TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue Special II, September, 2022

CONTRIBUTIONS ABOUT THE ENERGY EFFICIENCY USING GREEN ROOFS FOR A SPECIFIC OFFICES BUILDINGS IN OLTENIA

Veronica IORDAN, Madalina CALBUREANU, Adriana IONESCU, Diana CALBUREANU, Raluca MALCIU

Abstract: *This study presents the advantages of using green roofs for a specific office building from the II winter climatic zone and III summer climatic zone of Romania in increasing the energy efficiency through decreasing the consumption on the necessary of heat in winter season and the cooling energy during summer season. There is used an extensive green roof and it is presented a comparative analysis between this green solution and the classical one. There are presented the comparative consumptions for these two solutions in order to determine the advantages for the construction sector to implement the green solution on the large scale in our country. The purpose of this research was to describe the solution of specific kind of the green roof and to highlight the effects on roof heat and mass transfer provided by this solution.*
Key words: *green roof, energy efficiency, heat and mass transfer*

1. INTRODUCTION

Using the green roofs in buildings has a lot of advantages including an energy efficiency by saving on fuel used for heating and cooling and by providing a natural water filtration process. In the same time these green solutions increase in biodiversity, providing *habitat corridors*, reducing stormwater runoff and reducing the *urban heat island effect*. Because these solutions increase green space and biodiversity, they provide individuals a psychological sense of wellbeing. A study conducted in the United States in 2011 found that big green roofs might reduce heat transfer through a building by an average of 13% in the winter and 167 percent on average during the summer, considerably improving a building's thermal insulation [1]. It was shown that the extended roof displayed a wider range of temperature changes for a temperate environment. The intensive roof type was anticipated to be more insulating since it had a deeper developing base, and this was generally the case. However, the expansive roof was superior during the winter since the herbaceous plants held more snow accumulation.The researchers then predicted that the canopy shade and plant selection may be more important than the depth of the growing substrate for providing thermal insulation for buildings [2].

Reductions in heat gain during cooling months from the green roof are significant, about 75%. In the heating months the green roof allowed for reductions in heat loss, but they were fairly low, around 8%. From these results it appears that the green roof is more effective at reducing cooling loads than it is at reducing heating loads [3]. In comparison to a substrate that is more firmly packed, a green roof substrate that has fewer air gaps offers higher insulation [4]. It is also important to consider the materials that make up the growing substrate's thermal conductivity values.

The benefits of using green roofs are very extensive and include visual comfort, significant value for fresh air, and energy savings for cooling and heating. In terms of energy conservation, when sunlight strikes a roof, some of it is reflected back to the sky or onto nearby buildings, and some is absorbed by the roof. For instance, a typical roof surface may reflect 30% of the sunlight, and according to the rules of thermodynamics, the remaining 70% must be passing through.

The green terraces reflectivity is treated likewise other materials in physics, related with all wavelengths of sunlight: visible light, ultraviolet radiation, and infrared (long-wave) radiation. [5]

If it is chosen one kind of green roof, the location of it, what are the vegetation is growing on it, the energy for cooling and heating can be determined.

2. HEAT AND MASS TRANSFER FOR GREEN ROOFS

For analysis was chosen an office building from the II winter climatic zone and III summer climatic zone of Romania, Oltenia zone. Oltenia has a temperate climate with well-defined seasons; winters are cold with snowfall and summers are relatively hot. May through August was regarded as the cooling season. Accordingly, the heating season was defined as lasting from October through March. In the fig. 1, the processes for heat and mass transport in a green roof are shown and include the following elements for both the inside and exterior:

- Heat absorbed or released by high mass layers;
- Conduction heat transfer through roof system;
- Mass heat transfer – evaporation;
- Convection heat transfer with ambient air;
- Long-wave radiation heat transfer to sky/atmosphere;
- Reflected solar radiation;
- Solar radiation heat addition.

