GREEN LIVING ROOF IMPLEMENTATION AND INFLUENCES OF THE SOIL LAYER ON ITS PROPERTIES

by

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Affected by undeniable climatic change, the temperature of the urban areas rises continually, increasing rapidly the energy problem of cities and amplifying the pollution problems. The thermal stress is increased, thus both the indoor and the outdoor thermal comfort levels are decreased, enhancing the health problems. Green roof implementation in the building envelope is strategy that provides heat island amelioration, thermal comfort for occupants and reduces energy consumption of buildings. Green living roofs are a passive cooling technique, which can stop the incoming solar radiation from reaching the building structure below. In this paper, we assessed the importance of the green roofs in providing environmental and building energy benefits, and brief investigation on the different configuration of the soil layer in the green roof assembly influences to the temperature of the roof surface was presented. Investigation was conducted for first phase of the living roof growth. Four cells were designed in SolidWorks software where the transient thermal study was performed in order to determine differences between the behavior of the conventional roof and three green roof types.

Key words: *green roof, thermal comfort, soil, environment*

Introduction

Until the nineteenth century, less than 5% of the world's population lived in cities, and by 1950 a third of the world's population become urban. More than half of the global population is nowadays residing in cities, and the World Health Organization predicts that this proportion will continue to increase and rise up to two-thirds in 2050. Urban areas detrimentally invade natural landscapes impacting the entire planet, this process is leading to environmental degradation. Urbanization decreases the proportion of spaces dedicated to green infrastructures due to new building developments. A deficiency of green spaces is recognized as a major problem in many dense urban areas. According to the US EPA, cities of over one million people can be as much as 12 °C warmer than the surrounding countryside. Higher urban temperatures are due to the positive thermal balance of urban areas caused by the important release of anthropogenic heat, the excess storage of solar radiation by the city structures, the lack of green spaces and cool sinks, the non-circulation of air in urban canyons and the re-

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duced ability of the emitted infrared radiation to escape in the atmosphere. The urban heat island (UHI) is a reflection of the totality of microclimatic changes brought by urban alterations of the open spaces. Some large cities, such as Chicago, New York, and Tokyo have recorded summer temperatures that are 14 °C higher than adjacent rural areas.

Greening the building envelope is innovative technology in architecture that can regain losses of natural environment produced by erecting buildings. Adapting flat roof surfaces into green living systems is an efficient and sustainable solution for improving the environmental balance of cities and limiting the major negative effects of urbanization providing better comfort at building and urban level. Using an analysis of satellite data, roof area fraction may vary from 20% to 25% for less or more dense cities, and considering that urban areas occupy 1.2% of all land, it is estimated that the total roof area of the urban world is close to $3.8 \cdot 10^{11}$ m^2 [1]. This estimation is based on urban fabric research conducted for US cities but many metropolitan urban areas around the world are less vegetated than typical US cities so the percentage for the roof areas should be larger and it should be noted that majority of those roofs are conventional roof types, often called black roofs because of their color and albedo.

Most of the black roofs in Serbia were made of felt impregnated with asphalt or coal tar. These bituminous, or asphalt-based, roofs are damaged by UV rays from the sun and expands and contracts as the temperature changes over time and thus, not very durable. This leads to degradation of the roof that causes leaks into the building beneath making an uncomfortable environment for the occupants. In addition, these bituminous roofing systems are subject to damage from bacteria, moss, and plant roots. These roofs are now installed less frequently around the country and being replaced with state-of-the-art roofing materials that are much more durable than these impregnated-felt roofs, but more cost expensive. The most commonly used conventional roof types materials now are polymer-modified bituminous sheet membranes and related hot liquid-applied membranes. Other modern materials can be used in conventional roofs, such as ethylene propylene diene monomer (M-Class) rubber, polyvinyl chloride, thermoplastic olefin polymer alloys, and liquid-applied polyurethane membranes. The problem with the black roof, that can not be overseen, is that they contribute to UHI effects on the city scale. Their dark colors cause these roofs to absorb energy from the sun to the point that they can reach high temperatures in summer. Knowing that there is a high potential for building retrofit with the green roof in Serbia, this innovative architectural approach should be considered.

