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Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential

Ignacio Zabalza Bribián*, Antonio Valero Capilla, Alfonso Aranda Usón

CIRCE - Centre of Research for Energy Resources and Consumption, Campus Río Ebro—University of Zaragoza, Mariano Esquillor Gómez, 15 - 50018 Zaragoza, Spain

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ABSTRACT

The building industry uses great quantities of raw materials that also involve high energy consumption. Choosing materials with high content in embodied energy entails an initial high level of energy consumption in the building production stage but also determines future energy consumption in order to fulfil heating, ventilation and air conditioning demands.

This paper presents the results of an LCA study comparing the most commonly used building materials with some eco-materials using three different impact categories. The aim is to deepen the knowledge of energy and environmental specifications of building materials, analysing their possibilities for improvement and providing guidelines for materials selection in the eco-design of new buildings and rehabilitation of existing buildings.

The study proves that the impact of construction products can be significantly reduced by promoting the use of the best techniques available and eco-innovation in production plants, substituting the use of finite natural resources for waste generated in other production processes, preferably available locally. This would stimulate competition between manufacturers to launch more eco-efficient products and encourage the use of the Environmental Product Declarations.

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1. Introduction

At world level, civil works and building construction consumes 60% of the raw materials extracted from the lithosphere. From this volume, building represents 40%, in other words 24% of these global extractions. In Europe, the mineral extractions per capita intended for building amount to 4.8 tonnes per inhabitant per year [1], which is 64 times the average weight of a person, highlighting the need to work towards dematerialisation in building.

In Spain, every habitable square metre[1] of a conventional building requires a total of 2.3 tonnes of more than 100 types of materials. This figure represents only those materials that directly form part of the construction site. Additionally, if we consider the “Material Intensity per Service Unit” concept, which expresses the relationship between the weight of the resources (biotic, abiotic, air, water, erosion, etc.) affected by the manufactured goods process on the weight of the material produced, the previous figure is multiplied by 3, reaching 6 t/m^2 [1].

The manufacture, transport and installation in a building made of materials such as steel, concrete and glass require a large quantity of energy, despite them representing a minimal part of the ultimate cost in the building as a whole. This contradiction is known as the “Rule of the Notary” [2]. In addition, the extraction of minerals causes a significant reduction in the exergy of our planet’s natural stock, which is mainly concentrated in iron ore with 63% of the total, aluminium with 24%, and copper with 6% [3,4], all of which are commonly used in construction.

The life cycle focus must help decision-making when selecting the best technology available and minimising the environmental impact of the buildings through their design or refurbishing [5,6]. Often, products that are presented as cheap in the medium term can have high maintenance or waste management costs and highly technological products can have very high production costs that are never recouped. Contrarily, it may be that when we consider the

* Corresponding author. Tel.: +34 976761863; fax: +34 976732078.
E-mail address: izabal@unizar.es (I. Zabalza Bribián).

[1] The habitable area of a building is the usable area for housing, excluding other areas such as corridors, staircases, gardens, garages, streets, etc.

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Nomenclature

LCA	Life Cycle Assessment
GHG	Greenhouse Gases
EPD	Environmental Product Declaration
EPS	Expanded Polystyrene
CED	Cumulative Energy Demand
GWP	Global Warming Potential
IPPC	Intergovernmental Panel on Climate Change
BREF	Best Available Techniques Reference Document

whole life cycle, materials with significant CO_2 emissions, such as concrete, can see their emissions reduced by giving them a second life as a filler material in infrastructure, with a double effect: the reduction of emissions compared with obtaining filler materials from quarries and the absorption of CO_2 due to the recarbonation processes. Therefore, it is fundamental to apply the life cycle vision and take into account both the economic and environmental costs when identifying the most eco-efficient technology.

The aim of this paper is to evaluate, based on the life cycle assessment method, the high impact in terms of energy and the environment of the construction materials most used at the moment in the building sector in comparison with the reduced impact of different eco-materials, proposing and assessing, whenever possible, specific measures for the reduction of these impacts in all stages of the product: manufacture, transport and final disposal. The improvements proposed in the manufacturing stage are based on the BREF on the best techniques available for energy efficiency, and for the different sectors to analyse (ceramic, cement, polymers, steel, etc.) with a time frame between 2007 and 2009.

2. State of the art: lca studies of building materials

Energy behaviour in several building materials [7] has been investigated outlining the importance of using recycled and natural building materials [8] due to their low level of incorporated energy, whenever quality requirements allow it.

