

Importance of CO₂ Emissions in Construction Phase. Two Case Studies: New Construction and Renovated Building

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ABSTRACT

With the new Technical Code for Construction and Energy Certification (application of the EPBD in Spain) energy consumption and carbon dioxide emissions are now taken into consideration during building's operating phase. There is no doubt that this is a step forward. However, economic cost and emissions involved in extracting materials, manufacture, transport and installing on site (embodied energy in the materials used in construction) can be considerable and even more when promotor seeks to improve the building's energy rating with the corresponding increases in insulation, improvements in cladding and so on. Two case studies are used (new construction and renovation) in order to analyze both economic cost and CO₂ emissions in construction and operating stage (using LIDER and CALENER softwares) of two actual cases.

Keywords: Carbon Dioxide; Embodied Energy; Building; Energy Certification

1. Introduction

Construction sector and in particular the building sector is responsible for more than 40% of the energy consumed in Europe [1,2] and it is estimated that the implementation of the Technical Code for Construction will mean an energy saving of 30% - 40% and a reduction in CO₂ emissions of 40% - 55% [3] in the operating phase of the buildings. However, the EPBD (Energy Performance Building Directive) does not include the indicator of Embodied Energy (EE) in the construction materials.

As other authors have observed [2,4] the strategies at EU and national level are concentrating on increasing the energy efficiency of buildings, notably reducing energy needs during the operating phase without this necessarily means a reduction of energy consumption in the other stages of the building's life cycle (construction, maintenance or demolition). This fact is logical when one considers that the energy cost of buildings in the operating phase is estimated to be approximately 80% [5]. However, given that political strategies are attempting to reduce the energy consumed in the operating phase by a huge percentage, the embodied energy (EE) in the construction phase is acquiring an ever greater relative importance [5-7] and may mean between 10% and 60% of total energy used throughout the life of the building [2,8].

After Royal Decree 47/2007, of 19 January, which has been mandatory in Spain since November 2007 and which

fixes the bases for classifying and certifying the energy efficiency of newly constructed buildings, as well as the provisions of directive 2002/91/EC on the need for energy certification of existing buildings, which will entail a series of measures for improving the energy efficiency of every building, there is some doubt about whether improvements in thermal insulation and glazing and the introduction of new technologies aimed to reducing energy consumption in the operating phase do not considerably increase the energy consumed in the construction phase (EE).

It is clear that a reduction in energy consumption of buildings during their use is very important. However, this should not blind us to study the energy consumption in an holistic approach, what is called Life Cycle Energy Assessment (LCEA), and thus increasing the energy saving and efficiency during operation, while taking care not to increase the EE in construction phase as a result of the increased insulation materials and glazing or with the introduction of more sophisticated technological systems.

2. Objectives and Scope

After this short introduction, it arises the concern to study how buildings will react when they are subjected to energy classification, and how energy savings increase in the operation stage while at the same time it is analysed

the increase of embodied energy in construction phase. RD 47/2007 gives a classification on a scale of seven letters: from class A (most efficient) to class G (least efficient) using a calculation program called CALENER, which provides theoretical ratios of energy consumption and CO₂ emissions for the building during the operation phase. Buildings constructed prior to 2006, it is assumed that 40% would be in class D, whereas for buildings constructed from 2007, it is estimated that 35% will be C and 55% will be D [9].

Following this idea, two actual projects have been chosen involving two buildings as case studies. The first is a newly constructed building and the second, anticipating the future Royal Decree, is a renovated building.

In both cases, the buildings were planned to be classified as D (although the classification was not yet mandatory) and the promoter insisted it should be attempted to raise its energy classification to C. For this, an analysis of emissions was done both in construction phase and in operational phase (according to the CALENER program) comparing the project as it was originally conceived and the project finally completed to obtain the certification required by the promoter. A very brief analysis was also done of the economic cost involved in the improvement of the project and the economic saving for future users from the fact that the building is more energy efficient.

It should be pointed out that the total emissions in construction phase have not been quantified. Only the emissions of those materials that have been changed or modified during the project have been quantified.

