Energiteknologisk udvikling og demonstration

EUDP 64014-0185

PV BALCONY FENCY

a highly aesthetic cost efficient PV integrated balcony

FINAL REPORT

PROJECT PARTNERS

SolarLab

DTU Fotonik
Institut for Fotonik

Title:
PV BALCON FENCE
a highly aesthetic cost efficient PV integrated balcony

EUDP Project number
64014-0185

Project Partners
DTU Fotonik (project managers)
Solar Lab

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Front page
Top: PV integrated balcony developed in the project
Bottom: New Campus for Copenhagen International School. The Blue building skin are solar panels developed and installed by SolarLab as individual energy harvesting units with inspiration from the EUDP project.

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1.1 Project details

Project title	PV BALCONY FENCE - a highly aesthetic cost efficient PV integrated balcony
Project identification (program abbrev. and file)	Jnr. 64014-0185
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	DTU Fotonik, Frederiksborgvej 399, 4000 Roskilde Peter Behrensdorff Poulsen, ppou@fotonik.dtu.dk
Project partners	Solar Lab (CVR number. 34720975)
CVR (central business register)	DK 30 06 09 46
Date for submission	December 31st 2016

1.2 Short description of project objective and results

English

The purpose of the project PV BALCONY FENCE, has been to develop self-sustaining power producing balcony fences, for application as fence and railings primarily in apartment buildings.

The product is expected to have a marginal installation cost around 1€/Wp and has a design being attractive for architectures and is easy to install. Due to the odd angles of installation to the sun, optical characterization facilities has been built to help in the process of choosing the right glass structuring/coating for a given installed position.

During the project the project group established:

- A functional prototype
- A supplier to develop a microinverter which fits in the mounting rail
- Large scale deployment of colored aesthetic panels
- Facility for measuring the angular performance of PV panels.

All achievements that can be used in future work and on the market for building integrated photovoltaics.

Dansk

Formålet med projektet "PV BALCONY FENCE – Et højæstetisk kosteffektivt solcelleintegreret altanrækværk til bygningsintegration" har været at udvikle og demonstrere et solpanel, der både virker som altanrækværk og samtidig producerer energi til el-nettet. Solpanelet er bygningsintegreret og lavet så det er mest muligt ensfarvet og har en mekanisk styrke, der lever op til myndighedskrav for rækværk

Produktet forventes at have en marginal installationspris på 1€/Wp og er arkitektonisk attraktivt, og æstetisk integreres i altaner vha. simpel installation. Solcellerne på altanrækværkerne har generelt en suboptimal placering, hvor det må forventes at hele installationen i længere periode ikke vil være belyst ens, og yderligere vil solindstrålingen ramme panelet i store vinkler fra vinkelret. En optisk metode til karakterisere vinkelafhængigt respons af forskellige strukturerede og coatede glastyper er realiseret.

Projektet er primært opdelt i 4 delmål.

- Udvikling af optimal opstrengning og konnektering
- Udvikling af et elegant og attraktivt design med smart og holdbar til indpakning af elektronik
- Undersøgelse af optimal lysindkobling
- Realisering af demonstrator

Produktet forventes at vil blive attraktivt at bruge til både renovering af eksisterende og opførsel af nye etageejendomme. Markedsføringen vil blive målrettet arkitekter og bygherrer rådgivere, der vil værdsætte produktet som en enkel æstetisk komponent, der bidrager til at overholde energiklasse 2020.

1.3 Executive summary

The purpose of the project PV Balcony Fence, has been to develop self-sustaining power producing Balcony Fences, for application as Fence and railings primarily in apartment buildings. The project was divided into the following work packages.

- WP 1 Project Management
- WP 2 Stringing Analysis
- WP 3 Development of the aestetics
- WP 4 Optimizing the light capture into the system
- WP 5 Ensure compliance with the building regulations
- WP 6 Demonstrator Creation
- WP 7 Marketing
- WP 8 Reporting and dissemination

In General the overall goal of the project has been achieved, and the concept is ready to enter the market. Particularly WP 2 (Stringing analysis), WP3 (Aesthetic development) and WP 4 (Optical characterization of glass) has been successful. Overall the prices for solar cells, solar modules and inverters has decreased during the project period and even more than expected due to overcapacity in the market. This price decline will favor the product and make it easier to achieve the prices goal.

