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THERMAL CHARACTERISTICS AND POTENTIAL FOR RETROFIT BY USING GREEN VEGETATED ROOFS

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ABSTACT: Green roof strategy is one of the sustainable practices that not only provides thermal comfort for occupants but also reduces energy consumption of buildings as well as add aesthetic values to the environment. Over the years, there has been a substantial development in designing and constructing vegetated building envelope. Green roofs provide environmental benefits by protecting buildings against solar radiation and temperature fluctuations and by reducing building's energy consumption by direct shading. As most of the existing buildings in Serbia were built before building regulations that require higher levels of insulation, it is older, non-insulated buildings that will benefit most from green roof retrofit. This article reviews the current literature and compares findings, based on the type of the green roof and climate, to consider the potential building energy benefits of green roofs, and the acceptability of implementation on a wider scale in Serbia, on the basis of real economical application.
Keywords: green roof, retrofit, insulation, temperature fluctuations, energy performances

1. INTRODUCTION

On average, people spend 90% of their lives indoors, where all aspects of human life occur, so we have to acknowledge that it is vital to provide safe, healthy and comfortable conditions in buildings. In Serbia, the building sector is responsible for 60% of the total energy consumption and over 40% of total CO_2 emissions. It is estimated that up to a 50% of the energy consumed by buildings is due to the use of heating, ventilation and air conditioning (HVAC) systems and that over 400 thousand houses have no or unprofessionally installed insulation, which lead to the average consumption of energy up to 220 kWh/m^2 annually. Compared to the average consumption in EU (of 70 kWh/m^2 annually), Serbia has to take necessary measures to scale down the average consumption.

Greening the building envelope is innovative technology in architecture that can regain losses of natural environment produced by erecting buildings. Green roofs are considered an effective contribution to the solution to some environmental problems at the building scale and urban levels. In addition to 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 increasing thermal efficiency, providing reduction in stormwater runoff and improving stormwater quality, reducing interior noise levels, reducing dust and air pollution levels. 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 [1]. There are two main classifications of green roofs, extensive (with soil thickness less than 0.10 – 0.15 m) and intensive (with soil thickness more than 0.15 – 0.20 m). In addition to higher aesthetic and living qualities, the first attempts of quantifications of energy benefits were performed in Germany, around the 1960. Germany has the largest uptake of green roof technology, of which 80% are extensive systems, offering the most cost effective solution over intensive types [2].

2. THERMAL CHARACTERISTICS AND BUILDING ENERGY BENEFITS

In the thermo-physical model of the green roof, three main components can be identified: structural support, soil layer and foliage layer. The structural support includes all the layers between the inner plaster and the drainage layer or filter layer. In most cases the structural layer is considered as a single layer with constant thermal properties and the specific value of thermal conductance. The soil layer is complex with the solid phase (organic and mineral material), the liquid phase (water) and the gaseous phase (water vapor and air). The foliage layer (canopy) is composed of the leafs and the air within the leafs.

Modeling the thermal behavior of green roofs requires the study of several interacting phenomena and many green roof models, from simple to detailed, are available in the recent literature by various authors. The green roof soil parameters, such as thermal conductivity, specific heat capacity, short wave reflectivity and albedo, vary as a function of the moisture content, and the properties and geometry of foliage (such as Leaf Area Index, height of plants, stomata resistance) vary as a function of age, vegetation water content, soil water content, mineral deficiencies, outdoor conditions, etc. The energy balance of the canopy is determined by the solar radiation absorption by the foliage, the long wave radiation exchange between the foliage and the sky as well as between the foliage and the soil surface, the convection heat exchange between the foliage and the air in the canopy and the latent heat flux by evapotranspiration in the foliage. While the energy balance of the soil is determined by the soil solar radiation absorption, the exchange of long wave radiation between the soil and the sky as well as between the soil and the foliage, the sensible heat flux exchange with the air in the canopy, the latent heat flux and the heat flux conducted through the soil (Sailor's energy balance model for green roofs).

Green roofs benefit the buildings through direct and indirect thermal impacts. The direct effects are those, which are related to the building components such as the effects of shading on reducing the surface temperature of buildings [3]. Indirect impacts are those, which contribute to buildings surroundings such as reducing outdoor thermal environment. Improvement of thermal performance is due to the increment of shading, better insulation, and higher thermal mass of the roof system [4, 5].

2.1. Thermal mass

The green roof act to reduce the heat loss from the building in winter and heat gain into the building in summer, and also adds thermal mass to help stabilize internal temperatures year round. Thermal mass influences bodily comfort by providing heat source and heat sink surfaces primarily for the radiative heat exchange processes.

Table 1. Density, specific heat and thermal mass vol. heat capacities of materials[1]

Material	Density [Kg/m³]	Specific heat [KJ/kgK]	Thermal mass vol. heat capacity [kJ/m³K]
Water	1000	4.186	4186
Concrete	2240	0.920	2060
Autoclaved Aerated Concrete	500	1.100	550
FC sheet (compressed)	1700	0.900	1530
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

Table 2. Time Lag Figures for Various Materials[2]

Material	Thickness [mm]	Time lag [h]
Concrete	250	6.9
Autoclaved Aerated Concrete	200	7.0
Rammed Earth	250	10.3
Compressed Earth Blocks	250	10.5

The effect of using heat generated during the day to heat at night in winter and vice versa in summer is known as the 'thermal flywheel' effect. The effectiveness of the flywheel depends on the time lag introduced to a building by a boundary element, in this case the green roof.

