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CONTENTS

BIPV-MULTIFUNCTIONAL BUILDING

NAPREDNE MULTIFUNKCIONALNE STAKLENE FASADE U NOVIM ZGRADAMA

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Review Paper

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ABSTRACT

Building Integrated Photovoltaic (BIPV) is a branch of Photovoltaic (PV) system that describes the process of using building parts to generate energy. The building materials serve their construction purpose and are used to generate energy concurrently. It is an integration of PV into the building envelop rather than using separate mounting material and space. Growing concern for reduced cost of installing PV system brought about innovation in developing multifunctional PV products that are applied as building materials. PV modules still do not have the spread and wide usage in buildings, mainly because certain designers (architects and builders) do not take them into account as an additional option while creating projects. This paper tries to indicate what are the main causes of this poor photovoltaic receiver application in the form of building components. There are also some potential solutions presented to inform key stakeholders about BIPV as a common structural component of the building envelope. This paper begins with an overview of the current definitions used in the field of BIPV application and indicates the need for further research.

***Key words** – integration; energy; multifunctional; building, materials.*

REZIME

Zahvaljujući integraciji najsavremenije tehnologije, savremene staklene fasade mogu da preuzmu različite funkcije. Fasade zgrada regulišu unutrašnju klimu ili klimatizaciju i značajno smanjuju energetske potrebe zgrada. S druge strane, integrisani fotonaponski elementi u omotaču zgrade mogu obavljati proizvodnju zelene energije na licu mesta.

Danas je planiranje i izgradnja inovativnih zgrada presudno određena zahtevom maksimalne energetske efikasnosti. Direktiva Evropskog parlamenta zahteva da sve nove zgrade moraju biti potpuno energetski efikasne do 2020. godine (2019. za javne zgrade). U tom smislu fokus je na razvoju arhitektonski atraktivnih zgrada, koje kombinuju minimalne zahteve za primarnu energiju uz maksimalne benefite i proizvode energiju na licu mesta. Veliku fleksibilnost uz najviši stepen energetske efikasnosti pružaju staklene fasade najnovije generacije. Pored svojih karakteristika otpornosti na vremenske uslove, ove multifunkcionalne fasade preuzimaju i funkcije proizvodnje energije, grejanja i hlađenja.

Integrisani fotonaponski uređaji u zgradama (BIPV) imaju veliki potencijal za primenu u zgradarstvu, jer se može instalirati na širok spektar spoljašnjih površina i integrisati u različite krovove i fasade. Kombinovanje proizvodnje energije sa drugim funkcijama omotača zgrade, kao što su senčenje od sunca, toplotna i akustična izolacija i otpornost na vremenske uslove, čini fotonaponske sisteme atraktivnijim.

***Ključne reči:** integrisani fotonaponski uređaji, multifunkcionalnost, fasada*

1. INTRODUCTION

In the last decade, the problems related to the field of solar design have been mainly related to the large information gap between the results of scientific research and the knowledge applied in practice. In the past, the failure to promote the BIPV product was generally present, which is a prerequisite for the widespread use of new technologies. This has been reflected in the sense building professionals were deprived of technical knowledge and the general decrease in interest in BIPV technologies. And, among the most relevant critical aspects is the perception that the integration of photovoltaic components is not economically justifiable.

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Several barriers were perceived to the widespread use of BIPV, including aesthetic (aesthetic-formal inadequacy of proposed solutions), regulatory, technical (lack of experienced installers and criticality in meeting durability, reliability, and maintainability requirements of modules), market (incomplete or inadequate product information), economic (lack of government subsidies).

Some of these critical issues are now considered to have been overcome. In particular, the analysis of the case studies shows a renewed interest in these technologies, due to increased awareness of the benefits deriving from the use of BIPV solutions in the current context of energy transition, and a much broader and more articulated market offer compared to the one on the market ten years ago.

2. BIPV INTEGRATION APPROACHES

The only obstacle to a number of the BIPV products currently on the market, and the way they can be integrated into façade, is the imagination of the designer and BIPV system style A great number of various building integration techniques can be used for the perfect BIPV module application (Fig. 1).