Green living roofs

Green roof technology, as architectural tool, was originated in Germany in 1880s, although, the history of green roof in the form of roof gardens have started in Babylon around 500 B. C. Germany is regarded as the world leader in employment of green roof strategy with the greenest roofs in the world and as country with the most advanced knowledge in modern living roof technology. Green-roof coverage in Germany alone now increases by approximately 13.5 million square meters per year. Approximately 14% of all new flat roofs in Germany will be green roofs [2]. According latest studies conducted by Fachvereinigung Bauwerksbegrunung, Germany, 80% of green roofs implemented are extensive type. According to ADIVET (French association of green roofing companies), from 100,000 m^2 to 1,000,000 m^2 of green roof has been implemented yearly in France for the past ten years. Green roofs in London are covering of 9300 m^2 only in the Greater London area. In US, Chicago is a leading city in green roofs technology with more than 50,000 m^2 installed vegetative roofs only in 2008. In Canada, the city of Toronto approved a by-law mandating green roofs on residential and industrial buildings. From February 1, 2010 – March 1, 2015, 260 green roofs have been created in Toronto, consisting of

196,000m^2 of green roof area. A total of 444 green roofs exist in the City of Toronto. Serbia is late in practical work, as well as research, due to constrain from infrastructure investment, lack of relevant laws, regulations and national policies concerning the green roof strategy.

Over the years, there has been a substantial development in designing and constructing green vegetated roofs. In addition to the creation of a pleasant environment, the aesthetic and visual impressions, green roofs offer several substantial benefits in comparison to conventional roofs. Recent papers offer a complete review of the main environmental benefits that green roofs can achieve, such as providing reduction in storm-water runoff and improving storm-water quality, reducing interior noise levels, reducing dust and air pollution levels, increasing thermal efficiency. Depending on the types of plants and soils, a green roof can provide a natural habitat for animals, insects and plants and can increase the biodiversity of an urban area and, at the city level, contribute to the mitigation of the urban heat island effect [3].

Green roof construction and classifications

Green roof construction mimics in a few centimeters what normal soil does in a couple meters, as shown in fig. 1. The green roof accomplishes the natural balance through several layers. Three main layers can be identified: foliage layer (canopy), soil layer (substrate) and support layer. The foliage layer depends on the plant selection. The growing medium, filter and protection layer act to support plants and protect lower levels. The drainage layer provides water for upper layers in relatively small space and with light-weight, excess water overflows and easily passes underneath it away and down the roof drain. The support layer is roof construction similar to the flat convectional roofs.

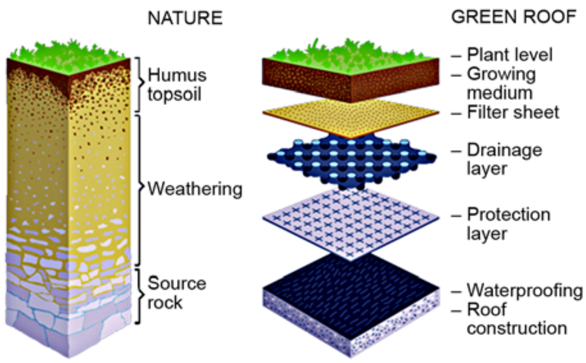

Figure 1. Green roof systems mimics' earth's natural soil layers

There are two main classifications of green roofs:

– extensive green roofs lightweight in structure with a thinner substrate, and
– intensive green roofs with a deeper substrate layer to allow deeper rooting plants such as shrubs and trees to survive.

Extensive roofs require little maintenance once they are established. Cost effectiveness of extensive green roofs makes them suitable for retrofit of public and commercial buildings.

Intensive roofs have a thicker soil layer and should be considered a landscape with plants found in parks and gardens and may require irrigation during dry periods. Because of their thicker soil, intensive roofs require greater structural support than extensive ones. The effectiveness of the green roof depends on the plant and soil in the green roof assembly and the selection of the green roof materials can impact potential building energy savings [4]. Characteristics and variations of green roofs are shown in tab. 1.

