

Building stock's renovation in urban areas by BIPV design: energy, structural and fire safety considerations

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Abstract. Only a small percentage of renovated buildings in urban land harness the solar electricity potential of building façade-integrated photovoltaic (BIPV) systems. The goal of this research is to review the limits of the current practice for renovating building stock in urban areas through BIPV. Due to the ageing building stock, most buildings in seismic-prone regions do not meet modern seismic standards, and often they do not even follow the latest Italian fire protection guidelines for PV building-integrated systems. Through consolidated energy load curves, the study enables estimation of the building's overall energy need by correlating it with the energy generated by the BIPV systems. The integration of photovoltaics must be accompanied by an adaptation and optimization of the entire electrical systems, along with other important related areas, such as the charging infrastructure for electric vehicles and battery storage. The study concerns the power output of a BIPV façade optimally balanced to meet households' daily needs. The BIPV-related building's seismic and fire safety engineering considerations open new challenges and new concepts for those addressing the façade. This analysis constitutes a strategic potential in terms of design approach transferability. It has positive repercussions for urban, architectural and construction design practices.

1 Introduction

Reducing energy consumption and increasing energy efficiency in the building sector are key objectives that the European Community has pursued in recent decades. According to the new goals of the European Green Deal for the energy transition from fossil energy to renewable energy, Europe aims to be climate neutral in 2050. In 2023, the EU adopted a set of Commission proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. In Europe, the buildings account for 40 % of final energy consumption in the European Union (EU) and 36 % of its energy-related greenhouse gas emissions while 75 % of buildings

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in Europe are still energy-inefficient (EU Parliament, 2024). According to the European Climate Neutrality Observatory report [15], between 2005 and 2021, the direct GreenHouse Gas (GHG) emissions from buildings in the EU decreased by 20%. The improvement of energy efficiency and the electrification of end-uses it is remarked also by the recently published Directive 2024/1275 [5] of the European Parliament and Council of April 24, 2024 on the Energy Performance of Buildings (EPBD recast) (EU Parliament, 2024) proposed in 2021 in the context of “Fit for 55” legislative package to deliver on the EU’s 2030 climate targets [27].

This paper will answer the following question: *Can retrofits improve energy performance by BIPV in urban building stock while maintaining structural and fire safety?* A comprehensive literature search was conducted for this purpose.

The search strategy targeted BIPV retrofits, energy performance, structural safety, and fire safety in urban buildings. This review synthesizes recent research on the energy, structural and fire aspects of BIPV-driven urban building renovations, highlighting best practices, regulatory gaps and future needs. BIPV systems replace conventional building materials with photovoltaic modules, enabling on-site renewable energy generation and reducing operational energy demand. BIPV retrofits are increasingly recognized as a promising strategy for improving the energy performance of urban building stock, contributing to decarbonization and the transition to net-zero energy buildings [14,25]. However, the integration of BIPV introduces new challenges, particularly regarding structural integrity and fire safety. Recent research highlights that while BIPV can be safely implemented, fire hazards—such as increased risk of ignition, flame spread, and smoke propagation—must be addressed through careful design, material selection, and compliance with evolving fire safety standards [6]. Advances in fire-resistant coatings, module design (e.g., glass-to-glass configurations), and rapid shutdown technologies have demonstrated effectiveness in mitigating these risks. Overall, the literature supports the feasibility of BIPV retrofits that enhance energy performance without compromising safety, provided that best practices and regulatory requirements are followed [28]. Research highlights the importance of accounting for additional loads, wind and seismic forces, and thermal effects introduced by BIPV modules. Structural safety is also maintained when BIPV systems are properly engineered to account for additional loads and thermal effects [4]. When a structural building engineer utilizes digital tools and Building Information Modeling (BIM), the integration and performance of the building’s structural model are optimized [26]. While BIPV façade retrofits can reduce building energy consumption and support achieving plus-energy or NZEB targets, with façade energy-saving rates around 30–40% according to many studies [22]. Reviews argue that retrofit planning still treats “energy upgrade” and “fire/structural safety” as separate disciplines, leading to sub-optimal or risky solutions rather than integrated trade-offs [9].

