COMPARISON OF LCA ON STEEL- AND CONCRETE-CONSTRUCTION OFFICE BUILDINGS:A CASE STUDY

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ABSTRACT

A life-cycle inventory model for the office buildings is developed in this paper. The environmental effects of two different building structures, steel and concrete, are intercompared. The results show that the steel-framed building is superior to the concrete-framed building on the following two indexes, the life-cycle energy consumption and environmental emissions of building materials. It is found that the life-cycle energy consumption of building materials per area in the steel-framed building is 24.9% as that in the concrete-framed building, whereas, on use phase, the energy consumption and emissions of steel-framed building are both larger than those of concrete-framed building. As a result, lower energy consumption and environmental emissions are achieved by the concrete-framed building compared with the steel-framed building on the whole life-cycle of building. The present study also provides a good method of assessing the performance of energy saving and environmental protection of different building structures based on a whole life-cycle.

KEYWORDS

Life cycle assessment, Inventory analysis, Emission, Energy consumption, Building materials

INTRODUCTION

The ratio of building energy consumption in overall energy consumption of China is increasing year by year, which has increased from 10% at 1970s to 27.45% by now. This ratio in the developed countries has been long larger than 33%. While consuming large amounts of energy, building industry has also cause large burden on the environment due to the environmental emissions by the production of building materials and the running of building system. Two main building structures, i.e. steel and concrete, are increasingly utilized in our modern buildings. It is difficult to figure out that which kind of the building structures is quantitatively energy-saving and environment-friendly on the whole. Compared to concrete-construction building, the steel-construction building has many apparent advantages, such as saving water under dry construction condition, making less noise and dust, and destroying less land resource. Also, the steel-construction building is more propitious to protect environment, for it produces less solid rubbish and is prone to recycle in end-of-life phase.

However, more detailed quantitative studies are necessary to finally determine their effects of energy and environment.

Only a few studies have been published to date on the LCA comparison of steel- and concrete-construction office buildings. But there have been many studies of the materials production or

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E-mail address: e-mail: zhangxu-hvac@mail.tongji.edu.cn the air conditioning cold and heat source of the using phase. Environmental assessment of steel piles has been performed using LCA, including energy use and other impacts from the construction process, recycling, and reuse of piles (Gorgolewski 1999). Excluding some construction and demolition activities, an LCA of building frame structures has been attempted (Bjorklund et al. 1996). The energy consumption and greenhouse gas emissions (except for the end-of-life phase) for wood, steel, and concrete structural commercial building frames have been compared (Canadian Wood 1997; Cole 1999). The life-cycle energy consumption and environmental emissions of steel- and concrete-construction office buildings (except for the use phase) have been compared by life-cycle cost (Angela 2005).

Ideally, all life-cycle phases should be studied to well understand the total energy consumption and environmental emissions of steel- and concrete-construction buildings and their comparisons.

The objective of this paper is to identify and quantify the energy consumption and environmental emissions during all life-cycle phases of two typical office buildings in Shanghai.

LCA of BUILDINGS

As a significant tool of environmental management, life-cycle assessment has become an international recognized criterion. It is the basis for establishing environmental policy and is generally used to guide clean producing, developing green production and environmental harmonization designed. LCA is an only quantitative and the most potential tool for environmental management (Ross 2002).

The inventory analysis is the most important stage in the process of LCA. Energy, greenhouse gases and principal pollution emissions are covered in the life-cycle inventory (LCI) models of building energy system. The LCI result of all variables are the integrations of directed value of building use and the stage life cycle value of energy feedstock recovery, energy production, transportation, and building materials production. The energy consumption of building is calculated by the BIN method (Long Weiding 1992), the emissions are calculated by energy consumption and emission factors, the model of building materials analyzes production's direct and indirect values of variables, and also takes into account raw and processed materials. The model can study the LCI of various building raw materials. The correlation of energy resources in life-cycle of building is very complex, special software is needed in LCA, BESLCI (Huang Zhijia 2003) is used in this paper.

INVENTORY MODEL

Object of study

The LCI of two typical office buildings in Shanghai, China are investigated and intercompared in this study. Of these two buildings, one is steel-constructed with glass-walls and another is concrete-constructed whose east and south walls are glass ones and west and north walls are aerated concrete constructed. Tab. 1 presents the basic data of these two buildings, the steel used was counted from the construction drawings. The heat conduction coefficient of window in two buildings is the same to ensuring the availability of comparison.

