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Cost-effective renovation of a multi-residential building in Spain through the application of the IEA Annex 56 Methodology

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Abstract

This papers presents the application of the Methodology developed in the IEA Annex 56 to a case study located in Tudela, northern Spain. The life cycle cost and impact assessment of three renovation scenarios (including different types of heating systems in two of them) and a reference case have been evaluated. Results show that all renovation scenarios studied are cost-effective achieving at least a heating demand reduction of 40%. The actually executed renovation, if additional on-site renewables are installed, constitutes the most cost-effective scenario; however a deeper renovation has lower final energy use and carbon emissions associated.

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Keywords: building renovation; cost-effectiveness; carbon emissions optimization; EPDB; case study; district heating; envelope refurbishment

1. Introduction

The existing building stock accounts for more than 40% of the final energy use and 35% of carbon emissions [1]. Therefore, if we want to reach the carbon saving ambition of 88-91% set at for the building sector in the Commission's 2050 Low Carbon Economy Roadmap the depth and rate of renovation must be substantially increased alongside a rapid decarbonisation of the energy supply system [2].

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Nomenclature

BITS	building integrated technology systems
DHW	domestic hot water
GWP	global warming potential
LCC	life cycle cost
LCIA	life cycle impact analysis
NRPE	non renewable primary energy
PE	primary energy

The project “Cost Effective Energy and Carbon Emissions Optimization in Building Renovation” from Energy in Buildings and Communities Programme of the International Energy Agency was triggered by the need of integrating costs into the assessment and evaluation framework of energy and carbon emissions in building renovation. It aims at developing a methodology that allows the establishment of cost optimized targets for energy use and carbon emissions in building renovation and determine cost effective combinations of energy efficiency measures and carbon emissions reduction measures among other goals [3].

Within the project six Detailed Case Studies have been investigated. One of the goals of the Detailed Case Studies was to perform a deep analysis “in order to evaluate the impact and relevance of different renovation measures and strategies within the project objectives and also validating the methodology of the IEA EBC Annex 56” [4]

The Case Study presented in this paper constitutes one of them. It is a multi-residential building with 20 dwellings from 1970 located in northern Spain that has been renovated in 2011. This Case Study constitutes a common Spanish building typology of the period 1940 to 1980 which results can be applied to a wide stock with similar constructive and building characteristics.

2. Methodology

To identify the cost optimum renovation parametric studies to calculate the Life Cycle Cost (LCC) and Life Cycle Impact Analysis (LCIA) have been performed in accordance with the methodology developed in the project. First of all, three renovation packages plus a reference scenario have been defined. These renovation packages include different levels of energy efficiency (insulation of the envelope), energy sources for heating and domestic hot water (including the use of renewables) and ventilation (natural or mechanical).

To define a starting point to which compare the different packages a reference scenario is established. This reference scenario includes those measures that would be carried anyway “because the end of the technical life of building elements has been achieved or the functionality or service quality of a building element is not sufficient any more” [3]. These measures can be for example the waterproofing of the roof or the repainting of façade and windows. The replacement of the existing heating system is included in the reference scenario.

For each of these packages, primary energy use, carbon emissions associated to the energy use and renovation (materials) and life cycle cost (investment, maintenance and energy costs) have been calculated taken into account a period of 60 years. The scope of the calculations include:

- Operational energy use for use for space heating, space cooling, ventilation (HVAC), domestic hot water heating (DHW) and auxiliary energy use for heating, cooling and DHW.
- Operational energy use for lighting.
- Operational energy use of built in household and common appliances (lifts).
- Embodied energy use for building materials, technical equipment and appliances.

With these data a global cost curve can be drawn in such a way that the global cost depending on the primary energy use or carbon emissions can be compared.

3. Case Study description

In 2009 the project "Lourdes Renove”, located in a neighborhood of Tudela, in northern Spain, was included in a European Project ECO-CITY of the CONCERTO Programme. The main goals of this project were the integral renovation of this social housing neighborhood built between 1954 and 1972 and the upgrade of the inefficient district heating that provides heat to part of these dwellings.

First of all, the district heating was renovated: the distribution network was replaced and new biomass and gas boilers were installed. Afterwards several pilot buildings were renovated during 2011. Our paper is focused on one of these buildings to which the methodology developed in Annex 56 has been applied. This building lacked of any kind of insulation and the scope of the renovation included the improvement of the performance of façade, roof, ground floor ceiling (in contact with unheated locals) and windows. All the decisions were based on technical and economic criteria, being one of the constraints that occupants stayed in their dwellings during the works.