In WP 2 a Microinverter manufacturer (AE Conversion) developed a special microinverter which fitted in the mounting rail for the balconies, and is efficiently converting the power from the solar panels to the AC mains. In WP 3 SolarLab got the opportunity to use special colored solar glasses in a large deployment for the façade of the new campus for Copenhagen international school. In WP 4 DTU Fotonik developed a measurement setup enabling measurement of the angular response of mini solar panels which enables a qualified selection of front glass and several scientific contributions was made on the topic.

SolarLab is eager to market the balconies and have benefitted from the new microinverter development, which can be applied in many of their other BIPV products and solutions. Good angular characterization of PV panels is absent in the industry, and is crucial in order to make reliable estimates on energy production. DTU Fotonik will continue this research path and also offer the facility to the industry for better estimation of angular resolved performance of solar installations.

Figure 1: PV installation on Copenhagen International School inspired by this project.

1.4 Project objectives

The purpose of the development project PV Balcony Fence, was to develop self-sustaining power producing Balcony Fences, for application as Fence and railings primarily in apartment buildings. The project was divided into the following work packages:

- WP 1 Project Management
- WP 2 Stringing Analysis
- WP 3 Development of the aesthetics
- WP 4 Optimizing the light capture into the system
- WP 5 Ensure compliance with the building regulations
- WP 6 Demonstrator Creation
- WP 7 Marketing
- WP 8 Reporting and dissemination

The execution of the project has been well organized and productive, and a prototype for further marketing were build, and at Fotonik we established a measurement facility to characterize glass for PV applications. In addition a microinverter has been developed at an external partner which is fitting in the mounting rail for the balcony, and their inverter technology has also been used for connection the many colored BIPV panels mounted on the new Copenhagen International school, which were setup by Solar Lab.

1.5 Project results and dissemination of results

In General the overall goal of the project has been achieved, and the concept is ready to enter the market. Particularly WP 2 (Stringing analysis), WP3 (Aesthetic development) and WP 4 (Optical characterization of glass) has been successful. Overall the prices for solar cells, solar modules and inverters has decreased during the project period and even more than expected due to overcapacity in the market. This price decline will favor the product and make it easier to achieve the prices goal.

WP 2 Stringing Analysis

In work package 2 the goal was to develop optimal stringing of the system. In order not to complicate designing and planning of installations, the project group went for a modular system, where each unit is operating independent and is through a microinverter connected to the AC mains. The full modularity of the system omits design and planning of the installation. The modularity also enables individual metering for each unit, which is commonly used in Denmark.

Contact to AE-conversion which is a micro inverter manufacturer was established and during the project period they have developed an efficient microinverter that fits in the mounting profile for the balconies.

Figure 2: Microinverter made for the project to fit into the rail system of the balcony.

This microinverter is currently under test at AE conversion and will be launched during spring 2017, which is perfect timing with the other parts of the project.

The choice of microinverter allows each balcony unit to operate independently, and in contrast to traditional systems where 10-20 modules are connected in the same string and thus the performance of the full string is limited to the performance of the lowest performing module. The traditional way provides a more efficient electronic conversion, however gives mismatch losses and complicated wiring, which complicates the design phase because shades from building features limits the performance of several units. Thus despite the slightly lower efficiency and higher price, significant savings and freedom of design are achieved and these savings compensates the downsides. The choice of microinverter also makes direct metering of the individual apartment possible.

WP 3 Development of the aesthetics of the solar panel

The aesthetic appearance has also been optimized, and a glass supplier delivering colored glasses which used quarter wavelengths films to reflect 1 wavelength has been identified and tested. The company is called Swissinso, and there products is letting approximately 90 % of the solar rays passing through the glass- which is comparable to the transmission of standard glass.

