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LIFE CICLE ASSESMENTS OF THREE DWELLINGS IN ANDALUSIA (SPAIN): THE SIGNIFICANCE OF THE REGIONAL CONTEXT

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Abstract. In the developed countries, the construction sector now accounts for 20 to 40% of the total energy consumption. This sector is a key factor in national economies, and it not only represents a critical consumption of resources, but also creates the built environment. These are some of the reasons why researchers around the world have recently developed procedures to determine the environmental impacts of whole buildings. In this context, Life Cycle Assessment (LCA) is a useful tool to analyze buildings from the environmental point of view. This article shows the results obtained by applying the LCA methodology to three residential buildings. Each studied dwelling is located in different urban context and is different from a typological and constructive point of view. This article discusses the importance of the choice for a building location and selection of source materials relating to the total environmental impact. All the studied buildings were designed and built by researchers from the Architecture School of Seville.

Keywords: sustainability in buildings, Life Cycle Assessment (LCA), building eco-design, environmental impacts of construction.

Introduction

In the developed countries, the construction sector now accounts for 20 to 40% of the total energy consumption, and has overtaken the other key sectors: industry and transportation (Perez-Lombard *et al.* 2008).

In 2005, the residential sector in Europe accounted for 26.6% of final energy consumption (European Environmental Agency 2008). This energy demand amounts to approximately 44% of total consumption of raw materials and almost one third of total CO_2 emissions (Erlandsson, Borg 2003), (Zhuguo 2006). Furthermore, construction is a key sector in national economies which not only produces a critical consumption of resources, but also creates the built environment. Ultimately, it is an important sector in terms of economy, society and environment (Perez-Lombard *et al*. 2008).

These are some of the reasons why researchers around the world have recently developed procedures to determine the environmental impacts of buildings. Many organizations, both public and private, are making a significant effort to develop procedures to predict the environmental performance of buildings. In this context the LCA, as a method to evaluate the environmental impacts of a material, product or service through its entire life cycle (Baumann, Tillman 2004), is a useful tool to analyze buildings from the environmental point of view. The knowledge gained from these studies can help architects and civil engineers to select the most appropriate constructive alternatives from the point of view of sustainability.

LCA of Three Dwellings. Goal and Scope Definition

The main purpose of this study is to obtain values of the impact categories which are commonly used in the LCA studies of buildings, in order to determine the contribution of transport of materials in relation to the total impact due to construction of each dwelling as such.

Implementing the LCA, the life cycle is frequently divided into two main systems**:** the product as such and its operation, (Adalberth 1997), (Ortiz *et al.* 2010), (Peuportier 2001), (Verbeeck, Hens 2010), (Zabalza *et al.* 2011). For the purpose of this study, seeking to make the results more understandable, the operation phase is excluded.

According to the proposed framework, this study seeks to answer the following question: What are the impacts produced by the processes related to the dwelling as such?

1. Goal. The objects of the study are the following dwellings:

- C-1 is a multi-storey building on Plot 2.2. SUNP-AE-1, Seville (Spain) which has been recently built (2010). The building consists of 204 dwellings subsidized by the government. It is a conventional concrete structure building. The ground floor is also used by commerce. Moreover, it has an underground parking lot. The total building floor area is 23,906.23 m^2 (Fig. 1).

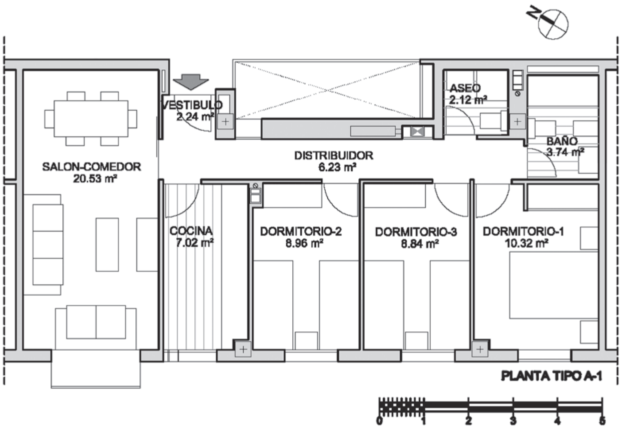

Fig. 1. C-1 Dwelling floor plan

− C-2 is a two-storey detached wood frame house located in a countryside zone of the municipality of Alcalá de Guadaira (Seville). The rooms are lighted and ventilated from the street. The building is located at six meters from the public space and three meters from other plots (Fig. 2).