This residential building was built in 1970 and is part of a big social neighborhood with low quality construction. It is a five story building with a northwest – southeast axis. Main façade is 20 meters long with a depth of 21 meters. It has 4 dwellings per floor of approximately 80 m^2 of gross area (70 m^2 of net area). The staircase is located in the middle of the building and a new elevator was installed some years ago. Private and commercial locals at street level are nowadays empty. The gross heated floor area is 1,474 m^2.

The existing façade was made of a single hollow brick 25 cm width. The floor of the first floor (in contact with unheated spaces) is made of a concrete beam slab with ceramic hollow fillers. The old pitched roof has an unheated space under it and is covered by ceramic tiles. The original wooden windows were nearly all replaced by owners at different times during the last years so their thermal performance is variable.

The building was connected to an inefficient district heating network with gas boilers (originally oil boilers with the burner changed to use gas). This district heating is used for 486 dwellings and a total of 40.448m^2 are heated. The distribution network had huge thermal losses. There were neither any kind of individual controls nor energy meters in the dwellings. The heating was paid according to dwelling’s area. Individual electrical or gas boilers for domestic hot water have been installed at different times by occupants. There are only a few individual air conditioning units and no energy saving system for lighting or common appliances. The specific heating energy demand is 120 kWh/(m^2a).

More detailed information about the original condition of the building and its renovation can be found in the Report of Detailed Case Studies [4].

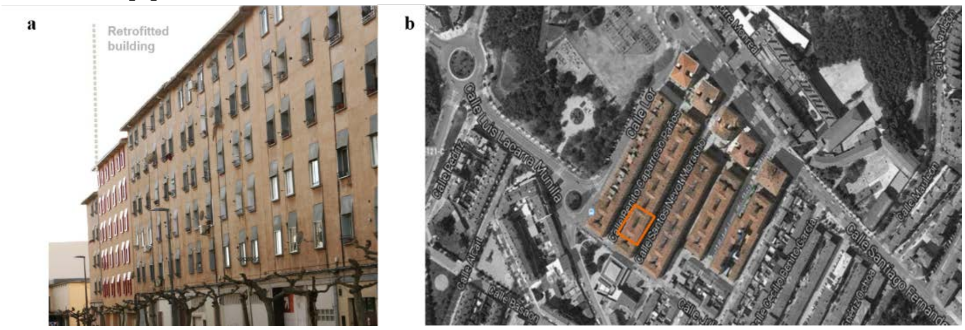

Fig. 1. (a) View of the renovated building within the lineal block to which it belongs; (b) urban context, in colour the buildings whose heating is supplied by the same district heating system.

4. Renovation measures

Three different renovation scenarios have been studied in addition to an anyway renovation. From the minimum performance required by building regulation (at the moment of the renovation) to a deep renovation. Following the studied scenarios are described.

Reference case. Existing building performing an anyway renovation. Maintenance actions are carried out in facade, roof and windows. Heating and DHW systems are replaced by a collective gasoil boiler with a standard efficiency.

Alternative scenario 1, v1. Minimum required by Spanish building code (2006). The main objective of scenario 1 is to achieve only the minimum performance required by the Spanish building regulation at the moment of this renovation for this climatic zone (40 mm EPS in façade, 40 mm XPS in roof, 40 mm MW in ground floor ceiling and new windows with an U average of 2.2 W/m^2K. A new condensation gas boiler for heating and DHW has been considered. No additional measures have been performed to reduce other energy uses.

Alternative scenario 2, v2. Deep renovation. Enerphit Passivhaus Standard. The performance of the envelope has been improved much more than is required by regulation and more than in a business-as-usual new building (220 mm EPS in façade, 240mm XPS in roof, 240 mm MW in ground floor ceiling and new windows with an U average of 1.4 W/m^2K). An air-water heat pump is selected for the low heating demand needed and DHW. Solar panels contribute to cover 50% of the DHW. Individual mechanical ventilation is installed.

Chosen renovation, v3. Average retrofit with on-site renewables. All the actions performed during the actual renovation are taken into account in this scenario: improvement of the envelope (60 mm EPS in façade, 60mm XPS in roof, 100 mm MW in ground floor ceiling and new additional windows with an U average of 2.6 W/m^2K mounted on the exterior of the existing ones) and district heating renewal (only for heating, individual DHW boilers aren't improved). Additional measures (not performed in reality) are taking into account for the scenario comparison: prefabrication and on-site photovoltaic system that covers 50% of the DHW demand.

