Energy and CO_2 emission of university dormitories in sub-tropical China: Life cycle perspective

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Abstract:

This paper aims to estimate energy use and CO_2 emission of university dormitories in sub-tropical China, as part of a sustainability assessment of the university campuses in China. This study is conducted by use of a simplified economic input-output life cycle assessment (EIO-LCA). The front ground date are tenders information of university dormitories built in the Fuzhou university town during 2007- 2011 and energy bills of those building over past 5 years. The background data stem from Chinese environment Input-output table 2007. The results indicate that 1) the use stage is the dominate part of the life cycle energy use and CO_2 emission of university dormitories. 2) The consumption of electricity constitutes the main elements causing the life cycle CO_2 emission of university dormitories.

Keywords:

Energy, CO_2, University Dormitories, Life cycle perspective, Input-output analysis

1. Introduction

The university student population in China has increased from 12 million in 2000 to 34 million in 2013 [1]. Such incredible growth results in increasing demand of university dormitories. In China, it is the university's responsibility to supply accommodation to its students. Therefore, there is huge investments in university dormitory constructions. These investments have considerable influences on the environment owing to material and energy consumptions for dormitory construction, maintenance and use.

Assessing the environmental impacts of university dormitories is not a trivial task, due to the complexity of their construction, maintenance and uses. Nevertheless, it is deemed important to estimate these impacts in order to identify more sustainable options for reducing their environmental footprints [1]. Numerous studies has analysed the environmental impacts of buildings/dwelling with life cycle perspectives. Several studies provide the review on the life cycle studies on buildings, see literatures [2-6]. On the other side, universities work as facilitators for sustainable development [7]. Thus, the sustainability of university/campus is analysed in several studies, including, carbon footprint [8-11], energy use assessment of educational buildings [12], university level sustainable transportation [13], etc.. However, the literature studies reveal that there are few studies to highlight the environmental impact of Chinese University dormitories. Given the nowadays challenge of climate change, the importance of energy use and CO_2 emission for buildings in China cannot be ignored. This study tries to add the knowledge of energy consumption and CO_2 emission caused by construction and use of university dormitories, especially those in sub-tropical China. Consequently, this paper aims to answer these two research questions:

1) What is the level of life cycle energy use and CO_2 emission of university dormitories in sub-tropical China?
2) What are the hot spots and improvement opportunities of those buildings?

In order to identify the processes and inputs with the highest energy consumption and CO_2 emission, this study considers all the processes in the university dormitories life cycle.

The paper is organized as follows; section 2 outlines the theoretical framework of our analysis, the development of models and the source of data, section 3 explains the main results of our analysis, while section 4 discusses the potential of environmental friendly university dormitories in Sub-tropical China. The last section concludes our findings.

2. Method and data

This study is conducted as a simplified EIO-LCA. The main foreground system data are mostly the field data, complemented with literature data when site-specific data were missing. The background data are calculated with Chinese environmental Input-output table in 2007 [14].

2.1. Goal, scope and reference unit

The goal of this LCA study is to estimate the life cycle energy and CO_2 emission of university dormitories projects in the sub-tropical China. These results are then used to identifying the hot spots and improvement opportunities along the supply chain. While some LCA studies on buildings defines 1 m^2 floor area [15] or 1 m^3 gross volume [16] as functional unit, EN15978 uses the whole building as a functional equivalent [17]. Since the function is delivered by the building as a whole, and not by the floor area/gross volume, the study can chose to use number of beds, m^2 floor area or m^3 gross volume as reference units usable for bench marking or comparison. Thus, the reference unit in this study is defined as “the construction, use and demolition of one m^2 useful space of university dormitories over the lifetime of 50 years”. The lifetime of a building is a difficult parameter to standardise since it depends on many factors. This study assume the lifetime as 50 years [18-20]. However, to assess the impact of lifetime on the studied results, sensitivity analysis with 60 years (20%) and 75 years (50%) are carried out.

