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OUTDOOR CHARACTERIZATION OF COLORED AND TEXTURED PROTOTYPE PV FAÇADE ELEMENTS

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ABSTRACT: The aim of this study is to assess the performance of prototype PV façade elements of various PV technologies, colors and textures. Within this context, a prototype PV façade demonstrator was constructed and monitored at SolarBEAT, Eindhoven. This prototype demonstrator consists of 9 façade PV panels of c-Si and CIGS technologies with flat and textured solar glasses and black, grey and red colors. The field-testing results indicate a limited performance drop of less than 20% for all colors and textures.
Keywords: Photovoltaic Façade, Colored Photovoltaics, Outdoor Characterization, BIPV, Solar Façade

1 INTRODUCTION

Regulations for energy performance of buildings in Europe are becoming more demanding [1]. This requires innovative approaches for integration of solar energy in the building skin. At the same time, especially for façades, the aesthetic appearance is crucial, and the architectural demands are posing a challenge for PV developers [2].

This study has been performed as part of the Interreg PV OpMaat project [2]. The aim of this project is to assess power generating photovoltaic materials, based on newly developed production methods, and tailored in a way that they can be optimally integrated in building elements. In this context, a novel prototype PV façade was constructed at SolarBEAT, the outdoor field-testing facility of SEAC [3]. This research evaluates how various textures and colors affect the performance of c-Si and CIGS PV modules and assesses different coloring techniques in order to obtain aesthetically the best possible result.

2 THE TEST FIELD

The prototype PV façade was commissioned in February 2018 at SolarBEAT, it is facing due south and will be field tested for a complete calendar year. It consists of 9 PV panels of two different PV technologies (conventional crystalline silicon and thin film CIGS), two different textures (normal flat glass and textured glass), and three different colors (black, grey and red). A schematic representation of the demonstrator can be seen in Figure 1 and the constructed PV façade demonstrator in Figure 2.

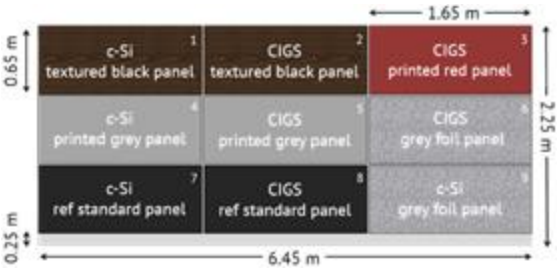

Figure 1: Schematic representation of the colored PV façade demonstrator.

Both the commercial CIGS and the custom-made crystalline silicon PV panels are 1650 x 650 mm in size while the power rating is 185 Wp for the c-Si PV reference panel and 135 Wp for the CIGS PV reference panel.

Figure 2: The outdoor colored and textured PV façade demonstrator installed at SolarBEAT, Eindhoven.

For the grey coloring, two different techniques have been used and are being compared next to each other. At first, there is the standard solar glass dot printing technique which is also being used for the red panel, as reported in other studies [5], [6]. Complementary to it, two standard black panels are equipped with a grey dot printed foil which is glued on the outer surface of the solar glass. This is a quicker and more cost effective solution having the additional advantage that it can be modified in a later stage according to the architectural wishes. Similar foils are already widely used by architects on passive facade elements of commercial buildings. In both coloring techniques used, the color print coverage was 30%.

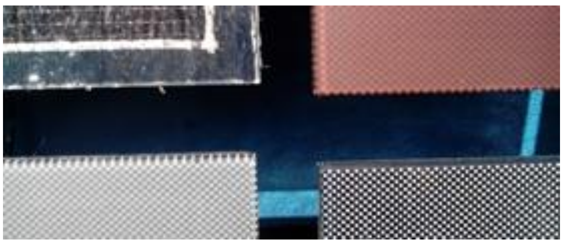

Figure 3: Close-up photo of the various CIGS panels of the prototype demonstrator. At the top left the black textured glass panel is depicted, at the top right the printed red panel, at the bottom left the printed grey panel and at the bottom right the grey foil panel.

All 9 panels are IV traced with the help of an IV tracer, therefore all DC characteristics of the PV panels can be accurately and individually measured. A secondary standard pyranometer is used for measuring the in-plane irradiance and the panels' temperatures are measured using thermocouples. The individual panels are all connected with a Power Optimizer (PO), to keep the panels in Maximum Power Point (MPP). All the PO's are connected to an inverter. The façade is facing south, and all the panels will be monitored for a complete year.

3 OUTDOOR CHARACTERIZATION RESULTS

The prototype colored PV façade demonstrator is operational since the beginning of March 2018, so already half a year of data have been recorded and analyzed and will be presented below. All data used and analyzed are DC data recorded by the IV tracer to exclude any influence of the power electronics.

The effect that colors and textures have on the performance of the PV panels can be seen in the IV curves shown in Figure 5. Among them, the red color-printed PV panel is performing least optimal followed by the grey colored PV panels of both coloring techniques.