2 BIPV’s energy considerations

When we talk about energy in the construction market, we have two fundamental principles: the first one is to save energy, and the other is to increase renewable energy sources. In this context, in the last years, photovoltaic systems have seen wide success worldwide for their adaptability to the building shape. The greater widespread use of PV panels in buildings is to conceive them as independent technological elements, similar to ventilation, lighting, and heating systems. They do not contribute to the structural and aesthetic integration objectives. This kind of application belongs to the BAPV Building-Attached Photovoltaic (BAPV) systems, which are installed by mounting structures fixed to the buildings. Another possibility of using PV panels in buildings is to adopt a major integration of them with the built environment. A Building-Integrated Photovoltaic (BIPV)

system is a photovoltaic system in which the photovoltaic modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building (Fedorova A. et al. 2018). Replacement versus integration is an added value in the new approach to BIPV systems: unlike BAPV systems, BIPV systems must ensure waterproofing, wind resistance, and protection from atmospheric agents such as rain and snow so that the functionality of the building envelope is completely redesigned for improved performance. Another fundamental characteristic of BIPV systems is their customisability, adaptability and versatility of the modules employed in BIPV systems, encompassing modifications in colour, texture, dimensions, and shapes [21,23,24].



Fig. 1. Large area demonstration modules with blue, green and red (from Fraunhofer ISE). Customability of different PV panel shapes for BIPV solutions



Fig. 2. First two images represent colourful printed custom-size solar panels for facades applying SissINSO Kromatix™ – Solar Silo Kahlesio, Basel (CH), Industrial buildings (from SUPSI;<http://www.bipv.ch>). Other images are projects taken from [21]

Most building energy renovation projects involve renewable energy sources, mostly solar sources, to satisfy the high energy consumption of households in our contemporary society. The ultimate aim of Net-Zero Emission and Net-Zero Energy buildings moves the professional designers to select outside building surfaces suitable for the application or integration of PV panels. For multi-storey buildings and multi-family block apartments, façades are often the main available solar surface and for these types of buildings solar energy production is more profitable for households. Research focuses on how much energy they can provide, where to place them, and when they are economically worthwhile [20].

In the complex yield of energy generation and consumption, the Italian Regulatory Authority for Energy, Networks and Environment (Autorità di Regolazione per Energia Reti e Ambiente - ARERA), carries out regulatory and monitoring activities in the sector of electricity. This study, by using consolidated energy load curves from ARERA, enables estimations of the overall energy demand of the construction, while associating with the energy power generated by the BIPV systems. The study examines the power output of a BIPV façade optimally balanced for the daily needs of households in different typological houses built in Italy. To perform different calculations of energy production balanced to energy real consumption of a representative cluster of buildings in Italy, it has been followed the classification made by ISTAT for buildings and population of 2024-year. It is reasonable on the basis of the 2024 Italian national census that the more representative buildings are

single-family and terraced, multi-family with 4 floors, and block apartments with 8 medium floors [11].

3 Methodology

By starting from an extensive review of the different building architectural typologies present in Italy, four fundamental groups of buildings have been selected, based on common morphological characteristics. For each group, standardized BIPV solutions have been adopted to provide strategic potential in terms of design approach transferability and practices, and to effectively support new tailored urban renovation policies. The methodology consists of four main steps: Selection of main representative buildings of Italy's building stock in urban areas (*a*); Definition of geometric features by number of households and floors into the buildings (*b*); Implementation of BIPV installations tailored to each group and consequent solar energy production (*c*); Definition of building's grid context and climatic conditions (*d*). A final step is also necessary to have some contributions for the costs and benefits of BIPV systems application and to discuss.

