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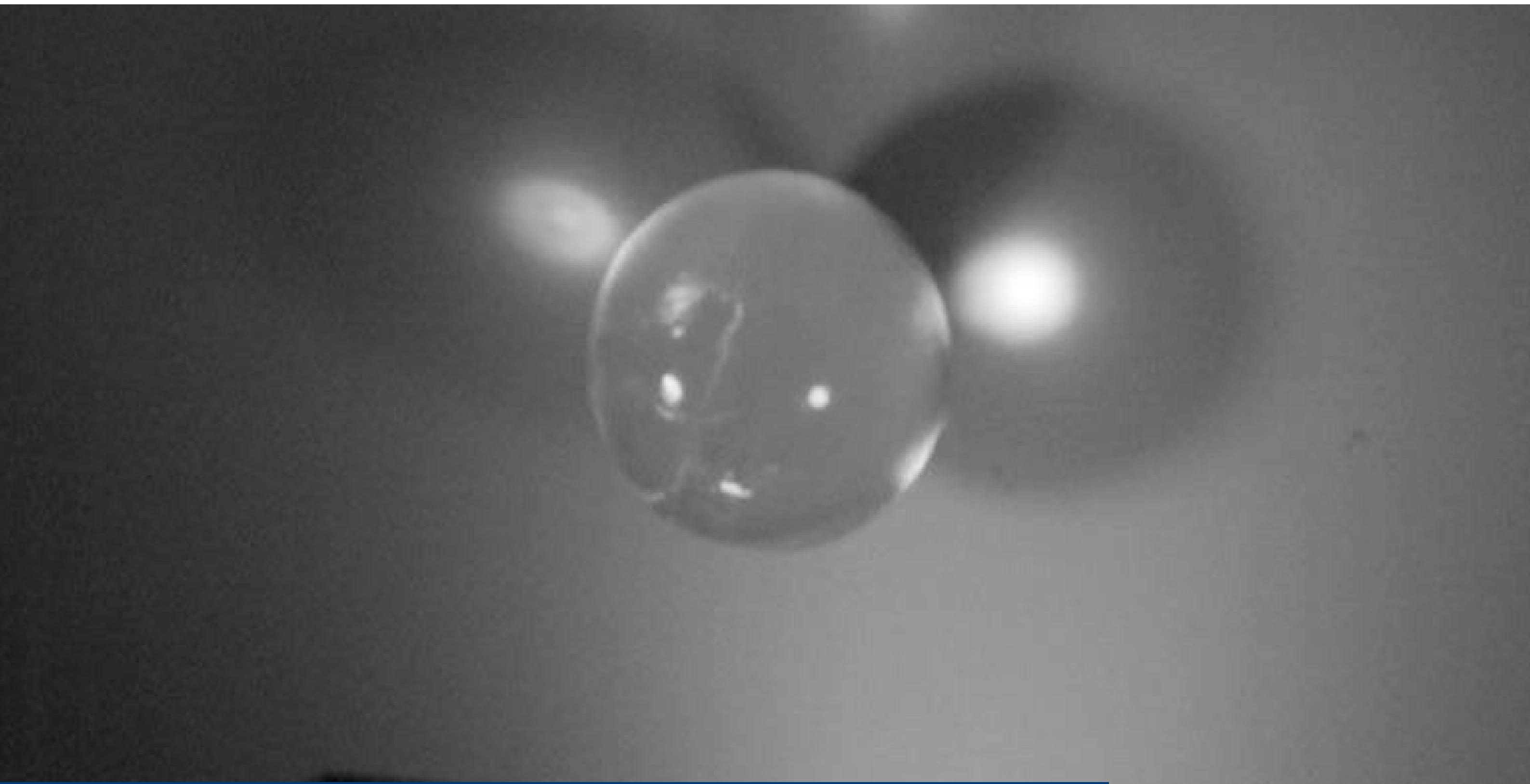

Task 15 Enabling Framework for the Acceleration of BIPV

PVPS

Advancing BIPV Standardization: Addressing Regulatory Gaps and Performance Challenges 2024

Report IEA-PVPS T15-24:2024

What is the 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, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkiye, and the United States of America. The European Commission, Solar Power Europe, the Solar Energy Research Institute of Singapore and Enercity SA are also members.

Visit us at: www.iea-pvps.org

What is IEA-PVPS Task 15?

The objective of Task 15 of the IEA Photovoltaic Power Systems Programme is to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products, BAPV products and regular building envelope components, respecting especially economic, technological, legal, aesthetic, reliability and normative issues.

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COVER ILLUSTRATION: The cover image depicts the hail test (MQT 17) specified in IEC 61215-2:2021 being performed on a BIPV module. This image emphasizes the essential role of mechanical resistance testing in ensuring the reliability of BIPV products, both as electrical components and as integrated building components. It is worth noting that the resistance to impact or external mechanical stresses directly affects electrical functionality, involving the active photovoltaic elements responsible for converting solar energy into electricity.
Test made by the SUPSI PVLab. (Source: University of Applied Sciences and Arts of Southern Switzerland - SUPSI)

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PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

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LIST OF ABBREVIATIONS

BAPV	Building-Applied PhotoVoltaics
BIPV	Building-Integrated PhotoVoltaics
BOM	Bill of Materials
c-Si	Crystalline Silicon
CPR	(European) Construction Products Regulation
DUT	Device Under Test
EAD	European Assessment Document
EPBD	(European) Energy Performance of Buildings Directive
ETA	European Technical Assessments
EVA	Ethylene Vinyl Acetate
GHG	GreenHouse Gas
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEQ	Indoor Environmental Quality
IGU	Insulating glass unit
ISO	International Organization for Standardization
JBs	Junction Boxes (j-boxes)
JWG	Joint Working Group
LS	Limit States
LVD	(European) Low Voltage Directive
MQT	Module Qualification Tests
MST	Module Safety Tests
NTNU	Norwegian University of Science and Technology
nZEBs	Near-Zero-Energy Buildings
OIB	Austrian Institute of Construction Engineering
SfSL	Safeguard Limit State
SLS	Serviceability Limit State
STC	Standard Test Conditions
ULS	Ultimate Limit State
TAB	Technical Assessment Body
WDRT	Wind-Driven Rain Test
WP	Work package

EXECUTIVE SUMMARY

The aims of this report are to:

- Provide a comprehensive overview of the challenges and advances in the standardization and testing procedures for Building-Integrated Photovoltaics (BIPV).
- Identify and analyze the regulatory gaps and the need for a new performance approach to BIPV.
- Present in detail the electrical and mechanical safety testing procedures specific to BIPV products.
- Highlight the importance of harmonizing testing procedures and certification processes to reduce costs and simplify market introduction.

The overall goal is to emphasize the necessity of a unified regulatory framework to support the widespread deployment of BIPV technologies. This framework aims to ensure consistent quality and safety standards across different regions, facilitating easier market access and fostering international cooperation.

An overview of the BIPV standardization challenges was prepared, presenting the main regulatory gaps, the need for standardization adaptation, and the specific testing procedures required for BIPV products. The report explores critical aspects of electrical and mechanical safety, structural integrity, and performance assessment necessary for BIPV products. It also discusses the current requirement for double certification of products and the associated costs, time, and uncertainties.

Furthermore, this report reviews specific projects such as the BIPVBOOST initiative, which focuses on developing adapted testing protocols for BIPV products. This initiative documents state-of-the-art criteria and requirements for BIPV product qualification and proposes initial testing protocols, including operating temperatures and impact resistance tests.

In conclusion, this report underlines the significant challenges faced by the BIPV industry due to the lack of clear testing and certification procedures. It suggests that international consensus and harmonization of certification processes are crucial for the widespread adoption of BIPV products. This approach aims to streamline regulatory processes, reduce costs, and support the development of a sustainable built environment through BIPV technology.

1 INTRODUCTION

Around the world, the energy issue is becoming increasingly central, with many countries recently implementing regulations to optimize building efficiency. In the European context, for example, the European Commission has introduced the "Clean Energy for All Europeans" package, which includes updates to both the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive. As of December 2023, the revised EPBD sets higher performance standards for new buildings and more ambitious targets for reducing energy consumption in existing buildings. This revision includes a specific focus on greenhouse gas (GHG) emissions throughout the life cycle of buildings, indoor environmental quality (IEQ), and fossil fuel phase-out. While not explicitly focused on Building-Integrated Photovoltaics (BIPV) technology, the emphasis on energy efficiency implicitly suggests the importance of BIPV, especially considering that many member states are integrating renewable energy into their energy regulations.

Today, solar PV technology offers an exciting prospect: converting building surfaces into electricity generators instead of relying on landscape areas. The demand for PV systems integrated into buildings is growing. They need to be versatile, design-flexible and offer more than just electricity generation. Thanks to advances in technology and digitalisation, these systems are poised to revolutionize the construction market, aligning with the ambitious energy goals for nearly-zero-energy buildings nZEBs. BIPV has come a long way in the past decade, evolving from basic electricity generators into multifunctional building materials that can also generate renewable electricity. There have been more than two decades of research and development, resulting in innovative products and impressive showcase projects.

Reflecting on BIPV's journey requires an understanding of the parallel growth of the traditional PV sector. Between 2008 and 2012, the PV sector's costs plummeted by around 80%, paving the way for BIPV. However, BIPV growth has not always met expectations, primarily due to integration challenges, lack of standardization, and cost-effectiveness. Traditional PV solutions have dominated the market, with BIPV only making up about 2% of the PV market in 2017 in Europe. Even today, BIPV's unique characteristics and regulatory mandates for energy-efficient buildings offer potential for significant expansion. However, with the market estimated between 300 MW to 500 MW in Europe and around 2 GW globally, BIPV occupies a niche in the PV sector. At the end of the year 2022, the PV market passed the 1 TW mark with 1183 GW of PV power plants producing electricity worldwide and only a small fraction of the PV market consisting of BIPV [1].

Despite positive market perspectives and technical maturity in building-integrated photovoltaics (BIPV), challenges persist in widespread BIPV adoption due to limited education among construction professionals, a shortage of skilled individuals combining PV and building expertise, and competition from traditional solutions. This is also related to the fact that a distinct difference in standardization between the two sectors of buildings and electrical equipment exists. While traditional PV boasts a comprehensive set of standards, BIPV still seeks standardized testing that encompasses both PV and construction needs and avoids duplication of similar tests.

Currently, BIPV regulation at the international level is still mainly addressed by IEC standards for the electrical part and ISO standards for the building part, although Joint Working Group 11 (JWG 11) was created by IEC TC 82 and ISO TC 160 in 2021 specifically to address BIPV standardisation jointly. The dual approach makes it more complicated to address the quality and certification challenges for multifunctional products like BIPV. There is also a difference between the two sectors in the degree of internationalism. The standards in the relatively young photovoltaic sector have mainly been developed through international co-operation for an international market. By contrast, the building sector is much older and has developed over centuries in reaction to regional differences in climate and building materials. Although a degree of harmonisation for construction product standards has been achieved e.g. within the European Union, authorisation for their use in buildings is still largely regulated by national or even regional building codes. To obtain validation and certification of their products, BIPV manufacturers must conduct tests and follow compliance procedures established by both sectors, often highlighting the need to adopt customized testing procedures developed specifically for the particular product. A targeted and clear standardization framework is crucial for BIPV's future, considering factors like quality, reliability, performance, and safety.

TARGET AUDIENCE

This report is intended for a diverse audience, including policymakers, researchers, industry stakeholders, and professionals involved in the development, implementation, and standardization of BIPV technologies. It aims to provide actionable insights and a framework for advancing BIPV integration across global markets.

1.1 RELEVANT PREVIOUS REPORTS

Building-integrated photovoltaics (BIPV) is a centrepiece in the evolving field of sustainable architecture and urban planning. The three main reports on aspects of BIPV standardisation that were produced in the first four-year phase of IEA Task 15 are briefly reviewed to present a holistic view of the landscape, user needs, regulatory requirements, and multifunctional characterization of BIPV.

1. Report IEA-PVPS T15-06: 2019 Compilation and analysis of user needs for BIPV and its functions [2].

The first report delves into the many nuances of needs associated with BIPV, seen through the lens of multiple stakeholders. These "users" range from direct entities such as building owners and occupants to indirect entities such as investors, banking institutions, insurance companies and city authorities. Each user's perspective brings out unique requirements and converging needs, which the report carefully outlines. In particular, the report underlines the dual functionality of BIPV: as a building component and as an electricity generator. Emphasis was placed on the associated technical needs, statutes, standards and guidelines and the more holistic needs relating to energy performance, aesthetics, and financial considerations. The target is to provide an "international framework for BIPV specifications" that meets the diverse needs of users.

2. Report IEA-PVPS T15-08: 2019 Analysis of requirements, specifications and regulation of BIPV [3].

Based on fundamental user needs, the second report explores the intricate global web of regulatory requirements, specifications, and their implications for BIPV standards. [3]. The crux of the document is to analyse BIPV-related regulations to offer insights that can stimulate the creation of international BIPV standards, thus accelerating market adoption. The European standard series EN 50583 [4], [5] is the one that lays the foundations for the "basic requirements" for BIPV modules both as construction products and as electrical components. The corresponding international BIPV standards were still being prepared when this report was published. Furthermore, the report highlights the absence of a direct correlation between EN and ISO standards for construction products. The recommendations were presented as categorisation requirements based on urgency, relevance, and scope of standardisation, supporting areas that international standards should address.

3. Report IEA-PVPS T15-11: 2020 Multifunctional characterization of BIPV [6].

The third report, focusing on the multifunctional characterisation of BIPV, highlights the need for international standardisation. A systematic approach is taken, starting with identifying BIPV characteristics that require changes to existing test procedures. Then, the report describes proposed testing changes in line with BIPV capabilities. An attached section of the report gathers valuable information from questionnaire responses on experience with BIPV module evaluation, particularly in the context of the EN 50583 [4], [5] standard. The report addresses the urgent challenge of harmonising photovoltaics testing to simplify the multiple requirements for BIPV products, setting the stage for the second four-year phase of IEA-PVPS Task 15.

The combined outcomes of these three previous reports emphasise the needs of users and the need for a clear regulatory framework, underlining the multifunctional aspect of BIPV. The aim is to support the adoption of harmonised international standards in the future that consider the multifunctionality of BIPV and simplify its testing procedures.

An analysis of the BIPV regulatory framework in Europe was conducted as part of the BIPVBOOST project [7]. The project's main aim was to reduce costs in BIPV, also considering the issue of BIPV standardisation. The results of this study can be found in two reports:

- D5.1: Report on Standardization, Performance Risks and Related Gaps Identification for Performance-Based Qualification in BIPV [8].

and

- D5.2: Report on the project developments of specific performance-based laboratory testing procedures for BIPV products [9].

The reports include the current regulatory landscape, highlighting the performance gaps in BIPV and outlining strategies for a new approach to performance-based qualification.

2 CHALLENGES TO THE STANDARDIZATION OF BIPV

2.1 REGULATORY GAPS IN BIPV

Internationally, there are key reference standards for the PV industry. Specifically, the main standards include IEC 61215:2021, Parts 1 and 2 [10], [11] , which establish requirements for the design qualification of terrestrial PV modules suitable for long-term operation in outdoor climates. In addition, IEC 61730:2023, Parts 1 and 2 [12], [13] specify and describe the essential construction requirements for photovoltaic (PV) modules to ensure safe electrical and mechanical operation.

Regarding BIPV (building-integrated photovoltaics) modules, IEC 63092:2020, Parts 1 and 2 [14] [15] specify requirements for BIPV modules used as construction products. This standard focuses on properties relevant to basic building requirements and applicable electrotechnical requirements. Part 1 addresses the specific requirements for BIPV modules based on their mounting purpose but does not deal with the mounting structure itself, which is covered in Part 2. This international standard is based on the European standard EN 50583-1 [4] which covers photovoltaic modules used as construction products, focusing on properties relevant to the essential building requirements as specified in the European Construction Products Regulation CPR 305/2011 [16]. The purpose of European Regulation CPR 305/2011 [16] is to establish the conditions for offering construction products on the market within Europe by setting out provisions for the description of performance in relation to characteristics and the use of CE marking. A revision of Ed. 2 of EN 50583-1 [17] was initiated by the European standardization committee CLC/TC 82 in May, 2023.

