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International Energy Agency
Photovoltaic Power Systems Programme

Task 15 Enabling Framework for the Development of BIPV

PVPS

Categorization of BIPV applications
2021

Report IEA-PVPS T15-12:2021

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The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6.000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the TCP's within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems." In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks,' that may be research projects or activity areas.

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What is IEA PVPS Task 15?

The objective of Task 15 is to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products, BAPV products and regular building envelope components, respecting mandatory issues, aesthetic issues, reliability and financial issues.

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COVER PICTURE

Picture of a BIPV facade detail under construction. Source: Pierluigi Bonomo

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INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA PVPS
Task 15

Categorization of BIPV applications

Breakdown and classification of main individual parts of building skin including BIPV elements

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering & Construction
AC	Alternating Current
a-Si	Amorphous Silicon
ASTM	American Society for Testing and Materials International
BIM	Building Information Modelling
BAPV	Building-Added Photovoltaics
BIPV	Building-Integrated Photovoltaics
CdTe	Cadmium Telluride
CIGS	Copper Indium Gallium (di) Selenide
c-Si	Crystalline Silicon
DC	Direct Current
DSSC	Dye-Sensitized Solar Cell
EIFS	Exterior insulation and finish systems
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IFC	Industry Foundation Classes
IGU	Insulating Glass Unit
ISO	International Organization for Standardization
PV	Photovoltaics
TCO	Transparent conductive oxide
UNI	Italian Organization for Standardization

EXECUTIVE SUMMARY

The transfer of photovoltaics (PV) into buildings is a tangible “cause” of innovation. Today, it is much more than an energy-converting solution: it represents a new fundamental aspect in architectural aesthetics and technology [1]. For decades, many classification schemes have been conceived and are intended to be as practical as possible, summarizing the knowledge needed to integrate active solar technologies into buildings. However, the BIPV community has never reached consensus about a reference categorization of BIPV applications in the building skin. Thus, various classifications appeared in literature, guidelines and standards which, according to each target (market, research, feed-in tariffs, dissemination, etc.) have taken different fragmented and not homogeneous criteria into account. The complexity of the BIPV domain, typically bridging construction and electrotechnical perspectives, traditions and innovations, made it complex to make an exhaustive BIPV classification clear since it opens a large potential for interpretation and different uses [2].

The purpose of this proposal is to present a streamlined hierarchical approach as a reference for classifying BIPV building skin technology. By taking into account the main technical subsystems of the multifunctional building skin, the main features in terms of function, performance, morphological, structural and energy-related aspects are organized into five levels from application categories to materials.

The proposed categorization implements a set of taxonomic principles for BIPV based on an integrated and analogical approach drawn upon experience on building and PV sector, by matching a construction technology approach that relates to the main sequences for construction of the building envelope (systems), with more specialised “BIPV” and electrotechnical criteria for the smaller sub-systems (module, component, material). Since many interpretations and definitions are also different in the various countries, a glossary of BIPV systems is reported along with the most widely used synonyms and their translations in different international languages.

We aspire that this paper will be able to provide a first milestone to encourage an integrated perspective and an interdisciplinary effort at the core of the BIPV field and that it will overcome some current obstacles that are still obstructing effective exchange of innovation and cooperation among all the stakeholders.

1 INTRODUCTION

The BIPV community has not yet reached well-defined consensus about a standard categorisation of any BIPV applications in current industrial reports, websites, academic publications and standards. This creates hurdles to making the BIPV classification clear for BIPV designers and manufacturers. Many classifications appeared in literature, guidelines and standards in recent years, taking into account many and different criteria, applying more or less market-oriented approaches or focusing on the perspective from the PV and/or building sectors. Harmonised categorization is needed in order to have a common base of terminology and approaches. Starting from the categorization goals defined in the framework of IEA-PVPS Task 15 Activity “B.2: Identification of representative BIPV installation scenarios”, Task 15 agreed to prepare a harmonized set of references to BIPV application categories. Thus, the purpose of this proposal is to provide a streamlined hierarchical approach as a reference for classifying BIPV building skin technologies. The objective is to take into account the main levels of the technical subsystems of the active and multifunctional building skin and a description combining the main features in terms of function, performance, morphological, structural and energy-related aspects, which are of crucial importance for design and construction [3].

Up to now, there has been a fragmented and inhomogeneous set of categories, because the complexity of the building skin (which was further expanded by the introduction of PV) opens up a large potential for interpretations. Standard IEC 63092 [4] classified the BIPV applications into five main categories listed as “Application Categories” applicable to different types of BIPV modules that contain one or more glass panes, polymer waterproofing sheet or metal sheet. The European reference can also be found in EN50583 [5] which is the relevant standard for BIPV modules in Europe.

In this framework, the options for developing BIPV building skin categories are inevitably very diverse in terms of functions, construction systems, materials, surface treatments and colours, shapes and performances. However, if we stick to the basic features of BIPV which, in contrast to a conventional PV application, is primarily a construction product/system, we can justify the basic orientation of definitions as referring to the **building envelope.** Since the building envelope normally cannot be produced in one piece, it is necessary to break it down into **individual parts**. When considering this system, the basic scientific terms resulting from various building technology literature can be organized into five levels resulting in the following sequence:

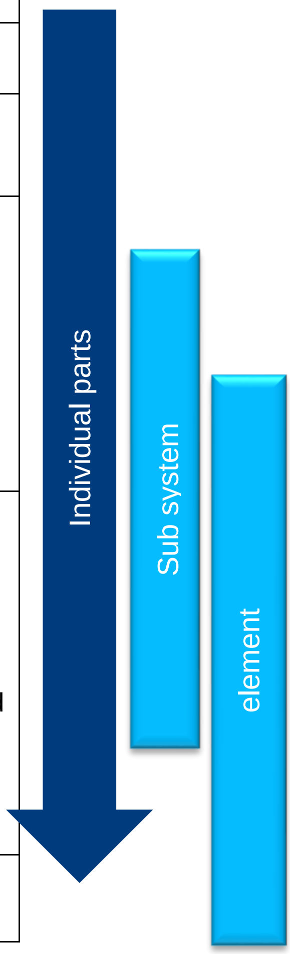
- **Application category**
- **System**
- **Module**
- **Component**
- **Material**

The proposed categorization attempts to implement a set of similar taxonomic principles, matching a construction technology approach that relates to the main sequences for construction of the building envelope (systems) with more specialised “BIPV” and electrotechnical criteria for the smaller sub-systems (module, component, material).

It should be emphasized that any categorization is designed to be suitable for the intended scope. This means that there are many possible approaches, and that the scale of the investigation (and therefore the analysed elements) can be as small as required for the specific investigation. Here, as the purpose refers to the use of PV in buildings, and the scale is that of the building envelope, some simplifications have been made when analysing the smallest scales, i.e., those applying to the modules, components and materials. For a more detailed analysis of the technological design options of BIPV, reference can be made to a recent review paper [6].

Table 1. Structure of BIPV building skin classification. Normative definitions and building-technological criteria for individual levels are included.