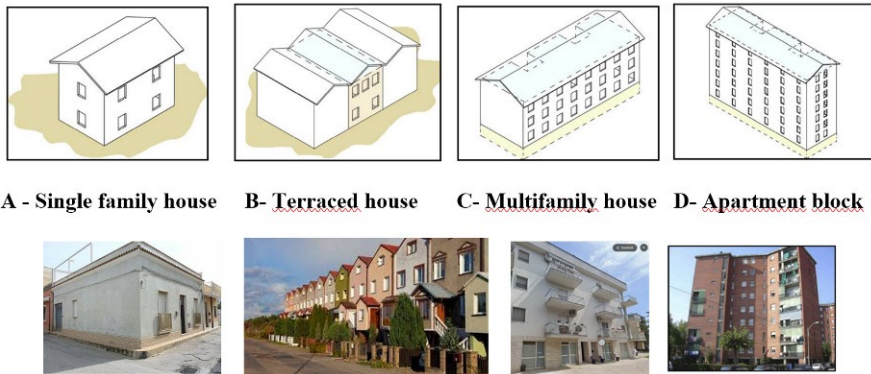


Fig. 3. Selection of the different building architectural typologies

Concerning points (*a*) and (*b*), the main groups are: *A*- single-family dwellings with one storey, *B* - multi-family buildings with 4 floors, *C*- multi-family buildings with 8 floors, *D*- block apartment with 10 floors and 100 households, see Figure 3. Regarding point (*c*), all vertical and horizontal surfaces outside the building will be taken into account, and the calculation of electric energy production from the BIPV installation will be performed using the PVGIS-EU tool. Regarding point (*d*), it is important to define the grid context and the building's climatic conditions, as these two factors determine the impact on climate change. Integrating renewable energy systems like PV and BSS (Battery Storage System) can significantly contribute to climate change mitigation in high-emission grids. Context-specific renewable energy strategies are essential to maximize decarbonization potential and address global climate challenges effectively. The new target of Net Zero Emission Buildings and the Net Zero Energy buildings standards are the EU directives and national laws' reference points to drive sustainable construction and the development of climate-resilient cities. The climate change impact depends on the adoption of PV integration into the building and it varies significantly from grid context (with or without BSS) and climate conditions (warm or cold climate zones or different latitudes) [19,10].

It is well known that different case studies highlight the significance of factors such as building surface area to volume ratio (A/V), window-wall ratio (WWR), orientation, facade design, shadowed surfaces by dense urban environment, efficiency of PV panels and others in achieving high-efficiency buildings, as NZEB standards (Kong J. et al.2023).

This methodology, discussed in this paragraph, will be managed differently when integrating photovoltaic systems, whether BIPV or BAPV, into existing buildings located in prestigious historical and landscape settings or in protected contexts under the Italian Code of Cultural Heritage and Landscape (Legislative Decree 42/2004). Indeed, important guidelines for achieving the integration of PV systems relate to a sound methodological approach to ensure adequate protection of the built-up heritage, as well as balancing the aesthetic, technological and energy integration aspects (BIPV Meet the History, 2022).

Analysis of each typological building case is based on these building design choices: BIPV systems occupies the major facade, exposed to south; PV panels are high efficient ones; the building is located in urban area (Bari, south of Italy) so that any shadows is cast on the facade; rooftop is plane in each cases; PV are integrated to external vertical wall of building envelope, PV-integrated parapets of balcony; PV walkable terrace floor is admittable and it will be well motivated for its adoption; horizontal louvers create a visually dynamic façade and offer optimal solar control especially on the South facades of residential buildings and offices [8]. See Figure 4 below.

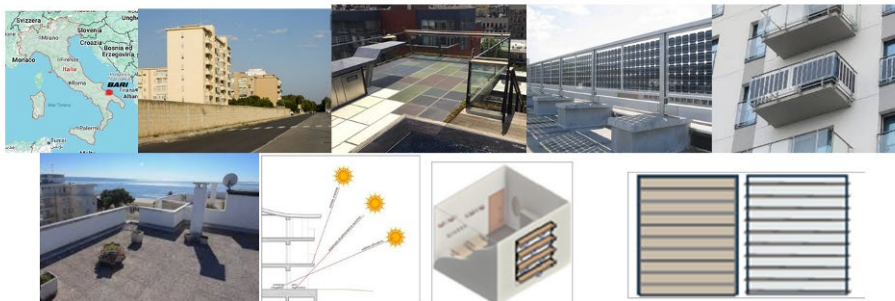


Fig. 4. Adopted building design's choices: location, urban environment, PV walkable floor, Parapet's photovoltaic panels, cantilever balcony, plane terrace, South orientation, horizontal louvers, window shading systems

4 Results and discussion

4.1 Analysis of energy needs compared to the photovoltaic production

To better define the size of a BIPV façade in an exemplary building within an urban district, we need to compare the energy load curve with the potential PV solar energy, while minimizing the need for large battery storage systems.

In the following analysis, the average monthly energy need of all residential clients linked to the energy distributor for a power between 1,5 and 3kW (kilowatt) and 3 and 4,5kW in the Province of Bari (Italy), referred to the 2023 registered data of Regulatory Authority for Energy, Networks and the Environment [1], is considered.

As shown in Figure 5 below, the building geometrical model is representative of the 4-floor Italian building stock, and it serves as a building unit for composing clusters C and D of typological architectural buildings. The C- case is obtained by elevating the other 4 floors of this unit, and the D- case is obtained by elevating the building unit of 6 floors to reach 10 floors and to position these buildings next to each other. The cluster A will be a simply independent house, with one floor, due to the rooftop, with a floor area of 105 m² (7x15metres) and a height of 3 metres. Its southern façade is 45 m². The different average energy need, detected by ARERA, is compared to various evaluations of the size of façade BIPV installations.

