Sustainable Cities and Society 4 (2012) 22–28

Contents lists available at SciVerse ScienceDirect

Sustainable Cities and Society

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

Life cycle environmental assessment of an educational building in Northern India: A case study

Varun [a], Aashish Sharma [b], Venu Shree [c], Himanshu Nautiyal [d,*]

[a] Department of Mechanical Engineering, National Institute of Technology, Hamirpur (HP) 177 005, India
[b] Department of Engineering, Lovely Professional University, Jalandhar (Punjab) 144 402, India
[c] Department of Architecture, National Institute of Technology, Hamirpur (HP) 177 005, India
[d] Department of Mechanical Engineering, THDC Institute of Hydropower Engineering and Technology, Tehri (Uttarakhand) 249 001, India

ARTICLE INFO

Keywords:
Building
LCA
GHG
Embodied energy

ABSTRACT

This paper quantifies the significant environmental effects of a three storey building in Northern India. The building has a floor area of 3960 m^2 and projected service life of 50 years. In this study, a comprehensive life cycle environmental assessment of the building was conducted to find out the energy consumption and greenhouse gas (GHG) emissions by the building. This study shows that RCC framework and steel in the building are the highest contributor in GHG emissions for all three floors. Also, it has been shown that second floor has the biggest share in contribution to the total impact. In addition to this, 59% of the total energy is consumed only in the operation phase. In most of the buildings, life cycle phases have significant impact in some category, however; only two life cycle phases viz. construction and operation seem to be more significant in all impact categories (energy and emissions).

1. Introduction

As real estate sector is increasing rapidly, the need for quality internal environment and micro-surroundings has become key issue for both, home buyers and estate developers. Buildings have significant effects on environment from its construction to demolition. From past few years, environmental impacts related to buildings i.e. global warming, ozone layer depletion, greenhouse gas (GHG) emissions, waste accumulation, etc. are rapidly increasing. Research from the past years indicates that these changes in global climate are increasing rapidly and will continue with time (Hulme et al., 2002; International Panel on Climate Change, 2011a). As the population of the world is increasing rapidly, construction is taking place at massive rate globally in order to accommodate world's migrating population towards urban sector, a proportion which is expected to reach 60% by the year 2030 (Sayal, Hastak, Mullens, & Sweaney, 2006). In Western Europe, building material production accounts for as much as 8–12% of the total CO_2 emissions (Gielen, 1997). The construction and building sector have been found to be responsible for a large part of environmental impacts on human activities.

Building uses energy throughout its life i.e. from cradle to grave. The building sector accounts for 40% of the primary energy consumption and 36% of the energy related to CO_2 emissions in the industrialized countries (International Panel on Climate Change, 2011b). There is significant influence of building sector over the total natural resource consumption and on the emissions released, along with their associated environmental impacts. If we take a look on resource consumption during its construction, then the building consumes 40% of the stone, sand and gravels, 25% of wood, 40% of energy from fossil fuels; and 16% of water globally every year in the world (Arena & Rosa, 2003). The domestic energy consumption, in terms of per capita net consumption, increased by 56% (Kim, 1998) which is an important issue of concern.

During use (operation) phase of the building, a lot of electrical energy is consumed by lighting and electrical appliances. According to California Energy Commission, California alone uses over 8800 GWh of electricity in operating air-conditioning systems (CEC, 1998). Over 40% of the total energy used in a building is consumed by heating, ventilation and air-conditioning (HVAC) systems (Little, 1999).

The above data indicates that a large amount of energy is consumed by buildings for heating and cooling purposes. Therefore, there is a great need to minimize the energy consumption by buildings so that the environmental impacts can be reduced. But before going into the reduction of building energy consumption, the primary thing is to obtain the quantitative values of environmental impacts associated with building's entire life cycle i.e. GHG emissions, energy consumption, etc. In this study, life cycle assessment (LCA) technique is used to carry out the environmental analysis of

* Corresponding author.
E-mail address: h2nautiyal@gmail.com (H. Nautiyal).

2210-6707/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.scs.2012.03.002

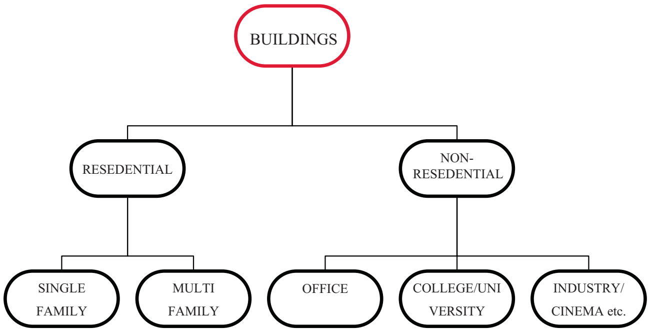

Fig. 1. Classification of buildings.

a commercial building. LCA is one of the well known tools for analyzing the environmental impacts by a product through its entire life i.e. from procurement of raw material to disposing of it. LCA is applicable for all the stages of building and finding out the important alterations to maximize the performance of building (Horne, Grant, & Verghese, 2009).

