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INVESTIGATING THE ENVIRONMENTAL IMPACTS OF GREEN ROOF INSTALLATION

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Graphical abstract

Energy saving
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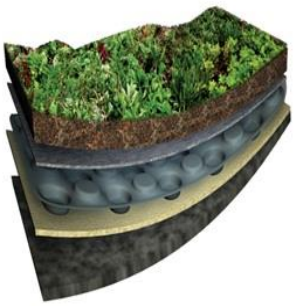
Increasing longevity
Reducing UHI



Abstract

Green roof installation has been used as a sustainable approach for many years in order to reduce the adverse impacts of environmental issues all around the world. These environmental issues include: global warming, air pollution, flood, carbon footprint and so on. Green roofs are practical as a sustainable approach, especially in developed countries; however, there is an increasing trend of implementing green roofs in developing countries. This paper is reviewing the benefits of green roof installation and how green roof might contribute to reduce the negative environmental issues. The environmental problems that can be solved or reduced by these benefits are discussed separately in this paper. It is concluded that due to the environmental benefits of green roof installation, it leads to many economic benefits. Moreover, green roof implementation is beneficial in both urban areas and rural places.

Keywords: Environmental issues, green roofs, sustainability

Abstrak

Pemasangan bumbung hijau telah digunakan sebagai pendekatan mapan selama bertahun-tahun untuk mengurangkan kesan buruk isu alam sekitar di seluruh dunia. Isu-isu alam sekitar termasuk: pemanasan global, pencemaran udara, banjir, kesan karbon dan sebagainya. Bumbung hijau praktikal sebagai pendekatan yang mampan, terutamanya di negara-negara maju; Walau bagaimanapun, terdapat trend yang meningkat melaksanakan bumbung hijau di negara-negara membangun. Kertas ini mengkaji manfaat pemasangan bumbung hijau dan bagaimana bumbung hijau mungkin menyumbang kepada mengurangkan isu-isu negatif alam sekitar. Masalah-masalah alam sekitar yang boleh diselesaikan atau dikurangkan dengan faedah-faedah ini akan dibincangkan secara berasingan dalam kertas kerja ini. Ia membuat kesimpulan bahawa disebabkan oleh faedah alam sekitar pemasangan bumbung hijau, ia membawa kepada banyak manfaat ekonomi. Selain itu, pelaksanaan bumbung hijau adalah baik dalam kedua-dua kawasan bandar dan tempat-tempat luar bandar.

Kata kunci: Isu alam sekitar, bumbung hijau, kelestarian

1.0 INTRODUCTION

Construction industry is responsible for more than 30 per cent of energy consumption and CO_2 emission. This gives a great importance to sustainable construction as an effective strategy for energy saving, overcoming economic problems and global warming [1]. It is found that there is an urgent need to find a solution or an alternative for the activities that cause environmental problems [2]. Construction industry has the potential of reducing or addressing some of the environmental issues [3]. These issues are already identified by many researchers as globally issues; however, some of them might be more serious in some countries. For instance, in the countries with rainy climate, flood and storm water runoff need more attention. Moreover, energy consumption is a serious problem for the hot and cold countries [4].

One of the most important techniques in sustainable construction is developing such systems, which integrate natural environmental in the construction [5]. Among all, implementing green roofs (vegetated roofs) can lead to more environmentally friendly construction and also having sustainable buildings. Since the green roofs technology provides significant economic, technical, ecological, climatic, and social advantages in both industrial and residential areas [6], this is known as an important greening technology in urban areas. The benefits from this technology include reducing the surface runoff in large cities [7], filtering the air pollutants [8], reducing the transmission of sound [9], enhancing the durability of waterproofing membrane due to the better protection from solar radiation [10], improving the urban environment, because of decreasing the urban heat island (UHI) effect [11], and supporting bio diversity [12]. Because of the higher thermal capacity, green roofs can decrease the thermal fluctuation [13]. The air temperature of underneath rooms can be kept warmer in winter and cooler in summer, which leads to the reduction of energy consumption for heating and cooling [5,6,13-17]. On the other hand, some environmental conditions make challenges for sustaining plant materials on roofs; these conditions include wide temperature fluctuations, limited water availability, and high exposure to solar radiation and wind [13].

