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A MULTI-CRITERIA APPROACH FOR THE ASSESSMENT OF HOUSING RENOVATION STRATEGIES

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Abstract

The building sector is well known to be one of the key energy consumers worldwide. The majority of the current European housing stock was built during 1940-1970s, with low standards especially with regard to energy performance. The challenge now is to act in this stock.

In this paper, a multi-criteria methodology is proposed for the comparative analysis of retrofitting solutions. First, environmental impacts and financial costs are evaluated via a life cycle approach. Secondly, Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) are combined through the Pareto optimization method. For this, environmental impacts are expressed in monetary values.

To illustrate the applicability of our approach, a case study has been selected: the renovation of a representative housing block from the 60s located in Madrid. Three scenarios have been proposed for the analysis of energy saving measures: scenario 1, where typical solutions used in Spain are applied; scenario 2, where strategies to achieve energy requirements fixed by Spanish regulation are assumed; and scenario 3, where Passive House standard is achieved. Energy saving measures are therefore defined for each scenario considering roof, facade and windows.

Results show how housing renovation involves important benefits, not only from the environmental point of view but also from the financial perspective. For the building typology analysed, located in Madrid, the current retrofitting strategies are not optimal from an environmental point of view. The necessary extra investment for the improvement of the envelope with a higher insulation thickness (8%) is arguable taking into account the extra environmental and financial savings (45% and 87% respectively).

Keywords:

Housing renovation; life cycle assessment (LCA); life cycle cost (LCC); retrofitting; monetary valuation

1 INTRODUCTION

Nowadays, it is broadly recognized that the improvement of the energy efficiency of buildings is an urgent and important challenge. In Spain, 54% of the housing stock was built before 1980, i.e. before the first regulation concerning energy efficiency in buildings [1]. This large stock is a consequence of the high housing need in the middle of the last century, in a context with a low industrial production and without any comfort standards. The main effort should be hence focused on the renovation of this stock.

During the last years, different programs have been conducted in order to promote housing renovation in Spain. However, requirements to get the subsidies have focused mainly on the reduction of the energy consumption during the use phase.

With the aim to explore how efficient the current practices of retrofitting are, a multi-criteria methodology was proposed combining LCA and LCC. The assessment of the solutions currently used was illustrated by a representative case study in Madrid, Spain.

2 MATERIALS AND METHODS

2.1 Case study

As it has been mentioned, the renovation of a representative housing block from the 1960s located in Madrid was selected as a case study. Current strategies used in Spain were analysed in terms of efficiency by applying the multi-criteria approach. Different scenarios were analysed from the Business as Usual scenario (BAU), through the requirements of the Spanish Building Regulation [4] up to the Passive House standard.

Selection of a representative housing block

The most representative typology of the Spanish housing stock is the multifamily housing block built between 1950 and 1980, which represents 43% of the residential stock [1]. Based on an in-depth analysis of the housing stock in Madrid [2], a representative housing block has been identified.

The studied building is a ten-story building, containing 120 dwellings of 2 and 3 bedrooms, with a net floor area of 49 and 64 m^2, respectively, and a floor to ceiling height of 2.50m (Fig. 1). Table 1 summarizes the design features of the building enclosure.

