Building Energy Consumption and CO_2 Emissions in China

ZHOU WEI[1] , MI HONG[2]
[1,2]Superviser of Administration School
Zhejiang University
CHINA
[1]ttomcc@gmail.com [2]spsswork@163.com(Corresponding author)

Abstract: - Based on the theory of Life-Cycle Energy Analysis, the energy consumption of macro-level buildings in China was analyzed, and the key factors in every Life-Cycle phase were pointed out. With the analysis of building life-cycle energy consumption, carbon dioxide emissions related to buildings were calculated. It was indicated that the energy consumptions of building materials production and building operation account for largest share in building energy consumption. Reducing energy consumption on building operation and building materials were important to building energy saving and carbon dioxide mitigation.

Key-Words: - Energy consumption; Macro building; Life-Cycle analysis; CO_2 emissions; Energy saving

1 Introduction

According to the report of the United Nations Environment Programme (UNEP), energy use of building sector account for 30% to 40 % of global primary energy consumption[1], and therefore contribute to significant greenhouse gas (especially carbon dioxide, CO_2) emissions. EC research has indicated that by improving energy efficiency, carbon emissions from buildings could be reduced by 22% [2].

Now China is the country which emits most carbon dioxide in the world (IEA, 2009)[3], China has been considered responsible for more than half of the global increase in carbon dioxide emissions of 3.1%[4]. Now China is undergoing urbanization and on an unprecedented scale, about 200 millions people will move to cities in China in the future 20-30 years. They need more building and more infrastructural facilities. Now energy use for space heating, cooling, ventilation, lighting of building accounts for 30% of total energy consumption in China.

Urbanization ratio of China increases from 17.92% in 1978 to 45.68% in 2008, and grows 0.93 percent per year, and it will keep a same speed in the next 20-30 years. The living space of the average Chinese grow from 22.7 square meters in 2000 to 30.2square meters in 2008. In 2008, 760 millions square meters building were built in urban areas and 834 millions square meters building were built in rural areas.

So energy consumption of building will grow in a large scale, the same is true of carbon dioxide emissions. It is essential for the building construction industry to improve the energy efficiency and reduce environmental impact (pollution, carbon dioxide emissions, etc). An effective assessment system is needed to estimate the impact of building on environment. For this purpose, *Life-Cycle Energy Analysis* (LCEA) is applied in this paper to calculate the energy consumption.

LCEA provide better understanding and better estimation of energy aspects in the Life-Cycle of building. The Life-Cycle of a building can be divided to several phases, these phases are production of building materials, on-site construction, operation, demolition and waste management[5]. Previous life-cycle studies found that energy for operation is accounting for the dominating part (Cole, 1996)[6]. Researches of low energy buildings showed that the energy demanded for material production accounts for largest share of the total energy consumption. (Nemeth Winter, 1998)[7]. Study on the potential energy savings by recycling the building materials indicated that it may be more important to design a building for recycling than to use materials which require little energy for production (Catarina Thormark,2000)[8]. Research on China's energy use of buildings indicated that if manufacturing techniques remain the same as current trend, Challenges to the goals for energy consumption in China will appear in the next decade [9].

More than 90% of conventional buildings in China are high-energy buildings, and little of newly built buildings are low-energy buildings. If buildings continue to be constructed according to current trends, the energy demanded and environmental impact of the pressure on urban areas will be enormous. This paper focuses on energy consumption of national buildings with LCEA, and estimates the building-related carbon emissions.

2 Energy Consumption of Buildings Life-Cycle

Building energy consumption can be expressed by two perspectives: single building energy consumption and macro-level building energy consumption. There are various buildings (constructed for residential, office and commercial, public buildings, etc) in one country, and they consume energy in different ways. It is impossible to analyze energy consumption of every building, but we can get result in average level. On this basis, energy consumption of buildings in the whole country (macro-level) can be estimated.

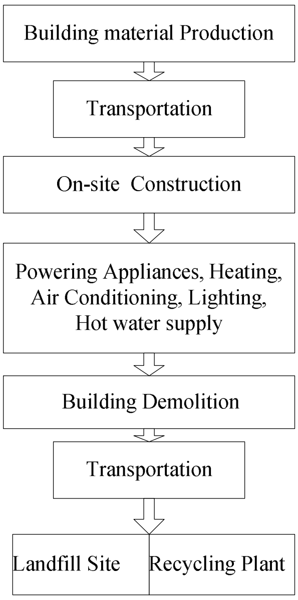

Fig.1 Phases of Life-Cycle energy analysis

For single building, LCEA is an approach that accounts for all energy consumption of a building in different phase: building material production; construction phase; operation phase; demolition and waste management (as shown in Fig.1). Energy consumption of single building in its Life-Cycle can be expressed as (in term of primary energy):

$$E_T = E_{mp} + E_{bc} + E_{op} + E_{de} \quad (1)$$

where E_T is the total energy consumption of a single building; E_{mp} is energy consumption in building material production; E_{bc} is energy consumption in building construction; E_{op} is energy consumption in operation phase; E_{de} is energy consumption in building demolition.

