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OPTIMAL COST AND THE ECONOMIC VIABILITY OF ENERGY-EFFICIENT HOUSING RENOVATION IN SPAIN

COSTE ÓPTIMO Y VIABILIDAD ECONÓMICA DE LA REHABILITACIÓN ENERGÉTICA DE VIVIENDAS EN ESPAÑA

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RESUMEN

Las exigencias europeas de ahorro energético en edificación establecen las directrices para que cada país miembro defina su propia metodología de coste óptimo, basada en términos de coste-eficacia, tanto para obra nueva como para rehabilitación. En el caso de España, actualmente esa metodología se encuentra en fase de desarrollo, por lo que el presente estudio aplica las directrices europeas y plantea diferentes medidas de rehabilitación pasivas en la envolvente para dos tipologías de edificios representativos en dicho país, un edificio entre medianeras en casco histórico y otro bloque de viviendas aislado, situados en cinco zonas climáticas diferentes. El trabajo relaciona la demanda y consumo energético (kW•h/m2 año) con el coste global (€) para diferentes propuestas, obteniendo los valores de coste óptimo y períodos de amortización. Se propone, además, el indicador de "coste30", como el coste adecuado para conseguir amortizaciones inferiores a 30 años, y se amplía el análisis incorporando el salario mínimo interprofesional a la inversión. Los resultados concluyen que la metodología de coste óptimo permite obtener valores adecuados y que, en ese marco, existe un abanico de intervenciones válidas que dependen principalmente de la tipología, la zona climática y los costes de inversión.

Palabras clave

desempeño térmico, renovación arquitectónica, ahorro de energía, costes de construcción.

ABSTRACT

The European requirements for energy savings in buildings set the guidelines by which each member country establishes their own optimal cost methodology with respect to cost-effectiveness, both in new buildings and renovations. In the case of Spain, this methodology is currently in the development phase. Therefore, this study applies the European guidelines and proposes different passive renovation measures in envelopes for representative building typologies in Spain: a building between party walls in a historic district and an apartment building, located in five different climatic zones. The study relates energy consumption and demand (kW•h/m2 year) and global cost (€) for different proposals, and determines optimal cost values and amortization periods. In addition, it proposes the cost30 indicator as the appropriate cost that enables amortization periods of less than 30 years; furthermore, the analysis is broadened by considering minimum wage in the investment. The results conclude that suitable values may be obtained with the optimal cost methodology, and that there are a variety of different valid renovation measures that depend mainly on typology, climatic zone and investment costs.

Keywords

thermal performance, building renovation, energy savings, construction costs.

INTRODUCTION

According to the recommendations of the European Community, it is currently crucial to reduce energy consumption in all sectors, with the building sector being responsible for 40% of total consumption. The bases for this reduction are laid on Directive 2010/31/EU (European Union, 2010), which develops new approaches and requirements in the area of energy efficiency in buildings and which have been transposed to the regulations of Spain (Building Technical Code, 2017).

Regarding the rehabilitation of buildings, according to modifications of the European Union (2019), 35% of the buildings are over 50 years old and 75% of the stock is inefficient, with a renovation percentage of less than 1.2%, so that rehabilitation has great potential for energy improvement, which can mean reducing consumption and CO_2 emissions around 5%.

The two main lines to address the energy problem of building in Europe are the commitment to standards of nearly zero energy consumption buildings (Nearly zero-energy buildings, nZEB) and rehabilitation. In the latter case, the main problem is the physical limitation of an existing building, and the measures to be adopted will differ from those proposed in new buildings, so solutions must be "technically, functionally and economically feasible", according to Article 7 of the Directive (European Union, 2010).

But in the energy equation it is necessary to include the economic parameter that is key to the economic viability of interventions, forcing to define among all the possible options those most suitable to achieve an optimal balance between investments made and energy costs saved up to depreciation.

For this reason, the European Community has established the need for each Member State to define its own methodological framework (under development in most countries) that allows calculating and comparing the profitability optimum, established in Delegated Regulation RD 244/2012 and in its explanatory guidelines (European Union, 2012b).

The methodology to be applied must be particularized and will depend on each Member State:

> "Despite a common methodology to calculate cost optimal levels, the results are not fully comparable between countries, as member states are free, for example, to choose the macroeconomic or financial perspective when calculating cost optimal values or have different national rules to calculate energy performance of buildings" (ECOFYS and EURIMA, 2015).

With a methodology not yet approved in Spain according to RD 244/2012 and the UNE-EN 15459: 2008 standard (AENOR-CEN, 2008), the only official reference (Ministry of Development, 2013) establishes a comparative analysis of different measures and measurement packages in existing and newly constructed buildings, for different climatic zones. Given the current absence of regulation and increasing energy requirements in the regulations, towards NZEB standards, the analysis of the optimal cost is considered as a key aspect on which the present study is raised.

There are other works that have already addressed the issue and that analyze a wide spectrum of buildings, among them the following stand out: the Episcope Project (2016); the Concerted Action project (CA-EPBD, 2016) or the guides published by ECOFYS in collaboration with the European Insulation Manufacturers Association (EURIMA) (2015); the TABULA project (2012), which establishes common criteria for classifying the stock of buildings according to age, size and climatic zone, in addition to other energy parameters.

