phase based on Building Information Modeling (BIM) and carbon emission measurement models. In this system, the labor force's carbon emission per person per hour is set at 0.30 $kgCO_2$. A study investigated the carbon footprint of prefabricated buildings during the materialization phase [10]. The study compiled a carbon emission factor database and used BIM technology to establish a carbon footprint calculation model for the PC building construction stage. The calculation data of the carbon emissions per labor force per day comes from China's per capita data 2018, which is 6.61$kgCO_2$. The carbon emissions of workers in the project reached more than 10% of the total carbon emissions in the construction and installation phases of the project. A study on precast concrete stairs indicated that the carbon emissions of precast concrete stairs in the production construction phase mainly come from the consumption of raw materials in the production phase [11]. The carbon emissions of workers in this study also use the data of 6.61$kgCO_2$. The carbon emissions of workers accounted for 12.9% of the total carbon emissions in the production stage of component factories. They accounted for 63.4% of the total carbon emissions in the production and installation stages. In 2023, the research team calculated the carbon emissions of the prefabricated concrete composite plate in the materialization stage. It calculated the per capita daily carbon emissions of 9.41 $kgCO_2$ from China's 2020 annual carbon emissions [12].

2.2 Research Gaps

The above studies show that the carbon emissions of construction workers generally account for more than 10% of the carbon emissions in the complete construction stage, and some subdivided stages can reach more than 60%. Therefore, ignoring workers' carbon emissions or using data that does not consider the characteristics of construction workers will lead to biased estimates of carbon emissions for the overall construction project. Moreover, there is also a vast difference in the per capita carbon emission values commonly used at present, from a relatively early 2.4 $kgCO_2$ (according to eight-hour working hours) to a reasonably moderate 6.61 $kgCO_2$ and then to the 9.41$kgCO_2$ used in the latest research. The per capita data has a difference of nearly four times. The reason is that there are theoretical flaws in the calculation method. The calculation method of per capita carbon emissions can be simplified as "total carbon emissions of the country/total population of the country" and then divided by the number of days

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and working hours per year. Among them, the working hours generally include 8 hours, accounting for one-third of a day, so the researchers can directly divide the daily data by 3 to obtain the above-mentioned per capita daily carbon emission data. Taking the latest research in 2023 as an example, the study pointed out that China's total carbon emissions in 2020 will be about 14,546 million tons, and the population will be about 1.41 billion. It can be concluded that the per capita annual carbon emissions are 10.316 tons, and the daily carbon emissions are about 28.2 kilograms. Based on eight hours of working time, the carbon emission per person per working day is 9.41 kg [12].

However, there are two shortcomings in the above calculation process. On the one hand, the country's total carbon emissions for a whole year are not entirely determined by the country's people, and the country's macro-policy will also affect the proportion of carbon emissions in a particular year of the country. It is unreasonable for people to pay for these carbon emissions that do not belong to them. On the other hand, after obtaining the 24-hour per capita carbon emission data, directly dividing by three to calculate the carbon emission under working conditions lacks sufficient theoretical basis. It has not yet been proved that the carbon emissions of human beings during sleep can be equally divided into the daily carbon emissions with the carbon emissions of working status and carbon emissions of home leisure according to the ratio of three equal parts. This study suggests that the researchers who use per capita data should discuss in detail the carbon emission behavior determined by the people of a country and the corresponding data, as well as the proportion of carbon emission in three different states of human work, leisure, and sleep. The national annual carbon emission data can be used for calculation only after the "proportion of carbon emissions determined by the people" and "proportion of carbon emissions during working hours" are determined.

This study believes that the carbon emissions of construction workers have a particular impact on the overall results. It is necessary to provide a systematic calculation plan for the per capita carbon emissions of construction workers based on the actual situation and according to the actual living conditions of construction workers rather than simply and crudely selecting per capita daily carbon emissions data based on national annual data.

