Energy and Buildings 119 (2016) 323–330

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A detailed analysis of the embodied energy and carbon emissions of steel-construction residential buildings in China

Xing Su*, Xu Zhang

HVAC & Gas Research Institute, School of Mechanical Engineering, Tongji University, Shanghai, 200092, China

ARTICLE INFO

Article history:
Received 11 December 2015
Received in revised form 18 February 2016
Accepted 25 March 2016
Available online 26 March 2016

Keywords:
Life cycle assessment
Steel-construction
Residential building
Embodied energy
Embodied carbon emissions

ABSTRACT

Some previous studies on the embodied energy of the residential buildings in China show that the percentage of embodied energy in the building total energy use varies from 20% to 50%. It is believed that the accuracy of data acquisition, the differences in the definition of the embodied energy boundaries and the lack of building life cycle inventory (LCI) standards contribute to the large variation in findings. Often researchers should acquire data through typical process technology (national average level), engineering estimation and the professional judgments. There is a need to further study on embodied energy and carbon emissions of building, in this study, an embodied energy consumption and carbon emissions of the residential buildings model was created to study three steel-construction residential buildings in China. This model includes the materials production phase, transportation phase, construction phase, recycle and demolition phase as well as upstream of energy. The direct materials and energy consumption of these three residential buildings with different volumes are investigated on site. The results show that the embodied energy consumption of steel members, concrete and cement account for more than 60% of the total energy consumption of all building components, the proportion of energy consumption of steel members increases with the increasing of the floors, while the proportion of energy consumption of concrete and cement decreases, the embodied energy and environment issues of the building components of the steel-construction buildings is sensitive to building height rather than building volumes.

1. Introduction

Building sector consumes about 40% of primary energy utilization and 33% of the global greenhouse gases emission [1], a lot of studies have been done to investigate the energy consumption and the carbon emissions of buildings using the life cycle assessment (LCA) method which is accepted internationally as a tool to improve processes and services environmentally. The implementation of LCA can help designer, engineer and decision maker by providing analytical evaluation environmentally.

Life cycle energy consumption is made up of embodied energy and operational energy, the embodied energy of building sector is the energy that is consumed during the building acquisition, while the building sector operational energy is the energy used to fulfill building functions and provide a comfortable indoor environment. Embodied energy is the energy required to provide a product through all processes upstream in both direct and indirect ways [2]. For building, embodied energy usually refers to the energy that is used during construction, including the energy used for raw materials exploitation, building materials production, transportation, onsite construction and installation, maintenance and demolition.

It was recently generally considered that the embodied energy content of a building is smaller than operational energy in the building life cycle, Keoleian et al. [3] have evaluated a single family house by input–output LCA in Michigan, the results clearly highlighted the dominance of the building use phase, which accounted for over 90% of energy use, many other studies [4–6] also concentrated on energy saving and emission reduction during use phase of buildings, such as installing higher insulation on external walls and roof, employing high thermal performance windows, and many HVAC technologies, similar conclusions are found that the ratio of building use phase is high. On the other hand, other studies have reported that the ratios of construction to operation is larger than 50% [7,8]. To the best knowledge of the authors, this large discrepancy can be attributed by at least two sources. First, the gap can be caused by the uncertainties in LCA analysis, including differences in system boundaries, assumptions, chosen lifetime and so on. Second, the energy use and emission in use phase indicates a considerable disagreement among literatures because of their specific properties

* Corresponding author.
E-mail addresses: suxing@tongji.edu.cn, cc8801314@163.com (X. Su).

