Impact of Construction Project Designs on CO_2 Emissions

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Summary

Carbon dioxide (CO_2) is regarded as a leading cause of global warming [9], with the construction industry a main source of CO_2 emissions worldwide. But proper methods for assessing CO_2 emissions in construction projects are lacking. This paper outlines a method for calculating CO_2 emissions and compares CO_2 levels in various construction projects in relation to their design and building materials. The study reveals that a steel structural frame emits higher CO_2 levels than reinforced concrete, whereas a curtain wall emits less CO_2 than a reinforced concrete wall. Such knowledge could help designers in selecting building materials and designing construction projects.

Keywords: CO_2 emissions; value management; case study

1. Introduction

Climate change and global warming are of great international concern, as the last 20 years have seen a significant rise in global air temperatures (see Figure 1). Global warming is caused mainly by the emission of greenhouse gases, including water vapour, carbon dioxide (CO_2), methane, nitrous oxide, and chlorofluorocarbons. CO_2 is now regarded as a leading cause of global warming [8], with the construction industry a major source of CO_2 emissions.

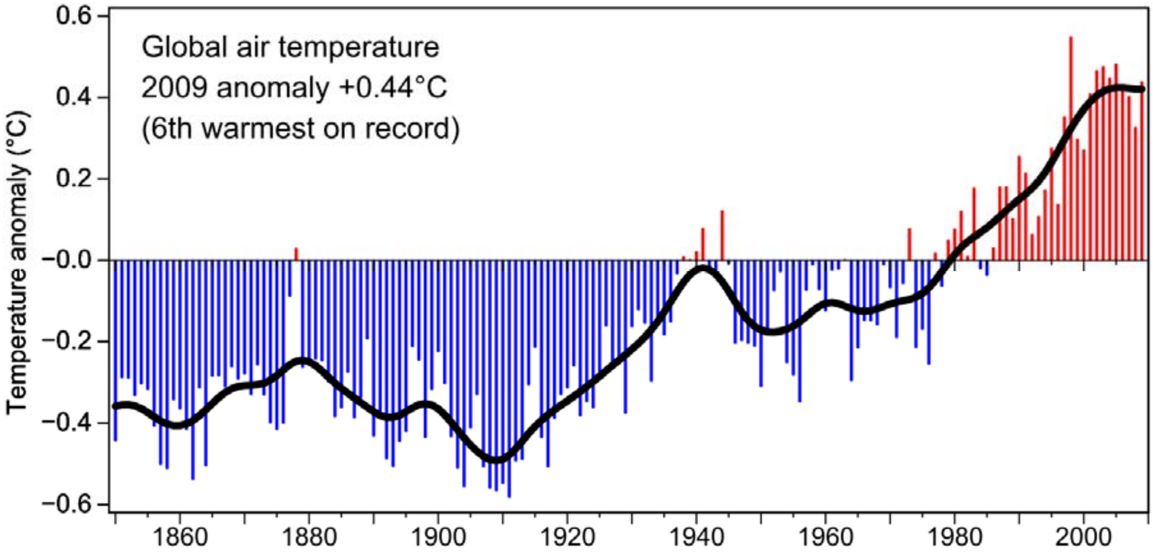

Figure 1 Global Temperature Records [11]

2. CO2 Emissions in Construction Projects

In Japan, CO_2 emissions associated with the construction and operation of buildings amount to one-third of all CO_2 emissions [21]. CO_2 can be emitted in different construction processes, such as materials manufacturing, building design, construction, operations, and demolitions [12]. Energy consumption in the construction industry is a major component (40%) of the annual EU final energy use [4], with more than 5% of CO_2 emissions coming from the production of Portland cement [7].

Although many studies have focused on emissions from materials and energy consumption [1, 2, 10, 16, 18], few have evaluated the impact of project design on CO_2 emissions.

Design can have an important effect on the emission of CO_2 [15], since different types and quantities of materials are used for different architectural designs (e.g. reinforced concrete frameworks for traditional buildings; curtain walls for high-class residential or commercial buildings; steel for special types of buildings and accelerated construction). Table 1 lists a sample of building materials for different building frameworks and enclosures.

