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Proposal for a modified cost-optimal approach by introducing benefits evaluation

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Abstract

The recast of the Energy Performance of Buildings Directive introduced the concept of nearly-zero energy building and encouraged setting the nearly-zero energy target with a view to cost-optimal level - the energy performance that leads to the lowest cost during the building estimated economic lifecycle. To searching this regard, the cost-optimal methodology based on the global cost was defined providing a tool to assess different nearly-zero energy scenarios. Nowadays, the cost-optimal analysis is used as a decision-making tool between different energy design alternatives mostly on a theoretical level; but it has spread little among the professional field. The aim of this paper is to give a more holistic and all-comprehensive approach to the cost-optimal methodology. This paper proposes and applies a modified approach of the cost-optimal evaluation, which will lead to the achievement of more interesting results for all the actors involved, including investors and final users. This study highlights the usefulness of including not only costs but also benefits that can derive from each energy design scenario. Choosing different energy efficiency solutions, the related benefits evaluation could turn the tables. Different kinds of benefits could be considered as the increase of the real estate market value, the enhancement of the indoor comfort, the reduction of CO₂ emissions and others. Thus, a proposal of how quantifying these qualitative benefits in monetary terms is shown to introduce them in the global cost formula. Actually, benefits conversion into monetary values is the most challenging issue. Precisely, this paper shows a list of benefits that can affect the choice of different envelope and HVAC system solutions, pointing out their influence on the global cost evaluation. Certainly, introducing benefits in the global cost formula means using a more holistic and complete approach, while the already complex degree of the cost-optimal methodology – due to the numerous input data – increases. To validate the reviewed global cost formula, it will be necessary to apply it to various case studies.

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1. Introduction

Reducing energy consumption and CO₂ emissions is among the main goals of the European Union. Precisely, the recast version of the Energy Performance of Buildings Directive (EPBD) led moving towards new and retrofitted nearly-zero energy buildings (nZEBs) and introduced the cost-optimal methodology to compare different energy scenarios and set the minimum energy requirements for buildings.

Considering both energy and economic evaluation, this methodology represents an efficient decision-making tool in preliminary energy design phases. However, currently cost-optimal analysis is used mostly at a theoretical level by scientific researchers. Indeed, the methodology was conceived for national authorities to develop regulations at national level. Cost-optimal levels identified at national level will not be necessarily cost-optimal for every single building or investor [1], so the possibility to calculate specific cost-optimal conditions could be crucial. Referring to the current literature, different researches outlined the importance of including not only costs but also benefits to evaluate different energy design scenarios referred to both new and retrofitted nZEBs. [2]. Some studies considered as benefits the added real estate value [3,4], others the environmental impact, indoor comfort conditions and indoor air quality (IAQ) [5]; other studies illustrated the possibility to incorporate additional gains such as increased productivity and reduced sick leave in life cycle cost calculation (LCC) [6]. Despite several researches took into account different types of benefits in their evaluation, only a few arrived at their quantification in economic values [7]. Since until now benefits evaluation has not been included in the cost-optimal analysis, thus this paper aims to individuate, propose and summarize several benefits related to different energy design scenarios and shows different methods to convert them into monetary values. In this way, cost-optimal methodology could acquire a more holistic approach useful for choosing among different design configurations and give back results more interesting for all the actors involved in the design, construction and operation phases. The study began focusing on the identification of some benefits, evaluating their prerogatives and chances to monetize them. In particular, the current global cost formula was analyzed to individuate chances, lacks and opportunities and modified.

2. Benefits evaluation

An energy efficiency design is more and more important in the construction sector. Different design scenarios determine a variety of consequences in terms of esthetics, comfort, vendibility, sustainability and investment costs. Generally, design solutions, which are energy efficient, are considered as the most expensive. This is because considering an economic appraisal of an energy-saving investment for a building, the only benefit normally monetized is the energy cost saving, yet doing so undervalues the full impact. The next paragraphs attempt to list some benefits and examine how they were quantified or in case converted into money. In particular, real estate value, reduction of greenhouse gases (GHG), enhancement of indoor comfort, chance to access subsidies and incentives and possibility to obtain a low level of embodied energy were analyzed through a literary review and introducing a proposal for their economical quantification.

