U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Welcome to the Energy Department's "Building-Integrated Photovoltaics: Beyond the Shingle" Workshop!

Agenda Overview

9:00a – 9:10a	**Introductions**
9:10a – 9:30a	**SETO/BTO Report** G. Stefopoulos (SETO), R. Narayanamurthy (BTO)
9:30a – 10:00a	**Barriers & Strategies for Integrating Architectural Solar – A U.S. Market Perspective** Chris Klinga, Stan Pipkin (ASA)
10:00a – 10:15a	**Break**
10:15a – 11:00a	**Industry Panel Discussion** Moderator: Jennifer DiStefano (SETO) Panelists: Cory Fry, Veeral Hardev, Hunter McDaniel, Vaiva Razgaitis
11:00 – 11:15am	**Transparent BIPV work at LBNL** Jacob Jonsson (LBNL)
11:15 – 11:30am	**Observations & Lessons Learned in Residential BIPV** Jeff Cook (NREL)
11:30 – 11:45am	**BIPV at the Solar Decathlon** Rachel Romero (NREL)
11:45am-12:00pm	**Closing remarks**

Challenges and Opportunities for Building-Integrated Photovoltaics

SETO/BTO Request for Information Report

Solar Energy Technologies Office / Building Technologies Office

Greenbuild International Conference and Expo

U.S. DOE BIPV Workshop – November 1, 2022

Outline

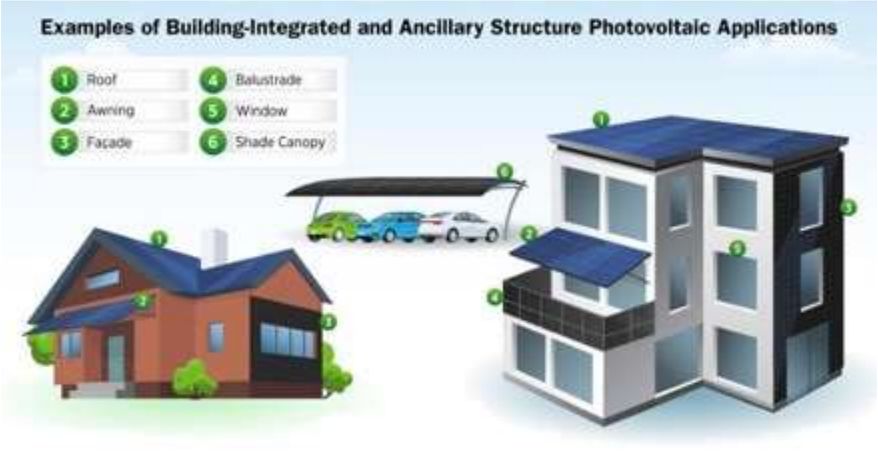
- Background
- RFI overview
- Responses and learnings
- Workshops
- Further discussion

Background

- **Building-sited distributed PV was about 30% of new solar capacity installed in 2020**
- **Roof-mounted systems are currently the dominant design**
- **Other approaches and technologies could provide a competitive value proposition for building decarbonization**
  - Providing better potential given the building aspect ratio
  - Combining redundant parts
  - Reducing overall system costs
  - Improving efficiencies

Background

Building-applied PV (BAPV)	Building-integrated PV (BIPV)
Conventional PV modules	Specialized PV modules
Fully-functional building	Integral part of building
Electricity generation	Electricity generation and building function



RFI Details

- Collaborative DOE RFI between SETO and BTO
- March 7 to April 1, 2022
- 37 responses from a variety of stakeholders
- Focus on current state of the industry, challenges and barriers, gaps, and R&D needs
- Summary report at https://www.energy.gov/eere/solar/summary-challenges-and-opportunities-building-integrated-photovoltaics-rfi

RFI Details – Focus areas

State of the industry and key domestic markets

Product requirements

Key barriers and perceptions

RDD&C needs and opportunities

Stakeholder engagement processes

Market Segments and Opportunities

Products

- **Roofing**
- Covering/Shading Elements
- Glass products
- Vertical products

Customer Segments

- **Commercial buildings**
- Residential buildings
- Government, education, healthcare
- Agriculture and greenhouses

Domestic Manufacturing

- Proximity to market
- Building products typically produced close to consumption
- Cost/emission reductions

Key Product Requirements

Performance

Cost

Aesthetics

Reliability, durability, and safety

Process integration

Supply chain integration

Key Barriers and Perceptions

Technical Barriers	**Costs**
	Performance
	Aesthetic considerations
	Technical **complexity** in installation, operation, and maintenance
	Certification and permitting challenges
Resource Shortages	Availability of **products**, product and supply chain reliability
	Expertise shortage and lack of educational resources
	Lack of sales, estimation, and other **decision support** tools
	Lack of financial **incentives** specific to BIPV
Awareness and collaborations	Technology awareness by **designers and end-users**
	Existing **silos** in operating and business models of various affected groups
	Disconnects between partnering groups and affected industries
Research and Development	Lack of **fundamental research**
	Lack of **demonstration projects**

RDD&C Needs

Product demonstration	**Testing** facilities and **demonstration** projects
	Availability of **data**
Models and tools	Production **cost** modeling
	Energy yield modeling
	Installed system cost modeling with consideration for **O&M** costs
	Comprehensive **assessment of benefits**
Performance improvements	Improved BIPV product designs – **aesthetics**, **installation**, **O&M**
	Efficiency and **energy yield** improvements
	Thermal management improvements
	Installation and maintenance processes
	Systems **integration**

Stakeholder Engagement and Outreach

Underrepresented groups	**Architectural** community
	Construction industry
	Manufacturers and product implementation teams
	Power-electronics companies
	T**rade associations** and organizations
	Local/state **regulators**
	Investors
Outreach mechanisms	Publishing **case studies**
	Supporting and promoting **demonstration projects**
	Establishing dedicated **BIPV conferences**, trade shows, workshops, and other **educational opportunities**
	Creating a steering committee to make **recommendations for specific certification standards** for BIPV
	Providing **funding opportunities** for research and commercialization of BIPV solutions
	Instituting BIPV rebate programs or **financial incentives**
	Creating a coordinated national effort, like establishing a U.S.-based **consortium**
	Promoting early-stage **innovation**

Purpose of Workshop

- Bring together various BIPV stakeholders from industry, academia, and research entities
- Create a forum for discussion and exchange of views and ideas
- Understand the current status and needs of the industry
- Receive input that would guide future DOE plans and activities

DOE BIPV Workshops

- **RE+**
  - https://www.re-plus.com/power/
  - Thursday, September 22, 2022, 8:00 – 12:00p
- **Greenbuild International Conference and Expo**
  - https://informaconnect.com/greenbuild/
  - Tuesday, November 1, 2022, 9:00 – 12:00p
- **Buildings XV**
  - https://www.ashrae.org/conferences/topical-conferences/2022-buildings-xv-conference
  - Thursday, December 8, 2022, 1:00 – 5:00p

Questions and Further Discussion

George Stefopoulos
georgios.stefopoulos@ee.doe.gov

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US DOE BIPV Workshop - Building Technology Office

Ram Narayanamurthy, Marc LaFrance
US DOE
Advanced Technology and Energy Policy Manager

Greenbuild International Conference and Expo
November 1, 2022

Core functions of building envelopes

- Keep the rain out
- Keep the heat out in summer
- Keep the heat in the winter
- Maintain a view to the outdoors
- Provide safe and comfortable space
- Avoid mold, bugs and rot
- Reduce chances of condensation
- Ventilate indoor pollutants
- Avoid infiltration of outdoor pollutants and latent loads

Building envelope infrastructure example – standards and ratings

Fenestration:

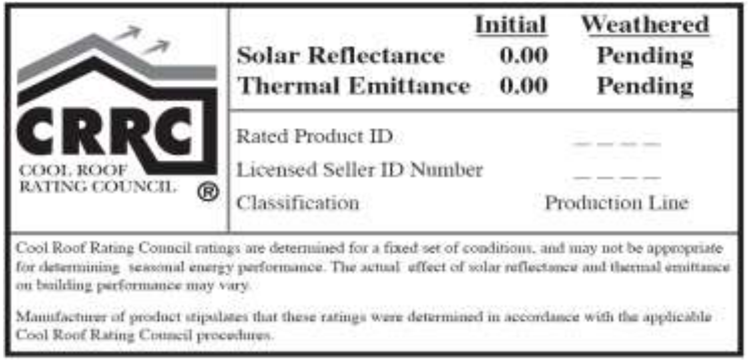
- Simulation of U-factor, Solar Heat Gain Factor and Visible transmittance - ISO 15099
- U-factor testing - ASTM C 1363, C1199, NFRC 102
- Solar Heat Gain Testing – NFRC 201
- Spectral Optical Property – ISO 9050, ASTM E903, NFRC 300, 301
- Air Leakage – ASTM E283, NFRC 400

Wall Insulation

- ASTM C 518, C 177

Wall System

- ASTM C1363, ASTM C1155



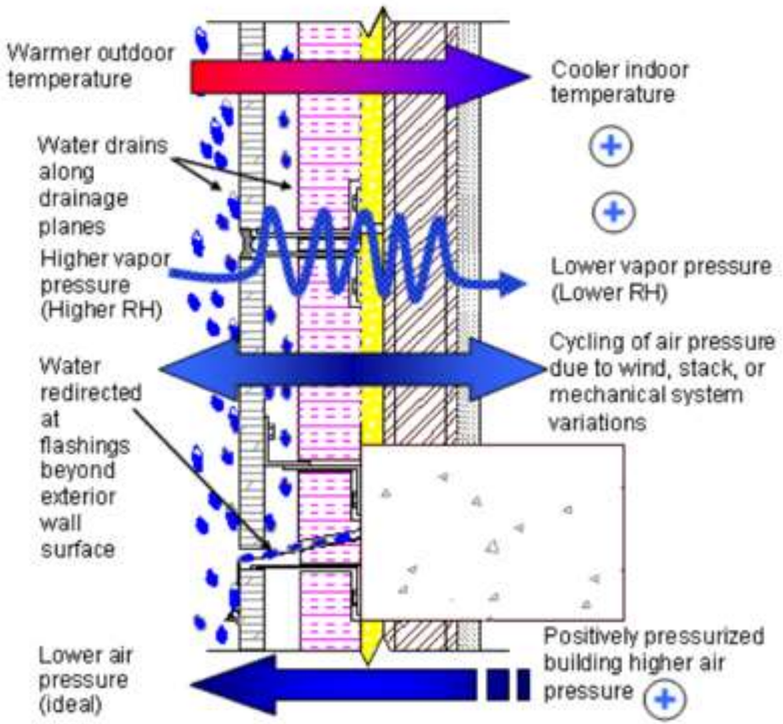

Air Leakage


Hot Box


Solar Calorimeter


Spectrophotometer

Wall systems – complex moisture and air management



Courtesy: Whole Building Design Guideline

BIPV needs to ensure core functions are maintained

Roofing conventional PV vs BIPIV

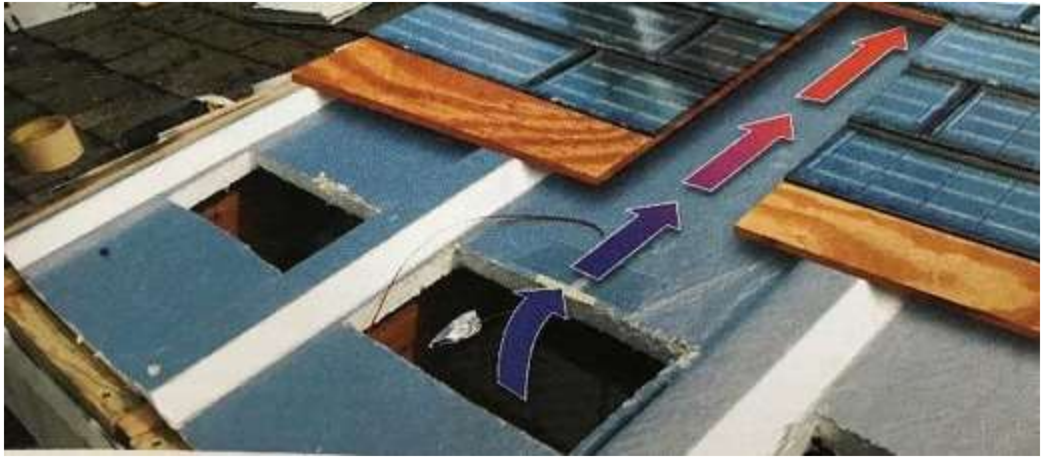
Conventional

- Shades roof from heat gain
- Allows panels to cool to produce higher output
- Not always aesthetically pleasing to some

BIPV

- Higher cell temperatures, lower output
- Increase in heat flux to attic/plenum compared to cool roofs
- Generally greater aesthetics

Above Deck Ventilation – lower peak cooling



Example of BIPV with high efficiency

Key Benefits

- Highest output PV
- Cells allowed to cool
- Optimized sun angle
- Shades windows from sun

Concerns

- Aesthetically less appealing
- Window cleaning is more difficult/costly

Source: "Transition to Sustainable Buildings, Strategies and Opportunities to 2050", IEA 2013

Thermal Performance of Spandrels in Glazing Systems

Issues:

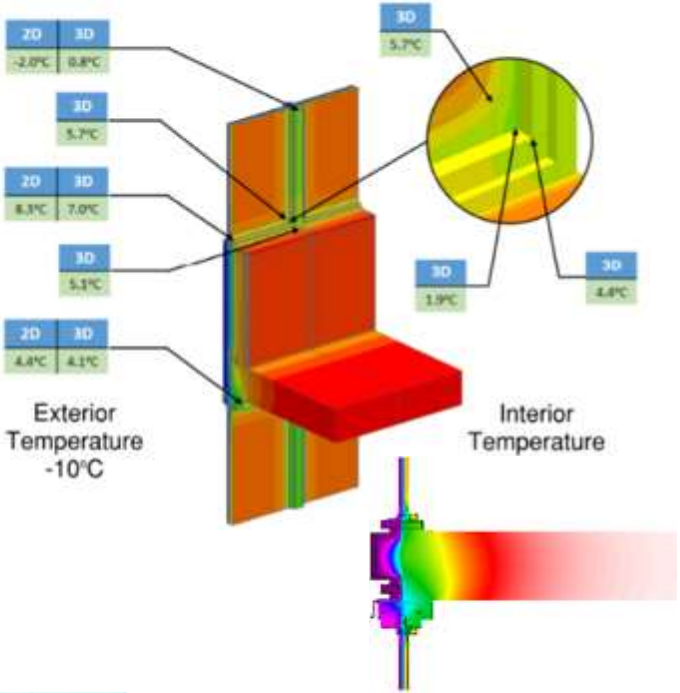
- Thermal-bridging of aluminum framing
- Differing construction of opaque wall areas vs. transparent areas
- Lack of consensus in thermal modeling

Needs:

- Higher performing spandrel systems to meet more stringent codes
- Thermal modeling consensus based on validation and experimentation

Outcome:

- *Design Guidance* document with best practices and recommended modeling procedures



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To learn more, contact Anne Ellis

aellis@pankowfoundation.org

Perovskite materials for photovoltaic windows project

Thermochromic PV

Dynamic solar heat gain control + PV generation

Transparent

ΔT

Colored + PV

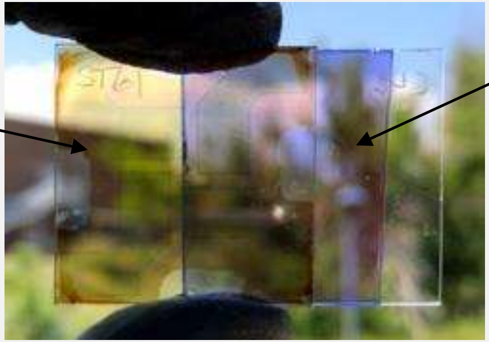
- Generates electricity and modulates solar heat gain for significant building energy savings
- Proof of concept demonstrated.
- NREL holds >10 patents on the technology
- Durability improved
- Significant investment makes them market viable in ~5 years

Lance Wheeler, PhD
NREL

Neutral color semitransparent PV

High efficiency without sacrificing aesthetics

Perovskite PV



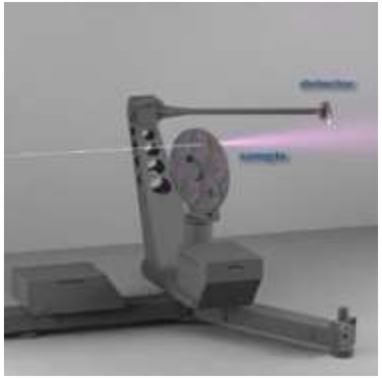
Color balance layer

- >6% geometric efficiency with >30 visible light transmittance and neutral gray color
- Compatible with current glazing and lamination processes
- Investment makes technology market viable in ~3 years.

