# BUILDING INTEGRATED PHOTOVOLTAICS
## Overview of Barriers and Opportunities

by

***Mladen BOŠNJAKOVIĆ [a], Marko KATINIĆ [b], Ante ČIKIĆ [c], and Simon MUHIČ [d,e,f*]***

[a] Technical Department, University of Slavonski Brod, Slavonski Brod, Croatia
[b] Mechanical Engineering Faculty, University of Slavonski Brod, Slavonski Brod, Croatia
[c] Department of Mechanical Engineering, University North, Varaždin, Croatia
[d] Institute for Renewable Energy and Efficient Exergy Use, Ivančna Gorica, Slovenia
[e] Rudolfovo – Science and Technology Centre Novo mesto, Novo mesto, Slovenia
[f] Faculty of Industrial Engineering Novo mesto, Novo mesto, Slovenia

Original scientific paper
https://doi.org/10.2298/TSCI221107030B

*Based on the available literature, the status and prospects for further development of the building integrated photovoltaics (BIPV) market were analyzed. The results of the analysis show that the high investment costs and the lack of information about installed BIPV systems and BIPV technology are a problem for the stakeholders. The BIPV technology is an interdisciplinary problem, so the cooperation of a large number of different experts is important. However, it is not yet at a satisfactory level. Another problem is the overlapping of responsibilities of HVAC installers, interior designers and façade manufacturers. On the other hand, the incentives of the EU regulatory framework and beyond to use RES in both new buildings and renovation of old buildings, as well as the desire for energy independence, encourage the application of BIPV technology. An analysis of the electricity production potential of BIPV integrated into the walls and roof of the building was made for four geographical locations. A comparison of the production of electricity on the walls and on the roof of the building was carried out. The analysis shows that on the four walls of the building, where each wall has the same area as the roof of the building, approximately 2.5 times more electricity than on the roof can be generated. In the absence of available surface for installing a photovoltaic power plant on the roof, the walls represent a great potential for BIPV technology.*

Key words*: solar energy, building integrated photovoltaics, barriers, opportunities*

## Introduction

The great potential of RES and their contribution the protection of nature and the environment are the focus of interest in many countries. The increasing use of electricity, most of which is generated from conventional energy sources, increases $CO_2$ emissions, which has a significant impact on the environment [1, 2]. Buildings in the EU account for 40% of total energy use and 36% of $CO_2$ emissions, and more than 60% of annual energy in buildings is used for heating.

[*] Corresponding author, e-mail: simon.muhic@inoveks.si

Intuitively, reducing energy demand in buildings will significantly limit the required energy supply and thus minimize GHG emissions [3, 4]. Therefore, there is a genuine interest from engineers and scientists in net zero energy buildings (NZEB), which focus on the tangible level of energy savings and improved performance efficiency [5-7]. By definition, NZEB are buildings that use as much electrical/thermal energy as they produce [8]. The use of electricity from PV systems installed on residential and commercial buildings could be a good solution to reduce $CO_2$ emissions and meet the requirements of net-zero buildings [9]. In many countries, PV systems are recognized as a very important technology in the process of decarbonization of energ systems [10-13]. This is line with the EU Renewable Energy Directive (RED), which foresees a 32% renewable energy share by 2030 [14].

Nowadays, the architect is obliged to inform clients about the benefits of energy efficient buildings that can drastically reduce energy demand and use renewable energy. Therefore, the architect must know about the possibilities of BIPV. It is necessary to understand and consider the possibilities, obligations, advantages and disadvantages of the BIPV project. If BIPV is considered in detail at an early stage of the design, an architectural design can ensure a good integration of PV from an aesthetic, structural, energy and economic point of view [15-17].

The most common PV material used for BIPV is crystalline silicon (c-Si), as it has been shown to have high efficiency. However, the high cost of silicon has led scientists to develop cheaper technologies, such as thin-film PV cells, which require less silicon but have relatively low energy efficiency. While c-Si is the predominant technology, thin-film technology is used when there is shading from trees or structures such as chimneys that could reduce efficiency when c-Si panels are used. Recently, for example, semi-transparent thin-film PV (STPV) modules for BIPV in windows and façades have encouraged many studies due to their excellent performance values [18-21].

Finally, accessory types include shading devices such as parapets, balcony components, or louvers [22]. When active heat recovery systems work together with BIPV systems, either in a closed loop or in an open loop with forced circulation of the working fluids, they are called building integrated PV-thermal (BIPVT) systems [23, 24]. In cold weather, air-based BIPV thermal systems have the advantage of providing space heating throughout the year due to low ambient temperatures [25]. The design and operation of net zero energy buildings can be achieved by incorporating BIPVT systems. An experimental analysis of the properties of BIPVT installed in the façade under real conditions in the Mediterranean climate was performed by Bot *et al*. [26]. Lee *et al.* [27] experimentally investigated the operational performance of color BIPV modules based on comparative analysis under outdoor experimental conditions. Rounis *et al.* [28] studied the BIPVT curtain prototype experimentally in a closed solar simulator. Zhao *et al.* [29] used the simulation model validated by experiments to analyse the performance of building with innovative bifacial PV wall system. Thermal enhancement techniques were evaluated, including multiple inlets, semi-transparent rather than opaque PV, and the newly introduced flow deflector. It was found that a multiple-inlet configuration supported by a flow deflector behind the PV panel improved thermal performance by up to 16% and lowered peak PV module temperatures by 3.5 °C, with a slight increase in electrical efficiency.

The use of BIPV is promoted by the European Strategic Energy Technology Plan (SET) [30] and the European Energy Performance of Buildings Directive (EPBD) [31]. The EPBD requires all new buildings to be near-zero energy buildings from 2020. First, the EPBD requirement that all new buildings be near-zero energy buildings from the end of 2020 may be beneficial and help promote future market adoption of BIPV. Implementation can be a combined result of reducing energy demand and increasing on-site energy generation. For high rise buildings, the roof area on which PV panels can be placed may not be sufficient to meet the building's needs. Attaching PV systems to the façade provides a solution this problem [32, 33]. In addition, the EPBD calls on EU countries and the public sector to improve the energy performance of the building stock and to develop only energy-efficient buildings. These are goals that multifunctional BIPV solutions can help to achieve.

Then, the renewable energy directive (RED) aims to empower consumers to increase their role in the energy transition by enabling them to consume the electricity they feed into the grid themselves without undue restrictions and to receive fair compensation for doing so. This provides guarantees to investors willing to install distributed PV systems such as BIPV and reduces risks by predicting the future cash flows of the systems. This can contribute to the development of reliable and innovative business models based on self-use.

Similarly, the requirements set forth in the revised electricity Market Design Regulation and Directive can help reduce uncertainties in the market valuation of electricity generated by distributed PV systems such as BIPV. For example, it is recommended that market rules comply with the principles of non-discrimination and transparency and ensure access for all market participants, with prices reflecting market fundamentals, including the real-time value of energy.

Since PV modules are to be used as components of or integrated into building envelopes, they must comply with both PV module electrical property standards and building standards. Therefore, BIPV elements available as building products on the European market must comply with the European Construction Products Regulation CPR 305/2011 [34].

In order to simplify compliance with BIPV standards and avoid possible ambiguities, specific standards have been/are being developed. They combine the technical and electrical requirements with the building regulations.

The European Standard EN 50583: 2016 on the application of PV in buildings, which consists of two parts (Part 1 – BIPV Modules [35], Part 2 – BIPV Systems [36]), provides a definition for BIPV modules used as building products and a definition for BIPV systems (*e.g.* façade systems) integrated into buildings.

In general, one or more building functions are realized by BIPV modules (*e.g.* weather protection, thermal insulation, sound insulation, *etc.*), so that conventional building products can be dispensed with. The BIPV elements can be used to build roofs, façades, overhead glazing, balustrades, semi-transparent windows or skylights. In this context, the European Technical Approval Guidelines can serve as a basis for building the regulatory framework for BIPV products and provide important suggestions for BIPV manufacturers [37]. However, in general, the lack of appropriate test methods and references, as well as the existence of regulatory gaps, hinder the faster diffusion of this technology.

In many countries, more permits are required for building integration than for conventional solar modules that are not integrated into the wall or roof.

Depending on the performance of BIPV, the traditional roles of façade manufacturers, HVAC installers, interior designers, *etc.* may overlap to some degree during the building design process and during the production and installation of solar elements. This raises questions about roles and responsibilities, information and material flow, accountability to the customer, warranties, and maintenance that need to be clarified and adequately addressed.

