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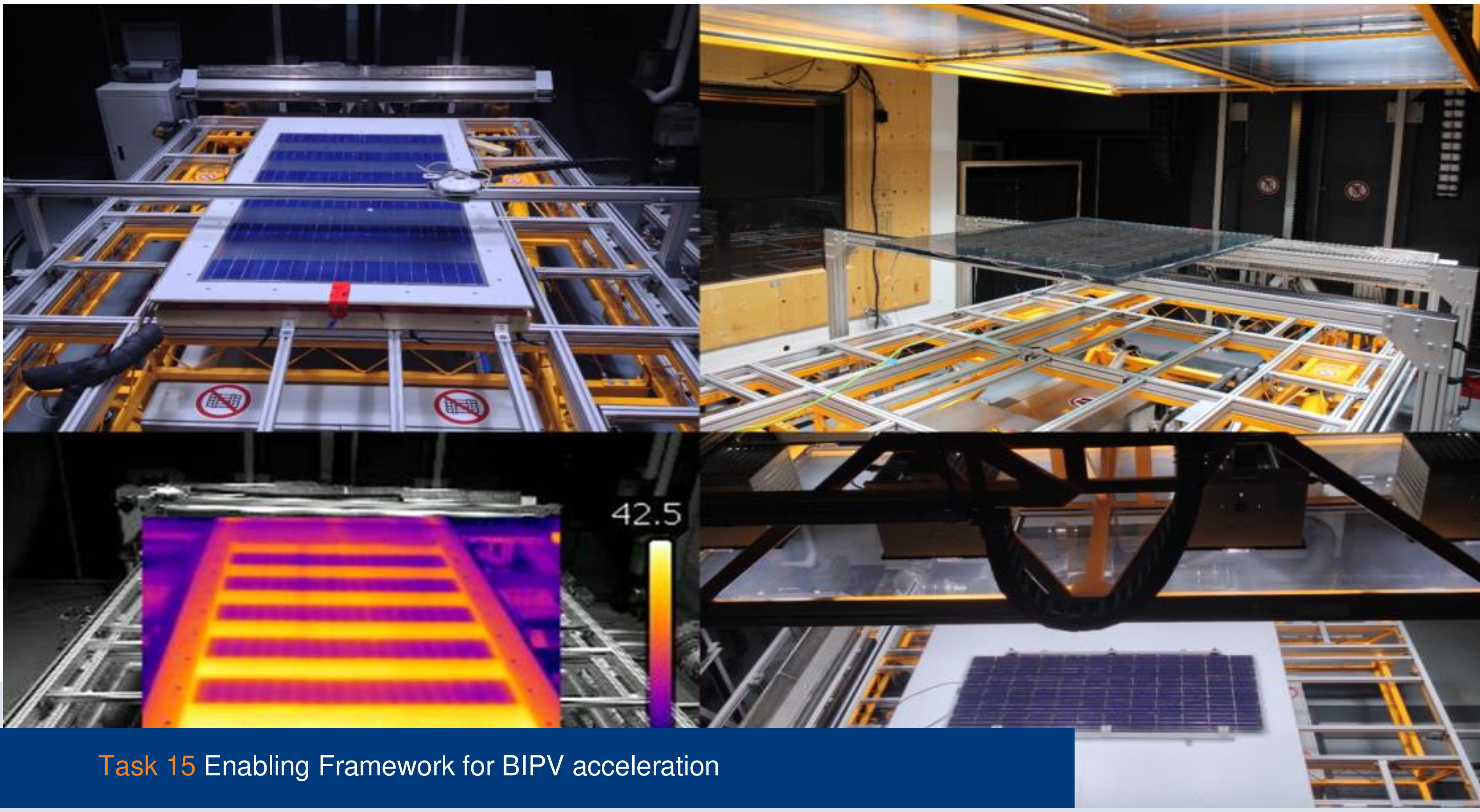

Task 15 Enabling Framework for BIPV acceleration

PVPS

Multifunctional Characterisation of BIPV

Proposed Topics for Future International Standardisation Activities

2020

Report IEA-PVPS T15-11 : 2020

What is IEA PVPS TCP?

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.

The IEA PVPS participating countries are Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America. The European Commission, Solar Power Europe, the Smart Electric Power Alliance (SEPA), the Solar Energy Industries Association and the Cop- per Alliance are also members.

Visit us at: www.iea-pvps.org

What is IEA PVPS Task 15?

Building Integrated PV (BIPV) is seen as one of the five major tracks for large market penetration of PV, besides price decrease, efficiency improvement, lifespan, and electricity storage. IEA PVPS Task 15 is an international collaboration to create an enabling framework and to accelerate the penetration of BIPV products in the global market of renewables and building envelope components, resulting in an equal playing field for BIPV products, Building Applied PV (BAPV) products and regular building envelope components, respecting mandatory, aesthetic, reliability and financial issues.

To reach this objective, an approach based on five key developments has been developed, focussed on growth from prototypes to large-scale producible and applicable products. The key developments are dissemination, business modelling, regulatory issues, environmental aspects, and research and development sites.

This Task contributes to the ambition of realizing zero energy buildings and built environments. The scope of this Task covers new and existing buildings, different PV technologies, different applications, as well as scale difference from single-family dwellings to large-scale BIPV application in offices and utility buildings.

The current members of IEA PVPS Task 15 include: Austria, China, Belgium, Canada, Denmark, France, Germany, Italy, Japan, Korea, Norway, The Netherlands, Spain, Sweden and Switzerland.

Further information on the activities and results of the Task can be found at www.iea-pvps.org.

Michiel Ritzen, operating agent IEA PVPS Task 15

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COVER PICTURE

Optical, thermal and electrical characterization of BIPV monofacial and bifacial modules at Concordia University's Solar Simulator and Environmental Chamber (SSEC) laboratory (K. Kapsis, 2019)

ISBN 978-3-906042-90-9 Multifunctional Characterisation of BIPV – Proposed Topics for Future International Standardisation Activities

INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA PVPS
Task 15
Enabling Framework for BIPV acceleration

Multifunctional Characterisation of BIPV – Proposed Topics for Future International Standardisation Activities

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Table of Contents

EXECUTIVE SUMMARY

This report aims to identify areas where there is still a need for international standardisation on multifunctional characterisation of BIPV modules and systems and to recommend approaches which could be taken to meet this need.

To achieve this, **Chapter 2** identifies **Features of BIPV which require modifications to existing testing procedures.** This Chapter contains brief descriptions of BIPV features, followed by a list of tested properties where a modification of an existing test is needed to take account of the specific BIPV feature. Chapter 2 does not present the proposed test modifications as such.

This is dealt with in **Chapter 3**, entitled **Types of testing and proposed test modifications** to account for BIPV features. The types of testing are initially summarised in an overview table, including those proposals which are not further elaborated in the sub-sections. Where existing papers are referenced or more details concerning a proposed test modification are available, brief outlines of test methods to take the addressed feature of BIPV into account are given in the sub-sections of the chapter.

Following the Summary in **Chapter 4** of the main content of this report, and the associated references, an **Annex** has been included that documents the responses received to questionnaires on experience made with multifunctional evaluation of BIPV modules and systems within Activity C.3. Two versions of the questionnaire were provided, one that was applicable internationally (“Multifunctional BIPV evaluation”) and another intended for European countries (“Experience with EN 50583”). As EN 50583 was the first BIPV standard to be introduced, and was the only BIPV standard to exist at the time, it formed the basis for both surveys. As a total of ten responses was received to the two questionnaires, statistical analysis is not appropriate. Instead, the Annex summarizes the answers received from various participants for future reference.

The challenges of additional requirements resulting from the use of PV modules in the built environment have not yet been overcome. The most pressing challenge is to simplify and generalize the tests and requirements for BIPV products to allow easier and wider international market introduction. The combination of tests used today in the PV world and in the construction world is one approach that can be followed to reduce the complexity and number of tests required for BIPV modules and systems. This and other approaches to multi-functional characterization of BIPV will be addressed internationally at the pre-normative level during the next phase of IEA-PVPS Task 15.

1 INTRODUCTION

As has been documented in an earlier report by this Subtask, there are currently several different definitions for BIPV modules and systems [1]. For the purposes of this report, where topics for future international standardisation activities involving quantifiable, multifunctional characterisation are proposed, the definition used in IEC 63092-1 is used as the basis. There, a BIPV module is defined as a "Photovoltaic module that provides one or more of the functions of the building envelope". This definition immediately indicates that a BIPV module is a multifunctional element; as a photovoltaic module, it has the function of generating electricity, and as a building component, it must provide one or more of the building-envelope functions as listed in IEC 63092-1:

a) Mechanical rigidity or structural integrity
b) Primary weather impact protection: rain, snow, wind, hail
c) Shading, daylighting, thermal insulation
d) Fire protection
e) Noise protection
f) Separation between indoor and outdoor environments
g) Security, shelter or safety

As a result, the characterisation of BIPV modules – and systems – must be multifunctional, addressing both electrotechnical and building requirements.

This report aims to identify areas where there is still a need for international standardisation on multifunctional characterisation of BIPV modules and systems and to recommend approaches which could be taken to meet this need.

To achieve this, **Chapter 2** identifies **Features of BIPV which require modifications to existing testing procedures.** This Chapter contains brief descriptions of BIPV features, followed by a list of tested properties where a modification of an existing test is needed to take account of the specific BIPV feature. Chapter 2 does not present the proposed test modifications as such.

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Following the Summary in **Chapter 4** of the main content of this report, and the associated references, an **Annex** has been included that documents the responses received to questionnaires on experience made with multifunctional evaluation of BIPV modules and systems.

It should be noted that this report concentrates on BIPV modules that contain at least one glass pane. BIPV modules with polymer waterproofing sheets or metal sheets as the substrates are not considered explicitly, as this segment of the BIPV market was not represented among the team of authors.

2 FEATURES OF BIPV WHICH REQUIRE CHANGES TO EXISTING TESTING PROCEDURES

2.1 Modifications compared to "conventional" building components

For the purpose of this report, "conventional" building components are defined to be existing building components which do not contain photovoltaic cells (i.e have purely passive functions and do not generate electricity). Such components could be replaced by the BIPV components under consideration. The "conventional" building components may have flat or curved surfaces, e.g. curved glazing units for the corners of buildings.

BIPV features shall be considered to be "modifications" to conventional building components if they are intrinsic to or widespread among BIPV products but do not occur or are uncommon in the conventional building components which they would replace.

2.1.1 Inhomogeneous surface coverage

BIPV modules, particularly those based on crystalline silicon cells, typically contain not only the photovoltaic cells but also interconnectors and a back sheet or cover layer, which may be transparent, translucent or opaque. These different materials are characterised by different solar absorptance values, i.e. the area exposed to the sun is optically inhomogeneous.

In addition, the front cover and/or the encapsulant in front of any type of photovoltaically active layer may also be optically inhomogeneous because decorative patterns have been added for aesthetic reasons, e.g. by printing processes.

As a result of inhomogeneity in general:

- the different optical properties of the different areas must be taken into account when the optical properties of a BIPV module are determined (See Sections 3.4.1 to 3.4.7 and 3.4.9)
- on exposure to solar radiation, the differing solar absorptance values result in the different areas reaching different temperatures, causing thermal gradients across the surface of the BIPV module (See Sections 3.2.4 and 3.5.7), which may cause thermal stress.

As a result of inhomogeneous transmittance over the layers in front of the solar cells:

- electrical mismatch between cells may occur, reducing the module efficiency (See Section 3.1.3.4)
- the risk of hot spots developing may increase (See Section 3.1.5)

2.1.1.1 Presence of decorative components

The decoration, e.g. in the form of a coloured film between the glass cover and the cells, may change (lower) the resistivity of the encapsulant and/or (increase) ion mobility. This could also drive PID shunting. If, in a specific application, frequent condensation may occur, this could lead to high leakage current values driving PID effects. Another problem may arise in the combination of voltage and humidity causing reduced adhesion between encapsulant materials and the cells and/or front and back sheets (PID delamination).

2.1.2 Presence of junction box and cables

In a BIPV system, the modules must be electrically connected to each other; the state-of-the-art solution to achieve this is by means of power cables. The connection from the power cable to the cells in each module is managed by means of a junction box, normally positioned at the back of the module. For aesthetic reasons, the box is sometimes placed at the edge of the module or concealed below or within the module frame. In most cases, the presence of a junction box results in a geometrical perturbation compared to a conventional building product. As a result of this perturbation,

- determination of thermal conductance using guarded hot-plate apparatus, which assumes flat surfaces, may need a modification, see section 3.4.8.