The construction stage involves the extraction and manufacture of construction materials and fuels, transportation through the supply chain and on-site construction activities of the buildings. The use stage considers operation and maintenance. In this study, operation includes energy used by occupants for space cooling, lighting, hot water, and appliances. Maintenance includes the repair of windows, doors, ceramic tile changes, new sealing, roof tiles and so on. Due to the data access, the treatment of waste produced during construction and demolition are excluded, while the transportation of such waste to the disposal site are included. Due to the difficulty to forecast transportation, machines and tools consumed for maintenance, the study consider they will be equal to today’s technologies.

The life cycle of university dormitories comprises three main stages: construction, use and demolition. Therefore, the total energy use or CO_2 emission are calculated as Eq.1.

$$E_t = E_c + E_o + E_d \qquad (1)$$

Where E_t is total energy use (kWh) or CO_2 emission (kg) over the whole lifetime of dwelling. E_c includes embodied energy or CO_2 emission in building material and machines, energy use or CO_2 emission owe to transportation and on-site construction process. E_o is the energy use or CO_2 emission during the use stage of dwelling including operation and maintenance; and E_d is the energy use or CO_2 emission during the demolition stage of dwelling.

2.2 System description, assumptions and data

The following provides an overview of system boundaries, the assumptions made for and the data estimated. Table 1 summarises the main material and energy consumption information considered in this study. The data for construction stage is taken from the five tenders completed in the Fuzhou University town during 2007-2011 and on-site report. The projects used for this study totally have 997 rooms for students and 5 rooms for administration. Every room is 30 m^2 (useful space[1]) and occupied by three students. Energy consumption for operation in use stage are average values of the last 5 years water and energy bills of these projects. The consumption data of maintenance is estimated by the damage and repair reports of the real estate administration of Fuzhou University over past 10 years. The demolition is assumed to be done by excavator, which is one of typical methods in China.

Machines and tools for tunnel construction are used for more than one construction site. This study uses effective hours (eh) to take the consumption of machines and tools into account. The on-site daily energy consumption are used to calculate the energy consumption for equipment operation and transport on construction site. It excludes the transportation of construction machines, equipment and tools to the site.

The steel and cement are produced in Longyan and Sanming, which are 300 km away from the construction site. Other materials are supplied locally. They are assumed to be transported 50 km from the manufacturing gate to the construction site and all transport is assumed to be by road using 16 t capacity trucks. The waste during the construction stage and demolition stage are transported 100 km.

Due to the difficulty of access to China-specific background LCI data, this study explores the embodied energy and CO_2 emission from input-output (I-O) analysis. The CO_2 emission factor of on-site energy burned stem from the results of several studies [21, 22].

2.3 I-O analysis

The I-O analysis estimates, the materials and energy resources required for, and the environmental emission resulting from, activities in the economy. For the input-output model, this study follow the method described the literatures [23] and [24] . The total embodied energy and emission intensity matrix ‘‘E’’ was calculated by

$$E = S(I - A)^{-1} \qquad (2)$$

Where A is the technical coefficient matrix, I is the identity matrix, and S is the satellite matrix. The satellite matrix “S” includes direct energy use intensity and CO_2 emission intensity. The ‘‘E’’ matrix is the total energy use intensity and the total CO_2 emission intensity for all sectors economic output. For the calculations, the Chinese IO table 2007 updated with energy and CO_2 emission by Liang et al. [14] is used for matrix A, S and for the final total output of all sectors.

Table 1: Material and energy consumption of per m^2 university dormitory

Stag	item	unit	amount	I-O table sector	Comments
Construction	aerated concrete block and brick	kg	138.685	Nonmetallic mineral products	The amount will multiply with the unit cost of items, which including all the process for it became a part of buildings. Then this consumption will be allocated to economy sector in the IO table. The
	cement	kg	102.850		
	ceramic tile	kg	49.001		
	concrete	m^3	0.480		

[1] There are two main concept of space in China: useful space and construction space. Useful space refer to useful area for occupants. The construction space include useful space, structure space, and service space (for example, main entrance, steps). People only cool the space they use. Therefore, this study will use useful space for analysis. Useful space normally equal to 75-85% of construction space in China dependent on the type of buildings.

