Life cycle assessment and life cycle cost of university dormitories in the Southeast China: case study of the university town of Fuzhou

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Abstract:

The aim of this paper is to assess university dormitories in terms of life cycle environmental impact and cost, as part of the university campuses sustainable development in southeast China. This life cycle assessment follows the ISO 14040/44 methodology, considering the construction, operation, maintenance and demolition stages. The reference unit of this study is defined as 'one useful square meter university dormitories with 50 years life time'. This study estimates the life cycle inventory by: 1) tenders information of university dormitories built in the university town of Fuzhou during 2007-2011, 2) water and energy bills of those building over past 5 years, 3) damage and maintenance report of dormitories in Fuzhou University and Fujian University of traditional Chinese medicine during 2004-2014. The Ecoinvent database provides the background data to the analysis.

The results indicate that 1) the use stage, including operation and maintenance is the dominate part of the life cycle environmental impacts and cost of university dormitories. 2) The consumption of electricity constitutes the main elements causing the environmental impacts over the life cycle of university dormitories. The technology for more energy efficient building is more important than other factors. 3) The window, concrete, steel, and cement have the largest contribution to the embodied environmental impacts but with the relative small contribution to the life cycle cost. Therefore, two main improving oppertunities for reducing the environmental impacts of Chinese university dormitories developement are identified: 1) improving building with deep renovation for current dormitories and implementing low energy buildings standards for new built dormitories the buildings energy efficiency and 2) increasing the use of low environmental impacs building material by implementing the carbon tax on main building material and introducing timbers as structure material. Moreover, policies to promote the more renewable energy supply and the implementation of carbon capture and storage technology constitute another import issue.

Keywords:

Life cycle assessment, life cycle cost, CO_2, University Dormitories, China

Abbreviations:

LCA: Life cycle assessment

LCC: Life cycle cost

GWP: Climate change

ODP: Ozone depletion

TAP: Terrestrial acidification

FEP: Freshwater eutrophication

MEP: Marine eutrophication

HTP: Human Toxicity

POFP: Photochemical oxidant formation

PMFP: Particulate matter formation

TETP: Terrestrial ecotoxicity

FETP: Freshwater ecotoxicity

RMB: Ren Min Bi (Chinese Currency)

1. Introduction

Universities work as facilitators for sustainable development (Sedlacek, 2013). The sustainability of university/campus is analysed in several studies, including, carbon footprint (Larsen et al., 2013; Li et al., 2015; Ozawa-Meida et al., 2013; Townsend and Barrett, 2013), energy use assessment of educational buildings (Agdas et al., 2015), university level sustainable transportation (Wu et al., 2014), etc.. Obviously, the operating of universities require the using of the classrooms, office, libraries, and laboratories. The heating and construction of buildings is identified as the 'hot spots' in the system, for most environmental impacts (Lukman et al., 2009). As one of the main emerging economics, China produced the higher education booming over the past decade. The university student population in 2013 (34 million) is nearly three times compare with 2003 (12 million) (NBSC, 2013). This incredible growth results in the increasing demand of university buildings, especially university dormitories (It is universities' responsibility to supply the dormitories to the students in China). Naturally, the construction and using of the buildings generate environmental impacts.

The life cycle assessment (LCA) is proved as a well suitable tool for obtaining the full picture of the environmental implications of running buildings (Abd Rashid and Yusoff, 2015; Chau et al., 2015). Numerous studies have analysed the environmental impacts of buildings/dwelling with life cycle perspectives. Several studies provide the review of the life cycle studies on buildings, see literatures (Abd Rashid and Yusoff, 2015; Buyle et al., 2013; Chau et al., 2015; Islam et al., 2015a; Ortiz et al., 2009). Moreover, the cost-effectiveness is one of the key components of the building development. The life cycle cost (LCC) analysis, working as the effective tools, looks at the cost over the life cycle of building. There are number of life cycle cost studies on building, see literatures (Cuéllar-Franca and Azapagic, 2014; Ehlen, 1997; Hastak et al., 2003; Islam et al., 2015a). To seek solutions to support the progress in the environment friendly and cost-effective, some recent studies try to combine the life cycle assessment and life cycle costing. For example, the standard home (SH) and the function equivalent energy-efficient house (EEH) was compared with life cycle perspective in U.S. (Keoleian et al., 2000). It is found that the EEH indicated significant life cycle energy saving relative to the SH, but this did not translate into life cycle cost advantage. Lazzarin et al. conducted the LCA+LCC analysis on building insulation materials in Italy with respect to different climatic conditions (Lazzarin et al., 2008). Atmaca analysed the life-cycle energy (LCEA), emissions (LCCO_2A) and cost (LCCA) assessment of two residential buildings constructed in urban and rural areas in Turkey (Atmaca, 2016a, b). Islam et al. evaluated the effect of the selection of buildings components (wall, roof, floor) on environmental impacts and life cycle cost over the various life stages of the typical Australia residential buildings (Islam et al., 2015b; Islam et al., 2014; Islam et al., 2015c; Islam et al., 2015d).