National Laboratory expertise and advanced facilities

LBNL Flexlab

ORNL Guarded Hot Box



LBNL Goniophotometer

NREL Differential Thermal Cycling Unit

PNNL Lab Homes

Resources and contact info

US DOE – Pathway to Zero Energy Windows – Advancing Technology and Market Adoption - Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption (nrel.gov)

US DOE - Opaque Envelopes: Pathway to Building Energy Efficiency and Demand Flexibility Key to a Low-Carbon, Sustainable Future

Opaque Envelopes: Pathway to Building Energy Efficiency and Demand Flexibility

Grid-interactive Efficient Buildings Technical Report Series Windows and Opaque Envelope

Grid-interactive Efficient Buildings Technical Report Series: Windows and Opaque Envelope (energy.gov)

LBNL Core Window Lab – Primer videos and resources

Outreach | Windows and Daylighting (lbl.gov)

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Barriers & Strategies for Integrating Architectural Solar – A U.S. Market Perspective

Christopher Klinga
Architectural Solar Association

- Technical Director of the Architectural Solar Association
- Principal at SolMotiv Design.
- Past experience with Lighthouse Solar and Lumos Solar
- B.S. in Mechanical Engineering from the University of Colorado in Boulder, CO.
- NABCEP PV Installer certification
- Licensed professional engineer in Colorado and Texas.

Stan Pipkin
Architectural Solar Association

- US Regional Manager of the Architectural Solar Association
- Owner of Lighthouse Solar and Pipkinc.
- Master of Architecture from the University of Texas.

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BREAK 10:00 - 10:15am

BIPV Industry Panel Discussion

Moderator: **Jennifer DiStefano**
Contractor to the U.S. Dept. of Energy

Veeral Hardev
Ubiquitous Energy

Cory Fry
Mitrex

Vaiva Razgaitis
Independent Consultant (formerly at Tesla)

Hunter McDaniel
UbiQD, Inc.

Transparent BIPV work at LBNL

Jacob Jonsson
Lawrence Berkley National Laboratory

Dr. Jacob C. Jonsson got his Ph.D. in Solid State Physics at Uppsala University and started work at Lawrence Berkeley National Laboratory in 2005. Focus on optical characterization, simulation and modelling of traditional facade materials like glass and shades, but also on electrochromics, hermochromics, and transparent PV.

Observations & Lessons Learned in Residential BIPV

Jeff Cook
National Renewable Energy Laboratory

Dr. Jeffrey J. Cook is the Acting Subprogram Manager for Solar Analysis at the National Renewable Energy Laboratory and program lead for the Solar Automated Permit Processing Plus Platform. He has been on staff at NREL since 2014, and focuses on solar photovoltaics, permitting, resilience, technology cost reduction, and distributed energy resource aggregation. He received his Ph.D. in political science from Colorado State University in 2017, where he continues to instruct environmental and public policy courses. He received his Master of Science in environmental science and policy from the University of Wisconsin – Green Bay in 2012.

BIPV at the Solar Decathlon

Rachel Romero
National Renewable Energy Laboratory

Rachel Romero, PE, is an energy engineer and project leader at the National Renewable Energy Laboratory. Rachel obtained her Bachelor of Science in Mechanical Engineering from Hope College and then received her master's degree in Building Systems Engineering at the University of Colorado Boulder. Rachel is an active member of ASHRAE, currently service on the Residential Buildings Committee. At NREL, Rachel is the competition manager for the U.S Department of Energy Solar Decathlon Design Challenge, which has inspired over 5000 collegiate students in 8 years to be the next generation to design net zero buildings. Also, she provides technical assistance to the to the Department of Energy's Smart Labs program, which provides technical assistance to university and national laboratory partners across the US. She was a main author of the Smart Labs Toolkit, which describes a systematic process to achieve safe, efficient, and sustainable laboratories.

Thank you! Join us at upcoming DOE BIPV events

Buildings XV Conference – December 5-8, 2022 – Clearwater Beach, FL

– DOE BIPV Workshop on Thursday, 12/8, 1-5pm

For questions about our BIPV workshop series, please reach out to George at georgios.stefopoulos@ee.doe.gov.

Learn About Upcoming Funding Opportunities

EERE Funding Opportunity Updates

Promotes the Office of Energy Efficiency and Renewable Energy's funding programs.

SIGN UP NOW:

energy.gov/eere/funding/eere-funding-opportunities

SETO Newsletter

Highlights the key activities, events, funding opportunities, and publications that the solar program has funded.

SIGN UP NOW:

energy.gov/solar-newsletter

Thank you!

Thank you!

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Barriers & Strategies for Integrating Architectural Solar
A US Market Perspective

Christopher Klinga, PE
Technical Director, ASA

Stan Pipkin
Regional Manager, ASA

November 1, 2022

Image courtesy of Issol

Who We Are

The Architectural Solar Association (ASA) represents a growing industry with a common goal of transforming building facades and other architectural surfaces into generating assets.

ASA

- Expands Awareness
- Acts as a Supply Chain Resource
- Develops Standards

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Image courtesy of Spotlight Solar

Christopher Klinga P.E.
T*echnical Director*, ASA
Principal, SolMotiv Design

- 2007-2016 - VP of Product Development Lumos
- Actively consulting in architectural solar product & project development
- B.S. Mechanical Engineering University of Colorado
- Colorado & Texas licensed professional engineer

Stan Pipkin
US Regional Manager, ASA
Owner, Lighthouse Solar & Pipkinc.

- 2007-Present, Lighthouse Solar Austin - hybrid solar EPC and architectural design firm.
- Principal of Pipkinc. design firm focusing on residential sustainable architecture.
- Masters of Architecture from the University of Texas
- Policy expertise at Solar Austin, TXSES
- IREC Design Award
- Product Design with Lumos Solar

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Learning Objectives

- Definition of Architectural Solar
- Architectural Integration Opportunities
- Market Barriers
- Path to Widespread Adoption

Image courtesy of Lumos Solar

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Definitions of BIPV and BAPV

per EN 50583 / IEC 63092 / IEC 61730

3.3.1 Building Attached PV (BAPV)

Photovoltaic modules are considered to be building attached if the PV modules are mounted on a building envelope and do not fulfil the criteria for building integrated PV

3.3.2 Building Integrated PV (BIPV)

Photovoltaic modules are considered to be building integrated if the PV modules form a building component providing additional functions as defined in 4.5 b

Building Functions: (in addition to power generation)

Mechanical rigidity or structural integrity, Primary weather impact protection: rain, snow, wind, hail, Energy economy, such as shading, daylighting, thermal insulation, Fire protection, Noise protection, Separation between indoor and outdoor environments, Security, shelter or safety

Thus, the BIPV module is a prerequisite for the integrity of the building's functionality. If the integrated PV module is dismounted , the PV module would have to be replaced by an appropriate building component.

Image courtesy of Lumos Solar

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BIPV
Solar Technology with Architectural Significance

Image courtesy of Lumos Solar

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Architectural Solar

Image courtesy of Lumos Solar

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Architectural Solar

Solar energy generating technologies that are coordinated with the architectural design process.

Image courtesy of Lumos Solar

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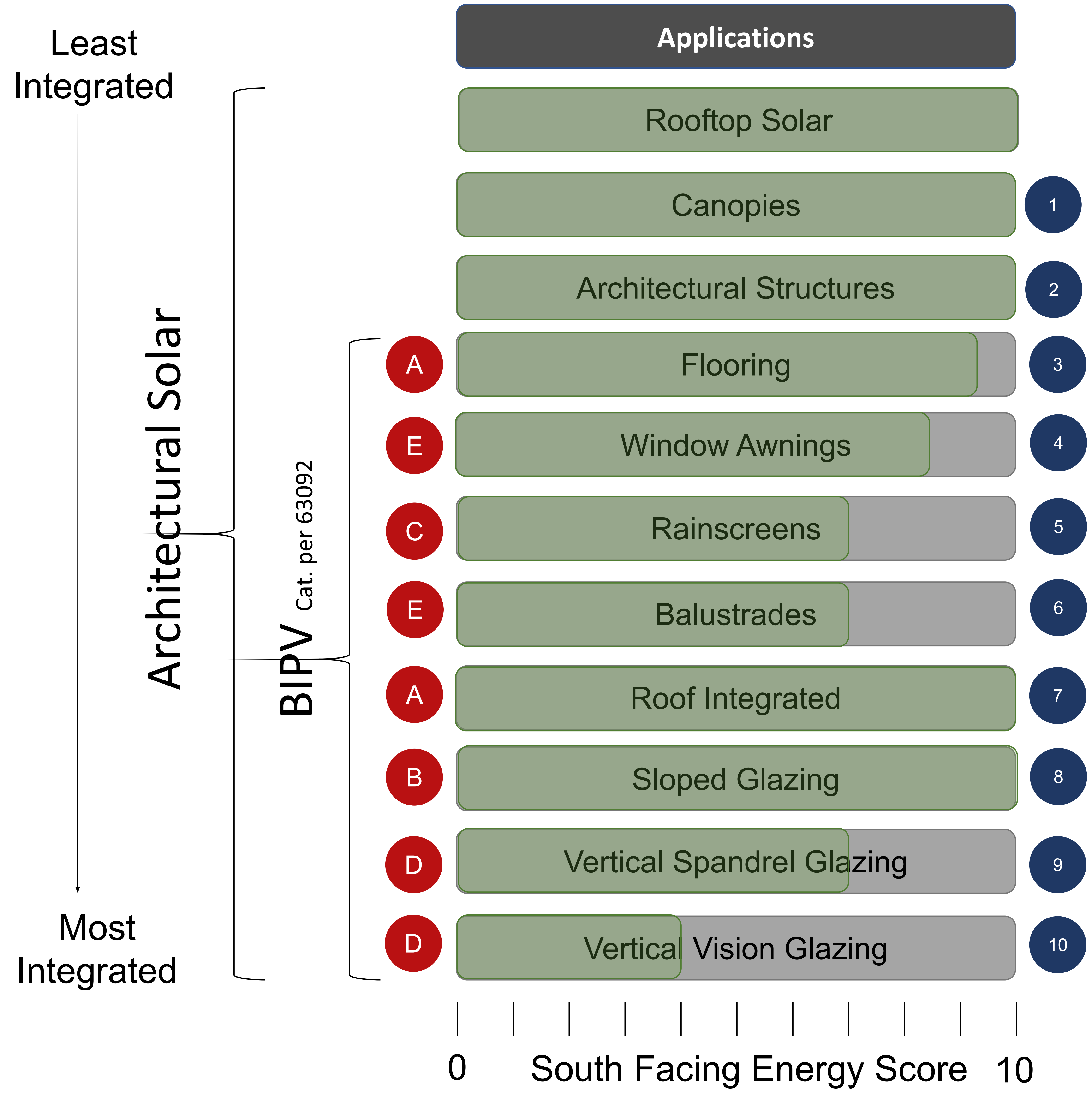