3. Method and Data Source

3.1 Methodology

At present, the standard method used to estimate the carbon emissions of a specific material or energy in the LCA framework is the carbon emission factor method. For people or families, the consumer lifestyle method can also be used to estimate the total carbon emissions of the year by measuring the consumption of individuals or families (including consumption of food and daily necessities and energy consumption) [13], [14]. Based on the above theories, administrative departments or companies such as the Hong Kong Special Administrative Region Environment and Ecology Bureau, Hong Kong and China Gas Co., Ltd., and Hong Kong Electric Co., Ltd. have developed carbon emission calculators for individuals and families, aiming to estimate the annual carbon emissions of individuals or families based on daily necessities, food, housing, and transportation. This study investigates the daily consumption of construction workers working on an actual construction project in Chongqing, China, based on the carbon emission calculator provided by the Hong Kong Environment and Ecology Bureau's Climate Change page [15].

3.2 Data Source

The calculator is divided into four sections: food, clothing, housing, and transportation. Among them, clothing and transportation used the form of interviews and surveys to roughly collect the daily necessities consumption habits of construction workers, as well as travel patterns and frequencies. For food and housing, relevant data are obtained directly from the logistics support department of the project, such as the daily consumption of meat, vegetables, eggs, and other ingredients in the canteen, as well as the daily water consumption and electricity consumption in the workers' accommodation area. After obtaining the above per capita actual data, this study brings all the data into the carbon emission calculator for calculation. Then the per capita and daily carbon emission data that conforms to the real lifestyle of construction workers can be obtained.

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4. Results

4.1 Calculation results

The project is located in Chongqing, China. The data was obtained in early June 2023, and the data recorded by the logistics department is related to May 2023.

Clothing: Construction workers buy 4.5 new clothes and shoes annually, corresponding to the "1-10" option in carbon emission calculation. The per capita annual carbon emission calculated by this item is less than 0.1 tons of CO_2.

Food: According to the procurement data recorded by the project logistics department in May 2023, the average meat consumption per person in the project month was 1678g, and the average daily consumption of meat per person was 54.13g, which corresponds to the option of "50-99g of meat per day" in the calculator. According to the grocery store accounts on the project, the average daily consumption of prepackaged drinks per person on the project is 1.82 servings, corresponding to the "1-3 servings per day" option in the calculator. This calculation results in a per capita annual carbon emission of 2.1 tons of CO_2.

Housing: The construction workers on the project generally have a dormitory for six people, which corresponds to the option of "number of people living together 6" in the calculator. Each dormitory used an average of 258 kWh of electricity in May 2023, which corresponds to the option of "201-400 Hong Kong dollars" after conversion according to the electricity price in Hong Kong. No renewable energy is used on the project, corresponding to the option "My family does not purchase a renewable energy certificate" in the calculator. Gas and natural gas are unavailable on the project, corresponding to the options "I do not use gas" and "I do not use LPG" in the calculator. The water used in the living area of the project is 8.13 tons per person per month, which corresponds to the option of "51-100 Hong Kong dollars" in the monthly water fee in the calculator after conversion according to the Hong Kong water fee. Each worker's dormitory in the project is equipped with two garbage cans to fill domestic garbage, producing three garbage cans about every two days. Each dormitory is estimated to produce about 20 liters of garbage per day on average, corresponding to the "16-30 liters" option in the calculator. Based on the above data, the per capita annual carbon emission is 0.6 tons of CO_2.

