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

Welcome to the DOE Buildings XV Post-Conference Workshop

“Current Challenges, Opportunities, and Research Needs of Building-Integrated PV Systems”

Agenda Overview

1:00p – 1:10p	**Welcome and Introductions**
1:10p – 1:30p	**BIPV and EE Envelopes to Achieve Low Carbon Buildings** M. LaFrance (BTO)
1:30p – 2:00p	**Building Integrated PV at the Solar Energy Technologies Office** G. Stefopoulos (SETO)
2:00p – 2:45p	**BIPV System Integration and Implementation** Marcus Bianchi (NREL) – 15 mins Mengjie Li (University of Central Florida) – 15 mins Discussion
2:45p – 3:15p	**Break**

Agenda Overview

3:15p – 3:30p	**European perspectives regarding BIPV** Targo Kalamees (TalTech) – 15mins
3:30p – 4:00p	**BIPV International Markets: Current State and Future Projections** Jacob Jonsson (LBNL) – 15 mins **IEA PVPS Task 15 Review** Jacob Jonsson (LBNL) – 15 mins
4:00p – 4:45p	**Standards requirements for walls, windows, and roofs – Breakout sessions** Facilitators: Roofs (Andre Desjarlais), Walls (Diana Fisler), Windows (Marc LaFrance)
4:45p – 4:55p	**Report out**
4:55p – 5:00p	**Concluding Remarks –** Marc LaFrance/George Stefopoulos

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BIPV and EE Envelopes to Achieve Low Carbon Buildings

Marc LaFrance
US DOE
Advanced Technology and Energy Policy Manager

Buildings XV Conference
December 8, 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:

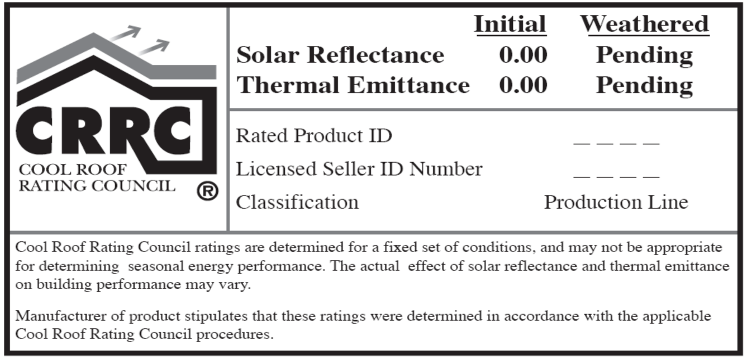
- Simulation of U-factor, Solar Heat Gain Factor and Visible transmittance - ISO 15099
- U-factor testing - ASTM C 1363, C1199, NFRC 102
- Solar Heat Gain Testing – NFRC 201
- Spectral Optical Property – ISO 9050, ASTM E903, NFRC 300, 301
- Air Leakage – ASTM E283, NFRC 400