Under the same methodology, other studies analyze a wide spectrum of building typologies, for representative climates of Europe and even consider buildings of almost null consumption NZEB (Zangheri, Armani, Pietrobon and Pagliano, 2018), in Italy (Corrado, Ballarini and Paduos, 2014) or including other uses such as offices (Arumägi, Simson, Kuusk, Kalamees and Kurnitski, 2017) or educational (Niemelä, Kosonen and Jokisalo, 2016).

Some authors propose different levels defining "mild rehabilitations, shallow renovations" for interventions that achieve energy savings of 32%, or "intense rehabilitations, deep renovations", which reach 80% (ECOFYS and EURIMA, 2012), referred to in other investigations as "Basic rehabilitations" or "plus" (Pérez, Calama and Flores, 2016).

Social aspects have also been incorporated that value the cost of investment per family (De la Cruz, De la Cruz and Simón, 2018) in mild, moderate or intense levels of investments, depending on the cost in €/housing (Re-Program, 2015), (Luxán, 2017).

There is no official methodology of optimal cost that provides a representative database of residential buildings in different climates in Spain, nor an assessment of the economic impact on families. Based on these deficiencies, the current study is formulated, for passive interventions in the envelope, with the objective of assessing the cost and amortization of different energy rehabilitation proposals in five climatic zones of Spain, in the Autonomous Community of Andalusia, quantifying fundamental parameters of energy demand for heating and cooling together (kW•h/m^2 year) and economic investment (€).

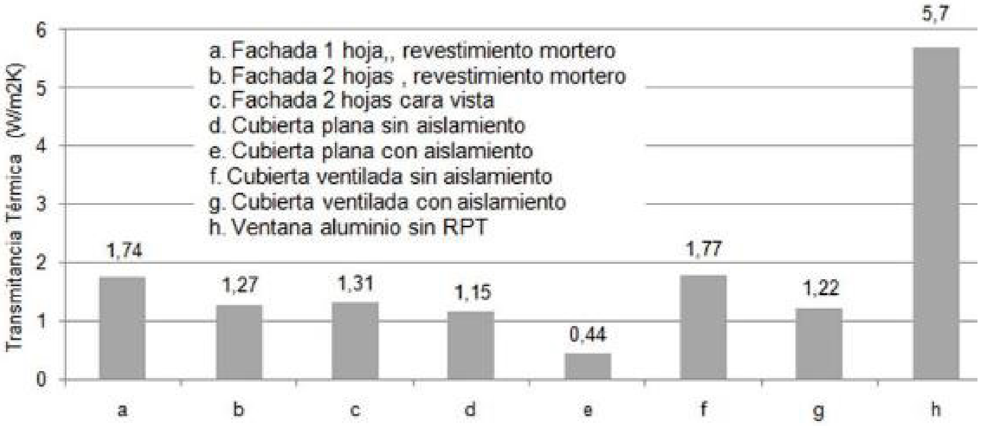


Figure 1. Thermal transmittance values U (W/m2K) in reference buildings.Source: Made by the author.

To achieve this goal, two typologies of residential buildings representative of a large part of the built park are analyzed. One of them is a building between town houses, located in an area of the historic center, and the second, a block building, located in a new residential area.

It is part of the objective to follow the optimal cost guidelines, prioritizing passive interventions in accordance with the global spirit of Directive 2010/31/EU, and incorporate the financial capacity of families including the minimum interprofessional salary.

METHODOLOGY

The methodology used in the study is indicated below:

- Definition of two reference buildings, a building between town houses (EM, by its initials in Spanish) and a block building (EB, by its initials in Spanish), as well as its constructive and geometric conditions, representative of much of the park built in Spain, based on statistical data.
- Definition of five climatic zones of study, according to CTE (2017).
- Definition of passive interventions to be carried out on the envelope, grouped into measures/packages/variants, according to the guidelines of the optimal cost methodology of RD 244/2012.
- Energy calculation, through the use of the dynamic simulation application LIDER-CALENER Unified Tool (HULC) (2017), a tool recognized in Spanish regulations, to obtain values of joint energy demand for heating and cooling, and primary energy consumption (kW•h/m^2 year).
- Economic calculation, through which the overall cost and residual value of each measure/package/variant is obtained. The overall cost is made up of the initial investment according to market prices and construction databases, plus the cost of energy during the useful life. The study is extended by assessing the economic impact per family with respect to the minimum interprofessional salary (SMI, by its initials in Spanish).
- Graphical representation of optimal cost and amortization. The study is extended with the proposal of "cost30", to achieve amortization of less than 30 years.

DEFINITION OF REFERENCE BUILDINGS

To cover the scope of the study, two reference buildings of the built park have been defined, according to statistical publications, which will allow expand the area of knowledge and perform a comparative analysis between both.

Regarding the surface, in Andalusia most of the houses (29.51%) have an area between 76 and 90 m2 (National Statistical Institute [INE], 2019), with a large percentage of brick facades (54, 35%) with mortar coatings (34.99%), passable flat roof and aluminum exterior carpentry (86.25%), (Development Ministry, 2018).

With this constructive characterization, envelope elements of reference cases have been defined, whose resulting thermal transmittance values are shown in Figure 1.