Generally, green roofs categorize into two or three major types: intensive green roof and extensive green roof and in some references, the third category is semi-intensive green roof [14]. In terms of intensive green roofs, a thick layer of growing medium or substrate is applied, wherein a variety of plants can be grown, especially in cases where irrigation is available. Note that additional structural support is needed due to the heavy weight of substrate; thus, this type of green roofs can be applied to the buildings considering additional structural support [6, 15]. Whereas, in terms of extensive green roofs, a thinner layer of substrate is applied, which is a relatively lightweight and thus in some cases little or even no additional structural support is needed. It makes this type of roofs applicable to a wider range of buildings. This advantage, together with a reduced need for irrigation and lower maintenance requirement, has led to a wider application of extensive green roofs. On the other hand, the extensive green roofs provide a harsh environment for plant growth with wide temperature fluctuations, limited water availability, and high exposure to solar radiation and wind, which causes a highly stressed environment for growing plants [6,15,18]. Fig. 1-2 show two different buildings with both extensive and intensive green roof. Moreover, semi-intensive green roof includes the characteristics of both intensive and extensive green roof. As shown in Fig.3, The layers of the green roofs are generally consisted of the followings:

- Vegetation layer.
- Substrate layer that is generally made up of garden soil. This layer provides physical support as well as nutrients for plants. In addition, it retains water.
- Filter layer that is normally formed by polypropylene or polyester geotextiles membranes.
- Drainage layer that is aimed to achieve a balance between water and air in green roofs. This layer retains water while it rains and, at the same time, it ensures good drainage and the aeration of the substrate and roots.
- A layer made up of porous stone materials with the capacity for water retention, such as expanded shale, expanded clay, natural puzolana, and pumice.
- Protection layer that is normally formed by geotextiles polypropylene or polyester membranes. This layer plays the role of a mechanical protection for lower layers, particularly for the waterproofing layer.
- Root barrier and waterproofing layer that is used to protect the building from roots and water. This layer is generally made up of materials such as bitumen or PVC membranes that are reinforced with plastics, fiberglass, polyester, and mineral granules. In some cases, this layer is formed by synthetic rubber or polyethylene [16,19-21].

Figure 1 Extensive green roof

Figure 2 Intensive green roof

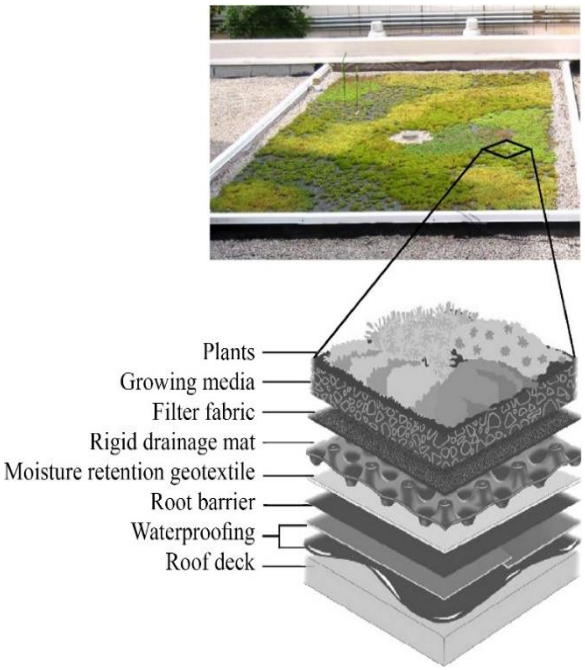


Figure 3 Construction detail of a typical green roof [21]

As discussed above, there are lots of researches conducted in the field of green roof. Additionally, some authors have listed the benefits of using this sustainable approach; however, the disadvantage of using green roof is rarely mentioned. Moreover, all the reviews of green roof installation focused on the researches and environmental challenges in developed countries. The aim of this paper is reviewing the impacts of green roof installation considering the current environmental challenges, especially in developing countries.