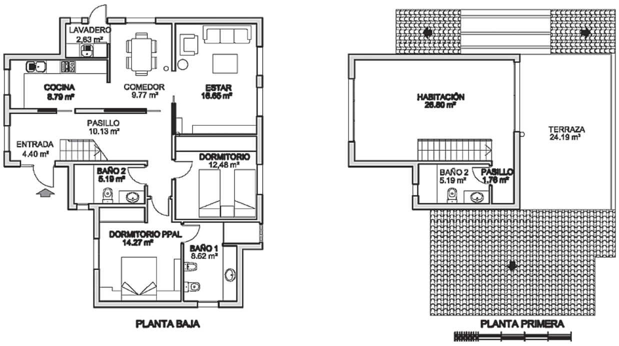

Fig. 2. C-2 Dwelling floor plans

− C-3 is a traditional single-apartment town house with bearing brick walls, located in a small town called Villamanrique de la Condesa (Seville). The house has two interior courtyards that allow for ventilation and lighting. The building is attached to the boundaries of the plot (Figs. 3 and 4).

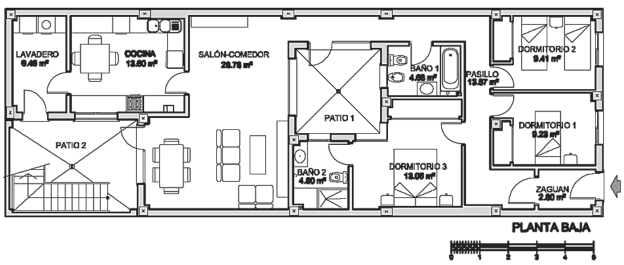

Fig. 3. C-3 Dwelling ground floor plan

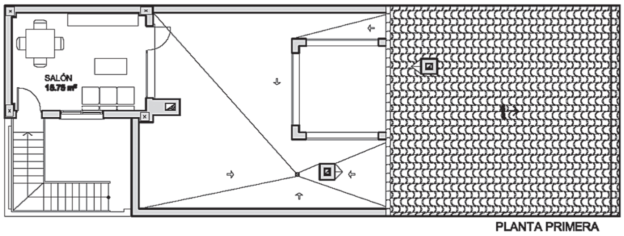

Fig. 4. C-3 Dwelling first floor plan

2. Scope.

a) Functional unit. The aim of this study: a person per year living in standard comfort conditions determined by the Spanish CTE Código Técnico de la Edificación (Thechnical Building Code).

b) Considered Impact Categories. 1. Climate change; 2. Acidification potential; 3. Eutrophication potential; 4. Eco-toxicity in water; 5. Terrestrial Eco-toxicity; 6. Human Toxicity; 7. Photochemical Oxidation; 8. Resources; 9. Photochemical Oxidation; 10. Primary energy.

c) System boundaries. The system consists of all processes involved in the production, construction, maintenance, deconstruction and recycling of each component of the dwelling as such. All processes related to the operation phase of the dwelling are excluded. The system includes the following phases:

− Manufacturing of building products phase: Considering separately each building material with every good and service involved in its production. Manufacturing of employed machinery and territorial infrastructure processes have also been considered.

− Assembly and construction phase: Covers every process aimed at integrating all products and services in the site. The transportation of building materials from the factory to the site and placement of building products have been considered.

− Maintenance and reparation phase: Includes all reparation and maintenance operations throughout the useful life of the building components. The renewal of those materials which have a lower durability has been considered.