The presence of the junction box will affect the temperature of the module in its vicinity and moreover an electrically defect junction box will further increase the thermal gradient over the glass. As a result,

- The glass could break, see sections 3.2.4 and 3.5.7 regarding thermal stress

Cables and junction boxes transfer high voltages and currents and thus, as for the modules themselves, represent potential risks for electrical failures and fire. Furthermore, since these components are mainly made of polymers, they can also contribute to fire propagation in a building even if the fire started elsewhere. Thus,

- Reaction to fire properties of cables and junction boxes may need further attention in testing, see section 3.3.

2.1.3 Extraction of energy as electricity

When solar radiation is incident on the surface of a BIPV module, it is partly reflected (ρ), partly transmitted (τ) and partly absorbed (α). A fraction of the energy absorbed is transformed to solar electricity while the rest is transformed into heat according to the following equation:

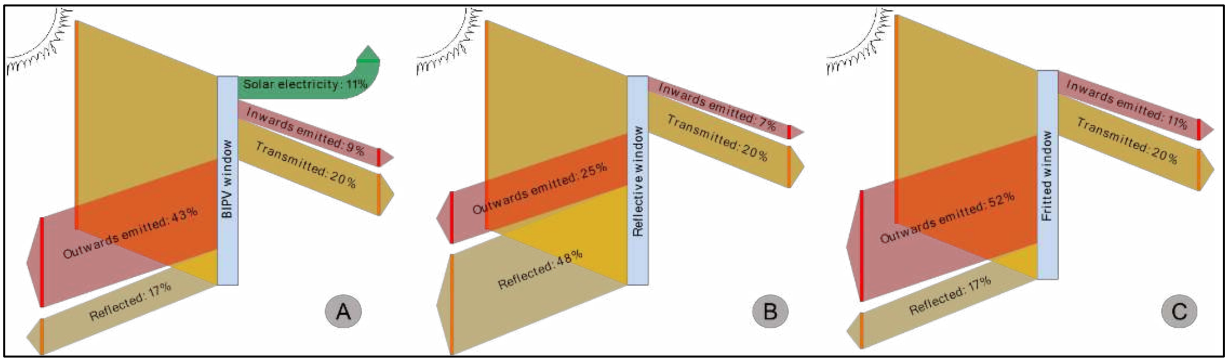
$$\rho + \tau + (N_{out}\alpha + N_{in}\alpha + \eta_{el}) = 1 \qquad (1)$$

where N_{out} is the fraction of absorbed solar energy re-emitted outwards, N_{in} is the fraction re-emitted inwards, and η_{el} is the fraction of incident solar radiation that is absorbed and converted to solar electricity, also known as the electrical conversion efficiency.

When a BIPV module is thermally characterized (e.g. for assessing the solar heat gain coefficient SHGC) under the “sun”, using experimental methods or calculations, it is important that the extraction of energy as electricity is taken into account in the energy balance.

However, the solar electricity generated is strongly affected by the spectrum of the illuminating source, the angle of incidence of the light beam to the module and the module’s conditions of operation. Thus, it is important that the module characterization is performed both under open circuit (V_{oc}, under which all absorbed solar radiation is converted into heat) and also under realistic Maximum Power Point Tracking (V_{MPPT}) conditions (under which some of the absorbed solar radiation is converted into electricity).

Sections 3.4.8 and 3.4.9 further discuss the proposed test modifications to account for extraction of energy as electricity when the thermal transmittance (U value) or the Solar Heat Gain Coefficient (SHGC or g value) are measured.



Sankey diagrams for solar energy transmission, reflection, absorption and electricity conversion (when applicable) for a) a BIPV window, b) a reflective window and, c) a fritted window. All windows have an average solar transmittance of 20% (Source: K. Kapsis, 2019).

2.2 Modifications compared to “conventional” PV modules

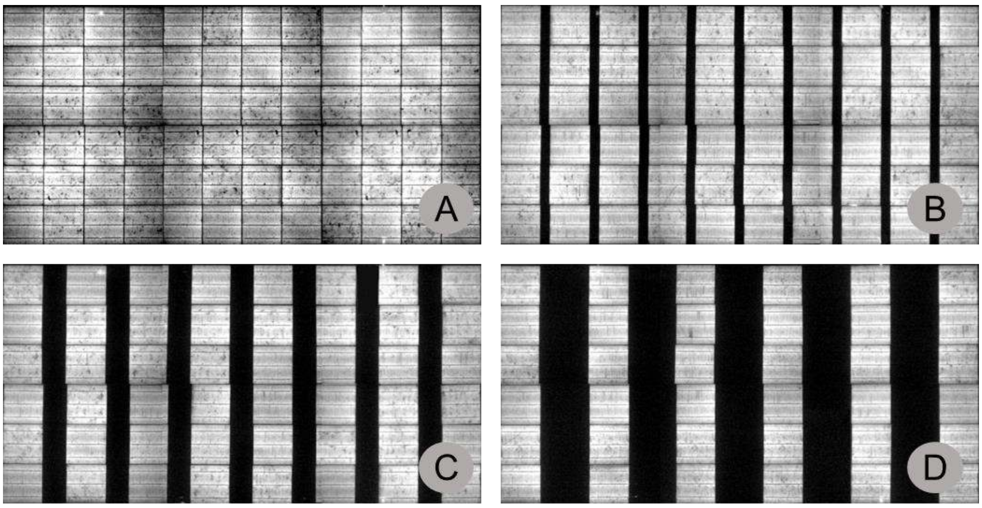
In the context of this report, “conventional” PV modules are defined to be PV modules with crystalline silicon or thin-film cells which are designed to function solely as electricity generators and which are intended to be mounted e.g. in open racks or above a building roof.

2.2.1 Inhomogeneous surface coverage

“Conventional” PV modules are designed to maximise the photovoltaically active area per module, such that non-active areas (opaque or transparent) between and around the solar cells are reduced to the minimum dimensions needed to ensure electrical insulation. By contrast, those BIPV modules that are intended to transmit light and/or solar radiation into a building also include non-negligible transparent or translucent areas.

As a result:

- The relevant “aperture area” should be clearly specified for electrical testing and for the specification of area-dependent quantities.



Electroluminescence images for four BIPV prototype windows with solar cell coverage percentages of a) 99% , b) 82% , c) 66% and, d) 49% (Source: K.Kapsis, 2019).

If the surface of modules is decorated (i.e. by using different coloured layers or surface treatments), locally differing absorptive and/or reflective properties may occur. This may cause mismatch between module substrings that are paralleled by bypass diodes. In particular:

(i) If the bypass-diodes operate regularly, this causes losses in energy yield because bypassed substrings do not contribute to the power generation.

(ii) If the (inhomogeneous) decoration is highly absorptive, this may – in combination with the low or zero electrical output – lead to significantly higher temperature in such bypassed substrings, while highly reflective parts can lower the local module temperature. Due to different thermal expansion coefficients of materials used, these differences in local module temperature cause thermo-mechanical stresses, that can lead to material fatigue failures of interconnects, or glass breakage.

(iii) In addition, higher temperatures in module materials may cause higher degradation rates, particularly of polymer components like encapsulants and backsheets. If a bypass diode is active for long periods of time, it may itself undergo degradation and/or thermal runaway processes. See Sections 3.1.3.5 and 3.5.7 for effects of higher operating temperature.

2.2.2 Large module dimensions and prefabricated elements

Existing and upcoming flexible, rollable thin-film PV-modules, that are used mainly for roof integration, are often narrow, but are several metres in length. Even very large-scale solar simulators (flashers) are often not large enough for the power measurement of such devices, so it is not easy to characterize them in indoor laboratories. Other options, such as outdoor measurement procedures, suffer from the disadvantage of less controllable environmental and measurement conditions that cause larger measurement errors. Also (rigid) curtain wall and glazing elements, possibly spanning the total floor-to-floor height of buildings, or large prefabricated roofing or wall elements may exceed the maximum available size of testing facilities required in the certification process, such as stationary solar simulators, climatic chambers, etc.

Due to the large module dimensions, it will also be difficult to pack the modules for transportation as carefully as is done for conventional PV modules. Thus, they will be more vulnerable when exposed to vibrations and shocks during transport from the production site to the installation site. In order to pave the way for the failsafe, large-scale introduction of these products to the market, it is important that these phenomena are further analysed. Furthermore, appropriate test methods that can simulate the stresses in a realistic way and assess the potential damage need to be introduced, see Section 3.2.5.

2.2.3 Many different module dimensions and designs

In the certification process of PV modules, the IEC 61215:2016 series for the design qualification and type approval (in combination with the IEC 61730:2016 series for safety issues) is normally applied for a specific product, with given dimensions, bill of materials, and manufacturing processes. The retesting guideline, IEC TS 62915:2018 gives guidance as to when and which retesting is required if significant design changes are made. In the case of changes in dimensions, retesting is required if the length, width or module area changes by more than 20% of the certified product dimensions (which are those of the reference module).

In contrast to the case of conventional PV modules, a very specific feature and challenge of BIPV products is the variation in sizes, designs and formats that is often needed to meet architectural design requirements and to match building dimensions. So-called 'custom-sized PV modules' are mostly glass-glass modules based on crystalline silicon or thin-film PV technology. More recently, modules based on thin films deposited onto metal foil or organic, perovskite or dye solar cells have entered the market. Typically the producers of custom-sized BIPV modules have a general 'recipe' to produce the solar modules. This means that the type of glass, the interlayers, the interconnectors, the junction boxes and the cells are always the same, but the dimensions and power output might vary. In the case of glass-glass modules, the glass thickness is individually calculated according to the area of the module, function of the module, local building requirements, location in the building (height, wind load), fixings and use of the solar module.

Most custom-sized module producers also work, due to design considerations, with more than one cell type. Totally black cells, back-contact cells, bifacial cells, coloured solar cells, semitransparent cells and others are on offer.

Furthermore, variations in cover glass treatment, such as sandblasting or screen-printing, are demanded by the market.

If the rigid rules applying to the definition and electrical testing of conventional modules are applied, this represents a major obstacle to bringing tested and approved custom-sized and/or individually designed BIPV modules to the market in a safe, economic and reliable manner. More flexibility and options for design variations need to be taken into account for viable BIPV module standardization, testing and certification. This affects the testing of electrical, mechanical and optical properties.

2.2.4 Many different substructures and mounting methods of BIPV modules

The testing for conventional PV modules includes mechanical testing of the modules with the specific fixings attached under conditions applying for the specified locations. Both are specified by the producer. Corresponding processes occur with custom-sized BIPV modules manufactured e.g. as glass-glass modules. A BIPV module of given dimensions has a different mechanical resistance depending on the attachment fittings. Regarding glass panes and laminates, different types and thicknesses of glass and interlayers may be required, depending on whether the attachment fitting extend along all four sides or are at only individual points.

Again, more flexibility and options for design variations need to be foreseen to achieve practicable BIPV module standardization, testing and certification.

2.2.5 Curved modules

Different elements with different tilt directions within a "single BIPV element" can affect power production when differently oriented cells are connected in series. On a curved surface, each cell receives a different irradiation level at the same time, which leads to energy mismatch and therefore can lead to hot-spot generation and power decrease. This affects:

- the dimensioning of electrical and safety elements if the module uses an unconventional number of cells, requiring modification of e.g. diode characteristics, ribbons or string size.
- stress constraints with wind, water and snow loads (and combinations thereof), stress constraints with suction (reverse load) and thermal stress (due not only to a difference between front and back surface temperatures but also to the modification of radiation absorption according to the orientation with respect to incident solar radiation).

2.2.6 Presence of junction box and cables

The fact that the junction box in a BIPV system in general will be concealed in a space between the module and the underlying surface makes it more difficult to access compared to a BAPV installation. This will impede inspection, e.g. by means of an IR camera, and thus increase the risk of electric failures not being detected.

2.3 Effect of installation in the built environment

A very general distinction can be made between conventional PV modules and BIPV elements:

Conventional modules:

- Conventional solar modules as "electric products" are defined by an almost globally accepted general set of IEC standards and UL standards
- Conventional modules are therefore standardized as "objects" in their own right in an internationally "homogeneous" manner

BIPV modules installed in the built environment:

- BIPV modules are not only subject to the set of PV standards mentioned in Section 2.2.3 but their installation in the built environment also means that construction standards, rules and requirements apply.
- Requirements on BIPV modules are imposed – often in a legally binding manner - by the environment / location / installation and use.

