Green roof for zero energy buildings: a pilot project

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Abstract. Zero Energy Buildings (ZEBs) and nearly Zero Energy Buildings (nZEBs) can be designed from scratch or they can be obtained after deep refurbishments of existing constructions. Both passive and active strategies are fundamental to achieve the ZEB or nZEB target. According to this, among passive systems, green roofs can be a viable solution because they allow to achieve energy savings, also reducing the urban heat island phenomenon. In this research, an innovative roof-lawn system was preliminary analyzed by installing several measurement instruments for obtaining information about thermal heat exchanges. Heat-flow meters, surface temperature and air temperature probes were installed, comparing the performance of the roof-lawn system with a nearby simple old roof, in order to quantify the two different behaviors from a thermal point of view. The roof-lawn system revealed its advantages, showing a higher thermal inertia with no overheating and a lower thermal transmittance, as well as better indoor conditions for the occupants of the building. The study is the first step of a path which aims to design a more complex and complete system, also considering the structural part of the roof.

1. Introduction
During the last century, due to the increase of urbanization, polluting sources and industries that contribute to global warming, the Urban Heat Island (UHI) phenomenon has been strongly developed in urban areas. This phenomenon (defined as phenomenon of local thermal pollution) consists of a temperature increase in urban areas with a high building and housing density, compared to the rural areas surrounding the cities. If on one hand, it is interesting to quantify this phenomenon to be able to adequately design plants and to assess the buildings energy consumption; on the other hand it is equally interesting and important to propose interventions aimed at mitigating this phenomenon and reducing its intensity. This goal is important because the increase of the UHI phenomenon involves an increase of buildings energy consumption, especially during summer, due to the need of lowering the internal temperature. But if it is possible to control the internal temperatures, and therefore establishing the comfort conditions, what happens in the external environment it is not governable, except through mitigation interventions aimed at reducing the effects of pollution and establishing equally comfortable climate conditions. In fact, the high temperatures that can be reached in urban areas in summer can lead to significant and harmful consequences on daily life, but also on the health of human beings and, more in general, of living beings within the urban ecosystem [1-6].

Among these interventions, the effect and the thermal behavior of a "lawn-roof" will be studied in this research. In particular the thermophysical and thermal characteristics are analyzed which assesses the actual impact on the optimization of energy performance of buildings [7-10].

Due to its significant consequences, the UHI phenomenon is the topic of several scientific researches, aimed at defining its intensity and finding solutions to mitigate its effects, such as focused buildings design strategies [11-13]. Over the years, several mitigation measures were proposed to reduce the strong impact of this phenomenon on many environmental, energy, economic and social aspects. Some of these interventions are related to the correlation between the UHI and the polluting gases present in atmosphere: the goal is to reduce the amount of pollutants released into the air and energy...
consumption within urban contexts [14,15], through an intelligent design of buildings, but also through the reduction of emissions caused by means of transport or industrial industries.

Other mitigation measures are linked to the helpful effect of employing construction materials characterized by a high albedo’s value with respect to solar radiation.

Among these interventions, the effect and the thermal behavior of a "lawn-roof" will be studied in this research. In particular, its thermophysical characteristics and thermal behavior are analyzed revealing the actual impact on the optimization of energy performance of buildings. The roof-lawn system demonstrates its advantages, showing a higher thermal inertia with no overheating and a lower thermal transmittance, as well as better indoor conditions for the buildings occupants.

Therefore, it is possible to affirm that a green roof is able to improve the thermal inertia of a roof, consequently improving the quality of the internal comfort and decreasing energy consumption. Furthermore, a green roof, if installed in areas characterized by significant urbanization, can contribute to the mitigation of the Urban Heat Island phenomenon in the surrounding environment, and has the advantage of being capable of absorbing fine dust and polluting gases in the atmosphere.

The study is the first part of a wider study which aims at designing a more complex and complete system, also considering the structural part of the roof, and at defining the green roof effects and applicability under a nearly zero energy buildings perspective.

2. Material and method
The monitoring campaign was carried out on a green roof installed on a single-story building, located in Aprilia (LT), a small town close to Rome (climatic zone D). The aim of the study is assessing the benefits and the thermal characteristics of the green roof using an experimental approach. It is an innovative patent, which exploits the characteristics of a species of the Zoysia genus, characterized by a very slow growth. The system is equipped with a sub-watering, wells, a pump for the water circulation, water-drain pipes and an eaves for the water recovery, all in a close hydraulic system.

The green roof was installed on half the roof of the building, with a proper insulation layer following the producer procedure, while the other half was left in the original condition. The building is an old construction (office use), characterized by a concrete slab with a thickness of about 8 cm (considered without tiles), reinforced, and covered with tiles. The two rooms have the same exposure and the same occupation rate.

