

# Carbon Footprint Accounting Models and Methodologies for Industrialized Buildings

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## Abstract

With the ongoing advancement of the "Dual Carbon" goals, the development model characterized by high carbon emissions in the traditional construction industry has become increasingly incompatible with the demands of green and low-carbon development. Industrialized construction, leveraging its advantages of standardization and intensification, has emerged as a critical pathway for carbon reduction. Carbon footprint accounting serves as a core mechanism for monitoring and managing carbon emissions throughout the entire life cycle of industrialized buildings. The scientific rigor of its accounting models and methodologies directly influences the effectiveness of carbon reduction efforts. This study concentrates on the essential issues of carbon footprint accounting for industrialized construction, conducting a systematic investigation into the construction rationale of accounting models and specific methodologies. It aims to provide data support and practical references for the formulation of comprehensive carbon reduction strategies and the practical implementation of low-carbon transformation in the industrialized building sector.

## Keywords

**Industrialized Construction; Carbon Footprint; Accounting Model; Accounting Methodology.**

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## 1. Introduction

### 1.1 Overview

This article focuses on the core objective of "developing a refined carbon footprint accounting method for building materials adapted to industrialized building scenarios", using a certain residential project as the empirical carrier. By combining the theory of Life Cycle Assessment (LCA) with BIM technology, it clarifies the full life cycle accounting boundary of the carbon footprint of industrialized buildings (covering the three core stages of material production and transportation, construction and installation, operation and maintenance, and dismantling and removal), and determines the data sources (drawings, lists, simulation software, etc. from the design, construction, and operation and maintenance stages). It divides the building's full life cycle into three modules: embodied carbon in the building, carbon emissions during operation, and carbon emissions during dismantling. It establishes corresponding mathematical accounting models for each stage. It specifies the selection criteria and data sources for key carbon emission factors such as electricity, energy, building materials, transportation, and construction shifts. Finally, it forms a low-error-rate, implementable carbon

footprint accounting system for industrialized buildings and provides a benchmark reference for similar projects.

## 1.2 Features

Firstly, the characteristics of industrialized building "prefabricated production, assembly construction, and full-cycle disassemblability" are focused on, which have strong targeting. It breaks through the traditional building accounting framework and clearly defines the exclusive accounting boundary and core coverage stage. Relying on BIM software (Revit), precise data of building materials is extracted, and multiple types of carbon emission factor libraries are matched to establish a mathematical accounting model in stages (material production, transportation, construction, operation, and dismantling), ensuring that the error rate of the accounting is  $\leq 5\%$ [1]. Its level of refinement is high. Additionally, the data source is clear (drawings, lists, simulation software, etc.), and the carbon emission factors are sorted according to national standards (GB/T51366-2019). The accounting results can directly provide a benchmark reference for the carbon footprint accounting of similar industrialized buildings and have high practicality. From target setting, boundary and data determination, to life cycle division, accounting model construction, and selection of carbon emission factors, a complete accounting logic chain is formed, ensuring the accuracy and credibility of the accounting results and achieving a complete logical loop.

## 2. Determination of System Boundaries and Data Sources

### 2.1 Determine the System Boundary

According to the six categories of greenhouse gases stipulated in the Kyoto Protocol, this study does not conduct a unique quantitative analysis for each type of greenhouse gas[2]. Instead, it uses "carbon dioxide equivalent (CO<sub>2</sub>e)" to refer to "carbon emissions". Different greenhouse gases will eventually cause the greenhouse effect, and carbon dioxide equivalent is a "universal ruler" in this paper as a unified measurement unit for various greenhouse gases, thereby obtaining the equivalent carbon dioxide emissions of different greenhouse gases. Regarding the functional unit of building carbon footprint, although some scholars believe that buildings are used by people and it is more fair to measure with "per capita carbon emission indicators", due to the influence of personnel mobility, the statistical difficulty is relatively large. Therefore, this paper adopts "carbon dioxide emissions per square meter of building area" and "carbon dioxide emissions" as the carbon footprint analysis units, that is, kgCO<sub>2</sub>e/m<sup>2</sup> and kgCO<sub>2</sub>e. Among them, kgCO<sub>2</sub>e can directly express the absolute value of carbon emissions in each stage of the building, facilitating the analysis of the emission proportion of different stages of the same building. While kgCO<sub>2</sub>e/m<sup>2</sup> can be compared horizontally among different buildings, thereby determining which building has a lower carbon emission intensity [3]. In the full life cycle carbon footprint accounting, theoretically, it should cover all carbon emissions during the entire operation process. However, due to the limitations of the research status and data availability, it is necessary to clearly define the accounting boundary. This paper divides the boundary into two categories: time boundary and spatial boundary. The time boundary covers all stages of the building's entire life cycle; the spatial boundary: adopts the principle of "related directly to the building entity or forming the intermediate product and unit process flow of the building entity and function within the base area".

### 2.2 Determine the Source of the Data

The data for this article is derived from three stages: the design stage, the construction stage, and the operation and maintenance stage. Therefore, accurate data were obtained from various documents such as drawings, lists, and simulation software in each stage, as shown in Table 1 below.

