Embodied Carbon Emissions of Office Building: A Case Study of China's 78 Office Buildings

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Abstract: A CO₂ emission in construction materialization stage is the key research point of architectural life cycle assessment, which is concentrated in emission time and in absolute emission volume. To build a calculation model for CO₂ emissions in the materialization stage of office buildings, it should take into consideration the CO₂ emissions generated from production and transportation of construction materials and equipment as well as the CO₂ emissions generated from the construction process. By this calculation model, the CO₂ emissions are analyzed and calculated of 78 office buildings in construction materialization stage. On average, the CO₂ emissions in construction materialization stage are 326.75 kg - CO₂/m²; with the increase of building height, CO₂ emissions per unit area increase significantly and the CO₂ emissions per unit area of super-high-rise buildings are 1.5 times that of the multi-storey buildings; the CO₂ emissions of Civil Engineering account for 75% of the whole construction materialization stage; And the carbon emissions of steel, concrete, mortar and wall materials reach over 80% of the Civil Engineering. The storeys of the building and the consumption of construction materials are taken as two independent variables to set up a prediction model for CO₂ emissions of office buildings in materialization stage. By statistical analysis and comparison, it can be found that the prediction formula using steel reinforcement, concrete and wall materials as independent variables can better predicate CO₂ emissions in the construction materialization stage.

Keywords: CO₂ emission, life cycle assessment, materialization, office building

1. Introduction

The impact of human activity on the climate has been regarded as a huge threat to the earth [1]. Against such background, it has become a major concern of the world, particularly of China to save energy and reduce greenhouse gas (GHG) emissions represented by CO₂ [2]. Globally, the construction industry consumes about 30%~40% energy while producing 40%~50% GHGs [3]. Thus, it is not only a top environmental issue for construction industry but also a must-taken international responsibility to study how construction industry should reduce GHG emissions [4]. It is generally agreed that our climates are changing and that the average temperature will rise gradually. In response to this, there have been a number of researches on the impact of climate change on energy consumption and carbon emissions of office buildings in China [5-7], Sweden[8], Greece[9], and Australia[10].

The life cycle of a building includes the materialization stage, the operation stage and the disposal stage [11]. The materialization stage comprises the production of construction materials, the processing and manufacturing of components, the field construction and installation required for the formation of engineering entity prior to the building being put into use [11]. The CO₂ emissions in construction materialization stage include (1) underlying CO₂ emissions generated from the production, manufacture and transport of construction materials (such as building pipelines and equipment, etc.) [12-13]; (2) direct carbon emissions generated from the use of energy during building construction [14-18]. Previous studies have attempted to investigate primary energy use for the preparation of building materials and to establish a CO₂ emission inventory [19-21], which are considered to be preconditions for the analysis of building carbon emissions. In general, the evaluation of CO₂ emissions of the materialization stage has become increasingly common in recent years. For example, Onat et al. [22] calculated CO₂ emissions of the materialization stage for the benchmark year 2002 by using a comprehensive hybrid economic input-output life cycle analysis. Wan Omar et al. [23] derived hybrid embodied with energy and carbon emission intensities for reference cases in Australia and Malaysia, with the results compared with the previous hybrid models to identify key parameters and issues.

Researches at home and from abroad show that the CO₂ emissions in construction

materialization stage make up 5%~20% of that of the architectural life cycle (the building life is taken as 50 years) [24-30]. Although the proportion is relatively small, the absolute volume of emissions are quite considerable because our country has a large amount of construction, and the CO₂ emissions in materialization stage are mainly concentrated in construction period of 1~2 years [31]. From a macro perspective, the building industry uses 40%~50% national resources and consumes 30% of the total societal energy [32]. The underlying carbon emissions of the building industry account for 26.47% of that of all social sectors [33]. As a very common public building, office building has a greater impact on energy and environment and is a big consumer of energy and resource. Thus, it is representative to do a quantitative research of CO₂ emissions of office buildings in materialization stage.

By the process-based LCI method, this paper sets up a calculation model for CO₂ emissions of office buildings in materialization stage, taking into consideration the CO₂ emissions generated from the production, transport and construction of construction materials and equipment. 78 office buildings are collected as samples, the CO₂ emissions of each sample in materialization stage are calculated, and the proportion constitution of CO₂ emissions in materialization stage are analyzed. On this basis, the CO₂ emissions of office buildings in materialization stage can be predicted according to the statistical data.