The information carry out the study is based on papers at journals, conferences, and specific scientific literature and scientific databases, including Science Direct, Scopus, Google Academic, Google Scholar, and specific topics on the web pages. This paper also utilizes certain reports and documents published by the EU and PV Magazine that relate to BIPV. The technical aspects of the BIPV system were analyzed first. Then, environmental, economic and other aspects affecting the application of BIPV were analyzed.

## The BIPV applications

There are a variety of methods for installing PV systems as presented on fig. 1 [38]. In general, three types of BIPV applications could be categorized: modules mounted in the roof [39], modules installed in the façade, and external integrated systems [40, 41]. The first type consists of PV modules that are part of the building roof. These include in-roof systems, full-roof solutions, solar tiles, and skylights. The second type includes cladding, curtain walls, and windows. Façade is further distinguished between cold and warm façades, depending on whether the BIPV modules include a ventilated air gap or not. The third type includes external integrated systems (parapets, balconies, louvers, or interlayer Venetian blinds for façades or balustrades) that are not directly part of the building envelope [42]. While shading solutions are now commonplace in new public buildings, façade-integrated PV and solar thermal products remain a niche market.

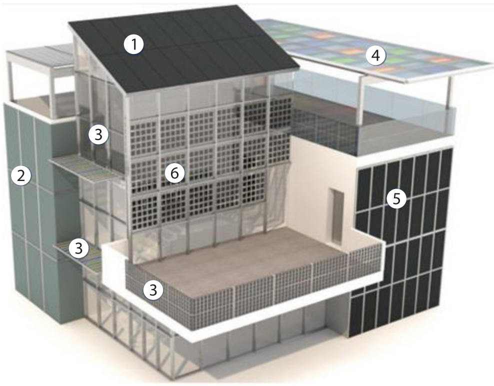

**Figure 1. The BIPV applications areas [38];**
*1 – roof, 2 – rainscreen, 3 – external integrated devices, 4 – skylight, 5 – pre-assembled element, and 6 – curtain wall*

Key factors in determining the suitability of PV integration into a building envelope include the design of the building, the materials used, electrical loads, size of the modules to be installed, and also the type of building application. In addition the aforementioned factors, the suitability of integration should be systematically investigated based on the following factors if the design is conditioned by other factors [43, 44]:
– Location, slope and orientation of the external envelope suitable for the installation of PV elements.
– Level of solar radiation.
– Determination of the degree of shading of the PV panel.
– Operating temperature of the module and ventilation of the system.
– Maintenance of the system.
– Other factors, such as humidity, wind velocity and dust issues.

In the Northern hemisphere, the maximum annual amount of PV energy generated is achieved with a southern orientation of the building and an inclination of the PV module of about 20° less than the latitude of the installation site.

The efficiency of PV technology decreases as the temperature of the PV module increases. Since PV cells convert only 10-25% of the received solar energy into electricity, most of the received energy is converted into heat [45]. For monocrystalline and polycrystalline Si cells, the efficiency decreases almost linearly by about 0.4-0.5% for a temperature increase of 1 °C and by 0.2-0.25% for amorphous Si cells [46]. The temperature of the PV cell depends on its irradiation and on the outside air temperature, which can exceed 40 °C in extreme cases. Due to high outdoor temperatures, the PV cell reaches temperatures of 7-72 °C [47]. The temperature of PV cell also depends on how the heat is dissipated from the cell. In order to increase the efficiency and productivity of the PV system, an air cavity is required between the PV elements and the building structure so that the heat can be dissipated.

The energy-related behaviour of BIPV modules includes thermal, solar, optical, and electrical aspects. It is important to remember that BIPV elements behave differently than the building elements they replace. The optical properties of BIPV modules, such as light transmittance or color rendering, also play a role in finding a balance between energy savings, electricity generation, aesthetics, and visual acceptability. However, the architectural design of BIPV modules can also affect electrical performance and reduce the efficiency of BIPV modules and systems compared to standard PV modules. Therefore, this area is still in the development and research phase. The development of existing and innovative materials for BIPV leads to lower production costs, better integration into buildings and higher efficiency of BIPV modules.

Cracking problems in BIPV systems are important issue involving system maintenance and reduced performance. Lee *et al*. [48] investigated the effects of cracks in BIPV modules on power output using experimental systems and simulated analysis. The results of the study show that cracks in BIPV modules reduces the power output of the BIPV module by up to 43% during the experimental period, and on an annual basis, the power reduction is estimated to be 34.6-35.4%.

### *Roofs*

The BIPV modules on the roof include solutions for partial and entire replacement of the roof. The major difference from classic rooftop PV systems is that BIPV are integrated and part of the roof itself, while classic PV modules sits on the top of existing roof. There are several ways to install BIPV roofs systems. It is possible to create a full-roof solution or to replace only certain parts of the roof, for example, those that are most exposed to the Sun.

Integrated solar panels or in-roof solar panels are designed to be installed in the plane of the existing roof. The PV modules can be integrated into curved roof shapes [49]. In case of replacement, the existing tiles are removed and the modules are installed in their place. The concept of in-roof solar panels has several advantages. Replacing the old or installing a new roof does not add weight to the building, which is especially important for buildings where additional weight can cause problems. Solar panels on the roof are much more aesthetically pleasing and blend into the visual identity of the building. They are also better protected from the weather condition, especially stronger winds. The main disadvantage is lower efficiency due to the lack of empty space for cooling (gap – which classic roof panels have), and they usually operate at higher temperatures.

Solar tiles and solar shingles represent a BIPV solution whose design is determined by the size and shape of the individual elements. Unlike in-roof solar panels (which are panel-based), the basic unit of this approach is a PV tile or shingle. This approach is the most aesthetic, and it is sometimes difficult to tell whether it is a normal roof or a BIPV system. Manufacturers of solar tiles and shingles emphasize durability (*e.g.*, against hail) and resistance beyond the characteristics of a conventional roof. The main disadvantage is the high price, lower efficiency (as in the case of the in-roof solar panels), more demanding installation and greater possibility of malfunction, due to the many interconnections between the PV elements.

### *Façades*

The building envelope should mediate heat transfer between the exterior and interior to create a comfortable indoor environment with minimal energy use. The building envelope is also the interface between the indoor climate, which is controlled from the inside, and the changing outdoor climate. The BIPV façade systems can reduce cooling loads and generate energy in office buildings [50]. The authors studied two cases, with and without BIPV systems, to determine the optimal orientation reduce cooling demand and still generate energy. Akinyele *et al*. [51] concluded that energy costs for office buildings can be reduced by up to 33.5% when transparent solar panels (PV glass) are used.

In addition its thermal protection function, the building envelope is designed to withstand the harmful effects of wind and additional loads from various shocks such as seismic vibrations, strong detonations near the building, solid precipitation (hail), and so on. Shameri *et al*. [52] found that double skin façade systems have a significant impact on building safety, fire spread maintenance, and glazing thermal break. Vassiliades *et al.* [53] concluded that most researchers prefer single façade systems, followed by double façade systems, since the second system has a cavity that can be used as an air duct for BIPV and BIPVT solutions. In addition, façade cladding is a function of daylighting control, ventilation, solar heating, privacy, and security.

The BIPV modules can generally be installed on the entire façade of a building. The area of the façade increases with the height of the building, so there are good opportunities for BIPV application here. However, it should be kept in mind that the efficiency of BIPV can be affected by the installation angle and the shadow of surrounding buildings, so not all façade surfaces are equally suitable for installation. However, vertical PV façades produce relatively more energy in the winter than in the summer months [54] and in the morning and evening hours when the sun is low in the sky.

Glass has become a very important building material in modern architecture. Glass offers the possibility to build a lighted, open and bright building. However, glass significantly affects the energy efficiency of buildings and the comfort of living. In this sense, BIPV windows have good characteristics and have shown great potential for energy savings, *e.g.*, about 12-21% in annual energy use and 14% to 26% in peak cooling demand [55]. It should also be noted that practice to date has shown that most applications of BIPV systems relate to various glazed surfaces, then to roof systems, and only 15-18% to wall systems [56]. The reason why BIPV systems are least integrated into walls is due to the complexity of performance and lower efficiency compared to other systems. The additional aspects to be considered when integrating a PV system into a building envelope are:

- Color, reflectance, and size. The material and finish of PV modules should match those of other cladding and finish elements of the building envelope. To improve aesthetics and give architects more freedom to customize their PV modules, digital ceramic printing technology on glass can be applied to the shingled PV module. Digital ceramic printing offers architects the ability to print custom patterns, text and images on the residential surface of a shingled PV module that is UV-resistant, weatherproof and environmentally friendly.
- Atmospheric impermeability.
- Wind gusts.
- Durability and maintenance.
- Safety during installation and use (stability, fire protection, electrical safety).
- Price.