3. First Case Study: New Construction

3.1. Situation

This concerns a development in the province of Valencia of detached houses consisting of two floors (ground floor plus one) as well as a cellar. The following characteristic data should be emphasized:

- Useful surface area of cellar: 29.88 m²
- Useful surface area of ground floor: 58.65 m²
- Useful surface area of first floor: 57.14 m²
- 3 bedrooms, 2 bathrooms, kitchen, hall and toilet

They are built using the usual materials found in this area of Spain (walls of brickwork, reinforced concrete structure and glass wool insulation) and the fuel used for heating and hot water is natural gas by means of individual combination boilers in each house.

In order to obtain an improved energy classification (from D to C) and meet the limitation of energy demand, the thickness of the insulation was increased and its thermal conductivity improved in accordance with the requirements of the original project. The following **Table 1** shows the modified elements of the initial project.

Table 1. Original and improved project—new construction building.

		Original Project	Improved Project
Wall against Ground	Mineral Wool	e (cm) = 5; λ = 0.05 W/mK	e (cm) = 5; λ = 0.029 W/mK
Wall C1	Mineral Wool	e (cm) = 7; λ = 0.05 W/mK	e (cm) = 7; λ = 0.029 W/mK
Wall C3	Mineral Wool	e (cm) = 5; λ = 0.05 W/mK	e (cm) = 5; λ = 0.029 W/mK
Roof	EPS	e (cm) = 5; λ = 0.029 W/mK	e (cm) = 10; λ = 0.029 W/mK
Floor Slab	EPS	e (cm) = 0,1; λ = 0.037 W/mK	e (cm) = 6,1; λ = 0.037 W/mK
Terrace	EPS	e (cm) = 5; λ = 0.037 W/mK	e (cm) = 5; λ = 0.029 W/mK
Insulated Floor	EPS	e (cm) = 1; λ = 0.037 W/mK	e (cm) = 8; λ = 0.037 W/mK
Windows	Glass 4-12-4	U = 2.9 W/m ² K; Fs = 0.75	U = 1.3 W/m ² K; Fs = 0.64
Windows	Glass 3-3-12-3-3	U = 2.8 W/m ² K; Fs = 0.71	U = 1.2 W/m ² K; Fs = 0.62

3.2. Analysis

As a result of the improvements introduced in the insulation and glazing, the cost of these has been evaluated, as well as the economic saving achieved during the operation (**Tables 2 and 3**).

So it can be seen that economic cost of applying the thermal improvements to the house being studied shows a difference between the cost of the elements introduced into the improved project (6210 €) and the cost of the existing units in the previous project (4623 €), which means an increase of 1587 €

On the other hand, the economic saving in the operating phase has been calculated considering the consumption per kWh/year which resulted from the application of the CALENER to each project, original and modified (**Table 4**).

This means an economic saving in operation for the future owner of 12% with respect to the project as it was initially conceived, this means 63.14 €/year less for the future user.

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Likewise, the carbon dioxide emissions incorporated into the construction materials have been calculated (**Table 5**), as well as the emissions in the operating phase from the data collected by the CALENER program (**Table 6**).

Table 2. Cost of eliminated elements from the original project.

	Material	Area [m ²]	Unit Price [10]	Total [€]
Wall against Ground	Mineral Wool	10.4	3.63 €/m ²	38.98
Wall C1	Mineral Wool	226.3	4.49 €/m ²	1016.08
Wall C3	Mineral Wool	45.9	3.63 €/m ²	166.62
Roof	EPS	67.67	5.15 €/m ²	348.50
Floor Slab	EPS	31.16	-	-
Terrace	EPS	9.17	9.35 €/m ²	85.73
Windows	Glass 4-12-4	5.24	40.13 €/m ²	210.28
Windows	Glass 3-3-12-3-3	30.11	91.56 €/m ²	2756.87
			TOTAL	4623 €

Table 3. Cost of new elements introduced into improved project.

