

Environmental and Economic Comparative Analysis of Green Roofs: The Case of Singapore and Bahrain

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Abstract—Green roof integration in buildings reduces energy consumption, which mitigates climate change and the Urban Heat Island (UHI) effect. The significant case of green roof adoption in Singapore can potentially be reflected in Bahrain, considering both countries are Small Island Developing States (SIDS), with high urbanization rates and land scarcity. This paper investigates environmental and economic benefits and drawbacks affected by the climatic and contextual conditions comparing the hot and arid climate in Bahrain with the tropical climate in Singapore. Based on the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis results, conclusions, and recommendations are listed to maximize the environmental benefits of green roofs and reduce the economic costs related to installation, maintenance, and water consumption. Solutions may include the application of financial incentives and using treated wastewater.

Keywords—Green roof, Economic, Environmental, Comparative Analysis, Singapore, Bahrain

I. INTRODUCTION

Urbanizing cities has long led to a variety of negative consequences; from rising global temperatures, and air pollution, to excessive noise and the loss of habitat [1]. The severity of global warming is particularly more evident in dense areas where the impervious surfaces of the buildings absorb more radiation thus contributing to the Urban Heat Island (UHI) effect [2]. According to the World Bank [3], Bahrain has the 6th highest density of population per km² globally and thus may be particularly vulnerable to such consequences, while Singapore ranks 3rd [3]. Both Singapore and Bahrain are Small Island Developing States (SIDS), which puts them under the threat of sea level rise hence making them among the most vulnerable countries to climate change [4].

Green infrastructure has shown multiple environmental benefits. These benefits include a reduction in stormwater runoff [5], limiting UHI, providing energy savings, and promoting biodiversity. The creation of large parks can be challenging in population-dense areas, and thus green roofs are proposed as a solution to land limitations [6]. Bahrain is committed to achieving the United Nations Sustainable Development Goals (SDGs) [7] through Bahrain's Economic Vision 2030 [8]. Green roofs contribute to achieving the following SDGs: 11- sustainable cities and communities, 13- climate action, and 15- life on land [9]. Moreover, green roofs may particularly be of interest as Bahrain heads towards its

Net-Zero goal by 2060 [10]. Green roofs are specifically referred to in Article 27 of the Green Building Guide under Bahrain's Green City initiative [11].

Research however has a gap in exploring the environmental and economic sustainability benefits of green roofs in Bahrain and comparing it to that of leading countries in green infrastructure such as Singapore. The climate of Bahrain is hot and arid with minimal rainfall [12], while Singapore has a hot humid tropical climate [13,14]. Studies suggest that extreme temperatures create larger risks for the successful implementation of green roofs [6]. Both Singapore and Bahrain suffer from land scarcity in the face of a growing population [15].

Like Bahrain, Singapore has developed the Singapore Green Plan 2030 to align the country's commitment to that of the United Nations SDGs and Singapore's Net-Zero 2050 vision [16]. This, however, is not a new initiative; Singapore's vision of becoming a Garden City dates back to 1967 [17]. Currently, Singapore surpassed the World Health Organization's recommendation of 50m² of urban green space per capita [18]. While Singapore's model can be inspiring; some climatic differences to Bahrain are present. Particularly, Singapore's weather is not as extreme in heat as Bahrain's and has plenty of rainfall [14]. This study will compare the environmental and economic implications of the sustainability of green roofs in both countries.

II. METHODOLOGY

Economic and Environmental Comparative SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is used as a methodology for this paper. Comparison is conducted between Singapore (tropical climate), and Bahrain (hot and arid climate) or similar contexts. Results are extracted from the literature focusing on the last decade, where recent studies are prioritized [19].

III. RESULTS (SWOT)

The results of the analyzed literature showed multiple strengths and opportunities to adopt green roofs in any climate. Yet it also highlighted various weaknesses and threats that can affect the efficiency of green roofs, especially in hot and arid climates.

A. Strengths

Singapore green roofs have multiple strengths including the property value, payback period, reduction in taxation, life span of the roof, and energy savings. A case study conducted on The Shaw Centre in Singapore which was equipped with an intensive green roof in 2013 indicated a payback period of 3 years. The results of this study can only be limited to commercial properties with green roofs; other properties may have longer payback periods. One of the contributing factors was that greening the commercial building has increased the flow of visitors. The attractiveness of green roofs to visitors will also depend on factors such as the choice of plants in the design phase. Moreover, implementing green roofs can reduce taxes due to Singapore's incentive policies [20]. Another major benefit of green roofs is that they increase the lifespan of the roofing membrane. A study by Calheiros and Stefankis [21] shows that green roofs can double the lifespan of a traditional roof, although the location of the green roof as a factor is not considered in the study. This is because it covers the membrane and protects it from damage via cleaning, stepping, and contact as well as it reduces solar exposure by up to 87% in comparison to a traditional roof.

