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A comparison between cost optimality and return on investment for energy retrofit in buildings-A real options perspective

Sérgio Fernando Tadeu[a,*], Rafael F. Alexandre[b,1], António J.B. Tadeu[a], Carlos Henggeler Antunes[c,d,2], Nuno A.V. Simões[a], Patrícia Pereira da Silva[d,e,3]

[a] Department of Civil Engineering–FCTUC, University of Coimbra, Rua Sílvio Lima–Pólo II, 3030-790 Coimbra, Portugal
[b] Department of Computer and Systems, Federal University of Ouro Preto, Rua 37, 115, 35931-008 João Monlevade, Brazil
[c] Department of Electrical and Computer Engineering–FCTUC, University of Coimbra, Pólo II, 3030-290 Coimbra, Portugal
[d] INESC Coimbra, Rua Antero de Quental, 199, 3030-030 Coimbra, Portugal
[e] Faculty of Economics, University of Coimbra, Av. Dias da Silva, 165, 3004-512 Coimbra, Portugal

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ABSTRACT

European Union (EU) regulations aim to ensure that the energy performance of buildings meets the cost-optimality criteria for energy efficiency measures. The methodological framework proposed in EU Delegated Regulation 244 is addressed to national authorities (not investors); the optimal cost level is calculated to develop regulations applicable at domestic level. Despite the complexity and the large number of possible combinations of economically viable efficiency measures, the real options for improving energy performance available to decision makers in building retrofit can be established. Our study considers a multi-objective optimization approach to identify the minimum global cost and primary energy needs of 154,000 combinations of energy efficiency measures. The proposed model is solved by the NSGA-II multi-objective evolutionary algorithm. As a result, the cost-optimal levels and a return on investment approach are compared for a set of suitable solutions for a reference building. Eighteen combinations of retrofit measures are selected and an analysis of the influence of real options on investments is proposed. We show that a sound methodological approach to determining the advantages of this type of investment should be offered so that Member States can provide valuable information and ensure that the minimum requirements are profitable to most investors.

1. Introduction

Following the Energy Performance of Buildings Directive (EPBD) (EPBD, 2010), Member States shall comply with the Delegated Regulation 244/2012 (EU, 2012) to calculate the cost of energy efficiency measures applied to reference buildings over the estimated economic life cycle. Common information, such as long-term estimates of carbon prices and the evolution of energy prices (expected up to 2050), is provided by the European Commission (Eurostat–EU Energy, 2013; Eurostat, 2014).

In July 2013, Portugal sent the nationwide report (DGEG, 2013) specified in Article 6 of the Delegated Regulation (EU, 2012) containing the data and assumptions used for cost-optimal calculations. However, this report only refers to new buildings, which annually represented less than 1% of Portugal's building stock (INE, 2013). The cost-optimal measures were selected using the Monte Carlo simulation techniques. It neither includes a sensitivity analysis of the discount rates and the evolution of energy prices, nor indicates the use of renewable energy sources required in (EU, 2012).

When transposing the methodological framework proposed in EPBD (2010), the Portuguese legislation established a methodology for calculating the economic feasibility (REH, 2013). However, this methodology only applies to wholesale and retail building trade services in the following situations: (1) design and construction of new buildings; (2) "major renovation" of the envelope or technical systems in existing buildings; and (3) energy assessment and

* Corresponding author. Tel.: +351 913734586.
E-mail addresses: sergio.tadeu@itecons.uc.pt (S.F. Tadeu), rfalexandre@decea.ufop.br (R.F. Alexandre), tadeu@itecons.uc.pt (A.J.B. Tadeu), ch@deec.uc.pt (C.H. Antunes), nasimoes@itecons.uc.pt (N.A.V. Simões), patsilva@fe.uc.pt (P.P.d. Silva).
URLs: http://www.uc.pt/fctuc/dec. (S.F. Tadeu), http://www.uc.pt/fctuc/dec. (A.J.B. Tadeu), http://www.uc.pt/fctuc/dec. (N.A.V. Simões).
[1] web: http://www.ufop.br
[2] web: http://www.uc.pt/fctuc/deec
[3] web: http://www.uc.pt/fe.uc.pt

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maintenance of new and existing buildings undergoing major renovation under the energy certification system for buildings.

The Order (extract) 15793-L/2013 (Despacho, 2013) states that projects are contingent upon economic feasibility, with mandatory implementation when the relevant study shows that there are no technical, legal or administrative limitations or constraints on the installation and the simple payback period is eight years or less.

The term "major renovations" mentioned by EPBD is transposed into the national context as changes in the envelope and/or technical systems amounting to 25% or more of the building market value. Thus, an investment analysis to assess profitability should not be restricted to a mere simple payback period study. However, despite the inherent risk and uncertainty, energy retrofit projects offer options and flexibility for making subsequent decisions that affect the future cash flows and the project life cycle.

In short, Portugal faces the same difficulties of other countries in the EU-28: the large amount of possible combinations of efficiency measures for energy retrofit of buildings hinders the selection of the cost-optimal ones and the lack of a clear policy does not attract private investment.

