OPTIMIZATION OF THE REFURBISHMENT OF THE ENVELOPE THROUGHOUT ITS LIFE CYCLE

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Summary

The importance of energy efficiency in existing buildings and the need for refurbishment appear as key elements in different European regulations. In the same way, the concern about the environmental impact of the products used in refurbishment projects is increasing. Based on those two key issues, this paper presents a methodology for the environmental optimization of refurbishment projects with a life cycle perspective. This methodology has been applied to a real case study, consisting on an apartment building built on the 70´s in the district of Amara (San Sebastian). As a result, the best refurbishment solution among several options has been identified.

Keywords: Refurbishment, Life Cycle Assessment, embodied energy, Life Cycle Zero Energy Building

1 Introduction

The current building stock in Spain is about 10 million buildings, of which nearly 9 million and a half are residential, and correspond to a total of 25 millions of dwellings. About 60 % of all Spanish dwellings [1] were built before 1980 when the first energy efficiency regulations were published aimed mainly at increasing thermal insulation levels. Therefore, similarly to other EU countries, the Spanish residential sector is characterized by high energy consumption. In terms of total energy consumption residential sector amounted respectively to 17 % in Spain and 25 % in EU, and for electricity consumption this share increases to 25 % in Spain and 29 % at EU27 level.

Several factors such as the size increase of dwellings, or the increase of equipment and consumption patterns, suggest future upward trends for the energy use for the residential sector. As a result, the energy efficiency in existing buildings, the need for refurbishment and the declaration of performance of the products to be used in the construction sector appear as key elements in different regulations such as the EU Energy Action Plan [2], the Recasting of the Directive on Energy Efficiency in Buildings [3] and the Construction Products Regulation [4], implying that energy requirements for refurbishment will tend to be increasingly stringent.

1.1 Refurbishment throughout its life cycle

Up to now, in the performance evaluation of refurbishment strategies, it was only taken into account the potential reduction of energy demand in the usage phase of the building. However, following the guidelines defined by the CEN/TC 350 Sustainability of construction Works [5] and the methodology known as Life Cycle – Zero Energy Building (LC-ZEB) [6], this research project applies the life cycle perspective, taking into account in addition to the environmental impact of the use phase of the building and the environmental impact of the production of the materials used in the rehabilitation project (new envelope and new windows).

The life cycle assessment (LCA) is a concept that originated in the late 1960s. It was originally used as a way to study energy use and emissions associated with any product [7]. The LCA of a product is a methodology that identifies, quantifies and characterizes the various potential environmental impacts associated with each of the stages of the life cycle of a product [5]. This methodology can be used as a tool to propose improvement strategies for each product and provides the opportunity to study the benefits of different design options for each product.