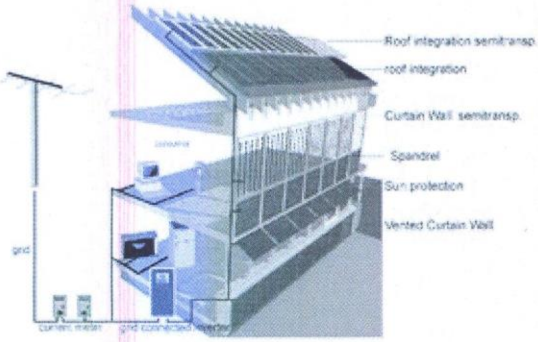


Figure 1. Potential building envelope locations for the BIPV module integration (Eisenchmid, I., Alonso, R., 2008)

As you can see in figure three, there are many sophisticated and elegant ways for electrical energy to be delivered and solar industry has foreseen the integration of solar modules into building (PV cladding) a long time ago. The most attractive side of this integration is the fact that structure itself is a producer of electrical power, which includes electrical energy requirements for some or all buildings. The entire sustainable building energy construction becomes indeed full of potential when PV power generation, conservation strategies, and high-performance building products intertwine.

Apart from the fact that production of building electricity can be practical and successful, these modules can serve as exterior cladding of the façade, as a roof, or sunshades. As the sunshades, they actually combine sun protection and generate electricity. The combination between conventional glazing, generation of electricity, heat insulation and noise protection are also possible and recommended.

Roofs, whether they are sloped or pitched, are usually the most suitable location for PV modules. There are three approaches for implementation:

– The most intense occasional solar radiation is on south-facing sloped roofs (in the Southern Hemisphere – north facing).

– Roofs are in almost all cases free of any obstructions. Therefore, some large PV modules areas can be easily installed without any customization or panel adjustments.

– The PV modules can have the function of the conventional roofing system, and thus to decrease the roofing costs. A roof can be covered with many different materials and imitate the conventional way. It can be slate, polymer tiles or clay (Fig. 3). What should be highlighted is that the regular tiles have their special adoption slots, and they are already adopted for the matching PV module direct integration of. These PV tiles do not require