Investors have ranked some criteria as more important than others. From previous projects, it appears that the priorities are generally the aesthetics of the solution, the ability to build a green building (this may be required by law), cost, and energy efficiency.

### *Externally integrated systems*

Externally integrated PV system is the simplest way, as the PV modules are installed above the windows or glass panes, depending on the construction of the building. The suitability of integration with the shading system has great potential due to the ease of installation method, relatively low installation cost compared to other design approaches, and the clear expression of sustainable development through the ease of PV module ventilation and solar energy efficiency.

According to the research of Baghoolizadeh *et al*. [57] for buildings in Tehran, the use of solar shades can reduce electricity use by approximately 4-11%, 1-4%, and 10-22%, respectively for the annual period, *i.e.* winter and summer season.

The use of PV modules is possible in forms that replace the usual horizontal and vertical grids in metal or wooden frames, which today in most cases are made of aluminum. They can be mounted with metal profiles and brackets on the building envelope itself or on a separate structure that forms the space between the building and the module. The shading system can be made in two forms: mobile and fixed. The efficiency of a mobile system is higher in northern climates, where the Sun is always low, than that of a stationary system, which blocks the useful rays of the Sun in winter.

The possibility of installation in the shading system depends on the façade design. Usually it can be implemented only on façades with maximum 50% glazing due to the *parking space* for the shutters. The system cannot be applied to the currently popular all-glass façades. The appearance of the façade is changed by the installation of roller shutters. Roller shutters require regular maintenance.

It is possible to effectively manage solar heat gains to reduce the cooling requirements of spaces and/or reduce the risk of overheating. External shading from the urban environment affects the performance of the system. Thus, Custodio *et al*. [58] evaluated the integration quality of PV shading systems considering design, functional and aesthetic aspects.

Glass roofs and skylight are a feature of modern construction of large buildings and structures. The integration of PV modules into this system can play an important role as a shading element. In Kovilpatti, India, the roof window PV cell coverage ratio was 0.62 with a daylight factor of 4% and 0.72 for a total energy saving potential of 450 kWh per year [59]. According to the analysis of Zhu *et al*. [60] the application of PV in skylights shows a promising energy saving potential in China. Valencia-Caballero *et al.* [61] presents the development and performance demonstration of a novel low concentration PV skylight system that ensures seasonal solar control in buildings.

Horizontal PV canopies act as window shades and greatly reduce the need for cooling in Mediterranean climates, while in hot desert climates they are less efficient than PV windows [62].

As with the double façade cladding system, the system of covered surfaces achieves integration by placing PV modules between layers of laminated glass. One of the main functions of this system, as with any other, is to protect the structure of the system from gusts of wind, heavy rains and the stress of maintenance and replacement of PV modules.

## Discussion

Building-integrated PV help designers to achieve sustainability goals and reduced $CO_2$ emissions while maintaining or improving indoor comfort. The synergy between the main functions of integrated PV, on-site energy generation and building component formation, along with increased cost competitiveness, makes integrated PV an attractive option. Due to the specific interdisciplinary problem, the co-operation of a large number of different experts, such as architects, civil engineers and planners of PV systems, is important. To date, most BIPV systems are designed with little communication between the design and simulation processes [63]. For example, architects design the floor plan, structure, and lay-out of a building in CAD or BIM platforms. For simple buildings use of monthly method is usually preferred, even dynamic simulations offer more information on energy performance of buildings [64]. According to the architectural design, energy engineers then remodel the building in energy efficiency simulation software such as TRNSYS, EnergyPlus, and IDA-ICE. Due to the complexity of the BIPV system, they are likely to use other tools such as PVSyst and Polysun because the model developed by the architects is not compatible with the energy efficiency simulation tool [65].

When checking the possible integration of the PV system into the building, it is important to create a 3-D model of the building with a diagram of the Sun's path and the immediate surroundings in order to predict and prevent shading of the PV system. The problem of shading occurs mainly in urban areas, where the possibility of mutual shading of buildings and surrounding vegetation is very high. However, some buildings can also shade their own envelope. If the building envelope shades the PV module, the shading must not exceed 10% of the total area of the PV module at any time between 10 a. m. and 2 p. m., when solar radiation is highest [66]. Such a repetitive modelling process from architectural design results in lost time, additional work, and possibly some loss of information (*i.e.*, geometric and component inconsistencies due to incomplete understanding of the model). Overall, the gaps in BIPV system design and research are in the following areas [63]:

– there is a lack of a comprehensive simulation framework for building design and energy efficiency analysis and
– the most existing studies have not fully addressed the integrated techno-economic assessment of BIPV systems (solar radiation, object shading, building location, system components, and economic analysis).

In summary, the main characteristics of BIPV application in the building envelope that should be achieved by design are:

– The façade has an attractive appearance.
– Maintenance and durability are comparable to those of passive glass façades.
– Electricity is generated from renewable source directly on site.
– The market for BIPV is large, as it can be used in both new and renovated buildings.
– Investment costs are higher compared to classic solutions, which is an important factor in most states.
– The design phase is longer than for non-integrated solutions, such as roofs PV.
– Electrical interconnection between PV panels and inverters is a challenge.
– The power generation potential of façade-integrated PV is lower than that of roof-mounted PV, especially in summer.

Solar envelopes are difficult to establish in the construction market because the main players (architects, contractors*, etc.*) are not sufficiently familiar with the relevant regulations, design calculations and electrical installations of such solutions.

In the literature, there are very few published experimental studies on the characteristics of installed BIPV systems. This is certainly one of the reasons for the distrust of this technology. One of the few experimental studies available is by Giraldo-Perez *et al*. [67]. This study addresses the sustainability of BIPV in selected tropical urban regions from the point of view of energy production. The results indicate that the implementation of these technologies is sustainable for urban spaces in the regions studied, as vertical modules facing east and west require only twice as much space as horizontal modules to generate the same amount of electricity, and the vertical area available in buildings can be up to 20 times larger than the horizontal.

Electricity from non-renewable sources has low costs for private investors, but high social costs due to carbon emissions during production and transmission [68]. The long-term potential of solar energy to contribute to the world's electricity supply is large and supports plans to grow the global economy while reducing $CO_2$ emissions. The benefits of BIPV to society are primarily twofold: environmental and health benefits from reduced particle and $CO_2$ emissions and economic benefits to society. Branker and Pearce [69] also discussed the social impacts of carbon emissions such as loss of biodiversity and ecosystem services, and disease and early mortality due to air pollution.

The economic impacts caused by carbon emissions are referred to as the *social cost of carbon* [70]. In the EU, the price per tonne of carbon emissions reached $100 in 2022. It is estimated that a price increase of 1 EUR per tonne of $CO_2$ would lead to an average reduction in emissions of 0.73% over time [71]. The application of a BIPV system can help reduce these costs. The losses associated with transporting and distributing electricity between generation plants and consumers can also be reduced through the use of BIPV. In the EU losses on the grid are ranging from 4-17% de-pending of the country.

In addition, Byrnes *et al.* [68] found that BIPV leads to social welfare because less land is used for electricity generation. As for the benefits to end users (tenants), they are supported by the reduction of electricity bills.

The main barriers are the high capital cost of BIPV modules, the high cost of developing customized BIPV systems, low public understanding and low cost perception of BIPV. Investors and end users lack the knowledge of cost analysis to make decisions about the deployment of BIPV. Cost-benefit analysis of BIPV should consider not only initial costs, but also ongoing maintenance costs throughout the life of the building. In addition, the scope and factors of the cost-benefit analysis need to be expanded to include community and environmental aspects, as well as electricity price and government subsidies.

Several factors are expected to drive market growth in the post COVID-19 period, including the price of PV modules per watt, the improved aesthetics of BIPV [72, 73], improvements in the efficiency of c-Si modules and flexible thin-film modules, and the desire of home and office building owners to *go green*. In the post COVID -19 period, construction activity and BIPV use are expected to increase in many countries. In addition, BIPV technology is expected to be adopted in countries such as China, India, Africa, and Latin America that do not yet have adequate power grid infrastructure. Not only new buildings, but also reconstructions and renovations are expected to boost demand for BIPV products in the coming years.

