THE PASSIVHAUS STANDARD IN THE MEDITERRANEAN CLIMATE: EVALUATION, COMPARISON AND PROFITABILITY

Saldaña-Márquez, H.[1], Gómez-Soberón, J.M.[2], Arredondo-Rea, S.P.[3], Almaral-Sánchez, J.L.[4], Gómez-Soberón, M.C.[5], Rosell-Balada, G.[6]

INTRODUCTION

One of the main environmental problems faced by the global community in the twenty-first century is unquestionably the reduction of greenhouse gas emissions (Fuller and Crawford 2011). To face this challenge, the European Union (EU) has set the so-called 2020 Horizon as one of its main objectives: limiting the emission of greenhouse gas emissions by 20%, satisfying 20% of all energy needs through renewable sources, and improving energy efficiency by 20% (The European Union 2012). The last projection forecast in 2012 by the European Environmental Agency (EEA) established that Spain was one of the countries in the EU furthest from reaching these objectives (The European Union 2013). As a result, implementing measures devised to meet the 2020 objectives is currently a priority for the Spanish government.

In recent decades, the housing sector has played a decisive role in increasing global energy demands and greenhouse gas emissions (Nejat et al. 2015). In 2014 Spain's housing sector's energy consumption needs represented 19% of total national consumption and 31% of the electricity demand (IDAE 2013). Starting from the design phase, reduction in energy consumption per square meter has become a prerequisite for the majority of buildings (Parameshwaran et al. 2012; Koo et al. 2014).

The importance and urgency exhibited by the EU housing sector in achieving the government objectives outlined in the 2020 Horizon have led the energy market to show a clear trend towards buildings with higher energy performance in the future (Shimschar et al. 2011). Similarly, the success factor of energy efficiency initiatives will depend to a large degree on the method or the indicators used when measuring energy performance in each building (Abu Bakar et

1. Universitat Politècnica de Catalunya, Escola Tècnica Superior d'Arquitectura de Barcelona, Departament de Construccions Arquitectòniques I, Departament d'Estructures a l'Arquitectura, Barcelona, Spain.
2.,6. Universitat Politècnica de Catalunya, Escola Politècnica Superior d'Edificació de Barcelona, Departament de Construccions Arquitectòniques II, Barcelona, Spain, josemanuel.gomez@upc.edu (corresponding author2)
3.,4. Universidad Autónoma de Sinaloa, Facultad de Ingeniería Mochis, Los Mochis, Mexico.
5. Universidad Autónoma Metropolitana, Escuela de Ingeniería Civil, Departamento de Materiales, Mexico D.F., Mexico.

* A significant value in the Spanish housing sector, the total consumption of isolated houses is double that of block houses; in the specific case of heating consumption, the proportion is 4 times greater, exceeding 6 times in the Mediterranean zone (IDAE 2011).

** According to Asdrubali et al. (2008), the isolated house is the least favorable in Spain.

al. 2015; Day and Gunderson 2015). As a result, selecting one energy evaluation methodology over another can be decisive in the path taken by Spain, change the current perception of the country, and increase Spain's standing within the EU.

Several studies (Feist et al. 2005; Schnieders and Hermelink 2006; Mahdavi and Doppelbauer 2010; Mlakar and Strancar 2011; Hatt et al. 2012; Dahlstrøm et al. 2012; Dequaire 2012; Proietti et al. 2013; Ridley et al. 2013; Stoian et al. 2013; Moran et al. 2014; O'Kelly et al. 2014) indicate that the Passivhaus standard (PS) can be used as a highly effective tool in both limiting greenhouse gas emissions and increasing building energy efficiency.

Other studies (Audenaert et al. 2008; Moeseke 2011; Allacker and De Troyer 2013; McLeod et al. 2013; Mlecnik 2013; Stephan et al. 2013) challenge the adoption of the PS because they consider other options within the energy market to be better from both environmental and financial perspectives. Nonetheless, the precursors to the PS claim that the benefits of the standard can be replicated in any part of the world through its use during the design phase (Feist 2014; Passive House Institute 2010, 2015; Passipedia 2015).

The main objective of this study was to analyze the viability of using PS through the Passive House Planning Package (PHPP) tool in the Spanish housing sector, focusing on its use in the Mediterranean climate in the Province of Barcelona. To that end, we selected an isolated semidetached home, that exhibits the typical characteristics of current Spanish housing so that any possible deficiencies or virtues of adopting the PS are easily observable.

The study was conducted using 3 construction proposals (PC, P1, and P2); the initial proposal (PC) is defined by conventional construction technology, while the remaining 2 proposals (P1 and P2) offer different construction alternatives focused on optimization (window glass, the building envelope, and improved installations), enabling evaluation of the PS criteria compliance. To test the ease of obtaining PS compliance without the need for changing the architectural design of the project, the design and space distribution of the PC alternative remained the same for the P1 and P2 options.

KEYWORDS:
passivhaus standard, energy efficiency, PHPP, Mediterranean climate, construction costs

THE PASSIVHAUS STANDARD

The Passive House (PH) concept was first developed in Sweden from collaboration between Bo Adamson of Lund University and Dr. Wolfgang Feist (Proietti et al. 2013). This concept is characterized by a holistic approach, combining several measures into a consistent framework (Feist 2005). More specifically, PH refers to "a building, for which thermal comfort can be achieved solely by post heating or post cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions" (Passipedia 2015). One of the main advantages of PH is that even though building a PH implies a higher construction cost, the additional expense will be recovered in a few years by the energy savings (Stoian et al. 2013).

According to Schnieders and Hermelink (2006), "the standard has been named 'Passive House' because the 'passive' use of incidental heat gains—delivered externally by solar irradiation through the windows and provided internally by the heat emissions of appliances and occupants—essentially suffices to keep the building at comfortable indoor temperatures throughout the heating period." The standard fundamentally consists of three elements: an energy limit, a quality requirement and a defined set of preferred passive systems that allow the energy limit and quality requirement to be met cost effectively (EERG 2015).

The combined heat and electric energy demand of a building is the Primary Energy demand (PE). Therefore, the PS includes a requirement for the PE (see methodology) to prevent the space heat demand from being reduced at the expense of large internal gains from electric appliances and to discourage direct electric heating (Feist 2005).

With approximately fifty thousand Passive Houses in use worldwide (2012 data), the Passivhaus standard is rapidly spreading all over the world (Passipedia 2015). Several authors (Feist 2005; Schnieders and Hermelink 2006; Hatt et al. 2012; Moran et al. 2014) claim that PH can save up to 50% of the total primary energy consumption.