	Stone plate	kg	2.265		allocation is according to the classification and definition of sectors in Chinese input-output table 2007. The cost in the tenders are recalculated to be 2007 price.
	Glass	kg	3.856		
	roof tile	kg	2.908	Nonmetallic and other ores	
	Gravel and sand	kg	1191.197		
	lime and clay	kg	1.700		
	slag	kg	22.856	Rubber	
	rubber products	kg	0.001	Plastics	
	PVC	kg	0.029	Raw chemical materials	
	XPS	kg	0.302		
	paints	kg	3.269		
	other chemical products	kg	1.410		
	Bitumen seal	kg	0.923		
	steel	kg	61.036	Ferrous metals	
	metal products	kg	2.038	Metal products	
	door and window	m2	0.321		
	Textile	kg	0.025	Textiles	
	oil and gas (for non-energy purpose)	kg	0.052	Petroleum and natural gas	
	wood	m^3	0.045	wood process	
	water	m^3	0.822	Water	
	machine and tools	eh	21.885	Special purpose machinery	
	electricity	kwh	17.886	Electricity and heat power	
	diesel	kg	1.738	Petroleum and natural gas	
Maintenance	cement	kg	10.285	Nonmetallic mineral products	80% of ceramic tile will be changed once. All stone plate will be changed once. PVC pipe will be changed twice owe to high temperature and
	ceramic tile	kg	39.201		
	Glass	kg	9.639		
	roof tile	kg	5.817		

	Stone plate	kg	0.800		much sunlight in hot summer. Due to the high humidity, the paints will be renewed twice, bitumen seal for roof will be changed every 15 years, and roof tile will be changed twice. 80% of doors and windows will be change once. Wood products will be changed every 20 years. There will be around 5% glass products damage owe to Typhoons and some other unexpected accidents.
	PVC	kg	0.058	Plastics	
	paints	kg	6.538	Raw chemical materials	
	Bitumen seal	kg	2.891		
	door and window	m^2	0.257	Metal products	
	wood	m^3	0.089	wood process	
Occupation	electricity	kWh	2991.000	Electricity and heat power	
	water	m^3	179.460	water	
Demolition	diesel	kg	6.345	Petroleum and natural gas	

3. Results

Table 2 presents the results of IO-LCA and sensitivity test. Fig.1 illustrates the relative contribution of each stage to total energy use and CO_2 emissions. Fig.2 explains the relative contribution of the process to the construction stage. Fig.3 demonstrates the relative contribution of each input to the energy use and CO_2 emissions owe to material and machine consumption during the construction stage. Equally, Fig.4 presents the relative contribution of each input to the energy use and CO_2 emissions during the use stage.

The use stage is the dominate contributor to the energy use (70%) and CO_2 emissions (79%) over 50 years, mainly owing to the consumption of electricity. The energy use and CO_2 emissions at the use stage depends on the service life of dormitories. As indicating in the table 2, the energy use and CO_2 emissions will increase 13% and 15% respectively, if the service life improve from 50 years to 60 years (20% growth). Moreover, the use of electricity causes 88% of energy use at the use stage. Around two thirds of electricity in China is produced by coal [22]. Such coal dependent electricity is the main source of Chinese air pollution. As a result, electricity consumption respond to the 92% of CO_2 emission during 50 years occupied.

The construction, mainly the use of buildings materials, contributes with 28% of the total energy and 21% of CO_2 emissions over 50 years. These energy consumption and CO_2 emissions mainly stem from the up-supply chain process of building materials and machines. This part is so-called embodied energy and emissions in the building material. This embodied one contribute 91% of energy and 95% of CO_2 at the construction stage. However, this use and emission are not form the construction site. On-site construction process have similar contribution as transportation of buildings materials and construction waste. However, the transportation cause more CO_2 emissions than on-site construction process, due to the burn of diesel.

The largest contributor to the embodied energy and CO_2 emissions is non-metallic mineral products, including tile, cement, and concrete. They are responsible to 44% of embodied energy and 50% of embodied CO_2 emissions. The second largest contribution sector is ferrous metals, mainly steel, 31% of embodied energy and 30% of embodied CO_2 emissions. This indicate that the consumption of tile, cement, concrete and steel are dominate contributors to the embodied energy and CO_2 emissions.

Table 2 Results of one useful m2 university dormitories with 50 years lifetime and sensitivity analysis results expressed as percentage of variation relative to the reference case.

