GREEN ROOFS: ENHANCING ENERGY AND ENVIRONMENTAL PERFORMANCE OF BUILDINGS

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ABSTRACT

The increase of peak and energy demand during the cooling and warming seasons is becoming a critical issue, as well as air pollution and the intensification of the urban heat island effect. Green roof has been identified as a solution to mitigate the above-mentioned issues and implement principles of sustainable development in building features. There are many operational and environmental benefits of green roofs such as enhancement of buildings' energy efficiency, improvement of storm water management, decrease of urban heat island effects, decline of air and noise pollutions, and increase of urban wild life habitats. This paper discusses the current literature and evidence for the benefits of green roofs while highlighting the influences of green roofs on buildings' energy efficiency. Researches conducted on the potential benefits of green roofs have proved that they can enhance energy performance of buildings in summer and winter as well as improving indoor air temperature.

KEYWORDS: Green roofs, Building energy efficiency, urban heat island effect, air pollution

1 INTRODUCTION

After Industrial Revolution, due to urbanization and industrialization of human civilization more population moved to urban areas and urban spaces expanded much faster. Growing the population forced developers to construct more buildings and therefore, more green areas were destroyed and converted to build environment (Alexandria and Jones, 2008). Rise of constructed areas without enough vegetation has changed the flow of energy and material through urban ecosystem which causes many environmental problems. As roof surfaces of the building comprises of 20–25% of the total urban surfaces, hence, they can successfully be used to decrease the air and surface temperature of the urban areas (Akbari et al., 2003). Green roof systems are living vegetation installed on the roofs and could reduce several negative impacts of buildings on local environment.

Green roofs can be traced back through time beginning with the Hanging Gardens of Babylon. Constructed around 605 BC (Oberndorfer et al., 2007). More recently, the relatively high industrialization and dense populations in European countries have led them to develop a strong environmental consciousness many years ahead of North Americans. Europeans now have 40 years of technical and practical experience with green roof construction and maintenance. In Germany, one out of every seven new roofs is green and therefore, this country has been known as a world leader in green roof technology (Metro Vancouver, 2009). Although green roofs are primarily more expensive to construct than conventional roofs, they can be more economical over the life duration of the roof because of the energy saved and the long life of roof membranes (Porsche and Köhler 2003).

This paper reviews the current literature and evidence for the positive impacts of green roofs on the environment with especial focus on improving buildings energy consumption.

2 GREEN ROOFS AND THEIR FUNCTIONS

A modern green roof is a conventional roof with a waterproofing membrane which layers of drainage and vegetated are installed on top of it. A green roof generally consists of five constituents from the bottom to the top: a roof support, a roofing membrane (membrane protection and roof barrier), isolation, a drainage layer, a growing media and vegetation (Ouldboukhitine, et al., 2011). A typical cross-section of a green roof is illustrated in Figure 1. Typically, two types of green roof are defined, extensive and intensive.

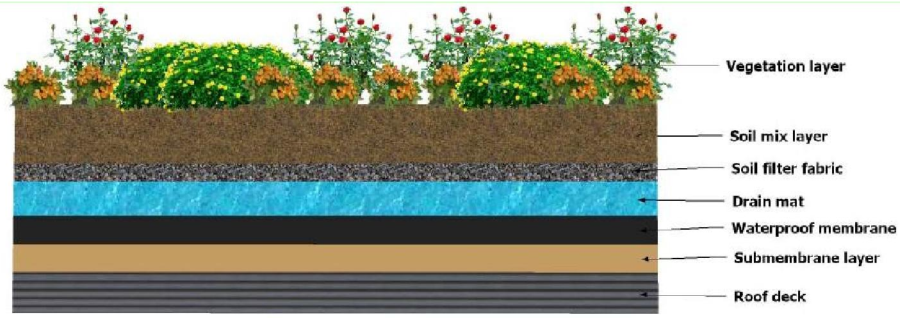

Figure 1. Typical cross-section through a green roof.

Intensive green roofs are often designed as public places and generally require substrate depths between 150 and 1200mm. Therefore, they may comprise of trees and shrubs similar to landscaping found at ground level (Snodgrass and McIntyre, 2010). Intensive roofs are more expensive than extensive roofs because of the need for more structurally sound building in order to support the weight. In contrast, an extensive green roof needs a growing medium between 50 and 150mm to support plant life. This confines the size of plants that can be used on the roof, thus, confining the weight of the green roof on the building structure (Molineux et al., 2009; Bianchini and Hewage, 2012). In comparison with intensive roofs, extensive green roofs are more widely used due to their low costs, light weight, shallow soil layer and independence from slight maintenance. There is a third type of green roofs called semi-intensive. Semi intensive green roof is a combination of extensive and intensive, nevertheless, the extensive type needs to represent 25% or less of the total green roof's area (Yang et al., 2008).