2.1 Real estate market value

Emerging evidences show that buildings with high-energy performance are more valuable in terms of resale or rent comparing to their less efficient counterparts as demonstrated by a study led in the Netherlands [2]. Regarding to the residential sector the increase in the real estate market value after the application of energy efficient design configurations has already been individuated by many studies. Probably, to reach a real awareness on this topic, a more in-depth study has to be conducted about the

perception of energy saving by owners/tenants in their double role, as energy consumers and real-estate customers. This is relevant because the increase of value due to energy performance is directly related to the willingness to pay more for an energy efficient building. Regarding to the eco-label award Seinre et al. [7] asserted that the real estate value for green-labeled buildings was 10-25% higher than the no-labeled ones, while rental value account was about 6% higher. Concerning the energy-retrofitted buildings, a same trend was observed. The application of energy efficiency measures (EEMs) in buildings produces both lower operational costs and an increase in market value of the building, recognized by D.Popescu et al. as the net additional value obtainable [4].

That study showed also three procedures to quantify this added value; hedonic pricing method (HPM), used by Morrissey et al. in [3] as well, the method based on the direct comparison between transaction prices and the method based on the willingness to pay (WTP) investments in EEMs – tested by Banfi et al. in [8] as well. The former one quantifies the value taking into account real data from actual market transactions; the second method is based on the idea that identical properties should have identical prices, so it uses transaction prices of very similar properties. The last method is based on the WTP investments in EEMs; precisely, it uses a scoring model that includes aspects affecting social, political and psychological factors that can affect the WTP more for energy efficiency. In the current study, it was proposed to incorporate the added market value after the implementation of energy design configurations, as a benefit represented by a negative quantity and identified as V_{mv} .

2.2 Reduction of GHG level

The influence of building sector on reducing pollutants levels, particularly in terms of CO₂ emissions, is evident. Therefore, the benefits of EEMs related to the reduction of emissions involve both environmental and economic aspects. The necessity to consider these indirect costs and benefits (or externalities) has encouraged the inclusion of CO₂ emissions in macroeconomic perspective of cost-optimal analysis [1]. As for the calculation of the cost-optimum at macroeconomic level, the Regulation requires the consideration of GHG emissions costs by taking the sum of the annual GHG emissions prices per ton CO₂ equivalent of GHG allowances issued in every year. In addition, Member States (MS) are free to expand the category of costs GHG emissions to include a wider range of pollutants. EPBD Guidelines [1] indicated also, which minimum environmental costs per unit of emission have to be used in calculations. This research wanted to include the evaluation of pollutants emission in the calculation of the global cost in order to reward EEMs producing low gas emissions. Precisely, the modified global cost formula will show it as an annual cost, identified as $C_{p,i}(j)$.

2.3 Enhancement of indoor comfort

Comfort affects acoustics, lighting, thermal environment and indoor air quality, but this paper wants to focus particularly on the last two ones. According to the UNI EN 15251 [9], recent studies showed that costs of poor indoor climate for the employer, the building owner and for society as a whole are often considerable higher than the costs of energy used in the same building. Indeed, indoor climate quality (concerning thermal, hygrometric and indoor air quality aspects) strongly influences the well-being in the buildings and the productivity in working and educational environments [10]. In addition, benefits related to comfort include improved physical health. Furthermore, occupants who do not feel comfortable usually take actions that have energy implications. Economic benefits related to a good indoor comfort have been identified by several studies. Penna et al. [5], defining cost optimal solutions in terms of energy consumption and the minimization of thermal discomfort, demonstrated that the most conventional EEMs used to achieve cost-optimal levels often caused a worse indoor thermal comfort. Indeed, it was proved

that conventional EEMs approached the zero energy target maintaining the economical convenience but worsening the indoor thermal comfort. Pursuing the comfort condition in energy design configurations, the investment costs increased. Thus, it is desirable to provide incentives to be allocated on those measures able to improve the internal comfort. Most of the studies that attempted to quantify the economic benefits due to a better indoor comfort refer to office buildings. For instance, in their study Gvozdenović et al. [6] quantified the benefits associated to productivity increase and sick leave reduction. These values were included in the LCC methodology subtracting monetary benefits related to increase of productivity and sick leave reduction from the total cost. Seinre et al. [7] analysed and quantified (in €/m²y) the effect of ventilation rate on productivity and short-term sick leave, considering the European indoor environmental quality standard and ventilation classes.