This means that BIPV modules are not only the subject of **"object"-defined standards**, but also of **"context"-defined standards**:

- **Geographical location and height of the building / BIPV application** changes the required characteristic of the BIPV element regarding its ability to deal with the resulting natural forces like snow loads, wind loads, heat, hail, fire safety requirements
- **The location in the building and building type can change the** requirements regarding e.g. the required fire safety classes and certificates as well as the required structural strength and testing
- **National / regional construction codes (laws) and standards** might set out different requirements

2.3.1 Frequent (partial) shading

Partial shading occurs when one or more PV cells in a PV module receive less irradiance than the rest, due to the existence of nearby or distant objects that prevent radiation from reaching the complete PV module surface. Due to architectural and urban constraints, partial shading occurs more frequently in PV modules integrated in buildings than in ground-mounted power plants.

Partial shading can lead not only to significant reduction of the energy yield of the PV system but also to appreciable temperature increase (hot spots) of shaded PV cells if they are forced to work as loads for the other PV cells. This can even cause irreversible damage to the materials. Both electrical and thermal effects will depend on the geometry and distance of the shading object and on the design of the PV module. The BIPV module location in the building envelope and its electrical configuration (number, distribution and connection of PV cells and bypass diodes) are decisive.

The most critical situations occur if the differences in irradiance on different parts of the modules are large. Especially harmful is partial shading under high irradiance conditions, for instance around noon under clear sky conditions and with shading from a close object.

Shading from close objects, i.e. objects causing an umbra shadow on the module's active cell area may cause

(i) excessive heat in shaded parts (hot spots), accelerating degradation processes, and/or

(ii) sudden, permanent power degradation in some thin-film technologies with monolithic, series-connected cell structures, if a linear shadow covers one or a few series-connected cells over almost the whole cell width.

In general, shading from distant objects during the first or last hours of the day does not impact significantly on the PV modules' durability, although it reduces the PV energy yield.

Photo of a building equipped with a complex BIPV system and its RADIANCE model, illustrating cases of partial shading [2].

2.3.2 Radiation frequently incident at non-normal incidence

The reflectance of a flat-surface PV module under real operating conditions, with light coming from different angles, is generally greater than the reflectance at normal incidence at which the electrical characteristics of a PV module are commonly supplied.

The reflectance increase with the angle of incidence (AOI) means a decrease of the PV electricity generation. Reflection losses on an annual basis can become especially significant in those BIPV applications in which PV modules are positioned far from the optimum orientation regarding the maximum annual yield [3].

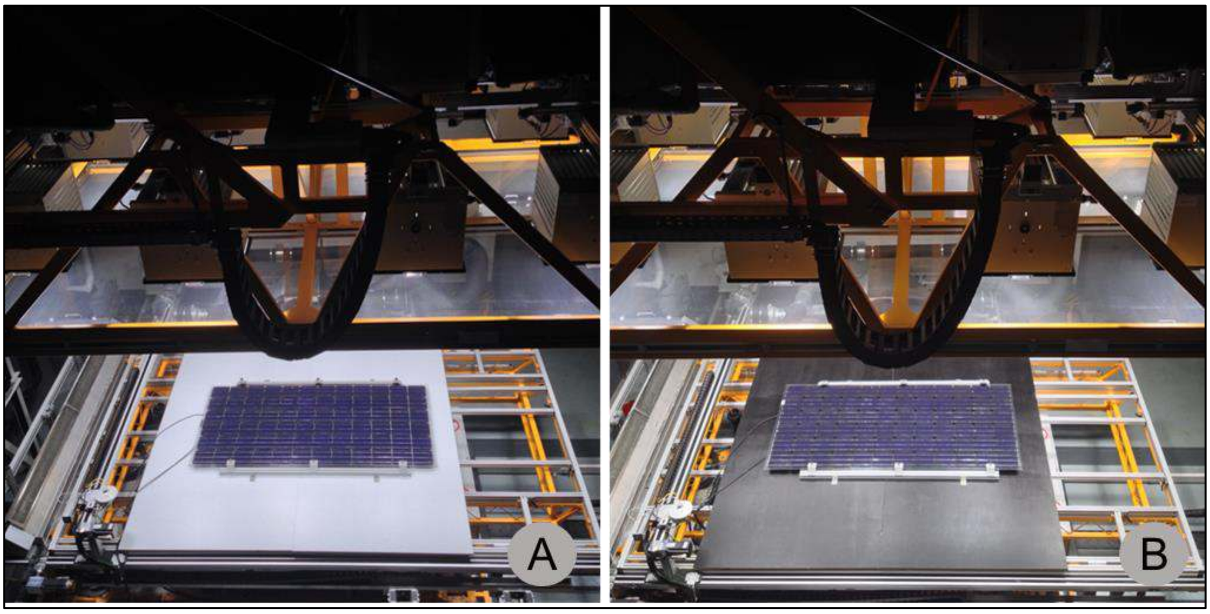
The determination of such annual angular losses for each surface should be considered for the case of BIPV, as a tool to help in the decision-making when designing a building with BIPV.

2.3.3 Indirect irradiation

The proximity of different objects and building surfaces can cause indirect irradiation of the BIPV modules, increasing their electricity yield [4]. To be aware of the local irradiation of the PV modules, it would be necessary to monitor the plane-of-array irradiance.

This is particularly relevant for bifacial modules, where the plane-of-array irradiance for both surfaces should be known. Bifacial PV modules can significantly increase their performance when installed in applications such as awnings over surfaces having high albedo coefficients, such as white painted walls (albedo coefficients up to 0.9).

Indirect radiation will be incident on different cells or sections of curved elements at different angles of incidence. This can create inhomogeneous power generation from the different cells. The correct impact of partial or non-uniform reflection has to be evaluated under corresponding conditions.



Bifacial BIPV window testing at Concordia University's Solar Simulator and Environmental Chamber laboratory, under background solar reflectance of A) 66% and B) 6% (Source: K.Kapsis, 2019).

2.3.4 Application as a daylighting element

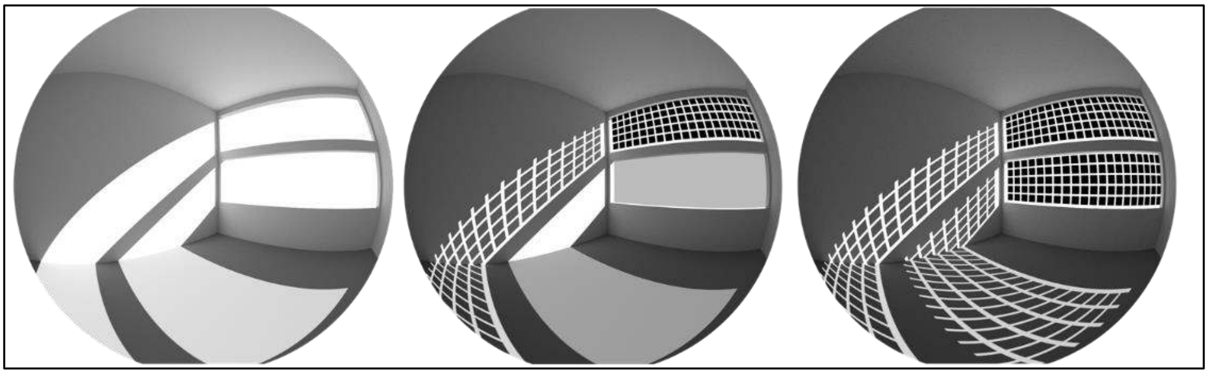
Semi-transparent PV modules integrated into building envelopes allow electricity generation to be combined with solar control and daylighting properties. The procedures included in the current standards for determining the luminous characteristics of glazing in buildings, such as ISO 9050 and EN 410, can also be applied to semi-transparent PV modules for building integration. The parameters obtained, such as light transmittance, combined with the colour rendering index describe the daylighting properties of the semi-transparent BIPV modules.

Sections 3.4.1 to 3.4.5 discuss test modifications with regard to optical and colour rendering properties.

2.3.5 Potential source of indoor glare

BIPV modules, consisting of photovoltaic cells surrounded by areas of transparent encapsulant, result in alternation between transmitted light and shadows cast by the opaque PV cells. By altering the spacing between opaque PV cells, simple (e.g., equally spaced cells) to complex patterns (e.g. PV cells acting as pixels of an image drawn on the building façade) can be generated by the distribution of darker and brighter areas on the building façade. However, this alternation between bright and dark spots within the visual field of the occupants creates the potential for discomfort glare to occur.

Section 3.4.6 discusses the assessment of discomfort glare due to daylight in buildings with a non-uniform source luminance such as a BIPV window and the associated challenges with such a procedure.



Daylight rendering studies to assess indoor glare for various BIPV window technologies (Source: K.Kapsis, 2019).

2.3.6 Potential source of outdoor glare

Sunlight that is reflected from the front glass cover of a BIPV module can cause veiling glare in the same way as reflected sunlight from any other reflective surface. High reflectance is not an intrinsic property of BIPV (or any other PV) modules; on the contrary, it reduces the amount of solar radiation that can be converted into electricity. As a result, the outer surface of glass covers for (BI)PV modules are often treated with an anti-reflective coating or texture, so that they often reflect less sunlight than conventional glazing. Despite this fact, in many legal systems, glare from (BI)PV modules is evaluated differently to that caused by e.g. windows or greenhouses. Glare from BIPV modules may affect more people than from "conventional" PV modules, because the probability of a person being in a position to perceive and be disturbed by the reflected light is usually higher in the built environment than around ground-mounted PV modules that are usually installed in rural areas. In addition, in areas where glare should be reduced as much as possible, for instance at or near airports, PV module glare should be characterized. There is a need to develop appropriate methods for this characterization [10].

2.3.7 Different temperatures compared to PV mounted on open racks

Higher average temperature is expected in several BIPV cases; this parameter is really important in an insulating glazing unit, which is intended to provide good thermal insulation of the building. Cells are placed in the gap between panes, where the lack of back-surface ventilation often results in high temperatures that can have a large impact on cell voltage. Other non-vented, back-insulated installation conditions, including photovoltaic-thermal modules under stagnation conditions, will also result in a different temperature than for free-standing PV, see [12].

In some cases, a lower average temperature can be reached by promoting high thermal exchange (conductive, convective and radiative effects). In photovoltaic-thermal applications, electricity generation benefits from increased thermal dissipation (convective with air cooling, conductive with liquid cooling). Clear distinctions have to be made between natural and forced thermal dissipation that affects the thermal balance significantly.

Finally, the effect of module colour should be considered together with the mounting system design and the BIPV application category (from EN 50583), as they all modify the thermal radiation balance by changing the thermal absorption (α).

Approaches to take different temperatures into account are described in Sections 3.1.3.5 and 3.5.7.

2.3.8 Building-specific fire safety requirements

BIPV modules have to meet the requirements set out by local and national construction rules. In some countries, e.g. Germany, the so-called **"hard roofing test"** is demanded for roofs. These fire tests vary even within European countries.

However, when the building with a BIPV roof is far enough away from other buildings, this test may not be necessary (context-driven requirement).

Regarding façade installations, the required fire resistance class depends on:

- Building type and usage
- Building height
- Construction of the wall as a whole element (wood, concrete etc. might result in different requirements for the fire resistance class of the cladding)
- Application of 'sprinklers' in the building

Given these factors, the required fire resistance class of the BIPV element can range between 'no requirements' and the legally binding requirement of 'non-combustible', which most BIPV products cannot fulfil due to the lamination material incorporated.

Fundamental requirements related to fire safety are not internationally harmonized and if national regulations are not established, the range of tests in IEC 61730-2 for conventional PV modules can be applied as an initial set of minimum tests for BIPV. Annex B of IEC 61730-2, namely "Fire-test, spread-of-flame and burning tests for PV modules", refers to the well-established tests e.g. ENV 1187:2002, Parts 1 to 4 (now superseded by CEN/TS 1187:2012), and UL 1703:2015 (used in USA for the past decades). The UL 1703 in turn, refers to UL 790 in the case of building-integrated PV.

Further improvements need to be achieved by combining the requirements of BIPV as an electrical device (under IEC standards) and building material (under ISO, BS, EN standards). Combined fire safety tests need to comply with the building codes existing in each country. Additional preventive measures may be included, such as fire-break requirements (laterally and vertically), active fire-fighting systems and extinguishment solutions. It can be well justified to impose more strict requirements for automatic fault detection- and handling in systems where connectors and junction boxes cannot be easily accessed for routine inspection and maintenance.

In order to speed up the urgently needed practical implementation of new standards and requirements, the development of practical guidelines should go hand in hand with the former.

