

552. Towards sustainable construction in a developed and a developing country based on Life Cycle Assessment

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Abstract

In order to analyze environmental and energy considerations within the residential building sector, it has been carried out LCAs on two types of house in Colombia (Dwelling 1 and 2) and a typical Spanish Mediterranean house (Dwelling 3). The findings of this research showed that approx. 85 - 95% of the environmental impact during the Mediterranean dwelling's life cycle took place during the operation phase (use and maintenance). In Spain, Dwelling 3 had the highest impact on climate change during the use with approximately 2.08E+03 kgCO₂-Eq/m². On the other hand, for both Colombian dwellings, the total kg of CO₂-Eq/m² for Dwelling 1 was 4.99E+02 while for Dwelling 2 it was 4.29E+02.

In summary, the use phase has more influence in Spain because of the high-energy requirement for heating, ventilating and air conditioning (HVAC) needs. In Colombia the energy requirements for HVAC are much lower because of the bioclimatic conditions, thus, impacts through energy consumption during the operation phase of buildings depend mainly on behaviour patterns of citizens and are directly linked to construction materials.

Keywords: developing countries, LCA, sustainable construction.

1. Introduction

The construction industry, a worldwide emerging sector, is gaining attention through the improvement of environmental assessment due to the significant negative effects on the environment. Therefore, sustainable construction has emerged as one of the key issues during the last decade. Sustainable construction can be defined as a subgroup of sustainable development, of which covers principles such as: understand what sustainable development means for you, your clients and your customers; use whole-life thinking, best value considerations and high quality information to inform your decision-making; design to minimize operational environmental impacts; engage organizations within your supply chain about sustainable development and select responsible contractors who have embraced sustainable development principles [1].

By applying Life Cycle Assessment (LCA) it is possible to evaluate environmental loads emitted into the atmosphere both globally and locally, thereby achieving sustainable development [2]. There have been some LCA studies explicitly dedicated to evaluate environmental impacts to the full building life cycle [3]. While the previously referenced studies describe various environmental considerations and energy use for dwellings in Europe and USA, there are no

comparable studies from developing countries, especially Latin America.

Therefore, this paper covers the assessment of environmental impacts and also brings together the operational energy for activities during the operation phase such as heating, ventilating, air conditioning (HVAC), domestic hot water, electrical appliances, cooking and illumination for residential dwellings located in Spain and Colombia. Additionally, the present paper concerns environmental sustainability indicators and broader results in both developed and developing countries in order to support the decision-making within the construction industry. Finally, the promotion of the principles of sustainable construction in developing countries is important, and the following questions should be considered:

1. How developed and developing countries can lead towards sustainable construction, thereby contribute to sustainable development integrating: social, economic and environment aspects?
2. Which environmental management tools should be applied to achieve better practice in sustainable construction?

2. LCA: methodology

Life cycle assessment (LCA) is an environmental management tool that evaluates the environmental impacts of a product or service, starting from extraction of raw materials, manufacturing, production, use and finishing with the final disposal, that is, from cradle to grave [4]. LCA within the construction industry has been used since 1990 and also has been an important tool for evaluating buildings [5]. Besides, LCA has become a widely used methodology because of its integrated way of treating issues such as framework, impact assessment and data quality in accordance with the International standards of series ISO 14040 [6].

2.1 Definitions and systems boundaries

Colombia is located between the Caribbean Sea and Pacific Ocean in latitudes 15° north and 5° south. It is important to stress that due to geographic location, Colombia has no conventional seasons as autumn, winter, summer or spring, but instead have two main periods: one of heavy rains (called humid) and other isolated rainfall or drought (called hot). The Colombian dwelling is located in the Province of Pamplona. Pamplona city has latitude and longitude of 07°23'N and 72°39'W and elevation of 2342m, the annual average temperatures rise between 17 – 20°C. The average of sunshine per year in Pamplona is 1300 – 1700 h, and the total average radiation value is between 4.0 – 4.5 kWh/m²/day. Therefore, the normal behaviour is the use of domestic hot water equipments (DHW) without heating and air conditioning loads.

On the other hand, it has been chosen a typical Spanish Mediterranean home in Barcelona. Barcelona is located on the Mediterranean coast at 41°23'N, 2°11'E, and elevation of 12m, with mean annual global horizontal (H) radiation between 13.7 ≤ H ≤ 15.1 MJ/m².

The following sections describe the definitions and system boundaries for each phase as it is illustrated in the figure 1.