Table 1 summarise the comprehensive overview of the main recent LCA+LCC studies on buildings. These existing studies concentrate on the energy efficiency of new design residential buildings and studies in the developed countries. In addition, the most data used for analysis is simulation information. This could produce some difference between the studies and real world, which will probably mislead the decision-making. Moreover, the literature studies reveal that there are few studies to highlight the environmental impact of university dormitories in China. As a result, the knowledge of life cycle environmental impacts and cost of university dormitories in Chinese context is not enough. Given the nowadays challenge of environmental pollution and the large university student population in China, the importance of environmental impacts for university buildings in China cannot be ignored. This study tries to add the knowledge of environment impacts and cost caused by the construction and operation of university dormitories, especially those in the southeast China (Which is one of main areas for higher education cluster in China). Consequently, this paper aims to answer these two research questions:

1) What is the level of life cycle environment impacts and cost of university dormitories in the southeast China?
2) What are the hot spots and improvement opportunities of those buildings?

In order to identify the answers, this study conducts life cycle assessment and life cycle costing, with considering all the processes over the life cycle of dormitories. The paper is organized as follows. Section 2 sets out the theoretical framework of the analysis, the development of models and the data source. Section 3 explains the main results of the analysis. Section 4 discusses the potential of environment friendly and cost effective university dormitories. Section 5 concludes the findings.

2. Method and data

This LCA study follows the ISO 14040/44 methodology (ISO, 2006a, b). The ReCiPe Midpoint (H) V1.1 method has been used to estimate the environmental impacts. The main foreground system data originate from 1) tenders information of university dormitories built in the university town of Fuzhou during 2007- 2011, 2) water and energy bills of those building over past 5 years, 3) damage and maintenance report of dormitories in Fuzhou University and Fujian University of traditional Chinese medicine during 2004-2014.

2.1. Goal, scope and reference unit

The goal of this LCA study is to estimate the life cycle environment impact and cost of university dormitories projects in the southeast China. These results are then used to identify the hot spots and improvement opportunities along the supply chain. As buildings are similar, therefore it is possible to use some typical case to create genetic profile (Cuéllar-Franca and Azapagic, 2014). The relocation and concentration of universities campus have occurred to most of Chinese universities over past 15 years. To support this relocation, many cities developed the university town during this period. As the results, the buildings in these new-developed university towns use similar technology and follow the same building code. The university town of Fuzhou is new developed area for universities in Fuzhou. Most of the universities in Fuzhou moved to this new developed area over past 10 years. Fuzhou locates in the southeast china, which is the climate zone with hot summer and warm winter. Therefore, this study will use some cases in the university town of Fuzhou as a typical case for the southeast China.

While some LCA studies on buildings defines 1 m^2 floor area (Cuéllar-Franca and Azapagic, 2012a) or 1 m^3 gross volume (Asdrubali et al., 2013) as functional unit, EN15978 uses the whole building as a functional equivalent (Standards, 2011). Since the function of building 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 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 (Adalberth, 1997; Cuéllar-Franca and Azapagic, 2012b; Zabalza Bribián et al., 2009). However, to assess the influence of lifetime on the studied results, sensitivity analysis with 75 years (50%) is 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. In this study, the operation stage considers energy used by occupants for space cooling, lighting, hot water, and appliances and water consumption by the occupants. 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 is included. Due to the difficulty to forecast transportation, machines and tools consumed for maintenance in the future, the study considers that they will be equal to today's technologies.