Considering the above parameters, two real reference buildings have been determined, a building between town houses (EM) and a block building (EB) (Figure 2), whose characteristics are summarized in Table 1.

Figure 2. Reference buildings: town houses building (EM) and block building (EB). Source: Photographs made by the author.

	Description of building	Geometry (Useful surf. /n° homes)	Windows (m^2 / %)	Constructive features U (W/ m^2K)
Town houses building (EM)	Years: 1900-1920 Lot: 180m^2 Vol.: 2.250m^3 Facades surf: 111,56m^2 Construct. Surf.: 450m^2	100 m^2 / 2	18,54m^2 / 2,56 %	Brick wall, 1 hoja: U=1,74 Town houses: U=2,33 Flat roof "andaluza": U=1,15 Aluminum window, single glass. U=5,70, g (lot factor)=0,85
Block building (EB)	Years: 1961-1980 Lot: 392,95m^2 Vol.: 19.254,55m^3 Facades surf: 2.732,80m^2 Construct. Surf: 2.841m^2	90 m^2 / 20	771,20m^2 / 18,60 %	Brick wall seen, 2 plates: U=1,31 Flat roof "catalana": U=1,22 Aluminum window, single glass U=5,70, g (lot factor)=0,85

Table 1. Characteristics of reference buildings. Source: Made by the author.

- Building between town houses (EM): located in the historic center, three floors, an exterior facade and an interior yard.
- Block building (EB): residential housing, isolated, twelve floors and four exterior facades.

DEFINITION OF CLIMATE ZONES

In Spain, fifteen climatic zones are defined in CTE (2017), covering a broad spectrum of hot and cold areas and that have generated in the traditional architecture different passive bioclimatic solutions and strategies in their adaptation to the environment, from the use of plant covers (Molina and Fernández-Ans, 2013) to natural ventilation strategies also used in continental temperate climates (Mercado, Esteves, Barea and Filippín, 2018).

The study cases are established for the Community of Andalusia (Spain), which comprises seven types of climate represented in Figure 3; which, in turn, correspond to five climatic zones, in accordance with the climatic zoning established by regulations (CTE, 2017, appendix B), so that the study can be extrapolated to other provinces.

The determination of climatic zones is defined by a letter, corresponding to the winter division, and a number, corresponding to the summer division, according to the following classification:

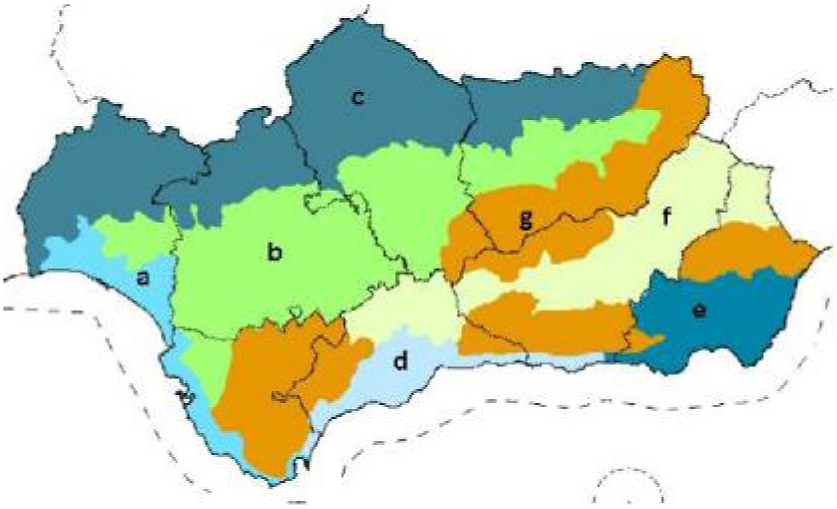


Figure 3. Types of Mediterranean climate in Andalusia: Oceanic (a), Continental (b), Semi-arid (c), Subtropical (d), Sub-desert (e), Continental (f), Mountain (g). Source: Ministry of Environment (2019).

