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FENESTRAE

Market Analysis of Smart Building Envelope Components

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CURRENT PRACTICES AND MARKET READINESS

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Abbreviations

ADRION	Adriatic–Ionian Region
BACS	Building Automation and Control Systems
BIPV	Building-Integrated Photovoltaics
BMS	Building Management System
CAPEX	Capital Expenditure
DHW	Domestic Hot Water
EC	Electrochromic
EE	Energy Efficiency
EMS	Energy Management System
EN	European Norm (European Standard)
EPC	Energy Performance Certificate
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Service Company
ETICS	External Thermal Insulation Composite System
EU	European Union
GHG	Greenhouse Gas
GIS	Geographic Information System
HVAC	Heating, Ventilation and Air Conditioning
IFI	International Financial Institution
IPA	Instrument for Pre-Accession Assistance
KNX	Open Standard for Commercial and Domestic Building Automation
LCD	Liquid Crystal Device
LCC	Life-Cycle Cost
MEP	Mechanical, Electrical and Plumbing
nZEB	Nearly Zero-Energy Building
NECP	National Energy and Climate Plan
NZEB	Nearly Zero-Energy Building
PDLC	Polymer Dispersed Liquid Crystal
PV	Photovoltaic
RES	Renewable Energy Sources
ROI	Return on Investment
SHGC	Solar Heat Gain Coefficient
SRI	Smart Readiness Indicator
SPD	Suspended Particle Device
TA	Technical Assistance
TOTEE	Technical Directive of the Technical Chamber of Greece
TRL	Technology Readiness Level
UNI	Ente Nazionale Italiano di Unificazione (Italian National Standards Body)
UV	Ultraviolet
VLT	Visible Light Transmission
WB	World Bank
ZEB	Zero-Emission Building

Executive Summary

This report presents a comprehensive market analysis of smart building envelope technologies across the IPA-ADRION region within the framework of the FENESTRAE Project.

Building on the prior regulatory assessment phase, the analysis evaluates real market readiness, supplier ecosystems, implementation capacity, and investment conditions for eight priority smart façade technology groups, including dynamic glazing, building-integrated photovoltaics (BIPV), dynamic shading, and façade automation (BACS). The objective is to bridge EU policy ambitions particularly the recast Energy Performance of Buildings Directive (EPBD) and the transition toward Zero-Emission Buildings (ZEB) with actual deployment realities across participating countries and regions.

At EU level, technological maturity is high and solutions are commercially validated, with documented potential to reduce cooling demand by 20–60%, improve daylight autonomy, enhance occupant comfort, and increase Smart Readiness Indicator (SRI) performance. However, regional readiness is heterogeneous. Slovenia demonstrates the strongest alignment between regulation, domestic supplier presence, and implementation capacity. Italy shows overall structural strength, yet with clear regional disparities: innovation and industrial capacity concentrate in metropolitan areas, while regions such as Molise function primarily as installation and distribution markets dependent on imported systems. Greece presents a regulatorily advanced but commercially selective market, with dynamic shading and automation progressing, while advanced dynamic glazing remains limited to premium and pilot projects.

Western Balkan markets remain at earlier stages of development, though not uniformly. Albania and North Macedonia lack active domestic production of advanced smart envelope systems but possess existing façade and glazing actors capable of forward integration if supported through structured financing and technical assistance. Bosnia and Herzegovina currently lags behind these markets, with minimal identifiable activity, limited supply-chain presence, and no established demonstrator base.

The core finding is that technological availability is not the primary barrier but the implementation confidence, integration capacity, and bankability are. Smart façade technologies are rarely deployed as fully integrated systems combining glazing, shading, automation, and renewable generation with monitored and verified performance outcomes. The absence of demonstrator buildings and transparent performance data constrains investor trust, procurement normalization, and replication.

Demonstration projects therefore represent the most effective accelerator for market transformation. Public buildings such schools, hospitals, municipal and administrative facilities should function as monitored pilot platforms integrating dynamic shading, BACS, smart glazing, and BIPV. These projects must include structured performance monitoring, post-occupancy evaluation, and open dissemination of results to build regional confidence and technical capacity.

Scaling beyond pilots requires blended financial instruments and structured technical assistance. Commercial banks and development finance institutions must complement traditional lending with grant components, concessional loans, risk-sharing mechanisms, and advisory support tailored to integrated façade systems. Performance-based procurement aligned with SRI criteria and life-cycle cost methodologies will be essential to shift markets from lowest-cost construction models toward performance-driven renovation and new-build standards.

The decisive next step is institutionalizing demonstration-driven, performance-verified implementation supported by coordinated financing and capacity building. Through a phased pathway from activation and de-risking to scaling and institutionalization, smart façade systems can move from niche innovation to standard market practice, contributing directly to ZEB targets, overheating mitigation, and long-term decarbonization of the building sector across both mature and emerging IPA-ADRION markets.

1. Introduction

Project Context

This Market Analysis of Smart Building Envelope Components has been developed within the framework of the **FENESTRAE Project – Fostering Energy Efficiency by means of Smart Technologies to Retrofit Apertures and Building Envelope**, co-funded by the European Union under the **IPA-ADRION Programme**.

The present analysis builds upon recently published *Report on the State-of-the-Art Regulations and Technical Standards across IPA-ADRION Regions* (Albania, Bosnia and Herzegovina, Republic of Srpska, Greece, Italy – Apulia and Molise Regions, North Macedonia, and Slovenia). While the initial phase focused on regulatory and technical frameworks, this report addresses **market readiness, supply chains, investment potential, and commercial maturity** of smart envelope solutions.

The document aims to bridge regulatory ambitions EPBD recast, SRI, nZEB/ZEB standards) with real market deployment conditions in the IPA-ADRION macro-region.

Strategic Market Context

Buildings account for approximately **40% of final energy consumption and 36% of energy-related GHG emissions in the EU**. In the Western Balkans, energy intensity in buildings is even higher due to:

- Ageing building stock,
- Poor thermal insulation,
- Limited automation, and
- High summer overheating risk.

The revised **EPBD 2024** and the transition toward **ZEB** place strong emphasis on:

- Dynamic solar control,
- Smart envelope systems,
- Building automation,
- Integration of renewable energy systems, and
- Smart Readiness Indicator (SRI).

Within this policy framework, smart glazing, adaptive façades, dynamic shading, and BIPV represent high-impact technologies capable of:

- Reducing HVAC demand by 20–60%,
- Improving daylight autonomy,
- Preventing overheating,
- Increasing resilience to climate change, and,
- Enhancing occupant comfort and productivity.

The IPA-ADRION region shows significant heterogeneity in regulatory enforcement, purchasing power, and construction sector maturity. Therefore, understanding **market availability, supplier presence, and technology penetration** is essential for investment planning and scale-up strategies.

Objectives of the Market Analysis

The specific objectives of this market analysis are to:

- Identify and classify smart glazing and façade systems currently available on the world/EU market and look into each partner country practices,
- Assess the market maturity level (TRL,[1] commercial readiness, pilot deployment),
- Map key market actors such as manufacturers, suppliers, distributors, installers, integrators,
- Evaluate the construction sector's technical readiness and supply chain capacity
- Identify regulatory, financial, and awareness gaps, and
- Provide investment-oriented recommendations to stimulate market uptake.

The report serves policymakers, investors, architects, engineers, construction firms, and financial institutions seeking to accelerate smart envelope adoption in alignment with EU climate targets.

[1] Technology readiness level (TRL)

2. Smart Façade Technologies Mapping

Smart building envelope technologies enable dynamic regulation of light transmission, solar heat gains, and overall energy flows within buildings. By adapting to external climate conditions and indoor comfort needs, these systems contribute to overheating prevention, reduced cooling loads, improved daylight performance, and enhanced occupant comfort. They also play a critical role in achieving compliance with nZEB/ZEB standards and increasing SRI scores in line with the revised EPBD framework. [2]

Technology Selection Criteria

The technologies included in this analysis were selected based on their technological maturity (TRL 7–9), demonstrated energy savings in peer-reviewed research. Additional selection factors included applicability in both retrofit and new construction projects, market availability in EU Member States, and practical import feasibility for Western Balkan countries where local production remains limited.[3, 4,5]

Although there are numerous technologies, for the purpose of the market analysis, eight priority technology groups relevant for IPA-ADRION markets were identified, in particular:

- Electrochromic glazing,
- Thermochromic glazing,
- Photochromic glazing,
- Suspended Particle Device (SPD) glazing,
- Liquid Crystal Devices (LCD/PDLC),

[2] Dimitrova, M. Samardzioska, T., Dimitrov, K. Analysis of national regulations and technical Standarsd on Smart Buildings. Macedonian Center For Energy Efficiency. Fenestrae Project. 2025.