http://dx.doi.org/10.1016/j.enbuild.2016.03.070
0378-7788/

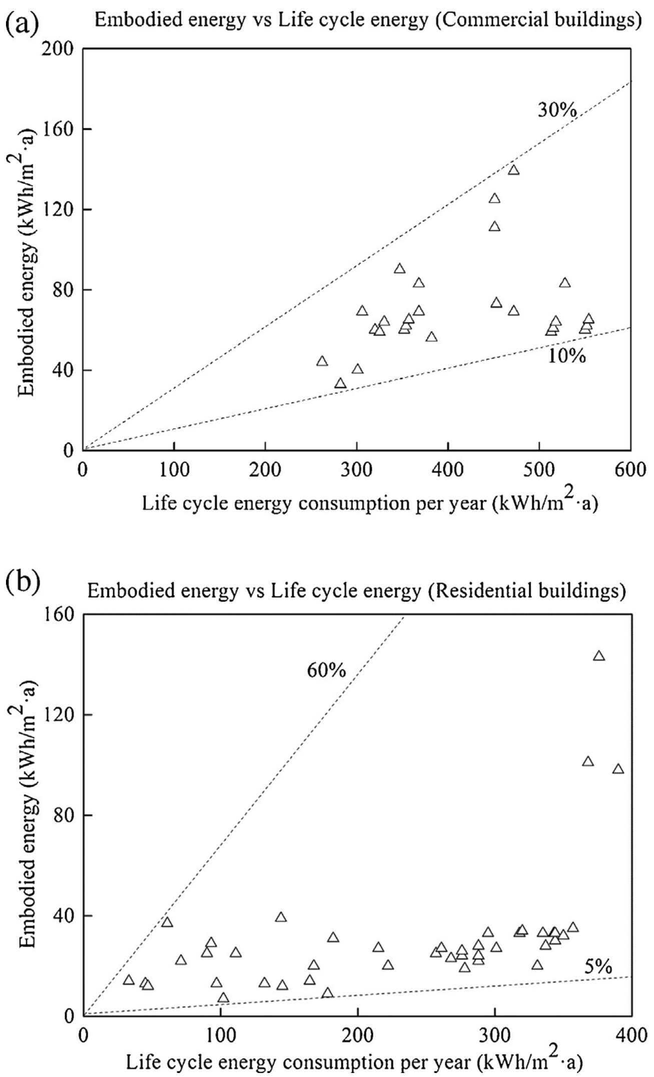

Fig. 1. Relation between embodied and total energy.
(a) Commercial buildings
(b) Residential buildings
Data Source: Refs. [9,13–27]

like building types, climatic conditions, occupants behavior habit, thermal comfort requirements, economic condition, etc.

However, according to Ramesh's investigation [9], the embodied energy can represent from 10 and up to 30% of the total life cycle energy consumption in commercial buildings, and that of 5–60% in residential buildings (see Fig. 1). Fig. 1 indicates that embodied energy of buildings cannot be neglected, especially for the fact that the operational energy is being continuously reduced via multi-pronged efforts related to technology and policy aspects, such as improvement of heating, ventilation, and air-conditioning performance, utilization of new and renewable energy, adoption of the zero-energy building design, and the introduction of green building certification policies, the potential for curbing operating energy has increased and as a result, the current emphasis has shifted to include embodied energy in building materials [10–12].

Guggemos and Horvath [28] have highlighted the importance of assessing environmental impacts at the construction stage at an aggregate level. Embodied energy and carbon emissions of buildings vary enormously between products and materials, which need a comprehensive research, however, assessing the embodied energy of whole building is rather a complex task. For it is difficult to collect the onsite data of upstream process of products, many studies mentioned above used input-output LCA method to evaluate the embodied energy and emissions of building components, this made it difficult to gain a detailed understanding of production. To overcome this shortcomings, I-O based hybrid analysis method was developed by Treloar [29] and has been used in several life-cycle studies [30], which require extracting energy pathways from I-O data, and then replaces the energy path generated by the I-O model with reliable and accurate process data. The I-O based hybrid model has been considered as a nearly perfect tool for life cycle assessment. However, such model needs sufficient process data [31]. And for most of the countries like China, the classification of sectors is too coarse to target a specific product, and the sector definitions used by sectoral energy and environmental pollution statistics usually fails to exactly match that in the economic I–O Table [32]. Chen and his co-workers have contributed a lot in establishing embodied energy and embodied carbon emission intensity databases on the basis of a multi-scale input–output model in China [33–38], on the basis of these database, the carbon emissions of products and complicated systems can be calculated. In terms of buildings, they have presented a low-carbon building evaluation framework with detailed carbon emission account procedures supported by integrated carbon intensity databases based on multi-scale input–output analysis [39], Shao et al. [40] performed a method of systems accounting to calculate the CO_2 emission of six commercial buildings in E-town, Beijing. Han et al. [11] presented an embodied energy consumption evaluation framework and applied it in some six commercial buildings. These studies have contributed significantly to the development of the assessment for buildings, however, several limitations are also observed for this I-O based hybrid studies: firstly, embodied energy and carbon emission intensity database were based on the Chinese economy before 2007, which may be out of date while energy efficiency in production, transmission and distribution have all improved rapidly in the past decades, especially in developing countries; secondly, most studies focus on commercial buildings or traditional construction buildings, studies on embodied energy and carbon emissions for steel-construction residential buildings are rarely found; thirdly, the upstream data in production stage for some products may vary significantly from different industries, for instance, the CO_2-equivalent emission values for steel bar varies from 1.03 to 3.51 kg CO_2-eq/kg as Chau et al.'s investigation [41].

A process based LCA, which is a bottom-up approach to evaluate environmental emissions considering the activities in the process, can be an alternative approach to evaluate LCA analysis. In case of a specific case study analysis, process based analysis is suited to analyzing large atypical products such as an entire building to evaluate environmental impacts [42]. However, the availability and accuracy of data play an important role in the reliability of building life cycle inventory. Many researchers sought and collected data by literature review, questionnaire surveys, engineering estimation and the professional judgments. These data are easily accessible, but they are occasionally subjective, which makes it difficult to provide in-depth and objective results. In this paper, embodied energy and carbon emissions analysis was conducted by focusing on steel-construction building in China, which has been developing rapidly in recent years due to advantages of prefabrication technology using, efficiency, safety and sustainability etc. [43]. Process based LCA method is used in this study to demonstrate and identify the detailed embodied energy and carbon emissions of three steel-construction residential buildings with different building volumes in China, this approach is based on plentiful and detailed survey data at a micro level, direct data were collected along with project progress through long-term onsite follow ups, and indirect data related to upstream of main materials production stage were investigated from industries. The presented method can provide us with clear scientific guidance in low carbon building and eco-building