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GREEN ROOF THERMAL PERFORMANCE

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Abstract. *With the development of architecture and technology, various forms of green roofs have evolved. Green roofs are not a completely modern technological idea because they existed centuries ago but in a different form than today. With the increase in the population in urban areas, both the climatic conditions and the quality of life have significantly changed. The need has emerged to change the shape and properties of traditional building construction materials, as well as roofs that must meet today's needs of modern people. Green roofs, as roof structures, are one of the green construction segments that represent a modern approach in finding sustainable solutions for large cities. They allow the unused surfaces of flat roofs to be put into the function of environmental protection, improvement of internal comfort and energy savings. This paper presents values of thermal fluxes and temperatures obtained in the summer period by measurements at a conventional (bare) roof and an extensive green roof up to 12 cm in thickness on a building in New Belgrade. Based on the conducted measurement of thermal fluxes and temperatures, the U-values for the conventional and green roofs were calculated and it is shown that the heat transfer coefficient can be significantly reduced by adding an extensive green roof to the existing conventional flat roof of the building. It is concluded that installing a green roof on an existing flat roof can be considered a very effective measure to improve the energy performance of old buildings due to the reduction in the heat transfer coefficient.*

Key words: *Green roof, U-value, Energy efficiency, Green Buildings.*

1. Introduction

Green roofs have been around since the Stone Age, when communities covered their homes with sod, but today it is a growing urban trend in cities all around the world, inspired by a desire for a better environment, financial relief and even legislation. Green roofs have received considerable attention in recent years. Increasing global population inevitably leads to an increase in urban population and to a significant increase in the number of built

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facilities. This results in an increase in energy required to establish satisfying comfort in cities, which leads to deterioration of the microclimatic conditions in the urban environment. In addition to the aesthetic value that green roofs can add to buildings, they have a positive effect on improving the microclimate in cities by reducing noise levels. An extensive green roof can reduce external sound by 40dB, and an intensive green roof by 46-50 dB. Plants and the substrate can absorb sound waves or repel them. The substrate blocks lower and the plants block higher sound frequencies. Green roofs can mitigate heat islands. Through daily evapotranspiration cycles, plants on horizontal and vertical surfaces can lower temperatures in the summer months and can reduce the effect of heat islands. Green roofs also help reduce the distribution of dust and pollutants in the city, as well as smog production. This can play a role in reducing greenhouse gas emissions and adapting to harvested environments for future climates with warmer summers. Green roofs can also purify rainwater. On green roofs, water is retained in the substrate and then taken from the plants and returned to the atmosphere through the process of transpiration and evapotranspiration. In the summer months, depending on the type of plants and the depth of the substrate, green roofs retain 70-90% of precipitation, and in winter between 25-40%. Green roofs, in addition to retaining rainwater, also act as natural filters for cleaning. In addition to reducing rainwater, green roofs also extend runoff time, which reduces the load on sewer pipes. Plants on green roofs can greatly reduce air pollutants and filter out harmful gases. Reducing the temperature through green roofs can reduce energy consumption and potentially reduce the amount of CO_2 and other pollutants released into the air. Also, green roofs can provide additional living space for people to grow edible plants and habitat for birds and insects. Increasing biodiversity can have a positive impact on three domains: the ecosystem, the economy and the social domain.

A green roof, as part of a building's thermal envelope, also affects the thermal performance of the building and the building energy consumption for heating and cooling. In paper [1] the authors used a simulation program to determine the effects of three different types of rooftop gardens on the annual energy consumption in a five-story commercial building in Singapore. The results showed that the insulation of the rooftop garden can lead to savings of 0.6-14.5% in the annual energy consumption. The results also showed that the increase of soil thickness would further reduce the building energy consumption and that the moisture content of the soil can affect the outcome quite substantially. In paper [2] the authors investigated the potential for building retrofit in the UK. The authors found that as over half of the existing UK building stock was built before any roof insulation was required, it is older buildings that will benefit most from green roofs. They reviewed the case for retrofitting existing buildings and it was found that there is a strong potential for green roof retrofit in the UK. Simulation was conducted in paper [3] for a single-family house with conventional and green roofs in a temperate French climate. The results showed that in the summer, the fluctuation amplitude of the roof slab temperature was found to be reduced by 30°C due to the green roof. The heat flux through the roof was also evaluated and it was found that the roof passive cooling effect in the summer was three times more efficient with the green roof and annual energy demand was reduced by 6%. The authors suggest that green roofs are thermally beneficial for hot, temperate and cold European climates. The study performed in [4] investigated the thermal characteristics of an extensive green roof under air-conditioned and non-air-conditioned states by using experimental data obtained on successive sunny summer days. The authors found that bottom of the soil layer functioned as a “cooling source” that absorbed heat from both upside and downside. The authors concluded that the green cover reduced the cooling energy consumption by 14.7% and the heat flux by 76.1%. Paper [5] provides a detailed description of seven different green roofs (different thickness, materials and construction layers) and insulating performance. Their results show that green roofs respond differently on climatic framework conditions. Calculated U-values range from 0.94 W/m^2 for 12cm thick one-layer green roof to 0.3 W/m^2 of a 30cm thick two-layer green roof.