Table 1 General situation of two buildings

Material	Building area (m^2)	Steel used (t)	Aerated concrete brick (m^2)	Use life (year)
Steel-	34620	400	91000	50
Concrete-	46240	2844	61000	50

Parameters for analysis

Energy, greenhouse gases and criteria pollution emissions are covered in the life-cycle inventory (LCI) models of building energy system. Greenhouse gases are made up of CO_2, CH_4, N_2O and CFC. Criteria pollution emissions (O_3, CO, NOx, PM10 and SOx) are divided into overall emissions and urban emissions due to the pollution impacting regionally. Functional unit is 1 m^2 building area.

Boundary

The LCA process has three major stages, building materials production phase, use phase, and end-of-life phase. Each phase includes producing, transportation, distributing and so on. Fig.1 shows the model boundary.

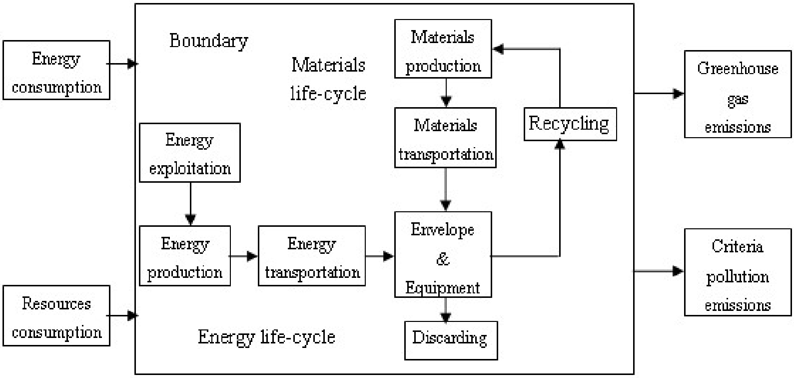

Figure 1. Boundary of LCA in Building Energy System

INVENTORY ANALYSIS

Life-cycle energy consumption and environmental emissions of building materials

In the present study, the concrete is assumed to be one-off due to its significantly low recovery rate. The recovery rate of steel is very high, thus its production can be considered be of electrosmelting of steel. , Data of energy consumption and environmental emissions of steel come from “China Iron and Steel Industry Annual (1998)”. Based on the assumption above and data used, BESLCI program is performed to obtain the inventory data.

Table 2 shows that the life-cycle energy consumption of materials for steel-construction building is 75.1% as that for concrete-construction building. It is also shown that the CO_2 emission of the steel-framed building is 48.1% less than that of concrete-construction building, and the SO_X urban emission is 51.6% less than that of later.

Table 2 LCI of Envelope

	Concrete-construction	Steel-construction	Relative percentage (steel/concrete(%)
Mineral consumption(kg/m^2)	487.0	104.7	21.5
Energy consumption(kJ/m^2)	3911861	2936920	75.1
Fossil fuel consumption(kJ/m^2)	3910766	2935195	75.1
Emissions(g/m^2)			
PM	1436.5	527.0	36.7
SO_X	2051.3	1401.1	68.3
NO_X	966.8	784.0	81.1
CO	1262.4	411.4	32.6
NMHC	8.5	4.2	49.9
CH_4	3.9	3.3	84.0
N_2O	3.3	2.3	70.9
CO_2	606000	314548	51.9
Urban emissions(g/m^2)			
PM	33.8	12.1	35.8
SO_X	128.4	62.2	48.4
NO_X	70.9	42.7	60.3
CO	24.4	10.7	43.6
NMHC	2.1	0.7	34.4

Energy consumption and environmental emissions in use phase

For the cooling and heating sources of air conditioning are various, suppose the air conditioning system is screw chiller for central cooling and oil fuel boiler for heating in either building. The type of equipments could be chosen after the air conditioning load of each frequency (Table 3-6.) calculating by the BIN method.

Table 3 Cooling Load of BIN Frequency in one Steel-Construction Office Building

BIN	22	24	26	28	30	32	34	36	Total
Hours(h)	282	248	231	272	271	169	70	14	1554
CL(W/m^2)	54.2	57.0	70.3	89.2	97.3	106.1	113.2	119.2	
Cooling load(kW)	2438	2565	3165	4014	4380	4774	5095	5366	
Refrigeration(kWh/m^2)	15.28	13.97	16.25	24.26	26.38	17.93	7.93	1.67	123.7

Table 4 Heating Load of BIN Frequency in one Steel-Construction Office Building

BIN	-4	-2	0	2	4	6	8	10	12	Total
Hours(h)	12	31	101	191	202	181	189	204	194	1305
CL(W/m^2)	48.3	42.8	37.3	31.7	26.2	20.7	15.2	9.6	4.1	
Heating load(kW)	2174	1926	1677	1428	1180	931	682	434	185	
Refrigeration(kWh/m^2)	0.58	1.33	3.76	6.06	5.30	3.75	2.87	1.97	1.80	26.41