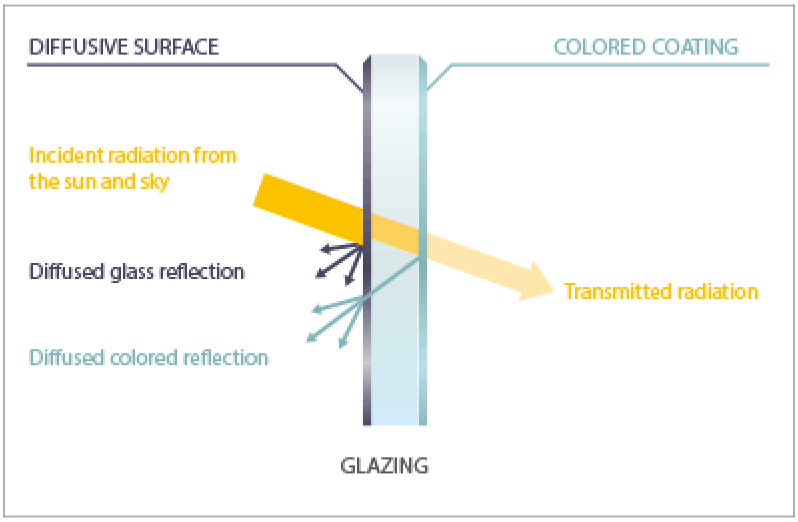

Figure 3, Optical concept of the Swissinso colored PV glass solution.

SolarLab have deployed this technology and the new campus for the Copenhagen International School in Nordhavn, which is a good example of a building where sustainability and modern architecture meets in a synergetic way. The Swissinso glass is a price wise a high-end solution and for price efficient solutions normal PV glass is expected to be used.

Figure 4: New Campus for Copenhagen International School the blue façade modules are solar panels with Swissinso glass.

WP 4 Development of optimized Light coupling

Due to the vertical orientation of the balconies PV modules most of the light during a day will reach it at very large angles. This demands solar cell glass with as high performance as possible for large angles. The market was investigated mapping the different anti-reflective methods manufactures use. Small samples fitting to the smaller lab setups were acquired and characterized both as raw glass and as mini solar panels.

A PV panel consist of solar cells that to Ethylene Vinyl Acetate copolymer (EVA), that in the cured from have a refractive index matched to that of glass. Behind the cell another layer of EVA is used to adhere a polymeric back sheet to the laminate, protection the cells from humidity. The light ray's possible interactions with the laminate are shown in Figure 5

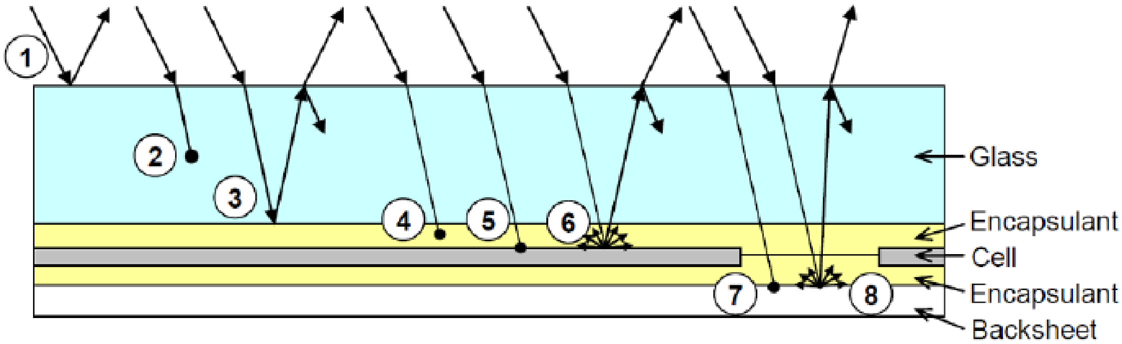

Figure 5: Interaction between light rays and the laminate.

Since the EVAs refractive index is matched to the glass reflection at the glass-EVA interface is very limited. Glasses used for PV modules are mostly low iron tempered glass with and Antireflective coating. Some manufactures make surface structures of different depths in the glass surface. The first two increases the normal transmittance of the glass from below 90% up to 95 %. The structured surfaces increase the performance at large incident angles due to light trapping effects and increase the adhesion to the laminate.