Table 1 Factors Affected by Design

Building Component	Building Materials	CO_2 Emission Intensity
Framework	Steel frame	0.96 t-CO_2/t for primary steel [14]
	Concrete frame	0.81 kg-CO_2/kg for Portland cement [6]; 0.96 t-CO_2/t for primary steel [14]; and 115 kg-CO_2/m3 for timber
Exterior enclosure	Curtain walls with glass	1.05 t-CO_2/t for glass [13]
	Concrete	0.81 kg-CO_2/kg for Portland cement [6]; 0.96 t-CO_2/t for primary steel [14]; and 115 kg-CO_2/m^3 for timber

Large quantities of building materials are used in all construction projects, with concrete, steel, wood, and glass being the most popular choices. To calculate CO_2 emissions in construction projects, the relevant emission intensity should be identified, for instance, 0.81 kg-CO_2/kg for Portland cement [6], 0.96 t-CO_2/t for primary steel [14], 115 kg-CO_2/m^3 for timber, and 1.05 t-CO_2/t for glass [13]. To reduce CO_2 emissions in construction projects, the design should incorporate materials that will emit the least CO_2.

3. Case Study

To study the effect of CO_2 emissions on different designs and materials, we used four sites in a case study – a residential building, a hotel tower, and two office buildings – and three different foundation types: RC ball pile, steel pile, and raft footing. The super-structural frameworks were concrete flat-plane structures, concrete shear wall structures, and steel core wall systems. Three of the four projects were enclosed by curtain walls, and one by reinforced concrete (see Table 2).

Table 2 Backgrounds of the Four Cases

Project	P1	P2	P3	P4
Project type	Residential	Hotel	Office	Office
CFA	22,704	11,974	87,760	170,815
Substructure	RC ball pile	Steel pile	-	Raft footing
Superstructure				
Structural frame (major materials)	Flat-plane structure (concrete)	Shear wall structure (concrete)	Shear wall structure (concrete)	Core wall system (steel)
Enclosure	RC wall	Curtain wall	Curtain wall	Curtain wall

3.1 Data Collection

We abstracted the quantities of building materials (measured in m^3 for concrete, kg for steel, and m^2 for timber and glass) from the Bills of Quantity document. CO_2 is normally measured in kg, whereas the CO_2 emission factor is calculated in kg for concrete and glass, m^3 for timber, and kg for steel. We thus applied a unit factor to adjust the quantity of concrete from m^3 to kg, timber from m^2 to m^3, and glass from m^2 to kg (see Table 4).

Table 3 Factors for the Adjustment of Units

Items	Adjustment Factors	Sources
Concrete	22,400 $m^3 \rightarrow kg$	Swartz et al. 1988 [20]
Timber	0.021 $m^2 \rightarrow m^3$	Eyre et al. 1997 [5]
Glass	22.47 $m^2 \rightarrow kg$	Stepanov et al. 1998 [17]

3.2 Calculation Method

We converted the data collected from the Bills of Quantity document into CO_2 emission levels using the following steps:

Procedure		
A. To collect qty of materials from BQ	=	Concrete (m^3) /Steel (kg) /Timber (m^2) /Glass (m^2)
B. To adjust the unit into kg	=	A x Adj. factor
C. To calculate CO_2 emission	=	B x CO_2 intensity (kg-CO_2/kg)
D. To calculate CO_2 emission per CFA	=	C / CFA (m^2)

3.3 CO2 Emissions

Table 4 shows the levels of CO_2 emissions from the three main building components (substructure, super-structural frame, and super-structural enclosure). Because the Bills of Quantity did not provide data on the foundation, the P3 project was not part of the substructure analysis.

Table 4 CO2 Emissions from Various Building Components

Building Design	CFA (m2)	CO_2 Emission (kg)	Major Characteristics	Average CO_2 Emission (kg)
Substructure				
P1 Deep - RC ball pile	22,704	308.26	RC deep fdn	367.42
P2 Deep - Steel H-pile	11,974	426.57	Steel deep fdn	
P4 Shallow - Raft footing	170,815	151.57	RC shallow fdn	151.57
Super-structural frame				
P1 RC - flat-plane structure	22,704	712.46	RC flat plane	712.46
P2 RC - shear wall structure	11,974	1,274.57	RC shear wall	1,149.53
P3 RC - shear wall structure	87,760	1,024.48		
P4 Steel - core wall structure	170,815	1,214.69	Steel	1,214.69
Super-structural enclosure				
P1 RC wall	22,704	243.76	RC wall	164.94
P2 Curtain wall ~20%	11,974	86.11		
P3 Curtain wall >80%	87,760	13.91	Curtain wall	8.17
P4 Curtain wall >80%	170,815	2.42		

- Substructure: Projects P1 and P2, representing RC and the steel deep foundation of construction buildings, emitted 308.26 and 426.57 kg-CO_2/m2, respectively, while the P4 constructed raft footing emitted 151.57 kg-CO_2/m2. Clearly, substantially less CO_2 is emitted for projects using shallow foundations (P3). Steel structures normally emit higher CO_2 levels than RC structures, explaining why the substructure of the P2 project emitted over 35% more CO_2 than that of the P1 project.