The Passive House Institute (2015) stated that "the PH concept itself remains the same for all of the world's climates, as does the physics behind it. Yet while Passive House principles remain the same across the world, the details do have to be adapted to the specific climate at hand."

A comparison of PH and low-energy houses revealed that PH CO_2 emissions were approximately 25-40% lower than low-energy houses, with a 5% increase in initial construction costs (Mahdavi and Doppelbauer 2010). Another investigation by Audenaert et al. (2008) concluded that a PH costs 16% more than a standard house; the insulation and ventilation are the main causes for this extra cost. They also noted that "when energy-saving buildings are to be promoted at a large scale, governments should aid with larger subsidies to make passive houses more attractive to individuals planning projects in the residential sector."

The existing situation might determine which design strategy should be pursued more actively to achieve better energy performance. However, the large number of elements in the market today makes it necessary for architects to have a tool to assist them in identifying the best combinations for any specific situation (Ochoa and Capeluto 2008; Kallaos and Bohne 2013; Chen et al. 2015). This study sought to clarify some aspects regarding the adoption of the PS criteria in the Mediterranean climate during the design phase for the Spanish context. The research discussed in this paper investigated the PE, CO_2 emissions and profitability.

METHODOLOGY

The PHPP V-1.2.1 software was used to evaluate the PS among the study samples (PC, P1 and P2). According to Mlecnik et al. (2010), "the tool was developed independently of German building legislation and the German implementation of the Energy Performance of Buildings Directive (EPBD). The accuracy of the PHPP tool as a predictor for energy use has been validated on several demonstration projects. Its main advantage compared with other design and evaluation tools is that is has been specifically created as a design and certification tool for passive houses and that it regularly incorporates new research results in its calculation procedures."

To obtain more conclusive results on the implementation of PS in Spain, a parallel assessment was performed in PHPP; the energy efficiency assessment of the proposals was run in CERMA software, which is an application recognized by the Ministry of Industry, Energy and Tourism and the Ministry of Public Works, that obtains the qualification energy efficiency in new construction buildings for the entire Spanish territory (MINETUR 2015).

The PS is only favorable when it is in compliance with its specifications (Feist 2013): a maximum value of 15 kWh/(m^2a) in the specific heating demand or a maximum of 10 W/m2 in the heating load; a maximum value of 15 kWh/(m^2a) + 0.3 W/(m^2aK) * Dry degree hours[3] (DDH) in the specific cooling demand or a maximum of 10 W/m2 in the cooling load; and a maximum specific primary energy demand (including domestic electricity) of 120 kWh/(m^2a). Therefore, proposals P1 and P2 were forced to comply with the PS requirements (using alternative construction systems). As a result of these study variables, external criteria were required to facilitate equivalence between them (and with respect to the PC proposal).

In this study, we selected an economic assessment and cost-effectiveness as the comparative criteria of the study samples because these are considered the usual parametric criteria in the construction sector; these criteria were used as discrimination or rejection variables for the equivalent alternatives (Georges et al. 2012; Allacker and De Troyer 2013; Alam et al. 2014; Galvin 2014). With the use of financial and energy evaluations of the variables, we were able to compare the results and assess the cost-effectiveness of changing from a PC system to the P1 or P2 system; this comparison allowed us to determine trends, draw parallels and identify optimum action alternatives.

The proposals for the modifications studied did not affect interior spaces, the project geometry, volumes or the established uses of each space. To prevent uncontrolled variables from affecting the results of the study, no variations or modifications in the building surroundings or orientation were allowed.

Energetic assessment

Because primary energy can be produced on the building site by renewable energy, the boundaries between total energy demand, delivered energy and primary energy are difficult to define (Dequaire 2012). Therefore, the values referring to occupation, equipment, and energy consumption were limited in accordance with the guidelines established in the PHPP, for which the following considerations were made:

- Data entered into the PHPP concerning the climate for the proposed location were determined by the software Meteonorm V-6.1.0.23 (°N Lat: 41.668, °E Long: 2.255, Altitude: 282, Time Zone: 1, Random Seed: 1-5, Albedo: Automatic, Diffuse and Tilt Radiation Model: Perez, Temperature Model: Standard (hour), Period Radiation: 1981-2000, Period Temperature: 1996-2005).
- The typology and properties of the ground were considered as clays and silts: Thermal conductivity: 1.5 W/(mK), Heat capacity: 3.0 Mj/(m^3K), Floor slab area: 115.4 m^2, Floor slab perimeter: 46.4 m, U-Value for PC: 3.521 W/(m^2K), U-Value for P1 and P2: 0.447 W/(m^2K); the U-value varies between proposals because the P1 and P2 have insulation in the slab construction system that contacts the ground. The depth of the groundwater table was 3 m, and the groundwater flow rate was 0.05 m/d.

- The maximum of the supply and extract air demands was 363 m³/h, and the supply air per person was assumed for dwellings: 30 m³/(P*h). For summer ventilation, the ratio of time during which the windows are opened to total time was 50% at night and 70% during the day. The preceding parameters are useful to assess the energy consumption from forced ventilation and air conditioning.
- The solar collector that provided hot water was assumed to have a deviation from north of 180º, an angle of inclination from the horizontal of 40º and a collector field height of 1.04 m.

  The assumptions of the appliance electricity consumption in the home were as follows: Clothes Washing: 1.25 kWh/Use, for a standard 5 kg wash load and considering the most unfavorable consumption. Clothes drying: 4.00 kWh/Use, assuming a standard 5 kg wash load and considering the most unfavorable consumption. Dishwashing: 0.92 kWh/Use, assuming a standard load of twelve place settings and considering common consumption. Cooking with electricity: 0.20 kWh/Use considering the PHPP value for an induction ceramic cooktop. Refrigerating: 0.31 kWh/Use considering common consumption. Freezing: 0.64 kWh/Use considering common consumption. Consumer electronics: 80 W considering the PHPP value for residential use.

Economic assessment

The budgets used were based on the quantification of various items included on every construction proposal (PC, P1 and P2) for which the Bank BEDEC of the Institute of Construction Technology (ITeC) was used (ITEC 2015). Determining the basic prices is necessary for the construction or realization of each unit of work (quantities of raw materials used, commitment length of operators, equipment and tools, and auxiliary means required).

Once the basic prices of each item have been obtained and multiplied by the total volume, the Execution Material Budget (EMB) was obtained. This budget will increase with (by applying the usual coefficients) indirect costs (2%), overhead costs and industrial benefit (13% and 5%, respectively), and finally taxes (10%, reduced rate), resulting in the Contract Execution Budget (CEB) (State Agency 1987) using 2013 prices.

