Survey of biosolar roofs in the world

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Abstract. In this article, we will continue our study on biosolar roofs. Biosolar roofs have become an inspiring system for us because it creates a sustainable place and reduce carbon emissions. This types roofs are different from classic green roofs in that it uses a renewable source of energy, in this case the Sun, and produce electricity that we can supply the building with. What is interesting is that the vegetation stored under the photovoltaic panels can use evaporation to cool the panels and therefore increase their efficiency. We know from the world that biosolar roofs are not so widespread due to implementation factors such as initial costs and limited experimental data. It is very important that new experimental studies be carried out to evaluate the performance of this system in urban areas. Another important factor that should not be forgotten is location of the system. It is necessary to know all climatic conditions before implementing the system. In this article, we will focus on the benefits of this type of roofs and how the system can improve the energy efficiency of photovoltaic panels and reduce CO2 emissions with long-term benefits.

1 Introduction

Photovoltaic panels represent a prime example of renewable energy sources available on-site. Their simplicity in deployment and ability to function independently of microclimatic conditions make them a favored choice [1]. Broadband photovoltaic panels specifically find extensive application as environmentally friendly components in architectural designs [2 - 4]. This trend is particularly noticeable in regions with abundant solar radiation. Nonetheless, despite these advantages, the efficiency of PV panels remains relatively low compared to other renewable energy generation systems. Even with the most advanced technologies, the efficiency of solar PV panels struggles to surpass the 30% mark [5]. Various factors, including the lifespan of the PV system, choice of materials, and operating temperature, continue to influence the overall efficiency of PV systems [6]. Several strategies have been employed to enhance the energy efficiency of the building. These strategies encompass the implementation of green roofs, low-E glazing, and daylighting. Among these methods, green roofs stand out for their ability to diminish energy consumption by moderating the temperature of the building's roof, thereby mitigating the urban heat island effect [7-11]. The ambient temperature can be effectively reduced through an accelerated rate of vegetation

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evapotranspiration [10]. Numerous investigations focusing on green roofs [12-15] have highlighted various social, environmental, and economic advantages. These include the promotion of recreational activities, enhancement of building aesthetics, improved stormwater management, augmentation of urban greenery, alleviation of the urban heat island effect, betterment of air and water quality, fostering biodiversity, and reduction of building energy expenses [16-18]. While numerous investigations have shed light on the advantages of improved renewable energy efficiency through PV-green roofs, there is presently a dearth of comprehensive review studies scrutinizing the benefits and obstacles of PV-green roofs at the building level. Hence, there is a clear advantage in obtaining an extensive overview of the literature focused on the performance of PV-green roof technologies, encompassing their advantages and challenges. With the aim of offering a thorough examination of the benefits and challenges associated with PV-green roofs, this review endeavors to identify recent advancements in the realm of PV-green roofs on a global scale. Such a review is poised to furnish researchers with a substantial knowledge base to propel further research endeavors in the domain of PV-green roofs, while also aiding policy makers and practitioners in facilitating the broader implementation of PV-green roofs within the context of future smart cities. In this article, we will try to point out various experimental researches from the world regarding the combination of photovoltaic panels and green roofs depending on other climate zones.

2 Aim

The PV-green roof represents a viable approach for generating sustainable energy within urban environments. Research conducted by [1] delved into the energy efficiency of PV-green roofs in Spain, highlighting that PV-green roofs outperform PV-gravel roofs in terms of energy production. Nonetheless, there exists a need to assess the efficacy of various layers within the solar power systems integrated into PV-green roofs to ascertain methods for optimizing power generation [1]. Implementing a PV-green roof, also known as a biosolar roof, is regarded as an efficient method for two primary reasons. Initially, incorporating a green roof atop a building fosters the development of fresh habitats for biodiversity, diminishes the surface temperature of the building, consequently leading to a decrease in the building's total energy consumption required for both cooling and heating purposes [19, 20]. Secondly, the fusion of a green roof with a PV system serves to cool down the surface of the PV system, thereby enhancing its energy production efficiency, particularly in urban settings [1, 21-23].