[3] Riganti, M., Castri, G. L., Serra, V., Manca, M., & Favoino, F. (2025). Energy saving potential of advanced dual-band electrochromic smart windows for office integration. Energy and Buildings, 327, 115084. https://doi.org/10.1016/j.enbuild.2024.115084

[4] DeForest, N., Shehabi, A., Selkowitz, S., and Milliron, D. J. A comparative energy analysis of three electrochromic glazing technologies in commercial and residential buildings. United States: N. p., 2017. Web. doi:10.1016/j.apenergy.2017.02.007.

[5] Xiao, L., Mokhtar, N. A., & Mat Sulaiman, M. K. A. (2025). Building-Integrated Photovoltaic (BIPV) Shading Systems: A Critical Review of Design Strategies, Energy Performance, Integration Potentials, and Malaysian Context. International Journal of Built Environment and Sustainability, 13(1), 91–104. https://doi.org/10.11113/ijbes.v13.n1.1634

- Building-Integrated Photovoltaics (BIPV),
- Dynamic shading systems, and
- Façade automation and sensor integration.

Each technology profile presented in this report provides a structured overview comprising a technical description, key performance indicators, recommended building applications, market development status, and identification of relevant suppliers within the IPA-ADRION region. Investment-related parameters including indicative cost ranges, lifespan, and potential payback considerations, where available are also included to support strategic planning and decision-making.

2.1. Electrochromic Glazing

Technology Description and Benefits: Electrochromic (EC) glazing consists of multilayer thin-film coatings that dynamically adjust visible light transmission (VLT typically 5–65%) through low-voltage electrical stimulation.

Figure 1. Electrochromic Window (Source: Electrochromic Window Report. US Department of Energy. 2022.)

Performance benefits include:

- 20–40% reduction in HVAC and lighting demand,
- SHGC modulation between approx. 0.10–0.50,
- Reduction in glare and thermal discomfort (up to 30%),
- Improved occupant productivity,
- Potential contribution to BREEAM, LEED, and WELL certifications, and
- Switching time ranges from 2–5 minutes depending on pane size.

Recommended Use	Key suppliers
Households: High-end homes/multi-storey with large façades for glare/cooling control **Commercial:** Offices/hotels with high glazing ratios. **Institutional buildings:** universities, hospitals **Industrial:** Atria/control rooms	- Saint-Gobain SageGlass (Switzerland CH, global production) - SCHOTT (Germany, EU) - Glasstinte (EU, Turkey) - Glasspecialist (Italy) - Converlight (Sweden) - Camglass (Turkey, EU) - ChromoGenics (Sweden, EU) - Convertlight (Sweden, EU)

Market Development: Strong commercial maturity in EU markets (Italy/Slovenia pilots), but limited deployment in Western Balkans (primarily imported systems).

Parameters	Value
Energy savings	20–40% HVAC/lighting
Switching time	<5 minutes
Lifespan	20–30 years
Cost	€500–1,000/m^2
Certification contribution	BREEAM / LEED / WELL
SRI contribution	High (dynamic solar control)

Investment note:

Higher upfront cost but long-term operational savings; strongest case in commercial buildings.

2.2. Thermochromic Glazing

Technology Description and Benefits: Thermochromic glazing is a passive smart window technology that alters its solar and thermal transmittance in response to temperature variations without requiring electrical input. The most common material used is vanadium dioxide (VO_2), which undergoes a reversible phase transition at a critical temperature (typically 55–70°C). Below the transition temperature, the material allows higher solar infrared transmission. Above this threshold, it shifts to a metallic state that reflects near-infrared radiation, thereby reducing solar heat gain while maintaining moderate visible light transmission.

Studies show 3–10% total energy reduction vs. selective static glazing in offices, plus 5–20% better daylight/glare control; gel-based variants cut cooling by 12–20% vs. low-E glass.

Figure 2. Thermochromic window (Source: Villium Window Collection)

Unlike electrochromic systems, thermochromic glazing does not provide user-controlled modulation; its performance depends entirely on surface temperature conditions.

Performance benefits include:

- Solar Heat Gain Coefficient (SHGC): typically shifts from ~0.6 to 0.3–0.4,
- Cooling load reduction: 3–15% (climate dependent),
- Passive overheating mitigation in hot climates,
- Zero operational energy demand, and
- Long-term durability comparable to low-E glazing.

Advantages include no wiring or control systems required, lower upfront cost compared to electrochromic systems, suitable for retrofit applications and reduced lifecycle operational carbon. **Limitations** are limited precision in solar control, transition temperature may not align perfectly with occupant comfort thresholds and less effective in mild climates.

Recommended Use	Key suppliers
Households: South- and west-facing residential windows **Commercial:** Skylights exposed to high solar radiation **Institutional buildings:** Educational and public buildings in Mediterranean climates **Industrial:** Industrial roofing and warehouse glazing	- Brightlands Materials Center (Netherlands, EU) - Global Smart Glass (EU distributors, with Turkey focus) - GOOGLASS Smart Glass Technologies (Istanbul, Turkey) - ChromoGenics (Sweden, EU) - Guardian Glass (Luxembourg HQ, EU-wide production incl. Turkey facilities) - IQ Glass (UK, EU)

Market Development: Currently in early commercial stage (TRL 7–8). Widespread research activity in EU laboratories but limited mass-market deployment. Adoption remains modest in ADRION countries due to low awareness and conservative construction practices.

Parameters	Value
Energy savings	3–15% cooling load
SHGC modulation	~0.6 → 0.3–0.4
Transition temperature	55–70°C
Lifespan	20–30 years
Cost	€200–500/m^2
Operational energy	None
SRI contribution	Moderate (passive solar optimization)

Investment note:

Lower capital cost makes it attractive for large-area applications, but financial returns are more climate-dependent than active smart glazing systems.

2.3. Photochromic Glazing

Technology Description and Benefits: Photochromic glazing is a light-responsive smart glazing technology that changes tint intensity depending on the level of incident ultraviolet (UV) or solar radiation. The glazing incorporates photo -reactive compounds that darken when exposed to sunlight and revert to a transparent state under reduced radiation. Unlike thermochromic glazing (temperature-driven), photochromic performance is directly dependent on solar irradiance intensity. The response time is typically rapid under high UV exposure and reversible without external control systems.

Performance benefits include:

- Visible Light Transmission (VLT) variation: approx. 20–60%,
- Reduction in glare and peak solar heat gain,
- Cooling demand reduction: 10–15% in high solar exposure climates, and
- No wiring or control infrastructure required.

Advantages include fully passive system, lower installation complexity, reduced glare in high-radiation zones, retrofit-friendly and 99% UV-rejection. **Limitations**

are limited control precision, no integration with building automation, reduced effectiveness in low-UV climates, and limited impact on heating optimization.

Figure 3. Photochromic film (Source: Dynaclime)

Recommended Use	Key suppliers
Households: Residential skylights **Commercial:** Atriums and glazed corridors **Institutional buildings:** Any type **Industrial:** Daylighting Suitable for Mediterranean and high-irradiation regions	- SolarScreen (Belgium EU, distributors EU-wide incl. Turkey) - Global Smart Glass (EU distributors, with Turkey focus) - NewTechStore.eu (EU online, ships EU/Turkey)

Market Development: Niche commercial presence in EU with limited deployment in Western Balkans. Technology maturity 8–9, but modest market penetration.

Parameters[6,7]	Value
Energy savings	10–15% cooling
VLT modulation	20–60%
Response time	Seconds–minutes
Lifespan	15–25 years
Cost	€150–400/m^2
SRI contribution	Limited

Investment note:

Cost-effective passive alternative but limited impact in advanced energy-performance buildings targeting ZEB levels.

[6] Garzia, F., Van Thillo, L., verbeke, S., Pozza, C., Audenaert, A. Co-benefits of building automation and control systems: an analysis of smart office buildings. HERVA 14th HVAC World Congres. 2022.
[7] Giovannini, L., Favoino, F., Pellegrino, A., Lo Verso, VRM., Serra, V., Zinzi, M. Thermochromic glazing performance: From component experimental characterisation to whole building performance evaluation. Applied Energy. Volume 251. 2019. Https://doi.org/10.1016/j.apenergy.2019.113335

2.4. Suspended Particle Device Glazing

Technology Description and Operating Principle: Suspended particle device glazing (SPD) glazing contains microscopic, suspended particles embedded in a liquid film between glass layers. When electrical voltage is applied, particles align to allow light transmission; when voltage is removed, particles scatter light, producing a darkened state. This allows rapid and precise control of solar radiation and glare, with switching times in milliseconds. SPD provides stronger solar modulation than many passive systems.