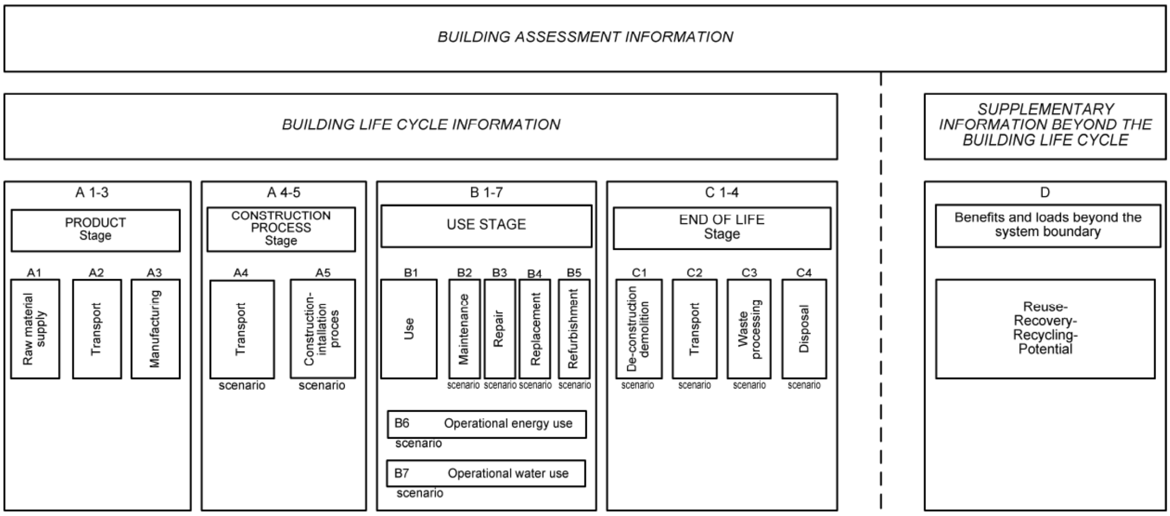

Fig. 1 Modules and life cycle stages of a building according to CEN TC 350

Applying the life cycle perspective, several alternative refurbishment strategies included in the rehabilitation project have been assessed. To evaluate and compare each rehabilitation strategy, it takes a single indicator (kWh primary energy), allowing to compare and evaluate different configurations and giving rise to propose a new concept of refurbishment strategies methodology.

The system boundaries are defined by the concept "cradle to gate", taking into account the Embodied Energy associated with the processes of extraction of the raw material and processing to factory gate. Due to lack of information not considered the construction and maintenance phases. Respect to end of life, the impact generated by the new facade about the impact from the structure and floors will be minimum and therefore not be taken into account in the calculations.

2 Case Study

This paper presents a comparison of different energy upgrading strategies for Amara neighbourhood in San Sebastian, Spain, where the most typical buildings are apartments built between 1965s and 1975s. This analysis is based on a real case, where apartment' owners decided to invest on the building refurbishment due to the existing constructive pathologies, high energy consumption and especially due to thermal discomfort. The main objectives of the refurbishment project were therefore to increase occupant comfort and reduce the energy use on the apartments.

2.1 Climate Analysis, San Sebastian

San Sebastian is one of the rainiest cities in Spain, where the annual average temperature is 14 °C. In summer, the daily average temperature is below 20 °C, so cooling systems are generally unnecessary, particularly if measures such as solar shading or night cooling are projected. In winter, the daily average temperature is about 10 °C, making the presence of heating systems needed. The consumption of the latter can be significantly reduced by an adequate level of insulation.

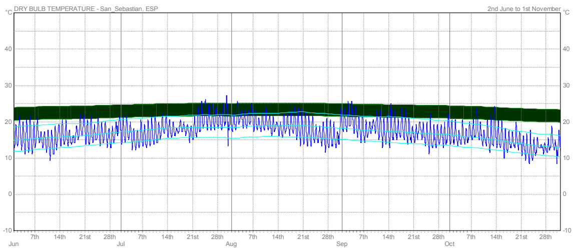

Fig. 2 *Dry Bulb Temperature – Summer*

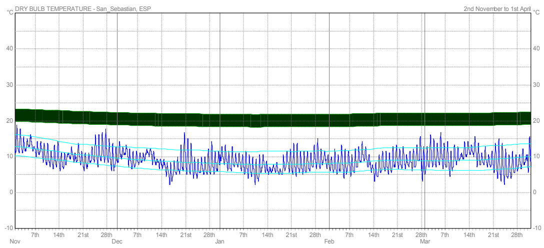

Fig. 3 *Dry Bulb Temperature – Winter*

2.2 Constructive typology

With the need to build more homes in less space, the environmental quality of the new districts of San Sebastian was reduced considerably after 1960´s, which had some effects on building design. Features such as very reduced dimensions of the inner courtyards, apartments with a single orientation or reduced distance with the surrounding buildings with consequent reduced solar access, had the effect of increasing the problem of energy consumption and decreasing indoor comfort. Among these new districts it is located the residential district of Amara, whose morphology is based on wide pads, towers and large blocks of commercial ground floor and 9 floors for residential use.

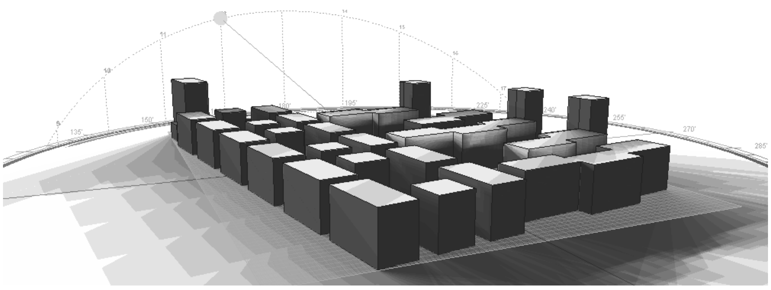

Fig. 4 *Shadow Range- 21st of December.*

2.2.1 Current State

Throughout this report is analyzed the energy performance and the refurbishment project of an existing building located on the street Isabel II of the district of Amara, whose construction features include the typology of the 1970´s in this district.