− Dismantling and demolition phase: Every process carried out at the end of the life cycle of the building to remove and demolish the dwelling has been taken into consideration: Demolition, removal of the building elements and transportation of demolition materials to recycling or disposal sites have been included.

- Disposal and recycling phase: Covers all processes that take place after dismantling i.e. the disposal of building materials.

The environmental data of materials used were obtained from the following databases: ECOINVENT V.2.; IVAM; BUWAL 250; IDEMAT 2001; LCA food DK.

Life Cycle Inventory Elaboration

The calculation procedure to obtain the life cycle inventory is as follows:

1. Identification and quantification of the initial building products and auxiliary materials including replacement materials that are used over the life cycle. This data has been basically obtained from the project documentation (Fig. 5).

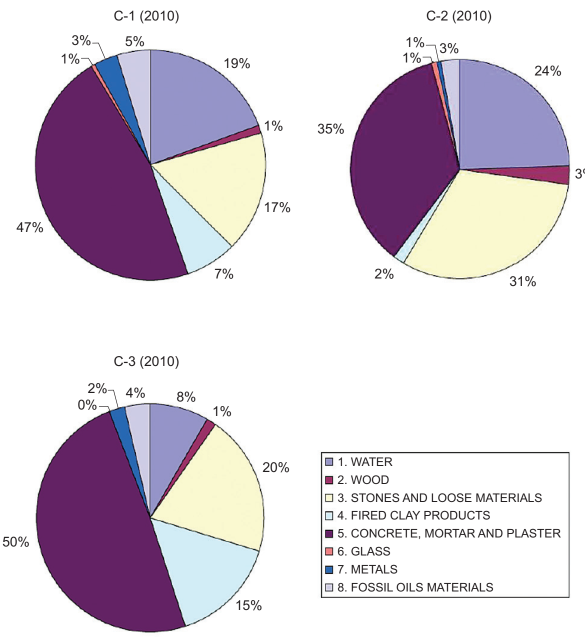

Fig. 5. Building materials percentage per floor surface (kg/m^2)

2. Identification and quantification of the basic processes associated with the construction and deconstruction (Table 1): identification of building material transport from the factory to the site and from the site to the disposal or recycling plant and the allocation of materials in the case of multi-family dwelling C-1 have been calculated using the procedure described by García Martínez, (2010) (García 2010). Assessment of the energy consumed during the construction and demolition is obtained using a similar procedure as described by Kellenberger *et al.* (2004).

3. Assessment of inputs and output of each unitary process (Tables 2 and 3). The database Ecoinvent V.2 has been used to obtain environmental information of unitary processes.

Table 1. Construction and deconstruction processes

Total dwelling				
Energy used		C-1	C-2	C-3
Diesel consumption	MJ	92,215.9	302.229.9	318,204.8
Electricity consumption	Kw/h	10,978.1	35,979.7	37,881.5
Building materials transport				
transport, lorry 32t	tkm	7,129.9	31,776.5	40,864.9

Table 2. Dwelling unit input processes

Basic process	Unit	C-1	C-2	C-3
Wood	m^3	2.90	19.10	8.90
Water	Kg	45909.60	45568.10	84621.50
Gravel	Kg	38022.80	197468.10	205939.50
Stone	kg	2228.90	3302.00	488.90
Ceramics	kg	16793.90	9362.60	156260.40
Sanitary ceramic	kg	131.80	226.80	169.30
Concrete	m^3	41.60	84.00	188.20
Mortar	kg	2598.50	8840.50	21124.00
Plaster	kg	4537.30	8204.80	9822.20
Glass	kg	794.90	763.30	464.10
Fiberglass	kg	530.40	3075.60	0.00
Aluminum	kg	360.00	466.20	223.80
Copper	kg	490.80	34.20	38.00
Structural steel	kg	5364.90	1470.40	6056.80
Low alloy steel	kg	900.10	1941.70	3834.30
Zinc	kg	447.10	0.00	11826.10
Paint	kg	7191.90	5023.40	23216.00
Polyethylene	kg	122.00	145.40	150.70
PVC	kg	322.50	498.70	1355.70
Synthetic rubber	kg	1239.80	4128.10	4938.10
Extrusion prosess	kg	322.50	498.70	1355.70
Bitumen and asphalt	kg	45.00	73.00	19.80
Exp. Polystyrene	kg	14.50	0.00	44.70
Packaging: Plastics	kg	72.60	524.20	446.70
Packag.: Cardboard	kg	220.40	769.60	989.70
Packaging: Wood	m^3	0.60	4.70	1.60
Packaging: Metal	kg	122.10	405.00	519.80
Detergents	kg	2317.00	7042.10	5938.20
Lubricants	kg	21.10	18.40	17.30
Lorry transport	tkm	92215.80	302229.90	318204.70
Fuel machine.	MJ	7129.90	31776.50	40864.90
Power Consumtion	Kwh	10978.00	35979.70	37881.50

