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The impact of building orientation and discount rates on a Portuguese reference building refurbishment decision

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HIGHLIGHTS

- Building refurbishment decision based on technical and economic points of view.
- 35.000 Packages of thermal rehabilitation solutions considered.
- Building orientation and discount rate impact on the cost-optimal package of solutions.
- Portuguese reference building case base.

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ABSTRACT

Refurbishment, as part of the construction industry, has a strong global impact, not only from the viewpoint of economies but also from social and energy-efficiency perspectives. A thermal refurbishment process, in particular, involves numerous decisions and choices; the decision-makers being ultimately confronted with two major questions: which criterion should be adopted in the choice of the refurbishment construction solutions and which refurbishment construction solutions should be chosen?

In this paper, a criterion based on technical and economic points of view is proposed, aiming to identify the cost-optimal package of energy efficient solutions from among a set of possible refurbishment measures, within the life cycle of buildings. Sensitivity analyses are also performed so that the results may help the decision-maker choose the appropriate refurbishment solutions to be adopted when different discount rates and building orientations are taken into consideration. A total of seven scenarios, for a macroeconomic perspective, and nine, for a financial perspective, are performed.

The costoptimal methodology adopted, following the Directive 2010/31/EU (2010) recommendations, is applied to a Portuguese reference building. The analysis carried out allows obtaining low global life cycle costs solutions and points towards nearly Zero Energy Building (nZEB) concept. The results are important for drawing national political instruments on buildings energy efficiency.

1. Introduction

In 2014, refurbishment was the prevailing segment within EU's housing construction market, accounting for 61.2% of the total, with the balance being represented by new housing construction. These proportions are in contrast with the situation that prevailed during the peak period (2007) when new constructions represented over half (51.2%) of the total housing construction output when compared with refurbishment, which accounted for 48.8% (Euroconstruct, 2014).

Refurbishment relies on the making of numerous decisions and choices. Therefore, life-cycle perspectives are being increasingly considered in the decision-making process and involving participants with different interests (Hernandez and Kenny, 2011; Sartori and Hestnes, 2007). Indeed, on the one hand, owners want to minimise the likely costs of the project, but they also want to achieve the highest acceptable quality standards and satisfy the technological, architectural and comfort requirements. On the other hand, designers and contractors are interested in maximising profits, being also concerned with other aspects such as

Abbreviations: COP, Coefficient of Performance; EER, Energy Efficiency Rate; EPBD, Energy Performance of Buildings Directive; GHG, Global Greenhouse Gas; RB, Reference Building; SA, Sensitivity Analysis; nZEB, nearly Zero Energy Buildings

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company growth, market share, and the state institutions' interests (Banaitiene et al., 2008).

As part of the construction industry, refurbishment has a strong global impact, not only from the viewpoint of economies, but also from social and energy-efficiency perspectives (Comstock et al., 2012; Ferreira et al., 2013; Keivani et al., 2010). Globally, buildings represent 40% of the world's energy consumption and one third of the global greenhouse gas (GHG) emissions (Graham, 2010). As urbanisation increases in the world's most populated countries, building sustainability is more and more seen as a key factor in achieving sustainable development.

As a result of these energy efficiency challenges, the European Energy Performance of Building Directive (EPBD) (Directive 2010/31/EU, 2010) recast, which aims to ensure energy savings and CO_2 emission reduction, required the Member States to establish a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Higher energy performance buildings (Hernandez and Kenny, 2010; Marszal et al., 2011), like nearly Zero Energy Buildings (nZEB), should also be economically feasible.

Thus, within a building refurbishment process, and taking into account those requirements, decision-makers are ultimately confronted with these two questions:

1) Which criterion should be adopted in the choice of the refurbishment construction solutions?
2) Which refurbishment construction solutions should be chosen?

Following these EU Directives' recommendations, the authors propose a criterion based on technical and economic points of view, with a view to identify the cost-optimal package of energy efficient solutions from among a set of possible refurbishment construction solutions (Brandão de Vasconcelos et al., 2015a, 2015b, 2015c, 2014), within the life cycle of buildings.