<Figure 1>

2.1.1 Pre-construction phase

The processes involved during the pre-construction phase mainly involve the production of materials, which implies the use of natural resources, energy and water consumption, solid waste generation, global greenhouse gas emissions, external and internal pollution, environmental damage and resource depletion. The pre-construction phase plays an important role in achieving sustainable development by minimizing environmental burdens before a dwelling has been built. For example, a variation during the pre-construction phase would affect the environmental impact of the final product. This phase includes analyzing the building materials involved in the system such as concrete, mortar, brick, timber, PVC, ceramic tiles etc., and can be categorized into their main categories: concrete, masonry, metals, covering (flooring, roofing and insulation), pipes and wood.

In the present research, it has been done an LCA case study in which we compare two types of urban dwelling in Colombia (Dwellings 1 and 2), with a typical Spanish Mediterranean home (Dwelling 3).

Dwelling 1 and 2 are located in the Province of Pamplona, Colombia. Dwelling 1 is a typical standard home that corresponds to an existing semidetached housing divided up into two storeys, with approximately 140m² of usable-floor area with three bedrooms, living and dining room, kitchen and two baths. The main construction materials are brick, concrete and steel, and the upper ceiling is covered with a material made of asbestos. Dwelling 2 is also a type of existing single family detached home in Colombia located in the same area as Dwelling 1. It has with 140m² of living area and the main construction materials are timber, concrete blocks and ceramic tiles. Dwelling 3 is a Mediterranean house located in the Province of Barcelona which has an area of 160m², is two-storeys high and is mainly made of brick. The house is insulated with gypsum plasterboard, fiber cement roof slate and polystyrene.

2.1.2 Transportation

Together with other activities involved in the preconstruction phase, transportation to the building site it is also a significant step to consider. Therefore, for each dwelling the mode of transportation of building materials is 100% truck and the distances from manufacture to the building site are assumed to be 50kms.

2.1.3 Operation Phase

The operation phase activities consist of the full service life for HVAC: Heating, Ventilation and Air Conditioning, and other services such as lighting, domestic hot water, electrical equipments and cooking. Other environmental impacts such as those resulting from water supply and wastewater treatment will not be considered in the present study.

Dwelling 3 has been modelled in accordance with the Spanish Building Technical Code (CTE) [7]. Therefore, to evaluate the building's energy consumption during the operation phase, the annual energy consumption of the building during the operation phase has been evaluated using the building energy simulation software DesignBuilder and considering typical weather conditions for Barcelona. DesignBuilder is a user interface for the EnergyPlus thermal simulation engine of which lead to annual electricity consumption of 1.22E+04 kWh ≈ 76 kWh/(m² per year).

The dwellings are existing and it can be observed that the energy bills are high. With 4 persons living in each dwelling, it has been assumed an annual electricity consumption of 6.12E+03Wh/year ≈ 43kWh/(m²per year) for Dwelling 1 and 5.26E+03kWh/year ≈ 37 kWh/(m²per year) for Dwelling 2.

2.1.4 Maintenance

During this phase, it is estimated that the maintenance activities needed to keep the dwellings in good conditions are painting, PVC siding, kitchen and bathroom cabinet replacement and reroofing. Other maintenance activities such as replacing household electrical appliances, changing light bulbs and windows will not be considered in the present study.

2.1.5 Dismantling phase

Due to the lack of information on materials recovery, the dismantling phase has not been considered in the present case study. Nevertheless, the dismantling phase often results in landfill disposal or recycling of the majority of materials such as concrete, wood, drywall and metals. However, of the building's whole life cycle, the dismantling step is not usually significant because most of the environmental effects are generated during the operation phase. Kotaji S. et al., stated that energy consumed during pre-construction accounted from 10% - 20%; during the occupation phase, the energy household activities are estimated between 40% and 50% and for the dismantling phase, the energy use is less than 1% through treatment of their final disposition [12].

2.2 Energy considerations for both countries.

The traditional forms of generating the energy habitually consumed in domestic activities are electricity and heat of combustion of fossil energies such as oil, gas and coal. In order to evaluate the environmental impacts that occur during the operation phase, the energy demand management considerations in both countries during 2006 must be known [13] and [14]. Figure 2 illustrates the Sankey diagram which is the graphic representation of the energy flow considering the methodology of international energy balances (IEA Methodology).