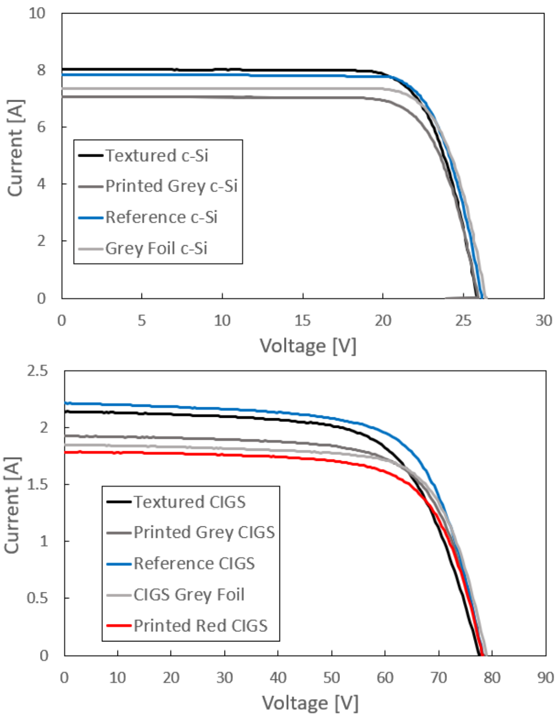

Figure 5: Measured IV curves of the c-Si (top) and CIGS (bottom) panels with various colors and textures, measured on Feb 27, 2018 at 12:00.

In order to compare the performance of the various PV panels, the DC Performance Ratio (PR) was used and compared with the DC PR of the two reference PV panels (one c-Si and one CIGS) installed at the bottom of the demonstrator [5]. The cumulative results of the first 6 months show a relative performance difference of about 9% for the grey colored PV panels of both coloring techniques and 16% for the red colored PV panel when compared to the reference PV panels. The two panels equipped with textured solar glass perform similarly to the reference PV panels if not slightly better. It should be taken into account that there might be a power rating deviation within PV panels of ± 2% according to their manufacturers, which also applies for the performance results shown in Figure 6.

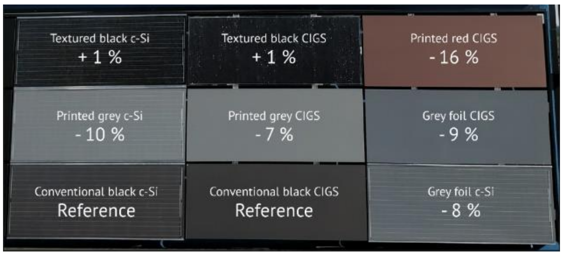

Figure 6: Cumulative DC Performance Ratio differences for all PV panels in regards to the reference ones for the first 6 months of field testing.

The monthly breakdown of the specific yield data for each PV panel is shown in Figures 7 & 8. The performance differences shown above are repeated in the data of every month with the reference and textured black panels performing similarly followed by the grey colored panels while the red colored panel is falling slightly behind.

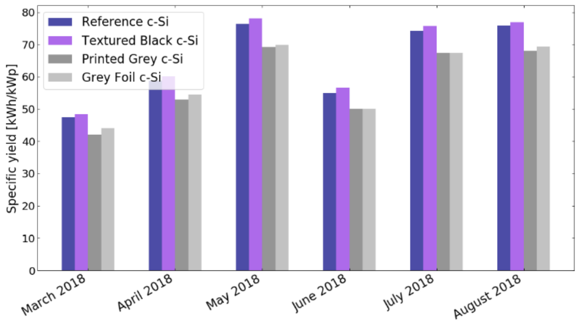

Figure 7: Monthly specific yield of the c-Si PV panels.

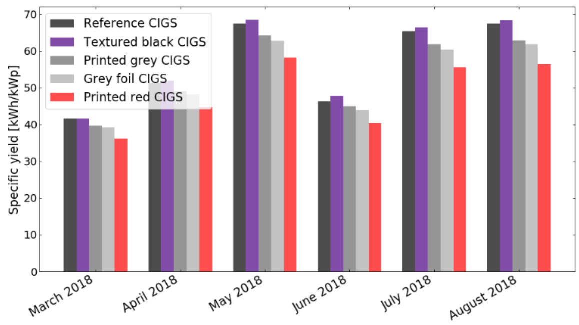

Figure 8: Monthly specific yield of the CIGS PV panels.

Temperature data analysis shows that the CIGS PV panels have higher operating temperatures than the c-Si owing to their lower efficiency, following the trends as reported in other publications [6], [7], [8]. Between them, the red colored and the textured black CIGS PV panels appear to be the hottest, with temperature differences between the 9 PV panels reaching up to 10ºC on a warm summer day as shown in Figure 9.

