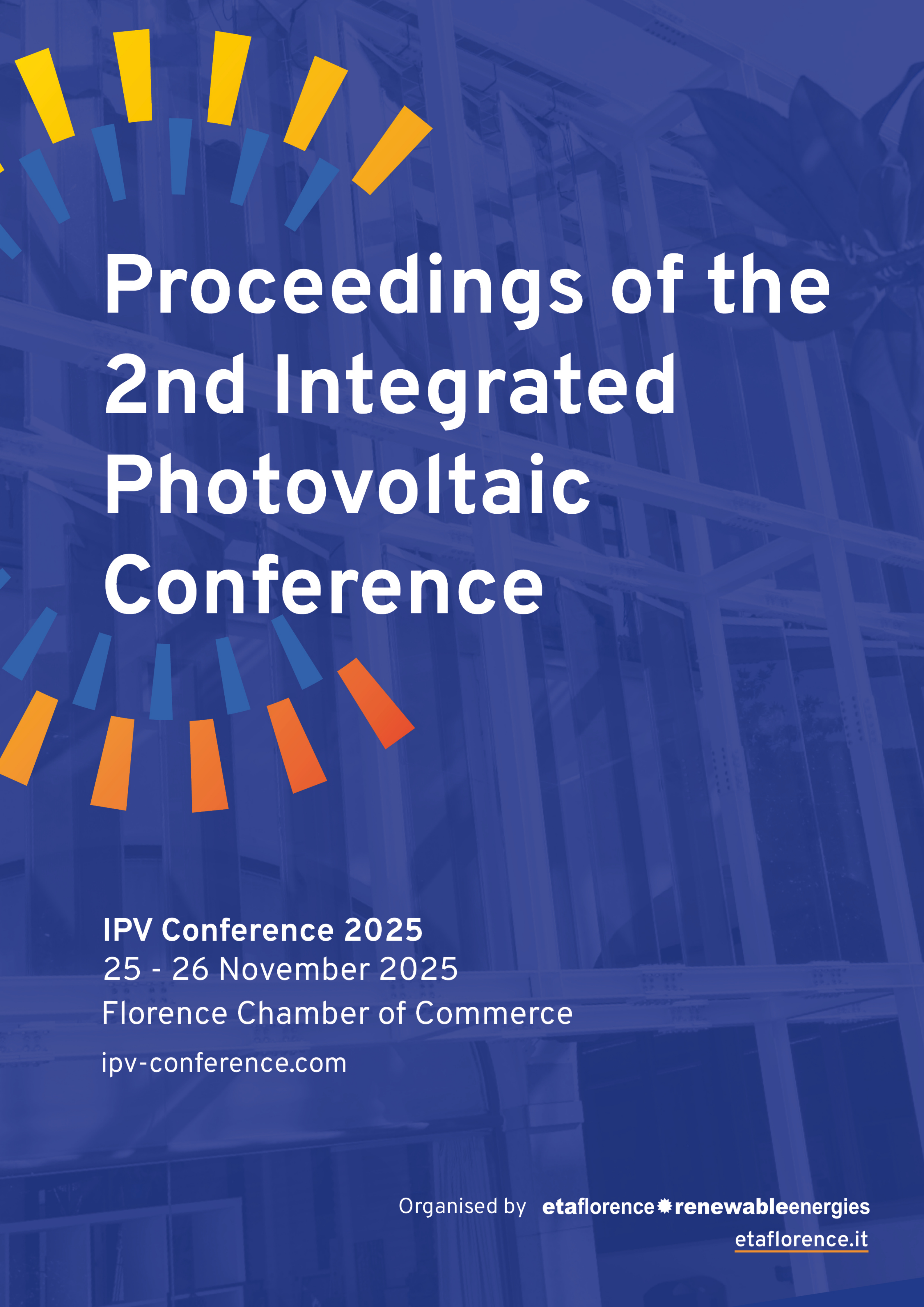

# Proceedings of the 2nd Integrated Photovoltaic Conference

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# 2nd Integrated Photovoltaic Conference

