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MITIGATING CLIMATE CHANGE THROUGH GREEN ROOF IMPLEMENTATION: A REVIEW OF SIGNIFICANT LITERATURE

Wan Zuriea Wan Ismail and Mat Naim Abdullah

Universiti Teknologi Malaysia, Johor, Malaysia

ABSTRACT

Climate change is a threat to the world. Problems resulting from climate change such as global warming, floods, environmental pollution, high carbon dioxide emissions, and loss of biodiversity may be solved by the implementation of green roofs. Green roof benefits the environment, economy, aesthetics, and recreation and are proven effective through studies conducted from around the world. This paper reviews the existing literature on green roof benefits and performance and specifically focuses on their potential to address climate change issues. A review of significant literature on green roof performance and benefits is the method of this study. From the review, it is proven that green roofs have the potential to reduce problems related to climate change. The depth of a green roof substrate is a key factor that can optimize potential benefits. Thus, intensive types of green roofs provide significant contribution towards reducing storm water runoff; mitigate the urban heat island effect and pollution; increased biodiversity; and carbon sequestration. Local research is highly encouraged in mitigating climate change because the optimal performance of green roofs is subject to local climate and conditions.

Keywords: green roof, climate change, meta-analysis, environmental, biodiversity

INTRODUCTION

By 2050, the world population is estimated to be 9.6 billion and 66% of the world's population is projected to be urban (Nations U. General Assembly. 2015; 50071, August). As people live in cities, cities are expected to experience rapid urbanization that will result in a scarcity of land in major cities and urban areas will be confronted with environment destruction, such as global warming, environmental degradation, pollution, and resource depletion, among others (Felix N. Hammond, Kwasi Baffour Awuah Gyau SYA, 2012). Environmental problems that are related to climate change remain the core urban challenge (IPCC, 2014). The reduction of green areas in cities is a contributing factor to the climate change phenomena because there is less area available to absorb carbon dioxide (CO2) emissions and other anthropogenic greenhouse gas emissions (Booth CA, Hammond FN, Lamond J, Proverbs DG, 2012). Green space is not limited to ground areas only, unused building's rooftop provides potential sites for roof greenery. Left bare roofs contribute to urban heat island effect and can increase in energy consumption (Jim CY, 2015). Green roofs are well recognized throughout the world as an effective strategy to solve environmental problems and space scarcity. The benefit of green roofs has been proven through many studies conducted across the region. The potential benefits that can be offered based on local climate and context will be explored. Therefore, this article reviews the existing literature on green roof benefits and performance. The environmental benefits of green roofs will be reviewed because it is a strategy that deals with climate change.

METHODS

This paper presents a review of the significant literature from 2005–2016. Literature relating to green roof benefits and performance were obtained from ISI Web of Science, Universiti Teknologi Malaysia's online databases, Google Scholar, and other websites using the following search terms: 'green roofs', 'green roofs benefits', 'green roofs performance', and 'green roofs review'. Additionally, guidelines and books related to green roofs are also reviewed. Through initial review, research papers and information are grouped according to specific performance.

The structure of this articles is as follows: Section(s) 1, 2, and 3 consist of the introduction, our research methodology, and green roofs to provide fundamental information. Section 4 concentrates on green roof benefits and performance regarding environmental improvements. Each green roof benefit and performance in the literature will be reviewed separately in different sections. This section will highlight green roof performance that reduces storm water runoff, mitigates the urban heat island effect, air pollution, increases biodiversity, and carbon sequestration. The main findings for the optimization of green roof potential towards mitigating climate change will be highlighted. Our conclusions and future research direction will complement this study.

GREEN ROOFS

Green roofs have a remarkable reputation in Germany, the United States, Canada, other European countries, as well as in Singapore, Japan, and Hong Kong. These countries are leading on the implementation of green roofs in their environment. Currently, green roof implementations are increasing accepted and appreciated by industry. Green roofs can be defined as a vegetated layer on top of a roof structure that has certain components and depths (Townshend D, Duggie A., 2007). Green roofs can be classified as extensive, intensive, and semi-intensive green roofs. These categories are determined by depth, component, and maintenance required (Raji B, Tenpierik MJ, van den Dobbelsteen A., 2015 and Vijayaraghavan K., 2015). Green roofs, in addition to their aesthetic value, provide an abundance of benefits. Generally, green roof benefits can be categorized as economic, environmental, amenity, and aesthetic benefits (Townshend D, Duggie A., 2007),

