Building and Environment 44 (2009) 643–650

Contents lists available at ScienceDirect

Building and Environment

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

Greenroof potential to reduce temperature fluctuations of a roof membrane: A case study from Estonia

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ARTICLE INFO

Article history:
Received 31 March 2008
Received in revised form 20 May 2008
Accepted 21 May 2008

Keywords:
Bituminous membrane roof
Greenroof
LWA
Sedum spp.
Temperature fluctuations
Thermal insulation

ABSTRACT

This paper analyses the temperature regime of a light weight aggregates (LWA)-based greenroof in comparison with a modified bituminous membrane roof. The measuring period was from June 2004 to April 2005. Both seasonal and daily results showed that in Estonian climatic conditions, an extensive greenroof is sufficiently capable of protecting the roof membrane from extreme temperatures. In the summer period, the 100-mm-thick substrate layer of the greenroof significantly decreased temperature fluctuations compared with the bituminous roof surface. In autumn and spring the substrate layer protected the base roof's membrane from rapid cooling and freezing. It also provided effective thermal insulation in winter. In addition, measurements showed that the surface of the LWA media in the greenroof heats and cools more than the surface of the bituminous roof; however, its influence on temperature in the substrate layer was not considerable. Indexes to characterize greenroof's temperature effects are proposed.

1. Introduction

Greenroofs have been increasingly investigated in order to determine how they could improve the quality of the urban environment. Greenroofs consist of the following layers: a waterproofing membrane, a drainage layer, a filter membrane, a substrate layer and plants. The composition and thickness of the substrate layer is decisive. One benefit of greenroofs is to protect the base roof membrane against solar radiation, thus lowering its temperature and also minimizing temperature fluctuations. Research has confirmed that greenroofs also have the following benefits: the ability to reduce urban stormwater runoff problems, reducing the total runoff by retaining part of the rainfall and distributing the runoff over a long time period [1–5]; the ability to reduce the pollution of urban rainwater runoff by absorbing and filtering pollutants [1,5–7]; helping to keep buildings cool in summer and also to reduce a building's energy consumption by direct shading, evaporative cooling and additional insulation [8–13]; improving air quality by catching a number of polluting air particles and gases, including smog. The evaporation and oxygen-producing effect of vegetated roofs can contribute to the improvement of the microclimate. Considering the above-mentioned benefits, it may be concluded that greenroofs can thereby mitigate the urban heat island effect [14,15]. Planted roofs also provide food, habitat and a safe habitat for many kinds of plants, animals and invertebrates [16]. Greenroofs can also mitigate noise pollution [17]. In city centres, where access to green space is negligible, greenroofs create space where people can rest and interact with friends or business colleagues. Greenroofs provide a psychological benefit because of their appearance, which differs greatly from ordinary roofs. Therefore, aesthetic value is the most apparent benefit of vegetated roofs [17].

An exposed roof membrane absorbs solar radiation during the day and its temperature rises, while in the evening its surface temperature drops. Daily temperature fluctuations create thermal stresses in the membrane and reduce its durability. The greenroof blocks the solar radiation from reaching the membrane, thus lowering its temperature and also minimizing temperature fluctuations. The life span of the membrane of a conventional roof is usually 20–25 years, but it is believed that a greenroof membrane may last twice as long.

Some investigations have been performed concerning the temperature regime of greenroofs, in which the main research topic was temperature fluctuations in greenroofs and reference roofs. Much more research has been done to investigate greenroofs' heat transfer and the ability to reduce buildings' energy consumption by other researchers. Thorough research has been done by Liu and Baskaran from the National Research Council in Ottawa, Canada [18]. During the 22-month observation period (660 days), Liu and Baskaran found that the membrane temperature of the reference bituminous roof exceeded 30 °C for 342 days, was above 50 °C for 219 days and above 60 °C for 89 days.

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doi:10.1016/j.buildenv.2008.05.011

In comparison, the membrane under the greenroof only exceeded 30 °C for 18 days, and never reached 40 °C. The temperature fluctuation in the exposed membrane of the reference roof had a median of 42–47 °C. The greenroof reduced the temperature fluctuation in the roof membrane to a median fluctuation of 5–7 °C throughout the year. Bass and Baskaran [9] showed the results of the same roof temperature profile monitoring on typical days in different seasons. On a typical summer day the membrane temperature on the reference roof reached 70 °C, but the membrane temperature on the greenroof fluctuated at around 25 °C. On a typical winter day without snow coverage, the membrane temperature on the reference roof fluctuated from −15 to 10 °C depending on the air temperature, while at the same time the membrane temperature on the greenroof remained relatively stable between 1 and 5 °C. Wong et al. [15] found that surface temperatures measured under different kinds of vegetation were much lower than those measured on hard surfaces. The maximum temperature of the hard surface and under all kinds of plants was 57 and 36 °C, respectively.