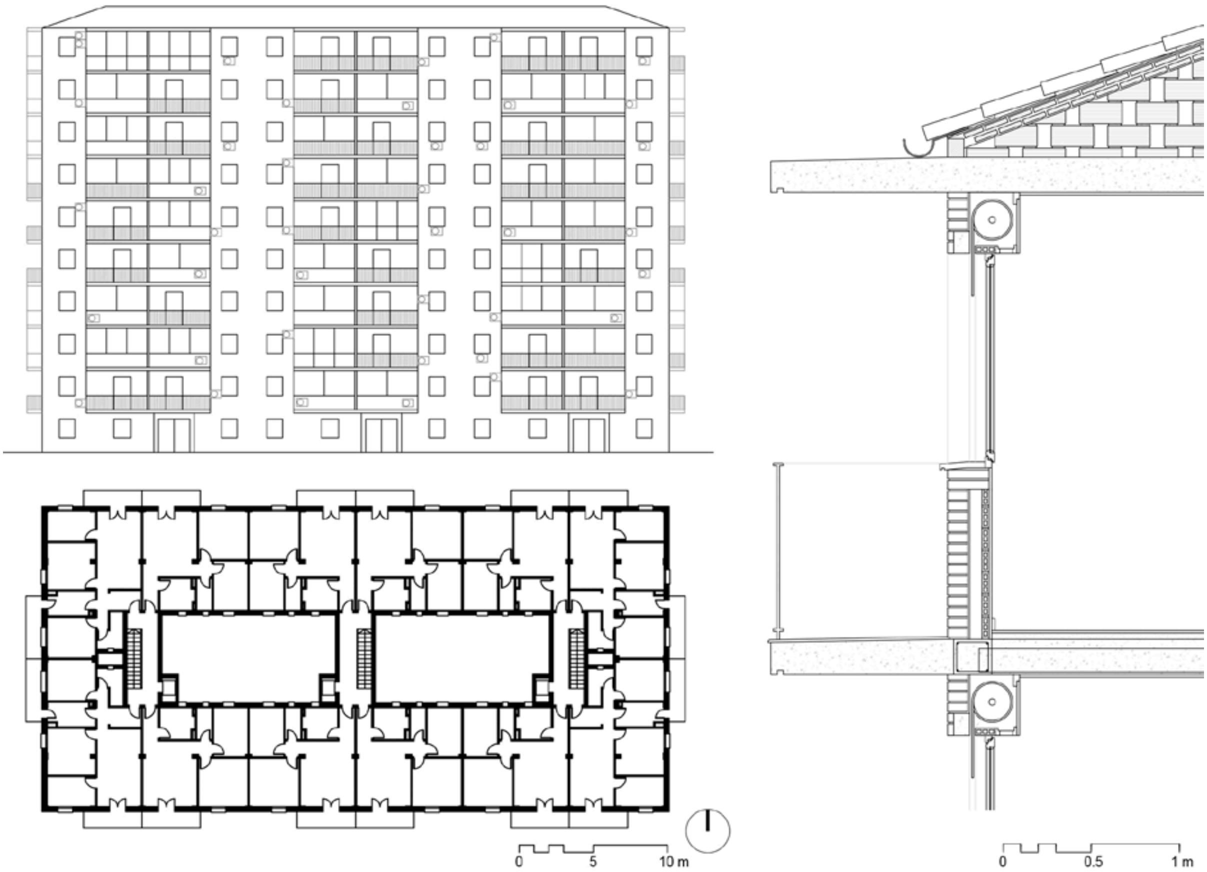

Fig. 1: Layout of the existing building: elevation, floor plan and vertical section of the top floor [2].

	Construction	U-values (W/m^2K)
Roof	Ceramic tiles, brick board, supported by ventilated brick walls placed every 1m, 200 mm reinforced concrete	1.48
Facade	Brick veneer, air cavity, hollow bricks, gypsum plaster	1.69
Windows	Aluminium without thermal break, 6 mm single glazing	5.7

Table 1: Design features of the building enclosure.

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Definition of retrofitting scenarios

The aim of this case study was to know whether the current retrofitting solutions in Madrid are suitable if the life cycle approach is considered, and if the requirements in housing renovation could be strengthened. Therefore, three scenarios were defined: Business as Usual (BAU) practices (E1), solutions to achieve Spanish Building Regulation for both existing and new buildings (E2A and E2B respectively) and actions to achieve Passive House standard (E3). Table 2 summarizes the requirements for each scenario for the city of Madrid.

	Heating demand* (kWh/m^2)	**Cooling demand*** (kWh/m^2)	**Infiltration rate** (ac/h)
E1	-	-	-
E2A	36.44	15.66	-
E2B	27.37	15	-
E3	15	15	0.6**

* Maximum final energy demand; **ac/h at 50 Pa

Table 2: Energy requirements for the retrofitting scenarios proposed.

BAU solutions were defined on the basis of an in-depth case study of the projects financed by the Municipal Housing and Land Company of Madrid (EMVS). It was observed that materials used in housing renovation in Madrid are the same in every building. Therefore, in this research, the additional scenarios were proposed based on these solutions, adapted to the requirements of each scenario (Table 2). To do so, EnergyPlus [3] was used, considering the usage profile established by the Spanish Building Regulation [4]. Table 3 presents a brief description of the solutions considered in each scenario.

2.2 Methodological approach

A multi-criteria methodology was proposed for the comparative assessment of the retrofitting solutions. Life cycle assessment (LCA) and life cycle cost (LCC) methodologies were applied to evaluate environmental impacts and financial costs.