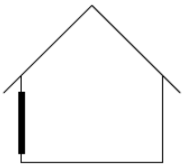
Classification criteria	*Building technology level*	*Example*
Normative reference (IEC 63092):		
Application category	Application classification according to the type of integration, slope and accessibility criteria	Non-sloped (vertically) mounted accessible from within the building
Building skin technology:		
System	**Technological construction unit**	Curtain wall
Module	**Technological solution** for the multifunctional active element typically representing the “module”. It is typically defined in terms of requirements and construction technology features	Semi-transparent panel
Component	Each part of the PV module: Different **technical alternatives** can be found for the same technological solution, to translate it into a real construction product/system. A component is typically defined in terms of performance	Extra-clear tempered glass pane with low-e coating
Material	Basic material composing an element/layer	Glass



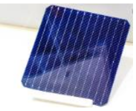
In **application categories**, the classes defined in IEC 63092 are reported in order to reference the system application type to the integration and accessibility criteria defined in the standard. With the specific goal to refer the categorization to a building construction interpretation, two other levels are considered. In each **system category**, the classes of building skin systems are identified as *technological construction units* by adapting specific categories from the main technological alternatives to realize walls, facades and fenestrations as used in the technical literature. In each **module,** the scale of the active and multifunctional building element is further reduced to include the **technological solution** for the multifunctional PV “module”

within the previous systems and to satisfy certain technological *requirements*. Each module can be produced by implementing a technical detail as an alternative on the basis of market availability and product readiness, by implementing a real solution in terms of geometry, layering, **materials** and technical **components** with related *performance*.

Table 2. Example of analysis of a facade system according to the defined hierarchical categorization

<table>
<tr><th>APPLICATION</th><th>SYSTEM</th><th colspan="2">MODULE</th></tr>
<tr><td rowspan="7">Example:

Category D:
Non-sloped (vertically) mounted accessible from within the building</td><td rowspan="7">Example:

Curtain wall</td><td colspan="2">Example:


</td></tr>
<tr><td colspan="2">Insulated semi-transparent pane (e.g. requirements= transparency, thermal insulation, acoustic insulation)</td></tr>
<tr><th colspan="2">COMPONENT</th></tr>
<tr><td>
transparent pane</td><td>
Solar cell</td></tr>
<tr><th colspan="2">MATERIAL</th></tr>
<tr><td></td><td></td></tr>
<tr><td>glass</td><td>c-Si</td></tr>
<tr><td>APPLICATION</td><td>SYSTEM
Curtain wall</td><td colspan="2">MODULE/COMPONENT/MATERIAL
Technological options to implement the system</td></tr>
<tr><td>Accessibility and integration categories are defined</td><td>Different systems, depending on the building skin engineering approach, can be used

(e.g. either a window or a curtain wall could be adopted as the fenestration system)</td><td colspan="2">Different technological alternatives can be realized with available products and materials, depending on required performance, aesthetic intentions, etc.

(e.g. performance= 90% light transmittance, 0.15 W/(m^{2}K) thermal transmittance, 45 dB acoustic insulation)</td></tr>
</table>

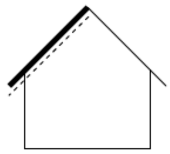
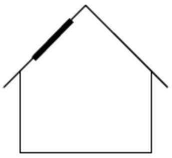
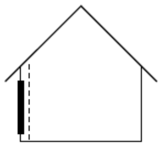
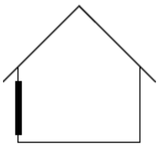
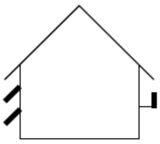
2 APPLICATION CATEGORIES

The BIPV Standard IEC 63092-1:2020 differentiates five categories – from A to E - of mounting according to combinations of the following criteria:

- integrated into the building envelope: yes/no
- accessible from within the building: yes/no
- sloped: yes/no

“Not accessible” means that another construction product still provides protection against mechanical impact from within the building, even if the PV module has been damaged or removed.

Table 3. BIPV Application categories in Standard IEC 63092-1

Category A	**Sloping, roof-integrated, not accessible from within the building** The BIPV modules are installed at a tilt angle between 0° and 75° from the horizontal plane [0°, 75°], with another building product installed underneath (see NOTE).	
Category B:	**Sloping, roof-integrated, accessible from within the building** The BIPV modules are installed at a tilt angle between 0°and 75° from the horizontal plane [0°, 75°].	
Category C:	**Non-sloping (vertically) envelope-integrated, not accessible from within the building** The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°,90°], with another building product installed behind (see NOTE).	
Category D:	**Non-sloping (vertically), envelope-integrated, accessible from within the building** The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°, 90°].	
Category E:	**Externally-integrated, accessible or not accessible from within the building** The BIPV modules are installed to form an additional functional layer that provides a building requirement as defined in 4.1. E.g. balcony balustrades, shutters, awnings, louvers, brise soleil etc.	

NOTE: *A BIPV module is considered to be “not accessible” when another building product (represented by a dashed line in the pictograms) is present, which among other functions prevents: (i) the interior surface of the module from being touched and (ii) large pieces falling onto adjacent accessible areas within the building.*

A more complete overview is available in the following standards:

- IEC 63092-1:2020 Photovoltaics in buildings - Part 1: Requirements for building-integrated photovoltaic modules
- IEC 63092-2:2020 Photovoltaics in buildings - Part 2: Requirements for building-integrated photovoltaic systems

3 SYSTEM

Clients increasingly request buildings that inspire and delight, along with buildings that operate with lower costs and fewer resources. Design and engineering of building skin systems draw on many disciplines such as architecture, building physics, structure, geometry, glass design and software development. Thus, in contrast to the situation some decades ago, it is almost impossible today to define a classification scheme in a unique way due to the growing implementation of sophisticated approaches integrating architecture and engineering in complex and ground-breaking envelope concepts.

In the built environment, many different system classifications have appeared during the last fifty years. The primary purpose has been to support standardization and data exchange between partners in building construction projects. Various system classifications have been developed by different nations and institutions, e.g. OmniClass, [7] used in AEC in North America, has 15 tables on various facets of construction information. Uniclass 2015 [8], the U.K. building industry classification system, has 10 tables and the ISO 12006-2:2015 [9] defines a framework for the development of built environment classification systems.

Lack of standardization in the identification of the objects in the supply chain, in the collection, transmission and storage of information since the 1980s motivated the Italian Standard UNI 8290:1981, which was designed to allow an orderly and organic decomposition of a building system into several levels, with homogeneous rules. It prefigured a classification sequence based on the breakdown of the building into classes of technological units and classes of technical elements with the purpose to articulate a list of items according to the logic of the works carried out, in order to allow analytical estimates (see the cost per unit of individual works). The implementation of a management process based on Building Information Modelling today recalls the need for a Work Breakdown Structure (WBS) [10]. Open specifications recognized as a worldwide standard to ensure software interoperability for the construction industry are developed by the International Alliance for Interoperability (IAI International) - also known as BuildingSmart (2016) - and are generally known as IFC, or Industry Foundation Classes. In 0, a short review of building envelope system classification schemes is given. In 2.2, a proposal to classify BIPV systems is formulated.

3.1 Existing classification schemes for building envelopes

3.1.1 US building envelope design guide

According to the US Federal Guide for building envelope design and construction [11], “the building envelope includes…everything that separates the interior of a building from the outdoor environment. The envelope has to respond both to natural forces and human values. The natural forces include rain, snow, wind and sun. Human concerns include safety, security, and task success. The envelope provides protection by enclosure and by balancing internal and external environmental forces...”