The Belgrade housing stock is very old and characterized by very poor thermal envelope characteristics. A large number of multi-story buildings with flat roofs were built between the 1960s and the 1980s [6]. Consequently, one of the most important goals nowadays is to increase the energy efficiency of those buildings by finding ways to improve their thermal properties. One way to convey this action is to improve roof thermal performance by adding some living dynamic systems on the top of buildings and to decrease roof thermal flux. It is very important to examine exactly how the green roofs respond to Belgrade climatic framework conditions.

2. MEASUREMENTS AND MEASURING EQUIPMENT

The lifespan of green roofs is twice as long comparing to the conventional ones. There is an opinion that they can reduce the cost of draining rainwater. They are very effective as a thermal insulation element and the roofs of a plant-covered building with only 10 cm of substrate can reduce the need for cooling during the summer by 25%. In order to quantify the impact of the green roof on improving the energy performance of the building envelope, a green roof was installed on the existing flat conventional roof as shown in Fig. 1.

Fig. 1 Experimental green roof

The building chosen to install the green roof is an educational institution located in Belgrade. From an architectural point of view, the building is complex and consists of three levels, while from the energy point of view, the building has very poor thermal envelope characteristics. The flat roof surface of the building was suitable for the installation of a green roof. The experimental green roof surface area is about 20m^2 and it is set at a height of about 4m above the ground level. The conventional roof with the same surface area, at the same height above the ground, was chosen and compared to the green one. Measuring devices were situated on both roofs in order to determine their thermal characteristics. Measurements were conducted simultaneously: on the existing conventional and on the green roof from 21 to 29 August 2019 and recorded every 10 minutes.

U-value is one of the commonly used values to evaluate thermal quality of each individual element of the building envelope. To calculate this value, actual values of the heat flux through the observed element and, indoor and outdoor air temperatures are required. In order to obtain valid heat flux measurement results, it is necessary to achieve 15°C of indoor and outdoor air temperature difference. To keep the temperature difference large enough, air conditioners were used.

In addition to already mentioned values, conventional roof surface temperature and roof surface temperature under the green roof were measured respectively.

Temperatures of the conventional roof outer surface were continuously measured by K-type thermocouples at two measuring points (Fig. 2 - red dots on the top), and then the mean temperature for the conventional roof was calculated. On the other hand, temperatures on the green roof were measured at two measuring points between layers 1 and 2 (Fig. 3) and mean temperature was calculated, too. Construction of the conventional and green roofs by layers are also shown in Fig. 2 and Fig. 3.