2.0 ENVIRONMENTAL BENEFITS OF GREEN ROOFS

Construction industry satisfies the human development requirements and, on the other hand, in many cases destroys the environment. Construction sector is known as one of the most important contributors to the environmental issues because of using non-renewable materials. As reported by the United States Green Building Council (USGBC), residential and commercial buildings are responsible for 30% of the greenhouse gases' emission and the consumption of 65% of electricity in the United States [22]. To diminish the damages caused by the construction industry, environmentally friendly applications have been introduced, which have the contribution to saving energy, reducing the emissions, and recycling materials. Peri *et al*. [23] identified abiotic depletion, acidification, eutrophication, global warming, human toxicity, fresh water aquatic eco-toxicity, marine aquatic and terrestrial eco-toxicity, as the environmental impacts of green roof installation. However, in this paper we focused on the most significant factors that can be partially addressed by construction industry. Table 1, shows the current environmental challenges and also the positive contribution of green roof installation on these challenges.

2.1 Energy Consumption Reduction

Installing green roof has a positive impact in the energy performance of buildings. Green roofs also directly affect the urban environment, and they can efficiently reduce the variation of indoor temperature and decrease the energy consumption of buildings in both cold and warm climates [24]. Nonetheless, the characteristics of building affect the contribution of green roofs. In non-insulated buildings compared to insulated ones, the effect of green roofs is much higher. Similarly, the characteristics of energy load of building (more heating or cooling load) help understanding the contributions of a green roof. In areas with warm climate, green roofs prevent the direct influence of solar radiations and diminish the indoor temperature. Figure 4 depicts the temperature profile for a conventional and green roof in summer [4].

Extensive green roofs have shown a positive effect for subtropical climates with strong rain and high temperature. As reported in a related study, in Greece, green roofs have decreased the energy consumed for cooling between 2% and 48% depending on the area covered by green roof with an indoor temperature decrease up to four K. Several studies that carried out in warm climates have shown the significance of the climate characteristics [25-27]. In a study recently conducted in Singapore, the temperature variations of a green roof and a typical roof were compared to each other. Analyses demonstrated the significant effect of green roofs on decreasing the variation of the surface temperature [28].

A study conducted in terms of green roof energy saving and showed that green roofs improve the buildings' thermal insulation; this way, they reduce heat loss between 10% and 30% in the winter and decrease the solar heat gain by around between 70% and 90% in the summer [14].

Table 1 Green roofs' impacts on the environmental challenges

Environmental challenge	Green roof benefit	Reference
High amount of energy consumption	Reducing the variation of indoor temperature; Decreasing the energy consumption of buildings in both cold and warm climates. Reducing the environment temperature in hot climate improving the buildings' thermal insulation decrease the solar heat gain	Ascione *et al*. [14] Pérez *et al*. [16] Djedjig *et al*. [24] Berardi *et al*. [28]
Urban heat island	High amount of evapotranspiration Lower amount of absorption the energy of sun Increasing the urban albedo	Berardi *et al*. [28] Bianchini & Hewage [31] Susca *et al*. [33]
Increasing trend of carbon footprint	Absorbing CO2 in the daytime	Li *et al*. [34]
Air pollution	controlling the temperature variations of a building, heating and air conditioning demands The photosynthesis process of plants sequesters the carbon dioxide from the air and stores it as biomass.	Schrader & Böning [6] Berardi *et al*. [28]
Storm water runoff	controlling and decreasing the quantity of runoff water reducing the risk of flooding better quality of runoff water Storm water retention	Bianchini & Hewage [18] Palla *et al*. [19] Berardi *et al*. [28] Bianchini & Hewage [31]
Noise pollution	Reducing the noise by high absorption coefficient of vegetation layer. Depth of soil and substrate	Berardi *et al*. [28]
Lack of recreational space	intensive green roofs are also recognized as park-like roofs making the places more beautiful	Bianchini & Hewage [18]