2.2. Moisture content

The moisture content of the soil affects the extent of heat lost through evapotranspiration. In cases

[1] Note: Figures are based on a number of sources and include estimations and interpolations.
[2] Source: Baggs, SA, JC, DB. 1991, Australian Earth Covered Buildings.

of wet soil, one can notice that heat can be drawn out of a building where evapotranspiration effects are high [6]. The soil conductivity increases with moisture content, meaning dryer soil conditions offer better thermal insulation.

2.3. Solar reflectivity

Green roofs are able to reflect 27% of solar radiation, absorb 60% through photosynthesis and transmit the remainder as much as 13% to the growing medium [7]. Direct shading of roof surfaces and cooling the ambient air are two important phenomena that provide more thermal comfort. This thermal benefit is the result of solar heat gain decrease through transpiration and photosynthesis.

The surface temperature of conventional roofs can reach very high values in the summer; exposed area of a black roof can reach 80°C when the equivalent area beneath a green roof is only 27°C [8]. Green roofs cool through latent heat loss and improved reflectivity of incident solar radiation. Albedo is defined as the ratio of total reflected to incident electromagnetic radiation. Green roofs cool as effectively as the brightest possible white roofs, with an equivalent albedo of 0.7–0.85, compared with the typical 0.1–0.2 of a bitumen/tar/gravel roof. Over 10 month period, the albedo of the concrete roof became 27% lower, of the fiber cement roof 20%. Older roofs are almost black with an albedo as low as 0.1. This means an even more pronounced temperature difference between green roofs and conventional roofs.

By measuring the air temperature at various heights above the green roof, Wong found that after sunset the ambient air temperature above the vegetation was reduced significantly and continued to cool the ambient air throughout the night. The hard ground however reradiated the stored heat, increasing the ambient air temperature [3].

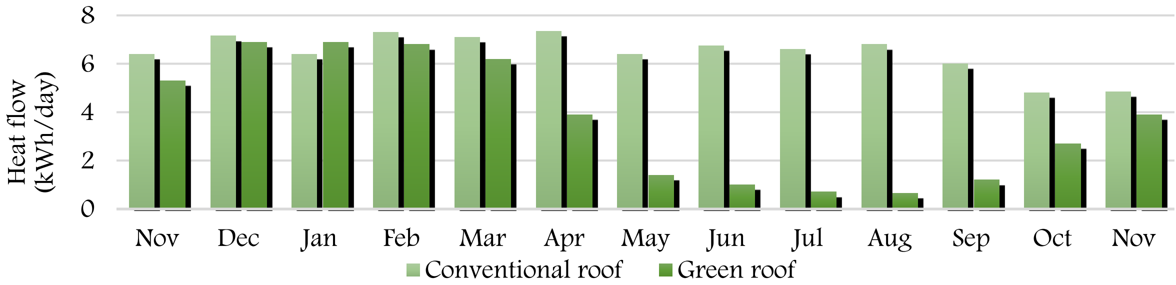

Figure 1. Average Daily Heat Flow through Green Roof and Conventional Roof Systems[3]

The heat flux through the green roof is affected because of foliage shading, soil thermal resistance, evapotranspiration, etc., which influences the building energy demand and the indoor and outdoor thermal conditions. The summer and winter temperatures on the exterior surface of the roof slab are less extreme, and their fluctuation amplitude is lower than that of a conventional roof.

3. RETROFITTING

The majority of current buildings in Serbia were built before regulations for insulation requirements existed. This led to the conclusion that many buildings in Serbia have much lower insulation levels if any at all. It can, therefore, be assumed that the additional insulation of a green roof will result in better energy savings for less insulated, older buildings. In retrofitting the existing buildings with green roofs, the issue of dead loads increase and structural failure is considered an important obstacle. Commercial and institutional buildings are normally repaired/refurbished every 10–15 years and do not require planning permission. This provides a great opportunity for the building owner to green the roof, the additional loads associated with an extensive green roof (typically about 120–150 kg/m^2) do not require any additional strengthening. Kosareo and Ries [9] performed a comparative environmental life cycle assessment of the green roof. They compared an intensive green roof, an extensive green roof and a conventional ballasted roof. The increased roof lifetime of 45 years compared to the control roof lifetime of 15 years, along with the thermal conductivity of the growing medium were found to have a significant impact on the life cycle analysis. It was concluded that although initial costs were high, the energy and cost savings made over the building lifetime meant that the green roof was an environmentally preferable choice.

Carter and Keeler [10] identified that if the energy costs increase, or green roof construction costs decrease, or storm water prevention becomes a higher public priority, then green roofs will become more economically attractive. They also noted that the positive social benefits of planting green roofs should not be overlooked and provide additional incentive to the decision process.

[3] Source: National Research Council of Canada 2003.

4. CONCLUSION

Green roofs save energy due to increment of shading. These architectural features also save energy due to better insulation, improves the thermal comfort of users (both indoor and outdoor), damper the solar radiations by absorbing more than a half of them through photosynthesis, reduce the air conditioning energy between 25% and 80% depending the climate, and absorb lower irradiative temperature in comparison to other conventional types of roofs. In addition, green roofs decrease the surface temperature of the roof from 30°C to 60°C in most cases. The summer and winter temperatures on the exterior surface of the roof slab are less extreme, and their fluctuation amplitude is lower than that of a conventional roof. Thus, the thermal stress applied to roofing membranes is substantially limited, which improves their longevity. Buildings that have concrete slab structure can withstand 8 – 10kN/m² of dead load, which is adequate to support a growing medium up to 0.80 m.

Many energy losses annually due to lower insulation levels if any at all, in old buildings are the reason there is a high potential for retrofit of buildings with the green roof in the Serbia, although more support from the government's regulations and policies are needed, especially financial supports, education and popularization. Green roof can improve the insulation properties of a building, hence reduce annual energy consumption and benefit from all of the above mentioned.

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