The price of conventional energy has a great impact on the cost-effectiveness of BIPV systems. Due to the recent war in Ukraine, the prices of natural gas, oil, electricity and other energy sources have increased. It is not expected that these prices will decrease even after the war ends. On the other hand, the desire for energy independence from the import of conventional fuels promotes investments in renewable energy sources and the growing demand for PV modules. For all these reasons, it is difficult to predict with certainty the development of the BIPV market.

Polysilicon is an important raw material for the production of solar modules. For years, its price reduction was an important factor in the decline of solar module prices. However, in 2021 and 2022, polysilicon prices have multiplied, leading to higher module prices, fig. 2.

How polysilicon prices will develop in the future (*e.g.*, by the end of 2024) depends heavily on the development of gross margins of polysilicon producers and the development of electricity prices. Gross margins are likely to decrease as new polysilicon production facilities are built, but the price of electricity plays a very large role. This is exactly the case, as polysilicon prices are surprisingly high right now, even though polysilicon production in China has increased in the first two months of 2022.

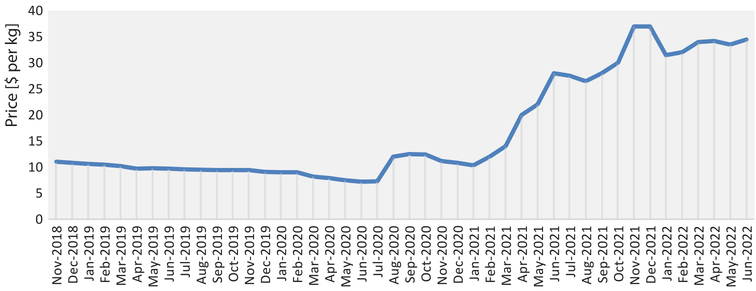


**Figure 2. Global polysilicon spot price average [74]**

The high demand for solar modules will affect the growth of component prices and put pressure on the increase of solar capital costs in the near future. Upstream polysilicon production will be insufficient to meet the strong demand in the near future, which will push up module prices and increase the cost of solar capital in 2022. In fact, Si wafer production is concentrated in only five manufacturers worldwide. The Chinese have displaced many manufacturers (South Koreans) and hold a monopoly position.

Even though a solar module today does not contain much polysilicon (about 500 grams in a 60-cell module) thanks to advances in manufacturing technology, this is not the only price pressure on solar modules. Other factors impacting the module supply chain include rising prices for commodities such as glass, steel and aluminum. Glass prices are rising not only because of rising energy prices, but also because of high demand from PV module manufacturers.

Prices are also affected by the shortage of containers and the increase in freight rates due to the rise in fuel prices. Steel and aluminum prices increased by about 95% and 115%, respectively, from January 2020 to March 2022. These disruptions were mainly caused by various pandemic blockages.

Mainstream module prices in EU have increased by over 57% from about \$0.21 per watt in October 2020 to about \$0.33 per watt in Jun 2022 as presented in fig. 3 [75]. This is mainly due to higher prices for polysilicon, which is an important raw material for PV modules.

Thanks to some country-specific subsidies and the recently lowered VAT, some end users are able to absorb the additional price increase. According to the announcements of some manufacturers, no major jumps in module prices are expected and prices will soon stabilize at the current high level. All previous price analyses apply to the PV market in general. This means that the BIPV market is included, although it has its own peculiarities.

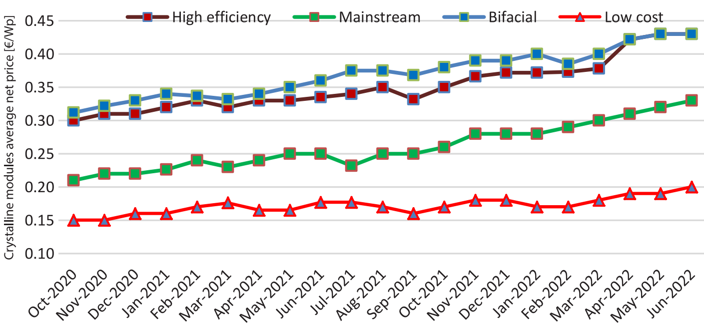


**Figure 3. The EU spot market module prices by technology [75]: high effeciency – crystaline modules 340 Wp and above with Cello, PERC, HIT-, *n*-type, mainstream – modules with 60 cells, standard Al frames, white backing, 275-335 Wp, bifacial – modules with bifacial cells, transparent backsheet, and low cost – reduced-capacity modules, factory seconds, used modules**

Existing energy policy targets will be significantly revised in 2021 and 2022 in many European countries and beyond. In Germany, for example, the number of new PV installations was relatively high last year and the planned new capacity will be exceeded by 100%. This will lead to a sharp reduction in feed-in tariffs. After all, given the desire to install 10 GW of capacity per year, it is clear that demand for modules is high. Whether these wishes will come true also depends on the development of module prices.

The attractiveness of applying the BIPV system in a given country also depends on the regulations and laws that govern the conditions for the compensation of energy generated in the building and drawn from the grid. Net metering is a system in which electricity exports are offset by imports and electricity bills decrease by subtracting the electricity generated from the total electricity used over a period of time. Adjustments can be made monthly, semi-annually, or annually. A bidirectional *net meter* typically accounts for both electricity imports and exports. If the exported electricity is greater than the imported, the excess fed into the grid is paid or not, depending on the state's net metering rules. The main difference between net billing and net metering is that the surplus energy delivered to distribution companies and the energy received under net billing are valued at different rates. This means that companies can inject the electricity generated by the building into the grid at much lower prices, but sell it at a higher cost. This gives distribution companies a greater advantage over consumers.

According to the author's opinion, the application of BIPV for net metering systems is profitable based on a billing period of one year, as it is at the moment in Republic of Slovenia. One of the reasons why BIPV systems are not used in Croatia is probably the net metering system based on a billing period of one month and energy compensation within the same tariff. But at the moment there are very few BIPV applications also in Slovenia, regardless to the difference in a billing period.

The situation in the BIPV market in Europe is shown in fig. 4. Since 2012, there has been a sharp decline in installed capacity. The lowest amount of installed capacity was from 2016 to 2018, as could be seen from fig. 4. The predictions given for 2020 to 2023 are questionable whether they are realized considering the large increase in prices. At the time of writing the manuscript, the authors did not find real data for 2020 and 2021.

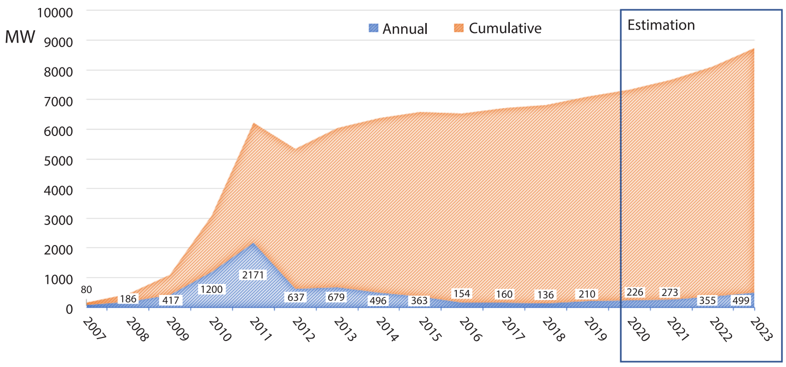


**Figure 4. The BIPV market history in Europe [38]**

To estimate the potential of BIPV on different façades and on different locations several calculations were made, using BIMsolar software [76] with weather data for a typical meteorological year, imported from TRNSYS [77]. Building geometry of 10 × 10 × 10 m were made in Sketchup format, imported into BIMsolar software where BIPV modules were placed on the

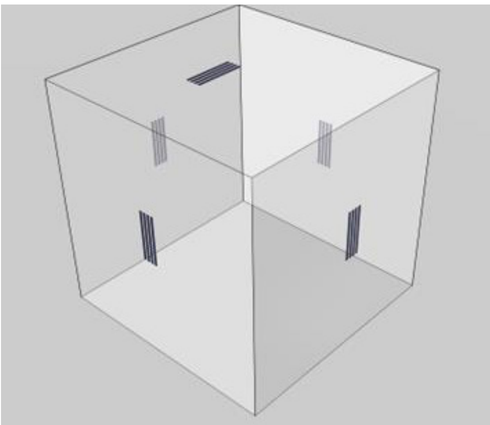

**Figure 5. The 3-D presentation of the calculation model**

middle of roof and façades, fig. 5. Façades were oriented to east, south, west and north, roof slope was 0°. The BIPV lay-out was used with Onyx Solar X6 mono Si, non-bifacial module, with dimension 765 × 2212 mm with peak power 192 W. Accurate precision setting was used for calculation. Results for Ljubljana, Slovenia, Split, Croatia, Belgrade, Serbia and Brussels, Belgium are presented in this paper in cases where there is no shading on BIPV modules.