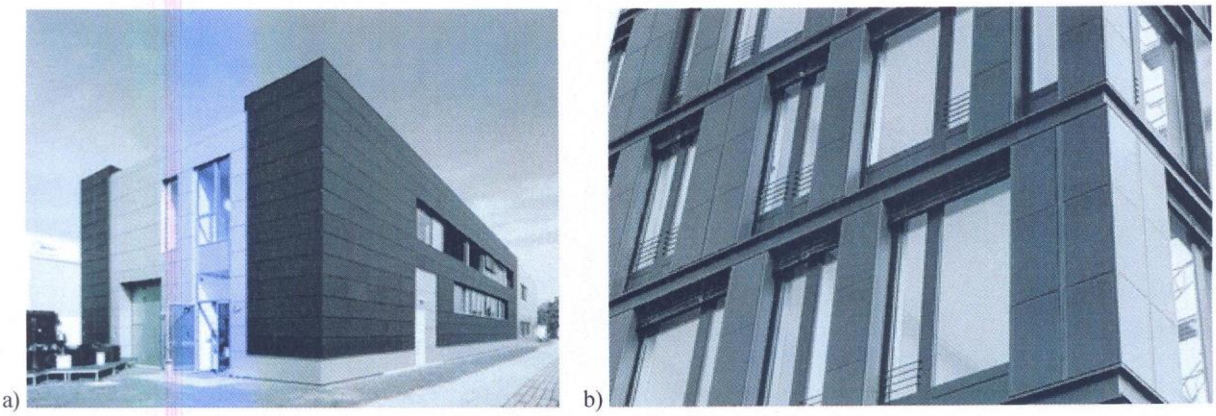
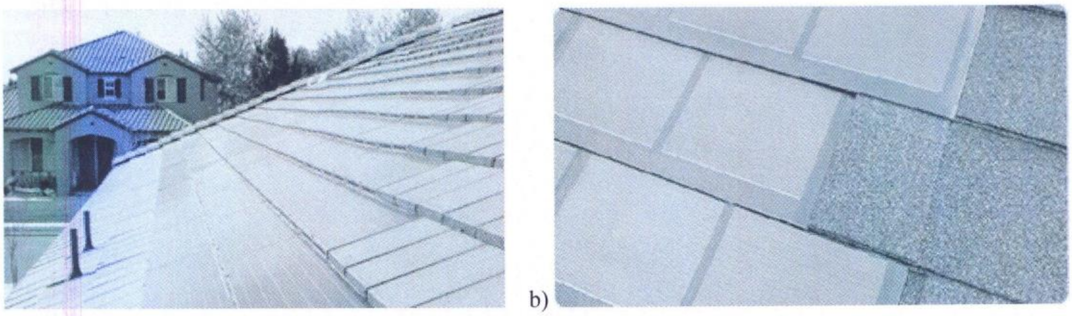
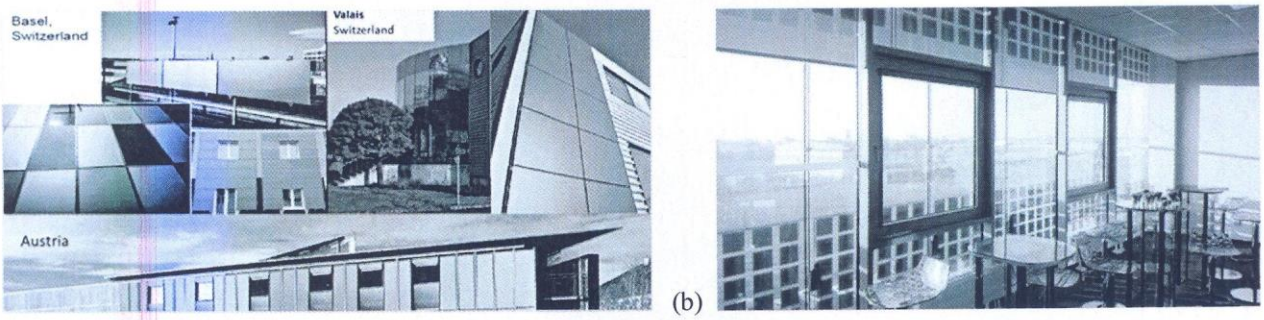


Figure 2. Photovoltaics integrated in buildings: a) https://www.pv-magazine.com/wp-content/uploads/2021/09/mis_3816-1200x900.jpg (12.09.2023.), b) https://thesolarlabs.com/ros/content/images/2022/01/solar-facade.jpg (12.09.2023.)



a) b)

Figure 3. Slate, clay and polymer PV roofing elements: a) https://www.solarreviews.com/content/images/blog/suntegra.JPG, (12.09.2023.), b) http://www.greenworldinvestor.com/wp-content/uploads/2011/09/PowerShingle3.png (12.09.2023.)



a) (b)

Figure 4. BIPV cladding façade: a) https://wfmmedia.com/wp-content/uploads/2017/08/KROMATIX-beautifully.jpg (12.09.2023.), b) https://metsolar.eu/wp-content/uploads/2019/05/smartflex-metsolar.jpg (12.09.2023.)

any kind of supporting structure when integrated into PV modules. As a result, we get the roof which becomes a solar power station.

The most interesting BIPV solution today is facade glazed cladding (Fig. 4). The tendency is to design the module which can substitute the regular glazed wall constructions and its elements. The additional benefits of these modules will be power generation done simultaneously.

On the list of the most attractive BIPV solutions and applications, a curtain wall is somewhere at the top of it. The (vertical) curtain wall itself is not practical for energy production, yet it offers one of the most attractive solutions for PV application.

Exterior curtain wall construction is used for majority commercial buildings since these BIPV modules can be seamlessly integrated in standard commercial building curtain wall construction. A wall framing system which is part of this construction can be attached to the building structure. It is modular and can be both spandrel (opaque) panels and vision (transparent). Architects can design specific the back-sheet glass, color and pattern of solar cells. BIPV laminates can also be integrated into the double-glazed units while the BIPV elements for wiring can be easily integrated throughout the curtain wall mullions.