The main Building Envelope Systems include:

- **Exterior Walls**, both structural (providing support for the building) and non-structural (supported by the building structure)
- **Fenestration**, both windows and metal/glass curtain walls
- **Roofs**, both low- and steep-slope

The building skin, especially in the cases of walls, roofs and fenestrations, is the dominant system in all subsystems of the building (load-bearing structure, mechanical services, etc.). The design of the envelope is very complex, and many factors have to be evaluated and balanced to ensure the desired levels of thermal, acoustic, light and visual comfort together with safety, accessibility and aesthetic excellence. For a selected set of components, multiple classifications can be developed. It is therefore necessary to select a classification criterion to determine the nodes of the taxonomy. Hence, different classification criteria result in different taxonomies of the same components. By considering walls, fenestrations and roofs, the following criteria proposed by the US building skin design guide and Standard UNI 8290 [12] (respectively in Figure 1 and Figure 2) are quite similar apart from some grouping and taxonomic conventions. In Figure 3 and 4 other classifications for building elements are reported. Considering a BIPV building skin, and the complexity of its construction parts (see Figure 5 as an example of BIPV facade detail) the first level of technological classification can be done according to the main sub-systems, namely the **technological construction units** representing the main typologies of sub-systems of the Building Envelope. A proposal for classification is presented in **Erreur ! Source du renvoi introuvable.**.

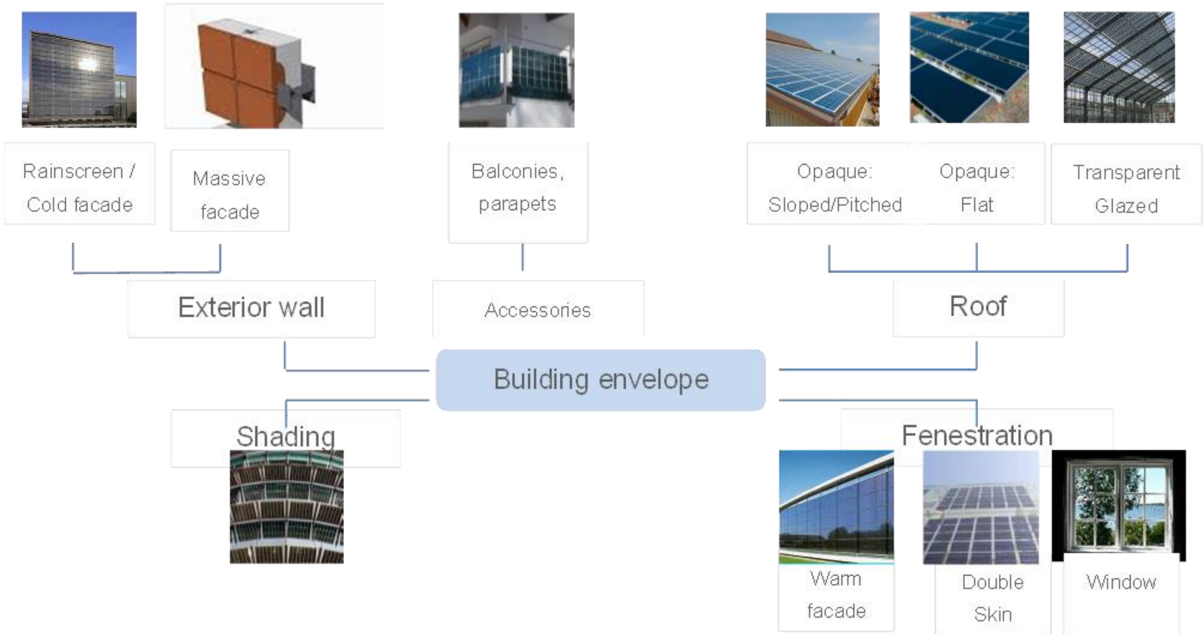


Figure 1. Technological construction units for BIPV building skins. Source: Building Envelope Design Guide, [11] .

3.1.2 Italian standard UNI 8290

The Italian Organization for Standardization defined in the standard UNI 8290 classification criteria for technological construction units of buildings for residential construction to allow an orderly and organic breakdown of a building system in several levels, with homogeneous rules. OmniClass® is a comprehensive classification system for the construction industry and it provides a method for classifying the full built environment through the full project life cycle.

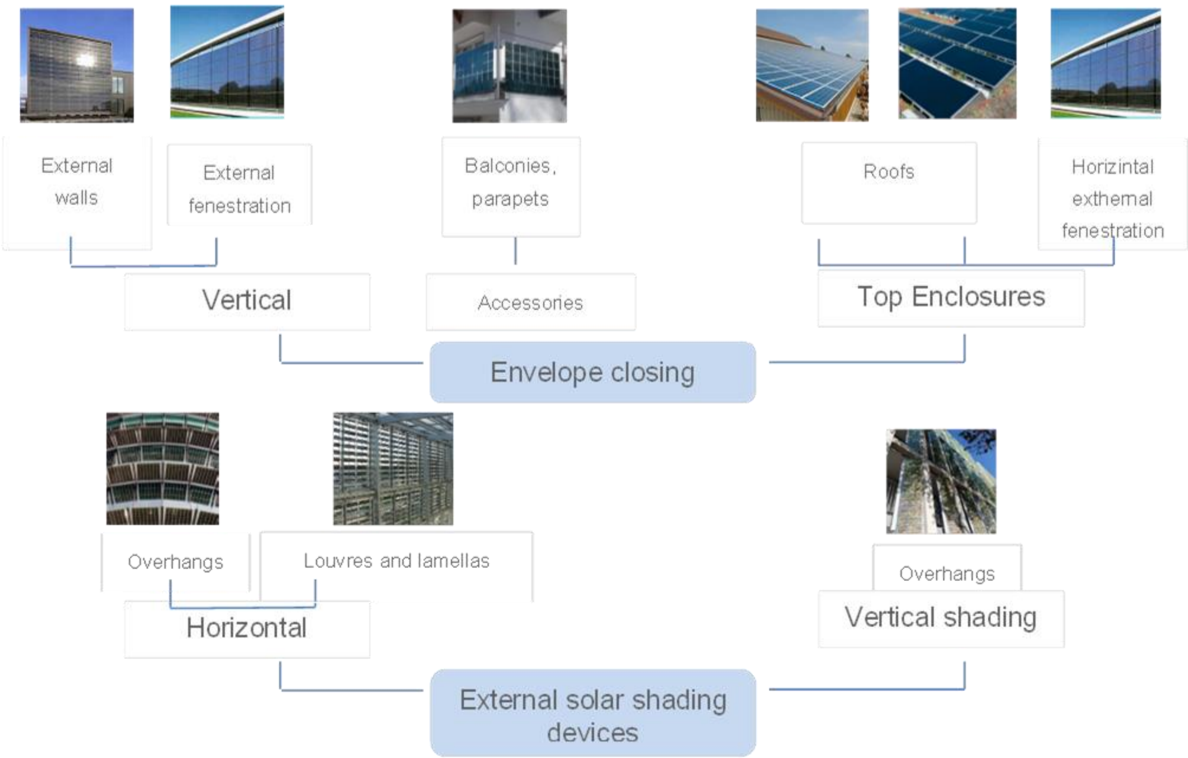


Figure 2. Technological construction units of BIPV building skins (source: UNI 8290) [12].

3.1.3 Classification schemes – ASTM and Omniclass

ASTM E1557, Uniformat II, defines a standard classification for building elements and related sitework. Its integration in the design process results in improved communications and coordination among all project participants, an accelerated design, and significantly increased productivity.