**Table 1.** Data Source Table

Stage	Source of data / Simulation software	Core information / Accounting object
Design stage	Architectural design specification, CAD drawings	Region, structural type, area and height, roof and wall, etc.
Construction stage	Engineering budget, cost list, Revit building materials list	The types of materials, their quantities, the sources of materials, the types of construction and demolition machinery, and the usage hours of these machinery.
Operation and maintenance stage	DesignBuilder	Energy consumption of systems such as air conditioning, heating, lighting, and elevators.

### 3. Life Cycle Classification and Mathematical Accounting Method for Carbon Emissions

#### 3.1 Life Cycle Classification

According to the Chinese national standard GB/T 51366, this article divides the entire building life cycle into three parts for calculation, including carbon emissions during the building operation stage, the embodied carbon of the building, and the carbon emissions during the building demolition stage[4]. The calculation formula for the total carbon emissions of the entire building life cycle and the building carbon footprint accounting framework are shown in Figure 1.

$$C_{LC} = C_E + C_M + C_{CC} \tag{1}$$

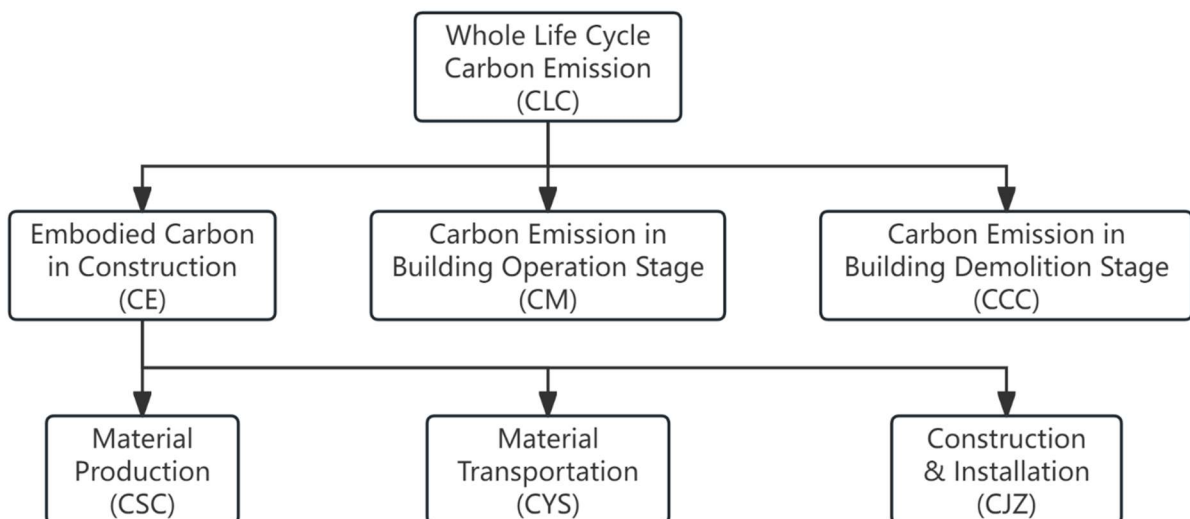
In the formula:

$C_{LC}$ -Total carbon emissions throughout the entire lifecycle of buildings,  $kgCO_{2e}$ ;

$C_E$ -The embodied carbon emissions of buildings,  $kgCO_{2e}$ ;

$C_M$ -Carbon emissions during the building operation stage,  $kgCO_{2e}$ ;

$C_{CC}$ -Carbon emissions during the building demolition stage,  $kgCO_{2e}$ .



**Figure 1.** Building Carbon Footprint Accounting Framework

Since the carbon emissions of buildings are significantly influenced by their area and type, simply comparing the total amount is unfair and not scientific. Therefore, a unit area carbon emission index should be adopted to enable reasonable comparisons among similar or similar-sized buildings. The formula for the carbon emission volume per unit building area throughout the building's life cycle is as follows:

$$C_A = \frac{C_{LC}}{A} \quad (2)$$

In the formula:

$C_A$ -Carbon emission per unit area during the entire building life cycle,  $\text{kgCO}_2\text{e}/\text{m}^2$ ;

$C_{LC}$ -Total carbon emissions throughout the entire lifecycle of buildings,  $\text{kgCO}_2\text{e}$ ;

$A$ -Building area,  $\text{m}^2$ .

### 3.2 Building Implicit Carbon Emission Accounting Method

Buildings' embodied carbon refers to the carbon emissions during the physical production stage of the building, including material production, transportation, and construction. The emissions from the building material production process come from the processing and production energy consumption. The transportation process mainly stems from transportation tools such as roads and railways. In the construction process, it is mainly the operation of mechanical equipment. Research shows that the production of building materials is the stage with the highest proportion in the entire life cycle, accounting for approximately 10% to 30%. Although these emissions are usually counted in industrial production, given that they serve the construction activities, they should be included in the carbon footprint of the building's entire life cycle [1]. Therefore, the formula for calculating the embodied carbon emissions of buildings is as follows:

$$C_E = C_{SC} + C_{YS} + C_{JZ} \quad (3)$$

In the formula:

$C_E$ -The embodied carbon emissions of buildings,  $\text{kgCO}_2\text{e}$ ;

$C_{SC}$ -Carbon emissions during the construction material production stage,  $\text{kgCO}_2\text{e}$ ;

$C_{YS}$ -Carbon emissions during the construction materials transportation stage,  $\text{kgCO}_2\text{e}$ ;

$C_{JZ}$ -Carbon emissions during the construction process of building materials,  $\text{kgCO}_2\text{e}$ .