ENVIRONMENTAL BENEFITS

Many studies have been conducted to assess the benefits and performance of green roofs at the building, site, or city scale. Green roof implementation should be emphasized as a strategy to encounter environmental issues (Khadaijah Hussin & Maryanti Mohd Raid, 2013). Most of these studies regarding performance are focused on environmental and economic assessments (Belussi L, Barozzi B, 2015). According to the studies, green roofs can contribute towards carbon reduction (Getter KL, Rowe DB, Robertson GP, Cregg BM, Andresen JA. 2009 and Ismail A, Abdul Samad MH, Rahman AMA, 2012 and Luo H, Liu X, Anderson BC, et al., 2014), temperature reduction ([Tsang SW, Jim CY, 2011 and Jaffal I, Ouldboukhitine S-E, Belarbi R, 2011), a reduction of rain water run-off (Zhang Q, Miao L, Wang X, et al. 2015 and Shin E, Kim H, 2015), reductions in the urban heat island effect (Jim CY, 2015 and Razzaghmanesh M, Beecham S, Salemi T., 2015 and Gagliano A, Detommaso M, Nocera F, Evola G., 2015), reduction in air pollution (Rowe DB, 2010 and Yang J, Yu Q, Gong P., 2008), and increased biodiversity (Cook-Patton

SC, Bauerle TL., 2012 and Williams NSG, Lundholm J, Scott MacIvor J., 2014). Research related to the local conditions are highly encouraged since each country possesses different climates and urban conditions (Vijayaraghavan K., 2016).

Storm Water Run-off Reduction

Green roof performance on storm water management received the most attention from researchers and is most frequently cited in academic journals. Many researchers have conducted studies regarding the contribution of green roofs on storm water management (Zhang Q, Miao L, Wang X, et al., 2015 and Shin E, Kim H., 2015 and Sultana N, Akib S, Aqeel Ashraf M, Roseli Zainal Abidin M., 2015 and Nawaz R, McDonald A, 2014 and Czemiel Berndtsson J., 2009). Delayed rain water run-off can reduce the risk of urban flooding and can also provide a source of water when there are shortages in the water supply. Green roofs can prevent polluted water from impervious surface run-off into water ways (Getter KL, Rowe B., 2006). Zhang et al., (2015) conducted measurements through experimental plots and indicated that green roofs can effectively retain storm water run-off with an average retention of 77.2%.

Similar findings from Nawaz et al., (2015), which confirmed an overall mean water run-off retention of 66% from green roofs. Shin & Kim (2015) showed that a smaller average retention of 20%. The authors have claimed that green roof contribution was not significant as claimed by other researchers. The different results are caused by many factors such as different green roof designs, study duration (Czemiel Berndtsson J., 2009), green roof properties, and rainfall characteristics (Nawaz R, McDonald A, 2014). Sultana et al., (2015) found that the average quality of rain water run-off on green roofs complied with Interim National Water Quality Standards (INWQS) and the Water Quality Index (WQI). This stored water can be used for toilet flushing and watering gardens; however, water treatment is needed to make it potable. Soil substrate for green roofs plays a vital role as it will affect the quality of water (Zhang Q, Miao L, Wang X, et al., 2015) and a deeper substrate retains more water (Nawaz R, McDonald A, 2014). Vijayaraghavan (2016) has summarized the important factors that influenced the quality of run-off as vegetation and substrates played a significant role.

Getter & Rowe (2006) indicated that water retention depends on substrate depths, composition, plant species, and weather factors such as intensity and duration of rainfall. Intensive green roofs are better than extensive green roofs in terms of storm water management since they are deeper (Sadat S, Hashemi G, Bin H, Aqeel M., 2015). Based on the aforementioned studies, green roofs play a significant role in storm water management. Future studies should be based on specific climates (Nawaz R, McDonald A, 2014).