In order to foster energy design scenarios, which are also efficient in terms of indoor comfort, the current study proposed to quantify the benefits related to comfort as a penalty – identified by a cost – that the higher would be, the worst was the associated comfort category [9]. The term was introduced in the global cost formula as $C_{c,i}$.

2.4 Chance to access subsidies and incentives

The cost-optimal methodology recommends MS to consider all applicable taxes that customers have to pay for the financial level calculation. Incentives and subsidies, instead, are usually excluded, since they might change in time and they cannot be considered for the entire time in which nearly zero energy requirements are supposed to be the national benchmarks. On the other hand, analysing a single case study, or making decisions about a single design process, period is defined. Therefore, subsidies and incentives should be taken into account comparing design alternatives, because economic benefits could concern only specific EEMs, and this could become an important parameter in decision-making. The quantification of subsidies and incentives should follow the specific conditions. In this study, they were integrated in the global cost formula as a negative quantity $V_{s,i}$ (j) to be deducted for the expected number of years.

2.5 Chance to obtain a low level of embodied energy

A building is an energy consumer throughout all its life, from its construction to its demolition. Embodied energy represents energy content in all materials used in the building and the systems, and energy incurred during enforcement processes of new construction or renovation of the buildings and at the time of demolition works. Evaluating the possibility to elaborate a holistic design methodology, these environmental aspects should not be ignored. Cabeza et al. [11] for instance, described two methodologies to ensure a systemic approach to environmental evaluation: Life Cycle Assessment (LCA) and Life Cycle Energy Assessment (LCEA). The study considered energy use and global warming potential (GWP) as the environmental indicators, taking into account manufacturing, construction, use, maintenance and disposal. The implementation of EEMs can determine a short-term period to repay the embodied energy; indeed, it was found that the addition of higher levels of insulation in Australia paid back its initial embodied energy in life-cycle energy terms in around 12 years [11]. EEMs involving less embodied energy should be prioritized. This study proposed to monetize these benefits as an initial cost C_E (j) to be added to the investment cost – including all the embodied energy apart from the one related to the demolition because it would be beyond the calculation period.

2.6 An exemplification: HVAC systems and their benefits

All the benefits listed above can affect the choice of different materials and HVAC system solutions. In particular, every HVAC system alternative should be considered in terms of potential benefits; in this way, for example HVAC systems that are more expensive could result more viable. For instance, a geothermal heat pump coupled with terminals operating at moderate temperature, that typically entails a high investment cost compared to other basic solutions, can ensure high efficiencies, energy savings and reductions of CO₂ – related to other traditional possibilities. If coupled with radiant panels, it allows getting an improved indoor comfort thanks to the heat uniform distribution.

Introducing benefits in cost-optimal analysis will demand to consider also HVAC systems in their profit perspective, going beyond their general performance and considering all their indirect consequences. Currently, future studies are needed and recommended to evaluate in which terms a specific HVAC system can give more benefits with respect to another one.

3. A proposal for amending the existing global cost formula

The cost-optimal framework methodology is based on the global cost method. It was defined with the purpose to evaluate different EEMs by an energy and economic viewpoint. According to the European Standard EN 15459:2007 [12] the global cost formula can be written as in Eq. 1:

$$\mathbf{C}_g(\boldsymbol{\tau}) = \mathbf{C}_I + \sum_j \left[\sum_{i=1}^{\tau} (\mathbf{C}_{a,i}(j) \times \mathbf{R}_d(i)) - \mathbf{V}_{f,\tau}(j) \right] \quad (1)$$

Where $\mathbf{C}_g(\boldsymbol{\tau})$ corresponds to the global cost referred to starting year $\boldsymbol{\tau}_0$; \mathbf{C}_I is the initial investment cost; $\mathbf{C}_{a,i}(j)$ is the annual cost for component j at the year i (including running costs and replacement costs); $\mathbf{R}_d(i)$ is the discount rate for year i ; $\mathbf{V}_{f,\tau}(j)$ is the final value of the component j at the end of the calculation period (referring to the starting year $\boldsymbol{\tau}_0$). Global cost method specificity consists in the use of a uniform calculation period (because also long-lasting equipment are taken into account within their residual value). As already expressed, the global cost method considers only cash out-flows and it omits the benefits that each measure can lead to the intervention. In order to use it as a decision-making tool in single design cases, it could be advantageous to implement a profit perspective, considering direct and indirect earnings related to the different alternatives. Each EEM determines a specific energy performance and presents an own global cost. It is necessary to note that by the implementation of a specific EEM many other consequences as change of the indoor air quality, alteration of the external appearance of the building and others could derive. Certainly, from the design and investment perspective these characteristics should not be neglected. Considering all the benefits listed above, cost-optimal analysis could be renovated, and precisely the global cost formula could be modified by the introduction of benefits as in Eq.2:

$$\mathbf{C}_g(\boldsymbol{\tau}) = \mathbf{C}_I + \sum \mathbf{C}_E(j) + \sum_j \left\{ \sum_{i=1}^{\tau} \left[(\mathbf{C}_{a,i}(j) + \mathbf{C}_{p,i}(j) + \mathbf{C}_{c,i} - \mathbf{V}_{s,i}(j)) \times \mathbf{R}_d(i) \right] - \mathbf{V}_{f,\tau}(j) - \mathbf{V}_{mv} \right\} \quad (2)$$

where new terms were introduced. Precisely, $\mathbf{C}_E(j)$ is the overall embodied energy cost for component j , except the embodied energy related to demolition works; $\mathbf{C}_{p,i}(j)$ is the annual pollutants cost for component j at the year i ; $\mathbf{C}_{c,i}$ is the annual comfort-penalty cost referred to the chosen energy configuration at the year i ; $\mathbf{V}_{s,i}(j)$ is the annual subsidy/incentive of the component j ; \mathbf{V}_{mv} is the added value of the building after the implementation of the chosen energy design scenario. In this way, it is possible to evaluate different energy scenarios in a more completed approach, which includes not only costs but also benefits and where the global cost would prioritize the more virtuous energy configurations.

The Fig.1 shows an example of the cost-optimal analysis applied to an energy design of a new residential building. Two curves are represented: one is referred to the base scenario obtained by the regular global cost formula; the other one is the result of the global cost that included the benefits deriving from a hypothesis of incentives. Specifically the incentives constituted of a tax deduction of 65%. Taking into account the incentives as benefits, the global cost of each energy scenario was considerably lower, making the high performing energy scenarios more advantageous.

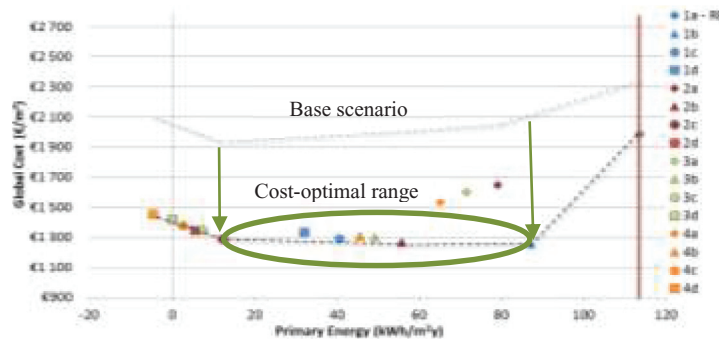


Fig. 1. Example of cost-optimal curve by considering incentives

4. Conclusion

The aim of this paper was to individuate the possible benefits related to energy-design of buildings and evaluate the chance to give them a quantification in monetary terms, in order to include them in the global cost formula on which the economic evaluation of the cost-optimal methodology is based. Enhancement of economic value and indoor comfort conditions, reduction of CO₂ emissions, possibility to access subsidies/incentives and level of embodied energy were the benefits analyzed. In particular, an example of how considering benefits could influence cost optimal results was given considering tax deduction in a residential case study. Finally, a benefits quantification proposal was attempted reviewing the global cost formula. By a more holistic approach, this study focused on a theoretical introduction of benefits in cost-optimal methodology. On the other side the degree of methodology complexity was increased. Therefore, to validate the reviewed global cost formula the application to numerous case studies will be necessary.

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Biography

Cristina Becchio is a grant researcher at the Department of Energy of Politecnico di Torino, where she holds a Ph.D. in Technological Innovation for Built Environment. Her activity focuses on buildings energy performance assessment and economic evaluation, in particular applied to nZEB.