The EN 50583 series [4], [5] also considers applicable electrotechnical requirements as set out in the European Low Voltage Directive (LVD) (2014/35/EU) [18] and CENELEC standards. As with IEC 63092-1 [14], Part 1 addresses the requirements for BIPV modules based on their mounting purpose, but does not address the mounting structure itself, which is discussed in Part 2 [15]. It is important to note that this standard is voluntary and not mandatory, and it is crucial to understand the European context in which BIPV fits as a construction product. However, the process to have EN 50583-1 [17] mandated as a harmonised product standard also under the European CPR was started in May, 2023, and is expected to take several years.

Internationally, some ISO standards considering the behaviour of BIPV as construction products have also been developed. For example, ISO/TS 18178:2018 [19] focuses on laminated solar photovoltaic (PV) glass used in buildings and provides specific guidance on BIPV products, specifying appearance, durability and safety requirements, test methods, and designation.

However, the mentioned standards have limitations in addressing the general requirements of BIPV, considering the multifunctionality of BIPV products and the fact that most of the reported procedures have been developed separately for the electrical part in the PV case and the building part, respectively, without a unified vision. The voluntary nature of the standards also contributes to difficulties in achieving consistent quality and performance parameters for BIPV installations, particularly with respect to their performance as construction products.

Earlier research efforts, notably the Report IEA-PVPS T15-11: 2020 titled " Multifunctional Characterisation of BIPV - Proposed Topics for Future International BIPV Standardization Activity" [6], pinpointed areas needing international standardisation for multifunctional BIPV modules and systems. This study offered potential approaches to achieve such standardisation, emphasising the unique attributes of BIPV that demand modifications to standard testing methods. As a result, it has been concluded that there are discernible gaps at various stages, ranging from the individual PV element to the system and building application levels. Consequently, these gaps prevent a comprehensive characterisation of BIPV elements.

In practical terms, industry players and professionals frequently struggle with choosing the appropriate standards for qualifying the products and defining the application requirements for integrated photovoltaics as functional, active components in the building envelope.

A clear regulatory framework based on established standards and codes would ensure consistent quality and performance metrics for BIPV installations and give manufacturers a more transparent process.

It is essential to consider that conventional PV modules, designed primarily as electrical devices, do not meet specific building requirements per se. Although they meet electrotechnical standards like the IEC standards and comply with the European LVD [18], they do not align with building application requirements. Notably, IEC 61215-1:2021 [10] [11] underscores that any alteration in a module's design or materials may necessitate retesting, which dramatically contrasts with the building sector’s engineering approach suited to mass customization.

On the other hand, existing regulations for conventional PV modules are often ill-suited to address specific regional building standards and requirements, creating gaps in the full potential for BIPV installation.

2.2 SOLAR ARCHITECTURE, FLEXIBILITY, AND QUALITY ASSESSMENT

Building-integrated photovoltaics (BIPV) has the potential to transform buildings from simple envelopes to dynamic electricity-generating entities. As these innovations evolve, by transforming the dynamics of construction technology and building concepts, it becomes essential to understand the balance required between design flexibility, quality assurance, and market demands for product standardization [20].

This is evident when comparing BIPV with standard photovoltaic products that only serve for electricity-generating functions. Although many PV modules, certified according to IEC standards, are applied to buildings as Building-Applied Photovoltaics (BAPV), they are often not suitable for the functions of the building envelope. For this reason, to meet these needs, manufacturers have developed multiple BIPV solutions to satisfy building requirements, particularly architectural demands and building-related performance.

Unlike standard PV, the key advantage of BIPV is its ability to adapt to the specific requirements of a building. It can offer architects and designers various options for the entire building envelope. It is possible to develop products ranging from transparent to opaque modules that are integrated within roofs, facades, windows, and balustrades and meet architectural requirements. The new BIPV modules allow the creation of structures that blend energy efficiency with aesthetic appeal [21]. This adaptability, however, comes with its challenges when BIPV must meet architectural and energy requirements. They are often required to comply with design and construction demands to ensure optimal operation that fits seamlessly into architectural designs, ensuring cost efficiency and meeting all performance standards and certification requirements for building permits.

However, this goal is not without its challenges, since it involves both the product qualification for the market introduction and the product suitability for the specific application related to the building type, building skin technology and component functionality. Tailoring each BIPV solution to specific architectural requirements creates a dichotomy. On the one hand, there is a push toward customisation to meet different design needs, while, on the other hand, there is a push toward mass production and requirements standardization to achieve cost reductions.

BIPV products not only require adherence to electrical and energy standards, ensuring efficiency, safety, and reliability, but also demand a comprehensive understanding of their role within the building skin structure. Ensuring compliance with building codes and identifying the appropriate regulatory framework becomes critical, since this field is typically not only regulated at the national level, but also at regional and local levels.

Manufacturers find themselves in a maze of standards that can lead to repeated performance verification and possible retesting according to different procedures. It can also lead to overlapping of very similar testing procedures that, in most of the cases, are adapted from conventional construction or PV procedures and are not appropriate to the specific use case of the product.

The maze of design flexibility, regulatory compliance, and market demands remains a challenge that must be addressed to take full advantage of BIPV's potential.

2.3 BIPV AS A BUILDING PRODUCT

BIPV presents a significant advantage by seamlessly integrating renewable energy into the built environment, being a versatile product that not only complements but also replaces traditional building components.

Furthermore, its diverse construction types offer the flexibility to be applied across the entire building envelope, serving as facades, windows, roofs, canopies, balustrades, and other envelope elements.

Given its inherent nature as a building product, BIPV is subject to a complex regulatory framework. BIPV products have to adhere to building requirements while concurrently meeting electrical standards. This dual compliance underscores the intricate nature of ensuring both structural and electrical conformity in BIPV installations.

In Europe, for example, every construction product must comply with the requirements imposed by the Construction Products Regulation CPR [16] and all harmonised standards applicable to the product. Having established that BIPV is a construction product, the approach originating from and applied to standard PV is no longer primarily usable in the design, qualification, and description of the product, although electrical safety must, of course, be ensured. On the contrary, the construction-related approach must be assimilated and used.

While specific references may differ based on legal regulations in various states, certain overarching principles can be highlighted, aligning with established standards and guidelines for construction product compliance and BIPV. The list provided below serves as an illustrative example. It is imperative also to refer to specific local, national and international codes, standards, and regulations within each relevant category to ensure adherence to current requirements.

1. Building standards:
   - Structural integrity: weight variation, potential stresses on BIPV components, and different operating temperatures must be considered in building design to ensure structural safety.
   - Watertightness: BIPV installations, especially those on roofs or facades, must maintain the watertight characteristics of the building envelope.
2. Safety standards:
   - Electrical safety: BIPV systems must comply with electrical safety standards since they are electrical installations.
   - Mechanical safety: BIPV components and systems must have the same impact and bending resistance capacity as conventional building products.
   - Fire safety: the integration of PV into building materials must not compromise the fire safety of the building. This includes flammability, smoke production, and other fire-related properties of materials.
3. Performance standards:
   - Durability: since they are building products incorporated into buildings, their durability should align with the expected lifespan of the buildings themselves. They should also maintain a significant percentage of their initial performance through their service life as part of the building.
4. Aesthetics and design:
   - Since they are architecturally integrated products, a harmonious fit into the architectural language must be ensured. They should maintain their original

characteristics, including colour, throughout their lifespan, while ensuring the intended aesthetic functionality.
- In areas with heritage-related constraints, they must not detract from the historical and aesthetic value of the building and its surroundings.

5. End of life and recycling:
   - Measures must be taken for end-of-life treatment of BIPV components, emphasising recycling and waste minimisation.
6. Monitoring and data collection:
   - As smart grids and smart buildings advance, regulations may emphasize the need for BIPV systems to incorporate monitoring mechanisms to provide performance data connected to safety aspects and optimization of energy flows within the building.

Given the rapid development of new BIPV components to address market demands, the speed of new product development surpasses that of regulatory adaptation and thus compliance. Hence, it becomes crucial to establish a regulatory framework ensuring safety, performance, and longevity. This framework can be derived from existing requirements in the conventional construction sector, addressing the gaps arising from the integration of electrical components.

2.4 NEW PERFORMANCE-BASED TESTING APPROACH FOR BIPV

Currently, PV products utilized as building components face the lack of unified international standards or technical guidelines. Consequently, manufacturers are compelled to adjust their products to align with the specific requirements of each country. The analysis reveals that standardisation for BIPV is underdeveloped, indicating the need for new performance benchmarks and test methods to validate the quality of PV modules used in building structures.

Prescriptive codes have been used extensively in the photovoltaic industry, although parts referring to performance-based approaches have been included in the reference standards in recent years. Unlike performance-based codes, prescriptive codes set clear benchmarks, offering a step-by-step approach that does not require complex calculations. However, their one-size-fits-all nature has limitations when applied to BIPV. Indeed, the multifunctionality of BIPV products cannot be evaluated using the prescriptive method alone, as it leads to overly rigid criteria that do not meet actual market needs.

Using performance-based testing procedures is typical of the building industry, since it allows flexibility by promoting a transparent and fair regulatory environment based on the actual functionality required by the product according to its intended use. Instead of dictating specific criteria, it outlines tools to evaluate those criteria. The performance-based approach allows designers to input data into models to find the optimal solution, thus saving resources. Performance-based design, already prevalent in many areas of construction, such as energy and structural engineering, is gaining ground in the BIPV sector.

To implement the performance-based approach, limit states (LS) must be defined for each of the different requirements that need to be achieved. A limit state describes a situation in which a system no longer meets specific established criteria, such as design specifications, due, for example, to external forces acting on the system, such as a load on a building structure. The criteria could relate to structural integrity, usability, durability of the system, or other factors. It is essential to consider that in BIPV products, limit states must consider two essential requirements, electrical and construction. To efficiently apply the performance-based approach, specific definitions will have to be developed for the different technical requirements of the various types of products.

This approach makes it possible to apply test procedures that consider the required levels of performance (different limit states) according to different uses, thereby helping the designer to find the best implementation solutions by simulation. The change of approach will allow a considerable reduction in the number of required tests by minimising retesting sequences for component variations.

A proposed solution in the EU, as summarized in this chapter, has been developed in the framework of the BIPVBOOST Horizon2020 project [7] in order to create a qualification process for BIPV products. This qualification process, focused on testing activities, is valid only for certain technical requirements and product classes. It is a performance-based scheme and it includes the logic of filling missing gaps in BIPV integrated qualification. It integrates building performance levels along with electrotechnical requirements into new testing procedures, while also optimizing the time and cost of the process.

2.5 NEEDS FOR STANDARDIZATION ADAPTATION

BIPV presents the opportunity to seamlessly incorporate photovoltaic systems into the building envelope. However, for this sector to fully realize its potential, it is essential to establish precise standards. This demands a collaborative effort among all stakeholders to prevent redundant and overlapping tests stemming from both building and electrical requirements. Such cooperation should take into account manufacturers' requests and should encompass testing of product quality, safety and durability requirements, and aesthetic considerations.

A starting point might be to leverage existing standards. Many photovoltaic standards can be adapted or modified to suit BIPV applications. On the other hand, starting from the building regulations, changes could be made to correctly describe the BIPV elements. An example for this is the current revision of the EN 410 standard [22], which contains an Annex specifying a procedure to determine light and solar energy characteristics of BIPV glazing [23]

Furthermore, it is important to define when it is necessary to repeat the tests and how many tests will have to be carried out again on a product that has been modified in part by changes in components, dimensions, type of material used, and so on.

The impact of the cost of repeating qualification tests can become minimal and negligible in the context of series production of large quantities of identical products. By contrast, the cost of repeating tests in projects that require customization of limited product quantities can significantly impact the total budget. In instances where only a few tens of modules are involved, the cost of repeating testing for dimensional changes can be comparable to the overall supply cost.

The following subsections 2.5.1, 2.5.2, and 2.5.3 will describe what is required for retesting PV and BIPV modules and what the needs are related to repeating tests for BIPV products.

2.5.1 PV-RELATED RETESTING

In the framework of the IEC 61730 series [12], [13], the sequence of tests may not verify all possible safety aspects associated with the use of PV modules in all possible applications, particularly of BIPV modules where building codes must be also verified and met.

The IEC 61215 series [10] [11] serves for the design qualification of PV modules intended for prolonged operation outdoors. The standard is comprised of two parts, defining test requirements and procedures. If manufacturers modify their products, retesting may be required to ensure consistent reliability, safety, and durability. The IEC 61215 [10] [11] and IEC

61730 series [12] [13] state that retesting shall follow the guidelines outlined in IEC TS 62915 [24].

IEC TS 62915 [24] states that "Any change in the design, materials, components, material combinations, manufacturers or processing of the PV module type family from the last tested version may require a repetition of some or all of the qualification tests according to the clauses that follow in order to maintain type and safety approval”. This technical specification provides guidelines for conducting the necessary tests on photovoltaics (PV) to confirm safety and performance after the change.

When, following a change in a parameter such as thickness, height or width, if the final value exceeds a specific tolerance dictated by the standard, it is necessary to repeat the test. The tolerance is specified as a predetermined value compared to the nominal one (initial reference sample, last tested version). If the variation is less than the predetermined value, it is not necessary to repeat the test. For all requirements, IEC TS 62915 [24] specifies the tolerance, beyond which the qualification tests must be repeated.

The rationale for retesting a PV product lies in the fact that changing material may lead to different behaviour over time. For example, a different material might react differently to UV exposure or mechanical stress. Variations in size or internal components could lead to electrical or mechanical failure over time, and exposure to thermal cycling could lead to reduced efficiency. The IEC TS 62915 technical specification [24] ensures that modules continue to meet safety and performance requirements throughout their lifetime.

The time required for retesting becomes a critical factor. While manufacturers of standard PV modules are in a better position to absorb the time impact when dealing with millions of modules, the relationship is completely out of proportion for productions involving tens of units. Even in the case of series-produced PV modules for ground-mounted PV power plants, the time required for retesting can sometimes exceed the time needed to produce the actual modules. In fact, a system may require 3 months to be constructed, but getting permission for interconnecting with the grid may take 3 years.

Even large-scale PV manufacturers face challenges in maintaining the certification of their products due to several factors:

- (i) the rapid evolution of PV products that are, however, intended for long-term utilization;
- (ii) reliance on multiple material sources for risk management purposes;
- (iii) the competitive disadvantage faced by manufacturers who fail to continuously improve their products in terms of cost and efficiency, as rapid advances can quickly render their products obsolete.

In conclusion, it is essential to consider whether the retesting methodology outlined in PV standards can be feasibly applied to products where flexibility, adaptation, and variation are intrinsic qualities, as seen in the case of BIPV products. The most recent amendments to IEC TS 62915 [24] already benefitted manufacturers of BIPV modules, but they need further BIPV-specific amendments. At the time of writing, an initiative in this direction has been taken within the ISO/IEC JWG 11, with the proposal for a standard entitled “Supplemental Test requirement of building-integrated photovoltaic (BIPV) module containing an addtional glass to a certified PV module”.

2.5.2 BIPV RETESTING

All participants in the BIPV value chain are actively seeking an optimal balance between customizing PV components and ensuring their quality while achieving competitive costs. The primary objective is to create a cost-effective product suitable for architectural and building integration, considering the strategies to optimize factors like production, performance, qualification, and certification.

Manufacturers have been actively engaged in workshops and conferences within the E4 Activity of Task 15, and have consistently advocated for avoiding redundant product qualification tests when there are variations in size, layer thickness, or basic components. The importance of obtaining a "flexible certificate" for a family of products was emphasised, which shares the same bill of materials (BOM) and remains within limits on dimensional variation, that is defined during the certification process through modelling and verification. This streamlined approach would simplify implementation and significantly reduce the economic impact during the certification process.

A crucial step in minimizing economic impact involves preventing duplicate testing required by both electrical and building codes. As a BIPV module is not only a building product but also an electrical product, any significant changes in design or product BOM necessitate new qualification tests. For photovoltaic products like BIPV, the IEC document addressing retesting requirements for changes is, as seen in the previous paragraph, the IEC TS 62915 [24]. However, specific BIPV typologies, such as PV glass laminates, are addressed by another international technical specification - ISO/TS 21486:2022 [25]. This ISO technical specification outlines the tests required for photovoltaic glass laminates when the product is modified compared with the originally tested configuration.