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# 2nd Integrated Photovoltaic Conference

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# BIPV FOR TEGOLA CANADESE ROOFING: PHOTOVOLTAIC INTEGRATION WITHOUT SUBSTRUCTURES

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ABSTRACT: In the context of the building sector's significant contribution to global emissions, Building Integrated Photovoltaics (BIPV) represent an effective strategy for improving energy performance. This research presents the development of a fully adhered BIPV roofing system for metal asphalt shingles by Tegola Canadese, developed in collaboration with Università Iuav di Venezia. The work addresses a key technological gap: as existing BIPV solutions for metal roofs typically require ventilated substructures, limiting architectural compatibility and installation efficiency. The methodology included: (1) analysis of existing BIPV systems and integration barriers, (2) design of a configuration compatible with full-adhesion metal shingle technology, and (3) prototyping and installation testing. The system integrates custom flexible CIGS thin-film photovoltaic modules directly onto Ultimetal HD© Slate shingles using high-strength adhesive bonding, preserving waterproofing, structural integrity, and visual continuity. Tailored protective components matching material and finish ensure cable routing and maintain aesthetic uniformity.
Validation demonstrated technical feasibility, electrical performance, simplified installation, and architectural integration. The system offers competitive advantages such as elimination of substructures, reduced system costs, lower weight, and backward compatibility with existing products. This solution supports wider BIPV adoption and contributes to decarbonization goals in the building sector.

Keywords: Architectural integration, BIPV (Building-Integrated PV), BIPV roofs, Flexible PV, Metal Asphalt Shingles, Metal Roofs.

## 1 INTRODUCTION: PROBLEM CONTEXT

The energy and environmental transition in the building sector represents one of the most significant challenges for achieving climate neutrality by 2050. The construction sector is responsible for a substantial share of global greenhouse gas (GHG) emissions [1][2]: in 2023, buildings accounted for about 32% of global energy demand and 34% of $CO_2$ emissions, including 9.8 Gt from operations and 2.9 Gt from embodied carbon (Fig. 1) [3]. Other analyses indicate that global building energy consumption exceeds 30% [4], and historical $CO_2$ emission values reaching up to 39% [1][5][6]. In 2022, buildings sector emissions represent around a third of total energy system emissions, including buildings operations (26%) and embodied emissions (7%) associated with the production of materials used for their construction (Fig. 2) [28].

This situation largely derives from an obsolete and poorly efficient building stock, the result of decades of limited attention to environmental issues. High energy consumption and the use of high-carbon intensity materials make the construction sector a critical point for climate mitigation [1][2]. The Global Status Report for Buildings and Construction 2024/2025 (UNEP/IEA) indicates the decarbonization of the sector as a necessary condition to achieve carbon neutrality by 2050 [7].

## 2 REGULATORY CONTEXT

### 2.1 Regulatory Framework on Building Energy Efficiency: NZEB and ZEB

In response to these critical issues, the European regulatory framework—particularly the EPBD Recast (Energy Performance of Buildings Directive, 2024)—introduces binding targets for the zeroing of operational emissions and the progressive reduction of Embodied Carbon (EC) [3][6][8], that measures the overall environmental impact and GHG emissions associated with materials and building processes across the entire life cycle of the building (from raw material extraction to end-of-life management). This analysis considers all stages, including raw material extraction, transport, manufacturing, installation, and end-of-life phases [27]. The Directive promotes the adoption of integrated renewable technologies, such as Building Integrated Photovoltaics (BIPV), to reduce reliance on fossil fuels and foster on-site energy self-generation. BIPV systems integrate photovoltaic modules directly as construction materials and energy generators [2][5][7][9].

