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Economic assessments of passive thermal rehabilitations of dwellings in Mediterranean climate

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ABSTRACT

This work presents an energy and economic analysis to assess the profitability of energy rehabilitation operations in the envelope of a block of residential dwellings in Southern Spain. The work rates the influence that a set of hypotheses of interventions in the opaque part of the envelope exerts on annual energy demand (better insulation of the façade, interior partitions, roof and ground floors) in addition to its semi-transparent part (improvements in the airtightness of the building openings, the glass windows, devices of control of solar radiation and their possible combinations or settings of energy rehabilitation). These models have been designed for the context of a Mediterranean climate, and the simulation tool, Design Builder-Energy Plus has been selected to generate the computing models and establish their energy demands. This work concludes that the most profitable setting is that which combines: a façade restored by inner cladding with insulation superior to the regulatory limit, roof and ground isolation provided by the inner facing, double-glazed windows with low emissivity and aluminium frames with a break in the thermal bridge, protection from mobile device shading, and an efficient use of the terraces as solar collectors.

1. Introduction

In today's society, greater awareness is perceived in everything related to environmental impact and sustainability. The rise of these concepts is manifested by the creation of an entire industry around energy saving and energy efficiency, and has been intensely promoted at government level since the beginning of this century.

One of the sectors with the greatest impact on energy consumption is the existing building sector, in which the majority of energy consumed in its lifecycle is attributable to the operational phase of the buildings [1], especially with regard to the internal climatic requirements for thermal comfort. Hence many regulation policies and urban planning strategies have been designed to promote housing renovation in this new era [2]. These interventions can be focused both on HVAC systems, which include smart grid thermal systems at district level [3,4], and through passive improvements, where much energy saving is owed to the thermal performance of the building envelope. To this end, work has been addressed on green roof strategies [5–7], as well as specific studies dealing with thickness optimization of the insulation layer [8] and types of thermal insulation materials [9]. The exploration of alternative solutions by simulation in residential buildings to reduce energy consumption is proposed through the application of several approaches [10,11] for the various climate scenarios [12,13].

In the case of Spain, we are faced with an inefficient, uncomfortable building stock with excessive energy consumption. Approximately 25 million dwellings in 2011, from which 72% were primary residences [14], accounted for 19% of the total energy consumed in the country in the same year [15], and were also responsible for 32% of the greenhouse gas emissions of the total allocated to Spain for the 1990–2009 period.

These figures highlight the need to reduce energy consumption in the residential sector, as required by Directive 2010/31/EC of the European Union [16].

To achieve these objectives, various policies and regulations have been launched in Spain. Among these are the Construction Technical Code (Código Técnico de la Edificación CTE [17]) and subsequent updates on its core documents on Energy Saving (HE) [18] as well as the incorporation of the basic procedure for certification of energy efficiency of existing buildings [19].

Based on this legislative framework, the thermal rehabilitation of the existing housing in Spain has become necessary [20,21], especially for those dwellings built prior to 1979, the year in which the first legislation on thermal conditions of buildings was introduced

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Nomenclature

D_r	Discount rate (%)
FB_i	Flow of benefits in the period i (€)
I_0	Total initial investment costs (€)
NPV	Net present value (€)
PB	Payback period (year)
U	Thermal transmittance (W/(m^{2}K))
Greek letters	
λ	Thermal conductivity (W/(mK))

[22], since these older dwellings account for 58% of all registered houses as of 2011.

Due to the immersion of Spain into a scenario of economic crisis since the end of 2007, which is especially pronounced in the construction sector of new buildings, intervention into the existing buildings must become a priority in the coming years: one of the ways that may encourage energy rehabilitation work is precisely through its economic viability.

Although there are numerous publications issued from state, regional and independent agencies that address energy rehabilitation of Spanish housing stock and provide guidance percentages of energy savings, these studies fail to take into account the particularities of each context, such as the climatic conditions of each area, and the type and geometry of the building itself.

In this regard, Jaber et al. [23], perform an analysis to optimize the energy design in residential buildings located in the Mediterranean climate. For Seville, at least 2 studies are worthy of note: the work by León et al. [24], which assesses the impact on energy demand for various types of sunscreens on a block of flats in the city and obtains reductions of between 10% and 27% depending on orientation; and work by Domínguez et al. [25], where a multifamily residential building is altered only in terms of the properties of their windows, and savings in annual demand of around 20–25% are obtained.