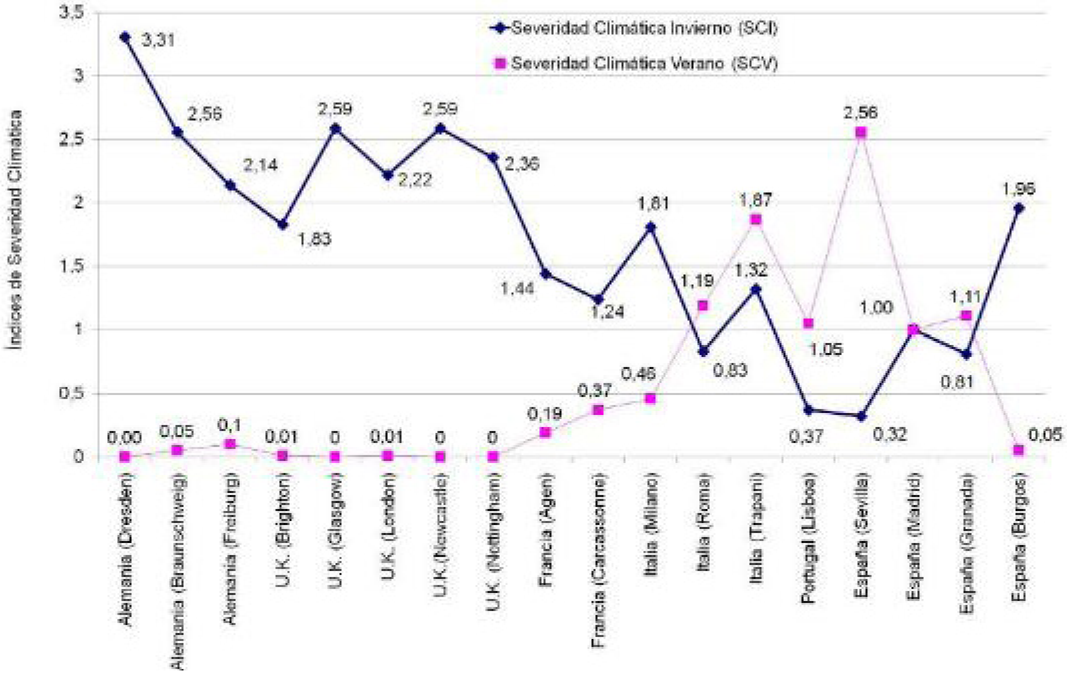


Figure 4. Climate Severity Indices in Europe. Source: Passive-On Project (European Commission, 2007).

- Climatic zone A3: Cádiz-Málaga
- Climatic zone A4: Almería- Huelva
- Climatic zone B4: Córdoba- Sevilla
- Climatic zone C3: Granada
- Climatic zone C4: Jaén

Compared to other European cities, some areas have high rates of climatic severity in summer (SCV) and intermediate levels in winter (SCI), as shown in Figure 4.

DEFINITION OF PASSIVE INTERVENTIONS

At this point, different passive rehabilitation interventions are determined that offer a reduction in the building energy demand, grouped into: measures, packages and variants, in line with Directive 2010/31 /EU and other studies (Suárez and Fragoso, 2016).

The measures are interventions on facades and roofs, inside and outside (SATE, External Thermal Insulation System - by its initials in Spanish) as well as the replacement

Measures		Variant 1: Individual packages	Variant 2: Total intervention
Exterior facade	5 cm EPS (U =0,52) 5 cm PIR (U =0,42)	Exterior facade (EPS) Interior facade (XPS) Exterior roof (BA) Interior roof (MW) Aluminum window, low glass e PVC window, low glass e	Exterior facade (EPS) + Exterior roof (BA) + PVC window, low glass e
Interior facade	5 cm EPS (U=0,50) 5 cm XPS (U=0,47) 5 cm MW (U=0,53) 5 cm TER (U=0,23) 5 cm PUR (U=0,48)		
Exterior roof	7 cm XPS (U=0,34) 7 cm BA (U=0,47)		
Interior roof	7 cm EPS (U=0,35) 7 cm MW (U=0,37)		
Aluminum carpentry	Al +vidrio (U=2,92) Al +vidrio bajo e (U=1,84)		
PVC carpentry	PVC + glass (U=2,74) PVC + low glass e (U=1,66)		

Table 2. Adopted measures/packages/variants. Source: Made by the author.

Setpoint temperature (°C)	Summer: 25-27 °C. Winter: 17-20 °C
Ventilation	Summer: 4/perf./hour at night (1-8h)
Infiltrations	0,24 perf. /hour for housing blocks
Gaps	Shadow factor 0,7; blinds down 30%.
ACS/Housing Demand	56 liters/day at 60°C
Air conditioning	60% homes: Air/air heat pump 2x1 (EER 2,5; COP 2,7) 40% homes: Air/air heat pump 1x1 (EER 2,5; COP 2,7) + electric heater 2kW thermal (Joule effect)

Table 3. Main calculation parameters considered in HULC. Source: Made by the author.

of windows. In all cases the thermal transmittance limit values have been met (CTE, 2017).

The packages define constructive solutions using various insulators (EPS, expanded polystyrene; PIR, Polyisocyanurate; XPS, extruded polystyrene; PUR, Polyurethane foam; MW, mineral wool).

The variants group different measures and packages, offering several energy rehabilitation options.

As for the thicknesses of insulations, on facades they are defined of 5cm and on roofs of 7cm, composed of concrete tiles with built-in XPS insulation (BA, insulating tiles). The exterior carpentry is made of aluminum with thermal bridge break or PVC, in both cases with insulating glass and low emissive.

Finally, a Variant 1 has been analyzed, composed of several individual measures, and another Variant 2 as a total intervention (Table 2).

ENERGY CALCULATION

The calculation has been carried out with the HULC dynamic simulation application that allows to establish the demands and consumption of primary energy necessary to maintain predefined comfort conditions, according to operational conditions of setpoint temperature, occupation, lighting and ventilation indicated in Appendix C, residential use profiles (CTE, 2017, appendix C).