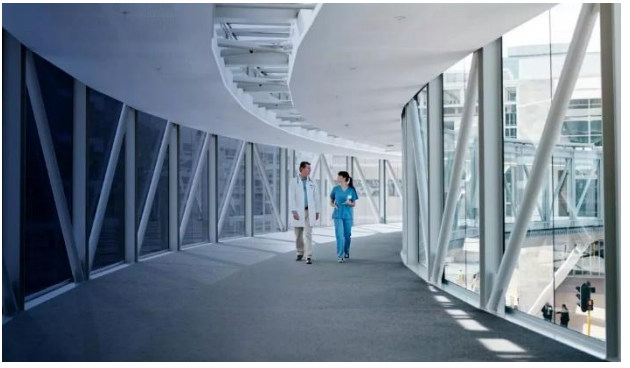

Figure 4. SPD Installation (Source: Gauzy)

Performance benefits include:

- Visible Light Transmission: 1–65%,
- SHGC: 0.02–0.60,
- Cooling load reduction: 25–30%, and
- Near-instant switching.

Advantages include fastest switching among dynamic glazing, high precision solar control, strong glare reduction and suitable for premium architectural applications. **Limitations** are high upfront cost, continuous low-voltage power required and limited penetration in standard construction markets.

Recommended Use	Key suppliers
Households: Luxury residential buildings **Commercial:** Premium/ high-performance office façades, showrooms and commercial glazing **Institutional buildings:** Airport terminals, **Industrial:** Controls	- Gauzy (Israel/global, EU factory near Stuttgart, Germany) - SPD Control Systems (U.S., global incl. EU automotive/marine) - Smart Glass International (Ireland EU) - Smartglass World (EU network, UK-based marketplace) - Research Frontiers Inc. (U.S., licenses EU partners like Gauzy/Mercedes)

Market Development: Commercial maturity 9, active in EU, U.S., and Middle East in premium segments, yet limited adoption in ADRION countries due to cost.

Parameters	Value
Energy savings	25–30% cooling
Switching time	Milliseconds
Lifespan	20–25 years
Cost	€600–1,200/m^2
Certification contribution	BREEAM (UK)/ DGNB/HQE(DE/FR)[8]
SRI contribution	High

Investment note:

Best suited for high-value commercial buildings where comfort and aesthetics justify higher CAPEX.

2.5. Liquid Crystal Devices

Technology Description and Operating Principle: Polymer Dispersed Liquid Crystal (PDLC) glazing consists of liquid crystal droplets dispersed in a polymer matrix. When voltage is applied, crystals align and allow transparency; without voltage, they scatter light, producing an opaque or translucent appearance. The primary function is privacy control, with secondary solar modulation.

Performance benefits include:

- Switching time: <1 second,
- Solar heat reduction: 10–25% (secondary benefit), and
- Electrical demand: low-voltage continuous.

Advantages include **i**nstant privacy control, suitable for interior partitions and integration with smart office systems. **Limitations** are lower thermal performance than electrochromic glazing and continuous electricity required for transparency.

[8] BREEAM (Building Research Establishment Environmental Assessment Method), DGNB (German Sustainable Building Council Certificate), HQE (Haute Qualité Environnementale)

Figure 5. PDLC applied in commercial building (Source: Gauzy)

Recommended Use	Key suppliers
Households: Privacy **Commercial:** Offices for meetings **Institutional buildings:** Conference rooms **Industrial:** Laboratories	- Gauzy (Israel/global, EU factory near Stuttgart DE) - Smart Glass International (Ireland EU) - Intelligent Glass (UK, EU) - SwitchFilm (Italy, EU) - PDLCGlass (China/global export EU)

Market Development is at level 9 and it's fully commercial with broad supplier base in EU, while there is increasing interest in smart office retrofits.

Parameters	Value
Energy savings	10–25%
Switching	<1 sec
Lifespan	15–20 years
HVAC savings	25–30%
Cost	€400–900/m^2
SRI contribution	Moderate

Investment note:

Primarily a comfort and privacy investment, energy savings are secondary. Moderate payback driven by privacy/flexibility value in commercial/healthcare (indirect HVAC savings); cost-effective retrofit via films, boosted by WELL/LEED credits and EU digital building passports. Credits boost certification level, enabling premium rents (5–15% uplift), tax incentives, and EU Taxonomy alignment for green finance.

2.6. Building-Integrated Photovoltaics

Technology Description and Operating Principle: Building-Integrated Photovoltaics (BIPV) integrates photovoltaic cells directly into building envelope elements such as façades, curtain walls, glazing, and roofs. These systems simultaneously function as building material and electricity generator. Available technologies include crystalline silicon modules, thin-film PV and semi-transparent solar glazing.

Figure 6. BIPV Installed in School Building (Source: Rethinking the Future Awards 2026)

Performance benefits include:

- Module efficiency: 10–25%,
- Cooling load reduction due to shading: up to 30%,
- On-site renewable electricity generation, and
- Contribution to ZEB compliance.

Advantages include dual functionality (energy + envelope), supports decarbonization targets, reduces operational carbon and increasing architectural integration. **Limitations** are higher design complexity, structural integration requirements and cost sensitivity to electricity tariffs.

Recommended Use	Key suppliers
Households: Roofs, High-rise residential buildings **Commercial:** Façades **Institutional buildings:** All types	- Onyx Solar (Spain, EU) - Metsolar (Lithuania, EU) - Solarstone (Finland/Estonia, EU)

Industrial: Industrial warehouses, sheds	- Vitro Architectural Glass (Solarvolt™) (U.S./Germany, EU) - Pilkington Sunplus™ BIPV (NSG Group, UK/global, EU)

Market Development is growing strong in Italy and Slovenia, while emerging in Western Balkans. The TRL 9 with increasing EU policy support.

Parameters	Value
Efficiency	10–25%
Cooling reduction	Up to 30%
Lifespan	25–30 years
Cost	€300–800/m^2
SRI contribution	Very High

Investment note:

Payback strongly dependent on electricity pricing, subsidies, and self-consumption schemes.

2.7. Dynamic Shading Systems

Technology Description and Operating Principle: Motorized external louvers, blinds, or shading panels integrated with sensors that adjust according to solar position, irradiance, and indoor comfort conditions. Unlike smart glazing, shading acts externally to block radiation before entering the building envelope. Dynamic solar shading technologies advance façade engineering by integrating sun-tracking, Internet of Things/Artificial Intelligence controls, and smart materials (incl. PV glass) to optimize glare control and energy efficiency.

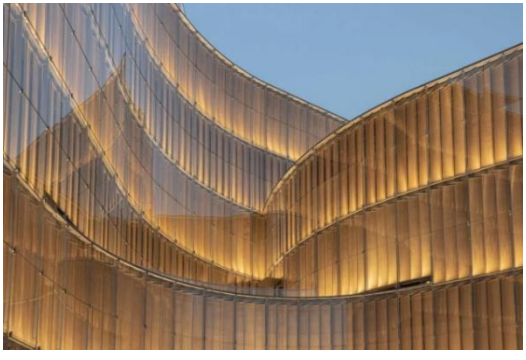

Figure 7. Dynamic solar shading at the YOFC Headquarters, China (Source: Fasade Today; Image Courtesy of Gensler)

Performance benefits include:

-Cooling reduction: 30–60%,
-Daylight autonomy: up to 65%, and
-High integration with BACS systems.

Advantages include cost-effectiveness, strong energy impact, retrofit-friendly and high SRI scoring potential. **Limitations** are focused on the required mechanical maintenance and the aesthetic considerations.

Recommended Use	Key suppliers
Households: Façades **Commercial:** Façades, offices **Industrial:** Annexes	- WAREMA Renkhoff SE (Germany, EU) - Hunter Douglas (Netherlands, EU/global) - Somfy (France, EU/global) - Duco Ventilation & Sun Control (Belgium, EU) - Lutron Electronics (U.S./EU offices)

Market Development: Mature EU market, and widely available with potential feasibility in IPA - ADRION countries.

Parameter	Value
Energy savings	30–60%
Autonomy	65% daylight
Lifespan	15–25 years
Cost	€100–400/m^2
SRI contribution	High

Investment note:

Rapid ROI (3–7 years) via 30–60% cooling savings and HVAC rightsizing; payback accelerated by subsidies (Exoikonomo in Greece or Eco Fund Slovenia) and rising energy tariffs in sunny climates in the IPA-Adrion region.

2.8. Façade Automation and Sensor Integration

Technology Description and Operating Principle: Façade automation integrates sensors, actuators, and control algorithms into Building Automation and Control Systems (BACS) to coordinate the glazing, shading, ventilation, HVAC and lighting. This enables predictive, adaptive energy management.

Performance benefits include:

- 10–30% total energy reduction,
- Integration with Smart Readiness Indicator framework, and
- Enhanced occupant comfort.

Advantages maximize performance of smart envelope components, provide essential for ZEB compliance and are scalable across building typologies. **Limitations** are focused on high technical expertise requirements and higher system integration complexity.