Urban Heat Island Effect (UHI)

Higher surface or air temperatures in city centers when compared to the surrounding rural or suburban area is referred to as the urban heat island (UHI) effect (Razzaghmanesh M, Beecham S, Salemi T., 2015 and Akbari H, Cartalis C, Kolokotsa D, et al., 2015). UHI study has gained attention from researchers as green roofs are a leading technology to mitigate the impact of global warming apart from cool roofs and reflective materials (Akbari H, Cartalis C, Kolokotsa D, et al., 2015). Changing the urban environment and applying low-albedo materials that contribute to temperature increases and are key factors that result in the UHI phenomenon (Razzaghmanesh M, Beecham S, Salemi T., 2015). Wong & Yu (2005) studied green area contribution towards temperature reduction in well planted areas and the central business district (CBD) in Singapore and found a difference in temperature of 4.01°C. Similar studies done by Susca, Gaffin, & Dell'osso (2011) at four areas in New York City, found an average of 2°C difference of temperature between the maximum and minimum vegetated areas. A maximum 0.8°C reduction of air temperature and mean radiant temperature if urban greening is increased at 10% (Wang Y, Berardi U, Akbari H., 2015).

Increased vegetation density in urban areas such as green roof application help mitigate UHI as cooling effects by the plants can reduce ambient air temperature of up to 4.2°C (Lee JS, Kim JT, Lee MG., 2014). Increased albedo effects and transpiration process in plants will help temperature reduction and the addition of 30% green roof space can reduce energy consumption by 2.57 (/m2/day (Razzaghmanesh M, Beecham S, Salemi T., 2015). In Malaysia, a few studies have addressed green roof potential towards temperature reduction and performance that will help to mitigate UHI (A. Shaharuddin MHN and MJY., 2007 and Asmat I, Muna Hanim AS, Abdul Malek AR., 2008 and Mohd P, Bin H., 2009). Shaharuddin (2007) found temperature reduction of up to 4°C with an extensive green roof when compared to a flat bare roof. The effect of green roof also affected the reduction of internal temperature between 4–5°C during the day and 2°C at night (Mohd P, Bin H., 2009). Asmat et al., (2008) discussed the plants and substrates that effect thermal reduction and performance with green roofs. These studies have confirmed the positive effects of green areas in mitigating UHI and will reduce the problem of global warming. Deeper green roof systems provide constant thermal distributions (Razzaghmanesh M, Beecham S, Salemi T., 2015). Additionally, Speak, Rothwell, Lindley, & Smith (2013) stressed the importance of green roof plant maintenance as damaged green roofs will affect their cooling properties and result in higher maintenance involved.

Air Pollution Reduction

Green roofs can contribute to the reduction of air pollution because trees as a main component of green roofs, have a major impact on reducing air pollution (Currie BA, Bass B., 2008). Plants can filter out particulate matter and gaseous pollutants in the air through leaf stomates. Air pollutants in urban areas are a major threat to human health (Yang J, Yu Q, Gong P., 2008). Health problems such as respiratory distress and decreased lung functions are related to air pollution, which makes the reduction of air pollution crucial (Getter KL, Rowe B., 2006). Yang et al., (2008b) have conducted a study to quantify the level of pollution removal by intensive green roofs in Chicago by using a dry deposition model. The result indicated that in 1 year, 19.8 ha of green roofs can remove a total of 1,675 kg of air pollutants. If all rooftops in Chicago were covered with intensive green roofs, the amount of pollutants removed would increase to 2,046.89 metric tons. Currie & Bass (2008) concluded that intensive green roofs can play a significant role in improving air quality. Intensive green roofs are proven to be more effective than extensive in mitigating air pollution (Currie BA, Bass B., 2008 and Rowe DB., 2010), but there are higher costs involved. With the implementation of green roofs in urban areas, air pollution can be reduced. Specific research on green roof contributions in reducing air pollution is gaining less attention from the researchers compared to research on plants (Rowe DB., 2010).

Increased Bio Diversity

Green roofs, although not equivalent to natural habitats, can contribute to mitigating the loss of ecosystems in urban areas. Green roof potential in conserving habitats for birds is highlighted by Canero, R. Fernandez and Redondo (2010) and Marinelli (2006). Marinelli (2006) observed the ability of green roofs to conserve fully protected and rare breeding birds such as the black redstart. Additionally, green roofs are also promising for bee conservation sites in urban areas. MacIvor, Ruttan, & Salehi (2015) found the abundance of bee species at sedum plant type green roofs. Being a highly mobile insect, bees are acknowledged to gain greater benefits from green roofs than other insects. A field measurement that was conducted at three different types of green areas at Chicago region by Tonietto, Fant, Ascher, Ellis, & Larkin (2011) indicated that native bees are present on green roofs, although with lower presence and diversity compared to their natural habitats. A similar finding was noted by MacIvor & Lundholm (2011) through field measurement at five intensive green roofs and nearby ground habitats. The authors highlighted green roof insects richness and abundance are likely to be greater at ground level sites; however, green roofs provide habitats for a wide variety of insects including rare species.

