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Selection of optimization objectives for decision-making in building energy retrofits

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ABSTRACT

Building energy retrofitting has emerged as a primary strategy for reducing energy use and carbon emissions. The decision about which retrofit measures should be implemented in a particular project is a single- or multi-objective optimization problem subject to many constraints and limitations. Different objective(s) have been used in the literature, however the identification and selection of the objective(s) for this optimization problem is still a challenge. This study develops a decision matrix that guides decision-makers on how to select the objective (s) for a single- or multi-objective optimization problem that results in the selection of the best energy retrofitting strategy, by considering and defining the "investor benefits" term, the type of potential investors, and the type of potential benefits of building energy retrofits. Four types of investors are considered in this study: owner-occupant, absent owner, leaser, and external investor. In addition, a case study is used to illustrate how different types of investors may affect the selection of objective functions and, therefore, the final decisions for optimum energy retrofits. Results show that when the investor is the owner-occupant, a higher investment is suggested for energy retrofits to achieve optimum benefits.

1. Introduction

Buildings are major consumers of energy [1] and, therefore, have a significant adverse impact on the environment. In the United States, over 60 percent of the housing inventory is more than 30 years old and a large number of these homes are energy inefficient [2]. Building energy retrofitting has emerged as a primary strategy for reducing energy use and carbon emissions [3]. An energy retrofit is the physical or operational change in a building, its energy-consuming equipment, or its occupants' energy-use behavior to reduce the amount of energy to convert the building to a lower energy consuming facility [1,4]. Energy retrofitting of a building not only can improve energy efficiency but also can offer sustainable benefits such as reducing maintenance costs, reducing air emissions, creating job opportunities, enhancing human health, and improving thermal comfort [5–9].

Various retrofitting measures that improve building performance in terms of energy efficiency can be classified into different basic categories such as controlling measures, load reduction measures, enveloping measures, and renewable energy technologies [10–12]. In addition to the above energy measures, human factors such as changes to the energy consumption patterns of occupants can be considered as another energy retrofit measure category [4,5].

One of the main challenges in building retrofitting is that several hundred combinations of applicable energy measures can be considered to retrofit a building and it is not easy to choose the best strategy among them [13]. Because every building exhibits unique architectural, geographical, and operational characteristics, retrofit options must be rationally investigated for every individual building in a building stock [14]. Despite the numerous resources that provide advice on how to retrofit a building, decisions regarding the optimal combination of retrofitting measures for a specific building are typically complex. The decision about which retrofit measures to implement in a particular project is a multi-objective optimization problem subject to many constraints and limitations [5]. In this field of study, the "decision-maker" usually refers to the professional building owner, who has knowledge and experience in the field of building energy retrofits, and who has a professional team of specialized advisors and designers [15]. However, as Kontokosta [3] stated, ownership type does, in fact, influence the retrofit decision. Therefore, this study goes beyond the traditional definition of decision-maker and defines all potential energy retrofits investors as the decision-makers in an energy retrofitting project.

Several studies have used a single- or multi-objective optimization approach to select the best retrofitting measures for a specific building, using a wide variety of objective(s) such as minimizing life-cycle costs, maximizing indoor air quality, maximizing thermal comfort, and

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minimizing payback period, among others. However, still lacking is a method to identify and select the objective function(s) for this optimization problem. This study proposes a decision matrix that guides decision-makers on how to select the objective function(s) for a single- or multi-objective optimization problem that results in the selection of the best energy retrofitting strategy, while also considering the benefits to investors. The authors believe that the concept of "investor benefits" is neglected in previous literature on decision-making for building energy retrofits. Therefore, defining and characterizing investor benefits and integrating them with the selection of objective function(s) can contribute to the body of knowledge to improve single- or multi-objective optimization for selection of energy retrofit measures for a specific building.

This study proposes a process for selecting objective function(s) that is typically used for optimum energy retrofit decisions in buildings, while also taking into consideration investor benefits. The approach used in this study includes three main stages: (1) identifying different potential investors in energy retrofitting projects, (2) identifying possible sustainable benefits of energy retrofitting projects, and (3) developing a matrix that relates the identified energy retrofitting benefits to different identified investors. The authors believe that this matrix will help decisions-makers to select adequate objective function(s) in any single- or multi-objective energy retrofit decision-making process. In addition, a case study is presented to illustrate how different types of investors may affect the selection of objective functions, and accordingly the final decision for optimum energy retrofits.