Category	Total results	Sensitivity analysis results of 60 years (%)	Sensitivity analysis results of 75 years (%)
Energy (kWh)	5047	13	36
CO_2(kg)	4822	**15**	**39**

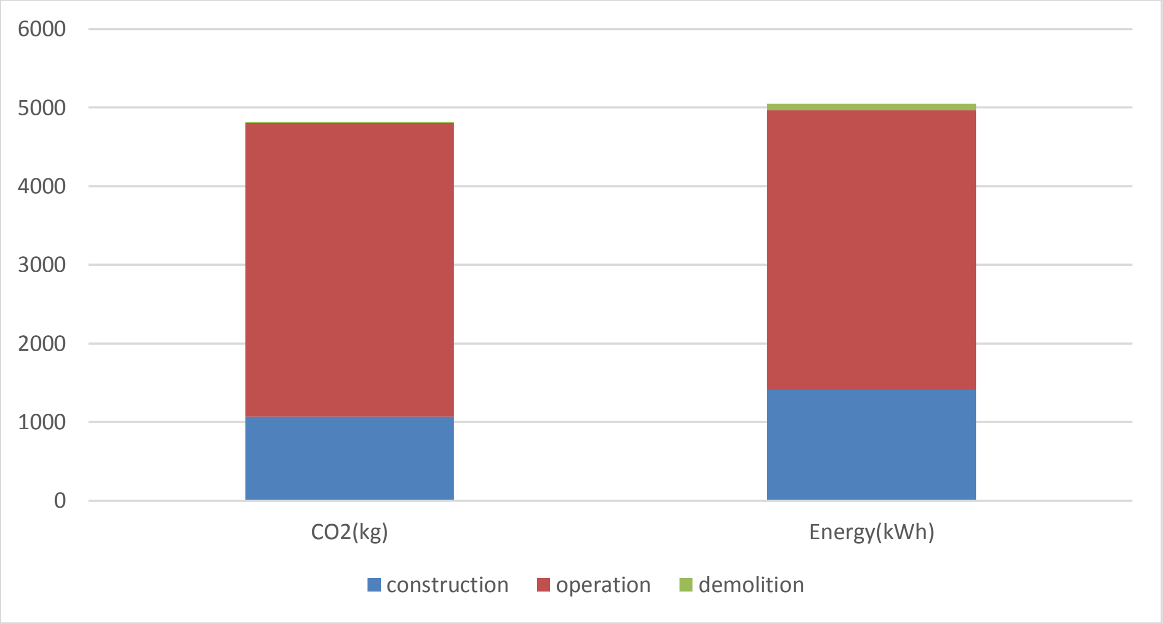

Fig. 1. Energy use and CO_2 emission 1 m^2 useful area of university dormitories over 50 years life time

