Energy Rehabilitation of Social Housing in Vulnerable Areas

Case study: a 1950s Building in a Medium-sized Mediterranean City

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Abstract

In the urban context, buildings play a key role as they are energy consumers. In well-established cities with a high percentage of aged building stock, the focus should lie on sensitive urban areas where the weakest population sectors and the worst physico-economic conditions are usually encountered. In this work, the energy refurbishment of social housing is proposed. A block of municipally owned buildings is selected as a case study to consider that public buildings play an exemplary role according to Directive 2012/27/EU. The group is formed by 12 buildings, which account for 120 dwellings.

This study is grounded on two levels. First the urban level. The building is located in a prioritised urban Area of Rehabilitation, Renovation and Urban Regeneration (ARRU), according to the new local Land Plan. This area presents multidimensional vulnerability and considers urban, building, socio-demographic and socio-economic features. Second, the building presents very low energy performance. It was built in 1959 when a high demand of dwellings and the economic resources then available led to low-quality buildings that are far from meeting today's standards.

Some proposals are made, having in mind the specific features of the urban context. The energy refurbishment of the building is proposed, selecting the optimal solution, considering technical, environmental and economic criteria. The energy performance simulation shows a remarkable improvement of the energy performance, resulting in an improvement of the thermal comfort of the dwellers. Besides, a reduction in the energy consumption is reached, which would reduce the energy bills and, on the other hand, a reduction of the carbon emissions to the atmosphere, contributing to a better environment quality. Having in mind that the building is intended for social housing, energy poverty situations could be avoided, as dwellings are inhabited by low-income dwellers.

1. Introduction

Cities and urban settlements consume lot of resources and generate emissions and waste, which spells detrimental environmental effects. Buildings have a strong impact as they consume resources such as land, water and energy. They are also responsible for one third of the green gases emissions that reach the atmosphere. However, buildings

are necessary to live in and to conduct human activities.

According to the 11th Sustainable Development Goal (SDG) of the United Nations, for sustainable cities and communities, the objective is "to make cities inclusive, safe, resilient and sustainable". This implies urban sustainability involving social inclusion. Within this new framework, distressed areas should be firstly observed as they present high physical and social vulnerability. The latter implies the incapacity of some groups and individuals to solve their housing needs. Therefore, these areas should be prioritised by the authorities to undertake urban plan actions.

Hence the building should be analysed from a holistic perspective by considering its urban context and interactions with citizens. The well-established urban areas with many initial limitations are especially challenging because very often they present old obsolete buildings inhabited by vulnerable populations.

This work proposes the energy refurbishment of social housing. The selection of the building was based on a threefold perspective. On the one hand, the typology of the block of buildings, together with the constructive analysis, show a low-quality building with a typology dating back to a time where resources were scarce and, consequently, energy performance was very poor. Earlier studies have identified urban areas in Spain with inefficient buildings, which have been linked with their construction period (Martín-Consuegra, Hernández-Aja, Oteiza & Alonso, 2016).

Second, social housing is intended for low-income people at risk of social exclusion. Last, but not least, the building is a municipal property, so its refurbishment should reinforce the exemplary role that the authorities play (Energy Efficiency Directive, EDD 2012/27/EU) regarding the renovation of existing buildings.

2. Methodology

Some stages were followed (see Figure 1) to undertake this work. First, the case study was selected according to three main pillars. On the one hand, the urban area was selected based on a previous work in which vulnerable urban areas of the city were defined. On the other hand, the building's poor energy performance was the main observed feature. Finally, the building's social housing condition guaranteed vulnerable dwellers, e.g., low-income citizens.
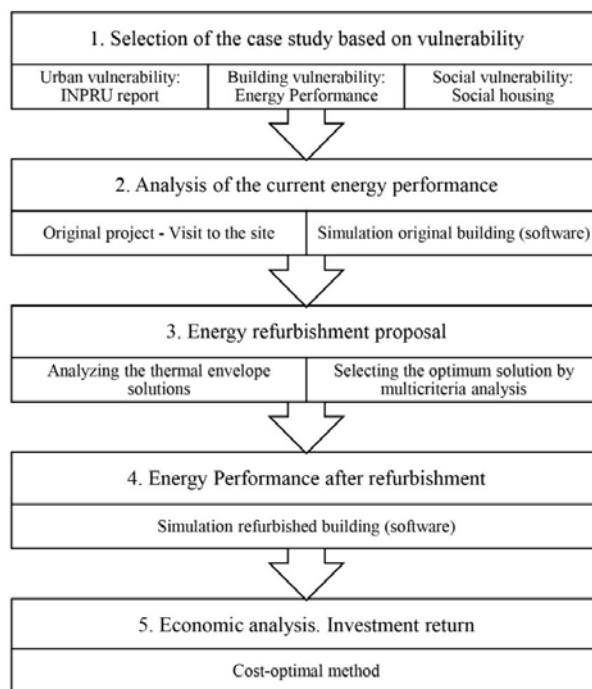

Figure 1. Methodology

Once the building was selected, a diagnosis of its current state was made by analysing the scarce available project information and visiting the site to collect complementary and necessary information. This permitted the building to be simulated in officially recognised software to determine its energy performance. The third stage consisted in analysing the refurbishment solutions and selecting the optimal solution according to a multicriteria analysis after bearing in mind the actual conditions the building was in by looking for a real applicable one.