3 Methods

Research team [24] conducted a thorough examination into the impact of a roof garden, comprising shrubs, lawn, and trees, on the yearly energy usage of a commercial structure in Singapore. Employing building energy analysis utilizing, their investigation revealed that implementing a roof garden could lead to a reduction in the building's annual energy consumption by a range of 0.6% to 14.5%, with the most effective configuration being a roof garden incorporating shrubs. Furthermore, the study found that augmenting the soil thickness could yield additional reductions in the building's energy consumption. Additionally, the presence of vegetation on the roof surface was demonstrated to mitigate heat gains on the building's roof. Also team [25] corroborated similar findings at the building scale. Their research delved into the energy-saving potential of air conditioning systems in buildings equipped with green roofs across Europe. Three distinct types of green roof vegetation—grass lawn, grass, and sedge—were examined. The outcomes indicated that green roofs proved to be efficacious in energy conservation, particularly in warmer climates, owing to the vegetation's ability to intercept solar radiation. The study documented annual energy consumption reductions ranging from 1% to 11% in Tenerife, 2% to 8% in Rome, and 0% to 11% in Seville. Similarly, [26] conducted a study on the energy-saving potential of a green roof on a larger scale in Thessaloniki, Greece. Their findings revealed that green roof technology could lead to a reduction in energy consumption for heating by up to 16% and for cooling by 5%. These investigations collectively underscore the efficacy of green roofs as a technique for enhancing the energy performance of buildings situated in urban environments. Additionally, [27] explored the advantages of green roofs for energy efficiency through a comprehensive review of various studies. Their analysis suggested that green roofs could effectively decrease energy consumption in buildings with subpar insulation.

4 Results

The integration of green roofs (GR) with photovoltaic (PV) systems serves a dual purpose of maximizing PV system output power via evaporative cooling and offering additional advantages such as rainwater harvesting and enhancement of urban ecology. This synergy has been highlighted by various studies [1, 28, 30]. Furthermore, GRs contribute to mitigating the direct radiation effect caused by PV systems on building roofs. This not only aids in cooling the PV surface temperature but also helps alleviate the urban heat island effect in warmer climates. As depicted in Figure 1, the integration of green roofs with PV systems demonstrates a reduction in building energy consumption. Additionally, the process of evapotranspiration emerges as a crucial factor in enhancing the performance of rooftop PV systems. Furthermore, employing green roof technology can effectively lower roof temperatures and subsequently reduce the overall energy consumption of buildings [25]. Several investigations have highlighted that the performance of photovoltaic (PV) systems is enhanced by the presence of vegetation on green roofs. Noteworthy studies supporting this notion include those by [1, 22, 31] conducted an experiment in Berlin, Germany, to assess the efficacy of a PV-green roof featuring sedum species alongside a bitumen roof. The findings demonstrated that the PV-green roof effectively cooled the PV surface temperature and resulted in a 6% increase in electricity production compared to the bitumen roof alone. Research team [32] conducted a comprehensive investigation encompassing both simulation and experimental studies on a PV-green roof incorporating sedum vegetation in Hong Kong. Utilizing the EnergyPlus program for building energy simulation, their findings revealed that the power output of the PV-green roof exceeded that of a PV-only roof by 8.3%. Additionally, an experimental study conducted on a rooftop garden at the University of Hong Kong during a sunny summer, featuring PV systems on both a green roof and a bare roof, showcased that the PV green roof generated approximately 4.3% more electricity compared to the non-PV roof counterpart. These results provided robust support for the utilization of green roofs in conjunction with photovoltaic systems to enhance the energy efficiency of such systems.

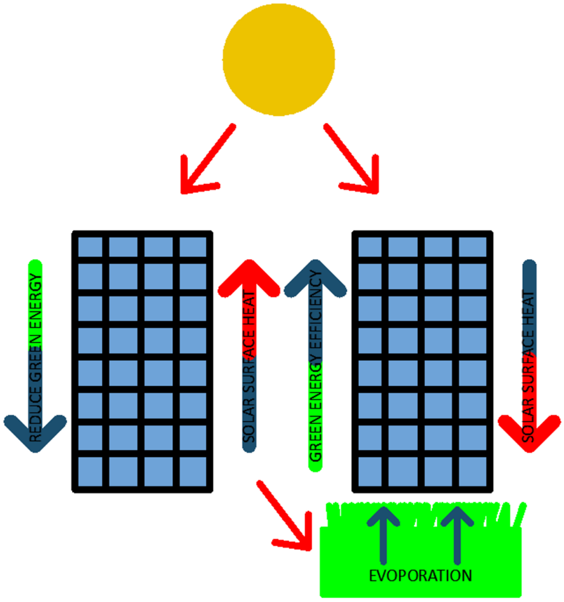

Fig. 1. PV system and PV-GR system.