		A2020 Basement Walls
B SHELL	B10 Superstructure	B1010 Floor Construction B1020 Roof Construction
	B20 Exterior Enclosure	B2010 Exterior Walls B2020 Exterior Windows B2030 Exterior Doors
	B30 Roofing	B3010 Roof Coverings B3020 Roof Openings

Figure 3. ASTM Uniformat II Classification for Building Elements (E1557-97) [13]

OmniClass Number	Level 1 Title	Level 2 Title	Level 3 Title	Level 4 Title	Table 22 Reference
21-01 90 30 60				Ground Freezing	22-31 54 00
21-01 90 30 70				Slurry Walls	22-31 56 00
21-01 90 40			Soil Treatment		22-31 31 00
21-02 00 00	Shell				
21-02 10		Superstructure			
21-02 10 10			Floor Construction		
21-02 10 10 10				Floor Structural Frame	
21-02 10 10 20				Floor Decks, Slabs, and Toppings	
21-02 10 10 30				Balcony Floor Construction	
21-02 10 10 40				Mezzanine Floor Construction	
21-02 10 10 50				Ramps	
21-02 10 10 90				Floor Construction Supplementary Components	
21-02 10 20			Roof Construction		
21-02 10 20 10				Roof Structural Frame	
21-02 10 20 20				Roof Decks, Slabs, and Sheathing	
21-02 10 20 30				Canopy Construction	
21-02 10 20 90				Roof Construction Supplementary Components	
21-02 10 80			Stairs		
21-02 10 80 10				Stair Construction	
21-02 10 80 30				Stair Soffits	
21-02 10 80 50				Stair Railings	
21-02 10 80 60				Fire Escapes	22-05 51 23
21-02 10 80 70				Metal Walkways	22-05 51 36
21-02 10 80 80				Ladders	22-05 51 23

Figure 4. Omniclass Table 21 – Elements [7]

3.2 Proposed classification of BIPV systems

In the proposed BIPV **system** category, the classes of building skin systems are identified as technological construction units by adapting specific categorization emerging from the construction technology literature for the main technological alternatives to realize walls, facades and fenestration. Many proposals were appeared in the literature in recent years [14] [15] [16] [17] [18] [19] [20], based on different criteria.

In this chapter we stick to the basic trait of BIPV which, in contrast to a conventional PV application, is primarily a construction system. In this framework, we adopt the basic orientation of defining BIPV as a building envelope system and breaking it down into individual functional parts related to the construction work structure. In conventional constructions the definition of the main building skin construction systems can be grouped in:

- **ROOF:** A roof, in a traditional building construction with a top distinguishable by the facade, is the top covering providing protection and separating indoor and outdoor environments (application categories A and B).
- **FACADE:** A facade, in a traditional building construction with parietal walls distinguishable by the roof, is the vertical (or tilted) exterior surface which is the architectural showcase and separates indoor and outdoor environments. (application categories C and D).
- **EXTERNAL INTEGRATED DEVICES:** Elements and systems of the building skin which are in contact only with the outdoor environment (application category E).

However, in complex building skins such as continuous envelopes or roofs, facades and other elements cannot be easily demarcated. In addition to the construction components, there are other elements that complete the electrical PV system, such as the power conversion equipment – with the DC/AC inverter (also optimizers with DC/DC conversion) being the main component of a grid-connected electrical installation – or other electronic control and security devices, cabling, junction and connection boxes, storage systems. All of them should be considered in the BIPV system design.

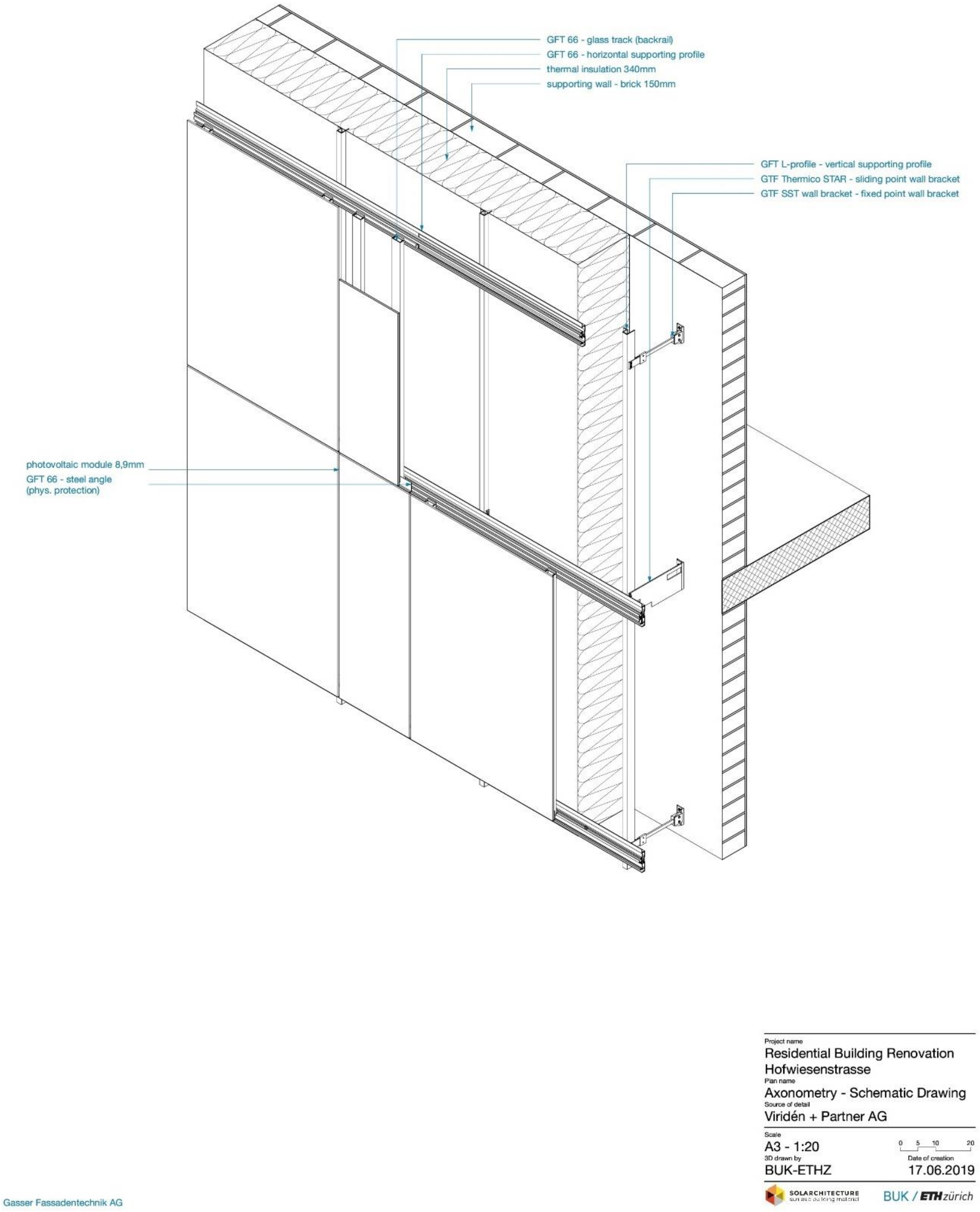


Figure 5. BIPV facade system. Multi-family building renovation in Zurich, Viriden+Partner (source: www.solarchitecture.ch).

A more specialised "taxonomy" will be introduced in the smaller sub-systems (module, component, material). In Figure 6, a scheme for the BIPV systems is reported, and graphically represented in Figure 7.