#### 3.2.1 Carbon Emission Accounting Model for the Construction Materials Production Stage

The carbon emissions generated during the production of building materials or building components, doors and windows, etc., are calculated according to the "Calculation Standard for Carbon Emissions in Buildings" (GB/T 51366-2019). The carbon emissions accounting for the building material production stage is calculated using the following formula:

$$C_{sc} = \sum_{i=1}^n M_i \times F_i \quad (4)$$

In the formula:

$C_{sc}$ -Carbon emissions during the construction material production stage,  $\text{kgCO}_2\text{e}$ ;

$M_i$ -The consumption volume of the  $i$ -th major building material;

$F_i$ -The carbon emission factor of the  $i$ -th major building material,  $\text{kgCO}_2\text{e}/\text{Unit material quantity}$ .

### 3.2.2 Carbon Emission Accounting Model for Building Materials Transportation Stage

The carbon emissions during the construction materials transportation stage are calculated according to the following formula:

$$C_{YS} = \sum_{i=1}^n M_i \times D_i \times T_i \quad (5)$$

In the formula:

$C_{YS}$ -Carbon emissions during the construction materials transportation stage, kgCO<sub>2e</sub>;

$M_i$ -The consumption volume of the  $i$ -th major building material, t;

$D_i$ -The average transportation distance of the  $i$ -th type of building material, km;

$T_i$ -The carbon emission factor per unit weight and transportation distance for the  $i$ -th type of building material, kgCO<sub>2e</sub>/(t·km).

Under normal circumstances, the distance for transporting building materials should be determined based on the actual distance. However, during the design phase, the actual manufacturers of the building materials and the distances they are sourced from cannot be obtained. Therefore, in accordance with the provisions of the "Building Carbon Emission Calculation Standard" (GB/T51366-2019), the default values specified in Appendix E of the standard shall be used for calculation. The carbon emission factor ( $T_i$ ) for the building material transportation stage should include the direct carbon emissions during the transportation process of the materials from the production site to the construction site, as well as the carbon emissions from the production process of the energy consumed during the transportation process. The carbon emission factor ( $T_i$ ) for the building material transportation stage can be set according to the default values in Appendix E of this standard.

### 3.2.3 Carbon emission accounting model during the construction stage of buildings

The carbon emission accounting during the construction stage should be calculated according to the following formula:

$$C_{JZ} = \sum_{i=1}^n C_{Bi} \times N_i \quad (6)$$

In the formula:

$C_{JZ}$ -The carbon emissions of the construction teams during the construction process, kgCO<sub>2e</sub>;

$C_{Bi}$ -The energy consumption of the  $i$ -th type of construction shift, kWh or kg;

$N_i$ -The carbon footprint factor of the  $i$ -th type of construction machinery, kgCO<sub>2e</sub>/kWh or kgCO<sub>2e</sub>/kg.

The energy consumption of the construction shift unit (kWh/shift) per shift, but when there are available empirical data, it will be determined based on the empirical data (for construction machinery, one shift is considered for every eight hours), and it will be determined according to the carbon footprint factor table mentioned later.

### 3.3 Carbon Emission Accounting Method During Operation Stage

The carbon emissions during the building operation and maintenance stage include two parts: the usage of the building and the maintenance of the building. They can be calculated using the following formula:

$$C_M = C_{SY} + C_{RT} \quad (7)$$

In the formula:

$C_M$ -Carbon emissions during the building operation stage,  $\text{kgCO}_2\text{e}$ ;

$C_{SY}$ -Carbon emissions during the building's usage stage,  $\text{kgCO}_2\text{e}$ ;

$C_{RT}$ -Carbon emissions during the building maintenance stage,  $\text{kgCO}_2\text{e}$ .

### 3.3.1 Carbon Emission Accounting Model for the Operation Stage of Buildings

This article mainly calculates the carbon emissions for four aspects: winter heating, summer cooling, year-round lighting and elevator operation. The carbon emission amount should be calculated according to the following formula:

$$C_{SY1} = \frac{(C_H + C_C + C_W + C_L - C_{RE}) \times L}{A} \quad (8)$$

In the formula:

$C_{SY1}$ -Carbon emission per unit area during the building's usage stage,  $\text{kgCO}_2\text{e}/\text{m}^2$ ;

$C_H$ -Annual carbon emissions of the building heating system,  $\text{kgCO}_2\text{e}$ ;

$C_C$ -Annual carbon emissions of the building air conditioning system,  $\text{kgCO}_2\text{e}$ ;

$C_W$ -Annual carbon emission of the building's domestic hot water system,  $\text{kgCO}_2\text{e}$ ;

$C_L$ -Annual carbon emissions of the building lighting system,  $\text{kgCO}_2\text{e}$ ;

$C_{RE}$ -Annual carbon emission reduction volume of the renewable energy system,  $\text{kgCO}_2\text{e}$ ;

$L$ -Design life of building, years;

$A$ -Building area,  $\text{m}^2$ .

