

Energy Conservation Analysis of Various Green Roof Systems

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Abstract- The present paper illustrates an experimental analysis on the comparative analysis of air-conditioning energy savings of different green roof applications based on experimental measurements. Tests were carried out on nine different green roof samples, involving three types of growth media (lava, arkalyte, pumice) matched with three sedum types (kamtchaticum, spurium, sexangulare). Temperature readings at the bases of each sample were recorded for 32 months continuously at every 15 minutes. The data was processed and the heat gain of a sample building with each green roof application was calculated theoretically. The energy consumption comparisons showed that the right selection of growth media and vegetation can yield significant energy savings for air-conditioning applications.

I. INTRODUCTION

In recent years, the effect of building insulation on heating and air-conditioning energy consumption has become more significant as energy costs have been increasing. In order to combat rising costs, insulation technologies have been improving. Most of the insulation materials available in the market are synthetic. However, there is also a natural insulation technique that is becoming more popular all over the world. This new revolution is green building technology - where the roofs and/or the side walls of buildings are covered with vegetation. This application is considered to deliver several benefits such as reducing heating and cooling energy costs, reducing storm water run-off, filtering pollutants and CO₂ out of the air, decreasing the heat-island effect in large cities, and increasing the lifespan of roofing materials.

Green buildings have been significantly more popular in Europe due to higher energy costs and new European Union regulations. In Germany, 17% of all new roof constructions are green, summing up to 140 million square feet of green roof area [1]. In Basel, Switzerland, 20% of the flat roofs were turned into green roofs by 2005 [2]. In recent years, green buildings have started to become popular in the U.S., as well. Washington, DC has been utilizing green roofs as an alternative storm water retention technique. Chicago, IL has started an elaborate green roof initiative to green a significant portion of roof area in the city. The city today has about three million square feet of green roof area [3].

One of the main advantages of green roofed buildings is the energy savings due to reduction in required heating and air-conditioning loads in winter and summer seasons, respectively. According to the studies conducted by Liu [4]

and Sidwell et al. [5] that evaluated the thermal performance of rooftop gardens, in warm seasons the plants and growing medium of the green roof keep the roofing membrane cool by direct shading, by evaporative cooling from the plants and the growing medium, and by the added insulation from the plants and growing medium. Kumar and Kaushik [6] developed a mathematical model for evaluating cooling potentials of green roofs. The suggested model used a control volume approach based on the finite differences method. The validation results against the experimental study yielded a maximum error range of $\pm 6.1\%$. Lazzarin et. al. [7] performed a numerical modeling study investigating the green roof system in a dynamic state with a uni-dimensional analysis using the finite differences method. The study also focused on evapotranspiration which was found to be significantly beneficiary, especially in winter seasons. Niachou et. al. [8] studied the thermal properties of green roofs and energy savings of buildings employing these roof systems. One of the variables of the parametric analysis was the vegetation type where thick dark green and sparse red vegetation was used. Results showed that the dark green sample yielded lower roof surface temperatures than the ones with sparse red covering.

Although many aspects of thermal benefits of green roofs have been studied in literature, not much is found focusing on types of vegetation. In this study, different vegetation types with varying growth media are compared in terms of their insulative behavior and energy savings, based on experimental data.

II. THEORY

For the heat transfer analysis, the green roof systems can be decoupled into two regions, which are the plant canopy and the growth medium as illustrated in Fig. 1.

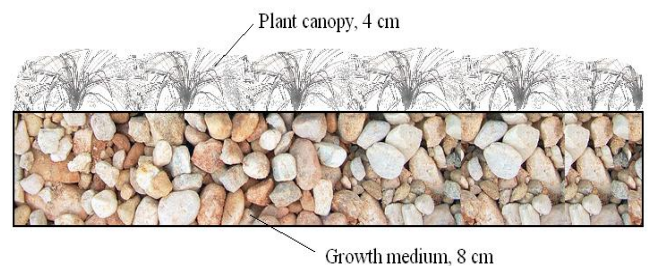


Fig. 1. Decoupled green roof model.