An identical treatment was applied to each proposal studied, only changing the alternative building system improvements proposed in P1 and P2; therefore, the budget variances that are identified relate to the environmental certification in economic terms.

The economic assessment corresponding to operational energy accounted for a 20-year period, for which the following considerations were made:

- The energetic demands were considered by the PHPP results.
- To determine the potential future increases in the annual kWh price, the reported average percentage in the five years previous to 2013 was used.
- The price and taxes for electricity (0.146230 € and 5.11%, respectively) and natural gas (0.050789 € and 0.23%, respectively) were established for April 2013. Therefore, we considered an annual rate of increase of 4.1% and a monthly flat fee of 7.65 € for electricity and an annual rate of increase of 2% and a monthly flat fee of 2.42 € for natural gas.

[3] Time integral of the difference between the dew-point temperature and the reference temperature of 13 °C throughout all periods during which this difference is positive (Feist 2013).

- The price of pellets (0.484848 €) was established by their consumption in kg and was determined using 2013 values. Therefore, we considered an annual rate of increase of 2%; we did not consider a monthly flat fee and taxes because these are subsidized by the government.
- A VAT of 21% was considered for electricity, natural gas and pellets.

Profitability

Two common and widely used indicators were used in the economic assessment: the Internal Rate of Return (IRR) and the Net Present Value (NPV). Both indicators were determined using spreadsheet software. For these calculations, a number of periods (n = 20 years) was used, and the initial investment cost was calculated as the difference in CEB between the PC alternative and the other two proposals (P1 and P2).

The cash flow or the predicted annual income from alternatives P1 and P2 was determined based on the savings from reduced energy consumption. Finally, the IRR calculation was made starting in the fifth year, and the NPV calculation considered three different inflation scenarios: 2%, 4% and 6%.

DESCRIPTION OF THE OBJECT OF STUDY

The project is a 3-story building (see Figure 1 and Figure 2) that includes two housing units, with each unit covering 223.14 m^2 of useful area; both units are symmetrical and have the same distribution of spaces and use (see Table 1 and Table 2). The main orientation of the homes is north-south; the glass surface of the northern facade represents 11.25% of the total surface, while the southern facade has 61.42% glass coverage. Due to the descending slope of the lot on which they were built, their basements begin to diverge from the ground in a southerly direction.

FIGURE 1: Project description.

FIGURE 2: Project render.

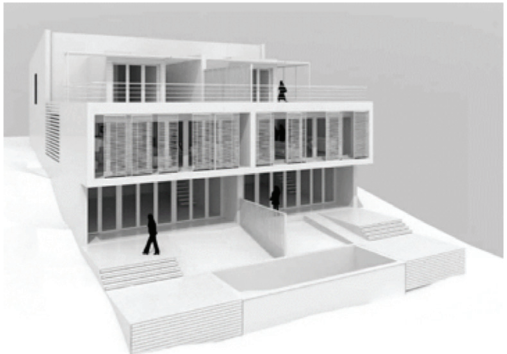


TABLE 1. Useful Areas and Treated Floor Areas (PHPP)

Floor	Useful Areas		Treated Floor Areas	
	1 Unit	2 Units	1 Unit	2 Units
BS (m²)	68.39	136.78	28.10	56.21
GF (m²)	92.00	184.00	80.40	160.80
FF (m²)	62.75	125.50	55.34	110.68
TOTAL	**223.14 m²**	**446.28 m²**	**163.84 m²**	**327.69 m²**

TABLE 2. Area groups (PHPP)

Area Group	Surface
Exterior wall (m²)	336.87
Partition wall (m²)	100.90
Accessible roof (m²)	148.5
Non-accessible roof (m²)	111.0
Basement ceiling (m²)	115.36
Floor slab (m²)	157.30
TOTAL THERMAL ENVELOPE	**982.26 m³**

The horizontal and vertical structural members of the buildings consist of monolithic unidirectional reinforced concrete beams and columns; the foundations consist of spread footings and isolated footings according to the location of the columns and retaining walls.

GENERAL FEATURES

The project is located in the town of l'Ametlla del Vallès, which is part of the province of Barcelona (41°40'5.24"N, 2°15'20.03"E), and the plot covers 1053 m^2 (39 m x 27 m), with a mean slope of 20% at 282 m above sea level. According to the Koppen-Geiger scale, the climate region corresponding to the location is "Csa" (C: Warm temperate, s: Summer dry, a: Hot summer) (Kottek et al. 2006). Before evaluating the project based on PS criteria, the PC alternative of this study and the construction variations that result in P1 and P2 are all subjected to meticulous compliance with all construction codes and regulations typical of the Spanish construction sector (see Table 3).

Specific features

The basic initial data for the PHPP included the calculated U-values (the thermal transmittance of the materials used in the envelopes) and their corresponding thicknesses because these

TABLE 3. Legal Framework

Normative	Description	
Technical Building Code (TBC) Article 3 of law 38/1999	DB-HR	Noise protection.
	DB-HS	Sanitation.
	DB-SI	Safety in case of fire.
	DB-SE	Structural safety.
	DB-SUA	Safety in use and accessibility.
	DB-HE	Energy saving.
EHE-08	Compliance requirements: Reinforced concrete.	
REBT	Low voltage electrical regulations, Royal Decree 842/2002 of August 2, 2002.	
RITE	Rules of installation: Thermal installations in buildings, Royal Decree 1027/2007.	
Decree 68/2010:	Processing and approval of technical documents recognized by the technical edification code.	
Decree 135/1995	Accessibility Code of Catalonia.	
Decree 21/2006	Adoption of environmental criteria and eco-efficiency in buildings.	
Municipal scope	General Urban Plan (14/01/1987).	

are some of the main parameters that control energy consumption and energetic efficiency in residential buildings (see Table 4).