PV modules can be used for cooling load reduction, passive solar heating, and light/solar control. In other words, they can generate electricity and provide additional energy benefits. Opaque PV modules (which are usually installed as PV skylight enclosures and sunshades, or window awnings), can protect interiors against direct sunlight and harness sun power simultaneously (Fig. 5). In general, windows do need some kind of solar and light control which is usually achieved with interior blinds or drapes. There are some obvious disadvantages while applying this – the potential solar energy ends up in the space and the outdoor view is pretty restricted or totally eliminated. That being said, one of the viable solutions and alternatives is a PV system glazed awning which can be sloped for maximum solar energy accumulation while simultaneously providing a filtered light (resembling the

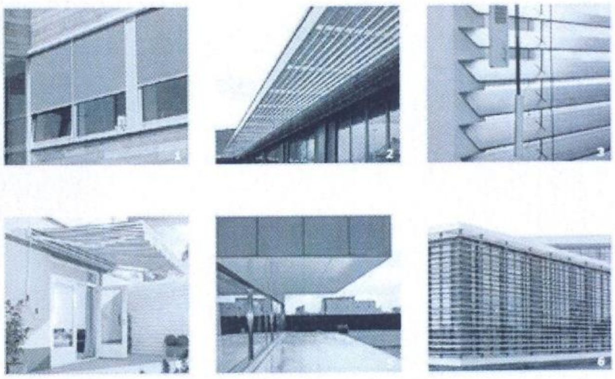


Figure 5. BIPV light control elements and sun shading , (Van den Ouweland, etc. 2014)

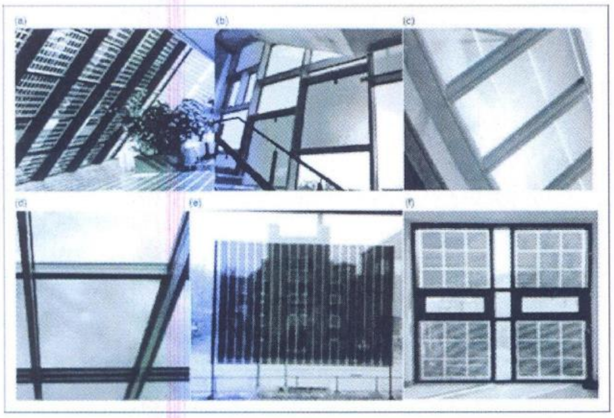


Figure 6. Types of PV modules applied in windows. (a) Crystalline silicon (c-Si); (b) amorphous silicon (a-Si); (c) multijunction thin film silicon (a-Si/mc-Si); (d) cadmium telluride (CdTe); (e) organic photovoltaic (OPV); (f) dye-sensitized solar cells (DSSC). (Xu, C.; etc. 2019)

atria glazing to the interior). A large number of different PV materials can be applied on facades with the purpose to improve the look or to have the function of awnings. Many others BIPV elements can have a function of window overhangs entranceways covers or even walkways.

A different degree of shading can be provided by introducing the BIPV glass elements. Different designs and approaches can significantly improve indoor thermal comfort and daylighting. There are solid and semitransparent BIPV modules which can accordingly have different usage and advantages. The solid ones are usually used when light transmission is not required. And, semitransparent can be applied when there is a need for some solar transmission so they can be used as a light screening material. This is often applied in atria where the reduction of cooling loads and interior shade is needed.

In cases when you want to provide indirect light to the building interior and diffuse, PV light shelves can protect against direct sun and thus serve the purpose. A certain part of the light shelves exposed to sunlight should be photovoltaics and the part which stays in shade should be made of some type of reflective material. In this way the light would bounce back against the module surface and end up on the ceiling inside the building.

The semi-transparent photovoltaic module can provide passive solar advantages same as PV window. These are designed to admit a certain amount of view and light into the interior space (Fig. 6).

If the amorphous silicon thin-film PV devices are designed along with conductive glass substrate coating they can be essentially semi-transparent. On the other hand, opaque PV devices may be considered as significantly transparent when a pattern of clear areas is created on the places where the opaque materials are removed. The solar benefits of these modules can be less impactful when comparing against the opaque PVs since there is a less active PV area. Nevertheless, what should be taken into consideration are the outcoming vision and the passive benefits.