Table 1. Characteristics and classification of green roofs

	Extensive	Simple-intensive	Intensive
Soil depth [cm]	4-20, 10-15 typical	10-50	10-200 +
Plant heights [cm]	5-30	30-60	30-90 +
Roof slopes	Slopes up to 30 degrees	Low slopes; flat roofs	Low slopes; flat roofs
Irrigation	No	Periodic	Regular
Storm-water reduction	Low	Medium	High
General weights [kgm^{-2}]	60-145	120-195	170-500 +
Plant communities	Low growing plants; self-sufficient and self-propagating	Grass-herbs and shrubs	More varied, larger species, and specialty species
Use	Eco – protection layer, usually non-accessible	Designed green roof	Park, garden, designed for access (typically)

Features of the soil layer in green roof assembly

The soil layer resides above the drainage layer, usually separated by a dense mesh fabric cloth. Agricultural soil is a complex, dynamic and living system where biological processes continuously take place. Soil is a complicated material consisting of solid particles of various compositions, including both mineral and organic, and various shapes and sizes that are randomly arranged with pore spaces between. Pores can contain air and water in its various phases as vapor, liquid or ice. The size of mineral particles in soils usually ranges from below 0.002 mm to above 2 mm in diameter. The fraction above 2 mm is classed as gravel, and the fractions below 2 mm are classed as clay, silt, or sand as is indicated in tab. 2

Table 2. Classification of soil particles as a function of their diameter [mm]

Sand					Silt	Clay
Very coarse	Coarse	Medium	Fine	Very fine		
2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	0.05-0.002	< 0.002

The relative proportions of clay, silt, and sand determines the soil texture. Texture affects other soil properties as shown in tab. 3. Pore spaces of dry soils are mostly filled with air while water fills the pores of wet soils. In pores processes such as infiltration, groundwater movement, and storage occur. The result of movement in pore spaces of the soil being the transfer both mass and heat. Permeability is the rate at which fluid can flow through the soil pores. Water-holding capacity is the ability of soils to hold water for plant use.

Table 3. Properties of soils as a function of texture

	Sand	Silt	Clay
Porosity	large pores	small pores	small pores
Permeability	rapid	low to moderate	slow
Water holding capacity	limited	medium	very large

The most important characteristics of the soil are its thermal conductivity, specific heat capacity, density and albedo. Various changes in soil structure, and therefore in density or porosity, may occur naturally. Drying of soil leads to shrinking and consequent fissuring, while water intake leads to swelling. Changes in soil structure leads to changes in its thermal conductivity. An increase in the dry density of a soil, with its associated decrease in porosity, leads to an increase in thermal conductivity, mainly due to three factors: more solid matter per unit soil volume, less pore air or pore water per unit soil volume, and better heat transfer across the contacts.

Dark soils absorb more heat than smooth light-colored ones and thus warm faster. On its part, soil moisture affects the rate of temperature change: more heat is needed to warm a wet soil than a dry one. As a general rule Sailor [5] found that diffusivity and conductivity varied linearly with soil moisture saturation level with saturated soils having a 40% higher specific heat capacity and twice the thermal conductivity of their dry counterparts. As moisture was added to soils they showed an albedo decrease from the dry value to a lower limit of about 0.08. The temperature of soils follows the temperature of the air, but with a time lag. This effect diminishes with soil depth.

Thermal properties and mineral composition for selected soils for the green roof assembly are shown in tab. 4. The values shown for the substrate are averages of dry and saturated conditions taken from the study [6] where they were validated.

Table 4. Properties and mineral composition of selected substrate

	Clay (G1)	Cellar (G2)	Rooflite media (G3)
Mineral compositions	Mainly quartz, SiO_2; trace leucite; trace dolomite	Mainly quartz, SiO_2; trace leucite; trace dolomite	Mainly quartz, SiO_2; moderate dolomite; moderate kaolinite clay; slight mica clay and slight chlorite clay
Thermal conductivity [$Wm^{-1}K^{-1}$]	0.32	0.40	0.93
Density [kgm^{-3}]	682	800	1347
Specific heat [$Jkg^{-1}K^{-1}$]	1065	1373	1113
Albedo	0.12	0.13	0.11

Soil depth in the green roof assembly is set to 0.12 m, which is appropriate for the extensive green roof types.

Simulation results and discussion

Four cells were designed in SolidWorks software where transient thermal study was performed. Three of cells had green roofs with soil characteristics from tab. 4 and another had the conventional flat roof (figs. 2 and 3). All had the same dimension and area for the roof was 9 m^2. Influences from the walls and floor were neglected because in this study only changes in the roof surface were examined.