Figure 8. Building automation and sensor integration (Source: Carel)

Recommended Use	Key suppliers
Households: EMS **Commercial:** Offices **Institutional buildings:** Campuses **Industrial:** Complexes	- Siemens Building Technologies (Germany/global, EU) - Schneider Electric (France/global, EU) - Johnson Controls (Ireland, EU HQ) - Honeywell Building Solutions (U.S./EU)

Market Development: This technology is rapidly scaling in EU markets driven by EPBD mandates (Art. 14/15 BACS) and SRI requirements, with www.eu.bac (EU Association for certified BACS), certified systems ensuring EN 15232 compliance across 25+ EU states. Western Balkans adoption lags but accelerates via municipal pilots (EMS/GIS) and donor programs, positioning the technology for cross-border standardization in nZEB renovations.

Parameters	Value
Energy savings	10–30%
Cost	Project-specific
Lifespan	15–25 years
Certifications	BREEAM
SRI contribution	Critical

Investment note:

Payback 4–8 years through 10–30% total energy optimization and demand response; enhanced by EPBD grants, www.eu.bac certification for tenders, and SRI premiums in EU markets.

The Table 1 below presents key information on each featured technical solution.

Table 1. Comparative Technology Matrix – Smart Building Envelope Solutions

Technology	Active / Passive	Energy Savings Potential	Control Precision	Typical Cost Range (€/m²)	Market Maturity (EU)	Suitability for Retrofit	SRI Contribution
Electrochromic Glazing	Active (low-voltage)	🟢 20–40% HVAC & lighting	🟢 High (user-controlled)	🔴 500–1,000	🟢 High	🟡 Moderate	🟢 High
Thermochromic Glazing	Passive (temperature-driven)	🟡 3–15% cooling	🔴 Low (automatic, no control)	🟡 200–500	🟡 Medium	🟢 High	🟡 Moderate
Photochromic Glazing	Passive (light-driven)	🟡 10–15% cooling & glare	🟡 Low–Moderate	🟢 150–400	🟡 Medium	🟢 High	🔴 Limited
SPD Glazing	Active (electrical)	🟢 25–30% cooling	🟢 Very High (instant switching)	🔴 600–1,200	🟢 High (premium)	🟡 Moderate	🟢 High
PDLC / LCD Glazing	Active (electrical)	🟢 10–25% (secondary)	🟢 High (privacy control)	🔴 400–900	🟢 High	🟢 High (interior retrofit)	🟡 Moderate
BIPV (Façade/ Glazing)	Active (RES generation)	⚪ On-site RES + 10–30% shading effect	🟡 Not solar-control focused	🟡 300–800	🟢 High (growing)	🟡 Moderate	🟢 Very High
Dynamic Shading Systems	Active (motorized)	🟢 30–60% cooling	🟢 High (sensor-based)	🟢 100–400	🟢 Very High	🟢 Very High	🟢 High
Façade Automation (BACS)	Active (integrated system)	🟢 10–30% total building energy	🟢 Very High (predictive control)	🟡 Project-based	🟢 Very High	🟢 High	🟢 Critical
Legend: 🟢 =High/Strong; 🟡 =Medium; 🔴 =Low; ⚪ =Not primary function/Neutral							

Key Observations

- ✓ **Highest energy impact**: Dynamic shading + electrochromic glazing
- ✓ **Most cost-effective solution**: Dynamic shading systems
- ✓ **Highest SRI impact**: BACS integration + dynamic systems
- ✓ **Most mature in ADRION markets**: Dynamic shading and BACS
- ✓ **Most investment-intensive**: SPD and electrochromic glazing
- ✓ **Strongest ZEB alignment**: BIPV + automation systems

3. National Market Research

3.1. Albania

Albania is at an early but emerging stage of market development for smart building envelope technologies. The market for advanced components (such as electrochromic glazing, suspended particle device glazing and building-integrated photovoltaic façades) is nascent and concentrated mainly in Tirana, with some activity also noted in other urban centres such as Vlora and Durrës. Demand is driven primarily by premium offices, hotels and mixed-use developments, and increasingly by the planned long-term renovation of public buildings.

Technology availability in Albania is uneven. LCDS and "smart film" are already marketed and installed (for example through Aber Smart Glass) mainly for privacy and shading needs in commercial and hospitality projects, while high-performance double and triple glazing, low-emissivity glass, thermally broken curtain walls and ventilated façades are widely available through local façade and glazing firms. In contrast, fully electrochromic façades, suspended particle device smart glass and building-integrated photovoltaic façades are technically accessible only through international suppliers and have very low local penetration, generally limited to design-stage considerations or small-scale applications.

Albania's readiness is supported by strong local competence in aluminium-glass façades and ventilated façade systems, but practical experience remains limited for integrated smart control systems, façade-integrated photovoltaics and electrochromic glazing. Adoption is largely cost-driven and smart technologies are mainly considered in landmark projects or in international institutions or donor-funded public buildings. The policy and investment context indicates a large potential renovation pipeline toward 2050, and international programmes are beginning to channel green finance into building energy retrofits, which can open space for more integrated envelope solutions.

The Table 2 below presents technology availability & implementation status on each featured technical solution given the market context in Albania.

Table 2. Albanian Comparative Technology Matrix for Smart Building Envelope Solutions

Technology	Availability	Implementation	Market Development
Electrochromic Glazing	Available on request via international suppliers	Very low; limited to small premium applications	Early-stage awareness; high cost barrier

Technology	Availability	Implementation	Market Development
Thermochromic Glazing	Not identified as standard product; import possible	No confirmed implementation	Very low awareness and penetration
Photochromic Glazing	No architectural use identified	None	Negligible market presence
SPD Glazing	Accessible via specialized distributors	Very low; niche/premium use	Cost-sensitive; limited local expertise
PDLC / LCD Glazing	Present in market; local providers active	Low–medium use in commercial interiors	Most mature smart glazing segment
BIPV (Façade/ Glazing)	Technically available via imports	Very limited; mostly conceptual	Emerging; integration complexity limits uptake
Dynamic Shading Systems	Widely available	Low–medium; mainly commercial buildings	Growing awareness; linked to cooling demand
Façade Automation (BACS)	Available through system integrators	Medium in large projects	Moderate readiness; integration-based deployment
Low-E / Double Glazing	Widely available	Moderate–high in urban projects	Standard energy-efficiency upgrade; urban-driven adoption; high cost & limited awareness
Ventilated Façade Systems	Available through façade contractors	Low–moderate; mainly high-end commercial	Emerging; skills and cost barriers remain
ETICS (External Thermal Insulation Composite Systems)	Widely available	High in new builds and public retrofits	Most established envelope solution; quality control; workmanship issues

Policy & Financial Support Framework

Albania is progressively aligning national legislation with European Union energy efficiency and energy performance of buildings requirements through laws on energy efficiency and energy performance of buildings & energy production supported by related government decisions establishing professional roles and enforcement structures. The long-term renovation planning and national energy and climate planning provide a strong context for envelope upgrades, while international financing programmes (named in the country report) are beginning to support energy-efficient renovation and climate-resilient buildings, especially for public and large buildings.

Market Enablers	Market Obstacles
✓ Large pipeline of building renovation needs, including thousands of public buildings planned for renovation by 2050 ✓ Strong local capability in aluminium-glass façades, curtain walls and ventilated façades ✓ Existing market presence of liquid crystal device and smart film solutions (with identified provider) ✓ Active local value chain of façade contractors and glass suppliers capable of integrating imported components ✓ Increasing number of large-scale, façade-intensive developments in Tirana that can act as early adopters ✓ Emerging access to international green finance	- High upfront costs for advanced smart glazing and façade-integrated photovoltaics compared to standard solutions - Limited practical experience with electrochromic glazing, suspended particle device systems and façade-integrated photovoltaics - Dependence on imported advanced products, affecting cost, availability and integration capacity - Market demand remains cost-driven and concentrated in a small number of high-profile developments

channels supporting building renovation and public building upgrades	- Current regulatory practice emphasizes static performance indicators, with limited explicit focus on dynamic and adaptive façade solutions

Overall Market Development

Albania's smart envelope market is early-stage but promising. Core envelope solutions are already widely available and installed, while smart and adaptive technologies remain concentrated in premium projects and public building programmes supported by international finance and institutional actors. The next decade is positioned as decisive for building local integration capacity and linking smart envelope technologies to the renovation wave.

Technology Uptake Potential

✓ High potential: Dynamic external shading; façade automation and sensors; liquid crystal device and smart film solutions
✓ Moderate potential: Electrochromic glazing and suspended particle device glazing in premium applications; building-integrated photovoltaics in future public and large commercial pilots
✓ Limited near-term impact: Thermochromic glazing and photochromic glazing (no identified architectural use and very low market presence)

3.2. Bosnia and Herzegovina

Based on conducted research, Bosnia and Herzegovina currently shows no active market presence in smart building envelope technologies covered under the FENESTRAE framework. The assessment was carried out through online research, consultation with the Regional Chamber of Commerce in Banja Luka, and communication with one of the largest companies in the western region of the country. The collected information indicates that there are no small, medium, or large enterprises presently engaged in electrochromic glazing, thermochromic glazing, photochromic glazing, suspended particle device systems, liquid crystal device systems, building-integrated photovoltaic façade applications, dynamic shading automation, or façade automation technologies.

