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EPBD cost-optimal methodology: Application to the thermal rehabilitation of the building envelope of a Portuguese residential reference building

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ABSTRACT

The Energy Performance of Buildings Directive (EPBD) recast sets out for all Member States the establishment of a comparative methodology framework to calculate cost-optimal levels of minimum energy performance requirements for buildings and building elements. In recent studies, the cost-optimal energy performance of buildings has been calculated in line with the EU's Directive, despite the calculation methodology there mentioned being only a framework that provides a general approach for national calculation methods.

This paper defines the parameters needed for the EPBD phasing methodology. The results obtained from the thermal rehabilitation of the building envelope of a Portuguese residential reference building, which are conditioned by the reference building characteristics and by Lisbon's climatic conditions, make it possible to identify the best cost-efficient thermal rehabilitation measures. Conclusions on cost-efficient thermal rehabilitation are as follows: (i) the thermal rehabilitation of the roof produces the greatest variation in the primary energy building consumption (and the floor measures the smallest), (ii) the combination of thermal envelope rehabilitation measures creates synergy effects that lead to better results than single measures (regarding global costs and primary energy consumption), and (iii) it is more advantageous to proceed with a thermal rehabilitation package of measures rather than doing nothing.

1. Introduction

The building sector is responsible for about 40% of Europe's total energy consumption and for one third of the global greenhouse gas (GHG) emissions [1,2]. Therefore, a major effort is being done nowadays, all over the world, to find methods for optimising the energy performance of buildings. At European level, these efforts can be observed in the European Energy Performance of Building Directive (EPBD) [2] recast, which aims to ensure energy savings and CO_2 emission reduction. This Directive required the Member States (MSs) to establish, by means of a delegated act, a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. This Directive was further supplemented by the Commission's Delegated Regulation (EU) No. 244/2012 of 16 January 2012 [3] and by the guidelines accompanying this Regulation [4], which are not legally binding.

At individual level, various decision aid tools were developed to introduce optimisation and evaluation methodologies. Poel et al. [5] presented an overview of methods and software that can be used to perform building energy assessment in a uniform way. The decision support software presented has been developed, over the past few years, within the framework of European projects with a view to assess the different scenarios occurring during renovation or refurbishment of buildings [6–10]. Mills [11] compared different North American residential energy analysis tools, which are integral to the process of identifying and implementing building energy saving measures. Having evaluated 50 web-based and 15 disk-based residential tools, the author finds that few tools offer substantial decision-support content [12]. Other authors introduce

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methodologies and simulation programs for optimising and improving the energy efficiency of buildings [13–16].

These various decision aid tools were developed to support and advise energy building experts and other stakeholders. Most of the available tools focus on the technical aspects of energy efficiency measures and, as a consequence, economic aspects are insufficiently or inaccurately addressed [11,12]. Most analysts stop halfway the appraisal process when they carefully assess net present values and their sensitivity to uncertain future events [17]. The importance of a comprehensive techno-economic evaluation method is needed and some examples of decision-making tools have emerged [12,18,19] after taking due account of this aspect.

Recent studies have been calculating the cost-optimal energy performance of buildings in line with the EPBD recast [20–25]. However, this calculation methodology is just a framework and provides only a general approach for national calculation methods; being, then necessary to adapt this framework to the different national factors. This paper proposes the steps and objectives involved in the calculations of the cost-optimal levels referred to in the EPBD recast, within the Portuguese context. It is particularly focused on cost categories and cost calculations applicable to a Portuguese reference building (RB), with a view to develop a national optimal methodology within the Portuguese market conditions.

The characterisation of the steps to achieve the methodology proposed by EPBD aims to contribute to the definition of parameters needed for the methodology phasing; the results obtained for the Portuguese RB making it possible to determine which thermal rehabilitation measures of a building envelope are the most cost-efficient.

In Section 1, this paper sets out the main objectives of the research work. Section 2 proceeds with the definition of the steps that make up the cost-optimal methodology. The results of this research applied to a Portuguese case study are shown in Section 3 and discussed in Section 4. Finally, in Section 5, the conclusions of all the research work are presented.