Materials, with properties, used in the conventional and green roof assembly are given in tab. 5.

The green roof was analyzed in its starting phase and leaf area index (LAI) was assumed close to zero so the foliage layer was set to zero depth. Absence of the foliage layer can also occur in winter period, adverse climate conditions, or can be consequence of plant

Figure 2. Cell with conventional flat roof

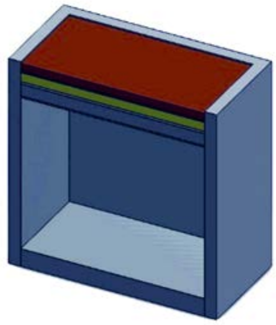

Figure 3. Cell with green roof assembly

Table 5. Materials for the conventional and the green roof assembly

	Roof layer	*d* [m]	*ρ* [kgm^{-3}]	*λ* [Wm^{-1}K^{-1}]	*C* [Jkg^{-1}K^{-1}]
S2	Filter membrane	0.002	900	0.137	1926
S3	Drainage layer	0.025	25	0.033	1170
S4	Roof membrane	0.0095	1121.3	0.16	1460
S5	Thermal insulation	0.06	30	0.032	840
S6	Vapor barrier	0.002	1370	0.19	1046
S7	Screed layer	0.04	2200	1.4	1050
S8	Concrete slab	0.2	2400	2.04	960
S9	Ceiling	0.025	1700	0.85	1050

diseases. For soil layer conduction heat transfer was assumed to be uniform in the horizontal and that thermal properties did not vary in response to the moisture content of the soil media, natural convection in the roof has been taken into account. We specified the values of emissivity, thermal conductivity, specific heat capacity, and density for dry soil media (S1), as in tab. 4. A section of the conventional and the green roof assembly is given in fig. 4.

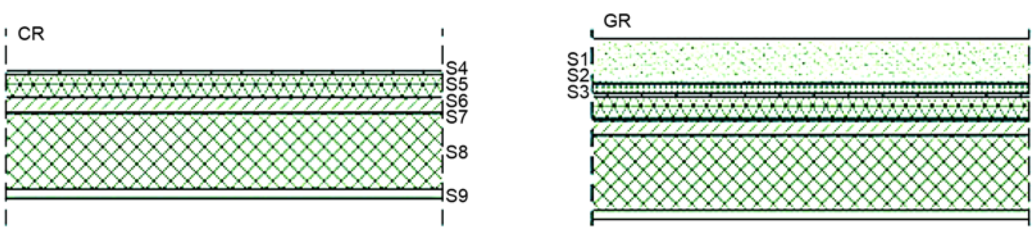

Figure 4. Convectional (CR) and green roof assembly (GR)

Weather data was obtained from a weather station Kotež latitude/longitude: N44°51'8", E20°28'14" located in Belgrade, Serbia. Temperature and radiation data from weather station for August 29-31, 2015, used in the simulations are shown in figs. 5 and 6.

With the simulated sensor at rooftop surface, and also for the roof membrane top surface in case of the green roof assembly (G1, G2, G3) data was collected and presented in the following charts.

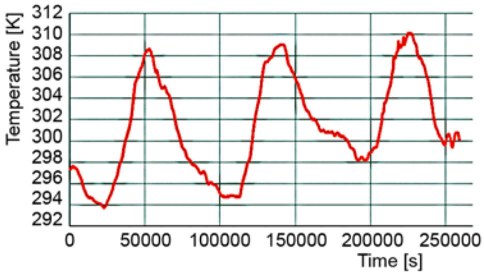

Figure 5. Temperature data

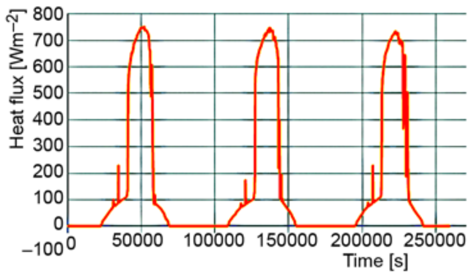

Figure 6. Solar radiation data

Without foliage layer dry soil does not seem to have much influence in top surface heat reduction, this can be observed in fig. 7. Temperature maximum for conventional roof was 61.59 °C, and for the green roof G1, G2, and G3 temperature maximum was 59.31 °C, 56.29 °C, and 58.38 °C, respectively. Considering that vegetation need time to grow and that green roofs are not always fully covered with plants this should be taken in concern.