The fourth stage consisted in determining the building's energy performance after refurbishment. Finally, economic feasibility was estimated by the cost-optimal method to acquire an order of magnitude of the investment and other costs.

3. Background

3.1. Vulnerable urban areas

The definition of Areas of Rehabilitation and Urban Renovation and Regeneration (ARRU) is included in new Spanish urban plans to contribute to sustainable development by structurally intervening in the city (LOTUP, 2014). This intends to support those responsible for local administration decision making by selecting the urban areas that require priority interventions and to undertake durable actions over time. Therefore, the buildings included in an ARRU would be prioritised when addressing potential refurbishment subsidies. Moreover, considering the most vulnerable areas will affect the whole city's substantial improvement.

3.2. Social Housing

One of the first obligations that Franco's Government had to face after the end of the Spanish Civil War was to reconstruct the country. One major part of this work was to recover urban areas, which entailed not only repairing destroyed heritage, but also constructing new housing that could accommodate a population with scarce resources.

To fulfil this purpose, immediately after the Civil War was over the first law for low-income housing was introduced, as was the government institution responsible for ensuring the promotion and control of building such housing all over the country, the National Housing Institute (Law 19 April 1939). In this way, apart from updating the legislation on such interventions, governmental institutions sought to tightly control the promotion of public housing, so it was left as a private initiative on the sidelines (Gómez, 2004).

However, the economic precariousness that the country was in during the first post-war period years did not allow the agreed quantitative targets for the building stock in successive National Housing Plans to be achieved. During the first two decades of Franco's Government, countless laws were introduced (see Table 1) to promote building stock growth rather than regulate housing.

Table 1. Main Legislation on Social Housing during Franco´s Government. 1939 -1975

Date	Introduced Legislation	Repealed Legislation
19 April 1939	Law on **Protection for a Low-Income Housing System** and establishing the National Housing Institute	Law of 12 June 1911 (Law on Cheap Houses)
23 February 1944	Order regulating **Basic Hygienic Conditions** for Housing	
25 November 1944	Law on contributions and tax reduction to Build **Income Housing for the Middle Class.**	

Table 1 continued

19 November 1948	Decree-Law that amended Law 25 November 1944 on **Protection for a Low-Income Housing System**	Law of 25 November 1944
29 May 1954	Decree-Law to build **Social Housing: Low-Income and Minimum-Income Housing**	
15 July 1954	Law on **Protection of Limited-Income Housing**	Law of 19 April 1939 Law of 25 November 1944 Decree-Law of 19 November 1948
12 July 1955	Order introducing the text of **Technical Ordinances and Building Standards** for Limited-Income Housing	
24 January 1958	Decree extending the new type of **Subsidised Housing** throughout Spain	
24 July 1963	Decree introducing the Revised Text of Social Housing legislation	All previous legislation
20 May 1969	Order introducing the adjustment of **Technical Ordinances and Building Standards** to Social Housing	

This objective would definitely not be met until the beginning of the 1960s, in 1963 with the last social housing legislation of Franco's Government. Governmental institutions would lose the strong interventionist character they held thereafter to behalf of the private promoter who was consolidated as a preferred agent in the building of this type of housing.

Apart from the limited implementation of successive Housing Plans, the economic shortage led to restrict the use of materials in the building, especially iron (Decree 11 March 1941), to avoid increasing the construction cost of housing buildings. Consequently for housing, builders were forced to use building systems from the beginning of the century and use alternative materials in those elements in which steel had become the most suitable option.

This meant a delay in the building technology progress made in Spain as social housing built during the first two decades of Franco's Government brings to light. After the Spanish economy opened out to the international scene and thanks to the Stabilisation Plan of the late 1950s, it managed to overcome years of shortage and, thus, the liberalisation of building stock, which would lose the tight constructive control normalisation by governmental institutions (Sambricio, 2004).