- Super-structural frame: The P1, P2, and P3 projects used concrete for the super-structural frame. Among the four projects, the one using an RC flat-plane structure emitted the least CO_2 (712.46). Flat-plane structures are supported mainly by columns and beams, whereas shear wall structures employ load-bearing walls. The results indicated that RC shear walls likely consume more building materials than other types of structural frames and therefore emit more CO_2.

- Super-structural enclosure: The P3 and P4 projects enclosed by curtain walls emitted 8.17 kg-CO_2/m^2 on average, which is much lower than the amount emitted by the P1 (RC external wall: 243.76 kg-CO_2/m^2) and P2 (RC external wall plus 20% curtain wall: 86.11 kg-CO_2/m^2) projects. To reduce CO_2 emissions in construction projects, we thus recommend that curtain walls be used instead of traditional RC walls.

In summary, the results revealed the following phenomena:

1. A steel deep foundation emitted more CO_2 than an RC deep foundation.
2. A surface foundation emitted less CO_2 than a steel deep foundation.
3. An RC flat structural framework emitted the least CO_2 compared with RC share walls and a steel framework.
4. A curtain wall emitted less CO_2 than an RC external wall.

4. Limitations

This study does involve some limitations. Firstly, calculation methods for CO_2 emissions have not yet been standardised; CO2 emission intensity factors are inconsistent among different regions or companies (Environment Agency 2010). In this study, we employed the widely used CO^2 emission intensity factors and adjusted them into the same measurement units, thereby increasing the validity of the findings. Secondly, this study was limited to only three project types involving eight building designs, making it difficult to generalize the results to other project types and designs. Therefore, we strongly recommend the investigation be extended to diverse project types and designs to further explain the impact of building designs on CO^2 emissions. Thirdly, our research involved four main construction materials (i.e. steel, concrete, glass, and timber), thus excluding other materials such as brickwork, tile, asphalt, and so forth, as well as other construction activities, such as transportation and construction. Future studies should cover all construction materials and activities in order to calculate an integrated CO^2 emission for different types of buildings.

5. Conclusion

The construction industry is one of the main sources of CO_2 emissions throughout the world. The design and manufacture of building materials could play an important role in reducing CO_2 emissions. Although this study measured CO_2 emissions in only four construction projects, it still clearly revealed that both building design and building materials affect CO_2 emissions in the construction process. To validate the results, we suggest that more data covering different types of building designs and materials be collected. To identify total CO_2 emissions in the construction process, we also recommend that CO_2 emissions in the manufacture and transport of building materials, especially concrete, steel, and glass, be measured as well.

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Table 6 CO^2 Emissions from Various Building Components

