Energy and Buildings 68 (2014) 25–32

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Evaluation of the energy performance and irrigation requirements of extensive green roofs in a water-scarce Mediterranean climate

Orna Schweitzer[a], Evyatar Erell[b,*]

[a] The Porter School of Environmental Studies and the Department of Plant Sciences, Tel Aviv University, Israel
[b] Desert Architecture and Urban Planning, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Israel

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form 3 September 2013
Accepted 7 September 2013

Keywords:
Energy efficiency
Water use efficiency
Plant species
Drought tolerance
Passive cooling

ABSTRACT

Green roofs are generally seen as a desirable building element, providing numerous benefits where water availability does not restrict their implementation. However, most Mediterranean locations have long, dry summers, requiring irrigation to sustain vegetation throughout extended dry periods. The cooling effect and water use of several types of plants suitable for extensive green roof systems were assessed using small test cells, which were insulated and equipped with internal thermal mass to provide a thermal response comparable to that of real buildings. The water requirements of the plant species tested ranged from 2.6 to 9.0 L/m^2 per day. *Aptenia cordifolia* was the most efficient in its use of water, providing the highest cooling benefit per unit water required for irrigation. However, the cooling efficiency of all roof variants studied was very low, and the reduction in the sensible heat load of the model building attributed to the green roof system was less than 5% of the latent heat content of the water lost to evapotranspiration. In this context, it is hard to justify green roofs in such environments on the basis of their contribution to building energy conservation, although other benefits may nevertheless make green roofs attractive.

1. Introduction

The benefits of green roofs are numerous, and they have been claimed, inter alia, to reduce building energy consumption for heating and cooling [1–5]; to mitigate the urban heat island effect [6–8]; to absorb airborne pollutants and dust [9,10]; to attenuate storm water runoff [11,12]; to extend the life of water-proofing layers by reducing their exposure to the damaging effects of sunlight, especially UV radiation [13]; to provide a habitat for diverse forms of wildlife, such as insects and birds [14]; to provide acoustic insulation [15,16]; to provide pleasing aesthetics; and to generally provide social and psychological benefits [17].

It is not surprising, therefore, that despite their cost and a variety of technical problems associated with such roofs, mainly with water-proofing, they are gaining popularity all over the world – including the Mediterranean area. However, planted roofs – by their very nature – require water to flourish. While water availability is not an issue in most climates, the growing scarcity of this resource in some regions, such as the eastern Mediterranean basin, will limit the adoption of green roofs unless they can be shown to be completely self-sustaining. Alternatively, should they require irrigation for limited periods in order to survive, the benefits must outweigh the costs substantially.

Not all green roofs are alike. In particular, their effect on interior temperature of the building depends on several factors [18]: the thermal properties of the soil (such as its conductivity, heat capacity and diffusivity, all of which may vary with changes in its moisture content) and its thickness; the characteristics of the plant cover (such as the leaf area index, the orientation of the leaves and their shape factor); and the unique combination of meteorological conditions (including air temperature, solar radiation and wind speed). The effects of leaf density and shape are of particular importance in regulating radiant heat transfer through the roof [4,19,20].

Green roofs are generally classified into two major categories [21]: so-called 'extensive' green roofs, which may be established on a very thin layer of soil and which are designed to require minimal maintenance; and 'intensive' green roofs, which have a soil layer of 20 cm or more, and which can support a large variety of plants including bushes and even some types of trees. While intensive green roofs require special structural support and must therefore be part of the initial design of a building, extensive roofs may be installed as a retrofit on practically any existing building with a flat, massive roof, since they impose only a small additional static load on the building structure (20–50 kg m^{-2}, depending on soil properties and moisture content). They are also cheaper to construct and to maintain than intensive green roofs. However, extensive green roofs with a shallow layer of soil limit the development of the plant root systems and have limited water retention. This may expose the

* Corresponding author at: The Jacob Blaustein Institutes for Desert Research, Midreshet Ben Gurion 8499000, Israel. Tel.: +972 8 6596878; fax: +972 8 6596881.
E-mail addresses: ornaschweitzer@gmail.com (O. Schweitzer), erell@bgu.ac.il (E. Erell).

0378-7788/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.09.012

plants to extreme stress in the absence of regular precipitation or irrigation. The rate of water loss by evapotranspiration depends on environmental factors such as water vapour deficit, solar radiation and wind speed – but is also affected by the adaptation of the plants themselves. A shallow soil layer is also susceptible to build-up of salts, which may be introduced by irrigation water. The problem is exacerbated if the rate of evaporation is high and natural precipitation is low, so that water must be replenished on a regular basis and no leaching takes place.