4. Case study

4.1. The urban scale

The development of the new Land Use Plan of the city of Castellón de la Plana (Spain) needs to define ARRU. This definition was created by using 29 *ad hoc* selected indicators of vulnerability. They were grouped into four categories: urban (4), building (4), socio-demographic (16) and socio-economic indicators. The ARRU were those areas where all the categories concurred, so they presented multidimensional vulnerability. As a result, 17 ARRU were defined in the city (García Bernal et al., 2017; Ruá et al., 2017). The building used as a case study in this work is included in one of the ARRU. The defined ARRU are indicated in Figure 2. The selected block of buildings is included in ARRU 01. The location of the block is indicated in the top-right corner of Figure 2.
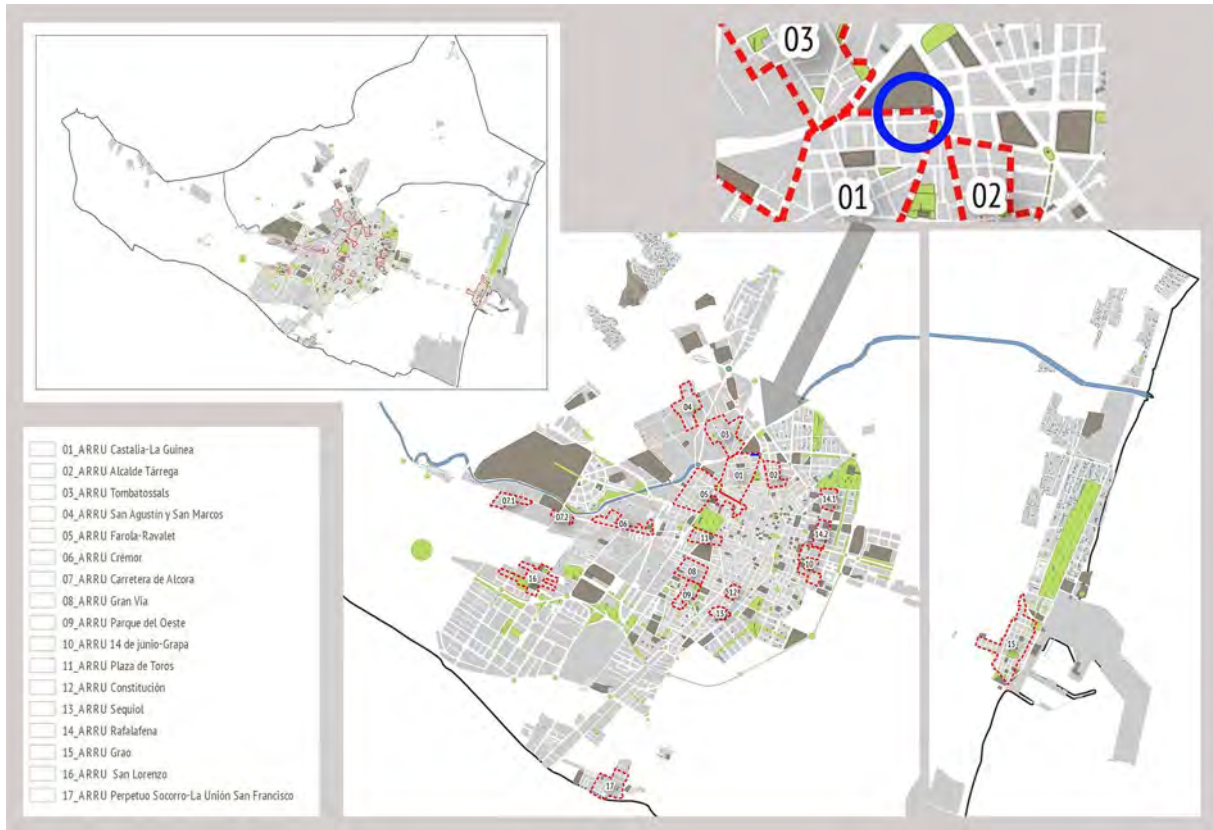
Figure 2. Situation

4.2. The block of buildings

The block of buildings was built in 1959 as social housing by Ministry of Housing subsidy. The group is formed by 12 buildings, the north façade, with odd numbers 1 to 11, to Huesca Street, and opposite the Castalia football stadium. The south façade is in Martínez Tena Street, numbers 2 to 12. Figure 3 shows a general view of the block of buildings. The block forms an internal courtyard and each building is formed by one ground floor and four upper floors, with two dwellings per floor, which means 10 houses per block and 120 houses in all, which account for 2339 m^2.

Figure 4 shows the front side view and the side elevation plan, section and roof plan. Figure 5 represents a 3D image of the block using the Revit software, drawn after the visits made to the site.
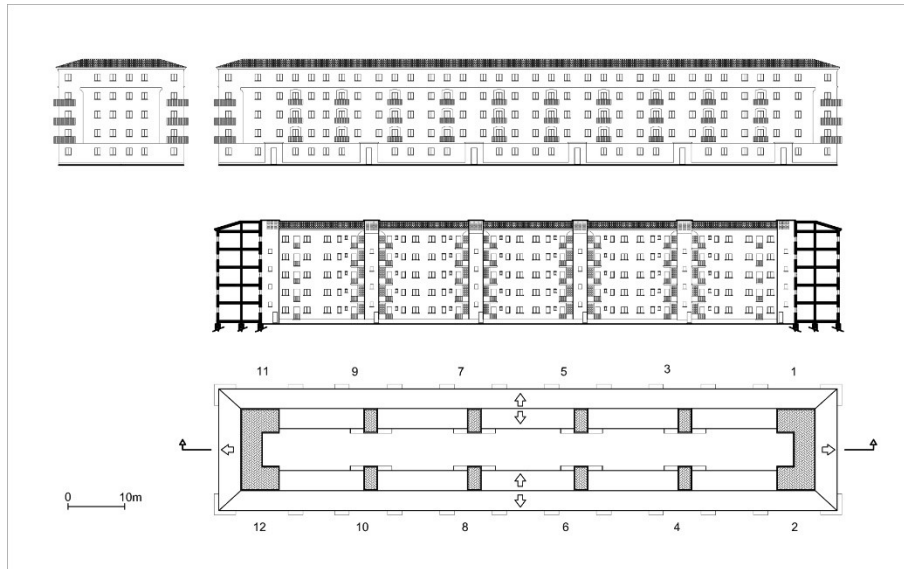

