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Probabilistic Life Cycle Cost analysis of building energy efficiency measures: selection and characterization of the stochastic inputs through a case study

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Abstract

In recent years, the boost to the realization of "nearly Zero Energy Buildings" (nZEB) could require so high investment costs which may be not justifiable with the reduced consumptions (and costs) during the use phase. So, even if the estimated potential saving of energy efficiency projects seems to be very high, investors are often discouraged by a high-risk perception, linked to difficulty in knowing the real costs of advanced and innovative technologies, assessing unforeseen costs, or taking into account the significant fluctuations in energy costs. Life Cycle Cost Analysis (LCCA) in buildings could be a useful estimation method, but a large set of input parameters and accurate predictions is required to achieve an effective assessment. Aim of this study is the selection and characterization of the stochastic inputs to be exploited in a probabilistic LCCA to find the cost-optimal energy efficiency measures. We developed a Monte-Carlo based methodology for uncertainty quantification and sensitivity analysis, which combines Global Costs calculation with Building Energy Simulation and we applied it to a building case study, representative of the typical Italian stock. We characterized the stochastic inputs typically involved in the Global Cost method (related to the initial Investment Costs, Annual Costs, Residual Values, and Discount Rates) and analyzed the impact of these parameters on the final results in different renovation scenarios. Results showed that the financial factors (inflation and discount rate) and the energy trend uncertainty are the most influential parameters. Nevertheless, pushing towards nZEB makes it increasingly important the accuracy of investment costs data.

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Keywords: nZEB; LCC; Monte-Carlo; sensitivity analysis; uncertainty analysis

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1. Introduction

In the last 50 years the significant changes to the regulatory framework in the context of building energy efficiency have led to substantial reductions in buildings consumptions (and therefore costs during the use phase), even through modest efficiency measures. In recent years, the additional boost to the realization of "nearly Zero Energy Buildings" (nZEB) could instead require so high investment costs which may be not justifiable with the reduced consumptions (and costs) during the use phase. So, even if the estimated potential saving of energy efficiency projects seems to be very high, investors are often discouraged by a high-risk perception, linked to difficulty in knowing the real costs of advanced and innovative technologies, assessing unforeseen costs, or taking into account the significant fluctuations in energy costs that alter the return on investment over time.

Life Cycle Cost Analysis (LCCA) in the field of building construction or renovation is a useful assessment method to compare the effectiveness of different energy efficiency measures (EEMs) and chose the most profitable design options. LCCA provides the total expected costs and benefits (expressed in terms of money) due to the application of an EEM, evaluated during an established time frame and adjusted for the time value of money.

Nevertheless, a large set of input parameters and accurate predictions are required to achieve an effective assessment. Data uncertainty is a well-recognized issue associated with LCC deterministic calculation methods [1–3]. In particular, results are heavily dependent on future trends for economic data and the corresponding uncertainty (e.g. inflation rate and energy prices) or on service life of building components [1,4,5].

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 [6]. A probabilistic approach provides more realistic informations about results uncertainty and enables more useful analysis of potential benefits of a design option.

The probabilistic methodology described in this work is based on an uncertainty and sensitivity analysis via Monte Carlo (MC) approaches. They consist of randomly selecting or sampling input variables according to their probabilistic characteristics and inserting them into the output-equation to predict the corresponding output parameters. MC are effective methods used to build the entire output probability density function and to asses global uncertainty and sensitivity [6]. Uncertainty analysis (UA) is the study of the model output distribution as a function of the input parameters' distribution. Sensitivity analysis (SA) goes one step further by apportioning the output variations to the input variations [7]. While a deterministic analysis approach requires input variables that are fixed, in a probabilistic approach every input parameter is considered as a stochastic variable, modelled using a probability density function (PDF). The quantification of the uncertainty of the output is a result of possible variance of the input parameters.

In this paper we applied MC methods for the probabilistic LCCA of different energy efficiency scenarios for a building case study, representative of the typical Italian stock. We characterized the stochastic inputs typically involved in the Global Cost method established by European Standard EN 15459 [8] (related to the initial Investment Costs, Annual Costs, Residual Values, Discount Rates) and we analyzed the impact of these parameters on the final result in different renovation scenarios.

Nomenclature

C	cost	[€]	L	lifespan	[years]
η	efficiency	[-]	R	rate	[-]
t	time	[years]	U	thermal transmittance	[W/m^{2}K]
Val	value	[€]	F	factor	[-]

Subscripts

a	annual	disc	discount
env	envelope	e	evolution (rate)