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Economic viability of extensive green roofs through scenario and sensitivity analyses: Clients' perspective

Serdar Ulubeyli*, Volkan Arslan

Department of Civil Engineering, Bulent Ecevit University, 67100, Zonguldak, Turkey

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ABSTRACT

Extensive green roofs (EGRs) are known to provide many public and private benefits. Nevertheless, their initial investment and maintenance costs form a high barrier in front of their installations for private users. Although the life cycle costing approach can have capacity to draw a real picture of this view, related previous studies using this approach present highly different results. Therefore, the aim of the current research was to carry out a sensitivity analysis to determine the causes behind these highly instable results. Moreover, scenario analysis was performed to reveal a full perspective for potential clients. In doing these analyses, four methods of economic viability were employed. For comparison purpose, a real world case study was considered and an EGR was compared with a wooden roof. Consequently, only energy saving characteristic out of 14 inputs was found to have a significant effect on the concluding result. Also, EGR was found to be both more viable than wooden roof even in the worst scenario and feasible as an individual investment except the worst scenario. However, based on highly variable results in international and national levels, it is obvious that regional practices and case-specific conditions can have vital aspects in economic viability investigations.

1. Introduction

In todays's highly energy intensive environment, the increased urbanization causes higher energy consumption in urban areas, and thus, the energy efficiency of buildings has become a vital issue for sustainable built environment. Since roofs constitute a significant percentage (approximately %20) of urban surface [1,2], new solutions for building roof systems, such as cool (i.e., white or reflective) and green (i.e., vegetative) roofs, play an important role in increasing the energy performance of buildings and in mitigating potential environmental problems [3]. Both technologies can lower the surface temperature of roofs and thereby decrease the corresponding heat flux released to the atmosphere [4]. In this context, cool and green roofs represent two passive techniques to reduce the level of energy requirement and improve the thermal-energy performance in buildings [2,5].

Cool roof technology has gained too much interest in the last few decades as an effort to mitigate negative effects of urban heat islands [6]. They are preferable to conventional black (i.e., non-reflective) roofs, based on their positive effects on the environment such as (i) reduction of building heat-gain, (ii) energy savings from air conditioning expenditures, (iii) improvement of thermal comfort conditions of buildings, (iv) reduction of peak electricity demand, (v) enhancing life expectancy of roof system, (vi) reducing expenses for maintenance, (vii) reduction of air pollution and CO_2 emissions [4–8], and lastly (viii) the further indirect contribution to the global warming mitigation for reflecting the incoming radiation to the space [9]. For instance, heat island in Athens in Greece doubles the cooling load of buildings and almost triples their peak electricity demand [10]. Therefore, this kind of roofs has great potential to reduce cooling loads of buildings and to minimize the heat flux from roof by means of providing a lower roof surface temperature [6,11–14]. Some previous studies show that the daily average of the ambient temperature decrease ranges between 0.18 K and 2.2 K [15–19]. In addition, the related literature reveals that the increase of urban albedo may substantially decrease the CO_2 emission in the atmosphere, based on the solar reflectance. Akbari and Matthews [20] and Akbari et al. [21,22] calculated a CO_2 emission reduction of 0.05 t/m^2 by 0.20 increase of albedo of roofs while Akbari et al. [23] measured that of 0.007 t/m^2 by 0.01 increase. Moreover, Van Curen [24] estimated that the mean radiative forcing per 0.01 increase of albedo is −1.38 W/m^2 in California because of the use of cool roofs and that this may result in removing 1.76 million tons of CO_2 emissions in the State [2]. Besides their aforementioned environmental and energy-related benefits, cool roofs are also financially viable as their cost is comparable to conventional black roofs [4].

* Corresponding author.
E-mail address: ulubeyli@beun.edu.tr (S. Ulubeyli).

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Today, green roofs are chosen both as a technological device that has potential to decrease energy and pollution based environmental problems and as a construction application that can minimize the lack of green fields in urban areas in many countries around the world [25]. This is because they present numerous benefits for societies and individuals, such as savings from energy and storm water [26], fall in the temperature of roof membrane [27], mitigation of urban heat island effect [2], rise in habitat and biodiversity [28], fall in greenhouse gas emissions [29], noise reduction and aesthetic view [30], and formation of recreation areas [31]. Some past researches reported that the ambient temperature reduction through the use of green roofs is between 0.37 K and 4.2 K and depends on design and climate conditions [32,47,33,34]. In fact, these numerical values seem to have superiority over those of cool roofs. Green roofs are also expected to have positive effects on the air quality improvement [1,35]. The mitigation of NO_2 per year was calculated 0.27 kg/m^2 in the USA [1] and 0.09 kg/m^2 in Hong Kong [36]. Moreover, green roofs have potential to use in avoiding annual air pollutant of 0.13 kg/m^2 of SO_2 and that of 0.062 t/m^2 of CO_2 [36]. In terms of this second group of values, green roofs also seem to be superior to cool roofs.