Figure 3. General view

Figure 4. Front side view, side elevation, section and roof plans

Figure 5. 3D image of the block

4.3. The building's energy performance

There are four buildings in the corners of the block, while the rest are terraced buildings which present better energy performance as they are less exposed to the outer environment. The building located in the north-west corner (357º north) is the worst in energy performance terms. In order to simplify simulation, only this building was simulated. There are three types of housing, as seen in the original plans presented in Figure 6, where the selected building is indicated. Figure 7 shows the floor plan, with dwellings types I and II, included in the building selected in the block. Dwelling type III is included in the terraced buildings in the block.
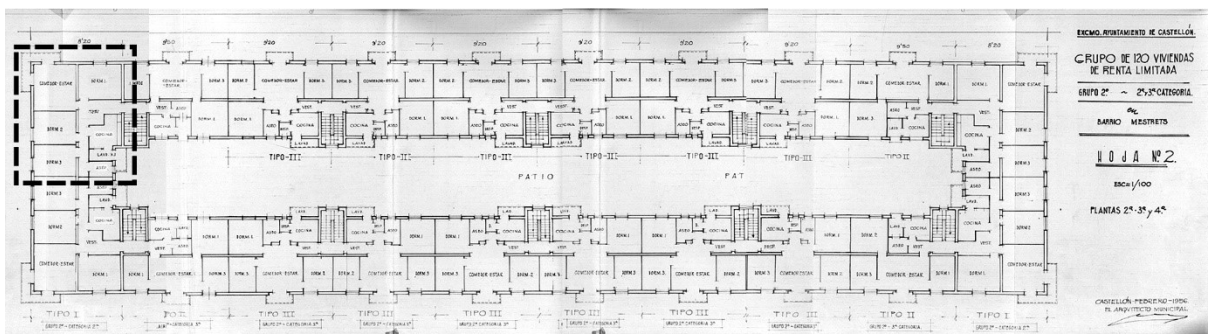

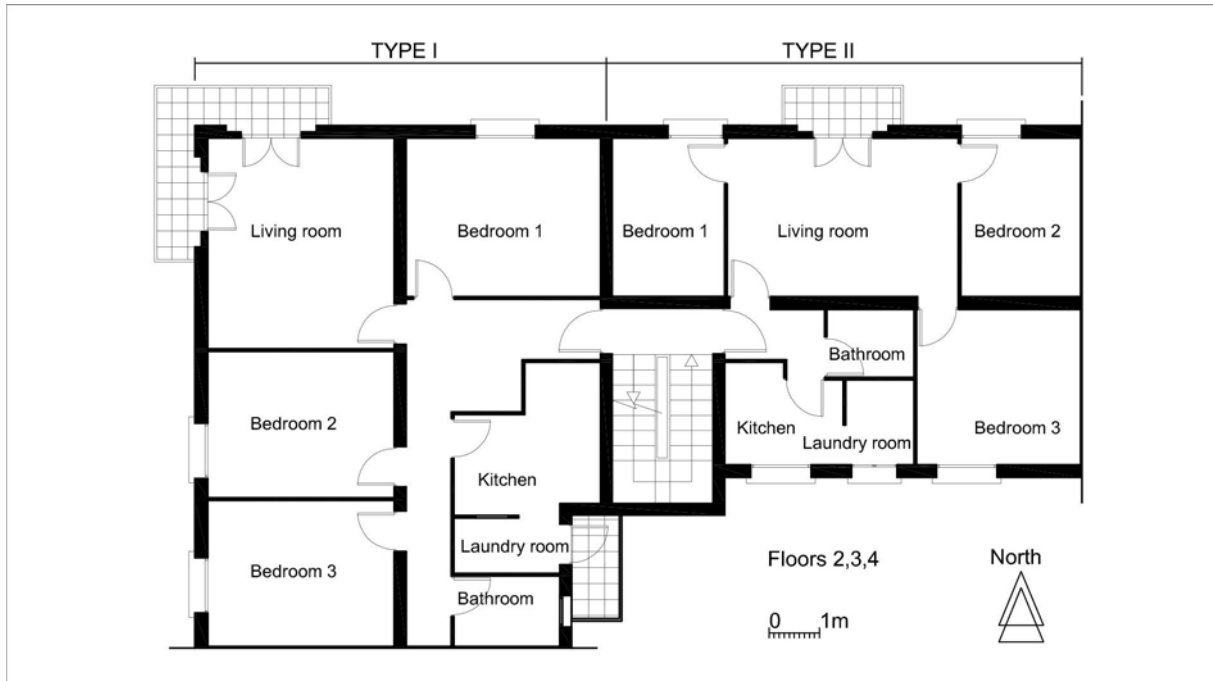Figure 6. Second Floor (Original plans)

