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ENERGETIC INFLUENCES OF GREEN ROOFS ON BUILDINGS: A REVIEW

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Abstract: *The main purpose of this paper is to present a review of the energetic influences of green roofs on buildings. The direct energetic influences of green roofs on buildings are related to the influences on the air temperature inside and outside of the building, the roof surface temperature, the heat flux transferred into the building through the roof, the albedo value of the roof. Indirect energetic influences are related to the costs with the heating and cooling. This paper indicates that the influences on the parameters presented above are dependent on the type of the green roof used. In literature, green roofs are considered to be a passive cooling method rather then a thermal insulation method.*
Key words: *green roofs, temperature, energy, heat transfer.*

1. INTRODUCTION

In the current global warming period, urban areas face with rising of average air temperature from year to year. Because of this fact urban areas are named “urban heat islands”. To mitigate this phenomenon a vegetation layer with a growing medium can be placed on the top of the buildings. When these layers are applied on classical roof surface the roof is named "green roof" ([1], [2], [3], [4]).

Most of residential buildings have a large roof area which is exposed to the solar radiation all day time. This means that during a day, the roof temperature can rich high values and accumulates heat, which is transmitted inside the building. In this way the air temperature inside the building rises. To mitigate the rising of the air temperature can be used the active or passive cooling methods or systems. One of the passive cooling methods of a building is considered to be the green roofs. These are considered to be a passive cooling method more than an insulating method because the amount of energy saved in summer (energy used by air conditioning devices) is grater then in winter (energy used for heating) ([5], [6]).

By converting classical roofs into green roofs it can be obtained a lot of benefits, like reduction of air temperature inside and heat flux transferred inside the building during the summer, reducing energy consumption of air conditioning systems, increasing albedo value of the roof ([3], [4], [6 - 10]).

The main purpose of this paper is to present a review of the energetic influences of green roofs on buildings.

2. BACKGROUND

The most common structure of green roofs, presented in fig. 1, is made by five layers:

- root barrier system,
- drainage system,
- geotextil membrane (soil filter),
- growing medium (e.g. soil), and
- vegetation ([1], [11]).

These layers are emplaced on the roof concrete slab which was previously waterproofed.

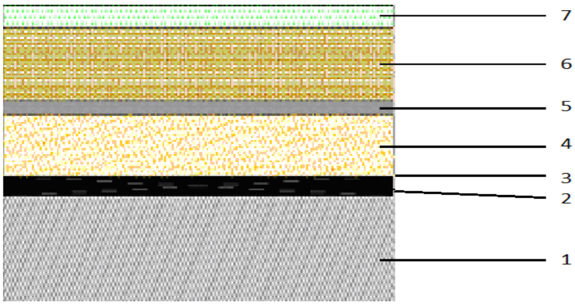

Fig. 1. Green roof structure
1 - Classical roof concrete slab; 2 - Waterproof membrane; 3 - Root barrier; 4 - Drainage layer; 5 - Geotextil membrane; 6 - Growing medium layer; 7 - Vegetation layer;

Green roof are divided in three categories, depending of the soil layer thickness: extensive, intensive and semi-intensive ([6], [12], [13]).

Extensive green roofs are characterized by applying a growth medium with a thickness up to 15 cm. This type of green roof involves choosing less demanding plant species that do not require major maintenance (e.g. watering, weeding) and the thickness of the growing medium mentioned before is too small to develop normally. In this case, the vegetation recommended to be used is *sedum* or *ruderal plant species*. The maximum weight of this type of green roof can reach up to 170 kg/m^2 ([12], [13]).

Intensive green roofs are characterized by a thickness of growing medium higher than 15 cm. This weight of this type of green roofs is in range between 732 kg/m^2 and 970 kg/m^2. With such a weight on it, buildings roof structure is subjected to high load applications. Vegetation that can be placed on intensive green roofs is varied: lawn, flowers, perennials, shrubs, trees. Intensive green roofs are more difficult to maintain than extensive green roofs due to vegetation that is suitable for the growth medium thickness adopted; vegetation of intensive green roofs requires permanent irrigation and weeding ([12], [13]).