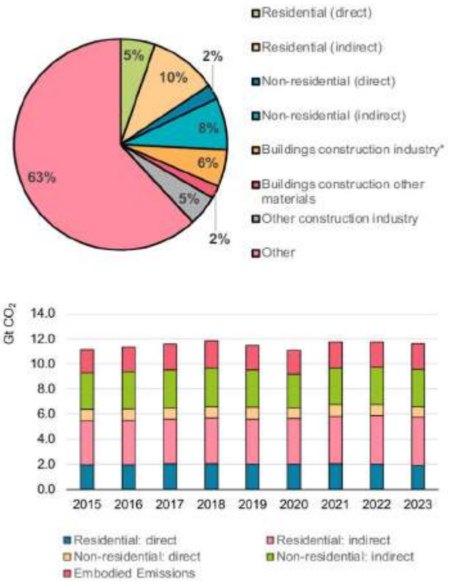

**Figure 1:** Global share of energy demand and $CO_2$ emissions attributable to the building sector, including operational and embodied components (2023).

European policies are founded on two key concepts:

the Nearly Zero-Energy Building (NZEB) and the Zero-Emission Building (ZEB). NZEB is defined "a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" [29]. Operationally, an NZEB must balance its annual consumption with renewable energy production, thereby achieving an overall neutral energy balance [5][10]. Meanwhile, ZEBs represent the natural evolution of NZEBs, characterized by zero operational emissions and relying on total energy coverage from on-site or nearby renewable energy. ZEB is defined as "a building with a very high energy performance […] requiring zero or a very low amount of energy, producing zero on-site carbon emissions from fossil fuels and producing zero or a very low amount of operational greenhouse gas emissions". By 2030, all new buildings must adhere to the ZEB standard, while the entire existing building stock is mandated to achieve carbon neutrality by 2050 [3][5][8][10]. These regulatory objectives align with the trajectory outlined in the IEA Net Zero Emissions Scenario (NZE), according to which operational emissions from the building sector must be reduced by approximately 50% compared to 2022 levels by 2030, while embodied emissions must decrease in parallel—by 25% for steel and 20% for cement within the same timeframe (Fig. 2) [28].

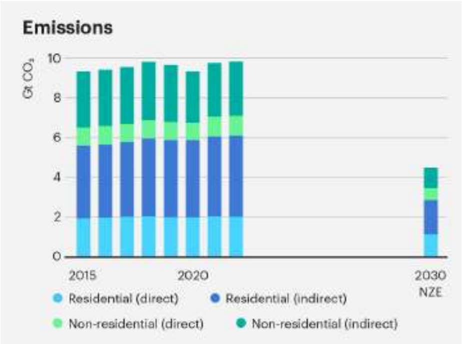

**Figure 2:** Breakdown of operational and embodied emissions of the building sector within total energy system emissions, with decarbonization targets toward the IEA Net Zero Emissions Scenario (2022).

## 2.2 Role of BIPV in the Energy Transition

To successfully achieve the Nearly Zero-Energy Building (NZEB) and Zero-Emission Building (ZEB) standards, energy policies robustly advocate for energy efficiency, the utilization of low-carbon materials, and localized energy production [7]. The incorporation of renewable energy sources, particularly BIPV, is recognized as a pivotal component of this strategy. ZEB mandates require the integration of local renewable energy sources, where technically viable, such as photovoltaic (PV) systems, solar thermal collectors, and geothermal energy [7][8]. BIPV systems are among the most promising technologies for this transition. They facilitate the seamless integration of energy production directly into the building envelope, concurrently reducing construction costs and minimizing negative aesthetic impact [5][4]. The diffusion of BIPV is bolstered by specific economic and financial incentive policies, such as subsidies and concessional loans [2]. Owing to their inherent architectural and functional versatility—which permits application across roofs, façades, windows, and shading elements—BIPV systems represent a strategic asset necessary for attaining carbon neutrality objectives within the building sector.

