Achievements of EU funded project BFIRST on BIPV technology

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Abstract: EU funded "Building-integrated fibre reinforced solar technology" **(**BFIRST) project (Grant Agreement number 296016) was launched in 2012 by a consortium of EU companies, research institutes and universities, led by Tecnalia. The project, which will end in early 2017, is focused on the design, development, fabrication and demonstration of a set of standardized multifunctional photovoltaic products for building integration using an innovative manufacturing solution based on glass fibre-reinforced composite materials. This novel encapsulation technology is the basis for a wide range of new BIPV (building-integrated photovoltaic) products with enhanced building integration possibilities. The resulting modules present advanced characteristics in terms of flexibility of design, adaptability to non-planar geometries, structural properties and lightweight, among others. They provide additional advantages related to cost reduction in transport, manipulation, assembly and installation.

1. Introduction

Building-integrated photovoltaics (BIPV) is currently a growing market worldwide, with an estimated compound annual growth rate (CAGR) of 18.7% and a total of 5.4 GW installed between 2013 and 2019 (Transparency Market Research, 2014). One of the main drivers for BIPV market growth in the EU is the increasingly demanding legislation related to energy performance in buildings, given the fact that buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU. Europe has therefore an urgent need to make its building stock more energy efficient and smarter.

Despite this favourable framework, it is a fact that the estimations for a steady BIPV market growth have not been fully met by the industry during the past few years. A series of demands from the stakeholders which have not been properly addressed by the BIPV value chain is amongst the main reasons for this deviation. These key requirements are partly related to the flexibility in design and aesthetics considerations, demonstration of long-term reliability of the technology, compliance with legal regulations and cost effectiveness.

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BFIRST project is aimed to contribute to bridging the gap between technological development and market demands, being oriented at the design, development and demonstration of a portfolio of innovative photovoltaic products for building integration, based on crystalline silicon cell encapsulation within fibre-reinforced composite materials. The resulting modules are monolithic and lightweight structures, highly versatile in terms of geometries, shapes, colours and surface finish. Multifunctionality in the building environment is addressable through design and materials tailoring. Full architectural integration of the developed products is pursued. The compliance with the corresponding IEC test standards and the demonstration of multifunctional performance in real operation conditions are the ultimate objectives of the project.

The project has run from May 2012 to April 2017, although the gathering of information from the demonstration installations will be continued beyond this date. The multidisciplinary consortium involved in this project was built to involve the main actors necessary for the development and demonstration of BIPV products: designers, technology developers, manufacturers, testing laboratories, building owners and installers. The project is coordinated by Tecnalia, private research centre and main developer of the composite encapsulation technology and joins efforts between the building industry (represented by Acciona, BEAR Holding, Optimal Computing and Heron), the photovoltaic industry (Atersa) and RTD performers (Tecnalia, CRES, ENEA and Cyprus University of Technology). Specific attention is paid to dissemination and communication activities, led by CRES.

2. Technology and products

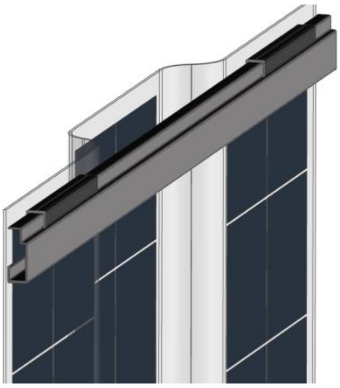
2.1. Technology

The BIPV products development and demonstration activities proposed within BFIRST project are based on a novel encapsulation technology based on embedding the solar cells in a transparent composite material. This material consists of a transparent resin and glass fibers with coupled refractive indices, which reduces the internal reflections and light diffusion at the front side of the cells. The mechanical performance of the products is optimized through simulation and reinforcement lay-out (number of fiber layers, fabric waving weight) together with a thorough control of vacuum and temperature during the manufacturing process, including curing of the composite material. The resulting modules are monolithic, lightweight, while displaying the characteristic high mechanical strength of fibre-reinforced composite materials. They can be curved and different surface finishes are possible. Additional multifunctional properties can be achieved through surface coatings or bulk additives.