In order to avoid inconsistencies, the goal and scope was defined equally for LCA and LCC. Functional unit was defined as 1 m^2 of heated and cooled net floor area of a single unit in a multifamily apartment block, located in Madrid in 2014. A life span of 50 years was considered.

The scenarios analysed did not differ in the amount of existing materials being demolished, so the materials of the existing building were excluded from the comparative analysis. Only the impacts and costs of the new materials and the reduction in energy consumption due to the ESM were considered. The analysis included the production of the required materials for the renovation, the transport of the materials to the construction site, construction (limited to the material losses during construction), use stage (maintenance, replacements, heating and cooling final energy savings) and the end-of-life (EoL) (limited to the separation of waste, the transport to the EoL treatment plant and the EoL treatment, which included both landfill and recycling).

	E1	**E2A**	**E2B**	**E3**
Roof	8 cm XPS under tiles	8 cm MW over the last slab	16 cm MW over the last slab	16 cm MW over the last slab
Facade	ETICS. 6 cm EPS	ETICS. 4 cm EPS	ETICS. 12 cm EPS	ETICS 12 cm EPS
Windows	AL(TB) + 4/6/4	AL(TB) + 4/6/4	N: PVC + 8/16/8 Low-E S/E/O: PVC + 4/10/4 Low-E	PVC + 4/10/4 Low-E
Ventilation	Natural ventilation	Natural ventilation	Natural ventilation	Mechanical ventilation + HR

XPS: extruded polystyrene; MW: mineral wool; EPS: expanded polystyrene; AL(TB): aluminium with thermal break; ETICS: External Thermal Insulation System; N: North; E: East; W: West; S: South; HR: heat recovery.

Table 3: Retrofitting solutions for the renovation scenarios proposed.

For the energy calculation, energy savings for heating and cooling compared to the existing building were considered. The systems' efficiencies were 75% for heating production with natural gas and 138.6% for cooling production with electricity.

Life cycle assessment

Due to the lack of inventory data or Environmental Product Declarations (EPD) in the building sector in Spain, the Ecoinvent life cycle inventory database (version 2.2) was used [5].

The life cycle assessment was conducted following the European (CEN) standard. The seven impact categories of the European (CEN) standard on environmental impact of buildings [6] are considered as there is a large consensus on their relevance as well as scientific robustness of the impact assessment models related to them: abiotic depletion potential – non-fossil (ADP-non-fossil); abiotic depletion potential – fossil (ADP-fossil); acidification potential (AP); eutrophication potential (EP); global warming potential (GWP); ozone layer depletion potential (ODP); photochemical ozone creation potential (POCP).

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According to the current version of the CEN standard, CML version 4.1 (dated October 2012) was used for the impact assessment.

A multiplicity of individual impact scores is rarely a good basis for decision making. Therefore, a weighting was used by means of monetary valuation. Monetary valuation is an optional evaluation step in LCA. The objective of monetary valuation in the research was to express, in monetary terms, how the welfare of current and future generations is affected by the environmental impacts caused by activities in the building sector. These environmental costs (also referred to as “external costs” or “shadow costs”) arise when the activities of one group of people have an impact on others, and when the first group fails to fully account for these impacts [7]. For each individual environmental indicator, the characterization values are multiplied by a monetization factor (e.g.: X kg CO_2 equivalents times Y €/kg CO_2 equivalents). This factor indicates the cost of the damage to the environment and/or humans for avoiding potential damage or settling any damage incurred [8]. The West-European monetary values from the OVAM:MMG method developed in Belgium were used in our approach [8,9]. For the analysis, the central values of the OVAM:MMG method were used (Table 4). Environmental costs can be then compared/added up with/to the financial costs.

Environmental indicator	**Unit**	**Monetization factor** (€/unit)
ADP-non fossil	kg Sb eq	1.56
ADP-fossil	MJ net caloric value	0
AP	kg SO_2 eq	0.43
EP	kg $(PO_4)^{3-}$ eq	20
GWP	kg CO_2 eq	0.100
ODP	kg CFC-11 eq	49.10
POCP	kg C_2H_4 eq	0.48

Table 4: Overview of West-European monetary values (central) for CEN indicators, 2014 [9].