Table 5 Cooling Load of BIN Frequency in one Concrete-Construction Office Building

BIN	22	24	26	28	30	32	34	36	Total
Hours(h)	282	248	231	272	271	169	70	14	1554
CL(W/m^2)	46.8	47.2	59.1	77.1	83.3	90.2	95.3	99.2	
Cooling load(kW)	1592	1606	2010	2620	2831	3066	3240	3372	
Refrigeration(kWh/m^2)	13.2	11.57	13.66	20.96	22.57	15.24	6.67	1.39	105.3

Table 6 Heating Load of BIN Frequency in one Concrete-Construction Office Building

BIN	-4	-2	0	2	4	6	8	10	12	Total
Hours(h)	12	31	101	191	202	181	189	204	194	1305
CL(W/m^2)	34	30.9	27.7	24.5	21.4	18.2	15	11.8	8.7	
Heating load(kW)	1157	1050	942	834	726	618	510	402	294	
Refrigeration(kWh/m^2)	0.41	0.96	2.8	4.68	4.31	3.3	2.84	2.41	1.68	24.7

Rated performance of the screw chiller and cooling pump selected is shown in Table 7. Multiple screw chillers are chosen for each building. When the summer energy consumption of air conditioning is calculated, not only the number of chiller in operation, but also the performance under partial load should be considered. And suppose the pumps are supposed to be constant-rate of flow, thus only the number is controlled in operation. As the method proposed by Ju Xiaoli (2003), the relationship between screw chillers power and partial load rate is fitted. The power of chillers under each frequency can be calculated by the partial load rate, and therefore the summer energy consumption can be eventually obtained.

Table 7 Rating Performance of Screw Chiller

	Quantity	Refrigeration	Power	COP	Cooling pump			
					Quantity	Flow rate	Lift	Power
		kW	kW			m^3/h	m	kW
Concrete-construction building	2	1758	323	5.443	2	300	25	30
Steel-construction building	3	1758	323	5.443	3	300	25	30

As for the heating source of boiler used in winter, the energy consumption can be calculated by the equivalent time of full load (see Tabs 4 and 6). The efficiency of oil fuel boiler is assumed to be 88% (Lin Zonghu et al. 1999).

Table 8 presents the annual energy consumption of air conditioning on an unified unit, kJ/m^2.

Table 8 Energy Consumption of Air Conditioning per Year (kJ/m^2)

	Summer energy consumption			Winter energy consumption		
	Chillers	Pumps	Total	Boiler	Pumps	Total
Concrete-construction building	69762	8654	78416	101045	2160	103205
Steel-construction building	82961	9890	92851	108027	2160	110187

As shown in Tab.9, the annual life-cycle energy consumption of air conditioning is the sum of annual energy consumption of air conditioning, upstream energy stage and transportation stage.

Table 9 Life-cycle Energy Consumption and Environmental Emissions of Air Conditioning per Year

	Concrete-construction	Steel-construction	Relative percentage (steel/concrete(%)
Energy consumption(kJ/m^2)	401105	458578	114.3
Fossil fuel consumption(kJ/m^2)	383871	438320	114.2
Emissions(g/m^2)			
PM	11.38	13.11	115.2
SO_X	154.59	181.12	117.2
NO_X	115.15	134.41	116.7
CO	21.53	24.94	115.9
NMHC	0.45	0.51	113.6
CH_4	0.29	0.33	113.8
N_2O	0.32	0.37	115.8
CO_2	36065	41434	114.9
Urban emissions(g/m^2)			
PM	2.05	2.24	109.2
SO_X	11.04	12.60	114.1
NO_X	13.10	14.57	111.2
CO	3.22	3.54	109.9
NMHC	0.15	0.16	107.9

It is found in Tab. 9 that the annual life-cycle energy consumption of air conditioning in steel-construction building is 12% more than that in concrete-construction building in the use phase. It is also found that the total environmental emissions and urban emissions of air conditioning in steel-construction building are 14% and 10% more than those in concrete-construction building, respectively.

The use life of the two buildings is both 50 years. In the total life-cycle of 50 years, the energy consumption and environmental emissions of the two buildings are then calculated and shown in Tab. 10.