The main calculation parameters are indicated in Table 3; 60% of the houses have been considered to have a

A3			Climate zones demand / consumption (kW•h/m2 year)				
			A4	B4	C3	C4	
Variant 1: Individual Packages							
Walls	EM	Exterior facade -EPS	28,37/65,2	38,89/71,9	56,18/91,6	78,72/ 128,3	73,83/ 117,4
		Interior facade-XPS	32,92/74,5	40,22/76,1	58,06/93,4	80,58/ 137,7	76,08/ 114,9
	EB	Exterior facade -EPS	40,27/91,8	51,72/97,7	72,88/120,9	113,03/192,1	100,61/151,9
		Interior facade-XPS	42,01/94,94	53,55/102,8	75,79/125,8	115,95/197,1	101,99/164,2
Roofs	EM	Exterior roof-BA	35,62/80,6	43,86/84,49	61,85/110,5	88,60/ 151,4	82,07/ 132,3
		Interior roof-MW	35,24/79,8	43,32/83,4	61,04/109,1	87,54/ 149,6	81,09/ 130,7
	EB	Exterior roof-BA	47,33/107,1	59,39/114,4	83,76/149,1	130,14/222,4	114,87/185,2
		Interior roof-MW	47,13/106,7	59,15/113,9	83,44/148,5	129,67/221,6	114,45/184,5
Windows	EM	Aluminum window, low e	27,79/62,9	33,41/64,4	47,93/85,6	66,33/ 113,3	63,13/ 101,8
		PVC window, low e	30,16/68,3	36,69/70,7	51,47/91,9	71,03/ 121,4	67,71/ 109,1
	EB	Aluminum window, low e	41,19/93,1	52,45/100,7	74,04/131,8	112,51/191,3	100,02/161,2
		PVC window, low e	40,80/92,2	52,02/99,8	73,42/130,7	111,31/189,2	99,14/ 159,8
Variant 2: Total intervention							
Wall + Roof + Window	EM	Exterior facade-EPS Exterior roof-BA PVC window, low e	28,37/63,8	34,63/57,1	45,22/71,4	54,79/ 83,82	63,66/ 94,6
Wall + Roof + Window	EB	Exterior facade-EPS Exterior roof-BA PVC window, low e	36,18/81,4	46,29/76,4	63,43/100,2	89,48/ 136,9	100,41/148,6

Table 4. Joint demand/Consumption (kWh/m2 year). Town house building (EM), block building (EB). Source: Made by the author.

2x1 multi-zone direct air/air expansion system, and the remaining 40%, a 1x1 compact system, including an electric heater support.

Table 4 shows results of joint demand for heating and cooling, and consumption (kW•h/m^2 year), for the different variants and the five climatic zones.

ECONOMIC CALCULATION

GLOBAL COST

For each proposal a global cost is calculated, sum of the investment, operation and replacement cost, as well as the cost of disposal, according to the European methodology (European Union, 2012a) (Figure 5).

The initial investment costs include the previous demolition and preparation work, materials and the installation (labor, tools, scaffolding, rubble containers), considering the negligible design derivatives. Manufacturer prices (DANOSA, s/f; URSA, s/f) and construction price bases in Spain (ATAYO, s/f) have been taken as reference; COAATGU, 2018; Junta de Andalucía, 2017).

The annual cost includes those due to operation over a period of 30 years, mainly associated with energy costs. Replacement and maintenance costs are considered null.

The cost of energy is quantified with a 59.10% electric mix (€ 0.12/kW•h) and 40.90% from other sources (€ 0.035/kW•h), according to official passing factors of primary energy (Government of Spain, 2016) and the price of kW•h (Institute for Diversification and Energy Saving [IDEA], 2016). The annual increase in energy cost has been estimated at 4%.

RESIDUAL VALUE

It is necessary to consider the residual value in 30 years of the interventions, discounting it from the initial investment cost according to the linear depreciation defined in RD 244/201 (Figure 6).

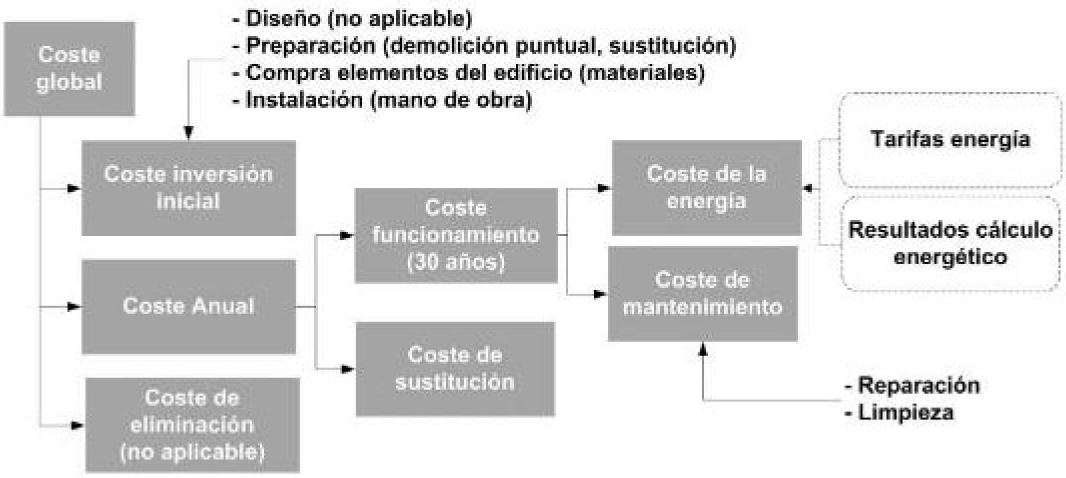


Figure 5. Cost categorization according to the European framework. Source: Guidelines RD 244/2012 (European Union, 2012a).