In order to investigate the thermal behavior of the green roof and to determine the characteristics of the system in terms of thermal transmittance, attenuation and phase shift, an instrumentation for measuring air temperatures and surface temperatures was installed. The measurement system enables the monitoring of the thermal behavior of the roof, thus making possible to evaluate its performance and to understand the benefits that can derive from the installation of this kind of system.

To make clearer the sensor installation scheme, figure 1 shows a graphical representation of the measurement system. All the instruments are connected to data-loggers, which record the measured parameters every 10 minutes, for 24 hours a day.

**Figure 1.** Simplified representation of the measurement system (section of the investigated building).

Table 1 shows the technical details of the employed measuring apparatus.
Table 1. Technical specifications of the measuring instruments.

| Measuring instrument          | Manufacturer | Model  | Measuring range | Resolution | Accuracy |
|-------------------------------|--------------|--------|-----------------|------------|----------|
| Heat-flow meter               | Hukseflux    | HFP01  | -2000÷2000 W/m² | 0.01 W/m² | 5% on 12 h |
| Thermometer                   | LSI          | Pt100  | -40÷80 °C       | 0.01°C     | 0.10°C (0°C) |
| Surface temperature probe     | LSI          | EST124 | -40÷80 °C       | 0.01°C     | 0.15°C (0°C) |

3. Results and discussion

The measuring instruments were installed on the 20th September 2018, and the parameters registration started on the same day. The first monitoring phase was carried out from the September 20th until the 4th October 2018. The measurements conducted in the autumn season, a period that can be defined as "transitional" from the summer season (characterized by high temperatures) to the winter season (characterized by cold climate conditions), show a stable thermal behavior of the part of the roof on which the roof-lawn was installed. In fact, observing figure 2, the external and internal surface temperatures trends (dashed green curves) are always clearly distinguished among each other, with no overlapping. Moreover, the external surface temperatures of the original roof (characterized by tiles and represented by the black dashed curve) show higher maximum values compared to the green roof, with extremely marked temporal fluctuations, typical of a structure characterized by a low thermal inertia. Comparing the external surface temperatures of the two roofs and the outdoor air temperatures (continuous red curve) it is possible to notice that the surface temperature fluctuations of the original roof are in phase with the outdoor air temperature. This cannot be observed making the same comparison between the surface temperatures of the green roof and the outdoor air temperature.

Aiming at carrying out a more detailed analysis, figure 3 shows the trends of the thermal flows and the indoor air temperatures, distinguishing them from the surface temperatures, for a shorter time, from September 30th to October 4th.

Starting from the heat fluxes’ comparison, it is possible to observe a greater stability of the green roof (with positive heat flow values). On the contrary, original coverage shows wide fluctuations of the thermal flow trend, with positive and negative values, typical of a light structure subject to thermal inversion phenomenon (Fig.3).
The higher stability of green roof behavior in terms of thermal performance can be deduced observing the trend of indoor air temperatures over time (Fig. 3). The indoor environment covered by the green roof shows an almost constant air temperature value compared to the air temperature value measured in the room under the original roof.

Taking into account a longer period of time, from 4th October to 3rd December, Figure 4 shows the trend over time of the heat fluxes that characterize the behavior of the green roof (green dotted curve) and of the original roof (black dotted curve), as well as the temperatures of the respective indoor environments (continuous green and black curves, respectively) and outdoor air temperatures (red continuous curve). Comparing the indoor air temperature values, it is possible to observe that when the external climate conditions become colder (November), the air temperature of the environment covered by the green roof is higher, demonstrating a good thermal insulating behavior of the roof-lawn. In addition, taking into account the original roof, it is possible to notice a significant variation of the heat flow values (positive and negative values), related to a worst thermal insulating behavior of the roof. The rooms exposure is the same, as well as the occupation rate, due to this the internal gains are comparable and do not provide any different contributions on the air temperature values.

Moving to the measured data processing, the thermal conductance (C) of the original roof and the one related to the green roof were calculated. Furthermore, the thermal resistances (R) and the thermal transmittance (U) were obtained. Figure 5 shows the thermal conductance trends related to the green
roof, the original roof and the roof-lawn layer obtained by means of the progressive average method suggested by the standard ISO 9869-1.

![Figure 5](image-url)  
Figure 5. Thermal conductivity of green roofs, original roof tiles and grass only.

