WIT CONFERENCES This paper is part of the Proceedings of the 2nd International Conference on Energy Production and Management (EQ 2016)
www.witconferences.com

The impact of height installation on the performance of PV panels integrated into a green roof in tropical conditions

G. Osma, G. Ordóñez, E. Hernández, L. Quintero & M. Torres
Industrial University of Santander, Colombia

Abstract

This paper presents a study on the effect of the height installation of PV panels in a green roof integrated photovoltaic system (GRIPV) considering warm and humid climate conditions. According to recent work, there is mutual benefit between these two applications in temperate conditions. However, it is necessary to study this interaction in tropical conditions and to establish the significance of height as a factor of installation. Therefore, an experiment was designed using three PV panels of 250 W in portrait configuration with 10° of inclination; each PV panel uses a micro-inverter. The monitoring system can gather data such as ambient temperature, PV panel temperatures, solar radiation and electrical variables. The green roof used (440 m^2) is located on the Electrical Engineering Building of Universidad Industrial de Santander (Colombia), where the latitude is +7.1° and the ambient temperature varies between 24°C and 30°C during daily sun-time (6 am and 6 pm), while the relative humidity fluctuates between 60% and 90%. The experiment considers two height installations (50 cm and 75 cm) for both types of roof – black and green – for three weeks. According to the results, the lower height installation and the green roof increases the power output by 2.0% and 1.0%, respectively and the combined effect is nearly 2.8%.
Keywords: green roof, PV system, GRIPV, energy efficiency, tropical condition.

1 Introduction

Roofs can provide security and protection to users; however, these also have sustainability functions such as renewable energy by PV panels and thermal isolation by green roofs [1]. The implementation of these technologies are increasing mostly because their application is recognized by the LEED standard

WIT Transactions on Ecology and The Environment, Vol 205, © 2016 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/EQ160141

[2]. Hence, they can be installed simultaneously in some cases, which is known as green roof integrated photovoltaics (GRIPV) [1, 3]. Currently, there are some studies of this integration for temperature climates in summer conditions mostly.

This integration could be positive for PV systems because the green roofs reduce the surrounding air temperature, which can mitigate the negative thermal impact on PV generation when the ambient temperature is greater than 20°C. The efficiency of PV panels decreases roughly 0.4% per °C increases in PV module temperature [4].

Scherba *et al.* [1], Witmer [3], Köhler *et al.* [5, 6], Hendarti [7] and Nagengast [8] amongst others, have studied GRIPV systems. However, the existing information about these systems is limited with respect to characterization of phenomenon. Hence, it is necessary to carry out studies to analyze the influential factors such as height installation, type of roof, wind speed and inclination. In addition, the findings from these works indicate that best performance of GRIPV can occur in tropical and warm conditions.

Therefore, the following research question is addressed: what is the influence of each factor on PV performance for GRIPV systems considering tropical and warm conditions? This paper shows the first part of the experiment to answer this question, which consists of analyzing the influence of height installation (0.50 m and 0.75 m) and the type of roof (black and green).

Initially, the paper presents the thermal effect on PV output performance (Section 2). Subsequently, the design of the experiment (Section 3) and results (Section 4). Finally, the conclusions (Section 5) are stated.

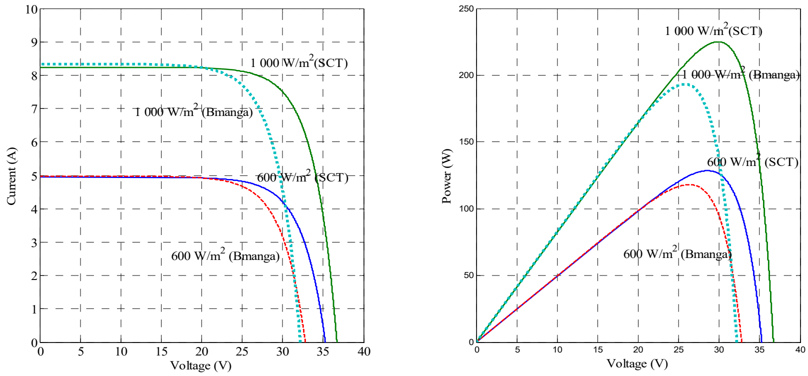
2 Thermal effect on PV output performance

The power output of PV systems depends on the technical characteristics of the PV panels, the irradiance level and the PV operating temperature. The last two factors behave in a similar way, although each one causes an opposite effect. While a greater irradiance increases the PV output, the greater air temperature reduces it.