Figure 2 shows that the total electricity production in Spain in 2006 rose to 21477 ktoe, while in Colombia it was about 3657 ktoe [8] and [9]. For the present research, it is assumed that the energy supply will remain constant during the building life cycle and the losses, exports and imports in the energy balances have not been counted. Finally, in order to evaluate the environmental impact, data was gathered from the processes inventoried in the Ecoinvent Database V1.3. [10]

<Figure 2>

3. Results

Figure 3 presents the distribution of the life cycle environmental impacts for three impact categories. Results show that the operation phase in Spain has the highest environmental impact, approximately 85-95% of the environmental impact during the dwelling's life cycle. In Spain the pre-construction phase has strong influence in energy consumption and consequently in the operation phase. Hence, the operation phase has more influence in Spain because of the high-energy requirement for HVAC needs [11]. In Colombia the energy

requirements for HVAC are much lower due to the bioclimatic conditions and the impacts resulting from energy consumption in the operation phase of dwellings are mainly dependent on the behaviour pattern of the citizens and are directly linked to construction materials.

<Figure 3>

Comparing both Colombian dwellings, the figure 3 shows that Dwelling 1 had the highest impact on climate change with a total of $8.11E+02$ kgCO₂ Eq/m² of which construction represented 30%, transport was 4%, use accounted for 62% and maintenance 5%. The total kg of CO₂-Eq/m² for Dwelling 2 was $5.93E+02$ during the full building life cycle of which was distributed as follows: construction (21%), transport (4%), use (72%) and maintenance (3%). The difference between dwelling 1 and 2 during the construction phase is due to a large proportion of building materials, with concrete and steel accounting for 52.5% and 29.7% of the total weight respectively and the energy consumption during the use phase.

Finally it is observed that dwelling 3 produced a total of $2.31E+03$ kg of CO₂-Eq/m² represented by the construction phase (7%), transport (1%), use (90%) and maintenance (2%).

Regarding the significant environmental challenge of climate change, the major reason why the Colombian technologies emit less CO₂-Eq is because of the current electricity source. For instance, in Spain there was a total emission of $5.43E-01$ kg CO₂-Eq during the electricity production where 83% accounts for generation and 17% for transportation. Therefore, there are significant emissions due to combustion processes and employing of no-renewable resources of which about 60% came from thermal power plants using coal (anthracite) and 22% from combined cycle.

In terms of the Colombian dwelling's technologies, 47% accounts for thermal plants coal (lignite) and 48% accounts for gas from a total of $2.28E-01$ kg CO₂-Eq. Hence, it can be stated that Colombia currently plays an important role in meeting energy efficiency as part of consumer demands for environmentally friendly products, and also to increase the productivity and competitiveness for all industrial sectors as well as the green construction markets.

Finally, according to the global household energy use, the total production of electricity in Colombia is about six times higher than in Spain explained by the household energy consumption during the operation phase because of the thermal installations (HVAC and domestic hot water) and lighting installations and also because of residential equipment such as electrodomeestic appliances, and cooking and offmatic equipment. Therefore, this paper has also paid particular attention to the environmental impact resulting from the energy requirements during the dwelling use. The environmental impacts for 1year/m² have been assessed in detail. As a result, of all the Spanish environmental impacts resulting from

household energy consumption, almost 33% of the electricity was used for HVAC needs, 21% for domestic hot water, 21% for illumination, 16% for electrical appliances and 9% for cooking, see Table 1.

<Table 1>

For the environmental burdens in Colombia it is important to stress that electrical appliances are the most important household activity with 55-62%, illumination accounted for 21-23%, domestic hot water 5-12% and cooking 10%-12, see Table 2 and 3.

<Table 2>

<Table 3>

4. Conclusion

Dwelling 3 had the highest environmental impact, for example climate change was 2.31E+03 kg CO₂-Eq/(m² per 50 years); while in Colombia, Dwelling 1 accounted for 8.11E+02 and Dwelling 2 was 5.93E+02 kg CO₂-Eq/ (m² per 50 years).

In summary the operation phase is the most critical part because of the higher environmental burden emitted into the atmosphere. Approx. 85 - 95% of the environmental impact during the Mediterranean dwelling's life cycle took place during the operation phase. Dwelling 2 compared with Dwelling 1 uses more wood and less concrete, steel and bricks, therefore its impact on the construction is lower, nevertheless because the fewer HVAC requirements there is no significant effect in its operation phase.

The promotion of the principles of sustainable construction in developing countries is important, and the following questions were considered in this research:

1. How developed and developing countries can lead towards sustainable construction, thereby contribute to sustainable development integrating: social, economic and environment aspects?

