



When Design Meets Decarbonization: Colored Photovoltaics in Sustainable Architecture





Introduction:

As cities accelerate toward net-zero targets, the role of renewable energy in the built environment is evolving. The challenge is no longer limited to how much clean energy buildings can generate but increasingly concerns how renewable technologies integrate with architectural design, cultural identity, and urban character.

Global institutions such as the International Energy Agency (IEA) have repeatedly emphasized that buildings must play a central role in achieving climate targets, particularly through envelope-level interventions rather than isolated rooftop solutions.

(IEA – Buildings Sector: <https://www.iea.org/topics/buildings>).

In dense cities, heritage districts, and high-visibility developments, conventional photovoltaic panels often face resistance. Their standardized dark appearance can conflict with carefully curated façades, planning guidelines, and the visual language of landmark architecture. As a result, large portions of the building envelope—particularly façades—remain underutilized for renewable energy generation, despite their significant solar exposure.

Colored photovoltaics (PV) have emerged as a response to this challenge. By enabling solar modules to adopt a range of colors, textures, and finishes, colored PV allows renewable energy systems to be treated as intentional architectural elements rather than technical add-ons—supporting what the European Commission increasingly refers to as design-integrated energy systems

(EU BIPV Research: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings_en).



Colored Photovoltaics within the Evolution of BIPV

Building-integrated photovoltaics represent a shift from rooftop-mounted systems toward deeper integration within the building envelope. Façades, skylights, balustrades, shading devices,

and cladding systems are increasingly expected to perform multiple functions, including energy generation, thermal control, and daylight modulation.

According to the IEA PVPS Task 15 on BIPV, this approach allows PV systems to serve multiple roles—electricity generation, weather protection, thermal modulation, and architectural expression—while reducing redundancy in materials.

Despite these advantages, early BIPV adoption remained limited due to visual rigidity and limited design flexibility. Most systems offered little variation beyond dark blue or black modules, reinforcing the perception that solar technologies were incompatible with refined architecture.

Colored PV extends the BIPV concept by addressing one of its most persistent barriers: visual uniformity. Conventional PV modules are typically black or dark blue, which may conflict with architectural intent, material palettes, or planning regulations. Colored PV technologies allow solar elements to align with the architectural language of a building—particularly in projects where visual coherence is critical.



Technology Overview: How Color Is Achieved without undermining the performance

Introducing color into photovoltaic modules requires careful manipulation of light while preserving the core photovoltaic function. Several technological approaches have matured in recent years, supported by extensive laboratory and field research.

Spectrally selective coatings

These coatings reflect targeted wavelengths of visible light to produce color while allowing the remaining solar spectrum to reach the photovoltaic cells. Research published in *Nature Energy* and *Progress in Photovoltaics* demonstrates that optimized coatings can limit efficiency losses to single-digit percentages.



Nano-structured and textured glass surfaces

Micro- and nano-scale surface treatments scatter incoming light to create matte, stone-like, or metallic finishes. These technologies are widely documented in façade-integrated PV research due to their glare-reduction benefits, particularly in dense urban environments



Laminated colored glass systems

In this approach, color is embedded within the glass laminate rather than applied directly to the solar cell. This allows the photovoltaic layer to remain optimized while the external appearance is controlled independently. Systems such as **Kromatix™** have published long-term performance and durability data under real operating conditions

(Kromatix Technical Publications: <https://www.swissinsolar.com/kromatix>).

While all colored PV technologies involve trade-offs, **IRENA** emphasizes that façade-based renewable generation should be evaluated based on usable surface area, lifecycle performance, and urban acceptance, not peak module efficiency alone

(IRENA – Innovation Landscape for Buildings: <https://www.irena.org/Publications>).

Global Adoption and Architectural Case Studies

Colored photovoltaics have progressed from experimental concepts to proven architectural solutions. Adoption has been strongest in projects where design quality, public visibility, and planning sensitivity are paramount.

