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Application of the cost-optimal methodology to urban renewal projects at the territorial scale based on statistical data—A case study in Spain

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ABSTRACT

As tomorrow's cities are already largely built, many strategies stress the importance of urban renewal processes to address current energy issues. This paper focuses on the Spanish residential building stock built until 2001, which has a low level of energy performance.

Considering the current economic crisis, the future lies in renovating the built environment, which holds a significant energy-saving potential. This potential is here quantified by applying the cost-optimal methodology, initially proposed by the Energy Performance of Buildings Directive, and which calculates cost-optimal levels of minimum energy performance requirements at the building and component scale.

The originality of our study lies in the application of this methodology at the territorial scale, comparing different retrofitting scenarios by scaling-up building-scale results through an archetypal approach. We also describe an Excel-based tool allowing two types of studies: (i) at the building scale, for one archetype in a particular climatic zone; (ii) at the territorial scale, to have an overview of all building archetypes and climatic zones simultaneously. Results include economic aspects, energy consumption and savings and associated emissions.

The outcome can help construction-sector firms adapt their business plan, while also providing stakeholders with decision-support to promote a sustainable renewal of the building stock.

1. Introduction

1.1. European and Spanish building stock

One of the top priorities regarding the built environment in European countries is to reduce energy consumption and greenhouse gas (GHG) emissions and increase the use of renewable energy [1–5]. Due to the low replacement rate of existing buildings – about 1–3% per year in EU countries [6] – the majority of buildings that will exist in 2050 is already built, with many of them having a low level of energy performance [7]. In this context, the retrofit of existing buildings offers significant opportunities for reducing energy consumption and GHG emissions [8]. In fact, the International Energy Agency (IEA) estimates that the potential energy savings for 2050 are of about 1509 million tonnes of oil equivalent [9], with a 50–75% saving when considering only the improvement of the building envelope [10]. It therefore seems clear that the residential building stock in EU-27 offers high potential for energy efficiency gains [11,12]. This large potential energy saving is particularly relevant to the Spanish context [7], where most residential buildings were constructed before 2001, when thermal regulations were modest [13–18].

According to the Energy Performance Certification (EPC) in Spain, which rates buildings from A (best) to G (worst), 96% of the certified 1.4 million existing buildings are below the current legal requirements set at an EPC level C [19]. The EPC rate depends on the type of building and the climatic zone where it is located. In

Abbreviations: CDD, cooling degree days; CE3x, official software for energy performance certification; CTE, technical building code; DHW, domestic hot water; EEM, energy-efficient measures; EPBD, energy performance of buildings directive; EPC, energy performance certification; EU, European Union; GIS, geographic information system; GHG, greenhouse gas; GTR, rehabilitation working group; HDD, heating degree days; HVAC, heating ventilation and air conditioning; LCA, life-cycle assessment; LCC, life-cycle cost; LoD, level of detail; MF, multi-family; MS, member states; NPV, net present value; nZEB, nearly zero energy buildings; ORIG, current status scenario; PE, primary energy; RD, royal decree; REF01, minor retrofit scenario; REF02, deep retrofit scenario; RET, renewable energy technologies; SF, single-family; PBP, payback period; TABULA, typology approach for building stock energy assessment; VAT, value-added tax.

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general, the different levels follow a linear dependency: a building with the lowest qualification consumes ten times more than a building with the highest level of performance [20,21].

The residential building stock as a whole emits about 35 $kgCO_2/m^2$ per year in terms of primary energy (PE) consumption [22], a value that is far from the ambitious objectives of the EU horizon 2050 for new and existing buildings of around 3 $kgCO_2/m^2$ [23].

However, by considering only envelope retrofitting, it would be possible to reduce the energy used by residential buildings up to 25% by 2020 [24]. For the 2050 horizon, the total savings could reach 71% in terms of energy and 73% in terms of GHG emission [22]. These values highlight that it is theoretically possible to achieve the EU's 20% energy-saving target for 2020, as well as the long term 80–95% GHG emissions reduction target for 2050.

1.2. European and Spanish regulations and cost-optimal methodology

In response to the strong demand for housing, the construction of residential buildings in Spain underwent unprecedented growth, especially between 1960 and 2001 [13,14]. Unfortunately, these buildings were designed either without ensuring a minimum level of construction quality, in terms of comfort and energy efficiency, or relying on insufficiently restrictive regulations.