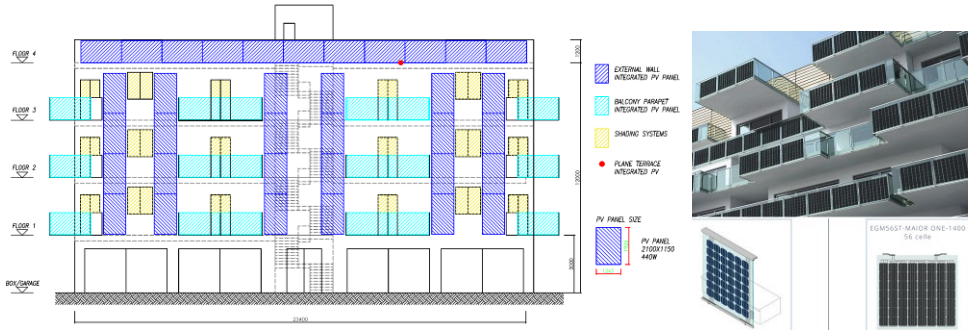


Fig. 5. Typical BPV's systems used for PVGIS calculation (CASE B - multi-family buildings with 4 floors - PV panel power size is 440 W). PV balustrade Balcone Fotovoltaico™ Gruppo STG

Performance of grid-connected PV systems. By taking into account the three cases, we can collect data from ARERA to define the hourly, monthly and yearly energy need for each province and we can estimate the solar electricity generation of the façade BIPV by using the PVGIS-5 EU tool. This tool makes it possible to estimate the average monthly and yearly energy production of a PV system connected to the electricity grid, without battery storage. The calculation takes into account the solar radiation, temperature, wind speed and type of PV module. The user can choose how the modules are mounted, either on a free-standing rack, by mounting, or integrated into a building surface. PVGIS can also calculate the optimum slope and orientation to maximize yearly energy production.

The adoption of energy generation by means of photovoltaic panels addresses the definition of each panel that constitutes the BIPV system, whose productivity will determine the final result of the balance between energy need and consumption. The energy generator's size is a crucial point in discussing the best approach. In fact, the selection of PV panels is an influential factor for economic investment and the BIPV's return on investment.

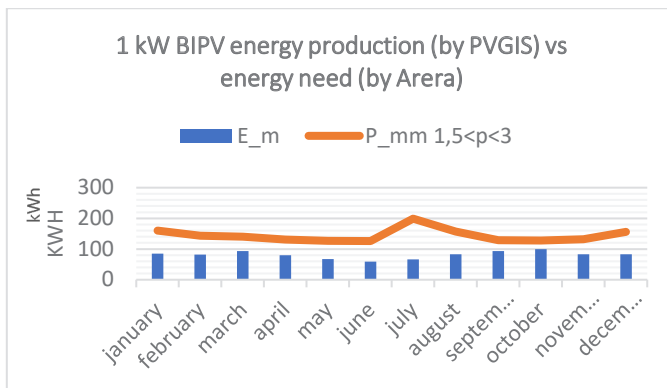


Fig. 6. Monthly Energy production from BIPV in vertical position, slope angle 90° (source: PVGIS) positioned on the building envelope versus monthly energy need in the province of Bari [1]. Symbols: E_m=average monthly electricity production; P_{mm}= monthly energy demand (prelievo medio mensile) by point of delivery with a power between 1,5 and 3 kilowatt; kWh=kilowatt-hours

In the following tables we take into account these assumptions: there will be consider three types of photovoltaic panels: wall PV and rooftop PV 400 Wp (peakWatt) 1,75x1,15 meters; glass balustrade parapets PV with bifacial photovoltaic cells 205 Wp 1,69x1,13 m; window shading system with solar louvers approximately 150 Wp for each window opening on the south facade; walkable terrace to motivate if it is required. In the building case A,

where the terrace is not normally used by households, 100% of its area is utilised for the PV plant. In the building case B-C-D, where the terrace is often used by households for different purposes or to account for some underutilized area, for instance due to shadow, only the 30% its total area (218 m²) is harnessed. Each tenant has their own apartment and requires electric energy from the grid by means of a POD (Point of Delivery) number that uniquely identifies the physical connection point for electricity in an Italian home. It is essential for activating, transferring, or switching electricity suppliers and remains constant regardless of the provider. The number of tenants corresponds to the number of energy delivery points connected to the electric grid. Façade BIPV's power generation is based on 0° azimuth and 90° slope in PVGIS, which implies a vertically positioned PV panel that is fully exposed to the South. Average monthly electricity production (indicated as E_m in Figure 6) for 1 kWp (Cryst Sil 2025) by PVGIS data is equal to 75kWh (panel slope angle 0°). Monthly average electricity production for 1 kWp (Cryst Sil 2025) by PVGIS data is equal to 120 kWh (panel slope angle 90°). BIPV productivity comes from a calculation useful tool: *PVGIS* ©European Union, 2001-2026. Energy needs for each tenant (indicated as P_{mm} in Figure 6) come from ARERA's data collection.