# 3 STATE OF THE ART REVIEW AND RESEARCH GAPS

## 3.1 Building Integrated Photovoltaics (BIPV): A Comparative Analysis with Building Applied Photovoltaics (BAPV)

Building Integrated Photovoltaics (BIPV) systems constitute a technology that integrates solar energy generation with the structural and aesthetic functions of buildings [13][19][22]. The fundamental distinction from Building Applied Photovoltaics (BAPV) resides in the integrative approach: while BAPV systems are considered add-ons or PV products added on or mounted onto the building without replacing conventional building envelope materials, BIPV modules are specifically designed to replace the conventional building materials or roofing materials themselves, functioning simultaneously as both a building envelope component and an electricity generator. This dual functionality results in compelling cost savings [5][13][14][15]. In contrast, BAPV systems, despite potentially maximizing electricity production through optimal orientation, necessitate additional supporting structures, such as brackets and rails, which generally increase structural loads and may negatively impact the aesthetic integration. Furthermore, traditional BAPV installation often relies on mechanical fixings, which can lead to water tightness issues due to required penetrations into the building structure or envelope.

Conversely, BIPV modules become an integral component of the envelope, providing significant advantages for building retrofitting and renovation, a context where BIPV technology is considered essential. BIPV systems are required to fulfil all the requirements of the building envelope skins they are substituting, including essential performance criteria like weather protection and durability [5][13][14][15].

Economically, BIPV systems offer a reduction in the total construction material costs and mounting expenses. These financial advantages are obtained by offsetting the expenditure associated with conventional envelope materials (such as standard roofing membranes) that are replaced by the BIPV elements. Crucially, BIPV eliminates the need for additional assembly components such as specialized brackets and rails, which are typically required for non-integrated PV systems [5][13][14][15].

The lightweight nature of BIPV components, particularly when utilizing thin-film PV modules (photovoltaic panels where semiconductor layers, only a few micrometres (µm) thick, are deposited onto flexible substrates), makes them inherently suitable for structures with limited load-bearing capacity or for applications on curved architectural surfaces [15][14][16].

Energetically, BIPV systems enhance the thermal performance of the host building by providing a higher insulation value and effectively mitigating the thermal load imposed on the Heating, Ventilation, and Air Conditioning (HVAC) systems [5][9][18]. For instance, studies have demonstrated that BIPV systems can achieve substantial energy savings, including reductions of 12–21% in the annual energy consumption and 14–26%

in the peak cooling demand. Additionally, generating electrical energy directly at the point of use (on-site) leads to savings by avoiding transmission and distribution (T&D) losses associated with centralized power networks [17].

Architecturally, BIPV systems afford considerable design flexibility through the customization of colour, shape, and transparency. This capacity allows for both harmonious aesthetic integration with existing/traditional building materials and the creation of technologically advanced envelope designs. The appearance of BIPV systems is a pivotal factor in adoption decisions [9][18][22].

### 3.2 Analysis of the BIPV Market for Roofing Systems

Roof systems currently constitute the most widespread BIPV application area, accounting for approximately 80% of global BIPV installations [21]. Rooftops are generally the preferred location for solar module deployment, primarily due to the abundance of solar irradiance [15][21] and their tendency to be less susceptible to shading effects caused by adjacent buildings or vegetation compared to façades [12][15]. Pitched or sloped roofs (often referred to as discontinuous roofs) are frequently considered the ideal setting for BIPV applications as they often provide the best energy harvesting conditions [11]. The ability to integrate PV into existing building surfaces negates the need for additional land allocation, which is a significant advantage given the scarcity of ground space [13][14][15][21]. This benefit is particularly pronounced in high-density urban environments [12][16].