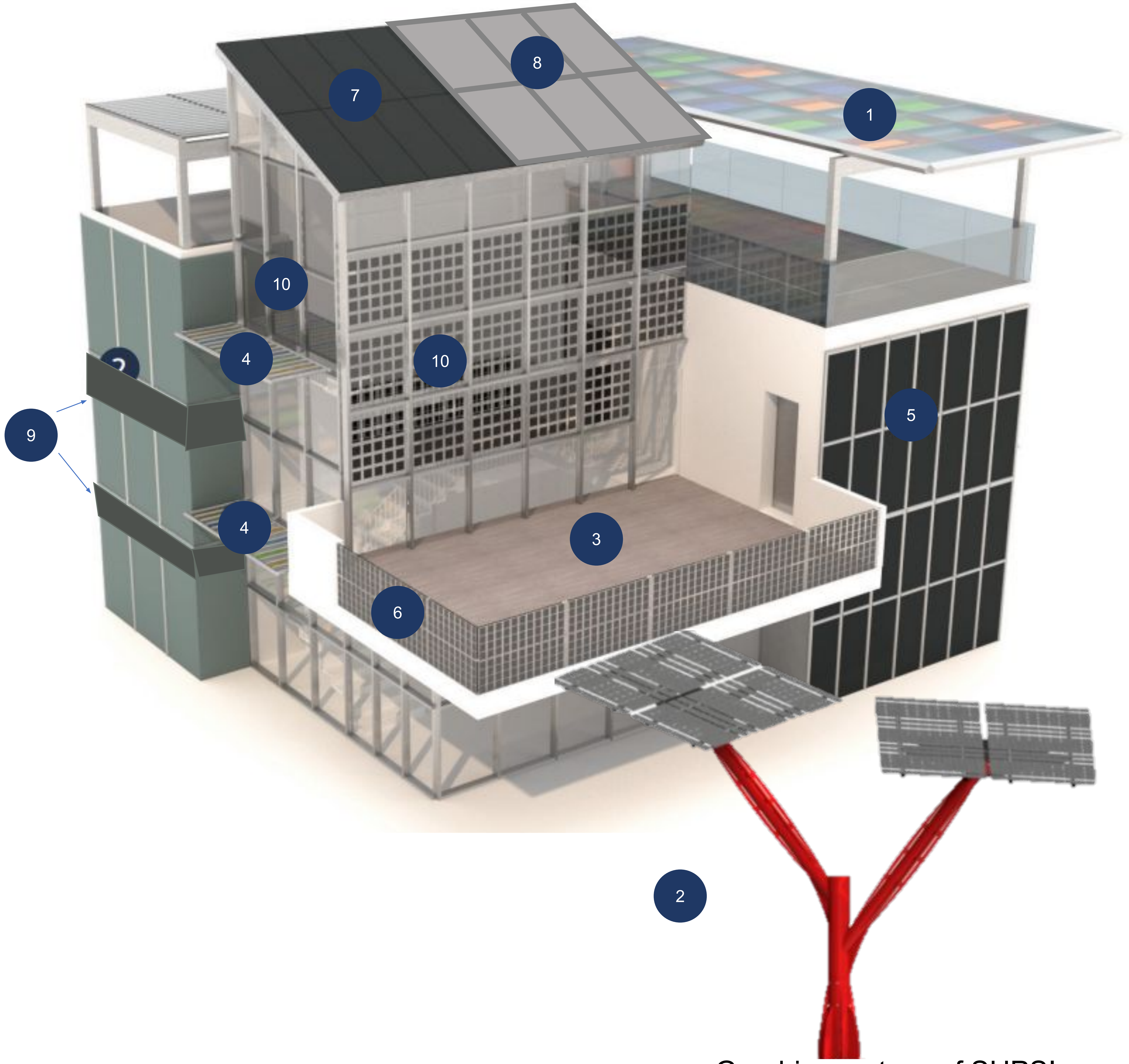

Graphic courtesy of SUPSI

Architectural Applications

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Rooftop Solar

Least Integrated Most Integrated

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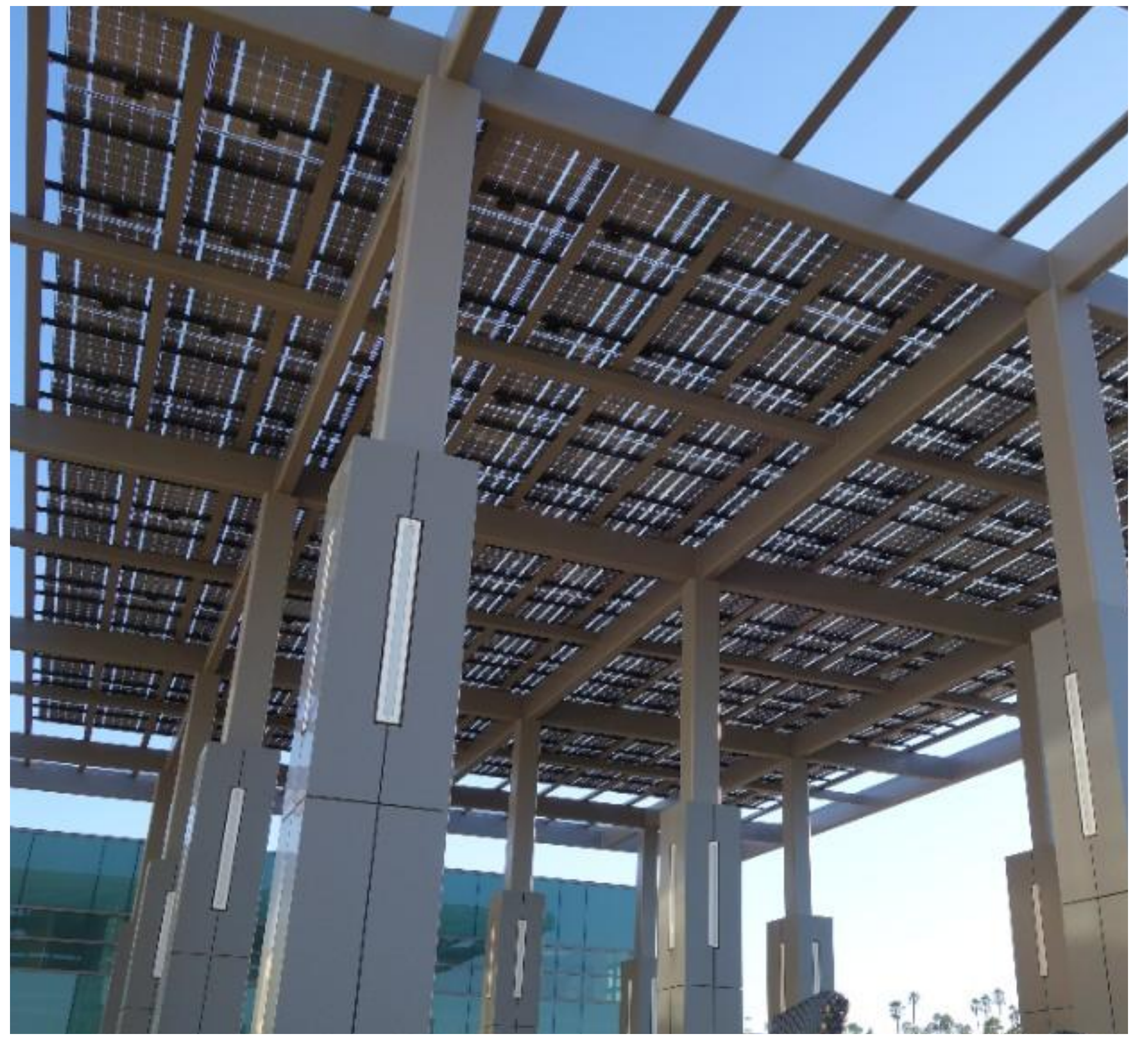

Canopies

Least Integrated

Most Integrated

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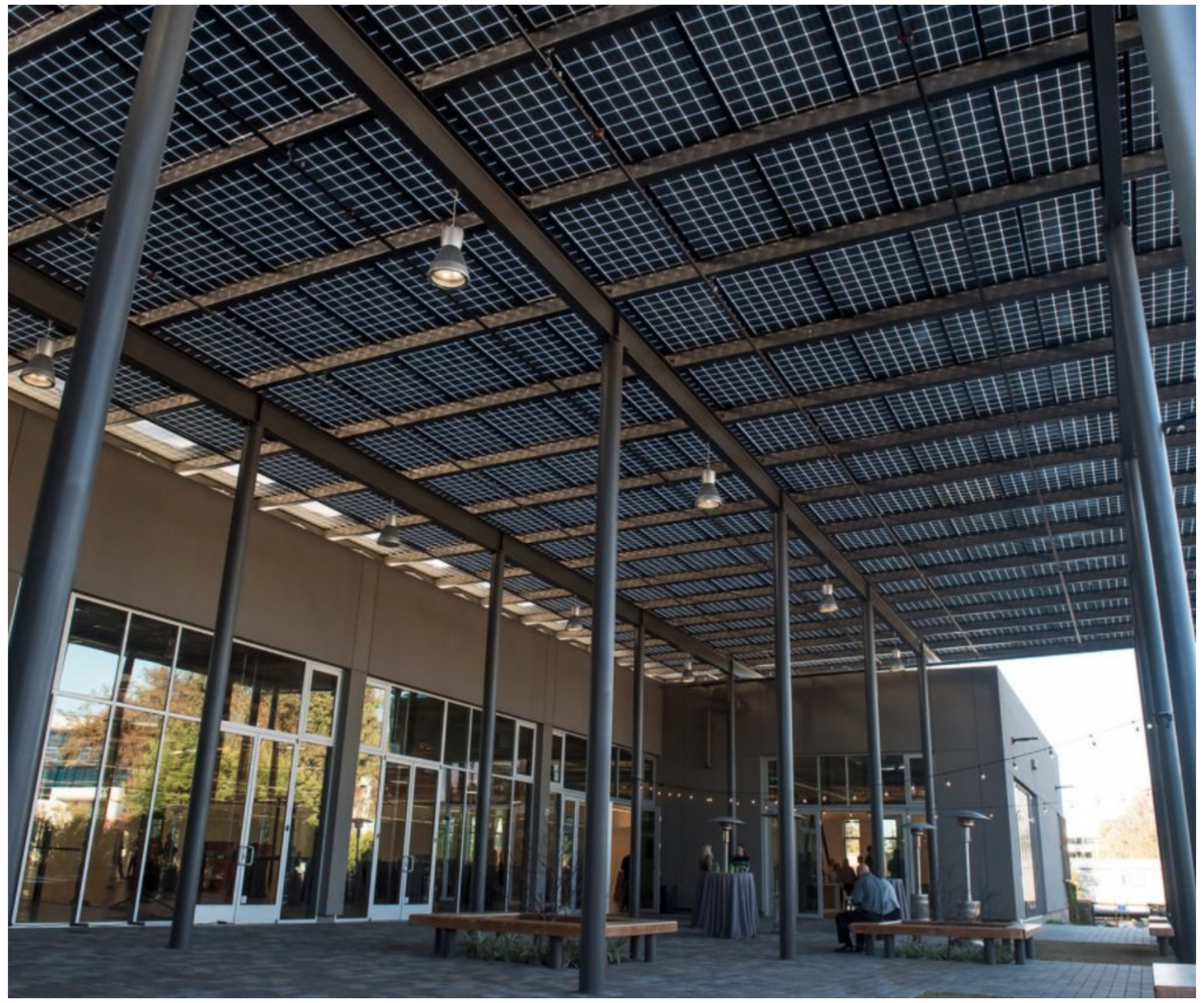

Canopies

Least Integrated

Most Integrated

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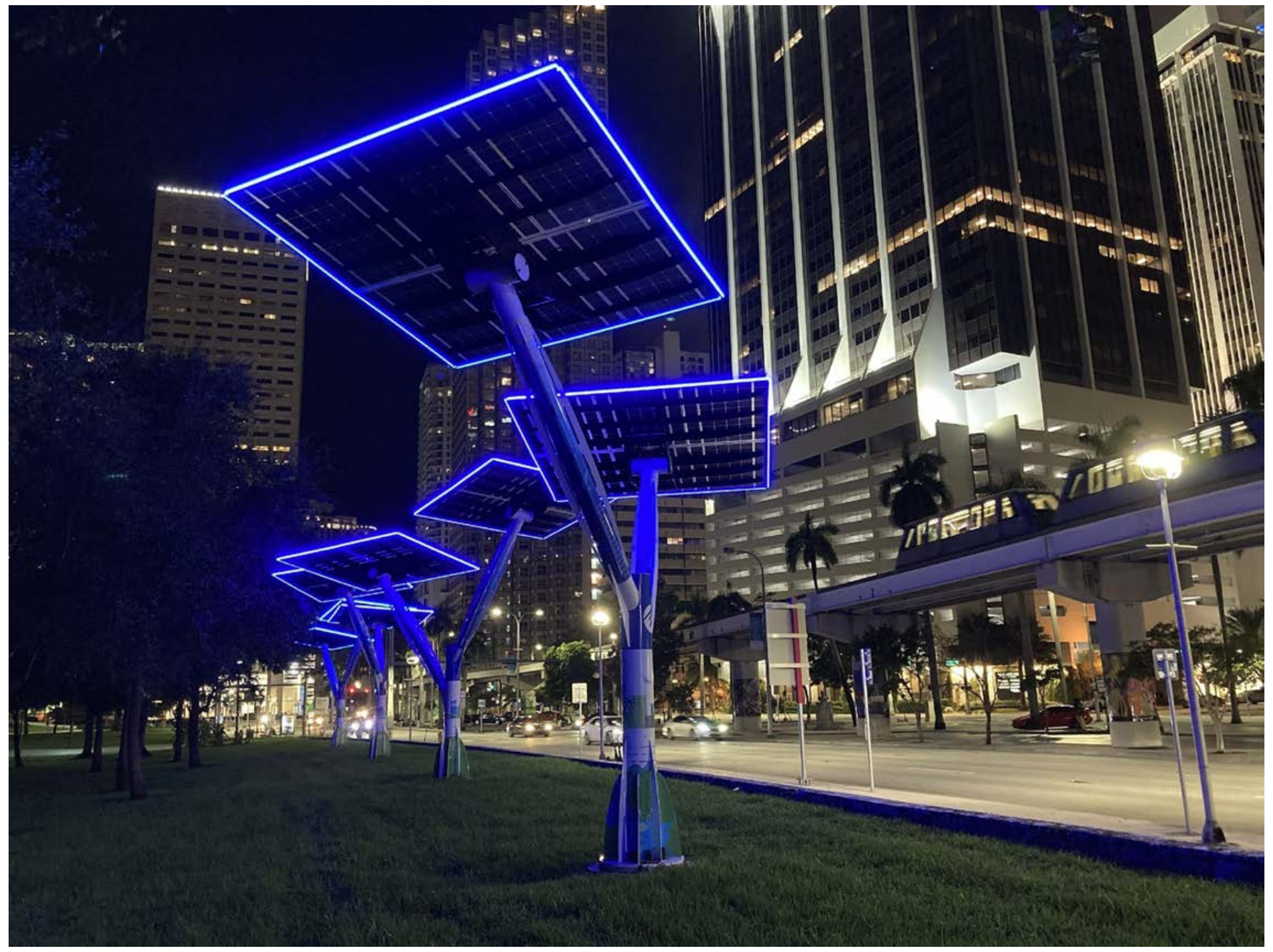

Architectural Structures

Least Integrated

Most Integrated

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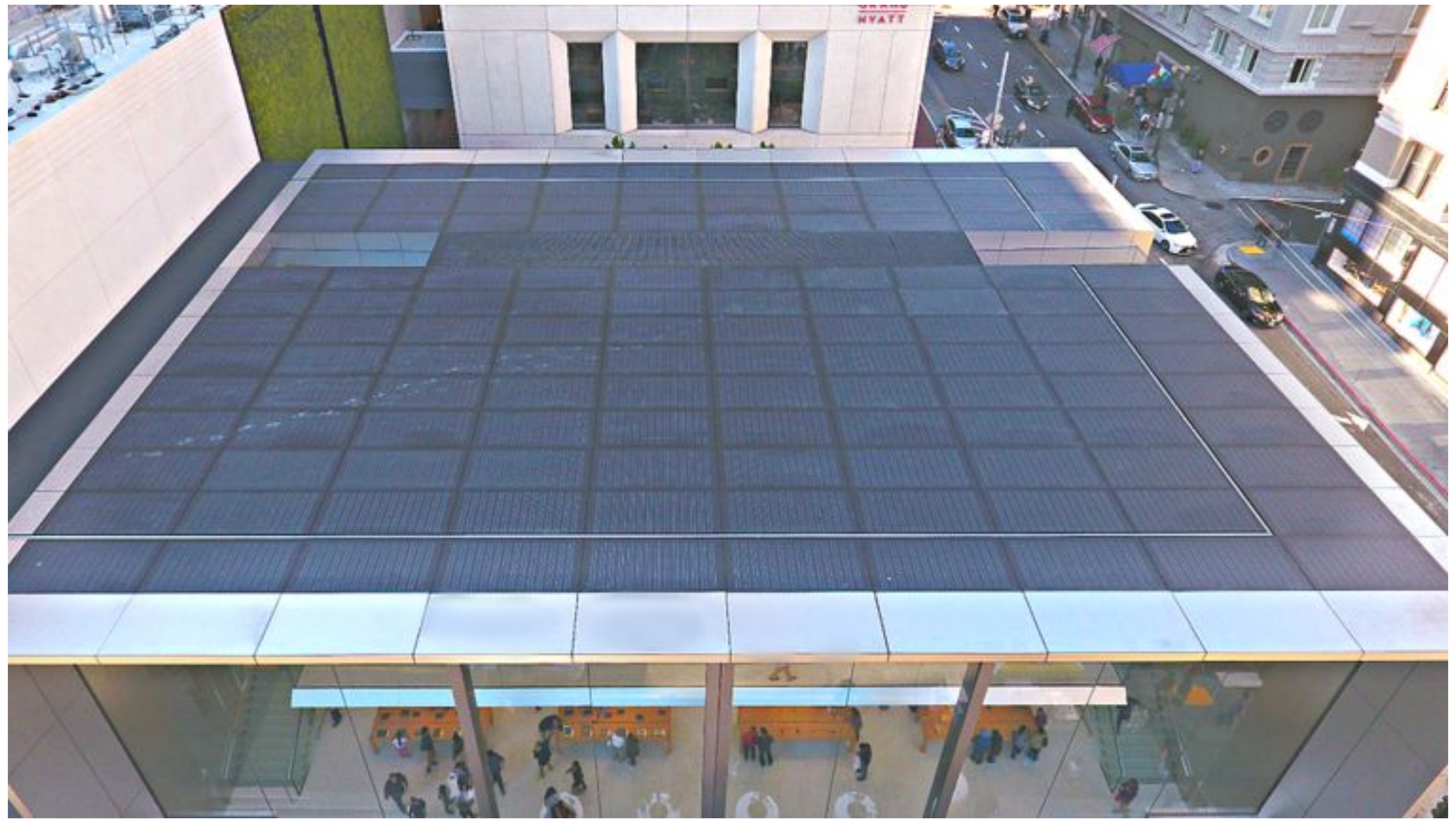

