D14: Review of technical solutions/products available on the market

ImpAct BIPV

Innovative Design for Improved Application of Glass BIPVs on Buildings

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Deliverable author: Yerasimos Yerasimou

Contributors: All ImpAct-BIPV Partners

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Contents

1. Introduction

Building–integrated photovoltaics (BIPVs) are defined as photovoltaic (PV) elements integrated into the building envelope, thus providing the same functionality as conventional construction materials, such as glass, in addition to the collected energy. In contrast to building–applied photovoltaics (BAPVs) that are added to the building envelope after its construction and are an afterthought rather than part of the initial design, BIPVs can serve functional purposes and add to the architectural and aesthetic design of the building. BIPVs can be adopted in various building elements, such as curtain wall systems, windows, shading structures, canopies, and balconies. The BIPV technology offers the potential to create local micro–renewable energy generation systems that can be cost competitive to conventional energy sources, as the initial cost can be significantly reduced by implementing the PV cells within materials that are already part of the building envelope.

This report constitutes a comprehensive review of available BIPV solutions in the market, mainly focusing on the PV module technology used. The review has investigated aspects such as different BIPV cell technologies in the market, efficiency and output, module design, cost, etc. in order to enable the design of the most appropriate as well as cost-effective solutions for Cyprus for the pilot testing.

2. BIPV considerations

Before the installation of BIPV systems on the building envelope numerous factors that affect the aesthetic appearance and performance of the PVs, while meeting all the regional standards–compliance, should be considered. More specifically, the selected cell technology is of utmost importance, as it influences the performance of the BIPV system and the overall visual appearance of the building.

2.1 Cell technologies

The main cell technologies used for BIPV applications are crystalline silicon (c–Si) and thin–film. Crystalline silicon is split in two types; monocrystalline and polycrystalline. They usually have metallic blue or black colour, although, other colours are achieved by applying antireflective coatings. To achieve transparency through c–Si modules, the spacing between the cells can be varied. On the other hand, thin–film uses thin semiconductor material attached to conductive glass through vapor deposition. The semiconductor material can either be amorphous silicon, cadmium telluride (CdTe), or copper indium diselenide (CIS). Semi–transparency is achieved by using laser ablation to remove layers within the semiconductor, however, there is a reduction of the PV performance analogous to the level of transparency. Although that under standard test conditions (STC), crystalline silicon modules demonstrate higher efficiencies, thin–film technology is more tolerant to partial shading [1], which could make them a better choice for BIPV surfaces that are not positioned optimally, such as north–facing façades. Therefore, thin–film technology is installed in 8% and 44% for roof and façade BIPV systems, respectively, despite that it occupies only about 5% of the PV market share globally [2].

Table I shows a comparison between the different cell technologies. Monocrystalline silicon provides the highest efficiency and can achieve the highest output power per m^2. However, they are the most expensive choice. Thin – film technologies on the other hand, achieve the lowest efficiency and output power but can provide uniform transparent appearance throughout the whole PV module area.

Table I: Comparison of cell technologies [4]

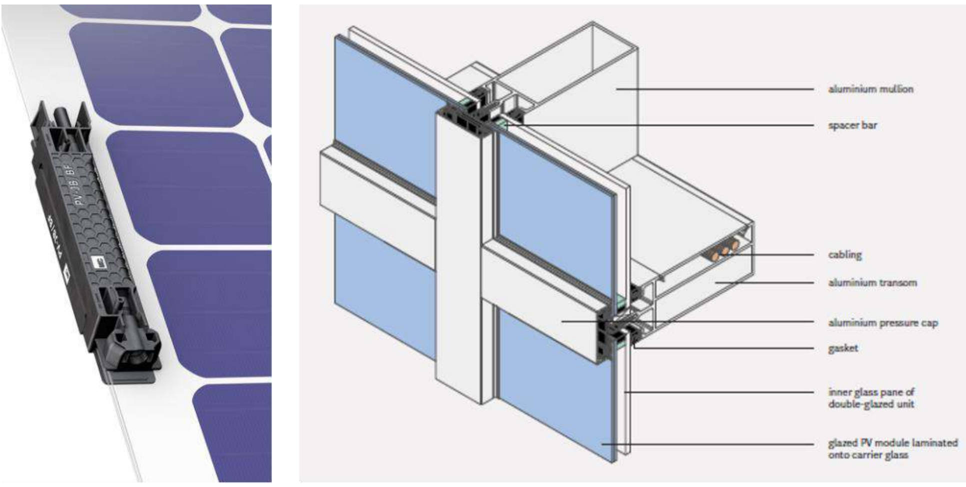
Cell technology	Cell efficiency (%)	Module efficiency (%)	Area/kW (m^2/kW)	Cost
Monocrystalline silicon	16 – 22	13 – 19	7	High
Polycrystalline silicon	14 – 18	11 – 15	8	Low
Amorphous silicon	4 - 8		15	Medium
CdTe	10 – 11		10	Medium
CIS	7 – 12		10	Medium