Other pieces of work delve into the cost factor of energy rehabilitation interventions, such as that by Pérez-Fargallo [26], where an analysis of the savings produced by standard measures of rehabilitation is carried out exclusively on single-family homes, and work by Alguacil [27], which makes comparisons between saving solutions that are economically viable. The economic evaluation of energy retrofitting of buildings is a question of interest that has led to recent research in northern Spain [28] and central Spain [29], and to the thermal study and energy cost analysis (based on electricity) for various scenarios in several regions of Portugal [30,31].

Thus, this study starts with the energy savings achieved after the implementation of various passive strategies of refurbishment, whereby a value of the economic profitability of such measures is obtained. The initial investment cost (at current prices, 2015) is counterpoised with the savings in the cost of energy (2015 prices). The feasibility of such operations is hence analysed when there are no external funding sources, by assessing whether a particular community of neighbours could undertake this operation autonomously, and provide a repayment of the overall operation.

To this end, this work focuses on the assessment of the energy consumption of a model, in order to study its behaviour via computer simulation with various scenarios of improvements and combinations. This model is one of the H-shaped blocks of the residential neighbourhood *Virgen del Carmen* in Seville (Southern Spain), built between 1955 and 1960. Although this analysis cannot be considered representative for all buildings constructed in the same period in this city (due to differences in architectural type, orientation, solar obstacles, etc.), it acts both as a methodological example and as an indicative reference, generalizable to other buildings and thermal refurbishments in the Mediterranean area.

2. Description of the model

The *Virgen del Carmen* neighbourhood consists of a set of 636 flats designed by the architect Luis Recasens [32] between 1955 and 1960, where the rigorous geometric arrangement of linear blocks of five storeys conjugates with others of greater height: ten-storey symmetrical H-shaped blocks around the perimeter of the neighbourhood, creating a wide network of public spaces between them. Currently, the blocks have an acceptable degree of conservation thanks to a reform in the façades and enclosure of the balconies performed in 1983 by the architect Enrique Taviel de Andrade [33].

The ten-storey H-shaped blocks (Fig. 1), whose ground plan has a variation from the standard H-shaped type are taken as an object of study: two slightly curved wings in search of greater sunlight, in which the outside has 10 storeys and the interior resembles the rest of the neighbourhood scale, with a ground floor plus four upper storeys. These blocks are grouped in pairs, and at the point of contact between the two blocks a volume is added which forms an extra room in the first six storeys (Figs. 1 and 2a).

Two basic provisions exist for these H-shaped blocks: three pairs of blocks directing their tallest body (10 storeys) to the west (similar to block A in Fig. 2a), and two pairs of blocks with said body towards the northeast (similar to block B in Fig. 2a). Due to their placement, the influence in terms of solar exposure of each pair exerted on the remaining blocks remains negligible. Having performed the analysis of the insolation of openings, the shadow cast by the blocks farther south, in each pair, onto the adjacent block exerts a very small influence on the demand for both cooling and heating. Hence, the block located further south is the only one evaluated (Fig. 2a).

The interior layout of the flats starts with the main room, which is broken into two enclosures, each linked to an orientation but united diagonally. The centred position of this piece divides the dwelling into two zones, interpretable as a parents' area (1 room) and a children's area (2–3 rooms), instead of the typical modern division of day and night areas. The kitchen and dining area are associated with the terrace, and hence is understood as a utility terrace. Three types of dwellings exist in the floor plan of an H-shaped block: Dwelling Type I, Type I' and Type II (Table 1) and there is a great perimeter surface of the façade of all the flats in the neighbourhood (Fig. 2b).

3. Simulation: methods

The software chosen for developing nodal simulations is DesignBuilder v3.4.0.041. This software works as a graphical user interface of the nodal simulation Energy Plus 8.1, designed by the US Department of Energy [34], which is one of the most advanced dynamic simulation tools of phenomena related to the environmental and energy performance of buildings, whether they operate in mechanical mode (with air conditioning systems), in passive mode (using only natural resources, such as wind and solar radiation), or in mixed mode.

3.1. Configuration of the simulation

Given that the study sample must be comparable with the standard case studies, simulation conditions are established (Table 2) by the document on the conditions for acceptance of alternative computing programmes (Condiciones de aceptación de programas informáticos alternativos) [35,36] , and also by the CTE document [18,37].