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Carbon Emission of Energy Efficient Residential Building

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Abstract

Carbon emission of residential buildings is calculated based on LCA (life cycle assessment). The influence factors, such as the insulation thickness, air conditioning form and service life are analyzed. A typical energy efficient residential building was selected to calculate its carbon emission in different conditions. In this case, when the insulation thickness is 100mm, the life cycle carbon emission is the minimum. In other words, each residential building has its optimum insulation thickness. And with the building service life extending, the emission will decrease. As for the air conditioning forms, the results show that the carbon emission of residential building with split air conditioning is less than with centralized air conditioning.

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Keywords: *LCA(life cycle assessment), Carbon emission, Residential building*

1. Introduction

Greenhouse gas (GHG) emission has become a common concern to the international community. In recent years, the ratio of building energy consumption of China is increasing rapidly. Building industry cause large burden on environment due to environmental emissions caused by the production of building materials and running of building system. Meanwhile it was also pointed out in IPCC [1]: the cost for reducing the GHG of the construction field could be quite low, the marginal cost for reducing about 50×108 tons of carbon emissions would be zero. On this basis, to bring down 5-6×108 t carbon emission, it will cost only 20-100 dollars/t. Throughout all the industries, the cost to control emission of construction is the minimum. It is therefore essential to involve the building construction industry to achieve sustainable development in the society [2]

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Thus, evaluation of energy consumption and carbon emission assumes great significance. The evaluation of carbon emission based on LCA theory has been studied [3] methodology of life-cycle carbon emission calculation of residential buildings has been put forward [4]. Anders C. Schmidt et al [5] conducted the comparison of foam, rock wool, bio fiber insulation materials in global warming, acidification, energy consumption and human health and environmental impact based on LCA. Heikkila [6] compared the life cycle of the Swedish office building with two types of air conditioning. In his study it could be found that the different types of energy consumption had great impact on environmental assessment results of the entire life cycle air conditioning system. However, in order to formulate strategies to achieve reduction in carbon emission, the evaluation results should receive further comprehensive analysis.

This article provides a carbon emission evaluation of a residential building based on LCA theory. And the influence factors of carbon emission are analyzed. A typical energy efficient residential building was selected as an example to study. Finally, according to the analysis results, various kinds of emission reduction ways and the reduction potential are concluded.

2. Carbon emission evaluation model

2.1. Goal and scope definition

The system boundaries of this analysis include carbon emissions in the following phases: materials production, manufacture, operation, and demolition. Materials production includes all the raw material mining and processing. Manufacture phase includes transportation of building material and technical installations used in erection[7]. Operation phase encompasses production of heating and cooling devices and all activities related to the use of the buildings over its life span and renovation of the buildings. These activities including maintaining the comfort condition inside the building, and power appliance, but the household appliances were not included. Finally, demolition phase includes destruction of the building and transportation of the construction rubbish.

On the analysis of building life cycle carbon emission, if there are renewable energy sources (solar power as an example) and carbon absorption by vegetation which benefit the environment, the corresponding carbon emissions and electricity input should be deducted.

2.2. The accounting model

GHG emissions in various phases multiply the corresponding greenhouse gases potential equivalent factor and add up to the building life cycle carbon emissions [8]. It can be expressed as:

$$P_n = \sum_{i=1}^{n} W_i \times GWP_i \quad (1)$$

Where *Pn* is the total carbon emissions in certain phase; *Wi* is gross of greenhouse gas(i) in phase n during its life cycle; *GWPi* is global warming potential of greenhouse gas (i).

$$P_{tot} = P_{manu} + P_{erect} + P_{occup} + P_{demo} \quad (2)$$

Where *Ptot* is the total carbon emissions during the life cycle of building; *Pmanu* is carbon emissions during the production of construction materials; *Perect* is carbon emissions during the construction; *Poccup* is carbon emissions of the use phase; *Pdemo* is carbon emissions during the demolition phase.

