Brief literature review on environmental benefits of Green Roofs

Mohammad Mehdi Sadeghian

Faculty of Agriculture,

Department of Landscape

Islamic Azad University,Isfahan (Khorasgan)Branch,

ABSTRACT

Green roofs have numerous environmental benefits and are broadly used around the world. Green roofs can possibly improve the quality of urban runoff, reduce the energy intake of buildings, and enhancevisual value to the environment. This review paper focuses on various benefits related with green roofs. Thisliterature review also emphasizes knowledge on the basis of survey with Library, Journas, Internet, Various seminar papers, and reports of research organization. Green roof is an effective energy efficiency measure to reduce the building cooling load in summer and heating load in winter.The most important green roof Environmental benefits are the ability of rainwater locking up and retaining and reduction in energy ingesting. This paper aims to provide an overview of the effects of the application of the green roof on the environmental benefits such as runoff water, reduction of energy consumption, Thermal benefits, Water quality enhancement, Noise reduction, Air pollution, Enriching biodiversity, Cooling, Carbon fixation, Dust capturing.

Keywords: Green roof, Environmental benefits, urban runoff, Thermal benefits.

INTRODUCTION

Planting vegetation at the building rooftop is an old technique. The most famous ancient green roofs were the Hanging Gardens of Babylon constructed around 500 BC.Green roofs can be viewed as a tool to enhance aesthetic application of any building. Green roofs also support to restore biodiversity that have been lost due to urban development. Green roofs offer a safe place for birds, insect and other plants to grow. Green roofs protect roof membrane from extreme heat, wind and ultra violet radiation. Due to the presence of vegetation and thick substrate layer, the daily expansion and contraction of the roofing membrane can be avoided.Green roofs are also named ''eco-roofs'', ''living roofs'' or ''roof gardens'', and are basically roofs with plants in their final layer (Cox, 2010; Parizottoand Lamberts, 2011). Green roofs are generally built to enhance the energy efficiency of their buildings.Due to the high rate of energy and resource consumption of buildings, various sustainable approaches and environmentally responsive energy efficient technologies have been proposed and applied to realize low-energy buildings (Zhou et al., 2014; GhaffarianHoseini, 2013). These include advanced eco-technologies, energy efficient systems and renewable energy sources. Green roofs are often identified as a valuable strategy for making buildings more sustainable (GhaffarianHoseini, 2013).

MATERIAL AND METHODS

The research has been conducted on the basis of literature survey. Library, Internet, Various seminar papers, team reports of research organization, journals and some bulletins on benefits of green roofs have been surveyed for the purpose of collecting information.

Environmental and Ecological benefits of green roofs

Incorporating vegetation, growth medium and other landscape components on the rooftop of buildings offer several direct and indirect environmental benefits. There are numerous operational environmental benefits of green roofs and they can be listed as follows: reduction of urban heat island, mitigation of energy demand for heating and cooling, reduction and delay of storm water runoff, improvement in air quality, replacement of displaced landscape, enhancement of biodiversity, provision of recreational and agricultural spaces, and insulation of a building for sound (Currie and Bass, 2010;Bianchini and Hewage, 2012). Peng et al. (2015) reported that the establishment of Extensive Green Roof has an annual total value of USD 12.98 million with unit value of USD 10.77/m2 of green roof, and Intensive Green Roof, USD 22.02 million with unit value of USD 18.33/m. Extensive Green Roof is more economically attractive than Intensive Green Roof in terms of benefit cost ratio and payback period. The main benefits of implementing green roofs at the building scale are as follows: storm water infrastructure, energy savings (Niu et al., 2010).

Enriching biodiversity in urban area

Green roofs in urban and suburban areas act as green corridor, which are the stepping stones for wildlife to enter the nearby habitats. They can connect the fragmented habitats with each other so as to promote the urban biodiversity (Kim, 2004). A total number of 30 species or even more of organisms were observed in the green roof (Fountain and Hopkin, 2004; Schrader and Boning, 2006). The distributions of organisms in soil were move away from young and old roofs. There are three factors contributing to the biodiversity in the green roof. First is the type of growing substrate; second is the process of soil formation during the maturation of substrate; and the last is the increasing biological activity as well as increasing organic matter from dead leaves or organisms. Nonetheless, it is suggested that green roof could not be a justification for put an end to the natural nor replace the nature (Schrader and Boning, 2006).