2. Methods

2.1 Case Description

For more accurate, with the detailed and comprehensive understanding of the characteristics of CO₂ emissions of China's office buildings in materialization stage, this study collected large amounts of engineering quantity data of office building construction. After screening, 78 office buildings were chosen as study samples (all being reinforced concrete structures), of which 19 are multi-story buildings (below 24m), 44 are high-rise buildings (24m~100m) and 15 are super high-rise buildings (above 100m).

2.2 Functional Unit

Functional unit refers to the quantified product system performance as the base unit [34]. The

basis role of functional unit is to provide reference for relevant inputs and outputs so as to ensure the comparability of LCA results. The definition of functional unit follows two basic principles: 1) functional unit must be measurable; 2) a system may have several functions simultaneously and what function should be chosen depends on the purpose and scope of the study [35].

As the buildings are different in size, the consumption of materials and machines varies differently, which would directly result in the great difference in CO₂ emissions. Therefore, it lacks comparability to merely list the total carbon emissions of the buildings and evaluation indicators need to be established of horizontal comparability. It can effectively eliminate the effects caused by the difference in building size and other factors by using CO₂ emissions per unit construction area as an indicator to evaluate CO₂ emissions of office buildings in materialization, ensuring consistency and comparability among the results. Thus, LCCO_{2M} (kg-CO₂/m²), CO₂ emissions per unit construction area, can be taken as the functional unit of CO₂ emissions of office buildings in materialization stage.

2.3 Analysis Model

In the materialization stage of office buildings, there are two main sources of CO₂ emissions, that is, (1) the underlying carbon emissions generated from the production and transport of construction materials and the production of construction equipment; (2) the direct carbon emissions resulted from fossil fuels and electricity during the transport of construction materials and equipment, the construction process and the decoration process. Thus, the calculation model of CO₂ emissions in construction materialization stage is as follow:

$$TLCCO_{2M} = TLCCO_{2ma} + TLCCO_{2tr} + TLCCO_{2co} \quad (1)$$

where TLCCO_{2M} (kg-CO₂) represents the CO₂ emissions in the materialization stage of office buildings, TLCCO_{2ma} (kg-CO₂) represents the CO₂ emissions generated from the production of construction materials and equipment of office buildings, TLCCO_{2tr} (kg-CO₂) represents the CO₂ emissions generated from the transport of construction materials and equipment of office buildings, and TLCCO_{2co} (kg-CO₂) represents the CO₂ emissions generated from the construction of office buildings.

To be more specific,

$$TLCCO_{2ma} = \sum_{i=1}^n (Q_i \times N_i) \quad (2)$$

where Q_i (kg-CO₂) refers to the CO₂ emissions generated from the production of some construction material, such as civil work, electric, water supply and drainage, decoration materials and HVAC (heating ventilation and air conditioning) equipment, etc; N_i (kg/ m² / m³) refers to the quantity of some construction material.

$$TLCCO_{2tr} = \sum_{i=1}^n (T_i \times M_i \times L_i) \quad (3)$$

where, T_i (kg-CO₂/t•km) refers to the CO₂ emissions generated by some transportation mode per unit distance-and-weight, M_i (t) refers to the gross weight of some construction material, L_i (km) refers to the transportation distance of some construction material.

$$TLCCO_{2co} = \sum_{j=1}^m \left| \sum_{i=1}^n (Q_{pj,i} \times M_{j,i}) \right| \quad (4)$$

where, $Q_{pj,i}$ (kg-CO₂) refers to the CO₂ emissions generated from the processing of the i construction material in the j construction process of the office building, $M_{j,i}$ (kg/m² /m³) refers to the quantity of the processed i construction material in the j construction process of the office building.

The calculation model of the function unit in the construction materialization stage:

$$LCCO_{2M} = \frac{TLCCO_{2M}}{A} \quad (5)$$

where, A (m²) refers to the total construction area of the building.

For some designated office buildings, the smaller the $LCCO_{2M}$ is, the smaller the CO₂ emissions per unit construction area are, thus causing little influence on the environment.

2.4 CO₂ Emission Inventory Analysis of Constriction Materials

This study detailed the CO₂ emissions of each section in materialization stage of each sample. The author's related research results are used for the CO₂ emission data of construction materials of civil work and transport. [15][36] (see Table 1). The CO₂ emission data of construction materials covered by installation and decoration projects is taken from Taiwan's database [37].