Table 1. BIPV power generation (kW)

	Typological Description	Number of tenants	Building envelope	Shading systems	Rooftop	Parapet	Total
CASE A	Single-family scenario (1 floor) Htot=3m	1	22	0,7	22	1,8	46,5
CASE B	Multi-family scenario 3-storey (4 floors) Htot=12m	6	15,4	2,7	35	6	59,1
CASE C	Multi-family scenario 7-storey (8 floors) Htot=24m	14	28,6	6,3	35	14,3	64,2
CASE D	Block apartment 9-storey scenario (10 floors) Htot=30m	54	36,5	8,1	14,3	18,4	168

Table 2. Monthly façade-bipv's productivity (kWh)

	Monthly External wall-BIPV's production	Monthly Shading systems-BIPV's production	Monthly Rooftop-BIPV's production	Monthly Parapet - BIPV's production	Total BIPV production	Total monthly average energy production for each tenant
CASE A	1650	52	1650	135	3487	3487
CASE B	1155	202,5	4375	450	6182	1030
CASE C	2145	472	4375	1072	8064	576
CASE D	6225	607,5	13125	1380	21337	395

Table 3. Monthly energy need in Bari vs BIPV productivity (kWh)

	Average Hourly Energy Need	Average Yearly Energy Need	Average Monthly Energy Need- one family	Monthly average energy production except rooftop contribution
Required power 1,5<p<3kW	0.2003	1729	160	Case D 152; Case C 263 Case B 301; Case A

				1837
Required power 3<p<4,5kW		2770	225	Case D 152; Case C 263 Case B 301; Case A 1837

4.2 Discussion

The results, obtained by comparing average energy needs [1] with grid-connected PV performance (PVGIS source), provide significant energy considerations when BIPV is adopted in a building retrofit. The building box's morphological feature leaves ample room to use not only the rooftop but also all vertical and horizontal surfaces of the 4 facades. The PVGIS tool shows that a slope angle of 90° for PV orientation produces a non-negligible amount of electric energy if it is not shaded by other buildings. In many Italian urban areas, due to different urbanistic and safety standards and social laws, we have many buildings that are unshaded and positioned directly on the southern side. The untapped potential is a hidden asset essential for achieving the zero-emission target in urban areas, and facades are also a key means for resilience.

The calculations show that the BIPV systems on the facade can meet the energy needs, and the contribution of rooftop power becomes significant when the energy needs of each tenant are high. In certain cases, the plane rooftop may not be for all building tenants or may be allocated to other common uses for all tenants inhabiting the building. As not all of the rooftop's horizontal surface can meet energy needs, this study shows that the building remains an energy-generating source through the use of a BIPV system on the facade. The rooftop's PV plant has been around for years and is currently the best choice for producing solar energy in multi-storey buildings in Italy. Due to low rainfall frequency, above all in southern Italy, most buildings in Italy follow the last floor plane surfaces' architectural concept. Most PV systems on flat rooftops with flat terraces are BAPV using a mounting system that reacts to wind load for its own load due to ballasts at the feet of steel supporting structures.

If we consider the geometry of a flat rooftop, a slight slope is also included to allow rainwater drainage. Notably, the optimal slope angle in Italy is 35°, making it advantageous to construct the PV integrated-sloped paver at this angle. This type of system challenges the traditional architectural concept of the rooftop being solely dedicated to walkable features. Due to this inclination, the rooftop's perimeter parapet can simultaneously hide the PV panels. This potential solution could save money for achieving the double functionality of a walkable RES integration. Regarding glass balustrade parapets made by bifacial PV cells, this solution replaces the standard iron-grating balustrade and allows more light to the balcony and home. Excellent technical solutions for solar parapets have been developed and tested, including the one used in this analysis, confirming their special purpose of ensuring structural safety against horizontal pushing forces from a person on the balcony and meeting the energy needs of building occupants. The shading systems considered in our analysis are PV-integrated windows whose energy production contribution to solar gain is not significant, as the louvre technology is more effective for window shading during summer to reduce solar radiation through the window glass. Anyway, the alternative solution of using transparent photovoltaic glass in a window shading system does not allow for overall light penetration in the apartment.