The Table 3 below presents technology availability & implementation status on each featured technical solution given the market context in Bosnia & Herzegovina.

Table 3. Bosnia & Herzegovina - Comparative Technology Matrix for Smart Building Envelope Solutions

Technology	Availability	Implementation	Market Development
Electrochromic Glazing	Not available	None	No local companies active
Thermochromic Glazing	Not available	None	No market presence identified
Photochromic Glazing	Not available	None	No market presence identified
SPD Glazing	Not available	None	No companies active
PDLC / LCD Glazing	Not available	None	No suppliers identified
BIPV (Façade/ Glazing)	Not available	None	No market actors identified
Dynamic Shading Systems	Not available	None	No companies active
Façade Automation (BACS)	Not available	None	No companies active

Policy & Financial Support Framework

Bosnia and Herzegovina has a formal legal framework for energy efficiency in buildings, but implementation and enforcement remain uneven. Current regulations focus on conventional building performance measures, while nearly zero energy building standards and advanced smart envelope technologies are not yet fully integrated. Smart glazing, dynamic façade systems, and adaptive transparency solutions are not explicitly addressed in legislation, and no dedicated financial instruments support their deployment. Municipal initiatives show openness to innovation and international cooperation, but at the national level structured support mechanisms remain limited. In the Republic of Srpska, existing strategies do not cover advanced glazing systems in non-conventional structures such as greenhouses, creating a policy gap despite their high energy intensity and potential for performance improvement.

Market Enablers	Market Obstacles
✓ Opportunity for technology import and transfer ✓ Potential alignment with European energy efficiency standards in the future ✓ Untapped market segment with no domestic competition	- Absence of domestic companies active in relevant technologies - Lack of market awareness and technical capacity - No identified pilot projects - No established supply chains - No targeted financial or regulatory support identified - Limited industry engagement with smart envelope solutions

Overall Market Development

Bosnia and Herzegovina currently represents a non-developed market for smart building envelope technologies within the ADRION region. The absence of local companies and implementation activity indicates that significant groundwork would be required before market scaling could occur. Future development would depend on awareness-raising, policy alignment, and the introduction of pilot or demonstration projects supported by international partnerships.

Technology Uptake Potential

- ✓ Short-term potential: low due to the absence of market actors, supply chains, and implementation experience
- ✓ Market entry would likely depend on external suppliers.
- ✓ Pilot and demonstration projects would be required to initiate adoption.
- ✓ Structured capacity-building initiatives would be necessary to develop local expertise.
- ✓ Initial adoption would most likely rely on imported technologies rather than domestic production.

3.3. Greece

Greece presents a regulatorily advanced but commercially selective market profile for smart building envelope technologies, where the baseline market is dominated by proven high-performance solutions and the "smart" segment is still consolidating. The market continues to prioritize conventional low-e double and triple glazing as the most widely understood, readily available, and procurement-safe option, while smart façade technologies appear mainly in premium projects, pilot contexts, or as add-ons within broader smart-building packages.

Electrochromic glazing remains at an early stage of adoption. While global suppliers such as Saint-Gobain (SageGlass) are present and referenced in the local market, partner inputs indicate low awareness and limited active importing, with the ecosystem not yet fully prepared to deliver electrochromic systems routinely with integration design, commissioning, and long-term serviceability. In terms of local market actors linked to electrochromic glazing discussions and

collaborations, the key names include iGlass, Vlavianos, Vasglass, and Patsis Glass, while Zervas-Alouminia is explicitly visible as a local provider showcasing a SageGlass-related electrochromic product offer. The existence of a demonstration project, the General State Hospital of Nikaia "Agios Panteleimon in Athens under the Switch2Save H2020 program, is important because Greece's current constraint is not "technology absence" but insufficient accumulation of credible local reference projects that could reduce perceived risk and normalize specification practices. Thermochromic glazing is even more limited, with minimal market penetration and a narrow supplier base; Vasglass (Vasiliko Chalkidas, Evoia) is identified as a key local actor providing thermochromic variable-tint products, with the Passivistas "Tavros Project" referenced as a pilot context for advanced envelope approaches.

Within "chromogenic/adaptive" solutions, Greece shows the clearest commercialization in two areas that offer straightforward value propositions and manageable delivery requirements. First, film-based photochromic solutions are present primarily as retrofit products with strongervisibility in transport/automotive applications than in façade performance, with Protection Window Films (Athens) identified as a local implementation actor; these solutions tend to remain niche for buildings because performance outcomes depend heavily on installation quality and warranty compliance. Second, smart privacy glazing (PDLC/LCD) is notably more mature than electrochromic and thermochromic categories, with a broader local network and clearer demand drivers in offices, hotels, and healthcare environments. Local suppliers and installers associated with PDLC/LCD offerings include Smartspace (Kifissia), Vlavianos (Aspropirgos), Filmark (Volos), Glassco (Volos), iGlass (Sindos Industrial Area, Thessaloniki), and Vasglass (Evoia). In parallel, SPD glazing is technically available but remains a premium niche; Vlavianos is identified as a key local actor in collaboration with Gauzy for SPD film solutions, which are attractive for fast switching and architectural shading but still constrained by cost and the limited scale of local deployment.

On the renewables-in-envelope side, building integrated photovoltaics are increasingly relevant in Greece because PV as a technology is mature and broadly accepted, while façade integration is emerging as a newer market concept that requires architectural coordination and specialized supply chains. Local implementation actors identified for BIPV include Solar Innova and Schüco, with the Passivistas "Tavros Project" serving as a visible pilot reference.

The main barriers remain the investment premium and technical integration complexity, but the opportunity is strong in residential and public buildings where envelope upgrades can be packaged with energy renovation measures.

Greece appears comparatively stronger in dynamic shading and building automation segments that align directly with cooling/overheating needs and with policy emphasis on operational efficiency. Dynamic shading systems with KNX-based integration are represented locally through P-J Savvidis (in collaboration with WAREMA), with reported deployments including commercial retail (e.g., LIDL locations) and residential projects. Building automation and façade-related controls (KNX + BMS integration) are supported by local integrators such as Depia Automations and MSS Electrolincs, with adoption visible across hotels, residences, commercial buildings, offices, and industrial facilities.

The Table 4 below presents key information on each featured technical solution given the Greek market context.

Table 4. Greek Comparative Technology Matrix – Smart Building Envelope Solutions

Technology	Availability	Implementation	Market Development
Electrochromic Glazing	Available via international suppliers	Limited / Pilot-based	Low awareness; high-cost barrier
Thermochromic Glazing	Very limited	Minimal	Niche / Experimental
Photochromic Films	Available (film-based)	Automotive niche	Low architectural uptake
SPD Glazing	Available via installers	Niche / Premium	Cost-sensitive segment
PDLC / LCD Glazing	Widely available	High (privacy-focused)	Mature domestic supplier base
BIPV (Façade)	Available	Growing	Integration complexity; RES-aligned
Dynamic Shading Systems	Widely available	High in commercial sector	Strong regulatory alignment
Façade Automation (BACS)	Available (project-based)	Growing	Increasing KNX/BMS demand

Policy & Financial Support Framework

Greece's policy environment for smart building envelope solutions is structured around a performance-based regulatory model rather than technology specific incentives. The national framework, built on KENAK and the TOTEE technical guidelines, transposes EPBD requirements into enforceable minimum energy performance standards, EPC obligations, and calculation methodologies that reward measurable reductions in heating and cooling demand rather than particular product categories. The National

Energy and Climate Plan and the Long-Term Renovation Strategy reinforce this direction by prioritizing deep renovations, digitalization, renewable integration, and operational efficiency in buildings. In parallel, recent public-sector measures such as mandatory shading provisions, temperature setpoint regulation, and the requirement for energy management systems in public buildings create an indirect but important enabling environment for dynamic shading, automation, and smart façade solutions.

Financial support mechanisms follow the same logic, as there are renovation and performance driven, not "smart-glazing-specific." The flagship "Exoikonomo" program supports envelope upgrades, including window replacement and insulation, provided they improve EPC ratings and energy performance indicators.

As a result, advanced glazing or façade technologies can qualify when embedded in broader renovation packages and justified through energy calculations, but they do not benefit from dedicated subsidy lines. Additional leverage exists through ESCOoriented models under the transposition of the Energy Efficiency Directive, particularly in public buildings where performance guarantees can de-risk higher upfront investments.