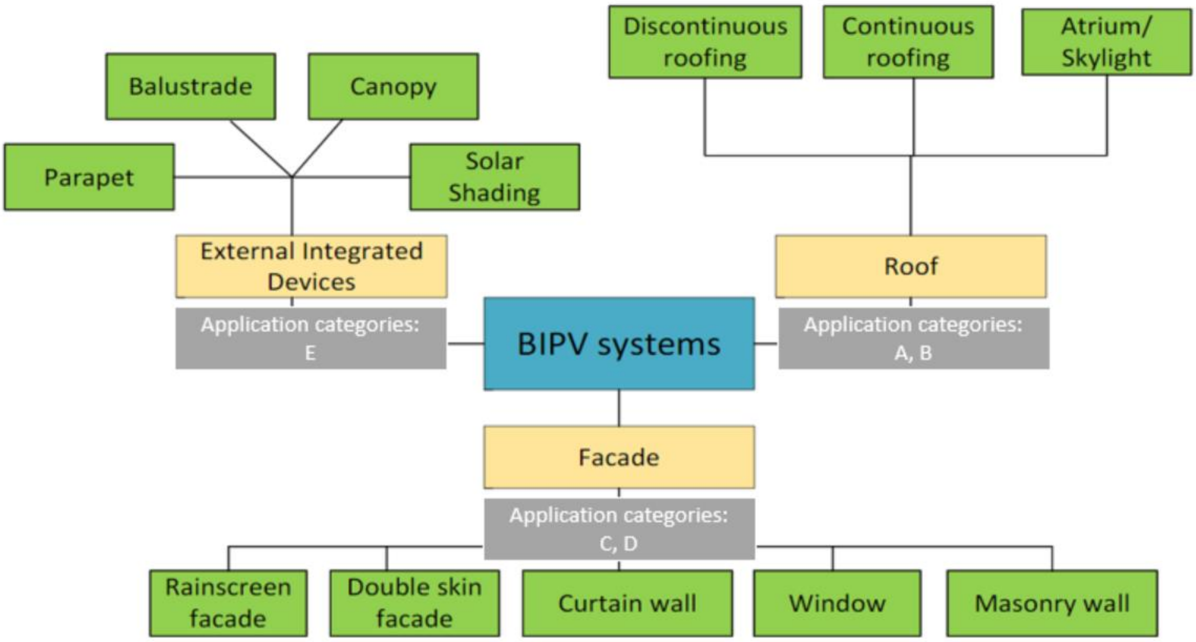


Figure 6. BIPV system classification.

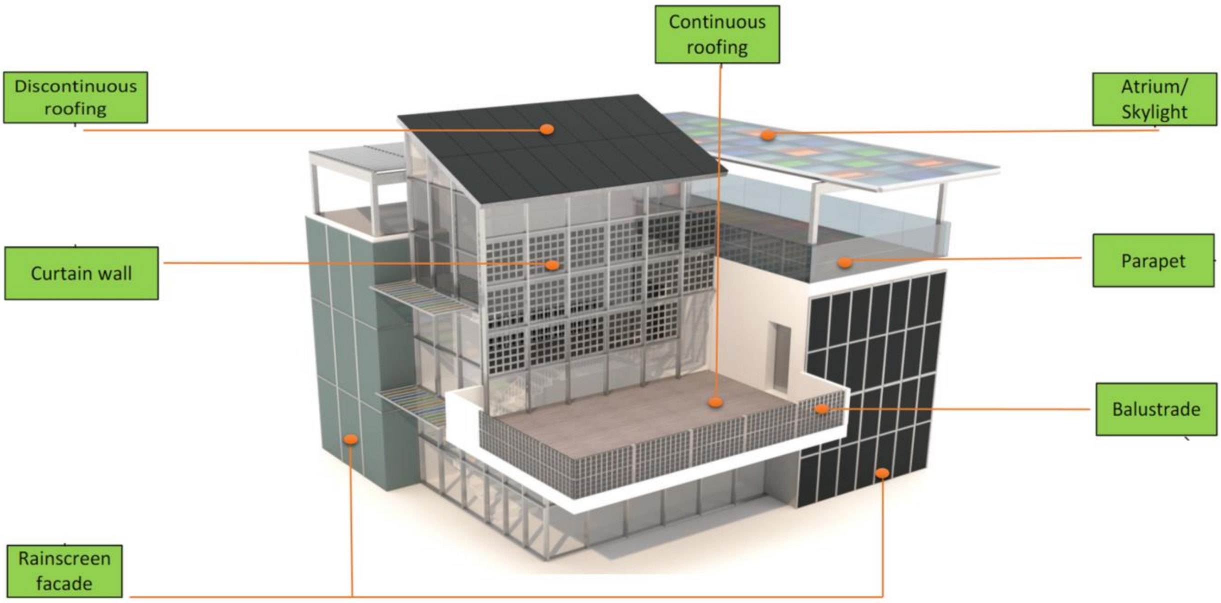
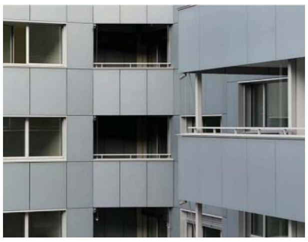


Figure 7. Some examples of BIPV systems in a real building case (source: SUPSI)

Table 4. List and description of BIPV systems

ROOF A roof, in a traditional building construction, is identified with the top covering providing protection as part of the building envelope separating indoor and outdoor environments.	
Discontinuous roof  (source: Schweizer AG)	A “discontinuous roof” is typically a pitched/sloped opaque envelope part consisting of small elements (tiles, slates, shingles, etc.) with the main function of water drainage. It is the part of the building envelope where the PV transfer had its first successes due to the advantages of optimal orientation of pitches and the simplicity of installation. BIPV is typically part of the discrete elements composing the roof tiling which form part of the roofing layer.
Continuous Roof  (source: Flisom)	A “continuous roof,” flat or curved roof, is characterized by a large uninterrupted layer with the main function of being water-resistant. Usually, membranes are used as a water barrier. In the first applications, the PV was mainly placed on top of the roof (BAPV). Lightweight and self-bearing systems represent the second generation of PV applications (BIPV). Flexible membranes, solar flooring and other solutions can be used for integrating PV as a multifunctional part of the building envelope.
Atrium/Skylight  (Source: Onyx Solar)	These are light-transmitting building elements that cover all or a part of the roof. They are typically (semi)transparent for daylighting purposes, with additional thermal, acoustic and/or waterproofing functions when protecting an indoor environment. Alternatively, they serve mainly as a shelter if protecting outdoor (non-heated) areas (atriums). They can be fixed or openable and retractable. PV is typically part of the glazed layer, applying both crystalline or thin-film PV technologies, and with various possibilities for transparency degrees and visual appearance.