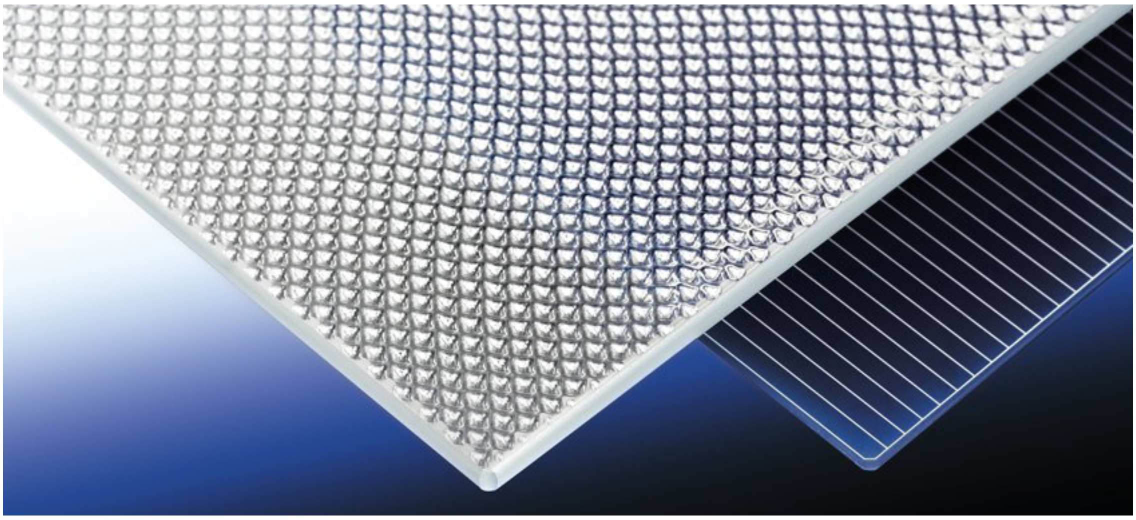

Figure 6: Picture of a deep structured PV glass

An overview of the glasses used for the experiments are listed in table 1 below.

Table 1: Samples and preparation

Glass Category	Identification	Thickness (mm)	ARC-details
Structured	A	3.2	One prismatic side
Structured	B	3.2	Matt – prismatic , ARC
Structured	C	3.2	Matt - matt, ARC
Structured	D	4	Matt - matt, ARC
Structured	E	3.2	Matt – matt, ARC
Structured	F	4	Matt - prismatic
Structured	G	3	Matt
Structured	H	4	One prismatic side
Deeply structured	I	4	Deeply pyramidal structured
None	J	6	None

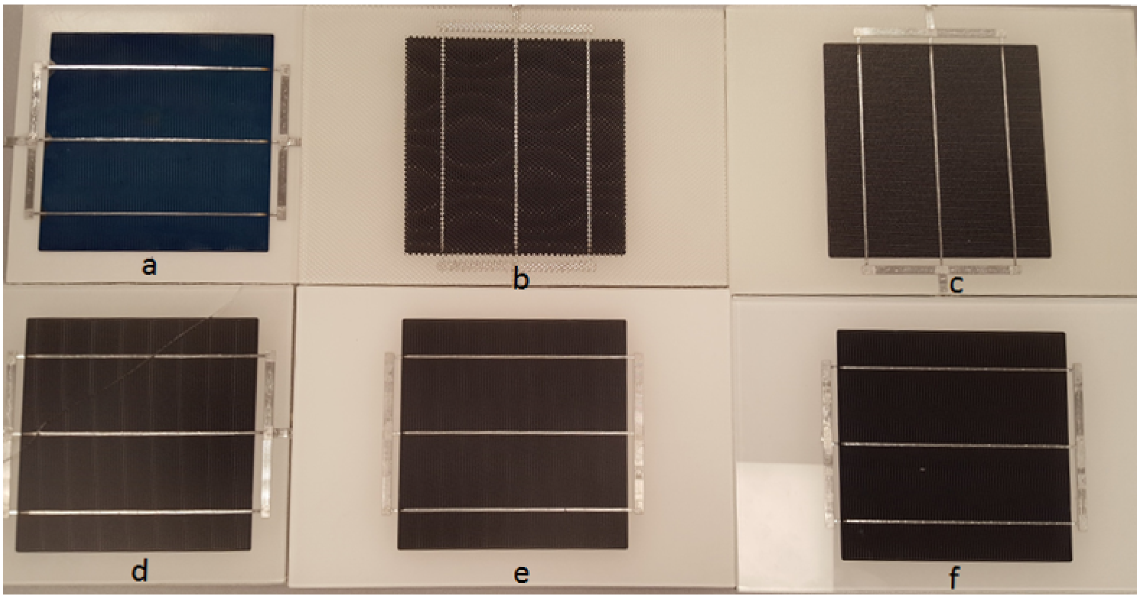

Figure 7: Picture of some of the mini modules with different structuring. The letters doesn't resemble the letters in table 1.

All of the above glasses followed the exact same characterization process: First laboratory measurements of angle resolved transmission were made. All glasses were afterwards sent to a European module manufacturer, where one full cell mini modules were made. The cells were taken from the same box, so all cells came from the same binning and were most likely produced in the same batch, ensuring the cells were as similar in performance as possible. All the mini modules were flashed post lamination, and sent back to our research facility, where the angular response of the mini modules where measured using natural sunlight as described later.