TABLE 4. Description of U-Values

Building elements	Building assembly Description	Proposal (s)	U-Value [W/(m²K)]	Thickness (cm)
Exterior wall	Coating (20 mm) + gero brick (140 mm) + air chamber (50 mm) + expanded polystyrene panel (50 mm) + totxana brick (70 mm) + gypsum plaster (15 mm)	PC	0.448	34.50
	Coating (15 mm) + thermal clay (190 mm) + gero brick (100 mm) + expanded polystyrene panel (80 mm) + totxana brick (40 mm) + gypsum plaster (15 mm)	P1	0.310	44.00
	Coating (15 mm) + thermal clay (190 mm) + gero brick (100 mm) + expanded polystyrene panel (120 mm) + totxana brick (40 mm) + gypsum plaster (15 mm)	P2	0.230	48.00
Partition wall	Gero brick (140 mm) + expanded polystyrene panel (50 mm) + gero brick (140 mm)	PC, P1 and P2	0.476	33.00
Accessible roof	Reinforced concrete slab (300 mm) + expanded polystyrene panel (80 mm) + perlite (50 mm) + mortar (20 mm) + ceramic tile (20 mm)	PC	0.370	47.00
	Reinforced concrete slab (300 mm) + expanded polystyrene panel (120 mm) + perlite (50 mm) + mortar (20 mm) + ceramic tile (20 mm)	P1 and P2	0.260	51.00
Non-accessible roof	Reinforced concrete slab (300 mm) + expanded polystyrene panel (80 mm) + perlite (50 mm) + gravel (70 mm)	PC	0.370	50.00
	Reinforced concrete slab (300 mm) + expanded polystyrene panel (120 mm) + perlite (50 mm) + gravel (70 mm)	P1 and P2	0.260	54.00
Basement ceiling	Reinforced concrete slab (300 mm) + gypsum plaster (15 mm) + marble flooring (20 mm)	PC	2.460	33.50
	Reinforced concrete slab (300 mm) + gypsum plaster (15 mm) + marble flooring (20 mm) + perlite (80 mm)	P1 and P2	0.424	41.50
Floor slab	Reinforced concrete slab (250 mm) + gravel (50 mm)	PC	3.520	30.00
	Reinforced concrete slab (250 mm) + gravel (50 mm) + perlite (80 mm)	P1 and P2	0.447	38.00

The terms "Gero and totxana" brick are used in Catalonia. For more information, see the UPC (2015).

For the carpentry details corresponding to envelope openings (windows), improvements were proposed for the types of glass used, their number on each element, their thickness, and the characteristics of their insulating chamber according to each one of the proposals: PC, P1 and P2 (see Table 5).

TABLE 5. Description of Windows

Windows characteristics	PC	P1	P2
Winter / Summer reduction factor of north orientation (average value)	63% / 47%	62% / 46%	62% / 46%
Winter / Summer reduction factor of east orientation (average value)	81% / 65%	43% / 55%	52% / 55%
Winter / Summer reduction factor of south orientation (average value)	61% / 35%	68% / 36%	68% / 36%
Winter / Summer reduction factor of west orientation (average value)	27% / 30%	43% / 55%	52% / 55%
Window/Glazing Area of north orientation (m²)	18.24 / 15.70	18.24 / 11.60	
Window/Glazing Area of east orientation (m²)	1.80 / 1.50	7.56 / 5.00	
Window/Glazing Area of south orientation (m²)	75.03 / 68.20	75.03 / 59.50	
Window/Glazing Area of west orientation (m²)	13.32 / 11.60	7.56 / 5.00	
Total (Window / Glazing) Area (m²)	108.39 / 97.10	108.39 / 81.00	
U-Value of glazing (W/m²K)	2.90	1.10	0.60
U-Value of frames (W/m²K)	3.30	0.97	0.97
G-Value (Perpendicular radiation)	0.77	0.56	0.54

Different installation systems were used for each of the proposals in compliance with indoor air quality requirements to satisfy indoor comfort and improve heating and cooling for the different study variables, in addition to those necessary for the solar energy contribution to useful heat, as shown in Table 6.

TABLE 6. Description of Facility Systems

Facility systems	Description	PC	P1	P2
Ventilation data	Effective heat recovery efficiency	0%	50%	
	SHX efficiency		100%	
	SHX heat recovery efficiency		62%	
Heating and cooling load	Heating load (W)	18,195.00	5,034.00	3,943.00
	Specific heating load (W/m²)	55.50	15.40	12.00
	Cooling load (W)	8,345.00	4,464.00	4,146.00
	Specific max. cooling load (W/m²)	25.50	13.60	12.70
Hot water provided by solar	Estimated solar fraction of DHW production	64%	60%	84%
	Solar contribution to useful heat (kWh/m² year)	17.00	18.00	26.00
Heat generation	Ratio of heat generator space heat run	101%		139%
	Ratio of heat generator DHW run	132%	135%	
	Ratio of heat generator, DHW and space heating	103%	116%	

SHX: Subsoil Heat Exchanger; DHW: Domestic Hot Water.

Based on the specific characteristics of the PC, P1 and P2, the EMB varied by submitted proposal. The facade, facilities, insulation and cover were the budget lines that presented more variations between the different projects (see Table 7).

TABLE 7. Breakdown of the Contract Execution Budget (CEB)

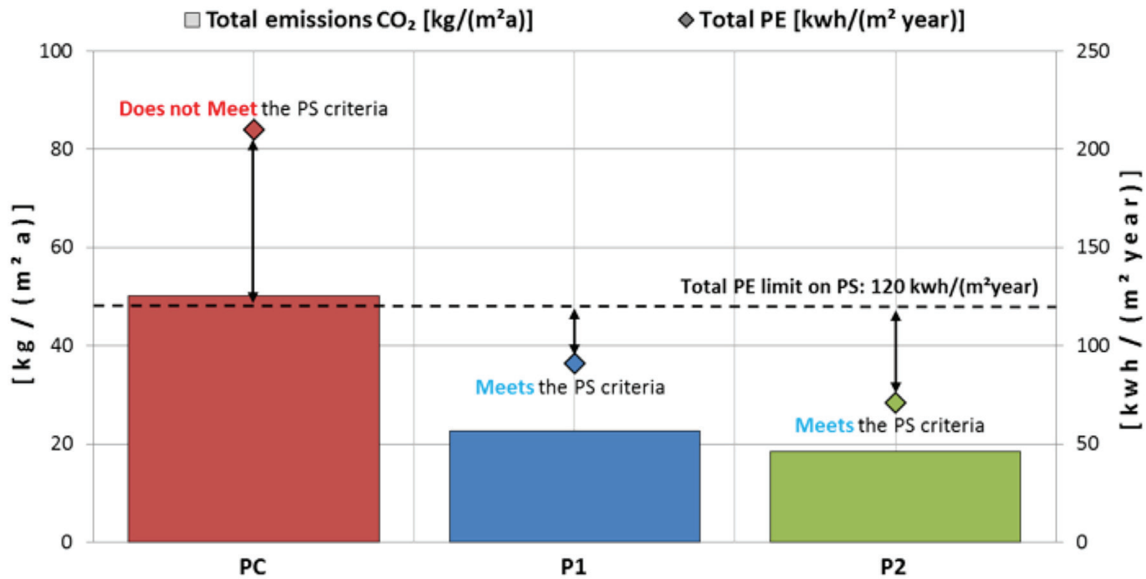
Data	PC	P1	P2
Ground preparation	18,493.25 €		
Foundations	37, 557.94 €		
Structure	93,751.10 €		
Coating	110,129.58 €		
Waste management	6,012.29 €		
Quality control	2,927.79 €		
Health and safety	17,186.97 €		
Signaling	16,824.60 €	16,825.50 €	
Urbanization	76,327.31 €	76,537.05 €	
Partitions	32,116.82 €	32,338.17 €	
Facade	78,474.62 €	99,542.30 €	100,365.45 €
Facilities	54,498.30 €	70776.53 €	100,317.91 €
Insulation	9,910.94 €	18,404.15 €	19,241.22 €
Cover	23,583.53 €	27,319.51 €	27,319.51 €
Execution Material Budget (EMB)	***577,795.02 €***	***627,802.13 €***	***659,003.72 €***
Overhead costs and industrial benefit	*109,781.05 €*	*119,282.40 €*	*125,210.71 €*
Value Added Tax (VAT)	*68,757.61 €*	*74,708.45 €*	*78,421.44 €*
Contract Execution Budget (CEB)	**756,333.68 €**	**821,792.99 €**	**862,635.87 €**