2.3.9 Building-application-specific mechanical requirements

BIPV modules must be characterised by the property of "post-breakage integrity". This is the property that a broken BIPV element must remain safe (e.g. not fall apart or slip out of its frame) under a load for a predefined period of time. This is to ensure both that persons cannot be injured by a broken BIPV element falling down onto them and that a BIPV module that is used for a barrier function, e.g. as a balcony balustrade, continues to prevent a person from falling through it for a predefined period of time even after breakage.

Requirements relating to mechanical resistance and stability vary extensively depending on the application, whether as a roofing or façade element or a solar shading device, and also on the building typology (e.g. private or public). Compared to ground-mounted PV modules, some aspects of the built environment affecting mechanical requirements include higher mounting positions and thus greater wind loads, and the greater safety margin needed when building occupants are nearby, e.g. underneath glass-glass modules applied as overhead glazing.

2.3.10 Long expected lifetime as a building product

The expectation of durability for BIPV modules may be greater than for conventional modules, because replacement of a failed BIPV module is often mechanically more difficult than is the case for conventional free-standing PV modules. Therefore longer usage times of BIPV than for conventional modules should be taken into account for the test methods and the benchmark criteria for both functions, as an electricity generator and as a building component.

3 TYPES OF TESTING AND PROPOSED TEST MODIFICATIONS TO ACCOUNT FOR BIPV FEATURES

The Table below provides an overview of types of testing for BIPV modules and systems, classified according to tested properties, and brief proposals for modifications which could be made to account for specific BIPV features. In the remainder of this Chapter, more detailed proposals are elaborated, where relevant methods were known to the authors of this report.

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
1. Electrical	Module defect identification	Module	Inhomogeneous surface coverage	Electroluminescence testing - Mask back surface with opaque material
1. Electrical	Module defect identification	Module	Inhomogeneous surface coverage	IR imaging (problems with IR-transmissive materials like thin polymers)
1. Electrical	PID	Module	Module decoration	PID test, See Section 3.1.2.1
1. Electrical	Rated module power output	Module	Bifacial modules	Refer to IEC standardisation work on bifacial modules: Define BIPV-relevant illumination conditions for I-V measurement.
1. Electrical	Rated module power output	Module	Curved modules	Test under natural sunlight to achieve a realistic variation of incidence angles
1. Electrical	Rated module power output	Module	Large module dimensions	Test “representative-size” modules and apply extrapolation procedures; Outdoor testing; measure IV curves of individual strings within module separately
1. Electrical	Rated module power output	Module	Modules of many different dimensions	Testing “representative-size” modules and interpolation procedures
1. Electrical	Rated module power output	Module	Frequent partial shading (by close and distant objects)	Adapt IEC hot-spot test to BIPV-relevant boundary conditions
1. Electrical	Rated module power output	Module	Module decoration causing mismatch within module	Area-weighting; Optical modelling; I-V measurement
1. Electrical	Annual electricity yield	System	Treatment of front glass surface, e.g. structured, anti-reflective, anti-glare	Simulation, taking correct angular dependence of electrical data into account

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
1. Electrical	Annual electricity yield	System	Frequent shading	Simulation; take discussions of IEC Energy Rating approach into account;
1. Electrical	Annual electricity yield	System	Higher temperatures than for free-standing PV (e.g. due to installation in architectural glazing)	Simulation, including appropriate thermal modelling; Determination of Nominal Module Operating Temperature for each BIPV application, using relevant boundary conditions, and apply it in testing procedures.
1. Electrical	Electrical safety	Module	Large module dimensions	Add tests of reverse-bias cell characteristics and include results in PV cell data sheets
2. Mechanical stability	Encapsulant adherence	Module	Higher temperatures than for free-standing PV (e.g. due to installation in architectural glazing)	Test as laminated (safety) glass at higher temperatures
2. Mechanical stability	Deformation under load	Module	Mounting conditions and different dimensions affect deformation under load	Determine dependence of deformation on dimensions and mounting conditions; declare result
2. Mechanical stability	Post-breakage integrity	Module	Presence of junction box	Add further specifications to soft-body and hard-body test procedures from glazing to account for weakness introduced by junction box
2. Mechanical stability	Resistance to thermal stress	Module	Frequent partial shading (due to close and distant objects)	Glazing tests of mechanical resistance against temperature differences and sudden temperature change
2. Mechanical stability	Resistance to thermal stress	Module	Inhomogeneous surface coverage with materials of different solar absorptance	Glazing tests of mechanical resistance against temperature gradients
2. Mechanical stability	Resistance to vibrations	Module	Large module dimensions. Prefabricated roof or façade elements with PV-modules being transported from factory to building site without being packed like conventional PV modules	Apply IEC standards specifying vibration tests for transport of construction products; electroluminescence and IV-curve measurement for diagnosis

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
3. Fire safety	Different aspects of fire safety	System	(Often poorly accessible) electrical components installed within building envelope Items identified in [39]	For BIPV roofs: Make IEC 61730/UL 61730 mandatory For BIPV facades: Address BIPV components explicitly when developing fire safety standards for façade materials
4. Optical (usually spectrally dependent) / thermal	Transmittance / reflectance	Module	Inhomogeneous surface coverage, including cells, interconnectors, back sheet, module decoration	Area-weighting
4. Optical (usually spectrally dependent) / thermal	Transmittance / reflectance	Module	Treatment of front glass surface, e.g. structured, anti-reflective, anti-glare	Determine angular performance experimentally
4. Optical (usually spectrally dependent) / thermal	Specification of BIPV module colour: CIE L*a*b*	Module	Application as a daylighting element	Measure transmittance spectra and reflectance spectra and calculate colour coordinates Conduct research to determine approach for inhomogeneously covered areas
4. Optical (usually spectrally dependent) / thermal	Colour rendering	Module	Application as a daylighting element	Measure transmittance spectra and calculate colour rendering coefficients Conduct research to determine approach for inhomogeneously covered areas
4. Optical (usually spectrally dependent) / thermal	EML equivalent melanopic lux	Module	Application as a daylighting element	Measure transmittance spectra and calculate EML
4. Optical (usually spectrally dependent) / thermal	Daylighting properties	System	Application as a daylighting element	Daylight autonomy
4. Optical (usually spectrally dependent) / thermal	Glare toward interior	System	Source of internal glare	Apply DGP methodology (daylight glare probability)

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
4. Optical (usually spectrally dependent) / thermal	Glare toward exterior	System	Source of external glare	Measure BRDF (bidirectional reflectance distribution function) and calculate glare effect
4. Optical (usually spectrally dependent) / thermal	Thermal transmission (U value)	Module and system	Presence of junction box	Remove junction box for experimental testing and take account of its effect theoretically
4. Optical (usually spectrally dependent) / thermal	Solar heat gain coefficient (g value)	Module	Inhomogeneous surface coverage, including cells, interconnectors, back sheet and module decoration	g-value measurement with large-area illumination under MPP and short-circuit or open-circuit conditions
4. Optical (usually spectrally dependent) / thermal	Solar heat gain coefficient (g value)	Module	Treatment of front glass surface, e.g. structured, anti-reflective, anti-glare	Determine angular performance experimentally
4. Optical (usually spectrally dependent) / thermal	Solar heat gain coefficient (g value)	Module	Power generated by cell	Determination (by experiment or calculation) under MPP and I_{sc} or V_{oc} conditions. Add ISO 19467 to IEC 63092
5. Durability and reliability	Cyclic me-chanical load	Module	Large module dimensions	Should be approached as in standards for construction products
5. Durability and reliability	Degradation in building product properties	Module	Long expected lifetime in buildings	Accelerated aging tests in climatic chambers
5. Durability and reliability	Degradation in electrical properties	Module	Long expected lifetime in buildings	IEC 61215, with adapted boundary conditions, e.g. higher temperatures, more cycles, longer testing times
5. Durability and reliability	Electrical degradation due to cyclic mechanical load	Module	Large module dimensions	Adapt procedure to test modules with large dimensions
5. Durability and reliability	Mechanical degradation due to thermal cycling	Module	Higher temperatures than for free-standing PV	Conduct research to determine whether the temperature range for thermal cycling must be extended or whether increasing the number of cycles is sufficient

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
5. Durability and reliability	Thermal cycling	Module	Frequent shading	Increase number of cycles compared to standard IEC tests
5. Durability and reliability	Thermal stress	Module	Frequent partial shading (by close and distant objects)	Adapted IEC hot-spot test to new boundary conditions
5. Durability and reliability	Thermal stress	Module	Frequent partial shading (by close and distant objects)	Make IEC 62979 (bypass diode thermal runaway) mandatory if frequent shading may occur

3.1 Electrical

3.1.1 Module defect identification

See Table above

3.1.2 Potential-induced Degradation (PID)

PID is a failure mode that occurs both in glass-backsheet PV module packages with EVA encapsulation systems and glass-glass designs. In fact, PID has also been observed in the encapsulation systems for other crystalline cells and thin films as well [19], [20].

Degradation effects in PV systems due to ion migration caused by leakage currents in modules have been known for a long time [14], both in crystalline and thin-film based modules. Whether a string of PV modules suffers from Potential-Induced Degradation (PID) effects in an application or not strongly depends on the bill of materials, the electrical system configuration and micro-climatic effects. Within the IEA PVPS Task 13 “Performance and Reliability of PV Systems” the review reports IEA-PVPS T13-01:2014 [15] and IEA-PVPS T13-09:2017 [16] include a brief overview of these degradation effects. For a detailed review see [18].

3.1.2.1 Surface decoration

Coloured intermediate layers in front of the cells, and glass coatings used in BIPV, may significantly change the electrical resistivity of the insulation system, and therefore PID susceptibility.

Potential-induced degradation effects, such as reduced parallel resistance, polarization effects, cell degradation, delamination, TCO corrosion and “bar-graphing” may lead to severe power loss, aesthetic issues, and electrical and mechanical safety problems. Up to now, PID tests are not mandatory in PV certification. In addition the test conditions of existing tests focus on “conventional” module design and field applications. If frequent condensation occurs, or more generally, if modules are used in a very wet environment, the ‘foil test’, described as one of two optional PID tests in IEC TS 62804-1:2015 (Ed. 1), may reflect the usage conditions better than the ‘chamber test’ that will be referenced in the future IEC 61215-2 Ed.2. Therefore, both test variants should be kept for BIPV products.

3.1.3 Rated module power output

See Table above and elaboration below

The rated PV module power output under Standard Test Conditions (STC) is obtained under a combination of temperature and solar irradiance conditions that was defined in IEC standards for the purpose of testing PV devices under reproducible and practicable conditions.. These conditions are seldom experienced either in conventional PV systems or in BIPV systems, so there is no need to modify STC for BIPV modules.

However, a realistic evaluation of BIPV module output power should consider all the BIPV electrical features described in the Table above. Assessment of photovoltaic conversion could be validated by using IEC 60904-1:2006, which specifies procedures for measurement of photovoltaic current-voltage characteristics.

The nature of thermal exchange can drastically affect the thermal balance of BIPV components, so specific values of NOCT (nominal operating cell temperature, measured under open circuit) are to be evaluated according to each building-integration mode in order to modify thermal models and their effect on electricity generation. NMOT (nominal module operating temperature, measured at MPP) or an equivalent model should be adapted for its application to BIPV. It is recommended to add a note to the relevant standards explicitly mentioning the need to choose relevant testing conditions for BIPV systems.

In IEC 60891, procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices are specified. When the relevant temperatures experienced by BIPV modules are to be determined for these corrections, account must be taken of the generally higher levels of thermal insulation compared to conventional PV.

When applying IEC 60904-5 to determine the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method, again it must be ensured that the thermal conditions during testing are applicable for BIPV modules.

The calculation of the angle of incidence modifier AOI is addressed in the IEC 61853-2, currently under revision, and is applicable to BIPV modules. There is no need to modify the current standard.

The second edition of IEC 61215-2, currently in preparation, adds test conditions considering bifacial PV modules and applications based on the nameplate values stated by the manufacturer according to IEC 61215-1. The recent IEC TS 60904-1-2:2019 describes the procedures to determine I-V curves and power generation by means and measurement of bifaciality coefficients of a PV module. Care must be taken to use an appropriate maximum irradiance value for the back surface, taking underlying surfaces with high albedo into account, when the necessary additional nameplate irradiance value is determined.

3.1.3.1 Large module dimensions

If modules are too large to test them as a whole in a solar simulator,

(i) the measurement of the I-V characteristics may be split up into several sequential measurements in some cases, if inner electric connections (e.g. at the points of bypass diodes) are accessible, or

(ii) a measurement of the I-V of a "representative sample"[1] with smaller dimensions may be executed, or

(iii) such a large module may be measured outdoors.