The adopted BIPV solutions involve four types of solar integration, but many other ones are possible. For instance, it is also possible to position the shading systems above the head of a window with a PV panel in a horizontal orientation. The window could be horizontal on the roof to favour building-integrated skylight systems. The integration of PV panels could

also increase through cladding systems on the building envelope or by incorporating light glass or flexible panel layers into the building envelope's material.

In the case of multi-storey buildings, electrical energy is mostly provided by a PV roofing system whose power does not always meet the energy needs of each tenant. Consequently, the buildings require a large battery energy storage system to compensate for their energy-hungry nature, also during nighttime. At the same time, in many multi-storey buildings, especially older ones, it is necessary to maintain the façades and few building maintenance solutions involve façade-integrated PV systems. As previously mentioned in this study, various factors influence this issue, but it is helpful to show tenants the potential of BIPV solutions to enable them to make the best choice in terms of overall economic convenience. For instance, many building maintenance works involve extensive activities on the façades, often changing the aesthetic appearance at a high cost of refurbishment.

Mainly due to the technicians and construction firms, there is a lack of knowledge that creates a barrier to the adoption of new innovative PV systems. At the same time, even when all positive factors influencing BIPV adoption are considered and building maintenance works are defined, tenants focus solely on the insulation panel applied to the façade for energy considerations, without reflecting on the possibility of implementing a BIPV system. If we analyse in depth the construction process and the different steps involved in deciding on energy renovation of multi-storey buildings, we find that there aren't currently many firms in Italy specialising in BIPV due to the low number of successful BIPV projects in the country.

In conclusion, the fear of new acquisition, the not ready competence to BIPV market, and the lack of expertise for the technicians and the PV firms, don't stop a process in which all the surfaces created by the builders, such as façades, occupy the Italian landscapes of urban environment but does not quite participate to the energy transition and the climate change fight.

The analysis takes into account the BIPV system selected for a standard building stock by choosing only four typological building cases that are more representative of Italian real estate. The comparison, in terms of kilowatt-hours, between the energy demand, as recorded by ARERA, and the actual energy production, based on the building facade surfaces, shows that only tenants' economic reasons or obstructing geometrical or position-related building factors could stop the adoption of BIPV systems. In the considered both case of power energy delivery point of power delivery point, corresponding to the tenant (family and its components), the total monthly average energy production, coming only by the harnessing of facade (vertical wall surface plus shading systems and parapets), could satisfy the energy need with the implication of reduced dependency on the grid or the necessity of battery energy storage systems. Only in the case of buildings with more than 10 floors (Case D), in both cases of energy delivery point, as shown in Table IV, the BIPV solution requires denser panels on the facade or the contribution of PV rooftop, to increase the energy production and to reduce the BESS adoption and the dependency on the grid. However, this discussion is influenced by various economic, social and environmental factors leading to different final decisions for each building.

Clearly, the building energy renovation will be pushed forward in the building sector, above all, by the recovery of investment through public financial funding that will amortize the major costs of BIPV systems and products and will move tenants to an overall sustainable building refurbishment aligned with the latest EU directives.

5 BIPV's structural and fire safety considerations

Structural considerations include the need for robust mounting systems, compatibility with existing materials, and the ability to withstand additional loads and environmental

stresses. Structural safety is generally maintained in BIPV retrofits when systems are properly engineered. However, it is considerable to highlight some BIPV retrofits' limitations center on structural capacity (existing structures may not handle added weight/wind loads), integration complexity (designing new systems into old buildings, potential thermal bridging, air gaps), and technical/regulatory gaps (lack of standardized systems, codes combining BIPV with building needs, and skilled labor). From these limitations, the challenges affect load-bearing structures, facade systems, and even roof integrity, requiring careful assessment for seismic zones or areas with high wind loads.

It is appropriate to highlight some practical and economic hurdles for the BIPV market uptake. In the case of building structural reinforcements, BIPV systems often have high initial costs and long payback periods that represent an obstacle to choosing them for RES utilisation in the building. Another factor of influence is the skill gap. A lack of trained professionals familiar with both BIPV technology and older building systems hinders adoption. Moreover, there are also regulatory hurdles due to the unstable or complex frameworks for integrating new energy technologies into existing structures. Other key structural and seismic limitations to highlight when we want to maintain structural safety concern: weight and load, due to the adding BIPV panels increases dead loads (weight) and potentially wind loads, which existing roofs or facades might not be designed to support, requiring structural reinforcement; seismic vulnerability because earthquake-prone areas, BIPV integration must be carefully assessed; energy retrofits should only proceed if the building meets modern seismic safety standards, potentially requiring integrated structural upgrades; Facade Integration Challenges due to the matter that vertical facades have limited space due to building shapes (overhangs, balconies) and existing glazed surfaces, impacting structural support and potential shadows; thermal performance issues because poor airflow or inadequate design can lead to heat accumulation or increased winter heat loss, affecting the overall building envelope performance, not just energy generation.