IEC TS 62915 [24] and the ISO ISO/TS 21486 [25] outline different test sequences, depending on which component has been changed with respect to the original product, forcing manufacturers to follow both standards. For example, in the case of modification of the encapsulation system, IEC/TS 62915 [24] prescribes the following sequence:

Repeat for IEC 61215 [10], [11] (w/o IEC 61730 [12], [13] ; stand-alone):

- Hot-spot endurance test (MQT 09)
- UV preconditioning test (MQT 10) / Cyclic (dynamic) mechanical load test (MQT 20) / Thermal cycling test, 50 cycles (MQT 11) / Humidity freeze test (MQT 12)
  - Can omit cyclic (dynamic) mechanical load test (MQT 20) for change in amount or type of additives but same material
- Thermal cycling test, 200 cycles (MQT 11)
  - Only required if reduction in thickness or g/m^2 by more than 20 %
- Damp heat test (MQT 13)
- Hail test (MQT 17) if frontsheet is polymeric
  - Can omit hail test (MQT 17) for change in amount or type of additives but same material
- Potential induced degradation test (MQT 21)
  - If volume resistivity (according to IEC 62788-1-2 [26]) specified for the sunny-side or rearside stack decreases by more than 1 order of magnitude (e.g. 1017 Ω-m vs. 1018 Ω-m)

- Bending Test (MQT 22) if module is considered to be "flexible" per the definition specified in IEC 61215 [10], [11]

Repeat for IEC 61730 [12], [13] (w/o IEC 61215 [10], [11] ; stand-alone):

- Hot-spot endurance test (MST 22)
- UV test (MST 54) / Thermal cycling test, 50 cycles (MST 51) / Humidity freeze test (MST 52)
- Thermal cycling test, 200 cycles (MST 51)
    - Only required if reduction in thickness or g/m^2 by more than 20 %
- Damp heat test (MST 53)
- Cut susceptibility test (MST 12) If frontsheet or backsheet is polymeric
- Impulse voltage test (MST 14) if reduced thickness or if different material
- Module breakage test (MST 32) if material composition changes
- Peel test (MST 35) or Lap shear strength test (MST 36) If design includes encapsulant as a part of a qualified cemented joint
- Materials creep test (MST 37)
- Sequence B (only for different materials or reduction in thickness)
- Sequence B1 if design qualified for pollution degree 1

Repeat for IEC 61730 [12], [13] (if IEC 61215 [10], [11] already included):

- Cut susceptibility test (MST 12) If frontsheet or backsheet is polymeric
- Impulse voltage test (MST 14) if reduced thickness or if different material
- Module breakage test (MST 32) if material composition changes
- Peel test (MST 35) or Lap shear strength test (MST 36) If design includes encapsulant as a part of a qualified cemented joint
- Materials creep test (MST 37)
- Sequence B (only for different material or reduction in thickness)
- Sequence B1 if design qualified for pollution degree 1

Meanwhile, ISO/TS 21486 [25] provides a separate set of tests, with some overlap and variations as reported in Table 2-1 below.

Table 2-1 Parameters, changes, and retesting items as specified by ISO/TS 21486 [25] due to an interlayer change according to ISO /TS 18178

Parameters	Changes	Retesting items
Thickness	Decrease: ≥0,38 mm	1) Appearance 2) High temperature test 3) Damp heat test 4) Radiation test 5) Thermal cycling test (200 cycles) 6) Humidity freeze test 7) Insulation test 8) Wet leakage current test 9) Ball drop test 10) Impact test
	a) Increase, or b) Decrease: <0,38 mm	Does not require retesting
Material	The chemical composition of the interlayer changes such as polyofefin elastomer (POE) and polyvinyl butyral (PVB) and vice versa.	All testing items[a]

[a] Under this condition, the module shall be considered as a new product and subjected to all the testing items in accordance with ISO/TS 18178.

The comparison between IEC TS 62915 [24] and the ISO ISO/TS 21486 [25], shows that some tests are the same, others as in the case of the thermal cycles vary in number, while other tests as in the case of impact are different (see the comparison between the module breakage test (MST 32) and the Ball drop test). This differentiation in testing protocols is because the tests are derived from two different sectors: PV and construction.

A clarification is given here regarding the hail test. The IEC retesting includes repeating the Hail Test MQT17 only if the front sheet is polymeric. MQT17 has a standard hail ball diameter of 25 mm, while hail balls in building material testing are required to have a diameter of 20 or 30 mm. With IEC TS 63397:2022 (2022) "*Photovoltaic (PV) modules - Qualifying guidelines for increased hail resistance*" [27], an extended hail resistance test is available where the hail ball diameter varies from 25 to 80 mm in 5 mm increments. This would serve both IEC and ISO. However, hail testing is not included in the ISO TS 18178 [19].

In the current landscape, manufacturers aiming to comply with the complete PV and construction standardization frameworks find themselves compelled to execute the sequences specified by both IEC and ISO standards and technical specifications. Consequently, there is a need to strike a balance between BIPV customization and quality assurance through clear retesting when modifications are made. Ideally, efforts should be directed toward establishing a common agreement to define a unified sequence that accommodates the expressed needs of both standards. This would contribute to a more streamlined and efficient process for manufacturers in the BIPV value chain. Clarification and improvement of the current situation is a task for JWG 11-Building-Integrated Photovoltaics (BIPV) linked to ISO/TC 160 and IEC/TC 82.

2.5.3 DOUBLE CERTIFICATION

Standard PV modules are subject to electrotechnical certifications according to IEC standards. By contrast, BIPV modules, being building components that perform a specific function, are subject to building certifications in addition to electrotechnical ones.

Manufacturers wishing to market their BIPV products would thus have to test them for electrical and building requirements. Testing against IEC or equivalent standards alone would only meet the electrical requirements. However, as seen above, the claimed performance will not be related to any building application, and the manufacturer would have to perform/repeat other tests complying with the regulations for market introduction of construction products.

As a reference example, the path for manufacturers to bring their products to the European market would be as follows:

Since PV modules are electrotechnical products used in systems with a maximum DC system voltage of 1500 V, the LVD (2014/35/EU) [18] applies for the electrotechnical requirements. Communication C 326/4 (14.9.2018) [28] lists the harmonized standards for LVD compliance. These include EN IEC 61730-1 and -2 [29], [30]. Since testing according to safety standards is linked to those of the 61215 series, manufacturers must comply with both the EN IEC 61215 and EN IEC 61730 series.

It should be noted that, as of the publication of this document, the EN IEC 61730 (2018) standard [29], [30] remains valid in Europe since the 2023 version has not undergone parallel voting. The EN version is currently under development.

Finally, for inverters, the EN 62109 series [31], [32] safety standards are listed but EN 50583-2 [5] is not mentioned.

For the construction part, the European manufacturers will have to take the path specified by the Construction Products Regulation (CPR) [16] that refers to specific harmonized standards. In the absence of such standards, they can voluntarily use the reference EAD of the construction systems such as the EAD for ventilated facades, EAD090062-00-0404 "Kits for External Wall Claddings Mechanically Fixed" [33], to assess other system-related performance such as wind resistance, impact resistance, and mechanical strength.

As a result, manufacturers have to test their products for both the electrical and construction regulations that define the market introduction conditions, often having to perform the two different tests required for the same or very similar technical requirements.

Furthermore, existing procedures are frequently designed for products with singular functions, unlike BIPV modules that are multifunctional. For instance, in the construction industry, tests typically exclude electrical components such as solar cells from the assessment.

While having double certification to meet diverse product requirements is seen as acceptable by the industry, the need for double testing of the same requirement raises concerns about increased costs, time, and uncertainty for manufacturers in choosing the appropriate path.

2.5.4 COST, TIME, AND UNCERTAINTY

The integration of BIPV, incorporating renewable energy into the built environment, holds the potential to define the future of sustainable architecture. However, realizing the effective market deployment of BIPV technology hinges on addressing three key challenges: cost, time, and uncertainty.

1. Cost

The multifacetted capabilities of BIPV products, as previously emphasized, demand the fulfilment of specific requirements tailored to different target sectors both for market introduction and for application. Given the interfaces between sectors and diverse technical regulations, there is a heightened need for comprehensive planning and a clear understanding of the process leading to appropriate authorisation.

The inherent complexity of these products contributes to elevated costs associated with the qualification and certification process. BIPV laws and regulations are extensive, and often these systems must undergo testing and approval to secure a building permit, thereby further increasing their costs.

Insurance companies frequently impose additional requirements on buildings with BIPV systems due to the system's complexity and the absence of clear procedures for fully describing BIPV.

It is essential to consider that BIPV technologies are often produced in small series with a low degree of automation, and specialized modules are in demand in building-integration projects. To address these challenges, a promising strategy involves implementing new testing procedures, based on existing ones, that account for the unique nature of BIPV products while avoiding redundant testing.

Estimating the cost increase of BIPV over traditional building methods is complex, as it varies with factors such as product type, required functionality, and specific location within a building. Nevertheless, it is crucial to acknowledge that the pursuit of customization is often essential for expressing innovative architectural languages, even if it necessitates additional testing due to product variations.

2. Time

The certification process outlined for BIPV modules not only increases costs but also extends the time required to bring a BIPV product to market. The need for extensive testing to meet diverse requirements related to product multifunctionality prolongs the certification process considerably.

Most building standards for building skin systems do not consider products generating electricity, including electrical and electronic components, necessitating adaptations that are not readily evident. This often requires interpretation of how to conduct a BIPV module performance assessment or test, further complicating timelines in conventional construction processes that do not align with the practical needs of production or construction sites.

Achieving full certification for a PV product according to IEC standards typically takes four to six months, assuming that no issues arise during testing. This duration is relatively lengthy for certifying the PV electrical component but is necessary.

However, given the multifunctional nature of BIPV, the building component must also undergo testing with distinct validation paths for different countries.

In Europe, for example, when a particular product lacks coverage by a harmonized standard, manufacturers can voluntarily follow the relevant European Assessment Document (EAD). EADs are documents adopted by the TABs (Technical Assessment Body) organization for issuing European Technical Assessments (ETAs). Normally, EADs have been developed for other products than BIPV, and lack references for electrically active components or materials like structured glass commonly found in PV modules.

For instance, in the absence of a harmonized standard, a manufacturer intending to build a facade using a cladding kit with a BIPV component featuring a front glass cover may be tempted to follow EAD 090062-00-0404 [33], which is applicable to mechanically fixed wall cladding kits. However, the EAD explicitly states that "This EAD does not cover cladding kits or cladding elements made of glass".

The manufacturer should submit an application to the referenced TAB and initiate a procedure. In such cases, the timeline could extend by up to two years.

This issue is evident, making it challenging for manufacturers to fully adhere to certification formalities for each different product. Consequently, manufacturers often follow independent testing paths and assessment procedures taking responsibility on the final product quality and performance warranty.

3. Uncertainty

Given the complex nature of the BIPV certification framework, there is a significant level of uncertainty in the market, particularly among small producers. While large manufacturers can navigate these complexities with appropriate time and cost planning for the most relevant projects and involving specialized consultants and experts, smaller counterparts often encounter challenges that act as barriers to the mass market deployment of their BIPV products.

Straddling the construction and renewable energy sectors, each with distinct regulatory landscapes, BIPV manufacturers are grappling with the challenge of defining a clear regulatory path. BIPV products encounter different standards and regulations, also derived from regional, national and local/municipal regulations, resulting in additional costs and complexities. For example, in Austria, it is possible to construct buildings with BIPV products according to Austrian Institute of Construction Engineering (OIB) guidelines, but these are not harmonized among all Austrian federal states and as a result, additional local municipal requirements may apply. Internationally, for example in the United States, most building codes follow the International Code Council (ICC), but municipal and county governments (about 40000) have exercised the right to specify local changes.

In large-scale projects, the necessary resources are probably available to meet the required costs and timelines, affording the flexibility to implement tailored validation procedures developed specifically for the project. By contrast, in small projects, these challenges are too demanding, the cost is too high and there are no resources to address and develop specific tests and procedures.

To address these challenges, building upon existing standards and developing procedures that consider the unique nature of BIPV products with clear and standardized rules, balancing the producer’s responsibilities and the performance assessment/testing, could facilitate market entry for all manufacturers and enable global product sales.

3 BIPV TESTING PROCEDURES

Successful integration of photovoltaic (PV) technology into building products requires appropriate evaluation of their performance, which must be in line with both building codes and PV-specific standards. The specific criteria for this assessment depend on the intended use of the building components integrated into the PV system. Although European standards, particularly the EN 50583 series [4] [5], have outlined a framework for these assessments, and international standards, such as the IEC 63092 series [14] [15], also refer to them, multifunctional BIPV products are in a state of uncertainty when it comes to the qualification processes. The absence of a clear framework and some regulatory gaps hinder the efficient implementation and widespread acceptance of these innovative products.

In bringing BIPV products to market, a key consideration is harmonious compliance with two sets of standards: electrical standards (such as those specified by the International Electrotechnical Commission, IEC) and standards and requirements derived from the building codes. BIPV products are designed to perform multiple functions in addition to power generation. They increasingly use different materials that must coexist within a single, unified building component. These components include electrically active and non-active elements which, when assembled, affect each other, leading to changes in electricity-generating performance and building requirements. These changes include critical aspects such as energy performance, heat dissipation, mechanical and electrical safety and fire behaviour, among others.

What makes this assessment particularly complex is that the different performance aspects of BIPV products are intensely interdependent. For example, changes in the active PV component can affect the overall behaviour and safety of the entire product. These complex performance relationships have only been partially explored.

In addressing these interactions, the quality evaluation must extend beyond the application of testing methodologies outlined individually in PV standards or building codes. This report underscores the necessity for a comprehensive approach, wherein a BIPV module is assessed against pertinent building and electrotechnical requirements.

Some testing methodologies and approaches developed in the BIPVBOOST project by SUPSI, Tecnalia and CSTB [9], relating to the mechanical and electrical safety of BIPV products, are summarized in the following chapters. The BIPVBOOST project proposed new performance-based techniques for testing and evaluating BIPV products to fill existing regulatory gaps and provide a comprehensive framework to address the challenges and uncertainties associated with the certification and widespread acceptance of multifunctional BIPV products in the construction industry. These innovative procedures are distinguished by their utilisation of a performance-based approach focused on Limit States (LS). The reported procedures, which are currently undergoing validation, are presented for informative purposes regarding R&D on BIPV quality. More information can be found in D5.2 BIPVBOOST project [9].

Other procedures regarding energy economy and fire risk were developed in the BIPVBOOST project but are not reported here as they are outside the scope of this Activity E4 report. Some of them are included in reports from other Activities in Subtask E of the second four-year phase of Task 15.

The following chapters provide a summary of the contents published in the D5.2 report [9] of the BIPVBOOST project [7] relating to electrical and mechanical safety.

In addition, Section 3.4 presents the results of a testing procedure developed at NTNU [34], [35] to quantitatively implement the wind-driven rain test of BIPV roofing that is outlined in EN 50583-2 [5].

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3.1 ELECTRICAL SAFETY

Assessing the electrical safety and performance of BIPV systems or components is of paramount importance when transitioning from conventional passive building materials to electrically active elements. This transition represents the convergence of two historically separate fields.

To address the dual nature of BIPV products, the proposed testing procedures are designed to evaluate the electrical aspects, as already set by reference PV standards, while ensuring compliance with limit states representative of BIPV operating conditions. These procedures focus on the following key considerations:

- Assessing potential increases in operating temperatures of BIPV products caused by variations in thermal insulation and shading conditions, which can lead to an increased risk of overheating.
- Evaluating the suitability and durability of materials and components used in constructing BIPV products to ensure they can function as intended under potentially higher temperatures while maintaining long-term safety and performance levels.

