LOOKING AT THE ANNUAL YIELD FROM VARIOUS ANGLES: OPTICAL MODEL VERIFICATION FOR STRUCTURED GLASS

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ABSTRACT: In software for yearly yield calculations, normally an empirical formula is used to take the angular dependence into account. This has been shown to work nicely for standard modules. Recently light management by structures on or in the cells or module has become increasingly important. They are used to increase the path length of the light inside the module or cell, thereby increasing the response in those parts of the spectrum where the light is weakly absorbed. The response of these modules as a function of the angle of incidence is however different compared to modules without these structures. As a result, the current yearly yield calculation methods do not work for these modules. In order to derive trustworthy yearly yield estimates, the models need to be adapted. The purpose of the work is to provide a model to determine the angular dependence of output from PV modules with light management structures in the module glass. These models provide both the means to optimize light management structures and to predict performance through yearly yield calculations.
Keywords: Module, Modelling, Simulation Yearly Yield

1 INTRODUCTION

The power output of Photovoltaic (PV) modules is normally given as the power output for 1000 W/m^2 AM1.5 perpendicular illumination. In reality, a module will almost never face these conditions. The actual yield will be strongly dependent on the location and the orientation of the module. To derive an estimate for the yearly yield at a specific location and for a specific orientation, yearly yield calculation tools exist.[1,2] These tools are commonly used for flat glass modules, but the angular dependence in these tools needs to be adapted for modules containing light management structures.[3,4,5] Here we provide a model that is able to derive the angular dependence of modules with light management structures and we present a verification of the model for flat glass as well as two different types of structured glass. The verification has been made both with controlled STC measurements, and an in- an outdoor monitoring campaign. These models have then been used to derive incident angle modifiers which have in turn been applied to annual yield calculations using PVsyst for various location and orientations, including façade installations.

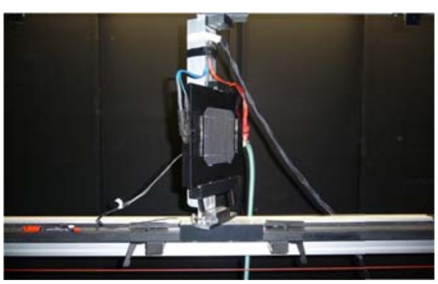

Figure 1: Setup for the PASAN flash tester to measure output of the laminates under various angles of incidence

2 APPROACH

A ray-tracing model is used to derive the response of a PV module as a function of the angle of incidence. It is especially designed to implement various light management structures in the module glass. The output is the External Quantum Efficiency for the specific modules which is converted into a current density using a specific illumination spectrum. The EQE of modules with light management structures will depend on the angle of incidence of the incoming light. This angle can be changed in the model to obtain the angular dependence of the module.

To verify the model several single cell laminates were manufactured and then measured in a PASAN flash tester under different angles. For the measurements a special setup was used to be able to change the angle of incidence, see Figures 1 and 2.

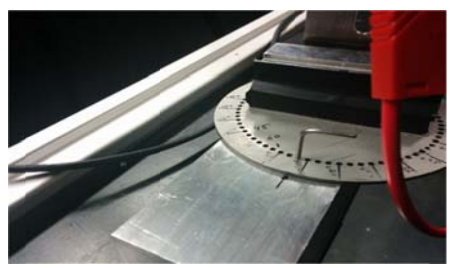

Figure 2: Close-up of the setup for measuring under various angles of incidence

A set of these laminates has also been installed outdoors, see Fig. 3., providing further verification of the modelled results. The model results are then used to estimate the influence of orientation and location on the yearly yield.

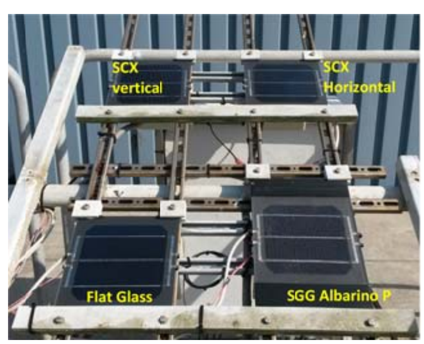

Figure 3: Close-up of the setup for measuring under various angles of incidence

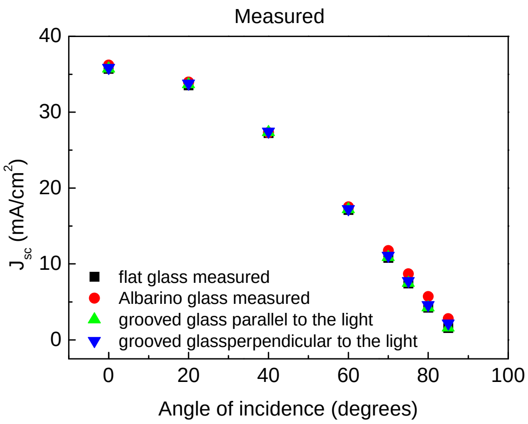

Figure 4: Measured short circuit current density of single cell laminates

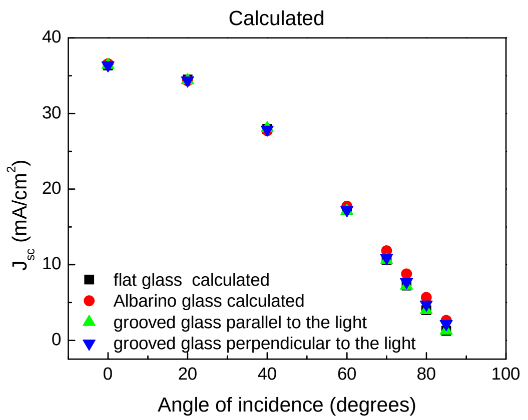

Figure 5: Calculated short circuit current density of single cell laminates

3 RESULTS

Three different glass types were measured, flat glass, random pyramid structured glass (Albarino P from Saint-Gobain), and SCX Sologlass a grooved glass from SCX Solar B.V. Per glass type there were several laminates to check reproducibility of the measurement. Figure 4 shows the results of the measurements and Figure 5 the calculation results.