Direct, diffuse, reflected and total irradiation for calculation are presented on figs. 6 -9. There is no reflected radiation on the roof surface while it is the highest on the northern façade. Diffuse irradiation is the highest on the roof surface, while it is the lowest on the northern façade.

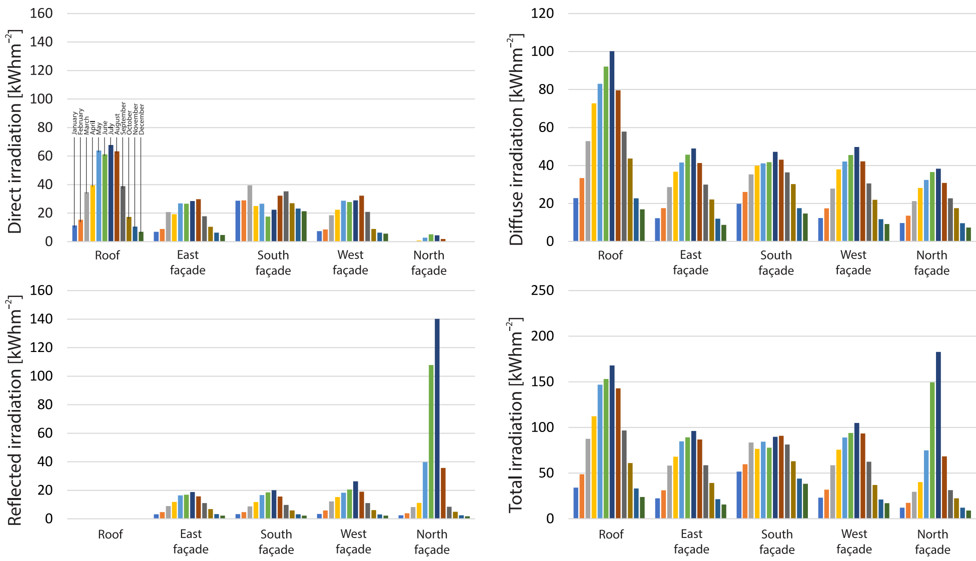


**Figure 6. Irradiation data in [kWhm$^{-2}$] in numerical model for Ljubljana, Slovenia**

Figure 10 shows results from calculation. It could be seen that electricity production from BIPV is highest on the roof surface and at the same time low on the northern façade. The generation of electricity on walls of the building is lower than the generation of electricity on the roof surface and ranges from 0.2-0.8.

For the south-facing wall, PV production during January, Februray, October, November, and December is higher than for the roof area, and in the other months it is lower. It is interesting that for Ljubljana the contribution electricity production of the north-facing wall in July is higher than that of the roof by 12%. Based on the results, it can be concluded that the production of electricity on the walls of the building in relation the production of electricity on

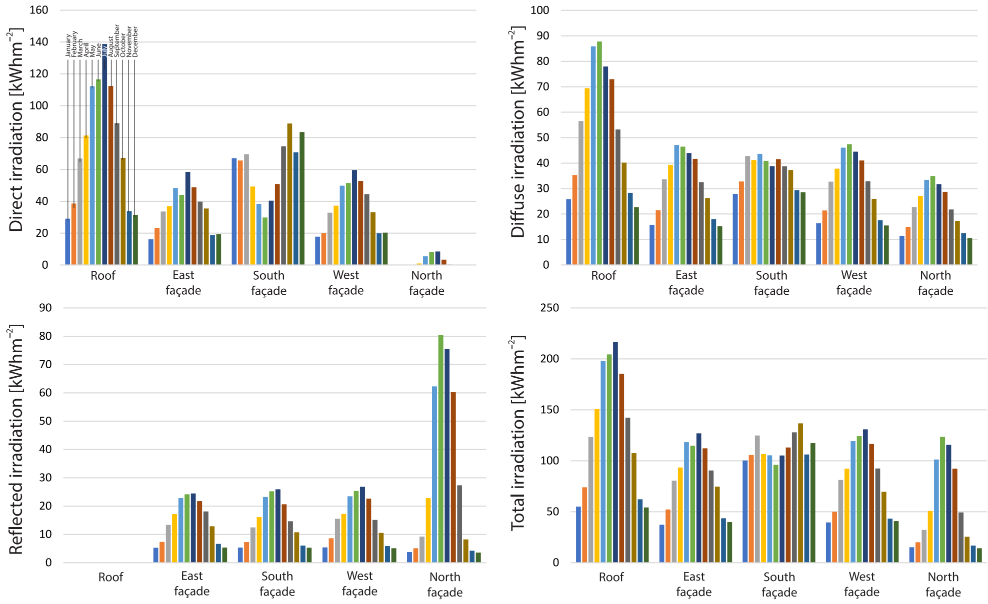


**Figure 7. Irradiation data in kWh/m² in numerical model for Split, Croatia**

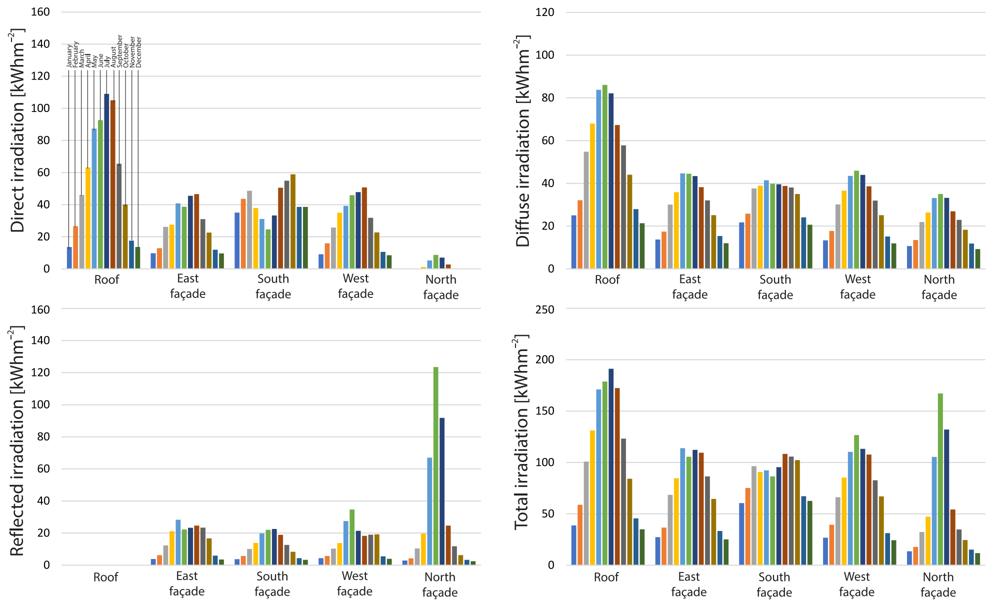


**Figure 8. Irradiation data in kWh/m² in numerical model for Belgrade, Serbia**

the roof for Belgrade is 2.1-3.6 times higher depending on the month, for Ljubljana from 2.3-3.4 times for Split from 2.1-4 times, and for Brussels from 2.1-3.7 times. From all of the previously mentioned, it follows that in the absence of available surface for installing a PV power plant on the roof, a good possibility is also the walls of buildings, which enable the power of the power plant to be increased.