The influence of the time lag caused by the soil layer over the roof membrane should be noticed, in fig. 8, causing temperature on the roof membrane layer to be less extreme. For the conventional roof, temperature maximum was 61.59 °C and temperature minimum was 20.82 °C at the roof membrane top surface. The difference of 40 °C in 24-hour period is consequential and can induce serious damage over time. For the green roofs G1, G2, G3, temperature maximum was 41.11 °C, 42.64 °C, and 40.16 °C, and temperature minimum was 24.83 °C, 24.49 °C, and 25.19 °C, respectively. The surface temperature of the roof membrane located beneath soil layer, for every case scenario in the green roof assembly, was around 20 °C lower than one in the conventional roof. The difference of 16 °C, 18 °C, and 14 °C in 24 hour period for G1, G2, and G3 respectively is significantly lower comparing to the C1 case. Best case scenario was for G3 configuration with rooftile media where temperature maximum on the top surface of the roof membrane was 21.43 °C lower compering to the conventional roof. Lower temperature fluctuations can be spotted in fig. 9 for all tree cases of green roof assembly.

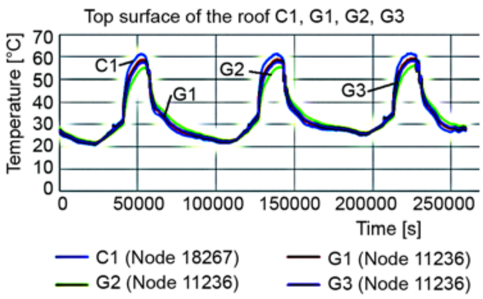

Figure 7. Comparison of the roof top surface temperature for selected cases

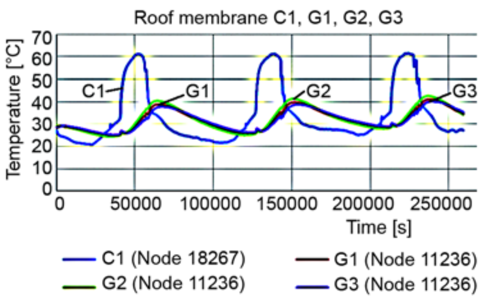

Figure 8. Comparison of the roof membrane temperature for selected cases

Various studies showed that under a green roof, indoor temperatures, in room without cooling, were found to be at least 3-4 °C lower than outdoor temperatures of between 25 and 30 °C. The total heat flux entering the building below the green roof was reduced, compared to a conventional roof without green roof. For this case we assumed air conditioning and constant temperature of 22 °C inside the cells. Differences in the heat flow can be noticed in fig. 10.

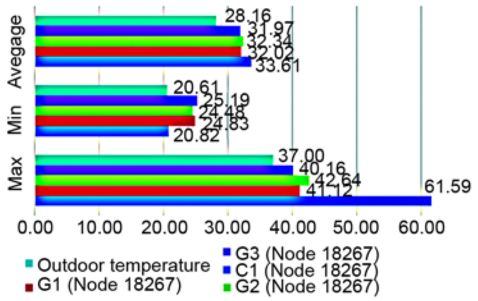

Figure 9. Comparison of the extreme and average temperatures for selected cases
(for color image see journal web-site)

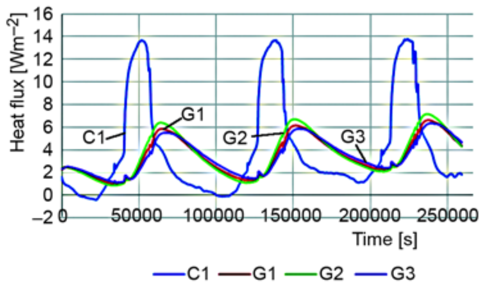

Figure 10. Comparison of the heat flux entering the cell below the roof membrane

Yaghoobian and Srebrić [7] showed in their research that the green roof substrate surface temperature decreases with an increase in plant coverage predominantly due to the decrease in the amount of received solar radiation at the soil surface as well as the increase in the amount of near surface moisture content and soil surface evaporation. The daily peak value of the substrate surface temperature for the bare-soil roof was 24 °C (34%) higher than that over the fully-covered green roof.

