Science of the Total Environment 408 (2010) 2435–2443

Contents lists available at ScienceDirect

Science of the Total Environment

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

Life cycle assessment of two dwellings: One in Spain, a developed country, and one in Colombia, a country under development

Oscar Ortiz-Rodríguez [a,b,*], Francesc Castells [a], Guido Sonnemann [c]

[a] University of Rovira i Virgili, Environmental and Analysis Management Group (AGA), Department of Chemical Engineering, Av. Països Catalanes 26, 43007, Tarragona, Spain
[b] University of Pamplona, Faculty of Engineering and Architecture, Department of Industrial Engineering, Km 1 Vía Bucaramanga, Pamplona, N de S, Colombia
[c] University of Rovira i Virgili, Environmental and Analysis Management Group (AGA), Spain

ARTICLE INFO

Article history:
Received 23 November 2009
Received in revised form 5 February 2010
Accepted 10 February 2010
Available online 7 March 2010

Keywords:
Colombia
Electricity supply
Environmental impacts
LCA
Single buildings

ABSTRACT

The main objective of this paper is to study and quantify the differences in energy consumption and environmental impacts of two dwellings during the full building life cycle: one in Spain, a developed country, and one in Colombia, a country under development. In both scenarios, we assessed the construction, use and end-of-life phases.

Results show that the use phase in the Pamplona house (Colombia) represents a lower percentage for all impacts in the total than in the Barcelona house (Spain). The findings of this study showed that the difference in consumption in Colombia and Spanish dwellings analysed is not only due to the variation in results for bio-climatic differences but also because of the consumption habits in each country. The importance of consumption habits of citizens and the need to decouple socio-economic development from energy consumption are sought for achieving sustainability from a life cycle perspective. There is a crucial necessity to provide satisfaction to basic needs and comfort requirements of population with reasonable and sustainable energy consumption. Then, the type of standard dwelling varies substantially depending on the geographic location where it is built. Climate, technological, cultural, socio-economical differences clearly define the standard of a building in any context and in any region. However, the function is always the same, to provide protection and housing for its habitants.

1. Introduction

The construction and building industry is a highly sector in both developed and developing countries, which is particularly relevant in these days of economic renewal activities by the governments. It has also been identified as one of the most relevant sectors for its environmental performance, in particular due to its energy intensity with corresponding Greenhouse Gas (GhG) emissions and its land use (UNEP, Industry and Environment, 2006).

During the last decades, there have been plenty methodologies to promote sustainable building (Boonstra and Pettersen, 2003; Cole, 2005; CRISP, 2004; Ding, 2008; Haapio, 2008; Peuportier and Putzeys, 2005). Currently, Life Cycle Assessment (LCA) is a well known environmental methodology to evaluate environmental impacts throughout a system (Fava, 2004).

LCA has been used to evaluate environmental sustainability in the construction sector throughout all stages of the building life cycle, from origin (raw materials) to end of life (waste disposal) (Fava, 2006). Sartori and Hestnes stated that increased interest in better methodologies such as LCA has provided a better understanding and better estimates of the energy (and other environmental) aspects in the life cycle of any kind of a building (Sartori and Hestnes, 2007). LCA has become a crucial approach for the environmental assessment of industrial activities in developed countries, while financial support and technical assistance are still needed to apply LCA throughout industrial activities in developing countries (Udo de Haes, 2004) and (Ometto, et al., 2006).

A review of the existing literature shows that there have been various studies on complete LCAs within the residential building industry (Ortiz et al., 2009a). One of the first LCAs was performed on the full dwelling life cycle for a home in the USA, which analysed the total life cycle energy consumption and the global warming potential (GWP) of a standard home of 228 m² located in Michigan. The life cycle's GWP was 1.01E+06 kg CO_2 (Blanchard and Reppe 1998). Another study was carried out to evaluate the life cycle of four dwellings with different construction characteristics in Sweden. The results showed that the electricity mix had the highest environmental impact and also this study concluded that the greatest environmental impact occurs during the use phase (Adalberth et al., 2001).

Peuportier (2001) compared three types of house each with a different specification and each located in France. Results were

* Corresponding author. University of Pamplona, Faculty of Engineering and Architecture, Department of Industrial Engineering, Km 1 Vía Bucaramanga, Pamplona, N de S, Colombia. Tel.: +57 3132613340; fax: +34 977559621.
E-mail addresses: oscarortiz@unipamplona.edu.co (O. Ortiz-Rodríguez), francesc.castells@urv.cat (F. Castells), Guido.Sonnemann@unep.fr (G. Sonnemann).

0048-9697/$ – see front matter
doi:10.1016/j.scitotenv.2010.02.021

presented according to the environmental impact per 1 m² of inhabitable area. The house that had the greatest environmental impact was the one with the greatest surface area and was constructed with common materials such as stone and wood (Peuportier, 2001). Koroneos and Kottas evaluated in Koroneos and Kottas, 2007 the annual energy consumption of an existing house in Greece, showing the environmental impact of the energy it used (Koroneos and Kottas, 2007).