Table 1: The data and corresponding options of the four major sectors

Item	Question	Data	Selection
Clothing	How many new clothes and shoes do you buy each year?	4.5	1-10
Food	Days and amount of meat eaten per week	54.13g per day	Seven days, 50-99g per day
	Number of prepackaged beverages consumed per day	1.82 per day	1-3
Housing	Number of people living with you	6	6
	Room electricity per month	258kWh (May)	201-400 HKD
	Number of Room Renewable Energy Certificates	NA	None
	Gas and natural gas per month	NA	None
	Water per month	8.13 tons per capita	51- 100 HKD
Transportation	Household waste generated per room per day	On average, 3 packs of garbage are produced in 2 days	16-30 liters
	Number and mileage of private cars	None	None
	Daily travel style	Subway, bus, taxi, cycling	MTR, bus, taxi
	Travel destinations and times	Most of them come and go during the Spring Festival, mainly by railway	2 times, Asia and Southeast Asia
	Cruise	None	None
			Total carbon emission: 3.8 tons CO_2

Transportation: Construction workers do not have private vehicles on the site. Usually travel by public transport such as subways and buses; a few workers also use taxis or bicycles. Every Spring Festival, almost all workers choose to go home, mainly by railway transportation, and a small number of them select airplanes or buses. Some workers will choose to go to work in the next city after the project is over, and the primary way is railway transportation. The final question is the number of cruise trips. The workers generally said that they had never been on a large ship, so they chose 0 times for this item. After calculation, it can be seen that this item's annual per capita carbon emission is 1.1 tons of CO_2.

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Combining the above four sectors, the per capita carbon emission of construction workers on this project is 3.8 tons of CO_2 annually. Then the carbon emission per person per day is 10.41 $kgCO_2$. Table 1 introduces the data of the four major sectors and the corresponding options.

4.2 Results comparison

This study brings the per capita data of 10.41 $kgCO_2$ into the related research mentioned in Chapter 2, aiming to show the changes in various results. In the calculation of carbon emissions in the construction phase of prefabricated concrete buildings in 2021 [10], the carbon emissions of workers in the construction and installation phase of Project B calculated using the data of this study are 20.82 tons, a year-on-year increase of 57.49%. The total carbon emissions at this stage were 102.02 tons, a year-on-year increase of 8.05%. In the 2022 study on the overall full-cycle environmental assessment of prefabricated buildings [11], the artificial carbon emissions in the production process of prefabricated components obtained by using the data of this study were 26.58 tons, a year-on-year increase of 57.49%. The total carbon emission of this process is 141.05 tons—a year-on-year increase of 7.4%. In the 2023 study on the carbon emission evaluation of prefabricated concrete composite panels during the materialization stage [12], the carbon emission data of workers increased by 10.63% year-on-year.

5. Summary

The construction industry produces many carbon emissions yearly, affecting global climate change. Researchers usually use the LCA method to assess the environmental impact of a particular stage or the entire life cycle of a building, and the most commonly used method for estimating carbon emissions is the carbon emission factor method. However, various studies directly use per capita carbon emission data calculated based on national annual carbon emissions for construction workers carbon emissions, which does not reflect the daily habits of construction workers and the calculation process of per capita values still has deficiencies and flaws.

Combining consumer lifestyle methods, this study visited construction projects in Chongqing and obtained accurate and reliable data on construction workers' living habits and daily consumption using surveys and interviews. Based on these data, this study brings these accurate data into the carbon emission calculator developed by the Hong Kong Environment and Ecology Bureau. It calculates the per capita carbon emission based on the living habits of construction workers. Then this study brought this data into three related studies from 2021 to 2023 and found that if the data obtained in this study were used, the carbon emissions of workers in the above studies would increase by 10.63% and 57.49%. The relative carbon emissions of the project and the proportion of carbon emissions of workers would also increase accordingly. This reflects the non-negligible position of construction workers' carbon emissions in the construction stage's environmental impact and demonstrates the necessity of reducing labor in the construction industry, a labor-intensive industry.

This article also has some limitations. For example, in the two sectors of "food" and "housing," the data used in this study is from May 2023. The hot weather in Chongqing in May will inevitably lead to more power and water consumption. Therefore, there may be some deviations in the calculation results of this study. The next step of the research team's plan is to obtain relevant data from multiple construction projects in numerous places for half a year or more and strive to reduce the impact of climate to calculate more accurate and more realistic per capita carbon emissions of construction workers and provide more solid data support for future LCA research on construction projects.

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