RESULTS

Energetic assessment

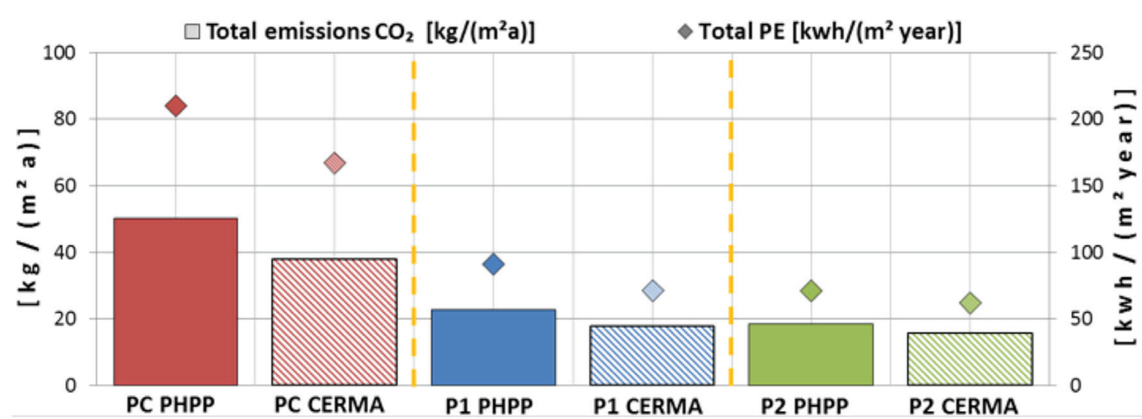
Once the data of any given proposal were introduced, the operational energy was evaluated and a comparison was made between each proposal. The PHPP verified the behavior of the 3 study alternatives; the values obtained by the PHPP highlight that proposals P1 and P2 (which meet the PS criteria) exhibit much lower PE and CO_2 emissions than the PE and CO_2 emissions of the PC (which does not meet the PS criteria), as shown in Figure 3.

FIGURE 3: PHPP results



These results show that the PE was reduced by 57% in P1 compared to PC, while P2 showed a greater reduction of 66%, which is within the estimated range of other studies (Feist 2005; Schnieders and Hermelink 2006; Hatt et al. 2012; Moran et al. 2014). The results show a 22% reduction for P2 compared to P1. The CO_2 emissions generated by PC are reduced by 55% using P1 and 63% using P2. The results show an 18% reduction for P2 compared to P1. The energy efficiency assessments from CERMA software show the values of total PE and CO_2 emissions of proposals P1 and P2 and demonstrate a large reduction compared to PC. A comparison between PHPP and CERMA shows a minimum differential range that varied between 13% and 20% for PE and 16% and 25% for CO_2 emissions on each proposal, as shown in Figure 4.

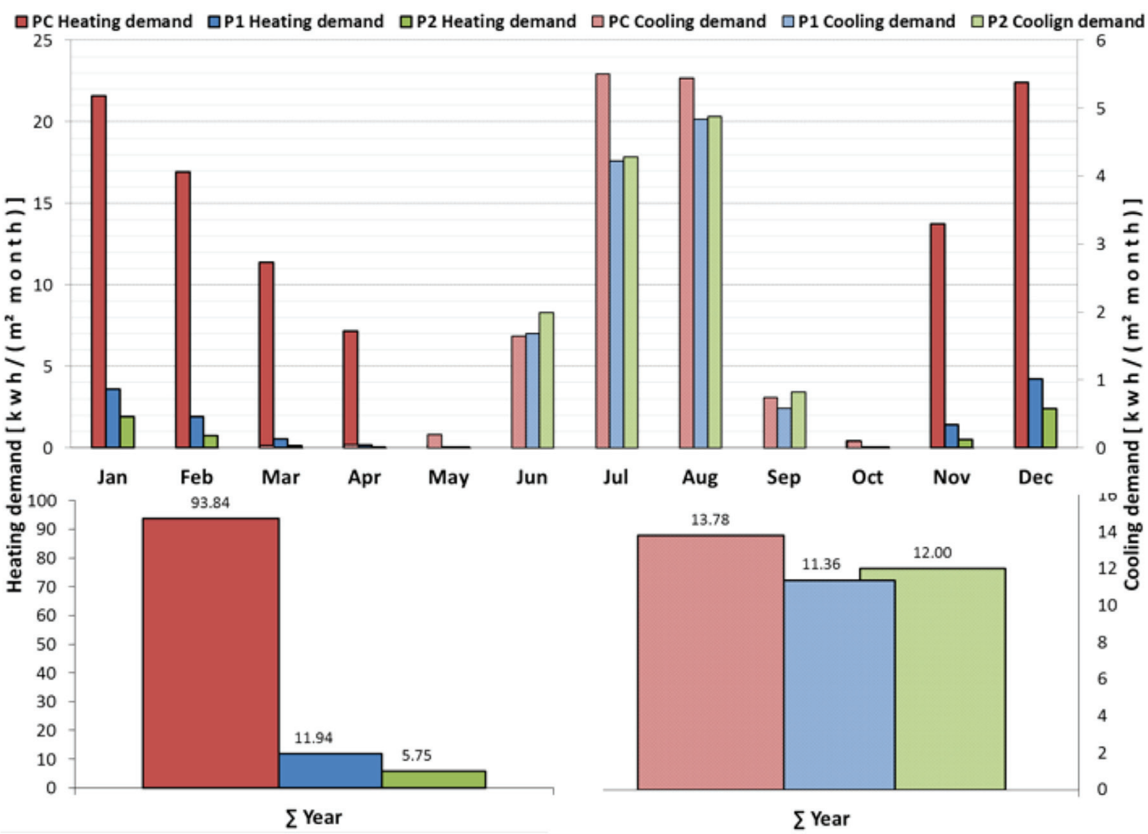
FIGURE 4: Results of the PHPP and CERMA



A comparison with other software reinforces the veracity of the PHPP results and obtains more conclusive findings. As a product of the changes made to each of the proposals (as given in the description of the study object) and following the assessment results, P2 is the most environmentally efficient proposal, followed by P1 and finally PC with a very large difference from the other two proposals.