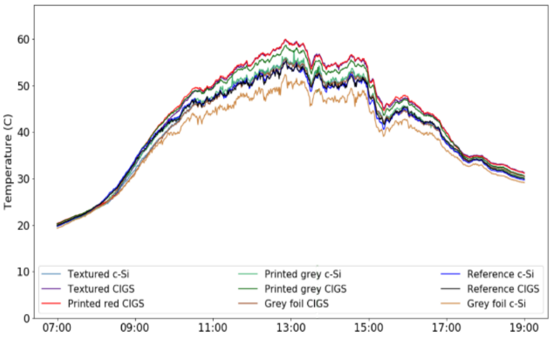

Figure 9: Module temperatures of the 9 PV panels composing the prototype PV facade demonstrator, on July 16, 2018.

More in depth analysis showed a lower performance of all CIGS PV panels under low light conditions. To further investigate this phenomenon, the DC Performance Ratio data were split into irradiance bins of 200 W/m^2. The results are depicted in Figure 10. It is clear that under low irradiances (<200 W/m^2) the DC PR of the CIGS PV panels drops significantly while the c-Si PV panels perform similarly regardless of the irradiance conditions.

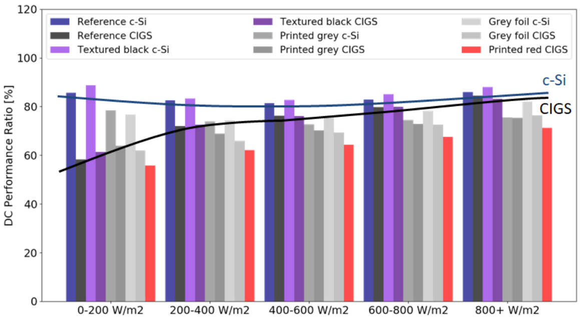

Figure 10: Performance Ratio results of all PV panels in 200 W/m^2 irradiance bins.

In order to identify the reason behind the lower performance of the CIGS PV panels under low light conditions, the Fill Factor (FF) of all panels for various irradiances was studied. In Figure 11 one can find the FF of the c-Si (blue dots) and CIGS (black dots) reference panels. It can be seen that the CIGS PV panels have generally lower FF which is greatly reduced for low irradiances while the FF of the c-Si PV panels remains unaffected. This FF drop is caused mostly by a drop in the voltage of these panels under low light conditions.

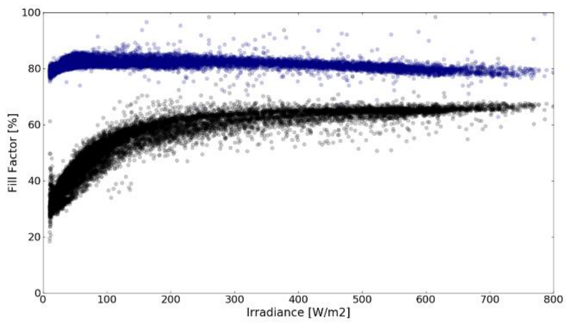

Figure 11: Fill Factor results of CIGS (black) and c-Si (blue) panels for various irradiances.

Finally, a simulation model was created with the PV_LIB tools of the PV Performance Modelling Collaborative (PVPMC) in order to predict the performance of aesthetic PV façades [9]. In Figure 12, indicative results of a simulation are shown for the Amsterdam area and for all PV technologies, textures and colors used in the actual prototype demonstrator. The results include all possible orientations of the PV façade. Such a tool can be a useful tool for architects, assisting them to design aesthetic BIPV projects with sustainability in mind.

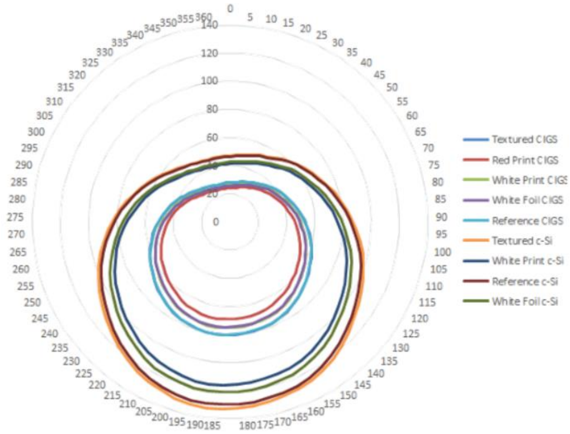

Figure 12: Simulation results for PV façades located in Amsterdam, of various PV techologies and orientations with various colors and textures. The annual yield is in kWh/m^2

4 CONCLUSIONS

Within this study, the performance of a prototype colored, and textured PV façade was successfully assessed. Results showed a limited performance drop (below 20% for 30% print coverage) for PV panels equipped with an aesthetic layer (texture, color) while the aesthetic result remained in accordance with the architectural requirements.

In general, the CIGS panels showed lower performance especially under low light conditions than the c-Si panels, owing mostly to lower voltages and fill factors under these conditions.

Lastly, two coloring techniques were assessed (colored foil on top of the solar glass, printed dots behind the solar glass) and yielded similar results. This is offering PV developers an alternative cost-effective way to customize the color of PV panels according to architectural needs.

5 ACKNOWLEDGEMENT

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