In all cases, appropriate measures are needed to transform I-V characteristics, which may be determined either from indoor measurements of parts or representative samples or from a series of outdoor measurements, to a single I-V characteristic of the whole (large) module.

The calculation of the combined current-voltage characteristic and total power of series and/or parallel connected sub-section is simple, if all parts have identical characteristics, but can be rather complicated if different current-voltage characteristics have to be considered. This is often the case for curved elements (see Section 2.2.5), and if inhomogeneous surface decoration is applied (see Section 2.1.1.1).

[1] The planned new edition of the IEC 61215 series (new Ed.2) and Amendments to the IEC 61730 Ed.2 series (new AMD1 Ed.2), will introduce the term "representative sample", defined as "a sample that includes all the components of the module, except some repeated parts. The representative samples shall use all key materials and subassemblies."

Therefore it is necessary to develop tests and procedures to derive I-V characteristics (and other properties as well, see 3.1.3.2) based on measurements and certified models in such cases. Also measurement under (varying and instable) outdoor conditions benefits from modelling approaches[2].

3.1.3.2 Many different module dimensions

In BIPV applications, not only (very) large module dimensions may be used but also a wide variety of different module dimensions (even within the same façade/roof system). The challenge is to specify a set of representative test samples and well-defined procedures to interpolate and extrapolate the properties to another set of real-world devices in a concise manner. This needs standardized and certified modelling of these properties including uncertainty margins and safety factors. For many properties required for building materials' "declaration of performance" such rules are well established, while this is a new approach in electrical standardization processes of PV components.

What is urgently needed for easier implementation of PV into the building's skin is an approach corresponding to comprehensive and exhaustive data sheets, that are derived from measurements and modelling and allow the calculation of the electrical output at given environmental and boundary conditions, mechanical properties depending on mounting conditions, as well as thermal interaction with the building, etc.. These would make it possible, for an intended application, to check whether mechanical and other properties are sufficient to meet the requirements from the building perspective (including those arising from local building codes).

This approach is well aligned with ongoing plans of the IEC management board on standardization and digitalization: It is planned for the near future to move toward issuing standards as XML documents that are machine-readable. Test reports and certification documents therefore could be "compiled" into input for building information modelling (BIM).

3.1.3.3 Frequent (partial) shading

Partial shading, both by nearby objects and more distant objects in the surroundings, may also have a significant impact on BIPV module/system performance, and lifetime. Four different cases are to be considered:

(i) partly shaded (single) cells result in a high series resistance of the shaded parts, quenching the string current through the unshaded cell area. If the voltage rise caused by this current distribution is high enough, the bypass diodes operate. These effects are considered in the design qualification and safety standards, but in BIPV applications such conditions may occur regularly in some arrangements, while they are seldom in other applications. Cell technologies are being developed to achieve higher efficiency and therefore also the fill factor (the ratio of power at maximum power point to the product of short circuit current and open circuit voltage) is rising. This makes highly efficient modules more prone to mismatch effects than previous ones. Sources of mismatch are partial shading, and inhomogeneous surface decoration. Therefore additional tests may be required for such BIPV elements to guarantee proper performance and reliability. This would involve identifying a worst-case scenario or cases and test procedures to check which performance problems, and safety issues may arise.

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[2] For PCE's (Power Conversion Equipment, such as inverters) the manufacturer has to provide models on how this equipment interacts with the grid, for supporting grid simulation. The verification of these models is also part of the tests for product certification. To provide proper models is also a prerequisite for electronic components used on printed circuit boards, because it is necessary to first simulate the electronic circuits before they are manufactured.

(ii) In some monolithic thin-film modules, partial shade conditions may cause reverse breakdown and immediate cell damage. Because such sudden power degradation effects are not covered by the existing standard test conditions, within the IEC TC 82 module working group a draft standard is under preparation: IEC TS 63140 ED1 Photovoltaic (PV) modules – Partial shade endurance testing. If sufficient guidance is given in the module documentation, no tests have to be performed, but if that is not the case, two different shading tests using shading masks should be applied, to check whether permanent power loss may occur.

(iii) It was observed that some bypass-diodes with low breakdown voltage may be affected by a thermal runaway effect: When the diode is operating as intended, because of shaded module parts and under high temperature, and the shadowing object suddenly disappears, the diode has to go to normal reverse bias conditions. However, at high diode junction temperature the residual reverse bias current may be high enough to further heat the diode, resulting in a thermal runaway. A test procedure, the IEC 62979:2017 Photovoltaic modules – Bypass diode –Thermal runaway test, has been published. This is not a mandatory test for PV modules, but it could make sense to implement this test for modules used in the built environment, because the bypass diodes may be stressed significantly more than in other applications, are often inaccessible after installation, and diode failures may cause an additional fire risk.

3.1.3.4 Module-internal mismatch due to surface decoration

See Table above, Section 3.1.3.3 (i) and (ii) and elaboration below.

In order to characterise the effect of surface decoration, causing different solar transmittance in front of different cells, on the PV module's electrical performance, an equivalent PV module, with identical PV cells and design, but with no decoration patterns, should be supplied by the manufacturer together with the decorated module. Existing partial shading testing procedures included in the standards for general PV modules (IEC 61215) can be applied, but in this case the "shaded condition" would be the decorated module and the "unshaded condition" the module without decoration.

3.1.3.5 Higher temperature

Within the IEC TC 82, a draft technical specification giving guidance on testing PV components at higher operating temperatures, IEC TS 63126, is under consideration. If, for given ambient conditions and application, a 98th-percentile temperature, which is only exceeded in 175.2 h per year, is above 70°C, test modifications in the IEC 61215 and IEC 61730 series, as well as in relevant component standards such as the IEC 62788 series for polymeric packaging materials, IEC 62790 for the junction boxes, and IEC 62852 for connectors, will be suggested. Test modifications will be defined for two additional temperature regimes, Level 1 for [70 - 80]°C and Level 2 for [80 - 90]°C, respectively.

3.1.4 Annual electricity yield

See Table above and elaboration below

Normally the annual electricity yield of a PV module can be determined according to IEC 61853-1, -2, -3 and -4. According to IEC 61853-1, the power generation performance in a real environment can be calculated if the power generation performance at low temperature, high temperature and low illuminance is known.

However, in BIPV, the temperature conditions and thus the electricity yield of the PV module also depend on the indoor environment of the building where it is installed, so indoor conditions should be taken into account when the annual yields of BIPV systems are calculated at a generic level, e.g. by adapting the existing NMOT (nominal module operating temperature) as described in IEC 61853 or by applying an improved temperature model adapted to BIPV. In the first case, a suitable set of ”typical“ conditions that are more applicable to BIPV could be proposed.

Furthermore, depending on the type and geometric configuration of the glass covering the module surface, the relationship between the incident angle and the amount of power generation in the PV module varies greatly. In IEC 61853-2, the short circuit current (I_{sc}) when artificial sunlight is vertically incident on the module is used as a reference. Then, the power generation performance at each angle can be calculated as the “relative transmittance” by examining the relative change of the short circuit current when the module is inclined with respect to the incident optical axis. At present, the incidence angle modifier (IAM) is obtained using this relative transmittance. However, in the case of BIPV, especially for vertical façade installations, a calculation method that takes into consideration the influence of the surrounding environment of the location and the indoor environment will be required.

In IEC 61853-3, the “generation capacity rating” can be calculated from the results of measurements based on the two standards IEC 61853-1 and -2, using the standard reference climate profiles given in IEC 61853-4.

In order to assess energy-related BIPV system characteristics, IEC 61724 can be applied. The standard recommends the procedures for parameters such as in-plane irradiance, monthly or annual PV yield, losses, efficiencies and system performance indices. This standard should be reviewed to ensure that all conditions relevant to BIPV systems are taken into account, and if not, they should be added.

Outdoor BIPV annual electricity yield testing at Natural Resources Canada’s CanmetENERGY research centre in Varennes (Source: Natural Resources Canada, 2019).

Currently a preparatory study on European Ecodesign / Energy Labelling for PV Systems is ongoing, where a realistic energy rating (on a system level) for different climates and applications is a necessary prerequisite. The recommendations of this study should also be taken into account, when modifications relevant to calculating the annual electricity yield from BIPV systems are proposed. For more details, see http://susproc.jrc.ec.europa.eu/solar_photovoltaics/index.html

The proposals above are intended primarily as generic procedures that are applicable to different types of BIPV modules and systems. When the annual electricity yield of a specific BIPV system is to be predicted and/or optimized, a much more detailed approach, that also takes the effect of the building surroundings explicitly into account, is recommended [11].

3.1.5 Electrical safety

3.1.5.1 Large module dimensions

Beside performance, safety-related restrictions, such as the maximum number of series-connected cells within a sub-string protected by a parallel bypass-diode, must be considered [4], [6]. As the maximum number of cells per substring depends on the reverse bias operating conditions of cells, variations between cell technologies and within production lots of the same cell type must be taken into account.

Typical conventional modules have 60 or 72 cells in 3 substrings, i.e. 20 or 24 cells covered by one bypass diode. In building applications the maximum number of cells per substring may limit the total dimension of photovoltaic elements. The currently valid hot-spot test procedures in IEC 61215-2 will change slightly in the new Edition 2, because of corrections of some errors and ambiguous wording from the previous edition of 2016. Nevertheless, there is still – as stated in [4] more than twenty years ago, a lack of information on reverse cell characteristics and statistics that shall be provided by the manufacturers. This could be overcome by trying to start a NP (New Work Item Proposal) within IEC TC82 WG8 (crystalline) cells for in-line cell testing during production or simply by specifying relevant information to be included in PV cell data sheets.

3.2 Mechanical

3.2.1 Encapsulant adherence

See Table above

3.2.2 Deformation under load

See Table above and elaboration below

In module testing only a pass/fail on specified mechanical load is included. Properties like deformation of modules under a given mechanical load, depending on size and mounting conditions, are needed as an input to check whether local requirements are met.

3.2.3 Post-breakage integrity

See Table above

3.2.4 Resistance to thermal stress

See Table above

3.2.5 Resistance to vibrations

See Table above regarding mechanical stability and elaborations below.

It may not be possible to pack large modules or prefabricated roof or façade elements with integrated PV modules for transport from the factory to the building as carefully as is normally done today for conventional PV modules. This will mean additional stress due to vibrations and mechanical shocks, which will challenge the mechanical integrity of cells and modules. According to [17], the quasi-static application of very high distributed pressures as required by qualification standards is not sufficient if we are interested in evaluating the actual degradation rate and possibly inferring the lifetime of produced PV modules. In fact, other unexpected forms of damage, like fatigue degradation are indeed possible due to the composite structure of the module and can be induced by very common sub-critical loads like vibrations due to transportation or wind gusts, phenomena that have not yet been characterized.

Until more appropriate methods to assess this are developed, products' ability to withstand this stress can be evaluated by applying the current IEC standard, IEC 60721-3-2:2018, which specifies vibration tests for transport of construction products. Electroluminescence and I-V characteristic measurements are used for diagnosis.

3.3 Fire safety

See Table above and elaboration below

Laukamp et al [39] in 2013 presented a summary of some 180 incidents of fire or heat damage caused by PV systems. Installation errors and faulty components, mainly inverters and junction boxes, were the main causes of fire. The report concludes that the risk for a fire incident is 20 times higher in a BIPV system than for BAPV. Since then, these alarming results have neither been verified nor questioned by later studies, which indicates an urgent need for further research. For reasons that have been explained in Sections 2.2.6, 2.3.1 and 2.3.7, BIPV does unquestionably exhibit some features that increase the risk of fire. In view of the events and the studies carried out so far, the fire risk for photovoltaic systems is evidently non-negligible and must be addressed to prevent injury to people and economic losses. A study conducted in 2017 [34] shows three main domains that can be further developed and investigated:

(i) Testing methods and procedures

(ii) Monitoring during operating conditions

(iii) Clear regulatory framework

A Norwegian review of standards and requirements [40] points out that the Swedish and Norwegian building codes have no other requirements currently applicable to roof-applied or roof-integrated PV than those defined in the EN 13501-5 and CEN/TS 1187:2012, method 2. The report concludes that this is far from sufficient and that the UL 1703 with its referenced UL 790 is the most appropriate currently existing test method for roof-integrated or roof-applied PV. The reason is that this standard provides methods to test the combination of roof covering materials, mounting systems and PV modules. The UL was recently harmonized to the IEC 61730 and has been replaced by UL 61730, which complies with the national US electrical code. It thus appears that the UL 61730 should be the basis for further development of methods, standards, requirements and guidelines aimed to assess the fire properties and prevent the corresponding fire risks of PV, either applied to or integrated into roofs.