The building under assessment is formed by a down floor of commercial stores and 9 dwellings floors, distributed through three portals that share the same heating generation system. Each floor contains 12 apartments with different orientations and dimensions, so that overall building consists of 108 dwellings.

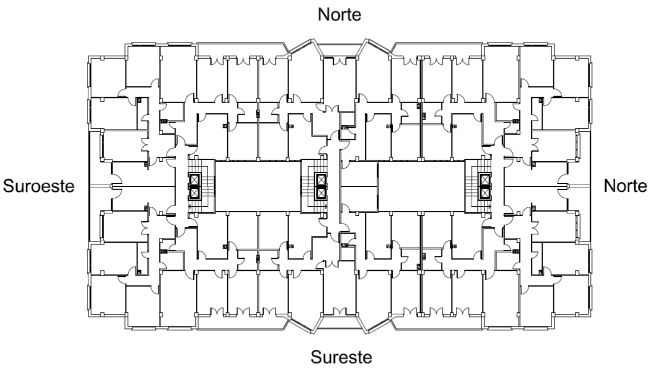

Fig. 5 *Plan view, building Isabel II 21-23-25*

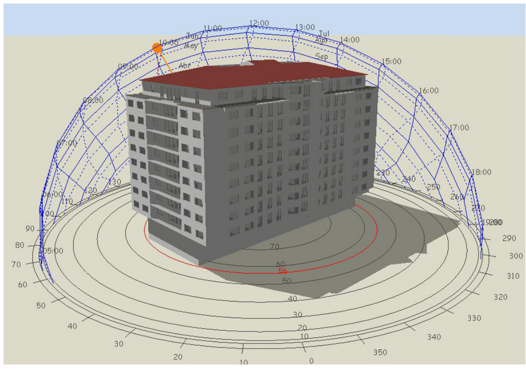

Fig. 6 *Design Builder Simulation Model*

Before refurbishment, the U-values of the building envelope did not meet any of the minimum requirements specified by current regulations [8].

Tab. 1 *Current construction layers and characteristic. Source [9]*

		Thickness (mm)	Density (kg/m^3)	Conductivity (W/mk)	U-value (W/m²k)
Façade	Exterior mortar	10	1350	0,70	1,12
	Brick	110	930	0,37	
	Air layer	50			
	Brick	110	930	0,37	
	Gypsum plastering	10	825	0,25	
Roof	Ceramic tile	20	2000	1,00	2,34
	Air layer	50			
	Reinforced concrete	200	2400	2,30	
Floor (F1)	Reinforced concrete	250	2400	2,30	1,79
	Air layer	500			
	Gypsum plastering	15	825	0,25	
Glass	6mm single glazing				5,77

Building models have been developed in the Design Builder [10] software in order to estimate the energy consumption of the building before and after refurbishment applying different alternative rehabilitation construction solutions. The simulation values have been defined following the guidelines of the current Spanish legislation [8]. The climate file used for the calculations is the file IWEC San Sebastian (International Weather for Energy Calculation) [11]. The building model has replicated building geometry, including overhangs, setbacks and the surrounding buildings. The common areas (stairs and portals) and the ground floor are unheated, without occupation and without internal gains.

Tab. 2 *Simulation Parameters*

	Quantity	Unit
Occupation	0,03	People/m²
Internal gains	4,4	W/m²
Heating setpoint	21	ºC
Lighting	300	Lux
Lighting	4,4	W/m²
Domestic Hot Water (DHW)	10,66	l/m²-day
ACH	0,7	1/h

In order to reduce the maximum the building energy consumption, different energy rehabilitation passive strategies have been proposed and simulated as shown in Table 3. The façade rehabilitated will consist in a ventilated façade. On the roof and on the floor of the first floor, will add a layer of XPS insulation.

Tab. 3 *Combination of passive refurbishment strategies*

Refurbishment	Option	Envelope	W-Double	W-Double LE	Triple
Opaque envelope	1	X			
Windows	2		X		
	3			X	
	4				X
Opaque envelope + Window	5	X	X		
	6	X		X	
	7	X			X

2.3 Inventory analysis and embodied energy analysis of building products

Through Inventory of Carbon and Energy [12] and Ecoinvent database [13] are defined values from primary embodied energy from non-renewable materials.