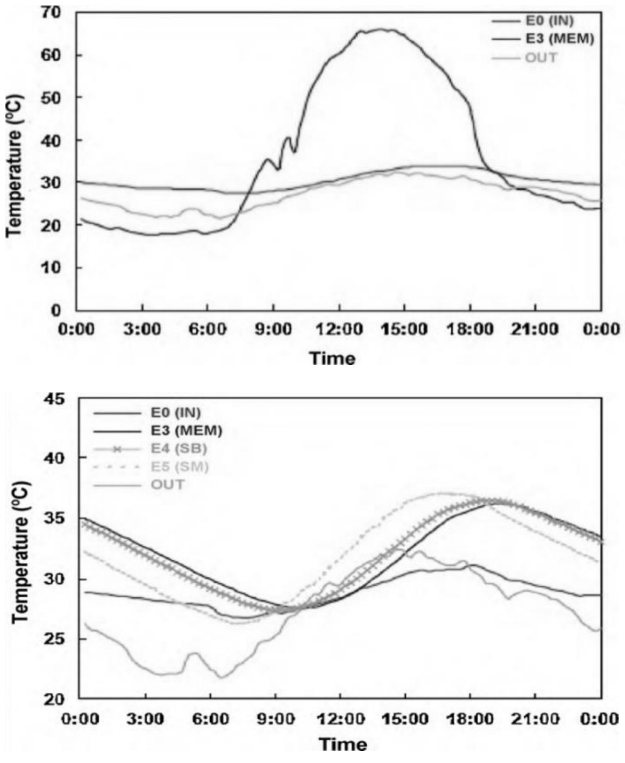


Figure 4 Top: Summer temperature profiles for a conventional roof, bottom: Summer temperature profiles for a green roof [4].

Furthermore, the durability of waterproof membrane is enhanced due to the reduction of peak temperature by roughly 30 °C. Although the results from these kinds of studies vary because of differences in vegetation and medium used, Ascione *et al*. found that the decrease of annual energy consumption can range from 0.6 to 14.5%, and it is observed primarily in the buildings' top floor. Furthermore, the extent of the thermal effect of the green roofs is correlated strongly with weather condition. As these findings indicate, such models should be developed that can evaluate the thermal behaviors of green roofs in various climates under different configurations [14].

It has been shown that green roofs have the potential of decreasing solar absorption by almost 50% compared to bare roofs, and the green roof system accounts for more than 50% of heat dissipation. The use of lightweight extensive green roof can appropriately retrofit old buildings with limited live load-bearing capacity. Reducing the summer heats gain, particularly in tropical countries, is of a great importance since a huge amount of electricity is consumed by air-conditioning systems. In tropical cities, green roofs can provide a cost-efficient mitigating measure associated with several environmental ecological advantages [29].

According to a study conducted to analyze the efficiency of green roofs in warm and humid climates of Hong Kong (comparing three plantations, including groundcover herb, shrub, and grass), the type of plantation applied to green roofs played a remarkable role in cooling effects [29]. The results showed the

significance for the plant type, form, and biomass structure to be used for cooling purposes. Considering the variations in temperature at various levels, the study concluded that biomass complexity and quantity were the most important factors that affected the energy saving.

High amount of energy consumption is one of the major challenges that almost all the countries, whether with hot or cold climate, are trying to find innovative solutions, new material and new approaches to cope with this issue [4]. Iran's government as the government of a developing country has warned that, increasing trend of energy consumption by people, leads to loss of power in many big cities. Moreover, the cost of energy consumption is increasing annually. High amount of energy consumption results in using non-renewable resources and following with adverse impact on environment. Although there are some new approaches such as photovoltaic panels that use renewable resources, there is still lack of using these methods due to the high initial investment. There are some studies conducted in Iran to investigate the potential of green roof in energy saving in every climate. In the study conducted in Tabriz (a big city in north of Iran with dry and cold climate) by Aein *et al*. [30] the results of simulation with "Energy Plus" have been compared with the experimental results, and it was found that green roofs can reduce the cold load by 18%. As a result, it could be very beneficial even for dry and cold climates.

A study recently carried out in Mediterranean coastal climate in the summer showed that with an increase in the density of plants in a green roof, despite the substantially-insulated roof structure (U-Value: 0.24 W/m2 K), the cooling consumption decreased by 60% compared to a traditional roof. In case of cold climates, green roof is globally recognized as a beneficial technology; however, some researchers have argued that insulating the roofs, besides the use of green roof structure, might have negative effects. In a study carried out in Canada, it was reported that the daily surface temperature variation with a green roof was around 6 C compared to a variation of 45 C in a conventional roof [28].

2.2 Urban Heat Island Effect

Urban growth, has caused many negative environmental consequences, including the increased air pollution, loss of habitats, and UHI effect. The use of green roofs is not only valuable in a building-scale, but also it provides several advantages at a city-scale. One of the benefits of green roofs is the mitigation of UHI effect [28].