Macro energy consumption of buildings (MECB) is energy consumption of all buildings in an area in a certain stage. Theoretically it can be calculated by summary energy consumption of all buildings, but it is impossible to get all energy data of buildings. Macro-analysis is suited for getting the energy data of different phases of MECB. The mathematical equations for macro energy consumption of buildings is similar with equations (1), just different details in life-cycle phases only.

2.1 Building Material Production

In order to calculate energy consumption of building material production, it is necessary to find the shares of the energy consumption of a certain material or a process (for instance, transportation) related with buildings to total energy consumption of a certain material or a process of national economy. Energy data can be obtained according related literatures and the data of *China statistical yearbook*[9].

Table 1 Share of material in building construction

Building Material	Share of material in building construction
Steel product	41%
Nonmetallic material	98%
Nonferrous metal	25%
Chemical material	25%

Data resource: Li Zhaojian, Jiang Yi. Analysis on generally energy consumption of buildings in China[J], Transactions on Building, 2006,53(7):30–33.

Six kinds of materials mostly used in building, they are cement, rebar and structure steel, plate glass, alloy aluminum, wood and PVC pipes[10]. When the building is demolished, parts of building materials can be reclaimed. The reclaimable rates of various types of materials are different. By investigation, the reclaimable rates of several building materials are defined respectively as 90% (metal), 50% (brick), 20% (wood), and 10% (cement). The rate of all other materials is defined as 0%[11]. So energy use of building material production can be calculated as following:

$$E_{mp} = \sum_{i=1}^{n} C_i \left[X_i (1-\alpha) + \alpha X_{ir} \right] \quad (2)$$

Where X_i is energy consumption of manufacturing material (i) all over the country; C_i is share of material (i) in buildings averagely; α is reclaim coefficient of material (i), X_{ir} is energy consumption in reclaiming material (i).

2.2 Building Construction and Demolition

The buildings construction phase, ranges from extracting raw materials to the building works on site.

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Energy is required to make various machines work. At the end of buildings' service life, energy is demanded to demolish the building and transporting the waste material to landfill sites and/or recycling plants. This energy is termed as demolition energy[12]. Construction industry is regard as an industry including building construction and demolition, so statistic data of building construction and demolition are included in China statistical yearbook. Energy consumption of building construction and demolition accounts for 1.4% to 1.7% in total energy consumption in recent years[13]. One of the reason is that buildings construction and demolition only last for a shot time in lifespan.

2.3 Operation Energy

Energy is used for space heating, cooling, ventilation, and light buildings, hot water supply and other electrical appliances. Energy consumption in this phase usually accounts for the largest share in total energy demand.

Considering different climate condition, operation energy of building vary from north to south in China. In the north, energy consumption of space heating is the dominating part in winter; while in the south energy consumption of cooling is the dominating part in more than four months. Lighting demands not much energy in private building, but it is opposite in public building. The hot water supply and household electricity use depend to a large extent on the users.

Operation energy can be expressed as following:

$$E_{op} = \sum_{i=1}^{m} L_i \qquad (3)$$

Where E_{op} is energy consumption in operation phase; L_i is energy consumption of service (i).

2.4 Indirect energy

Except the energy consumption in its life-cycle phases, there is indirectly energy consumption in building lifespan. Indirectly energy is demanded by construction equipment when they were manufactured, operated, transported; and by energy resource itself when they were explored, transferred, transported, etc. Indirectly energy can be expressed as:

$$E_{in} = \sum_{i=1}^{m} (Y_i E_{yi})$$

where E_{in} is indirectly energy in the lifespan of the building; E_{yi} is total value of indirectly energy (i); Y_i is the share of indirectly energy (i) in industry-related energy consumption. Y_i can be found in table 2.

Table 2 Share of indirectly energy

Building-related indirectly industry	Share in national industry-related
Transportation	30%
Energy industry	45.5%
Mechanical Manufactur	70%

Data resource: Li Zhaojian, Jiang Yi. Analysis on generally energy consumption of buildings in China[J], Transactions on Building, 2006,53(7):30–33.

3 Carbon emissions of Buildings

On the basis of analyses above we can calculate the total energy consumption of buildings in China. In order to study the carbon emissions of buildings, it is necessary to get the energy structure recently.

China still relies on fossil fuel heavily, especially coal. From 2001 to 2008, Coal accounts for 66% -70% in China's energy consumption, oil accounts for 20% or so. Clean energy such as nuclear power, hydropower and wind power sum up to 7%-8%. Consumption of fossil energy brings great carbon emissions, as well as serious pollution.

Table 3 Energy structure of China (%)

	coal	oil	natural gas	Clean energy
2001	66.7	22.9	2.6	7.9
2002	66.3	23.4	2.6	7.7
2003	68.4	22.2	2.6	6.8
2004	68.0	22.3	2.6	7.1
2005	69.1	21.0	2.8	7.1
2006	69.4	20.4	3.0	7.2
2007	69.5	19.7	3.5	7.3
2008	68.7	18.7	3.8	8.9

Data source: China statistical yearbook, 2009.