Table 3. Dwelling unit output processes

Basic process	Unit	C-1	C-2	C-3
Brick waste	kg	132.75	75.21	1226.90
Concrete waste	kg	836.60	1716.48	3856.75
Paint waste	kg	56.41	39.40	182.09
Glass waste	kg	6.23	5.99	3.64
Mineral wool waste	kg	4.16	24.12	0.00
Polyethylene waste	kg	10.68	33.52	39.91
PVC waste	kg	2.53	3.91	10.63
Wood waste	kg	15.94	105.34	88.91
Cooper waste	kg	3.85	0.27	0.30
Inert material waste	kg	315.70	1574.67	1619.05
Steel waste waste	kg	37.19	54.29	187.48
Asphalt waste	kg	0.35	0.57	0.16
Plaster waste	kg	35.59	64.35	77.04
Zinc waste	kg	3.51	0.00	92.75
Cardboard waste	kg	0.57	4.11	3.50
Plastic pack. waste	kg	0.96	3.18	4.08
Metal pack. waste	kg	3.72	26.07	9.17
Wood pack. waste	kg	1.73	6.04	7.76
Aluminum waste	kg	2.82	3.66	1.76
Steel waste	kg	26.28	0.33	24.68
Polystyrene waste	kg	0.11	0.00	0.35

4. Inventory and Assessment. The impact assessment is carried out using the CML 2001 method in relation to the main impact categories and using the "cumulative energy demand" in relation to the embodied primary energy.

Inventory Results

Fig. 6. shows the materials used in each of the dwellings, grouped into sets of similar nature. Concerning the usage phase, those resources related to the cleaning, maintenance, refurbishment and reparation of building components were taken into account.

In general terms, the C-3 dwelling is the one that consumes more resources in almost every set of materials, except in the group of "wood". C-2 house is the one that uses the biggest amount of wood, since it has a wooden structure. The main consumption of wood in the rest of the dwellings is mainly due to the construction of formwork for the floor slabs.

As shown in Fig. 6, the C-1 dwelling consumes considerably fewer resources than the rest. This is mainly due to two important factors: First of all, the floor area of the C-1 dwelling (90.88 m^2) is considerably smaller than that of the C-2 (158.16) and C-3 (158.16 m^2). Secondly, the C-1 architectural type (multi-family dwelling building) induces considerable material savings in comparison to the C-3 - (individual town house) or C-2 types (detached house). If the results related to the C-1 and C-2 are compared, it is found that, in general, the C-2 consumes more resources. This occurs despite the use of concrete. This is because, even though having a wooden structure, the C-2 dwelling is built on concrete footings. Given that the C-2 is an individual house, all the concrete which is used to build the foundations is allocated to the C-2 dwelling.