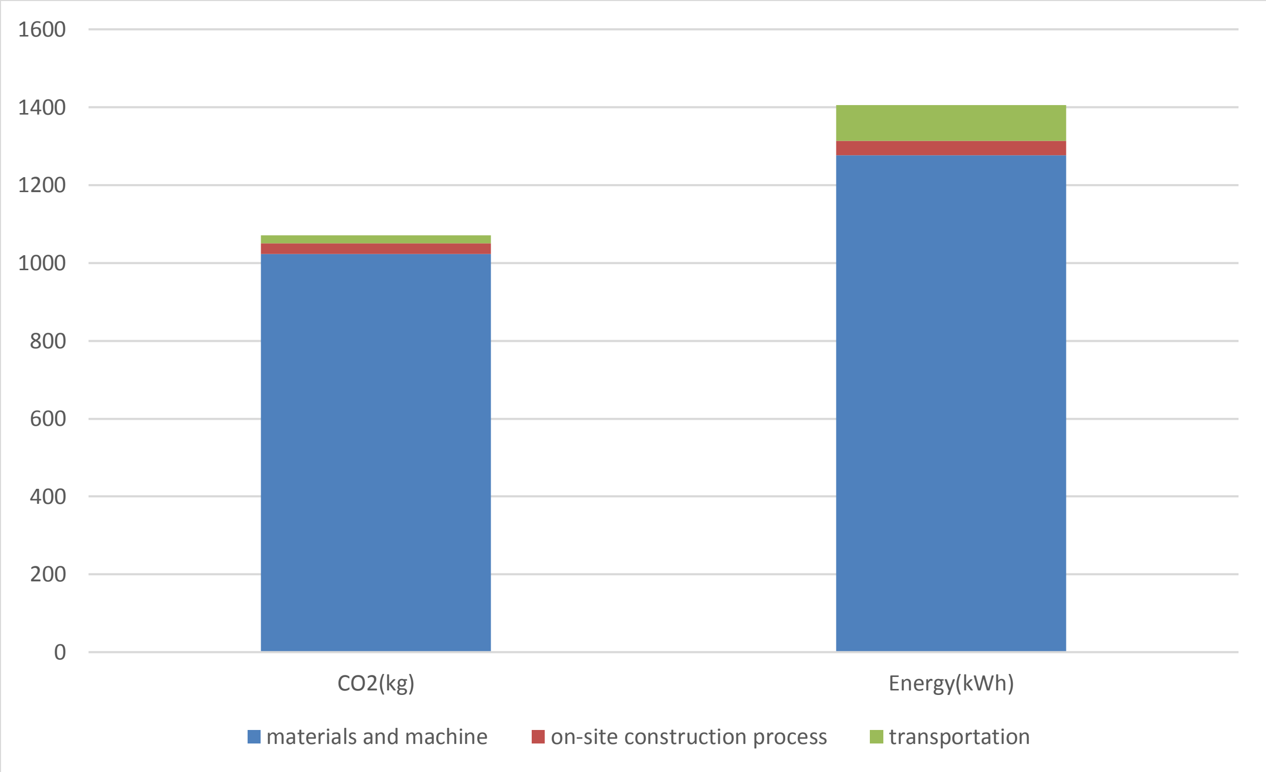

Fig. 2. Energy use and CO_2 emissions for construction 1 m^2 useful area of university dormitories