What can be seen in the close future is that many kinds of innovative PV systems will be integrated into other construction forms. For example, the sound barriers along highways can have a PV system integrated in (Fig. 7). In order to achieve this, PV elements are to be designed to cover double function – generating electricity and the protection of noise emission. In this way, photovoltaics and noise protection elements have a potential to become a harmonious façade and noise protection barrier structure.

Finally, it is important to highlight that colored solar modules (and cells) are not presenting an obstacle or a limiting factor to photovoltaic utilization. The roof tops and building facades should be functional and attractive, offering products in a wide range of shapes, styles and colors. This will certainly foster architects and designers to accelerate the improvement and technology adoption of solar photovoltaic modules.

3. PHOTOVOLTAICS GLAZED BUILDINGS IN MODERN ENVIRONMENT (BUILDING PHYSICS)

Any energy requirements for the building operation will be compensated by the equivalent amount of energy supplied by the building itself over the course of one year if we are to follow the European Parliament Directive 2010/31/EU, Article 9.1. If this trend continuous, the upcoming buildings will have to be "nearly net zero energy" by 2022. In addition, this energy that a building supplies has to be gained from renewable energy resources to keep the credibility. Otherwise, the energy from conventional sources will have the priority and will be used (Defaix, P.R. 2012). Three direct conclusions can be tak-

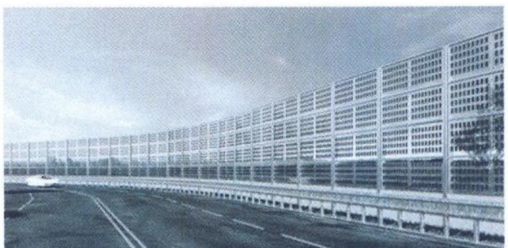
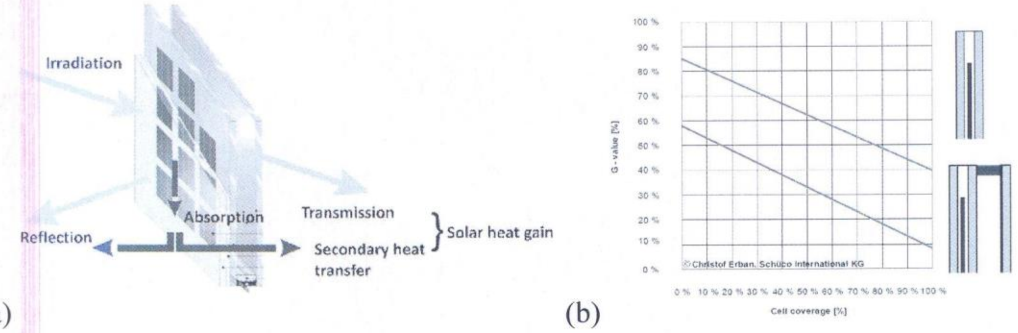
a)  b) 

Figure 7. PV in combination with sound barriers:

a) https://mitrex.com/wp-content/uploads/2022/05/NoiseBarrier_Heroimage.jpg, (12.09.2023.),

b) https://upload.wikimedia.org/wikipedia/commons/thumb/1/1b/PV_Soundless_Freising.jpg/600px-PV_Soundless_Freising.jpg?20110315093546, (12.09.2023.)



(a) (b)

Figure 8. (a) Solar radiation and PV module interaction. (b) Total solar energy transmittance (g value) of semi-transparent PV elements vs. solar cell coverage for monolithic panels and insulating glazing (Erban, Christof 2012)

en from applying this directive on the future application of energy within buildings:

– We need to significantly reduce the energy consumptions coming from the primary sources.

– We need to increase the level of efficiency when it comes to building energy usage.

– It is an imperative to utilize renewable energy resources in order to compensate for the energy acquired from sources external to the building.