For developed and developing countries, a proper construction can be sustainable by using fewer virgin materials, green materials and by applying renewable energies to reduce environmental loads and energy consumption, consequently promoting sustainable development. Therefore, using the correct materials and components without compromising the engineering specifications and quality of the final dwelling can reduce environmental impacts like climate change, acidification potential, etc. Besides, construction techniques using eco-materials, materials with land, green materials like bamboo or other traditional materials like adobe, concrete block and bricks have been used for sustainability within the construction industry. However, this is advisable to analyze the relationship between environmental impacts that occur during the full building life cycle. It is appropriate to verify whether the improvement of one environmental impact does not cause an adverse effect in another environmental impact. Nevertheless, the pressure could be for developed countries to customize the

environmental needs in developing countries and deploy knowledge and transfer technology to minimize environmental impacts and techniques within building sector activities.

On the other hand stakeholders such as governments, suppliers, industry members, architects, engineers, owners, academics, manufacturers, LCA advisors etc must be proactive in creating environmental conditions which accomplish building sector sustainability and promote the use of sustainable construction practices for both developed and developing countries. The government's involvement is needed to promote best practices and economic techniques like recycling, reusing and recovering materials for optimum waste disposal. Finally, cultural consumption behaviors, construction techniques for better insulation building materials and components and the use of renewable energies are options for improving customer satisfaction and consequently the final embodied energy for buildings.

2. Which environmental management tools should be applied to achieve better practice in sustainable construction?

This study concluded that LCA is definitely a tool that facilitates decision making and improves sustainability in construction. For industrial activities within the building sector, organizations must understand the application of LCA not only to meet consumer demands for environmentally friendly products, but also to increase the productivity and competitiveness of the construction green markets. Whenever possible, the present environmental management LCA tool is preferred because its international and broad acceptance can derive earlier in dwelling life cycle, leading to faster combinations and the introduction of selection of building materials and component combinations with low environmental impacts.

Regarding household energy consumption, the most recent methodologies which incorporate information regarding environmental aspects, embodied energy and efficiency are necessary for sustainable development. To achieve this, the European Commission officially released the European energy label which rates products from A, (the most efficient) to G (the least efficient). On the other hand, the most recent methodologies which incorporate information regarding environmental impacts and embodied energy in building materials are the Environmental Product Declarations (EPD). This strategy is also sought to building materials produced in Colombia. Therefore, any well focused methodology can look for the minimization of environmental loads, but there is need to go beyond industrial activities and lead developing countries towards sustainable construction using a combination of science and engineering.

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Figure 1

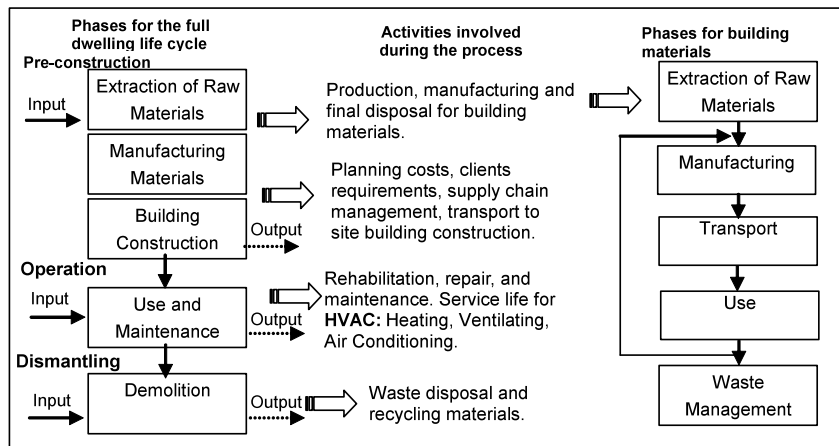
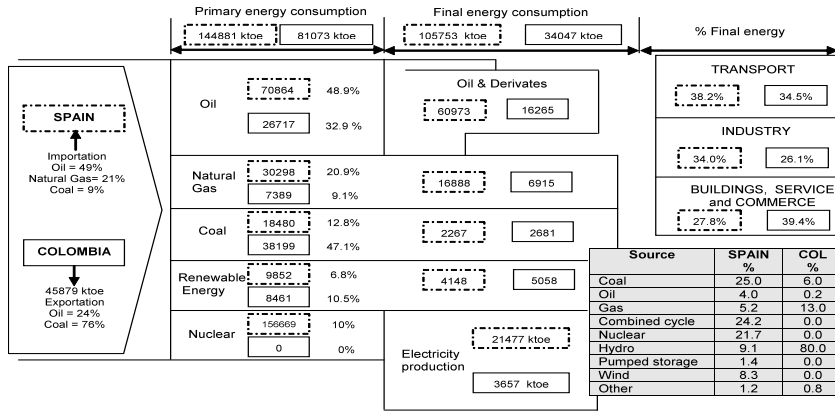