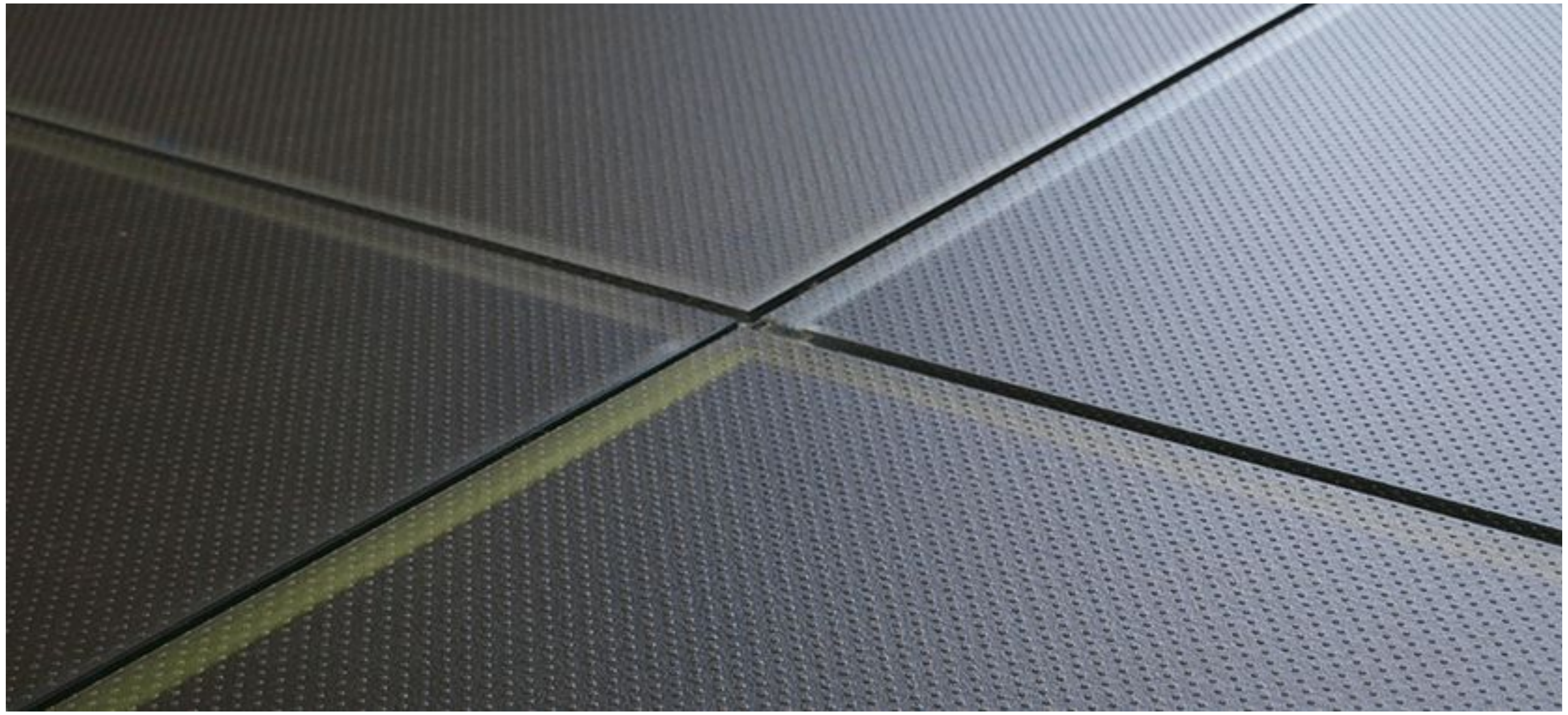

Flooring (Cat. A)

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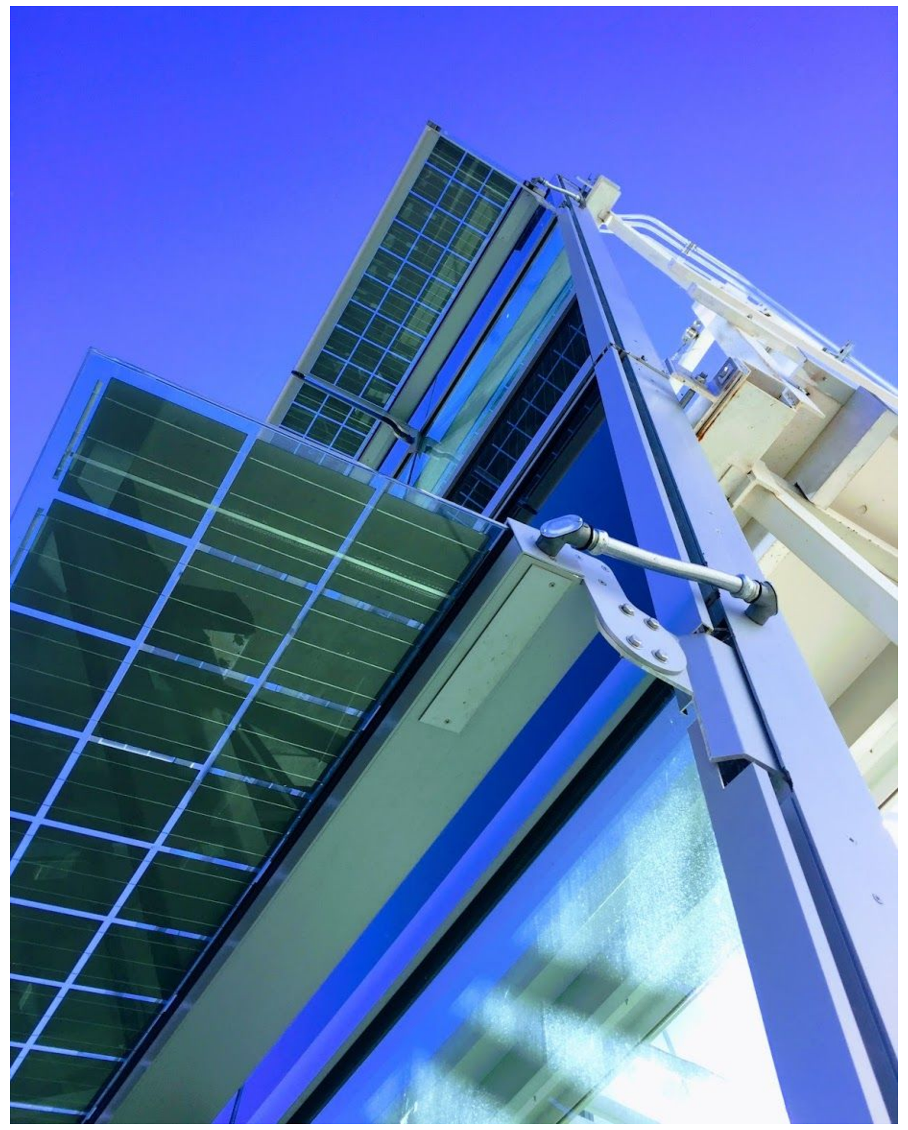


Awnings/Louvers(Cat. E)

Least Integrated

Most Integrated

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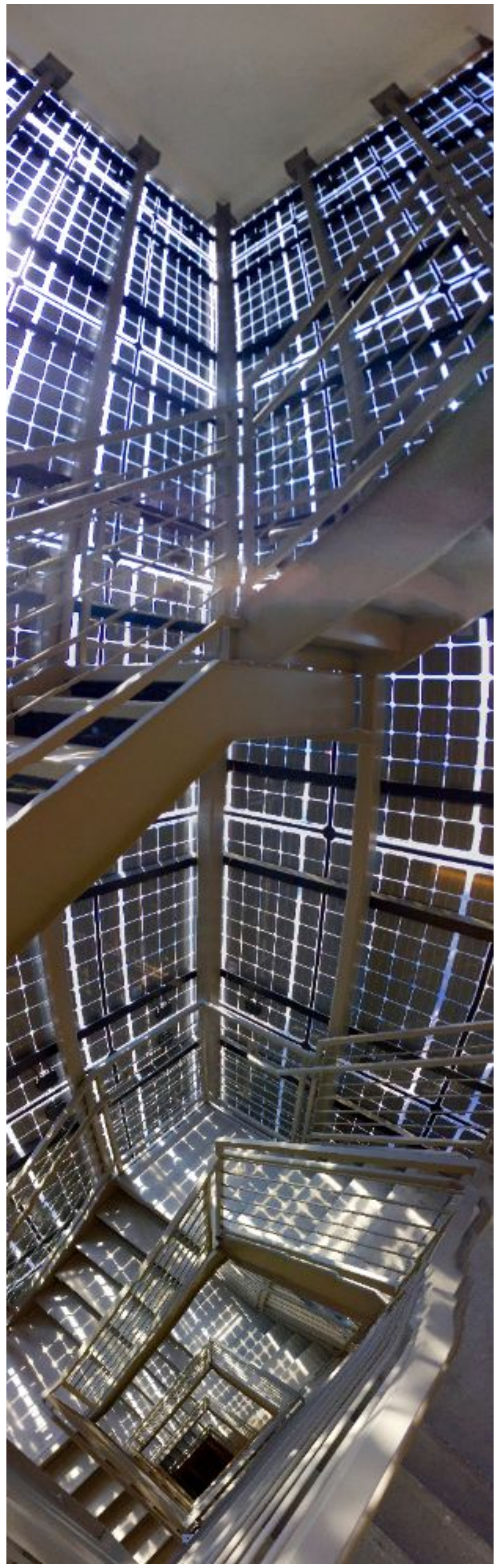

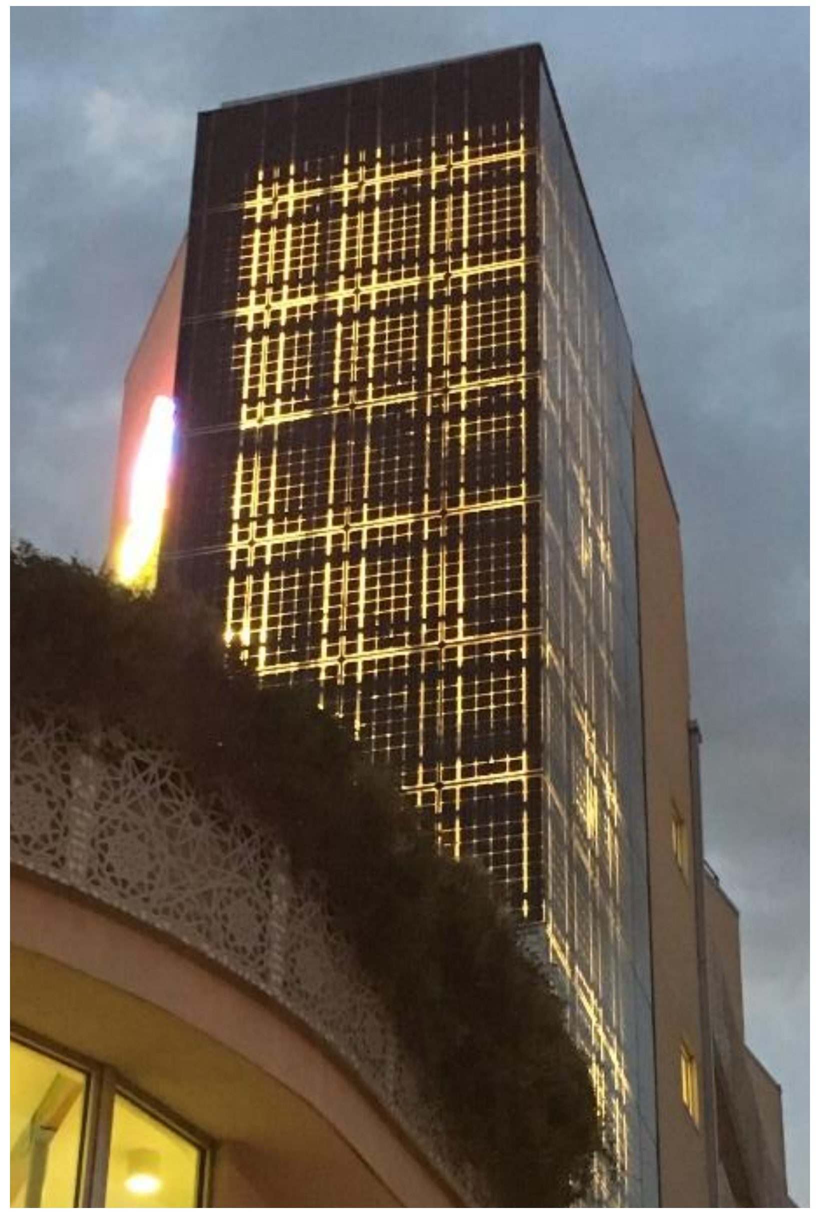

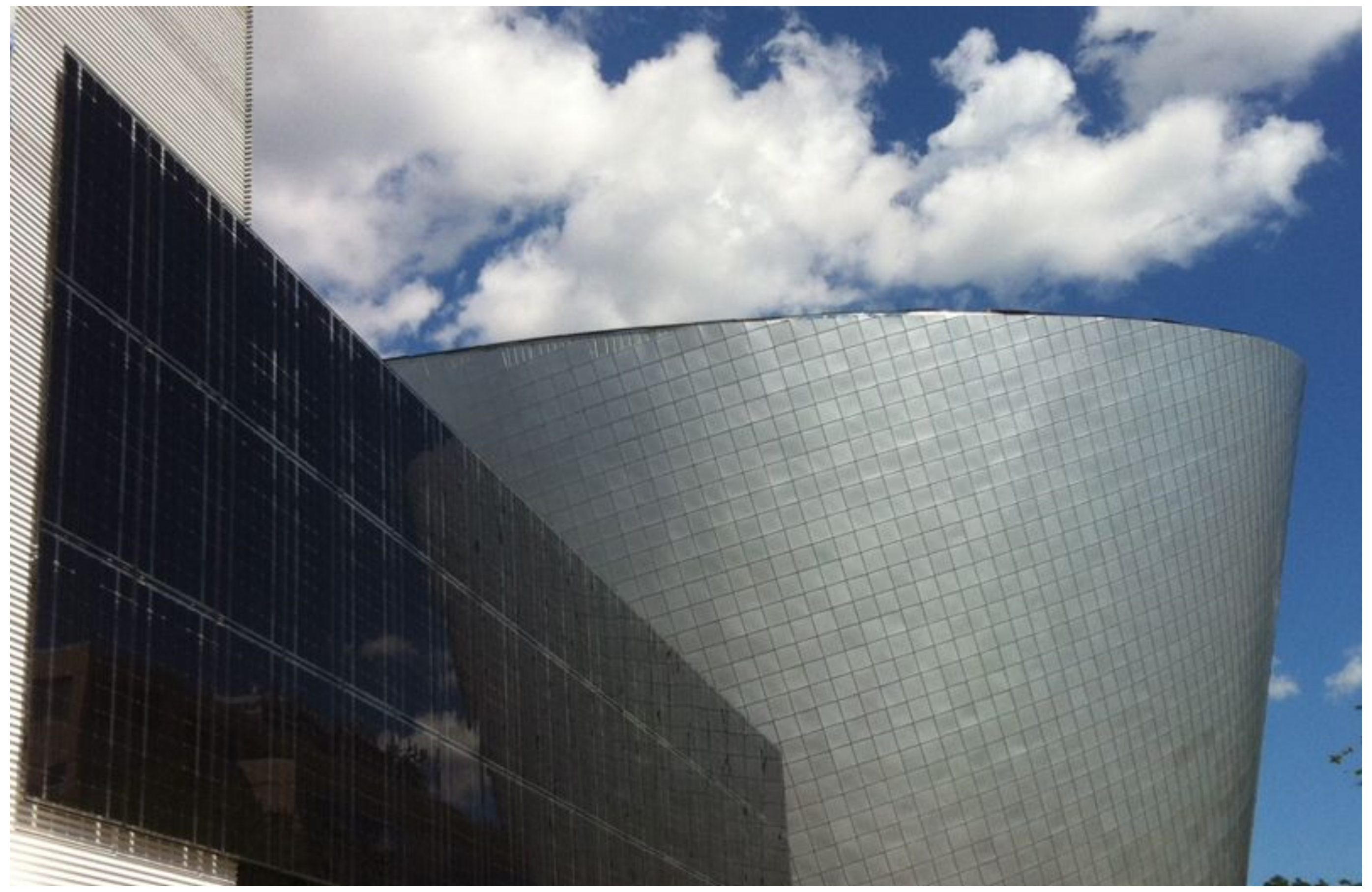

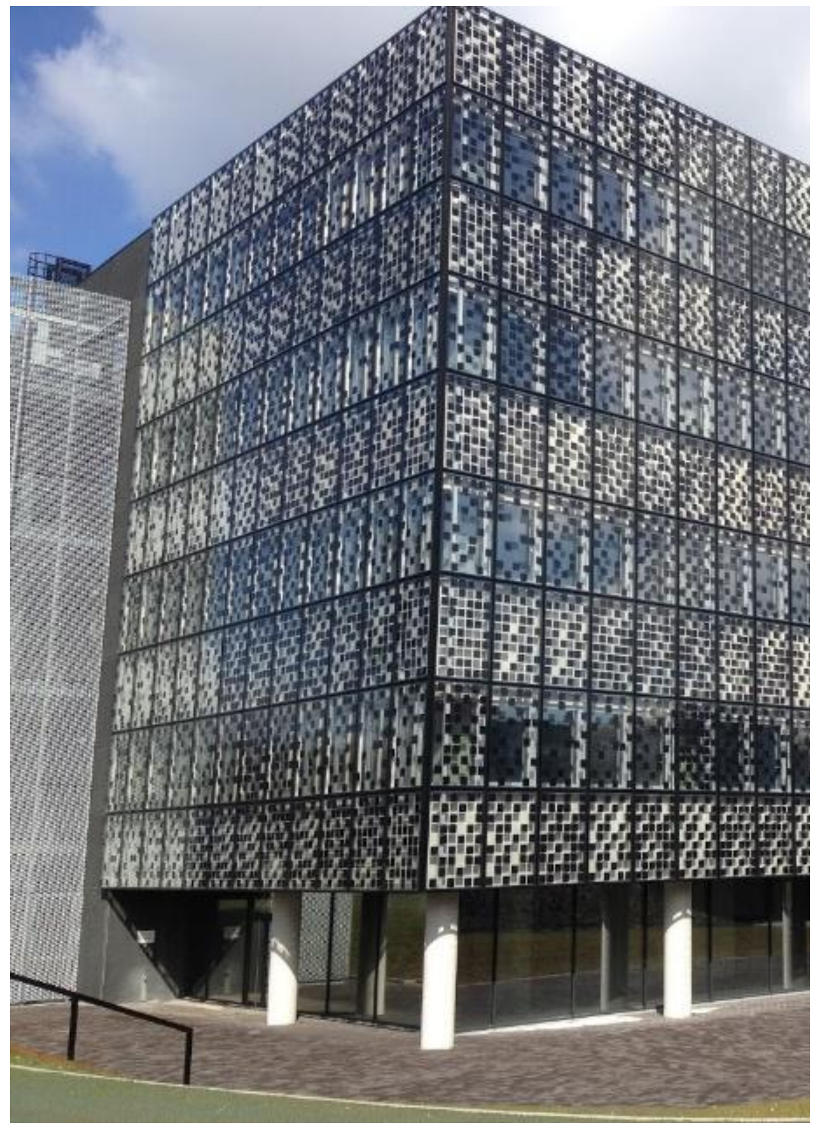

Ventilated Solar Facades Rainscreens Enclosures (Cat. C)