Table 1 CO₂ emission data of partial materials of Civil Engineering

Material	Sand	Gravel	Steel	Cement	concrete	Perforated	Aerated
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type						clay brick	concrete block
Unit	kg /m ³	kg /m ³	kg /t	kg /t	kg /m ³	kg /piece	kg /piece
CO ₂ emissions	3.19	4.00	894.75	685.74	301.97	0.75	1.18

3.Results

3.1 Analysis of CO₂ Emissions of Each Itemized Project

The construction process of buildings mainly include the Civil Engineering, installation project and decoration project, among which installation project consists of Water Supply and Sewage Engineering, electrical engineering, and HVAC engineering, etc.

Table 2 shows the CO₂ emissions per unit area of each itemized project of buildings of different heights and the percentage they make up of all the projects. It can be found that the CO₂ emissions per unit area of each itemized project increase with the height of the building. In general, the CO₂ emissions of Super high-rise office buildings are 1.5 times that of multi-storey office buildings, and 1.3 times that of high-rise office buildings. That is because with the increase of the building height, CO₂ emissions of Civil Engineering greatly increase while Civil Engineering is the main section in the entire building formation stage, making up an average of 75%; meanwhile, with the increase of the building height, installation project and construction project also increase in the number and difficulty and the CO₂ emissions of these sections also see a significant increase. Moreover, it can be found that there are few changes in CO₂ emissions of installation project and the percentage it makes up, indicating that there is little relationship between CO₂ emissions of installation project and the building height.

Table 2 CO₂ emissions per unit area of each itemized project and the proportion they make up

	Multi-story buildings		High-rise buildings		Super high-rise buildings		Weighted average	
	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)
Civil Engineering	215.93	79.39	239.25	78.04	280.51	69.83	241.50	76.32
Water Supply	2.02	0.74	2.59	0.85	7.45	1.85	3.39	1.07

	Multi-story buildings		High-rise buildings		Super high-rise buildings		Weighted average	
	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)	CO ₂ Emissions per unit area (kg/m ²)	Percent age (%)
and Sewage								
Engineering								
Electrical	2.22	0.82	3.45	1.13	9.99	2.49	4.41	1.39
Engineering								
HVAC	4.35	1.60	6.82	2.22	21.47	5.34	9.04	2.86
Engineering								
Decoration	28.93	10.63	30.15	9.83	36.62	9.12	31.10	9.83
Engineering								
Building	18.54	6.82	24.3	7.93	45.66	11.37	27.00	8.53
Construction								
Total	271.99	100	306.56	100	401.70	100	316.44	100

3.2 Analysis of CO₂ Emissions of Construction materials of Civil Engineering

It can be seen from the above analysis that the CO₂ emissions of Civil Engineering accounts for 76.32% that of the entire building formation stage. Thus, this section needs to be focused on.

3.2.1 Analysis of CO₂ emissions of Construction materials

Table 3 shows the consumption and CO₂ emissions of construction materials of Civil Engineering. We can find the followings: the higher the building is, the higher the consumption of steel and concrete. The steel consumption per unit area of super high-rise office building is 40% greater than that of multi-storey building, and the concrete consumption 60% greater. Higher building requires higher structural strength and it will increase steel consumption because steel is the major structural material of reinforced concrete structure; with the increase of building height, the cross-sectional area of architectural beam and column rises dramatically and the concrete consumption will increase because concrete is a compressive material of building structure. Steel reinforcement and concrete are the major construction materials of reinforced concrete building, and when they are calculated in CO₂ emissions, it can be found that CO₂ emissions of steel reinforcement and concrete of high-rise buildings are 1.2 times that of multi-storey buildings while CO₂ emissions of super high-rise buildings are 1.5 times that of multi-storey buildings.

By analyzing the mean values, it can be found that the CO₂ emissions are generated from the

four types of construction materials such as steel, concrete, mortar and wall materials, etc. account for nearly 90% that of the entire Civil Engineering. However, when comparing the total CO₂ emissions generated from the four types of construction materials among buildings of different heights, one can find little difference: the total CO₂ emission of high-rise building is 1.1 times that of multi-storey while the total CO₂ emission of super high-rise building is 1.25 times that of multi-storey. This is mainly because with the increase of the building height, the consumption of the mortar and wall material is gradually declining while the consumption of steel and concrete is just the opposite. The decline in the consumption of the mortar and wall material is caused by facade modeling and self-weight reduction required by super high-rise buildings and high-rise buildings. And more light materials as reflection glass curtain-wall are used, making the ratio of the window to the wall much bigger.