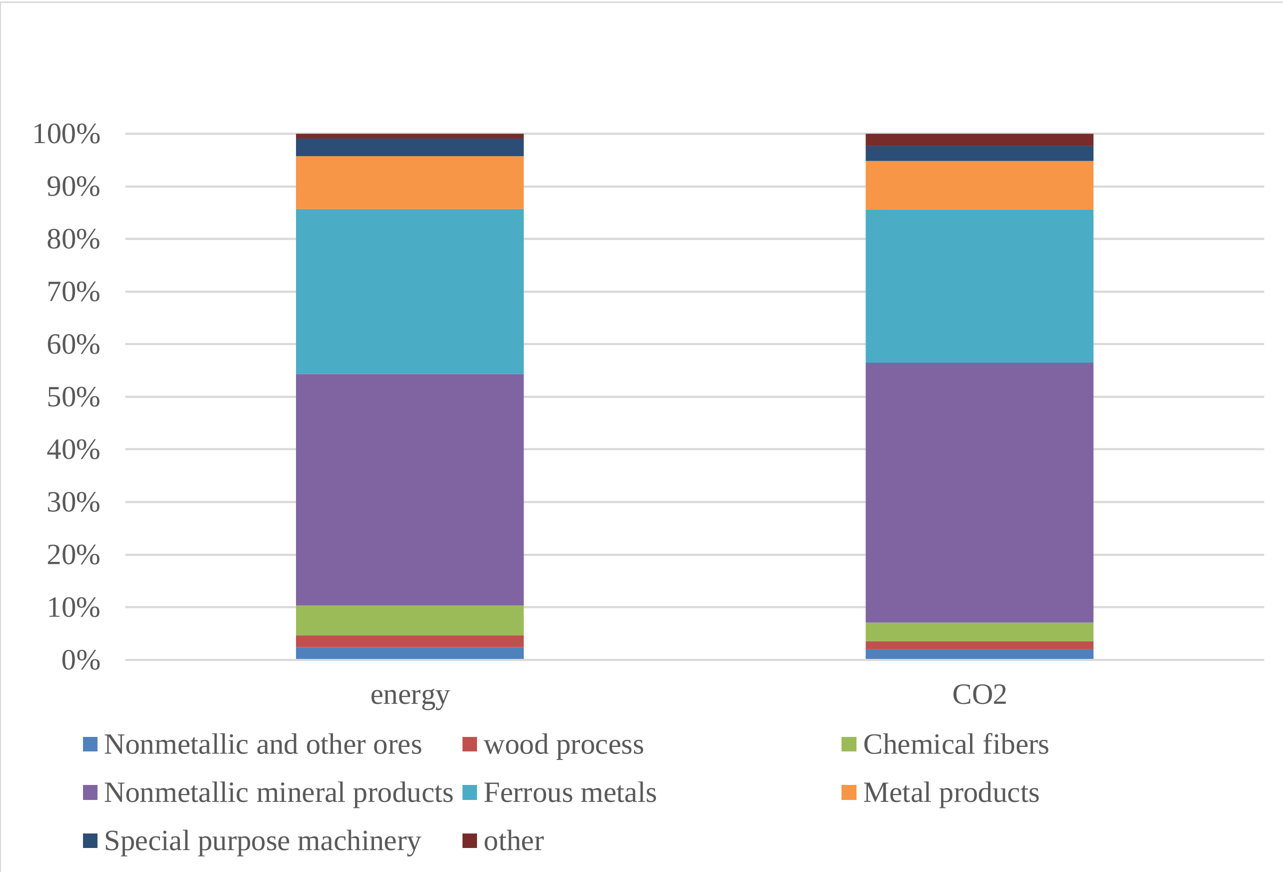

Fig. 3. Relative contribution of inputs to energy and CO_2 emission owe to the material and machine consumption for construction

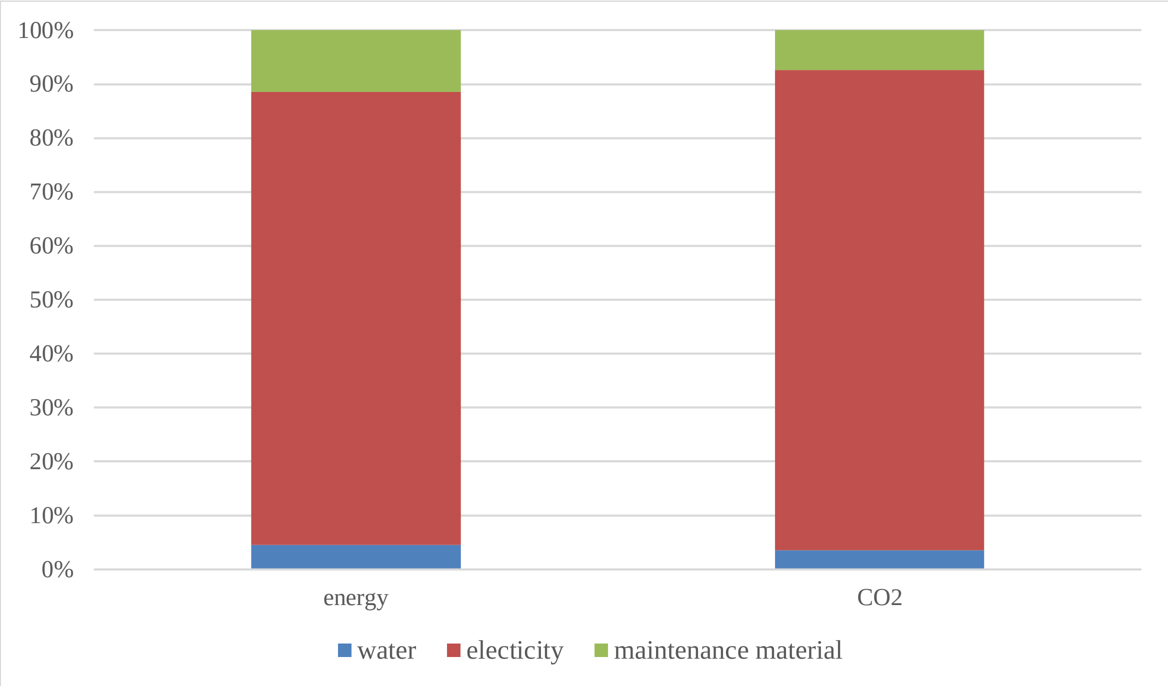

Fig. 4. Relative contribution of inputs to energy and CO_2 emission during use stage

4. Discussion

Sensitivity test results indicate that the lifetime of buildings have influence on the total life cycle energy and CO_2. However, it also indicate that the standard lifetime with 50 years is good enough to identify the hot spots. The main findings of the analysis are that material and electricity consumption entail rather significant energy use and CO_2 emission of university dormitories in China. Equally, electricity, steel, tile, concrete and cement are the five main contributors to the energy use and CO_2 emission caused by university dormitories over its life cycle.