FACADE A facade, in a traditional building construction with vertical (or tilted) parietal walls distinguishable by the roof, is the exterior surface of a building which is the architectural showcase and separates indoor and outdoor environments.	
Curtain wall  (Source: Ertex Solar)	It is an external and continuous building skin fenestration system, totally or partially glazed, composed of panels supported by a substructure in which the outer components are non-structural. A curtain wall refers to its construction since facade is hanging (just as a curtain) from the top perimeter of the building and is locally fixed to resist air and water infiltration, and is typically designed with extruded aluminium frames (but also steel, wood, etc.) filled with glass panes. The facade satisfies multiple requirements, such as a load-bearing function, acoustics and thermal insulation, light transmission, waterproofing, etc. In the case of a "warm facade", it divides, as a unitized skin layer, outdoor and indoor environments. It can be realized according to different construction systems such as stick-system, unitized curtain wall, Structural Sealant Glazing (SSG), point-fixed or suspended facade. In their most basic form, they are windows, while in more complicated forms they can be used to realize complex double skin facades. PV is typically part of the outer cladding layer, in form of glass-glass elements, with both crystalline or thin-film technologies and with various transparency degrees and visual appearance possibilities. Usually the glass is an IGU (double or triple glazing) in order to ensure adequate thermal insulation.
Rainscreen  (Source: Viridén + Partner)	Also known as a "cold" or ventilated facade, it consists of a load-bearing substructure, an air gap and a cladding. In summer, heat from the sun is dissipated thanks to the cavity that usually is naturally ventilated through bottom and top openings. A rainscreen is ideal for enhancing rear ventilation. It is typically categorized as "vented" with openings at the bottom; "ventilated" openings at both the bottom and top; and "pressure equalized" rainscreen with compartmentalization in the air cavity. Many construction models and technological solutions are available on the market, also with various joints and fixing options. Usually, PV elements are integrated similarly to opaque, non-active building cladding panels and can assume many aesthetic configurations especially thanks to glass customization (colours, textures, sizes, etc.). (see Figure 6)
Double Skin Facade  (Source : smartflex)	A double skin facade consists of two layers, usually glass, wherein air flows through the intermediate cavity. This space (which can vary from 20 cm to a few meters) acts as insulation against extreme temperatures, winds, and sound, improving the building's thermal efficiency for both high and low temperatures. PV is applied similarly to a curtain wall even though the outer facade, in this case, does not require thermal insulation. Thus, it is often a glass laminate rather than an IGU.

FAÇADE (next)	
Window  (Source: Physee)	A window is a glazed wall opening to admit light and often air into the structure and also to allow outside views. Windows, as a very ancient invention probably coincident with the development of fixed and enclosed constructions, are also strongly related with the building architecture, the space design, climatic conditions, functions, technologies and performance, etc. PV can be integrated into conventional PV glazing or also into some innovative applications.
Masonry Wall  (source: Flisom)	A “barrier wall” or “mass wall” is an exterior wall assembly of bricks, stones or concrete that relies principally upon the weather-tight integrity of the outermost exterior wall surfaces and construction joints to resist bulk rainwater penetration and/or moisture ingress (e.g. precast concrete walls, exterior insulation and finish systems EIFS, etc.) or upon a combination of wall thickness, storage capacity, and (in masonry construction) bond intimacy between masonry units and mortar to effectively resist bulk rainwater penetration.

EXTERNAL INTEGRATED DEVICES Elements and systems of the building skin which are in contact only with the outdoor environment.	
Parapet  (Source: solarinnova)	A parapet is a protective barrier at the edge of a roof.
Balustrade  (Source: energyglass-STG)	A balustrade is a protective barrier at the edge of a terrace, balcony, walkway or other structure.

EXTERNAL INTEGRATED DEVICES (next)	
Canopy  (Source: Onyx Solar)	A canopy is an unenclosed roof or else a structure over which a covering is attached, able to provide shade or shelter from weather conditions. Such canopies are supported by the building to which they are attached or also by a ground-mounting or stand-alone structure, such as a fabric-covered gazebo.
Solar Shading  (Source: Colt)	Solar shading encompasses solar-control devices such as shutters, blinds, louvres, or awnings that can be used to optimise the amount of solar heat gain and visible light that is admitted into a building.

4 MODULE

BIPV modules can come in various shapes and sizes, tailored for virtually any possible envelope application. The following section provides a general categorization of BIPV products available on the market, based on module properties and applications. However, current technological advances in photovoltaic technologies and composite materials may allow for the development of new BIPV modules yet to be realized. More detailed analysis of the technological design options of BIPV modules, are available in a recent review paper [6].

Categorization based on transparency

BIPV products can be categorized based on optical transparency as follows:

Opaque: refers to a module that does not transmit visible light.

Translucent: refers to a module that transmits visible light largely by diffuse transmission, so that objects are not seen distinctly through it**.**

Transparent: refers to a module that transmits visible light without appreciable scattering, so that objects are seen distinctly through it.

Figure 8. Opaque facade (left, source: Sunovation) and transparent fenestration (right, source: Physee)

Figure 9. Semi-transparent glazing with c-Si solar cells (left, source: Ertex Solar) and coloured, transparent glazing with dye-sensitised solar cells (right, source: Alain Herzog, Architect: Richter Dahl Rocher)

Intermediate categories also exist as a combination of the above-mentioned categories

- **Semi-transparent**: refers to a module that transmits visible light without appreciable scattering and with partial view obstruction due to the use of opaque solar cells.
- **Semi-translucent**: refers to a module that transmits visible light largely by diffuse transmission and with partial view obstruction due to the use of opaque solar cells.

Categorization based on planarity

- **Flat**: refers to a module that can be represented by a single planar surface.
- **Curved**: refers to a module that cannot be represented by a single planar surface.

Categorization based on mechanical rigidity

- **Flexible**: refers to a module that is capable of bending to conform to a curved surface (in frequent load conditions of use) but can also be mounted to a flat surface.
- **Rigid**: refers to a module that is not flexible (it's not supposed to change form in frequent load conditions of use if not with admissible deflections generally not visible). A curved module with a rigid shape is considered rigid.

Categorization based on size

- **Large**: refers to a module that exceeds 2.6 m in any dimension, or exceeds 2.1 m in both dimensions [21].
- **Shingle (or slate or tile)**: refers to a module that is less than 0.9 m in both dimensions.
- **Regular**: refers to a module that does not fall under the categories of large or shingle.

Figure 10. Flat discontinuous rigid roof with regular modules (left, source: Schweizer) and curved carport roof with large flexible modules (right, source: Flisom)

Categorization based on thermal insulation

- **Insulated**: refers to a module that has a thermal transmittance (U value) of less than 2.7 $Wm^{-2}K^{-1}$.
- **Non-insulated**: refers to a module that has a thermal transmittance (U value) of more than or equal to 2.7 $Wm^{-2}K^{-1}$.

We can also include the following categorization:

Standard: refers typically to the use of a “conventional / standard” PV module that has not been developed for any specific building skin system or application.

Customized. The opportunity to customize the basic architectural elements allows significant design flexibility that enables high adaptability of PV to different contexts. Customization can range from the material to the system level including size, aesthetic and construction aspects.

Figure 11. Use of a standard PV architectural language in a multifamily residential in Alleestrasse, Romanshorn, Switzerland (left, source: Viridén + Partner) or of a camouflaged appearance in customized PV glazing in the Z3 demonstration building in Stuttgart (right, source: Ed. Züblin AG)

5 COMPONENT

The design of a BIPV module includes some improvements with respect to a regular one for better constructional performance and appearance. Each different component of a PV module can be modified to some extent to match the requirements of the building better. Additionally, a PV module can be constructed with a multiple glazing structure, where the PV laminate is the outer pane of the glazing unit.

The following are definitions of the basic components of a PV module [22].

PV cell

(in turn, consisting of the PV material, the metal contact fingers or TCO, and the antireflecting coating). It is the elementary PV unit of a (BI)PV module that converts solar radiation into electricity.

(BI)PV encapsulant

protects cells and metallization from water and other environmental stresses, maintains electrical insulation, provides adhesion between layers of the laminate, and transmits irradiation for PV-relevant wavelengths [23].