At the early of the 20th century, only 15% of the whole population throughout the world lived in cities, while currently, around 50% of the people in the world live in urban areas. This increase of urban inhabitants has caused urban sprawl, particularly in the developing countries. Generally, this leads to an increase in urban temperatures, the so-called UHI effect. The UHI effect explains why in urban areas, the temperature is higher than rural areas. The UHI effect occurs mainly because the buildings' roof tops are in dark colors. Dark roofs absorb energy from the sun and reach high temperatures; while, thanks to the variety of vegetation and trees, roofs in rural places are not in such a condition [31].

The adverse effect of UHI is completely can be seen in many big cities in the world [32]. In terms of Tehran as the capital of Iran, in a long-term investigation, the average temperature has been increased by 4 centigrade. One of the consequences of this change in temperature is the deformation of precipitation from snow to rain. This is one of the symptoms of high-rise building construction without considering the destroying environment. Tehran Municipality announced that these were an abnormal phenomenon and results in an increase to the degree of thermal comfort, increase of air pollution and adverse effect upon the quality of drinking water. Tehran deputy municipality for planning and development in 2011 emphasized that there are four major solution to come up with UHI, first, prevention of horizontally expansion of cities, second, increase of greeneries and green areas in the roofs and facades, third, using standard materials and forth, developing public transportation.

Principally, the UHI is dependent on the changes of the balance of energy in urban areas; this is because of a number of factors: the thermal property of building materials, urban canyons, the reduction of urban albedo, and the change of green areas to inflexible surfaces with limit evapotranspiration. Several studies have shown the correlation between the increase of green areas and the reduction of local temperature, which suggests that through augmenting the urban vegetation, UHI can be mitigated [33].

2.3 Reduction of Carbon Footprints

Plants have a great role in reducing the concentration of CO2 in the environment through absorbing it in the daytime. In Hong Kong, for instance, in summer, in a typical sunny day, the CO2 absorption rate of a plant in the daytime is much higher compared with the CO2 emission rate at night. The extent of the green roof effectiveness depends on factors such as the ambient airflow condition, the green roof position, and the plants condition. Figures 5 and 6 show that in a sunny day, a green roof can reduce the CO2 concentration in the nearby region by nearly 2% [34]. Many investigations conducted for the evaluation of air purification ability of urban vegetation have revealed that plants are remarkably capable of improving air quality. The results of investigations carried out in Chicago based on the local weather, air pollutants' concentrations, and plants conditions showed that 19.8 ha of green roofs removed around 1675 kg of air pollutants.

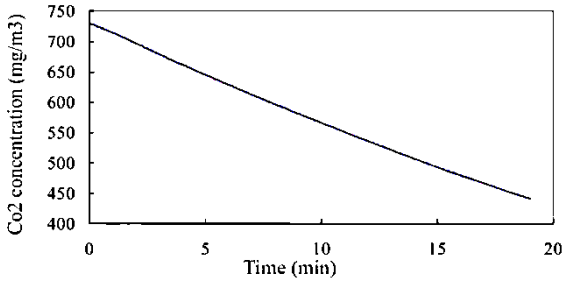


Figure 5 CO_2 concentration curve in a diurnal experiment.

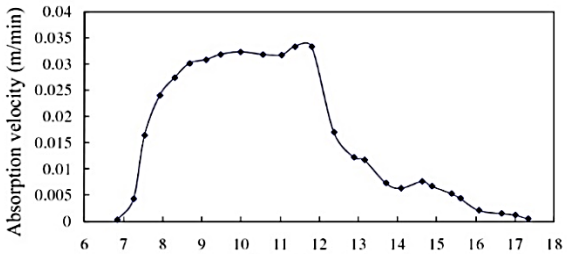


Figure 6 CO_2 absorption velocity of the plant in a sunny daytime of mid-August [34]

2.4 Air Pollution Mitigation

Pollution management is mainly focused upon the control over the sources of toxic chemicals released through the air, but it does not consider the pollutants that have been already in the air. Normally, in the urban areas, there are higher levels of toxic materials into the air [6]. Providing urban vegetation can partly decrease the air contamination. The green roof technology contributes to the reduction of air pollution in two different ways: first, by controlling the temperature variations of a building, heating and air conditioning demands can be reduced, hence releasing a less amount of carbon dioxide from power plants; and second, the photosynthesis process of plants sequesters the carbon dioxide from the air and stores it as biomass. It has been estimated that 7.87 metric tons of air pollution can be decreased annually by 109 ha of green roofs in Toronto. In spite of the valuable properties and ecological values of green roofs for urban landscapes, they should not be considered a justification for destroying natural habitats on the outskirts of cities. Green roofs revalue cities but do not replace nature [6].