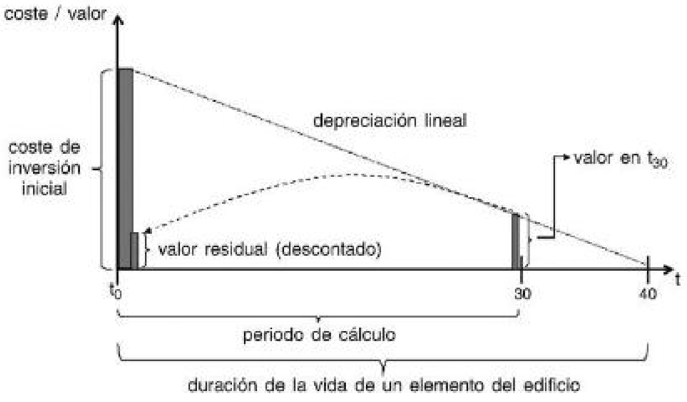


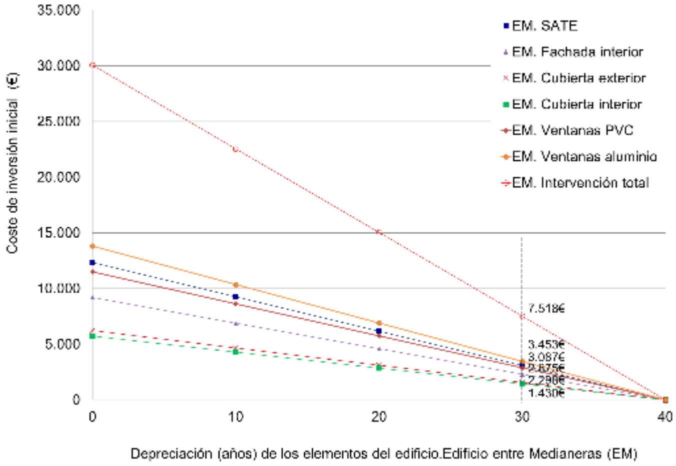
Figure 6. Depreciation of the element of a building. Source: Guidelines RD 244/2012 (European Union, 2012a).

Considering a maximum depreciation of 100% in 40 years, in 30 years a residual value of 25% is obtained, a limit associated with the useful life of facades; the respective results are indicated in Figures 7 and 8 for Variant 1 (6 individual measurements) and Variant 2 (total intervention), in the two types of the analyzed buildings.

ECONOMIC RESULTS

From the previous results, the global cost value results in 30 years (initial investment + consumption with 4% increase in energy price - residual value) in €/m^2 of constructed area, indicated in Table 5. The initial investment costs are valued in m^2 of each construction solution (facade, roof or window).

The social aspect is incorporated, valuing the economic capacity to address the cost of the initial investment by both housing and family unit, based on the minimum interprofessional salary (SMI), established in Spain at € 900/month for the year 2019 and considering two families in the



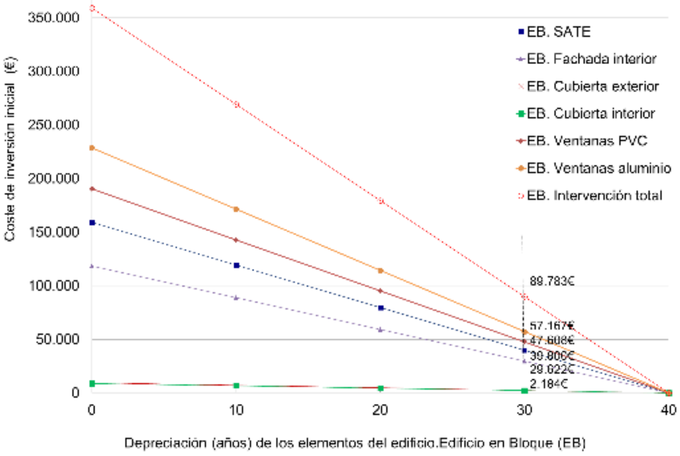


Figure 7. Depreciation and residual value in 30 years. Town houses building (EM). Source: Made by the author.

Figure 8. Depreciation and residual value in 30 years. Building in block (EB). Source: Made by the author.

	Global Cost €/m² constructed		Initial investment €/m² constructive solution	Impact €/m² housing		Cost €/family		N° times SMI	
	EM	EB		EM	EB	EM (2 fam.)	EB (20 fam.)	EM	EB
Variant 1. Individual packages									
Ext. facade - EPS	48,95	149,12	48,92	27,44	56,04	6.170	7.960	9	11
Int. facade- XPS	48,24	143,00	36,41	20,42	41,71	4.600	5.925	7	8
Ext roof. - BA	45,99	128,37	41,48	13,83	3,34	3.110	470	4	1
Int. roof. - MW	44,78	127,64	38,14	12,71	3,07	2.860	440	4	1
Al window	50,81	169,91	296,51	30,69	80,50	6.910	11.430	10	16
PVC window	49,33	158,78	246,93	25,56	67,04	5.750	9.520	8	14
Variant 2. Total intervention									
Ext. facade EPS +Ext. roof BA +PVC window	78,49	191,03	-	66,83	126,43	15.040	17.960	21	26

Table 5. Global cost and investment per family. Town houses building (EM), block building (EB). Source: Made by the author.

building between town houses and twenty families in the block building.