The integration of green roofs reduces energy consumption in buildings, and increases thermal comfort, especially in naturally ventilated buildings. It also improves air quality and reduces the UHI, reduces rainwater runoff, minimizes urban noise, and increases the service life of buildings [22]. Intensive green roofs can also lead to 63% energy savings especially due to the reduction of cooling required in buildings when compared to black roofs [23,24].

In Singapore, the surface temperature of concrete roofs reaches 8.96 °C higher temperature than the atmospheric temperature, reaching its peak at 2 pm. On the contrary, green roofs' temperature never exceeds atmospheric temperature during the same period, which proves effective thermal buffering. Moreover, in severe climate change conditions, the temperature difference during summer between green roofs and concrete roofs deviates from each other ranging from 0.43 and 1.66 °C in the near and far future [2]. Another study showed that Singapore's green roofs support biodiversity by attracting birds and butterfly species. Wildlife attraction increases when the building is lower than 50m high and the green area is bigger than 1100m² [25].

While Bahrain has a different climate condition, a published study showed the possibility of reducing air temperature above the green roof due to evapotranspiration and reduction of energy consumption in a hot climate. Moreover, vegetation increases the leaf cover creating shade and reducing air pollutants and dust by 10 to 20% [26]. In a similar context in Egypt, in three buildings of green roofs with various floors 5, 10, and 15, the energy consumption reduction ranged from 17 to 25 % respectively, which reflects huge economic savings. Also, for high to medium-rise buildings green roofs can affect the streets around the building, creating a cooling potential between 0.03–3 °C [27]. Another study showed that the air temperature above green roofs in Tehran is 3.06 to 3.7 °C cooler than a regular concrete roof. Also, the study showed after simulating the application of green roofs in three areas in Egypt, that warmer regions will benefit more from the application of green roofs due to the energy saving regarding cooling the building. The results showed that soils with thermal conductivities of 0.9 W/m-K provide more energy savings than soils with thermal conduciveness of 0.6

W/m-K and 0.3 W/m-K. Also, the 10cm thick soil was more efficient than the 15cm or 20cm soil. In addition to that, 10cm soil with thermal conductivities of 0.9 W/m-K is the most economically feasible among the other options [28]. Another study based in Saudi Arabia examined three different green roof options one with full coverage of the roof (Option A) and two with partial coverage as shown (Options B and C). The results show that energy reductions are more significant in summer months in comparison to colder months where not much difference is shown with full coverage providing the most benefit, Fig. 1 [29]. The reduction of energy consumption is more significant in green roofs covered with trees or shrubs followed by green roofs covered in grass. There is almost no difference in energy consumption with green roofs covered in low shrubs [30].

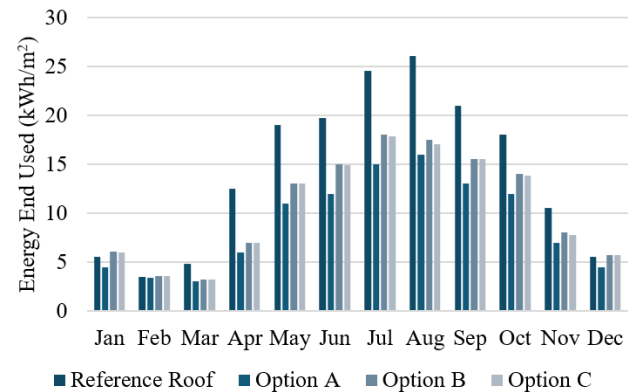


Fig. 1. Green Roofs Yearlong Energy Savings in Saudi Arabia [29]

A study based in Jordan has shown that cases of green roofs vary in payback periods depending on the type of soil and vegetation [30]. If the vegetation and soil were not optimum it can result in a payback period that is more than 10 years. Intensive green roofs have shown more economic gain than those of extensive green roofs but may require a longer payback period. Intensive green roofs may positively increase the property value due to their ability to provide recreational spaces and overall improve the building's aesthetic [31].