The results show a very good agreement between the model and the measured data (flash tester). The flat glass shows the lowest performance, almost similar to the grooved glass with the grooves parallel to the incoming light. Perpendicular to the incoming light the grooved glass performs slightly better and the Albarino P glass outperforms all three.

Outdoor measurements also showed good correlation with the modelled results. Those results will be published in a future paper.

From the angular dependence of the current density, the incidence angle modifiers (IAM)[6,7] were calculated, i.e. the ratio between the current for a specific angle of incidence and the current at normal incidence, see Fig. 6. The IAM was subsequently implemented in PVsyst. Annual yield calculations were performed for 3 different system designs, see fig. 7, in two locations, Amsterdam (location 52 21’ N) and Doha (location 25 15’ N). Figure 8 shows the sun altitude and azimuth during two different days, June 21 and December 21, for both locations. Clearly the sun is much higher in the sky in Doha compared to Amsterdam. The results of the PVsyst calculation are shown in Figs 8 and 9 respectively. It shows that both the Albarino P and the SCX glass give a gain with respect to flat glass. Albarino P gives the highest gain, between 0.92% and 2.38% depending on the location and orientation. The SCX glass shows a gain between 0.29% and 0.87%. The results also show that the high angle of incidence benefits of these structures are maximized in a façade type application where the incoming light is dominated by higher angles of incidence.

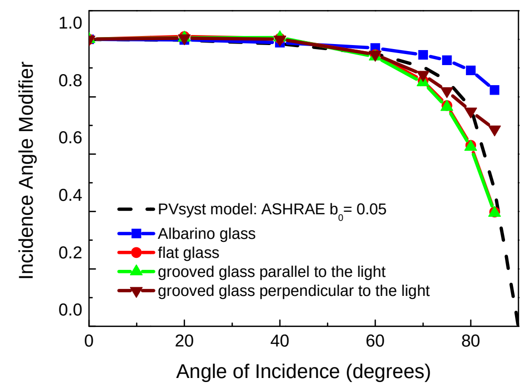

Figure 6: Incident Angle Modifiers for use of annual yield calculations. These are calculated based on the modelled results

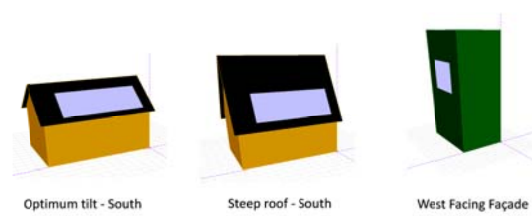

Figure 7: Three installations simulated in annual yield calculations. The annual yield calculations have been performed for a 5kW system with the shown orientation and at two locations.

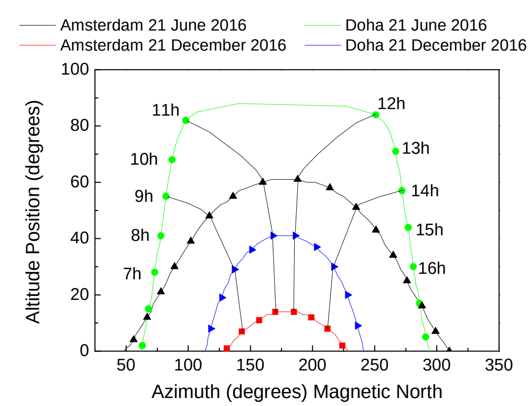

Figure 8: Sun altitude and azimuth during the day for Amsterdam and Doha on June 21 and December 21

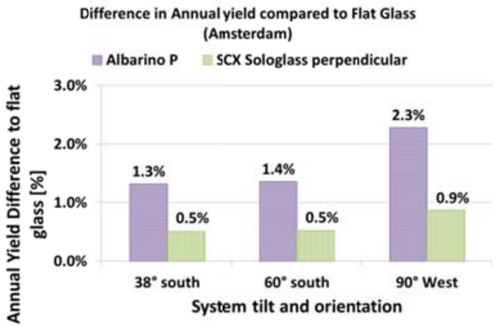

Figure 8: Annual yield comparison for Amsterdam. The results for the two glass types are relative to the flat glass.

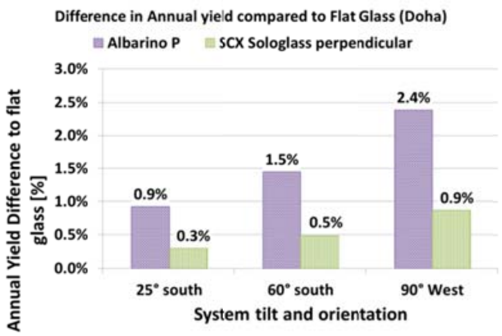

Figure 9: Annual yield comparison for Doha. The results for the two glass types are relative to the flat glass.

5 CONCLUSIONS

Single cell laminates with different types of structured glass have been made and measurements under indoor and outdoor conditions have been performed. A ray-tracing model has been made to predict the performance of the laminates as a function of the angle of incidence. The results correlate very well with the measured data. From the model the incidence angle modifier was derived and used in the PVsyst software to model annual yield for different locations and orientations. The result show that Albarino P structured glass performs best, but that the grooved glass from SCX also shows an improvement in output compared to flat glass. The effect of structured glass is highest for façade like applications where the angle of incidence in general is rather high.

8 ACKNOWLEDGMENTS

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