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Biosolar panels: An innovative solution for sustainable construction

Pavol Knut[1*] (*orcid id: 0000-0003-3571-4436*)
Mária Kocúrková[1] (*orcid id: 0009-0001-0057-8094*)
Zuzana Vranayová[1] (*orcid id: 0000-0003-1172-6248*)
[1] Technical University of Košice, Slovakia

Abstract: Biosolar panels represent an innovative solution in the field of energy efficient and eco-friendly buildings. They combine solar technologies such as photovoltaic panels and solar thermal collectors with living ecosystems, creating sustainable structures capable of generating energy while contributing to biodiversity conservation. Biosolar panels are gaining popularity in many countries, especially in large cities striving to reduce building carbon footprints and improve environmental quality. Their applications include commercial buildings, residential complexes, and public institutions. Notable projects include the "Daramu house" in Sydney consisting of a green roof and solar panels, and the "Guardian Building" in Saint Paul, which uses smart sensors to optimize energy efficiency, and other smaller projects that will be mentioned in the article. Research projects actively explore new technologies for biosolar roofs or facades. One example is the study of integrated biotic systems and solar panels, which has the potential to enhance the efficiency of a system. This paper focuses on defining biosolar panels, highlighting their advantages and disadvantages, providing an over-view of their global utilization, and finally showcasing significant projects and research in this field.

Keywords: biosolar system, biosolar roofs, sustainable construction, energy efficiency, biodiversity, solar technologies

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Introduction

Cities dominated by impervious artificial surfaces can experience a multitude of negative environmental impacts (Hlushchenko et al., 2022; Nash et al., 2016).

* Corresponding author: pavol.knut.tuke.sk

Restoration of green infrastructure has been identified as a mechanism for increasing urban resilience, enabling cities to transition towards sustainable futures in the face of climate-driven change (Čákyová et al., 2023; Reshma et al., 2017). In urban spaces, localised energy generation through rooftop solar power has become increasingly popular, and green roofs are often used for a range of services such as thermal insulation (Fleck et al., 2022).

The integration of plants into building structures through greening of roofs has been proposed as a vital and important solution in building resilient cities. Depending on the type of green roof; they can be low cost and low maintenance making them an ideal solution for modern cities trying to compensate for air pollution and emissions, while still allowing for sustainable, low-impact urban development (Čákyová et al., 2023; Irga et al., 2022). At the same time, the integration of renewable energy, in particular photovoltaic (PV) systems, into the building fabric is important in gradually reducing the amount of electricity produced from fossil fuels (Idzikowski & Cierlicki, 2021; Sattler et al., 2020). Due to availability and economic criteria, solar panels are by far the best-known and most used method for producing sustainable electricity Moreover, the use of green roofs is gaining momentum and can be used in many ways, such as balancing rainwater, cleaning air, maintaining the ambient temperature in the building, reducing ambient noise inside and outside the building, increasing the efficiency of solar panels and other utilizations. By combining these two systems, they can be made more effective (Aasma & Kuldeep, 2022). Solar green roofs, which are rooftops covered with properly selected living vegetation and photovoltaic modules, achieve an ideal symbiotic relationship in which the promotion of biodiversity and onsite renewable energy production are enhanced (Alonso-Marroquin & Qadir, 2023; Cavadini & Cook, 2021; Ciriminna et al., 2019). There are several types of roofing that have different thermal properties. Conventional roofing materials can reach temperatures of 80°C in the summer months, while a green roof stays below 50°C. Green roof temperatures depend on the roof's composition, moisture content, geographic location, and solar exposure (Wong et al., 2011). Several researchers have studied the improvement of PV system performance by using simulation for panel orientation (Knut et al., 2022). One method for improving performance is using a green roof, which, as already mentioned, creates a unified system with photovoltaic panels. Conventional roofing materials have higher surface temperatures during summertime because the material's solar reflectance ranges between 5 and 25%, which means 75-95% of the Sun's energy is absorbed (Ferguson et al., 2008). PV panels become less efficient as they become warmer, at a rate of 0.025% per degree celsius at ambient temperatures over 28°C so panel efficiency can be improved by cooling the surface of the panel. Since green roofs are cooler than black roofs and heat up more slowly than a white roof, they are expected to keep PV panels cooler and thus operating more efficiently (Schindler et al., 2018; Shafique et al., 2020; Walichnowska et al., 2023). Initial studies on PV-green roofs were conducted by Köehler et al. in Berlin, Germany (Köhler et al., 2002). Results showed that a PV-green roof can cool down the PV surface temperature and produce 6% more electricity when compared to a bitumen roof alone (Shafigue et al., 2020). Most green roof areas remain cooler than conventional roofs in summer due to plant shading and evapotranspiration (Ferguson et al., 2008). An experimental study conducted in Chicago, IL during the summer compared the roof surface and ambient air temperatures of a green roof to a conventional roof and it found that the ambient air temperature over the conventional roof measured about 45.5°C while the green roof was 41.6°C. The green roof surface temperature ranged from 32.7 to 48.3°C while the black roof was 76°C (Alshayeb & Chang, 2018). The research team (Perez et al., 2012). compared the performance of PV panels on green roofs. These studies report that PV panels installed on a green roof have performance gains ranging from 0.5 to 4.8% compared to PV panels covering conventional roofing materials. Investigating the performance of PV-Green and PV-Black through an experimental study is enough to fulfil the lack of quantitative data that identifies the effect of roofing materials on the performance of PV panels (Chemisana & Lamnatou, 2014).