For retrofits, especially on historic or masonry buildings, a holistic approach is needed, often requiring detailed structural analysis and potentially combining energy and seismic retrofitting for safety and performance. In terms of materials and technologies four main directions can be identified: integrated exoskeleton solutions; integrated interventions on the existing building envelope; replacement of the existing envelope with better performing materials; and interventions on horizontal elements such as roof and floor slabs [18,3].

There is a fragmentation of regulations that does not adequately integrate photovoltaic requirements with those for structural safety in building retrofit. The definition and capacity of BIPV systems require more advanced technological progress laws whose respect joins firmly structural and energy safety. The real-world situation involves professionals who specialise in their respective sectors (energy, seismic safety, fire safety, etc.) and does not take into account the potential of using a new technological system for building design. To renovate Italy's building stock, mostly built before the entry into force of anti-seismic regulations, a structural safety analysis is first required, followed by the implementation of energy renovation measures. For instance, the frequent use of thermal insulation panels to improve the building's energy performance cannot be implemented on structurally deficient buildings with damage, instability or fractures. Anyway, it is important to address building structural safety requirements when carrying out an energy renovation.

In Italy, there is the NTC 2018 (Technical Standard for Construction), a set of technical regulations in Italy governing the design, construction and renovation of buildings. It was introduced in 2018 to replace the previous 2008 version. These technical construction standards define the principles for the design, execution and testing of constructions, concerning the performance required for the essential requirements of mechanical resistance and stability, including in the event of fire, and durability. Chapter 8 of NTC 2018 collects the details and rules for the structural safety of existing buildings. According to the NTC

2018 (Technical Standard for Construction), we have different levels of building structural intervention to reduce seismic hazard and decrease vulnerability. The less invasive and simply structural intervention is classified by the law at paragraph §8.4.2 of Italian NTC 2018 (Technical Standard for Construction) and it allows the increase of the building's seismic performances by means of a steel structural frame and insulation panel on the external wall of the building envelope. Integrating seismic improvement and thermal insulation into a single project also reduces costs and makes the renovation project more accessible and realistic for structural and energy safety.

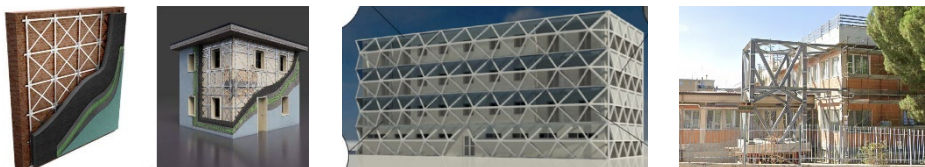


Fig. 7. The first two images represent the steel structure frame for energy refurbishment by thermal panels and simultaneously light seismic structural retrofit (From: Cappotto termico Resisto). The third image (from [3]) is a steel diagrid exoskeleton. The fourth image is a steel structure frame for the seismic reinforcement (from Google Maps) of the secondary school building structure positioned outside the building with horizontal branches at each slab level (Altamura, Scuola Ottavio Serena – Pacelli)

This kind of intervention does not involve the ability to generate renewable energy by photovoltaic systems. Earthquake reinforcement by a steel structural frame could be considered, at the same time, either supporting insulated panels or the racking system for the integration of PV panels on the building envelope. See Figure 7.

Besides, in the paragraph §8.4.3 of NTC 2018 (Technical Standard for Construction) it is also foreseen a superior (with respect to §8.4.2) level building seismic structural retrofit for existing buildings that is more invasive. For instance, some of these interventions might require special structures, especially when existing buildings are not adequate to accommodate them. This means that updated seismic structural requirements for the building create additional areas to harness energy generation through the adoption of BIPV. In Figure 7 above, an example of paragraph §8.4.3's classified intervention is shown.

