Estimation of energy consumption of different housing construction systems in study case in Spain

GONZÁLEZ DÍAZ María Jesús, GARCÍA-NAVARRO, Justo
Polytechnic University of Madrid. Department of Construction and rural roads.
E.T.S.I. Agrónomos

Keywords: Energy consumption; construction system; Spain.

Abstract:

First of all, this paper evaluates the energy consumption of a building in the construction and operation phase, within the whole life cycle analysis. The study establishes a methodology to evaluate the energy consumption in terms of MJ per square meter of floor area using a method based on accepted LCA practices.

Secondly, this evaluation is focused on two buildings composed by terraced houses in a region of the centre of Spain. Both buildings have been similarly built, and they have the same geometrical characteristics and typologies, such as place, volume, area, site, orientation and economic level. Nevertheless, both have different construction systems. One has been built with low environmental impact materials, such as structural wood, softwood window frames, cork as insulation, no PVC, low VOC paints, etc. The other one has been built with conventional construction materials, such as steel reinforced concrete, aluminium window frames, polyurethane insulation, PVC pipes, etc. Those latter materials are the most commonly used in housing construction in this region. Both evaluations are compared.

The aim of this study is to demonstrate the influence of the chosen construction system in energy consumption. Energy demand for construction operations depends on the construction system and on the selection of construction materials.

1 INTRODUCTION

The relationship between environmental harms and energy consumption has been sufficiently analyzed. The construction sector is a great energy consumer, and as a consequence, a great contributor to the production of CO2, greenhouse effect gases, to the development of harms to the Earth crust such as acidification, to the emissions of heavy metal into the atmosphere, to the use of non-renewable energies, to the effects of eutofization, and a large contributor to water consumption etc. It is well know that the material extraction process, the production of construction elements, the placing on site, maintenance etc, produces a strong environmental impact. Within the complete process of life cycle analysis of a building, the present paper studies the first phase, focusing on the construction of the building.

Summarizing, the close relationship between energy consumption and construction is defined here in the study of the following detailed points:

1. – Assessment of the energy consumption produced by all the industrial activity involved in the construction process of a building with specific characteristics and in a special location.

2. – Assessment of the energy consumption reduction achieved by a careful selection of materials used in the construction.

A new line o research on construction materials is opened, showing possible solutions to the problem of energy consumption and the decrease of the contaminating effects.

2. BACKGROUND

Previous studies in the matter analyse the energy expenses of the construction of a building. According to them, the consumption of energy greatly varies in relation to the type of building. Firstly, according to the location of the building and its climatic conditions, microclimate, prevailing winds, humidity, etc. Within Spain, and due to the different climatic conditions, Álvarez-Ude, (Álvarez-Ude et al, 2004) establishes that the consumption of energy per square meter in the material production is almost 6,000 MJ in Lanzarote, as opposed to 9,000 MJ in the Catalonian construction, "that is, an environmental factor smaller than 40 to 50% per square meter for the construction I the island." Secondly, the energetic consumption depends on the morphological and typological characteristics defined in the urban planning. Cepeda and Mandaras (Cepeda y Mandaras, 2004) state that the energy consumption for the construction of a collective building is 52% smaller than if detached or terrace houses are built. They estimate the energy consumption of the latter in 5,311MJ/$m^{2,}$ without including the services. Thirdly, the focus of this study, the energetic consumption of a building construction depends on the materials and constructive systems being used. Mithraratne and Vale (Mithraratne and Vale, 2004), state that "a comparison of 100-year embodied energy could aid in selecting construction types based on the life cycle embodied energy. Life cycle embodied energy for the three construction were 4425, 4764 and 5041 MJ/m2 for light, concrete and superinsulated construction, in New Zealand, respectively".

In Spain, in a conventional construction, certain materials are used which have been settled by tradition through a period of over fifty years. The introduction of reinforced concrete has extended a construction system to the point of banality, becoming almost the one and only structural type and totally displacing other alternatives. This extensive use of concrete as the structural element has brought functional and aesthetic changes, as well as important energy consequences –the ones this paper will analyze. In general, in Spain, conventional construction is developed with reinforced concrete orthogonal post-and-lintel frame, reinforced concrete slabs and brick masonry (Cepeda y Mandaras, 2004). This study aims at pointing out other alternatives to this conventional type of construction.