For facades, the Norwegian report suggests that solar cells should be treated like other external façade materials with a view to external fire stress and the risk of fire spreading in cavities behind the outer façade. For most cases, a façade of solar cells will in principle be similar to another ventilated facade. An additional factor for solar cells is that there are many electrical connections, and thus potential ignition sources, inside the cavity behind the PV modules. The challenge here lies in the fact that the regulations for fire spreading in façades are under development, and that it is therefore not clear which requirements are to be placed on solar modules mounted vertically as the outer skin of a façade.

The treatment of fire resistance performance in BIPV varies, depending on the region and country. Past studies of BIPV fire safety are cited for reference [32], [33]. In these studies, it was shown that the glass unit and BIPV module have the same performance when exposed to fire. An experiment was carried out using a heating furnace in accordance with a JIS standard and the heating curve of ISO 834. Also, experiments were conducted with the PV modules connected to a load device in order to evaluate the performance in use. It was clarified by the experimental result in accordance with the JIS standard and heating curve of ISO 834 that the tested BIPV module has the same flame insulation property as conventional fire protection glass. However, there are many other configurations of BIPV modules for which this is NOT the case.

It is recognised that there is a need for modification of standards concerning many aspects of fire safety but detailed proposals for modification exceed the scope of this report. Once it is published, further guidance may be given by IEC TR 63226, a technical report currently under development that discusses fire prevention measures during the design, installation, commissioning and maintenance of PV systems (including BIPV) on buildings.

3.4 Optical / thermal

3.4.1 Transmittance / reflectance

See Table above and elaboration in following paragraph.

The optical characterization of BIPV modules can be based on the international standard ISO 9050, which is equivalent (but not identical) to the EN 410 standard that is referenced in EN 50583. These standards specify the methodology for determining the luminous and solar characteristics of glazing in buildings. For partly transparent BIPV products that utilize flat glass or laminates, the overall optical properties can be determined by first measuring the optical properties of the part without cells in the laminate and then measuring the part that contains cells. An optical model can then be applied to calculate the weighted average value, following the guidelines of ISO 15099. When the weighted average value is declared, the section of the BIPV module to which it applies should be clearly stated. In the case of monolithic thin-film semi-transparent BIPV modules with a homogeneous appearance, an average representative area should be considered.

The dependence of the optical properties on the angle of incidence should also be taken into account, e.g. by specifying transmittance and reflectance at an incidence angle of 60°.

For translucent BIPV modules, current standards (e.g. ISO 9050) do not provide sufficient information on how to measure the optical properties of a product that includes a scattering layer such as glass, interlayer, laminate or photovoltaic thin film technology [35]. As the problem of characterising translucent products is also common among “conventional building products”, the relevant standards should be modified. These standards would then be applicable also to translucent BIPV products.

It must be remembered that if a BIPV module includes a coloured element such as ceramic frit on the glass cover or a coloured encapsulant material, the optical properties must be determined on the coloured BIPV module. It is incorrect to use the optical properties of the uncoloured PV module in this case.

3.4.2 Specification of BIPV module colour: CIE L*a*b*

See Table above and elaboration in paragraph below.

Scientifically based colour coordinates such as the CIE L*, a*, b* schemes [36], which allow the effect of the illuminant and the observer on perceived colour to be taken explicitly into account, should be used to specify colour and not only schemes such as RAL or NCS. In defining the test method, an appropriate geometrical configuration for the illumination (direct and/or diffuse) and the detection (direct and/or diffuse) should be specified. The choice of appropriate incidence and viewing angles should be relevant to viewing building envelopes, e.g. normal incidence (incidence angle = 0 °) is seldom the most relevant angle of incidence.

How to specify the colour of an optically inhomogeneous BIPV module is not immediately obvious, as area-weighting may not be applicable for this purpose.

3.4.3 Colour rendering

See Table above and elaboration in paragraph below.

The colour properties, in particular the colour rendering index of light-transmitting BIPV modules, can be based on the CIE procedure [37]. The colour rendering of objects in a room viewed through light-transmitting modules by an observer who is outdoors can be determined according to a procedure proposed in [38].

Again, which method should be applied to specify the colour rendering effect of an optically inhomogeneous BIPV module is not immediately obvious, as area-weighting may not be applicable for this purpose.

3.4.4 EML equivalent melanopic lux

See Table above and elaboration in paragraph below

The physiological effects of light on humans can be measured in Equivalent Melanopic Lux (EML), a proposed alternative metric that is weighted to the intrinsically photosensitive retinal ganglion cells (ipRGCs) of the eye (non-image- forming photoreceptors that regulate alertness, sleep, and circadian rhythms) instead of to the cone cells (colour vision photoreceptors), which is the case with traditional lux.

The use of thin-film and/or coloured BIPV window or skylight can affect the spectrum of the transmitted sunlight and thus, the EML that occupants receive. The measurement of transmittance spectra based on ISO 9050 and the calculation of EML is proposed.

3.4.5 Daylighting properties

For crystalline semi-transparent PV modules made of opaque cells, only the area between cells must be characterized, while in monolithic thin-film semi-transparent PV modules having a homogeneous appearance, an average representative area should be considered. Weighting between opaque and transparent or translucent areas should be performed to obtain the final daylighting behaviour of the BIPV element.

The angle-dependent light transmittance of a partially transparent or translucent BIPV module is needed to determine its daylighting properties in a building. Depending on the level of detail expected for the daylighting performance, the angle-dependent light transmittance or a BSDF (bidirectional scattering distribution function, which includes both the reflectance distribution BRDF and transmittance distribution BTDF) may be needed for each of the optically differing parts, together with their spatial distribution over the BIPV module surface.

The back-surface spectral reflectance of the element also affects indoor illumination. In the case of PV laminates, this reflectance could be significant due to the metallic back contacts of the PV cells. To properly evaluate this aspect, the back-surface light reflectance, defined as the fraction of the incident light from an indoor reference illuminant that is reflected and viewed by a standard photopic observer, has been proposed [23].

3.4.6 Glare toward interior

Sunlight which is transmitted directly through transparent parts of a BIPV component or which is reflected e.g. by edges of a cell or decorative structure can cause discomfort glare to occupants in the building interior. The angle-dependent light transmittance or a bidirectional scattering distribution function (BSDF) may be needed for the BIPV component to assess this glare, applying existing methods such as Daylight Glare Probability (DGP) [24]. A practicable method for assessing the annual glare risk from fenestration systems by building simulation is presented in [25]. No specific modifications of these methods are required for BIPV elements, but manufacturers and planners should be aware of the glare issue and apply existing test methods.

In the case of PV laminates, the back-surface reflectance could be significant due to the metallic back contacts of the PV cells, such that glare due to reflected internal light sources may be an issue. To properly evaluate this aspect, the back-surface light reflectance, defined as the fraction of the incident light from an indoor reference illuminant that is reflected and viewed by a standard photopic observer, has been proposed [23].

3.4.7 Glare toward exterior

See Table above and elaboration in paragraph below

The methods used for conventional PV modules integrated in sound barriers should be applicable [26], [28]. A tool such as PHANIE may be useful for this purpose[13]. However, it should be noted that no widely accepted metric to quantify glare toward the exterior has been developed yet; this is still the subject of active research.

To allow assessment of the external glare risk due to PV modules for building integration, test and data sheet specifications are needed to allow the calculation and simulation of their reflectance under different solar incidence angles and light conditions / climates [10]. BIPV modules with decorative prints on the front glass cover or structured glass will have more complex reflection properties than a flat pane of glass, so may need to be characterised by a BSDF.

3.4.8 Thermal transmittance (U value)

See Table above and elaboration below

To determine the thermal transmittance (U value) of a BIPV product or system under standardised (dark) conditions for product comparison, the calculation method (ISO 10292), the guarded hot plate method (ISO 10291), or the heat flow meter method (ISO 10293) can be applied. If a projecting junction box prevents the application of existing equipment with planar surfaces, the junction box should be removed before testing. A theoretical method/correction term to take the effect of the junction box on the thermal transmittance could be added to the corresponding test methods. The solar cell arrangement in the laminate does not significantly affect the thermal transmittance of the BIPV product [27], [29], [30], [31]. Some studies quantifying the impact of solar cell arrangement on a BIPV module's U value have been published [8], [22], [27]. If extremely accurate data is needed, BIPV products with different solar cell spacing are treated as different models and the thermal transmittance can be obtained for each variant.

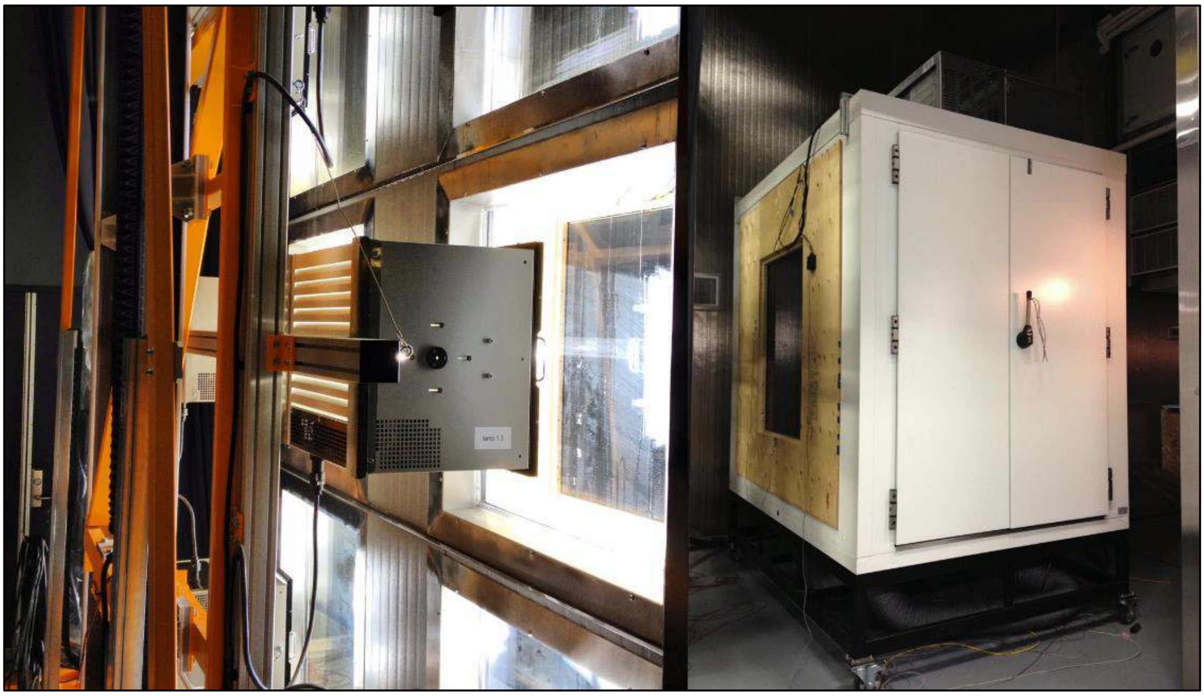
However, the thermal transmission through an installed BIPV module changes dynamically as the differential temperature between the front and rear surfaces of the BIPV product and incident solar radiation change throughout the day. When the U value of a BIPV is determined under irradiance conditions, it is also important that the extraction of energy as electricity is taken into account in the energy balance. In this case, the U value should be tested and reported both under open circuit and maximum power point conditions.

3.4.9 Solar heat gain coefficient (g value)

See Table above and elaboration in paragraph below

The solar heat gain coefficient (SHGC, also known as g value) of a BIPV product depends on the ratio of opaque to transparent areas, the thermal transmittance of the BIPV product and the operating point of the PV module. Significant variation in the g value occurs between the open circuit and maximum power point conditions, as some of the absorbed incident solar energy is removed completely from the glazing system as electricity under closed-circuit conditions [7], [8], [9]. Thus, it is important that the SHGC of a BIPV window product is tested and reported both under open circuit and maximum power point conditions, as recommended by ISO 19467. Any measurement or calculation that contains the density of heat flow rate through the BIPV product due to thermal transmission should account for the fact that part of the solar radiation that strikes its surface is converted into electricity. As a typical BIPV module will be optically inhomogeneous, it is important to specify which region of the module is characterised by the stated g value, e.g. corresponding to the centre of glazing or including also edge zones.

Currently, an IEC Project Team is conducting activities, including an inter-laboratory comparison, to propose measurement methods in the status of open circuit and closed circuit by the test method in accordance with ISO 19467 with reference to past research [29], [30], [31].



BIPV window Solar Heat Gain Coefficient (SHGC) characterization at Concordia University's Solar Simulator and Environmental Chamber laboratory (Source: K.Kapsis, 2019).