Two specific procedures for assessing electrical safety are reported, taking into account the unique operational challenges faced by BIPV products compared to traditional photovoltaic systems:

- The first procedure, reported in 3.1.1, aims to establish reference and maximum operating temperatures for BIPV, taking into consideration the mounting method and shading scenarios. This includes defining temperature-related boundary states, referred to as thermal classification, to facilitate performance evaluation. The proposed test procedure is still in a preliminary validation phase.
- The second procedure, reported in 3.1.2, following the previously introduced thermal classification, describes a novel accelerated ageing test, which combines external stress factors and severity levels as defined by IEC TS 63126. This innovative ageing sequence has been developed specifically for BIPV. It allows the evaluation of key performance and safety limit states, such as electrical insulation (according to MST 16, IEC 61730 [12] [13]) and relevant performance parameters, during thermal cycling and accelerated ageing tests. This approach significantly reduces testing time and laboratory costs compared to standard photovoltaic ageing tests.

3.1.1 BIPV OPERATING TEMPERATURES IN NON-CONVENTIONAL SCENARIOS

The primary goal of this testing procedure, which was proposed and developed by SUPSI [36], is to ascertain the operational temperatures of building-integrated photovoltaics (BIPV) when exposed to unconventional shading scenarios and limited cooling conditions. These conditions, specific to BIPV applications, can significantly impact the thermal performance of components exposed to solar radiation. This assessment is crucial for evaluating the effectiveness and durability of BIPV systems, mainly when used in applications like facades, curtain walls, balustrades, pedestrian floors, and BIPV roofs in urban settings that experience irregular shading and variable shading. These conditions can lead to cyclic stress and have implications for electrical safety.

It is important to consider that BIPV products differ from conventional PV modules due to their integration into multi-layer building systems, affecting heat dissipation. Moreover, increased shading leads to the more frequent operation of protective devices like diodes to prevent hot spots. Current PV standards, namely IEC 61215 [10], [11] and IEC 61730 series [12] [13], do not adequately address shading tolerance and the potential overheating of PV devices, a critical concern in BIPV applications.

The central question becomes whether unconventional shading scenarios during regular operation of BIPV devices can induce additional thermal stress that modifes their thermal classification. To address this challenge, three categories of high-temperature operation (Level 0, Level 1, and Level 2) were introduced, Table 3-1, drawing from the IEC TS 63126 technical specification [37]. IEC TS 63126 [37] defines the 98th percentile temperature ($T_{98\%}$), the temperature expected to be met or exceeded for 175.2 hours per year by a PV module.

Table 3-1 BIPV - Thermal Serviceability Limit States

SLS –BIPV Thermal class 0	SLS –BIPV Thermal class 1	SLS –BIPV Thermal class 2
$T_{98\%\ percentile}$ **<70 °C**	**70 °C <**$T_{98\%\ percentile}$ **<80 °C**	**80 °C <**$T_{98\%\ percentile}$ **<90 °C**

This new procedure investigates whether PV modules used in BIPV products will operate at higher temperatures than are usually experienced in open-rack structures. The procedure establishes the Serviceability Limit State (SLS)[1] by assessing potential overheating issues arising from unconventional shading conditions. Additionally, it introduces a Safeguard Limit State (SfLS)[2], which considers the added thermal stresses due to shifting partial shadows.

For the evaluation of Safeguard Limit States, potential events leading to permanent damage include:

- Extended operating time caused by repeated irradiation conditions can lead to the failure of protective devices, such as bypass diodes. During shading, these diodes prevent reverse currents, ensuring the protection of the photovoltaic modules.
- Abnormal load conditions for the BIPV module, such as an operating point near short-circuit conditions, due to severe mismatches between BIPV modules connected in series within a string.

[1] BIPV Serviceability Limit State (SLS): A BIPV product under a frequent use condition can change its behaviour/condition but it must remain reliable and functional for its intended use without damage.

[2] BIPV Safeguard Limit State (SfLS): BIPV under a rare event may suffer permanent damages but it must ensure that people and objects can be evacuated safely. It does not maintain the initial functionality.

- In the case of monolithically integrated BIPV products, which consist of multiple solar cells on the same substrate (typically thin-film technologies), "misuse" and "severe misuse" conditions, as defined in IEC TS 63140 [38], are also examined.

It is important to note that small areas of a PV module may reach high temperatures (>150 °C) during the "hot spot" test or partial shading of a module without bypass diode protection. However, these scenarios are not addressed by this procedure. Instead, it focuses on prolonged operation in thermally adverse mounting configurations and partial shading in operational environments. Finally, it is emphasised that this new test procedure does not replace the hot-spot resistance tests outlined in IEC 61215-2 MQT 09 [11] and IEC 61730-2 MST 22 [13], which serve another distinct purpose.

The main results expected are:

- Determination of expected operating temperatures under normal service conditions (SLS).
- Classification of BIPV products into the three SLSs reported in Table 3-1, which shows the temperature ranges that are the same as expressed in the IEC TS 63126 [37] technical specification.
- Determination of shading tolerance in terms of temperature rise in SfLS due to abnormal operation of protection devices (open bypass diode - refers to a bypass diode in a photovoltaic (PV) module that has failed in an open-circuit condition, meaning the diode no longer conducts electricity).
- Definition of severity levels for subsequent accelerated ageing tests according to IEC TS 63126 [37].

A newly designed test facility was developed, see Figure 3.1. A steady-state solar simulator is equipped with a motor-controlled axis capable of driving different shading masks over the PV module under test with adjustable velocities. The module temperature is monitored using a high-resolution IR camera. During the test, the PV module can be operated at any load condition, including short circuit, open circuit, and maximum power tracking.

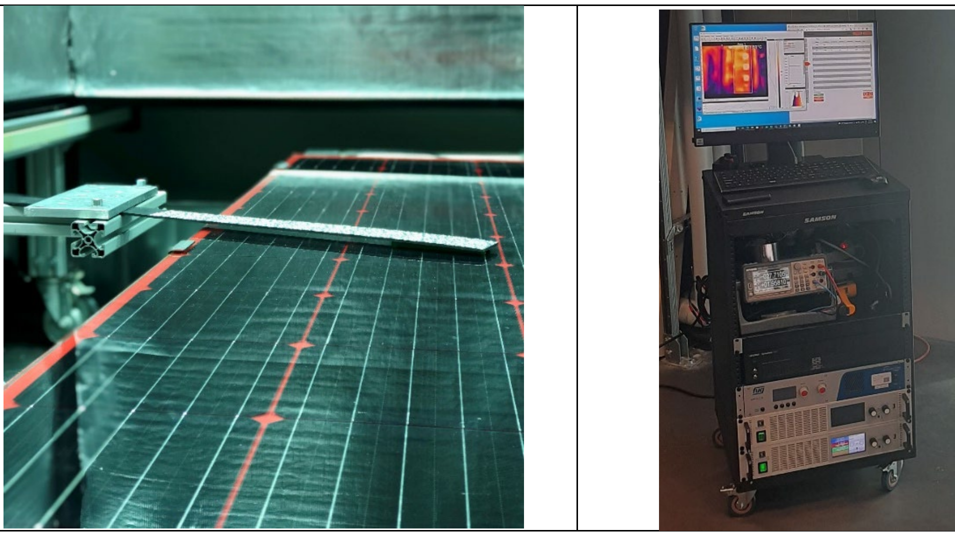


Figure 3.1 Hardware equipment – movable shading mask between the solar simulator and the module (left) and load control and monitoring (right) (source: SUPSI)

The main innovation expected through this procedure is a test method for evaluating and ranking BIPV products in terms of thermal classification, according to IEC TS 63126 [37]. Tests can be conducted on various types of BIPV modules to evaluate how gradual shading affects the operating temperature of BIPV components. Shading conditions can result from fixed elements near the installation, such as poles, chimneys, cables, antennas, or human presence.

The fixed shading masks required by the "hot spot" endurance test (MQT 09 - IEC 61215-2 [11]), where overheating could be caused by defective cells, mismatched cells, shading, or dirt can also be applied within the test procedure. The most challenging shading conditions, which depend on the type of cell used and the level of shunt resistance (low/high), occur based on the size of the shaded area on the cell. Different shading masks with different movement speeds cover the cell area differently and with the possibility of being precisely positioned to replicate the hotspot endurance test.

The test procedure is currently in a preliminary stage, and no relevant results have been achieved so far for validation. This could be a topic for a further research project.

It should also be noted for completeness that the second, revised edition of EN 50583-1 [17], to which various Task 15 participants contributed and should be published in 2024, will also include other types of testing and calculation related to inhomogeneous shading. The focus there is on assessing the risk of glass breakage due to the thermal stress caused by partial shading, and is the result of investigations within the German WIPANO research project, “Thermobruch” [39].

3.1.2 ELECTRICAL SAFETY AND DURABILITY OF ELECTRICALLY INSULATING MATERIALS FOR BIPV PRODUCTS

In the production of photovoltaic modules, the use of polymeric materials is very common. Electrical safety and the reduction of electrical shock and fire hazards in the whole BIPV system largely depends on the electrical insulation properties of such components. The test procedure presented here was developed and implemented by SUPSI [36] to achieve long-term evaluation of the reliability of materials and components, based on their previously determined thermal classification.

Sunlight, moisture, and extreme conditions are the main sources of damage to polymeric materials, including plastics, fabrics and paints. Existing accelerated ageing test sequences, as specified by the IEC standard, require, for this reason, long exposure to UV radiation, thermal cycling, moist heat, humidity, and freezing cycles, followed by measurement of performance and insulation resistance before and after the test. However, these standard procedures do not provide information during the test about the potential deterioration of relevant electrical parameters.

IEC TS 63126 [37] suggests modifications to the standard IEC 61215 series and IEC test methods for BIPV products intended to operate at higher temperatures based on their SLS thermal classification. These changes include increased test temperatures, longer test duration, and modification of test parameters such as current injection, see Table 3-2 below.

Table 3-2 The correlation between the test levels suggested in IEC TS 61326 [37], intended for PV modules operating at elevated temperatures, and the thermal classes defined by SLS for these products.

Standard	Test ref	Test name	SLS Thermal Class 0	SLS Thermal Class 1	SLS Thermal Class 2
IEC 61215	MQT 09	Hot spot endurance test	(50 ± 10) °C	+10 °C, (60 ± 10) °C	+20 °C, (70 ± 10) °C
	MQT 10	UV preconditioning	(60 ± 5) °C	+10 °C, (70 ± 5) °C	+20 °C, (80 ± 5) °C
	MQT 11	Thermal cycling test	(85 ± 2) °C	+10 °C, (95 ± 2) °C	+20 °C, (105 ± 2) °C
	MQT 18	Bypass diode testing chamber	(75 ± 2) °C	+10 °C, (90 ± 2) °C	+20 °C, (100 ± 2) °C
		Part 1	Isc	1.15 * Isc for diode T	1.15 * Isc for diode T
		Part 2	1.25 * Isc	1.4 * Isc for stress	1.4 * Isc for stress
IEC 61730		RTI / RTE / TI	min RTI 90 °C	min RTI 100 °C	min RTI 110 °C
	MST 22	Hot spot endurance test	(50 ± 10) °C	+10 °C, (60 ± 10) °C	+10 °C, (70 ± 10) °C
	MST 37	Material creep test	105 °C	no change	110 °C
	MST 51	Thermal cycle	(85 ± 2) °C	+10 °C, (95 ± 2) °C	+20 °C, (105 ± 2) °C
	MST 54	UV test	(60 ± 5) °C	+10 °C, (70 ± 5) °C	+20 °C, (80 ± 5) °C
	MST 56	Dry heat conditioning	105 °C	no change	110 °C

This test procedure introduces a combination of thermal, electrical, and environmental stresses covering and exceeding the IEC ageing procedures, see Figure 3.2. In addition, it includes the modifications required by IEC TS 61326 [37] for several SLS thermal classes. It also allows monitoring of key electrical safety parameters, such as insulation resistance and leakage current from the PV circuit to the ground, during highly accelerated ageing based on the SLS thermal classification of the BIPV product.

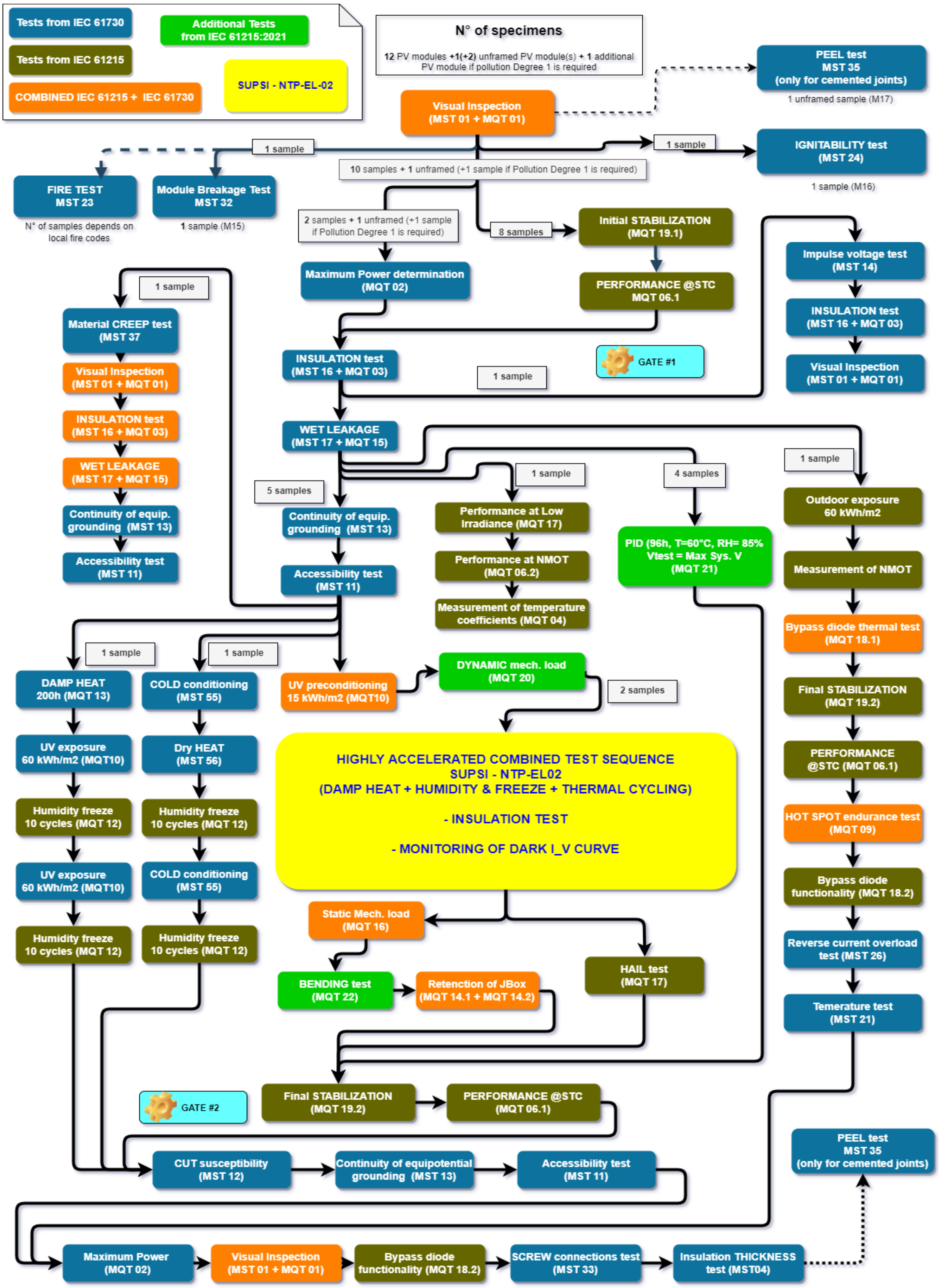


Figure 3.2 The designed test procedure consolidates various aging tests into a single item, significantly reducing the number of samples required. While the standard sequence needs 16 modules, this approach only requires 12 modules. Additionally, in the yellow area, the number of modules needed is reduced from 6 to 2. (Source: SUPSI)

Key points include:

- Definition of a combined test sequence. It is clarified that in this context, a “combined test sequence” means simultaneously performing other tests such as an insulation test while conducting a thermal test.

- Evaluation of degradation rate and electrical fault detection.

- Measurement of the insulation resistance.

The damp heat test is effective in ageing polymeric materials with a good correlation to field data. The inclusion of the humidity-freeze test superimposes additional stress to evaluate the module's ability to withstand the effects of high temperature and humidity followed by sub-zero temperatures, which is particularly challenging for BIPV products. Finally, the thermal cycling test provides the final thermal stress to the device under test (DUT).