Project	Bills of Quantity: CFA (m^2)	Elements	Qty(s)	Unit Adj.*	Emission Factor**	Amounts of Emission (kg)	Emission @CFA (kg/m^2)	%	Total Emission @CFA (kg/m^2)	Summary
Substructure										
P1	22,704	Concrete	3,485 m^3	8,364,000 kg	0.81	6,774,840.00	298.40	(96.80)	308.26	
(RC ball pile)		Steel	225,180 kg	225,180 kg	0.96	216,172.80	9.52	(3.10)		**Deep**
(Deep)		Timber	3,170 m^2	67 m^3	115	7,655.55	0.34	(0.10)		367.42
P2	11,974	Concrete	1,957 m^3	4,696,800 kg	0.81	3,804,408.00	317.74	(74.49)	426.57	
(Steel H-pile)		Steel	1,352,050 kg	1,352,050 kg	0.96	1,297,968.00	108.40	(25.41)		
(Deep)		Timber	2,132 m^2	45 m^3	115	5,148.78	0.43	(0.10)		
P4	170,815	Concrete	11,643 m^3	27,943,200 kg	0.81	22,633,992.00	132.51	(87.42)	151.57	
(Raft footing)		Steel	3,388,000 kg	3,388,000 kg	0.96	3,252,480.00	19.04	(12.56)		**Shallow**
(Shallow)		Timber	1,444 m^2	30 m^3	115	3,487.26	0.02	(0.02)		151.57
Superstructure										
P1 (concrete)	22,704	Concrete	7,580 m^3	18,192,000 kg	0.81	14,735,520.00	649.03	(91.10)	712.46	
		Steel	1,359,700 kg	1,359,700 kg	0.96	1,305,312.00	57.49	(8.07)		**Concrete**
(Flat-plane structure)		Timber	55,850 m^2	1,173m^3	115	134,877.75	5.94	(0.83)		1,003.82
P2 (concrete)	11,974	Concrete	7,071 m^3	16,970,400 kg	0.81	13,746,024.00	1,148.04	(90.07)	1,274.57	
		Steel	1,500,000 kg	1,500,000 kg	0.96	1,440,000.00	120.27	(9.44)		
(Shear wall structure)		Timber	31,069 m^2	652m^3	115	75,031.64	6.27	(0.49)		
P3 (concrete)	87,760	Concrete	43,262 m^3	103,828,800 kg	0.81	84,101,328.00	958.31	(93.54)	1,024.48	
		Steel	5,659,471 kg	5,659,471 kg	0.96	5,433,092.16	61.91	(6.04)		**Steel**
(Shear wall structure)		Timber	154,694 m^2	3,249m^3	115	373,586.01	4.26	(0.42)		1,214.69
P4 (steel)	170,815	Concrete	95,081 m^3	228,194,400 kg	0.81	184,837,464.00	1,082.09	(89.08)	1,214.69	
		Steel	22,764,740 kg	22,764,740 kg	0.96	21,854,150.40	127.94	(10.53)		
(Core wall structure)		Timber	329,242 m^2	6,914m^3	115	795,119.43	4.65	(0.39)		
Enclosure										
P1	22,704	Concrete	2,590 m^3	6,216,000 kg	0.81	5,034,960.00	221.77	(90.98)	243.76	
(RC wall)		Steel	460,850 kg	460,850 kg	0.96	442,416.00	19.49	(8.00)		**Non-**
		Aluminum	0 kg	0 kg	1.75	0.00	0.00	(0.00)		**curtain**
		Timber	19,200 m^2	403 m^3	115	46,368.00	2.04	(0.84)		**wall**
		Glass/glazing	4,070 m^2	10,053 kg	1.05	10,555.55	0.46	(0.19)		164.94
P2	11,974	Concrete	475 m^3	1,140,000 kg	0.81	923,400.00	77.12	(89.56)	86.11	
		Steel	85,388 kg	85,388 kg	0.96	81,972.48	6.85	(7.95)		
(Curtain wall)		Aluminum	0 kg	0 kg	1.75	0.00	0.00	(0.00)		
(~20%)		Timber	7,590 m^2	159 m^3	115	18,329.85	1.53	(1.78)		
		Glass/glazing	2,847 m^2	7,032 kg	1.05	7,383.69	0.62	(0.72)		
P3	87,760	Concrete	540 m^3	1,296,000 kg	0.81	1,049,760.00	11.96	(85.98)	13.91	
(Curtain wall)		Steel	92,000 kg	92,000 kg	0.96	88,320.00	1.01	(7.26)		
		Aluminum	0 kg	0 kg	1.75	0.00	0.00	(0.00)		**Curtain**
(>80%)		Timber	3,097 m^2	65 m^3	115	7,479.26	0.09	(0.65)		**wall**
		Glass/glazing	29,113 m^2	71,909 kg	1.05	75,504.57	0.86	(6.18)		8.17
P4	170,815	Concrete	38 m^3	91,200 kg	0.81	73,872.00	0.43	(17.77)	2.42	
(Curtain wall)		Steel	108,748 kg	108,748 kg	0.96	104,398.08	0.61	(25.21)		
		Aluminum	60,746 kg	60,746 kg	1.75	106,305.50	0.62	(25.62)		
(>80%)		Timber	3,409 m^2	72 m^3	115	8,232.74	0.05	(2.07)		
		Glass/glazing	46,586 m^2	115,067 kg	1.05	120,820.79	0.71	(29.34)		

* For the adjustment of units, please refer to Table 4.

** For the sources of emission factors, please refer to Table 3.