3.5 Durability and reliability

For the expectation of many users to operate BIPV throughout the lifetime of the building, all the functions, particularly electric ones, need to be tested considering a longer lifetime than for conventional PV.

In addition, the durability and reliability as both a building component and an electricity generator should be checked under the conditions unique to BIPV, such as large module dimensions, built environments, frequent partial shading etc.

Considering the different expectations on lifetime for a building component and a PV generator, it may be necessary to state two different guaranteed lifetimes, one for a specified building function and another for minimum power generation.

3.5.1 Cyclic mechanical load

See Table above

3.5.2 Degradation in building product properties

See Table above

3.5.3 Degradation in electrical properties

See Table above

3.5.4 Electrical degradation due to cyclic mechanical load

See Table above

3.5.5 Mechanical degradation due to thermal cycling

See Table above and elaboration below

In an annex of IEC 62892:2019, guidance is given to decide whether it is necessary to test for higher thermal cycling (TC) stress (standard test: 200 cycles TC-40/+85°C) or not, depending on the local micro-climate (1 year outdoor data, measured or simulated), and application and module type (or activation energy E_a for the process, materials, resp., determined in lengthy tests at different temperatures only).

The equivalence of tests over a different temperature span (T_{min}=-40°C, T_{max}>85°C) can be calculated, provided that the underlying aging processes remain unchanged at higher temperatures, by applying the Coffin-Manson model:

$$N_e = C(T_{MAX} + 40)^{-2} exp\left(\frac{1414}{T_{MAX} + 273}\right)$$

A case where this condition applies is documented in [41]. In the discussed example, the choice of maximum temperature as 85/100/115°C corresponds to a number of cycles of 200/136/96, respectively.

However, as it is not clear whether the aging processes that affect mechanical properties remain unchanged over the wider temperature range that can be experienced by installed BIPV modules, it is recommended that research be done to identify whether this criterion (no new ageing processes at higher temperatures) is indeed met. On the basis of this information, a decision can be made as to whether it is adequate simply to increase the number of testing cycles or whether the tested temperature range itself must be extended.

3.5.6 Thermal cycling

See Table above and elaboration below

Due to the greater number of thermal cycles that are often experienced in practice due to more frequent shading of BIPV systems than conventional PV systems, the number of thermal cycling should be increased for this reason.

3.5.7 Thermal stress

See Table above and elaboration below

In order to characterise the effect of surface decoration, causing different transmittance in front of different cells, on the PV module's temperature, an equivalent PV module, with identical PV cells and design, but with no decoration patterns, should be supplied by the manufacturer together with the decorated module. Existing partial shading testing procedures included in the standards for general PV modules (IEC 61215) can be applied, but in this case the "shaded condition" would be the decorated module and the "unshaded condition" the module without decoration.

In general, higher operating temperature of BIPV modules and its components may occur due to restricted cooling conditions. Therefore, check for module operating temperatures, taking application and climate into account.

If the 98th-% quantile temperature (175.2 h of 8760 h/a) is

- above 70°C, but not greater than 80°C → modify tests according to IEC TS 63126, Temperature Level 1,

- above 80°C but not greater than 90°C → Temperature Level 2 modification.

It was observed that some bypass diodes with low breakdown voltage may be affected by a thermal runaway effect: When the diode is operating as intended, due to shaded module parts and under high temperature, and the shading object suddenly disappears, the diode has to return to normal reverse-bias conditions. However, at a high diode junction temperature, the residual reverse bias current may be high enough to further heat the diode, resulting in a thermal runaway. As a high(er) temperature of the junction box and frequent shading may occur in BIPV applications, it is recommended to consider making the thermal runaway test of IEC 62979 mandatory for modules used in the built environment.

3.6 Testing of curved elements

When testing curved PV modules, it should be considered that once installed, they will receive diffuse irradiance from a wider solid angle than flat modules. Thus, it is convenient to test them under natural sunlight to better reproduce these conditions. Curved BIPV modules commonly have an extrinsic curvature and specular symmetry in one axis. The higher the curvature, the larger the solid angle seen by the surface, and the more the power output depends on string orientation and solar position under clear sky conditions.

A critical issue is therefore the position setting of the module with reference to the solar direction. A possible approach is to place the module in such a way that the normal to the surface in the central section is directed to the position of the sun, i.e., oriented such that the sun falls perpendicularly onto the surface at its midpoint. Also, the albedo should be specified.

Tests of mechanical, thermal and optical properties may also need to be modified where the existing test equipment is designed for test objects with planar geometry.

4 SUMMARY

The challenges of additional requirements resulting from the use of PV modules in the built environment have not yet been overcome. The most pressing challenge is to simplify and generalize the tests and requirements for BIPV products to allow easier and wider international market introduction.

After identifying features of BIPV modules that call for modifications of existing standards, proposals for modified or new tests and calculation procedures have been collected in this report.

The combination of tests used today in the PV world and in the construction world is one approach that can be followed to reduce the complexity and number of tests required for BIPV modules and systems. This and other approaches to multi-functional characterization of BIPV will be addressed internationally at the pre-normative level during the next phase of IEA-PVPS Task 15.

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7 ABBREVIATIONS AND ACRONYMS

AAMA	American Architectural Manufacturers Association
AOI	Angle of Incidence
BAPV	Building-Attached Photovoltaic
BIM	Building information modelling
BIPV	Building-Integrated Photovoltaic
BS	British Standards
BSDF	Bi-directional Scattering Distribution Function
BRDF	Bi-directional Reflectance Distribution Function
BTDF	Bi-directional Transmittance Distribution Function
CEN	European Committee for Standardization
CIE	International Commission on Illumination
CSA	Canadian Standards Association
DGP	Daylight Glare Probability
E_a	Activation energy
EC	European Commission
ECT	Equivalent Cell Temperature
EML	Equivalent Melanopic Lux
EN	European Standard
EVA	Ethylene vinyl acetate
IAM	Incidence Angle Modifier
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IGU	Insulating Glass Unit
ipRGC	intrinsically photosensitive Retinal Ganglion Cell
IR	Infrared
IS	International Standard
I_{sc}	Short-circuit current
ISO	International Organization for Standardization
I-V	Current-voltage
JIS	Japanese Industrial Standard
MPP	Maximum Power Point
NAFS	North American Fenestration Standard
NCS	Natural Colour System
NOCT	Nominal Operating Cell Temperature
NMOT	Nominal Module Operating Temperature
NP	New Work Item Proposal
PCE	Power Conversion Equipment
PID	Potential-Induced Degradation
pr	Project (of standard)
PV	Photovoltaic
PVPS	Photovoltaic Power Systems Program

RAL	Reichsausschuss für Lieferbedingungen
SHGC	Solar Heat Gain Coefficient
STC	Standard Test Conditions
TC	Technical Committee
TC	Thermal Cycling
TCO	Transparent Conductive Oxide
TR	Technical Report
TS	Technical Specification
UL	Underwriters Laboratories
V_{oc}	Open-circuit voltage
WDMA	Window & Door Manufacturers Association
WG	Working Group
XML	Extensible Markup Language

8 ANNEX - SURVEY RESPONSES ON EXPERIENCE WITH MULTIFUNCTIONAL BIPV EVALUATION

As part of Activity C3, "Multifunctional BIPV evaluation", in IEA-PVPS Task 15, participants were requested to fill out questionnaires on the basis of their experience in technically evaluating one or more BIPV installations (preferably from the selection which Subtask A has included in its book, but other installations were also possible). Two versions of the questionnaire were provided, one that was applicable internationally ("Multifunctional BIPV evaluation") and another intended for European countries ("Experience with EN 50583"). As EN 50583 was the first BIPV standard to be introduced, and was the only BIPV standard to exist at the time, it formed the basis for both surveys.

The authors of this report thank all those people who were involved in providing responses to the questionnaires. As a total of ten responses was received to the two questionnaires, statistical analysis is not appropriate. Instead, the following paragraphs summarize the answers received from various participants for future reference.

8.1 Multifunctional BIPV evaluation

Case	BIPV product	Material category as defined by EN 50583	Mounting category as defined by EN 50583	Further BIPV-relevant codes* or standards applied, not covered in EN 50583 * N.B. National building codes must always be taken into account – as for any other building component
Camrose building, Alberta, Canada	Standard off-the-shelf PV modules and racking clamps. The PV modules are Conergy PH 250M triple-black, mono-crystalline silicon solar cells.	Curtain wall (opaque)	Category C: Non-sloped (vertically) mounted not accessible from within the building	*National Building Code of Canada *National Energy Code of Canada for Buildings *Alberta Building Code
Retrofitting building, Wattignies, France	Glass-glass modules for ventilated façade	Glass	Category C	EN 356, Glass in Building-Security glazing-Testing and classification of resistance against manual attack. EN 13823, Reaction to fire tests for building products- Building products excluding floorings exposed to the thermal attack by a single burning item. EN 11925-2, Reaction to fire tests-Ignitability of products subjected to direct impingement of flame – Part 2: Single-flame source test.

Renewable energy building, Madrid, Spain	No special PV modules for BIPV, standard PV modules	none	Category C (ventilated façade).	*The Spanish Building Technical Code (Mechanical resistance and stability and resistance in case of fire). Royal Decree 1699 / 2011 (regulates the connection of PV installations of less than 100 kW to the grid). The Spanish Low Voltage Electrical Regulation.
DIA building, Yokohama, Japan	Laminated PV Glass with crystalline Si cell	Glass	Category D	JIS C8990 (equivalent to EN 61215, Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval (IEC 61215). JIS C8992-1 (equivalent to EN 61730 1, Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction (IEC 61730 1)). JIS C8990-2 (equivalent to EN 61730 2, Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing (IEC 61730 2)). *Japanese building codes.
Multi-purpose office building, Incheon, Republic of Korea	Standard off-the-shelf laminated PV modules with crystalline Si cell, produced by S-Energy company	Curtain wall (opaque)	Category C (non-sloped, mounted not accessible from within the building)	*Korean National Building Codes
Enwave Theatre, Toronto, Canada	Customized product (MGT Mayer Glastechnik): 155 W MGTherm Heat Mirror, integrating Sunways Solar Cells Mono 156 (AH50-F)	Insulating glass units (IGU)	Category B: Sloped, roof-integrated, accessible from within the building	CAN/CSA-A440.4-07 (R2007) - Window, Door, and Skylight Installation. AAMA/WDMA/CSA 101/I.S.2/A440-08 - NAFS - North American Fenestration Standard / Specification for Windows, Doors, and Skylights. A440S1-09 - Canadian Supplement to AAMA/WDMA/CSA 101/I.S.2/A440-08, NAFS - North American Fenestration Standard/Specification for

				windows, doors, and skylights. AAMA/WDMA/CSA 101/I.S.2/A440-11 (R2016) - NAFS - North American fenestration standard/Specification for windows, doors, and skylights. CAN/CSA-A440-00/A440.1-00 (R2005) - CAN/CSA-A440-00, Windows / Special Publication A440.1-00, User Selection Guide to CSA Standard CAN/CSA-A440-00, Windows. * Building Code of Canada. *National Energy Code of Canada for Buildings.