Some researchers have argued that the problem with the PS assumption is that the standard mainly focuses on heating demand (McLeod et al. 2013; Mlecknik 2013; Stephan et al. 2013) by switching the importance of the repercussions of cooling demand. The result of this particular case study shows that this argument is valid because the modifications made under the PH concept have indeed produced greater reductions in heating demand and very limited reductions in cooling demand (see Figure 5).

FIGURE 5: Specific heating and cooling demand



P1 and P2 presented significant reductions in heating demand with respect to PC, with P2 reducing heating demand by 94% and P1 reducing heating demand by 87%. The most significant reductions were those registered in the period from November to April. The P1 and P2 proposals also showed reductions in cooling demand; however, in contrast to the specific heating demand, the cooling demand had more moderate reductions, with P1 reducing the cooling demand by 18% and P2 reducing cooling demand by 13% compared to the PC. The months during which the cooling demands are critical are July and August.

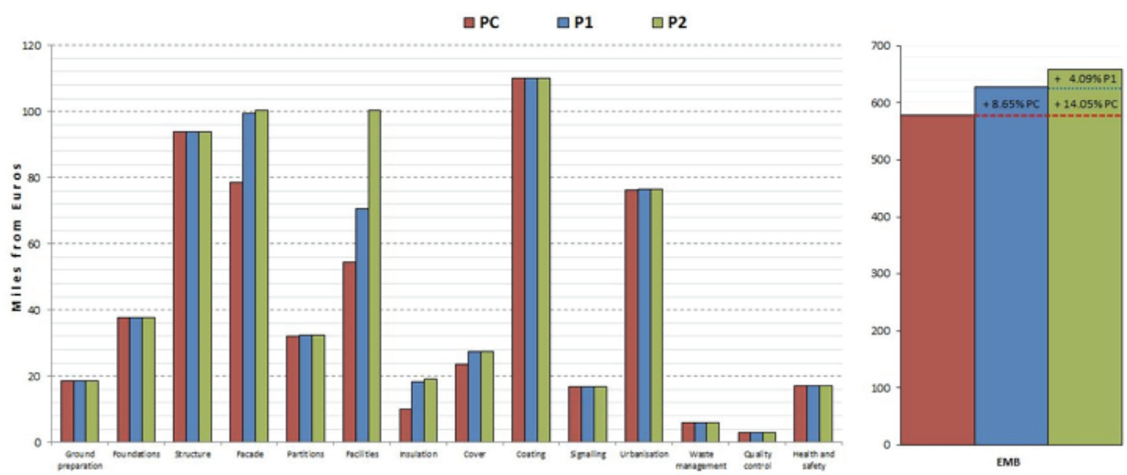
With further developments and diffusion of the Passivhaus standard, requirements to limit the energy used for space cooling are now taken into account (Dequaire 2012). The PS parameters are clearly more focused on reducing the specific heating demand, but to obtain better results in specific cooling demand, the PS parameters are changing. Feist (2013) mentioned that "the criteria for cooling and dehumidification apply provisionally and may possibly have to be adapted with advances in knowledge." In fact, some authors (Santamouris and Kolokotsa 2013; Kubota and Toe 2014) have shown various heat dissipation techniques that can be taken into account for the PHPP software, with the prospect of reinforcing the cooling demand assessment.

Economic assessment

A good residential building project depends not only on the available energy improvements, new and innovative materials and the construction quality. The economic aspect must also be evaluated because an improved project will be more expensive than the original, and whether this increased cost is worthwhile should be determined.

P1 shows an increased cost of 8.65% with respect to the PC, with the main variations resulting from the facade, insulation, facilities, and cover. Similarly, P2 shows an increased cost of 14.05% with respect to PC, with the main variations resulting from the same sources as those in P1. However, P2 costs 4.90% more than P1, with the main variation resulting from the insulation, as shown in Figure 6.

FIGURE 6: EMB budget line variations of the proposals



In terms of the EMB budget lines distribution of the proposals (see Figure 7), facilities play a greater role in P1 and P2 and show the highest increase compared to the other modifications. Regarding PC, the facilities are located in the medium range of the EMB. Moreover, coating represents the biggest line of the EMB on each of the proposals: 19% for PC, 18% for P1 and 17% for P2.

With initial inversion and the total amounts of energetic demands by year (see Table 8), the economic assessment of the proposals shows that improving PC to achieve compliance with the PS is cost-effective in P1 and P2 (see Figure 8). P1 becomes more cost-effective after the seventh year, while P2 begins to be more cost-effective after the ninth year compared to the initial investment and the energy cost of the PC alternative over time. However, P2 becomes more cost-effective than P1 after the seventeenth year.