The layers consist of the following elements, starting at the top:

1. The most complicated form of life is foliage, which employs every natural mechanism for regulating heat, including convection, evaporation, conduction, solar reflectance, radiative heat emission, and thermal mass. In order to save even more heat, plants can also defoliate their leaves in the winter.
2. Stem gap: The space created by the air between the foliage and the top of the planting media allows for only a tiny amount of heat to be conducted between the foliage and the roots.
3. Planting medium transmits heat and frequently has enough thermal mass to warrant consideration. If moist enough, it can also chill through evaporation.
4. Drain layer: Depending on how moist it is, the drain layer conducts heat differently.

The drain layer can play a more important part in mass transfer, which is the process of removing heat from saturated media by giving hot water a channel to drain. As a side note, this can also work in the winter to the contrary effect by quickening snowmelt and avoiding ice damming.

5. Waterproofing - The membrane offers some thermal mass and straightforward conduction.
6. Insulation (if required) - Insulation has very little thermal mass and inhibits the transfer of heat.
7. Roof deck: Although it can have a high thermal mass, the roof deck only offers simple conduction.[5]

Three characteristics [2]—which were used as input parameters in this analysis—make a green roof a good thermal insulator:

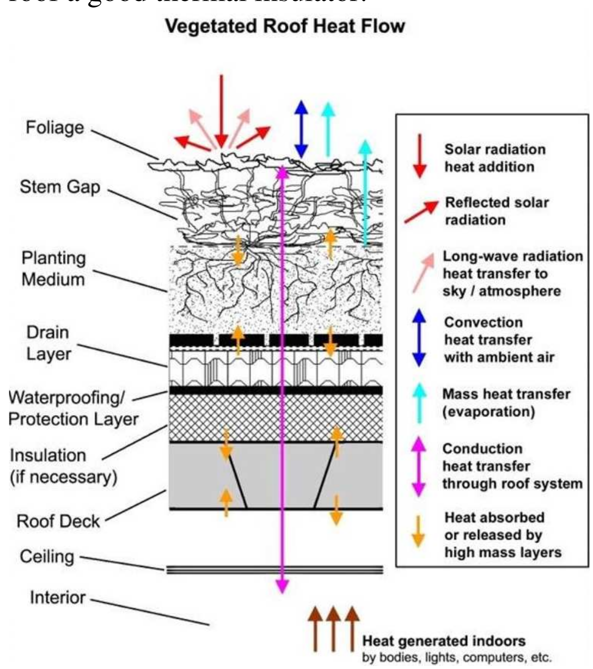

Fig. 1. Modes of Heat Transfer through Generic Green Roof [5]

a) The thermal resistance of the roof terrace is increased by the additional green roof layer on top of the roof membrane. In the same time, the depth of the green roof substrate can influence the thermal resistance of a building. Intensive green roofs provide greater insulation than vast green roofs because they increase the thickness of the building more than extensive green roofs do. Comprehensive green roof is included in this analysis. The plant canopy shields the roof surface and reduces light absorption.

b) The choice of plants has a significant impact on how large the canopy shadow is. According to one research from 2010, a building's green roof's heat flux (heat transfer) results were as follows:

- 0 kJ/m^2 for shrubs, 15.6 kJ/m^2 for trees,
- 29.2 kJ/m^2 for turf, 86.6 kJ/m^2 for soil with no plantation and
- 366.3 kJ/m^2 for the typical roof material [6].

Wider-leafed plants may shade a larger area, reducing the heat flow through the roof.

c) The plants and the substrate also contribute to cooling of the roof by a process called *evapotranspiration*: the process of water vapor being released into the atmosphere from land. Rainfall is absorbed by plants and substrates, which then vaporize the water molecules. The air in the area cools as a result of this process. The amount of evapotranspiration might vary depending on whether or not a green roof is watered.

For this process it is necessary to use the fundamental physical law: Conservation of Mass which simply states that the amount of water evaporating from a roof must equal the amount of water put on the roof by rain, irrigation, dew, e.g. A big amount of liquid water goes in through the roots – almost a half of amount and the other half of water vapour comes out through the stoma to remove the heat (thus the term mass heat transfer). The quantity of heat removal equals the heat required to evaporate that half pound of water.