8.2 Experience with application of EN 50583

Representatives	Which BIPV product and project	How did you find out about the standard	Material category and Mounting category in EN 50583 investigated	Any specific shortcomings of EN 50583
Sweden	Roof; testing within the Glava Energy Center in Sweden Façade; Kiwi Trondheim, Testing within the Glava Energy Center in Sweden, Other smaller projects within Innos AS and FUSen AS portfolios, Façade in social housing building, Wattignies, FRA	Other; Employees at Innos AS and FUSen AS has over 20-year experience from the solar market and has over the years been part of developing standards that leads up to EN 50583.	glass-glass modules, Categories A to D	No. More that you must describe the whole picture and take a walk through old standards and develop a communication tree into EN 50583

Representatives	Which BIPV product and project	How did you find out about the standard	Material category and Mounting category in EN 50583 investigated	Any specific shortcomings of EN 50583
Sweden	Anonymous report referring to a solar tile	Through own investigations about requirements for the Swedish market	The product in this case is a glass-glass solar tile which is to be mounted onto a rigid structure with a watertight membrane underneath it which will protect the underlying structure (I.e. a category A product).	Yes! (See further comments at end of table) - Should provide better guidance for the most common typical products so that the relevant standards can be easily identified - Should be accompanied by a “test it yourself-guide” for developers. To buy tests or calculations can be very expensive! - Our solar tile and our products for cold facades should not need to fulfil such strict requirements since there is a weather protection layer in place underneath it. - EN 61730 for photovoltaic module safety qualification→Delamination tests are included here. No need to include additional requirement according to EN 14449 (see also end of table!) **Tests/ standards that are missing:** => The referred fire test in case of category A only refers to EN13501-5 which deals with the reaction to an external fire exposure (Burning object falling on roof/ PV module). More extensive tests are probably required to determine how e.g. PV-modules or tiles interact with the underlying materials in case of fire from

Representatives	Which BIPV product and project	How did you find out about the standard	Material category and Mounting category in EN 50583 investigated	Any specific shortcomings of EN 50583
Sweden (cont.)				underneath or what happens if an overheating occurs in a junction box or connector embedded in a BIPV construction. CEN-TC128-WG3-N0068 TR referred to in EN 50583-2 Table 3 has been replaced by PD CEN/TR 16999:2019 Solar energy systems for roofs. Requirements for structural connections to solar panels
France	Façade in social housing building, Wattignies, France	From personal contacts.	Glass, Category C	A deep knowledge of the construction products related standards is needed in order to determine which of the standards listed within EN 50583 are relevant for a specific product. In some cases there is the need for additional testing due to national or regional regulations. Some specific features of BIPV products are not directly addressed by the standard.
Japan	No experience with application of EN 50583 in Japan	N/A	N/A	N/A
Republic of Korea	Roof Façade	From personal contacts	Curtain wall (opaque), Category C (non-sloped, not accessible from within the building	N/A

8.3 Overview of codes or standards applied not covered in EN 50583

* N.B. National building codes must always be taken into account – as for any building component

*National Building Code of Canada *National Energy Code of Canada for Buildings *Alberta Building Code
EN 356, Glass in Building-Security glazing-Testing and classification of resistance against manual attack. EN 13823, Reaction to fire tests for building products- Building products excluding floorings exposed to the thermal attack by a single burning item. EN 11925-2, Reaction to fire tests-Ignitability of products subjected to direct impingement of flame – Part 2: Single-flame source test.
*The Spanish Building Technical Code (Mechanical resistance and stability and resistance in case of fire). *Royal Decree 1699 / 2011 (regulates the connection of PV installations of less than 100 kW to the grid). *The Spanish Low Voltage Electrical Regulation.
JIS C8990 (equivalent to EN 61215, Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval (IEC 61215). JIS C8992-1 (equivalent to EN 61730 1, Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction (IEC 61730 1)). JIS C8990-2 (equivalent to EN 61730 2, Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing (IEC 61730 2)). *Japanese national building codes.
*Korean National Building Codes
CAN/CSA-A440.4-07 (R2007) - Window, Door, and Skylight Installation. AAMA/WDMA/CSA 101/I.S.2/A440-08 - NAFS - North American Fenestration Standard / Specification for Windows, Doors, and Skylights. A440S1-09 - Canadian Supplement to AAMA/WDMA/CSA 101/I.S.2/A440-08, NAFS - North American Fenestration Standard/Specification for windows, doors, and skylights. AAMA/WDMA/CSA 101/I.S.2/A440-11 (R2016) - NAFS - North American fenestration standard/Specification for windows, doors, and skylights. CAN/CSA-A440-00/A440.1-00 (R2005) - CAN/CSA-A440-00, Windows / Special Publication A440.1-00, User Selection Guide to CSA Standard CAN/CSA-A440-00, Windows.

8.4 Normative references for EN 50583-1

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 410, *Glass in building – Determination of luminous and solar characteristics of glazing*

EN 673, *Glass in building – Determination of thermal transmittance (U value) – Calculation method*

EN 674, *Glass in building – Determination of thermal transmittance (U value) – Guarded hot plate method*

EN 675, *Glass in building – Determination of thermal transmittance (U value) – Heat flow meter method*

EN 1279-5, *Glass in building – Insulating glass units – Part 5: Evaluation of conformity*

EN 1990, *Eurocode: Basis of structural design*

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 1993 (all parts), *Eurocode 3: Design of steel structures*

EN 1999 (all parts), *Eurocode 9: Design of aluminium structures*

EN 12179, *Curtain walling – Resistance to wind load – Test method*

prEN 12488, *Glass in building – Glazing requirements – Assembly rules for vertical glazing*

EN 12519, *Windows and pedestrian doors – Terminology*

EN ISO 12543-1, *Glass in building – Laminated glass and laminated safety glass – Part 1: Definitions and description of component parts (ISO 12543-1)*

EN ISO 12543-2, *Glass in building – Laminated glass and laminated safety glass – Part 2: Laminated safety glass (ISO 12543-2)*

EN ISO 12543-3, *Glass in building – Laminated glass and laminated safety glass – Part 3: Laminated glass (ISO 12543-3)*

EN ISO 12543-4, *Glass in building – Laminated glass and laminated safety glass – Part 4: Test methods for durability (ISO 12543-4)*

EN ISO 12543-5, *Glass in building – Laminated glass and laminated safety glass – Part 5: Dimensions and edge finish (ISO 12543-5)*

EN ISO 12543-6, *Glass in building – Laminated glass and laminated safety glass – Part 6: Appearance (ISO 12543-6)*

EN 12600, *Glass in building – Pendulum test – Impact test method and classification for flat glass*

EN 12758, *Glass in building – Glazing and airborne sound insulation – Product descriptions and determination of properties*

EN 13022 (all parts), *Glass in building – Structural sealant glazing*

EN 13116, *Curtain walling – Resistance to wind load – Performance requirements*

EN 13119, *Curtain walling – Terminology*

EN 13501-1, *Fire classification of construction products and building elements – Part 1: Classification using data from reaction to fire tests*

EN 13501-2, *Fire classification of construction products and building elements – Part 2: Classification using data from fire resistance tests, excluding ventilation services*

EN 13501-5, *Fire classification of construction products and building elements – Part 5: Classification using data from external fire exposure to roofs tests*

EN 13830, *Curtain walling – Product standard*

EN 13947, *Thermal performance of curtain walling – Calculation of thermal transmittance*

EN 13956, *Flexible sheet for waterproofing – Plastic and rubber sheets for roof waterproofing – Definitions and characteristics*

EN 14351-1, *Windows and doors – Product standard, performance characteristics – Part 1: Windows and external pedestrian doorsets without resistance to fire and/or smoke leakage characteristics*

EN 14449, *Glass in building; Laminated glass and laminated safety glass – Evaluation of conformity/ Product standard*

EN 14500, *Blinds and shutters – Thermal and visual comfort – Test and calculation methods*

EN 14782, *Self-supporting metal sheet for roofing, external cladding and internal lining – Product specification and requirements*

EN 14783, *Fully supported metal sheet and strip for roofing, external cladding and internal lining – Product Specification and requirements*

EN15804:2012, *Sustainability of construction works; Environmental product declarations - Core rules for the product category of construction products*

EN15941:2010, *Sustainability of construction works; Environmental product declarations - Methodology for selection and use of generic data*

EN15942:2011, *Sustainability of construction works; Environmental product declarations - Communication format business-to-business*

EN15978:2012, *Sustainability of construction works; Assessment of environmental performance of buildings - Calculation method*

EN 16002:2010, *Flexible sheets for waterproofing - Determination of the resistance to wind load of mechanically fastened flexible sheets for roof waterproofing*

EN 50380, *Datasheet and nameplate information for photovoltaic modules*

EN 61082-1:2015 *Preparation of documents used in electrotechnology - Part 1: Rules*

EN 61215, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval (IEC 61215)*

EN 61646, *Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval (IEC 61646)*

EN 61730-1, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction (IEC 61730-1)*

EN 61730-2, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing (IEC 61730-2)*

CLC/TS 61836, *Solar photovoltaic energy systems – Terms, definitions, symbols (IEC TS 61836)*

EN 62446, *Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection (IEC 62446)*

EN 82079-1:2012 *Preparation of instructions for use - Structuring, content and presentation - Part 1: General principles and detailed requirements*

8.5 Normative references for EN 50583-2

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 410, Glass in building – Determination of luminous and solar characteristics of glazing

EN 1027:2000, Windows and doors - Watertightness - Test method

EN 1990, Eurocode: Basis of structural design

EN 1991 (all parts), Eurocode 1: Actions on structures

EN 1993 (all parts), Eurocode 3: Design of steel structures

EN 1995 (all parts), Eurocode 5: Design of timber structures

EN 1999 (all parts), Eurocode 9: Design of aluminium structures

EN ISO 6946, Building components and building elements – Thermal resistance and thermal transmittance – Calculation method (ISO 6946)

EN 12179, Curtain walling – Resistance to wind load – Test method

prEN 12488, Glass in building – Glazing requirements – Assembly rules for vertical glazing

EN 12519, Windows and pedestrian doors – Terminology

EN ISO 12543-1, Glass in building – Laminated glass and laminated safety glass – Part 1: Definitions and description of component parts (ISO 12543-1)

EN ISO 12543-2, Glass in building – Laminated glass and laminated safety glass – Part 2: Laminated safety glass (ISO 12543-2)

EN ISO 12543-3, Glass in building – Laminated glass and laminated safety glass – Part 3: Laminated glass (ISO 12543-3)

EN ISO 12543-4, Glass in building – Laminated glass and laminated safety glass – Part 4: Test methods for durability (ISO 12543-4)

EN ISO 12543-5, Glass in building – Laminated glass and laminated safety glass – Part 5: Dimensions and edge finish (ISO 12543-5)

EN ISO 12543-6, Glass in building – Laminated glass and laminated safety glass – Part 6: Appearance (ISO 12543-6)

EN 12600, Glass in building – Pendulum test – Impact test method and classification for flat glass

EN 12758, Glass in building – Glazing and airborne sound insulation – Product descriptions and determination of properties

EN 13022 (all parts), Glass in building – Structural sealant glazing

EN 13116, Curtain walling – Resistance to wind load – Performance requirements

EN 13119, Curtain walling – Terminology

EN 13363-1, Solar protection devices combined with glazing – Calculation of solar and light transmittance – Part 1: Simplified method

EN 13363-2, Solar protection devices combined with glazing – Calculation of total solar energy transmittance and light transmittance – Part 2: Detailed calculation method

EN 13501-2, Fire classification of construction products and building elements – Part 2: Classification using data from fire resistance tests, excluding ventilation services

EN 13501-5, Fire classification of construction products and building elements – Part 5: Classification using data from external fire exposure to roofs tests

EN 13830, Curtain walling – Product standard

EN 13947, Thermal performance of curtain walling – Calculation of thermal transmittance

EN 13956, Flexible sheet for waterproofing – Plastic and rubber sheets for roof waterproofing – Definitions and characteristics

EN 14351-1, Windows and doors – Product standard, performance characteristics – Part 1: Windows and external pedestrian doorsets without resistance to fire and/or smoke leakage characteristics but including external fire performance for roof windows

prEN ISO 14439 [3)], Glass in building — Glazing requirements — Use of glazing blocks (ISO 14439)

EN 14500, Blinds and shutters – Thermal and visual comfort – Test and calculation methods

EN 14782, Self-supporting metal sheet for roofing, external cladding and internal lining – Product specification and requirements

EN 14783, Fully supported metal sheet and strip for roofing, external cladding and internal lining – Product Specification and requirements

CEN/TR 15601:2012, Hygrothermal performance of buildings – Resistance to wind-driven rain of roof coverings with discontinuously laid small elements – Test method

EN15804:2012, Sustainability of construction works; Environmental product declarations - Core rules for the product category of construction products

EN15941:2010, Sustainability of construction works; Environmental product declarations - Methodology for selection and use of generic data

EN15942:2011, Sustainability of construction works; Environmental product declarations - Communication format business-to-business

EN15978:2012, Sustainability of construction works; Assessment of environmental performance of buildings - Calculation method

EN 50583 Part 1 - Photovoltaics in buildings – BIPV modules

HD 60364-7-712, Electrical installations of buildings – Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems (IEC 60364-7-712)

EN 16002:2010, Flexible sheets for waterproofing - Determination of the resistance to wind load of mechanically fastened flexible sheets for roof waterproofing

3) Abandoned project.

EN 61082-1:2015 Preparation of documents used in electrotechnology - Part 1: Rules

CLC/TS 61836, Solar photovoltaic energy systems – Terms, definitions, symbols (IEC TS 61836)

EN 62446, Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection (IEC 62446)

EN 82079-1:2012 Preparation of instructions for use - Structuring, content and presentation - Part 1: General principles and detailed requirements

ETAG 002, Guideline for European Technical Approval for Structural Sealant Glazing Systems – SSGS

ETAG 006, Guideline for European Technical Approval of Systems of Mechanically Fastened Flexible Waterproofing Membranes

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