	Material	Area [m ²]	Unit Price [10]	Total [€]
Wall against Ground	Mineral Wool	10.74	5.15 €/m ²	55.31 €
Wall C1	Mineral Wool	226.3	7.11 €/m ²	1608.99
Wall C3	Mineral Wool	45.9	5.15 €/m ²	236.38
Roof	EPS	67.67	9.35 €/m ²	632.71
Floor slab	EPS	31.16	5.9 €/m ²	183.84
Terrace	EPS	9.17	5.15 €/m ²	47.22
Insulated Floor	EPS	5.6	7.11 €/m ²	39.82
Windows	Glass 4-12-4	5.24	44.87 €/m ²	235.12
Windows	Glass 3-3-12-3-3	30.11	105.3 €/m ²	3170.58
			TOTAL	6210 €

Table 4. Operating costs from consumption energy (according to CALENER).

	Original project		Improved project	
	kwh/year	€/year	kwh/year	€/year
Calefacción	3889.389	162.03	2196.60	91.51
Refrigeración	3729.152	335.13	3811.31	342.52
Total	7618.541	497.16	6007.91	434.03

Table 5. CO₂ emissions in Original and improved project.

		Emissions [kg CO ₂] Original Project	Emissions [kg CO ₂] Improved Project
Wall against Ground	Mineral Wool	13.21 kg	97.41 kg
Wall C1	Mineral Wool	391.50 kg	2871.75 kg
Wall C3	Mineral Wool	56.46 kg	416.31 kg
Roof	EPS	613.77 kg	1226.86 kg
Floor Slab	EPS	-	339.02 kg
Terrace	EPS	166.25 kg	83.17 kg
Insulated Floor	EPS	-	71.06 kg
Windows	Glass 4-12-4	114.23 kg	129.53 kg
Windows	Glass 3-3-12-3-3	1012.30 kg	1032.17 kg
TOTAL:		2367.71 kg	6267.28 kg

Table 6. CO₂ emissions in operation.

	Original Project		Improved Project	
	kg CO ₂ /m ² year	kg CO ₂ /year	kg CO ₂ /m ² year	kg CO ₂ /year
Heating	6.9	1003.743	4.4	596.427
Cooling	7.4	1076.478	8	1163.76
Total	14.3	2008.221	12.4	1760.187

The increase in carbon dioxide emissions in the construction phase due to the improvements is 3899.57 kg CO₂ (6267.28 kg - 2367.71 kg). On the other hand, it leads to an annual reduction of 15% during the operational phase, 320 kg of CO₂ per year less.

4. Second Case Study: Renovated Building

4.1. Situation

This concerns the renovation of a building consisting of four apartments in Madrid, two of them on the first floor and two on the second floor. The ground floor has an area for a garage. The renovation consists of increasing the number of apartments to seven, three on the first floor, three on the second and a new one in the attic retaining the ground floor as a garage and modifying the composition of the façades to improve the energy classification from D to C.

The surface area of each original floor is 111.62 m² (ground, first and second floor) and the attic is an additional 54.5 m².

The changes made to the original project for the renovation and to improve the thermal insulation are shown in the following table (Table 7).

Table 7. Original and renovated project.

	Original Project		Renovation Project	
Façade GF	solid brick	e = 26.5 cm	solid brick + 1.5 cm rendering	e = 28 cm
Façade AT	HD brick	e = 24 cm	HD brick + 3 cm PU + 1.2 cm PYL	e = 28.2 cm
Roof	16 cm + catalan terrace	e = 16 cm	16 cm + catalan terrace + asphalt sheet + EPS	e = 20 cm
Windows	Metal + glass	e = 0.4 cm Fs = 0.85 U = 5.6 w/m ² K	Lacquered Aluminium Windows and 2 glass 4-6-4	e = 1.4 cm Fs = 0.75 U = 3.3 w/m ² K

4.2. Analysis

After the project modification for its renovation, cost of the modified elements is analyzed as well as saving that will suppose during the operation phase. The **Table 8** shows the cost of the planned improvements that affect the insulation.

The total cost of the improvements introduced in the thermal insulation of the renovated building is 26,920 €. On the other hand the economic saving in the operational phase for energy consumption calculated by means of CALENER supposes an annual reduction of 10%, 140.08 €/year less (**Table 9**).

In view of this results, it might seems that the improvement is very small, but considering the indicators of consumption of kWh/m² for the house, the original project consumed 123.3 kWh/m² a year and after the renovation it is 88.3 kWh/m², and economically the original project had a cost for energy consumption in operation of 5.11 €/m² whereas the renovation lowers that amount to 3.66 €/m².

