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A dynamic life cycle carbon emission assessment on green and non-green buildings in China

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ABSTRACT

As most promoted solution of climate change, green buildings become more popular and widely promoted in China recently. This paper compared the carbon emissions of green buildings with non-green buildings; therefore, a life cycle carbon emission assessment approach (LCA) was attempted. In the present paper, we have integrated existing database Building Environmental Load Evaluation System (BELES) developed by Tsinghua University and twenty-six real existing buildings (nine residential and seventeen commercial buildings). Buildings located in two major climate zones were selected, namely, zone II and III. Five phases were defined for a whole life cycle of building: Phase 1 Raw Materials, Phase 2 Transportation, Phase 3 Construction, Phase 4 Operation & Maintenance and Phase 5 Demolishment. In each phase, the emissions were calculated separately.

It is found that whole life cycle CO_2 ($LCCO_2$) of green buildings are lower than that of non-green buildings, i.e., 10% for residential and 32% for commercial buildings, respectively. For both residential and commercial buildings, Operational & Maintenance phase contributes the majority of emissions in the whole life cycle, about 69.2–89.3%. Moreover, green buildings have slightly higher embodied CO_2 emissions than non-green buildings, but with much lower operational emissions, and this phenomenon is significant in residential buildings. This indicates that the $LCCO_2$ of green buildings start to match with $LCCO_2$ of non-green buildings after operating for certain years, which is the turning point. Furthermore, China implemented Standard for Energy Consumption of Buildings in December 2016, which listed two values for energy efficiency in operational phase, which represents requested and optional. It can be expected that the emissions in Operational & Maintenance phase of green buildings will be further reduced in the future. Consequently, in the future, the dynamic flow of turning point of residential buildings will be shifted downwards from existing 14 years found in this paper.

1. Introduction

1.1. Background

With attracting comprehensive people's attention, climate change and carbon emissions becomes more prominent. Recently it is found that building sectors take about 20% of China's total energy consumption in buildings' operational stage and account for as high as 43% of total energy consumption if measured from life cycle perspective [1]. Within building sectors, residential buildings take about 10.3% of national CO_2 emission of China in 2012 [2]. China government has promised to reduce 40–45% carbon emission by 2020 and 60–65% by 2030, by comparing with the baseline emission in 2005. Therefore, improving energy efficiency and reducing carbon emission from building sectors become more essential for the whole country and even the world [3].

Alias with the need of energy saving, green building becomes one essential strategy towards sustainable society. In China, the first version of green building standard was published in 2006, Evaluation Standard for Green Building (GB/T 50378-2006), ESGB for short, by Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) [4]. In 2014, the second version ESGB was published, which increased the ranges of buildings and further refined the evaluation process into design evaluation and operation evaluation. In ESGB of China, there are three rating levels labeled with star (⋆), one star, two star and three star, and more stars mean better building performance and more energy efficient. In the meanwhile, incentive schemes from financial per-

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spective was developed by government to promote green buildings to reach at least 30% of the total new buildings by 2020 [5].

Actually, in the past only the operational stage was considered in certification of one building in China. Since in building sectors, various types of resources, lots of stages and large ranges of energy consumptions & carbon emissions, Life Cycle Assessment (LCA) becomes a more acceptable and accurate way to evaluate the energy consumptions and carbon emissions of buildings. Therefore, to evaluate the performance of Green Buildings from LCA perspective compared with Non-Green Buildings becomes meaningful and can provide reasonable and comprehensive foundation and advices.

This paper studied amount of real projects to compare the differences between Green and Non-Green Buildings in China from LCA approach. Sensitivity analysis of various impact factors was carried out to understand the most important factor on emissions of buildings. In this study, existing database and real projects were integrated together to serve as solid base of CO_2 emissions calculations and an evaluation software ECOSEED was further developed based on this.

1.2. Literature review

In 1997, a method on how to calculate the energy use during the life cycle of a building was proposed [6]. A review of the life cycle energy analyses of buildings resulting from 73 cases across 13 countries was done in 2010 [7] and it was found that operating (80–90%) and embodied (10–20%) phases of energy use were significant contributors to building's life cycle energy demands. The mathematical models of embodied energy and greenhouse gases in construction processes were reviewed [8]. The key findings and limitations of the reviewed models were explored and a framework towards the development of a holistic mathematical model was presented. In 2015, review in residential building sectors of energy, CO_2 emissions and policy was published among top ten countries including China, the US, India, Russia, Japan, Germany, South Korea, Canada, Iran, and the UK, account for two-thirds of global CO_2 emissions [9]. A review on LCA method was carried out in 2015 and it was found that the methods were based on ISO 14040 series with variance to suit different scopes, aims and limitations [10].