Wall Insulation

- ASTM C 518, C 177

Wall System

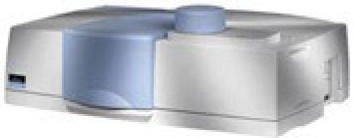
- ASTM C1363, ASTM C1155



Air Leakage

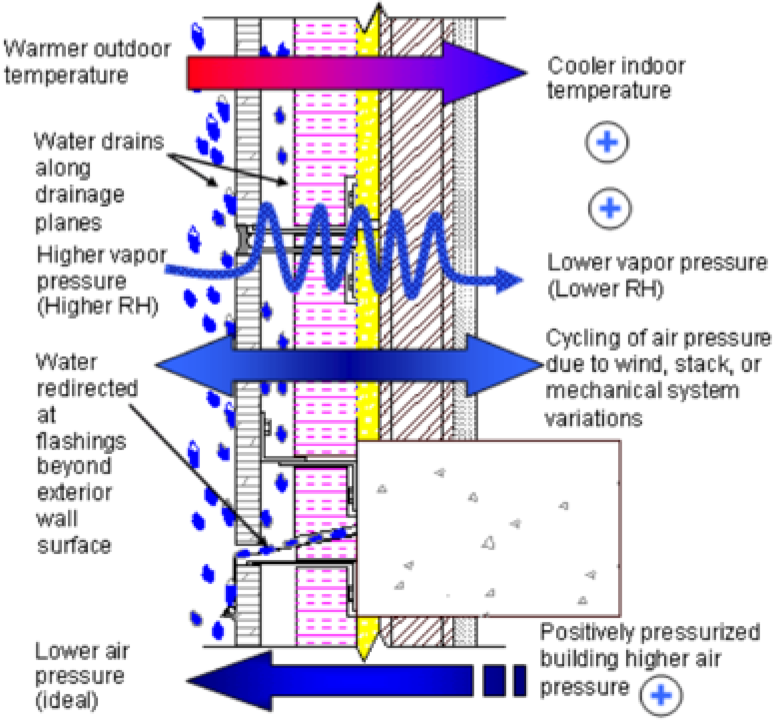
Hot Box

Solar Calorimeter



Spectrophotometer

Wall systems – complex moisture and air management



Courtesy: Whole Building Design Guideline

BIPV needs to ensure core functions are maintained

Implementing EE with BIPV Example

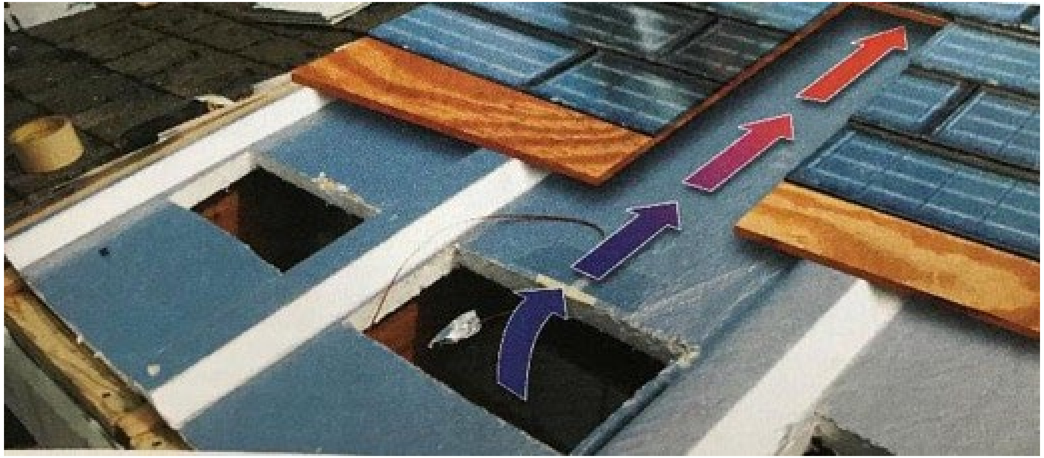
Conventional

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

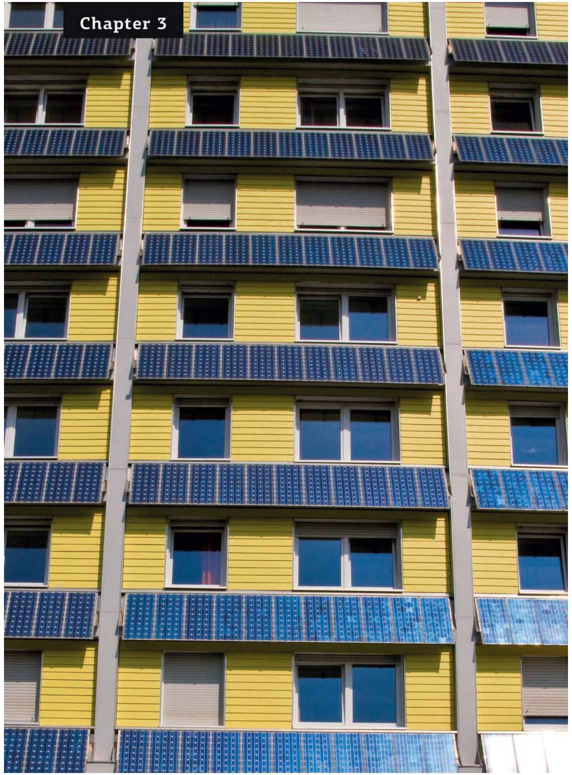
BIPV

- 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



BIPV with high efficiency facade



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

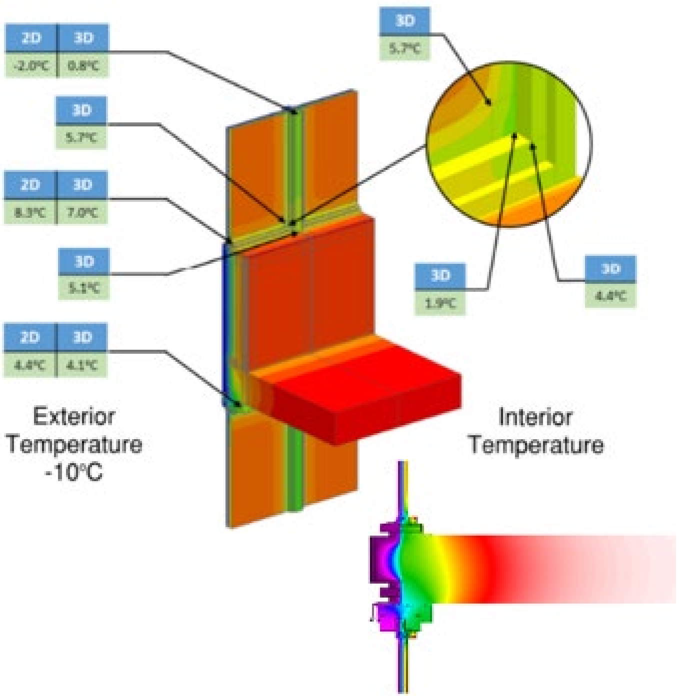
Source: "Transition to Sustainable Buildings, Strategies and Opportunities to 2050", IEA 2013