Discussion on thermal comfort with green roof implementation

Thermal comfort is condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55). Increased amount of green surfaces in urban community level by implementing green roof in building envelope helps to decrease both outdoor and indoor level air temperature and humidity in micro climatic condition and ensure thermal comfort among building occupants. Experimental measurement results [8] showed that shading plays the key role in cooling and humidification and have a close relationship with leaf area.

The direct cooling effect is proportional to the green area, the larger the greening area, the better is the effect on cooling and humidification. The choice of green roof characteristics depends greatly on climate and selection of the plants and soil, but nevertheless influence could be significant. For example, green roofs fully covered with plants can decrease the surface temperature of the roof 30-60 °C according to an experimental study conducted in Japan [9].

Indirect cooling effect brought by the green roof is done by using the Sun energy to turn water stored in plants, through transpiration, and soils, through evaporation, into water vapor rather than heat. Releasing large amount of water vapor into the air causes the moisture level near the green roof to increase. The research on cooling effects of the green roofs started at the same time with the research on the green roofs' impact on the relative humidity, however, as the occupants are less sensitive to humidity, there are less work done on the humidification effects. Increasing the height of vegetation improves humidification effect significantly. Combinations of bushes and grass, trees, grass and shrubs have better cooling and humidification effect than grass only. Roof covered with bushes and grass has the highest relative humidity, and compared to non-green space, the daily average humidity increased by 23.1%, for the shrub and grass humidity increased by 7.7% and for the turf space the relative humidity only increased by 5.4% [10].

For high-rise buildings the creation of rooftop landscape gardens is not only intended for viewing purposes. It is also meant for reducing building heat as well as providing open spaces for the building's occupants, in residential or commercial buildings. Past studies on thermal comfort in office buildings show a positive relationship between nature and the psychological well-being of occupants in offices. The open double volume space in a 21-storey high-rise office building in Penang, Malaysia, by allowing free air movement, and with the combination of water features and plants reduced both the air temperature and the mean radiant temperature [11]. The combination of various characteristics in the Sky Court Garden was very successful in creating a comfortable atmosphere for the occupants.

The College of Architecture and Landscape Architecture used integrating computer simulation at design stage to accomplish a climate responsive solution of the roof. By creating thermally comfortable spaces on its green roof not only environmental benefits were achieved but usable spaces was also multiplied, increasing the use of outdoor spaces, promoting outdoor living and conserving energy [12].

A study conducted by Teemusk and Mandar in Estonia [13] compared the temperature regime of a lightweight aggregates based roof garden with a modified bituminous membrane roof in a different season. The results of their study revealed that substrate layer of the extensive green roof can decrease the temperature fluctuations significantly in summer periods but also, green roofs provided effective thermal insulation in winter. Depending on the type and thickness of the different layers, the green roof also offers protection against extreme weather circumstances such as frost, hail storms and temperature fluctuations [14].

Conclusions

Foliage and soil layers protect the buildings from the solar radiation, control the temperature and the humidity of the indoor and outdoor environment. Plants absorb radiant energy to enhance biological photosynthesis preventing absorption of the radiation by the soil and the roof structure. Even in its starting phase, green living roof with LAI close to zero during the summer period had the external surfaces heated less than the traditional flat roofs. The difference of 14 °C, 16 °C, and 18 °C in 24 hour period for green roof assembly is significantly lower comparing to the conventional roof where difference of 40 °C in 24-hour period is consequential and can induce serious damage over time. The indoor thermal performance of the cells with green roof were also better than the traditional flat roofs.

Different soil types in the green roof assembly had a similar but significant impact on the roof membrane, temperatures beneath soil layer were less extreme and their fluctuation amplitude was lower than that of a conventional roof. Improving the insulation properties of a building, green roof could also reduce annual energy consumption. Absence of the foliage layer, wich could occur in winter period, adverse climate conditions, or as a consequence of plant diseases, should be taken into consideration in evaluation of thermal characteristic of the green living roof.

Occupants of buildings with implemented green living roof should benefit by low outdoor and indoor temperature, more air flow and less air pollution. By adopting green roof practice, at not only smaller scaled urban zone but also at the city level, environmental as well as social and economical benefits could be ensured.

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