B. Weaknesses

Applying green roofs in Singapore and Bahrain has its shortcomings when it comes to capital, operational, and lifecycle costs. Callheiros and Stefankis [21] pointed out that the additional costs in the design, installation, and maintenance phase act as a barrier to the installation of green roofs. Manso et al. [24] mentioned that generally, green roofs tend to be more expensive than traditional roofs requiring extra maintenance. They also added that depending on the type of the green roof system, additional weight capacity needs to be considered in the design of the structure. It is worth noting that extensive green roofs are lightweight and can be installed on an existing structure, unlike intensive green roofs which need additional structural load-bearing considerations [30]. To adopt green roofs in buildings, there are several amendments to the roof structure and layers including structural support, vapor control roof drainage layer, thermal insulation, roots protection layer, and plants suitable for the climate [26]. Wu et al. [20] did a case study in Singapore to highlight the cost of Singapore's Shaw Center green roof built in 2013. The center hosts over 200 species of plants with the system expected to be removed and replaced

every 30 years [20]. The cost is impacted by several factors; those include design & procurement fees, costs of the plant media and the plants, manpower, equipment, and logistics required for installations and the irrigation system. The irrigation system required by the green operations department needs to be weatherproof and that added a higher cost in comparison to the traditional system.

The Shaw Center case study has shown that the cost of plants' maintenance and replacement cannot be generalized as it mainly depends on the plant type and species. Tropical climate, however, may increase the replacement rate. The case also added that disposal fees are also another factor to consider. The equipment and logistics of the disposal fees and maintenance of green roofs are like that of a property garden in terms of the provision of fertilizers, watering, and garden care. In general, intensive green roofs will have the highest costs of installation, maintenance, and watering through regular irrigation [21, 24].

Mithartna studied the lifecycle costs shown in Fig. 2 for several types of green roofs; The study compared three types of green roofs. Type 1 is a continuous extensive green roof with a substrate of 100mm depth. Plants cover 100% of the roof area. Type 2 is a modular extensive roof: The tray is made of lightweight polypropylene; the thickness of the substrate is 70mm. Plants cover 100% of the roof area. Type 3 is an intensive green roof: Substrata thickness: 700mm; 80% of the area is covered with shrubs and the rest with covered plants.

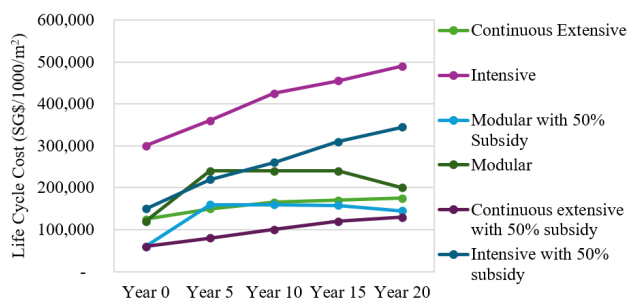


Fig. 2. Additional cost of green roofs in Singapore with and without incentives [34].

The lifecycle cost of both continuous extensive green roofs and modular green roofs is lower than the intensive green roofs at initial investment and maintenance. The continuous extensive green roof has the lowest cost, but if a period of 20 years is considered; the cost becomes similar to that of the modular green roof. It is also worth noting that the skyrise greenery scheme where the government pays 50% of the green roof cost can reduce the costs drastically as shown in the graph above. At the end of the lifecycle, none of the green roof types seemed to pay back the initial capital cost of installation for the office building.

In Singapore, even during severe climate change conditions, the temperature difference during winter between green roofs and concrete roofs is negligible and are $<0.41^{\circ}\text{C}$ [2]. Extensive green roofs are more suitable to be used in harsh weather, as intensive green roofs increase thermal storage and increase the energy required for cooling the building [27].

When it comes to Bahrain, water can be scarce and dependency on rainfall may not be an option. Moreover, when green roofs are tested in drought conditions, a study has shown

that scarcity of water is likely to reduce the survival of the green roof plants in comparison to other climates [32]. Additional costs may be incurred when installing green roofs due to the need for irrigation systems. Zaina et al. [33] specifically suggest using smart irrigation systems in harsh hot arid climates. While smart irrigation systems may have high costs [34], it may save up to half the water quantity needed for irrigation [33]. Overall, green roofs may tend to have higher lifecycle costs than traditional roofs [31].

C. Opportunities

Multiple opportunities are present in Singapore regarding green roofs such as governmental incentives, urban farming, and photovoltaic systems. Skyrise Greenery Scheme is a scheme developed by Singapore in 2009 to promote greenery in buildings. The competitive scheme offers up to 50% of the green roof installation costs if the projects manage to fulfill the sustainability criteria set by the government. The grant is offered to commercial, industrial, non-landed, mixed-use, institutional, and community projects. Moreover, Khoo Teck Puat Hospital in Singapore has created a green roof that is also used to farm different types of vegetables. The harvest is then sold to the employees of the hospital to help pay for the green roof's maintenance [35]. The roof farm offered opportunities for the local community to manage it [36]. Calheiros and Stefankis [21] suggests that more countries are considering green roofs as a potential source of urban food production, especially after the realization of how countries were reliant on food imports during the COVID-19 pandemic. Manso et al. [24] explored the potential of combining green roofs with photovoltaic technologies. Their study shows that the combination has the potential to improve the absorption capability of the panels. Greenery in roofs is shown to reduce the panel's surface temperature which in turn improves its solar absorption. Economically, photovoltaic systems have the potential to generate more affordable electricity [37]. However, the system is more effective in colder climates than hotter and tropical ones [38].