Cooling performance on the building and surroundings

The cooling performance of the green roof depends on the plant species chosen (Maclvor and Lundholm, 2011; Blanusa et al., 2013). Green roofs cool down the temperature because of the direct coverage of plants and the opening of stomata that allows transpiration during daytime. The textures of leaf surface and albedo effect also take place. The vegetation stores the heat and cools down the air. The daily maximum temperature on the vegetated rooftops was reduced and reducesday time temperature fluctuations. Researches in US indicated that vegetated rooftops decreased the peak temperature from 0.5 K to 3.5 K; along with dropping of temperature, the albedo increased from 0.05 Up to 0.61 (Santamouris, 2012).

Managing runoff quantity

First of all, the definition of water retention means the water storage capacity of a green roof. Green roof characteristics including the growing medium and the drainage layer influence the water retention capacity as well as the runoff dynamics (Banting et al., 2005).

Cooling and humidification

The configurations for different types of green spaces vary from each other, and therefore the cooling effects are also different. The three different types of green lands, namely bushes and grass, shrub and grass, and turf, their surface temperatures are all lower than non-green lands, especially for bushes and grass, the average daily temperature is the lowest (Li, 1999).

Carbon fixation and oxygen release

Green coverage rate is closely related with the concentration of CO2 in the air. Feng (1992) proposed that when green coverage is less than 10%, the concentration of CO2 in the air would be 40% higher than the one with 40% coverage rate, and when the coverage rate reached 50%, the concentration of CO2 in the air can maintain a normal rate of 320 ppm. As there are different tree leaf area indices, the carbon fixation and oxygen release capabilities are also different (Yang, 1996). Bushes and grass, trees, grass and shrubs are much better in controlling the CO concentration at certain level, improving the environment and maintaining oxygen balance than the lawn and vines. Shrubs structure is the best in carbon fixation and oxygen release (Li, 2011;Zhu et al., 2002; Li, 1998).

Storm water reduction

Green roofs are known to retain rainwater and delay peak flow, thereby reduce the risk of flooding (Mentens et al., 2006; Chen et al., 2015). Plants play a significant role in the runoff reduction depending on each plant's capacity for water interception, water retention and transpiration (Nagase and Dunnett, 2012; Razzaghmanesh and Beecham, 2014). Speak et al. (2012) indicated that average runoff retention of 65.7% can be achieved on an intensive green roof (University of Manchester campus), compared to 33.6% on an adjacent paved roof (Nagase and Dunnett, 2012).

Thermal benefits

Green roofs are attractive option for energy savings in building sector. They reduce building energy demand through improvement of thermal performance of buildings (Saadatian et al., 2013; Hashemi et al., 2015). A study in Greece revealed that green roofs reduce the energy utilized for cooling between 2% and 48% depending on the area covered by the green roof, with an indoor temperature reduction up to 4 K (Niachou et al., 2001).

Water quality enhancement

Green roofs buffer acidic rain (Teemusk and Mander 2007; Vijayaraghavan et al., 2012) and theoretically retain pollutants thereby produce good quality storm water runoff.The green roof system is a popular approach that could help to moderate air pollution in urban environments. Urban air often contains elevated levels of pollutants that are harmful to human health and environment (Mayer, 1999). Among several mitigation technologies, the ability of plants to clean the air is considered practical and environmentally benign technique (Rowe, 2011). In general, plants mitigate air pollution through direct and indirect processes, i.e. directly put away gaseous pollutants through their stomata or indirectly by modifying microclimates (Yang et al., 2008).Green roofs act as a sink for nitrogen, lead and zinc (Gregoire and Clausen, 2011); it is also the source of phosphorus (Kohler et al., 2002; Berndtsson et al., 2009; Gregoire and Clausen, 2011). On the thin soil of extensive green roofs which does not affect the concentrations of heavy metals in runoff water, i.e. the concentrations of heavy metals in runoff water were the same as that in precipitation (Ko¨hler et al., 2002). Nonetheless, the green roof retained over 65% of the zinc from precipitation (Gregoire and Clausen, 2011).