According to the definition of *"Kyoto Protocol"*, greenhouse gases includes the six gases: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and their *GWP* are as Table 1 shows.

Table 1. GWP of greenhouse gases (SDMA) [9]

Global warming potential			
Substance	Global Warming（CO2-eq）(kgCO2/kg)		
	20years	100years	50years
CO2	1	1	1
CH4	72	25	7.6
N2O	289	198	153
HFCS	3830	1430	435
PFCS	8630	12200	1820
SF6	16300	22800	32600

3. Case calculation and analysis

3.1. Reference building

A typical energy efficient residential building located in Tianjin was selected as the study object. It is 15-stoerys high with total construction area 4443.3m2. The design indoor temperature is 18℃ in winter and 26℃ in summer. Floor radiant heating and split air conditioning are adopted. The average energy efficiency ratio of air conditioning is 3.4.

Three most significant factors, thickness of insulating layer, air conditioning form and service life, are selected to study. The life cycle carbon emission will be evaluated and analyzed under different conditions. Then, according to the analysis results, various kinds of emission reduction ways and the reduction potential are discussed.

3.2. Insulation thickness

The wall of the selected building is 50-mm-thick extruded polystyrene (XPS) foam board and the roof insulation is 60-mm-thick extruded polystyrene (XPS) foam board. Wall heat transfer coefficient is 0.547W/m2·K. According to different hypothetical insulation thickness, the life cycle carbon emission of the residential building is calculated.

The carbon emission caused by heating and air conditioning energy consumption also changes because of the different cooling and heating load. Meanwhile, with the increase of insulation thickness, emission during building material production phase will increase due to more insulation material demanded. More detailed calculation results are shown in Fig.1and Fig.2.