2.2 System description, assumptions and data

The following provides an overview of system boundaries, the assumptions made for and the data estimated. Table 2 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 university town of Fuzhou 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 are estimated by the damage and repair reports of the real estate administration of Fuzhou University and Fujian University of traditional Chinese medicine 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 the construction are used for more than one construction site. Thus, this study does not consider the consumption of machines and tools. The on-site daily energy consumption are used to calculate the energy consumption for equipment operation and transport on the 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 respectively, which are both 300 km away from the construction site. Other materials are supplied locally. They are assumed to be 50 km from the manufacturing gate to the construction site. The waste during the construction stage and demolition stage are sent 100 km away.

2.3 Impact assessment

The ReCiPe Midpoint (H) V1.1 / World ReCiPe H (Goedkoop et al. 2012) method was used to estimate the environmental impacts. The following midpoint impact categories are used: Climate change (GWP), Ozone depletion (ODP), Terrestrial acidification (TAP), Freshwater eutrophication (FEP), Marine eutrophication (MEP), Human Toxicity (HTP), Photochemical oxidant formation (POFP), Particulate matter formation (PMFP), Terrestrial ecotoxicity (TETP), Freshwater ecotoxicity (FETP).

[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 70-85% of construction space in China dependent on the type of buildings.

The environmental impact, E_i is calculated by following the logic of total environmental impact ($\boldsymbol{E_{i_{tot}}}$), equation 1, but the end-of-life stage only considers the transportation of the waste;

$$E_{i_{tot}} = \sum_{E_i}\left(E_{i_c} + E_{i_o} + E_{i_m} + E_{i_d} + E_{i_e}\right) \quad (1)$$

Where tot= total impact, c= construction (including extraction of materials, production of construction materials, transport, on-site process), o= operation, m= maintenance, d= deconstruction and e= waste handling and end-of-life activities.

2.4 Life cycle costing

The life cycle cost analysis estimates the relevant cost throughout the life of buildings. The determination of the cost of building is a challenge task, due to the long lifetime of buildings. The price of labour, fuel, material and component can be significantly different from year to year and depend on the location, market and quality. The value of money today and in the future are not equal, because of inflation. Most of the exiting LCC studies follow the method developed by (Fuller and Petersen, 1996; Reidy et al., 2005), which eliminated inflation from all escalation and discount rates. However, the inflation rate of future several decades is difficult to be estimated. To decrease such uncertainty, this study follows the study (Keoleian et al., 2000) to use the undiscounted cost. This study assume that the technology and cost for maintenance and operation in future is the same to today. Equally, all cost here are calculated as 2007 price. Moreover, this study does not consider the mortgage.

In this study, LCC corresponds the system boundary of LCA, not including the buildings equipment and their installation. It considers the cost paid by the project owner for the pre-construction, construction, maintenance, operation and end of life. The cost of pre-construction includes survey, planning and designing (the cost of land is excluded). The cost estimation of construction, maintenance and demolition follow the Chinese standard (GB50500-2008, Code of valuation with bill quantity of construction works). This study includes all cost indicated in the code, including the labour, material, machine, process, administration, etc. The cost for operation considers the payment for water and energy bill. At the end of life, the buildings is considered to be demolished. The residual value is normally not considered in the demolition. Thus, the end of life stage only considers the cost for the transportation of the waste.

The life cycle cost, C, is calculated by following the logic of the cost ($\boldsymbol{C}_{tot}$), as equation 2.

$$C_{tot} = \sum \left(C_P + C_c + C_o + C_m + C_d + C_e\right) \quad (2)$$

Where tot= total impact, p= pre construction, c= construction, o= operation, m= maintenance, d= deconstruction and e= waste handling and end-of-life activities.

3. Results

Table 3 presents the results of LCA, LCC and sensitivity test. Figure 1 illustrates the relative contribution of each stage to total environmental impacts. The operation is the largest contributor to nearly all environment impacts, except ODP. The use of electricity causes more than 90% of most environmental impacts at the operation stage. The construction stage is largest contributor to the ODP and second largest contributor to other environmental impacts. These environmental impacts mainly stem from the up-supply chain process of building materials. This part is so-called embodied environmental impacts in the building material. This embodied environmental impacts of building materials contributes around 80-90% of most environmental impacts at the construction stage, excepting the FETP. However, these environmental impacts are not mainly produced on the construction site but the processes of up-supply chain. On-site construction process has the smallest contribution. Moreover, the transportation buildings materials and construction waste (between the factory/suppliers' gates to the construction site) cause the most FETP (64% of FETP at construction stage), due to the burn of diesel. Moreover, the operation is also the largest contribution to the life cycle cost (35%). Equally, the construction's contribution to the life cycle cost is nearly the same to the operation. However, the construction's cost will increase if the interest of mortgage is considered. Building materials respond to 91% of cost at construction stage. This significant contribution is the results of the low labour price in China.