Several studies have been carried out to evaluate the suitability of plant species for extensive green roofs, in a variety of climates, including Monterusso et al. [22] – humid continental; and MacIvor and Lundholm [23] – maritime climate. Plant species suitable for dry climates, and particularly for the Mediterranean, must be able to tolerate extended dry periods and high levels of insolation. Succulents, which can store excess water in their thick leaves, are well-adapted to extreme climates in general and to dry conditions in particular. The Sedum family, which employs Crassulacean acid metabolism (also known as CAM photosynthesis) to reduce evapotranspiration, is often recommended for extensive roofs, with *Sedum sarmentosum* particularly suited for roofs where the depth of soil cover is very shallow [24]. These plants, which are well-adapted to arid conditions, fix carbon dioxide during the night, allowing stomata to remain shut during the day [25]. *Sedum acre* and *Sedum floriferum*, which are suitable for arid conditions, are also suitable for cool conditions. Spala et al. [26] listed several additional plants species suitable for green roofs in the Mediterranean, most of which are non-succulent bushes ranging in height from 40 to 90 cm or more: *Cassia corymbosa*, *Hibiscus syriacus*, *Pyracantha sp.*, *Nerium oleander*, *Cotoneaster franchetti* and *Myoporum sp.*

As Wolf and Lundholm [27] noted, “drought resistance is critical for plant survival on shallow-substrate green roofs, but potential trade-offs exist between water-use efficiency and ecosystem functions like transpirative cooling”. Furthermore, as Simmons et al. [28] noted, not all green roofs are created equal, and their performance will vary substantially according to the design and the specific environment. Williams et al. [29] suggested that generic systems tried and tested in temperate northern hemisphere countries may not in fact be suitable for drier, warmer Australia.

The aims of this study were therefore to study extensive green roofs planted with different plant species in order to establish:

a. Which of the plants have the largest effect on the temperature inside buildings in a Mediterranean climate (represented by Tel Aviv) in summer, and what is their effect in winter?
b. Which of these species is best adapted to water shortage, specifically: (i) how much water do they require during the extended hot dry season; (ii) can they survive an extended period with no irrigation; and (iii) will they tolerate salt accumulation in the soil (which might be accelerated by irrigation with brackish water)?

Additionally, the study will demonstrate a methodology for evaluating the efficiency of water use of any green roof where irrigation is required, by means of an index that combines the benefit in terms of cooling with the cost in terms of water consumption.

2. Methods

Reduced-scale models of buildings equipped with planted roofs were constructed, each with a different plant species. Once the plants had matured, the effect of the roof treatments was compared by means of temperature measurements in the soil and inside the test cells. The water requirement of each type of plant was established, and their tolerance to brackish water tested.

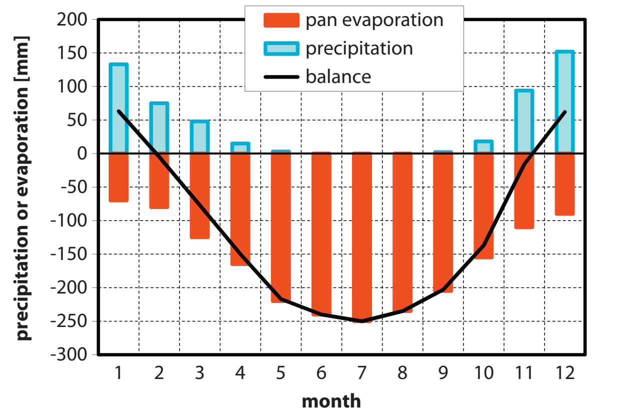

Fig. 1. Average monthly precipitation and pan evaporation for Tel Aviv. (Data: Bitan and Rubin [30]).

Monitoring of the models began in May of 2008, and continued, with some interruptions and changes to the experimental design, until September of 2009.

2.1. Location

The experiment was carried on the campus of Tel Aviv University. Tel Aviv, located on the eastern shore of the Mediterranean Sea (32°4′ N, 34°46′ E), has a Mediterranean climate with hot humid summers and mild, wet winters (Köppen climate classification Csa). Temperatures range from 9.6 to 17.5 °C in January and 23.7 to 30.2 °C in August [30]. Average annual precipitation is 530 mm, falling between September and May: there is no rain at all in summer. Annual pan evaporation is about 1945 mm, with a maximum of about 250 mm in July. As Fig. 1 shows, there is a moisture deficit for 10 months of the year.

2.2. Selection of plant species

Four types of plants with different appearance and adaptation strategies were selected, representing different classes of potential green roof solutions that would maximize benefit (in terms of thermal protection) and minimize cost (in terms of irrigation):

a. *Pennisetum clandestinum* (kikuyu grass) has dense roots and is a rapidly growing and aggressive species. It is propagated easily and is drought-tolerant, and is therefore sometimes used in lawns or as salt-tolerant forage grass [31].
b. *Aptenia cordifolia* is a succulent with bright green leaves and red flowers. Its vigorous growth and ability to be propagated by cuttings allow it to create a dense mat above the soil. It can thrive in a variety of soils and is capable of withstanding extremes of heat, cold and salinity.
c. *Sesuvium verrucosum* is a perennial psammophile and has been recommended for sand dune fixation, mitigating desertification, landscaping and ornamental uses. The *Sesuvium* genus is known to tolerate high salinity [32] and has shown durability and a capacity to regenerate after prolonged drought [33].
d. *Halimione portulacoides* is a small greyish-green shrub resembling the saltbush. It is extremely tolerant of salt content in the ground [34].

Several studies have suggested that the performance of a green roof could be enhanced by planting multiple species [27,35]. Nonetheless, the present study was limited in scope to monocultures, to allow comparison among the species and to highlight