A recent examination carried out by [31] explored the performance of PV-green roofs situated at the University of Kansas in Lawrence, Kansas, USA. Through a meticulous analysis of the findings, it was determined that the energy output of the PV-green roof surpassed that of the PV-black roof by 1.4%. Moreover, [31] demonstrated that integrating a green roof with a PV panel represents an optimal approach for mitigating roof temperatures. Furthermore, the outcomes revealed that the green roof was capable of sustaining lower surface temperatures on the PV-green roof over an extended duration.

A team of researchers from Australia [33] conducted an experimental study investigating the combined effects of a photovoltaic (PV) system and a green roof. Commencing in December 2021 and concluding in February 2023, the study lasted for a total of 15 months and 8 days. Due to occasional missing data, the experiment extended beyond 12 months. Throughout the observation period, sunlight exposure varied between 7 and 15 hours daily. The interaction between PV and green roof (GR) systems was scrutinized using both numerical simulations and physical models across four seasons. Assessing the performance of these systems involved evaluating thermal comfort within the building, PV panel temperatures, and energy generation. The integration of photovoltaic roofs with green roofs was found to enhance indoor comfort levels by 6% compared to traditional solar roofs. Furthermore, this combination led to a notable reduction in PV panel temperatures by as much as 8°C, thereby prolonging their lifespan, and simultaneously boosting energy output by 18%.

In comparison to standalone green roof (GR) and photovoltaic (PV) systems, the integration of a photovoltaic green roof (PV/GR) system offers notable reductions in greenhouse gas emissions and energy demand, along with increased electricity generation [34] and plant growth [20]. This combination resulted in a 28% decrease in energy demand during cold weather in Toronto, comprising 16% savings from PV-generated electricity and 12% savings in cooling and heating energy consumption attributed to the green roof [35]. Even in moderate climates, the annual electricity output from PV systems improved by 1.8% compared to conventional roofs [36]. However, the positive impact of green roofs on PV electricity performance becomes more pronounced in hot climates characterized by high solar radiation and air temperatures exceeding 25°C [28].

Conversely, the choice of plant species significantly influences the overall performance of PV-green roof systems. This is evident in an empirical investigation conducted by [1] in a subtropical climate. Their findings revealed that PV systems with sedum species exhibited a 2.24% higher power output compared to those with PV-Gazania rigens plants. However, most prior studies have focused on sedum species in PV-green roofs, indicating a need for further research to identify the optimal plant species for such systems. Additionally, a recent study by [23] proposed that regular irrigation of green roofs could further enhance the power output of PV-green roof systems, particularly in warm Mediterranean climates.

Dust poses a significant challenge that notably diminishes the energy output of photovoltaic (PV) systems [37]. This is primarily because the accumulation of dust particles on the surfaces of PV systems obstructs the passage of light through the glass, consequently reducing the efficiency of the PV system [38]. Consequently, regular cleaning of the PV system is essential throughout its lifespan to mitigate the impact of dust accumulation [39]. On average, a 200 W panel operates at approximately 93% capacity after a year due to dust accumulation, resulting in an effective output of around 186 W (200 × 0.93 = 186 W) [40]. However, it's important to note that the decline in PV system performance caused by dust is not uniform across different geographical locations due to variations in dust types and environmental factors such as precipitation, wind speed, air temperature, and humidity.

5 Conclusions

In conclusion, we would like to point out that all articles were studied in detail. Articles from around the world, from which we collected information about the photovoltaic system in combination with a green roof, served us as a good source for our future research on TUKE. The research will be carried out specifically at the university library. There are 3 experimental green areas on the flat roof of the library (Fig. 2.), on which we plan to install photovoltaic panels. The panels will be installed on the south side of the building for the best possible gain of solar radiation. First of all, we want to find out what the surface temperature of the PV panels will be in the climate zone of Eastern Slovakia. We believe that the effect of greenery will not be sufficient to cool the PV panels due to the lack of green space. This research would better help us with the issue regarding overheating of PV panels. As we already know, if the surface temperature of the panels rises above 25 °C, the efficiency of the panels starts to decrease. As a result, it is necessary to cool the system. One of the methods is the green roof which forms an excellent combination with this solar system. The next step that interests us is the symbiosis of certain types of plants. As we know, with such a system it is necessary to take into account the shading of plants. That is why it is very important to consult a plant expert, or to study articles from the world that have addressed this problem.

Fig. 2. Experimental green areas, library of TUKE.

This work was supported by the project run by the Slovak Research and Development Agency APVV-18-0360 “Active hybrid infrastructure towards to a sponge city” and by project SECOVE 101056201 “Sustainable energy centres for vocational excellence“.

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