Semi-intensive green roofs represent the boundary category between the two major categories presented before. Semi-intensive green roofs have a growing medium thickness around 15 cm covered by a layer of vegetation that can be composed by turf grass and/or shrubs. Maintenance of this type of green roof is less demanding than intensive green roof, but the necessity of an irrigation system remains. The weight of a semi-intensive green roof is about 170 to 290 kg/m^2 ([13]).

3. THERMODYNAMIC AND ENERGETIC PARAMETERS WHICH ARE AFFECTED BY THE PRESENCE OF GREEN ROOF

After studying specialized literature in the field of green roofs, were identified 5 parameters influenced by the presence of green roofs on buildings roof. These parameters directly influence the thermo-energetical activity of the buildings. Identified parameters are:

- external air temperature;
- interior air temperature;
- classic roof surface temperature;
- buildings roof surface albedo value;
- heat flux transferred through the buildings classic roof, and
- energy consumption.

Following paragraphs will present the influences of green roof on each of these parameters, influences found in specialized literature.

3.1 Influences of green roof on outside air temperature

In urban areas the trend is to replace green surfaces with black and impervious surfaces (e.g., asphalt, roofing insulation) ([1], [7]). Much of the urban area is covered by buildings, roads and other paved surfaces ([14]). Roof area of an urban area is estimated at about 20-25% of the total to ([7]).

In circumstances where the roof surface buildings, streets and paved surfaces have a low coefficient of reflection of sunlight temperature shows an increasing trend ([1], [6], [11], [15], [16], [17]).

Specialized literature present also that there are differences between urban air temperature and the temperature from rural sites. Some of these differences found in literature are presented in table 1.

Table 1
Differences between urban air temperature and rural air temperature.

Reference	$t_u - t_r$ [°C]
[7]	2.5
[18]	5.6 - 9
[15]	5
[26]	5.5

t_u – urban air temperature; t_r – rural air temperature

The studies presented in specialized literature suggest that the air temperature at vegetation level is lower than air temperature at hard surfaces (concrete, asphalt) ([6], [7], [19], [20]).

During the winter, in urban areas, the environmental air temperature from the places dominated by vegetation can be lower with up to 1.5°C than the air temperature from the places dominated by hard surfaces ([7]).

During the summer, the lower values of temperature in places dominated by vegetation can be attributed to the phenomenon called "evapotranspiration" ([7]).

3.2 Influences of green roof on inside air temperature

Climatic parameters of environment, like outside air temperature and wind velocity, have direct influences on the heat transfer through the buildings envelope, and by this indirect influence on inside air temperature.

By turning a classic roof into a green roof the increasing of inside air temperature can be delayed ([6], [21]). Also, the presence of green roof can reduce the fluctuations of inside air temperature ([22]).

A green roof with a 10 cm thickness of soil layer it is equivalent with 5 cm of normal insulation ([23]).

An experiment presented in ([24]) showed that a green roof can reduce the air temperature inside the building with a medium value of 2.4°C. The maximum reduction of air temperature was observed between hours 13:30 – 15:30.

In ([16]) is presented that in 5% of total registered values during the experiment (developed between 30.06. – 17.08.2008), the air temperature inside the building with green roof exceeded 30°C.

In same period the air temperature inside the building with classic roof exceeded 30°C in 18% of entire registered values.

The air temperature inside the building covered with green roof was lower than the air temperature outside the building with 4.4°C, while in case of the building with classic roof the difference between the two temperatures was 2.8°C ([24]).

3.3 Influences of green roof on classic roof surface temperature

During the daytime period, classic roofs store a quantity of heat from the solar radiation (depending of roof colour). This leads to the increase of classic roof surface temperature. The classic roof surface temperature can be reduced by transforming classic roof into a green roof ([24], [25]).

The temperature of uncovered classic roof surface can reach 70°C, while the classic roof surface temperature, measured under the growing medium of green roof, can reach 25°C ([26]).

