Analysis of the impact of roof construction design on the thermal exchange and electrical performance of monofacial photovoltaic modules

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***Abstract*— This paper investigates the impact of roof construction features on thermal exchange in the electrical properties of monofacial photovoltaic modules, with special attention to Tedlar temperature. Simulations were performed in EnergyPlus to model different scenarios combining thermal properties of materials and the use of insulators, considering their ability to limit heat flow from the roof to the module. The analysis also includes variations in the most common surface tones (white, red and others) and in the structural geometries of the roof, evaluating their influence on the thermal properties of the module. Results may show that the use of thermal insulators can reduce the heat transferred from the roof to the module, but could also cause heat accumulation in the tedlar, which would affect its thermal performance. This study aims to optimize the thermal conditions of photovoltaic modules on urban roofs, proposing construction design strategies to maximize their energy efficiency in hot climates.**

Keywords—roof surfaces, insulators, thermal perfomance

I. Introduction

. When a solar cell is illuminated by the sun, it naturally heats up. The efficiency of solar cells decreases with increasing temperature, mainly due to the decrease in the open circuit voltage. While the short-circuit current density is practically insensitive to the effects of temperature (it increases slightly), the open circuit voltage decreases in the order of a few millivolts per degree Celsius of temperature increase.

Given the dependence of the fill factor on the open circuit voltage, the latter also decreases with increasing temperature. As a final result, the efficiency decreases in the order of 0.4% to 0.5% per degree of temperature increase for a silicon solar cell (0.3% for a GaAs cell) [1].

Given the dependence of the open circuit voltage on temperature, it decreases linearly with it and is described by the following equation [2]:

$$V_{oc}(T_c) = V_{oc}{}^{*} + (T_c - T_c{}^{*}) \cdot \frac{dV_{oc}}{dT_c}, \qquad (1)$$

where $V_{oc}{}^{*}$ and $T_c{}^{*}$ are the open circuit voltage and cell temperature at standard conditions, respectively; V_{oc} and T_c are the open circuit voltage and cell temperature under normal radiation conditions and finally, $\frac{dV_{oc}}{dT_c}$ is the open circuit voltage variation for each degree Celsius of cell temperature, this information is given by the manufacturer, if not, 2.3 $\frac{mV}{°C}$ is considered as standard [2].

The construction sector offers great potential to optimize the quality of both energy supply and demand. It is estimated that implementing energy efficiency measures in new buildings could reduce energy consumption by 20% to 50% on average. The roof, being the part of the building that receives the most solar radiation, can reach temperatures of up to 65°C in summer on traditional roofs, which creates several disadvantages. In addition, these hot roofs emit heat into the atmosphere, contributing to the increase in air temperature and favoring the development of the phenomenon known as the urban heat island effect [3].

Additionally, the surface temperature of urban roofs is often significantly higher than the surrounding ambient temperature due to the common use of dark-colored roofing materials, which absorb solar radiation and lead to a notable rise in the air temperature above the roof [4].

The simultaneous integration of roof insulation and photovoltaic power production has its advantages in terms of cost savings, improved power production and energy savings. As photovoltaic power generation will expand in the future, it is crucial to consider roof integration and performance for an optimal photovoltaic power installation [5].

Housing construction in Mexico predominantly relies on bricks or hollow concrete blocks for walls and low-slope concrete roofs. These elements enhance the interaction of these structures with solar radiation, particularly infrared radiation [3].

The objective of this research is to analyze the impact of the constructive characteristics of urban roofs on the thermal exchange and electrical performance of monofacial photovoltaic modules, with special emphasis on the temperature of the backsheet. Through simulations in EnergyPlus, we seek to evaluate how factors such as surface tones, the use of insulating materials and the thermal properties of the roofs influence heat dissipation and module efficiency. This research aims to propose constructive design strategies that optimize the thermal conditions of modules on urban roofs, minimizing the negative effects associated with heating and improving their energy performance in hot climates.

II. METHODOLOGY

A simulation was performed using EnergyPlus to model the thermal behavior of the system. To obtain the long-wave radiation it was necessary to consider two aspects: the geometry of both the building and the PV module, and the climatic conditions under which the measurements were taken.
It is considered a building of the Technological Institute of La Laguna. Geometry was designed using the OpenStudio extension through SketchUp. Since the interaction between the building and the module is only through the exterior of the roof, the building was modeled as a box with no additional elements, as shown in Figure 1.