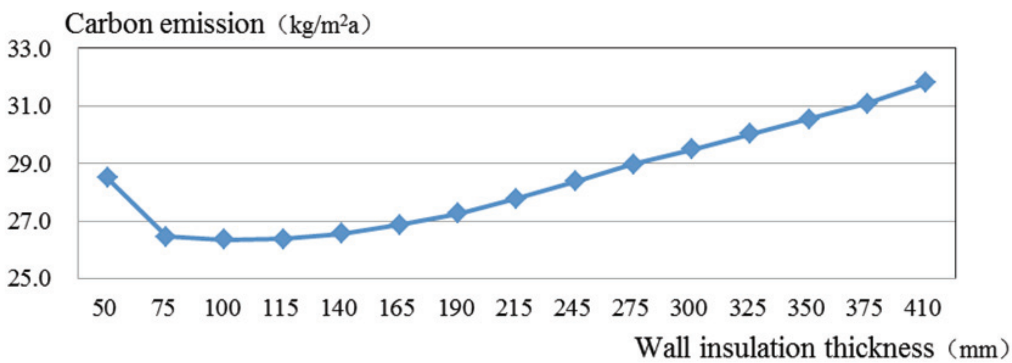

Fig. 1. Carbon emission under different insulation thickness

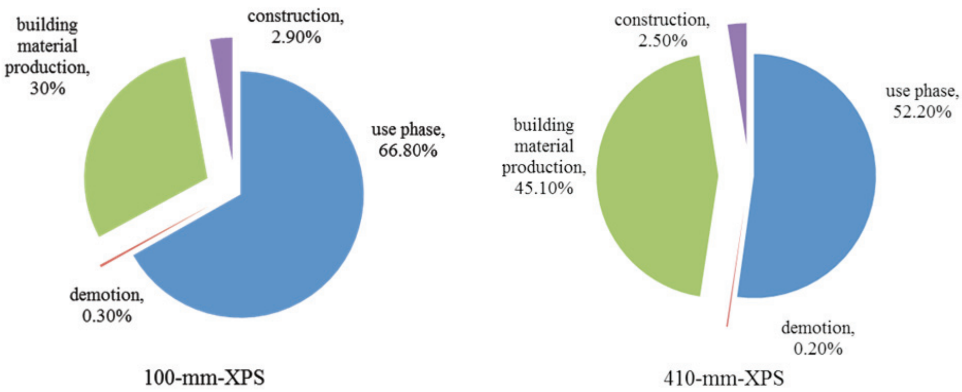

Fig. 2. Carbon emission during each phases

The calculation results show that during use phase, the emission will reduce observably with insulation thickness increasing. However, in the whole life cycle, there is another trend. The life cycle carbon emission increases after brief decline when insulation thickness increasing. It's because that the emission proportion during use phase reduces while proportion during production material phase increases observably. So there exists an optimal insulation thickness for certain residential building. As for the selected building, when the insulation layer is 100-mm-thick its life cycle carbon emission is the minimum.

3.3. Air conditioning forms

Carbon emission caused by energy consumption of air conditioning and heating is the major part of the life cycle carbon emission. As a result, the air conditioning and heating forms, as well as the cold and heat resources, make great differences on the life cycle carbon emission. In this paper, life cycle carbon emission of the residential building with centralized air conditioning (water-cooled) and split air conditioning are analyzed. In order to make the results of different air conditioning types comparable, the uniform regulations are stated as follows:

(1)The fresh air system is beyond consideration.

(2) Air conditioning terminal device can be controlled individually and in the term of intermittent operation. The equipment selection of centralized air conditioning is shown in Table 2.

Table 2.Air conditioning equipment selection

Mode	Equipment name	Device parameters	Unit	Quantity
Centralized air conditioning（water-cooled）	Water-cooled screw chillers	Qc=360kW,COP=4.74	pcs	1
	Chilled water pump	30t/h,4kW	pcs	3
	Cooling water pump	30t/h,5kW	pcs	3
	Make-up water pump	3.2t/h,5.5kW	pcs	2
	Cooling tower	38t/h,3kW	pcs	1
	Fan coil	FP3.5 Qc=2150W,N=28W	pcs	180

During the equipment production phase, the carbon emission of centralized water-cooled air conditioning is more than the split air-conditioning. Nevertheless, during the maintenance phase, the former carbon emission is less than the letter. The life cycle carbon emission and unit carbon emission of different air conditioning types are shown in Table 3.

Table 3. Analysis of carbon emissions of different air conditioning system

	Unit	Split air conditioning	Centralized air conditioning(water-cooling)
Operation	t	899.55	4271.15
Devices	t	35.3	48.57
Devices Replacement	t	134.97	97.14
Total emission	t	6321.6	9636.71
Unit emission	kg/m2·a	28.5	43.45

Compared with the split air conditioning, centralized air conditioning has a better aesthetics, and can provide more comfortable air-conditioned environment. But it is obvious that for residential building, the carbon emission of split air conditioning is less than centralized one. Because the carbon emission and energy consumption of centralized air conditioning are higher. Besides, its maintenance and management cost more.

3.4. Service life

Building service life has a great impact on the carbon emission. In China, ordinary buildings and structures service life is 50 years. The life cycle carbon emission of the building with 50 year, 60-year, 70-year and 80-year service life is analyzed. The changes in initial structure design and building materials caused by the increase of service life are not considered. The calculation results are shown in Fig. 3 and Table 4.