Table 3 Analysis of the consumption and CO₂ emissions of construction materials

	Multi-story buildings		High-rise buildings		Super high-rise buildings		Weighted average	
	Material consumption	CO ₂ Emissions (kg/m ²)	Material consumption	CO ₂ Emissions (kg/m ²)	Material consumption	CO ₂ Emissions (kg/m ²)	Material consumption	CO ₂ Emissions (kg/m ²)
Steel (kg)	53.18	47.58	64.51	57.72	72.6	64.96	56.64	22.43
Cement (m ³)	0.36	97.08	0.43	116.92	0.58	157.52	119.89	47.48
Plaster (kg)	65.55	44.95	54.36	37.28	39.49	27.08	37.19	14.73
Brick (m ³)	0.462	15.54	0.437	14.69	0.214	7.19	13.45	5.33
Template (m ²)	0.85	0.29	1.03	0.35	1.35	0.46	0.36	0.14
Window(m ²)	0.3	8.21	0.34	9.73	0.45	19.08	11.16	4.42
Insulation (m ³)	0.01	2.28	0.01	2.56	0.02	4.21	2.81	1.11
Others	-	9.57	-	10.85	-	13.46	11.04	4.37
Total (kg-CO ₂)	-	225.5	-	250.1	-	293.96	252.54	100

3.3.2 Analysis of the percentages of CO₂ emissions of major construction materials

Fig.1 the proportion pie charts of CO₂ emissions of each itemized project in building formation stage and of CO₂ emissions of major construction materials

Combining the statistical results of Section 2.3.1 and Section 2.2, we can get the proportion pie charts of CO₂ emissions of each itemized project in building formation stage and of CO₂ emissions of major construction materials, as shown in Fig. 1. It clearly shows what material in the building formation stage generates the largest amount of CO₂ emissions.

3.3 Correlation analysis of CO₂ emissions between building storeys and construction materials

In order to determine what construction materials have greater correlation with CO₂ emissions of Civil Engineering, this research used statistical analysis software SPSS to make a study of correlation. As shown in Table 4, the significant level α is zero between the carbon dioxide emissions of two construction materials and the building storey, and between the carbon dioxide emissions of four construction materials and the building storey, which shows significant correlation; however, the correlation is more significant between the building storey and CO₂ emissions generated from steel and concrete, with Pearson correlation coefficient reaching 0.909.

Table 4 Correlation analysis of CO₂ emissions between building storeys and construction materials

		Building storeys	CO ₂ Emissions of steel, concrete	CO ₂ Emissions of steel, concrete, plaster, and brick
Building Stories	Pearson correlation	1	0.909^a	0.810^a
	Sig. (2-tailed)	-	<0.001	<0.001

	N	78	78	78
CO ₂ Emissions of steel, concrete	Pearson correlation	0.909 ^a	1	0.877 ^a
	Sig. (2-tailed)	<0.001	-	<0.001
	N	78	78	78
CO ₂ Emissions of steel, concrete, plaster, and Brick	Pearson correlation	0.810 ^a	0.877 ^a	1
	Sig. (2-tailed)	<0.001	<0.001	-
	N	78	78	78

^a: Correlation is significant at the 0.01 level (2-tailed)

4. Discussion

Based on the above analysis, it can be found that there are strong correlation between the CO₂ emissions of major construction materials and the building storey. There come two questions: do the CO₂ emissions in the construction materialization stage have some relationships with the consumption of major construction materials and the building storey? Can the correlation between them be used to predicate the CO₂ emissions in the construction materialization stage?

4.1 Prediction of CO₂ emissions at different storeys

From Table 2 and Table 3, a trend can be found as follow: with the increase of building height, there are differences in CO₂ emissions per unit area of each itemized project in building formation stage. Therefore, this study made an actuarial study of statistical data of the 78 building samples and tested the correlation between building storeys and CO₂ emissions per unit area in building formation stage. Because CO₂ emissions per unit area of the samples in building formation stage obey normal distribution, only the linear correlation (as shown in Table 5) requires to be tested. From the results of correlation analysis, it can be determined that there is a strong correlation between the two, with the Pearson correlation coefficient reaching 0.883.