An energy balance can be defined between the adjacent regions. This analysis involves radiative and convective heat transfer through the vegetation, which is considered to be a porous media, and conduction through the growth medium, which is modeled as a packed bed of solid particles. A complete thermal analysis model is achieved by combining these two models with heat flux continuity conditions through the surfaces and at the interface between the adjacent layers.

$$q''_{\text{radiation}} + q''_{\text{convection}} = q''_{\text{conduction}} \quad (1)$$

The base temperature of the green roof can be determined by the continuity and energy equations applied to the model. Heat gain of building structures employing different green roof systems can also be evaluated and compared for energy savings analyses for summer seasons. A roof system having a total thermal resistance of R and an outer surface temperature of T_o that varies due to the type of the green roof setup being used will experience different heat transfer rates through its structure, which will change the required cooling load. The heat flux through a unit surface area of the roof is determined by:

$$\frac{q}{A} = U(T_o - T_i) \quad (2)$$

where T_i is the interior design temperature and U is the overall heat transfer coefficient, which is given by

$$U = \frac{1}{R} \quad (3)$$

Hence by knowing the varying daily outside temperatures, heat fluxes through different roof systems can be computed and compared for energy analysis. The results of this experimental study will be given in the results section.

III. EXPERIMENTAL WORK

A modular green roof system, Green Roof Blocks™, was used. The system consists of 60 cm (L) x 60 cm (W) x 10 cm (H) aluminum trays filled with growth media and vegetation. The experimental analysis involves the growth media and the sedum species as the varying parameters. Three different growth media (lava, arkalyte, pumice), with three sedum (kamtchaticum, spurium, sexangulare) were observed and measurements were collected continuously for 2 years and 8 months. The tested vegetation samples are shown in Fig. 2.



Fig. 2. Tested sedum species.

A letter coding was developed for identifying each combination. Table 1 illustrates the assigned codes.

TABLE I
CODING FOR EXPERIMENTAL VARIABLES

Growth Medium	Vegetation Species
L – Lava	K – Sedum kamtchaticum
A – Arkalyte	S – Sedum spurium
P – Pumice	A – Sedum sexangulare

Nine combinations (3 growth media x 3 sedum species) were observed throughout the experimental analysis. For simplicity, each sample was assigned a code where the first and the second letters represent the growth medium and the sedum type, respectively. These codes are listed in Table 2.

TABLE II
TESTED COMBINATIONS

LK	LS	LA
AK	AS	AA
PK	PS	PA

The dimensions of the growth media in each sample are 60 cm (L) x 60 cm (W) x 8 cm (H). The temperature readings were measured by high accuracy soil/water probes and recorded by weatherproof outdoor data loggers. Data were collected from each channel for two years and eight months every 15 minutes. Each data logger could store 43,000 measurements; hence recorded readings were transferred to a computer approximately every three months.

IV. RESULTS

Raw data collected from the data loggers were processed. For comparison of energy savings due to different green roof combinations in summer seasons, August 2007 was selected among the 32 months of experimentation. Fig. 3 illustrates the base temperatures of nine different tested combinations in the month of August in 2007.

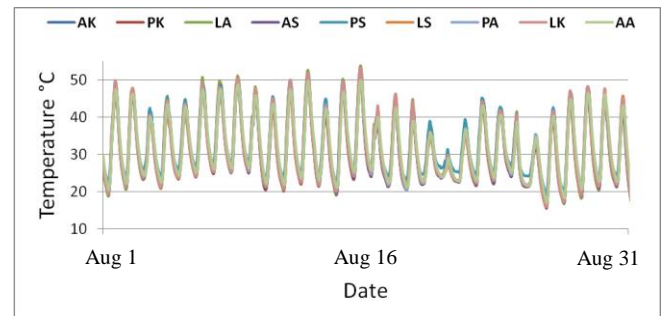


Fig. 3. August 2007 data for all combinations.

To get a better understanding of the thermal blockage behaviour of these test samples, temperature data on a sample day of August is given for the peak hours of the day in Fig. 4.