Other recent studies have also used the cost-optimal energy performance of buildings methodology, in line with the EPBD recast, to identify the cost-efficient set of solutions (Corrado et al., 2014; Ferrara et al., 2014; Ganiç and Yılmaz, 2014; Hamdy et al., 2013; Kurnitski et al., 2011; Pikas et al., 2014). Different authors have assessed the influence of base parameters on the calculation of the cost-optimal package of solutions, by performing Sensitivity Analysis (SA) on the results (Baglivo et al., 2015; Ferrara et al., 2014; Ferreira et al., 2014; Ganiç and Yılmaz, 2014; Hamdy et al., 2013; Morrissey et al., 2013; Stojiljković et al., 2015; Tol, 2012). All these studies provided approaches to the calculation framework at national levels. For the Portuguese context, an adaptation is required in order to consider specific national factors.

This paper aims to describe in detail the cost-optimal methodology applied to the Portuguese context and to evaluate how different circumstances, based on different discount rates and building orientation, may affect the decision on which the refurbishment construction solutions to be chosen should be based. This evaluation is made through SA in order to assess the impact on the cost-optimal results of the parameters chosen for the model as input data. The methodology established considers both financial and macroeconomic perspectives applicable to the whole life cycle of buildings and takes into account the national reference standards.

In the introduction (Section 1), this paper sets out the main objectives of the research work. Section 2 proceeds with the application of the cost-optimal methodology to a Reference Building (RB) representative of the Portuguese residential building stock. In Section 3, SA is carried out for the discount rate and building orientation parameters from macroeconomic and financial calculation perspectives. In Section 4 the influence of those parameters on the choice of the cost-optimal package of solutions for the RB studied is discussed and, finally, in Section 5, the main conclusions are presented.

2. Cost-optimal decision-making methodology

A cost-optimal methodology is proposed in this paper as a basis for a decision-making criterion as regards the choice of refurbishment construction solutions. This methodology phasing is fully described in Brandão de Vasconcelos et al. (2015a, 2014) and allows establishing a relationship between the performance and the correspondent costs of energy refurbishment solutions, thus enabling to determine the most cost-efficient package of solutions throughout the life cycle, which is called the cost-optimal level. In the following paragraphs, the application of the proposed methodology to the RB considered is described in detail.

2.1. Phase 1 – definition of a Portuguese residential reference building

The first phase of the methodology involves the definition of a RB. The option to chose a RB representative of the Portuguese building stock rather than considering different RBs is based on the objective set for this paper to present in detail all research issues that are likely to be useful at national or international level for cost-optimal methodologies and for the decision on refurbishment construction solutions considering different circumstances. Therefore, the RB selected is representative of the Portuguese residential building stock in terms of construction solutions and its configuration is representative of Lisbon's building typologies in the 1960–1990 construction period.

The RB characterisation took into consideration, among other aspects, the fact that 50% of the total housing stock in Portugal was built between 1960 and 1990 (INE [Statistics Portugal], 2012) and more than 85% of the buildings constructed before 1990 have been marked as C or less energy classification (ADENE, 2011). By combining these and other aspects, the RB adopted is mainly characterized as shown in Table 1. These characteristics make it nationally representative in terms of construction solutions and its configuration makes it representative of Lisbon's building typologies, in the 1960–1990 construction period. This RB is fully characterised in Brandão de Vasconcelos et al., (2015a).

2.2. Phase 2 – identification of the energy efficiency measures for the RB

The building envelope has been reported by several authors (Florides et al., 2002; IEA, 2013; Ramesh et al., 2010; Sadineni et al., 2011) as playing a key role in determining levels of comfort, natural lighting and ventilation; its energy performance (including external walls, floors, roofs, ceilings, windows and doors) being critical in determining how much energy is required for heating and cooling. Therefore, the energy efficiency measures selected to be applied to the RB are within the group of thermal refurbishment solutions of the building envelope (Brandão de Vasconcelos et al., 2015b), which is focused on the reduction of the building's energy consumption through the reinforcement of the protection of opaque elements (external walls, roofs and floors) and windows.

Table 2 lists the thermal refurbishment measures chosen to be applied to the RB envelope. For the determination of the cost-optimal level, the measures listed were combined so as to create 35.000 packages of solutions.

2.3. Phase 3 – calculating the primary energy consumption for each