3 ENVIRONMENTAL BENEFITS OF GREEN ROOFS

There are a lot of environmental benefits of green roofs. In addition to creation of a pleasant environment, green roofs provide a lot of benefits in comparison with conventional roofs. Their benefits can be listed as fellow: improvement of storm water management, mitigation of Urban Heat Island Effects, decrease of air and noise pollution, and increase of urban wild life habitats (Mentens et al, 2006; Yang et al., 2008; and Li et al., 2010).

3.1 Improvement of Storm Water Management

Urban development is increasing hard and nonporous surfaces in cities, bringing about decrease in storm water infiltration (Berndtsson, 2010). Green roofs are ideal for storm water management as they can store water during rainfall, postponing runoff until after peak rainfall and returning precipitation to the atmosphere through evapotranspiration (Mentens et al. 2005, Moran et al. 2005).The depth of substrate, the type of plant, the slope of the roof, and rainfall patterns affect the rate of runoff (Dunnett and Kingsbury 2004, Mentens et al. 2005, VanWoert et al. 2005b).

Several studies have been conducted on the impact of green roofs on storm water management. Some of these studies show, for roofs with more than 10 cm of substrate, rainfall retention of particular green roofs was 66% to 69% (Moran et al. 2005). For shallower substrates rainfall retention is various between 25% and 100% (Beattie and Berghage 2004). By green roofs, annual total building runoff can be decreased as much as 60% to 79% (Köhler et al. 2002). In addition, overall regional runoff could be reduced about 2.7%, if only 10% of roofs were green (Mentens et al. 2005). Generally, shallower substrate and steeper slopes increase total runoff (Mentens et al. 2005; Villarreal and Bengtsson, 2005, Oberndorfer et al., 2007). Figure 2 shows the results of a study conducted on the impacts of green roofs on storm-water runoff retention.

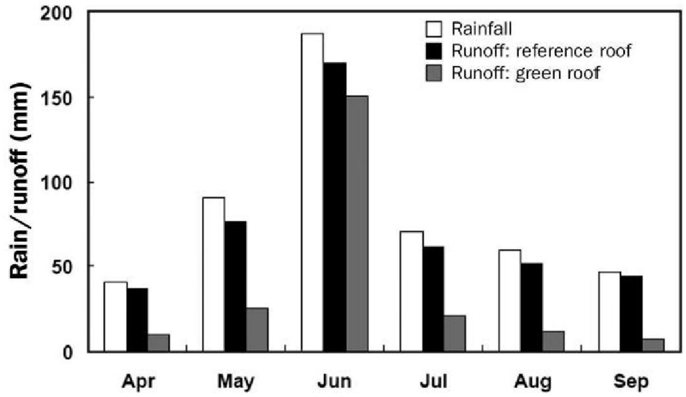

Figure 2.” Storm-water runoff retention in a green-roof test plot in Ottawa, Ontario, Canada, in 2002. (Values are sums of total runoff retained. The green roof had 15 centimetres of growing medium and was planted with lawn grasses; it was compared with an adjacent conventional roof of the same size.” (Oberndorfer et al., 2007: 827)

Although the amount of collected water from rain is important, the quality of that water is very important as well. Some studies show that despite of the roofing system, current roofing materials add chemicals or metal compounds to the runoff water. Mendez et al. (2005) and Nicholson et al. (2010) confirmed that every artificial roofing material influence the runoff, nevertheless, green roofs add less chemical compounds to the water.

3.2 Mitigation of Urban Heat Island Effects

The Urban Heat Island (UHI) is the characteristic warmth of urban areas compared to their (non-urbanized) surroundings. Figure 3 illustrates UHI phenomenon. The change of the land surface in the urban area and replacement of vegetation by expansively built surfaces (typically paved roads and buildings surfaces) is the main reasons of forming UHI. Urban surfaces bring about high solar absorption, high impermeability and favourable thermal properties for energy storage which increase air temperature in urban areas (Voogt, 2002).