The carbon emissions for each component during the building operation phase, such as the heating system, air conditioning system, hot water system and lighting system, are calculated according to the following formula:

$$C_{YX} = \sum_{i=1}^n E_{YXi} \times F_i \quad (9)$$

In the formula:

$C_{YX}$ -The total amount of carbon emissions during the operation of each component,  $\text{kgCO}_2\text{e}$ ;

$E_{YXi}$ -The total consumption of the  $i$ -th type of energy during the operation of each component;

$F_i$ -The carbon emission factor of the  $i$ -th type of energy.

For the projects in the design, the energy consumption of HVAC (heating, ventilation, and air conditioning), domestic hot water, lighting, and elevator needs to be simulated through energy consumption simulation software. In this paper, the DesignBuilder software is selected for the energy consumption simulation calculation of building heating and air conditioning systems, etc.

### 3.3.2 Carbon Emission Accounting Model for the Building Maintenance Stage

Due to the significant variations in the surrounding environment of the building, numerous uncontrollable factors, and the complex situation of building maintenance and updates, it is difficult to accurately determine the energy consumption and carbon emission factors consumed by the building maintenance measures. It is also challenging to conduct precise accounting. Moreover, according to existing research, the carbon emissions during the building maintenance phase account for a relatively small proportion of the total carbon emissions throughout the building's life cycle. Therefore, in this study, the carbon emissions during the building maintenance phase are estimated based on the research results of Wang Songqing and Luo Zhixing [5][6] using the following formula:

$$C_{RT} = (C_{SC} + C_{YS} + C_{JZ}) \times 1.05\% \times n \quad (10)$$

In the formula:

$C_{RT}$ -The greenhouse gas emission equivalents of building renovations,  $\text{kgCO}_2\text{e}$ .

### 3.4 Carbon Emission Accounting Method During the Dismantling Stage

Depending on the structure of the building, the methods for demolition vary. However, what remains constant is the need for corresponding manpower and equipment to cooperate. Building demolition is the reverse process of building construction. The energy consumption during the demolition process can be calculated by referring to the calculation methods used in the construction stage. The calculation formula is as follows:

$$C_{CC} = C_{cc} + C_{QY} \quad (11)$$

In the formula:

$C_{CC}$ -Carbon emissions during the dismantling stage,  $\text{kgCO}_2\text{e}$ ;

$C_{cc}$ -Carbon emissions during the demolition process,  $\text{kgCO}_2\text{e}$ ;

$C_{QY}$ -Disposal of waste building materials for carbon emission reduction,  $\text{kgCO}_2\text{e}$ .

#### 3.4.1 Carbon Emission Accounting Model for the Demolition Stage of Buildings

The carbon emissions during the building demolition stage are calculated based on the total fuel consumption of each construction shift in the dismantling process and the corresponding carbon emission factors. The theoretical calculation formula is as follows:

$$C_{cc} = \sum_{i=1}^n E_{cci} \times F_i \quad (12)$$

In the formula:

$C_{cc}$ -Carbon emissions during the demolition process,  $\text{kgCO}_2\text{e}$ ;

$E_{cci}$ -The total consumption of the  $i$ -th type of energy during the building demolition process, kWh or kg;

$F_i$ -The carbon emission factor of the  $i$ -th type of energy,  $\text{kgCO}_2\text{e}$  per unit.

Since the existing buildings make it difficult to determine the future demolition methods and the machinery to be used, the carbon emissions during the building demolition stage are estimated based on the research results as follows:

$$C_{cc} = C_{JZ} \times 90\% \quad (13)$$

#### 3.4.2 Carbon Emission Accounting Model for the Construction Materials Removal Stage

The carbon emissions during the construction waste removal stage mainly come from the fuel consumption of the transportation equipment, which leads to carbon emissions. To facilitate the calculation of the working time of the transportation equipment during the removal stage, the calculation formula for dismantled construction waste provided in the "Standard for Calculating Construction Waste Quantity" can be adopted. This formula usually depends on the volume or weight of the waste, combined with the situation of the demolition site and the efficiency of the transportation equipment, to determine the required working time and resources:

$$W_c = A_c \times Q_c \tag{14}$$

In the formula:

$W_c$ -The amount of waste generated from the demolition of buildings, kg;

$A_c$ -The total building area of the demolished structures, m<sup>2</sup>;

$c_c$ -The waste generation indicators for demolition of buildings can be found in the "Standard for Calculation of Construction Waste Volume".