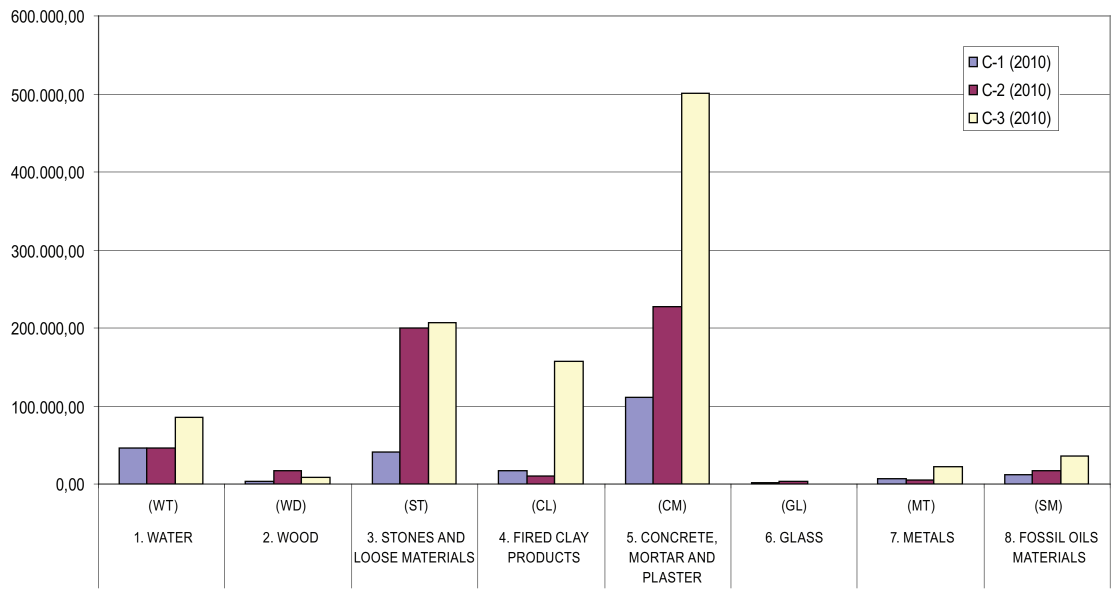

Fig. 6. Building materials used

In contrast, the C-1 dwelling is included in a residential multi-storey building, so the concrete used for its foundations should be divided between all of the dwellings of the building. The same happens to a greater or lesser extent, with other building materials.

Impact Assessment

Fig. 7. shows the impact assessment obtained by applying the CML 2001 method. The data is related to the functional unit. It clearly shows that C-1 dwelling is the one that obtains the best results in almost every impact category considered (except in the "Ecotoxicity in fresh water", for which the C-2 has a considerably better performance, mainly due to the used disposal scenario for metals). The C-3 obtains more negative results for almost every impact category. This is due to a large amount of resources that has been used in its construction and the use of building materials which produce a particularly significant impact in the studied categories. In consequence, the C-2, which uses only a slightly smaller amount of building materials than the C-3, produces a considerably smaller impact than the C-3. This is mainly due to the nature of the building materials used.

Consequently, the C-3 building materials are a better option from the environmental point of view. This is mainly because of reduction in the use of certain materials, especially those which have incorporated long processes of industrial transformations that demand large amounts of energy.

The environmental impact related to material transportation represents a significant proportion in relation to other unit processes considered (e.g. production). Tables 8 to 10 shows the impact of material transportation in relation to the total impact on each studied dwelling for each considered impact category.

The highest value of impact produced by the building material transportation in relation to the total in the C-1 and C-2 occurs in the eutrophication potential category (19.4% and 34.57% respectively). The highest value of building material transportation impact repercussion in the C-3 appears in the category of climate change (11.05%), of which the transport represents 13.88% and 21.84% in the C1 and C-2 respectively. Other impact categories, which significantly contribute to the transportation impact, are stratospheric ozone depletion, acidification potential and human toxicity (Figs. 8–10).

The high values of impact contribution of the transport in relation to the total impact, are mainly due to selection of the materials used in the dwelling construction, where the origins of such materials and their impact on the location have been failed to consider. In addition, the impact is higher the further away is the house from the building materials distribution networks. Thus, the impact of the material transport is considerably higher in the case of C-2 which is built in a rural environment, away from the main distribution hubs.