Ortiz et al., 2009a carried out a LCA study for a Spanish Mediterranean house located in Barcelona with a total area of 160 m² and a projected 50 year life span. This research concluded that even if the contribution of the building materials themselves is low compared with values of the whole life cycle, choosing them carefully, together with an appropriate design of the building structure and orientation, can lead to important energy savings in the operation phase (Ortiz et al., 2009b).

While the previously referenced studies describe various environmental considerations and energy use for dwellings in Europe and USA, there is a lack of studies from Latin American countries. There is simply little experience in applying LCA in these countries and considering that there is a need to continue promoting life cycle assessment, the main objective of this paper is to study and quantify the differences in energy consumption and environmental impacts of two dwellings during the full building life cycle: one in Spain, a developed country, and one in Colombia, a country under development. Finally, in order to avoid the shifting of environmental burdens from one life cycle stage and impact category like global warming to another like toxicity, this is the first case study for a dwelling in Colombia, where no peer reviewed published data for the life cycle of any building exist.

2. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) was standardised by the International Standardisation Organisation (ISO) in the 14040 series (ISO. International Standardization Organization, 2006). The four steps of this methodology are defined as: goal and scope definition, inventory analysis, impact assessment and interpretation.

2.1. Goal and scope definition

In this research, the functional equivalent is defined as: square meter of living area and each dwelling is assumed to have a 50 year life span and four inhabitants. The main goal of this study is to evaluate the environmental impact of residential dwellings.

2.1.1. System boundaries

We assess environmental impacts of electricity supply in both countries based on 1 kWh. This includes the domestic electricity produced by the technologies at the busbar, taking into account the generation, transmission and distribution to the final user.

In order to evaluate the full environmental impact over the whole building life cycle, we evaluate environmental impacts of each building phase: construction, use and end-of-life.

The construction phase includes the production of building materials, the transportation of materials to the building site, the energy consumed during the construction phase and management of the waste generated at the building site for each of the different construction materials.

The use phase includes the operation and maintenance activities. The operation phase covers the full service life for HVAC (Heating, Ventilation and Air Conditioning), as well as other household activities such as illumination, domestic hot water (DHW), electrical equipment and cooking. It is estimated that the maintenance activities needed to keep the dwellings in good condition are painting, re-roofing, PVC siding, changing windows, and replacing kitchen and bathroom cabinet.

The end-of-life phase evaluates the energy consumed by the machinery used during the demolition; also considers the amount of waste generated during dismantling of the original construction materials, including their transport to the final destination to landfilling.

The following assumptions have been considered:

- For both scenarios the mode of transporting building materials is 100% truck. In Colombia the distance from manufacture to the building site is assumed to be 30 km whereas for the Mediterranean home it is assumed to be 80 km.
- Other maintenance activities such as replacing household electrical appliances and changing light bulbs will not be considered in the present study, and neither will other environmental impacts such as those resulting from cleaning the houses and wastewater.
- All the wastes are disposed to landfill. Landfilling includes the dump infrastructure, the use of land and the effect of the landfilled waste (leachate). Construction wastes that are to be landfilled are special wastes disposed of in underground deposits or controlled landfills, inert wastes are disposed of in inert material landfills and non-special wastes are disposed of in landfills or sanitary landfills.
- It is assumed that the electricity supply will remain constant during the building life cycle. The losses, exports and imports in the energy balances have not been counted.

2.2. Inventory analysis

Electricity can come from various sources such as hydropower, nuclear power, coal, combined cycle, oil, wind etc, meaning that first we must find out what makes up the electricity supply is in each country. Therefore, the environmental loads assigned to electricity supply have been adapted respectively to the Spanish and Colombian electricity mix for 2006 taking into account the data originated from International Energy Agency (IEA) (IEA, 2009) (see Table 1).

For the inventory analysis of the dwellings, we analyzed one type of urban dwelling in Colombia and a Spanish Mediterranean home.

The Colombian dwelling is part of an existing semidetached house divided into two storeys, with approximately 140 m² of usable-floor area distributed over three bedrooms, a living and dining room, a kitchen and two bathrooms. The main construction materials are brick, concrete and steel, and the upper ceiling is covered in roof tiles.

It is important to stress that due to its geographic location, Colombia does not have conventional seasons such as autumn, winter, summer or spring, but rather has two main periods: one of heavy rains (called the humid season) and another consisting of isolated rainfall or drought (called the hot season). Pamplona city has a latitude and

Table 1
Input required for the electricity mix in Spain and Colombia.

Production from	Spain electricity (GWh)	Colombia electricity (GWh)
Coal	68,266	4084
Oil	23,829	118
Gas	90,284	6710
Biomass	2235	584
Waste	814	0
Nuclear	60,126	0
Hydro[a]	29,503	42,742
Solar PV	125	0
Wind	23,040	63
Other sources	4829	0
Total Production	303,051	54,301
Imports	8832	21
Exports	−12,106	−1813
Domestic supply	299,777	52,509

Observation:
[a] Includes production from pumped storage plants.