Energy and Buildings 84 (2014) 299–307

Contents lists available at ScienceDirect

Energy and Buildings

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

Snow depth and vegetation type affect green roof thermal performance in winter

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ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 25 July 2014
Accepted 26 July 2014
Available online 13 August 2014

Keywords:
Plant traits
Heat flux
Soil temperature
Insulation
Solar radiation
Wind

ABSTRACT

Green roofs reduce building energy consumption in hot seasons, but cold season thermal performance has received little attention. The goals of this study were to quantify heat flux in an extensive green roof system, relate heat flux to solar radiation, substrate temperature and snow depth, and to determine the relationships between vegetation type, snow accumulation, and substrate temperature. Over the building heating season, we found lower net heat loss from green compared to conventional roofs. Doubling green roof substrate depth had no additional impact in lowering net heat loss. We also quantified substrate temperatures and snow depths from green roofs in different microclimates and vegetation types. Different roof microclimates (sheltered, exposed, over unheated building) resulted in differential snow accumulation; deeper snow resulted in lower variability in heat flux. The benefits of green relative to conventional roofs were lower in extreme winter conditions when the substrate was frozen and/or had snow cover, but also during sunny conditions. Plant species differentially affected depth and duration of snow coverage. Substrate temperatures also differed according to plant growth form during both snow-covered and bare conditions. Net thermal benefits of green roofs in winter will depend on climate, plant choice, roof construction and location.

1. Introduction

Green roofs provide many environmental benefits, including reduction of energy consumption, stormwater retention, and provisioning of habitat [1,2]. The thermal benefits of green roofs during hot seasons are well-characterized in many areas [3–5], and result from evapotranspirative cooling [6,7], increased albedo [8,9], and the insulating properties of the growing medium [10]. For cold seasons, modeling studies predict modest reductions in heat flow out of buildings under green roofs compared with conventional roofs [8,10,11], but the overall impact on energy budgets should be less than that of cooling during hot periods. The few empirical studies of green roof thermal properties during cold seasons tend to confirm the reduction in heat flow out of buildings compared to conventional roof systems [12–15], resulting in energy savings.

In general, snow acts as an insulator, reducing temperature fluctuations and increasing average soil temperatures during winter [16]. Empirical studies of green roofs in winter suggest that snow cover reduces the magnitude of temperature fluctuations [17] and the relative advantage of green roofs compared with conventional roofs [15]. Green roofs may support greater snow accumulation [14], but there has never been a quantitative study of the effects of snow depth or coverage on green roof thermal performance nor of the effects of green roofs on the magnitude and duration of snow accumulation.

Shallow substrates on extensive green roofs challenge plant survival in cold regions [18]. Plant survival is important on green roofs as replacement of plants increases maintenance costs, and damaged vegetation can reduce aesthetic value and the performance of ecosystem services [19]. Plant overwintering survival depends greatly on substrate depth [18] and microclimate [20]. In general, snow cover promotes higher survivorship of overwintering perennial plants due to warmer soil temperatures [21]. Snow cover can also reduce the frequency of freeze–thaw cycles [16], which are detrimental to the belowground parts of overwintering plants [18].

Snow accumulation can be affected by plant structure above ground. Shrubs trap snow, leading to greater snow depths compared to more open areas [22]. The snow that accumulates around shrubs can be of lower density, with more trapped air, than snow cover in open areas; this increases the insulating value of a given depth of snow [22]. Given that most green roof plants have some presence above-ground during winter, whether as a canopy of

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http://dx.doi.org/10.1016/j.enbuild.2014.07.093
0378-7788/

Table 1
Summary of site characteristics and sampling dates.

Roof Type	Sampling Type	Thermal Variables	Treatment	Sample Size	Dates	Air temperature (°C) Min.	Mean	Max.
Sheltered	Thermal	Heat flux and Temperature	Control	2	Nov. 5–Dec. 15; Jan. 1–March 31	−17.2	0.4	16.6
			7.5 cm	2	Nov. 5–Dec. 15; Jan. 1–March 31	−17.2	0.4	16.6
			15 cm	4	Nov. 5–Dec. 15; Jan. 1–March 31	−17.2	0.4	16.6
	Snow		Control	1	Jan. 7–March 7	−17.2	−1.5	11.0
			7.5 cm	1	Jan. 7–March 7	−17.2	−1.5	11.0
			15 cm	2	Jan. 7–March 7	−17.2	−1.5	11.0
Raised	Thermal	Temperature	Control	2	Nov. 5–Dec. 15; Jan. 1–March 31	−17.2	0.4	16.6
			7.5 cm	5	Nov. 5–Dec. 15; Jan. 1–March 31	−17.2	0.4	16.6
			15 cm	5	Nov. 5–Dec. 15; Jan. 1–March 31	−17.2	0.4	16.6
	Snow		Control	2	Jan. 7–March 7	−17.2	−1.5	11.0
			7.5 cm	5	Jan. 7–March 7	−17.2	−1.5	11.0
			15 cm	5	Jan. 7–March 7	−17.2	−1.5	11.0
Exposed	Thermal	Temperature	Control	4	Feb. 21–March 31	−13.1	−0.2	11.0
			7.5 cm	24	Feb. 21–March 31	−13.1	−0.2	11.0
	Snow		7.5 cm	24	Jan. 7–March 7	−17.2	−1.5	11.0
Modules	Thermal	Temperature	6 cm	150	Nov. 5–March 31	−17.2	0.4	16.6
	Snow		6 cm	150	Jan. 7–March 7	−17.2	−1.5	11.0