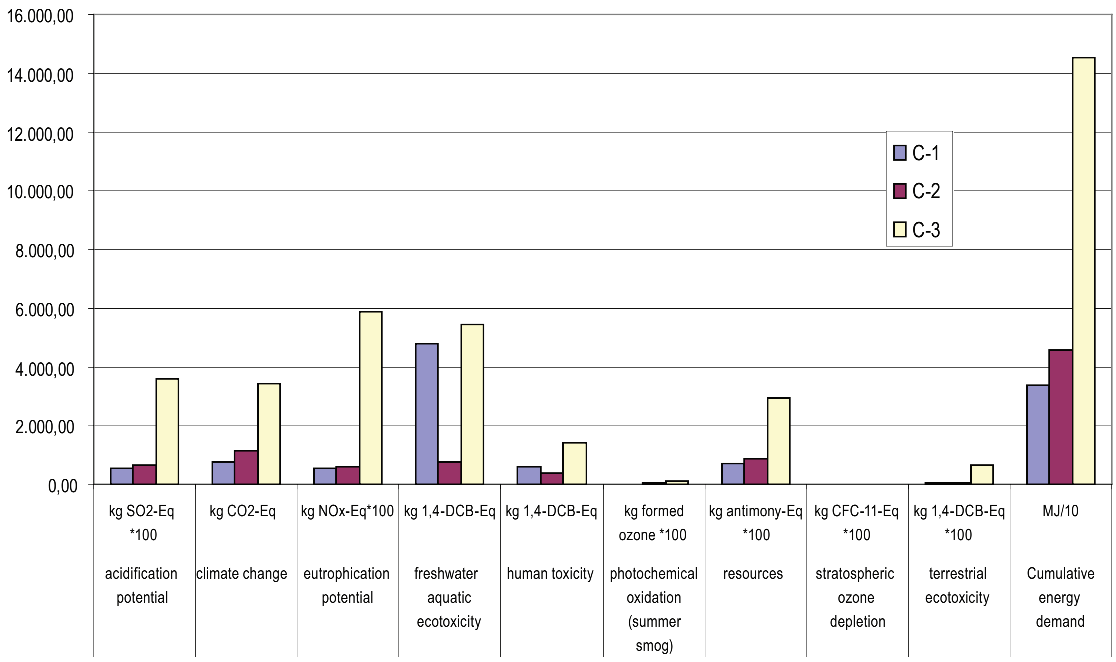

Fig. 7. Impact Assessment in the three cases of study

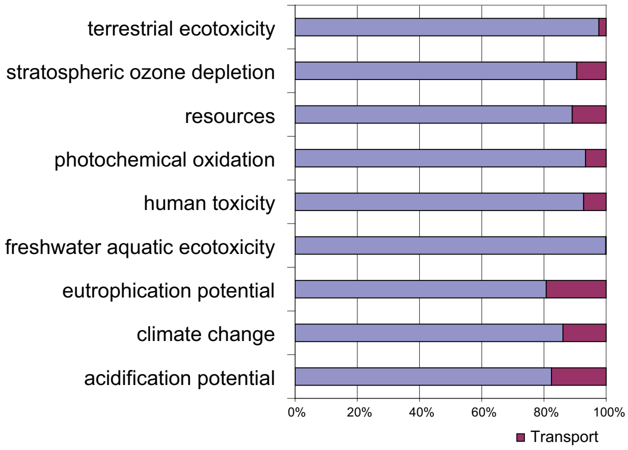

Fig. 8. Transportation impact repercussion. Dwelling C-1

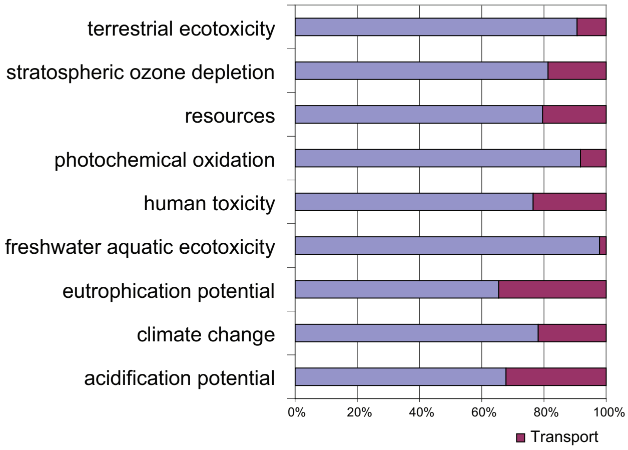

Fig. 9. Transportation impact repercussion. Dwelling C-2

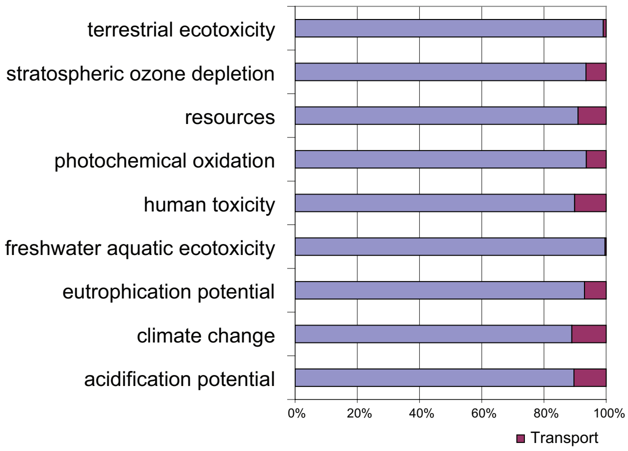

Fig. 10. Transportation impact repercussion Dwelling C-3

Conclusions

The results obtained by the LCA prove quantitatively:

1. The optimization of building materials results in a quasi-proportional reduction of negative impact on the environment. Consequently, C-1, the dwelling with the least amount of resources consumed, is also the dwelling that has the lowest associated impacts.
2. The selection of building materials and systems can considerably reduce the environmental impacts. Thus, the C-2 dwelling, despite of being the worst building type from the viewpoint of resource optimization, achieves the best results in the impact categories. This is mainly due to the environmentally friendly nature of its building materials and components.
3. The material transportation is accountable for an important part of total environmental impact caused in the process of construction and deconstruction of the studied cases.
4. The location of the dwelling in respect to the origin of building materials and distribution networks is a key factor from the point of view of the environmental impact.