To conduct this procedure, a fully programmable thermal chamber has been used together with the SMART RACK system and its control software. This system incorporates and controls all the necessary tools for measuring and recording local module temperatures, measuring the insulation resistance of the test sample with a programmable hi-pot (high-potential) tester, and monitoring the electrical load conditions of the test sample.

The overall ageing sequence takes about 60 days, during which key electrical performance and safety parameters, such as insulation resistance and leakage current, are monitored in real time.

This test procedure greatly reduces the time and number of samples required, as any failures or excessive performance degradation can be detected early, avoiding costly and time-consuming re-testing procedures.

The testing procedure, encompassing both the sequence and simultaneity of tests, can theoretically be applied to all families and types of modules. It is important to emphasize that this procedure is a preliminary proposal. The results will need to be evaluated through further research on this topic.

3.2 MECHANICAL SAFETY

The BIPV system and its components must be designed, installed, and maintained to ensure long-term functionality, and reliability for their intended purpose. The system must be able to withstand various actions and influences during installation and use, avoiding damage or experiencing only controlled damage from pre-defined events, impacts, or consequences. Reliability levels can be specified for the entire BIPV system or its components.

The "working life" of the system signifies the expected period for its intended use, considering maintenance but excluding major repairs. Designing working life aids in selecting design actions, evaluating material deterioration, estimating life cycle costs, and devising maintenance strategies. Mechanical requirements outlined in this report, such as wind load resistance, resistance to point loads, and impact resistance, not only for the modules but also for the mounting systems, are crucial for ensuring safety and accessibility during use.

Numerous studies in the literature have explored aspects of the mechanics of the BIPV system, discussed the verification of applicability for non-regulated building products such as BIPV, examined the mechanical strength of glass/glass modules according to encapsulant type and operating temperature, and discussed the post-breakage integrity of BIPV modules for overhead glazing applications [40] [41] [42] [43] .

However, despite these contributions, there are still technical gaps that require further experimental approaches.

The goal of this chapter is to address essential requirements for the mechanical resistance of building products. Factors like the presence of solar cells and different operating temperatures distinguish BIPV products from traditional construction products. BIPV products, for example, typically operate at higher temperatures and larger temperature gradients, e.g. induced by non-homogeneous shading conditions, causing thermo-mechanical stresses, as addressed in Annex C of the revised EN 50583-1:2024 [17] and the underlying research project report [39].

The following two sub-sections introduce procedures for assessing essential mechanical characteristics of BIPV products, integrating building standards' main criteria with essential electrical safety characteristics.

Specifically, the essential characteristics investigated include the impact resistance of the cladding component, using a performance-based approach considering hard and soft body impacts, with a focus on serviceability and safety during use. The second sub-section addresses the static load resistance (safety in use) of a BIPV cladding component.

3.2.1 BIPV IMPACT RESISTANCE

This paper reports a novel testing approach that integrates photovoltaic limit states into construction ones and assesses the impact resistance of BIPV technology to external forces. The objective is to evaluate the product's post-impact integrity, encompassing not only mechanical properties but also assessing electrical integrity implications. Current impact tests are conducted according to different standards for building and electrical requirements.

Commonly, impact tests for photovoltaic certification rely on the MST 32 module breakage test, as outlined in the IEC 61730-2 standard [13]. However, these tests employ prescriptive criteria that solely consider specified values relating to glass breakage, neglecting the overall product electrical performance and structural state. It is crucial to note that IEC 61730-2 [13] explicitly states that for integrated or elevated applications in buildings, additional tests may be necessary to comply with relevant building codes.

By contrast, impact tests on construction products do not consider the electrical components and vary based on the product type, function, and performance requirements. For instance, in Europe, the EN 12600 [44] standard outlines a pendulum impact method for glass components, classifying them based on impact performance and failure mode. However, this standard does not specify application-specific or durability requirements, which are defined by other standards that are relevant to different component applications.

The proposed procedure developed and implemented by SUPSI [45] integrates both aspects. It considers not only safety but also the application and specific use, considering the effect of temperature on BIPV material characteristics.

Initial results emphasize the importance of test conditions in BIPV products that have a significant effect on impact resistance. The temperature and polymer type used for encapsulation play crucial roles in determining impact resistance properties. Amorphous polymers, chosen for transparency, exhibit a "rubbery" behaviour at room temperature with substantial viscoelastic dependence on temperature.

Apart from temperature, impact resistance is also influenced by the materials and applied treatments. For laminated glass, thermal tempering provides a range of resistance probabilities, determined by equipment specifications and specific component characteristics.

While theoretically applicable to various BIPV products, such as prefabricated modules, roofing tiles, and glass-glass modules, specific tests tailored to product requirements must be developed based on this general procedure.

The methodology focuses on analyzing individual BIPV components, assessing both their electrical performance (e.g., electrical insulation) and mechanical behaviour (e.g., breakage and cracking after impact). Recognising the distinction between mechanical and electrical limit states is crucial, as some products may experience glass breakage without compromising electrical components, and vice versa.

Preliminary results from the BIPVBOOST project [46], conducted on a limited number of samples, suggest that the new procedure could potentially reduce costs and the number of tests required by existing regulations. However, further testing on a larger number of samples is essential to validate these findings. The goal is to provide guidance for the development and enhancement of BIPV products, establishing a potential reference procedure for qualification and market introduction.

This does not imply that the testing procedure conducted on a representative sample can be directly applied to BIPV modules of different sizes and varied mounting conditions. However, for various product types, one might rely on the procedure to avoid the repetition of numerous tests from different standards.

3.2.1.1 GENERAL PROCEDURE FOR IMPACT RESISTANCE TESTING OF BIPV PRODUCTS

To qualify BIPV products effectively, testing procedures with defined reliability requirements are crucial. The proposed procedure serves as a guiding framework for product development, avoiding specific value prescriptions. It assesses reliability performance based on design engineering principles, calculations, and software tools, aiming to simplify testing and reduce associated time and costs.

The procedure outlines, similar to the approach taken in the previous section 3.1.1 for evaluating potential shading issues, the Limit States (LS) with varying levels of electrical and construction safety, depending on the product.

Three key limit states are introduced:

- BIPV-Serviceability Limit State (SLS): Under normal conditions, the product should remain reliable and functional without damage, such as enduring wind loads without compromising safety.
- BIPV-Safeguard Limit State (SfLS): In rare events, the product may suffer permanent damage but must ensure safe evacuation, still withstanding unexpected mechanical loads.
- BIPV-Ultimate Limit State (ULS): The product collapses, and safety conditions are no longer guaranteed.

This procedure applies to BIPV products with polymeric materials and an electrically active component. The impact points are defined and tested in temperature-controlled scenarios to evaluate the polymer material used in solar cells as an encapsulant.

Three distinct testing scenarios have been defined:

Scenario 0: Laboratory Ambient Temperature

- Maintained at (25 ± 5 °C) to align with standard photovoltaic test conditions.
- Corresponds to the Performance at Standard Test Conditions (MQT 06.1) outlined in IEC 61215-2 [11].

Scenario 1: Low Temperature

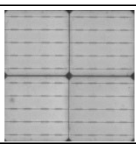
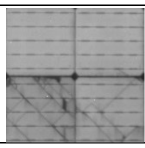
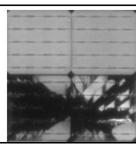
- Sets the cell temperature at -20 °C, following standards like EN 16613:2019 [47] for glass products.
- Aligns with the verification temperature for low-temperature impact resistance, determined by EN 16613 [47].

Scenario 2: High Temperature

- Defined based on IEC TS 63126 [37], with two categories (Level 1 and Level 2) for high-temperature operation.
- The specific high-temperature value detected is product-dependent and serves as a boundary condition, with Level 2 temperatures applicable to products with insulated substrates under elevated ambient temperatures.

For the building part, general limit states align with European standards, including European Assessment Documents (EAD) and harmonized EN standards. Electrical limits for photovoltaics consider insulation losses according to IEC 62446-1:2016 [48]. The limit state of the final product, given its multifunctionality, is determined as soon as the first condition (electrical or mechanical) is met in the construction or electrical part.

Table 3-3 Impact Safety - Limit state assessment for BIPV products

	Serviceability **SLS**	**Safeguard** **SfLS**	**Ultimate** **ULS**
		ELECTRICAL Limit States	
Electrical Insulation*	> 40 MΩm² ± 5% (measurement uncertainty)	> 1 MΩm²	< 1 MΩm²
Energy loss**	5%	5-20%	>20%
Cell crack f(T)***	**No circuit interruption or solar cell breakage**	**Micro-cracks or fractures in one or more cells may be present without involving most of the solar cell area**	**Breakage affecting most of the area of one or more solar cells**
Electroluminescence images.			

Note	* Quantifying electrical insulation provides a measurable metric for assessing electrical safety in BIPV products. This parameter facilitates the evaluation of the product's electrical condition post-impact, offering valuable insights into limit states. ** By contrast, energy loss, a quantitative measure, is not inherently tied to safety. Instead, it may be indicative of improper operation within the active component. Instances of energy loss due to failure also carry economic implications, impacting the initial investment. *** Cell failure, although not directly linked to electrical safety, leads to performance reduction and potential future concerns. This qualitative parameter is considered due to its implications for electricitiy generation and the prospect of subsequent failures. The crack detection procedure utilizes electroluminescence (EL) imaging, a non-destructive testing method applicable to components installed with specialized procedures.		
	MECHANICAL Limit States Detailed acceptance criteria will be specified in the specific procedure, aligning with EAD or harmonized EN standards. The criteria will be tailored based on the technology/material, product category, and intended use.		
	Serviceability SLS	**Safeguard SfLS**	**Ultimate ULS**
No deterioration, no penetration, no perforation	**No cracking is considered as showing "no deterioration" for all the impacts.**	**The presence of any cracking or penetration is observed.**	**Destruction of the skin (perforation) is shown**

3.2.1.2 IMPACT RESISTANCE TESTING ON VETURE KITS – FIRST TEST RESULTS

As part of the BIPVBOOST project, a procedure was implemented to assess the integrity of multifunctional BIPV facade cladding with integrated insulation. The tested Veture KIT (referring to a prefabricated unit for external wall insulation and its fixing devices), installed on the project demonstration site in Morbegno, Italy, consists of a photovoltaic glass laminate at the front, followed by fibre-reinforced mortar cladding, and mineral wool insulation at the back, see Figure 3.3.

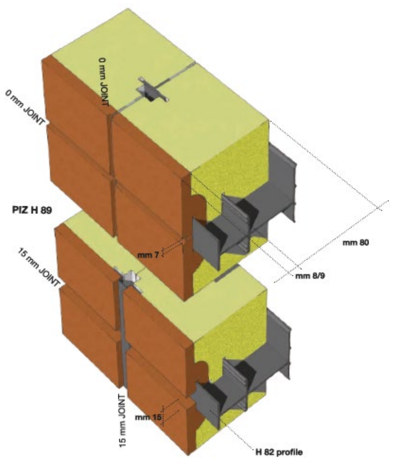


Figure 3.3 PIZ rock metabio H89 panel on the left and ePIZ with glass-glass PV laminate mounted on wall on the right.

The evaluation focused on resistance to external impacts, considering both mechanical properties for "safety in use" requirements and potential implications on electrical integrity after impacts. The testing adhered to primary construction product standards, including ISO 7892:2012 [49], EAD 040914-00-0404 for Veture kits [50], and the EN 50583:2016 series [4], [5]. International photovoltaic standards like IEC 61215 series [10], [11], IEC 61730 series [12], [13], and IEC 63092 [14], [15] were also considered.

Tests were conducted in the SUPSI PVLab using equipment compliant with the IEC 61730 series [12], [13], along with impactors specified by EAD 040914-00-0404 [50]. An infrared camera with electroluminescence imaging assessed the photovoltaic cells' integrity post-impact. Results are presented as a test case, organized by the specific usage category defined by EAD 040914-00-0404 [50] (categories IV and III, i.e. building facade zones that are “out of reach from ground level”, and not “likely to be damaged by normal impacts caused by people or by thrown or kicked objects”, respectively).

It is crucial to note that the performance-based approach for building products delineates distinct performance levels based on specific usage categories, whereas the standards for PV products only prescribe minimum resistance values. Due to the absence of information on impact resistance, testing according to the proposed procedure begins with lower forces, progressively increasing to ascertain the highest possible impact resistance, as illustrated in Table 3-4 for the case of Category IV.

Table 3-4 Impact test category IV (a facade zone out of reach from ground level).

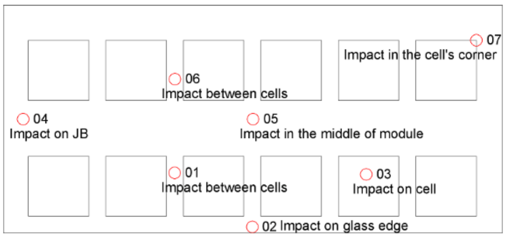
Hard body impact Weight: 0.5 Kg Impact: 1 J (height 0.2 m)	**Requirement after impact** Not penetrated Not perforated	
Soft body impact Weight: 3 Kg Impact: 10 J (height 0.34 m)	**Requirement after impact** No deterioration	

Figure 3.4 Hard body impact test equipment (left) and detail (right).

Figure 3.5 Soft body impact test equipment (left) and detail (right).

The outcomes demonstrate that the Veture KIT sustained its operational state within defined limits, with no compromise to the mechanical performance of the module, see Table 3-4 and Table 3-5, Figure 3.4, Figure 3.5 and Figure 3.6. This type of PV-VETURE KIT is suited for installation as a construction product in use category IV (e.g., high position on facades; warning against the use of cleaning gondolas on the facade).

Table 3-5 Veture KIT Performance results - Category IV (a facade zone out of reach from ground level).

ID	Impact	Position*	Mechanical status	Electrical results
1, 2	Hard body	From 01 to 07	No glass breakage No glass penetration/perforation No cell breakage	Insulation test MST 16 - No electrical insulation loss Insulation resistance > 500 MΩ -
1, 2	Soft body	From 01 to 07	No glass breakage No glass deterioration No cell breakage	Insulation test MST 16 - No electrical insulation loss Insulation resistance > 500 MΩ -

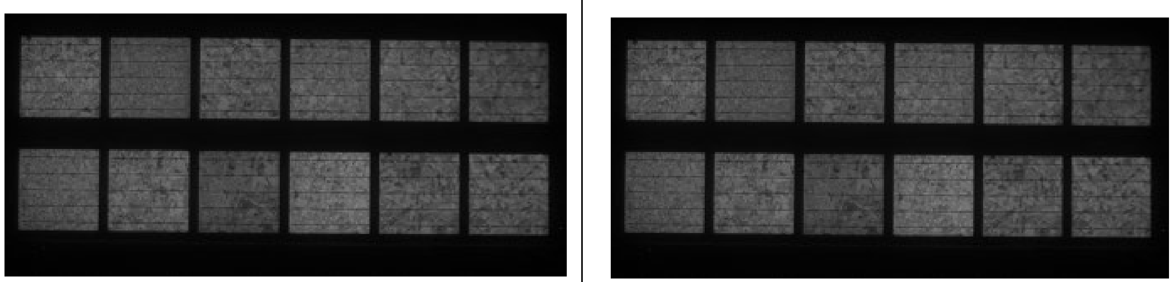


Figure 3.6 Electroluminescence images after a hard body impact (left) and after a soft body impact (right); no damage to cells (left and right).

The product underwent testing for Category III, characterized as "A zone liable to impacts from thrown or kicked objects." In the Category III assessment using a soft-body impactor, the PV Veture KIT maintained operational and mechanical integrity, meeting EAD 040914-00-0404 standards [50]. Electrical performance showed no deviations from the specified limit state, as confirmed by electroluminescence analysis.

In the hard body impactor test, rear glass breakage occurred in both samples without electrical loss or damage to photovoltaic cells (see Figure 3.7). While the mechanical integrity of the glass was not maintained, no penetration or perforation occurred, meeting Category III test criteria per building product standards.

