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Analysis of CO_2 emissions in the construction phase of single-family detached houses

R. Pacheco-Torres*, E. Jadraque, J. Roldán-Fontana, J. Ordóñez

Department of Construction & Project Engineering, University of Granada, Spain

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ABSTRACT

Within the European Union (EU), the implementation of strategies for smart, sustainable, and inclusive economic growth is a major priority. Sustainable growth is summarized in the following objectives for 2020: (i) 20% reduction in EU greenhouse gas emissions from 1990 levels; (ii) 20% energy consumption from renewable resources; (iii) 20% reduction in EU energy consumption by improving energy efficiency in member states. Within this context, this research analyzes the environmental impact of CO_2 emissions in building construction in the following Life Cycle Assessment (LCA) processes: (A1) raw material supply; (A2) transport; (A3) manufacturing; (A4) transport; (A5) construction/installation on-site processes. In the case of a single-family detached house, the value obtained was 385 kg CO_2/m^2 of the surface area of this building type. The distribution of these emissions among the construction work units was also obtained.

1. Introduction

According to the United Nations, “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Currently, a wide variety of actions are being carried out to foster sustainable development in cities (Communication from the commission to the European Parliament and the Council, 2010; European Council, 2007).

Life Cycle Assessment (LCA) is an effective method of evaluating the environmental impact of a product or service, which is increasingly being used for this purpose in the construction sector. According to the Society of Environmental Toxicology and Chemistry (SETAC):

> ‘Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal’ (SETAC, 1993).

In Europe, the Energy Performance of Buildings Directive (EPBD) (European Commission, 2010) includes performing an energy building certificate. This certificate shows environmental information about the building that can be met by performing a Life Cycle Assessment (LCA) (Malmqvist et al., 2011).

A detailed description of how to carry out Life Cycle Assessment is given in the ISO 14040 and ISO 14044 standards (ISO, 2006a, 2006b). In the case of building construction, the CEN/TC 350 (The European Committee for Standardization “Sustainability of construction works”) proposes the four stages listed in Table 1.

By 2020, the building sector will be responsible up to 31% of the CO_2 emissions in the world. This share is projected to be up to 52% by 2050 (International Panel on Climate Change, 2011). Meggers et al. (2012) stated that the problem of the carbon emissions is in the core of the reasons to transform the building sector into a more sustainable one.

The development of effective methods of evaluating the environmental impact of building construction is crucial for the implementation of measures that reduce CO_2 emissions in this sector. Although the use of LCA procedure is increasingly accepted, its use in the professional sector as a common tool is still one of the main targets to achieve. In order to fill this gap, Malmqvist et al. (2011) developed a tool directed to professionals.

Conducting LCA by focusing in those materials that contribute most to the environmental impact is a valid simplification to obtain general results (Malmqvist et al., 2011). Materials with high emission rates, such as cement and steel, can reach up to 50% of indirect

* Corresponding author. Tel.: +34 958249438.
E-mail address: rosapt@ugr.es (R. Pacheco-Torres).

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Table 1
Life cycle stages of a building according to the CEN/TC 350 (European Committee for Standardization "Sustainability of construction works").

Stage	Module
1. Product stage	Raw material supply Transport Manufacturing
II. Construction process stage	Transport Construction/installation on-site processes
III. Use stage	Maintenance Repair and replacement Refurbishment Operational energy and water use
IV. End-of-life stage	Deconstruction Transport Recycling/re-use Disposal

emissions (Omar, Doh, Panuwatwanich, & Miller, 2014). Baek, Park, Suzuki, and Lee (2013) pointed out the limitations of assessing life cycle CO_2 in the planning phase, due to necessity of a great amount of inputs.

González and García Navarro (2006) obtained a reduction of up to 30% of CO_2 emissions in the construction phase of three terraced houses in Spain through a selection of low environmental impact materials within the life cycle of a building. Firstly, they estimated the CO_2 emissions related to the buildings construction phase. Later, results were compared with a building constructed with conventional materials and estimated the potential savings that can be reached by selecting friendly environmental materials.