Calculation of construction waste for building demolition projects: For the demolition of structures, the construction waste volume is calculated based on the actual volume. Each cubic meter is equivalent to 1.1875 cubic meters of waste.

#### 4. Determine the Carbon Emission Factor

Carbon emission factors are the key data for calculating carbon emissions. They represent the amount of greenhouse gases produced per unit of energy or material. The following data have been collated and summarized based on the carbon emission factor information provided in the "Building Carbon Emission Calculation Standard" GB/T51366-2019, serving as the calculation basis for the carbon emission accounting in this article.

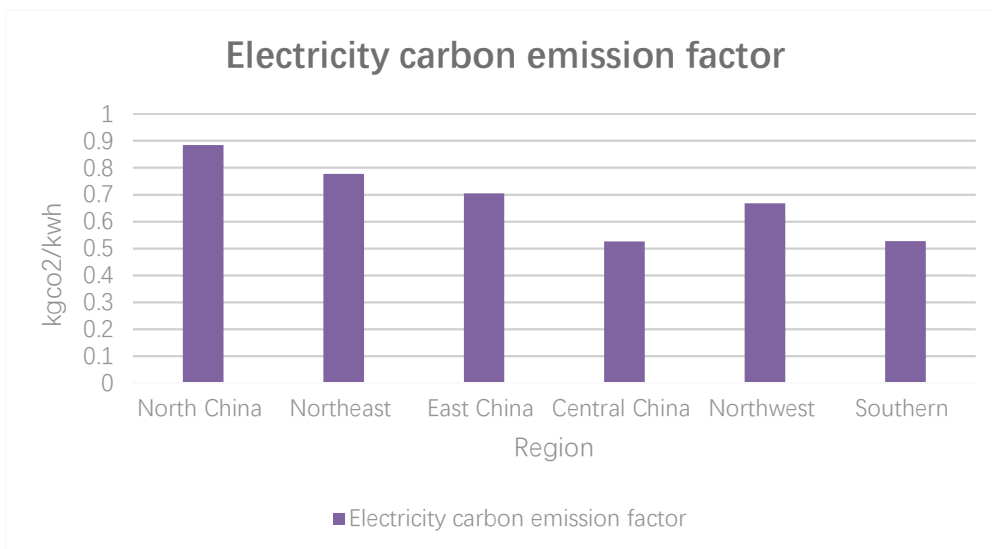
##### 4.1 Electricity Carbon Emission Factor

When calculating the carbon emissions caused by electricity consumption in buildings, the average carbon emission factor of the regional power grid published by the National Development and Reform Commission (NDRC) should be adopted. The power grid boundaries should be clearly defined as shown in Table 2 below.

**Table 2.** List of geographical areas covered by the power grid boundary

Grid name	Covering provinces and cities
North China Regional Power Grid	Beijing, Tianjin, Hebei Province, Shanxi Province, Shandong Province, the western part of Inner Mongolia Autonomous Region
Northeast Regional Power Grid	Liaoning Province, Jilin Province, Heilongjiang Province, and the eastern part of Inner Mongolia Autonomous Region
East China Regional Power Grid	Shanghai City, Jiangsu Province, Zhejiang Province, Anhui Province, Fujian Province
Central China Power Grid	Henan Province, Hubei Province, Hunan Province, Jiangxi Province, Sichuan Province, Chongqing Municipality
Northwest Regional Power Grid	Shaanxi Province, Gansu Province, Qinghai Province, Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region
Southern Regional Power Grid	Guangdong Province, Guangxi Zhuang Autonomous Region, Yunnan Province, Guizhou Province, Hainan Province

After the grid boundaries have been clearly defined, the selection should be based on the average CO<sub>2</sub> emission factor of regional power grids in China, as shown in Figure 2 below.



**Figure 2.** Average CO<sub>2</sub> Emission Factor Map of China's Regional Power Grid

The average CO<sub>2</sub> emission factor data of the power grid in Figure 10 is sourced from the "Average CO<sub>2</sub> Emission Factors of China's Regional Power Grid in 2011 and 2012" released by the National Development and Reform Commission. It was determined by the former National Development and Reform Commission's Department of Climate Change Response and the National Center for Climate Change Strategy and International Cooperation. This data can be used by governments, enterprises, universities, and research institutions for calculating the CO<sub>2</sub> emissions of power imports, exports, and consumption. It is consistent with the enterprise accounting requirements in the "Methodology for Accounting and Reporting of Greenhouse Gas Emissions of Key Industries and Enterprises" formulated by the National Development and Reform Commission. Until 2017, all enterprises participating in greenhouse gas verification and carbon trading across the country still used the data in Figure 10 when calculating carbon emissions caused by power consumption. In the future, when there is an update to the data, the most recent data published by the national authorities in the latest year should be selected.