The weight of the deck, medium, and plants determine nearly all of the total thermal mass.

It is mandatory to have in mind that the building is specific in losing heat or cool so the green terrace is chosen related to the location of building, of its design. This induces that the energy savings of the entire building are based on all of these factors. The specific values of energy savings are determined as part of a whole-building energy model.

In an office building a lot of gains are given from the people, light, computers. For a classic insulation it is very clear that all layers resisting to heat transfer during the winter. It is also necessary to think this aspect for entire year. The heat transfer works in both directions so the amount and the layers of a green roof should be determined for every building and location.

Accordingly to [5] there are following principles for green roofs:

1. Foliage employs every heat-transfer mechanism provided by nature to maintain a temperature that is only a few degrees above that of the surrounding air. If it is unable to accomplish this, the plant either becomes dormant, perishes, or changes into a cactus. This means that it is reasonable to predict that a green roof with active, healthy vegetation will remain quite close to the present ambient temperature. When the plants remain dormant in colder climates, it will generally be slightly warmer than the ambient temperature. The surface of a green roof may be correctly replicated as a nearly perfect solar reflector during the summer and with a reasonably high emissivity - 0.9 for active vegetation and 0.7 for dormant green - for those who appreciate performing the energy calculations thanks to this attribute of foliage.

2. The thermal mass dampens diurnal temperature variations more effectively as it increases. This indicates that, with an extensive green roof, the soil's center may be considered to constantly be close to the season's average temperature overall, especially if the soil can continue to be wet. This impact is lessened with depth for extended green roofs and also depends on the temperature, the density of the media, and the quantity of insulation underneath the green roof. Depending on one's interest in factors like accuracy and precision, this component demands some technical talent for constructing energy estimates.[5]

3. COMPARATIVE ANALYSIS OF GREEN ROOF AND CONVENTIONAL ROOF

Using an extensive type of green roof there were performed the analysis of energy efficiency in order to determine the advantages of this solution in front of the conventional type of roof.

The building office has the following input parameters:

- Built-up area: Ad = 90 m^2
- Usable area of heated spaces: Ah = 64.08 m^2
- Heated volume: Vh = 179,42 m^3
- House ground floor height regime

The characteristics of the extensive type of green roof are presented in the table 1:

Table 1

The characteristics of the extensive type of green roof

Characteristics	Column 2 Extensive roof
Thickness (cm)	5-15
Pressure (kg/m^2)	60-150
Substrate type	coarse
Irrigation layer	Not required
The drainage layer	Does not have a separate drainage layer
Vegetation layer	Grasses, succulents and mosses, the slopes used are generally local plants, is not necessary to import plants from other geographical regions
Applicability	Area with sufficient precipitation

For thermal resistances for those two solutions – extensive green roof and conventional type of terraces the comparative values are presented in the table 2.

Table 2

The thermal resistances values (R) and corrected ones with thermal bridges (R') for extensive type of green roof and conventional solution

Type of roof	R [m^2K/W]	r	R' [m^2K/W]
Green roof	8.273	0.872	7.214
Conventional solution	6.088	0.876	5.331

Using the Methodology for calculating the energy performance of buildings, reference Mc 001/2006 (reviewed) and for the same type of building installations, the comparative heating and cooling energy consumptions were calculated, and the results are shown in table 3.

Table 3

The energy efficiency parameters for extensive type of green roof and conventional solution

Energy efficiency parameters	Extensive green roof	Conventional terrasse
R'med	3.112	2.677
Qh,fin	23807.43	27089.32
EpCO2h	1323.759	1506.241
Ep h	34060.84	38756.17
QF,fin	1135.98	1915.383
EPCO2F	272.465	459.405
EPF	1329.097	2240.998

In the table 3 there are presented:

- the thermal resistance on the entire envelope – R'med [m^2K/W],
- the final energy consumption for heating – Qh, fin [kWh/y],
- the primary energy consumption for heating - – Eph [kWh/y],
- the GES from heating - $EpCO_2h$ – [kg/y],
- the final energy consumption for cooling
- QF, fin [kWh/y],
- the primary energy consumption for cooling - EpF [kWh/y],
- the GES from cooling – $EpCO_2h$ – [kg/y].