The calculated energy demand of the different scenarios is included in Table 1.

Table 1. Energy demand for the different scenarios.

Calculated energy demand (kWh/m²a)	ref. case	v1	v2	v3
Heating	120.0	55.0	9.3	45.3
DHW	25.4	25.4	25.4	25.4
Cooling	5.8	0.0	2.1	0.0
Electricity (miscellaneous)	18.8	15.3	16.6	14.5
Total	169.9	95.7	53.5	85.2

These four scenarios make it possible to compare the cost-effectiveness of different levels of energy efficiency of the building under consideration when carrying out a retrofit. In the same way, for comparison purposes, in scenario 1 and 2, four different energy sources are used for heating and DHW. Therefore the systems compared are: oil boiler (oil), condensing gas boiler (gas), air-water heat pump (elec.) and district heating (DH) based on biomass (75% of the share) and auxiliary gas. Additionally, in scenario 2 solar panels have been considered that cover 50% of the DHW demand and in scenario 3 PV panels that provide 50% of the electricity used.

5. Results

The life cycle cost and life cycle impact assessment of the different scenarios and their variants have been calculated in order to evaluate their cost-effectiveness. The annual cost calculations are based on a LCC-period of 60 years, inflation rate of 3 % and yearly increase of energy cost by 2 %. The yearly life cycle costs are summarized in Table 2.

Table 2. Results of the Life Cycle Cost.

Annual costs (EUR/m²a)	ref. case	v1 - oil	v1 - gas	v1 - elec	v1 - DH	v2 - oil	v2 - gas	v2 - elec	v2 - DH	v3
Building envelope capital costs	1.7	6.0	6.0	6.0	6.0	8.2	8.2	8.2	8.2	5.3
BITS capital costs	2.0	1.4	1.8	2.8	3.7	2.7	3.0	3.4	4.6	5.0
Maintenance costs	2.6	1.6	1.9	2.1	1.1	1.9	2.1	2.1	1.7	1.6
Energy costs	29.9	17.9	14.5	14.6	13.9	9.4	8.3	8.5	7.7	9.4
Total yearly life cycle costs	36.1	26.9	24.3	25.6	24.8	22.2	21.5	22.1	22.2	21.3

The investment costs in the building envelope are in most cases much higher than the costs associated to the building systems. In the chosen renovation, these envelope costs were reduced by means of installing an additional exterior window of standard quality instead of replacing the existing ones by new ones of better quality. Nevertheless, the cost associated to the district heating is high comparing the investment costs of other systems.

All the renovation scenarios studied are cost-effective due to the high energy consumption of the existing building. The most cost-effective scenario in terms of annualized costs is the chosen renovation. All the variants in v2 and v3 have similar total yearly life cycle costs. The scenario with the lowest annual costs for energy is v2-DH. Therefore, if yearly increase of energy cost is higher, v2-DH will be the most cost-effective option. That is why, a deeper renovation, as v2, has to be considered if a lower exposure to energy prices fluctuation has to be ensured.

On the other hand, these scenarios have also been studied in terms of their impact on the environment. These calculations were performed with Eco-Bat 4.0. Embodied energy (manufacturing, replacement, transport and elimination) of the materials used for renovation and impacts related to the energy use have been included. The data concerning the final and primary energy use and the global warming potential are gathered in Table 3.

Table 3. Results of the Life Cycle Impact Assessment.

	ref. case	v1 - oil	v1 - gas	v1 - elec	v1 - DH	v2 - oil	v2 - gas	v2 - elec	v2 - DH	v3
Final energy use (kWh/m^{2}a)	195.0	114.1	91.6	47.2	104.0	38.2	33.3	24.2	36.3	85.8
GWP (kgeq CO2/a/m^2)	65.5	40.7	28.3	30.2	17.5	22.8	19.2	19.7	15.7	20.9
NRPE (kWh/m²a)	282.0	176.9	138.6	153.4	83.5	104.2	93.1	98.0	74.0	97.2
PE (kWh/m²a)	290.4	183.4	144.7	169.9	185.4	111.2	100.0	108.1	116.1	161.5

In any scenario a reduction of at least 40% of the energy use is achieved, being the reduction of energy associated to the heating more than 55% in all of them; further reductions could have been achieved if additional measures in lighting or common appliances would have been implemented.