Market Enablers	Market Obstacles
✓ Mature EPBD-aligned regulatory framework (KENAK/TOTEE) ensuring performance-based compliance. ✓ Mandatory, fully digital EPC system driving measurable energy improvements. ✓ Strong national RES integration policy under NECP supporting envelope + PV synergies. ✓ Active renovation subsidy schemes (e.g., *Exoikonomo*) stimulating window and façade upgrades. ✓ Public-sector leadership (2024 shading & EMS mandates) normalizing smart controls. ✓ Climatic demand for solar control and overheating mitigation in cooling-dominated regions. ✓ Growing KNX/BMS integration ecosystem and façade automation expertise.	- Limited electrochromic importer and integrator network. - Confusion between smart-glazing technologies (EC, PDLC, SPD), weakening specification quality. - High upfront capital costs compared to conventional low-e glazing. - Value-engineering pressure favoring conventional, "safe" solutions. - Limited documented reference projects reducing investor confidence. - Installation, commissioning, and after-sales service capacity gaps. - Supply-chain and lead-time risks for imported advanced glazing systems.

Overall Market Development

Greece demonstrates a structurally supportive but commercially cautious environment for smart building envelope technologies. The regulatory and financial framework is sufficiently mature to accommodate advanced solutions, yet market uptake remains driven primarily by cost sensitivity, risk perception, and familiarity with conventional systems. Dynamic shading, BACS integration, and PV related envelope solutions show the clearest growth trajectory due to their strong alignment with climate conditions, operational savings, and policy direction. In contrast, advanced dynamic glazing technologies particularly electrochromic and SPD systemsremain in an early adoption phase, requiring demonstrator projects, clearer integration pathways, and stronger installer capacity to transition from premium, project-based deployment to standardized market practice.

Technology Uptake Potential

High potential: Dynamic shading systems (KNX-integrated) and BACS in commercial/public buildings
High–Moderate: BIPV façade integration in urban and public-sector decarbonization projects.
Moderate: PDLC/LCD glazing for hospitality, healthcare, and office applications.
Moderate–Low: Electrochromic glazing (requires demonstrators and integration support).
Low (short-term): Thermochromic and SPD glazing (premium niche, cost-sensitive).

3.4. Market Analysis - Italy

Italy shows a mixed market profile across smart building envelope technologies, with significant regional differentiation between metropolitan innovation hubs and smaller regions such as Molise. Awareness is increasing for electrochromic glazing, but practical implementation remains limited, mainly due to high cost and the premium positioning of this technology. The highest growth potential is reported for large metropolitan contexts such as Milan, where glass-clad high-rise buildings make investments in innovative glazing more financially sustainable.

Electrochromic solutions are available through European suppliers and local representatives, including SageGlass (Saint-Gobain) and Glass Specialist Building (Varese).

Thermochromic glazing has limited awareness and minimal market penetration, with very few products currently available via Tecnovati. Adoption is constrained by both cost and technology availability. Photochromic glazing is described as well established in optical glasses but still very limited in building applications, with no strong domestic production base. Suspended Particle Device glazing is present through suppliers and installers, including Innoptec (Trento) producing and selling smart film and Gauzy operating through professional installer networks in Italy. Liquid crystal device solutions are described as a mature, widespread technology, frequently used for indoor privacy control, with multiple Italian companies active (including Vitrik, Innoptec, Switch Film, Swicho Italia, SAP Sistemi, and Brixia Tech Italia) and clear technical specifications such as rapid switching times and low energy consumption.

Building-integrated photovoltaic solutions show good awareness and strong opportunities, especially for high-rise buildings and continuous façades where large surfaces are available, with semi-transparent photovoltaic solutions highlighted as a potential turning point. The main barriers are cost and building integration complexity. Local suppliers such as Polysolar and Onyx Solar offer the technology.

Dynamic shading systems have high awareness, supported by the emphasis of building regulations on shading control and integration with building management systems. Adoption is considered most relevant for medium to large scale buildings. Key barriers include costs and, when systems are integrated, the need to replace existing windows. BACS are available mainly through customized designs, with a broad range of smart controls and building management system options. Companies active in shading and automation include Somfy, Schüco, Bticino, Siemens, Master Italy, and TERA.

Molise Region Specifics

In the Molise region, the market structure differs from innovation-driven metropolitan areas. The regional market analysis conducted through the Chamber of Commerce and local SMEs indicates that Molise does not currently host producers of proprietary electrochromic or advanced smart façade technologies.

Instead, the region functions primarily as an installation and distribution market for international suppliers. A key regional intermediary identified is Laborvetro s.r.l., which provides access to external suppliers serving Molise.

Products available in the region include Powered by NSG TEC™ active glazing, which exploits conductive glass properties to provide transparent electric heating, supplementing traditional heating systems and improving thermal comfort in harsh climates. Triple-glazing configurations under this system allow electric current to heat the interior surface while maintaining transparency. Complementary solutions include the mywarm electric glass radiator (MONORAD system), which reduces required power by approximately 18–25%, heats more rapidly, and limits rear-wall heat loss.

On the renewable integration side, the Lumyra photovoltaic parapet transforms façade elements into laminated and tempered BIPV components with integrated cells that remain visually discreet. Additionally, innovative coated glass such as arconnect (radio wave permeable glazing) is commercially available in Italy and present in Molise through distributors, enabling improved mobile connectivity and reduced electromagnetic interference inside buildings.

Despite the availability of these advanced imported solutions, the Molise region lacks domestic production capacity and the relevant electrochromic systems and remains dependent on external supply chains.

This reinforces the observation that Italy's smart façade market strength is concentrated in industrialized northern regions, while smaller regions rely primarily on technology transfer rather than innovation generation.

The Table 5 below presents key information on each featured technical solution given the Italian market context.

Table 5. Italian Comparative Technology Matrix – Smart Building Envelope Solutions

Technology	Availability	Implementation	Market Development
Electrochromic Glazing	Available (imports + local distributors)	Limited / Premium projects	Increasing awareness; high cost barrier
Thermochromic Glazing	Very limited	Minimal	Few products; low market penetration
Photochromic Glazing	Niche	Very limited	Mainly optical applications
SPD Glazing	Available via installers	Niche / Premium	Local producer; cost-sensitive
PDLC / LCD Glazing	Widely available	High (mature market)	Strong domestic supplier base

Technology	Availability	Implementation	Market Development
BIPV (Façade/ Glazing)	Available	Growing	Good awareness; integration challenges
Dynamic Shading Systems	Widely available	High in commercial buildings	Strong regulatory alignment
Façade Automation (BACS)	Available (project-based)	Growing	Customized solutions; integration complexity

Policy & Financial Support Framework

Smart window technologies are not explicitly referenced in Italian decrees. However, they may qualify under general energy-efficiency and renovation incentive schemes when contributing to measurable building performance improvements:

- Ecobonus (energy efficiency deduction linked to thermal performance improvement)
- Bonus Ristrutturazioni (renovation deduction)
- Bonus Domotica (automatic control systems for energy optimization)

In Molise specifically, regional legislation (Regional Laws 30/2009, 7/2015, and 13/2015) provides incentives tied to improved energy class performance and renewable integration, including mandatory ≥60% DHW from RES for certain interventions and simplified permitting for PV/biomass systems. However, explicit provisions for smart glazing or advanced dynamic façades are not singled out, leaving performance-based compliance as the primary pathway for adoption.

Support is therefore performance-based rather than technology-specific.

Market Enablers	Market Obstacles
✓ Established fiscal incentive schemes linked to energy performance ✓ Strong domestic ecosystem for PDLC/LCD solutions ✓ High awareness of dynamic shading and building management integration ✓ Active European suppliers serving the Italian market ✓ Regional incentives in Molise tied to energy-class improvements and RES integration ✓ Growing interest in BIPV and façade-PV systems	- High capital cost of electrochromic and suspended particle device glazing - Limited availability of thermochromic and photochromic systems - Smart technologies not explicitly defined in legislation - Integration complexity in retrofit projects - Customization requirements for façade automation systems - Cost and coordination challenges for building-integrated photovoltaic integration - Lack of domestic production of advanced glazing in Molise (dependency on external suppliers)

Overall Market Development

Italy demonstrates a structurally favorable environment for smart envelope deployment due to fiscal incentives, strong regulatory alignment with EPBD, and technical standardization via UNI frameworks. The market is strongest in shading, automation, and PDLC technologies, while advanced dynamic glazing remains cost-constrained and concentrated in premium segments. Regional disparities are evident: innovation and industrial capacity are stronger in northern metropolitan regions, while areas such as Molise function primarily as technology adopters dependent on imported systems. Broader adoption will depend on cost reduction, integration simplification, strengthened regional supply chains, and improved diffusion of advanced glazing beyond high-end architectural contexts.

Technology Uptake Potential

- ✓ High potential: Dynamic shading systems, façade automation, liquid crystal device applications
- ✓ Moderate potential: Building-integrated photovoltaic systems (particularly in high-rise and large façade projects)
- ✓ Gradual / premium growth: Electrochromic and suspended particle device glazing
- ✓ Limited near-term impact: Thermochromic and photochromic glazing

Molise Region Related

- ✓ High potential (National) / Moderate in Molise: Dynamic shading systems and façade automation (KNX/BACS).
- ✓ Moderate potential (National) / Moderate–Emerging in Molise: Building-Integrated Photovoltaics (BIPV).
- ✓ Gradual / Premium Growth (National) / Low in Molise: Electrochromic and SPD glazing.