In this introduction, we have explored the significant challenges facing cities dominated by impervious artificial surfaces, while identifying important opportunities for green infrastructure renewal. Our analysis points to the benefits of integrating green infrastructure into the urban environment, particularly through solar green roofs. These roofs are not only preserved in urban areas, thereby mitigating climate change, but also localized energy production and supports biodiversity.

More importantly, our study highlighted that they not only obtain electricity, but also maintain a stable temperature in buildings and increase the performance of solar panels. The results of the analytical study show that these innovative systems can have a significant impact on the sustainability of cities and can be a key tool in building an environment with a low ecological impact. Given these insights, solar greens seem to hold a promising path to the future development of urban areas. Their further exploration and implementation can provide an important basis for creating more resilient cities in the fight against climate challenges. This study could serve as an inspiration for future research and projects in Slovakia, which will lead to a sustainable future and improvement of the environment for all residents.

1. Advantages and disadvantages of biosolar panels

The advantage of the system is environmental sustainability. Solar green roofs help reduce the negative environmental impacts of urban areas with artificially impervious surfaces by improving biodiversity and reducing emissions. The integration of photovoltaic panels on green roofs enables local production of renewable energy, which allows the city to be more independently supplied with electricity. Building thermoregulation is provided by green roofs and a stable temperature in buildings is maintained by absorbing and reflecting solar radiation, which can improve occupant comfort and reduce energy costs for air conditioning.

Greenery can improve the efficiency of solar panels, keeping photovoltaic panels cooler, which increases their efficiency and thus increases the production of electricity. Biodiversity support is also an important factor. Solar green roofs provide a habitat for plants and animals, increasing biodiversity in urban areas.

Another advantage is protection against climate change. These systems help cities adapt to climate change by improving resilience to extreme weather conditions. The disadvantage of these systems is mainly the initial cost. Installing solar green roofs requires a significant initial infrastructure investment, which can be costly for some cities. Green roofs require regular maintenance, including watering and plant care, to remain efficient and aesthetically pleasing. Another disadvantage is the limited possibility of installation. Not all buildings or houses are suitable for the installation of solar green roofs, as their structure may be incompatible with this type of system. In the case of disadvantages, we also have to consider the aesthetic impact.

Some people may find green roofs aesthetically unpleasant, which may be a barrier to their expansion in some urban areas. Installation and maintenance of solar green roofs require specialist knowledge and skills that are not always available in every city. Dependence on conditions is also an important factor in the design of this system. The efficiency of solar green roofs can be affected by a variety of factors, including weather, local climate and geographic location, which can cause fluctuations in their performance.