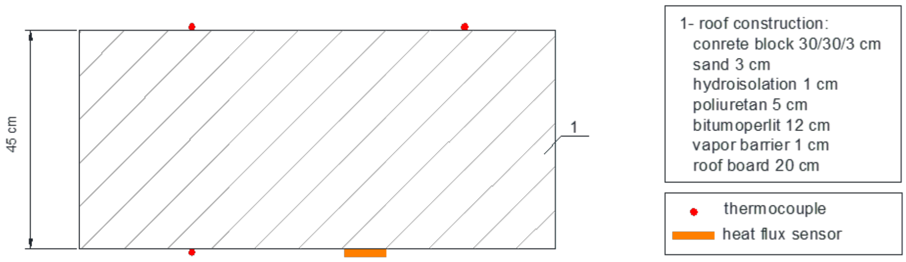

Fig. 2 Conventional roof – measuring setup

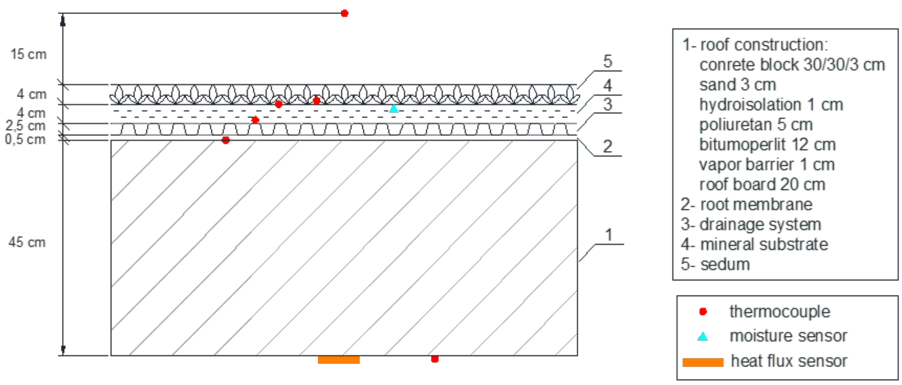

Fig. 3 Green roof – measuring setup

Values of the measured thermal flux through the conventional and green roofs are shown in Fig. 4 and Fig. 5. The obtained results indicate a significant decrease in the thermal flux by placing the green roof on the existing roof: the flux is reduced from (20-50) W/m^2 at the conventional roof to (0-10) W/m^2 at the green roof. Average values for the measurement period were 3.4 W/m^2 for the green and 41.5 W/m^2 for the conventional roof.

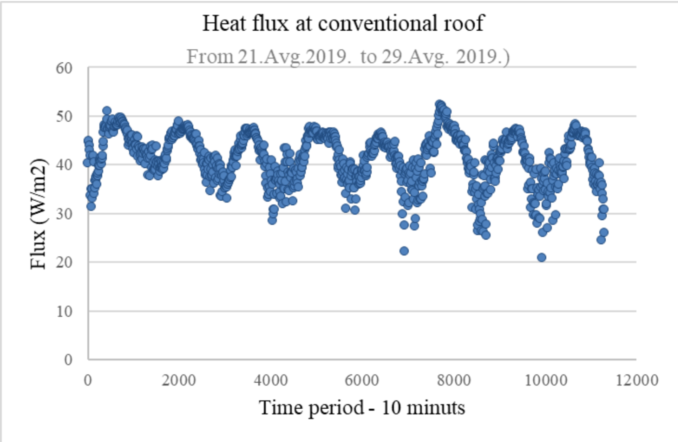

Fig. 4 Thermal flux measured at the conventional roof

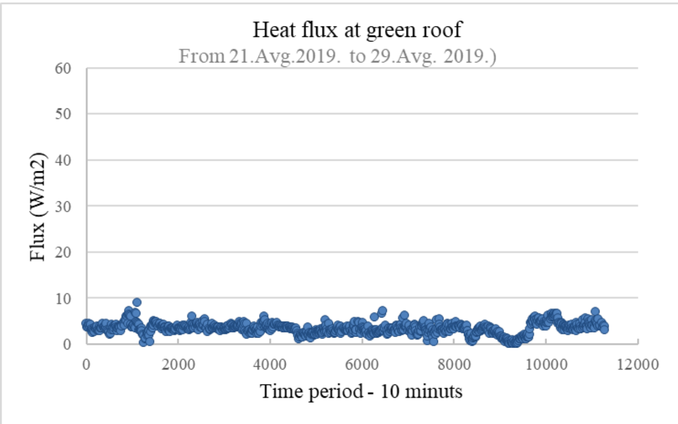

Fig. 5 Thermal flux measured at the green roof

U-values of conventional and green roofs were calculated as the quotient of the heat flux value and the temperature difference between outdoor and indoor air measured every 10 minutes. Mean U-values for both roofs and their standard deviations were calculated by considering only the values obtained for the temperature difference greater than 15°C:

$$U = \frac{q}{T_{a,out} - T_{a,in})} \quad (1)$$

Where:

U - heat transfer coefficients ($Wm^{-2}K^{-1}$),
q - heat flux (Wm^{-2})
$T_{a, out}$ - outdoor air temperature (°C) and
$T_{a, in}$ - indoor air temperature (°C).

The obtained values of the total heat transfer coefficient (U-value) for the conventional (bare) roof, and the same roof construction covered by the green roof are shown in Table 1.

The results show that the green roof, placed on the top of the conventional roof with very poor thermal characteristics, can significantly reduce the U-value.

Table 1 U-values

	Conventional roof	Green roof
U value ($Wm^{-2}K^{-1}$)	2.13	0.24
Standard deviation ($Wm^{-2}K^{-1}$)	0.35	0.05

Fig. 6 shows a graph of the mean value of the measured temperatures of the upper surface of a conventional roof exposed to solar radiation. Mean temperature ranges were from about 22°C to about 45°C. Mean values of measured temperatures of the conventional roof upper surface covered by green roof were, as expected, much lower. This temperature ranges from about 22°C to 29°C as is shown in Fig. 7. Obviously, the green roof cover dropped the conventional roof temperature significantly and decreased the temperature amplitude.