Overall, despite the aforementioned comparisons in favor of green roofs, the results of past studies concerning environmental advantages of cool and green roofs indicate that findings are case-sensitive and are highly influenced by characteristics and assumptions of the related study [37]. On the one hand, some researches claim that green roofs have higher mitigation potential than cool roofs [15,37–39]. On the other hand, some studies assert that the mitigation performance of cool roofs is better than that of green roofs [9,40–42]. From another viewpoint, Ray and Glicksman [43] and Sailor et al. [44] reported that, in insulated buildings, cool roofs present a better performance in warm climates while green roofs perform better in cold climates. Therefore, based on this efficient and competing environmental performance, green roofs need to be investigated from other perspectives (e.g., economic or social).

Given two types of green roofs, extensive green roofs (EGRs) have (i) a thinner and lighter layer including a substrate lower than 20 cm, (ii) lower diversity of plants (e.g., moss-sedum, sedum-moss-herbaceous, sedum-herbaceous-grass, and grass-herbaceous), (iii) less need for irrigation, (iv) an easier process of construction and maintenance, and lastly (v) a lower cost when compared with intensive green roofs, and present a more economic option in this regard [45,46].

However, considering traditional wooden roofs, many clients may largely be reluctant in preferring green roofs due to their higher initial investment and maintenance costs, and thus, they have not attracted the required attention of clients so far in some countries such as Turkey. In fact, cost savings are the most attractive benefits to disseminating green roofs in practice even if their application is mandatory (e.g., in some regions in Germany and Japan). Based on this argument, for example, green roofs are supported by subsidization in some regions in South Korea. In other words, attempts to increase their attractiveness will likely be very difficult in the absence of major economic incentives to drive the requisite behavioral change. Toward this aim, such incentives are supported technically since green roofs have been found to have more advantages than traditional because of the fall in the temperature of roof membrane, the reduction of the puddle effect, and high waterproofing standards [47]. In this context, it is necessary to evaluate green roofs through the life cycle costing approach besides their environmental benefits. Up to date, such research attempts have been carried out by taking into account EGRs as they cost less than intensive ones. However, it is seen that these life cycle costing analyses give highly different results in different geographical regions as such investments may be very sensitive to regional characteristics such as precipitation, climate, material costs, land prices, labor costs, and subsidies. Therefore, it seems to be inevitable to perform a sensitivity analysis in order to pinpoint the causes behind these highly instable results. This is because sensitivity analysis is an important tool especially when the input data is subject to uncertainty or variability, which is definitely the case of economic evaluations [48]. In addition, scenario analysis should also be performed to observe the results of the most expected case and two extreme cases. In fact, this will provide a full perspective for potential clients since it may enhance the resilience of environmental policies through the greater understanding of uncontrollable uncertainties of specific system changes for the decision support [49,50].

As a result, in the present study, the economic viability of EGRs was investigated based on private benefits (i.e., from the perspective of clients) by means of scenario and sensitivity analyses. By doing so, (i) variable cost inputs that can have a significant effect on the concluding result were determined as the early warning signals for clients, (ii) limits of the economic viability were found out to see possible slippages of results, and (iii) the most likely state was obtained to focus on the final investment decision to be taken. Thus, whether such an investment is a reasonable decision as an encouraging and motivating issue was revealed since cost-based benefits or losses are the key determinant of decisions and choices in green technologies and practices. Moreover, this study also presented a regional perspective for the economic viability in Turkey as the country has scarce examples of green roofs [51]. For all these objectives, a real world case study was considered and, for the life cycle costing analysis, an EGR was compared with a free standing wooden roof (FSWR) which is the most popular and common roof type in Turkey [52]. Consequently, the resultant findings obtained may attract attention of industrial practitioners for better decision making and of researchers for potential comparative works from local and international points of view.

2. Literature review

In the literature, there are several research efforts investigating EGRs as an economically viable option from the clients' point of view (Table 1). Although these studies, except Blackhurst et al. [54], found that EGRs are financially feasible investments as a concluding result, there are large deviations between numerical outputs of their life cycle costing methods. However, none of them has fulfilled a sensitivity analysis of all inputs to detect the main contributors of this consequence. Moreover, none of them has analyzed input-based different scenarios to determine the limits and the most likely solution of the result for presenting a full scale perspective. Overall, the present study seems to be the first in performing scenario and sensitivity analyses of EGRs based on private costs and benefits. This confirms that these two analyses are relevant parts of EGR studies as they may expose the potential burden of EGRs for clients, builders, and the natural environment. Considering previous works in Table 1, it is also seen that EGRs were examined in four regions only up to date. In this regard, the Turkish case may originally show another different regional perspective. Lastly, in terms of life cycle costing analysis, past studies have employed different computation methods. However, this paper covers all of these methods used by previous studies together and thus tries to present a complete view.

3. Research methodology

In order to analyze and support the economic viability of an investment, there are various mathematical methods in the literature. These methods employed can be described as a means of auditing financial consequences of a decision [59] and listed