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THE GAP BETWEEN NEAR ZERO EMISSIONS BUILDINGS AND THE SPANISH BUILDING REGULATION

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ABSTRACT

Due to the effects of climate change, energy has become one of the most relevant topics nowadays. Because of the increasing amount of electronic devices, the dependency to energy consumption is increasing every year. At the same time, in order to avoid the devastating effects of global warming, it is crucial to find ways to lower the energy consumption in buildings. In recent decades, the building regulations have been updated several times to account for this changing reality. However, is the local Spanish energy regulation restrictive enough to reach Near Zero Energy Buildings (NZEB)?

This study aims to answer this question through a case study. A single-family house built in Valencia in 2013 has been analyzed by comparing the current state and how it would have been constructed under the updated legislation. The work is conducted through energy simulation and Life Cycle Assessment (LCA). The energy simulation is performed with OpenStudio, which uses the calculation engine EnergyPlus. The LCA was carried out using SimaPro and the Ecoinvent database. By analyzing the results obtained in both cases, it is possible to analyze the effectiveness of the CTE DB HE 2019 compared to the applicable norm in 2013 in terms of reducing energy consumption and the CO2 equivalent emissions. It can be concluded that although the current legislation is a significant improvement over previous ones, it is not enough to reach NZEB.

KEYWORDS

NZEB; carbon footprint; Life Cycle Assessment; thermal simulation.

1. INTRODUCTION

The building sector has a dramatic influence on the environment. Buildings not only need a huge amount of resources for their construction, but also host most human activities, which commonly entail a massive consumption of energy. Therefore, buildings not designed adequately to reduce the need for energy consumption can be hugely detrimental to the environment. Many architects and industry professionals have been aware of the determinant relation between buildings and their environment. A great example of that is Solar architecture, which started as a trend in the 30s in the United States. Solar architecture involved taking advantage of orientation and glass surfaces to provide sufficient light and heat to interior rooms. The anxiety about the possible lack of sufficient energy supply after the Second World War gave a boost to solar architecture. Some remarkable examples are the Sloan House (1939) and the Duncan House (1941), both by Fred Keck, the MIT solar house

(1939), and the Dover House by Maria Telkes and Eleanor Raymond (1948). However, the increase in the use of oil and natural gas, as well as the fascination for the possibilities of nuclear power, undercut these innovative solar designs in the fifties (Barber 2016). Along those years, other pioneers in bioclimatic architecture started making their mark. Victor Olgyay published his book *Design With Climate*, published in 1963 (Victor Olgyay 1963). Baruch Givoni was also a pioneer in the field. He became well known for his book *Man, Climate and Architecture*, where he presented his famous bioclimatic diagram (Givoni 1969). In the 70s, due to the oil embargo, energy optimization was in the limelight again. Counter-cultural movements led to another wave of interest in designing with the sun (Denzer and Gardzelewski 2019). They felt attracted not only to the positive effect those houses had on the environment but also to the revolutionary shapes and designs they had. The work of those early adopters was instrumental to the development of our current standards for efficient and sustainable construction, such as Passivhaus (Santy et al. 2017).

Due to the need to mitigating climate change, reducing the energy consumption of buildings is now more important than ever before. As with every industry, the building sector needs to reinvent itself to meet the new sustainability standards. Terms such as Nearly Zero Emissions Buildings have gained relevance in the last decades (Hermelink et al. 2013). One of the key aspects in the mitigation of energy consumption is to construct highly insulating building envelopes. An adequate building envelope minimizes the thermal losses avoiding the need to increase or lower the indoor temperature through HVAC systems. Building regulations play a huge role in fostering thermally insulated building skins.