Table 5 Linear correlation between building storey and CO₂ emissions per unit area in the materialization stage of office buildings

		Building storeys	CO ₂ Emissions of unit area at materialization stage
<u>Building storeys</u>	Pearson correlation	1	0.883 ^a

	Sig. (2-tailed)	-	<0.001
	N	78	78
CO ₂ Emissions of	Pearson correlation	0.883 ^a	1
unit area at	Sig. (2-tailed)	<0.001	-
materialization	N	78	78
stage			

^a: Correlation is significant at the 0.01 level (2-tailed)

After determining the significant correlation between building storey and CO₂ emissions per unit area in the materialization stage of office buildings, the actuarial results were plotted as a scatter graph, where a linear regression analysis was made. It can be seen that CO₂ emissions per unit area in the materialization stage increase with the rise of building height; office buildings of the same height also see different distributions in CO₂ emissions because of individual variability, but the difference is not huge, showing the diversity and representativeness of the samples. By regression analysis, it can be found that deterministic coefficient R^2 of regression equation reaches 0.78, indicating that it is quite credible to use building storey to predicate CO₂ emissions in the materialization stage of office buildings.

Fig. 2 Scatter distribution and linear regression analysis of CO₂ emissions in the materialization stage of office buildings

Considering the slight difference among CO₂ emissions of individual cases, we could calculate the mean values of CO₂ emissions of buildings at the same storey, reducing the difference degree and making mean values more representative. Hence, the mean values were

plotted as a scatter graph, where a linear regression analysis was made, as shown in Fig.2. By regression analysis, it could be found that deterministic coefficient R^2 of regression equation reaches 0.78, indicating that the regression equation has a high degree of credibility in prediction.

By above analysis, we can get the predictive equation concerning building storey and CO₂ emissions in the materialization stage of office buildings,

$$LCCO_2M = 3.99 \times H + 289.94 \quad (6)$$

where, H refers to the storey of the building.

4.2 Prediction of construction material consumption and CO₂ emissions

Construction materials referred to in this section are mainly the four major categories, that is, steel, concrete, mortar and wall materials. The previous analysis has shown that CO₂ emissions of Civil Engineering account for over 75% that of construction materialization stage while CO₂ emissions of these four construction materials make up 90% that of the Civil Engineering. Thus, these four categories are the biggest source of CO₂ emissions in materialization stage of office buildings and may have a close relationship with the total CO₂ emissions. If the consumption of these four categories can be used for the prediction of CO₂ emissions in materialization stage, the complexity of evaluation will be greatly simplified.

At first, we can determine the correlation between these four categories and the total CO₂ emissions in materialization stage by dual-variable analysis of the linear correlation, as shown in Table 6. It can be found that the significant levels α are all zero between the total CO₂ emissions and the steel, the total CO₂ emissions and the concrete, the total CO₂ emissions and the wall materials, indicating that the three categories have significant correlation with the total CO₂ emissions; the significant levels α is 0.394 between the total CO₂ emissions and the mortar, indicating a weak correlation. In terms of Pearson correlation coefficient, the correlation between concrete and the total CO₂ emissions is the strongest, while the steel and the wall materials the weakest.

Table 6 Correlation between the four categories of construction materials and the total CO₂ emissions in materialization stage

CO ₂ Emissions	Steel	Concrete	Plaster	Brick
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CO ₂ Emissions	Pearson correlation	1	0.586^a	0.705^a	0.098	0.391^a
	Sig. (2-tailed)		<0.001	<0.001	0.394	<0.001
	N	78	78	78	78	78
Steel	Pearson correlation	0.586 ^a	1	0.421 ^a	-0.151	-0.103
	Sig. (2-tailed)	<0.001		<0.001	0.187	0.368
	N	78	78	78	78	78
Concrete	Pearson correlation	0.705 ^a	0.421 ^a	1	-0.417 ^a	-0.192
	Sig. (2-tailed)	<0.001	<0.001		<0.001	0.092
	N	78	78	78	78	78
Plaster	Pearson correlation	0.098	-0.151	-0.417 ^a	1	0.248 ^a
	Sig. (2-tailed)	0.394	0.187	<0.001		0.029
	N	78	78	78	78	78
Brick	Pearson correlation	0.391 ^a	-0.103	-0.192	0.248	1
	Sig. (2-tailed)	<0.001	0.368	0.092	0.029	
	N	78	78	78	78	78