The aim of this study is to contextualize the real options in energy retrofit of buildings and show the best options on the return on investment criteria (ROI), based on Portuguese market prices. The goal is not to assign quantitative and absolute values to these options, but to value measures more profitable than the *business as usual* (BAU) scenario. A multi-objective optimization problem designed to minimize the global cost and primary energy needs of the energy efficiency measures is developed. Section 2 discusses the risks, uncertainties and relevance of applying real options theory to cost optimality studies on the energy retrofit of buildings. The methodology and a case study are presented in Section 3. In Section 4, illustrative results are presented and their implications from the perspective of real options are discussed. Some conclusions are drawn in Section 5.

2. Risk, uncertainty and real options in energy retrofit of buildings

The evidence of financial gains of energy efficiency investments in existing buildings is to our knowledge still rather limited (Christersson, Vimpari, & Junnila, 2015). The energy retrofit of buildings involves irreversibility issues and the possibility of deferral associated with the investment. This investment can be considered low risk, but also with little or no liquidity. Traditional investment analysis criteria, such as the net present value (NPV), tend to underestimate its value since, in general, they do not incorporate operational flexibility issues and other strategic factors in the calculation process, in particular the possibility of deferral (Soares, 1996).

Although there is some commitment to keep a given solution for a long time once the decision to implement has been made, it is possible to revert previous decisions when circumstances and/or the technology change. For example, heating systems, whether conventional or based on renewable energy sources (RES), may be replaced by an alternative system at the end of their life cycle, appreciably shorter than the 30-year period recommended in (EU, 2012). Building owners can then decide to redirect their investment, which denotes a certain strategic adaptability. Therefore, real options increase the value of the project and should be added to the NPV. The greater the number of options and the associated uncertainty, the higher the project value (Silva, 1999).

The selection of actions to improve energy efficiency in buildings is a problem involving multiple, incommensurate and generally conflicting axes of evaluation of the merits of those actions. These problems may be tackled using multi-objective optimization models, in which the set of potential alternatives is implicitly defined by constraints defining a feasible region and multiple objective functions are optimized, or multi-criteria decision analysis, in which the alternatives are explicitly known a-priori to be appraised by (qualitative and/or quantitative) multiple criteria. Simulation techniques are also used to deal with this problem, in general focusing on particular aspects rather than following a global approach (Asadi, Silva, Antunes, Dias, & Glicksman, 2014; Caccavelli & Gugerli, 2002; Chidiac, Catania, & Morofsky, 2011a; Chidiac, Catania, Morofsky, & Foo, 2011b; Diakaki, Grigoroudis, & Kolokotsa, 2008; Doukas, Nychtis, & Psarras, 2009; Soares et al., in press; Verbruggen, Al Marchohi, & Janssens, 2011).

It is not always possible to establish numerical techniques either directly addressing the stochastic process (Monte Carlo simulation, for example) or based on the resulting differential equations (Pindyck, 1988). Monte Carlo techniques compute the expected value and the dispersion (standard deviation) of a variable (for example, cash flow), considering the variation range and the probability distribution of a set of uncertain parameters. However, these techniques do not distinguish between technical and economic uncertainty, so their use in cost-optimal approaches is not appropriate. It should be noted that future economic uncertainty overlaps technical performance uncertainty, so it cannot be easily defined in a probabilistic manner (Rysanek & Choudhary, 2013). The Monte Carlo simulation techniques are therefore limited and cannot optimize the profitability of energy efficiency measures in buildings. Instead of simulating all the combinations, the computation time can be significantly reduced through the use of genetic algorithms to cope with the combinatorial nature of the problem.

A range of real options can be considered in investments in the energy retrofit of buildings. Building owners may decide to defer, abandon, contract, expand or exchange a particular solution for insulation, heating, cooling, domestic hot water (DHW) or use of RES on-site as explained below.

Option of waiting or deferral: when there is no regulatory requirement, the building owner can postpone the implementation of a specific energy efficiency measure. It is straightforward to determine the optimal investment time when there is no uncertainty, since it is sufficient to calculate the project NPV associated with various start dates and select the one with the higher value. However, this simple rule does not apply in an uncertain context (Silva, 1999). One example is the uncertainty of future interest rates that affect the required return rate (the cost of capital) used as the discount rate. Dealing with uncertainty is still more difficult when different scenarios for the evolution of energy prices are considered. The combination of all these issues will determine the attractiveness of energy efficiency measures. For example, the replacement of systems may involve a waiting value, especially for fuel switching. In the case of highly volatile prices, waiting becomes a more profitable option. However, there is no waiting value in building envelope retrofit when energy price presents a moderate and smooth increasing (Kumbaroglu & Madlener, 2012).

Option to abandon or exchange: technically, abandonment occurs when the decision maker chooses waiving the project still in the investment start-up phase, and exchange is waiving in the operational phase. The optimal time of this waiver is the point where, when comparing future expected cash flows, immediate abandonment has the highest adjusted value (Robichek & Van Horne, 1967). In the case of rehabilitation investment, the abandonment option appears meaningless.

Option to contract or expand: the expansion option has various applications in pilot projects and research and development projects. These projects can have negative NPV in a first approach, but they can turn out to be quite valuable with a relatively small investment, since they can collect information leading to larger investments and less technical uncertainty. In energy retrofit, this