The metropolises in Iran, especially the capital, Tehran, are suffering air pollution and governments have found the necessity of planning to decrease the amount of air pollutants. Governor-general of Tehran recently declared a committee for reduction of air pollution will be established due to the increase in density of pollutants and decrease in the quality index. This situation is very dangerous for those who suffering heart and lung diseases, pregnant women, children and the elderly. As it is proved by Iran's government, creating green spaces is one of the major solutions to remove some parts of air pollution.

Generally, the use of intensive green roofs is considered as an appropriate strategy for reducing the air pollution. Indeed, plants on the rooftop substitutes partially the vegetation destroyed during the construction procedures. Trees have the highest influence upon the reduction of air pollution. The level of air pollutions (especially, sulfur dioxide) before and after the application of green roofs was investigated in Singapore. The results showed the removal of up to 37% pollution through extensively using green roofs [28].

2.5 Water Management

The development within the urban areas has led to an increase in impermeable surfaces, leading to the reduction of storm water infiltration. As stated by many researchers, the most significant environmental benefit of green roofs is the decrease of storm water runoff [19, 35]. The water retention capacity of green roofs contributes to the control over the quantity of runoff that can flow through the sewer system of cities. Compared to conventional roofs, the green roofs drain runoff water at a lower rate, which allows the storm-water sewer system to transport runoff to the disposal body of water, hence reducing the risk of flooding. The quantity of water harvested from rain is important; however, the quality of that water is of a great importance, too. Some studies carried out to investigate the impact of roof's materials on the quality of runoff water showed that current roofing materials add chemicals or metal compounds to the runoff water [28]

Flood is one of the two major causes of loss and damages among natural disasters in the world [36] and in Iran 70% of the allocated budget for reduction of natural disaster, spend for compensation of damages caused by flood. There is a significant increase in damages caused by flood in previous five decades in Iran. There is an increase trend in moving from rural areas to urban places in many countries. For instance, in east from the capital of Iran, Tehran, government had planned to settle around 200 thousand people to the new city which is named "Pardis", however, currently there are about 800 thousand people who stayed in this city. As a result, it's very difficult to control the storm-water runoff of this new city.

Studies have shown that the use of green roofs can lead to 100% in case of intensive green roofs and 60% runoff mitigation for extensive green roofs [35]. Figure 7 depicts the level of rainfall runoff in a conventional roof and a green roof. Lower values, in the range between 25% and 50%, were found in other researches. In a recent study, the level of storm water retention was compared for three different roof structures, i.e., a conventional roof, an extensive green roof with plantation, and an extensive green roof with no plantation. The findings revealed that the level of storm water retention was enhanced by 82.8% in case of the extensive green roof. In a recently-conducted study, three types of roofs have been compared to each other, including a traditional roof, a conventional green roof, and an extensive green roof integrated with a drainage system. The obtained results

demonstrated that the conventional green roof reduced the peak runoff to 57%, whereas in case of the extensive green roof, the reduction value was as much as 71.7%. Another research investigated the impact of green roofs on surface runoff using three different types of vegetation (short grass, long grass, and Sedum), and the results showed that sedum was less effective on the volume of surface runoff [28].

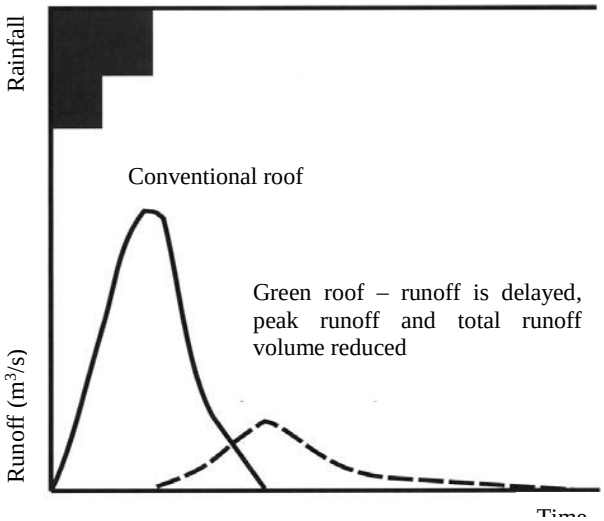


Figure 7 Rainfall runoff response (schematic) [35]