(BI)PV front cover

sheet made of one or more transparent layers that constitute the front of a photovoltaic module. It provides environmental protection and electrical insulation of the encapsulated PV cells and circuitry.

(BI)PV back cover

sheet made of one or more layers that constitute the back of a photovoltaic module. It provides environmental protection and electrical insulation of the encapsulated PV cells and circuitry and can also guarantee other construction-related performance requirements, such as mechanical strength and fire safety.

(BI)PV laminate

result of bonding front cover, encapsulant, photovoltaic cells, circuitry (e.g. busbars and string interconnections), and back cover. The PV module is complemented, whereas part of the component design, by a junction box and an edge seal (the frame is not mandatory)

junction box

closed or protected enclosure on a photovoltaic module in which circuits are electrically connected and where protection devices may be located if necessary

bypass diode

diode connected across one or more PV cells in the forward electric current direction to allow the current to bypass shaded or broken cells. Bypass diodes are especially important in BIPV modules, due to their higher probability of being shaded once installed.

6 MATERIAL

Within IEA PVPS Task 13, ST1.1 the state of the art of PV materials is summarized [24]. Based on this summary and extended by findings described in [25, 26], the following description is given.

A typical PV module consists of a number of interconnected solar cells encapsulated by a polymer (encapsulant) and covered on the front by a protective layer (glass or a polymer frontsheet) and at the rear cover layer (a glass pane, a polymer backsheet or a back cover consisting of a special construction material). This multi-material composite can be surrounded (not obligatory) by a frame (usually aluminium) providing additional structural support and being instrumental in module mounting. The electric current produced in the PV active layer is conducted via metallic wires/ribbons which are connected in a junction box installed outside the module. The following materials are in use:

(BI)PV front cover

Front covers usually serve at least three functions: (1) transparency for incoming light, (2) structural protection of the photovoltaic cells, and (3) barrier for moisture and oxygen ingress.

- **Low iron (<120 ppm Fe) float glass or tempered glass.** Functional surface coatings can be added to increase the light absorption (anti-reflective coatings) and/or to reduce the accumulation of dirt (anti-soiling coatings) or to colour the BIPV module (coatings, prints) [27].
- **Polymeric frontsheets** (fluor-polymers, e.g. ETFE or FEP films) for lightweight and/or flexible BIPV-modules.

(BI)PV encapsulant

Encapsulants have to fulfill the following functions: (1) protect cells and metallization from water and other environmental stresses, (2) maintain electrical insulation, (3) provide adhesion

between layers of the laminate, and (4) provide high transparency of irradiation for PV-relevant wavelengths (e.g. for c-Si cells 300-1100nm) [23].

- **Poly(ethylene-co-vinyl acetate) (EVA);** copolymer of ethylene and vinyl acetate units; Most prominent material used in PV modules (especially for conventional plants)
- **Polyvinyl butyral (PVB);** thermoplastic resin; mostly used for applications requiring strong binding, toughness and flexibility; preferentially used in glass/glass modules for BIPV applications.
- **Polyolefin (PO)** elastomers and thermoplastic elastomers (POE and TPO, respectively); recently developed encapsulation materials [28].
- **Ionomers**; exhibit very low water vapour transmission rate and are thus often used for the protection of humidity-sensitive thin-film solar cells.
- **Silicones** (curing and non-curing systems); chemically inert → very good reliability;
- **Poly-methyl methacrylate** (PMMA), thermoplastic elastomers.

PV-active material / solar cells

The recent Smart Wire [29] multi-wire [30] and shingling interconnection [31] technologies use thin metal wires (200-300 µm in diameter) and allow for new module designs.

- crystalline silicon; mono-crystalline Si or poly-crystalline Si; most commonly used solar active materials; c-Si cells, available also as bi-facial cells, are connected via electrically conductive metallic ribbons or wires (copper or silver) which are connected to the cells either via solder bonds (tin-lead solders or lead-free systems) or electrically conductive adhesive (polymer matrix and µm-scale Ag particles).
- thin-film solar cells: CdTe, CIGS, CIS, a-SI, organic molecules, Perovskites.

(BI)PV back cover

Back covers have to (1) provide protection from environmental stresses, (2) ensure total electrical insulation of the PV panel, (3) provide mechanical support and (4) give colour and/or opacity to the BIPV module [6].

- **glass panes**
- **construction material panels** (e.g. steel, composite laminates,)
- **polymer materials** (multi-layer backsheets) [32] with layers of:
    - Polyethylene terephthalate (PET); high mechanical strength and electrical resistivity; is used as the inner core of most backsheet stacks.
    - Fluoropolymers: polyvinyl fluoride (PVF, well-known as Tedlar) or polyvinylidene fluoride (PVDF); high weathering stability → material for the outer layer.
    - Low density polyethylene (LDPE) or ethylene vinyl acetate (EVA); good adhesion to the encapsulant → inner layer .
    - Polyamide (PA); Fluorine-free alternative for the outer and inner layer (laminated to a PET core).
    - Polypropylene (PP); new material; co-extruded all-polyolefin 3-layer; used in backsheets.

Frame and edge sealing

Most BIPV modules are mounted without frames, but some are protected with an aluminium frame that is connected to the panel via an adhesive (mostly polysiloxane). With respect to

the ingress of moisture into the encapsulant, the adhesive layer and the framing provide an additional diffusion barrier. Frameless glass/glass modules often have a polymer edge sealant to prevent outside moisture ingress (mostly polyisobutylene).

7 GLOSSARY OF BIPV SYSTEMS

In the following table, the BIPV systems defined in **Erreur ! Source du renvoi introuvable.** are reported along with the most widely used synonyms found in technical literature and including also translations in different international languages. Synonyms are intended to include other naming used to describe the same/similar systems under this category most commonly used in the sector.

Table 5. Glossary of BIPV systems

ROOF	
Discontinuous roof	*Terms used for similar systems:* Cold or ventilated roof, shingled roof, tiled roof, slate roof, pitched roof; sloped roof
 (Source: Schweizer AG)	ITALIAN / ITALY: copertura con manto discontinuo
	DUTCH / NETHERLANDS: schuin dak
	SPANISH / SPAIN: cubierta discontinua
	FRENCH / FRANCE: Couverture de petits éléments
	GERMAN / AUSTRIA: In-Dach-System
	GERMAN / GERMANY, SWITZERLAND: gedecktes Dach, schuppengedecktes Dach, tafelgedecktes Dach
	JAPANESE / JAPAN: 勾配屋根, 傾斜屋根
	CHINESE / CHINA: 坡屋顶
	FRENCH/ CANADA: couverture discontinue
	SWEDISH/SWEDEN: Taktäckning med mindre enheter (t.ex. tegeltak, shingeltak)
Continuous Roof	*Terms used for similar systems:* Flat/Planar Roof, low-sloped roof, corrugated iron roof, metal roof
 (Source: Flisom)	ITALIAN / ITALY: copertura con manto continuo
	DUTCH / NETHERLANDS: plat dak
	SPANISH / SPAIN: cubierta continua
	FRENCH / FRANCE : Couverture de grands éléments
	GERMAN / AUSTRIA: Flachdach
	GERMAN / GERMANY, SWITZERLAND: Foliendach, gedichtetes Dach, Blechdach
	JAPANESE /JAPAN: 平板屋根, フラットルーフ
	CHINESE / CHINA: 平面屋顶
	FRENCH/ CANADA : couverture en continue
	SWEDISH/SWEDEN: Taktäckning med större enheter (t.ex. plåttak, duktak, papptak)