2.2. Products

Six different products have been designed, simulated, tested and demonstrated in the framework of BFIRST project:

(i) Non-planar ventilated façade: the main purpose associated to this product was the design of an aesthetically pleasing BIPV solution which could take advantage of all the advanced features of the composite material. As a result, a design corresponding to a photovoltaic module based on a “podium” geometry was conceived, in which the flat surfaces are used for the integration of PV cells. The height of the step was limited to 50 mm in order to avoid shading over the solar cells, which would limit the energy yield. The chosen combination of height and cell distance to the step border ensures the correct operation of the module, preventing it from shadowing. Moreover, the middle step also creates a wider air chamber that contributes to favor the creation of a draught and allow for thermal ventilation purposes, as well as contributing to aesthetical purposes.



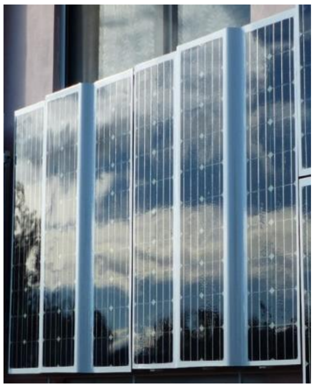


Figure 1: Ventilated façade mounting solution and profiles system (left) and final element as manufactured (right)

(ii) Folded-screen shading system (canopy and balcony): this shading element has been conceived from the design phase as a versatile product composed by modular PV basic units based on cells encapsulation in composite material. From the combination of these basic units a variety of solutions can be created, adapting the final product to different surface geometries. The versatility of this concept has enabled the design of two products within BFIRST project: a canopy shading system to be installed over windows, and a balcony shading system to be installed over balconies. The products show an appropriate balance between photovoltaic production and shading properties. Aesthetical aspects such as wiring hiding have been also considered. The mounting structures are commercial and have been selected to simplify the assembling process.

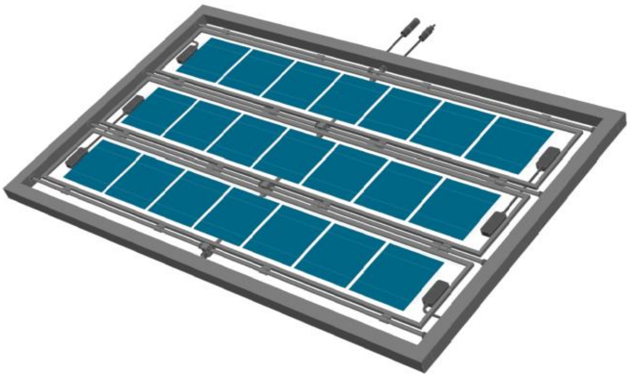


Figure 2: Designs of canopy (left) and balcony element (right)

(iii) Saw tooth roofing shingle: roof covering system consisting of overlapping elements with a saw-tooth profile that reinforces waterproofing and hides the profiles of the mounting system. Air circulation is possible throughout the chamber below the shingles, which will contribute to excess heat dissipation, thus enhancing PV performance. Aesthetically, the shingle is very similar to dark non-photovoltaic slates. The set-up of the modules requires a mounting system and a substructure directly connected to the building. The substructure consists of a series of wood rails together with omega aluminum profiles aligned with the sloping direction and mechanically attached to the wood beams of the roof. It serves both as a support of the mounting system and as a gutter to drain the rain water downwards along the roof. Additionally, compressive polymeric bands have been used to prevent the possible vibrations of the modules under strong wind conditions.

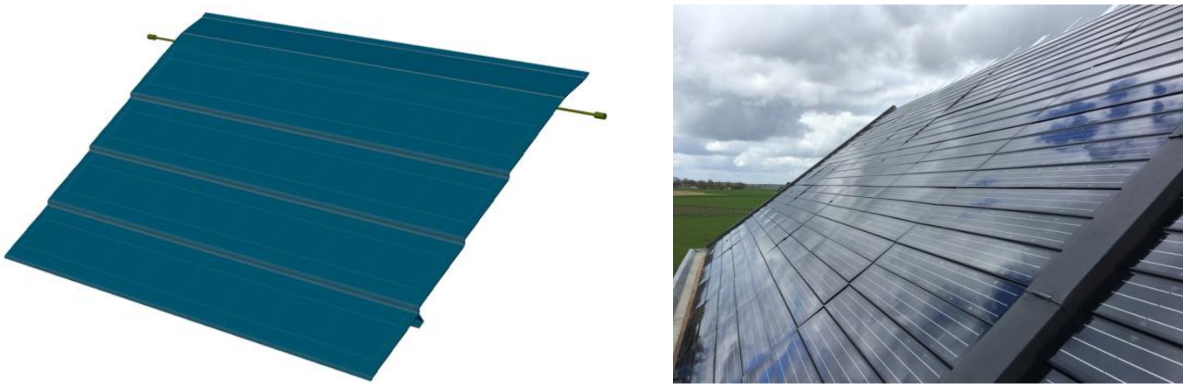


Figure 3: Design of saw tooth roofing shingle (left) and manufactured shingles (right)