2.6 Sound Absorption

One of the positive potentials of green roofs is noise insulation [37]. In an empirical analysis, in which the transmission loss (TL) was referred to as the extent of sound level decreased through partitions, it was concluded that green roofs increased TL from two dB to eight dB at high frequencies, and from 5 to 13 dB at low and mid frequencies. In a recent study, the sound TL of a reference roof (conventional type), and two green roofs have been measured. The roofs were identical with the only difference to the depth size of substrates (75 mm for GR1 and 150 mm for GR2). The results showed that, at different frequencies, the increase of TL through GR1 was less consistent, whereas the respective increase of TL through GR2 was more reliable. In addition, it was revealed that deep green roof enhanced TL from five dB to 13 dB at low and mid frequency bands (50–2000 Hz) and of less than six dB at higher frequencies.

In case of urban areas, green roofs have a considerable potential to reduce the noises generated in adjacent streets due to the high absorption coefficient of vegetation layer [28]. This property particularly works in green roofs above low buildings since the vegetation layer should be directly exposed to the urban sound field to absorb effectively noises. The problem of noise pollution is bold for the airports or train stations. Neighbors and the staff of Mehr-abad airport in Tehran, suffer from noise pollution, and planting is one of the recommendations to reduce the adverse effect of noise pollution, whether on roofs or walls.

2.7 Provision of Recreational Space and Aesthetic Aspects

Parks and green spaces as the most important centers and recreational services, are very important to the medical and psychological aspects and also for sustainable urban development [38]. Many cities of Iran are faced by the lack of green spaces, and intensive green roofs are capable of play a role as a recreational space in the public buildings.

Intensive green roofs have some similarities to public parks and may be recognized as park-like rooftops. This type of green roof, where designed for public use, plays the role of recreational spaces. De Sousa in Toronto, estimated that around $20/m2 is needed in order to turn the brownfields into parks. Although there are some differences between public parks and intensive green roofs, installing intensive green roof could lead to saving the public investment between 30% and 70%. In terms of aesthetics, it is a significant factor in design and operational phase of buildings; however, it is difficult to objectively estimate the economic impact of aesthetics on a given structure. In a study, individuals were asked if they were ready to pay extra for beauty [39]. Particularly in case of structures, it was asked how much more a consumer was ready to pay if the same structure was situated within a different area. The willingness for expending more can be taken into account as the value of aesthetic. As reported by the Commission for Architecture and the Built Environment (CABE), the price of buildings located close to a park or having view of a park can be increased by 6% and 8% respectively [18].

3.0 CONCLUSION

Green roofs offer many environmental benefits that lead to economic benefits. According to the literature, there are many researchers that focused on green roof's benefits from different parts around the world, and all of them emphasized that green roofs have a positive impact on environment. Green roof is proved as a sustainable approach and has the potential of implementing in almost all the countries.

Global warming and air pollution are two major environmental issues that cause some problems for human and also there are dangerous for animal lives and additionally lead to more energy consumption. Some of the major reasons of these adverse impacts are deforestation, destroying the environment due to construction purpose and lack of greeneries. In this case, integrating greeneries to the building is wise decision and installing green roof is the best solution in this way. Green roofs also offer some other benefits that can be suitable for specific purposes. For instance, intensive green roof can play the role of a recreational space for public places, especially somewhere there is lack of parks and entertaining places. Moreover, acoustical effect of green roof is an advantage, specifically near the airports, rails and somewhere there are too many noises.

The positive impact of installing green roof in developing countries like Iran is also proved. Green roofs offer a wide range of benefits on all parts of Iran. The studies conducted on energy saving prove that installing green roof result in lower energy consumption in all parts of Iran. Moreover, according to the current problem in storm water management in some parts of Iran, green roofs can be very beneficial due to the capability of water retention.

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