4. RESULTS AND DISCUSSIONS

There is used an extensive green roof and it is presented a comparative analysis between this green solution and the classical one. There are presented the comparative consumptions for these two solutions in order to determine the advantages for the construction sector to implement the green solution on the large scale in our country.

The advantages using the extensive green roof are:

1. Extended life of the roof –reducing maintenance costs, protects the roof from weather [7];
2. Reduced building's overall heating energy consumptions through extra roof insulation with 13.78% - Fig. 2;
3. Reduced building's overall cooling energy consumptions through extra roof insulation with 68.61% - Fig. 3;
4. Aesthetically pleasing – provides building users a green space [8];
5. Improved air quality for the people because green roofs lead to reduced carbon dioxide and other pollutants. The GES reduction

from energy consumptions is also in a percentage of 16.28%.

Stormwater built-up on conventional roofs can lead to overflowing of sewage systems which can result in flooding because the conventional roof surfaces are impermeable. Green roofs can be useful with reducing the quantity of stormwater runoff by absorbing some of the water and releasing it through evapotranspiration [9].

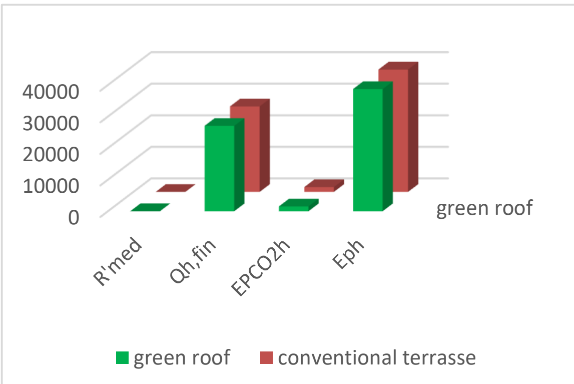

Fig. 2. Thermal resistance, final energy consumption for heating, GES from heating and primary energy consumption for heating, for green roof and conventional terrace

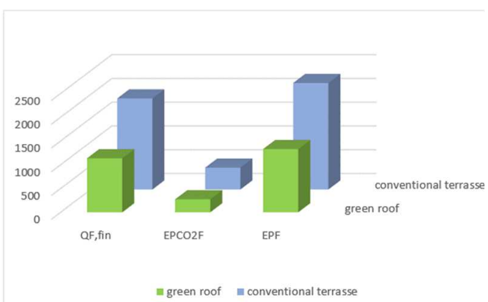

Fig. 3. Final energy consumption for cooling, GES from cooling and primary energy consumption for cooling, for green roof and conventional terrace

It is also important the way to design the green roof, the way to do the selection of plants, of materials of the growing substrate layer. The irrigation method is also a heavy parameter. With good knowledge it is possible to get to the most successful results and providing the appropriate insulation for buildings.

5. CONCLUSION

This study well established that green roofs provide insulation benefits for buildings. Of course, it is important to note that the conclusions related with energy efficiency of a green roof is applicable for the specific region. Although there are some known generalities on how to build a green roof for different climate regions, there is necessary all the time to use a *green roof specialist* for each individual project. Expertise and understanding of the local climate and ecology are necessary to construct a highly effective green roof.

For analyzed offices building from Oltenia Region using an extensive green roof instead of the conventional solution the energy efficiency is remarkable: building's overall heating energy consumptions reduction is 13.78% and cooling energy consumptions reduction is over 60%. The GES reduction from energy consumptions is also in a percentage of 16.28%.

As an important conclusion about the extensive green roof type should provide better insulation for a building than the conventional type of insulation, better mass transfer beside the advantages related with biodiversity and health for the people. Choosing a selection of plants that provide the maximum amount of shade, and a growing substrate composed of materials with low thermal conductivity and with low density led to a better choice in designing the buildings in our area.