(iv) Skylight: outer skylight, with a permanent inclination designed for maximum power production and an open position allowing the dissipation of the residual thermal energy produced by the PV cells through the natural ventilation of the back side of the modules. The skylight units are modular and provide an aesthetical architectural solution in accordance with the usual skylight construction criteria, with hidden wiring strategies.

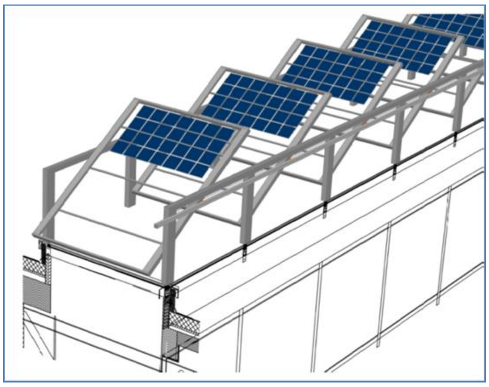


Figure 4: Design of skylight product

(v) Ventilated façade on aluminium tray: this product combines a composite PV module and an aluminium standard construction system. The concept is based on the direct integration of the composite PV modules over an aluminium ventilated façade component manufactured by Spanish company ASTRAWALL, thus transforming a standard aluminium construction solution into a lightweight and multifunctional active component.

Figure 5: Close-up of the ventilated façade on aluminium element

3. Demonstration sites

Real size products have been manufactured and installed in three demonstration sites located in Spain, Belgium and Greece, covering residential and office buildings, new buildings and retrofitting, roof and façade implementations and different climatic conditions. The installations are being monitored, and the available data show excellent production results with no apparent degradation of the PV modules. A more detailed description of the installations is provided below.

(i) Residential building (retrofitting), Greece: a detached family house owned by HERON in Pikermi. The building is a low energy house, completely designed and built by HERON and equipped with a geothermal heat pump, which covers the heating/cooling and the domestic hot water demand. The demonstration includes the ventilated façade element and the modular shading element applied in two places: as a shading system above the windows in the SE façade and as a shading system in the balconies in the SW façade. Nine ventilated façade elements were installed (18 m^2, total installed power 2.1 kWp). The solar shading occupies a surface around 10 m^2 including 2 balconies and shading systems (1.1 kWp installed).

Figure 6: Balconies (left), ventilated façade and canopies (right) in the Greek demo site.

(ii) Residential building (new), Belgium: this demonstration building is a passive solar single family detached house, located in Masnuy Saint-Jean, owned by Optimal Computing. The house has been designed following PassivHous principles. A related assessment has been done by PHPP (Passivhaus Institute Darmstad). The house was classified as PEB with A+ level. The BIPV installation has been performed with the saw-tooth roofing shingle. The roof faces SSW and has a 40º tilt. A total surface of 70 m^2 of roofing shingles have been installed, with 7.01 kWp total installed power.

Figure 7: roofing shingles installed in Belgium demo site.

(iii) INGRID office building (retrofitting), Spain: INGRID is the name of the Tecnalia experimental facilities for smart grids, located in Zamudio (Spain). It is composed by two buildings, used as offices and testing laboratories respectively. The office building is the one chosen for the demonstration activities within BFIRST project. Two products are being demonstrated in this building, the skylight and the ventilated façade on aluminium tray. The skylight shading has been installed over 30 m^2 of a central corridor, with 18 modules at 33º tilt and a total installed power of 1.89 kWp. As for the ventilated façade, placed on a vertical wall with SSE orientation, the demonstrator is composed by 34 modules (2.42 kWp), in a configuration of two parallel rows of 17 modules in series each, placed in the free concrete space under the testing laboratories.