The electrical tests revealed no evidence of insulation loss in the examined specimens. The Wet Leakage Current Test (MQT 15) [51] and electroluminescence analysis (Figure 3.8) did not detect impact-related issues. So, limit states were reached also with glass breakage. However, glass breakage could potentially impact the electrical limit state under future conditions, e.g. moisture penetration causing loss of insulating properties.

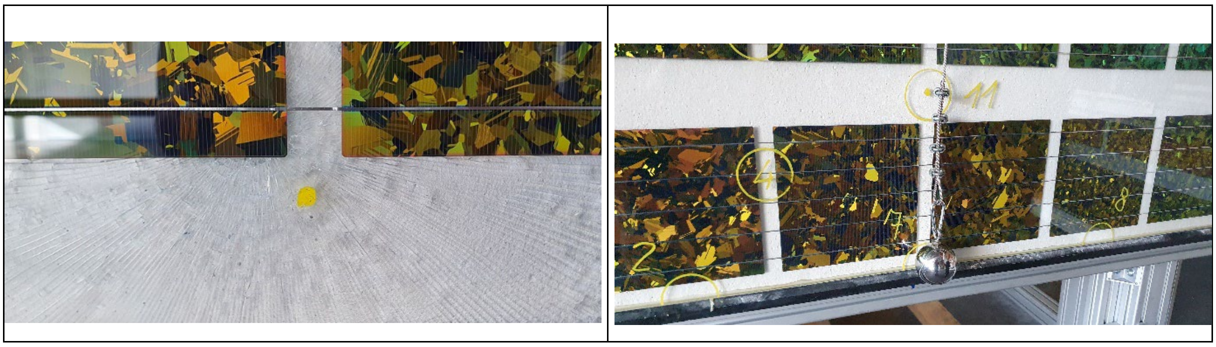


Figure 3.7 Hard body impact breakage of the rear glass - ID 1 (left) and on the edge ID 2 (right)

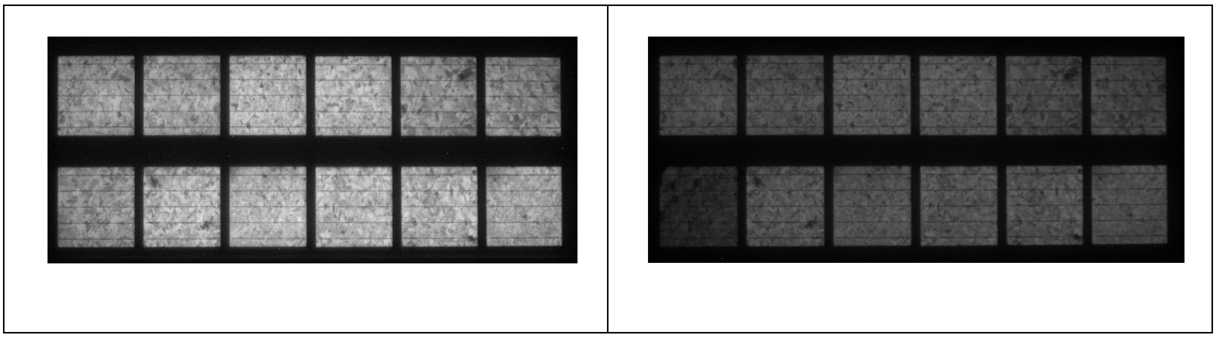


Figure 3.8 Electroluminescence before hard body test (left) and after a hard body impact - ID 2 (right)

Table 3-6 Summary of results

ID	Impact	Position	Mechanical status	Final Electrical Measurements After Mechanical Testing
1	Hard body	05	Rear glass breakage No glass penetration/perforation No cell breakage	No electrical insulation loss • Insulation test according to MST 16: Insulation resistance > 500 MΩ • Wet leakage current test MST 17: Insulation resistance > 500 MΩ
2	Hard body	02	Rear/front glass breakage No glass penetration/perforation Single cell dark response	No electrical insulation loss • Insulation test according to MST 16: Insulation resistance > 500 MΩ • Wet leakage current test MST 17: Insulation resistance > 500 MΩ
1, 2	Soft body	From 01 to 07	No glass breakage No glass deterioration No cell breakage	No electrical insulation loss • Insulation test according to MST 16: Insulation resistance > 500 MΩ • Wet leakage current test MST 17: Insulation resistance > 500 MΩ

3.2.1.3 ASSESSING IMPACT RESISTANCE: EXPLORING TEMPERATURE EFFECTS ON PHOTOVOLTAIC LAMINATED GLASS

An investigation has been initiated by conducting an impact test on a laminated photovoltaic glass to understand the impact of operating temperature on the tests and their consequences for limit states. Table 3-7 presents the product specifications.

Table 3-7 Product and system specification for the impact test

Module typology	Glass-glass BIPV
Module dimension	1,004 x 1,680 mm^2
Number of solar cells	60
Solar cell typology	Crystalline silicon (c-Si)
Electrical solar cell connection	Series
Number of junction boxes	1
Number of bypass diodes	3
Front glass thickness and thermal treatment	3.2 mm / Thermally toughened glass
Rear glass thickness and thermal treatment	3.2 mm / Heat-strengthened glass
Encapsulant type	EVA
Number of EVA films and thickness	4 / 0.38 mm each one
Fixing type and number	2 back rails attached to the long edges
Rail width	2 cm

The product is made of a 60-cell (6 x 10) crystalline silicon (c-Si) module encased in thermally toughened glass at the front and heat-strengthened glass at the back, with an area of 1,004 x 1,680 mm^2. The encapsulant used is ethylene vinyl acetate (EVA), a common material in photovoltaic applications.

Figure 3.9 Impact test equipment and sample ID 2 of laminated glass

The impactor used is a 0.5 kg steel ball. The choice of a hard-body impact test is motivated by the ability of the polymer to absorb impact energy through elastic/plastic behaviour. With soft-body impact, the deformations are higher due to a longer impact time than in the hard-body impact.

Elevated temperatures (90 °C) can cause thermal expansion and deformation in the size of the hard body (steel ball). However, this aspect is not considered to be critical to the test outcome.

To assess the post-impact integrity of the photovoltaic (PV) system, an infrared (electroluminescence) camera was positioned outside the chamber to allow internal sample imaging.

Tests were carried out at various temperatures, revealing intriguing outcomes, as indicated below. However, the results presented are not exhaustive given the limited sample size and the variability in observed behaviour. The mechanical performance of glazed elements under diverse temperature conditions warrants further investigation and in-depth analysis. This complexity arises from various factors, including glass treatment, impact point, and the lamination process. The tested glass modules were uniform in type, featuring identical dimensions, solar cell count, thickness, and composition.

To determine the change in mechanical state (breakage) of the solar module/cell, tests on each sample were performed by increasing the drop height by about 7 cm until the new mechanical state was reached.

Table 3-8 Correlation between fall height and impact energy

Hard body - mass [m] 0.5 kg	
Gravity acceleration – [g] 9.8 m/s^2	
Heigh [h] meter	Impact energy [Joule]
0.61	3.00
0.68	3.34
0.75	3.68
0.82	4.03
0.89	4.37
0.96	4.71
1.03	5.06
1.10	5.40
1.17	5.74
1.24	6.09
1.31	6.43

Test A - Ambient temperature (+25 °C):

In the case of the ambient temperature of around 25 °C, the glass breakage threshold was reached at various values of the impact energy, ranging from 4.37 J to 6.43 J (Joule), see Table 3-9. When breakage occurred, both the front and back glass layers were compromised, resulting in damage to the solar cells across all three modules.

Table 3-9 Hard body impact test conducted at an ambient temperature (25 °C) on laminated glass-glass BIPV module as specified in text.

ID	Position	Impact energy [J]	Cell temp	Mechanical status	Electrical results
1	Middle	3.00	25 °C	No glass breakage	No cell breakage
		...		No glass breakage	No cell breakage
		4.37		Glass breakage (front/rear)	Cell breakage
2	Middle	3.00	25 °C	No glass breakage	No cell breakage
		…		No glass breakage	No cell breakage
		6.43		Glass breakage (front/rear)	Cell breakage
3	Middle	3.00	25 °C	No glass breakage	No cell breakage
		…		No glass breakage	No cell breakage
		5.40		Glass breakage (front/rear)	Cell breakage

Electroluminescence analysis revealed that not only the solar cell corresponding to the impact point or its immediate vicinity (as indicated in Figure 3.10 by a red arrow in the image) was affected but also non-adjacent cells.

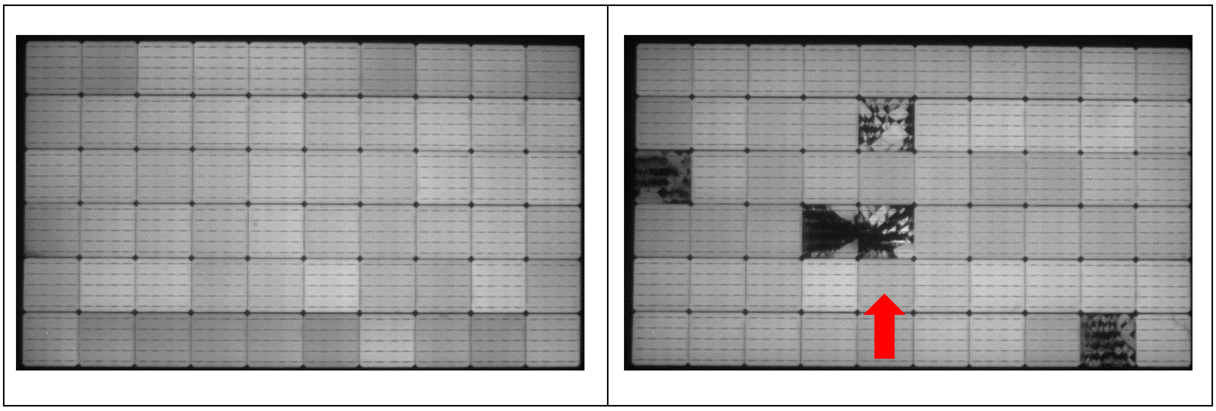


Figure 3.10 PV module before the impact (left) and after the impact (+25 °C) (right). Electroluminescence made on "ID 3"

This phenomenon suggests that the energy wave propagates through the module, causing high stress at positions where these waves are reflected (at the edges) or superimposed (in the middle between impact and the edge). However, to validate this hypothesis, further investigation involving a larger sample size is essential.

Test B - High Temperature (+90 °C):

The impact energy threshold resulting in glass breakage was slightly lower than observed in the room temperature test, ranging from 3.68 to 5.40 J, see Table 3-10 and Figure 3.11.

Table 3-10 Hard body impact test conducted at a high temperature (90 °C) on laminated glass.

ID	Position	Impact energy [J]	Cell temp	Mechanical status	Electrical results
4	Middle	3.00	90 °C	No glass breakage	No cell breakage
		...		No glass breakage	No cell breakage
		3.68		Glass breakage (front)	No cell breakage
5	Middle	3.0	90 °C	No glass breakage	No cell breakage
		…		No glass breakage	No cell breakage
		4.37		Glass breakage (front/rear)	Cell breakage
6	Middle	3.0	90 °C	No glass breakage	No cell breakage
		…		No glass breakage	No cell breakage
		5.40		Glass breakage (front/rear)	Cell breakage

In the "ID 4" test sample, only the front glass cover broke, with no discernible damage or power reduction in the photovoltaic cell. By contrast, test samples "ID 5" and "ID 6" exhibited breakage in both the front and back glass covers, along with damage to the PV cells, mirroring observations from the ambient temperature tests. Electroluminescence analysis revealed a distinct form of cell breakage compared to earlier tests, showcasing diagonal cracks on cells both adjacent and non-adjacent to the impact point (see Figure 3.11).

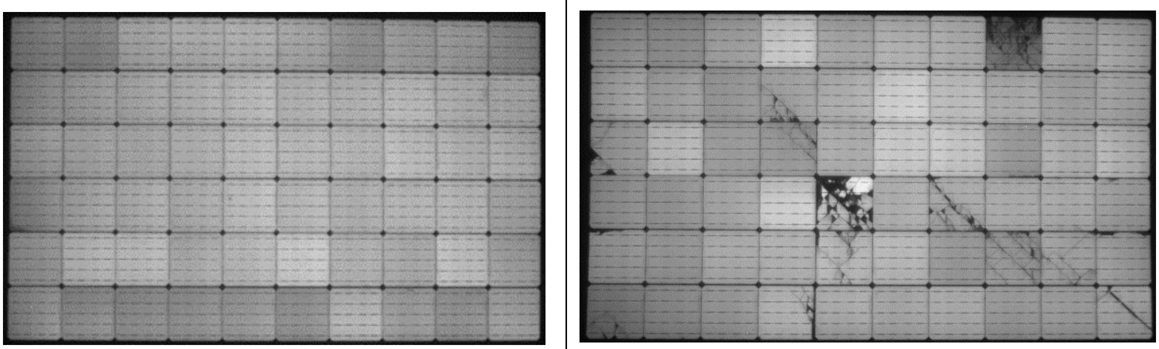


Figure 3.11 Electroluminescence images made after impact (+90 °C) on PV module "ID 4" (left) and on "ID 5" (right)

Test C - Low Temperature (-30 °C):

The impact energy threshold resulting in the low-temperature tests was conducted at a chilling -30 °C, resulting in glass breakage consistently observed at an impact energy value of 5.40 J across all tests, see Table 3-11 and Figure 3.12.

Table 3-11 Hard body impact test conducted at low temperature (-30 °C) on laminated glass.

ID	Position	Impact energy [J]	Cell temp	Mechanical status	Electrical results
7	Middle	3.00	-30 °C	No glass breakage	No cell breakage
		...		No glass breakage	No cell breakage
		5.40		Glass breakage (front)	Cell breakage
8	Middle	3.00	-30 °C	No glass breakage	No cell breakage
		...		No glass breakage	No cell breakage
		5.40		Glass breakage (front/rear)	Cell breakage
9	Middle	3.00	-30 °C	No glass breakage	No cell breakage
		...		No glass breakage	No cell breakage
		5.40		Glass breakage (front)	No cell breakage

In the "ID 9" test, the absence of solar cell breakage following the front glass cover breakage should be noted. For the photovoltaic laminated glass samples labelled as "ID 7" and "ID 8" (refer to Figure 3.12), electroluminescence analysis indicated a distinct pattern of solar cell breakage, differing from the observed behaviour at room and high temperatures.

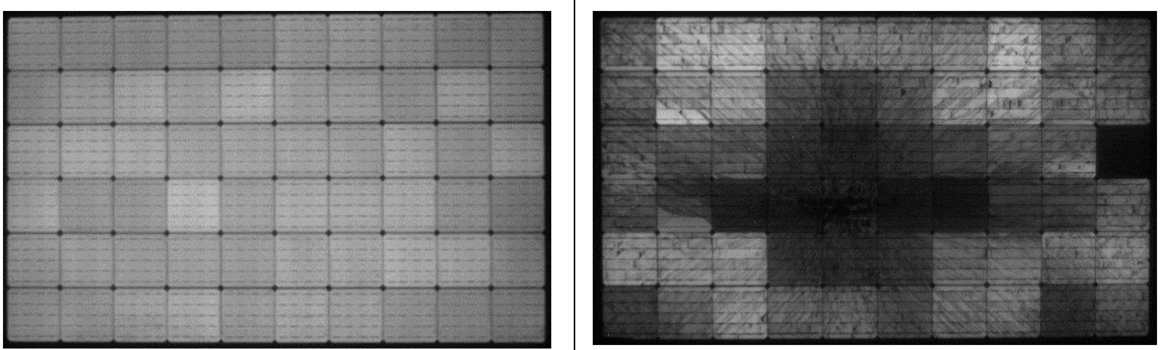


Figure 3.12 Electroluminescence made after impact (-30 °C) on PV module "ID 9" (left) and on "ID 7" (right)

3.2.2 STATIC MECHANICAL LOAD TESTING OF BIPV PRODUCTS

The outlined procedure is derived from the Static Mechanical Load Test (MQT 16) stipulated in IEC 61215 [10], [11] but refrains from enforcing prescriptive values. The assigned values are contingent upon the product's category and intended application, as dictated by pertinent construction standards. This method entails a laboratory examination conducted indoors on a single component, with the primary objective of assessing whether deformations induced by mechanical loading impact the active components (solar cells, ribbons, and electrical connections) rather than focusing on the structural safety of the whole system.