In the urban landscape, green roofs can act as habitats for native plants by creating new green space on top of the building. A field study at 115 green roofs in Northern France found 176 colonizing vascular plant species that were dominated by native plant species at 86% (Madre F, Vergnes A, Machon N, Clergeau P., 2014). Benvenuti (2014) highlighted the relationship between wildflowers on green roofs with pollinators such as bees. This finding demonstrates that green roofs can be part of habitats for wild biodiversity. Several authors have highlighted this approach to improve green roof biodiversity. Green roof substrates should be designed with a range of depth to increase more species (Bates AJ, Sadler JP, Mackay R., 2013). The substrate depths is the most important part in encouraging plant growth, survival (Brown C, Lundholm J., 2015), and species richness (Marinelli J., 2006 and Madre F, Vergnes A, Machon N, Clergeau P., 2014). Larger green space (Tonietto R, Fant J, Ascher J, Ellis K, Larkin D., 2011), increase plant mixtures (Lundholm JT., 2015), and microclimates (Brown C, Lundholm J., 2015), will also affect green roof performance.

Carbon Sequestration

In mitigating climate change, green roofs can play a significant role as an effective strategy to reduce carbon dioxide. Green roofs have the potential to mitigate carbon dioxide in the following ways: 1. through photosynthetic uptake during daytime; and 2. the storage of carbon in the form of stems, branches, or roots (Weissert LF, Salmond J a., Schwendenmann L., 2014). Green roof ability to sequester carbon is discovered from the use of field measurements, chamber experiments, numerical simulations, and literature reviews. Getter et al., (2009) have quantified carbon storage potential at 12 extensive green roof projects. Their findings indicated that the entire green roof system sequestered 375gCm^{-2} in above and below ground biomass and substrate organic matter. It is also noted that due to the types of species used and shallow depths, extensive green roofs basically cannot sequester a large amount of carbon dioxide. Ismail et al., (2012) found that 1 pot of Ipomoea pes-capre located on a flat roof indicated the amount of carbon dioxide uptake was estimated at 48.19kg carbon per year (0.048 tons carbon dioxide per year); and through implementation of the green roof concept, more carbon is expected to be sequestered. Absorbing carbon dioxide in a day time, plants can reduce the carbon dioxide concentration in the environment (Hong T, Kim J, Koo C., 2012 and Li J, Wai OWH, Li YS, et al., 2010).

The rate of carbon absorption at day time is greater than carbon emission rates at night by plants and it was estimated that green roofs can lower the carbon concentration in a nearby region in Hong Kong up to 2% (Li J, Wai OWH, Li YS, et al., 2010). Luo et al., (2015) found that to optimize green roof carbon sequestration by using two different substrates. A mixed sewage sludge when compared to local natural soil can sequester more carbon at an average of 6.47kg Cm^{-2} yr $^{-}$1 in the combined biomass and substrate organic matter. It showed that the type of substrate plays a significant role in carbon sequestration.

Whittinghill, Rowe, Schutzki, & Cregg, (2014) found that to quantify carbon sequestration at nine ground level ornamental landscapes and three sedum and prairie green roofs. This finding indicated that both landscape systems have the ability to sequester carbon but less carbon was quantified on green roofs. The depth of the substrate should be considered to optimize green roof ability to sequester carbon. Whittinghill et al., (2014) also highlighted the consideration on maintenance aspect that will affect the net carbon sequestration at green roofs. All research showed that green roofs are a promising strategy for combatting climate change through carbon sequestration by plants and substrates. Even though the amount of sequestration is lower than ground level, but with appropriate consideration, it can be optimized.

RECOMMENDATION AND FUTURE DIRECTION

Through this review, the researchers have assessed green roof environmental benefits and performance can potentially mitigate climate change. Green roof implementation among established countries can be a point of reference but it must accommodate the local environments and climates. As green roofs are promising strategy for land scarceness and mitigating environmental problems, the implementation of green roofs emphasized the environmental aspect is noteworthy. Intensive green roofs are more promising in mitigating climate change since deeper substrates will influence green roofs performance. Therefore, green roofs are carefully planned on environmental improvement must be studied. This article is a concept paper. The author aims to pursue research on green roof strategy towards carbon sequestration in Malaysia. This is aligned with the National Agenda since Malaysia has pledged its commitment to confront the climate change.

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