FIGURE 7: EMB budget lines distribution of the proposals

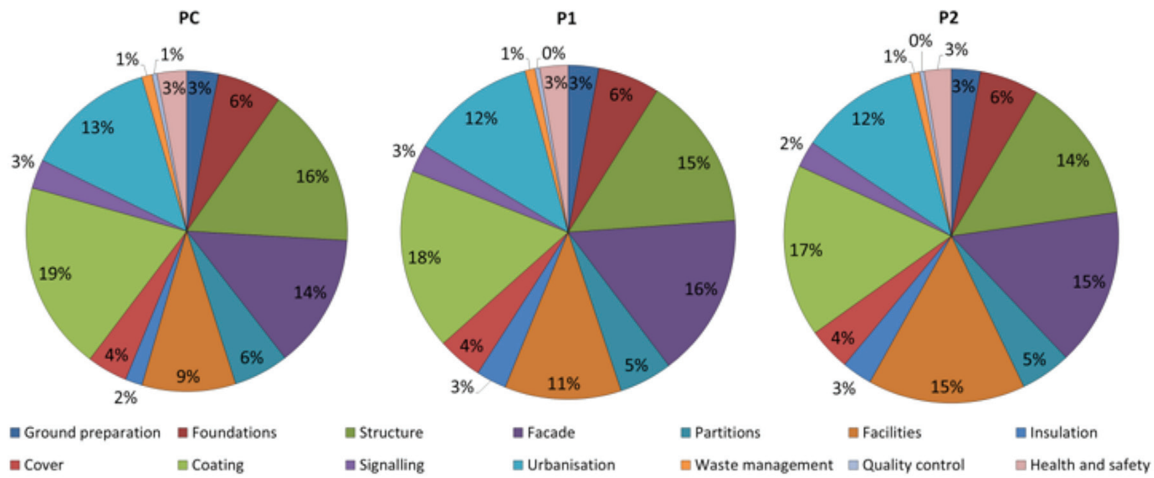
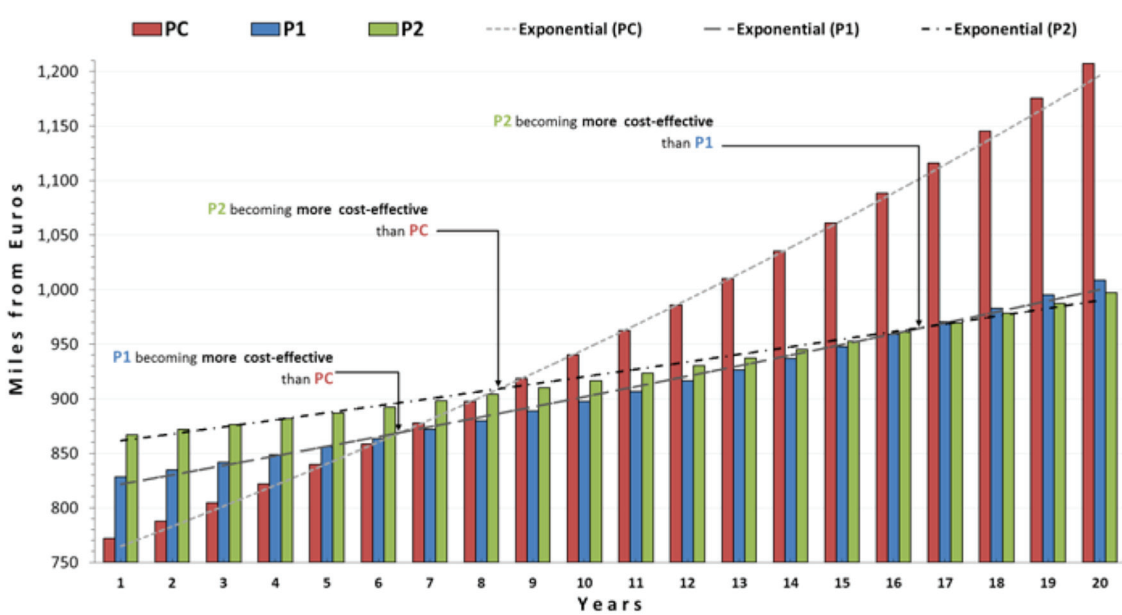


TABLE 8. Energetic consumption and initial inversion of the proposals.

Proposals	Initial inversion (€)	Total amounts of PE and Natural gas or Biomass* (€)	Year 1 (€)	Year 7 (€)	Year 9 (€)	Year 17 (€)	Year 20 (€)
PC	*756,333.68*	*15,481.04*	771,814.72	877,717.87	918,586.32	1116,309.27	1207,173.16
P1	*821,792.98*	*6,337.14*	828,130.11	871,662.40	888,534.10	970,591.17	1008,491.41
P2	*862,635.87*	*4,484.85*	867,048.71	898,059.08	910,158.25	969,481.20	997,091.27

*Notes: The table shows only the most representative years; *during the first year, increases described in methodology are projected in subsequent years.*

FIGURE 8: Accumulated economic costs of energy demands.



Profitability

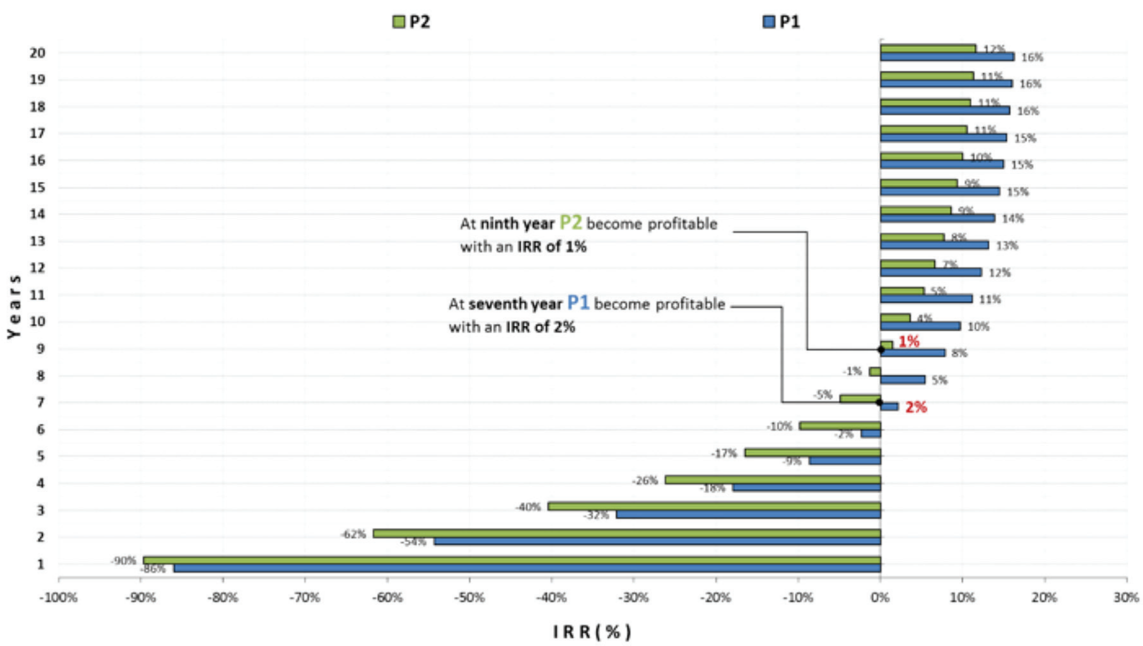
The benefit to the investor depends on the payback period. The IRR evaluation criterion used in proposals P1 and P2 confirms that P1 is profitable after the seventh year and P2 is profitable after the ninth year (see Table 9 and Figure 9). At the end of the study period (20 years), P2 reaches an IRR of 16.24% and P2 reaches an IRR of 11.67% (the change in behavior of the proposals occurs between the third and seventh years). Therefore, P2 is the most profitable proposal.

TABLE 9. IRR of P1 and P2.