BIPV solutions designed for metal roofs primarily focus on systems leveraging flexibility and low weight, particularly suited for flat roofs (or low-slope roofs) and curved surfaces. Alternatively, specific modules are engineered to replace traditional metal roofing components [13][16][23]. Metal roofs typically belong to the category of "continuous roofs", which are structurally defined by an uninterrupted, water-resistant layer [23]. The technological development of BIPV systems for metal roofing has primarily bifurcated into two major directions: Crystalline Silicon (c-Si), which is the dominant PV technology in this segment favoured for its high efficiency, and Thin-Film Photovoltaics (TFPV), valued for its inherent flexibility and capacity to provide a uniform aesthetic appearance [16][17][23].

The significant cost reduction documented in recent years, coupled with regulatory evolution that has established reliable technical standards, made these systems economically viable and created new opportunities, particularly for retrofitting interventions on the existing building stock [9][25][26]. BIPV systems are widely recognized as a fundamental solution for achieving the objectives of NZEB. Furthermore, it is anticipated that the acceptance and market penetration of building-integrated PV will increase progressively after 2020, driven by the mandatory nature of stricter energy regulations [5][9][11][22].

Despite these inherent advantages, significant barriers to adoption persist. For example, BIPV solutions designed for metallic roofs typically necessitate the provision of ventilated roofs using dedicated substructures. This requirement effectively compromises the distinctive advantages of fully adhered roofing systems and alters the original functional identity of the non-PV component.

A recent internal analysis of the European BIPV market validates this trend: 79% of the products still requires a ventilated substructure. The study examined 54 products sourced from 32 manufacturers, focusing exclusively on solutions marketed within the European context; aesthetic or highly customized modules were excluded from the scope of the survey (Fig. 3).

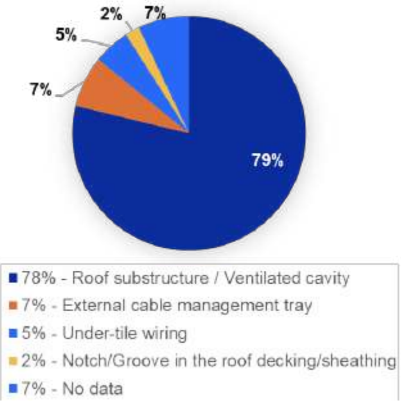

**Figure 3:** Internal market analysis, 2025 – sample: 55 products from 32 EU manufacturers

## 4 RESEARCH OBJECTIVE

This research project aims to address a technological and scientific gap identified in the literature and the building market. Specifically, fully adhered metal roofing systems are currently scarcely investigated in the BIPV domain, and most of the existing systems necessitate the installation of ventilated substructures. Consequently, the primary objective of this study is to develop a new generation of BIPV for metal roofs capable of overcoming the typical limitations of currently available solutions. Specifically, the development goals are :

(A) to eliminate the requirement for ventilated substructures, thereby maintaining the characteristic full adhesion installation method typical of metal roofing, preserving the original waterproofing performance and mechanical resistance of the roof;

(B) to ensure simple and rapid installation method, alongside facilitating easy maintenance;

(C) to guarantee a high-quality aesthetic outcome, ensuring that the photovoltaic elements are coherently integrated with the architectural design and the overall building envelope.

This work starts from a collaboration between Università Iuav di Venezia and Tegola Canadese S.r.l., a leading company in the production of metal roofing. The initiative is part of a broader joint research program aimed at enhancing the architectural and functional integration of photovoltaic systems into building envelopes.

The article presents the outcomes of this development process, emphasizing how the proposed BIPV solution offers a concrete contribution toward achieving the EU decarbonization targets and promoting the large-scale dissemination (or wider adoption) of BIPV technologies, recognized as a pivotal component for future zero-carbon built environments.

## 5 RESEARCH OBJECTIVE

The development and validation methodology of the BIPV system was organized into three sequential phases. To ensure consistency between theoretical analysis and practical application, the research employed a combination of analytical and experimental tools, including a comparative analysis of existing BIPV systems, physical prototyping of components, and installation tests on roof sections. This integrated and iterative approach allowed for progressive validation of the developed solutions and guided the project toward outcomes aligned with the technical, architectural, and aesthetic requirements of the sector.