Least Integrated

Most Integrated

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Balustrades (Cat. E)

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Roof Integrated (Cat. A)

Least Integrated

Most Integrated

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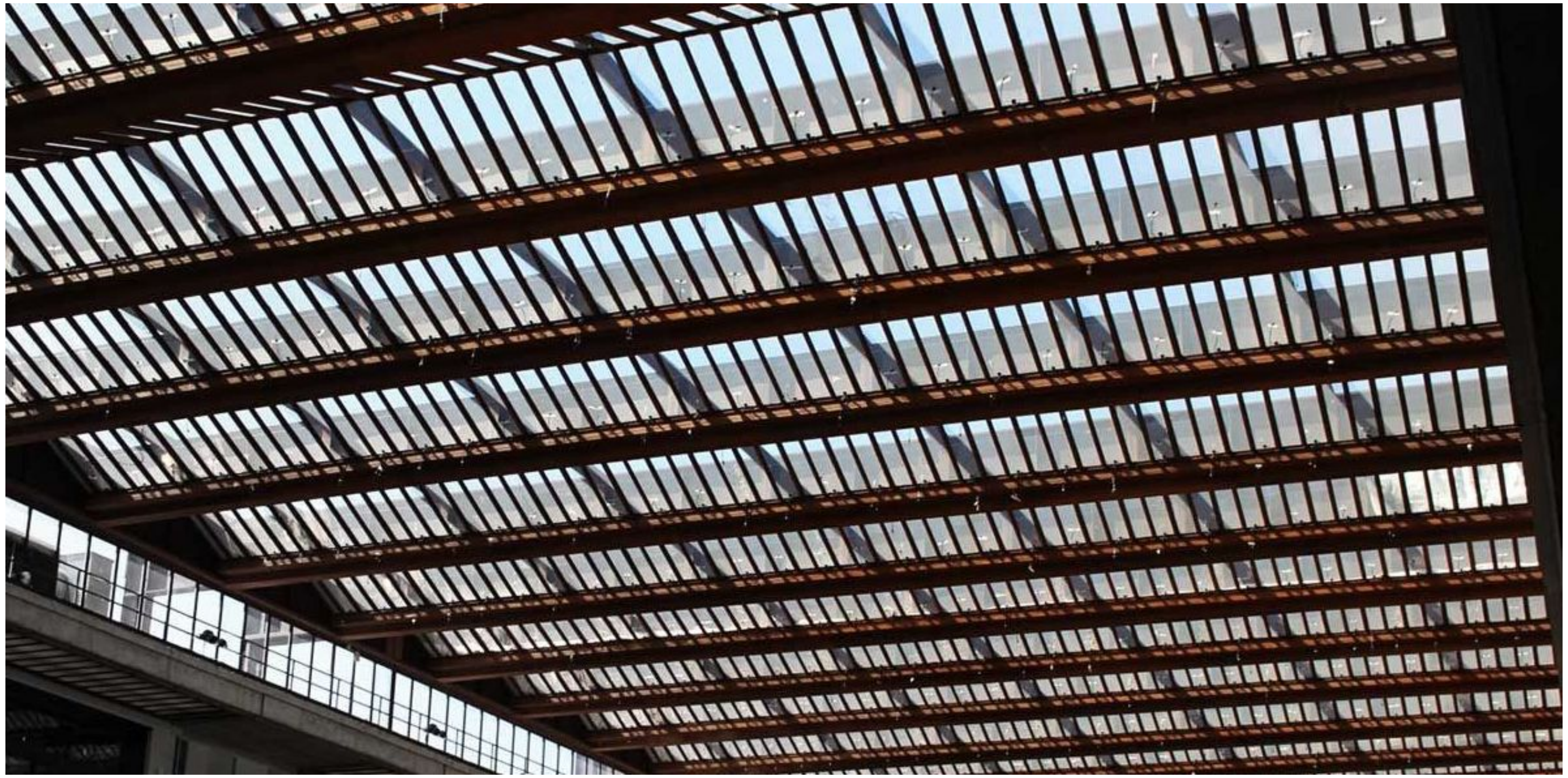

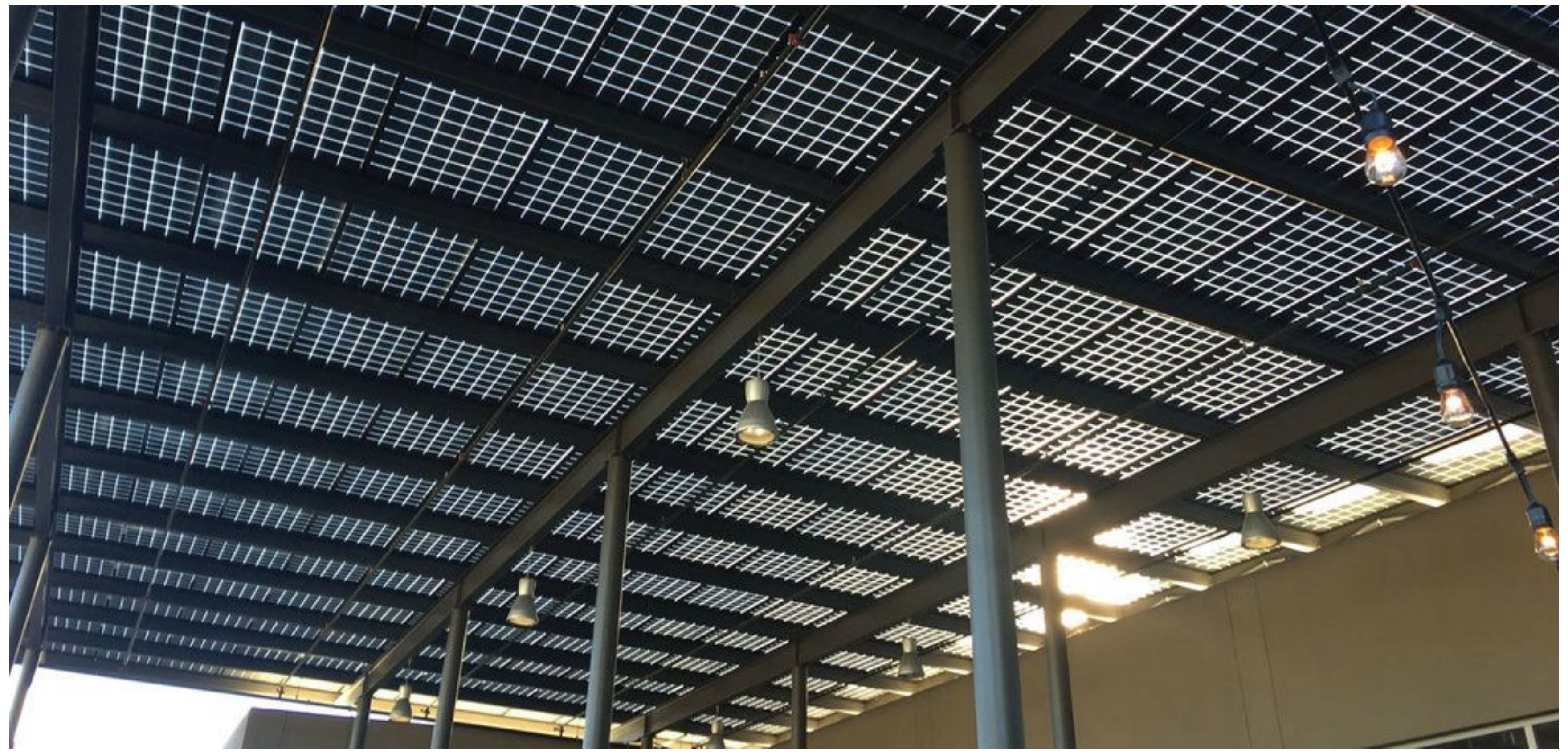

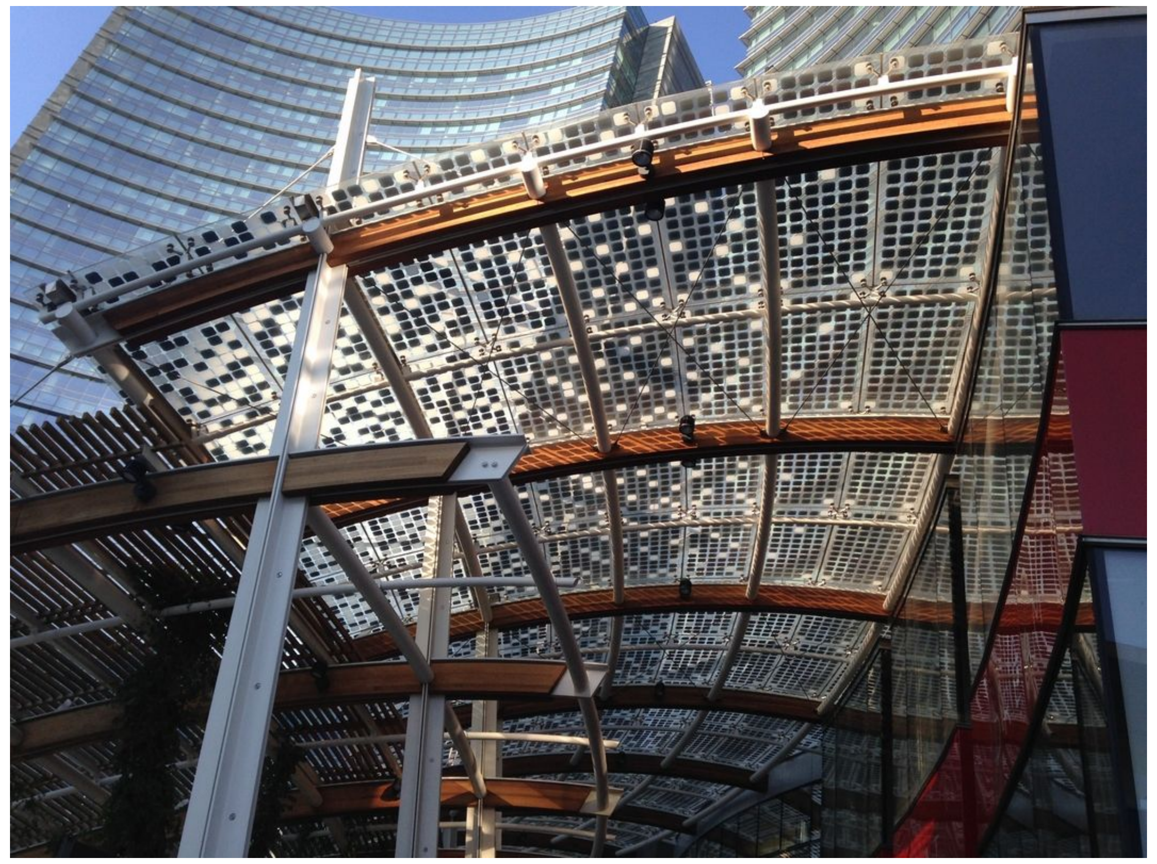

Sloped Glazing (Cat. B)

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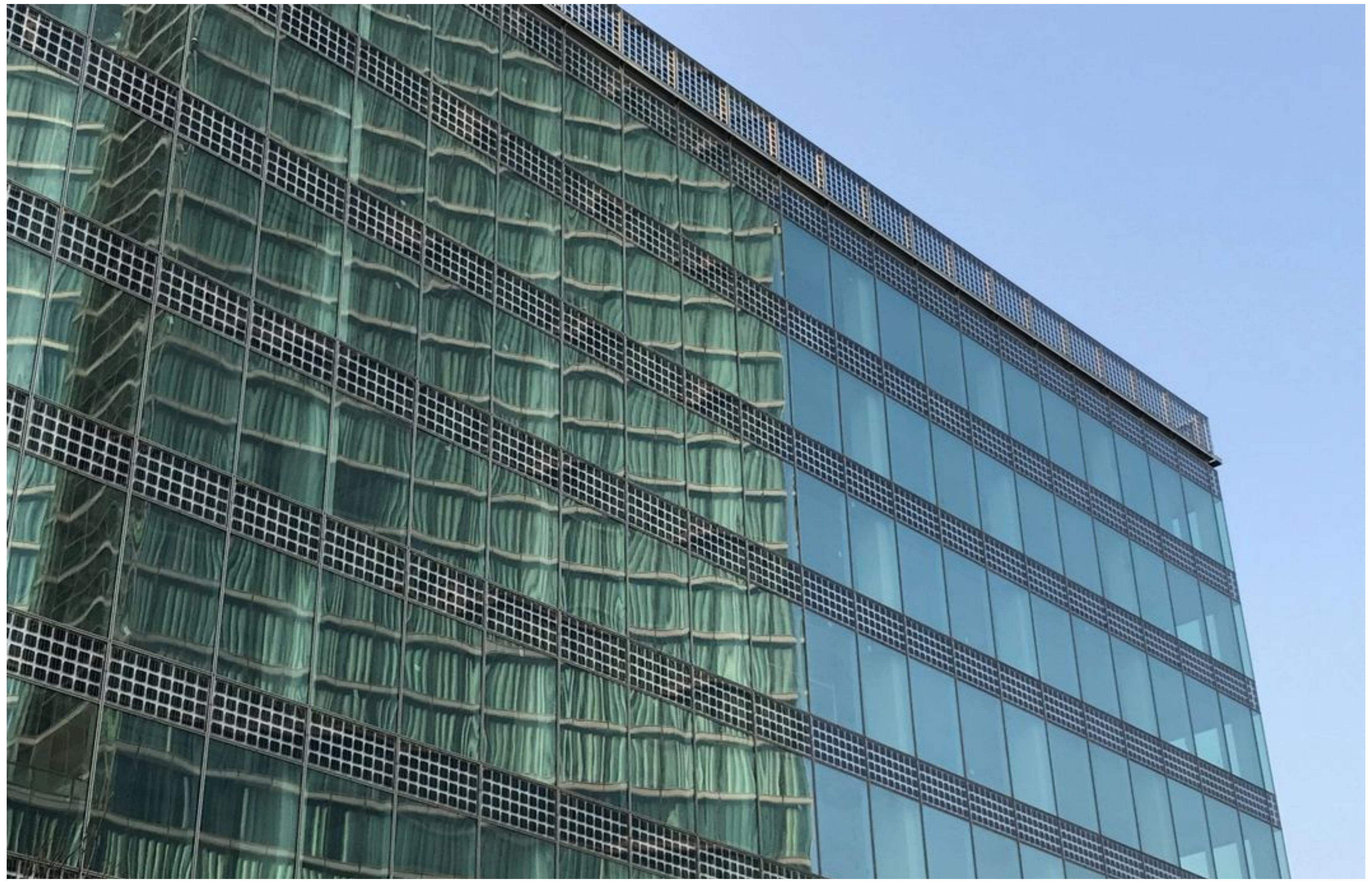