2. Scope and method of the analysis

The first study was conducted by a research team from Kansas (Alshayeb & Chang, 2018). In a field experimental study conducted by the research team, the relationship between building roofing materials and photovoltaic panels on the roof of the Center for Design Research (CDR) was thoroughly investigated. The research team investigated how different types of roofing materials affect the performance of photovoltaic panels by focusing on comparing PV panels over a green roof (PV-Green) and over a black roof (PV-Black). The experimental configuration included nine PV panels above each type of roof (Fig. 1). The angle of inclination of all panels was set to 10° to the south in order to maximize the collection of solar energy. The average dimensions of the photovoltaic panels were 1.65 m x 0.99 m. Each panel was equipped with an Enphase M250 microinverter, which allowed the team to monitor the precise energy production. The team installed multiple types of sensors for thorough data collection (Fig. 2). PV Bottom Surface Temperature (UST) sensors were placed in the center of each PV panel to accurately measure the surface temperature. Ambient temperature (AT) sensors were placed between the roof surface and the PV panel, providing data on the air temperature near the panels. Roof surface temperature (RST) sensors were also placed in the center of each PV panel and protected from direct sunlight. As part of this study, the team also paid special attention to the thermal properties of the green roof. Special sensors for measuring the soil temperature and humidity of the green roof made it possible to monitor how the soil temperature changes depending on solar radiation and weather conditions. Data from these sensors was collected every five minutes and then averaged every hour to minimize the impact of short-term changes in weather conditions. Before starting the experiment, a set of thorough calibration tests were performed to ensure the reliability and consistency of the measurement results. These tests provided the research team with reference values for panel temperatures and performance before the study began, allowing for the detection of even the smallest changes in the thermal behavior of PV panels over different types of roofs.

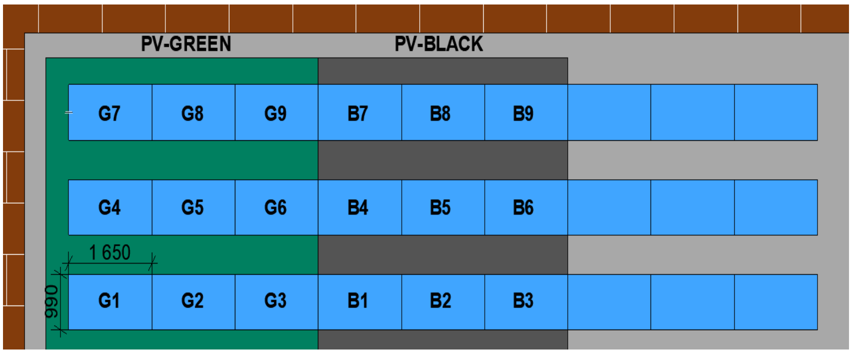

Fig. 1. PV panel installation schematic (*Alshayeb & Chang, 2018*)

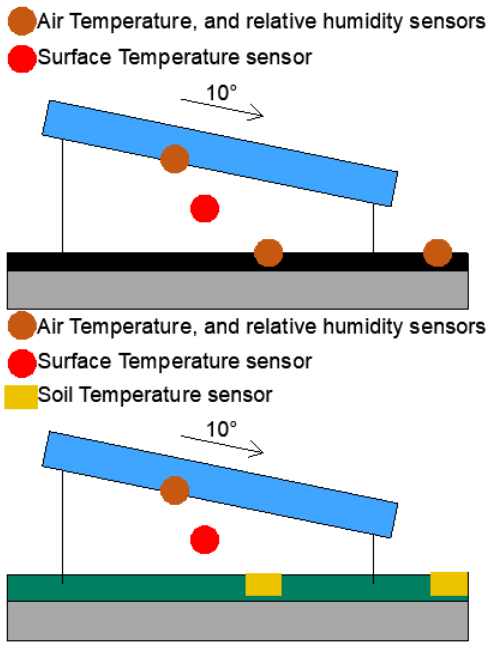

Fig. 2. Locations of sensor types schematic (*Alshayeb & Chang, 2018*)

This first comprehensive study provided important insights into the interaction between photovoltaic panels and different roofing materials, which may lead to better use of solar technologies in the future (Alshayeb & Chang, 2018).