3. RANGE OF ACTION

The building analysed is located in the city centre of Valladolid, a medium-size city in the centre of Spain. Construction finished in the year 2004. The estate is privately owned. The building is formed by three terraced houses, with 125 m2 housing surface, 50 m2 basement garage and 119 m2 of garden per house. The study therefore, affects to 526 m2 constructed surface of the different levels.

The design has been done integrating the principles of bioclimatic architecture, including a rigorous and careful selection of construction materials with lesser environmental impact and smaller production of pollutants, as well as inserting the estimation of alternative energies for each of the dwellings. The group of houses comprise passive solar energy reception systems, receptive trömbe type walls, thermal solar energy for the production of running hot water, and electric energy production by means of photovoltaic solar energy. The harnessing of rainwater is also foreseen as well as other economic cycle water measures, including a high presence of vegetation and green elements. (Pictures 1 and 2)

4. METHODOLOGY

The present research paper develops the following study line:

- PHASE 1. Identification of all the different construction units used in the housing construction of three low environmental impact dwellings, including the description and measurement, and their equivalence in weight. (For example, quantity of timber used for the window woodwork, and its translation into kilos of wood used.). All the data is summarised by chapters in table 1, column A.

- PHASE 2. Identification and quantification of all construction units used in conventional construction commonly built in Valladolid. In this type of construction no principle of energy saving is applied. This phase includes the description and measurement of the different units and their equivalence into kilos. Following the previous example the most frequently used material for window frames in conventional construction is aluminium. Therefore the kilos of aluminium used will be assessed in the window frames of the construction. The data is summarised by chapters in table 1, column C.

- PHASE 3. Assessment of the embodied energy in each of the construction materials, in energy units per kilo. A conversion table is used specifying the energy consumption of each of the construction materials. This is applied both to the three low environmental impact houses and to the conventional construction. (In the reference study case, the embodied energy of the constructive material wood, and in the conventional building the embodied energy of the constructive material aluminium, in MJ/Kg units). The data are summarised by chapters in table 1, showing in the B column, the energy consumption of the conventional building and in Column D, the energy consumption of the reference building.

- PHASE 4. Comparative assessment, in MJ energy units between the two constructive solutions for each of the units. (Continuing with the previous example, it would reflect the difference between the MJ used by wood as the selected material for window frames, and the MJ used for the case in which the conventional aluminium would be used). The resulting data appears in column E of table 1.

- PHASE 5. CONCLUSIONS. Total assessment of energy units in MJ used for the construction of the building, both for the case study building as well as for the conventional construction with no material selection. Assessment of the energy saving in energy units per constructed surface.

4.1 Selection of materials used

The identification of the construction units comes from the documents, Measurements, Estimated cost and Interim Certificates of the design project and they correspond to the ones used in the actual construction. For calculating and converting into weight units, the characteristics of each material, specified by the manufacturer, have been considered. When this has not been possible (in complex compound construction units), the factoring into simpler units has been followed. On these smaller units the data referring to bulk density and weight included in specific standards such as “Actions in construction” and the Code NBE-CT-79 (Norma Básica de la Edificación AE-88, 1988), about “Building thermal conditions” have been applied, both of them mandatory regulations and of national scope.

The materials selection used for the building has been carried out in agreement with the criteria of environmental preference methods based on the life cycle analysis, such as the “Green Building Handbook”, (Wooley et al.,.1998), the “Handbook of sustainable building” (Anink and Boonstra,1996) or the “Agenda de la construcción sostenible” (I.D.A.E, 1999). In this reference bibliography, although referred to different locations (London, Barcelona…), a clear coincidence in recommending some materials and stating the priorities to follow can be observed.

As an example, and always bearing in mind that they are plausible and possible elements, the structure and slabs have been made of timber, window and door frames are also made of wood, natural cork has been used for insulation, low burning ceramic materials have been used as finishes, plastic materials PE (polythene) and PP (polypropylene) have been installed for drains and pipings, gutters and down pipes have been made of steel, water based paints have been applied, and natural wood treatments have been chosen..

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4.2 Conventional materials

The study is based in the comparison, in terms of embodied energy, of the three dwellings with an identical building but constructed with conventional materials – the ones that would have been used if environmental criteria had not been applied.