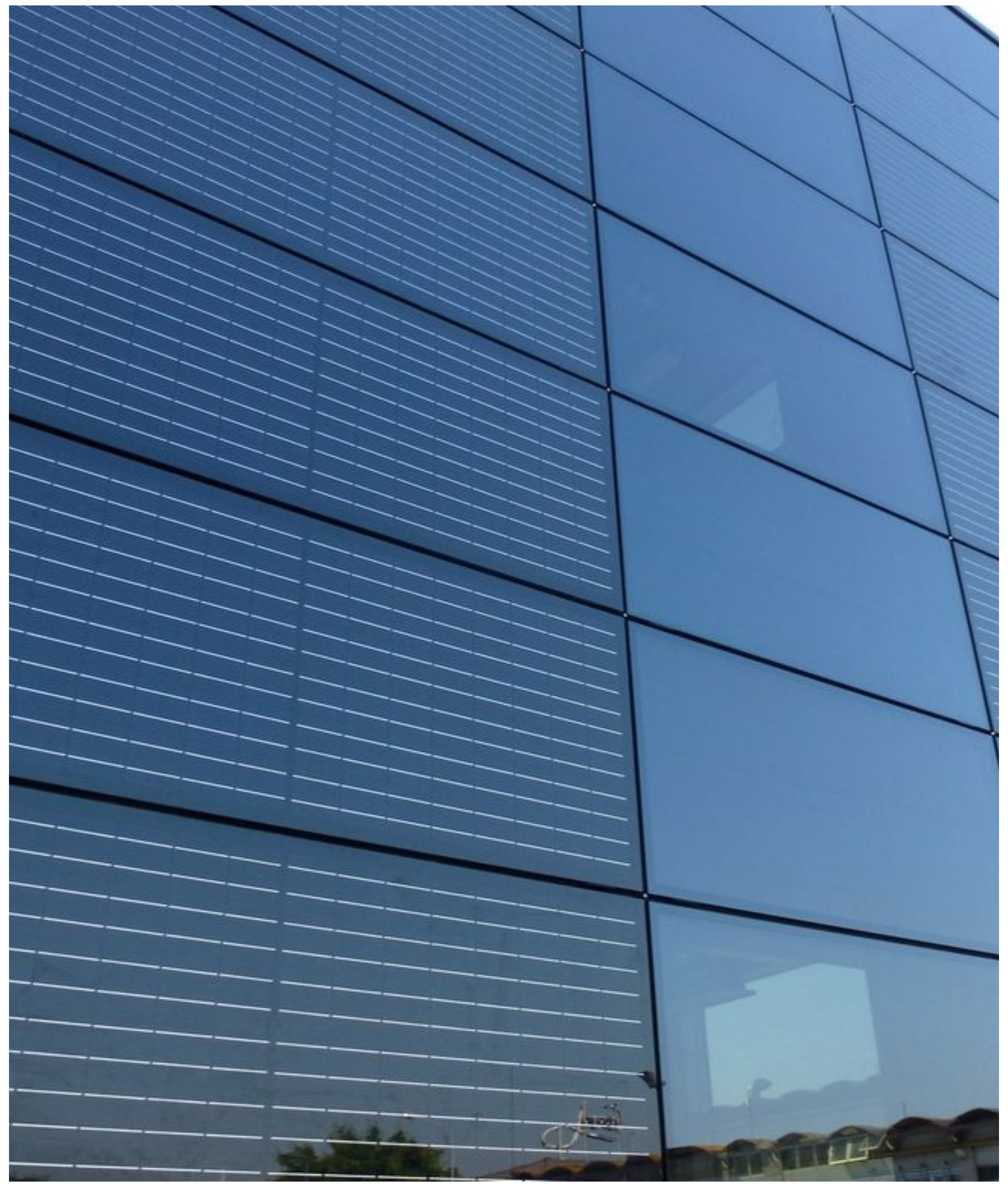

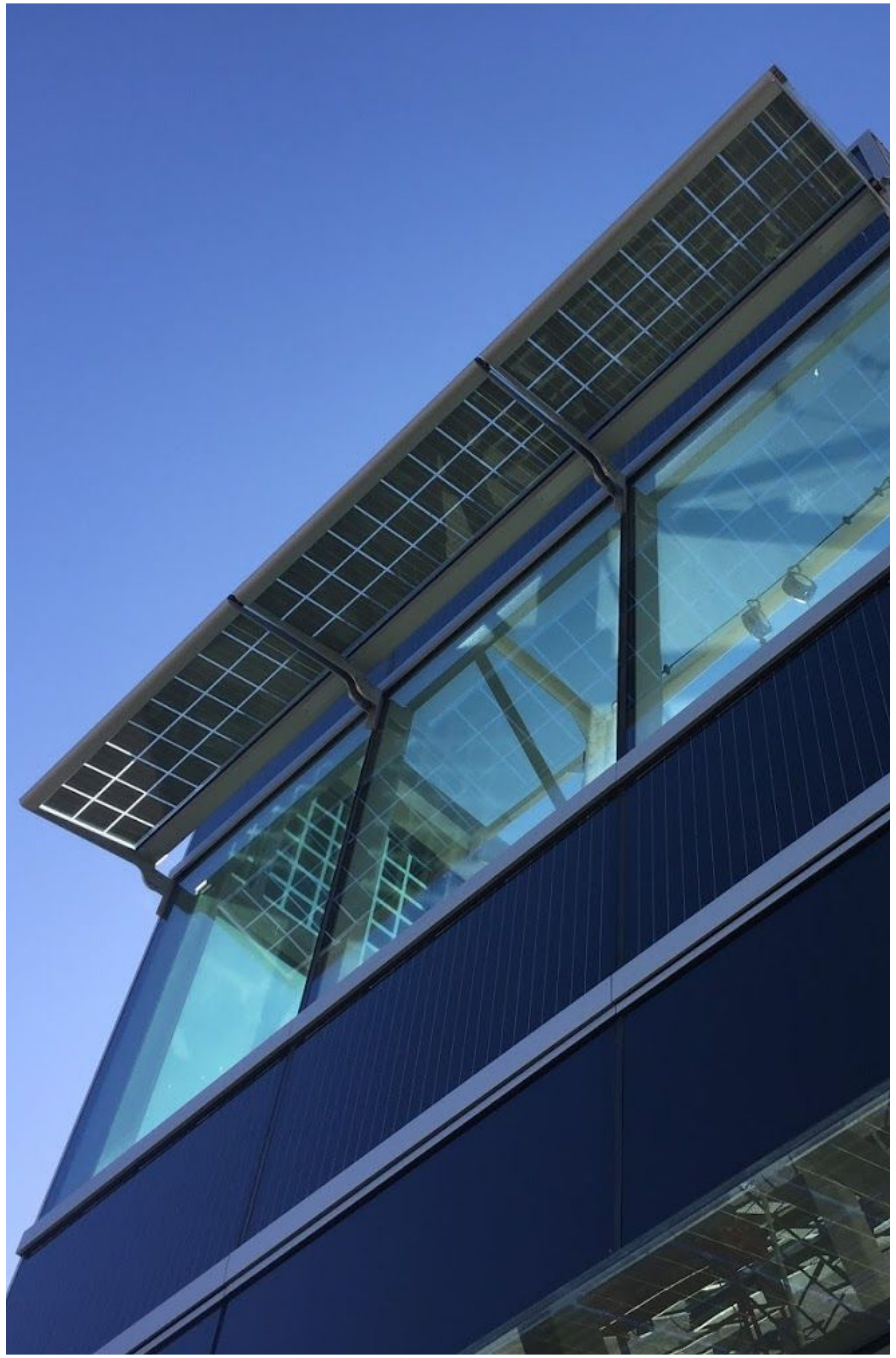

Spandrel Glazing (Cat. D)

Least Integrated

Most Integrated

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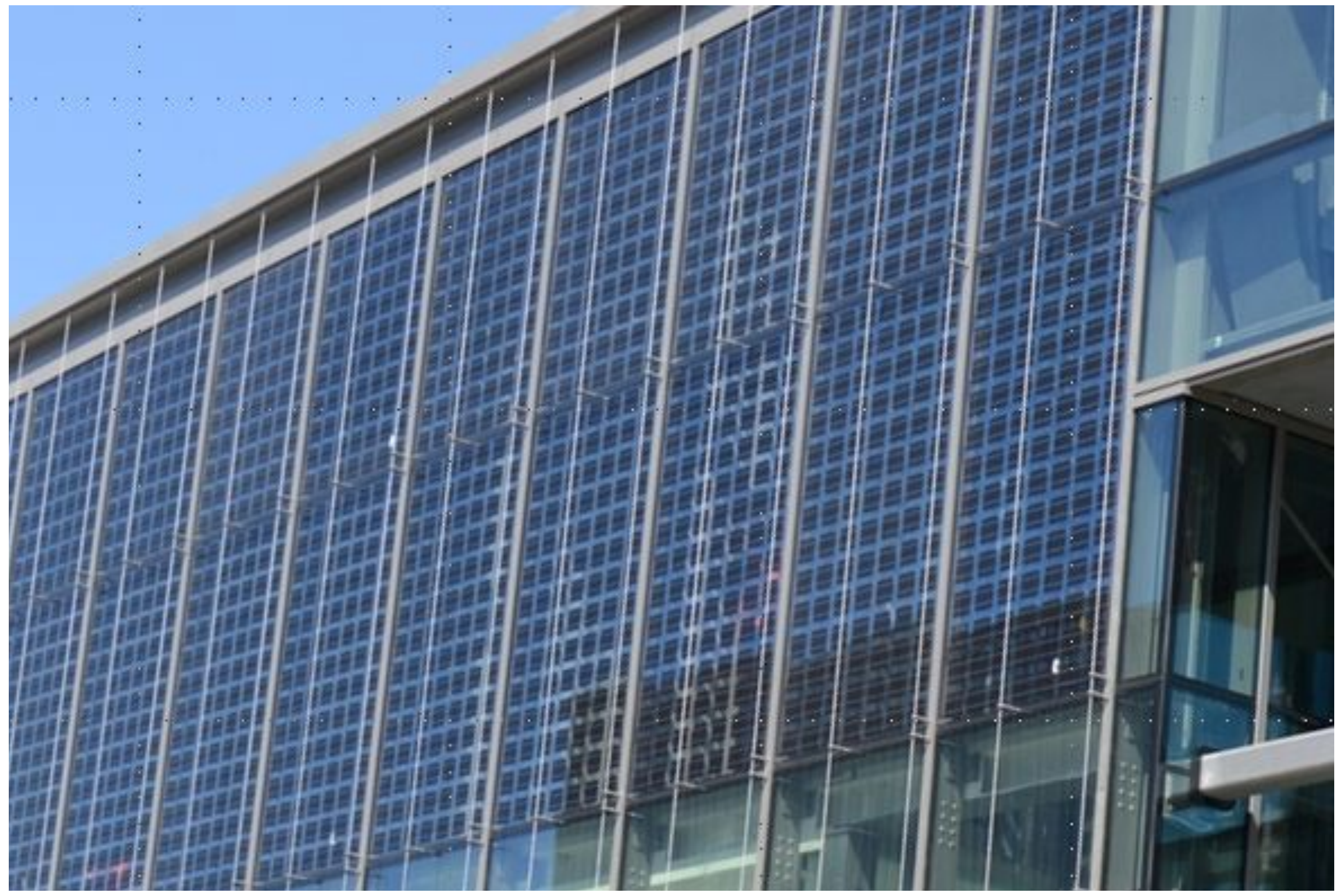

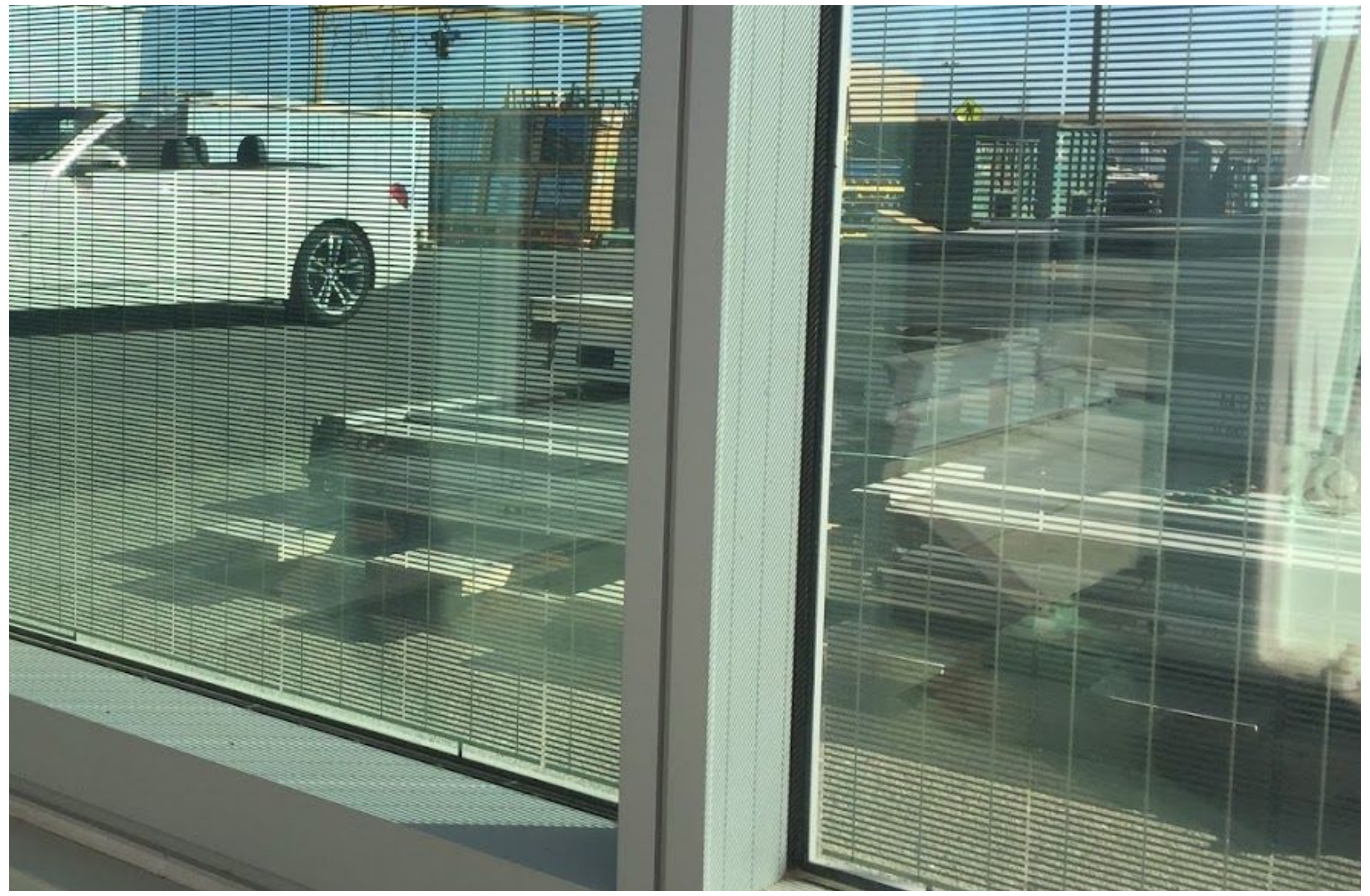

Vision Glazing (Cat. D)