Figure 7. Floor plan of dwellings types I and II

In order to analyze the building's thermal performance, some starting conditions need to be considered. Regarding external conditions, and according to Spanish Regulation for Energy Saving, CTE_DB-HE1, Appendix D, the building is located in climatic zone B3 (winter severity B on a scale from A to E, from the warmest to the coldest; summer severity 3 on a scale from 1 to 4, from the least to the most severe). The thermal envelope characteristics are summarised in Table 2, where the layers of the constructive solutions are represented, together with the exposed area and the thermal transmittance data. All this, plus the facilities used to obtain domestic hot water (DHW), heating and cooling services, in this case electric appliances, will be the starting data to simulate the building to estimate its energy performance in its current state:

Table 2. Original thermal envelope

Thermal envelope	Constructive solution	Transmittance U (W/m^{2}K)	Figure
Façade 1	Bearing wall formed by double leaf brick: exterior masonry wall of ceramic solid brick of 1 foot-thick with cement mortar joints + inner skin of hollow ceramic brick, 4-cm thick, with cement mortar joints + plastering. Exposed area: N 93.41 m^2; W 78.93 m^2	1.44	Figure 8

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Table 2 continued

|			
Façade 2	Bearing wall formed by double leaf brick: continuous outer coating with cement mortar + exterior masonry wall of ceramic solid brick of 1 foot-thick with cement mortar joints + inner skin of hollow ceramic brick 4 cm-thick with cement mortar joints + plastering. Exposed area: N 190.64 m^2; W 100.63 m^2; E 57.84 m^2; S 169.51 m^2	1.29	Figure 8
Windows	Wood carpentry with single glazing.	Carpentry: 2.20 Glazing: 5.50	Figure 9
Roof 1	Flat roof ventilated, trafficable: Finishing ceramic tiles + mortar layer 5 cm + bituminous sheet + ventilated air chamber + reinforced concrete one-way slab 30 cm, ceramic hollow plot + plastering. Exposed area: 38.83 m^2.	1.37	Figure 10
Roof 2	Gable sloping roof ventilated 16º: finishing ceramic gables + mortar layer + ceramic tiles for roof slope + ventilated air chamber + reinforced concrete one-way slab 30 cm, ceramic hollow plot + plastering. Exposed area: 116.03 m^2.	1.05	Figure 11
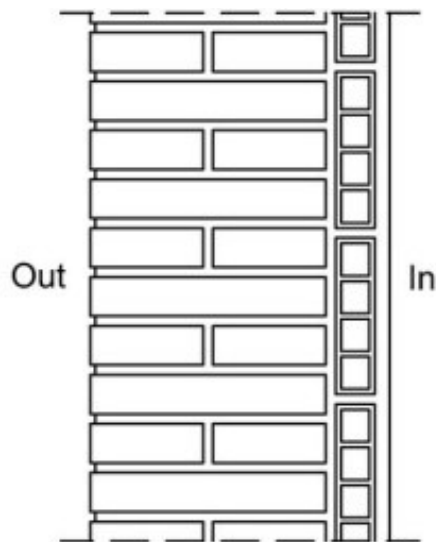
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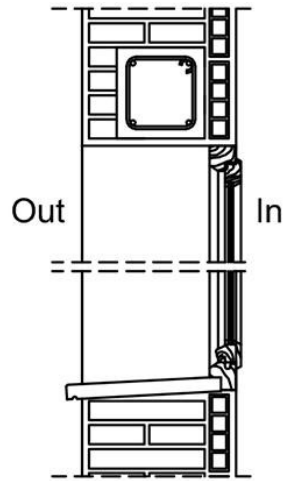
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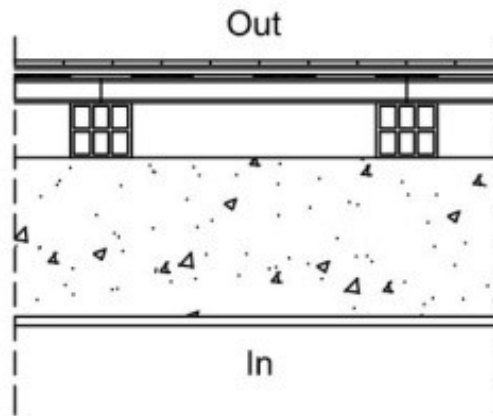
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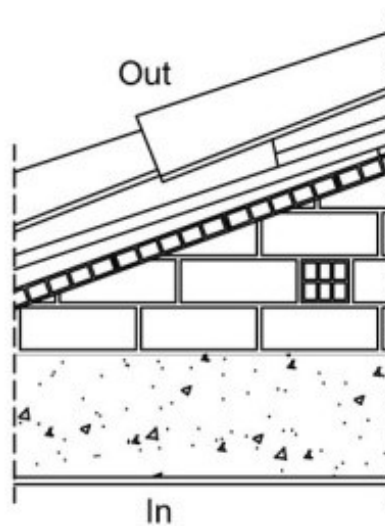
Figure 11.