Tab. 4 *Refurbishment material characteristics. Source [9, 12, 13]*

Envelope, roof and floor (F1)	Surface (m^2)	Thickness (mm)	Conductivity (W/mk)	Embodied Energy (kWh/kg)
Insulation XPS	5581,4		0,038	25,66
Aluminum profile			230	60,55
Ceramic tiles	4408,7	20	1,2	4,03
Glazing	**Surface (m^2)**	**U-value (W/m^2k)**	**Solar Factor (g)**	**Embodied Energy (kWh/m^2)**
Double	1322,6	2,7	0,7	112,5
Double Low Emissivity	1322,6	2	0,6	124,35
Triple	1322,6	1,1	0,5	242

Within the envelope thermal refurbishment, has worked with the concept of "value U", avoiding the definition of insulation thickness for each of the construction types and working with a universal value all types of enclosures.

Tab. 5 *Thicknesses and material surfaces for each rehabilitation strategy*

Material	U Value								Unit
	Actual	0,7	0,6	0,5	0,4	0,3	0,2	0,1	W/m²k
XPS	0	16	25	38	57	88	151	341	mm
Aluminum	0	312	330	368	500	605	1482	34263	mm²

2.4 Results

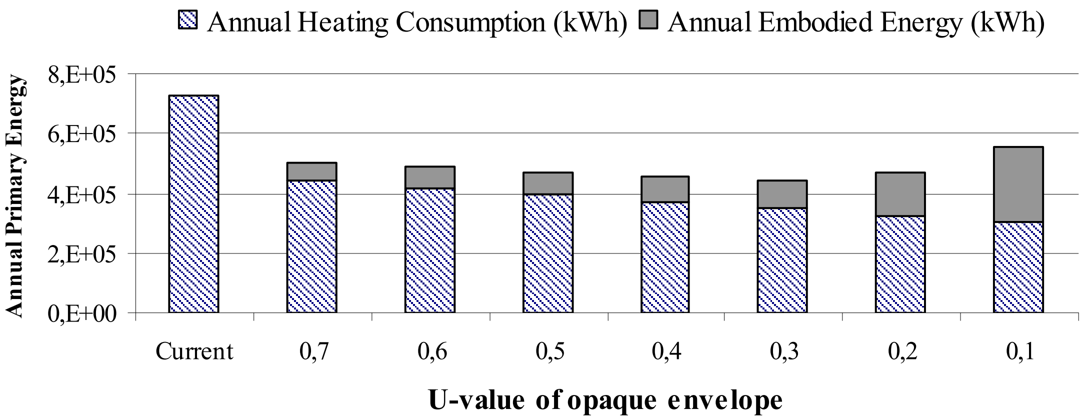

Fig. 7 *Reduction of Annual Primary Energy due to refurbishment with the Option 1*

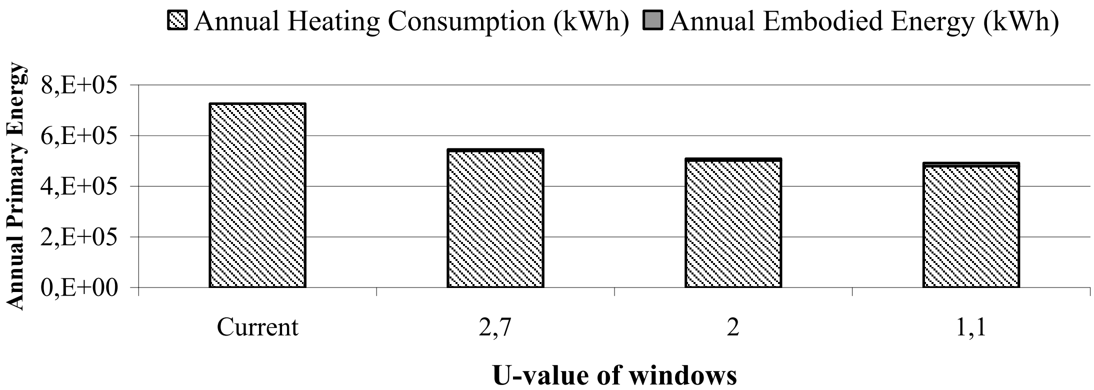

Fig. 8 *Reduction of Annual Primary Energy due to refurbishment with the Option 2–3–4*