Fire Safety of BIPV systems concerns fire risks and mitigation. BIPV façade systems introduce high-voltage ignition sources, carrying DC currents up to 1000 V, directly into façade structures, a hazard unprecedented in conventional façades. Fire safety is a critical concern in BIPV retrofits due to the flammable materials in some module components and the potential for rapid fire spread, especially in ventilated façade systems [6,28]. Studies report that improper design or installation can increase fire risk, but these hazards can be effectively mitigated through: use of fire-resistant coatings and materials (e.g., glass-to-glass modules, aluminum hydroxide coatings) [2,4,11,12,38]; Compliance with international and national fire safety standards (IEC 61215, IEC 61730, UL1703) [28]; Proper system design, including optimal module placement and integration of rapid shutdown technologies [13]; Regular maintenance and fire risk assessments [6]. In BIPV systems, the fire life-safety risk is underestimated. The location and detailing of BIPV systems in the envelope (near openings, fire lines, fire-separating elements) critically affect the hazard, but are often determined by energy yield and aesthetics rather than fire zoning. In fact, BIPV retrofits increase vertical flame spread, heat release, and smoke, raising overall fire risk by ~55% in a library case study and enabling rapid façade fire spread in full-scale tests. Ventilating cavities behind BIPV façades act as chimneys; even small amounts of combustible material can lead to severe vertical flame propagation and falling debris. Conventional sprinklers and

hydrants may not reach BIPV roof or façade zones, and systems continue to produce electricity during a fire, complicating firefighting and access [6]. Current qualification tests (small-flame, IEC 61215/61730) give little information about real façade fire development; codes still treat BIPV largely as conventional PV or cladding [12]. Large-scale façade tests of the actual retrofit assembly are seldom required, despite evidence that compliant components can still form hazardous systems.

In Italy, there are specific fire prevention guidelines (update of D.C. PREV. n. 1324/2012) concerning the design, installation, operation and maintenance of PV systems. See figure 8. The fire risks and mitigation-related topic of BIPV systems is highlighted in “Regola Tecnica Verticale (RTV) V.13 Chiusure d'ambito degli edifici civili, which involves all the frontiers of the buildings (i.e., rooftop, facades, etc.). Beyond the respect of the electrotechnical standard (CEI EN 61730-2) and the construction standards defined in (CEI EN 505583-1 Photovoltaics in buildings part I: BIPV modules), due to the building envelope integration, all PV modules will have fire classification according to UNI EN13501-1.

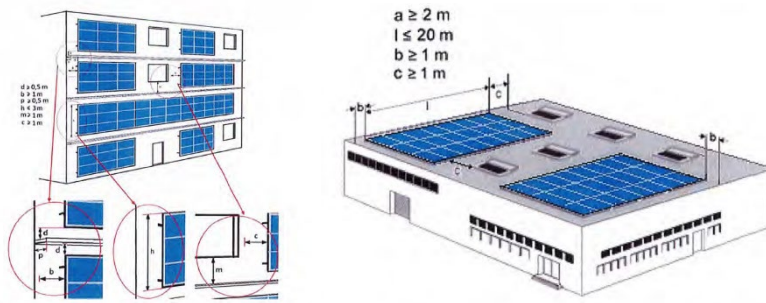


Fig. 8. Examples of PV system position on facade and rooftop for fire prevention guidelines [16]

A fire risk mitigation approach exists for BIPV systems, but it is not easy to adopt; it requires installation guidelines for a solar energy generator on a building façade. The professional competency for the above-specified purpose is broad and not always simply available. Furthermore, as discussed in the previous paragraphs, if BIPV systems fulfill more roles for the building’s occupants, it would be advantageous to develop fire safety building codes and performance criteria that are specifically focused on BIPV technologies.

6 Conclusions

The research underscores the importance of an interdisciplinary collaboration team between urban planners, architects, structural engineers, energy engineers and policymakers. It is not fully correct to cover only the available building façade when BIPV is chosen. The optimal BIPV solution strikes a balance between energy needs, influenced by end-users’ behaviour, and solar PV generation, based on the available façade area. In tall buildings, if each tenant requires high energy, BIPV solutions are not enough. In a dense city this matter is highlighted by the shadow effect. In these cases, PV rooftop is fundamental. This research on BIPV retrofits consistently warns that energy benefits are achievable, but robust fire and structural safety must not be negligible. System-level fire design (location, cavity design, materials, access, large-scale testing) and clearer, integrated codes are needed so that BIPV retrofits deliver high energy gains without introducing disproportionate fire risk. BIPV retrofits in urban building stock can significantly improve energy performance while starting with structural and fire safety considerations. Ongoing research and policy development are essential to ensure safe, large-scale adoption.

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