To evaluate the building's energy performance in its current state, the CE3x software was used, the official software for energy certification in Spain (the open access so

ftware provided by the Ministry of Industry). Using CE3x permits energy demand to be known, energy use and carbon emissions associated with the building's use. The software estimates the annual energy demand linked to heating and cooling in kWh/m^2, and the annual CO_2 emissions due to heating, cooling and DHW in kg CO_2/m^2. The sum of emissions will evaluate energy performance using a scale from A to G, with the best and the worst energy performance, respectively. This software is widely used professionally, but has also been included in research works (Alguacil, Lufkina, Reya & Cuchí, 2018; De Ayala, Galarraga & Spadaro, 2016), specifically to social housing (Escandón, Suárez & Sendra, 2016) to obtain simulation energy performance values.

The input data in the software result in the energy performance presented in Figure 12. According to the simulation, the building emits 29.5 kg CO_2/m^2 due to heating, cooling and DHW, with 15.98, 5.09 and 8.41 kg CO_2/m^2, respectively. Altogether, the building obtains an E energy label, where DHW presents the worst energy performance, with F, followed by heating with E and a medium D for cooling.

Figure 12. Energy certification label for the current building

4.4. Energy refurbishment proposal

The next stage consists in analysing some refurbishment solutions to improve the building's energy performance and to select the optimal one. To do so, four perspectives are observed: technical, environmental, economic and heritage. The technical perspective analyses the advantages and disadvantages of actually implementing the constructive solution. The environmental perspective is based mainly on the resulting transmittance of the refurbished solution, together with the reduction of thermal bridges. The economic perspective examines the viability of refurbishment. Finally, the building's heritage value is considered by looking at the aesthetic variation of the building's external envelope as it can be representative of the building type built at a particular socio-economic period of time, as explained in Section 3.2.

Regarding the thermal envelope, the refurbishment aimed to add insulation layers that did not exist in the original building's state. Insulation material is generally the most cost-effective solution when buildings are refurbished (Hamdy, Hasan & Siren, 2011; Ruá & López-Mesa, 2012). This should be done on façades together with improvements to carpentries, with double glazing solutions, and also in roofs. Adding insulation on façades and roofs could be done basically in two ways: on the outer or the inner layer.

Table 3 shows some constructive solutions (Huedo, Mulet & López-Mesa, 2016), along with their advantages, disadvantages and features by bearing in mind the technical, environmental, economic and heritage perspectives. The selected solutions are shaded in grey in Table 3 and represented in Figure 13. For façades, inner insulation (FI) was ruled out because of the dimensions of rooms. It would mean reducing the areas of rooms as they could not fulfil the minimum required dimensions according to new standards. Therefore, the outer solution with the External Insulation System was adopted in this case because it was more convenient than the ventilated façade,

and fell in line with different criteria. The convenience of this solution is supported by other studies (Sierra-Pérez, Boschmonart-Rives & Gabarrell, 2016) and can be applied to both façade types.

For roofs, the inner solution proved more convenience when looking at advantages and disadvantages. The same solution involving mineral wool and finishing plaster board could be applied to roof 1(SRI) and roof 2 (FRI).
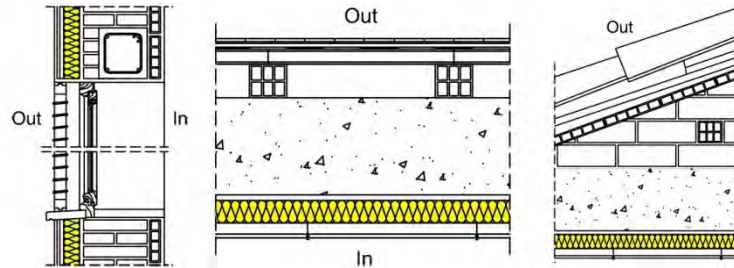

Figure 13. Façade, sloping roof and flat roof refurbishment solutions

Table 3. Multicriteria analysis of the constructive solutions for the thermal envelope