Raw transmission measurements on Glass

An explanatory picture of the used setup is shown in Figure 8. A directional fiber coupled light source is mounted on a rotating stage with the center of rotation being at the front surface of the glass. Behind the glass is an integrating sphere with a fiber coupled spectrometer which acts as a detector. For reference a normal incidence measurement without a sample is used, and subsequently a sample is mounted and the transmission is measured from 0 to 70°. The light source used is a deuterium tungsten halogen lamp (Ocean Optics DH-2000) providing light in the spectral range from 200-2500 nm. And the spectrometer used is an Ocean Optics QE65000 with the ability to measure from 200-1100 nm. However, despite the good spectral ranges only signals in the wavelength range 500 nm - 830 nm had a sufficient large signal to noise ratio. This is most likely due to the limited lamp power of 45 W in combination with the optical losses in the fibers the spectrometer signal was very low.

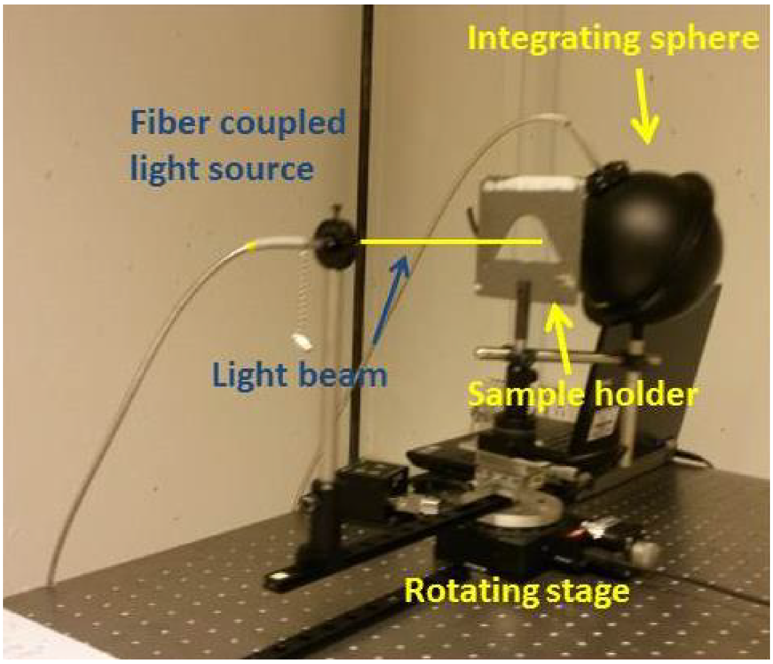

Figure 8: Explanatory picture of the measurement setup for characterization of raw glass

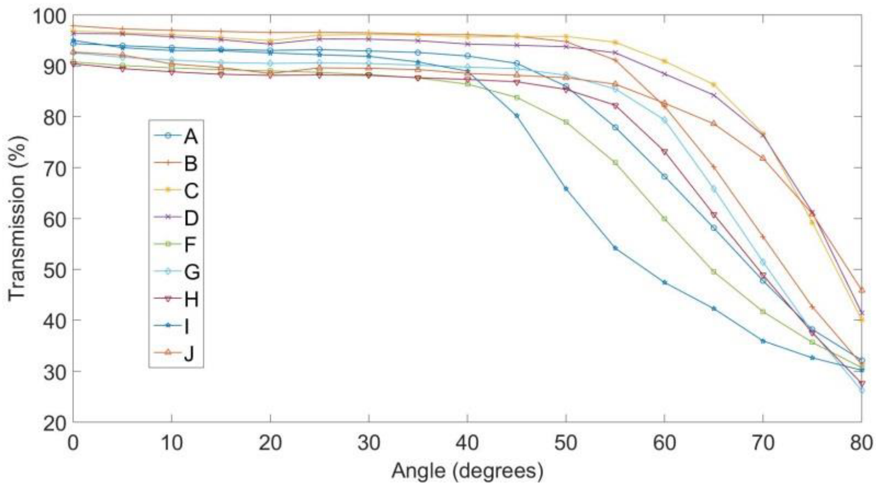

Figure 9: Transmission measurement for raw glass.