3.5. North Macedonia

North Macedonia shows a selective and still early-stage market profile across smart building envelope technologies, with PDLC/LCD clearly the most visible and commercially present segment. Demand is driven mainly by interior privacy applications (offices, meeting rooms, healthcare and higher-end residential),

typically delivered as imported film/glass solutions assembled by local glazing companies on a project basis; adoption is helped by straightforward installation and "instant effect" for users, but remains constrained by price sensitivity and frequent market confusion between PDLC and true solar-control smart glazing.

For BIPV (façade / glazing), awareness is emerging and is usually framed through the broader push for renewables and energy efficiency in buildings, yet uptake remains sporadic and opportunity-led, mostly where investors can justify the higher capex and the added design/engineering coordination. The practical market barrier is less about basic availability and more about integration complexity (façade engineering, electrical integration, warranties, and permitting), meaning BIPV is most likely to appear first in high-visibility commercial buildings, hotels, and flagship renovations once procurement starts valuing life-cycle performance rather than lowest initial price.

Dynamic shading systems are the most "market-ready" envelope technology after PDLC, because they fit well with everyday building needs (summer overheating, glare control) and can be implemented incrementally. Adoption is strongest in commercial and hospitality buildings where comfort and operational savings matter, but scaling is still hindered by upfront cost, fragmented design responsibilities (architect–MEP–façade contractor coordination), and the reality that deeper retrofits may require partial replacement of existing façade elements to fully benefit from automated or integrated solutions.

Finally, façade automation/BACS is not yet a functioning market segment in North Macedonia, and there are no identified pilot or demonstrator projects that would anchor market confidence. In practice, this keeps smart-envelope solutions from being deployed as "systems" (controls + façade + performance verification), and instead they appear as standalone products—so near-term progress depends on bundling shading/controls into renovation packages and building a small pipeline of reference projects that can prove comfort and energy results in local conditions.

The

Table 6 presents key information on each featured technical solution given the Macedonian market context.

Table 6. Macedonian Comparative Technology Matrix – Smart Building Envelope Solutions

Technology	Availability	Implementation	Market development
PDLC / LCD glazing ("smart film")	Present via local suppliers/fit-out market	Low–medium (mainly privacy/interior, selective commercial & hospitality use)	Emerging; most mature of the listed technologies
BIPV (façade / glazing)	Technically accessible via PV market + project-based integration	Very low; mostly concept/design-stage except isolated applications	Low–moderate readiness; tied to financing & capable integrators; aligned with NECP PV measures
Dynamic shading systems	Available through façade/shading contractors	Low–medium (more common in larger buildings than residential)	Moderate readiness; strong near-term potential
Façade automation (BACS)	Partner inputs indicate not present as a market offer	Non-existent; no pilots identified (per partner inputs)	Very low readiness until first demonstrators

Policy & Financial Support Framework

North Macedonia's policy and financial framework for building energy performance is gradually strengthening. The National Energy and Climate Plan is being updated to ensure alignment with European Union governance requirements, national building inventory project is underway. In parallel, the country is in the process of establishing a National Energy Efficiency Fund, with the legal basis anchored through amendments to the Development Bank framework in October 2023, while full operational rules are still pending. At present, the funding landscape for energy-efficient building upgrades relies heavily on international financial institutions and donor programmes, including European Union IPA instruments, the European Bank for Reconstruction and Development, KfW, and the World Bank, which means that advanced envelope solutions are most likely to emerge first within externally financed public and large-scale projects.

Market Enablers	Market Obstacles
✓ Pipeline effect from policy alignment + financing instruments: NECP implementation and the planned National EE Fund can create repeatable renovation demand and procurement pathways. ✓ Donor/IFI-backed renovation channels (EU IPA/EBRD/KfW/WB) can "carry" early demonstration projects where capex is a barrier.	- Low public awareness and limited outreach on energy efficiency, moreover on smart façades and smart façade systems, aweakening demand pull beyond a narrow group of informed investors. - Reliance on external finance can delay mainstream adoption and keep smart-envelope solutions concentrated in a small number of projects rather than becoming standard practice.

✓ Near-market maturity of PDLC/LCD makes it the most scalable "smart glazing" entry point, especially for privacy + fit-out markets. ✓ 'Prosumer' legal possibilities being enabled via the recent legislation	- Policy execution gap / pending operational rules (e.g., the EE Fund operational framework still to be adopted), which slows predictable market signals for integrated solutions.

Overall Market Development

Macedonian market is in premature stage for practical adoption of PDLC/LCD and dynamic shading, while BIPV façades/glazing is likely to progress through financed flagship renovations and premium developments, supported by PV policy measures and the gradual build-out of EE financing structures. The critical accelerator is moving from one-off deployments to repeatable public/procurement "reference packages" enabled by stable funding and clear implementation rulebooks especially given the currently low awareness and donor-dependent financing structure.

Technology Uptake Potential

- ✓ High potential (next 3–5 years): PDLC/LCD glazing (privacy + selective shading use cases); dynamic external shading (public + larger commercial).
- ✓ Moderate potential: BIPV façades/glazing (first via financed public/large commercial demonstrators; needs integrator capability).
- ✓ Limited near-term impact: Façade automation (BACS) (partner inputs indicate non-existence and lack of pilots).

3.6. Slovenia

Slovenia indicates mature market profile for smart building envelope technologies where domestic suppliers are present. The market enabling enviornment relate to liquid crystal device solutions and dynamic shading systems, both supported by identifiable Slovenian companies and defined product offers. Thermochromic rooflight glazing is also available as a marketed product line, accompanied with higher cost and integration burden.

Thermochromic glazing is present through Akripol's G-Lux within its Alux rooflight portfolio, positioned as a switchable glazing solution for controlling solar gain, glare and comfort. Market presence is evidenced through active marketing in catalogues, while adoption remains constrained by the cost premium of switchable interlayers, the need for electrical supply and transformer integration, installation complexity and certification requirements for special applications. The most relevant applications are commercial and public buildings and high-end residential rooflight solutions where glare control and comfort are critical.

Liquid crystal device solutions are represented by the domestic provider Sglass, which offers polymer dispersed liquid crystal films and laminated smart glass for rapid switching between opaque and transparent states. These solutions are positioned as mature and widely applicable for privacy and flexible interior use in offices, hotels and residential projects, with barriers mainly linked to higher cost compared to conventional options, the need for electrical connection, retrofit detailing and market education. In parallel, dynamic shading systems are strongly represented by Soltec, a Slovenian producer of motorized façade shading solutions with documented projects and established presence, offering a clear pathway for wider deployment in public buildings and commercial developments where solar control and comfort benefits are measurable.

The Table 7 below presents key information on each featured technical solution given the Slovenian market context.

Table 7. Macedonian Comparative Technology Matrix – Smart Building Envelope Solutions

Technology	Availability	Implementation	Market Development
Liquid crystal device glazing	Available via domestic supplier (Sglass)	Medium	Most developed smart glazing segment in country
Building-integrated photovoltaics	Available via domestic manufacturer example (Bisol)	Project-based (flagship projects not listed)	Developing; supported by general renewable incentives and enabling framework
Dynamic shading systems	Widely available via domestic supplier (Soltec)	Active implementation (referenced projects)	Strong growth potential; aligned with overheating prevention needs

Policy & Financial Support Framework

Slovenia's building policy and delivery framework is mature and implementation-oriented, combining national performance requirements with financing and procurement levers. The strong basis reflects in the national building rules and technical requirements that support high-performance envelopes and overheating prevention,

public financing via the Eco Fund for renovations and renewable energy, and mandatory green public procurement that drives demand for energy-efficient solutions. Slovenia also enables self-supply and energy community approaches that support renewable integration in buildings.

Market Enablers	Market Obstacles
✓ Mature building performance requirements and technical rules supporting high-efficiency envelopes and overheating prevention. ✓ Eco Fund grants and loans supporting renovation and renewable energy measures. ✓ Mandatory green public procurement creating consistent demand signals for high-performance building components. ✓ Domestic suppliers identified in the country inputs for liquid crystal device glazing (Sglass) and dynamic shading systems (Soltec).	- Premium cost of advanced dynamic glazing systems compared to conventional solutions. - Installation complexity due to electrical supply, transformers, and integration with façade systems. - Coordination requirements between glaziers, electricians, and façade engineers increase project risk. - Durability, certification, and long-term maintenance concerns for electrically operated systems. - Limited publicly visible flagship reference projects, reducing investor confidence and slowing market scaling.