The conditions, requirements and the usage of energy from some renewable resources (wind energy, biomass and hydroelectricity, for example) is very limited within any kind of buildings. There is greater probability that the compensated energy will have to be converted by using solar energy and photovoltaic systems. The obvious advantage of solar energy is that it is comparatively and evenly available to everybody. Solar energy systems are also extremely practical and harvestable with dimensions ranging from very small (such as those used in individual households), to very large (such are those for office and industrial buildings). Nowadays, we may rely on the BIPV products that ensure sustainable kWh generation. They have been carefully and meticulously developed and are available worldwide at reasonable prices.

The typical energy consumption of buildings is in the form of heat or electricity. Thermal energy is needed to heat or cool the building to a requested operation temperature. The required energy is therefore related essentially to the building application type and how much of thermal losses or gains is obtained through the building envelope. This correlation is mainly described by the product U value and g value, or the product combination (Sun, L.L, 2010). Based on the fact that both properties are presented in the building envelope products, we may calculate almost any wall construction and composition and predict the how much energy is required (Fig. 8).

As you can observe in Fig. 9 and 10, the glass characteristics, under varying incident angles, are not constant, unfortunately. We are constantly facing boundary conditions when the U or g value is defined experimentally or calculated as described in the relevant standards. That specially applies to the g value. The description of total solar component gain is significantly affected by the component transmittance, reflectance, and absorbance.

Apart from the number of panes, coatings, glass chemical composition, and surface structures, the values of transmittance and reflectance significantly depends on the configuration of the glazing. Thus, various glazing configurations can have various U and g values for normal incidence. And, accordingly, they can show different behaviors depending on the change of incident angles (Platzer, W, 2000).

Due to the fact that solar gain is the product of the g value and the incident solar energy, and in the cases

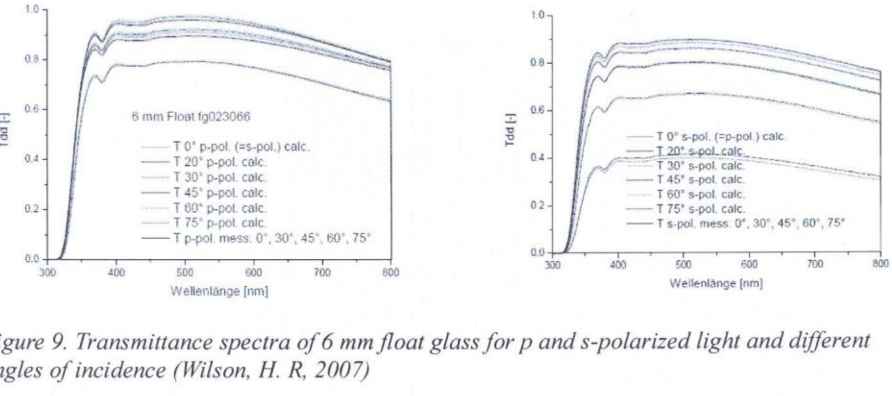


Figure 9. Transmittance spectra of 6 mm float glass for p and s-polarized light and different angles of incidence (Wilson, H. R, 2007)

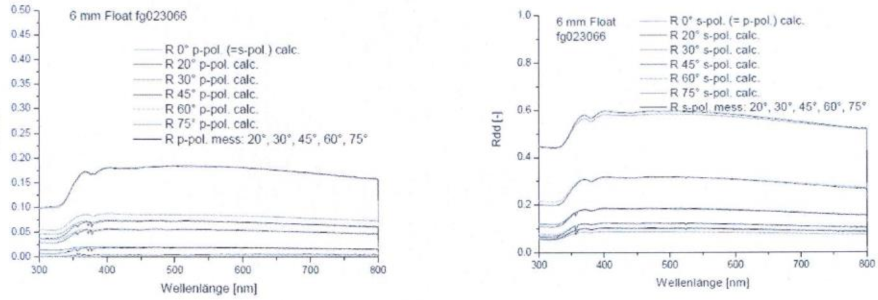


Figure 10. Reflectance spectra of 6 mm float glass for p and s-polarized light and different angles of incidence (Wilson, H. R, 2007)

where the total irradiation at non-zero angles did not contribute significantly, inadequate consideration of the incident angle dependence would not be important for calculating the thermal impact on buildings, the opposite is also the case. The incidence angle of 0°, for which the solar heat gain coefficient is determined conventionally, contributes insignificantly to the annual total. On the other hand, significant thermal impact results for solar irradiation at incidence angles deviating from 0°. The variations in terms of changing orientation have a less significant impact on the angular distribution than variations in terms of the tilt angle for constant orientation.

