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Review Article

A comprehensive study of green roof performance from environmental perspective

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Abstract

Green roofs have been established for over 100 years and they have been become one of the key elements in urban area in the past few decades. Many scientific researches focus on its cooling performance, efficiency and survival rates of plants. This article provides an overview mainly from two aspects, the vegetation on the green roofs and its benefits toward the surrounding environments. Vegetation is the key element in installing green roofs. It also provides some factors in choosing suitable plants on rooftops, factors including species that are drought tolerant, solar radiation tolerant, and cooling ability of plants. In addition, green roofs play a critical role in improving the urban environment by enriching the biodiversity, delaying the storm peak to the drainage system, diminishing the runoff quantity, purifying the air pollutants as well as the runoff quality.

Keywords: *Sedum*; CAM; Albedo effect; Biodiversity

Contents

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1. Introduction

Green roofs can be traced back as far as the gardens of Babylon and the Roman Empire, i.e. they grew trees on top of buildings (Peck, 2002). During 19th and 20th century, rooftops in major cities of the United States were greened to replace the rising land costs of building parks in the inner city (Herman, 2003). Nowadays, the world leader in green roof technologies is Germany, where more than 10% of houses have installed green roofs (Köhler, 2006). Köhler (2006) reported that the first wave of constructing green roofs in Germany came at the end of 19th century. It only covered less than 1% of roofs in Germany during this boom. However, incentive programs launched from 1983 to 1996 which required the installation of extensive green roofs for buildings in central part of the city and it allowed reduction of the additional costs of installation (Dunnett and Kingsbury, 2004). Nowadays, green roofs are also widespread in other European countries, for instance France and Switzerland. In addition, Portland government organized a few incentive programs to encourage the installation of green roofs on buildings. In Canada, Toronto also promoted wider construction of green roofs with sustainable alternatives to meet the urban environmental challenges (Banting et al., 2005). Green roofs are usually built in the inner city. Green roofs in the United Kingdom are also used in build-up areas, so that it can replace the gardens or local parks at ground level (Herman, 2003).

Generally, there are three types of green roofs: namely intensive green roof, semi-intensive green roof and extensive green roof. Different types of green roofs require different vegetations, and thus require different depths for growing medium (Banting et al., 2005). Researchers suggested few characteristics of extensive green roof plants: (1) they establish fast and reproduce efficiently; (2) they are short in height and cushion-forming or mat-forming; (3) their roots are shallow but spreading; and (4) their leaves are succulent or able to store water (Snodgrass and Snodgrass, 2006; Maclvor and Lundholm, 2011). Four types of vegetation have these characteristics: namely Moss-*Sedum*, *Sedum*-moss-herbaceous plants, *Sedum*-herbaceous-grass plants and grass-herbaceous plants; these types of vegetations require 2–20 cm depth of medium for growing (Banting et al., 2005). *Sedum* species are the most common choice of plant for extensive green roof because of their unique characteristics: grow with relatively shallow roots, able to store water, have crassulacean acid metabolism (CAM) to reduce water loss (Van Woert et al., 2005; Durhman et al., 2006; Maclvor and Lundholm, 2011). Another four types of vegetations can be applied in semi-intensive green roofs: grass-herbaceous plants, wild shrubs-coppices, coppices and shrubs and coppices; these types of vegetations require a deeper growing medium, i.e. 12–100 cm (Banting et al., 2005). Lastly, there are seven types of vegetations which can be planted on intensive green roofs: Lawn, low-lying shrubs and coppices, medium height shrubs and coppices, tall shrubs and coppices, large bushes and small trees, medium-size trees and large trees. They require even deeper growing medium, i.e. 15–200 cm (Banting et al., 2005). Extensive green roof is the least expensive among the three types of green roofs in terms of installation as well as maintenance, as it can be self-retained. Since the installation of extensive green roofs is easier and more flexible, most of the researches focused on the harsh environment on extensive green roofs provided. This article aims at summarizing the existing literature on the performance of intensive and extensive green roofs in subtropical maritime monsoon climate zone. Selection of plants is one of the essential components in resulting thermal benefits and storm water runoff, hence the energy savings follow.

2. Vegetation

2.1. Native, non-native and invasive plant

There are debates about using native plants on green roofs around the world (Currie and Bass, 2010). In Peck (2008)'s the book of award winning green roof designs, 45% of the award winning green roofs used native plants. Another book written by Cantor (2008) also recorded 59% of the green roofs used native plants. It shows the significance of using native plants on green roofs. Moreover, non-profit organizations, including the Ladybird Johnson Wildflower Center and the Peggy Notebaert Nature Museum in the United States, governmental organizations, namely the city of Toronto's Green Roof Pilot Program, and even commercial organizations, for example Rana Creek in the United States, also promoted the use of native plants on green roofs (Butler et al., 2012). Butler et al. (2012) also summarized the common reasons for choosing native plants in ground-level. First, Environmental Protection Agency (EPA) in the United States (2012) claimed that native plants were already adapted to the local conditions; once they are established, they do not need