Transparency is highly important for BIPV applications, as they offer visual connection to the outer environment and allow natural light to enter the building, thus reducing its energy consumption. An example curtain wall façade made of amorphous silicon is presented in Fig. 1 by Onyx Solar [3]. As shown, different transparency levels can be achieved, however, there is a 10% reduction in the peak power of the PV element per m^2 for every 10% increase in transparency. Similarly, increasing the transparency for c–Si cell technology also results in reduced peak power per m^2, as the degree of transparency depends on the spacing between the c–Si cells. Hence, the total area occupied by c–Si elements generating power is reduced by increasing transparency.

Fig. 1 Transparency level for amorphous silicon PV glass [3].

2.2 Electrical connections

In BIPV applications, one of the challenges associated to the integration of the PV modules to the building envelope is the electrical wiring. Usually, PV modules feature a junction box that contains the electrical power terminals and bypass diodes. The junction box is often attached to the backsheet of the PV panel. However, since the appearance of the PV elements is equally important for BIPV applications, the junction box and all the wiring connections should not be visible. Thus, they should be integrated within the framing structure of the BIPV. To achieve that, the junction box can be attached to the side of PV panel frame and the cables routed through the aluminium frame, as shown in Fig. 2.



(a) (b)

Fig. 2 Electrical wiring for BIPV applications: (a) Side–connected junction box and (b) Cabling routed through the aluminium framing in a mullion – transom configuration.

3. BIPV applications

The requirements for reducing buildings' carbon dioxide emissions and the ability to generate local energy are the main drivers for implementing BIPV solutions. Nonetheless, the successful adoption of BIPV products also relies on aesthetically pleasing solutions that are seamless integrated to the building envelope, have a long lifetime expectancy and have a relatively large rate of return. In this section, various BIPV applications are presented.

3.1 Photovoltaic skylight

A skylight is usually part of the building envelope. They are made of glass elements attached to aluminium or wooden frames and their purpose is to provide a transparent or semi–transparent roof. A PV skylight instead, replaces the conventional glass layer with PV glazed panels, whereas the electrical wiring is routed through the frames.

One of the largest skylights globally was installed during the transformation of Bell Labs facility into Bell Works (Fig. 3) [5]. The installed PV skylight has a dual purpose, as it allows natural light to enter the facility while generating about 89500 kWh per year. In order to achieve that, amorphous silicon thin–film modules have been laminated between tempered safety glass. In addition, the visible light transmittance has been reduced to 20% to minimise the solar heat gain. It is expected that the payback for this project is less than two years.

Fig. 3 PV skylight at Bell Works [5].

Another example of PV skylight was installed at Patras Scientific Park in Greece, where glass–glass PV modules where integrated in both a skylight that is part of one of the buildings and a pergola within the facility's car park premises, as shown in Fig. 4 [3]. The project consists of 88 crystalline silicon PV modules with a combined 20 kWp power capacity, generating about 33500 kWh per year.

Fig. 4 PV pergola at Patra Scientific Park [3].

3.2 Photovoltaic curtain wall

A curtain wall is defined as a non–structural outer wall that is part of the building envelope. It has all the features that characterise the envelope of a building, such as load bearing, weatherproofing, as well as noise and thermal insulation. In order to integrate PV elements within the curtain wall, a design structure similar to skylights is utilised. Hence, the PV element is fitted within the glass of the curtain wall. Parameters related to the building characteristics, such as thermal insulation, transparency and visual comfort, are related to the PV design attributes.

The Heineken production factory, shown in Fig. 5, is an example BIPV application utilising amorphous silicon PV curtain walls. The factory produces 66% of its energy demand by renewable energy sources and has an expected payback of less than a year [3].

Fig. 5 Heineken production factory in Mexico [3].

Moreover, the Twin City Tower building in Bratislava, shown in Fig. 6, is equipped with a BIPV curtain wall system that uses 192 black amorphous silicon units of different dimensions. The installed PV system reaches a peak power of 25 kW and has an expected payback time of 8 years [6].

Fig. 6 Twin City Tower in Bratislava [6].