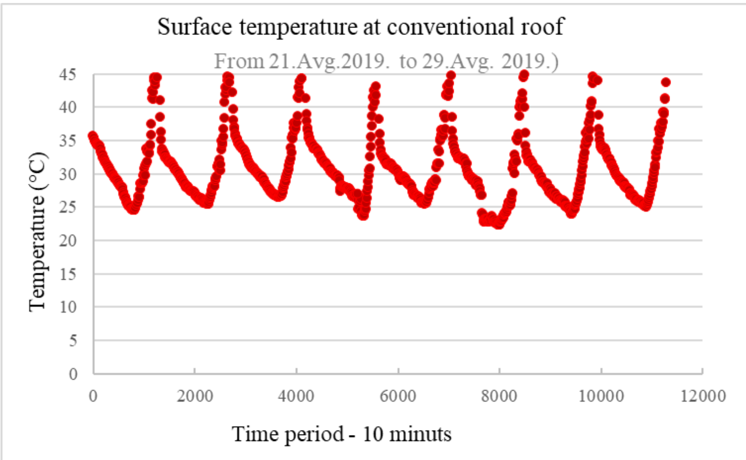

Fig. 6 Conventional roof surface temperature

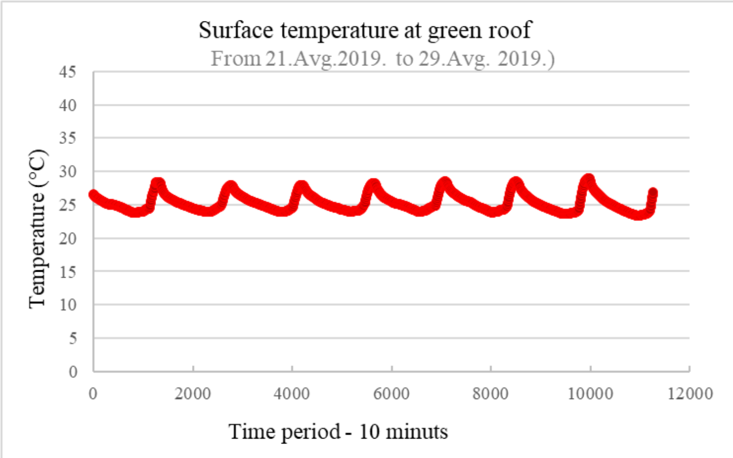

Fig. 7 Roof surface temperature under green roof

3. CONCLUSIONS

Green roofs, as a roof structure, covered with a vegetation layer can add the aesthetic value to the building. Nevertheless, green roofs have a positive effect on improving the global microclimate in big cities, reducing noise levels, purifying rainwater and air, being a habitat for various birds and insects. Green roofs are excellent thermal insulation of the building. They can retain the heat in winter and cool in summer. The green roofs provide additional space for staying in nature, and can be gardens for growing edible plants. The special advantage of green roofs is reflected in the economic savings in terms of reducing energy consumption, as well as increasing the value of the real estate. Green roofs should not be a privilege of cities with better economies, but they are certainly a privilege of countries with developed environmental awareness and should become a required part of built environment even in less developed regions.

This paper presents the experimental results obtained by measuring the energy characteristics of a flat conventional roof and a green roof mounted on the conventional roof.

Measurements were conducted from 21 to 29 August 2019 and recorded every 10 minutes on the existing conventional roof and on the green roof.

Measurement results show that setting-up a green roof over a conventional one may result in:

- Significant reduction of the heat flux through the roof during the summer period,
- Reduction of temperature of the concrete envelope element up to 16°C during the summer period,
- Reduction of temperature amplitude of the roof upper surface in the summer period.

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REFERENCES

1. Wong, N. H., Cheong, D. K. W., Yan, H., Soh, J., Ong C.L., Sia, A., 2003, *The effects of rooftop garden on energy consumption of a commercial building in Singapore*, Energy and Buildings, 35, pp. 353-364.
2. Castleton, H.F., Stovin, V., Beck, S.B.M., Davison J.B., 2010, *Green roofs; building energy savings and the potential for retrofit*, Energy and Buildings, 42, pp. 1582-1591.
3. Jaffal, I., Ouldboukhitine, S.E., Belarbi, R., 2012, *A comprehensive study of the impact of green roofs on building energy performance*, Renewable Energy, 43, pp. 157-164.
4. Tang, M., Zheng, X., 2019, *Experimental study of the thermal performance of an extensive green roof on sunny summer days*, Applied Energy, 242, pp. 1010-1021.
5. Scharf, B., Zluwa, I., 2017, *Case study investigation of the building physical properties of seven different green roof systems*, Energy and Buildings, 151, pp. 564-573.
6. Vučićević, B., 2014, Analysis and evaluation of sustainable development of the energy systems in buildings (in Serbian), PhD Thesis, University of Niš, Serbia, p.183.