Suppose energy consumption structure of building is the same as national energy structure, the consumption of every kind of energy (coal, oil, natural gas, etc) can be calculated. And according to the data of table 4 and table 5, carbon emissions of every kind of energy can be calculated too.

Table 4 CO_2 Emissions from the consumption of fossil fuel

Fuel	Coal	Crude oil	Natural Gas
Potential CO_2 emissions factor (g /10^6KJ)	24 780	21 470	15 300

Data sources: Workgroup 3 of the National Coordination Committee on Climate Change.

4 Conclusion

Table 5 energy consumption and CO_2 Emissions of buildings

phase		2003	2004	2005	2006	2007	2008
Production of materials	Energy consumption (Million tce)	234.14	286.75	326.24	366.20	402.62	435.48
	Share in life cycle energy consumption of buildings(%)	32.08	32.84	33.49	33.37	33.02	33.25
	Share in national energy consumption (%)	13.38	14.11	14.52	14.87	15.16	15.28
On-site construction	Energy consumption (Million tce)	25.20	29.06	33.93	37.68	43.02	47.88
	Share in life cycle energy consumption of buildings(%)	3.45	3.33	3.48	3.43	3.53	3.66
	Share in national energy consumption (%)	1.44	1.43	1.51	1.53	1.62	1.68
operation	Energy consumption (Million tce)	409.13	483.88	533.17	598.19	661.83	703.10
	Share in life cycle energy consumption of buildings(%)	56.05	55.41	54.74	54.51	54.28	53.68
	Share in national energy consumption (%)	23.38	23.81	23.73	24.29	24.92	24.67
demolition and waste management	Energy consumption (Million tce)	61.42	73.57	80.66	95.31	111.81	123.41
	Share in life cycle energy consumption of buildings(%)	8.42	8.42	8.28	8.68	9.17	9.42
	Share in national energy consumption (%)	3.51	3.62	3.59	3.87	4.21	4.33
Total energy consumption of buildings (Million tce)		729.88	873.27	974.00	1097.38	1219.29	1309.86
Share in national energy consumption (%)		41.71	42.97	43.35	44.56	45.91	45.96
Carbon dioxide emission of building (Mt)		1846	2095	2289	2481	2724	2853

From table 5 it can be found that energy consumption of buildings account for 41%-46% of total energy consumption, and keep increasing. Energy demand in buildings operation accounts for the largest share, more than 50% of life-cycle energy consumption of buildings. The second share is the phase of buildings materials production, more than 30% of life-cycle energy consumption of buildings. Carbon dioxide emissions of buildings are remarkable, and reach 2853Mt in 2008.

Most buildings in China are high-energy building. Energy consumption (per unit area) of large-scale public buildings is about ten times as much as private buildings. The survey and statistic analysis on public building energy consumption some cities reveals that it is common that energy consumption among similar public buildings has a large gap up to two times[14]. Energy demand of public buildings operation accounts for 30% of total energy consumption. Energy waste in public buildings is more heavily than private buildings.

Lifespan of buildings in China is 20-30 years averagely, and is much shorter than that in developed countries. Terrible quality of buildings and lack of scientific planning shorten the lifespan of buildings, and result in serious waste of energy and other natural resource. Further more, terrible quality of buildings may result in heavy casualties and loss of property. In Wenchuan earthquake (May 12, 2008), more than 3.3 thousand schools were destroyed and more than 19 thousand students died. So the short lifespan of buildings increase the carbon emissions in China.

5 Further Discussion

Because of the huge number of population and unprecedented urbanization, China's newly built buildings were the most in the world in recent years. 2×10^9 m^2 new buildings were built in 2007, at the same time, cement consumption accounted for 55% of the world and steel consumption accounted for 30% of the world.

As a developing country with low per capita income, China's government is in pursuit of growth of gross domestic product GDP excessively. Construction is both a driver and a consequence of increasing GDP. Construction industrial typically provides 5% to 10% of employment at the national level and normally generates 5% to 15% of the

GDP[15]. But in some areas, buildings which were built not more than 15 years often be demolish because higher buildings will be built on the same site. In 2007, China's GDP account for 6% of the world, but steel and cement consumption reached 30% and 55% of total consumption in the world.

So the buildings and construction sector has largest potential for energy saving and mitigating carbon emissions responsible for environment. It is essential for buildings construction to reduce energy consumption for sustainable development. Energy saving of large-scale public buildings is the key point of building energy saving. On the other hand, improving the buildings quality and lengthen the lifespan of building will also reduce the energy consumption and carbon dioxide emissions.

The choice of energy resource is also important. China needs to improve energy efficiency, and optimize the energy structure. If clean energy including nuclear power, hydropower and wind power account for higher share of the total energy, carbon emissions will be reduced notable.

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