EE Spandrels research – opportunity for BIPV

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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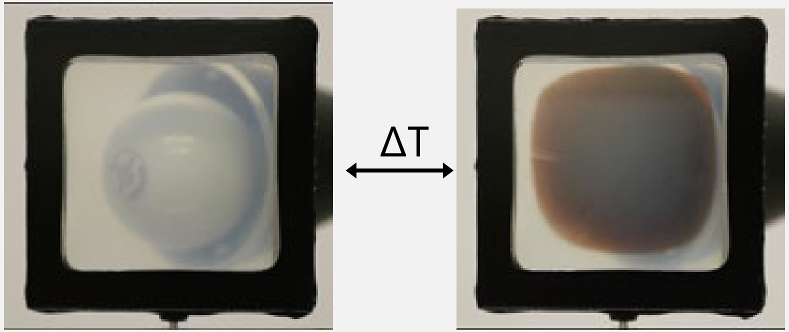
To learn more, contact Anne Ellis
aellis@pankowfoundation.org

Perovskite materials for photovoltaic windows project

Thermochromic PV

Dynamic solar heat gain control + PV generation



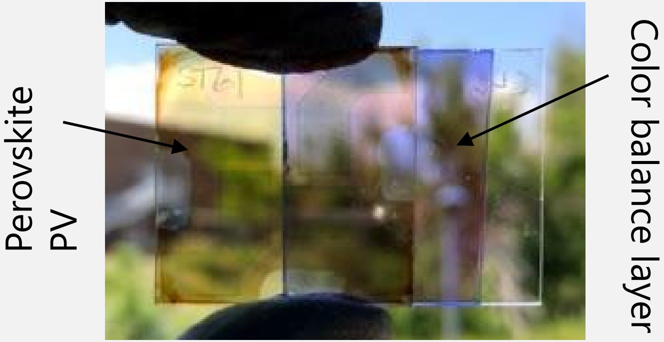
Transparent

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

Neutral color semitransparent PV

High efficiency without sacrificing aesthetics



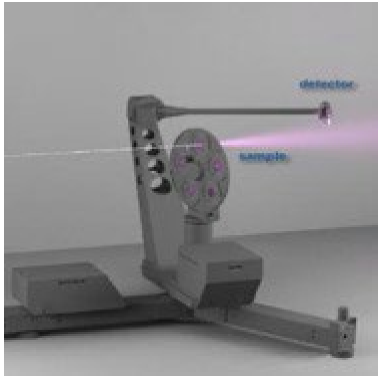
- >6% geometric efficiency with >30 visible light transmittance and neutral gray color
- Compatible with current glazing and lamination processes
- Investment makes technology market viable in ~3 years.