Figure 2 Sankey diagram



Source: [Colombian strategic plan energetic, 2006 - 2025] and [Energy in Spain, 2006]

Figure 3

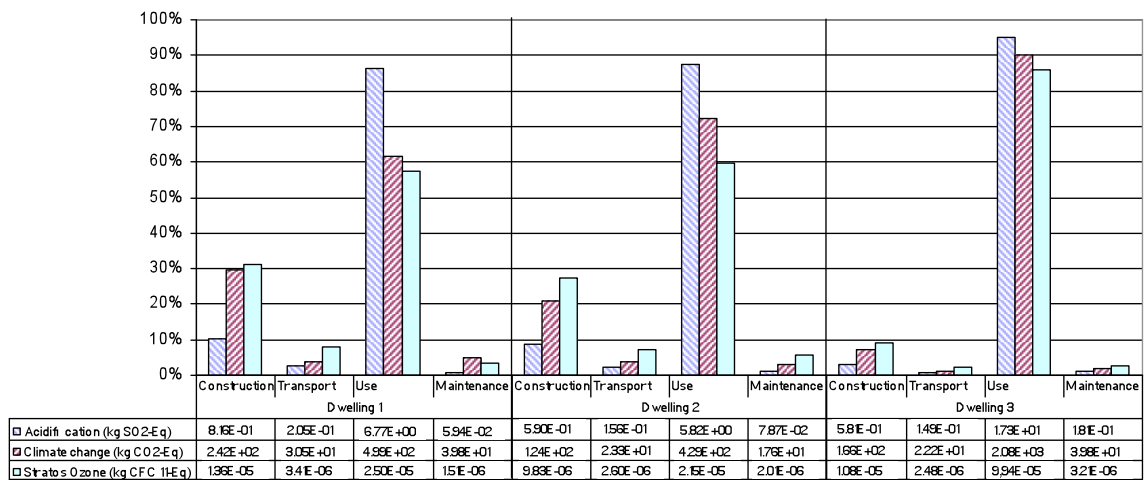


Table 1 Dwelling 3: Spanish Mediterranean home.

Indicator	Acidification potential kg SO ₂ -Eq	Climate change kg CO ₂ -Eq	Stratospheric ozone depletion kg CFC-11-Eq
100% electrical			
% Total	3.47E-01	4.16E+01	1.99E-06
7 Heating	2.51E-02	3.01E+00	1.44E-07
21 Domestic hot water	7.28E-02	8.73E+00	4.17E-07
16 Electrical appliances	5.40E-02	6.48E+00	3.10E-07
9 Cooking	3.02E-02	3.62E+00	1.73E-07
21 Illumination	7.28E-02	8.73E+00	4.17E-07
26 Air conditioning	9.18E-02	1.10E+01	5.26E-07

Table 2 Dwelling 1: Colombian dwelling made of concrete, steel and brick.

Indicator	Acidification potential kg SO ₂ -Eq	Climate change kg CO ₂ -Eq	Stratospheric ozone depletion kg CFC-11-Eq
100% electrical			
% Total	1.35E-01	9.98E+00	5.01E-07
0 Heating	0.00E+00	0.00E+00	0.00E+00
12 Domestic hot water	1.58E-02	1.17E+00	5.85E-08
55 Electrical appliances	7.46E-02	5.50E+00	2.76E-07
10 Cooking	1.37E-02	1.01E+00	5.05E-08
23 Illumination	3.14E-02	2.31E+00	1.16E-07
0 Air conditioning	0.00E+00	0.00E+00	0.00E+00

Table 3 Dwelling 2: typical Colombian dwelling made of timber, concrete blocks and ceramic tiles.

1year/m ²		Acidification potential	Climate change	Stratospheric ozone
Indicator		kg SO ₂ -Eq	kg CO ₂ -Eq	depletion
				kg CFC-11-Eq
100% electrical				
%	Total	1.16E-01	8.58E+00	4.30E-07
0	Heating	0.00E+00	0.00E+00	0.00E+00
5	Domestic hot water	5.61E-03	4.13E-01	2.07E-08
62	Electrical appliances	7.21E-02	5.31E+00	2.67E-07
12	Cooking	1.37E-02	1.01E+00	5.05E-08
21	Illumination	2.50E-02	1.84E+00	9.25E-08
0	Air conditioning	0.00E+00	0.00E+00	0.00E+00