In terms of CO_2 emissions, these are reduced more than 45% in all cases, being the highest reduction 75% in v2-DH. This scenario corresponds also with the lowest non renewable energy use. In terms of total primary energy scenario 2, v2-gas, with a condensation gas has a slightly lower impact.

Despite the fact that chosen renovation has the lowest total yearly life cycle costs of all the alternative scenarios, its CO_2 emissions associated and total primary energy use per year is bigger than in v2 which corresponds to a deeper renovation of the building envelope. Taking into account this fact, if it is possible to make a larger initial investment, it seems reasonable to perform a deeper renovation since the increase of total yearly costs is only 1-4% and the heating demand is reduced almost 80% (comparing scenario v2 to v3).

As already stated, further reduction in terms of CO_2 and primary energy use will be possible with the implementation of more on-situ energy production, more efficient lighting or electric appliances.

In Figure 2 (a) and (b) global cost curves are represented in relation to carbon emissions and total primary energy.

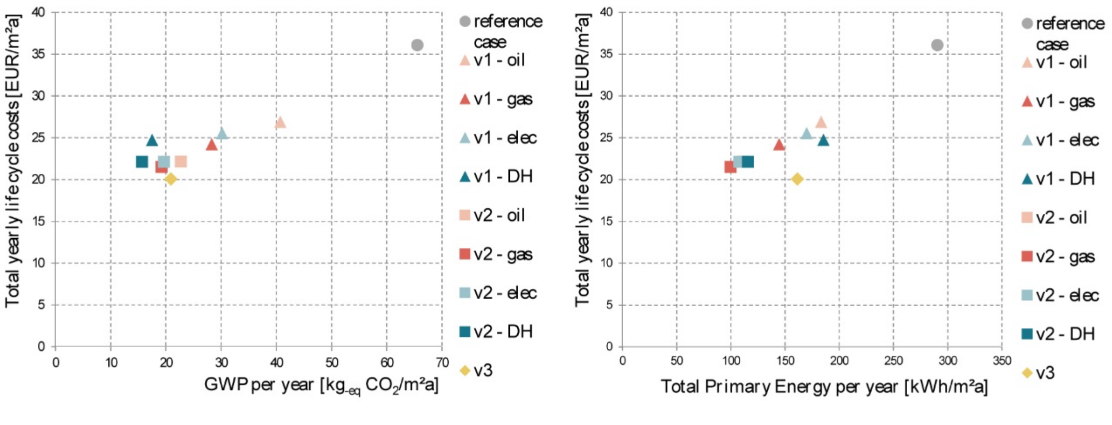

Fig. 2. (a) Total yearly life cycle costs curve in terms of the GWP; (b) total yearly life cycle costs curve in terms of the total primary energy.

To summarize, all the scenarios studied are cost-effective. Therefore energy renovations should be encouraged. Deep renovation is the most cost-effective in terms of energy use and CO_2 emissions. In relation to the cost, this option will be also the most cost-effective if energy prices keep on rising at a higher rate than 2% annually. The biggest barrier is the high investment costs so further work has to be focused on solutions that allow reduce their installation costs or financial formulas that allow their funding.

6. Conclusions

This residential building was built in 1970 as part of a big social neighborhood with low quality construction. Renovation was a necessity due to its poor conservation state, urban degradation and the increasing number of energy poverty cases. The main priorities of the process were grouped under two main concepts: renovation of the thermal envelope and district heating upgrade.

First the district heating was renovated and afterwards, only several buildings have been renovated. As a result the synergy of renovate the buildings' envelope and systems is not exploited. At the same time it has been found that the energy consumption in this neighborhood after the process is lower than the energy needed to maintain the dwellings in a comfortable temperature, so it is probably that exist numerous cases of fuel poverty.

The methodology developed in this project allows the comparison of different renovation scenarios. However in the decision making process other aspects, as the social and economic situation of the occupants and co-benefits of the renovation, have to be taken into account in order to guarantee the success of the intervention. In social housing deep renovation is needed so that occupants can afford the use of heating and avoid urban degradation.

In this case, the actually executed renovation, if additional on-site renewables are installed, constitutes the most cost-effective scenario. Therefore, despite the limited budget of this renovation, it has been used wisely making the most of it.

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