The first building regulation in Spain, NBE-AT-79 (Basic Building regulation), was passed in 1979. This regulation defined the amount of thermal insulation required in buildings for the first time. However, it was not a comprehensive code that regulated every significant aspect of buildings in Spain. After almost 30 years, in 2007, the Spanish Ministry of Development passed the Spanish technical building code (CTE) (Ministerio de Fomento. Gobierno de España 2007). The Energy Efficiency Document of the CTE (CTE DB-HE) divides the country into different zones to account for the significant climatic variation in the country. The different areas are characterized by a code composed of a letter and a digit. The letter refers to the severity of winters, on a scale from A to E, and the digit to the severity of summers, on a scale from 1 to 4. In late 2019, there was an update in the CTE DB-HE. For the first time, it introduces the concept of Near Zero Energy Buildings (NZEB). Its states that all Spanish buildings constructed under the current regulation must be NZEB (Ministerio de Fomento. Gobierno de España 2020).

However, there is not an accurate definition of what an NZEB actually is. This paper deals with the comparison between the energy consumption in a single-family house constructed under the 2007 regulation and the same hour if it had been built under the current legislation, factoring in the amount of thermal insulation that it would have needed.

1.1. Objectives

This research has two main objectives. First, to assess the influence that building regulations have over the energy consumption in buildings. Secondly, to evaluate how that energy consumption translates into environmental impacts, especially the carbon footprint.

2. METHODOLOGY

This paper has been structured as a case study. The Spanish Building Code's impact on the energy consumption of buildings has been studied through the analysis of a single-family house in Aldaia (Valencia). It is a three-floor row house with 229.23m2 of usable area. Its main façade faces north. The first floor is mainly used as a garage; the second floor has a kitchen, a living room, a bathroom and a bedroom. The third floor has two bedrooms, a bathroom, and a small studio. The Last floor serves as the entrance to the terrace. Figures 1 and 2 depict an extract of the building plans.

The façade of the building is formed by a cavity wall composed of the following elements: 11.5 cm exposed bricks, a 3cm air chamber, 3 cm of polyurethane foam, a 2cm cement mortar layer, 10 cm hollow bricks, and a 1 cm layer of gypsum plasterboard. The flat roof is composed of a layer of bitumen seal, 4 cm of polystyrene foam, a 3 cm cement mortar layer, and finished with ceramic tiles.

As this building was built in 2013, the main idea of the study is to compare the energy consumption at the current state of the house with the energy consumption that the house would have if it had been built under the 2019 version of the CTE DB-HE, the document that regulates the energy efficiency requirements of buildings in Spain. For the purpose of this study, the current state of the house will be named Case 1, and Case 2 will represent the house built under the 2019 regulation. To adapt the house to the current standard, the main change has been to increase the amount

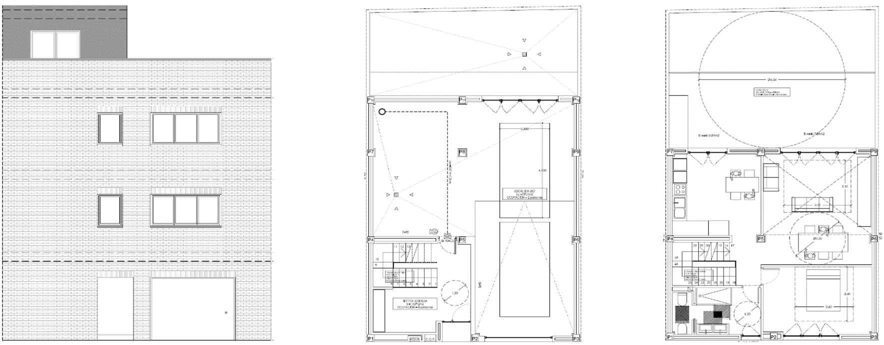

Figure 1. Plans of the house part 1: entry elevation and first and second floor section. Source: Own source