Dust capturing

Dust capturing study began in the former Soviet Union, where researchers found that during the growing season, average dust concentration in the forest was 42.2% lower than that in the open plaza (Zhang, 2007).

Sterilization

Plants can sterilize and inhibit the bacteria and other pathogenic microorganisms in their living environment to varying degrees. Garden plants as the major species in urban greening play a key role in reducing the amount of environmental harmful pathogenic microorganisms and improving the urban environment's ecological value and adding social benefits. High green coverage rate helps to reduce bacterial content in the air (Zhang et al., 1997).

Water retention

Water classification is a serious problem in China's urban drainage system. To resolve this problem, it requires a variety of ways to be applied at the same time, where reducing the water wastage is the key. Increasing the urban green area is a good approach to hold the water by the plants after the rain. Roof greening in the city basin helps to reduce the rainfall runoff and pollution load. At the same tune, the size and spatial distribution of green roof affect the quality of runoff water (Zhang et al., 2014).

Noise reduction

The noise levels of the buildings with green roof are lower compared with the ones without a vegetated roof. The plant and soil layers can absorb certain sound waves. Reduction of the noise level after application of green roof can be as high as 10 dB (Ren, 2005). Xu et al. (2004) expected a reduction of at least 3 dB for roof garden and up to 8 dB. Ni (2006) studied the impact of indoor greening on the reduction of noise annoyance level, and the result proves that the decoration through potted green plants can help to reduce the noise annoyance level of the occupants. Considering that green roofs are constructed boundary between the natural exterior and indoor environments, they generally reduce noise pollution in urban spaces arising from road, rail and air traffic (Van Renterghem and Botteldooren, 2008; Yang et al., 2012). Providing increased insulation of the roof system and by absorption of sound waves spreading over roofs (Van Renterghem and Botteldooren, 2011).

Reduction on air velocity

Roof greening can create a micro-climate over the building envelop thus affecting the convective heat transfer over the roof surface, and it can help to improve the urban climate (Wang et al., 2007).

Cooling effect

Cooling effect. Thermal performance of the green roofs is ultimately reflected on its cooling and energy-saving effects on the buildings. The cooling effect is mainly due to the water evaporation and the plants that prevent the solar radiation from hitting the roof directly. Meanwhile, because the thermal mass for the soil is large, there is an effect of temperature wave reduction, and it can also delay the outdoor temperature variation on the indoor temperature.

Energy savings

The green roofs apparently can help reduce the building energy consumption. However, typically it only has a significant impact on the rooms on the top floor. As the number of floors increases, the energy-saving effect for the whole building decreases gradually. Researchers obtained different cooling and energy saving effects for green roofs. It can be explained by the following three reasons: 1-Configurations of the green roofs are different. Small shrubs has better cooling effect than Sedum. 2-Structure of the roof and the entire building structure are different 3-The regional climatic conditions are different (Yin and Li, 2007; Li, 2007).

RESULTS AND DISCUSSION

Environmental and Ecological benefits of green roofsreduction of urban heat island, mitigation of energy demand for heating and cooling, reduction and delay of storm water runoff, improvement in air quality, replacement of displaced landscape, enhancement of biodiversity, provision of recreational and agricultural spaces, and insulation of a building for sound (Currie and Bass, 2010). Green roofs are known to retain rainwater and delay peak flow, thereby reduce the risk of flooding. There are numerous operational environmental benefits of green roofs and they can be listed as follows:

1. Enriching biodiversity in urban area
2. Cooling performance on the building and surroundings
3. Managing runoff quantity
4. Cooling and humidification
5. Carbon fixation and oxygen release

6. Storm water reduction
7. Water quality enhancement
8. Noise reduction
9. Air pollution
10. Dust capturing
11. Sterilization
12. Water retention
13. Noise reduction
14. Reduction on air velocity
15. Energy savings