As for the calculation method, the basic Japanese input/output table developed in 2005 was analyzed to create building industry-related intensities and, at the same time, compared the building industry with industries at large for distribution margins and transportation [11].

Participants from nearly 20 countries world-wide worked together on IEA Annex 57 “Evaluation of Embodied Energy and Carbon Dioxide Emissions for Building Construction” and several cases studies of Annex 57 method was introduced [12–14].

introduces the IEA Annex 57 case study method, consisting of a format for describing individual case studies and an evaluation matrix covering all case studies.

Many case studies over the world were investigated, e.g. Indonesia [15], Sweden [16], Spanish [17], Italy [18,19], Malaysia [20], Japan [21], Australia [22], China [23,24], the USA [25], etc. Besides, comparisons between buildings in different countries were also studied. LCA comparison between two buildings in two countries was studied, Spain and Colombia, and they found the use phase of the building in Colombia had a lower percentage for all impacts in the total than the one in Spain [26]. Similarly, comparison between buildings in China and Japan was examined as well [27].

The environmental effects of two different building structures, steel and concrete, were compared in 2008 and it was found that the steel-framed building was superior to the concrete-framed building on the following two indexes, the life-cycle energy consumption and environmental emissions of building materials [28]. In 2009 another study was carried out to find the effect of different exterior wall systems on environmental impacts in a single-story residential building by simulation [29]. The results showed that the insulated concrete buildings produce the greatest impact while traditional wood frames had the fewest in the pre-use phase. However, in the use phase, the insulated concrete buildings had the lowest impacts. In 2014, another study was carried out to examine where the embodied CO_2 of buildings is mainly located, by virtually cut a building into four typical stores according to their specific, typical characteristics [30].

A model for estimating the intensities of the embodied and demolition energy for buildings has been developed in Hong Kong and tested in two residential buildings [31]. Steel and aluminum was found to be the top two contributor of the total embodied energy use in a residential building envelope in Hong Kong. A region-type life cycle impact assessment (R-LCIA) was also studied to understand not only the total environment burden on a global scale but also the environment burden in a region scale [32].

Except one whole building, people enlarge the scale to include the surrounding environment, for example, a campus [33] and reduce the scale to one single building system, e.g. solar panel [34], heating and cooling ventilation system [35], vehicle emissions in China [36] and low carbon building materials, e.g. timber [37].

One method for applying LCA to early decision-making stage was developed and tested in a residential building [38]. It was shown that method can assist in the building design process by highlighting those early stage decisions that frequently achieve the most significant reductions in embodied carbon footprint. LCA was integrated together with health performance qualification model for pre-occupancy phases [39]. This model was tested in nine residential buildings with different structural types and proved that new model can effectively pre-evaluate the environmental and health performance.

2. Methodology

2.1. Overview

This paper mainly focused on the comparison between Green and Non-Green buildings via LCA approach through real projects. Twenty-six real buildings (nine residential and seventeen commercial buildings) are selected for calculation of life cycle energy and carbon emissions and compared with statistical data. All of these buildings are located in two main climate zones of China where more populations live. The whole flow chart is shown in Fig. 1.

Firstly, the boundary need to be defined properly where the surrounding environments are not considered. Then followed by Step 2 Raw Data Collection, energy consumptions and basic information of all twenty-six buildings and fourteen statistical cases need to be collected. Then the data collected are checked to be accurate and no missing data before entering to Step 4. If not, it will go back to Step 2 again. In Step 4 Data Calculation, CO_2 emissions from all five phases are calculated and summed up to be the overall LCCO2 of one building. The emissions of Phase 1 &2 use one database named as Building Environmental Load Evaluation System (BELES for short). BELES is developed by Department of Building Science of Tsinghua University and has been used in some research studies [40]. BELES compromises many general resources (e.g. iron ore, forest resource, clay, range resource, limestone, copper ore, natural gas, glass silicon, sand etc.), variety of processes (highway, railway, pipeline transportation of energies, general construction garbage landfill, PVC incineration, glass curtain wall cleaning etc.) and more than 100 different construction equipment to produce more than the six greenhouse (GHG) gases, including CH_4, HC, H_2S, CO_2, SO_2, NOx, smoke dust, chloroform, PM_{10}, N_20, $PM_{2.5}$ and so on.