Figure 8: detail of ventilated façade on INGRID building during installation (left) and skylight (right)

4. Results and discussion

4.1. Laboratory testing

Intensive laboratory testing has been performed over BFIRST products in order to determine their compliance with PV and building related standards. Given that the module encapsulation procedure is highly innovative and not directly in the scope of several of these standards, a specific testing plan was designed by the project partners in order to obtain a meaningful assessment of the products performance.

Photovoltaic standard IEC 61215 (2005) for crystalline silicon based modules was used and all test sequences therein were performed by ENEA either on representative samples or real size modules. All the samples were found to comply with the specific criteria of each individual test.

Construction testing has been focused on the roofing shingles and the non-planar ventilated façade. For the roofing shingle, the pull-out/wind suction test according to EN 14963 (2007) standard has been considered especially important. The aim of this test is to analyse the behaviour of the singles against an increased distributed load, up to 2400 Pa, which simulates a suction wind load. Two roofing shingles plus the corresponding mounting structure were tested and no damage was observed.

Additionally, impacts test according to EN 1873 (2015) standard were performed on the roofing shingles. The small hard body test consists in a 250 g steel ball drop from 1 meter height on 3 specific heights. The ball must not go through the samples in order for the result to be satisfactory. The big soft body test involves a 50 kg bag dropped in the center of the component, from a 2.4 m height. The test is successful if, one minute after the impact, the bag cannot go through the module and a 300 mm spherical caliper cannot go through the element. All tested BFIRST roofing shingles were found to comply with these tests.

Concerning the non-planar ventilated façade, hard and soft impact tests according to ETAG 034 (2012) were performed. Hard body impacts were made by dropping a 1 kg steel bag from a 1.02 m height and a 0.5 kg ball from 0.61 m, over 3 impact points. No damage was observed. Soft body impact tests use a 3 kg ball from 0.34 to 2.04 m, on 3 impact points and a 50 kg bag from 0.61 to 0.82 m on the centre of the element. No damage was observed either.

The adhesive system for the junction between the composite material and mounting of both the roofing shingles and the ventilated façade was evaluated, for two different adhesives. The tests included lap-shear strength, following ISO 4587 (2003), tensile strength, following ASTM C297 (2010) and ETAG 016 (2005), for exposure to ageing cycles. Testing results allowed the selection of one reference versus the other and the characterization of the adhesives performance against ageing.

4.2. **Demonstration activities**

The three demonstration installations of the project are currently set up and monitoring is on-going. The Belgian demonstration site, composed by 57 panels and resulting in a total peak power of 7.01 kWp, is connected to the grid since May 2016 and the monitoring system collects data continuously since August. The predicted annual production is 6.210 kWh. During the month of August the installation produced 908 kWh. In the period from August 1st to December 31st 2016 (5 months), the installation produced 2.795 kWh.

The Greek demonstration site, with 3.2 kWp installed power, was connected to the grid at the end of January 2017, and therefore only estimated production data are available. With the use of TRNSYS and PVsyst simulation software packages, the expected annual electricity production has been calculated to be 3.200 kWh, with a relative production yield of 1.000 kWhel/kWp.

The Spanish demonstration site installed power amounts to 4.31 kWp, and it is connected to a dual maximum power point tracker grid-tie inverter. The installation was connected to the grid at the end of July 2016. During August, the BIPV system's mean daily generation was

15.3 kWh (44% for façade and 56% for skylight); for September 12 kWh (51% for façade and 49% for skylight); within October 12 kWh (56% for façade and 44% for skylight); for the month of November 7.7 kWh (64% for façade and 36% for skylight) and during December 11 kWh (70% for façade and 30% for skylight).

Monitoring activities will still continue for several months and more detailed information will be published in the future. To date, the existing data show a remarkable performance of the BIPV products, with energy production in accordance with simulations and no appreciable signs of ageing.

5. Conclusions

BFIRST project, running from mid 2012 to the first months of 2017, has accomplished the design, development, testing and demonstration of a portfolio of BIPV products based on an innovative technology for cells encapsulation within fibre reinforced composite materials. The resulting modules have been proved to comply with EN 61215 standard for crystalline silicon modules. Six products (non-planar ventilated façade, roofing shingle, two shading elements, a skylight and a ventilated façade on aluminium tray) have been manufactured and installed in three demonstration sites in Greece, Belgium and Spain. All the installations are producing in accordance with simulated data, with no durability issues identified to date. Monitoring activities will continue for several months. Detailed analysis of these long-term monitoring results will be reported elsewhere.

6. Acknowledgments

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