The first regulation seeking to improve the energy performance of buildings resulted from the energy crisis of 1973: the NBE-CT-79 – *Thermal Conditions in Buildings*, published on July 6, 1979 [25]. However, this first regulation did not specify a target for reducing energy consumption. It simply established a set of acceptable constructive solutions, without defining a protocol for controlling the quality of the building envelope.

The most important change appeared with the European Directive 2002/91/EU concerning the energy efficiency of buildings. The transposition of this Directive in Spain is reflected by Royal decree (RD) 314/2006–*Technical Building* Code (CTE) [26], RD 1027/2007–*Thermal facilities in Buildings* (RITE) [27] and RD 47/2007–*Energy Performance Certification* (EPC) *protocol for new buildings* [28]. The mission of these new standards was to regulate all construction parameters and to define energy limits and steps to follow for the energy certification of new constructions [18,27,28]. This situation put the existing building stock in the spotlight, due to its enormous energy consumption and GHG emissions [7].

With the focus placed on the continuous increase in the demand for new residential buildings up until 2001, only recently has there been specific Spanish legislation in terms of building rehabilitation. The three most recent regulations appeared in 2013 [18]:

- RD 235/2013–New protocol for the EPC to include **existing buildings** [20].
- CTE 2013–Updated CTE for regulating the energy requirements of new and **existing buildings** [18].
- RD 8/2013–Law to promote **urban renewal projects** [29].

These changes in the regulatory framework try to respond to the requirements of the European Directive 2010/31/EU, which establishes that all public and privately owned buildings must be nearly Zero Energy Building (nZEB) from December 31, 2018 and 2020 respectively. In this directive, the cost-optimal methodology was mentioned for the first time [17]. Initially, this methodology was proposed by the EU to study different building retrofitting scenarios. It consists in a multi-criteria assessment that allows comparing different levels of intervention under various macroeconomic scenarios, in terms of cost-effective strategies and energy and environmental savings [8,12,17,22,30–33].

In parallel, the evolution of EU directives continued. In 2012, the 2012/27/EU Directive was presented [34]. It defines the PE and GHG emissions savings to be achieved, and requires all EU member states (MS) to define specific strategies to achieve those objectives. As a result, in the Spanish context, the current legislation does not yet meet the requirements of the latest EU directives.

Therefore, new regulatory changes are necessary in the short term in order to reach the required level, because all EU countries should have submitted plans and regulations for the promotion of nearly nZEB, as well as measures to promote building energy rehabilitation projects following the cost-optimal methodology to ensure the viability of the improvement strategies [17,22,35].

1.3. Overview of study

Attempting to address these issues, this research proposes an application of the cost-optimal methodology at the territorial scale to estimate the energy-saving potential of the residential buildings built before 2001 in Spain. The originality of this study lies in the application of this methodology at a large scale, using statistical and population census data and taking into account the 12 climatic zones of the Spanish territory. The paper moreover describes an Excel-based calculation tool, developed to enable professionals to make strategic decisions by helping them select the best strategy for achieving the European requirements for 2020 according to the nZEB. This research is based on the work conducted during the Master thesis of the first author [36], which represents the main source for the content of this manuscript.

The structure of the paper is articulated in seven sections: (1) introduction, (2) literature review, (3) definition of the main objectives, (4) proposed methodology to carry out the development of a decision-making tool, (5) presentation of the main results through a case study in Spain, testing different renovation scenarios and different temporal horizons, (6) discussion of results, and (7) conclusions and recommendations to promote energy renovation of the building stock.

2. Literature review

The EPBD recast [17] proposes that all MS establish a comparative framework to calculate cost-optimal levels of minimum energy performance requirements for buildings and building components, using the cost-optimal methodology. Table 1 summarizes how this methodology has been employed in various studies conducted in a specific climatic context for investigating renovation strategies over existing buildings.

In terms of scale, we observe that a majority of applications of the methodology have been at the building or component scale, especially to compare different constructive solutions and construction materials or to optimize the insulation thicknesses of the building envelope [8,12,32,33,37–42]. When at the building scale, studies typically consider only one specific typology for a given period of time or year (e.g. multi-family house of 1960–1990 [8]).

To analyse the existing building(s), and according to the purpose of the study, different approaches are used. The majority of the publications make a classification of the building stock in different categories using the concept of '*reference building*' based on real building examples in a specific context [40,43,44]. This concept is applied for example in the Typology Approach for Building Stock Energy Assessment (TABULA) project [45] with the aim to have a harmonized database of existing buildings at the European level. Unfortunately, this database presents a lack of information for specific countries (e.g. Spain) and does not contain enough information to depict the whole building stock according to climatic zones.