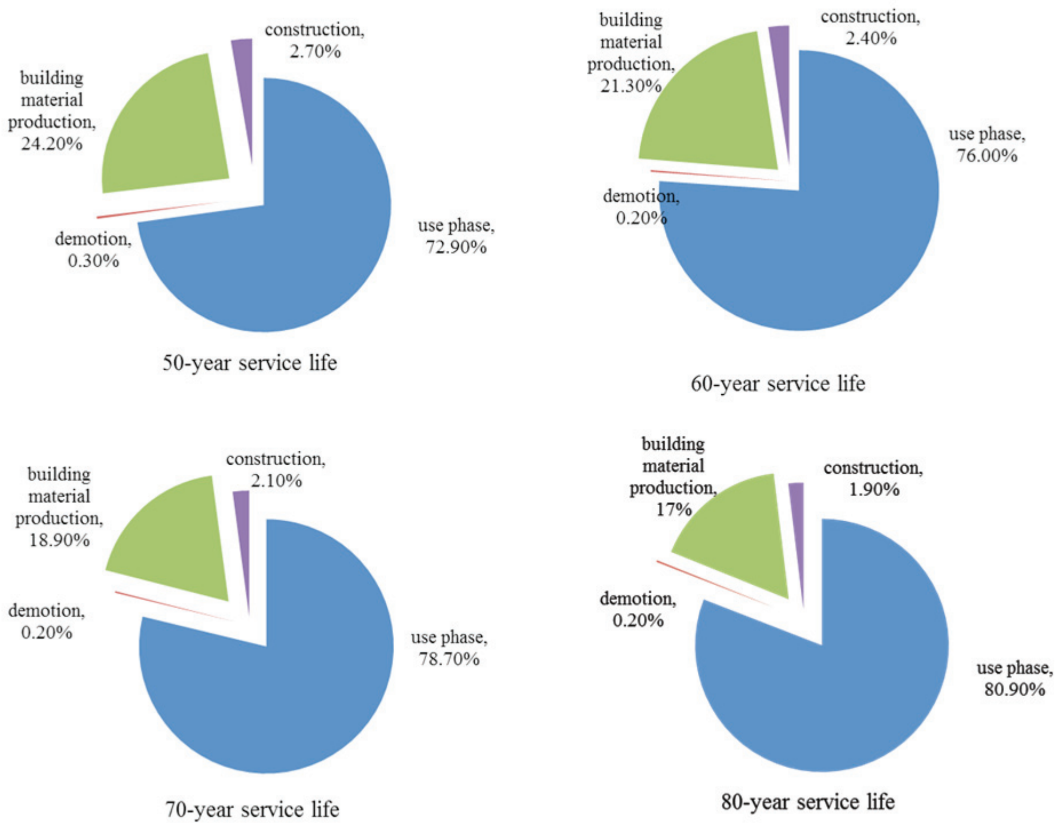

Fig. 3. Carbon emission during each phase

Table 4. Carbon emissions of residential building in different life cycle

Building service life	50years	60 years	70 years	80 years
total carbon emission of life cycle （t）	6321.6	7161.32	8069.95	8978.58
Unit carbon emission（kg/m2·a）	28.5	26.86	25.95	25.26
Growth rate of using age	0	0.20	0.40	0.60
Reduction rate	0	0.06	0.09	0.11

To see the reduction rate of the three factors more intuitive, the reduction effect is summarized in Table 5.

Table 5.Emission rate under different residential conditions

Variables	Total carbon emission（t）	Unit carbon emission （kg/m2·a）	Reduction rate （%）
Real project	6324	28.50	0
100-mm-XPS insulation layer	5844	26.30	7.7
410-mm-XPS insulation layer	7054	31.80	-11.7
60-year service life	7176	26.96	5.4
70-year service life	8.69	25.95	9.0
80-year service life	8978	25.26	11.4
Centralized air conditioning(water-cooling)	9636.71	43.45	-52.6

The table shows that when optimum insulation thickness is adopted and service life could be as long as possible, the reduction effect of carbon emission is the best.

4. Conclusion

During use phase, the emission will reduce observably with insulation thickness increasing. However, during the entire life cycle, carbon emission increases after brief decline when insulation thickness increasing. There exists an optimal insulation thickness for certain residential building.

As for the service life of a residential building, within the life span of this article, service life should be as long as possible to receive better reduction effect.

Some energy-saving technology has been adopted to reduce the energy consumption of centralized air conditioning system. However, in this case, the carbon emission of split air conditioning is much less than centralized one. Therefore, the centralized air conditioning mode may not be a proper choice for residential buildings.

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