#### 4.2 Energy Carbon Emission Factor

The carbon emission factors for fossil fuels should be selected according to Table 3 below:

**Table 3.** Table of Carbon Emission Factors for Fossil Fuels

Classification	Fuel type	Organization	Numerical value
Solid fuel	Raw coal	kgCO <sub>2e</sub> /kg	2.000
	Standard coal		2.790
Liquid fuel	Crude oil	kgCO <sub>2e</sub> /m <sup>3</sup>	3.030
	Fuel oil		3.180
	Gasoline		2.940
	Diesel fuel		3.110

#### 4.3 Carbon Emission Factors for Construction Materials, as Shown in Table 4:

**Table 4. Building Materials Carbon Emission Factor Table**

Category of construction materials	Carbon emission factor of construction materials
Ordinary Portland cement (average market level)	735 kg CO <sub>2</sub> e/t
C30 concrete	295 kgCO <sub>2</sub> e/m <sup>3</sup>
C50 concrete	385 kgCO <sub>2</sub> e/m <sup>3</sup>
Limestone production (average market price)	1190kg CO <sub>2</sub> e/t
Slaked lime (calcium hydroxide)	747 kg CO <sub>2</sub> e/t
Natural gypsum	32.8 kg CO <sub>2</sub> e/t
Sand (f = 1.6 - 3.0)	2.51kg CO <sub>2</sub> e/t
Gravel (d = 10mm - 30mm)	2.18kg CO <sub>2</sub> e/t
Shale rock	5.08kg CO <sub>2</sub> e/t
Clay	2.69kg CO <sub>2</sub> e/t
Concrete bricks (240mm × 115mm × 90mm)	336 kgCO <sub>2</sub> e/m <sup>3</sup>
Steam-cured fly ash bricks (240mm × 115mm × 53mm)	341 kgCO <sub>2</sub> e/m <sup>3</sup>
Sintered fly ash solid bricks (240mm × 115mm × 53mm, with a content of 50%)	134 kgCO <sub>2</sub> e/m <sup>3</sup>
Shale solid bricks (240mm × 115mm × 53mm)	292 kgCO <sub>2</sub> e/m <sup>3</sup>
Shale hollow bricks (240mm × 115mm × 53mm)	204 kgCO <sub>2</sub> e/m <sup>3</sup>
Clay hollow bricks (240mm × 115mm × 53mm)	250 kgCO <sub>2</sub> e/m <sup>3</sup>
Coal gangue solid bricks (240mm × 115mm × 53mm, with a content of 90%)	22.8 kgCO <sub>2</sub> e/m <sup>3</sup>
Coal gangue hollow bricks (240mm × 115mm × 53mm, with a content of 90%)	16.0 kgCO <sub>2</sub> e/m <sup>3</sup>
Steel pig iron for steelmaking	1700kg CO <sub>2</sub> e/t
Cast iron	2280kg CO <sub>2</sub> e/t
Iron alloys for steelmaking (average market price)	9530 kg CO <sub>2</sub> e/t
Open-hearth steel	1990 kg CO <sub>2</sub> e/t
Electric-arc furnace steel	3030 kg CO <sub>2</sub> e/t
Ordinary carbon steel (average market price)	2050 kg CO <sub>2</sub> e/t
Small-sized hot-rolled carbon steel sections	2310kg CO <sub>2</sub> e/t
Medium-sized hot-rolled carbon steel sections	2365kg CO <sub>2</sub> e/t
Large-sized steel rails and beams (round billets, tube billets)	2340kg CO <sub>2</sub> e/t
Large-sized steel rails and beams (heavy rails, ordinary sections)	2380kg CO <sub>2</sub> e/t
Medium-thick hot-rolled carbon steel plates	2400kg CO <sub>2</sub> e/t
Hot-rolled carbon steel H-shaped sections	2350kg CO <sub>2</sub> e/t
Hot-rolled carbon steel wide plates	2310 kg CO <sub>2</sub> e/t
Hot-rolled carbon steel high-quality wire rods	2340kg CO <sub>2</sub> e/t
Hot-rolled carbon steel bars	2375kg CO <sub>2</sub> e/t
Helical submerged arc welded pipes	2340kg CO <sub>2</sub> e/t