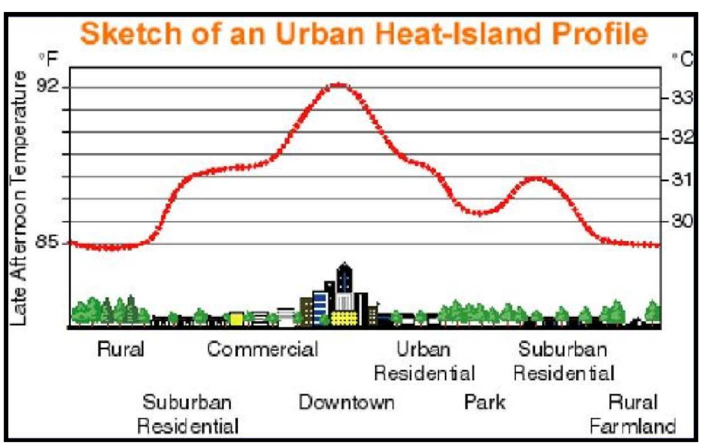

Figure 3. Urban Heat Island Effect phenomenon

Green roofs have been proved as a significant means of diminishing Urban Heat Island Effect with the help of removing heat from the air through evapotranspiration of the plants and reducing heat absorb, which leads to a decrease of the temperatures of the roof surface and the surrounding air. Furthermore, by providing a cooler surface at roof level, the green roof reduces the need for air conditioning during periods of higher than normal temperatures and consequently the anthropogenic heat could reduce. The combined effect is to mitigate the Urban Heat Island Effect (Susca et al. 2012 and Alexandria and Jones, 2008). The impacts of green roof on mitigating UHI have been examined in some research. Rosenzweig et al. (2006) found that greening 50% of New York City rooftops would reduce the average surface temperature by an estimated 0.1–0.8°C. Banting et al. (2005) determined that greening 30–100% of available rooftops in Toronto, Canada, could reduce average temperatures by 0.5–2°C.

3.3 Reduction of Air Pollution

Air pollution is a major hazard to human health particularly in the urban environment. Green roofs contribute to reduce air pollution in two ways: (1) mitigating UHI and improving buildings energy consumption decrease heating and air conditioning demand, therefore, less carbon dioxide is released from power plants; and (2) plants' photosynthesis sequestrate carbon dioxide from the air and store it as biomass (Mayer, 1999; Getter et al., 2009; Bianchini and Hewage, 2012).

There are some studies regarding the influence of green roofs on air pollution. In Chicago, a big-leaf dry deposition model was used by Yang et al. (2008) in order to calculate the air pollutants removed by green roofs. The result showed that green roofs could remove a large amount of air pollution in Chicago. Moreover, in Toronto, Currie and Bass (2008) used the Urban Forest Effects (UFORE) which is a dry deposition model developed by the USDA Forest Service to study the effects of green roofs on air pollution. The model quantified levels and hourly reduction rates of NO_2, SO_2, CO_2, PM_{10} (particles of 10 mm or less) and ozone as well as their economic value. The results showed in terms of reducing pollution, intensive green roofs with trees and shrubs are more constructive; however, extensive green roofs can still play a complementary role with regards to air quality.

3.4 Reduction of Noise Pollution

High noise levels are usually a difficulty in urban areas, particularly in enclosed spaces bordered by tall buildings, long street canyons, and near industrial areas and airports (Rowe, 2011). Vegetation in combination with the growing substrate will absorb sound waves to a greater degree than a hard surface (Rowe, 2011). Therefore, converting conventional roofs to green roofs could reduce sound pressure from roads and other sources in urban areas

The impacts of intensive and extensive green roofs on sound pressure were studied by Van Renterghem and Botteldooren (2008). They found a linear relationship between the percentage of roof space covered with vegetation and the reduction in sound pressure on the opposite side of the building from the noise source or street canyon. When sound waves enter the pore space the numerous interactions with the substrate elements of green roofs attenuate them. Noise reduction could be enhanced by increasing substrate depth up to 15-20 cm. Roofs with deeper substrate layers provided no further benefit. There are many variables that affect noise attenuation such as: the width-height ratios of the canyons, façade absorption, diffuse reflection, and building-induced refraction of sound (Van Renterghem and Botteldooren, 2008). "On the inside of a building noise levels also depend on façade insulation, the sound pressure level outdoors, and whether windows are open or closed" (Rowe, 2011: 2106).