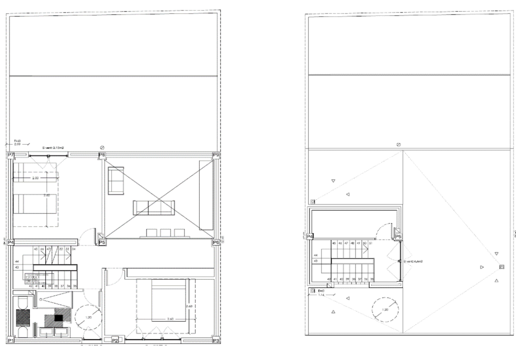

Figure 2. Plans of the house part 2: Third and fourth floor section. Source: Own source

of thermal insulation in the roof and in the façade. The façade maintains all its original layers mentioned in the previous paragraph but the polyurethane. The thickness of the polyurethane layer increases from 3cm to 10 cm. The roof also maintains all its layers but increases the thickness of the polystyrene slab from 4 to 13cm.
The aspects of energy consumption studied are heating, cooling, and DHW (domestic hot water). The HVAC systems used all use electricity. An air-to-air heat pump is used to cover both the heating and cooling demand. The efficiency ratios for heating and cooling, respectively, are 3.48 (SCOP) and 2.44 (SEER) (Table 1). The air distribution is done through ducts. The DHW demand is covered by a combined system of a solar domestic hot water system and a water boiler. The solar panel cover 60% of the total energy demand for hot water, which is the minimum required by the building regulations.

	Efficiency		
	SERR	**SCOP**	**$SCOP_{DHW}$**
Case 1	2.44	3.48	1.00
Case 2	2.44	3.48	1.00

Table 1. Energy efficiency of the HVAC systems

As explained in the two following subsections, the comparison of the two cases is conducted both from purely the point of view of the energy consumption and the effect it has on the environment. A comparison between the 2013 and the 2019 version of the DB-HE can be seen in Table 2.

2.1. Energy simulation

The simulation process employed aims to determine the building's primary energy consumption and the percentage of renewable and non-renewable energy. The software used is OpenStudy, an open-source software that uses EnergyPlus v9.1 as its calculation engine. The software performs an annual simulation at hourly intervals. Therefore, the software estimates the distribution of the energy demand every hour to maintain the defined operational conditions in every zone.

2.2. Life Cycle Assessment

The analysis of the environmental impacts produced by the house's energy consumption on the environment is performed through a comparative Life Cycle Assessment (LCA). LCA is a methodology used to account for the effect that every process involved in any human activity has on the environment. The ISO 14040 covers the process necessary to adequately conduct an LCA. The data used to model the electricity mix comes from the Ecoinvent database v3.6. The data has been handled using the software Simapro v9. The calculation method used to assess the impacts is the Environmental Footprint v3. This calculation method was developed by the European Commission and can be considered the most adequate for assessing the environmental impacts of products within the context of the European Union.

3. RESULTS AND DISCUSSION

This section deals with the energy simulation and LCA results.

3.1. Energy simulation results

The energy simulation results show a significant reduction of the energy demand, especially in the case of heating, in which the demand is reduced by almost 80% (Table 3). The reduction in the refrigeration demand is 20.5%. While it might seem like a small reduction when compared with heating, it is a significant difference in the time in which the use of air conditioning would be needed

			CTE HE 2017	CTE HE 2019
			$kWh/m^2 \cdot year$	*$kWh/m^2 \cdot yea$*
HE0		Non-renewable primary energy consumption	49.00	28.00
		Total primary energy consumption	-	56.00
HE1		Heating demand	15.00	-
	Thermal transmittance of the building envelope	*Unit*	*$W/m^2 \cdot K$*	*$W/m^2 \cdot K$*
		Walls in contact with the exterior	1.00	0.56
		Floors in contact with the exterior	0.65	0.56
		Roof	0.65	0.44
		Elements in contract with the exterior	1.00	0.75
		Dividing walls	1.00	0.75
		Windows and openings	4.2	2.3
		Doors	-	5.7
	Global heat transmission coefficient	*Unit*	*$W/m^2 \cdot K$*	*$W/m^2 \cdot K$*
		Compactness V/A ≤ 1	-	0.58
		Compactness V/A > 4	-	0.77
	Solar control	*Unit*	*$kWh/m^2 \cdot mes$*	*$kWh/m^2 \cdot me$*
		Solar radiation in July $q_{solo;jul,lim}$	-	2.00
	Building envelope permeability	*Unit*	*$m^3/h \cdot m^2$*	*$m^3/h \cdot m^2$*
		Air renewal rate of change in a 100 Pa overpressure	-	27.00
		Unit	*$n50\ h^{-1}$*	*$n50\ h^{-1}$*
		Air renewal rate of change in a 50 Pa pressure: V/A ≤ 2	-	6.00
		Air renewal rate of change in a 50 Pa pressure: V/A > 4	-	3.00
	Imbalance limitation	*Unit*	*$W/m^2 \cdot K$*	*$W/m^2 \cdot K$*
		Inner partition floor in the same house unit	1.55	1.55
		Inner partition wall in the same house unit	1.20	1.20
		Inner partition floor in a different house unit	1.10	1.10