The objective of this paper is to analyse how a light weight aggregates (LWA)-based greenroof functions in local weather conditions, as a result of observing an existing greenroof in Tartu, Estonia. The task was to assess the temperature regime on the greenroof's surface and in the greenroof's substrate layer, and to compare those with a modified bituminous membrane roof.

2. Materials and methods

2.1. Site description

The studied greenroof was established in May 2003 and is situated near the city centre of Tartu, Estonia (58°22′40″N, 26°44′07″E). It consists of the following layers: a modified bituminous base roof, a plastic wave drainage layer (8 mm), rock wool for rainwater retention (80 mm) and a substrate layer (100 mm) with LWA (66%), humus (30%) and clay (4%). The reference roof is a modified bituminous membrane roof; the distance between the roofs is approximately 350 m. Both the non-fertilized greenroof and the reference roof have no slope and the same area (120 m^2). The length of the greenroof is 18 m, and its width 6.60 m; its height from the ground is 4.5 m. The brick building (with 300 mm clay bricks), covered by the greenroof, is a one-storey printing-plant (Ecoprint) annex to a three-storey office building (stone house with wood weatherboarding impregnated with natural paint; with a conventional flat roof). During the measurement period, the amount of plant cover was 45% of the whole roof area. The most common plant species were *Sedum acre* (planted and seeded; covers 55%), *Thymus serpyllum* (20%), *Dianthus carthusianorum* (5%), *Cerastium tomentosum* (all seeded; 3%) and also *Veronica filiformis* (occasional species; 7%). This was the best possible roof to study, considering the presence of a suitable reference roof in the vicinity. Although the size, aspect and slope of the reference roof were similar to those parameters of the greenroof, there are still some differences behind the roofs' conditions, such as snow cover thickness in winter, which depends on wind direction.

2.2. Sampling and analysis

The measuring period was 10.06.04–25.04.05. The temperature was measured every 15 min using sensors Pt1000TG8/E, produced by Evikon MCI (Estonia), and recorded with data logger R0141, produced by Comet System Ltd. (Czech Republic). Data processing was performed using MS Excel. On the greenroof the temperature was measured in two places: at the eastern and western side of the roof. The temperature was measured both on the surface of the roof and at 1 m above the roof, and also at a depth of 50 and 100 mm in the substrate layer. Because the greenroof's bituminous membrane of the base roof was inaccessible, temperature measuring at the depth of 100 mm in the substrate layer was the best possibility to investigate temperature regime in the greenroof. As the greenroof's surface was mainly covered by LWA (plant cover was only 45%), the surface temperature expresses the temperature of the LWA. On the bituminous roof the temperature was measured on the surface and at 1 m above the roof. As the temperatures of both sides of the greenroof were similar, for comparison with temperatures on the reference roof only the results of the eastern side are used. In February and March, however, when snow cover on the western side was thicker and similar to that of the reference the results of that side were used. The air temperatures above the roofs were similar, and therefore these are used in comparison. Inside the building equipped with the greenroof temperature was not measured. Explanations of abbreviations used in figures are shown in Table 1.

Table 1
Explanations of abbreviations used in figures

Abbreviation	Explanation
GR at 100 mm	Temperature measured at the depth of 100 mm in the substrate layer of the greenroof
GR at 50 mm	Temperature measured at the depth of 50 mm in the substrate layer of the greenroof
GR surface	Temperature measured on the LWA surface of the greenroof
RR surface	Temperature measured on the surface of the reference bituminous roof
Air	Temperature measured at 1 m above the greenroof

2.3. Statistical analysis of data

The normality of temperature data was checked using the Lilliefors and Shapiro–Wilk tests (STATISTICA 7.0 software). Most of the temperature values (except for the air temperature measured at 1 m above the greenroof) were not normally distributed. For the analysis of these data we used non-parametric statistics (e.g. the Spearman Rank Order Correlation). For normally distributed temperature differences, parametric statistics (average and standard deviation values and Pearson correlation) were applied. The level of significance of $\alpha = 0.05$ was accepted in all cases.

3. Results and discussion

3.1. Temperature regime in the entire measurement period

Fig. 1 illustrates daily average temperature values. In summer (June–Mid-September), the daily average temperature values of the greenroof's substrate layer were lower than those on the surface of the reference bituminous roof. In winter the temperature relations were similar due to the snow cover.

In the warmer period the amplitudes of average daily temperatures (the difference between daily maximum and minimum temperatures) were highest on the surface of the greenroof, as it was warmed by the sun and cooled down at night (Fig. 2). Surprisingly, the amplitude of the surface temperature of the reference bituminous roof was even smaller. This clearly demonstrates that the surface of the LWA greenroof should be