Least Integrated — Most Integrated

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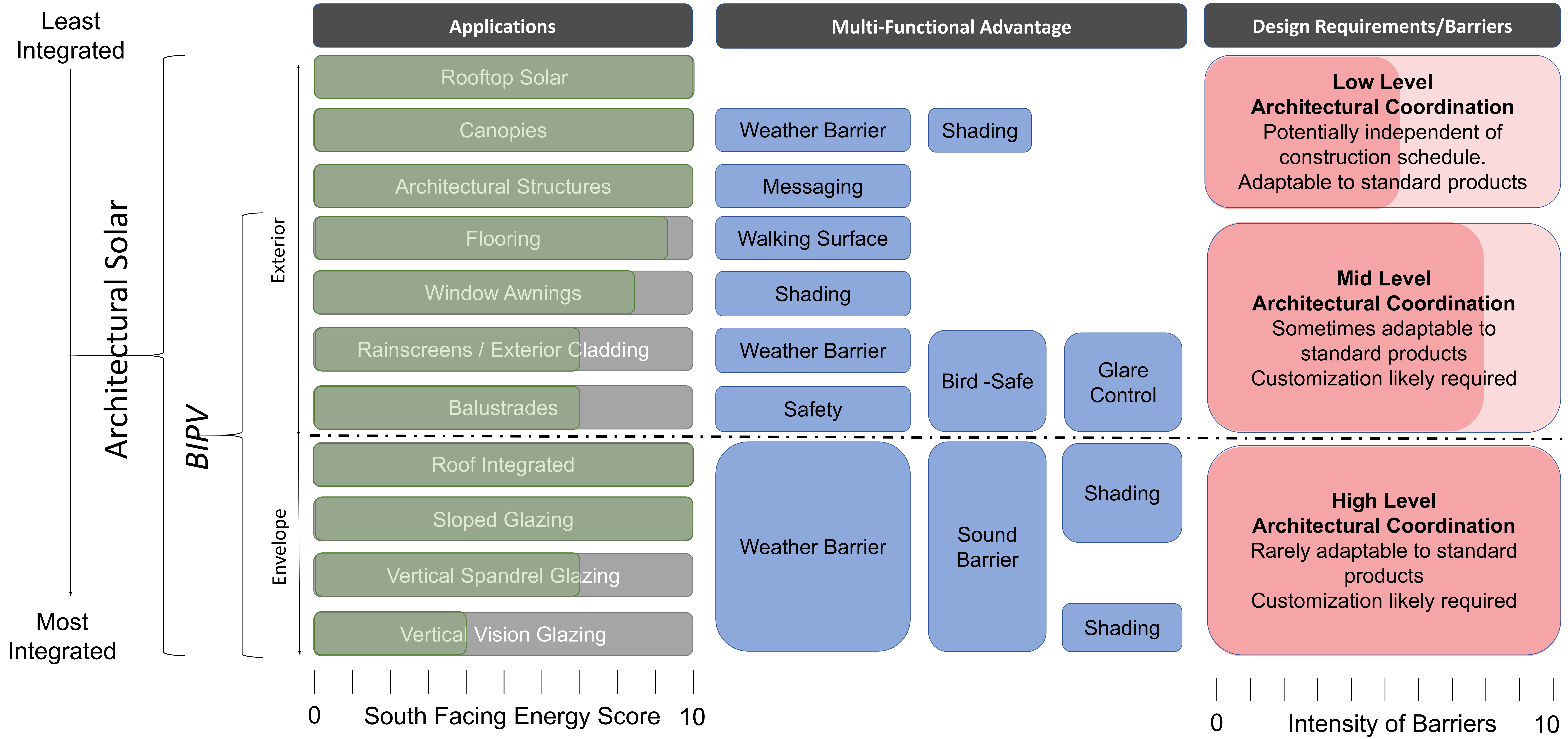

Architectural Solar - Advantages

ASA Architectural Solar Association

Market Barriers

Architectural Solar

Rooftop Solar

- Lack of Continuing Education
- High soft costs
- Incompatibilities with Arch. Workflows
- Lack of Awareness
- Building Industry Adoption
- Standards Development
- Limited Supply Chain

The Pull

New Construction Requirements

- Progressive Municipalities
- State Mandates

Net Zero Ambitions

- Maximizing energy potential

Cost Reductions

- Modules - $0.40/watt = $7.60/sqft*
- Installed Systems - $3.00/watt = $57/sqft*

*Assumes 19 watts/sqft technology

ESG

- Corporate Initiatives
- Climate Action Plans

Demand

- Market Growth
- IRA

Image courtesy of SolMotiv Design

ASA
Architectural Solar Association

The Path to Widespread Adoption

- Business model innovation in design workflow
- Simplified design processes and integration methodologies
- Supply chain integration
- Non-export interconnection protocols
- Embrace broad approach to integration
- A coordinated AEC community

Image courtesy of Morgan C

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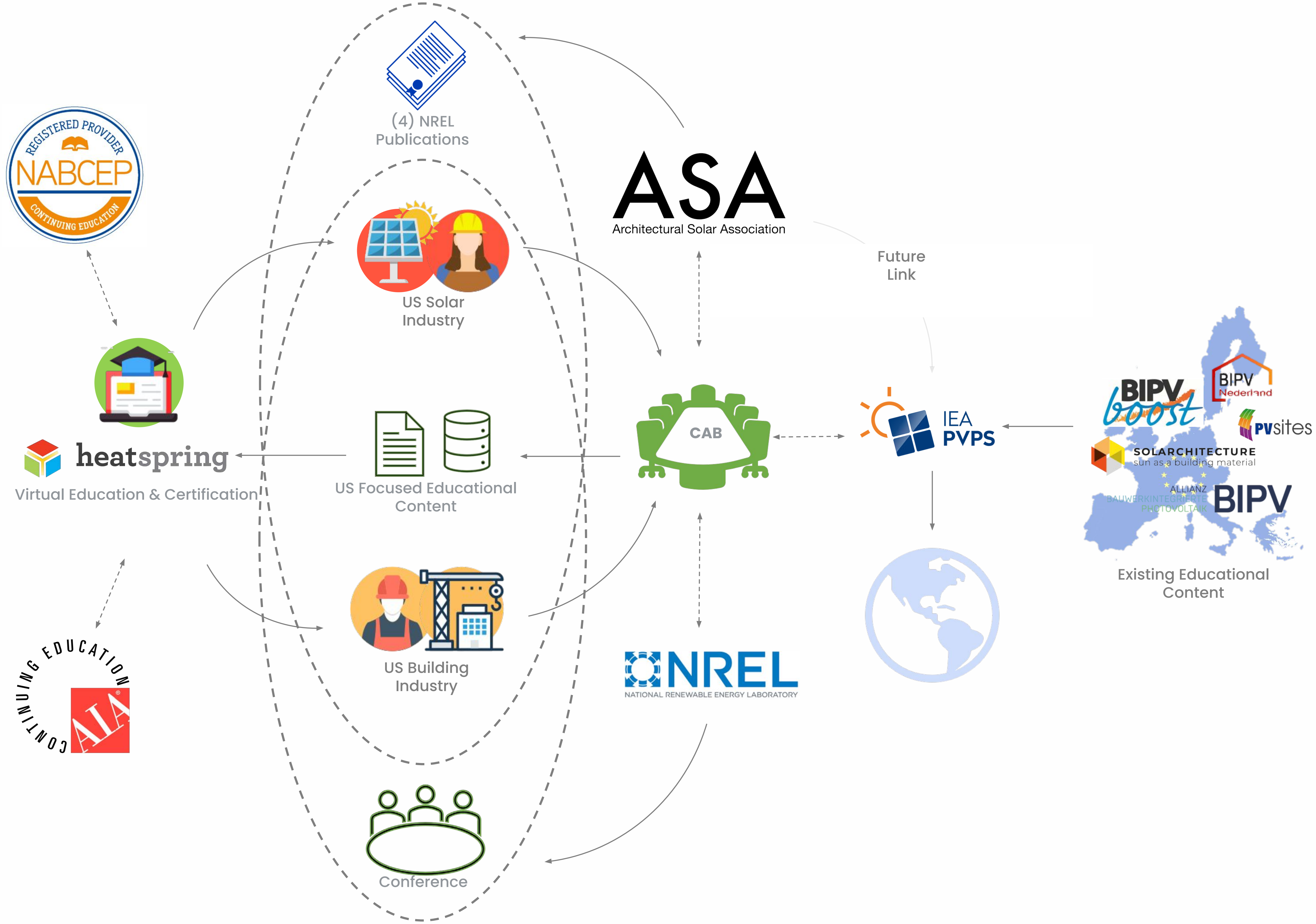
Architectural Solar Education
for
Design and Construction Professionals



ASA Educational Framework

ASA
Architectural Solar Association

Key Milestones

- Formation of the Content Advisory Board (Quarterly Meetings)
- Existing Research Synopsis
- (4) Publications & Accompanying Webinars sponsored by NREL
- Free Architectural Solar Short Course (~ 10 min Video)
- US Architectural Solar Project Database
- 20-hr Architectural Solar Course (Paid)
    - 3 modules administered via Heatspring.com
    - AIA & NABCEP Accredited
    - DOE Program integration
- Building Industry Tradeshow Seminar

ASA
Architectural Solar Association

Thank you!

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Images courtesy of BIPV Boost, Energy Glass, IEA, Issol, Lumos Solar, Lighthouse Solar, Morgan Creek Ventures, NRG, Onyx Solar, SolMotiv Design, Solaria, Spotlight Solar, SUPSI, Tres Birds, Walters & Wolf

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Transparent BIPV work at LBNL

Jacob C. Jonsson

Yuan Gao, Charlie Curcija

Windows and Envelope Material Group
Building Technology and Urban Systems

Strategic Collaboration: LBNL & NREL

	Foundational Science	Applied Science	Modeling/Road mapping
BERKELEY LAB	Non-energy/Human factors Thermal performance	Building Integration	WINDOW/THERM integration
Co-development	SHGC/PV measurements Materials development	Device performance Standards Development Field evaluation	Building Energy Analysis GEB Potential Industry outreach & education
NREL Transforming ENERGY	Materials development Device development	Durability Manufacturing	Technoeconomic analysis

The perfect transparent PV window

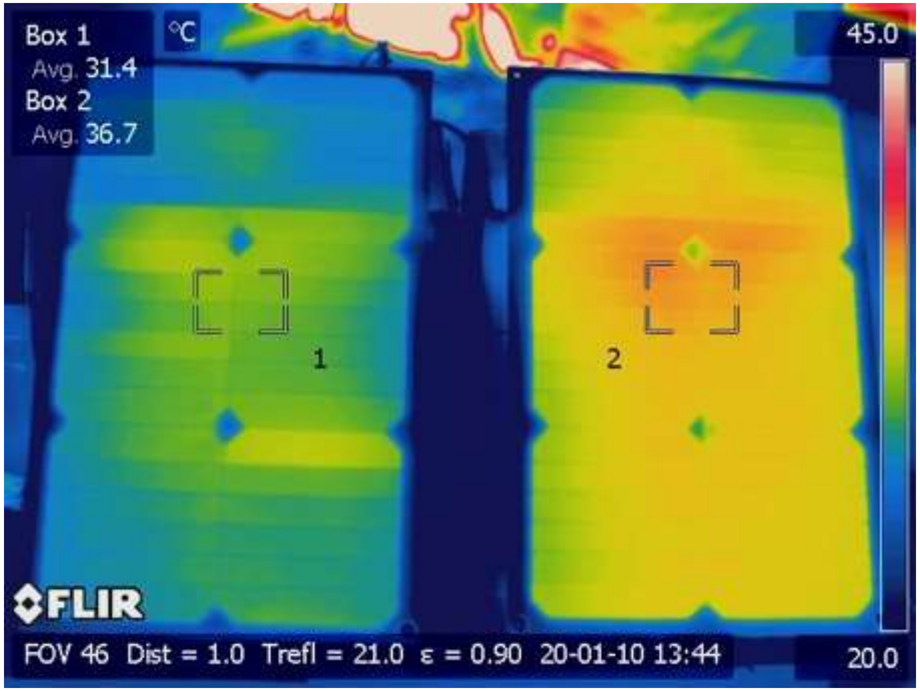
- Visible light level appropriate for the occupants
  - Number is different for skylight vs corner office vs cubicle land
- Solar heat-gain coefficient as low as possible when in cooling mode, as high as possible when in heating mode
  - Often varies between summer and winter

- U-value, lower is better
- Power output
  - As high as possible, but not VT = 0
  - In heating mode and electricity has to go to heating the room…
- Low cost and easy to install
- World peace

Field testing facilities

- FLEXLAB allow testing with side-by-side comparison of technologies
- Rotating test bed to look at different orientation
- Transparent PV study in 2016 on Solaria transparent PV predicted 15% energy saving compared to low-E reference case

Field testing facilities

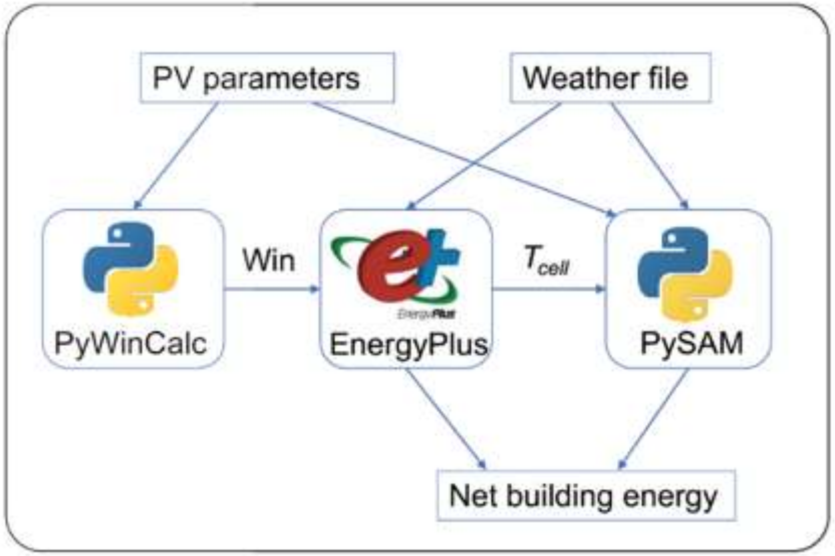


- MoViTT thermal and electrical performance
- Ubiquitous energy

- Thermal IR camera to show operating temperature difference

Simulation: method

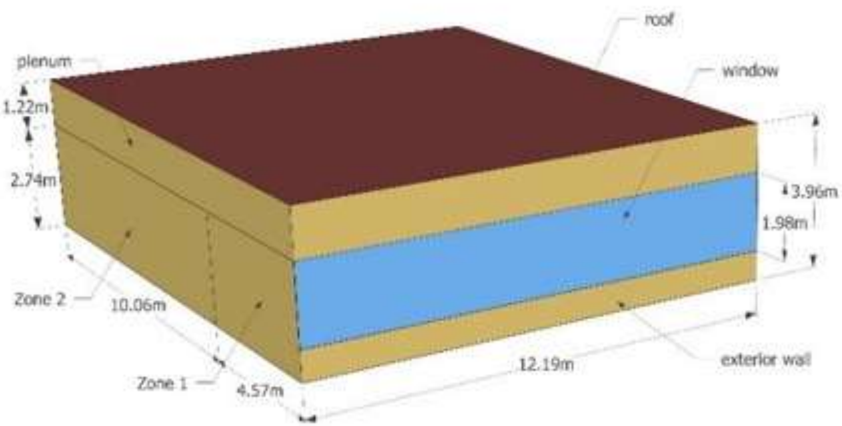
- PyWinCalc (LBNL): https://github.com/LBNL-ETA/pyWinCalc
- PySAM (NREL): https://github.com/NREL/pysam
- EnergyPlus
- Improved heat transfer taking generated electricity into account



Variable names	*Values*
Climate	Hot, mixed, cold
Window orientation	South, East, West, North
PCE	0-1 (0.1 interval)
T_{sol}	0-1 (0.1 interval)
A_{sol}	0-1 (0.1 interval)
T_{vis}	0-1 (0.1 interval)
U factor	0.4, 0.6, 1.5, 2.7, 5.4
Daylighting control (LC)	No, Yes

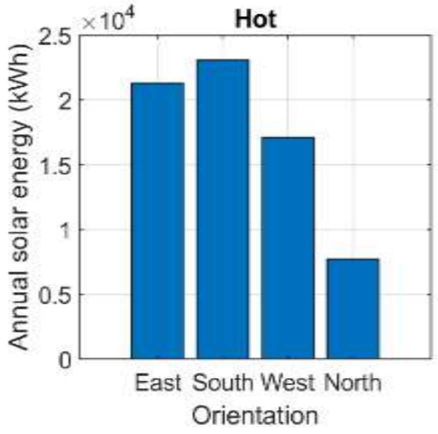
$$0 \leq PCE + T_{sol} + A_{sol} \leq 1$$

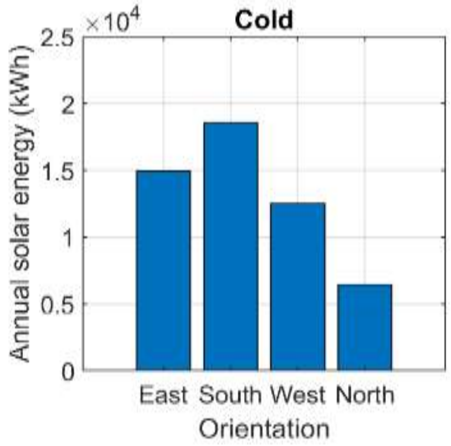
T_{vis} stays within the range defined by T_{sol}



Gao, Yuan, et al. *Applied Energy* 301 (2021): 117467.