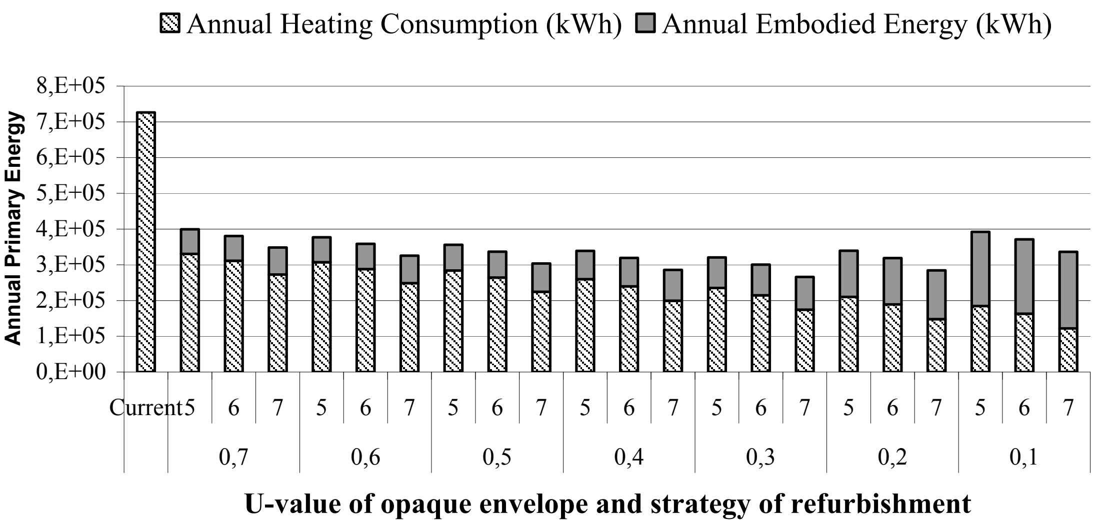

Fig. 9 *Reduction of Annual Primary Energy due to refurbishment with the Option 5–6–7*

2.4.1 Summary of results

Figure 10 shows the results of the total primary energy consumed by each refurbishment strategy applying the developed methodology. For each solution, the graph relates the primary energy consumption during the use phase (heating) to the primary energy consumption embedded in the materials used. In addition, a third axis has been included in order to quantify the total Annual Primary Energy consumption of each refurbishment strategy. This parameter can be used by architects and engineers to select the best strategy for building refurbishment taking into account a life cycle perspective.