The definition of a conventional material is difficult to establish since it depends on many different parameters. The daily architectural practice, nevertheless, allows taking this definition for granted. In a systematic way, the medium and small sized building constructions, used as dwellings, are built in Valladolid with a reinforced concrete structure, vitrified ceramic wallings, polyurethane foam or polystyrene insulation, aluminium or PVC framed windows, high burning ceramic interior finishings and parquet, PVC interior wood treatments, and chemical based paintings. This selection is also confirmed by Cepeda and Mandaras (Cepeda y Mandaras, 2004). Other possible alternatives are scarcely used. In conventional construction other alternatives such as using wood for the structure or the load bearing walls, or the use of natural materials (wood, cork etc) have almost disappeared. They are only used in very rare cases.

4.3. Embodied energy of construction materials

There is scarce data, although enough, about the concept of "embodied energy" of each material. This concept defines the energy load a material supports per weight unit, established in MJ/Kg. This data is included in Table 2, and is based in the life cycle analysis of each material.
For the research carried out, the identification based on the life cycle analysis, "Comparison of building elements- Life Cycle analysis.- New Zealand Institute of Architects",(New Zealand Institute of Architects. 1996) has been used. It comprises a total of 144 entries, it was done in a country with a similar economic level to that of Spain, and it is one of the most complete listings found in the bibliography in the market. A simplified listing is enclosed in Table 2. This data coincides with the account published by the Institute for Diversification and Energy Saving (I.D.A.E., 1999).

In addition to this data bases, the following calculation hypothesis have been considered:

Due to the complexity and variety of the constructive elements, a simplification had to be carried out. This has been specifically done in the chapter of machinery, or services, in which for the same unit, several materials take place, as for example, steel, plastics and various additives.

In these cases, the simplification has been done by taking the bulk part of the material used in a greater percentage. This strategy has been performed both in the reference or conventional building and in the group of three dwellings. Therefore, by comparing the two constructions, the final result will not be affected.

The use of recycled materials, such as stone coming from demolitions or elements recuperated from other construction works, is not considered in the embodied energy of the materials. It is a similar case to the ground movements being done in the chapter of foundations. Nevertheless, an energy consumption of transportation and placing can be implied. As a working hypothesis, zero energy consumption has been considered for these construction works, in both cases (the conventional reference building and the environmentally friendly group of dwellings).

4.4. Comparative assessment in energy units

For each construction unit, data of the material embodied energy has been applied.
In column B, results for the construction units of the group of dwellings constructed can be seen. In column D, the results for the building using conventional materials are shown.

Column E shows the difference between the energy units used by the reference building, constructed with conventional materials, and those used by the dwelling built with environmental criteria. The comparison almost always reveals smaller quantities in the construction with environmental principles, than in the reference building, as can be seen in the Summary table 1.

The data obtained can be summarized as follows:

- Embodied energy of the materials and constructive systems used for erecting the building: 4,118,601 MJ.

- Embodied energy of the materials and constructive systems used for erecting the conventional building: 6,472,084 MJ

- Embodied energy per surface unit of the constructed building: 7,830.03 MJ/m^2.

- Embodied energy per surface unit of the conventional building: 12,304.34 MJ/m^2

- Reduction of embodied energy achieved by the selection of materials and constructive systems: 36%.

5. CONCLUSIONS

A careful selection of materials and constructive systems can mean a reduction in the consumption of energy per square meter in the construction of a building of up to a 36%. The selection of low environmental impact buildings implies a decrease in energy expenses, maintaining the interior typological characteristics of comfort and well-being. Although some facts have to be pointed out:

1.- The strong influence of the foundation and basement concrete walls chapter. As Cepeda and Mardaras, (Cepeda y Mardaras, 2004) point out, the existence of a basement significantly increases this chapter. A representative percentage of the total surface of the building constructed in the basement increases the proportion of energy consumption, since the materials used for the underground level need to be of great weight, such as concrete.
2.- The greatest reduction of energy is found in the chapters of structure and window frames. In these tasks, the conventional construction uses reinforced concrete for the structure, and aluminium for the window frames. These materials have been substituted by wood, a commonly used material up to the 60's. It is important to note that, besides implying an important reduction in energy consumption, wood has an excellent behaviour towards some environmental aspects, acting as a drain for CO_2 emissions.

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