Simulation: results





Gao, Yuan, et al. *IEEE PVSC-49*, 2022.

- Sun movement combined with windows results in more uniform irradiance in different orientations.
- Annual stability as well as with less light but at lower sun angles in the winter reduces the seasonal swings

- The visible light transmittance should fall within the balanced range that results in satisfactory clarity, low glare, and high PCE.
- The relative increase in PCE is smaller than the relative decrease in Tvis when you go down in the VT = 0.2 range

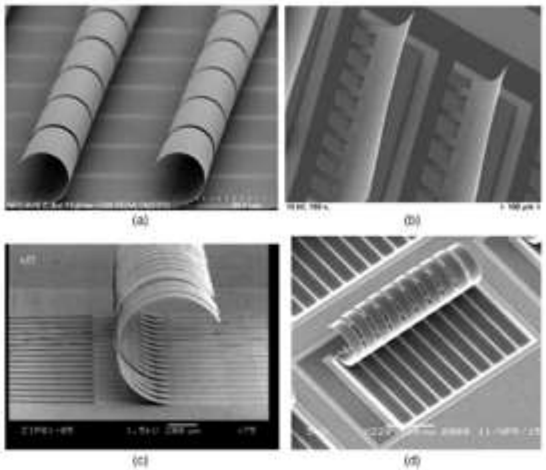
Development of self-powered dynamic window

◆ Current limit of dynamic windows:

- Thermochromic windows :
  - only passive control
  - not suitable for warm climates
- Electrochromic windows :
  - complexity of installation & wiring
  - limited modulation

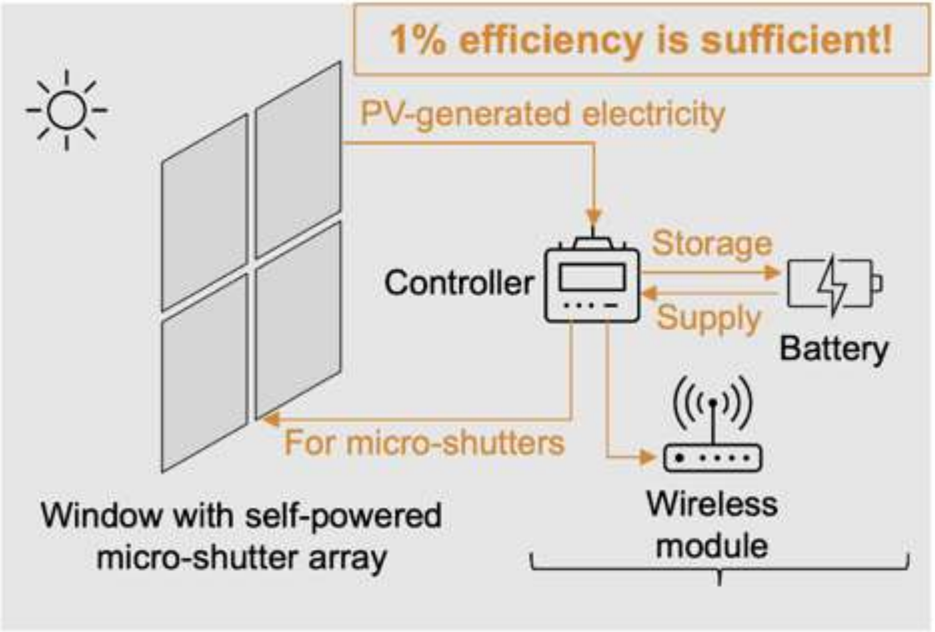
◆ Micro-shutters:

- Energy saving (high % heat rejection)
- High contrast (privacy)
- Fast switching speed
- Durability (> 500 billion cycles)
- + STPV → self-powered



MEMS-based micro-shutter arrays: invisible to human eyes

Development of self-powered dynamic window

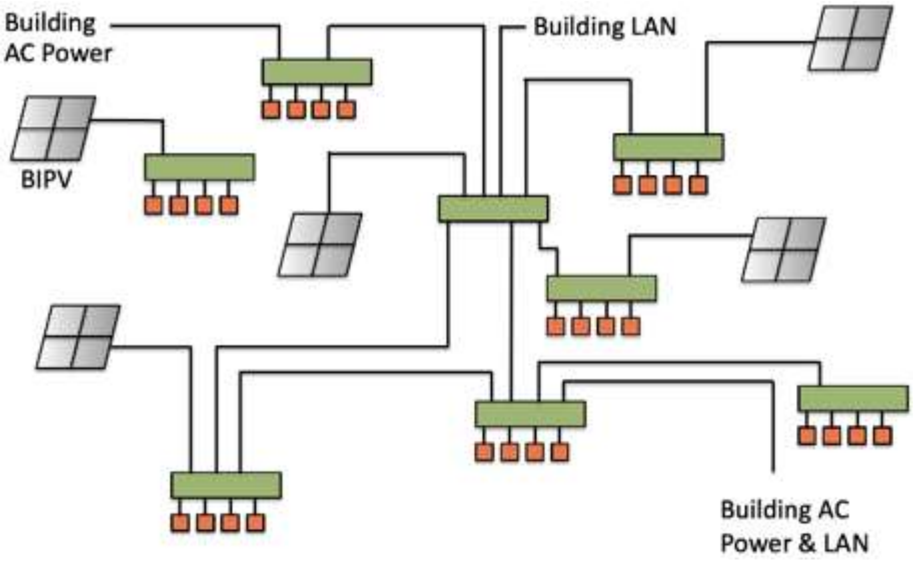


Energy saving potential of self-powered micro-shutter windows ($kWh/m^2/yr$)

Climate	PV generation*	Control consumption**	Dynamic window saving***	Total energy saving/decarb
Hot	122.4	8.3	323.0	437.1
Mixed	101.6	7.9	194.0	287.7
Cold	108.3	8.0	269.0	369.3

Building backbone

- Long-term goal
- Synergy between
  - BIPV power generation
  - DC-power grid
  - Storage (battery or car)
  - Control/monitoring communication



Increased building integration

◆ Interact with IoT based smart buildings

- Grid-interactive for resilience and optimized operation
- Daylighting steering
- Area/pixel control & window display

Resiliency

- Extending the time it is safe to stay in the building during emergencies
- Complement/replacement to generators for emergency power, especially in combination with storage
- Helpful both during grid failures and planned shut-downs

Questions/comments

- How can we help enable BIPV?
- Have had impact in traditional windows
- Have experts in windows, but also DC power and battery storage, micro grids
- Ideas that Should be done vs Can be done

Observations & Lessons Learned in Residential Building Integrated Photovoltaics (BIPV)

Presenter: Jeff Cook PhD

National Renewable Energy Laboratory (NREL)

1,800

Employees,
plus more than
400
early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

nearly
750

Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

$872M
annually

National economic impact

Project Overview

Source: GAF Timberline

NREL is partnering with roofing integrated PV manufacturers (and related installers) to analyze three research questions.

- How do current roofing integrated PV products compare to racked and mounted PV in terms of costs, install times and processes?
- How are roofing integrated PV products installed and are there opportunities for cost savings?
- What are the key barriers to expanding market opportunities for integrating solar and roofing products?

Source: Tesla Solar Roof

Source: Ghosh, 2020

BIPV Market and Potential Opportunity

BIPV Market

- Residential BIPV costs remain higher than conventional PV.
- BIPV markets are fundamentally constrained.
- Cost savings could encourage more adoption

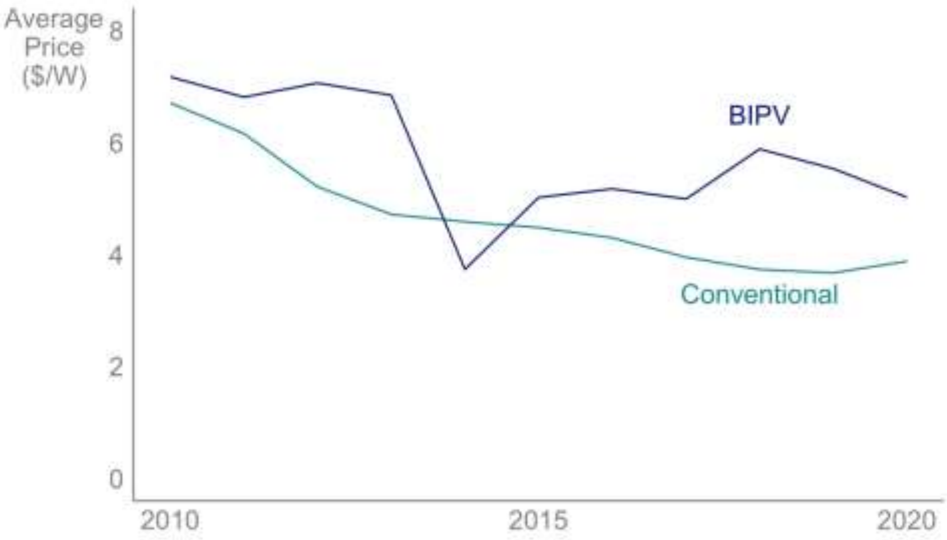


Figure 1. Average prices for BIPV and conventional systems, 2010-2020

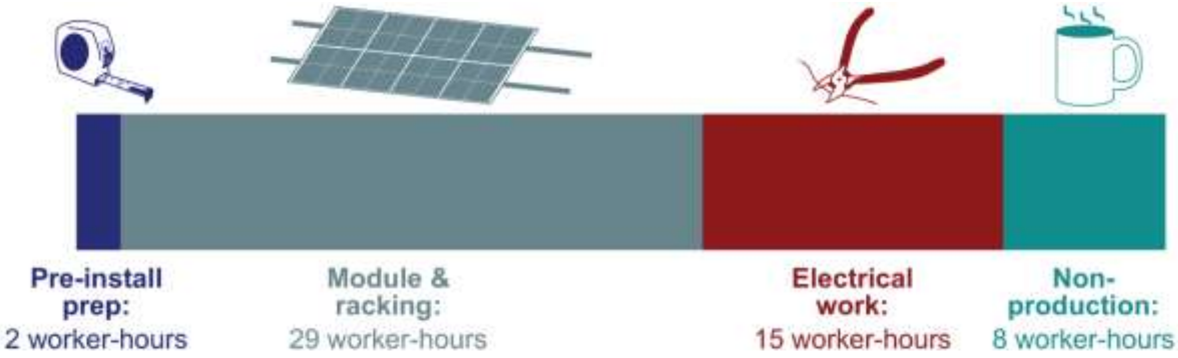


Figure 2. Time and motion study results for conventional residential rooftop PV system

BIPV Market Opportunity

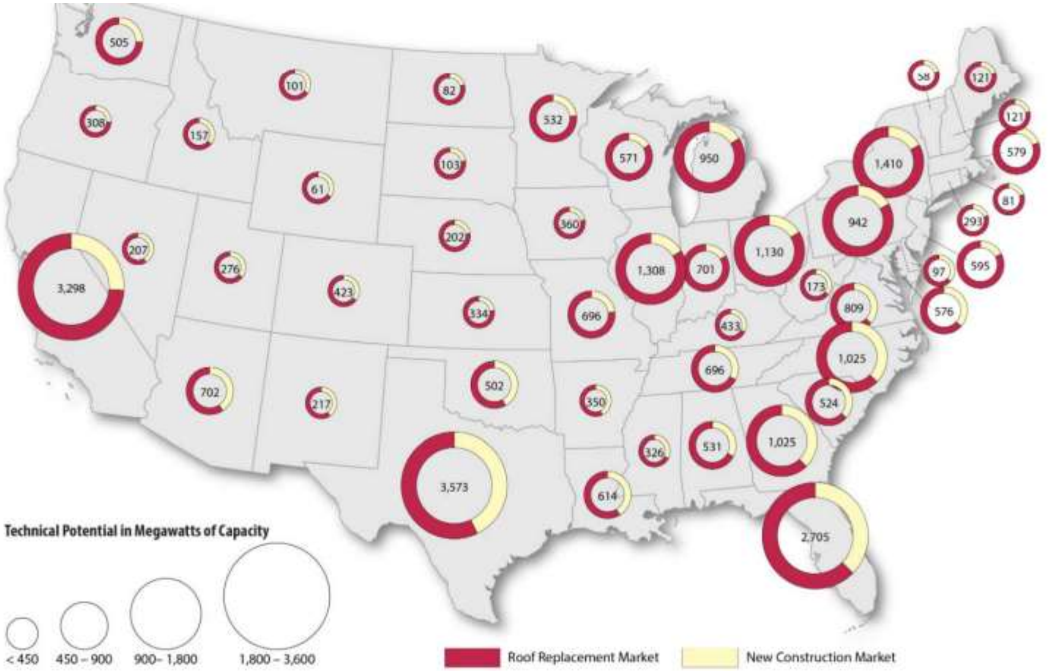


Figure ES-1. Annual average technical potential for residential rooftop PV at time of roof replacement and new construction projected between 2017 and 2030

https://www.nrel.gov/docs/fy18osti/70748.pdf

Methodology

Expert Interviews/Advisory Group

21 re-roof and new construction obs.

Market Barriers and Potential Solutions

- Cost uncertainties
- Permitting, inspection, and code enforcement
- Labor availability and training
- Architectural and design integration
- Roofing industry integration
- Product Manufacturing and supply chain
- Awareness and education

Conclusions/ Opportunities for Expansion

- Decision Support Tools
- Workforce Training
- Code reform
- Informational campaigns
- Manufacturing and supply chains
- BIPV consortium working group

Questions and Thank You!

For more information contact:

Jeff.cook@nrel.gov

www.nrel.gov

U.S. DEPARTMENT OF ENERGY
Solar Decathlon
Building the Next Generation







BIPV at the Solar Decathlon

Rachel Romero, Senior Engineer,

National Renewable Energy Laboratory

The U.S. Department of Energy Solar Decathlon
is a collegiate competition, comprising **10 Contests**, that challenges student teams to
design and **build**
**highly efficient, high-performance,
innovative, low-carbon buildings
powered by renewable energy**.

Two Challenges, 10 Contests

Germany 2009

- Focus on façade
- Two-story cube
- 11.1 kW system
- 40 single-crystal silicon panels on the roof and about 250 thin-film copper indium gallium diselenide (CIGS) panels on the sides
- Expected to produce an incredible 200% of the energy needed by the house

U.S. DEPARTMENT OF ENERGY
Solar Decathlon

Appalachian State University's 2011 Solar Homestead

- 833 ft^2 home
- Award
  - People's Choice Award
  - 2nd in Communications
  - 3rd place in Architecture

Appalachian State University's 2011 Solar Homestead

- Seamless integration into architectural design
- Sought for the panels not to be an "afterthought"
- Sanyo bifacial panels that collect sun from both the top and bottom of the panel
  - Yields 30% more efficiency

Swiss Team 2017 NeighborHub

- 2017 Winning Team
- Flexibility
- Shading aspect in the PV

U.S. DEPARTMENT OF ENERGY
Solar Decathlon

Solar Decathlon China: Swedish 2013 HALO

- Placed 3rd overall
- Monocrystalline silicone photovoltaics laminated in thin acrylic plastic and coated with a high strength polymer
- Applied to 10 mm polycarbonate sheets

Myongji University 2022 Hanok

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Thank You!

Questions?

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