2.1 Estimation of PV power reduction for tropical conditions

The thermal effect is more evident on DC voltage (as shown in Figure 1). This figure was established by Osma Pinto [9] using the PV thermal model and parameters of datasheet Schott Poly 225 (225 W) considering Standard Test Conditions (STC) for the tropical climate of Bucaramanga, Colombia, located at 7.1° latitude with an average ambient temperature of 26°C. The PV output reduction was near to 15% for 1000 W/m^2 and 8% for 600 W/m^2.

The thermal behavior of PV panels can be described by equations (1)–(4). The cell operative temperature given by (1) causes variation in the electrical parameters as maximum power current (I_m) and maximum power voltage (V_m), given by (2) and (3), respectively. The maximum point power (P_m) is given by (4). The temperature (T_a) and solar radiation (G) are considered hourly data during a



(a) I-V curves (b) P-V curves

Figure 1: Characteristic curves of the SCHOTT POLY 225 panel according to SCT and typical conditions of Bucaramanga (Colombia) (source: Osma Pinto [9]).

year. Technical data for $NOCT$, I_{mpr}, α_{mpr} and T_r vary with panel design, but can generally be obtained from the manufacturer. Calculation of V_{OC}, I_{SC} and R_S can be obtained from [9].

$$T_{cell} = T_a + G \cdot (NOCT - 20)/800 \tag{1}$$

$$I_m = I_{mpr} \cdot G \cdot \left(1 + \alpha_{mpr} \cdot (T_{cell} - T_r)\right)/1000 \tag{2}$$

$$V_m = V_T \cdot ln\left(1 + (I_{SC} - I_m)\left(e^{V_{oc}/V_T} - 1\right)/I_{SC}\right) - I_m \cdot R_s \tag{3}$$

$$P_m = V_m \cdot I_m \tag{4}$$

2.2 Mitigation of negative thermal effects on PV panels

There are some strategies to cool PV panels, such as irrigation [10], forced ventilation [4] and green roofs [1, 7].

Scherba *et al.* [1] indicate from simulations that green roofs reduce the surrounding temperature of roofs near to noon time in comparison with black roofs. Therefore, they are a good option to improve the typical thermal behavior of PV systems [3, 8, 11]. Also, green roofs reduce the thermal gains for the buildings.

These benefits are mostly caused by evapotranspiration (ET). According to Hendarti [7], a high ET rate is necessary to moderate the temperature of vegetation and keep it healthy during hot weather.

On the other hand, Köhler *et al.* [5, 6] described how shading from green roofs improved growth of plants and an increasing number of species. The PV panels reduce solar radiation on green roofs for which absorbed radiation is lower, despite PV panels reflecting a very low direct radiation due to technical characteristics. This improving of the performance of both systems would mean the reduction of the energy demand of an electrical network.

The PV panel reduces the short-wave irradiance on green roofs that mitigates the sensible and latent heat transfer, and consequently, the thermal stress of vegetation, such as Figure 2 describes.

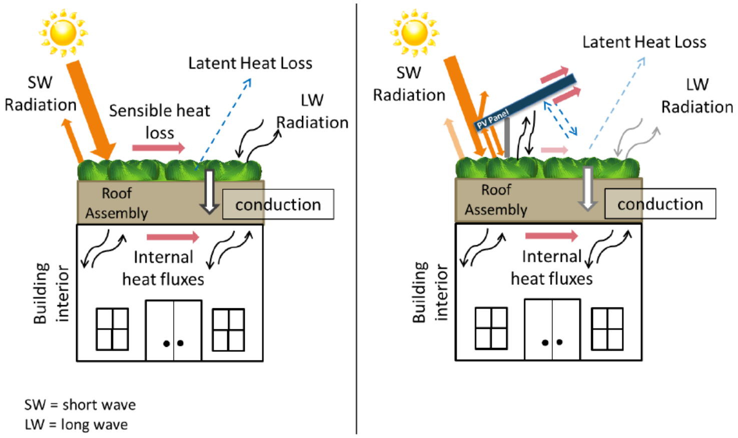


Figure 2: Schematic energy balance of green roof and GRIPV (source: Nagengast [8]).

Table 1 shows information on some monitoring work done on GRIPV performance.

Table 1: Description of works done on GRIPV.