Thermal Envelope	Criteria	Technical		Environmental		Economic		Aesthetic
	Solution	Advantages-disadvantages	U	Thermal bridges	€/m2	Time	External variation
Façades	FO1. Ventilated façade	Medium-high level of difficulty Requires scaffolding Does not interfere with users High embedded energy due to the aluminium substructure	0.49	Reduced	158.50	Medium	High
	FO. External Insulation System	Medium-low level of difficulty Requires scaffolding Does not interfere with users	F1: 0.49 F2: 0.47	Reduced	90.35	Medium	Medium
	FI. Inner mineral wool and plaster board	Low level of difficulty Interferes with users Does not fulfil minimum dimensions	0.48	Equal	27.99	Short	None

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Table 3 continued

Sloping Roof	SRO. XPS (extruded polystyrene) under the finishing layer	High level of difficulty, the finishing roof layers are removed to add insulation Requires scaffolding Does not interfere with users	0.44	Equal	93.47	Long	None
	SRI. Inner mineral wool and plaster board	Low level of difficulty Interferes with users	0.44	Equal	27.99	Short	None
Flat roof	FRO. XPS and gravel over the finishing layer	Adds loads to slab. It requires a structural analysis Does not interfere with users	0.49	Equal	75.08	Short	None
	FRI. Mineral wool and plaster board	Low level of difficulty Interferes with users The same solution for the two roof types	0.44	Equal	27.99	Short	None

Theoretically, other measures can be proposed. For example, solar energy to cover a high percentage of DHW demand could have been proposed. However, this would need a further structural analysis to check that the structure would support the new load added by fitting solar energy. The presented proposal is intended mainly to be realistic and economically viable by considering the building's socio-economic features.

4.5. Energy performance after refurbishment

The selected construction solutions, together with improved facilities, by going from electrical new boilers to condensed natural gas ones, shows a relevant improvement in energy performance and reduced annual carbon emissions from 29.5 to 15.3 kg CO_2/m^2. Table 4 shows the heating and cooling demands, together with emissions, due to different facilities and the savings made after refurbishment.

Table 4. Improvement of energy performance and savings in emissions obtained by the CE3x software

	Current state	Refurbished	Saving %
Heating demand kWh/m^2	64.5F	17.5C	72.8
Cooling demand kWh/m^2	17.8D	14.7D	17.3
Heating emissions	16.0E	4.3C	72.8
Cooling emissions	5.1D	4.2D	17.3

Table 4 continued

DHW emissions	8.4G	6.7G	19.9
Global emissions	**29.5E**	**15.3D**	**48.1**

4.6. Economic viability of refurbishment

To analyze the economic viability of refurbishment, the guidelines of Commission Delegated Regulation (EU) No. 244/2012, of 16 January 2012, which supplements Directive 2010/31/EU of the European Parliament and the Council on the energy performance of buildings by establishing a comparative methodology framework to calculate cost-optimal levels of minimum energy performance requirements for buildings and building elements, was used. According to this methodology, energy performance measures are considered an investment and the *Net Present Value* is used. This indicator is appropriate for long-term investments. Buildings are products of a long service life that require maintenance, replacing certain elements, etc. Therefore, the global cost, referred to as starting year τ_0, was calculated using the following equation (1) over calculation period , for a set of measures *j* during year *i*:

$$C_{g(\tau)} = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) R_d(i) + C_{c,i}(j) \right) - V_{f,\tau}(j) \right]^{\square} \tag{1}$$

Table 5 presents details for each term of Equation 1 and the estimated values using the macroeconomic perspective by considering the carbon cost.

The graphic represented in Figure 8 shows the accumulated NPV for two discount rates, r1% and r4%. NPV is €53,184.12 for 1% and is €4,736.1 for 4%. With the starting hypothesis of Table 5, we can see that the investment starts to be positive from year 20 and 28 for the 1% and the 4% discount rate, respectively. This is not a surprising result if we consider the private costs and only the carbon price a social cost.

Some subsidies can be considered in the calculations, if we bear in mind that the building is included in an ARRU, as mentioned in Section 3.1. This would result in a more optimistic scenario with a shorter payback, as calculated in previous studies (Alguacil et al., 2017). For example, estimating a hypothetical subsidy of €5,000.00/dwelling, the investment would be returned in less time, as seen in Figure 14.

Table 5. Terms for the global cost and hypothesis used for estimations

Term	Meaning	Estimated value and source
τ	Calculation period Starting year τ_0 2018	30 years R244/2012 suggests 30 years for residential and public buildings
C_I	initial investment cost for measure or set of measures *j*	Cost of refurbishment of façades, windows, roof and replacing boilers (price database) €10,5195.64 in τ_0 (€10,519.56/dwelling)
$C_{a,i}(j)$	annual cost during year *i* for measure or set of measures *j*	Cost of electricity: €0.24/kWh (savings from the original to the refurbished building: 35.16 kWh/m^2·year): €6416.70/year Maintenance cost: inspection of boiler, mandatory every 5 years: €50/dwelling Replacement cost: boiler 15 years of service life: €1800/dwelling Maintenance cost: to inspect boilers, mandatory every 5 years, estimated at €50/dwelling. Replacement cost: boiler ,15 years of service life