Life cycle cost

The Net Present Value (NPV) method was adopted for the LCC calculation on the basis of the existing literature. An energy efficient renovation of a building requires an investment cost, but generates savings in the energy consumption over the life span of the building. To be profitable, the energy cost saved by the measure over its use life will need to be greater than the capital investment, cost of maintenance and replacements and EoL cost [10].

The cost of renovation included building material costs, labour costs, indirect costs (which comprise the costs for indirect labour, machinery and tools, temporary facilities, and quality control), fees of architects and 10% VAT. The cost data was collected from a database valid for the Spanish context, for the year 2014 [11]. The cost of maintenance and replacements consists of the costs of building materials and labour costs. Energy savings are calculated for heating and cooling. A cost of 0.18 €/kWh for electricity and 0.075 €/kWh for natural gas were assumed. Based on a projection of the observed past trend according to the EUROSTAT data and the data from the Spanish Institute of Statistics, a yearly increase of 1.85% was considered for building materials, 0% for labour, 3.5% for natural gas and 5% for electricity. Moreover, a real discount rate of 3% was considered. Finally, the EoL cost includes the cost for the separation of waste, transport to the treatment place and the EoL treatment.

Multi-criteria optimization

The Pareto optimization principle was adopted to identify the retrofitting scenarios in order of priority. The preferred solutions are regard as the ones with lower investment cost and higher life cycle savings. Therefore, three objectives were defined for the combination of LCA and LCC:

- Highest life cycle financial savings (LF savings) and lowest financial investment (IF)
- Highest life cycle environmental savings (LE savings) and lowest environmental investment (IE)
- Highest life cycle environmental savings (LE savings) and lowest financial investment (IF)

Sensitivity analyses

According to the existing literature [12], sensitivity analyses were performed on the most important uncertain parameters: lifespan, monetary valuation factors, discount rate and growth rate of energy.

3 RESULTS AND DISCUSSION

Regarding energy issues, energy demand and demand reduction were assessed. The energy demand for each scenario and energy savings compared to the existing building (E0) are presented in Fig. 2 for heating and cooling. Scenarios E1 and E2A present similar results, which can be explained by the fact that the requirements to get renovation subsidies are similar to the current Spanish Regulation for housing renovation.

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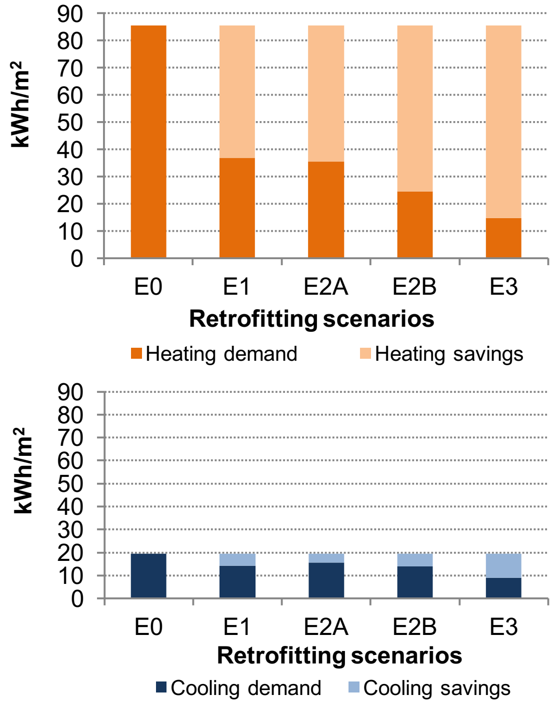

Fig. 2: Net energy demand and energy savings compared with the existing building of retrofitting scenarios for heating and cooling.

In all the retrofitting scenarios the net cooling demand is lower than requested. It was observed that, because of the geometry of the building, the addition of solar protection decreased the cooling demand only 1 kWh/m^2 year, while it increased the heating demand. Therefore, they were not considered in this analysis.

Environmental results are presented in Fig. 3. From the environmental point of view, scenarios E1 and E2A appeared to be unfavourable, as they had higher initial impact than scenario E2B, while life cycle savings are lower.