Overall Market Development

Slovenia demonstrates a comparatively structured and implementation-ready market for selected smart building envelope technologies, particularly where domestic suppliers are active. The strongest development is observed in liquid crystal device glazing and dynamic shading systems, supported by identifiable Slovenian manufacturers and documented applications in commercial and public buildings.

Technology Uptake Potential

- ✓ High potential: Liquid crystal device glazing; dynamic shading systems (domestic supply and described implementation).
- ✓ Moderate potential: Thermochromic roof light glazing (available and specified, but with premium/complexity barriers).

4. Conclusions and Recommendations

This Market Analysis confirms that technological availability alone is not sufficient to ensure smart building envelope deployment in the IPA-ADRION region. While dynamic shading, façade automation (BACS), PDLC/LCD systems, electrochromic glazing, and BIPV are commercially mature at EU level and technically accessible across partner countries, **market readiness differs significantly by country and by region**. The primary bottleneck is not product absence, but limited implementation confidence, insufficient system integration capacity, fragmented supply chains, and the absence of demonstrative, performance-verified reference projects, particularly in Western Balkan markets and in less industrialized regions.

EU Member States demonstrate differentiated maturity levels. Slovenia and Italy show the strongest implementation capacity, established supplier ecosystems, and growing deployment, especially in dynamic shading, façade automation, and selected smart glazing segments. Italy also illustrates regional disparity, where industrialized metropolitan areas are innovation-driven, while regions such as Molise operate mainly as installation and distribution markets dependent on imported technologies. Greece, although regulatorily advanced and aligned with EU energy performance requirements, remains commercially less mature than Slovenia and Italy in advanced dynamic glazing segments, with uptake concentrated in premium or pilot projects and a limited importer and integrator network for electrochromic systems.

Western Balkan countries present an early-stage but non-uniform picture. Albania and North Macedonia lack active local production of advanced smart envelope technologies, yet existing façade, glazing, and shading suppliers demonstrate the potential for forward integration if supported through structured import, integration, and commissioning models. Bosnia and Herzegovina lags behind Albania and North Macedonia in overall market maturity, with minimal identifiable activity across the assessed technology groups and limited integration capability. In these contexts, market activity remains largely dependent on imports, donor financing, or isolated flagship projects rather than systemic integration within mainstream construction practice.

Across all countries, the decisive accelerator for market transformation is the systematic development of demonstration projects. Smart façade technologies must move from isolated, product-based applications to integrated, monitored, and publicly documented pilot buildings that prove measurable outcomes and reduced cooling loads, improved daylight autonomy, enhanced user comfort, increased SRI

performance, and operational savings. Demonstration buildings, particularly in public facilities such as schools, hospitals, municipal buildings, and administrative offices, should function as living laboratories. These projects must include structured performance monitoring, post-occupancy evaluation, and transparent dissemination of results in order to build trust among architects, engineers, investors, financial institutions, and policy makers.

A strong and coordinated role of commercial banks and development finance institutions is essential. Beyond conventional lending, financial institutions should introduce blended support instruments combining grants, concessional loans, technical assistance, and risk-sharing mechanisms specifically targeting smart envelope integration. Grant components can offset the incremental capital cost of dynamic glazing, BIPV façades, or façade automation, while technical assistance packages should support feasibility studies, energy modelling, façade engineering design, commissioning protocols, and performance verification. In early-stage markets, such instruments are particularly critical to enable forward integration of existing suppliers and reduce perceived technological and procurement risk. Structured financing aligned with performance-based procurement will be key to accelerating mainstream adoption across both mature and emerging markets within the region.

To translate these strategic findings into actionable steps, the following roadmap outlines a phased pathway for scaling smart building envelope technologies from pilot implementation to full market maturity across the ADRION region, see Table 8.

Table 8. Roadmap Toward Market Scaling of Smart Building Envelope Technologies for IPA-ADRION Region

Phase	Timeframe	Strategic Objective	Core Actions	Expected Market Outcome
Phase 1 – Market Activation	Years 1–2	Build confidence through demonstration	➢ Launch flagship public building pilots ➢ Integrate shading + BACS + smart glazing ➢ Performance monitoring & public reporting ➢ Early engagement of commercial banks	✓ First verified reference projects ✓ Measured cooling reductions ✓ Improved SRI scores ✓ Increased awareness
Phase 2 – Structured Market Entry	Years 2–4	Reduce risk & standardize implementation	➢ Develop technical guidelines ➢ Introduce performance-based procurement ➢ Green bank products (grants + concessional loans + TA) ➢ Installer & integrator training	✓ Bankable project models ✓ Reduced integration risk ✓ Growing supplier ecosystem ✓ Early private adoption
Phase 3 – Market Expansion	Years 4–7	Scale to mainstream market	➢ Scale commercial bank financing lines ➢ Integrate smart façades into public procurement standards ➢ Promote life-cycle cost assessment	✓ Smart shading & BACS become standard ✓ Broader commercial deployment

Phase	Timeframe	Strategic Objective	Core Actions	Expected Market Outcome
			➢ Expand BIPV in large projects	✓ Cost reduction through volume ✓ Growing domestic expertise
Phase 4 – Market Maturity	Years 7–10	Institutionalize smart envelopes	➢ Mandatory BACS in large buildings ➢ SRI-based compliance incentives ➢ Green mortgages & performance-based lending ➢ Regional supply-chain integration	✓ Smart envelope = default solution ✓ Strong ZEB alignment ✓ High SRI building stock Stable financing ecosystem

Legend: **Blue** → Activation / Demonstration; **Green** → Structuring & De-Risking
Yellow → Scaling & Expansion **Orange** → Institutionalization & Maturity

To achieve scale, the following strategic priorities are critical:

- Establish tiered national flagship demonstration programs, tailored to market maturity: advanced integrated pilots (dynamic glazing + BACS + BIPV) in Slovenia and Italy; integration-focused pilots in Greece; and capacity-building demonstrators in Albania, North Macedonia, and especially Bosnia and Herzegovina, where foundational market activation is required.
- Position façade technologies explicitly within SRI scoring, overheating mitigation strategies, and nZEB pathways, ensuring that shading, automation, and dynamic envelope solutions are framed as compliance and performance enablers rather than optional upgrades.
- Support forward integration of existing façade, glazing, and shading suppliers in emerging markets (Albania and North Macedonia) through blended finance instruments that combine concessional loans, targeted grant components for incremental CAPEX, and structured technical assistance for design, commissioning, and performance verification.
- Introduce standardized, performance-based procurement templates, particularly in public buildings that prioritize life-cycle cost, measurable energy outcomes, and integration readiness over lowest-cost selection criteria, thereby reducing value-engineering fallback to conventional low-e solutions

Key Takeaways

- The ADRION region does not lack technological availability; most smart façade solutions are commercially mature at EU level and technically accessible across all partner countries, primarily through imports and European supplier networks.
- Market readiness is uneven. Slovenia and Italy demonstrate the highest maturity, Greece shows regulatory strength, but moderate commercial uptake, Albania and

North Macedonia are early-stage with forward-integration potential, and Bosnia and Herzegovina currently lags behind in active market presence.

- The primary bottleneck is not product absence but the lack of visible, performance-verified demonstration projects that prove real energy savings, overheating mitigation, comfort improvements, and SRI gains under local climatic and regulatory conditions.
- Smart façade systems are frequently deployed as isolated products (e.g., film, shading, PV modules) rather than as integrated, monitored building systems combining glazing, automation, and energy management, limiting confidence, bankability, and replication.
- In emerging markets (Albania and North Macedonia), existing façade and glazing suppliers could undertake forward integration into higher-value solution models if supported with technical assistance and structured financing. Bosnia and Herzegovina requires more foundational market activation and first-mover integrators.
- Demonstration projects in public buildings (schools, hospitals, municipal buildings, administrative facilities) represent the fastest pathway to build trust, develop commissioning expertise, and generate replicable procurement templates.
- Scaling requires structured implementation support, not regulation alone:
    - Grant components to offset incremental costs of dynamic glazing, BIPV façades, and automation systems,
    - Technical assistance for feasibility studies, façade engineering design, commissioning, and performance verification,
    - Risk-sharing and blended finance instruments through commercial banks and development finance institutions.
- Green banking instruments must move beyond standard lending and adopt blended finance models (grants + concessional loans + advisory support), particularly in less mature markets where perceived technological and integration risk remains high.
- Standardized, performance-based procurement frameworks aligned with life-cycle costing, SRI scoring, and ZEB pathways are essential to avoid value-engineering fallback to conventional low-e glazing.

- The transition from niche innovation to standard market practice will follow a clear pathway:

- Smart façade deployment is a strategic lever for achieving EPBD recast compliance and ZEB objectives across both mature and emerging IPA - ADRION markets.

This document has been developed within the framework of the project **"Fostering Energy Efficiency by Means of Smart Technologies to Retrofit Apertures and Building Envelope – FENESTRAE"**, through close cooperation between partner organizations, national experts, academic representatives, and technical contributors.

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