The reduction of classic roof surface temperature after the green layer are been installed may be caused by the evaporation of water from soil and vegetation layer photosynthesis, transpiration and respiration ([27]).

A green roof is capable to reduce the classic roof surface temperature fluctuations between day and night. For example, in winter, classic roof (black colour) temperature variations was around 30°C, while the same surface temperature variations of covered roof was around 10°C. During the summer the uncovered classic roof surface temperature can vary with opt to 60°C between day and night, while the covered classic roof surface temperature (measured under the soil layer of green roof) vary with up to 20°C ([7]).

Some of the results found in specialized literature regarding the classic roof surface temperature and its variation between day and night in the presence or absence of green roof are presented in table 2.

Table 2

Results presented in specialized literature

Reference	T_S [°C]		$\Delta T_{S\,max}$ [°C]	
	Green roof	Classic roof	Green roof	Classic roof
[24]	36.2	56	19.8	
[6]		80		
[28]	13.1 – 22.5	≈70	2.1 – 6	
[29]	25	≈70		
[30]		50		
[7]			10	30 – 60
[31]	39.4	51.7 – 57.5		

T_S – classic roof surface temperature; $\Delta T_{S\,max}$ – maxim value of classic roof surface temperature variation before day and night

From results presented in table 2 it can be easily observed the efficiency of green roof regarding the reduction of classic roof surface temperature.

3.3 Influences of green roof on roof surface albedo value

Any object has the property to absorb and reflect solar radiation. This capacity of an object to reflect the light is described by a reflection coefficient, called *albedo*, which is a dimensionless fraction. Surfaces with high values albedo indicates a high capacity of a that surface to reflect the light. The values of albedo coefficient are between 0 and 1; the value of albedo for a perfectly black body is 0 ([32]).

Albedo value of a roof surface directly influences the roof surface temperature. High values of roof surface albedo prevent the increasing of roof surface temperature. Indirect influences of albedo value of roof surface can be remarked on:

- environmental air temperature,
- heat transfer through the classic roof of a building, and
- lifetime roofs waterproofing membrane.

Low values of albedo for roof surface lead to increasing of environmental air temperature, heat flux transfer through the roof ceiling and decrease the lifetime of roofs waterproofing membrane (because of high variations of its temperature between day and night).

Because of them black colour, the most of classic roofs surface temperatures achieve 70°C (as was showed previously). There are two possibilities to mitigate the rising of roofs surface temperature:

- increasing the roof surface albedo value,
- shading the classic roof surface, in order to create a barrier against the solar radiation.

By transforming a classic roof into a green roof, the classic roof surface is entirely shaded. The albedo value of a green roof is higher than classics roof albedo ([16]).

Specialized literature present values of albedo for different types of roofs. Some of them are presented in table 3.

Table 3

Albedo values for different type of roofs

Reference	Green roof	Classic roof (bitumen)	White color roof
[7]	0.2	0.05	0.6
[33]	0.15		0.74
[34]	0.15 ÷ 0.32		

As it can be seen in table 3, albedo values for green roof are lower than white surface roofs and higher than classic roof covered with bitumen.

Regarding the roof surface albedo values, green roofs are a better solution than the classic roofs. Green roofs albedo values are higher than the classics roofs albedo up to 6 times, but lower than white roofs up to 3.5 times.

3.4 Influences of green roof on heat flux transferred through the buildings roof and energy consumption

External heat input and heat loss to the outside of a room is achieved by heat transfer through all surfaces of that room (floor, walls, ceiling). The largest amount of heat is lost (during the winter season) through the roof of the building and the top part of the walls, due to low density of hot air that rises to the top of the building.

Significant benefits of green roofs in terms of thermo-energetical influences on buildings were observed in warmer regions ([6], [35]).

The heat flux transferred inside the building can be reduced by transforming the classic roof into a green roof. A green is a living roof. Vegetation needs water to live. In this way green roofs temperature is controlled by the evapotranspiration process. A part of the accumulated heat from soil is transferred through the environment by evaporation of water from soil ([14]).