Table 2. Comparison between the current and the former Basic Document on Energy savings of the CTE regulation

in the house. The energy for DHW does not change, as the insulation does not affect the demand for hot water.
Table 4 shows the results of energy consumption. Unlike energy demand, energy consumption takes into account the energy efficiency of the HVAC systems employed in the house. The efficiency coefficients employed are shown in Table 2. After factoring in those coefficients, it becomes apparent that in case 1, the energy consumption is the highest in the case of heating, followed by the Domestic Hot Water and the refrigeration. However, after improving the thermal insulation of the building envelope, the biggest energy consumption becomes the DHW. The amount of energy needed for heating decreases significantly, almost to the point of evening out with the refrigeration consumption.

	Energy demand (kWh/m²·year)		
	Refrigeration	Heating	DHW
Case 1	3.47	29.17	5.85
Case 2	2.68	6.24	5.85

Table 3. Energy demand of case 1 and 2 obtained through the thermal simulation

3.2. Life Cycle Assessment results

Table 5 shows the LCA characterization results obtained through the Environmental Footprint methodology. The climate change category shows that by applying the 2019 version of the DB-HE, the house emits 65 tons of CO2e less than with the previous regulation. In general, as the energy savings are around 45%, the total environmental impacts of every category are reduced at the same rate. That was something to be expected due to the fact that the electricity mix is the same in both cases. The environmental Footprint methodology offers the possibility of normalizing and weighting the results. This allows a direct comparison between the relative importance of each one of the categories to the total environmental impact. Figure 3 shows the weighted results. The two categories with a higher environmental impact are Climate Change and Resource use. This result responds to the high content of energy generated from fossil fuels that there still is in the Spanish electricity mix. This result would probably be different in the near future as more percentage of renewable energy is incorporated into the electricity mix.

	Energy consumption (kWh/m2·año)			Annual energy consumption (kWh)			Total consumption (kWh)
	Ref.	Heating	DHW	Ref.	Heating	DHW	
CASO 1	1.42	8.38	5.85	376.82	2221.42	1551.11	4149.36
CASO 2	1.10	1.79	5.85	291.44	474.94	1551.11	2317.49

Table 4. Energy consumption of case 1 and 2 obtained by using the efficiency coefficients

Impact category	Unit	Energy case 1 (100 años)	Energy Case 2 (100 años)
Climate change	kg CO_2 eq	135827.33	75861.852
Climate change - Fossil	kg CO_2 eq	134483.97	75111.57
Climate change - Biogenic	kg CO_2 eq	254.46	142.12
Climate change - Land use and LU change	kg CO_2 eq	1088.90	608.17
Ozone depletion	kg CFC11 eq	8.81E-03	0.00492038
Ionising radiation	kBq U-235 eq	33572.21	18750.65
Photochemical ozone formation	kg NMVOC eq	526.76	294.20
Particulate matter	disease inc.	3.14E-03	1.75E-03
Human toxicity, non-cancer	CTUh	2.14E-03	1.20E-03
Human toxicity, non-cancer - organics	CTUh	5.15E-05	2.88E-05
Human toxicity, non-cancer - inorganics	CTUh	1.26E-04	7.05E-05
Human toxicity, non-cancer - metals	CTUh	1.98E-03	1.10E-03
Human toxicity, cancer	CTUh	7.60E-05	4.25E-05
Human toxicity, cancer - organics	CTUh	2.13E-05	1.19E-05
Human toxicity, cancer - inorganics	CTUh	3.46E-13	1.93E-13
Human toxicity, cancer - metals	CTUh	5.47E-05	3.05E-05
Acidification	mol H+ eq	1208.27	674.84
Eutrophication, freshwater	kg P eq	6.18	3.45
Eutrophication, marine	kg N eq	174.04	97.20
Eutrophication, terrestrial	mol N eq	1948.37	1088.20
Ecotoxicity, freshwater	CTUe	2559062.20	1429279.40
Ecotoxicity, freshwater - organics	CTUe	20466.86	11431.08
Ecotoxicity, freshwater - inorganics	CTUe	147913.27	82612.05
Ecotoxicity, freshwater - metals	CTUe	2390682.10	1335236.20
Land use	Pt	548530.54	306363.55
Water use	m^3 depriv.	90777.89	50700.98
Resource use, fossils	MJ	3195034.80	1784480.80
Resource use, minerals and metals	kg Sb eq	1.47	0.82