Figure 2 displays the relative contribution of different inputs to the environmental impacts at the construction stage. Moreover, window (21%), concrete (18%), steel (12%), cement (7%) and concrete block (6%) is the largest contributor to the embodied GWP emission (including the construction and maintenance). They are responsible to 80% of embodied carbon emissions. Windows, concrete and steel are also main contributors to other environmental impacts except FETP. On the other side, these five main embodied environmental impacts contributors only respond small part of total material cost: concrete (3.2%), steel (4.4%), window (1.8%), cement (2.1%) and concrete block (3.6%). The sensitivity analysis with lifetime indicates that service life of buildings is important for the results of life cycle assessment and life cycle costing. The cumulative environment impacts is dependent on the frequency of maintenance requirements and the period of occupied. The longer lifetime absolutely increasing the requirements of maintenance and the occupied time. For example, the maintenance impacts can range approximately 2% to 55% of the total life cycle impact, depending on the assumed service life, the assumed maintenance regimen, and the frequency and intensity of replacement (Grant and Ries, 2013). Therefore, the future research on enhanced service life modelling could be beneficial for buildings material and component selections for sustainable building design, maintenance and renovation.

4. Discussion

4.1 Energy consumption of university dormitories

Consumption of electricity is the dominate contributor of nearly all environmental impacts over university dormitories lifetime except ODP. This consumption at use stage is site-specific, influenced by a number of factors, especially the occupants' behaviour and energy efficiency. According the regulation of university dormitories, 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 the 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 require 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 2 month without the 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 (Li Z. H. et al., 2007). Moreover, unlike the residential buildings, the energy price and income are not important to the energy consumption in university dormitories. That is the result of two facts: 1) the energy bill is shared by the students in one room. There are normally 3-6 students in one room depending on the size of dormitory. 2) The time and amount students use the energy for cooling, hot water; lighting and computer are stable annually because their occupation is according to the school calendar. Therefore, the energy consumption of university dormitories is more dependent on the energy efficiency, including buildings physical performance and appliance performance. The study in EU conducted by Brion et al. found that technological effect are equally or more important than price effects in reducing energy demand for residential buildings (Ó Broin et al., 2015). Our study confirms this result in the universities dormitories. The dormitories in this study have already been required with the installation of good insulation according the building code. However, it is still not enough comparing with the low-energy buildings or passive buildings. To reduce the use of electricity, policies should encourage deep renovation for current and low energy standards (for example, nearly zero energy buildings) for new built dormitories.

4.2 Embodied environmental impacts of university dormitories

Embodied environmental impacts (including the construction and maintenance) are another important part to the total environmental impacts over the life cycle of university dormitories. Building materials are the dominate contributor to all embodied environmental impacts, expect FETP (mainly caused by the transport). Moreover, seeking the improvement of building energy efficient will require more advanced and effective materials and then result in the more embodied energy and environmental impacts (Pal et al., 2017). Therefore, it is important to have good performance material with less environmental impact.

For embodied GWP, cement and steel (used for concrete, concrete block and mortar) are main producers. Cement and steel are mainly main materials for base, structure and wall in China nowadays. Specially, cement production is an energy and carbon-intensive process, due to the calcination of limestone and the combustion of fuels. Several studies tried to address the CO2 emission and energy efficiency issues of cement industry in China (Chen et al., 2015; Chen et al., 2016; Hasanbeigi et al., 2010; Liu et al., 1995; Shen et al., 2015). However, it looks not enough for 2 degree global warming scenario according to the ETP15 (IEA, 2016). The carbon capture and storage (CCS) technology is identified as one of key for the decarbonisation in cement and energy industries (Benhelal et al., 2013; IEA, 2015; Pardo et al., 2011). CCS could reduce 57% of emissions from China's cement production by 2030, and the cost of capturing CO_2 from cement production is 5-20% lower relative to that of coal-fired power generation depending on the different capture technologies implemented (Zhou et al., 2016). For cement industries, CCS has not been pilot tested and demonstrated at the commercial scale in China. Given the size and growth rate of Chinese economy, such amount of CCS technology implementation is not enough. Policies need to development to deal with the various barriers and challenges for CCS, especially in term of economic factors and legislation.