Lance Wheeler, PhD
NREL

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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Cell 240-474-2177

Building Integrated PV at the Solar Energy Technologies Office

Dr. George Stefopoulos, *Solar Innovation Technical Advisor*

Buildings XV Conference – U.S. DOE BIPV Workshop

December 8, 2022

Outline

- SETO overview and background
- BIPV RFI description, responses, and learnings
- Further discussion

Solar Energy Technologies Office (SETO) Overview

MISSION

We accelerate the **advancement** and **deployment of solar technology** in support of an **equitable** transition to a **decarbonized economy no later than 2050**, starting with a decarbonized power sector by 2035.

WHAT WE DO

Drive innovation in technology and soft cost reduction to make solar **affordable** and **accessible** for all Americans

Enable solar to support the **reliability**, **resilience**, and **security** of the grid

Support **job growth**, **manufacturing**, and the **circular economy** in a wide range of applications

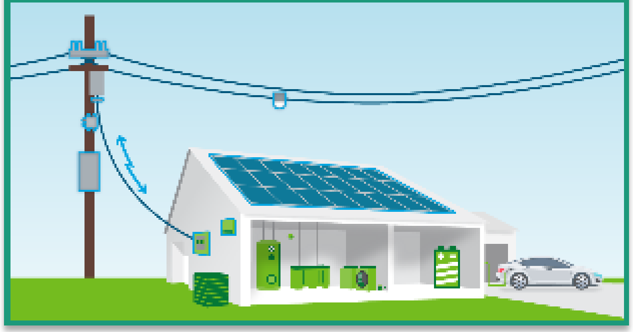
SETO Research Areas

PHOTOVOLTAICS

CONCENTRATING SOLAR-THERMAL POWER

BALANCE OF SYSTEMS/ SOFT COST REDUCTION

SYSTEMS INTEGRATION



MANUFACTURING AND COMPETITIVENESS

Driving Toward Decarbonization Goals

- SETO 2021 Multi-Year Program Plan was released Spring of 2021
- The Multi-Year Program Plan explains the purpose and the priorities of the office and sets goals for solar energy for 2025. Additionally, it explains how we will accelerate progress toward these goals

Accelerate solar deployment and associated job growth by **opening new markets**, reducing regulatory barriers, providing workforce training, and growing U.S. manufacturing.

Emerging Sectors – Dual-use solar systems

- Building-integrated photovoltaics (BIPV)
- Vehicle-integrated photovoltaics (VIPV)
- Floatovoltaics
- Agrivoltaics

BIPV 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

BIPV Background (EN 50583 / IEC 63092 / IEC 61730)

Building-applied PV (BAPV)

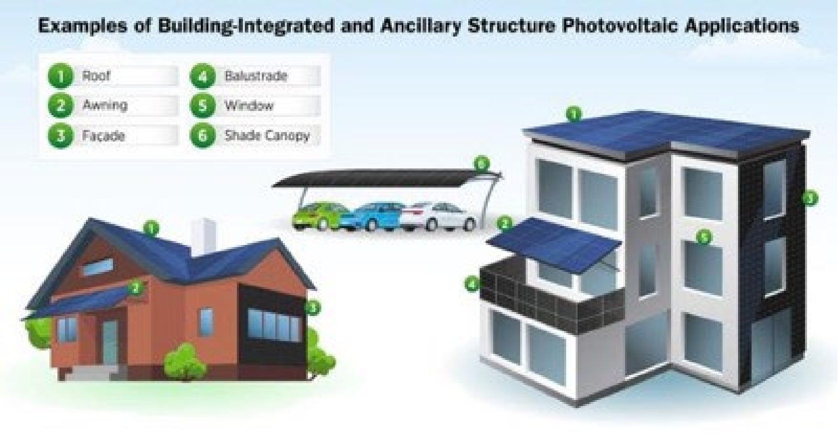
- PV modules are building-attached if they are mounted on a building envelope

- Conventional PV modules
- Fully-functional building
- Electricity generation

Building-integrated PV (BIPV)

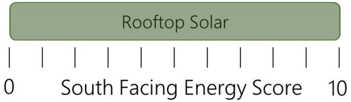
- PV modules are building-integrated if they form a building component providing additional functions