6. REFERENCES

[1] Getter, K., Bradley Rowe, D., *Seasonal heat flux properties of an extensive green roof in a Midwestern U.S. climate,* Energy and Buildings, 43, pp. 3548–3557, 2011.

[2] Mert Eksi, Bradley Rowe, D., *Effect of substrate depth, vegetation type, and season on green roof thermal properties,* Energy and Buildings, pp. 174-187, 2017.

[3] Dyanna Becker, D., Wang, D., *Green Roof Heat Transfer and Thermal Performance Analysis,* Civil and Environmental Engineering Carnegie Mellon University, 2011.

[4] Pianella, A., Clarke, R.E., *Steady-state and transient thermal measurements of green roof substrates,* Energy and Buildings*,* 131, pp. 123-132, 2016.
[5] Wark, C., *Cooler than Cool Roofs: How Heat Doesn't Move Through a Green Roof,* Green Roof Energy Series from 2010-2011 online on greenroofs.com.
[6] Bowler, D., Buyung-Ali, L., Knight, T., Pullin, A., *Urban greening to cool towns and cities: a systematic review of the empirical evidence,* Landscape and Urban Planning, 97(3), pp. 147-155, 2010.
[7] Dowdey, S., *What is a Green Roof?,* How Stuff Works, from: https://science.howstuffworks.com/environmental/green-science/green-rooftop.html, 2007.
[8] Hongming He, Jim, C. Y., *Simulation of thermodynamic transmission in green roof ecosystem,* Ecological Modelling, 221, pp. 2949–2958, 2010.
[9] National Park Service, Technical Preservation Services, *What is a Green Roof?* from: https://www.nps.gov/tps/sustainability/new-technology/green-roofs/define.html.

CONTRIBUȚII PRIVIND EFICIENȚA ENERGETICĂ A UTILIZARII ACOPERȘURILOR VERZI PENTRU O CLĂDIRE DE BIROURI DIN OLTENIA

Abstract: Acest studiu prezintă avantajele utilizării acoperişurilor verzi pentru o anumită clădire de birouri din zona climatică de iarnă II și zona climatică de vară III a României privind creșterea eficienței energetice prin scăderea consumului de căldură în sezonul de iarnă și de energie de răcire în timpul sezonului estival. Se foloseste un acoperis verde extins si se prezinta o analiza comparativa intre aceasta solutie verde si cea clasica. Sunt prezentate consumurile comparative pentru aceste două soluții cu scopul de a determina avantajele implementarii soluției verzi pe scară largă în țara noastră, pentru sectorul construcțiilor. Scopul acestei cercetări a fost de a descrie soluția unui anumit tip de acoperiș verde și de a evidenția efectele asupra căldurii acoperișului și transferului de masă oferite de această soluție.

IORDAN Veronica, PhD student, University of Craiova, Faculty of Mechanics, veronicaiordan81@gmail.com, +40251416630, 107, Calea Bucuresti, 200072, Craiova, Dolj, Romania.
CALBUREANU Madalina, Professor, **corresponding author**, University of Craiova, Faculty of Mechanics, madalina.calbureanu@gmail.com, +40251416630, 107, Calea Bucuresti, 200072, Craiova, Dolj, Romania
IONESCU Adriana, Lecturer, University of Craiova, Faculty of Mechanics, adita_i@yahoo.com, 107, +40251416630, 107, Calea Bucuresti, 200072, Craiova, Dolj, Romania.
CALBUREANU Diana, Master's student, University of Craiova, Faculty of Mechanics, diana.calbureanu@gmail.com, +40251416630, 107, Calea Bucuresti, 200072, Craiova, Dolj, Romania
MALCIU Raluca, Lecturer, University of Craiova, Faculty of Mechanics, ralucamalciu@yahoo.com, +40251416630, 107, Calea Bucuresti, 200072, Craiova, Dolj, Romania.