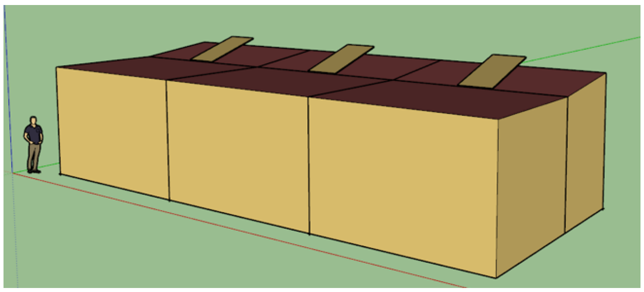

Fig.1. Building geometry for energyplus simulation

For the climatic conditions, a weather file, known as EPW (Energy Plus Weather), was generated, considering environmental conditions that reflect the climatic environment of Mexico. These variables included the latitude and longitude of the area, relative humidity altitude above sea level, atmospheric pressure, room temperature, irradiance, wind speed and wind direction. Figure 2 shows the python code for creating the weather file.

```
In [1]: import pandas as pd
        import matplotlib.pyplot as plt

In [7]: f = "../data/tabla_superficie_blanco_3.csv"
        sb = pd.read_csv(f)

In [8]:
        DATE_START = '2023-05-09 00:00:00'
        Cycles = 60*24*5  # Por ejemplo, para 1 hora de datos

        indice_datetime = pd.date_range(start=DATE_START, Cycles=cycles, freq='1Min')
        df = pd.DataFrame(index=indice_datetime)

        df['Irradiance'] = 374.8321313
        df["Room Temperature"] = 34.4
        df["Pression "]  = 90_000
        df["Relative Humidity"] = 30.
        df["Wind Speed"] = 0.
        df["Wind Direction"] = 0

        df["mdY"]  = df.index.strftime("%m/%d/%Y")
        df["HHMM"] = df.index.strftime("%H:%M")


        f = f"../epw/2023-05-10.csv"
        df[["mdY","HHMM","To","hr","ws","wd","P","Ig"]].iloc[1:] .to_csv(
            f,
            header=None,
            index=None
        )
```

Fig.2. Python code to elaborate the weather file

Material properties such as thermal reflectance, solar reflectance, density, conductivity, specific heat, roughness and thickness were modified.
Simulations were performed with these material properties and the climatic conditions corresponding to the study site. The selected output variable was the Surface Outside "Face Net Thermal Radiation Heat Gain Rate per Area", which represents the net thermal radiation exchanged on the surface of the photovoltaic module with the Backsheet. Figure 3 shows the output variable to be obtained.

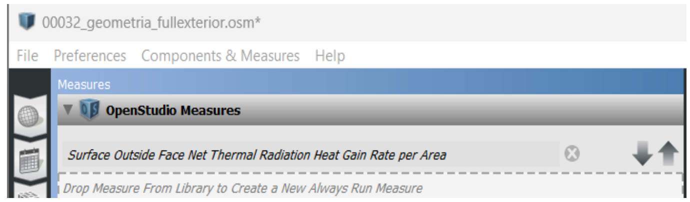

Fig.3. Face net thermal radiation output variable

III. RESULTS

These preliminary results show the incident radiation on the back of the module. The intention is to continue evaluating different configurations in order to propose strategies and materials that reduce the exchange between the roof and the module, optimizing its energy generation.

Figure 4 shows the graph of the incident radiation on the tedlar.

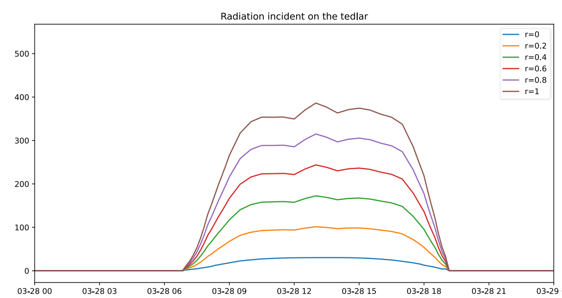

Fig. 4. Radiation inciden ton the tedlar.

From Figure 4, the first thing that can be observed is that there are different values of incident irradiance on the tedlar that cover a range of between 30 and 400 W/m², which indicates that there is a different contribution of reflectance from the roof. Likewise, it can be observed that the separation between the set of curves is more noticeable, thus there being a greater contribution of reflectance in the incident radiation on the tedlar than that found on the glass. This may be due to the fact that the viewing factor between the tedlar and the roof surface is greater than in the case of the glass. The curve with the highest irradiance is when r=1, followed by r=0.8, r=0.6, then r=0.4 and finally when r=0.2. This trend is the same as that found in Figure 4, which confirms the previously mentioned behavior where the higher the reflectance value, the higher the incident radiation.

Figure 5 shows the percentage contribution of each reflectance value to the total radiation incident on the tedlar relative to the reference value..

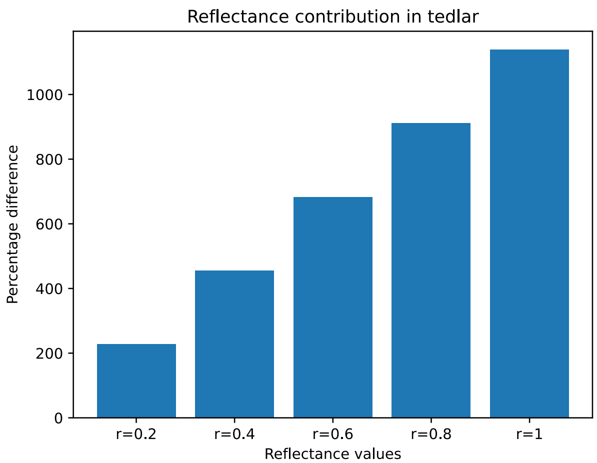

Fig. 5. Contribución de reflectancia para el tedlar.

Figure 6 shows the contribution percentages are different. The contribution for the value of r=0.2 is 227%, for r=0.4 455%, for r=0.6 683%, for r=0.8 910% and finally for r=1 1138%.

IV. CONCLUSIONS

The reflectance of a surface plays a critical role in determining the amount of incident radiation it receives, as variations in reflectance values directly influence the radiation levels on the surfaces of interest. Specifically, surfaces with higher reflectance values tend to exhibit a proportional increase in the total incident radiation. This relationship highlights the importance of considering reflectance in the design and analysis of systems exposed to solar radiation. Notably, the impact of reflectance is particularly significant for materials like tedlar, where the contribution of reflected radiation to the total incident radiation can increase by up to 1138%. This substantial effect underscores the need to carefully evaluate the optical properties of surfaces in applications where radiation management is critical, such as in the optimization of photovoltaic module performance. It is expected that by evaluating the other properties in detail, a better analysis of the heat exchange and its impact on the performance of the photovoltaic module will be obtained in order to propose improvements.

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