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Impacts of uncertainties in Life Cycle Cost analysis of buildings energy efficiency measures: application to a case study

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Abstract

Life Cycle Cost (LCC) analysis in the field of building renovation is considered an important decision support of the design process in order to compare the effectiveness of different energy efficiency measures (EEMs). Nevertheless, data uncertainty is a well-recognised issue associated with LCC deterministic calculation methods and probabilistic methodologies could instead provide a more effective decision support. This paper proposes a Monte Carlo based methodology for uncertainty quantification that combines parametric building simulation and LCC analysis, showing a great potential in the possibility of combining several EEMs and undertake the uncertainty calculation with low computational costs and high accuracy of the result. The work aimed to identifying and quantifying the main uncertain inputs of the LCC assessment and developing a tools suite to automate the process of evaluation of the energy impact due to the combination of several EEMs and quantification of the uncertainty distribution of the output. Results from the application to a case study are mainly intended to illustrate the methodology application and underline the impact that input uncertainties may have on the output variable. The difficulty to identify the robust EEMs is particularly due to the great influence of macroeconomic parameters uncertainty used in the calculation.

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Keywords: LCC, Monte-Carlo, uncertainty, probabilistic, building renovation, cost-optimal.

1. Introduction

An important part of the design process of a building renovation project is a cost-benefit analysis in order to compare the effectiveness of different energy efficiency measures (EEMs) to apply and finally chose the most

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profitable design option. Total expected costs and benefits (expressed in terms of money) due to the application of an EEM during a building renovation project could be evaluated during an established time frame and be adjusted for the time value of money, through Life Cycle Cost (LCC) methodologies.

The importance of using LCC analysis in the field of buildings and building renovation has been introduced at regulatory level in Europe by Directive 2010/31/EU on the energy performance of buildings [1]. The Directive established that Member States shall calculate “cost-optimal levels” of minimum energy performance requirements using a comparative methodology framework according to the consequent Commission Delegated Regulation and its Guidelines [2,3] based on EN 15459:2007 [4].

Unfortunately, accurate Cost Analysis rely on quality of data and data uncertainty is a well-recognised issue associated with LCC deterministic calculation methods [5–8]. In particular results are heavily dependent on future trends for economic data and the corresponding uncertainty (i.e. inflation rate and energy prices). In the methodology framework established by Directive 2010/31/EU, the practice of using constant market interest rate for calculating the discount rate ignores the possibility of variations over the life cycle of the building resulting from changes in national and international monetary and fiscal policies. Also the prediction of inflation rates over a long-term period increases the uncertainty. Another uncertain area in LCC forecasting is determining the service life of building components [9].

If LCC methodologies in the field of buildings are considered as important decision supports, it is then necessary to assess and communicate the problem of uncertainties properly. Otherwise decisions might be made, which are based on faulty assumptions [6].

Several studies address probabilistic analysis in Building Energy Simulation (BES) [6,10–12], in order to overcome the limits of deterministic models and to credit the solutions with “robustness” [13]. Nevertheless, specific literature on probabilistic methodologies in LCC of buildings is still very fragmented. While a deterministic LCC analysis approach requires input variables that are fixed and distinct in both time and cost, in a probabilistic approach variables are modelled using a probability distribution function (PDF) and the quantification of the uncertainty of the outputs is a result of possible variance of the input parameters.

In this paper a methodology for uncertainty quantification that combines parametric building simulation and LCC analysis is developed. The methodology is useful to: provide decision support during the design phase, giving insight into design robustness and possible ranges of the economic indicator of different design options; investigate and compare different EEMs, in order to identify the best performing alternative minimizing the likelihood of exceeding cost thresholds; provide an idea of the significance of uncertainties and their impact on the result. This paper presents a preliminary part of the work, which aims to:

- Identify and quantify the main uncertain inputs of the LCC assessment;
- Develop a tools suite to automate the process of evaluating the energy impact due to the combination of several EEMs and quantifying the uncertainty distribution of the LCC output variable;
- Underline the impact that LCC input uncertainties may have on the LCC output variable.

The methodology developed is based on an uncertainty analysis via Monte Carlo (MC) approaches. These are effective methods used to build the model output distribution as a function of the input parameters’ distribution. In MC methods, every input parameter can be considered as a stochastic variable with a specified probability distribution. The distribution of outcomes is calculated by running the model a number of times with randomly selected parameter representations (or according to precise sampling schemes).

The potential and effectiveness of MC methods are widely documented in the activities of Annex 55 [14] and could be briefly summarized as the possibility to use various parameter distributions (different types of PDFs or discrete variables) in the models and the ability to manage complex and non-linear models. If necessary, the computational efforts needed to increase the quality of the output can be reduced by using efficient sampling techniques and/or developing more efficient models (or metamodels).

The methodology proposed is applied to a building renovation case-study but can be scalable depending on individual project requirements. Further development are identified in the conclusions.