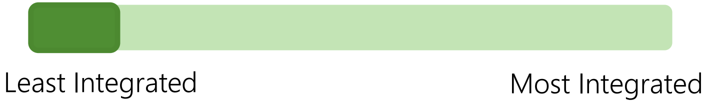
- Specialized PV modules
- Integral part of building
- Electricity generation and building function



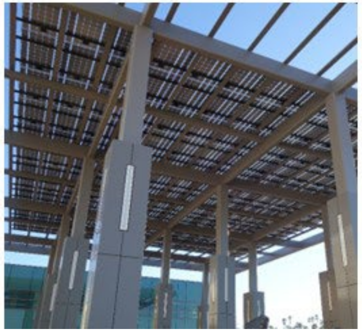
Rooftop Solar

Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/





Canopies



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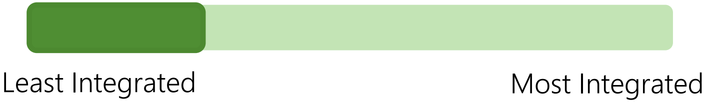
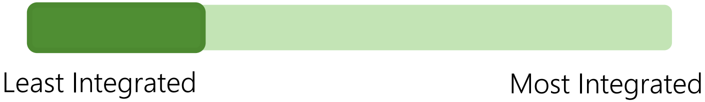


Canopies

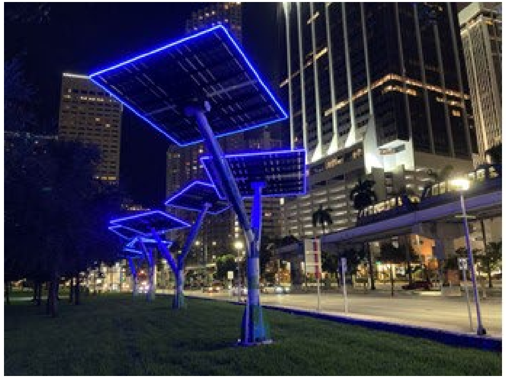





Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

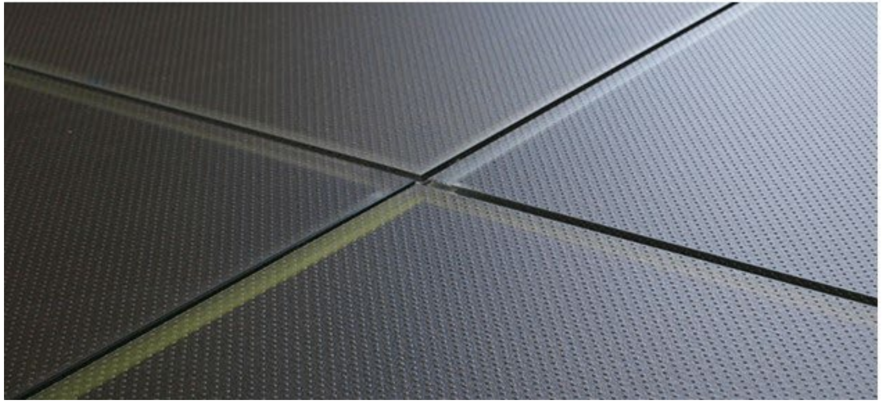


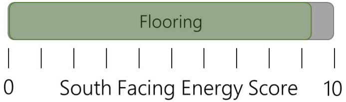
Architectural Structures



Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Flooring





Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Awnings/Louvers

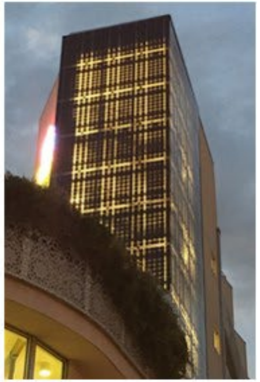
Window Awnings

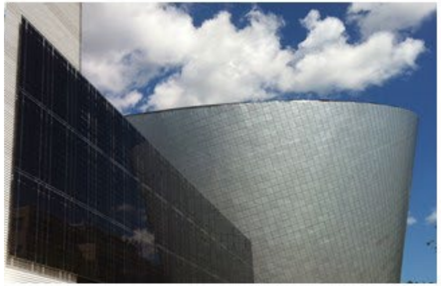
0 South Facing Energy Score 10

Least Integrated Most Integrated

Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Ventilated Solar Facades, Rainscreens, Enclosures