The incidence angle of solar irradiation on a glass surface depends on a few factors:

– the sun position;

– the surface orientation and the surface tilt angle;

– and the building location.

Therefore, surfaces that are differently directed will have immensely different thermal impacts. And vice versa, surfaces that are identically directed, yet situated at different locations, will have significant thermal impacts on a building.

Even though he constant solar heat gain coefficient (g value) (as it can be seen in the relevant standards) provides a simple solution/approach for product comparison. Yet, it is practically useless when the building energy consumption should be optimized. Namely, simulations that account for the orientation of the surface, as well as the solar position, are not exact enough to essentially optimize the building thermal behavior in cases when the dependence on incidence angle is not taken inti consideration (Ordoumpozanis, K, 2018). When residential buildings are in question, it seems that an adequate consideration of the angular dependence of the total solar transmittance is missing. There is a great probability that the same glass type is applied on all building's sides.

Thus, it can be concluded that it is not desirable when a solar heat gain coefficient is of a low value. While investigating the annual energy performance of a building, it does not necessarily lead to the optimum. Rather high and controlled solar heat coefficient is desired for passive heating during the cold seasons. And, opposite, a rather low solar heat gain coefficient is desired to reduce the risk of overheating or eliminate the need for active cooling during the warm seasons (Norton, B., 2011).

4. EFFECTIVENESS OF FN MODULES/COMPONENTS

Manufacturers today can offer the construction sector a variety of interesting finalized products that can be used by architects and planners. However, in the construction sector, PV modules are still perceived suspiciously. The PV module/component, the "integral material", is still complex for the designer to use, either because there are not enough precise instructions with design possibilities, or because there are no technical specifications that can be compared against the construction material data. Finally, although not the least important, because there are no relevant regulations, standards, technical and legal conditions.

PV modules are perceived as electrical elements, different from the traditional building elements, which should be "integrated" into the building envelope (with all possible consequences in terms of conditions and standards). Therefore, there is still a gap that needs to be bridged between the construction sector and the PV elements sector so that PV materials are no longer accepted as technical, but as construction components.

An international survey was conducted as part of IEA Task 41 "Solar Energy and Architecture", to understand the needs, barriers and strategies for the integration of solar technologies. The main group that the survey was aimed at consisted of architects and other professionals involved in construction itself (IEA SHC Task 41, 2013.). The result of a survey confirms that costs are the main problem for architecture when the spread of PV modules is in question (PV modules are still more expensive than conventional architectural ones (Fath, K., H. R., 2011). Meanwhile, the survey also showed that reducing the price of BIPV modules represents a strategy for the expansion of this technology rather than a major bottleneck (Figure 11).

In case we consider that the construction sector usually uses expensive technologies and noble materials (such as marble facades or windows with triple glazing), it is surprising that cost becomes a key element for using PV material. As the picture 12 shows, designers are looking for additional information useful for comparing PV modules with conventional building components.

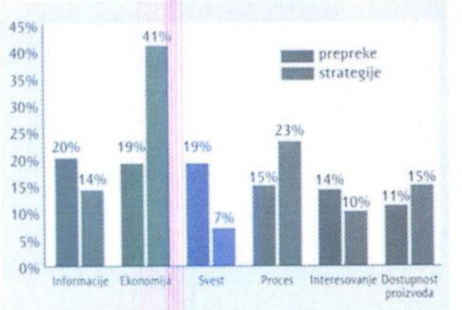


Figure 11. Diagram of obstacles and strategies for the spread of PV components in architecture (International Energy Agency (IEA) – Solar Heating and Cooling (SHC), 2013.

What is the reason for this? A possible answer is that it's not a question of cost, but rather availability and features aspects.