Measurements of the raw transmission of the glasses in the lab are shown in Figure 9. It is seen that all glasses have a normal incidence transmission of 90-98%, which is in good agreement with data sheets; however, some of the variance is also owing to measurement uncertainty. At angles above 45^{o} large differences in angular response is observed, and what appears a bit surprising is the bad angular response of sample J, which is deep structured and should have superior angular response. However, the glass/air interface on the back side is not present in PV modules due to the index matched EVA. Therefore, total reflection occurs at the back side and the slope sides on the front surface enables the light to escape, rather than being captured in the cell.

Transmission measurements on single cell panels

An illustration of a picture of the setup used is shown in Figure 10; we named it the Solar Canon. Two tubes are directed towards the sun, letting only the direct sunlight onto the sample, which is located in a box at the end of the tube. In the box the sample is placed on a rotating sample holder, and in the other box a reference sample is placed with an orientation normal to the rays. The short circuit current is measured for the reference sample and the sample under test simultaneous together with a time stamp. The time stamp enabling data afterwards can be correlated with a tracked pyrheliometer located on campus. The tubelightbox assembly is mounted on a platform where the tilt is adjusted manually with the help of a shaft that is rotated with a worm gear. This shaft is mounted on a stage that can rotate around its own axis.

The collimation of the light hitting the sample at normal incidence is determined by the diameter to length ratio of the tube, $\theta = \tan^{-1} dL$, with d being the diameter of the tube and L being the length of the tube. Initially, a 5 degree angle was the target, similar to measurements of direct sunlight, and with an inner tube diameter of 18 cm the length of the tubes was close to 2 meters. However, initial experiments showed that the direction of the sun was moving too fast for this kind of manual measurement. Thus the requirement was loosened a bit. An example of a measurement is shown in Figure 11. For this type of measurement the projected area normal to the sun decreases with increasing angles according to the projection – sometimes called the Cosine law, and the angular response is in this work normalized to the Cosine law.

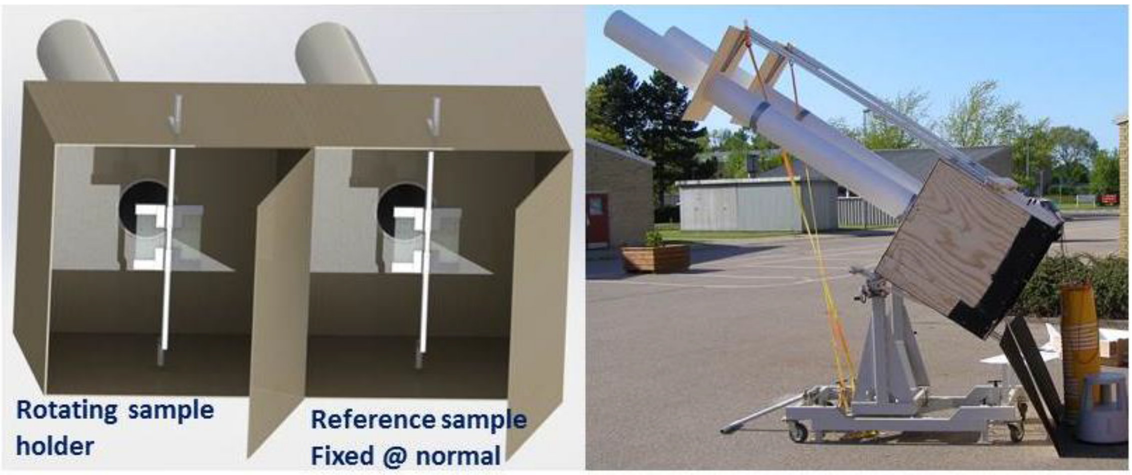

Figure 10: Solar canon, the outdoor setup for measuring the angular response.

Measurement of angular response of the mini modules are shown in Figure 11. Data acquisition software enabling simultaneous current measurements were not implemented at the time of measurements, and thus two handheld multi meters with manual reading were used to measure the current. The change in solar radiation is therefore a significant source of measurement error.

The repeatability was tested on sample J, which show similar qualitative behavior however the two curves are significantly displaced. Thus optimization where simultaneous data logging will be made and reducing the collimation of the light will enable more time for the same angular adjustment of the solar canon.