^a: Correlation is significant at the 0.01 level (2-tailed)

After the determination of the significant correlation between the total CO₂ emissions and the steel/ concrete/ wall materials, the consumption amounts of these three construction materials could be used as independent variables to predicate the total CO₂ emissions in materialization stage. Three groups of predictive variables are tested by statistical software, as shown in Table 7, and it can be found that when the consumption amounts of the three construction materials are taken as independent variables simultaneously, the adjusted R² reaches a maximum, which illustrates that the explicable variation of the regression equation accounts for the largest proportion of the total variation. The prediction equation is as follow:

$$LCCO_2f = 1.58X_1 + 378.97X_2 + 64.57X_3 + 94.19 \quad (7)$$

where X₁ (kg) is the consumption amount of the steel; X₂ (m³) is the consumption amount of the concrete; X₃ (m³) is the consumption amount of wall materials.

By variance analysis, this regression equation has a significant probability value of 4.24×10^{-36} , far less than 0.01, indicating that this regression equation has a considerable degree of practicability. Meanwhile, the P values of X₁, X₂ and X₃ are 3.63×10^{-13} , 4.29×10^{-25} and 3.21×10^{-23} , all far smaller than 0.05, showing their significant influence on LCCO_{2f}.

Table 7 Deterministic coefficient and variance analysis of the three groups of predictive variables

model	R	R ²	Adjustment of R ²	Std. Error of the Estimate
1	0.705 ^a	0.497	0.490	35.667
2	0.886 ^b	0.784	0.778	23.511

3	0.946 ^c	0.895	0.891	16.526
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a. Predictors: (Constant), concrete				
b. Predictors: (Constant), concrete, brick				
c. Predictors: (Constant), concrete, brick, steel				

4.3 Accuracy analysis of the two predictive methods

The relevant statistical data of 78 samples were substituted in Formula 6 and Formula 7, and a comparison was made between the calculations results and the actual statistical results, as shown in Fig. 3. It can be found that the predictive results are much closer to the actual statistical results by using Formula 7 than using Formula 6. And the standard error is 23.36kg-CO₂/m² between the actual results and the predictive results by using building storey, while the standard error is 16.09kg-CO₂/m² between the actual results and the predictive results by using construction materials.

The reason for the above results are that the CO₂ emission values predicted by using building storey are the mean values of the statistical data while the CO₂ emission values predicted by using construction material are the sample values of the statistical data.

These two prediction models are applied to different stages of architectural design: the prediction model of building storey is applicable to estimate CO₂ emissions of office building in planning stage of architectural design, and the prediction model of the three major construction materials is applicable to estimate CO₂ emissions of office building in architectural schematic design stage of architectural design.

Figure 3 Comparison and analysis of the predictive results and actual results

5. Conclusion

CO₂ emissions in the materialization stage are the important components of CO₂ emissions generated from the life cycle of office buildings, accounting for 5%~20% of the latter. Hence, we can analyze the CO₂ emissions in the materialization stage of office buildings and come to the following conclusions:

- (1) With the increase of building storey (height), CO₂ emissions grow significantly in materialization stage of office buildings. The CO₂ emission of super high-rise buildings is 1.5 times that of multi-storey buildings, and 1.3 times that of high-rise buildings.
- (2) In materialization stage, CO₂ emissions of Civil Engineering make up the largest proportion, being 75%; with the increase of building height, the CO₂ emissions of Civil Engineering rise greatly; in terms of installation project and construction project, the CO₂ emissions rise more obviously with the increase of building height; the CO₂ emissions of installation project has less correlation with the building height.
- (3) The CO₂ emissions of the four categories of construction materials - steel, concrete, mortar and wall materials make up nearly 90% of the CO₂ emissions of the whole Civil Engineering and the four categories are also the major CO₂ emission materials in the materialization stage.
- (4) By means of statistics, we can work out the prediction formula concerning building storey and

CO₂ emissions in materialization of office buildings as well as the prediction formulas concerning CO₂ emissions in materialization of office buildings and the steel/ concrete/ wall materials. These two kinds of prediction models are suitable for the planning stage and architectural schematic design stage of architectural design.

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