The study presented in ([31]) revealed that, during the warmer periods, the heat flux transferred inside the building through the green roof was lower with up to 97% than the heat flux transferred through the ceramic and metallic roofs. Heat loss increased in case of green roof with up to 49% compared to the other two types of roof.

Table 4 present the heat flux profile for 24 hours period for a classic and a green roof ([4]).

Table 4

Heat flux profile for 24 hours period

Heat flux [W/m^2]		Classic roof	Green roof
Convection	min.	-345.1	-51.3
	max.	128.6	99.9
Conduction	min.	-444.5	-
	max.	154.5	-
Evaporation	min.	-43.6	-593.2
	max.	170.6	-26.4
Radiation	min.	-158.2	-38.8
	max.	355.1	229.5

Positive values presented in table 4 show that the heat flux is transferred from the surface of the roof to environment and negative values shows the values of heat flux transferred from environment to roof surface ([4]).

Heat flux transferred inside the building (summer) and heat loss (winter) involve energy costs with cooling and heating to maintain a pleasant climate inside the building. In hot climates, the need for air cooling inside a building led to the choice of active cooling methods. An active cooling method is an energy consumption method (e.g. air conditioning systems). This method is widespread through the world. This fact leads to an increasing of energy consumption worldwide ([14]).

By covering classic roofs with soil and vegetation, an energy economy can be realized. Green roof are considered to be both thermal insulation layer (winter) and a heat transfer barrier from outside to inside (summer).

Green roofs are a passive cooling method (for warmer periods), because don't consume any amount of energy to decrease the air temperature inside the building ([6]).

As was specified before, the albedo value of the roof surface influences directly its temperature, and, as a consequence, the heat transferred through the buildings roof and the energy used for heating and cooling. By replacing a black roof with a white or green roof was observed a reduction in energy consumption. The energy consumption reduction in case of replacing black roof with green roof was situated between 40 and 110% ([7]).

Savings in terms of energy consumption after turning classic roof into green roof were noticed in the both [10] and [37].

The cooling demand, during the summer of the buildings monitored in [10] and [37] decreased after the green roof was installed with 6 – 58%.

The heating demand, during the winter, decreased also with 2 – 17%.

4. CONCLUSION

The main purpose of this paper was achieved. This review presents the thermo-energetic influences of green roofs on buildings.

Thermo-energetical parameters influenced by the presence of green roofs on the top of buildings remarked in specialized literature are: external air temperature, interior air temperature, classic roof surface temperature, buildings roof surface albedo value, heat flux transferred through the buildings classic roof and energy consumption. Each of these parameters was independently treated; were presented results found in specialized literature to show the range of influences of green roofs on each parameter.

According to the specialized literature, green roofs are considered to be both an insulating and a passive cooling method. Some of the articles consider that green roofs are more a passive cooling method (summer) than an insulation method (winter).

In the current context of global warming "green" solutions to produce or save energy are preferred. Green roofs represent one of these solutions for saving energy.

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Influențele energetice ale acoperişurilor verzi asupra clădirilor: Sinteză bibliografică

Rezumat: Scopul principal al acestei lucrări este de a prezenta o sinteză bibliografică a influenţelor energetice ale acoperişurilor verzi asupra clădirilor. Influenţele directe energetice ale acoperişurilor verzi asupra clădirilor sunt legate de influențele asupra temperaturii aerului din interiorul şi din exteriorul clădirii, temperatura suprafeței acoperişului, fluxul de căldură transferat în clădire prin acoperiş, valoarea albedo a acoperişului. Influențe indirecte energetice sunt legate de costurile cu încălzirea şi răcirea clădirilor . Această lucrare arată că influențele asupra parametrilor prezentate mai sus sunt dependente de tipul de acoperiş verde folosit. În literatura de specialitate, acoperişurile verzi sunt considerate a fi mai degrabă o metodă de răcire pasivă decât una de izolare termică.

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