Large-diameter submerged arc welded straight seam pipes	2520kg CO <sub>2</sub> e/t
Welded straight seam pipes	2430kg CO <sub>2</sub> e/t
Steel pig iron for steelmaking	2530kg CO <sub>2</sub> e/t
Hot-rolled carbon steel seamless pipes	3150kg CO <sub>2</sub> e/t
Cold-rolled and cold-drawn carbon steel seamless pipes	3680 kg CO <sub>2</sub> e/t
Carbon steel hot-dip galvanized coil	3110kg CO <sub>2</sub> e/t
Carbon steel electro-galvanized coil	3020kg CO <sub>2</sub> e/t
Carbon steel electro-galvanized tin-coated coil	2870kg CO <sub>2</sub> e/t
Rust-removed coil	1730kg CO <sub>2</sub> e/t
Cold-rolled carbon steel coil	2530kg CO <sub>2</sub> e/t
Cold-hardened carbon steel coil	2410kg CO <sub>2</sub> e/t
Flat glass	1130kg CO <sub>2</sub> e/t
Electrolytic aluminum (average grid power across the country)	20300 kg CO <sub>2</sub> e/t
Aluminum sheet strip	28500kg CO <sub>2</sub> e/t
Aluminum-plastic co-extruded window	129.5kgCO <sub>2</sub> e/m <sup>2</sup>
PVC window	121kgCO <sub>2</sub> e/m <sup>2</sup>
Random copolymer polypropylene pipe	3.72 kgCO <sub>2</sub> e/kg
Polyethylene pipe	3.60 kgCO <sub>2</sub> e/kg
Rigid polyvinyl chloride pipe	7.93 kgCO <sub>2</sub> e/kg
Polystyrene foam board	5020kg CO <sub>2</sub> e/t
Rock wool board	1980kg CO <sub>2</sub> e/t
Hard foam polyurethane board	5220kg CO <sub>2</sub> e/t
Aluminum-plastic composite board	8.06kgCO <sub>2</sub> e/m <sup>2</sup>
Copper-plastic composite board	37.1kgCO <sub>2</sub> e/m <sup>2</sup>
Copper single sheet	218kgCO <sub>2</sub> e/m <sup>2</sup>
Ordinary polystyrene	4620kg CO <sub>2</sub> e/t
Linear low-density polyethylene High-density polyethylene	1990 kg CO <sub>2</sub> e/t
Low-density polyethylene	2620 kg CO <sub>2</sub> e/t
Polyvinyl chloride (average market price) Tap water	2810 kg CO <sub>2</sub> e/t
Break Bridge Aluminum Windows (100% natural aluminum profiles)	7300 kg CO <sub>2</sub> e/t
Break Bridge Aluminum Windows (Natural aluminum: Recycled aluminum = 7:3)	0.168 kg CO <sub>2</sub> e/t
Aluminum-wood Composite Windows (100% natural aluminum profiles)	254kgCO <sub>2</sub> e/m <sup>2</sup>
Aluminum-wood Composite Windows (Natural aluminum: Recycled aluminum = 7:3)	194kgCO <sub>2</sub> e/m <sup>2</sup>
Hot-rolled carbon steel seamless pipes	147kgCO <sub>2</sub> e/m <sup>2</sup>
Cold-rolled and cold-drawn carbon steel seamless pipes	122.5kgCO <sub>2</sub> e/m <sup>2</sup>

#### 4.4 Carbon Emission Factor for Construction Materials Transportation

The default transportation distance value for concrete should be 40 km, while for other building materials, it should be 500 km. The carbon emission factors for various transportation methods should be selected according to Table 5, with the unit being kgCO<sub>2e</sub>/(t·km).

**Table 5.** Table of Carbon Emission Factors for Various Modes of Transportation

Transportation mode categories	Carbon emission factor
Light gasoline truck transportation (load capacity 2t)	0.334
Medium gasoline truck transportation (load capacity 8t)	0.115
Heavy gasoline truck transportation (load capacity 10t)	0.104
Heavy gasoline truck transportation (load capacity 18t)	0.104
Light diesel truck transportation (load capacity 2t)	0.286
Medium diesel truck transportation (load capacity 8t)	0.179
Heavy diesel truck transportation (load capacity 10t)	0.162
Heavy diesel truck transportation (load capacity 18t)	0.129
Heavy diesel truck transportation (load capacity 30t)	0.078
Heavy diesel truck transportation (load capacity 46t)	0.057
Electric locomotive transportation	0.010
Internal combustion locomotive transportation	0.011
Railway transportation (average in the Chinese market)	0.010
Liquid cargo ship transportation (load capacity 2000t)	0.019
Bulk cargo ship transportation (load capacity 2500t)	0.015
Container ship transportation (load capacity 200 TEU)	0.012

#### 4.5 Construction Shift Carbon Emission Factor

In the "Building Carbon Emission Calculation Standard", there are no specific numerical values for carbon emission factors. First, determine the types of energy consumed by the construction machinery, and then calculate the carbon emission factor by multiplying the carbon emission factor of the energy by the energy consumption. For example: the carbon emission factor of 1 kg of diesel is taken as the data mentioned above, which is 3.110 kg CO<sub>2e</sub>/kg. Then, multiply the energy consumption of 35.6 kg by 3.110 kg CO<sub>2e</sub>/kg to obtain a carbon emission factor of 110.7. Similarly, the carbon emission factors for the following construction shifts are obtained as shown in Table 6.

**Table 6.** Construction Shift Carbon Emission Factor Table

Machine Name	Performance Specifications	Energy consumption	Carbon emission factor (kgCO <sub>2e</sub> per shift)
Track-type Bulldozer	Power: 75kW	56.50 kg diesel	175.7
Track-type Bulldozer	Power: 105kW	60.80 kg diesel	189.0
Track-type Bulldozer	Power: 135kW	66.80 kg diesel	207.7
Track-type Single-Bucket Hydraulic Excavator	Bucket Capacity: 0.6m <sup>3</sup>	33.68 kg diesel	104.7