The second study was conducted by a research team in the South Bronx, NY (Perez et al., 2012). A research team comprised of students from the Smith campus and BDCA was tasked with designing and building model homes that were then used in the study (Fig. 3). Each house was equipped with a different type of roofing: a control house with a clay layer, a house with a green roof, a house with a simulated photovoltaic roof, and a house with a green roof and a simulated photovoltaic roof. The students also helped set up the data collection system, analyzed the collected data, and prepared study proposals and initial findings for Columbia University students.

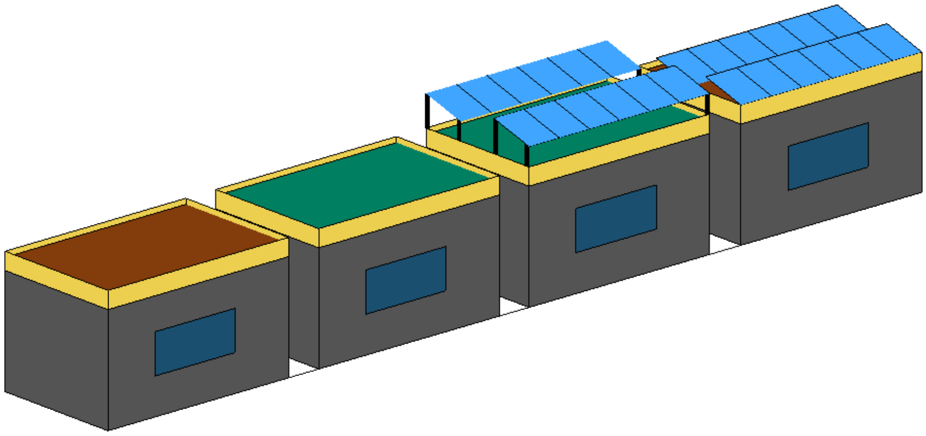

Fig. 3. The four test houses. From left to right: gravel roof, green roof, GRiPV-c, gravel + PV (*Perez et al., 2012*)

A special monitoring system was built to achieve goals and comparable data. Four monitoring devices were placed next to each other, each of which was aimed at collecting the data needed to increase the performance and efficiency of the GRiPV-c system. In addition, a pyranometer sensing structure and sensors for measuring ambient temperature and relative air humidity were built, which were located together with monitoring devices. Each "house" was built by the students using a structural framework of (5 cm x 5 cm) pine square boards, (6.4 mm) plywood and wrapped with (25 mm) rigid foam for insulation. Each house was then painted matte black to absorb as much sunlight as possible, and the temperature changes recorded by the data collection devices were clearly visible. On the roof covered with clay, they monitored the internal temperature and the temperature of the roof near the surface. On a house with a standard green roof, the internal temperature and the temperature of the green roof at the surface were monitored. Sedum boards were used as the material for the green roof. The clay and PV panel roof was designed to mimic a standard solar roof installation on a multi-layer roof structure. The monitoring parameters of this device included the internal temperature, the temperature of the roof near the surface, and the temperature outside the module. Photovoltaic panels were created from black painted Plexiglas rectangles tilted at an angle of 45° from the horizontal plane. Monitoring parameters for the GRiPV-c roof included the internal temperature, the roof temperature near the surface and the temperature of any part of the module.

In addition to the sensors on the houses, the ambient values of relative humidity and temperature and the intensity of solar radiation in the plane of the photovoltaic panels were also measured using thermometers and a Licor pyranometer. All parameters were originally to be taken at 15-minute intervals throughout the study.

3. Results of the research

In the first study, the research team focused on the energy production and thermal performance of the PV-Green and PV-Black modules during several days of research analyses. They examined differences in energy profiles, focusing on days with the highest, average and lowest performance values.