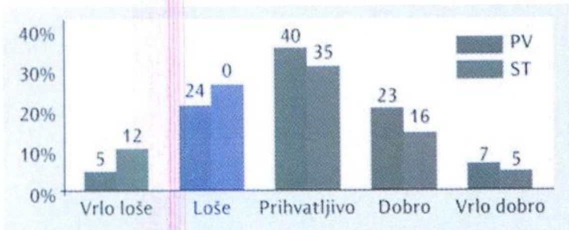


Figure 12. BIPV product offer qualification is an average, (International Energy Agency (IEA) – Solar Heating and Cooling (SHC), 2013.

5. PV MODULE INTEGRATION POTENTIALS AND NORMS

Conventional PV modules (which have a fixed number of cells, sizes, and shapes) are often not suitable to be replacements for building elements. Since they are clearly intended as energy-producing devices, they cannot meet the conditions required by the construction sector. Namely, the designer needs to understand what are the characteristics that the PV component should provide and what are the technical requirements. The question arises whether or not it is possible to choose a suitable PV component over the one available on the market. Specifically, the procedure for selecting the PV component should look like this (Scognamiglio, A.,2013.):

– Choose the technological unit where it will be used;

– Make a list of that technological unit's characteristics and design/choose an appropriate technological system (a sandwich consisting of different layers);

– Determine which layer the PV module should replace and describe the features it is supposed to provide;

– After analyzing the characteristics, make a list of requirements that the PV component must fulfill (e.g., thermal resistance, mechanical resistance, etc.) and choose the available and most suitable product;

– Check whether the usage of PV material/component is in accordance with all prescribed requirements. Then, to understand how this process is simplified, a comparison of conventional PV modules and building components is made to understand the key issues, and choose the available product that is most suitable;

– Check whether the use of PV material/component is in accordance with all of the prescribed requirements.

5.1. Categories for the integrability of photovoltaic systems in buildings and specific requirements

Within the EU project "Construct PV" (http://www.constructpv.eu/), the authors collect technical and functional requirements for the building component, with special attention to the opaque part of the building (facade and roof). The list of requirements is very long, reflecting a long history of architecture that has been practiced for centuries in order to optimize the building and meet the users' needs and the architect's wishes. In Table 1, these points are shown as a list of categories for the possibilities of integration of PV components in buildings, with a description of each category in connection with the specific requirements that PV components should provide.

5.2. Normative frameworks: electrical safety compared against building requirements

PV modules and PV installation constitute an entirety by themselves (AA.VV„,Photovoltaics, Technology-Architecture-Installation",Edition Detail) and their primary function is the transformation of solar energy into electrical energy. In order to be competitive in the PV module/component sector, manufacturers must comply with electrical safety standards and IEC regulations (such as IEC 61730 (IEC 61730-1, 2, Photovoltaic (PV) module safety qualification) or IEC 61215 for crystal modules (IEC 61215 Crystalline silicon terrestrial photovoltaic (PV) modules, Design qualification and type approval)). This makes it clear to all PV users what quality

Table 1. Integrability categories for the building component , (http://www.constructpv.eu/),

	Technological Integrability	Morphological Integrability	Passive energy effect
Special requirements	Constructional compatibility	Color variation	Retention and control of solar radiation
	Static compatibility	Granulation variation	The possibility of reusing or dissipating the heat coming from PV conversion
	Material compatibility	Texture variation	

control should be applied to evaluate PV modules and compare them to competitors.

CONCLUSION

Architects need PV modules suitable for adapting, in the form of building components, to many different design possibilities, variable sizes, and shapes, increasing the attractiveness of the object. This includes custom-made solutions, but the standard regulations only check the reliability of commercial standard solutions, extending the certification to obtain approval for multiple custom-made solutions. Furthermore, this compromise to oversimplify the approval procedures to impact the spread of these BIPV solutions cannot support the BIPV industry in the long run if these systems do not perform as expected due to the personalized manufacturing process (custom manufacturing). Likewise, new BIPV products are constantly being marketed, offering innovative solutions for building components, but their reliability and durability have not yet been proven, as is the case with other building materials. Major guarantees are required and this is the key to more detailed considerations.

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