REFERENCES

1) Banting, D., Doshi, H.H., Li, J., Missios, P., 2005, Report on the Environmental Benefits and Costs of Green roof technology for the city of Toronto. City of Toronto and Ontario Centres for Excellence— Earth and Environmental Technologies, Toronto.
2) Berndtsson, J.C., Bengtsson, L., Jinno, K., 2009, Runoff water quality from intensive and extensive vegetated roofs. Ecol. Eng. 35, PP 369 –380.
3) Bianchini F, Hewage K., 2012, How green are the green roofs? Lifecycle analysis of green roof materials Build Environ, 48, PP 57–65.
4) Blanusa, T., VazMonteiro, M.M., Fantozzi, F., Vysini, E., Li, Y., Cameron, R.W., 2013, Alternatives to sedum on green roofs: can broad leaf perennial plants offer better ‘cooling service’? Build. Environ. 59, PP 99–106.
5) Chen X-P, Huang P, Zhou Z-X, Gao C., 2015, A review of green roof performance towards management of roof runoff. Chin J ApplEcol, 26, PP 2581–2590.
6) Cox BK. (2010The influence of ambient temperature on green Roof R-values. Master Thesis. Portland State University.
7) Currie B, Bass B., (2010), Using green roofs to enhance biodiversity in the City of Toronto. City of Toronto Commissioned report. April.
8) Feng C., (1992), Research on the Environmental Effect of Greening. Beijing: China Environmental Science and Technology Press.
9) Fountain, M.T., Hopkin, S.P., 2004, Biodiversity of Collembola in urban soils and the use of Folsomia candida to assess soil ‘quality’. Ecotoxicology 13, PP 555–572.
10) GhaffarianHoseini A, GhaffarianHoseini A, Dahlan N, Berardi U, Makaremi N., 2013, Sustainable energy performances of green buildings: a review of current theories, implementations and challenges. Renew Sustain Energy Rev; 25, PP 1–17.
11) Gregoire, B.G., Clausen, J.C., 2011, Effect of a modular extensive green roof on storm water runoff and water quality. Ecol. Eng. 37, PP 963 – 969.
12) Hashemi SSG, Mahmud HB, Ashraf MA., 2015, Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: a review. Renew Sustain Energy Rev, 52, PP 669–79.
13) Kim, K.G., 2004, The application of the biosphere reserve concept to urban areas: the case of green rooftops for habitat network in Seoul. Ann. N. Y. Acad. Sci., 1023, PP 187–214.
14) Ko¨hler, M., Schmidt, M., Grimme, F.W., Laa, M., de Assunc_a˜oPaiva, V.L., Tavares, S., 2002, Green roofs in temperate climates and in the hot-humid tropics – far beyond the aesthetics. Environ. Manage.Health 13 (4), PP 382–391.
15) Li J., 2007, Research on the Grass Land Development Technology on a Slopping Roof. Yangzhou: Yangzhou University Press.
16) Li H, Zhao W, Gu R, et al., 1999, Effect of different types of green land in residential area on the economic value of vegetation carbon fixation and oxygen release, temperature reduction and increase in humidity. Chin J Environ Sci, 11, PP 41–44.