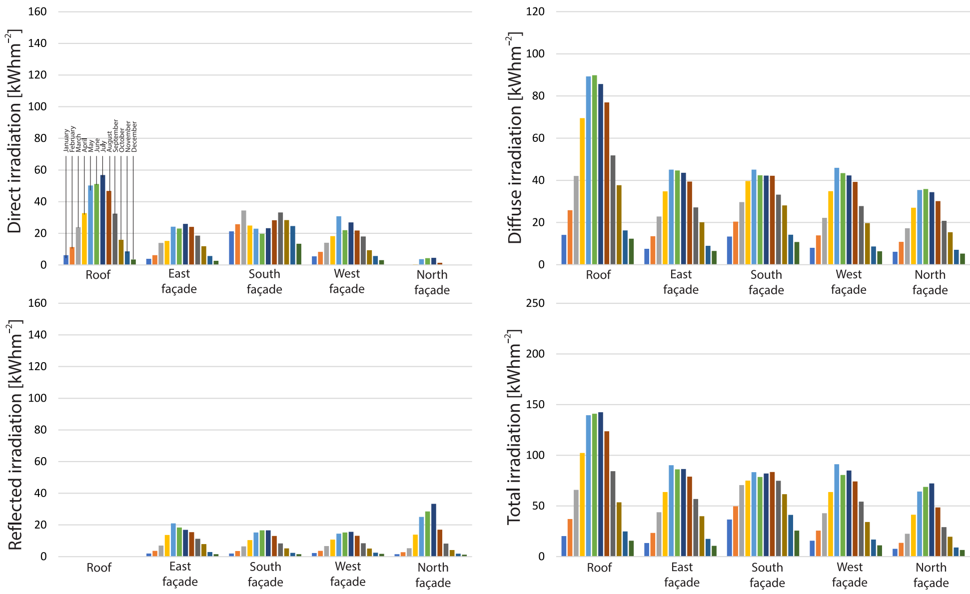


**Figure 9. Irradiation data in kWh/m² in numerical model for Brussels, Belgium**

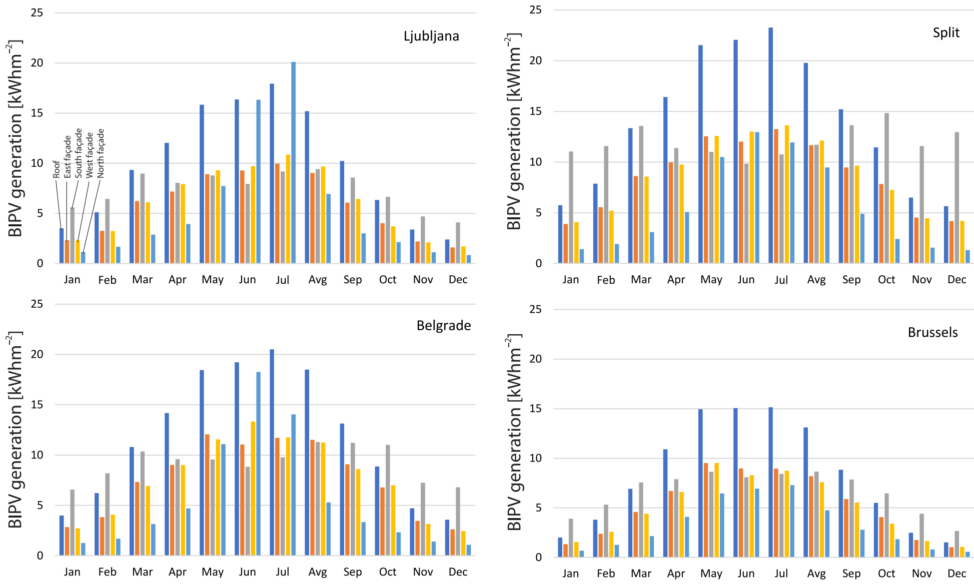


**Figure 10. The BIPV generation from numerical model**

Table 1 shows yearly BIPV generation on the roof and on the façades of the object. It is evident from the table that, in total, about 2.5 times more energy can be generated on the walls than on the roof surface for the observed case of the building, regardless of the location of the building. It should be mentioned that the area of the walls is four times bigger than the area of the roof, which means that on the walls around 63% of efficiency could be achieved compared to the roof, fig. 11.

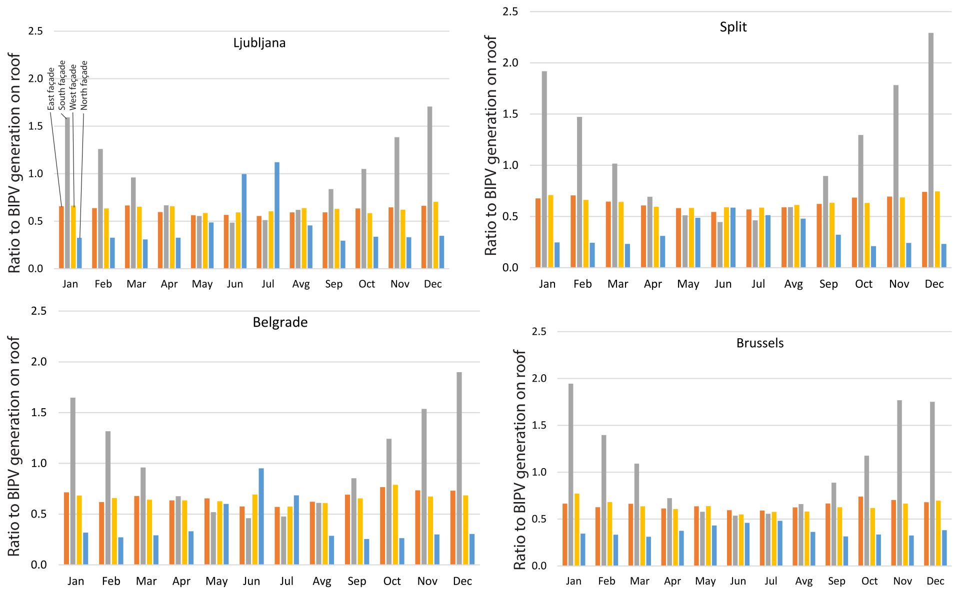


**Figure 11. Ratio of BIPV generation between façades and between roof**

**Table 1. Yearly BIPV generation in kWh/m²**

| City | ROOF | East façade | South façade | West façade | North façade | Total | Façade to ROOF |
|---|---|---|---|---|---|---|---|
| Ljubljana | 117.65 | 70.00 | 88.34 | 73.06 | 67.81 | 416.86 | 2.54 |
| Split | 168.84 | 103.54 | 143.93 | 104.54 | 66.56 | 587.41 | 2.48 |
| Belgrade | 142.19 | 91.37 | 110.51 | 91.92 | 67.71 | 503.70 | 2.54 |
| Brussels | 100.27 | 63.41 | 79.88 | 60.99 | 39.66 | 344.21 | 2.43 |

Table 2 shows average ratio of yearly BIPV generation on the façades and yearly BIPV generation on the roof. It could be seen that generation of electricity on the south façade is lower than on the roof in Ljubljana and Belgrade, but at the same time is higher on the roof in Split and Brussels.

**Table 2. Average ratio façade/roof BIPV generation**

| City | East façade | South façade | West façade | North façade |
|---|---|---|---|---|
| Ljubljana | 0.595 | 0.751 | 0.621 | 0.576 |
| Split | 0.613 | 0.852 | 0.619 | 0.394 |
| Belgrade | 0.643 | 0.777 | 0.646 | 0.476 |
| Brussels | 0.632 | 0.797 | 0.608 | 0.396 |

## Conclusions

To reduce GHG emissions and establish the development of a sustainable and decarbonized energy system for buildings, the opportunities for PV integration are great. The BIPV system holds enormous potential for using solar energy to convert and generate electricity in the building cycle. The benefits of BIPV to society are primarily two fold: environmental and health benefits from reduced $CO_2$ emissions and economic benefits to society.

The main EU directives provide an incentive for the application of BIPV technology through the mandatory construction of NZEB buildings and the installation of distributed PV systems. In this case, since the PV modules are integrated into the building, they must meet the requirements of the European Construction Products Regulation CPR 305/2011.

In general, three types of BIPV applications could be categorized: modules mounted in the roof, modules installed in the façade, and externally integrated systems. Care should be taken to avoid shading the PV modules. The area of the façade increases with the height of the building, so this is a good opportunity for the application of BIPV. From calculations it follows that in the absence of available surface for installing a PV power plant on the roof, a good possibility is also the walls of buildings, which enable the power of the PV power plant to be increased. For walls, which are oriented to north, east, south and west and have the same area as roof, about 2.5 times more energy can be generated on the walls than on the roof. On the wall, which is oriented towards south, the same production of electricity as on the roof could be expected. The main features of the application of BIPV in the building envelope should be highlighted, are as follows.

- Electricity is generated directly on site.
- Market for BIPV is large, as it can be used in both new and renovated buildings.
- New BIPV systems eliminate the conflict between aesthetics and PV to such an extent that they can even be installed on protected historical monuments.
- Investment cost is higher compared to traditional solutions, which is an important factor in most states.
- Design phase is longer than for non-integrated solutions, such as PV roofs.
- Solar envelopes have a hard time gaining a foothold in the construction industry market because the main players (architects, contractors, *etc.*) are not familiar with the installation, structural calculations and electrical installation of such solutions.