Consumption of electricity causes 60% of total energy use and 70% CO_2 emission over university dormitories lifetime, mainly because of occupation. This consumption at use stage is site-specific, influenced by a number of factors. According the regulation of university dormitory, students are not allowed to cook in the dormitory. The main equipment installed in the dormitory are air condition, hot-water cooker, and PC. Therefore, the energy use during occupation are mainly for cooling/heating, hot-water, PC and lighting. Those university dormitories locate in sub-tropical China, which have hot summer and warm winter. Occupants will required cooling during the period May- September. There are two facts of energy use in university dormitory: 1) The air condition will turn on during lunch break (12:00-14:00), after class and night (17:00-8:00). 2) During summer holiday (July and August), there is 1 month without occupation. Totally, the cooling is responsible for half of energy use for occupation. The percentage is much higher than ordinary residential buildings in the same climate zone, where cooking and cooling have similar importance for energy use. For example, cooling represents around 20% of total energy consumption in Shanghai [26]. Therefore, the energy efficiency of university dormitories (buildings physical performance and appliance performance) is the key issue for reducing energy use and CO_2 emission. To reduce the use of electricity, policies can include encouraging industry to build more low energy dwellings and deliver efficiency of appliance (air condition, PC, hot water cooker).

The environmental impacts (CO_2) resulting from electricity consumption do not only rely on the amount of consumption but also on the electricity production mix. Even through there is fruitful resources of hydropower, wind and solar in the Fujian province (Fuzhou is the capital of the province), coal is still the main resources for electricity production. The reason for this is that coal is cheaper. Therefore, subsidies and policies to encourage the use of cleaner electricity would be another policy choice.

Steel, tile, concrete and cement are the four main materials causing energy use and CO_2 emission over the dormitory lifetime. Steel, concrete and cement is mainly main materials for base, structure and wall in China nowadays. It is difficult for Chinese to use other materials for structure. Therefore, it is important to encourage the up-stream supply chain to decrease energy use. Seeking an environmental friendly up-stream supply chain of material, however, cannot ignore the role of electricity for manufacture. Ceramic tile is widespread use for bathroom wall, indoor floor and outdoor wall in south China (Fuzhou is located in southeast China). For such case, some other materials can substituted ceramic tile use. The humidity in Fuzhou is large. Wood products are not good enough to substitute ceramic tile. Therefore, chemical products can be one potential selection. However, it will be better to do detailed comparing with life cycle assessment of them before decision-making.

The energy mix and buildings technology will change over the long lifetime of buildings. Therefore, there are always some uncertainty with the results. The results in this study is based on the 2007 Chinese energy mix. When more renewable energy will be used in the future, the CO_2 emission will decrease. Therefore, the CO_2 emission during the occupied stage will be less than estimated here. However, study based today energy mix and technology level will help us to identify the way we will go for the more sustainable future.

5. Conclusions

Using university dormitories project tenders completed in Fuzhou university town during 2007-2011 and the energy bills of those buildings over past 5 years, this study reveals that:

1) 1 m^2 useful place of university dormitories in sub-tropical China at least consumes 5 MWh and emits 4.8 ton CO_2 over its 50 years life span. Such emission mainly stem from the consumption of electricity. The use stage has major responsibility to such consumption and emission.
2) Electricity, steel, tile, concrete and cement are the five main contributors for the life cycle energy use and CO_2 emission of university dormitory. Therefore, improving the energy efficiency of buildings and appliance, and optimizing framework design to reduce the amount of such main consumptions would play key role in reducing the environmental burden of Chinese university dormitories. Moreover, policies promoting more renewable energy production and consumption constitute another import issue for environmental friendly dwelling.

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