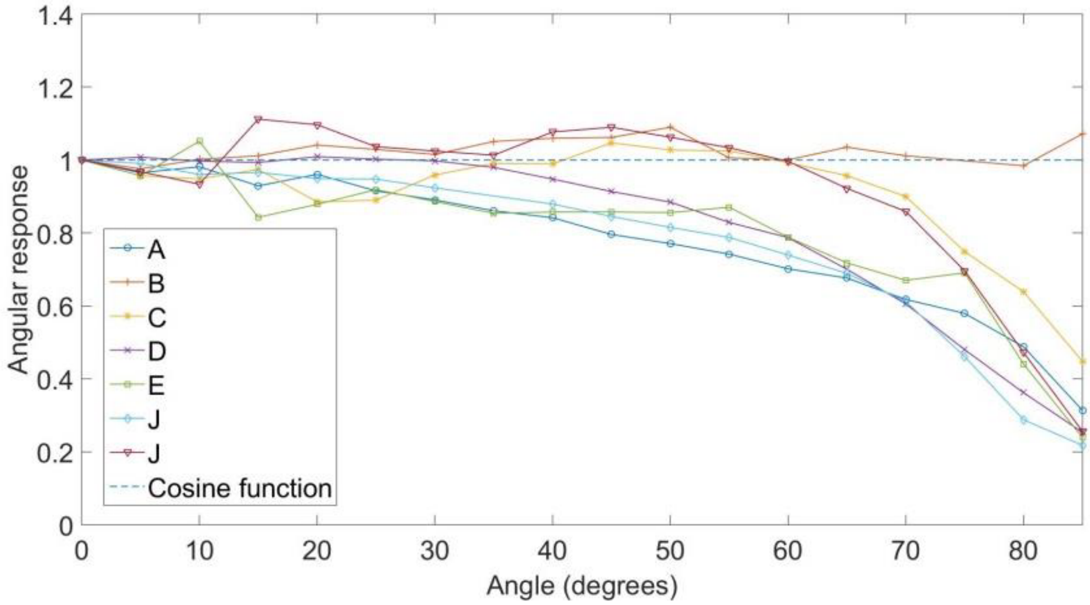

Figure 11: Angular response measurements for the mini modules.

When knowing the exact location of the building where balconies are being implemented and the orientation of these, an estimation of the annual yield for the various glasses that have been investigated can be made. This allows for choosing the best suited glass giving the largest energy output for a specific case. An example of such annual energy yield estimation is shown in Figure 12. The case shown is for a south faced balcony in Roskilde, Denmark. The results are obtained with irradiance data obtained from PV-gis folded with the results from the angular response curves and also considering the absolute transmission. Due to the large angular response values there is a constant overestimation of the energy yield. It can be seen that the deep structured and prismatic glass performs the best.

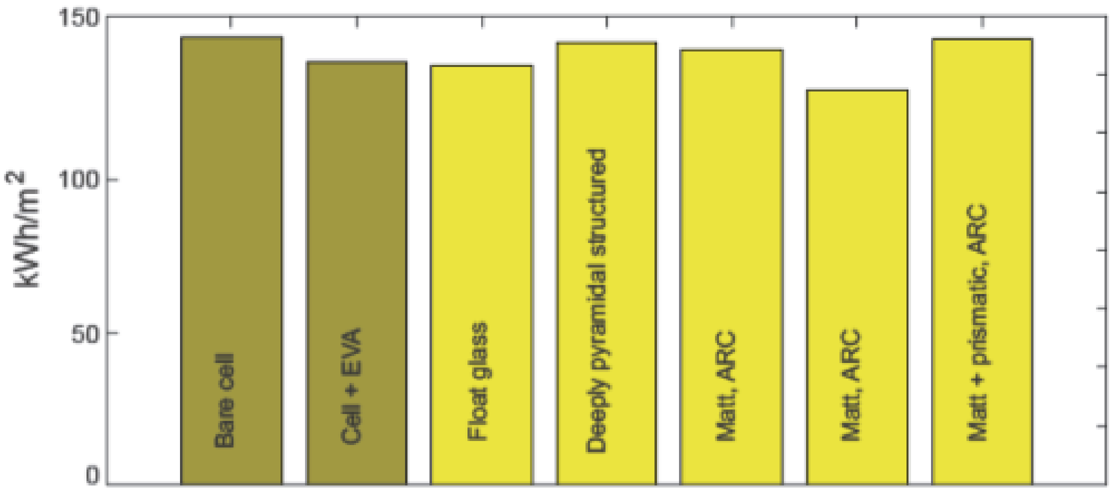

Figure 12: Annual energy production based on the measurements for the mini modules.