Ref	Country (Lat., Long.)	Time	Increasing PV output with respect a traditional roof
[3]	-	1 year	0.55%
[11]	Hong Kong, China (22.4°, 114.1°)	3 hours for a sunny day (11 am to 2 pm)	4.30%
[12, 13]	New York, USA (40.7°, -74.0°)	8 months Sampling time: 15 mins	2.42%
[8]	Phoenix, AZ, USA (33.4°, -112.1°)	1 year	1.3%
	San Diego, CA, USA (32.7°, -117.2°)	1 year	0.7%
	Hunsville, AL, USA (34.7°, -86.6°)	1 year	0.6%
[14]	Lleida, Spain (41.4°, -0.6°)	10 hours for 5 sunny days	1.29% (Gazania plant) 3.33% (Sedum plant)

3 Design of experiment

The experiment consisted of a PV system of 750 W installed on the modular green roof installed on the Electrical Engineering Building (EEB) at Bucaramanga. The system is formed by three PV panels of 250 W connected to an electrical network by means of microinverters, which ensure the independent operation in MPPT mode for each PV panel.

This system was designed to carry out a factorial experiment considering factors such as height installation, wind speed, inclination and type of roof. We carried out the first part of the whole experiment in this paper. This part considered two height installation values (0.50 m and 0.75 m) and two types of roof (black and green).

3.1 Electrical Engineering Building (EEB)

The Electrical Engineering Building (EEB) of the Industrial University of Santander (*Universidad Industrial de Santander – UIS*) is located at Bucaramanga (Colombia) at 7.1°N latitude, 71.3°W longitude and 969 m above sea level. The annual average solar radiation is 4.8 kWh/m^2/day, the ambient temperature varies mostly between 20°C and 30°C and mean annual precipitation levels are close to 1 279 mm; therefore, the climate of the location is warm–dry.

The EEB was remodeled and reopened in December of 2012; the area grew from 1500 m^2 to 2 700 m^2. Currently, it has 16 classrooms on the first four levels, administrative offices on the fifth level and two green roofs on a whole area of 600 m^2. The building is oriented along an east–west axis.

The remodeling process included the implementation of several strategies in order to reduce the energy consumption such as daylighting, natural ventilation, green roofs and automation system (illumination and air conditioning). These green applications reduced the consumption density from 67.5 kWh/m^2/year to 20 kWh/m^2/year, the equivalent to a reduction of 70% or 128 250 kWh/year.

3.2 Description of experiment

The PV systems is formed by 3 PV panels of 250W; each one installed on removable green roof by trays, which allows for a black roof of 7.5m^2. The experiment considered a two-height installation – 50 cm and 75 cm. The inclination was fixed at 10°. Figures 3 and 4 present the side view and the top view of the experiment.

The generated energy is injected into the electrical network through an electrical panel on the fourth floor, since the fifth floor is supported by an emergency plant. The monitoring system of the experiment measures solar radiation, ambient temperature, and DC and AC electrical variables, such as is shown in Figure 5. Table 2 shows the components of the whole system.

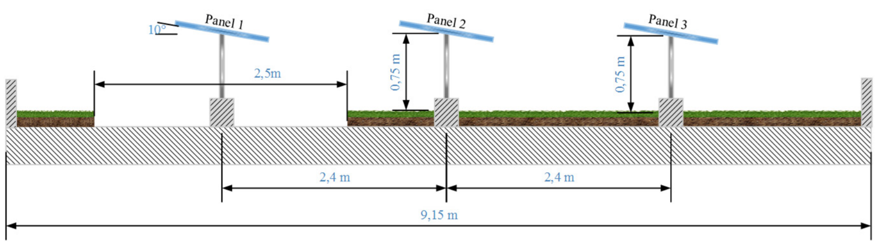


Figure 3: Side view of the PV system.

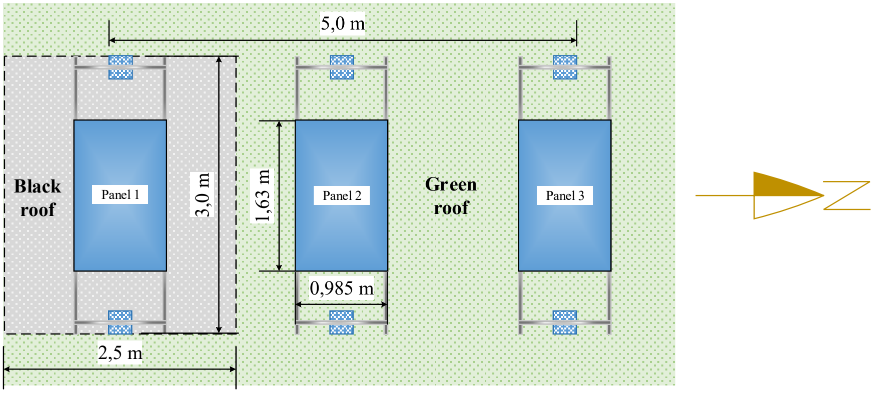


Figure 4: Top view of the PV system.