Buildings can be categorized according to their usage i.e. residential and non-residential buildings. Residential buildings can further be divided into single-family house and multi-family house, and non-residential buildings are those which are used for commercial purposes i.e. school, university, office, industry, etc. The classification of the buildings is shown in Fig. 1.

For the present study, Mechanical Engineering Department (MED) building of National Institute of Technology (NIT) Hamirpur (Himachal Pradesh, India) has been selected to study primary energy consumption and GHG emissions produced by the building. The building has three floors and the study of all the three floors has been conducted separately. After this, results of all the three floors have been compared. LCA technique is used to study the energy consumption and GHG emissions by the building. The aim of this work is to study the energy uses and GHG emissions of a commercial building in northern region of India.

2. Life cycle assessment

Management of environmental issues related to the buildings requires knowledge and tools that enable the control of environmental aspects (Roberts & Robinson, 1998). LCA is one of the well known tools used for the quantitative assessment of a material used, energy flows and environmental impacts of products. It follows a systematic approach to assess the impact of each material, process and product. LCA is the most appropriate framework for the identification, quantification, and evaluation of the inputs, outputs, and the potential environmental impacts throughout its life cycle (cradle to grave). LCA methodological framework comprises of four stages, i.e. goal and scope definition; life cycle inventory analysis; life cycle impact assessment; and life cycle interpretation. With the help of this tool it is possible to assess and compare the environmental impacts of different buildings.

Four stages of LCA methodological framework included in this study are shown in Fig. 2. The goal and scope definition is the one which establishes the functional unit, system boundaries, and quality criteria for inventory data. The life cycle inventory analysis (LCIA) deals with the collection and synthesis of information on physical material and energy flows in various stages of the products life cycle.

In the life cycle impact assessment, these environmental impacts of various flows of material and energy are assigned to different environmental impact categories. For this the characterization factor is used to calculate the contribution of each of the constituents for various environmental indicators (i.e. GHG emissions, ozone layer depletion, etc.). Finally the life cycle interpretation deals with the interpretation of results from both the life cycle inventory analysis and life cycle impact assessment. It includes the identification of significant issues and the evaluation of results.

Basically there are three types of LCA methodologies i.e. process based LCA, input–output LCA and hybrid LCA (Bullard & Herendeen, 1975; Facanha & Horvath, 2006; Guinea, 2002; Heijungs & Suh, 2002; Kofoworola & Gheewala, 2008; Suh & Huppes, 2005). In this study process based LCA has been carried out. In a process based LCA, the user outlines all processes associated with all life-cycle phases of a product, and associates inputs and outputs with each process, by which total environmental load energy can be determined.

2.1. Electricity scenario of India

India is presently the sixth-largest electricity generating country and accounts for about 4% of the world's total annual electricity generation. India is also currently ranked sixth in annual electricity consumption, accounting for about 3.5% of the world's total annual electricity consumption. Overall, India's need for power is growing at a prodigious rate; annual electricity generation and consumption in India have increased by about 64% in the past decade, and its projected rate of increase (estimated at as much as 8–10% annually, through the year 2020) for electricity consumption is one of the highest in the world. A summary of current electricity generation scenario in India is shown in Table 1 (Ministry of Power, 2010; Varun, Bhat, & Prakash, 2009).

3. Methodology

In this study, LCA is used to study the energy consumption and GHG emissions of MED building at NIT Hamirpur situated in state of Himachal Pradesh, India. The life cycle of the building is divided into three main phases: construction, operation (use) and maintenance. Annual operating energy of the building is assumed to be same throughout its life span. Due to changes in climate conditions, operating energy of the building may change in future, but this is not taken into consideration in the analysis. As the demolition requires very less energy (1%) as compared to the life cycle energy of the building hence it is not considered in the present study (Ramesh, Prakash, & Shukla, 2012). The operation phase of the building is assumed to be 50 years. The estimated environmental impact during this phase is based on the assumption that no extensions and re-construction are made during the 50 year life cycle. The impact of this phase has been evaluated by means of its energy use. The building materials have significant impact on operation energy of the building (Lee, Trcka, & Hensen, 2011). Energy requirement for space heating, cooling, lighting, ventilation, computer work and for operating heavy/small machinery was calculated. In maintenance phase, only sequential maintenance, i.e. re-painting has been taken into account. Hence, 2% of total energy use in construction phase is considered as per the standard practice.

Fig. 3 shows methodology used in the present study. The first step of this study was to calculate the inventory data of the material. The inventory data of the building was collected and calculated in order to perform LCA. The detail of the construction material used in the building was collected from the plan shown in Fig. 4 and by visual inspection of the building. Products which are major contributor in the emissions from building were considered. Then, their corresponding embodied energies for all the three floors were calculated independently. Embodied energy is referred to the energy consumed in extraction, manufacturing, assembly and transportation of a particular product. The embodied energy coefficients of the