On the other hand, multi-floor buildings such as university dormitories can also use timber as main structures to reduce the embodied environmental impacts. It is found that the timber structures cause a GWP that is 34-84 % lower than the reinforced concrete structures (Skullestad et al., 2016). The study in Finland also indicates that timber is cheaper than concrete (Pal et al., 2017). There is very few modern multi-floor buildings in China owe to the limitation of resource on timber and land. However, China released new policies in 2015 and 2016 to encourage the modern timber buildings in suitable area as one of mitigation to the climate change. This make it is possible to introduce the timber to the new built dormitories in China. However, due to the few practice of multi-floor buildings with timber in China, the knowledge on the environmental impacts and cost is rare within Chinese context. This requires future studies.

4.3 Cost-effective improvement

Findings also indicate that five main emissions intensive building materials/components only contribute less than 15% of total material cost. Carbon tax, which is a cost-effective instrument in achieving a given abatement target, can be another potential and effective policy for buildings sector. In 1990, Finland was the first country that introduced a tax on CO2. Later, several other European countries followed suit with tax reforms that shifted taxation from labour to carbon and energy. The practices in Europe have contributed to a reduction in the emissions of greenhouse gases with slightly negative impacts to economic growth (Andersen and Ekins, 2010). Several analyses of carbon tax policy in China were carried out currently, including macro-economic (Deng et al., 2015; Li and Jia, 2016; Tang et al., 2015) and micro-economic (Liu et al., 2015; Xu et al., 2016). Studies indicated that the carbon tax rate can range between 10-100 yuan/ton CO2 at the sector level in China (Wang et al., 2011). From the viewpoint of Chinese businesses, the option of carbon tax policy with tax rate at 10-30 Yuan/t-CO2 (Liu et al., 2015). The suitable carbon tax policy on building material sector and the effect of carbon tax on the buildings material selection in China is not clear yet. This requires more details study in the future. However, it is cost-effective to implement the carbon tax for these five main build materials to promote the development and using of low environmental impacts building material.

Moreover, the environmental impacts resulted from building material and electricity consumption depend on not only the amount of consumption but also on the energy mix. The more supply of renewable energy will decrease not only the embodied environmental impacts caused by the building material production, but also the environmental impacts caused by the occupation of university dormitories. There are fruitful resources of hydropower, geothermal, wind and solar in the southeast China. For example, the geothermal can be used for district cooling and hot water. However, coal is still the main resources for electricity production. The main reason for this is that coal is cheaper. Therefore, subsidies and policies to encourage the more supply or renewable energy would be another cost-effective policy choice.

5. Conclusions

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

1) One m^2 useful space of university dormitories in the university town of Fuzhou at least emits 4.8 ton GWP and costs nearly 6100 yuan (RMB 2007 price) over its 50 years life span. The operation has major responsibility to the cost and environmental impacts.
2) Electricity, window, concrete, steel, and cement are the five main contributors for the life cycle environmental impacts of university dormitories. However, the contribution of steel, concrete, window and cement to the life cycle cost is low. Therefore, improving building energy efficiency, and encouraging low environmental impacts building material are hot spots to reduce the environmental burden of Chinese university dormitories.
3) Opportunities to improve the energy performance for building with life cycle perspective include deep renovation for existing dormitories, implementing the more energy efficient standards for new built dormitories, using low environmental impacts building material and introducing the timber structure for multi-floor buildings.
4) The potential to promoting the use of low environmental impacts building material is the tax, such as carbon tax. Another potential is to increase the renewable energy supply, and promote the implementation of CCS constitute.

This study explores the level of environmental impacts and cost of university dormitories by case study in the university town of Fuzhou. Most current university dormitories in the southeast China are similar and were built in the same period. Therefore, the case study of the university town of Fuzhou can generate the typical profile and cover the pivotal points of university dormitories in the southeast China. To be more accurate, it require future study for sensitive test by more data collection.

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