dead leaves and stems (necromass), woody stems and/or evergreen leaves, it is possible that plants could influence snow accumulation and the thermal functioning of green roofs. The possibility that different vegetation types on roofs can affect depth and duration of snow coverage has never been explored.

In this study we quantified heat flux in one extensive green roof system, and soil temperatures in four different systems during the building heating season. We measured snow depths in green roof systems with different substrate depths and examined the effects of 14 plant species on snow accumulation and substrate temperatures.

2. Methods and materials

2.1. Sheltered and raised green roof systems

Snow depth and thermal properties were examined in three different built-in green roof systems and one modular green roof system (Table 1). The first two were installed in summer 2008 on a pre-existing sod roof on the 35-year-old, north section of the Patrick Power Library at Saint Mary's University in Halifax, Nova Scotia, Canada (44°39′N, 63°35′W) [23]. The pre-existing sod roof consists mainly of non-native grasses and some wildflowers on 45–60 cm of clay soil, and a 2–3 cm of extruded polystyrene insulation over a waterproofing membrane that covers concrete slabs and is approximately 5 m from ground level. This roof is sheltered by buildings 1 to 3 stories higher on the West, South, and East sides.

The "sheltered" system consists of three green roof panels and one control of conventional dark grey roofing shingle, each 2.4 m × 2.4 m (Fig. A.1), established on the pre-existing sod roof. The panels were placed at the same level as the top of the sod, with extensive green roof drainage containers (ELT EasyGreen, Brantford, Ontario) over a plywood base fitted with holes every 3 cm for drainage (Fig. A.1). The panels were separated from one another with a parapet 30 cm above the level of the surrounding sod (Fig. A.1), contributing shelter from wind. Before applying the plywood base, the original substrate (soil) was removed to the roof insulation below and backfilled with construction gravel to create a well-draining level surface (Fig. A.1). The four panels were assigned to three treatments: one control, two with 15 cm substrate depth and one with 7.5 cm substrate depth. The substrate was a commercially available growing medium designed for extensive green roofs (Sopraflor X, Soprema Inc., Drummondville, Quebec), and this was used in all of the experimental roofs described below. The fourth panel served as a conventional roof control and had a thin layer of dark grey shingle applied to the plywood base, with a drain in the center.

The "raised" system was on the same roof as the sheltered and used the same green and conventional roofing systems. Twelve panels, each 1 m × 1 m were installed on top of a single rectangular raised platform, in two rows of six panels each, clad around the sides with plywood (1.8 cm thick) to provide some protection from wind (Fig. A.2). The original purpose of the system was to quantify stormwater runoff beneath the panels. Each panel was bordered by a parapet with the top approximately 1 m above the ground, and 20 cm higher than the base of the substrate layer. Below the substrate layer were the drainage layers described above, then a 1.3 cm plywood protection layer, a 2.5 cm rigid insulation layer (R5), another plywood board (1.8 cm thick) then approximately 15 cm of spray applied insulation (R20), resulting in a 50 cm high air space between the gravel floor and the base of the insulation. This can be considered similar to green roof construction over and unheated building such as a parking garage (a green roof setting common in Halifax). Each panel drained into a regular roof drain. Two panels (at east and west ends of the rows) were conventional (as above) and there were five each of the 7.5 cm and 15 cm substrate depth green roof panels.

Both the sheltered and raised systems were planted with the same mixture of plants (Table A.1) from plugs in 7.6 cm pots, which in turn were propagated from wild cuttings (from the two *Sedum* species) and seeds (all other species); plants were from 4 to 18 months old at the time of planting. These were planted in May and June 2008 with an average of 4 cm between plants, and were not weeded or irrigated for the duration of the experiment. By the time of this study in winter 2010–2011, the plants had experienced three growing seasons and had close to 100% plant cover. While there were some differences in species composition after three growing seasons between substrate depths, and between the raised and sheltered systems (the subject of ongoing analysis) overall the systems were dominated by tall grasses and weedy forbs by the time of this study.

2.2. Exposed green roof system

The "exposed" system, was installed in spring 2010 on an adjacent, newly constructed building (Fig. A.3). This roof is considered more exposed as there is little shading from other buildings and it