Table 2 summarizes the values obtained by the data processing, in terms of thermal conductance, thermal resistance and thermal transmittance. The percentage difference found between the thermal resistances of the green roof and the original roof is equal to 50%. This means that the original roof is characterized by a thermal transmittance value which is about two times the value obtained for the green roof.

|                | Thermal Conductance [W/m²K] | Thermal Resistance [m²K/W] | Thermal Transmittance [W/m²K] | Percentage difference between green roof and original one |
|----------------|------------------------------|----------------------------|-------------------------------|--------------------------------------------------------|
| Green Roof     | 1.291                        | 0.775                      | 1.965                         | - 50%                                                  |
| Original Roof  | 2.587                        | 0.387                      | 3.776                         | -                                                      |

4. Conclusions
An experimental investigation was conducted on an innovative green-roof system, aiming at evaluating its thermal behavior. The acquired data reveal the actual impact of this passive solution on the optimization of energy performance of buildings. The roof-lawn system demonstrated its advantages, showing a higher thermal inertia with no overheating and a lower thermal transmittance, as well as better indoor conditions for the buildings occupants. Comparing the thermal resistance percentage difference between the green roof and the original one, a difference of about 50% was obtained. Moreover, it was observed that, due to the typical climate conditions of the cold season, the building is affected by heat losses, while, in warmer periods, the thermal inertia of the green roof guarantees heat dispersion towards the external environment. This is quite different to what happens through the part of roof covered with tiles, for which during the summer period, the incoming heat fluxes are considerable.

In conclusion, the valuable effect of a green roof is evident. This passive system allows to obtain stable thermal conditions, also reducing the building energy need. This leads to a significant improvement in terms of buildings energy performance and energy savings, both under economic and environmental point of view.

Future developments will regard experimental investigations in order to understand the thermal behavior and the benefits deriving from this passive system along the whole year.

Acknowledgment
This research has been carried out in association with the “Renovation of existing buildings in NZEB vision (nearly Zero Energy Buildings)” Project of National Interest (Progetto di Ricerca di Interesse Nazionale - PRIN) funded by the Italian Ministry of Education, Universities and Research (MIUR).
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References

[1] Castiglia Feitosa R, Wilkinson SJ, 2018. Attenuating heat stress through green roof and green wall retrofit, Energy and Buildings, 140 11-22.
[2] Mohajerani A, Bakaric J, Jeffrey-Bailey T, 2017. The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete, Journal of Environmental Management, 197 522-538.
[3] Rizwan AM, Dennis LYC, Liu C, 2008. A review on the generation, determination and mitigation of Urban Heat Island, Journal of Environmental Sciences, 20(1) 120–128.
[4] Jim CY, 2017. Green roof evolution through exemplars: Germinal prototypes to modern variants, Sustainable Cities and Society 35 69-82.
[5] Besir A, Cuce E, 2018. Green roofs and facades: A comprehensive review, Renewable and Sustainable Energy Reviews, 82(1) 915-939.
[6] Shafique M, Kim R, Rafiq M, 2018. Green roof benefits, opportunities and challenges – A review, Renewable and Sustainable Energy Reviews, 90 757-773.
[7] Teotonio I, Matos Silva C, Oliveira Cruz C, 2018. Eco-solutions for urban environments regeneration: The economic value of green roofs, Journal of Cleaner Production, 199 121-135.
[8] Huang YY, Chen CT, Liu WT, 2018. Thermal performance of extensive green roofs in a subtropical metropolitan area, Energy and Buildings, 39-53.
[9] Khabaz A, 2018. Construction and design requirements of green buildings’ roofs in Saudi Arabia depending on thermal conductivity principle, Construction and Building Materials, 186 1119-1131.
[10] Ziogou I, Michopolous A, Voulgari V, Zachariadis T, 2018. Implementation of green roof technology in residential buildings and neighborhoods of Cyprus, Sustainable Cities and Society, 233-243.
[11] Solcerova A, van de Ven F, Wang M, Rijsdijk M, van de Giesen N, 2017. Do green roofs cool the air?, Building and Environment, 111 249-255.
[12] Imran HM, Kala J, Ng AWM, Muthukumaran S, 2018. Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia., Journal of Cleaner Production, 197(1) 393-405.
[13] Yang J, Kumar DIM, A. Pyrgou, A. Chong, M. Santamouris, D. Kolokotsa, S.E. Lee, 2018. Green and cool roofs’ urban heat island mitigation potential in tropical climate, Solar Energy, 173 597-609.
[14] Zhang Q, Liping M, Wang X, Liu D, Zhou B, Zhu L, Jichao S, Jingtao L, 2015. The capacity of greening roof to reduce stormwater runoff and pollution, Landscape and Urban Planning, 144 142-150.
[15] Wang H, Qin J, Hu Y, 2017. Are green roofs a source or sink of runoff pollutants?, Ecological Engineering, 107 65-70.