Track-type Single-Bucket Hydraulic Excavator	Bucket Capacity: 1m <sup>3</sup>	63.00 kg diesel	195.9
Tire-type Loader	Bucket Capacity: 1m <sup>3</sup>	52.73 kg diesel	164.0
Tire-type Loader	Bucket Capacity: 1.5m <sup>3</sup>	58.75 kg diesel	182.7
Electric compactor	Impact Energy: 250N·m	16.6 kWh	9.5
Anchor bolt drilling machine	Anchor Rod Diameter: 32mm	69.72 kg diesel	216.8
Track-type diesel pile driver	Impact Weight: 3.5t	56.90 kg diesel	177.0
Track-type diesel pile driver	Impact Weight: 4.0t	61.70 kg diesel	191.8
Walking-type diesel pile driver	Power: 60kW	336.87 kWh	192.0
Rotary drilling machine	Pit Diameter: 800mm	142.5	81.2
Rotary drilling machine	Pit Diameter: 1000mm	163.72	93.3
Rotary drilling machine	Pit Diameter: 1500mm	190.72	108.7
Screw drilling machine	Pit Diameter: 600mm	181.27	103.3
Three-axis mixing foundation	Shaft Diameter: 650mm	126.42	72.0
Three-axis mixing foundation	Shaft Diameter: 850mm	156.42	89.1
Track-type crane	Lifting Weight: 5t	18.42 kg diesel	57.2
Track-type crane	Lifting Weight: 10t	23.56 kg diesel	73.2
Track-type crane	Lifting Weight: 15t	29.52 kg diesel	91.8
Track-type crane	Lifting Weight: 20t	30.75 kg diesel	95.6
Track-type crane	Lifting Weight: 25t	36.78 kg diesel	115.0
Track-type crane	Lifting Weight: 30t	41.60 kg diesel	129.3
Track-type crane	Lifting Weight: 40t	42.46 kg diesel	132.0
Track-type crane	Lifting Weight: 50t	44.03 kg diesel	136.9
Track-type crane	Lifting Weight: 60t	47.26 kg diesel	147.0
Tire-type crane	Lifting Weight: 25t	46.26 kg diesel	143.8
Tire-type crane	Lifting Weight: 40t	62.76 kg diesel	195.1
Tire-type crane	Lifting Weight: 50t	64.76 kg diesel	201.4
Car-type crane	Lifting Weight: 8t	28.43 kg diesel	88.4
Car-type crane	Lifting Weight: 12t	30.55 kg diesel	95.0
Car-type crane	Lifting Weight: 16t	35.85 kg diesel	111.4
Car-type crane	Lifting Weight: 20t	38.41 kg diesel	119.4
Car-type crane	Lifting Weight: 30t	42.14 kg diesel	131.0
Car-type crane	Lifting Weight: 40t	48.52 kg diesel	150.8
Self-elevating tower crane	Lifting Weight: 40t	164.31 kWh	93.6
Self-elevating tower crane	Lifting Weight: 60t	166.29 kWh	94.7
Self-elevating tower crane	Lifting Weight: 800t	169.16 kWh	96.4
Self-elevating tower crane	Lifting Weight: 1000t	170.02 kWh	97.0
Self-elevating tower crane	Lifting Weight: 2500t	266.04 kWh	151.6
Self-elevating tower crane	Lifting Weight: 3000t	295.60 kWh	168.4

## 5. Conclusion

This research focuses on the core requirements of carbon footprint accounting for industrialized buildings, integrating LCA theory and BIM technology to construct a comprehensive accounting system covering the entire life cycle of "material production and transportation - construction and installation - operation and maintenance - dismantling and disposal". It clarifies the temporal and spatial boundaries and the multi-stage data sources, establishes modular mathematical accounting models, and standardizes the selection criteria for key carbon emission factors such as electricity, energy, building materials, and transportation, ensuring that the accounting error is  $\leq 5\%$ . This system not only provides data support and practical reference for the low-carbon transformation of industrialized buildings, but also builds a standardized benchmark for carbon footprint accounting of similar projects. In the future, it can further expand the data dimensions and optimize the dynamic update mechanism of factors, helping to achieve the deep implementation of green and low-carbon development in the construction industry under the "dual carbon" goals.

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## References

- [1] Zhang Sen. Research on the Life-Cycle Carbon Footprint Calculation Method for New Residential Buildings in the Design Phase Based on BIM Technology [D]. Qingdao University of Technology, 2024.
- [2] The Chinese government. The Kyoto Protocol [Z]. Kyoto: United Nations Framework Convention on Climate Change Conference of the Parties, 1997.
- [3] Chinese Government. 28th United Nations Climate Change Conference - United Nations Framework Convention on Climate Change [Z]. United Arab Emirates, 2023.
- [4] GB/T 51366 - 2019. "Standard for Calculation of Carbon Emissions in Construction" [S]. China Building Industry Press, 2019.
- [5] Wang Songqing. Life Cycle Assessment of Energy Consumption in Residential Buildings in Cold Regions [D]. Harbin Institute of Technology, 2007.
- [6] Luo Zhixing. Research on Carbon Dioxide Emission Accounting Methods and Emission Reduction Strategies during the Building Lifecycle [D]. Xi'an University of Architecture and Technology, 2016.