ROOF	
Atrium/Skylight	*Terms used for similar systems:* Glazed roof, (semi)Transparent roof, Overhead glazing
	ITALIAN / ITALY: atrio (atrium), copertura vetrata (glazing roof), lucernario (skylight)
	DUTCH / NETHERLANDS: large: atrium; small residential version: veranda
	SPANISH /SPAIN: cubierta acristalada (glazing roof); atrio (atrium);
	FRENCH / FRANCE : puit de lumière
	GERMAN / AUSTRIA: Dachfenster, Oberlicht
	GERMAN / GERMANY, SWITZERLAND: Glasdach, Oberlicht, Atrium
(Source: Onyx Solar)	JAPANESE /JAPAN: アトリウム/トップライト, 天窓, スカイライト
	CHINESE / CHINA: 中庭/天窗
	FRENCH/ CANADA : puits de lumière; lanterneau
	SWEDISH/SWEDEN: glastak, atrium, takfönster

FACADE	
Curtain wall	*Terms used for similar systems:* Warm facade
	ITALIAN / ITALY: facciata continua
	DUTCH / NETHERLANDS: gevel, façade
	SPANISH / SPAIN: muro cortina
	FRENCH / FRANCE : Mur-rideau
	GERMAN / AUSTRIA: Vorhangfassade
	GERMAN / GERMANY, SWITZERLAND: Vorhangfassade, Pfosten-Riegel-Fassade (PR-Fassade), Riegel-Pfosten-Fassade (RP-Fassade), Elementfassade, Warmfassade
(Source: Ertex Solar)	JAPANESE /JAPAN: カーテンウォール(Curtainwall), ノックダウンカーテンウォール(Stick system), ユニットカーテンウォール(Unitized curtain-wall system), 構造接着構法 or SSG構法(Structural bonding-SSG)
	CHINESE / CHINA: 玻璃幕墙
	FRENCH / CANADA: mur-rideau
	SWEDISH/SWEDEN: Glasfasadsystem
Rainscreen	*Terms used for similar systems:* Ventilated facade, cold faCade, cavity wall
	ITALIAN / ITALY: facciata ventilata
	DUTCH / NETHERLANDS: vliesgevel, glasgevel
	SPANISH / SPAIN: fachada ventilada
	FRENCH / FRANCE : Façade ventilée
	GERMAN / AUSTRIA: hinterlüftete Fassade
	GERMAN / GERMANY, SWITZERLAND: (vorgehängte) hinterlüftete Fassade; Kaltfassade
(Source: Viridén + Partner)	JAPANESE / JAPAN: 通気壁構法(Rainscreen, Cold faCade), 換気型ファサード(Ventilated faCade)
	CHINESE / CHINA: 雨幕/覆盖板墙
	FRENCH / CANADA: façade ventilée
	SWEDISH/SWEDEN: ventilerad fasad

FACADE	
Double Skin Facade	*Terms used for similar systems:* Second skin
 (Source: Ertex Solar)	ITALIAN / ITALY: facciata a doppia pelle
	DUTCH / NETHERLANDS: geisoleerde gevel
	SPANISH /SPAIN: fachada de doble piel
	FRENCH / FRANCE: Façade double-peau
	GERMAN / AUSTRIA: Doppelfassade
	GERMAN / GERMANY, SWITZERLAND: Doppelfassade, Pufferfassade, Zweite-Haut-Fassade, Zuluft-/Abluft-Fassade, Schachtfassade, Korridorfassade, Kastenfensterfassade
	JAPANESE / JAPAN: ダブルスキン, ダブルスキンファサード
	CHINESE / CHINA: 双层幕墙
	FRENCH / CANADA: façade double-peau
	SWEDISH/SWEDEN: dubbelskalsfasad (accessible), hybridfasad (non-accessible)
Window	*Terms used for similar systems:* Fenestration
 (Source: Physee)	ITALIAN / ITALY: Finestra, serramento
	DUTCH / NETHERLANDS: raam
	SPANISH / SPAIN: ventana
	FRENCH / FRANCE: Fenêtre
	GERMAN / AUSTRIA: Fenster
	GERMAN / GERMANY, SWITZERLAND: Fenster, Fensterfassade, Fensterbandfassade
	JAPANESE / JAPAN: 窓 (window) or サッシ(sash: sash is window frame but sometime used insted of window.)
	CHINESE / CHINA: 窗户
	FRENCH/CANADA: fenêtre
	SWEDISH/SWEDEN: fönster
Masonry Wall	*Terms used for similar systems:* Solid masonry wall, massive wall, barrier wall
 (Source: Flisom)	ITALIAN / ITALY: muro, parete massiva
	DUTCH / NETHERLANDS: bakstenen muur
	SPANISH / SPAIN: muro de mampostería
	FRENCH / FRANCE : Mur maçonné
	GERMAN / AUSTRIA: Mauerwerkswand
	GERMAN / GERMANY, SWITZERLAND: Massiv(bau)wand Mauerwerkswand
	JAPANESE / JAPAN: 組積造(masonry)
	CHINESE / CHINA: 砌筑墙
	ITALIAN / ITALY : mur en maçonnerie
	FRENCH/ CANADA: mur en maçonnerie
	SWEDISH/SWEDEN: murad vägg (masonry), massivvägg

EXTERNAL INTEGRATED DEVICES	
Parapet	*Terms used for similar systems:* Railing
 (Source: solarinnova)	ITALIAN / ITALY: parapetto
	DUTCH / NETHERLANDS: borstwering
	SPANISH / SPAIN: parapeto
	FRENCH / FRANCE: Parapet
	GERMAN / AUSTRIA: Parapet
	GERMAN / GERMANY, SWITZERLAND: Parapet, Brüstung
	JAPANESE /JAPAN: パラペット
	CHINESE / CHINA: 女儿墙
	FRENCH / CANADA: parapet
	SWEDISH/SWEDEN: räcke (slim construction), sarg (wall-like construction, also low height)
Balustrade	*Terms used for similar systems:* Railing
 (Source: energyglass-STG)	ITALIAN / ITALY: balaustra
	DUTCH / NETHERLANDS: balkonhek, balustrade
	SPANISH / SPAIN: antepecho/barandilla
	FRENCH / FRANCE: Balustrade
	GERMAN / AUSTRIA: Geländer
	GERMAN / GERMANY, SWITZERLAND: Geländer, Balustrade, Brüstung
	JAPANESE / JAPAN: 手摺
	CHINESE / CHINA: 栏杆
	FRENCH / CANADA: balustrade
	SWEDISH/SWEDEN: räcke, balkongräcke (balcony)
Canopy	*Other synonyms: gazebo, carport roof*
 (Source: Onyx Solar)	ITALIAN / ITALY: pensilina
	DUTCH / NETHERLANDS: doek
	SPANISH / SPAIN: marquesina
	FRENCH / FRANCE: Verrière
	GERMAN / AUSTRIA: Vordach, Terrasse
	GERMAN / GERMANY, SWITZERLAND: Vordach, Überdachung, Flugdach, Baldachin, Membrandach
	JAPANESE / JAPAN: キャノピー or キャノピー屋根
	CHINESE / CHINA: 雨篷
	FRENCH / CANADA: Auvent
	SWEDISH/SWEDEN: skärmtak

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