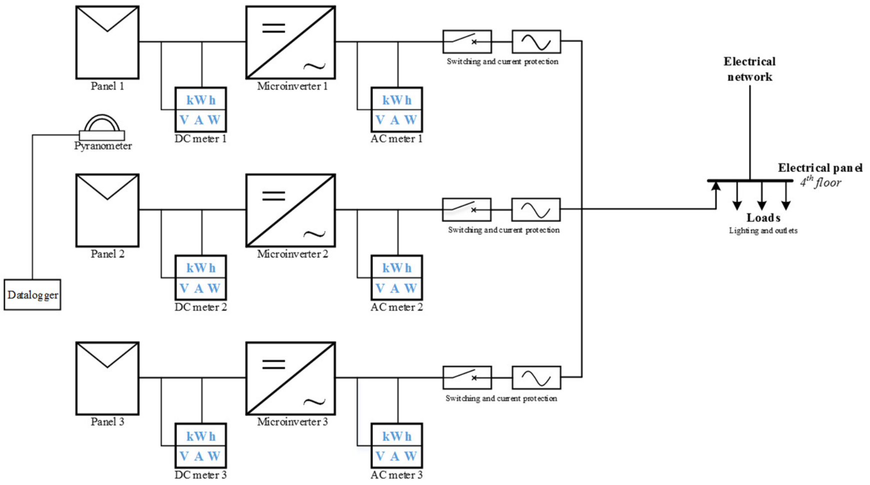


Figure 5: Diagram of the PV system and the metering solution.

Table 2: Components of the PV system and experiment.

Component	Reference	Quantity
PV panel	UP-M250P Upsolar (250W/1.0 m × 1.63 m)	3
Microinverter	Micro-0.25-I-OUT PowerOne	3
Communication module	CDD (microinverters) by Aurora	
Pyranometer	SMP3-V Kipp and Zonen	1
Datalogger	XR5-SE-20mV PACE	1
DC energy meters	Acu 243 with RS485 communication	3
AC energy meters	YTL DS-1Y UIS with Modbus communication	3

Figure 6 presents the experiment during construction. The green roof below the PV panels is formed by three *Sedum* species; the thickness of the substrate is 7cm.

The experiment consisted of the study and comparison of five cases for two types of roofs and/or two heights (as shown in Table 2). The time of the entire experiment was three weeks.

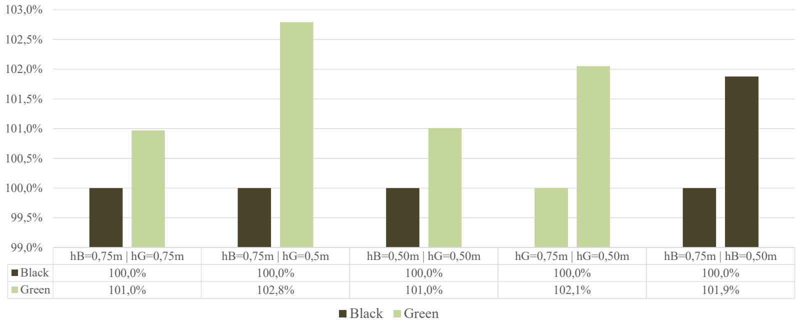
Figure 6: Actual experiment.

Table 3: Cases analyzed in the experiment.

Case	Panel A		Panel B	
	Roof	Height (m)	Roof	Height (m)
i	Black	0.75	Green	0.75
ii	Black	0.75	Green	0.50
iii	Black	0.50	Green	0.50
iv	Green	0.75	Green	0.50
v	Black	0.75	Black	0.50

4 Analysis of results

The experiment allowed us to establish the particular influence of the type of roof and height of installation for the ambient conditions considered. Figure 7 shows the results of the five cases studied. Cases one and three described the comparison between a black roof and a green roof for an installation of both heights, where the benefit on PV output is 1% caused by the green roof. Cases two and four analyzed the impact of height for both roofs. These cases indicate that the reduction of height from 0.75m to 0.5m increases the PV output by around 2%. Case five illustrates the combined effect of installation height reduction and the use of a green roof on PV generation, which generates an increase of 2.8%.



	hB=0,75m | hG=0,75m	hB=0,75m | hG=0,5m	hB=0,50m | hG=0,50m	hG=0,75m | hG=0,50m	hB=0,75m | hB=0,50m
■ Black	100,0%	100,0%	100,0%	100,0%	100,0%
■ Green	101,0%	102,8%	101,0%	102,1%	101,9%

Figure 7: Comparison of PV output performance for the five cases considered.