3.3 Rainscreen façade

This system is based on cladding panels mounted on load–bearing subframes. In this configuration, there is an air gap between the wall and the cladding. The PV panels can substitute the conventional claddings. Due to the air gap, the PV elements can be naturally ventilated in hot environments. This type of BIPV technology can provide an aesthetically pleasing result while generating electricity for the self–consumption of the building.

The Copenhagen International School (Fig. 7) that is part of a sustainable area in Denmark, is a project where rainscreen façades have been used, covering an area of 6000 m^2. The total installed power of 700 kWp is producing approximately 500000 kWh per year, thus covering 50% of the annual electricity consumption [7].

Fig. 7 The Copenhagen International School [7].

Another rainscreen façade application was developed for the Eastern Bank in Dhaka of Bangladesh (Fig. 8), where uniform semi–transparency is achieved by utilising amorphous silicon PV panels installed in slats. Moreover, this type of PV panels can filter ultraviolet and infrared radiation, resulting in thermal insulation. With a total installed power of 12.5 kWp, the BIPV system can generate 22600 kWh per year.

Fig. 8 Eastern Bank in Dhaka [3].

3.4 Other applications

The main applications for BIPV focus on integrating photovoltaic components on the building envelope, such as the roof, windows and façades, however, other elements of the building can be exploited. These include balconies, floor tiles, shading devices, canopies and atria. However, there are specific constraints that should be considered, depending on the applications. For example, minimum height restrictions for balconies should be considered, depending on the installation location, whereas, walkable photovoltaic floor tiles should comply with the maximum load–bearing specifications. Moreover, similarly to the aforementioned applications, these type of BIPVs should provide architectural harmony. Fig. 9 shows an example BIPV balcony.

Fig. 9 BIPV balcony application [8].

4. BIPV products available on the market

A review of available BIPV manufacturers has been performed. Table II lists BIPV manufacturers and vendors, as well as their available products. As shown, there are numerous companies around the world that offer prefabricated and bespoke solutions for BIPV applications. Such applications include windows, ventilated and rainscreen façades of different colours and transparency levels. One particular example of BIPV façade that is unique is the white PV by Issol, which is a product that aesthetically looks like a conventional wall and can be used as a skin to an existing building.

Fig. 10 White PV façade by Issol[9]

Table II: BIPV companies available on the market

Company	Website	Available products and applications
Physee	www.physee.eu	Windows and facades with optional integration of sensors for monitoring light intensity, temperature and air quality.
SCX solar	www.scx-solar.eu	Roof – mounted BIPVs and rainscreen façades.
KameleonSolar	www.kameleonsolar.com	Coloured façades, using polycrystalline silicon cells.
Avancis	www.avancis.de	CIGS façades and integrated rooftop systems at different colours and sizes.
Studio solarix	www.studio-solarix.nl	BIPV windows and façades of different colours.
OnyxSolar	www.onyxsolar.com	PV skylight, curtain wall, canopy, sprandel, ventilated façades, rooftops, floor utilising amorphous silicon and crystalline silicon technologies. Various transparencies and colours are available.
PolySolar	www.polysolar.co.uk	Thin – film curtain wall, ventilated façades, canopies of different transparency levels and colours.
Issol	www.issol.eu	PV glazing, façades in different colours and transparency levels, and white PV modules.
Tulipps	www.tulipps.com/nl/	BIPV integrated rooftops and façades.
ML system	www.mlsystem.pl	PV canopies, sunshades, ventilated façades, skylights and carports.

5. Conclusions

This report has presented a wide range of BIPV technologies, including real–case applications. Both crystalline silicon and thin–film technologies are utilized for BIPV applications. Although crystalline silicon PV is the most common material for rooftops and skylights, thin–film is preferred for curtain walls and rainscreen façades due to their uniform appearance and performance in shaded environments. In addition, for many projects a short payback period has been predicted, indicating that BIPV technologies can be a viable solution towards NZEBs. Nonetheless, considerations such as shading from surroundings and thermal insulation should also be reviewed during the design process.

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7. Contacts

Project Coordinator

K-ENERGY

Fanos Karantonis, Managing director

6 Pentadaktylou Street, CY-2682 Palaiometocho, Nicosia – CYPRUS

Email: f.karantonis@karantonis.com.cy

Phone: +357 22 311 234

Work Package Leader

Partner Responsible for WP: FOSS Research Centre for Sustainable Energy, University of Cyprus

Name of the contact person: Prof. George E. Georghiou

Address: 1 Panepistimiou Avenue, 2109, Aglantzia, 1678, Nicosia, Cyprus

Email: geg@ucy.ac.cy