Dubai Frame, UAE

Context: Globally recognized urban landmark

Application: Integration of photovoltaic glass within envelope elements

Value: Demonstrates that renewable energy systems can be embedded into iconic civic architecture without visual disruption

(Dubai Municipality - <https://www.dm.gov.ae/projects/dubai-frame/>)



Red River College, Winnipeg, Canada

Context: Educational campus with sustainability mandate

Value: Combined renewable generation with pedagogical and architectural value

(<https://resilientcolleges.ca/2021/04/22/rrc-celebrates-earth-day-with-upcoming-installation-of-new-to-north-america-sustainable-technology/#:~:text=Kromatix%2C%20developed%20by%20SwissINSO%2C%20is,and%20shared%20for%20future%20projects.>)



Kindergarten Building, Dubai, UAE

Context: Educational facility.

Application: Playful color-specific PV façade.

Value: Enhanced architectural identity and sustainability outcomes.

(<https://www.constructionweekonline.com/products-services/article-49434-uaes-first-coloured-solar-panel-faade-installed-in-dubai>)



Relevance for the Middle East and High-Identity Developments

The Middle East presents a compelling context for colored PV adoption. Across the region, large-scale developments emphasize architectural identity, cultural narrative, and global visibility while pursuing ambitious net-zero targets.

- Giga projects such as Diriyah, Red Sea Global, Roshn, Sports Boulevard, etc. require renewable energy solutions aligned with curated visual identities.
- Heritage districts often restrict conventional PV due to aesthetic considerations.
- Colored PV enables solar integration that complements stone façades, earth-toned materials, and contemporary architecture.
- Early deployments in Saudi Arabia and the UAE indicate growing confidence in performance and design flexibility.

Challenges and Market Considerations

Despite its potential, several factors continue to influence adoption:

1. Efficiency vs. Aesthetics

Colored coatings inevitably reduce panel efficiency by reflecting parts of the light spectrum. Ongoing R&D is minimizing this penalty, but it remains a consideration.

2. Premium Cost

Colored PV currently carries higher production and installation costs compared to standard modules. Large-scale adoption in MENA giga-projects could help achieve economies of scale.

3. Durability and Standards

Ensuring long-term weather resistance and performance in harsh climates (such as the Middle East's high heat and dust) requires rigorous testing and certification.

4. Policy and Incentives

Most solar incentives globally focus on kilowatt-hour generation, not architectural integration. Policies recognizing the dual value of colored PV (energy + aesthetics) would accelerate adoption.

At the same time, the opportunities are significant:

- › **Urban retrofits:** Heritage cities or urban districts reluctant to install standard PV can embrace colored solutions.
- › **Iconic branding:** Developers and governments can use colored PV as a visual symbol of sustainability leadership.
- › **Cross-sector synergies:** Integration with real estate, culture, and tourism industries creates new business models beyond electricity sales.



Conclusion: Design-Led Pathways to Net-Zero Architecture

Colored photovoltaics represent an important evolution in renewable energy integration. By reconciling aesthetics with performance, colored PV enables buildings to contribute to decarbonization while reinforcing architectural identity.

As net-zero targets become standard practice, the success of renewable integration will increasingly depend on design acceptance as much as technical performance. Colored PV will not replace conventional solar installations, but it will unlock applications where visual integration is decisive—supporting a more inclusive and design-conscious transition toward sustainable urbanism.

How AESG can help



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Dheeraj is a Senior Sustainability Consultant at AESG, with over 13 years of experience as a Building Science Engineer, specializing in sustainable design and climate action. He is a USGBC faculty, LEED SME and holds key sustainability credentials, including LEED AP, WELL AP, Envision SP, Parksmart Advisor, Activescore+Modescore AP, ISO 14064 GHG Lead Verifier/Validator and ISO 14001 Lead Auditor.

His expertise spans sustainable engineering, energy conservation, and integrated building design.

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For further information relating to specialist consultancy engineering services, feel free to contact us directly via info@aesg.com

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