5 Conclusions

This experiment was conducted for tropical and warm conditions and it corroborates that green roofs causes a benefit on PV output (an increase of around 1%) for the conditions analyzed. This increase is in accordance with values established in other papers, which is relevant to consider for calculating the expected PV generation and doing the financial analysis.

Based on results of the experiment undertaken, we can see that both factors – height installation and type of roof – cause an impact on PV performance for tropical and warm conditions. A lower height and a green roof increase the PV output by 2.0% and 1.0%, respectively, and 2.8% for both factors simultaneously. These findings must be analyzed in detail to characterize the influence by other factors, such as wind speed.

Acknowledgements

The authors wish to thank the Department of Electrical, Electronics and Telecommunications Engineering *(Escuela de Ingenierías Eléctrica, Electrónica y de Telecomunicaciones)* from the Industrial University of Santander, the Vicerectorate for Research and Extension (*Vicerrectoría de Investigación y*

Extensión) from the Industrial University of Santander (Project 1605 – Support on a Doctoral Thesis) and the Administrative Department of Science, Technology and Innovation – COLCIENCIAS (Project FP44842-386-2015).

References

[1] A. Scherba, D. J. Sailor, T. N. Rosenstiel, and C. C. Wamser, "Modeling impacts of roof reflectivity, integrated photovoltaic panels and green roof systems on sensible heat flux into the urban environment," Build. Environ., vol. 46, no. 12, pp. 2542–2551, Dec. 2011.

[2] L. X. Sheng, T. S. Mari, A. R. M. Ariffin, and H. Hussein, "Integrated sustainable roof design (Proceeding)," Procedia Eng., vol. 21, pp. 846–852, Jan. 2011.

[3] L. Witmer, "Quantification of the passive cooling of photovoltaics using a green roof (master thesis)," Pennsylvania State University, 2010.

[4] M. K. Smith, C. C. Wamser, K. E. James, S. Moody, D. J. Sailor, and T. N. Rosenstiel, "Effects of Natural and Manual Cleaning on Photovoltaic Output," J. Sol. Energy Eng. Asme, vol. 135, no. August 2013, p. 4, 2013.

[5] M. Köhler, M. Schmidt, M. Laar, U. Wachsmann, and S. Krauter, "Photovoltaic-panels on greened roofs: positive interaction between two elements of sustainable architecture (Proceeding)," in Conference RIO 02 – World Climate & Energy Event (Rio de Janeiro, Brazil), 2002, no. 1, pp. 151–158.

[6] M. Köhler, W. Wiartalla, and R. Feige, "Interaction between PV-systems and extensive green roofs," Green. rooftops Sustain. communities. Minneapolis, USA, pp. 1–16, 2007.

[7] R. Hendarti, "The influence of the evapotranspiration process of green roof tops on PV modules in the tropics (Doctoral thesis)," National University of Singapore, 2013.

[8] A. L. Nagengast, "Energy Performance Impacts from Competing Low-slope Roofing Choices and Photovoltaic Technologies (Doctoral Dissertation)," Carnegie Mellon University, 2013.

[9] G. A. Osma Pinto, "Master project in Electrical Engineering: Rational Use of Energy from of the design of sustainable applications in the Electrical Building of Industrial University of Santander (Uso racional de la energía a partir del diseño de aplicaciones sostenibles en," Industrial University of Santander. Master Work advised by PhD. Gabriel Ordóñez Plata, 2011.

[10] M. K. Smith, H. Selbak, C. C. Wamser, N. U. Day, M. Krieske, D. J. Sailor, and T. N. Rosenstiel, "Water cooling method to improve the performance of field-mounted, insulated, and concentrating photovoltaic modules," J. Sol. Energy Eng. Trans. ASME, vol. 136, no. August, pp. 1–4, 2014.

[11] S. C. M. Hui and S. C. Chan, "Integration of green roof and solar photovoltaic systems (proceeding)," in Joint Symposium 2011: Integrated Building Design in the New Era of Sustainability, 2011, vol. 2011, pp. 1–12.

[12] M. Perez, W. McGillis, and V. Fthenakis, “Update: the Green-Roof Integrated Pv Canopy Study At Bronx Design and Construction Academy (Proceeding),” in Annual Conference of American Solar Energy Society 2013, 2013, p. 7.

[13] M. Perez, N. Wight, V. Fthenakis, and C. Ho, “Green roof integrated PV canopies – An empirical study and teaching tool for low income students in the south Bronx (Proceeding),” in World Renewable Energy Forum 2012, 2012, no. 1, pp. 1–7.

[14] D. Chemisana and C. Lamnatou, “Photovoltaic-green roofs: An experimental evaluation of system performance,” Appl. Energy, vol. 119, pp. 246–256, Apr. 2014.