Table 5. Environmental Footprint Characterization of the energy consumption of case 1 and case 2 over 100 years

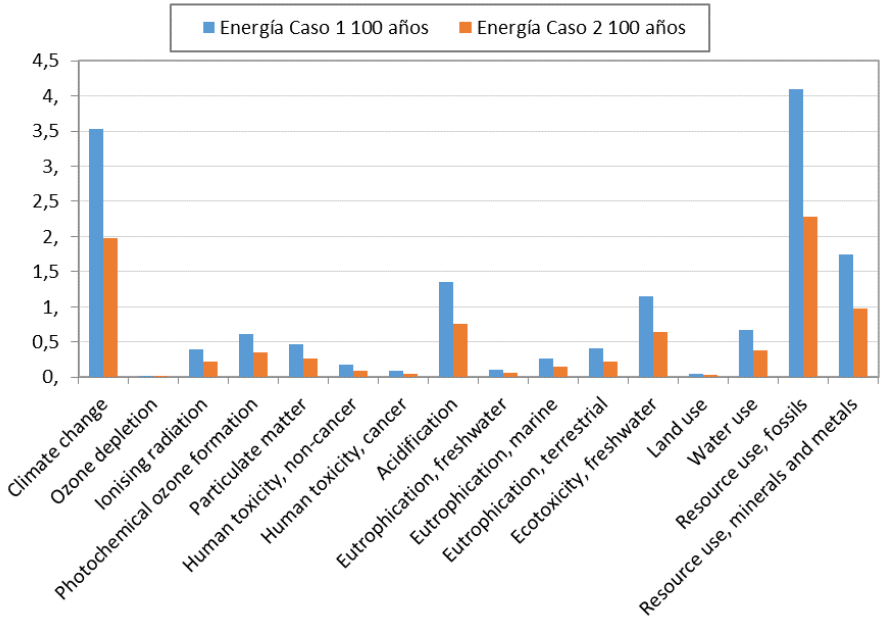

Figure 3. Weighting and single score Environmental Footprint result

4. CONCLUSIONS

After finishing this study, several conclusions can be drawn:

- While the first version of the CTE DB-HE was a step in the right direction, it was still not restrictive enough to provide a sufficient level of energy efficiency, and it was far from the standards of other European countries.
- The 2019 version of the DB-HE is a cornerstone in the evolution of sustainable and energy-efficient buildings in Spain. In the case of the case study house analyzed, the energy consumption of the building is reduced by 45%. In terms of carbon dioxide equivalent emissions, which entails a reduction of 65 tons of CO_2e over 100 years.
- Despite the improvement of the DB-HE 2019, the results obtained don't get near the idea of a Near Zero Energy Building (NZEB). Although the definition of NZEB is somewhat loose, the energy consumption of the house is still too high to be considered nearly zero.
- As the buildings transition more and more to consuming renewable energy, the focus should not be to talk about Nearly Zero Energy buildings, but to talk about Nearly Zero Emissions Buildings, or Nearly Zero Impact Buildings.

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