While irrigation might be a limitation to implementing green roofs in Bahrain, it can be made more sustainable by using rainwater, grey water, or the water produced by the air conditioning units due to humidification. A simple treatment process is required before irrigating the green roof [26]. Substrates that have higher water-holding capacity can improve plants' survival rate [32] and therefore reduce the plant replacement costs. There is also a potential to use the green roof to plant some heat-tolerant species, such as sweet potatoes, *Acacia berlandieri*, *Acacia gerrardii*, *Draceana bicolour*, *Eucalyptus subcinerea*, and *Pistacia vera* [26]. Moreover, some studies show that more succulent species may exhibit more tolerance to dry environments [39].

Another opportunity presented in a case study in Shiraz is the possibility of using green roofs as sound buffers to reduce noise pollution from busy roads and streets. Moreover, the possibility of integrating green surfaces with traditional architecture and near wind towers which aids in purifying and cooling the air before redirecting the breeze to the indoor spaces [40].

Flat concrete roofs, used in Bahrain, are more economical candidates to install green roofs in comparison to other shapes, as it may allow it to sustain the additional weight [30]. Finally, the potential of green roofs to reduce energy consumption locally may increase the capacity for the country to export fossil fuels abroad and lead to economic gains [41].

D. Threats

Singapore and Bahrain share some common threats when it comes to adopting green roofs: these include the dependency on foreign manpower and importing materials. The manpower required to maintain and install green roofs may need to be imported from outside of Singapore [20]. Foreign workers in Singapore usually are subject to taxes and need to be provided with accommodation [20]. Mithraratne [42] mentioned the possibility of importing green roof materials from other countries such as Malaysia and Indonesia which can add transportation costs. Those materials include drainage systems, recycled construction materials, organic matter, minerals, plants, substrates, and filter layers.

Threats to the lifelong maintenance of green roofs are also present. This indicates that improper installation can lead to leakage and damage to the building's structure. In addition, the disposal of plastic components on the green roof can lead to increasing pollution at the end of its cycle. In drought conditions such as Bahrain, green roofs may require regular fertilization and irrigation, besides maintenance and regular checkups on the plants [43]. Finally, the lack of financial incentives by the government for green roof implementation can threaten its feasibility in Bahrain [31].

IV. CONCLUSION

In conclusion, applying green roofs to buildings has multiple environmental and economic advantages. In Singapore, green roofs have a short payback period, leads to an increase in visitors rate, and may result in tax reduction. It is recommended to benefit from such initiative in Bahrain's commercial and touristic sectors.

In Bahrain, the expected temperature reduction is more significant than in Singapore. The reduction in energy bills may be less significant in Bahrain due to the electricity being subsidized by the Bahraini government [44]. However, energy efficiency can still reduce national spending on energy subsidies [45].

Green roof integration has multiple drawbacks, especially economically in both Singapore and Bahrain. Additional costs occur in the initial installation, maintenance, and application of additional roof layers. In Bahrain, the most significant weakness is water scarcity and the installation of costly smart irrigation systems. Mitigating these drawbacks can be implemented by using native plant species to maximize plant life and reduce water consumption. The species include sweet potatoes, *Acacia berlandieri*, *Acacia Gerrardii*, *Draceana bicolour*, *Eucalyptus subcinerea*, and *Pistacia vera*. Additionally, various water strategies can be incorporated. Those include using treated wastewater, incorporating a closed water cycle in buildings, and utilizing air conditioning condensate water. Smart irrigation systems are required to monitor the dryness of the soil and the frequency of irrigation. The system is recommended to operate mainly in the evening to reduce the effect of solar evaporation.

Singapore has been using incentives to encourage its population to invest in green roofs which may have contributed to its success in increasing its green infrastructure; such an initiative is recommended to be introduced in Bahrain. This could include funding part of the installation or maintenance costs or providing subsidized

smart irrigation systems. The legal framework for such a grant needs to be established and can be paired with legislative efforts to incorporate green roofs in building codes.

While urban farming through green roofs has been used in Singapore, such potential is yet to be studied in Bahrain with consideration to the extreme temperature. This might provide an opportunity for local farmers to create a substitute for the loss of agricultural lands.

Finally, training local workers on the installation and operation of green roofs can reduce the reliance on foreign manpower. It can also improve the quality of installation reducing the risk of future damage and leakage.

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