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Table 5 continued

| $Cci(j)$	carbon cost for measure or set of measures j during year i	Values recommended by the R244/2012 (savings from the original to the refurbished building: 14.2 kg $CO_2/m^2 \cdot$year). Prices CO_2: €20/ton until 2025; €30/ton until 2030; €50/ton from 2030
$V_{f,\tau}(j)$	residual value of measure or set of measures j at the end of the calculation period (discounted from the starting year τ_0)	The residual value is considered zero
$R_d(p)$	discount factor for year i calculated as $$R_d(p) = \left(\frac{1}{1+\frac{r}{100}} \right)^p$$ where p: number of years from τ_0 r: real discount rate	A sensitivity analysis must be performed with at least two rates. From a macroeconomic perspective of 4% (according to the Commission 2009's Impact Assessment guidelines). Sensitivity analysis: r_1: 1%; r_2: 4%
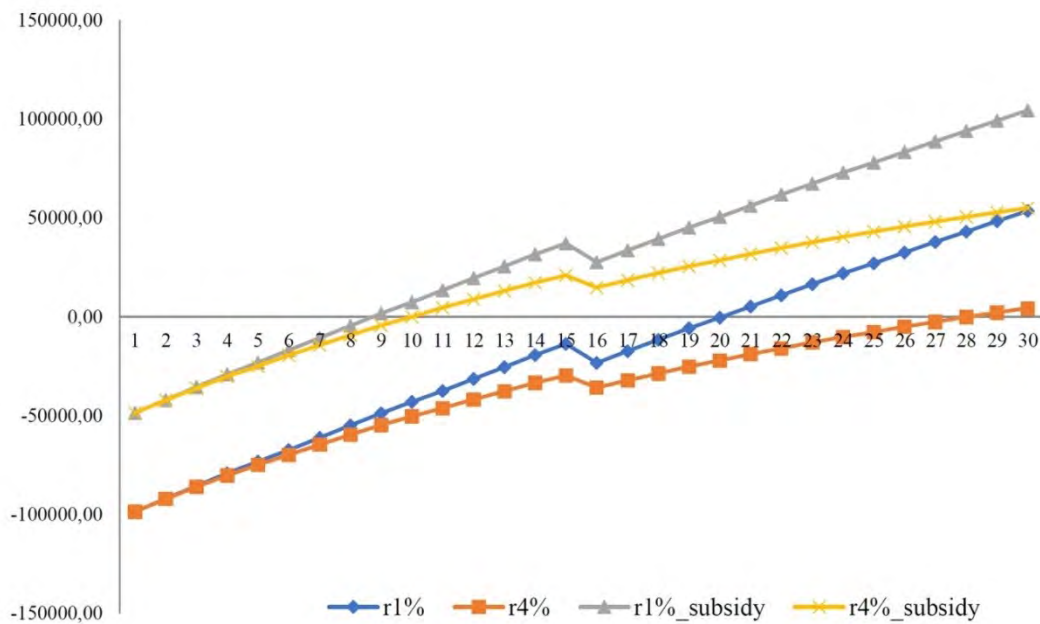
Figure 14. Façade, sloping roof and flat roof refurbishment solutions

5. Conclusions

In this work, the refurbishment of a block of buildings located in Castellón de la Plana (East Spain) is proposed. The selection of this building was based on various criteria: first, it is located in a vulnerable area of the city, as the new land plan reflects. Second, the year of construction is characterised by socio-economic circumstances, which represents a building typology that entails a heritage value. The scarce economic resources at that time led to poor quality dwellings that can still be found in many Spanish cities today. These buildings very often present low energy performance and obsolete quality standards. Moreover, in this case, the selected building is the property of the Municipality and is intended for social housing.

The refurbishment proposal requires a previous diagnosis being made according to its current state. Data were collected using the original project, visiting the site for measures, employing first-hand information and drawing new plans.

Some refurbishment solutions were analysed after bearing in mind the particularities of the case to select the

optimal solution. The selected refurbishment solution is based on different criteria. Although other solutions could have been proposed, the adopted solution was adapted to a realistic scenario by considering the building's specificities. The energy performance estimation shows major savings in both energy and carbon emissions.

The economic analysis conducted by the cost-optimal method shows an initial investment of €10,519.56/dwelling. With the starting hypothesis, the NPV is positive. The cumulative NPV shows that, in both cases, the NPV is over zero after 20 years. This term would be shorter if subsidies could address the building. Its location in an ARRU means that it is an area that should be prioritised to address potential subsidies. Refurbishment would also benefit users' quality of life by improving the thermal comfort of their dwellings as it would make the energy poverty situation more unlikely. Besides it would increase the market price of dwellings, which is an aspect that the economic analysis does not consider.

6. Acknowledgments

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