### 5.1 Phase 1: Sector Overview and Market Analysis

This phase was dedicated to analysing the technological and competitive context of the BIPV sector, with a specific focus on current market trends and the types of photovoltaic solutions available. This preliminary investigation provided the reference framework for understanding sector dynamics and identifying innovation opportunities. The primary objective of this phase was twofold: to understand dominant technological trends and to guide the development of a solution fully compatible with the distinctive characteristics of Tegola Canadese's fully adhered roofing. Phase 1 highlighted that the main limitation of current BIPV systems lies in their dependence on additional substructures, which are incompatible with the construction principles of fully adhered metal roofs. The new solution aims to overcome this limitation.

### 5.2 Phase 2: BIPV Solution Development

Phase 2 focused on the development of a BIPV solution specifically for Tegola Canadese's fully adhered shingles. The design emphasis was placed on achieving full functional and architectural integration while preserving the mechanical integrity and waterproofing performance of the existing roof. The developed solution maintains the distinctive characteristics of Tegola Canadese roofing (direct adhesion, absence of rigid substructures) by applying flexible photovoltaic modules directly onto the surface of the shingles. Engineering development requirements dictated that the system should feature inherent technological upgradability—allowing modules to be replaced or updated without compromising the functionality of the roofing system—high maintainability, facilitating access and intervention on PV components, construction simplicity, and maximum ease of installation.

### 5.3 Phase 3: Prototype Validation

Phase 3, the final stage of the methodology, focused on validating the developed solution. Validation was conducted through physical prototyping and installation testing on a real-scale roof section. The objective was to assess the overall technical feasibility of the system, specifically evaluating waterproofing effectiveness, mechanical resistance under load, and the quality of the final aesthetic integration.

## 6 RESEARCH OBJECTIVE

### 6.1 Base Roof System by Tegola Canadese

To understand our solution, it is essential to describe the base roofing system. The Tegola Canadese system is characterized by lightweight metal-bitumen shingles, installed in full adhesion without ventilated layers or mechanical substructures (Fig. 4). This configuration ensures waterproofing and resistance to extreme weather conditions.

**Figure 4:** Design Ultimetal HD© Slate

Installation occurs directly on the roof's supporting structure, typically over 18 mm OSB panels fixed to the framework. A self-adhesive waterproofing membrane (Safety R-evolution T©, 3 mm) is applied above these panels, followed by the metal-bitumen shingles. The Ultimetal HD© Slate shingles (1000 × 340 × 4.7 mm) combine a durable bituminous base with a pre-painted aluminium sheet 300 µm thick (Fig. 5).

Fixing is achieved through a combination of interlocking geometry, adhesion between layers, and nailing or hot welding onto the membrane. This existing system provided the foundation for our BIPV development: the main challenge was to integrate photovoltaic functionality without compromising the original characteristics of the roofing system.

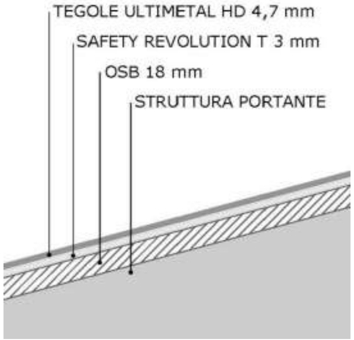

**Figure 5:** BIPV system components

### 6.2 Developed Solution: Tegola Canadese BIPV System

The developed BIPV system combines Ultimetal HD© Slate shingles with custom flexible Copper Indium Gallium Selenide (CIGS) photovoltaic modules (17% efficiency, 150 Wp/m²) (Fig. 6). This technology was selected for its flexibility, low weight, and compatibility with curved or irregular substrates. The custom modules have an extremely low profile (thickness <2 mm) and feature a high-strength adhesive back sheet that bonds directly to the shingle. The combination of flexible modules and the robust shingle structure creates a unified roofing element, maintaining the mechanical strength, waterproofing, and durability of the original system. Furthermore, the choice of flexible CIGS material is advantageous for non-ventilated roof solutions as it exhibits comparatively better performance at elevated temperatures than traditional crystalline silicon [13][14].