2. EPBD cost-optimal methodology: proposal

The methodology phasing proposed in this paper is based on the requirements established by the European Parliament and by the Council of the European Union through the Commission's Delegated Regulation (EU) No. 244/2012, of 16 January 2012 [3], and on the guidelines that accompany this Regulation [4]. Thus, five phases of actions were considered [26]. Through this phasing (Fig. 1), it is possible to determine the energy performance of buildings and building components and its economic issues, in order to establish an optimal balance between the investments made and the energy savings achieved throughout the life cycle of the building.

The five proposed phases are characterised in the following sections.

2.1. Phase 1 – Definition of the reference building (RB)

The first phase of the EPBD methodology involves the definition of the RBs. This is an important step as these buildings must be as representative as possible, in order to determine, as well, a representative economic optimum point for each building or for a market segment.

In order to create RBs, Brandão de Vasconcelos et al. [27] proposes three different approaches. The approach choice for the present study is the *RBv_data/exp methodology*, referred to as the most suitable approach for the Portuguese context, as it combines the existing Portuguese databases and the expertise knowledge. The *RBv_data/exp methodology* consists of the creation of a virtual building that, for each relevant parameter, includes the most commonly used materials and systems, making use of statistical data. Occasionally, in the absence of sufficient statistical information for a given parameter, experts in the area or other sources of information will be consulted.

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

This phase consists of the identification of the energy efficiency measures to be applied to the RB established in phase 1. By 'energy efficiency measure', we mean a change to a building resulting in decreased primary energy needs [3].

Several sources [3,4,28–30] indicate a number of energy efficiency measures to be applied to buildings. However, the energy building refurbishment requires a variety of solutions to work with different types of substrates. These solutions should be easy to implement, quick to execute, should avoid demolition and be chemically and mechanically compatible with the substrate – by simultaneously promoting a reduction in energy consumption.

To improve the energy efficiency of an existing building, several authors [31–33] described four groups of specific measures that can be taken into account. In this paper, the measures selected are included in the "Thermal rehabilitation of the building envelope" group, which aims to reduce the energy consumption of the building by reinforcing the protection of opaque elements (exterior walls, roofs and floors over unheated spaces) and windows.

2.3. Phase 3 – Calculation of the primary energy demands for the RB

The final and primary energy demands for the RB, both with and without the application of energy efficiency measures, are assessed in this phase. In Portugal, the new Portuguese EPBD thermal regulations for Residential Buildings – REH, 2013 [34] establish the methodologies to calculate the energy needs for heating and cooling and for the production of domestic hot water (DHW). At international level, a considerable amount of building software tools is available on the market for evaluating energy efficiency, renewable energy and sustainability in buildings and which include databases, spreadsheet programs and simulation of energy performance of buildings. The United States Department of Energy (DOE) listed 417 tools that can be used to assess those items [35]. Some authors [16,36,37] have published comparisons between the features and the capabilities of some of those programs as refers to energy simulation of buildings. Based on these studies, the building software tool *EnergyPlus* was selected as it suits the purpose of the present research.

2.4. Phase 4 – Calculation of the global costs for the RB

An economic calculation method is defined in phase 4. This definition is necessary for calculating the costs of the energy efficiency measures defined in phase 2, during the expected economic life cycle applied to the RB. This economic calculation method should take into account: the initial investment, the sum of the annual costs for every year and the final value, as well as the disposal costs.

From a variety of different economic calculation methods [38–42], the "Net Present Value (NPV) method" (also described as global cost) can deliver fairly accurate results for assessing long-term investments, as it takes into account discounted cash flows and covers the entire lifetime of the investment [43]. This global cost calculation method (NPV) also allows choosing a uniform calculation period (with long-lasting equipment by considering its residual value) and can be linked to activities of the life cycle, using the net present value calculations. The projections of energy costs and interest rates are also limited by the calculation period.