As was done with the first study, it is showed an analysis of the carbon dioxide emissions incorporated into the construction materials to be used for the improvement of the insulation during the construction phase (**Table 10**).

It can be seen that the carbon dioxide saving due to the renovation is 4134.21 kg CO₂ a year, it leads to an annual reduction of 34% with respect to the original project (**Table 11**).

5. Conclusions

In view of the results obtained in both case studies and from what is said in the introduction, we may conclude the following:

- The economic cost of the investments to improve the energy classification of a building can mean an important saving over the life cycle of the building (LCC) even though there may be a long period of amortization (20 - 25 years in the case of new construction).
- The increase in carbon dioxide emissions in the construction phase due to the increase in insulation and improvements in the glazing of the two buildings studied supposes high but amortizable values in the operating phase over a period of 12 years (case one

Table 8. Cost of new elements introduced into the improved project.

		Renovation project		
	Material	Area [m ²]	Unit Price	Total Cost [€]
Façade GF	Rendering 1.5 cm	137	17.46 €/m ²	2392.0
Façade AT	Polyurethano 3 cm	307	7.23 €/m ²	2219.6
	PYL 1.2 cm	307	25.4 €/m ²	7797.8
Roof	Asphalt sheet	151	19.97 €/m ²	3015.5
	EPS 4 cm	151	6.81 €/m ²	1028.3
Windows	Aluminum windows 1.15 × 2.25	8 u.	340.8 €/ud	2726.4
	Aluminum windows 1.50 × 2.25	11 u	408.47 €/ud	4493.2
	Aluminum windows 1.50 × 1.25	3 u	228.34 €/ud	685.0
	Glass 4-6-4	67	38.25 €/m ²	2562.7
TOTAL				26,920 €

Table 9. Operating costs for energy consumption.

	Existing Project		Renovated Project	
	kWh/year	€/year	kWh/year	€/year
Total	33648.57	1396.41	30273.24	1256.33

Table 10. CO₂ emissions incorporated into the insulated materials.

Materials		Total Emissions [kg CO ₂]
Façade GF	Rendering 1.5 cm	902.83 kg
Façade AT	Polyurethano 3 cm	3997.14 kg
	PYL 1.2 cm	5209.79kg
Roof	Asphalt sheet	6701.38 kg
	EPS 4 cm	1289.54 kg
Windows	Aluminum windows 1.15 × 2.25	11067.52 kg
	Aluminum windows 1.50 × 2.25	19022.3 kg
	Aluminum windows 1.50 × 1.25	2593.95 kg
	Glass 4-6-4	1460.6 kg
Total:		52245.05 kg

Table 11. CO₂ emissions in operation.

	Existing Project		Renovated Project	
	kg CO ₂ /m ²	kg CO ₂	kg CO ₂ /m ²	kg CO ₂
Total	45.3	12362.37	24	8228.16

and two). These results demonstrate the discrepancy between economic and environmental amortization (25 years against 12 years in the new building).

- It seems clear that, as we said at the beginning of the paper, the introduction into European norms of a limit to energy demand, together with the certification of buildings in the operating phase, are first steps and there is no doubt that this is the stage where most energy is consumed. However, the figures obtained in this study as well as the resulting values given in the literature consulted, make it clear that when the values of energy consumption are reduced during the operational phase, the construction phase starts to gain more importance.
- In order to reduce overall energy consumption, as well as carbon dioxide emissions, yet further, we believe it is necessary to introduce tools into the decision making that take into consideration the life cycle of the building, with special emphasis on the embodied energy of the materials. So, in the case of study one, the same energy certification could be obtained by reducing emissions far more in the construction phase. For example, expanded polystyrene (EPS) was used to improve insulation and this has an emission factor up to 10 times higher than that of glass wool.
- Finally, it must be stressed that any improvement in the energy classification of a building (such as the ones that have been studied here) means an increase in carbon dioxide emissions in the construction phase due to the increase of construction materials such as insulation and glazing, which means not only paying attention to improving energy classification but also making correct choices about the materials to be used.

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