During the development phase, the main challenges centred on managing electrical connections and ensuring cable accessibility, while simultaneously preserving the high aesthetic quality of the roof surface.

Aesthetic integration is achieved through two coordinated components made from materials and finishes identical to the Tegola Canadese shingles (Fig. 7). The first component consists of arched vertical covers that protect the junctions between shingles and the junction boxes, ensuring maintainability and facilitating cable installation. The curved geometry was chosen for its softer, less intrusive appearance compared to squared profiles, while maintaining full technical functionality.

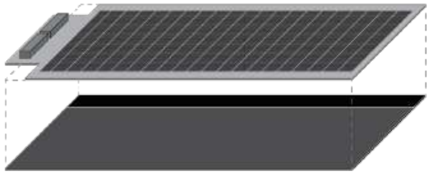

**Figure 6:** BIPV system components: Custom CIGS modules and Ultimetal HD Slate metal–asphalt shingles.

**Figure 7:** Render of a portion of the BIPV highlighting the two components: arched vertical caps and ridge caps

The photovoltaic modules are connected in vertical series configuration, while the horizontal electrical connections are discreetly housed within the second element: horizontal ridge that link all vertical elements. This design establishes a continuous, integrated cable protection and wiring management system within the roof geometry (Fig. 8). Collectively, these components enable clean architectural integration while ensuring complete accessibility for technical inspection and repair.

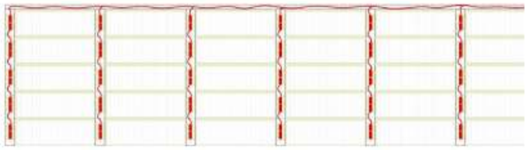

**Figure 8:** Simplified diagram of the electrical configuration

## 7 RESULTS

Validation confirmed both the technical feasibility and aesthetic integration of the system (Fig. 9). The curved protective elements transform what is typically a technical requirement into a coherent design feature, consistent with the material identity of the roof (Fig. 10). Performance assessment demonstrated the full operational capacity of the photovoltaic system while maintaining the distinctive characteristics of Tegola Canadese roofing: fully adhered installation without dedicated substructures, simplified installation processes, and guaranteed maintainability. The system thus presents the following competitive advantages: elimination of substructures, reduction of systemic costs, backward compatibility with existing Tegola Canadese systems, superior ease of installation compared to conventional systems, and optimal architectural integration.

**Figure 9:** Installation of the BIPV system in the test room

**Figure 10:** BIPV system installation rendering

## 8 CONCLUSIONS

The collaboration between Università Iuav di Venezia and Tegola Canadese resulted in the development of a fully functional BIPV system, technically mature and coherent with the identity of the original product. The system integrates photovoltaic technology without altering the distinctive features of the metal roof, preserving performance, durability, lightweight characteristics, and aesthetic continuity.

Beyond the technical outcome, the work demonstrates how energy generation can be integrated into architectural design without formal compromises. In this perspective, BIPV is not a mere technological add-on but a building component capable of transforming solar generation from a limitation into a design opportunity.

The proposed solution is fully adhered, free of ventilated substructures, and characterized by a simplified installation approach. The final configuration, based on modular vertical strips, is readily transferable to the market, offering a competitive advantage in terms of architectural integration, reversibility, and reduced installation complexity. This positions Tegola Canadese within a strategic segment of the rapidly growing BIPV market.

Future steps include life cycle assessment (LCA), cost optimization, certification, and preparation for industrial implementation. This work contributes to promoting the adoption of BIPV and supports European decarbonization targets, facilitating the transition toward Zero-Emission Buildings.

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