Due to the recent war in Ukraine and the Coronavirus pandemic, the prices of natural gas, oil, electricity and other energy sources have increased, which has affected the increase in the price of PV modules. The desire for energy independence from the import of conventional fuels promotes investment in RES and an increase in demand for PV modules, which also affects the increase in PV module prices.

At the same time, new capacity for PV module production is being built and the technical characteristics of PV modules are being improved, which is expected to have an impact on the reduction of PV module prices.

Due to the aforementioned reasons and other factors not listed here, which have an opposite influence on the prices of PV modules, it is difficult to predict with certainty the short-term development of the BIPV market. In the long term, BIPV has good conditions for development, especially since electricity is becoming the main form of energy obtained from primary energy sources and can be converted into any other form of energy.

Finally, to encourage the use of BIPV, the authors suggest:

- Governments should decide to apply net metering on an annual basis.
- Governments should offer certain incentives.
- Study programs need courses that cover BIPV in its entirety, not just in part.
- Export-import of data from different software programs should be enabled so that output data from one software does not have to be re-entered as input into another software program.
- Better promotion of BIPV to the public.

## References


[1] Yousef, B. A. A., *et al*., Perspective on Integration of Concentrated Solar Power Plants, *Int. J. Low-Carbon Technol*., *16* (2021), 3, pp. 1098-1125

[2] Wilberforce, T., *et al*., Progress In Carbon Capture Technologies, *Sci. Total Environ*., *761* (2021), 143203

[3] Košičan, J., *et al*., Life Cycle Assessment and Economic Energy Efficiency of a Solar Thermal Installation in a Family House, *Sustainability*, *13* (2021), 4, 2305

[4] Rezk, H., *et al*., Performance Evaluation and Optimal Design of Stand-Alone Solar PV-Battery System For Irrigation in Isolated Regions: A Case Study In Al Minya (Egypt), *Sustain. Energy Technol. Assessments*, *36* (2019), 100556

[5] Wei, W., Skye, H. M., Residential Net-Zero Energy Buildings: Review and Perspective, *Renew. Sustain. Energy Rev*., *142* (2021), 110859

[6] Wilberforce, T., *et al*., A Review on Zero Energy Buildings – Pros and Cons, *Energy Built Environ*., *4* (2021), 1, pp. 25-38

[7] Maghrabie, H. M., *et al*., Building-Integrated Photovoltaic/Thermal (BIPVT) Systems: Applications and Challenges, *Sustain. Energy Technol. Assessments*, *45* (2021), 101151

[8] Lindholm, O., *et al*., Positioning Positive Energy Districts in European Cities, Buildings, *11* (2021), 1, 19

[9] Hirvonen, J., *et al*., Emission Reduction Potential of Different Types of Finnish Buildings through Energy Retrofits, *Buildings*, *10* (2020), 12, 234

[10] Bošnjaković, M., *et al.*, Experimental Testing of PV Module Performance, *Teh. Glas*., *15* (2021), 1, pp. 127-132

[11] Bošnjaković, M., *et al.*, Cost-Benefit Analysis of Small-Scale Rooftop PV Systems: The Case of Dragotin, *Croatia, Appl. Sci*., *11* (2021), 19, 9318

[12] Dimnik, J., *et al*., Decarbonising Power System With High Share of Renewables and Optionally with Or Without Nuclear: Slovenia Case, *Thermal Science*, *26* (2022), 2B, pp. 1593-1602

[13] Pfeifer, A., *et al.*, Increasing the Integration of Solar Photovoltaics in Energy Mix on the Road to Low Emissions Energy System – Economic and Environmental Implications, *Renew. Energy*, *143* (2019), Dec., pp. 1310-1317

[14] ***, Directive 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02018L2001-20181221&from=EN

[15] Jelle, B. P., *et al.*, Building Integrated Photovoltaic Products: A State-Of-The-Art Review And Future Research Opportunities, *Sol. Energy Mater. Sol. Cells*, *100* (2012), May, pp. 69-96

[16] Sprenger, W., *et al.*, Electricity Yield Simulation For The Building-Integrated Photovoltaic System Installed in the Main Building Roof of the Fraunhofer Institute for Solar Energy Systems ISE, *Sol. Energy*, *135* (2016), Oct., pp. 633-643

[17] Stamenić, L. S., Erban, C., Building Integrated Photovoltaics – Technology Status, *Thermal Science*, *25* (2021), 2B, pp. 1523-1543

[18] Kapsis, K., Athienitis, A. K., A Study of the Potential Benefits of Semi-Transparent Photovoltaics in Commercial Buildings, *Sol. Energy*, *115* (2015), May, pp. 120-132

[19] Peng, J., *et al*., Numerical Investigation of the Energy Saving Potential of a Semi-Transparent Photovoltaic Double-Skin Facade in a Cool-Summer Mediterranean Climate, *Appl. Energy*, *165* (2016), Mar., pp. 345-356

[20] Yu, G., *et al*., A Review on Developments and Researches of Building Integrated Photovoltaic (BIPV) Windows and Shading Blinds, *Renew. Sustain. Energy Rev*., *149* (2021), 111355

[21] Xing, W., *et al*., Energy Performance of Buildings Using Electrochromic Smart Windows with Different Window-Wall Ratios, *Journal Green Build*., *17* (2022), 1, pp. 3-20

[22] Saretta, E., *et al*., A Calculation Method for the BIPV Potential of Swiss Façades At LOD2.5 in Urban Areas: A Case From Ticino Region, *Sol. Energy*, *195* (2020), Jan., pp. 150-165

[23] Debbarma, M., *et al*., Comparison of BIPV and BIPVT: A Review, *Resour. Technol*., *3* (2017), 3, pp. 263-271

[24] Ge, M., *et al*., Experimental Research on the Performance of BIPV/T System With Water-Cooled Wall, *Energy Reports*, *8* (2022), Nov., pp. 454-459

[25] Athienitis, A. K., *et al*., Assessing Active and Passive Effects of Façade Building Integrated Photovoltaics/Thermal Systems: Dynamic Modelling And Simulation, *Appl. Energy*, *209* (2018), Jan., pp. 355-382

[26] Bot, K., *et al.*, Performance Assessment of a Building-Integrated Photovoltaic Thermal System in a Mediterranean Climate – An Experimental Analysis Approach, *Energies*, *14* (2021), 8, 2191