Tae, Baek, and Shin (2011) focus on the environmental impact of a super tall building through its life cycle assessment. The energy consumption and CO_2 emission of a 35-story above ground building was assessed. Three cases were studied: existing building (service life 50 years); existing building-renovation (service life 50 years); high-strength concrete building (service life 100 years).

More information of published works on LCA applied within the building sector can be found in Ortiz, Castells, and Sonnemann (2009). A more detailed revision of the literature about energy use in the production phase of residential buildings was conducted by Nässén, Holmberg, Wadeskog, and Nyman (2007).

This article describes the evaluation of CO_2 emissions in the construction phase of a single-family detached house. Once the emissions level of the house was assessed, it was then possible to identify the construction phases that generated the most severe environmental impact. Accordingly, these stages were prioritized for the rapid application of corrective measures.

This research study calculated environmental impact as reflected in the measurement of CO_2 emissions in building construction in the Product Stage (A1–A3) and the Construction Process Stage (A4 and A5). As shown in Table 1, the processes included are: (A1) raw material supply; (A2) transport; (A3) manufacturing; (A4) transport; (A5) construction/installation on-site processes.

The sequence of steps in this study was the following:

- Characterization of the building type.
- Design of the building: relevant information was obtained regarding surface area, construction systems, and typical building materials for this building type, based on statistical data.
- Calculation of the structure of the building and the measurement of construction work units to be completed.
- Estimate of the CO_2 emissions corresponding to the work units that comprise the building type.
- Analysis of the results obtained for each work unit.
- Conclusions.

Table 2
Dimensional parameters for the case studied.

Total built surface area (m^2)		No. of floors	
Below ground level	Above ground level	Below ground level	Above ground level
90.91	222.22	1	3
Useful surface area per floor (m^2)			
Basement	Ground floor	1st floor	2nd floor
90.91	90.91	90.91	40.40

2. Methodology

2.1. Building characterization

The representative characteristics of a single-family detached house were obtained by analyzing statistical data from the *Informe de Construcción de Edificios* (Building Construction Report), published by the Spanish Ministry of Public Works for 2008–2010 (Ministerio de Fomento, 2010).

The data sources in this report were city authorities, who responded to a questionnaire regarding the building permits granted during this period. Although this is a national report, our study targeted the region of Andalusia, which is composed of eight provinces in the south of Spain.

As reflected in this report, there are three main residential building types in Spain: (i) single-family detached houses; (ii) single-family semi-detached/terraced houses; (iii) high-rise apartment buildings. This research study focuses on single-family detached houses. The statistical data were used to calculate the average surface area and the average number of rooms (i.e. 6 rooms and 3 bathrooms) for this residential building type. Table 2 shows the total built surface area as well as the number of floors.

The results of this analysis were used to design the typical layout for each floor of the house (see Fig. 1).

2.2. Construction systems and finishing materials

The building was designed with the most commonly used finishing materials and construction systems in Spain, as reflected in the statistics of the Ministry of Public Works. It also complied with government regulations (Ministry of Public Works, 2003) in regards to the limit value of the mean heat transfer coefficient, U (W/m^2 K).

2.3. Structural calculations

After defining the dimensional parameters, the foundation and structure of the house were then calculated. As evidenced in the life cycle of the building, these parts are responsible for a large percentage of all of the CO_2 emissions in the construction phase. Concrete and steel, the most frequent building materials used in both, have a high CO_2 emissions rate per construction work unit.

In consonance with the criterion in the previous stage, the structural type selected was the one most frequently found in newly constructed residential houses in Andalusia (Ministerio de Fomento, 2010). Accordingly, the house had a slab foundation, and the structure was composed of concrete floors and columns. Fig. 2 shows a schematic diagram of the building's structure.

This calculation was performed with the software program, CYPECAD (CYPE Ingenieros S.A., 2012)

The values of the actions considered for the dimensioning of the frame elements were the following: 0.9 kN/m^2 for gravity load floor; 3.50 kN/m^2 for gravity load roof; 3.00 kN/m^2 for use in floor,