3.5 Habitat Preservation

Green roofs provide spiders, beetles, butterflies, birds and other invertebrates with food, habitat, shelter, and nesting opportunities (Brenneisen, 2003; Gedge, 2003). Some studies are being conducted on green roofs in Europe and Chicago, in order to find their unique ability to create composed, practicable sanctuaries for rare species. In these studies green roofs has been recognized as an elevated urban ecosystem which is able to provide a unique protection from grade level predators, traffic noise and human intervention (Federal Technology Alert, 2004). These findings have encouraged local and national conservation organizations to advance green roofs, especially in the United Kingdom and Switzerland (Oberndorfer et al., 2007).

4 GREEN ROOFS AND BUILDINGS ENERGY PERFORMANCE

In addition to above-mentioned environmental benefits, green roofs improve the energy efficiency of the building envelope and decrease buildings' energy demand on space conditioning through reducing heat flux and solar reflectivity, improving insulation values, soil thickness, evapotranspiration and indoor air temperature.

4.1 Reduction of Heat Flux and Solar Reflectivity

In summer, the temperature of the area beneath a green roof is only 27 ◦C while the equal exposed area of a black roof can reach 80 ◦C (FiBRE, 2007). There are two factors which make green roofs cool: (1) latent heat loss and (2) enhanced reflectivity of incident solar radiation. "The ratio of total reflected to incident electromagnetic radiation is defined as albedo" (Castleton, 2010:1583). Some studies found out that green roofs could cool as efficient as the brightest possible white roofs, with the same albedo of 0.7–0.85, in comparison with the typical 0.1–0.2 of a bitumen/tar/gravel roof (Gaffin, 2005; Castleton, 2010).

In Toronto, Canada, Lui and Minor (2005) conducted a study on the impacts of greenery on heat gain and heat loss of roofs. They compared three roofs: two green roofs with 75-100mm of light weight growing medium and a reference roof of the same type (steel deck with thermal insulation above), without greening. This research indicated that green roofs reduced the heat gain by an average of 70–90% in the summer and heat loss by 10–30% in the winter. Some thermocouples were sited at different depths throughout the structure, involving inside the beneath room. They found that green roofs decreased the roof membrane peak temperatures and postponed it from about 2 p.m. to 7 p.m. The temperature profiles comparing the reference roof and typical green roofs are illustrated in Figure 4.

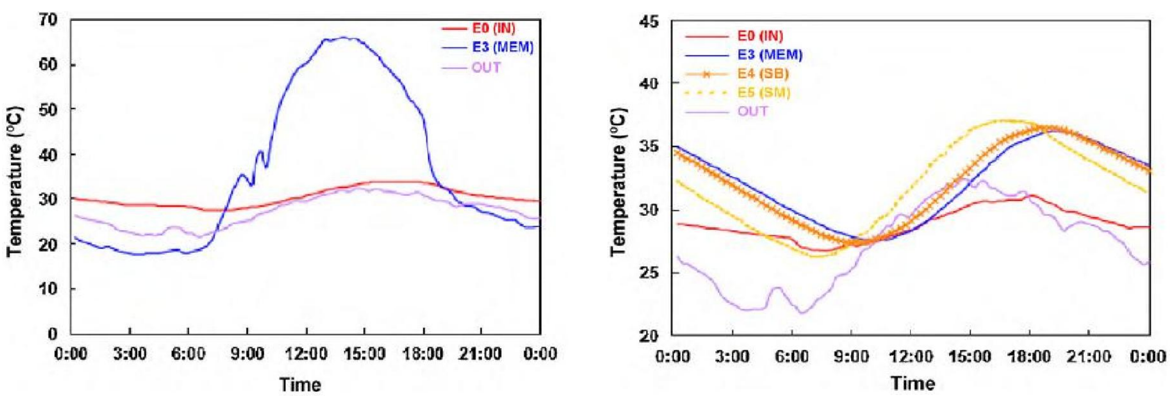

Figure 4. Summer temperature profiles for a reference roof and green roof respectively. The lines on the graphs represent the temperature recorded by the thermocouples where E0 was placed inside, E3 under the waterproof membrane, E4 under the growing medium, E5 in the middle of the growing medium, and OUT recording the outside temperature (Castleton, 2010).

As shown, in summer, the thermal mass effect of the green roofs brought about the temperature delay. Therefore, the peak indoor temperature is slightly put off and the general temperature is slightly lesser than that of reference roof. In winter, the temperature of internal space beneath the green roof was cooler in the morning and evening in comparison with reference roof; however, it was attributed to the different operational needs of the rooms under each roof. In this study, the differences in operational conditions of the room were not mentioned in summer. It was indicated that reference roof has a slightly higher heat loss during the day thus green roofs have increased heat loss through the roof (Castleton, 2010).