Proposals	Year 1	Year 4	Year 7	Year 9	Year 15	Year 20
P1	-86.03%	-17.93%	2.18%	7.87%	14.50%	16.24%
P2	-89.66%	-26.17%	-4.90%	1.47%	9.38%	11.67%

Notes: The table shows only the most representative years.

FIGURE 9: IRR of P1 and P2



With respect to the NPV of P1 and P2 (see Table 10 and Figure 10), P1 becomes profitable in 9 years. The evaluation of the NPV criterion is sensitive to predicted inflation rates (inexact and estimated data), which have a direct and incrementally ascendant relationship. However, the investment is safe even in the most unfavorable case; that is, in the hypothetical case in which one must decide between investing in a Passivhaus project and investing in a long-term financial product with an inflation rate of 6% for 20 years, after the ninth year, the P1 investment is more profitable than the financial product.

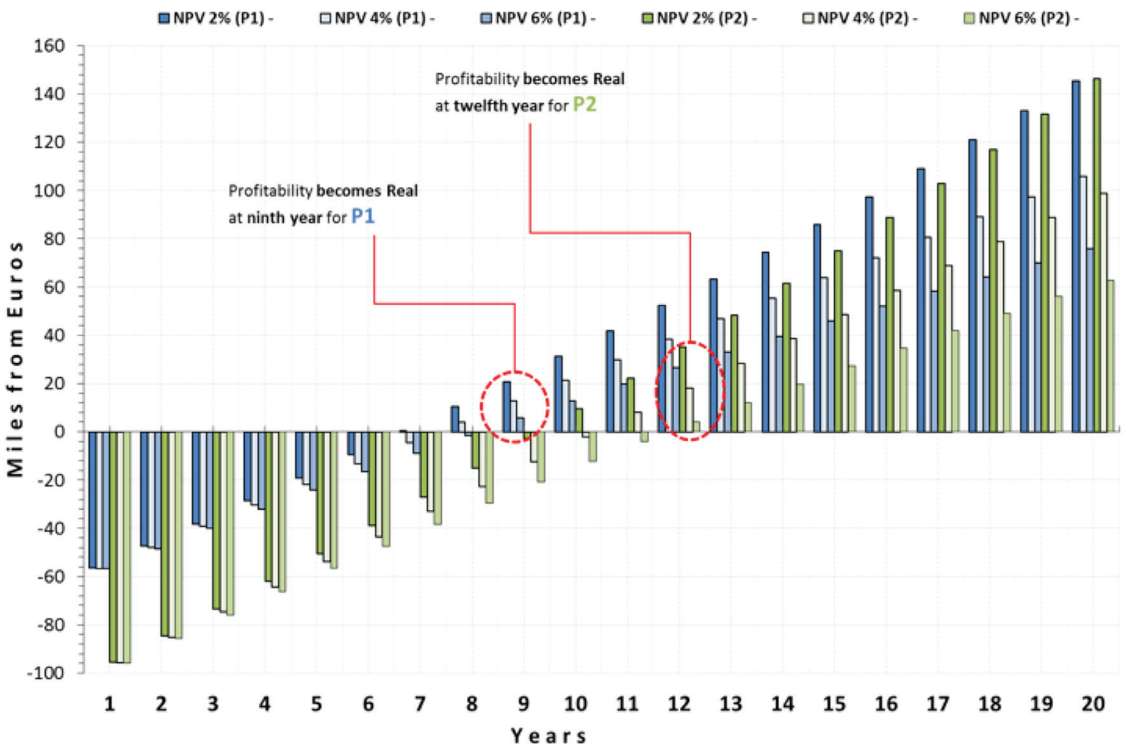
The results for proposal P1 also apply to P2; however, because the initial investment for P2 (see Table 8) is 5% higher than that for P1, the maximum period for the investment to become profitable is 12 years. Therefore, after that period of time, P2 will become more profitable than the financial product.

TABLE 10. NPV of P1 and P2 considering 2%, 4% and 6% inflation.

Proposal	Inflation	Year 1	Year 7	Year 8	Year 9	Year 15	Year 20
P1	*2%*	-56,494.69	472.13	10,526.06	20,748.67	85,826.49	145,377.55
	4%	-56,667.08	-4,486.55	4,120.82	12,704.30	73,736.23	105,708.87
	6%	-56,832.97	-8,905.43	-1,514.66	5,716.55	45,962.89	75,765.56
P2	*2%*	-95,521.61	9,647.96	22,308.59	35,179.17	75,094.26	146,239.69
	4%	-95,728.93	-2,202.78	8,022.87	18,218.17	48,629.40	98,774.62
	6%	-95,928.43	-12,366.72	-4,074.07	4,037.96	27,334.24	62,940.32

Notes: The accumulated amounts are in Euros. The table shows only the most representative years.

FIGURE 10: NPV of P1 and P2 (applying the inflation rates of 2%, 4% and 6%).



CONCLUSIONS

According to Abu Bakar et al. (2015), "the purpose of building energy analysis is to study the performance of energy consumption, perform system comparison and identify alternatives for improvement." The current investigation has shown that the PS is an effective tool when used during the design phase, reducing CO_2 emissions and increasing energy efficiency in the housing sector.

The results indicate that for a conventional home to obtain the PS certification, a final budget increase of only 8.65% is required (P1). However, with a slightly higher cost increase of 14.65% (P2), CO2 emissions can be reduced by up to 63% and the PE can be reduced by 66%. Similarly, the study also shows that using the PS is profitable, with profitability achieved for the P1 and P2 proposals in the ninth and twelfth years, respectively.

Based on this study, the use of the PS in the Spanish housing sector would help the country achieve the 2020 Horizon objectives prescribed by the EU. However, stating that this standard should be used in the entire country remains a largely theoretical and unpractical assertion. Additional studies similar to the one presented in this article still need to be conducted to determine how best to meet 2020 Horizon objectives.

Careful attention must be paid to the specific cooling demand (in the Mediterranean climate). This is clearly an area of study with great opportunities, which may help drive adoption of the PS in climates such as the one presented here. The reductions shown in the cooling demand are particularly visible compared to the reductions exhibited in the specific heating demand.

The results obtained may be more conclusive given that the variable established as "orientation" in the original project made the initial proposal (PC) less energy consuming. Similarly, the intent of preserving the design and distribution in proposals P1 and P2 demonstrates that obtaining the PS in a conventional home is fairly viable simply by modifying certain project characteristics, such as the type of glass, envelope, facilities, and equipment. More research is needed to obtain a wider understanding of behavior or adequacy of the standard in a global context, especially the viability and implications of the current limits that define the PS.

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