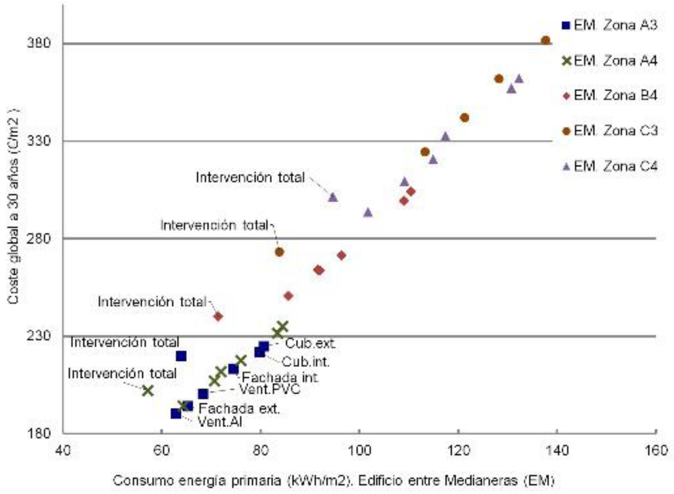
Results indicate that interventions in the building between town houses represent between 4 and 21 times the SMI, and 1 to 26 for the block building. The lowest values correspond to interventions on roofs and the highest for Variant 2 of total intervention.

The cost per family unit allows to define intervention levels according to other publications, which delimit them in light (<€ 2,500/house), moderate (€ 2,500-4,500/house) or intense (>€ 4,500/house) investment, (Re-Program, 2015). Similar studies establish for the Metropolitan Region of Chile three levels of intervention according to family income (Low-Medium-High incomes), with very low percentages of initial investment by families 2%-3%-0%, which are financed by government support and bank loans (García and Croxford, 2015); and other authors consider low-cost solutions for investments of less than € 4,200 /family (Luxán, 2017).

OPTIMAL COST AND AMORTIZATION

The values obtained from the global cost in 30 years are related to the annual consumption (kW•h/m²) calculated in HULC, obtaining the optimal cost represented in Figures 9 and 10. Here is the building between town houses that offers the lowest consumption.

The results allow select the most appropriate optimal cost among the different proposals, so that the values of the x-axis indicate the optimum level of profitability; and for those proposals with similar costs, the one with the lowest use of primary energy will be the one that defines the optimum level.



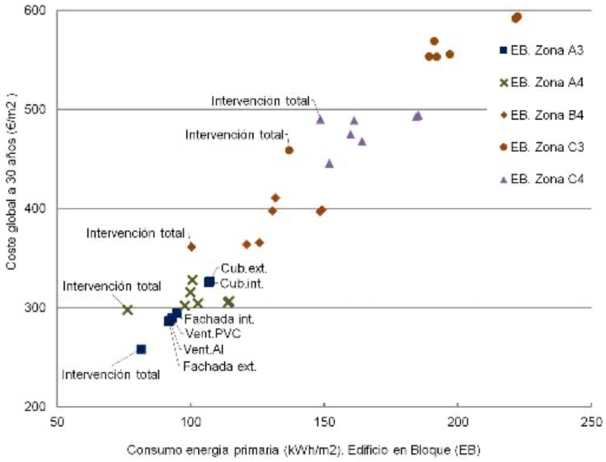


Figure 9: Optimal cost building between town houses (EM). Source: Made by the author.
Figure 10. Optimal cost. Block building (EB). Source: Made by the author.

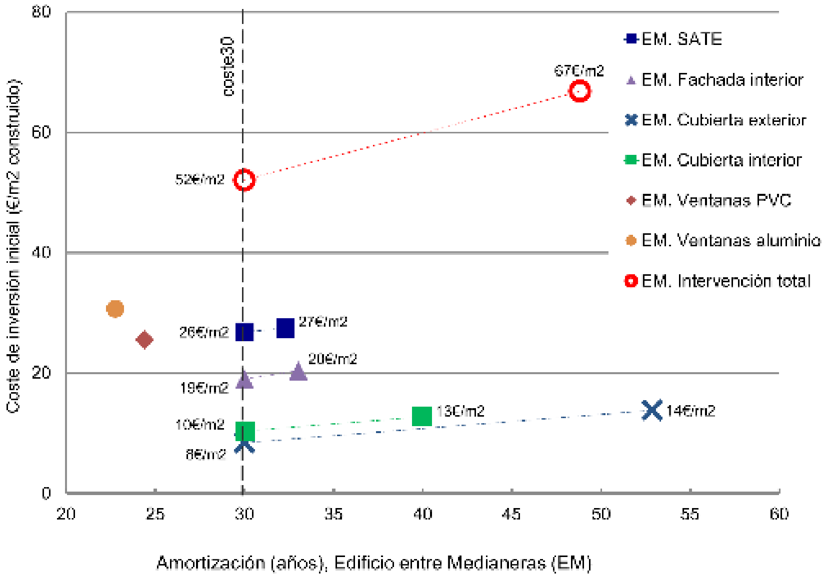


Figure 11. Amortizations (years) and "cost30" (€/m2), average values of the 5 climatic zones. Town houses building (EM). Source: Made by the author.