The results showed that PV-Green roof achieved a maximum energy production of 1868 Wh and PV-Black roof 1801 Wh during the 4th-5th June. Compared to the PV-Black roof, the production of the PV-Green roof was 3.7 to 4.1% higher. Similar patterns were observed for solar radiation. Temperature differences in the area of the ambient temperature reached up to 2.6°C and under the surface up to 4.2°C. Other days, 15th-16th June, demonstrated differences in energy production of up to 3.3% to 4% between the PV-Green and PV-Black roofs. With a maximum output of 1733 Wh for PV-Green roof and 1666 Wh for PV-Black roof, a difference of 67 Wh and 54 Wh was observed. Temperature differences reached 4.3 and 3.3°C at ambient temperature and 2.8 and 2°C below the surface. During the 19th-20th July, differences of 2.5 to 2.8% were observed between the PV-Green (1715 Wh) and PV-Black (1627 Wh) roofs. In the temperature range, differences of 0.5 to 2.6°C were observed in the ambient temperature and 1.9 to 2.8°C below the surface. Analyses from 3rd-4th April showed differences in output of 1.5 to 0.8% between the PV-Green (1795 Wh) and PV-Black (1735 Wh) roofs. Temperature differences were 1.4 to 2.1°C at ambient temperature and 2.2 to 2.8°C below the surface.

Based on thorough analyses, it is clear that the energy production and thermal performance of the PV-Green and PV-Black solar modules depend on the date and external conditions. These differences in outputs and temperatures underscore the need for careful monitoring and consideration of circumstances when designing and installing solar systems. The research team recommends further studies and testing to better understand these variabilities and to improve the efficiency of solar power in different conditions.

In the second study by the New York research team, temperature data was evaluated and it was found that the GRiPV-c house had lower variability and lower average temperatures for each parameter. During the period from 30.05.2011 to 25.01.2012, the variability of temperatures inside the house with a clay roof was 5.83% higher (10.0 versus 9.45°C) than the variability of temperatures inside the house with a GRiPV-c roof. Similarly, the average temperatures inside the house with the clay roof were 4.61% higher than inside the house with the GRiPV-c roof (18.4 versus 17.6°C). Average surface temperatures were 2.24% higher (19.3°C) on the clay roof than on the GRiPV-c roof (18.9°C). The variability of surface temperatures was 1.98% higher on the surface of the clay roof (10.2°C) than on the roof with GRiPV-c (9.9°C). Most importantly, the research team saw a 2.42% increase in photovoltaic system performance (in terms of generated electricity) with the temperature parameters of the JAMS(L) 72-180 module. For a 500 kW GRiPV-c system in New York City that produces 60,900 kWh/year, a 2.42% increase in output means an additional $88,500 in revenue over its 30-year lifetime. If just 10% of the 70 MW projected by the PlaNYC and NY Solar America Cities Initiative team were GRiPV-c, that would represent $1.2 million in incremental revenue over the system's 30-year life cycle. The team concluded that GRiPV-c technology can lead to significant increases in yield and is a potential direction for the future of photovoltaic systems.

4. Future research

Based on this research from around the world, we would like to do similar research in Slovakia, in the area of the Technical University of Košice, specifically in the building of the university library (Fig. 4).

Fig. 4. Experimental areas of green roofs, Technical University of Košice (*own photo*)

In regards to sustainable energy and green technologies, space opens up for several future research directions. While the current project would investigate the influence of the climate zone on the performance of photovoltaic systems, the next step may be to expand the research to different climatic areas of Slovakia. Comparing the performance of systems in different regions can provide detailed insights into the adaptation of specific technologies to climate requirements. Research can better continue to try to understand the optimal design of green roofs for use with photovoltaic systems. Whether its plant species, substrate or other factors or improving the design can increase yield and ecological benefit.

In the field of photovoltaic technologies, new materials and technologies are constantly being developed. Future research could include exploring these innovative approaches and applying them to green roofs. New materials can improve the efficiency and durability of photovoltaic panels.

Conclusions

Biosolar panels enable buildings to produce their own electricity and heat, reducing their dependence on traditional energy sources. Additionally, they enhance indoor environments and contribute to improved air quality. Furthermore, they promote the growth of plants and wildlife, positively affecting ecosystems. One disadvantage of this system is the cost and expertise required for their design and implementation. Moreover, they may not be suitable for all building types and locations. The research team at the Technical University of Košice plans to actively continue researching photovoltaic systems on green roofs. These future directives aim at sustainable development, improvement of energy supply and reduction of ecological impact, taking into account different climate zones and the needs of the city and rural areas in Slovakia. These studies have the potential to contribute to a better and more sustainable environment and energy solutions for future generations.

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