Sixty studies of different buildings [9] located in 9 countries (including Sweden, Germany, Australia, Canada and Japan) have been performed and found that the proportion of embodied energy in materials used and life cycle assessed varied between 9% and 46% of the overall energy used over the building's lifetime when dealing with low energy consumption buildings (with good insulation, adequate orientation, passive conditioning, etc.) and between 2% and 38% in conventional buildings. The lifetime usually considered is 50 years. A lifetime of 30 years is considered only in one building and a longer lifetime (between 75 and 100 years) is taken in eight buildings. Other studies assert that in conventional buildings, located mainly in Northern and Central European countries, the embodied energy in materials is around 10–20%, while 80–90% corresponds to energy in the usage stage, and less than 1% to energy for end-of-life treatments [10]. In these studies the lifetime presents significant differences in each country. For instance, in the Netherlands the usual value is 75 years for dwellings and 20 years for offices, where as in the UK, 60 years is used for both commercial and domestic buildings, and in Finland and Switzerland 100 years and 80 years are considered respectively. The wide range in results is due to the variety of buildings, materials, the lifetime considered and the geographic and climatic conditions.

Different approaches and simplifications can be considered in order to perform an LCA for building materials [11]. In Spain, the amount of energy invested in manufacturing some specific materials for one square metre (considering the gross floor area) in

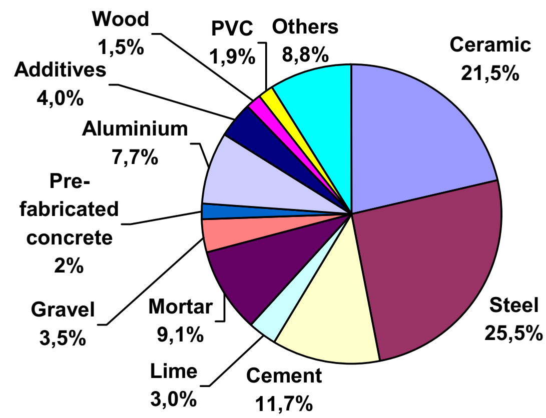

Fig. 1. Contribution of primary energy demand for the manufacture of the materials needed in the construction of 1 m^2 (gross floor area) [12].

a standard building equals the amount of energy produced from the combustion of more than 150 L of petrol [12]. Each squared metre built entails an average emission of 0.5 tonnes of carbon dioxide and an energy consumption of 5754 MJ (which is variable depending on the building design), only including the impact associated with materials. Fig. 1 and Fig. 2 show the relative contribution of the main building materials to the primary energy demand and CO_2 emissions associated with a square metre in a Spanish standard block of flats. The high impact of commonly used materials such as steel, cement and ceramics is notable.

There are numerous studies published in which the LCA is applied to evaluate the impact of different construction materials and solutions [13].

Within the area of thermal insulation, LCA studies have been carried out on kenaf [14] fibre boards, which lead to a significant reduction in environmental impact compared to other insulation based on synthetic materials. Similarly, based on the LCA and including energy, emissions and economic aspects, the advantages have been proven of External Thermal Insulation Composite Systems [15] that can reduce the energy consumption, CO_2 equivalent emissions and total economic cost in the life cycle by up to 20% when compared with conventional insulation.

At the same time, LCA studies have been carried out of different wood coverings for floors [16], whose opportunities for improvement are centred on the processes of laying, surface finish and maintenance, and the type of glues and varnishes used in each of these stages.

The environmental impact of phase change materials in Mediterranean buildings throughout the life cycle has been evaluated experimentally [17], obtaining a reduction in the energy

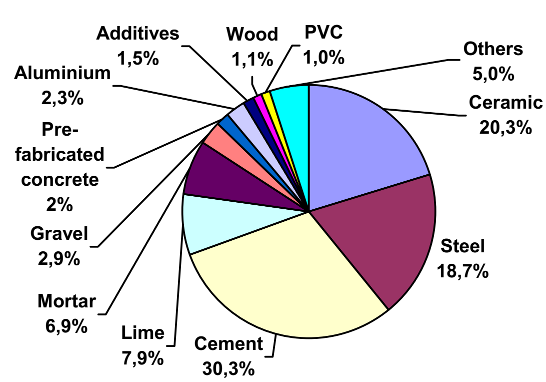

Fig. 2. Contribution of CO_2 emissions associated with the manufacture of the materials needed for the construction of 1 m^2 (gross floor area) [12].