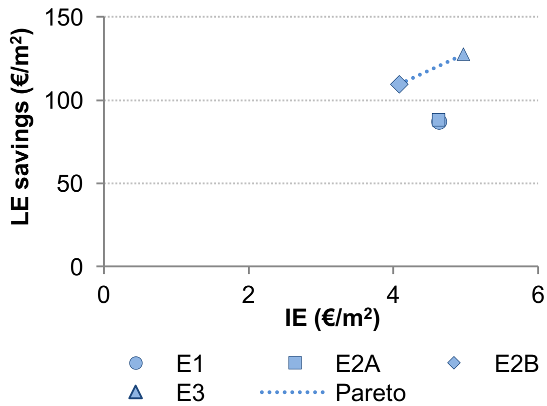

Fig. 3: Environmental assessment, initial environmental cost (IE) vs. life cycle environmental savings (LE savings).

According to the financial results (Fig. 4), all the scenarios are placed in the Pareto front. However, scenarios E1 and E2A are not recommended as LF savings are about 30% lower than the savings of scenario E2B, which requires only a limited additional investment cost. Moreover, scenario E3 requires higher investment than E2B (30%), while the savings are not high enough (10%).

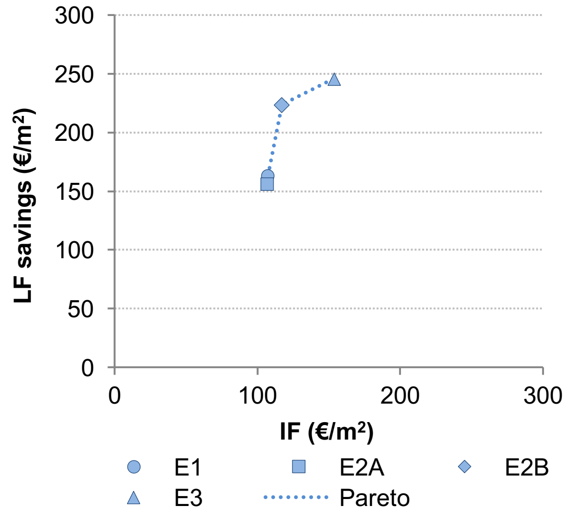

Fig. 4: Economic assessment, initial financial cost (IF) vs. life cycle financial savings (LF savings).

Regarding the objective to achieve the highest LE savings for the lowest IF cost (Fig. 5), E1 is out from the Pareto front. Although it is very similar to scenario E2A, the investment cost is a bit higher, while the LE savings are a bit lower. E3 presents the highest LE savings. However, it is also the most expensive scenario. The investment cost is 30% higher, while the LE savings is only 12% higher.

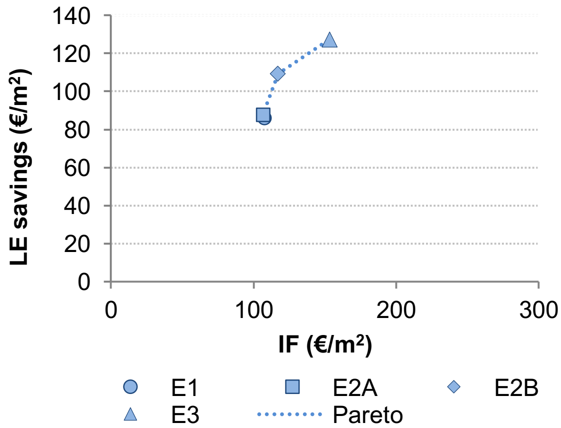

Fig. 5: Initial financial cost (IF) vs. life cycle environmental savings (LE savings).

Sensitivity analyses were made varying the life span of the retrofitting scenarios, the discount rate, the growth rate of energy prices and the monetary values. The same trend was found for all the parameters.

4 CONCLUSIONS

In this paper, a multi-criteria methodology was proposed to assess different retrofitting solutions

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from an environmental and financial perspective through the life cycle approach. A representative case study in Madrid was selected to illustrate its applicability.

The results show that, for the building typology analysed, the current retrofitting strategies (scenario E1) are not optimal from an environmental point of view. Moreover, the solutions chosen to fulfil the Spanish Regulation requirements (for housing renovation) were not optimal from an environmental approach either. Although Passive House standard (E3) meets the three objectives proposed, it requires higher investment costs than the achievement of Spanish Building Regulation for new buildings (E2B), due to the heating recovery system, reducing the life cycle financial savings. Therefore, scenario E2B seems to be the most favourable one. Finally, even if the results are specific for this case study, a representative case study was chosen as case study in order for the results to be applicable for other cases with similar building features.

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