Table 10 Energy Consumption and Environmental Emissions of Building System

	Concrete-construction	Steel-construction	Relative percentage (steel/concrete(%)
Mineral consumption(kg/m^2)	487.0	104.7	21.5
Energy consumption(kJ/m^2)	23967098	25865834	107.9
Fossil fuel consumption(kJ/m^2)	23104293	24851208	107.6
Emissions(g/m^2)			
PM	2006	1183	59.0
SO_X	9781	10457	106.9
NO_X	6724	7505	111.6
CO	2339	1659	70.9
NMHC	30.9	29.6	96.1
CH_4	18.2	19.6	107.5
N_2O	19.1	20.6	108.1
CO_2	2409237	2386251	99.0
Urban emissions(g/m^2)			
PM	136.5	124.2	91.0
SO_X	680.5	692.1	101.7
NO_X	725.8	771.1	106.2
CO	185.7	187.9	101.2
NMHC	9.6	8.8	91.5

Table 10 shows the mineral consumption in steel-construction building is only 21.5% as that in concrete-construction building, but the energy consumption per area is 8% more than in concrete-construction building, the CO_2 emissions are 99% as that in concrete-construction building, and the SO_X and NO_X urban emissions are 1.7% and 6.2% more than those in concrete-construction building respectively.

IMPACT ASSESSMENT (LCIA)

For the emissions of environmental burden are various, some emissions in concrete-construction building are lager than those in steel-construction building while other emissions are less. And the impacting of each emission to environment is different even if the quantity is same. So the impact assessment is needed to quantify the environmental burden of these two buildings.

The impact of emissions to environmental impacting is classified into energy exhaustion potential (mineral fuel exhaust), globe warming potential (greenhouse gas emissions), atmosphere environment impact (total contamination emissions) and urban atmosphere environment impact (urban contamination emissions).

The energy exhaustion potential and globe warming potential are characterized by the equivalent method (Wang M Q 1999). The atmosphere environment impacting is characterized by the critical volume dilution method (Postlethwaite D 1996). In this paper, the atmosphere environment impacting and urban atmosphere environment impacting are calculated based on the contamination emissions standard of three regions prescribed by Chinese Environmental Quality Standard.

Table 11 shows the result on environmental impact assessment and the comparison of LCIA between concrete-building and steel-construction building is showed as Fig.2. It shows that the total environmental burden of steel-construction building is a slightly higher than that of steel-construction building. The proportion of life cycle energy consumption of building materials is 16.9% in concrete-construction building, while in steel- construction building is 11.8%. And the other three indexes, the proportion of building materials in concrete-construction building are all larger than in steel-construction building.

Table 11 Result on Environmental Impact Assessment

	Concrete-		Steel-	
	Building materials	Use phase	Building materials	Use phase
Energy exhaustion potential	0.17	0.83	0.13	0.95
Globe warming potential	0.20	0.80	0.12	0.92
Atmosphere environment impact	0.22	0.78	0.14	0.91
Urban atmosphere environment impact	0.13	0.87	0.06	0.95
Total	0.72	3.28	0.45	3.73
	4		4.19	

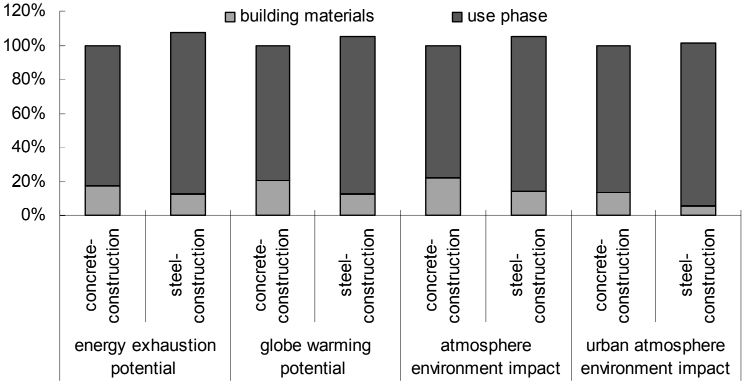

Figure 2. Comparison of LCIA Based on Concrete-construction Building

CONCLUSIONS

In this paper, the life-cycle energy consumption of steel is found to be 75.1% as that of concrete, and the environmental emissions less a half of the latter. And therefore, on the life-cycle energy consumption and environmental emissions of the building materials, steel-framed building is superior to the concrete-framed one.

However, the average heat transfer coefficient of the envelopes of steel-framed building is higher than that of the concrete-framed one due to the higher thermal conductivity of steel. The life-cycle energy consumption and environmental emissions of air conditioning in use phase of steel-framed building are therefore larger than those of the other building type. It results in a slightly higher life-cycle energy consumption and environmental emissions of the steel-framed building. The energy consumption of the steel-framed building in the use phase will be reduced if its heat preservation can be improved.

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