To address electrical limit states, the procedure includes electrical insulation tests and electroluminescence tests. Insulation loss is detected by the insulation test (MST 16) and wet leakage current test (MST 17) provided by IEC 61730-2 [13]. The integrity of the electrical circuits and solar cells is verified by analysing photographic images made using the electroluminescence technique and comparing the modules before and after performing the tests.

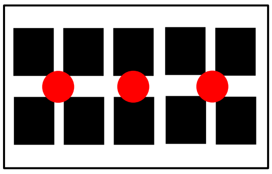
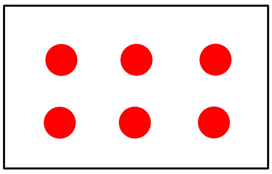
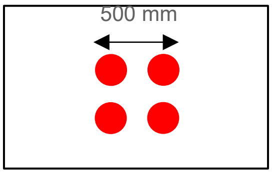
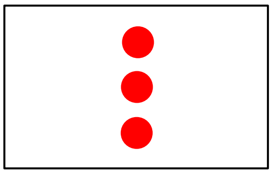
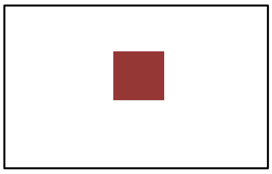
Beside homogeneous load conditions (IEC 61215-2, MQT16), the procedure further incorporates concentrated loads at various temperatures to assess the repercussions of thermal fluctuations on these load typologies, see Table 3-12. In these cases, equipment deliberately developed for mechanical load testing is used.

The BIPV products subject to analysis (taken among those developed in the BIPVBOOST project) consist of prefabricated modules designed for external wall insulation (Veture KIT), glass-free tiles incorporating polymeric materials applied as shingled roofing, and PV laminated glass modules.

Preliminary findings suggest that no insulation losses are evident during bending, and that the electric circuits, along with the solar cells, sustain their integrity both during and after the test. The procedure proves adaptable to diverse classes of BIPV products, demonstrating that, within the deformation limits imposed by construction requirements, the electrical characteristics consistently maintain stability.

The conducted tests affirm that deformations resulting from typical static loads encountered do not compromise the electrical integrity of BIPV modules. However, it is crucial to emphasize the need for further investigation to broaden the application of these results to other configurations of solar cells and PV modules. Table 3-12 documents specific details regarding the results for each product analysed.

Table 3-12 Static mechanical load test for BIPV products. Test description

Product	Distributed load design	Test description
PV Veture KIT		i) Test carried out using the minimum test load value of 2400 Pa reported in IEC 61215-2 [11] in the chapter Static Mechanical Load Test (MQT 16) ii) Test carried out increasing pressure ranges until failure or permanent deformation of the PV module. Starting from the minimum test load value of 2400 Pa given in IEC 61215-2 [11] in the chapter Static Mechanical Load Test (MQT 16), the test load value was increased with intervals of 200 Pa as given in EAD 040914-00-0404 [50] in Annex E Wind suction and pressure load test.
PV roof tile		i) Test according to IEC 61215-2 [11] in chapter Static Mechanical Load Test (MQT 16). The test has been carried out with a test load of up to 2500 Pa.
PV laminated glass	  	i) Deformation limited to 65 or 50 mm (EN 16612 [52]) "in absence of any specific requirement" (up to load test of 2500 Pa) ii) Concentrated linear load and 10 alternating cycles of compressive and tensile forces to verify positive/negative deformations iii) Concentrated load tested at different temperatures in a climatic chamber (25 °C, 85 °C, and -40 °C). The load consists of 5 cement cubes (each with a side length of 20 cm) stacked on top of each other, weighing 8 kg each. 2% module tilt to simulate the roof tilt angle.

- **PV Veture KIT:**

The test, see Figure 3.13, conducted in accordance with IEC standards 61215 [10], [11] (2400 Pa – minimum test load) revealed no alterations in the mechanical and electrical behaviour of the module during and after testing. However, increasing the pressure in line with the wind suction and pressure load test for a PV Veture KIT, as outlined in the EAD 040914-00-0404 [50], resulted in deformations and cracks of the sealing mortar. Nevertheless, the PV cells maintained their electrical insulation and cell integrity status.

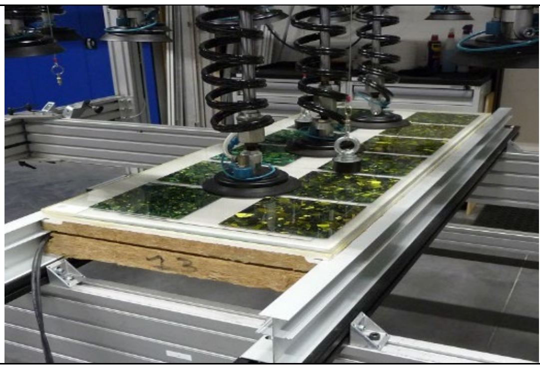


Figure 3.13 Mechanical load test applied on Veture KIT.

- **PV Roof Tile:**

The roofing tile, containing no glass and featuring a CIGS-based active photovoltaic component designed for flexible modules, exhibited no significant deformation-related issues under load, see Figure 3.14. Testing performed on a BIPV tile demonstrated no repercussions on the PV segment, even after substantial deformations. The tests indicated that, for this product type, there were no deviations in the electrical performance, even under substantial deformations exceeding the limit state for construction products.

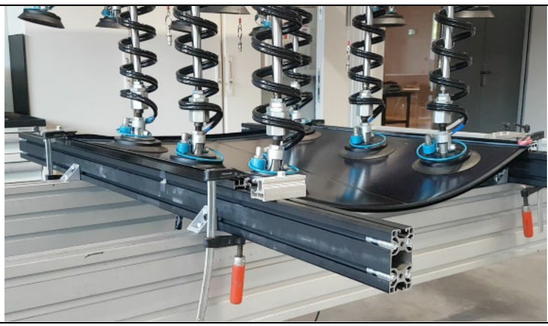


Figure 3.14 Deformation of PV roof tile under mechanical load. Great deformation is detected without damage

- **PV Glass Laminates:**

The photovoltaic glass laminates utilised have the characteristics as defined in the Table 3-13.

Table 3-13 Features of tested BIPV glass-glass laminates.

Front glass cover	Clear float glass, thickness 3 mm, thermally toughened glass
Encapsulant	POE transparent - 2 sheets each 0.5 mm thick
Cell	Monocrystalline cells M3 158.75 mm x 158.75 mm
Back glass cover	Clear float glass, thickness 3 mm, heat-strengthened glass
Area	701 mm x 1032 mm

The BIPV glass-glass laminate was positioned beneath the mechanical load test apparatus, supported by two rails perpendicular to its longer side at intervals of one-third and two-thirds of its length, see Figure 3.15. The module was attached by four fastening clamps typically utilized for conventional modules.

It is crucial to note that these tests were not conducted according to a specific standard or regulation. Various load scenarios that are feasible with the laboratory's equipment were employed to assess whether deformations could impact the electrical limit states.

Uniform static loads (non-dynamic loads) were applied, each with a distinct load footprint shape. Additionally, in certain described tests, sequences of positive and negative (static) loads were applied across 10 cycles.

The specific features of these tests are outlined below, see also Table 3-12.

i) In the first test, suction cups were centrally positioned to create a square-shaped load impression area measuring 500 x 500 mm². The glass underwent a maximum deformation of 50 mm, as specified by EN 16612 [52]. No changes in the electrical limit states of the module were recorded.

ii) A second test involved a linear load represented by suction cups positioned in the middle of the module, perpendicular to the long side. The maximum observed deformation was 80 mm. Additional tests to verify positive (compressive force on the front glass cover) and negative deformation (tensile force on the front glass cover) were conducted through 10 cycles of pressure and traction. The tests demonstrated that for deformations consistent with building product requirements on laminated glass, there were no alterations in the electrical state. Breakage of the solar cells or changes in electrical insulation were observed only together with glass breakage.

iii) Finally, three concentrated load tests were performed on the same type of PV laminated glazing at different temperatures to evaluate whether temperature could cause a change in the electrical limit state. Throughout the tests, no alterations in the electrical state of the tested samples occurred. At an operating temperature of 85 °C, a permanent deformation of 9 mm perpendicular to the surface of the photovoltaic laminated glass was observed. With the span between supports measured at 650 mm, this deformation translates to approximately 1.4% of the span length.

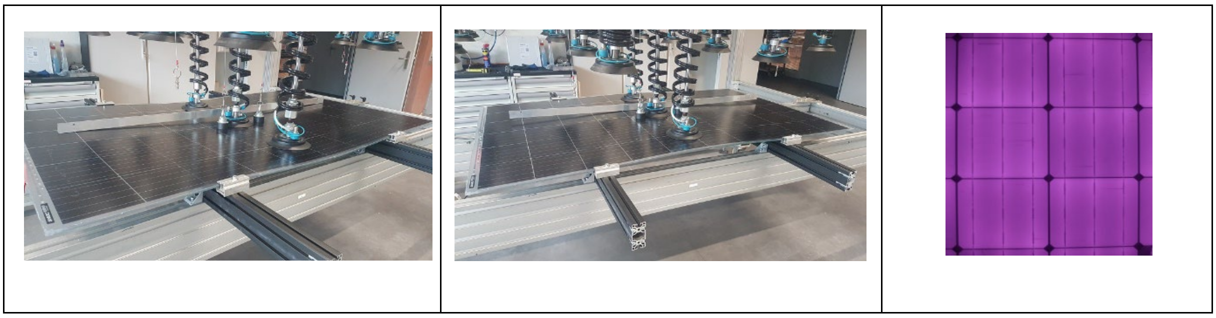


Figure 3.15 Tests made with compressive load (push; left), with tensile load (pull; centre), and electroluminescence image of a laminated PV module (right).

3.3 STRUCTURAL INTEGRITY IN STANDARDIZATION DEVELOPMENT FOR BIPV

The essential requirement of mechanical resistance refers to the fundamental criteria that construction products must meet regarding their ability to withstand mechanical stresses and maintain structural integrity. This includes factors such as load-bearing capacity, stability, and durability under various conditions. The purpose of testing is to ensure that construction products contribute to the overall safety and stability of buildings and civil engineering works, and that they can withstand the mechanical forces they are likely to encounter during their intended use. Adherence to these mechanical resistance requirements is crucial for the compliance of construction products with standards.

As construction products, BIPV modules have to be designed to withstand the wind, snow, and other applicable loads as well as meeting other requirements set out for structural and user safety. In this framework, the current revision of the BIPV standard, EN 50583-1 [4], applies this approach to photovoltaic modules that contain at least one glass pane and which are used as construction products. As stated in the scope, this standard applies to BIPV modules with one or more glass panes. Since ISO 12543-1 [53] defines laminated glass as “an assembly consisting of one sheet of glass with one or more sheets of glass and/or plastic glazing sheet material joined together with one or more interlayers”, most BIPV modules are per definition laminated glass units and shall comply to the corresponding standards.

The structural integrity of BIPV modules must be assessed to ensure compliance with design principles, material selection, durability requirements, and construction standards for the structural design of glass components. Mechanical loads on BIPV modules are caused by the wind, snow, use, maintenance, and – in the case of IGUs – cavity pressure variation caused by the difference between the conditions during IGU production, transport, and installation conditions (altitude difference, barometric pressure difference, and temperature difference). These loads are considered typically by national standards and national regulations that may require additional calculations or tests of unbroken or broken glazing units under static and/or dynamic loads, e.g. to verify residual load-bearing capacity or fall-through prevention.

Depending on the BIPV module configuration and application type, these regulations may apply. Each of the panes being used shall comply with one or more of the respective product standards/evaluations of conformity standards for glass in buildings depending on their composition and/or their thermal treatment.

The current revision of the BIPV standard in EU (EN 50583-1 [4], [5]) is introducing such specifications on BIPV modules that contain one or more glass panes. It also considers temperature effects on the glazing, stiffness properties of interlayers and other influencing factors in structural design, typically used in a performance-based design approach and that previously were not formally requested for BIPV module qualification. This marks a significant improvement on the previously encountered situation when only PV-related criteria were considered before introducing the products to the market.

The indication in the datasheet of the related BIPV category for modules compliant with the building-related standards should also be a criterion to label BIPV components.

3.4 WIND-DRIVEN RAIN TEST (WDRT)

As BIPV are functional elements of the building envelope, they should maintain the weather protection function on the same level as conventional building elements. One of the main types of climatic exposure that affect the building envelope is precipitation in the form of wind-driven rain (WDR).

The wind-driven rain test is a standardised procedure used to evaluate the resistance of building components, such as windows, doors, and wall systems, to water penetration under simulated wind-driven rain conditions. This test is particularly important in assessing the ability of building elements to prevent water infiltration, which is crucial for maintaining the integrity of the building envelope and preventing damage to interior spaces.

The primary purpose of the wind-driven rain test is to assess the water resistance of building components and systems when subjected to high winds and heavy rain.

Among building elements, the BIPV elements integrated into the building envelope should also be considered. These elements include solar panels, modules, or other solar-integrated components that serve as electricity generators and building materials.

The test helps identify potential vulnerabilities in the building envelope that could lead to water leakage, moisture damage, and related issues.

Below is a brief description of a wind-driven rain test and equipment developed at NTNU for BIPV elements applied on the roof [34], [35].

1. ADDRESSED BUILDING and PRODUCT FAMILY
   - Roof cladding system – products such as BIPV roof tiles, shingles, or large glass-glass modules for integration into the roof.
   - This could be extended to any BIPV roof solution claiming watertightness protection or improving it, e.g. PV on metal sheets or on membranes.

2. DEFINITION OF CONSTRUCTION PERFORMANCE REQUIREMENTS
   - place → Europe
   - building product regulation → CPR 305/2011 [16]
   - PV regulations in terms of durability or maximum mechanical load allowed during the test with a combined effect of WIND and RAIN load

3. SPECIFIC REQUIREMENT
   - Primary weather impact protection
     - Protection against rain (rain can be tested without wind – preliminary stage)
     - Protection against rain and wind impact
     - TBC

4. METHODS OF VERIFICATION
   - Watertightness testing
     - Wind-driven rain testing

For BIPV systems intended for roof integration, it is vital to assess their ability to withstand WDR. Information about a test procedure and apparatus is described in the standard EN 50583-2 “Photovoltaics in buildings. Part 2: BIPV systems” [5] in annex A “Resistance to wind-driven rain of BIPV roof coverings with discontinuously laid elements – test method” .

The watertightness level of a system can be expressed by the limit on the amount of water leakage entering through the system. In EN 50583-2 [5], the following criteria are given:

- “A water collector shall be provided, capable of recording/monitoring the amount of leakage water during any pressure step in the test”
- “Reference leakage rate (10 g/m^2)/5 min, 5 min being the duration of a single test step in the sub-test”.

- "The cases, in which leakages exceeding fine spray and wetting on the underside occur, are considered as being too severe for the application. In any case, the reference leakage rate of (10 g/m^2)/5 min shall not be surpassed".

There are four sub-tests (A, B, C, and D) defined in the standard EN 50583-2 [5]. Each specifies a WDR combination appropriate to specific climate zones.

- Sub-test A: low wind speed with severe rainfall rate;
- Sub-test B: low wind speed with high rainfall rate;
- Sub-test C: severe wind speed with low rainfall rate;
- Sub-test D: maximum rainfall rate with no wind (deluge).

As no structural details or drawings of the water collection system are given in EN 50583-2 [5], it is unclear how water collection should be executed. Design of a water collection system and its application for water leakage quantification were proposed by Fedorova et al [35]. If data on quantified water leakages is available, it may be used to evaluate various systems and rank them according to their watertightness level [34], [35].

The principle of the watertightness test for roof coverings is to apply a certain quantity of water spray at various ranges of air pressure differences at various slopes under defined conditions with respect to the exterior surface of a roof specimen to observe if water leakages occur [54], [55]. It is usual to apply a combination of runoff water applied on an upper side of the tested system and water spray that is distributed along the test specimen surface area. Simultaneously, a specific level of air pressure difference (ΔP) is reached between the outer and inner surfaces of the tested specimen [55]. A range of air pressure is applied and increased stepwise. The test specimen is inspected for water passage to its inner surface and water leakage points are registered. As a result, a limit of watertightness can be identified for the tested systems. The limit of watertightness may be described as the maximum level of air pressure applied simultaneously with water spray when no water leakages occur on the tested system's inner side. Test parameters from watertightness test standards are spray rate, air pressure and the duration of these two parameters [56]. Standards mainly focus on manipulation of air pressure ranges, while water spray rate is usually kept constant.