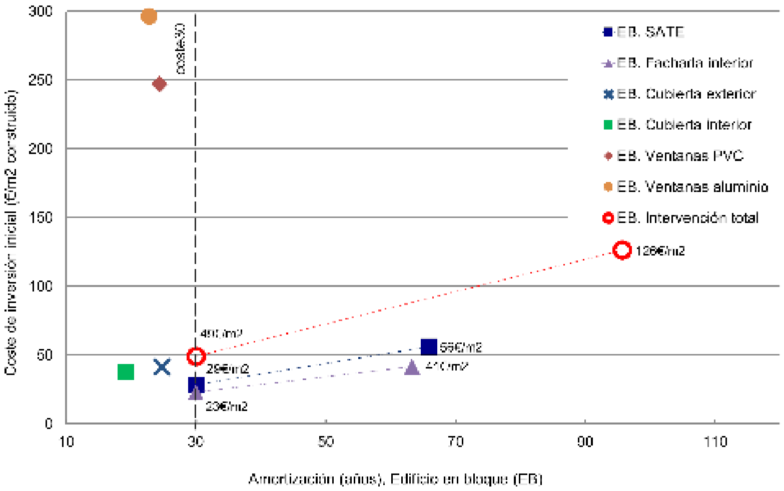


Figure 12. Amortizations (years) and "cost30" (€/m2), average values of the 5 climatic zones. Block Building (EB). Source: Made by the author.

AMORTIZATIONS AND "COST30" PROPOSAL"

Once the optimum cost is determined, amortization periods (years) of each intervention are calculated, dividing the initial investment cost (€) by the energy savings obtained (€/year).

For depreciation over 30 years, the study proposes the value of "cost30", setting the depreciation value and calculating the initial cost. This value is an indicator of how much it would be necessary to lower the initial cost in order to obtain amortizations in a maximum of 30 years.

In order to facilitate the interpretation of results, all values have been calculated with the average values of the five climatic zones. Figures 11 and 12 show the calculated depreciation and the "cost30" values".

It is necessary to indicate that some of the measures already offer amortizations of less than 30 years, such as PVC or aluminum windows, in both models, and roof interventions for block building.

Results indicate that, in the case of the total intervention, it is required to reduce the cost from 67 to € 52/m^2 built in the town houses building, and from € 126 to € 49/m^2 in the block building.

RESULTS AND DISCUSSION

The optimal cost methodology is based on energy calculation models under standard use conditions, which are still estimates of the real behavior of buildings.

The results of energy demands show great variability depending on the climatic zone: the lowest values occur in zone A3 (Cádiz-Málaga) and the highest in zone C3 (Granada).

It is necessary to disassociate the amortizations with the consumption, since high consumption offers very low returns on investment. Among the calculated models, the result varies significantly if they are considered standard or high consumption profiles, when European guidelines clearly bet on reductions in energy consumption.

The best amortizations are obtained with the renovation of carpentry, around 23 years, similar to the interventions in roofs for the case of the block building (Figures 11 and 12).

Results of the "cost30" indicator offer different values, depending on the model. In the block building costs should be reduced by 61% for total intervention, and around 45% for exterior and interior facade interventions. In the case of the building between town houses, results are less demanding, due to the lower surface area of the outer envelope with reductions of 23% being required for total intervention, 35% on roofs and approximately 5% on exterior and interior facade interventions.

CONCLUSIONS

The methodology developed in this work is based on the European framework and allows generating valid indicators, however, the definition of a methodology for Spain would clarify some criteria of calculation and energy prices that affect the obtained results.

A moderate increase of 4% in the price of energy has been considered, but its variability in a 30-year horizon would significantly modify the results obtained; however, its increase would improve amortization terms.

There is no single optimal cost value as various options are presented, depending on the case. In most of them, total intervention provides the best values; although it represents the highest initial investment cost, this is offset by the reduction in energy consumption and costs during its 30-year useful life. They also show adequate optimal costs for interventions on facades and windows.

Considering the climatic zones, the best optimal costs are obtained for zones A3 and A4, representative of milder climates and with lower consumption expenses. Regarding models, these costs are for the building between town houses, which is representative of buildings of low construction quality and that offer a wide margin of improvement in the reduction of energy consumption.

In addition to the optimal cost, it is necessary to include the family income parameter in energy accounting and assess interventions based on salary income. In that sense, the variant of total intervention is the one that involves more economic effort, being the most appropriate - due to its lower initial cost - improvement in facades and windows. There are different levels of investment, ranging from € 440/family to € 17,960/family, among which there is a range of proposals that represent from 1 to 26 times the minimum interprofessional salary.

In relation to amortization, not all interventions are viable and depend on the type of building and the climatic zone. Therefore, the study proposes the "cost30" indicator as an adequate value to set costs for amortizations in 30 years. In the case of the building between town houses, it is not necessary to significantly reduce the investment cost, on the contrary, in the block building some of the solutions should reduce more than 60% of their costs. This measure could be encouraged with state aid and subsidy plans, or through cheaper products.

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