4.2 Enhancement of Indoor Temperature

Solar absorption through the roof brings in the higher air temperatures of indoor environment. Consequently, greater air conditioning is used and therefore, more energy is consumed. A green roof prevents its surface from heating up by creating a buffer zone between the roof and the sun's radiation and shading the roof. Jaffal et al (2012) conducted a research on the impact of green roofs on indoor air temperature and cooling and heating demand. They used a model of green roof thermal behavior which was coupled with a building code to allow the evaluation of green roof foliage and soil surface temperatures. Simulations were conducted for a single family house with conventional and green roofs in a temperate French climate. In the summer, the fluctuation amplitude of the roof slab temperature was found to be reduced by 30 ^{o}C due to the green roof. They concluded that in summer the green roof decreased indoor air temperature by 2 ^{o}C, and reduced the annual energy demand by 6%.

4.3 Improvement of Insulation

A green roof could reduce annual building energy consumption through enhancing insulation properties of it. In addition to decreasing the heat gain of the building in summer and heat loss from the building in winter, a green roof helps internal temperatures to stay stable year round by adding thermal mass. Nichaou et al. (2001) determined how a green roof with different degrees of existing insulation could improve buildings energy consumption. In this study, they considered two buildings in Athens with similar insulation properties but one with a green roof. The internal temperatures of these buildings were recorded for three days in July. Without a green roof, the internal air temperature was higher than 30 ◦C for 68% of the period; however, with a green roof, this was just for 15% of the period. Daily mean, maximum and minimum temperatures were recorded 2, 3 and 1 ◦C lower respectively.

4.4 Soil Thickness and Moisture Content

Leaf foliage and soil media are two main factors which impact the solar radiation that reaches the roof deck. If the foliage density of an especial plant is more extensive, the heat flux through the roof decreases more (Del Barrio, 1998; Theodosiou, 2003) and as a result there will be more reduction in the surface temperatures (Wong et al., 2003). Moreover, the rate of evapotranspiration is increased through a dry environment and faster wind speed which consequently aid the absorbance of solar radiation by plants (Theodosiou, 2003). Feng et al. (2010) used a mathematical model to determine that for a typical summer in China, 58% of the heat from a green roof was lost by evapotranspiration, 30.9% long wave radiative exchange, with 1.2% stored or transferred to the room below.

In addition to foliage, the thermal properties of soil also influence heat transfer, especially for green roofs and, hence, it could be effective on buildings energy consumption. Sailor et al. (2008) evaluated eight distinct samples of green roof soil media with different quantities of pumice, expanded compost, and sand. They explored that thermal properties differed considerably as a function of composition and moisture content. For dry samples, thermal conductivity and specific heat capacity had lower ranges (0.25– 0.34 W/(m K) and 830–1123 J/(kg K), respectively) compared to a situation in which water was added (0.31–0.62 W/(m K) and 1085–1602 J/(kg K), respectively). As surface soil moisture increased, Albedo reduced; while thermal emissivity continued to be relatively constant regardless of moisture content. Results declare that moisture content — both bulk moisture and surface moisture — need to be incorporated into building energy modeling of green roofs.

5 CONCLUSION

Many comprehensive environmental problems have occurred in modern cities. Green roofs are considered to be an effective contribution to the resolution of several environmental problems at the building and urban levels. In addition to the creation of a pleasant environment, green roofs offer several benefits in comparison to conventional roofs. These include improving storm water management by reducing runoff and improving water quality, mitigating Urban Heat Island Effect through evapotranspiration and reducing heat absorb, as well as reducing air and noise pollution, and increasing urban biodiversity by providing habitat for wildlife. In addition to these environmental benefits, green roofs are effective on enhancing building energy performance through reducing of heat flux and solar reflectivity, enhancing of indoor temperature, improving of insulation, and soil thickness and moisture content. Research shows that, in summer, a green roof could decrease indoor air temperature by 2 ^{o} C, and reduce the annual energy demand by 6%. Moreover, it has been proved that green roofs are also effective in winter.

Assessing and realizing the impact of green roofs on energy and environmental performance of buildings needs further study on the following topics:

- Proper solutions for green roofs should be found, such as well-adapted vegetation and high performance soils and drainage layers. These solutions may be different in various climates.
- More detailed green roof models should be developed in order to consider plant physiology in addition to heat and mass transfer phenomena.
- Green roofs improve urban air quality and by extension public health and quality of life, but these benefits need to be quantified to a better degree.

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