It follows from the foregoing that a proper selection of the origin of building materials could produce significant reductions in the environmental impact of the construction and deconstruction of buildings.

Acknowledgments

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TRIJŲ GYVENAMŲJŲ BŪSTŲ ANDALŪZIJOJE (ISPANIJA) GYVAVIMO CIKLO VERTINIMAS: REIKŠMĖ REGIONO KONTEKSTE

A. García Martínez, J. Navarro Casas

Santrauka

Išsivysčiusiose šalyse 20–40 % viso energijos suvartojimo tenka statybų sektoriui. Šis sektorius yra pagrindinis nacionalinės ekonomikos veiksnys, kuris ne tik lemia išteklių naudojimą, bet ir sukuria užstatytą aplinką. Tai tik keletas priežasčių, kodėl visame pasaulyje mokslininkai neseniai sukūrė procedūras, kuriomis nustatomas pastatų poveikis aplinkai. Šiame kontekste gyvavimo ciklo analizė (GCA) yra naudinga priemonė statiniams aplinkos požiūriu analizuoti. Šiame straipsnyje pateikiami rezultatai, gauti taikant GCA metodiką trims gyvenamiesiems pastatams. Kiekvienas išstudijuotas būstas, įsikūręs skirtingose urbanistinėse situacijose, skiriasi tipologiniu ir konstruktyviniu požiūriu. Straipsnyje aptariama statybos vietos, statybos žaliavų pasirinkimo svarba ir bendras jų poveikis aplinkai. Visi šie pastatai buvo suprojektuoti ir pastatyti Architektūros mokyklos Sevilijoje mokslininkų.

Reikšminiai žodžiai: pastatų tvarumas, gyvavimo ciklo vertinimas, GCV, ekologinio projektavimo pastatai, konstrukcijų poveikis aplinkai.