WP 7: Marketing

SolarLab has contacted several housing unions for renovations projects for this product and have received positive feedback. They have made a few bids on some projects in Frederiksberg and Århus, however an enterprise has not yet been landed. In 2017 Solarlab expects to strengthen their marketing on this product, and price indications so far gives confidence that it is possible to reach the target of a marginal installation price of 1€/Wp. Thus the marketing follows the project plan, where the significant effort is to be done after project execution.

WP 8: Dissemination

The above results were disseminated at three different conferences:

Solar City Denmark General assembly 2015 and 2016, NSCC, Oslo, May 31-June 1, 2016, and EUPVSEC, Munich, Germany, June 20-24 2016.

PV BALCONY FENCE - a highly esthetic cost efficient PV integrated balcony.
Poulsen, Peter Behrensdorff ; Juutilainen, Line Tollund ; Thorsteinsson, Sune ; Thorseth, Anders ; Amdemeskel, Mekbib Wubishet ; Canulescu, Stela ; Rødder, Peter Melchior ; Rødder, Kristin Presented at: Norwegian Solar Cell Conference 2016, 2016, Oslo

Angle Resolved Performance Measurements on PV Glass and Modules.
Juutilainen, Line Tollund ; *Thorsteinsson, Sune* ; *Poulsen, Peter Behrensdorff* ; *Thorseth, Anders* ; *Amdemeskel, Mekbib Wubishet* ; *Canulescu, Stela* ; Rødder, Peter Melchior ; Rødder, Kristin Presented at: 32nd European Photovoltaic Solar Energy Conference and Exhibition, 2016, Munich

General Assembly for Solar City Denmark Yearly Meetings 2015+2016

1.6 Utilization of project results

SolarLab will use the project results to improve the quality the balcony fences, and will aim to make contracts for larger renovation projects. The Micro-Inverter developed to fit in a very slim casing is crucial for the success of the balconies, but this can be used in many other applications where modularity is required and space is limited.

Examples could be:

- Grid connect solar lamps
- AC modules for BIPV

Solar Lab specializes in providing solar based product (PIPV), and has thus got a crucial component for a large range of their products.

The lack of understanding and lack of good measurement procedure for measuring the angular response of solar panels is absent in the industry. The poor modelling is one of the most significant contributors limiting the accuracy of the forecasting estimations. The error in energy estimation becomes particularly large when the PV is applied on a building where the orientation cannot be optimized. Therefore especially BIPV installers have shown huge interest in precise measurement of the angular performance, which will facilitate better energy production estimates, and thus limit the safety portion on their energy production guarantees for the specific installations, which is one way to increase earnings.

DTU Fotonik will benefit from having a measurement facility that is able to accurately measure this, and will both use it to boost research and offer these measurements to the industry.

1.7 Project conclusion and perspective

The project has been successfully solved and all the technical challenges have found good solutions, and SolarLab save together with DTU Fotonik developed a product with a high market potential and attractive pricing.

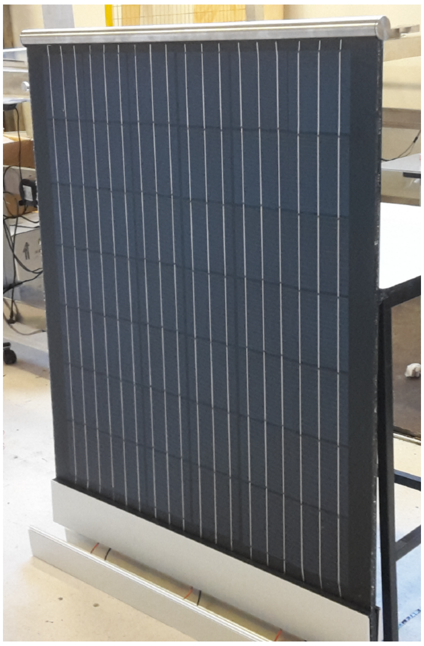

Figure 13: Picture of the first prototype.

SolarLab has in addition initiated development of a microinverter in a casing that fits in narrow spaces, which is a crucial component for some of the many PIPV products, and thus SolarLab will continue develop new PIPV products and market them as being part of larger projects like what they have done at Copenhagen International School.

DTU Fotonik established the angular performance setup, which is an important part of their research, and this measurement is synergetic to the DTU projects portfolio and will be used to characterize the black silicon modules angular performance. (EUDP 64016-0030)