Figure 3.16 Large-scale rotatable box for rain and wind tightness testing of sloping building surfaces (RAWI box), while test is running (left) and RAWI box without a test sample (right) [57].

NT BUILD 421 [58] describes a testing methodology for wind-driven rain exposure on roof systems. The duration of the water spray and air pressure exposure are combined in NT BUILD 421 and lasts for 10 min for each increase of air pressure, while the water spray rate stays constant. Parameters that can be used for such testing are given in Table 1.

The load level 0 (0 Pa air pressure, runoff water) was added along additional levels 6 (600 Pa) and 7 (750 Pa) compared to parameters given in NT BUILD 421. The test is initiated at load level 0, during which the nozzle boom is inactive and only runoff water is applied. At load levels 1-7 (between 100 Pa and 750 Pa, depending on the load level), air pressure inside the box is increased and decreased in cycles (pulses) lasting 5 seconds, for a period of 10 minutes.

Table 3-14 Parameters used during wind-driven rain testing [35]

Load level	Colour mark	Pulsating (dynamic) air pressure intervals (Pa)	Weather condition description	Maximum wind speed (m/s)	Duration (min)
0		0, runoff water	-	0	10
1		0-100	Strong breeze	12.9	10
2		0-200	Fresh gale	18.2	10
3		0-300	Strong gale	22.3	10
4		0-400	Storm	25.8	10
5		0-500	Violent storm	28.8	10
6		0-600	Violent storm	31.6	10
7		0-750	Hurricane	35.3	10

The maximum applied wind speed was 35.3 m/s, which corresponds to extreme weather conditions such as a hurricane. This level is identified as red danger warning, inhabitants usually receive message from municipalities about predicted weather conditions, hazards associated with it and recommendations on how to behave during the period while this condition lasts.

Details of sample mounting, the method of water collection and the approach to set the air pressure difference are provided in [34] [35] **, and illustrated in Figure 3.17, Figure 3.18 and Figure 3.19.**

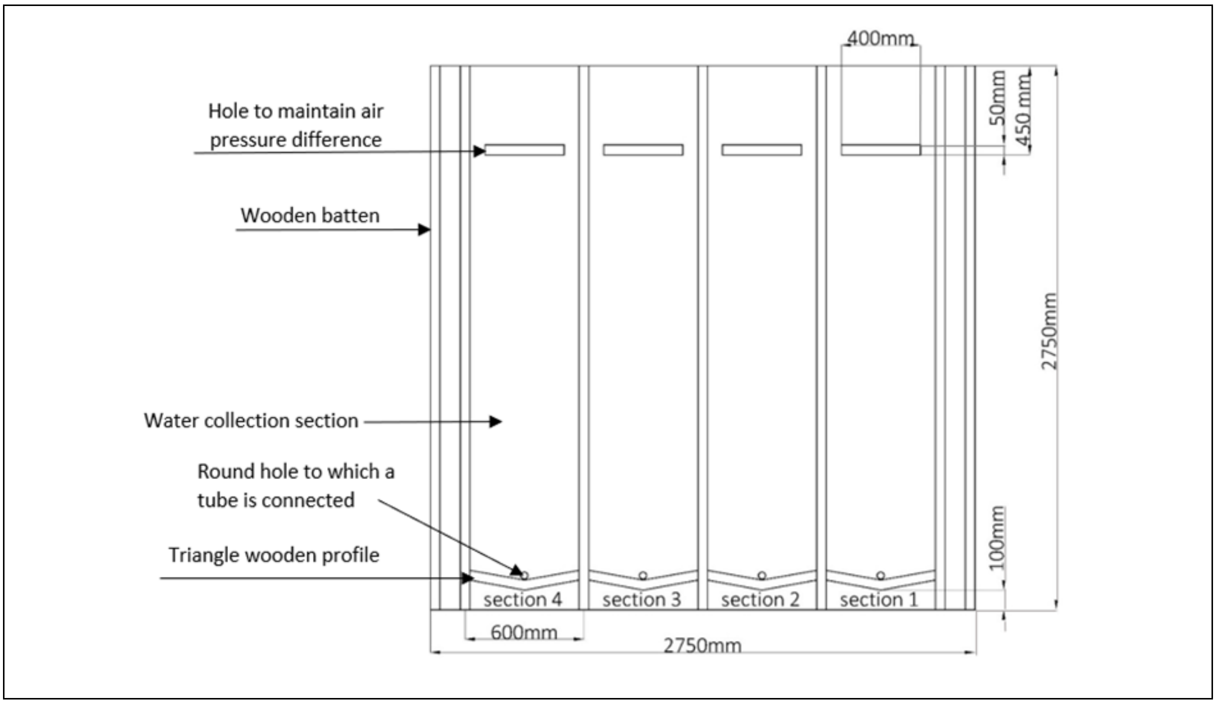


Figure 3.17 Outline of the water collection system [35]

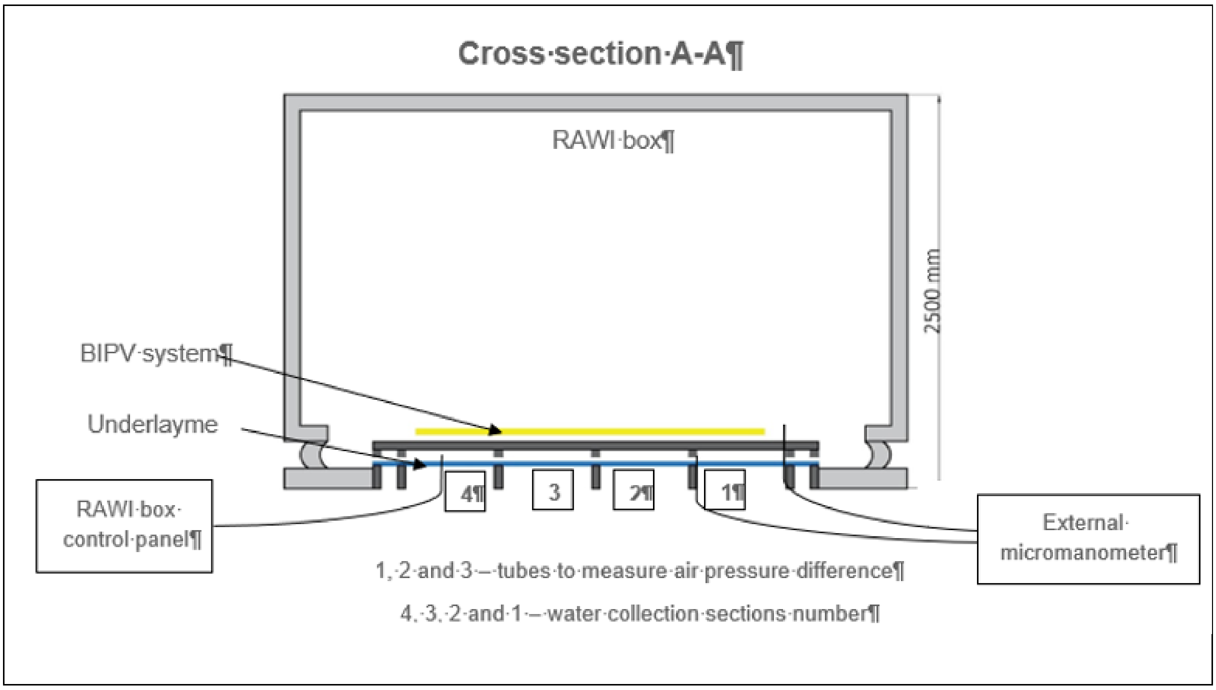


Figure 3.18 Top view of the RAWI box [35]

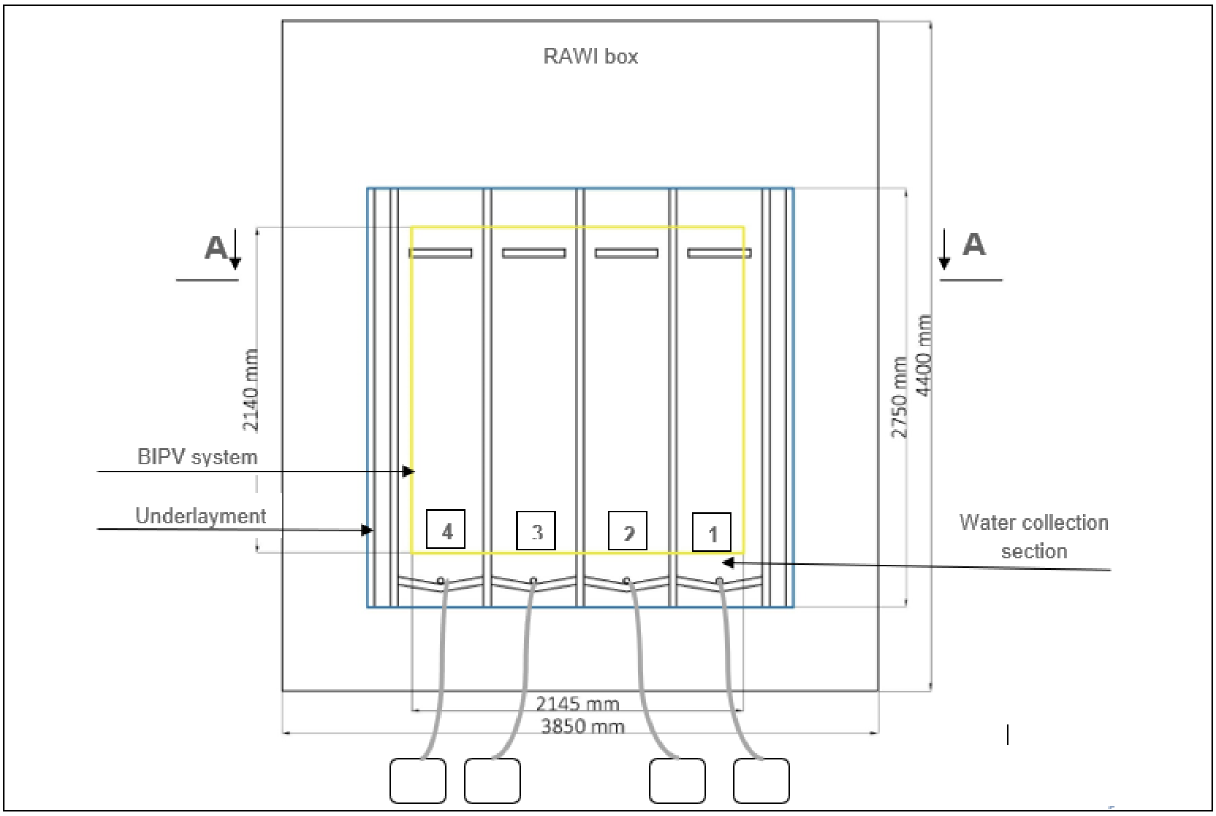


Figure 3.19 Front face of the RAWI box [35].

The testing methodology is summarized below.

Under roof structure

- First, the structure was built using wooden battens.
- Then the underlay, the transparent polycarbonate (Lexan) board, was placed on the wooden structure.
- The underlay was fixed usung wooden battens and screws.
- Holes were cut in the underlay. Four holes in the upper part of it and four small round holes in the lower part. Triangular wooden profiles were placed near each round hole.

BIPV installation

- BIPV system was installed according to instructions in the manual.
- The tube for measuring air pressure was placed on top of BIPV system and put through the closest hole in the underlay.

Sealing tapes

- Before sealing tapes were attached, the BIPV system was assessed to identify an optimal tape placement so water can be drained where it was designed to by BIPV system manufacturer.
- Sealing tapes were attached in the following order: first half of the width of the green tape was placed under the edge of BIPV system, then the 0.15 mm thick polyethylene sheet was attached to the other half of the green tape. White sealing tape (width 60 mm) was placed on top of the polyethylene sheet and the edge of BIPV system, and same tape type width 100 mm was attached on top of previous tape in overlap.
- The waterproof tape was placed on the side of the triangular profile. The double sided sealing tape was placed on each wooden triangular profile and the polyethylene sheet was attached to it.
- The other end of the polyethylene sheet was attached to the test frame using duct tape.

Pretesting

- After taping was finished, the test frame with BIPV system was placed in the RAWI box, tubes were attached to the round holes in the water collection sections and containers for water collection were placed to the respective sections. Tubes to measure air pressure difference were placed and attached to the external micromanometer and the RAWI box.
- A few trial runs were performed to test if taping was watertight. If needed, taping was fixed until there were no water leakages through taping both around BIPV system and in the water collection sections.

WDR testing

- After trial runs, BIPV system was tested with WDR exposure. The test consisted of two phases (30° and 15° inclination). Water leakage points were identified and noted during the test. Air pressure difference levels were monitored. BIPV system was elevated to around 90° and left to dry after phase 1 for around 2 hours. Water that was collected during the test was measured after each phase.

Figure 3.20 Summary of the presented test methodology [40].

4 RECOMMENDATIONS

This report concludes with the following actionable recommendations:

- For International Standards Organizations (IEC and ISO): Strengthen collaboration to address the unique characteristics of BIPV products, carefully analyzing and resolving overlaps between electrical and building standards.
- For Regional Working Groups (CEN and CENELEC): Establish a permanent joint working group that combines expertise from both domains to develop unified standards that incorporate the dual functionality of BIPV as both building and electrical products.
- For National Standards Bodies: Promote collaboration at both regional and international levels to ensure consistency and avoid regulatory discrepancies, at least within Europe.

- For Stakeholders: Leverage dedicated web platforms for BIPV products (e.g., solarchitecture.ch), academic research, and expertise from research institutes to communicate specific needs and requirements of different product types. This collaborative approach can help overcome regulatory limitations and streamline certification processes.

5 CONCLUSION AND OUTLOOKS

Advances in multifunctional building-integrated photovoltaic (BIPV) products, which incorporate various functionalities with both construction and electrically active components, necessitate a thorough quality assessment, including building and PV-related requirements. Product flexibility is key to meet architectural demands, a growing mass-customization is required for the industry, and the need to comply with rules for product market introduction and for the different application cases co-exist. The different scales from component, to building skin system, to building and urban factors, calls for an integrated approach in performance assessment and testing methodologies. This is particularly crucial to support the BIPV market on an international scale, where manufacturers are advocating for clear and streamlined regulations to favour product deployment and cost-competitiveness. Presently, the global market faces challenges due to the lack of uniformity in testing protocols and requirements across different nations. On the other hand, there are good reasons for different requirements in construction because of local requirements and the need to address local challenges such as safety, thermal comfort, climatic variations and local construction models. Such deviations can hardly be unified worldwide. Therefore, simplifying and clarifying the scheme for product market introduction is key. Products today require double market certifications/approvals and costly and complicated retesting procedures are often demanded for customized products because of the lack of a clear reference standard for BIPV products. Unifying testing procedures across some main countries (e.g. in Europe) to streamline the recognition process and reduce costs would also be a step to establish a unified reference framework to enable technical assessments at lower costs. Harmonization of certification processes for construction products to support standardization of BIPV products and enable wide deployment could further ensure consistency in standards and certification processes.

In the European context, a significant stride was made through the BIPVBOOST project [46], focusing on testing-related aspects and providing possible approaches for adapted construction industry standards for qualifying BIPV products. This initiative not only documented the state-of-the-art criteria and requirements for BIPV product qualification but also proposed initial testing protocols. Special attention was dedicated to evaluating operating temperatures, particularly under unconventional shading scenarios. This involved meticulous analysis to correlate shade tolerance with potential malfunctions of protective mechanisms. Furthermore, the project defined multiple levels of accelerated aging tests crucial for validating material suitability.

This proactive approach, currently being implemented in ongoing projects [59], aims to drive advances in BIPV technology by fostering international consensus and facilitating seamless integration into existing regulatory frameworks, paving the way for a promising future for BIPV.

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