17) Li H., 1998, Research on the ecological benefits on five grasslands in Beijing. J China Gard; 14(4), PP 36–38.
18) Maclvor, J.S., Lundholm, J., 2011, Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate. Ecol. Eng. 37, PP 407–417.
19) Mayer H., 1999, Air pollution in cities. Atm Environ; 33, PP 4029–4037.
20) Mentens J, Raes D, Hermy M., 2006, Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landsc Urban Plan; 77, PP 217–226.
21) Nagase A, Dunnett N., 2012, Amount of water runoff from different vegetation types on extensive green roofs: effects of plant species, diversity and plant structure. Landsc Urban Plan; 104, PP 356–363.
22) Ni Y. Effect of indoor greening on the reduction of low frequency noise annoyance level. J Zhejiang ForInst 2006; 23(1), PP 112–114.
23) Niachou A, Papakonstantinou K, Santamouris M, Tsangrassoulis A, Mihalakakou G., 2001, Analysis of the green roof thermal properties and investigation of its energy performance. Energy Build, 33, PP 719–29.
24) Niu H, Clark C, Zhou J, Adriaens P., 2010, Scaling of economic benefits from green roof implementation in Washington, DC. Environ SciTechnol; 44, PP 4302–8.
25) Parizotto S., Lamberts R., 2011, Investigations of green roof thermal performance in temperature climate: a case study of an experimental building in Florianopolis city, Southern Brazil. Energy Build; 43, PP 1712–22.
26) Peng LLH, Jim CY. Economic evaluation of green-roof environmental benefits in the context of climate change: the case of Hong Kong. Urban For Urban Green 2015.
27) Razzaghmanesh M, Beecham S., 2014, The hydrological behavior of extensive and intensive green roofs in a dry climate. Sci Total Environ, 499, PP 284–296.
28) Ren L., 2005, Research on Roof Garden Design. Beijing: Beijing Industrial University Press.
29) Rowe DB., 2011, Green roofs as a means of pollution abatement. Environ Pollut, 159, PP 2100–2110.
30) Saadatian O, Sopian K, Salleh E, Lim CH, Riffat S, Saadatian E, ToudeshkiA,Sulaiman MY., 2013, A review of energy aspects of green roofs. Renew Sustain Energy Rev, 23, PP 155–68.
31) Santamouris, M., 2012, Cooling the cities-a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy. http://dx.doi.org/10.1016/ j.solener.2012.07.003.
32) Schrader, S., Boning, M., 2006, Soil formation on green roofs and its contribution to urban biodiversity with emphasis on Collembolans. Pedobiologia 50, PP 347–356
33) Speak AF, Rothwell JJ, Lindley SJ, Smith CL., 2012, Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atm Environ; 61, PP 283–293.
34) Teemusk A, Mander U., 2007, Rainwater runoff quantity and quality performance from a greenroof: the effects of short-term rain events. EcolEng, 30, PP 271-277.
35) Van Renterghem T, Botteldooren D., 2011, In-situ measurements of sound propagating over extensive green roofs. Build Environ, 46, PP 729–738.
36) Van Renterghem T, Botteldooren D., 2008, Numerical evaluation of sound propagating over green roofs. J Sound Vib, 317, PP 781–99.
37) Vijayaraghavan K, Joshi UM, Balasubramanian R., 2012, A field study to evaluate runoff quality from green roofs. Water Res; 46, PP 1337–1345.
38) Wang D, Di H., 1998, Garden greening and human environment. J China Gard, 4, PP 9–12.
39) Xu P, Che W, Li J., 2004, Analysis on the effect of environmental benefits by green roofing. Chin J Environ Prot; 7, PP 41–44.
40) Yang HS, Kang J, Choi MS., 2012, Acoustic effects of green roof systems on a lowprofiled structure at street level. Build Environ, 50, PP 44–55.
41) Yang J, Yu Q, Gong P., 2008, Quantifying air pollution removal by green roofs in Chicago. Atm Environ; 42, PP 7266 –7273.

42) Yang S., 1996, Research on the carbon oxygen balance effect by urban greening. Chin J Urban Environ Ecol, 9(1), PP 37–39.
43) Yin L, Li S., 2007, Temperature character of roof greening on low energy demo building of Tsinghua University. SciSilvae Sin, 43(8), PP 143–147.
44) Zhang W., 2007, Research on Green Building Architecture–Example from Shanghai City. Wuhan: University of Huazhong Agriculture Press.
45) Zhang X, Gu R, Li Y, Li H., 1997, Impact of residential green lands on the bacterial level in the atmosphere. J China Floricult Flower Gard; 13(2), PP 57–58.
46) Zhang J, Wang S, Li X, Yu H, Hao Y., 2014, Impact of the popularity in green roofs on the quantity and quality of in urban areas. Chin J ApplEcol, 7, PP 1–8.
47) Zhou Y, Clarke L, Eom J, Kyle P, Patel P, Kim S, et al., 2014, Modeling the effect of climate change on U.S. state-level buildings energy demands in an integrated assessment framework. Appl Energy; 113, PP 1077–88.
48) Zhu N, Li M, Cha Y., 2002, Analysis on the ecological functions of green lands in Harbin. Chin J ApplEcol; 13(9), PP 1117–1120.