[27] Lee, H., *et al*., Performance Evaluation of Sputter-Coating Based Color BIPV Modules under the Outdoor Operational Condition: A Comparative Analysis with a Non-Color BIPV Module, *Energy Reports*, *8* (2022), Nov., pp. 5580-5590
[28] Rounis, E. D., *et al*., BIPV/T Curtain Wall Systems: Design, Development and Testing, *Journal Build. Eng*., *42* (2021), 103019
[29] Zhao, O., *et al.*, Experimental and Numerical Study on the Performance of Innovative Bifacial Photovoltaic Wall System, Sustain, *Cities Soc*., *85* (2022), 104085
[30] ***, European Commision, Strategic Energy Technology Plan: Accelerating the European Energy System Transformation, Brussels, Belgium, 2015
[31] ***, Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2010.153.01.0013.01.ENG&toc=OJ%3AL%3A2010%3A153%3ATOC
[32] Osseweijer, F. J. W., *et al.*, A Comparative Review of Building Integrated Photovoltaics Ecosystems in Selected European Countries, *Renew. Sustain. Energy Rev*., *90* (2018), July, pp. 1027-1040
[33] Defaix, P. R., *et al.*, Technical Potential for Photovoltaics on Buildings in The EU-27, *Sol. Energy*, *86* (2012), 9, pp. 2644-2653
[34] ***, Regulation (EU) No 305/2011 of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02011R0305-20210716
[35] ***, European Committee for Standardization, European Standard CSN EN 50583-1: Photovoltaics in buildings – Part 1: BIPV modules, https://www.en-standard.eu/csn-en-50583-1-photovoltaics-in-buildings-part-1-bipv-modules-2/
[36] ***, European Committee for Standardization, European Standard CSN EN 50583-2: Photovoltaics in buildings – Part 2: BIPV systems, https://www.en-standard.eu/csn-en-50583-2-photovoltaics-in-buildings-part-2-bipv-systems-2/
[37] ***, ACCIONA, *et al*., European Regulatory Framework for BIPV, 2016
[38] Corti, P., *et al*., Building Integrated Photovoltaics: A Practical Handbook for Solar Buildings' Stakeholders, Technical Report, Univ. of Applied Sciences and Arts, Lucerne, Switzerland 2020
[39] Pearce, J. M., *et al.*, Design of Post-Consumer Modification of Standard Solar Modules to form Large-Area Building-Integrated Photovoltaic Roof Slates, *Designs*, *1* (2017), 2, 9
[40] Verberne, G., *et al.*, BIPV Products for Façades and Roofs: A Market Analysis, *Proceedings*, 29th European Photovoltaic Solar Energy Conference and Exhibition, Amsterdam, The Netherlands, 2014, pp. 22-26
[41] Attoye, D. E., *et al.*, A Review on Building Integrated Photovoltaic Façade Customization Potentials, *Sustainability*, *9* (2017), 12, 2287
[42] Asfour, O. S., Solar and Shading Potential of Different Configurations of Building Integrated Photovoltaics Used as Shading Devices Considering Hot Climatic Conditions, *Sustain., 10* (2018), 12, 4373
[43] Peng, C., *et al.*, Building-Integrated Photovoltaics (BIPV) in Architectural Design in China, *Energy Build.*, *43* (2011), 12, pp. 3592-3598
[44] Bloem, J. J., *et al*., An Outdoor Test Reference Environment for Double Skin Applications of Building Integrated Photovoltaic Systems, *Energy Build*., *50* (2012), July, pp. 63-73
[45] Idir, A., *et al*., Thermodynamic Optimization of Electrical and Thermal Energy Production of PV Panels and Potential for Valorization of the PV Low-Grade Thermal Energy Into Cold, *Energies*, *15* (2022), 2, 498
[46] Kang, H., Crystalline Silicon Vs. Amorphous Silicon: The Significance of Structural Differences in Photovoltaic Applications, *IOP Conf. Ser. Earth Environ. Sci*., *726* (2021), 1, 012001
[47] Muhammad, F., *et al*., Low Efficiency of the Photovoltaic Cells: Causes and Impacts, *Int. J. Sci. Eng. Res*., *8* (2017), 11, pp. 1201-1207
[48] Lee, K. W., *et al*., The Impact of Cracks in BIPV Modules on Power Outputs: A Case Study Based on Measured and Simulated Data, *Energies*, *14* (2021), 4, 836
[49] Appelbaum, J., *et al.*, Curved Photovoltaic Collectors-Convex Surface, *Sol. Energy*, *199* (2020), Mar., pp. 832-836
[50] Salameh, T., *et al*., Analysis of Cooling Load on Commercial Building in UAE Climate Using Building Integrated Photovoltaic Façade System, *Sol. Energy*, *199* (2020), Mar., pp. 617-629
[51] Akinyele, D. O., *et al.*, Comparative Study of Photovoltaic Technologies Based on Performance, Cost and Space Requirement: Strategy for Selection and Application, *Int. J. Green Energy*, *13* (2016), 13, pp. 1352-1368
[52] Shameri, M. A., *et al*., Perspectives of Double Skin Façade Systems in Buildings and Energy Saving, *Renew. Sustain. Energy Rev*., *15* (2011), 3, pp. 1468-1475

[53] Vassiliades, C., *et al*., Building Integration of Active Solar Energy Systems: A Review of Geometrical and Architectural Characteristics, *Renew. Sustain. Energy Rev.*, *164* (2022), 112482
[54] Hsieh, C. M., *et al*., Potential for Installing Photovoltaic Systems on Vertical and Horizontal Building Surfaces in Urban Areas, *Sol. Energy*, *93* (2013), July, pp. 312-321
[55] Do, S. L., *et al.*, Energy Benefits From Semi-Transparent BIPV Window and Daylight-Dimming Systems for IECC Code-Compliance Residential Buildings in Hot and Humid Climates, *Sol. Energy*, *155* (2017), Oct., pp. 291-303
[56] Ballif, C., *et al*., Integrated Thinking for Photovoltaics in Buildings, *Nat. Energy*, *3* (2018), 6, pp. 438-442
[57] Baghoolizadeh, M., *et al*., Multi-Objective Optimization of Annual Electricity Consumption and Annual Electricity Production of a Residential Building Using Photovoltaic Shadings, *Int. J. Energy Res*., *46* (2022), 15, pp. 21172-21216
[58] Custodio, I., *et al*., A Holistic Approach for Assessing Architectural Integration Quality of Solar Photovoltaic Rooftops and Shading Devices, *Sol. Energy*, *237* (2022), May, pp. 432-446
[59] Karthick, A., *et al*., Performance Analysis of Semitransparent Photovoltaic Module for Skylights, *Energy*, *162* (2018), Nov., pp. 798-812
[60] Zhu, L., *et al.*, Energy Savings Potential of Semitransparent Photovoltaic Skylights under Different Climate Conditions in China, *Energies*, *15* (2022), 7, 2358
[61] Valencia-Caballero, D., *et al*., Performance Analysis of a Novel Building Integrated Low Concentration Photovoltaic Skylight With Seasonal Solar Control, *Journal Build. Eng*., *54* (2022), 104687
[62] Skandalos, N., Karamanis, D., An Optimization Approach to Photovoltaic Building Integrationwards Low Energy Buildings in Different Climate Zones, *Appl. Energy*, *295* (2021), 117017
[63] Quintana, S., *et al.*, A Preliminary Techno-Economic Study of a Building Integrated Photovoltaic (BIPV) System for a Residential Building Cluster in Sweden By the Integrated Toolkit of BIM and PVSITES, *Intell. Build. Int.*, *13* (2020), 1, pp. 51-69
[64] Manić, D. J., *et al.*, Energy Performance of Single Family Houses in Serbia: Analysis of Calculation Procedures, *Thermal Science*, *23* (2019), Suppl. 5, pp. S1695-S1705
[65] Ning, G., *et al.*, E-BIM: A BIM-Centric Design and Analysis Software for Building Integrated Photovoltaics, *Autom. Constr.*, *87* (2018), Mar., pp. 127-137
[66] Weissenbacher, M., Towards New Renewable Energy Policies in Urban Areas: The Re-Definition of Optimum Inclination of Photovoltaic Panels, *Journal Sustain. Dev. Energy, Water Environ. Syst.*, *3* (2015), 4, pp. 372-388
[67] Giraldo-Perez, J. P., *et al.*, Performance and Viability of Vertical BIPV in Tropical Zones: An Experimental and Simulation Approach, *Journal Renew. Sustain. Energy*, *14* (2022), 2, 023701
[68] Byrnes, L., *et al.*, Australian Renewable Energy Policy: Barriers and Challenges, *Renew. Energy*, *60* (2013), Dec., pp. 711-721
[69] Branker, K., Pearce, J. M., Financial Return for Government Support of Large-Scale Thin-Film Solar Photovoltaic Manufacturing in Canada, *Energy Policy*, *38* (2010), 8, pp. 4291-4303
[70] Lazos, D., Bruce, A., The Value of Commercial BIPV Systems in the Urban Environment, *Proceedings*, Solar 2012 – 50th Annual Australian Solar Council (AuSES), Melbourne, Australia, 2012
[71] Sen, S., Vollebergh, H., The Effectiveness of Taxing the Carbon Content of Energy Consumption, *Journal Environ. Econ. Manage.*, *92* (2018), Nov., pp. 74-99
[72] Sanchez-Pantoja, N., *et al.*, Aesthetic Impact of Solar Energy Systems, *Renew. Sustain. Energy Rev.*, *98* (2018), Dec., pp. 227-238
[73] Awuku, S. A., *et al.*, Myth Or Gold, The Power of Aesthetics in the Adoption of Building Integrated Photovoltaics (BIPV), *Energy Nexus*, *4* (2021), 100021
[74] ***, Bernreuter Research, Polysilicon Market Reports, https://www.bernreuter.com/polysilicon/price-trend/
[75] ***, PV magazine, Weekend read: Chaos with no end in sight, https://www.pv-magazine-australia.com/2022/08/06/weekend-read-chaos-with-no-end-in-sight/
[76] ***, EnerBIM, BIMsolar, https://www.bim-solar.com/
[77] ***, University of Wisconsin – Madison, Solar Energy Laboratory, TRNSYS, a transient simulation software

Paper submitted: November 11, 2022
Paper revised: December 11, 2022
Paper accepted: December 19, 2022