2. Literature review

When choosing among a variety of proposed measures, the decision-maker (the corresponding building expert and representative of the investor, who could be the investor him or herself) has to reconcile environmental, energy-related, financial, legal or regulatory, and social factors to reach the best possible compromise to satisfy needs and requirements [16]. Several studies have proposed single- or multi-objective optimization to select the most suitable solution for a retrofitting project (Table 1). In addition, Nielsen et al. [15] have provided a state-of-the-art overview of the development of decision support tools applicable in the predesign and design phase of energy retrofitting projects. As summarized in Table 1, different proposed models have tried to optimize a different objective or multiple objectives, such as energy consumption, energy saving, CO_2 emission, thermal comfort, and life-cycle impact, to find the optimal retrofit strategy. However, all prior models use at least one economic aspect (in terms of retrofitting investment cost, energy cost, life-cycle cost, or payback period) to find the optimal retrofit strategy. Life-cycle cost has been the objective considered most frequently for optimal building retrofitting planning.

Table 1
Selected objective(s) from previous studies.

Reference	Goal	Objective(s)
[17]	Minimizing	Life-Cycle Cost (Investment Cost; Energy Cost)
[18]	Minimizing	Life-Cycle Cost (Investment Cost; Late Investments; Energy Cost; Maintenance Cost)
[4]	Minimizing	Life-Cycle Cost (Investment Cost; Energy Cost; Maintenance & Replacement Cost; Tax Rebate; Resale Value)
[10]	Minimizing	Investment Cost (Material Cost)
	Minimizing	Building Load Coefficient
[19]	Minimizing	Investment Cost (Material & Installation Cost)
	Minimizing	Energy Consumption
	Minimizing	CO_2 Emission
[20]	Minimizing	Payback Period (Costs & Saving)
[21]	Minimizing	Retrofit Cost (Material Cost)
	Maximizing	Energy Savings
[22]	Minimizing	Life-Cycle Cost (Investment Cost; Maintenance Cost; Replacement Cost; Energy Cost)
	Minimizing	CO_2-equivalent
[23]	Minimizing	NPV of LCC (Investment Cost; Maintenance Cost; Energy Cost; Increased Value)
[24]	Minimizing	Retrofit Cost (Material Cost)
	Maximizing	Energy Savings
	Maximizing	Thermal Comfort
[12]	Maximizing	Energy Savings
	Minimizing	Payback Period
[25]	Maximizing	Energy Savings
	Minimizing	Life-Cycle Cost (Electricity Saving; Investment Cost; Maintenance Cost)
	Minimizing	Payback Period
[26]	Minimizing	Retrofit Cost (Material Cost)
	Minimizing	Energy Consumption
	Minimizing	Thermal Discomfort Hours
[27]	Minimizing	Total Cost (Material Cost; Energy Cost)
	Minimizing	Environmental Impact (Life Cycle Assessment): ● Climate change; ● Human toxicity; ● Aquatic toxicity; ● Terrestrial toxicity; ● Eutrophication; ● Acidification
[28]	Minimizing	Life-Cycle Cost (Global Cost; Energy Cost)
[7]	Minimizing	Net Present Value of Life Cycle Costs (Investment Cost; Maintenance & replacement Cost; Labor Cost; Energy Saving Cost; End of Life Cost)
	Minimizing	Environmental Impact (Life Cycle Assessment) ● Abiotic depletion potential—non-fossil; ● Abiotic depletion potential—fossil; ● Acidification; Eutrophication; ● Global warming; ● Ozone layer depletion; ● Photochemical ozone creation

3. Research approach

The objective of this study is to propose a decision matrix that helps in selecting the objective function(s) for a single- or multi-objective optimization problem that results in the optimum energy retrofits decision, considering investor benefits. Therefore, decision-makers will be able to select energy retrofit objective(s) based on their actual monetary or non-monetary benefits. The following stages are used to develop such a matrix.

- Stage (1): different *potential investors* for energy retrofitting projects are identified and categorized into four main groups.
- Stage (2): all possible sustainable *benefits of energy retrofitting* projects are determined based on the literature. These benefits are categorized in three main groups: economic, environmental, and social. For each group, the elements that may have been selected as an objective in any optimization problem are identified.
- Stage (3): a *decision matrix* is proposed to relate the determined energy retrofitting benefits to different identified investors based on expert opinion. This matrix can be used as a guide in determining the objective function(s) based on investor benefits.

4. Potential investors

Retrofitting an existing building in terms of energy efficiency has many benefits. These highly beneficial retrofits will pay for themselves over time and will provide direct benefits to the investor. However, reports show that relatively few people intend to implement energy retrofitting measures. The reason is the high initial capital investment required for performing these retrofits. This required initial investment often deters building owners from improving the energy efficiency of their properties, or else limits the retrofits to a smaller scope, which is often suboptimal [29]. This problem does not exist for new construction, where the costs of green development are barely noticeable. However, when retrofitting existing buildings, the upfront costs of energy-efficiency retrofitting may overwhelm the long-term savings possibilities [30].