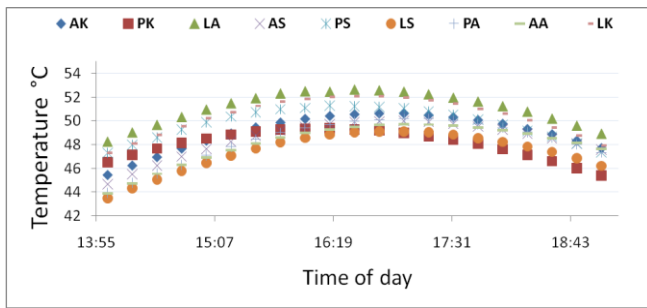


Fig. 4. Data during peak hours on August 12, 2007.

In terms of insulation, red lava rocks with sedum spurium (LS) yielded the best results. Pumice with sedum kamtchaticum (PK) also seemed to be very close to LS in terms of its peak temperature value being almost as low as that of LS. All nine combinations were also compared based on the heat fluxes through them into a building envelope with indoor design conditions at 25°C dry-bulb temperature and 50% relative humidity. A daily heat flux representation for August 12 is given in Fig. 5. As the outside air temperature falls below 25°C at night, reverse heat flow from the building to the outside air is observed, hence the negative heat flux values on the graph between approximately 02:30-09:30.

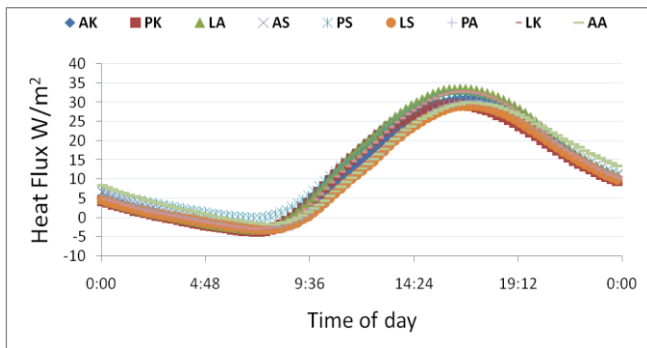


Fig. 5. Heat flux values on the sample day.

As an example, for a warehouse with a roof area of 50,000 m², cooling energy costs with four different green roof applications yielding best insulative results among nine combinations are given in Fig. 6 for peak hours of the day. The unit price for energy was considered to be 8¢/kWh, which is representative of electricity costs in the midwest.

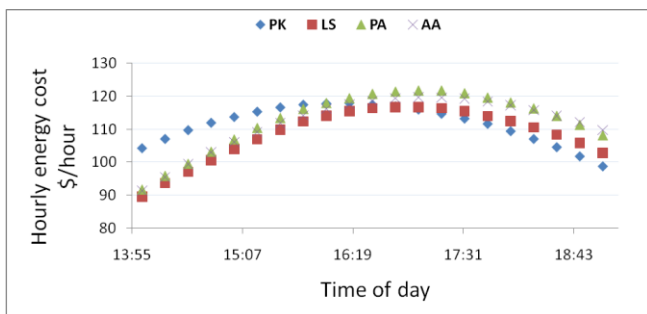


Fig. 6. Energy cost of a 50,000 m² roof during peak hours.

As can be seen from the figure, at any given time energy savings due to roof insulation for a sample warehouse with 50,000 m² roof area can be as good as \$15/h in August in midwest USA. It sums up to a significant amount of savings if the hourly savings are integrated over the 24 hour period and the analysis is performed over the whole cooling season.

V. CONCLUSION

Nine different combinations of growth media and vegetation in a modular green roof system were tested to compare their energy savings characteristics. The varying parameters of the tests were the growth media and the vegetation type. The results showed that the lava rock and sedum spurium combination (LS) had the best insulating characteristics. The daily temperature difference between this combination and the inside air was the minimum among all combinations tested. On the other hand, at the end of the peak hours pumice rocks with sedum kamtchaticum (PK) showed a steeper cooling trend than the LS application due to its thermal mass being larger than that of the LS sample.

Although particular combinations could be selected among all samples due to their isolative performances, it was observed that the same type of growth media with a different type of vegetation can yield significantly different results. Hence, further studies on the interactions of growth media and the plant roots should be conducted.

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