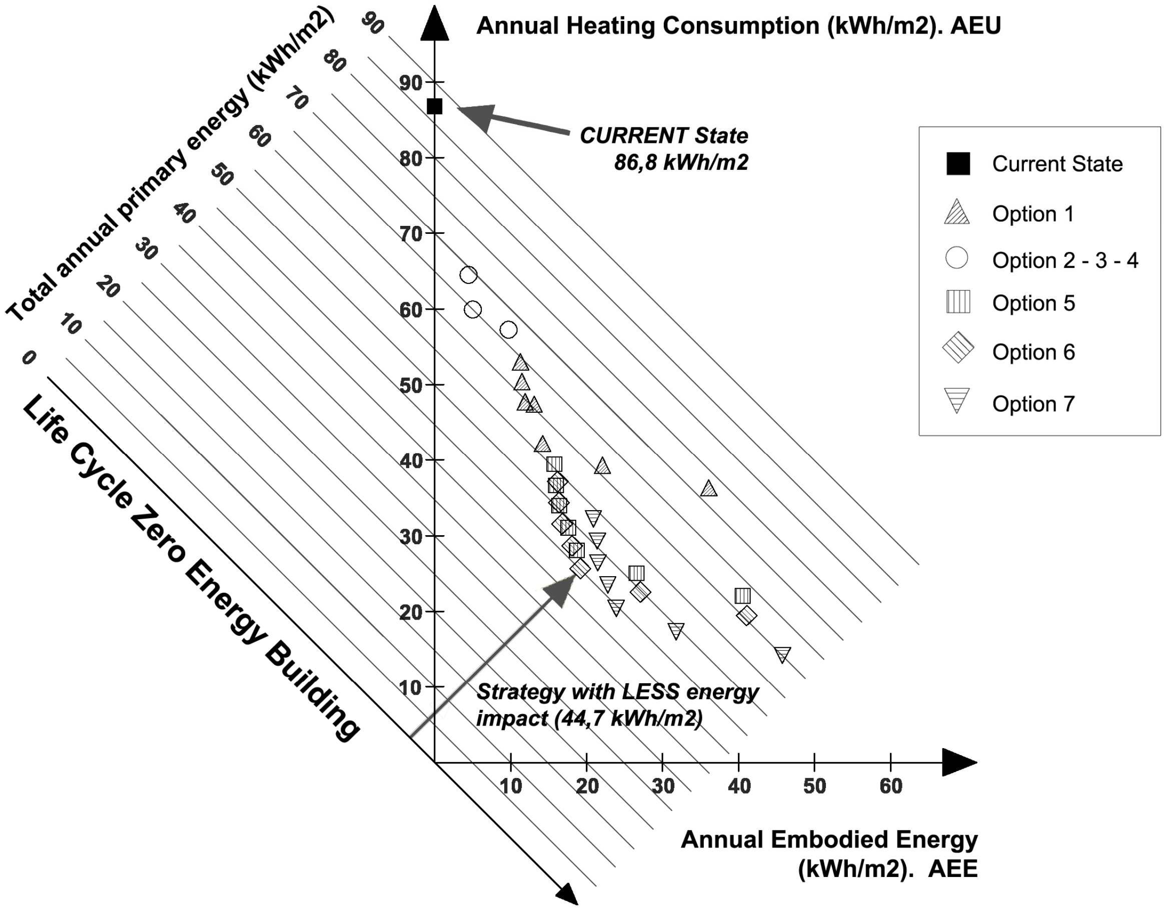

Fig. 10 *Total Annual Primary Energy graphic, showing annualized life cycle energy of each refurbishment strategies, as the distance to LC-ZEB line.*

For the particular building studied, the graph shows that the lowest life cycle energy impact of the building is obtained increasing the building wall insulation until a value of 0.3 W/m^2K and replacing the current glazing with double low-e. It has to be noted that a refurbished building with a very low heating consumption (AEU) but high embodied energy value (AEE) may need more energy than a building with average heating consumption but low embodied energy construction materials.

2.5 New materials

As a demonstration section of the importance of the embodied energy of the materials that make up each of the architectural strategies, plans to propose other constructive solution and the use of other materials for the rehabilitation of the façade and recalculate the value of AEE.

Much of the embodied energy associated with the ventilated façade is related to the use of aluminum, whose energy impact is high. However, aluminum is 100% recyclable material for which you do not harm their physical qualities after recycling. Furthermore, the recycling process requires only 5 % of the energy needed to produce the primary metal. Therefore, using aluminum with a high percentage of recycled metal could decrease the impact energy more than 80 %. [14]. AEU value (annual primary energy related with the heating consumption) will be the same, where we will work with the "optimal" thermal transmittance of the envelope (option 6 – U = 0,3 W/m²k and double glazing U = 2,0 W/m²K).

Tab. 6 *Annual embodied primary energy of each refurbishment strategy*

Refurbishment Strategy	**kWh/m^2**
1 – Ventilated façade with XPS insulation	20,16
2 – Ventilated façade with Mineral Wool insulation	17,82
3 – Ventilated façade with XPS insulation (recycled aluminum)	14,88
4 – Ventilated façade with Mineral Wool insulation (recycled aluminum)	12,55
5 – Façade SATE with XPS insulation	4,135
6 – Façade SATE with Mineral Wool insulation	1,709

3 Conclusions

The type of finish of the ventilated façade, the percentage of recycled aluminum used or the strategy of refurbishment (ventilated façade, SATE, indoor rehabilitation ...) can vary significantly the final results in terms of total energy required, decreasing the value of the embodied energy in the architectural solution by up to 91 %.

Therefore, in order to approach the goal of nearly-zero energy building (NZEB) marked by the European directive, it is essential to analyze and work with the embodied energy of each of the materials that make up the building envelope, structure, systems, etc. In that sense it is utterly important to help decision-makers (e.g. architects, engineers, promoters, owners...) to understand such need and take into account environmental aspects. To this end, the graphical presented in that paper may be useful.

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