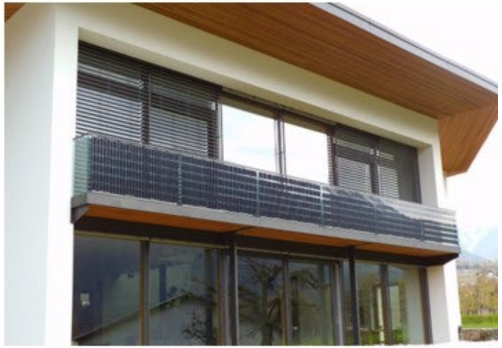
Rainscreens

0 South Facing Energy Score 10

Least Integrated Most Integrated

Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Balustrades



Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Roof Integrated

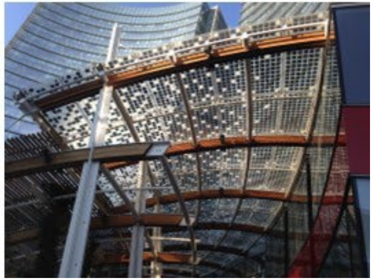
Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Roof Integrated

0 South Facing Energy Score 10

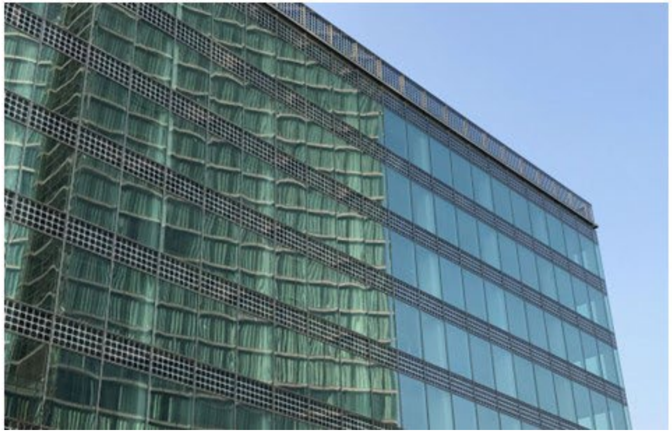
Least Integrated Most Integrated

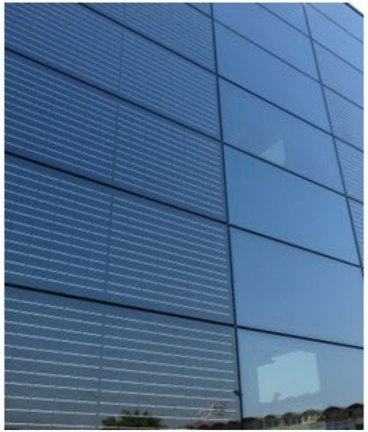
Sloped Glazing

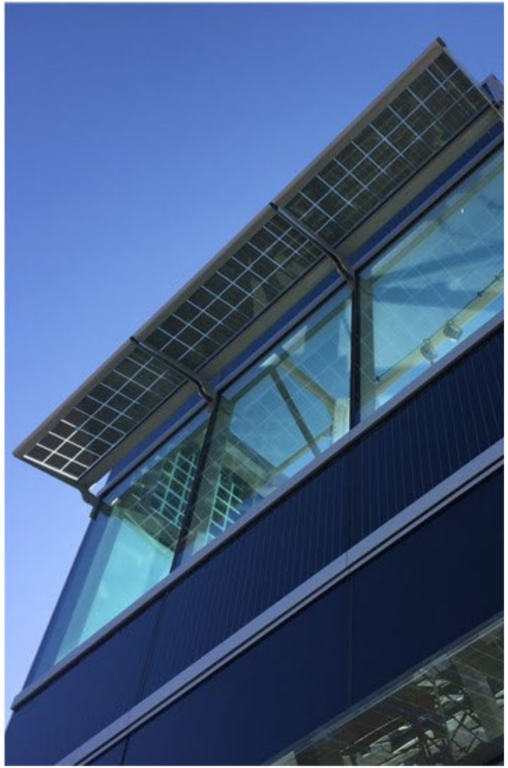


Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Spandrel Glazing







Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Vision Glazing

Courtesy of the Architectural Solar Association (ASA)
https://www.archsolar.org/

Vertical Vision Glazing

0 South Facing Energy Score 10

Least Integrated Most Integrated

BIPV 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

BIPV 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

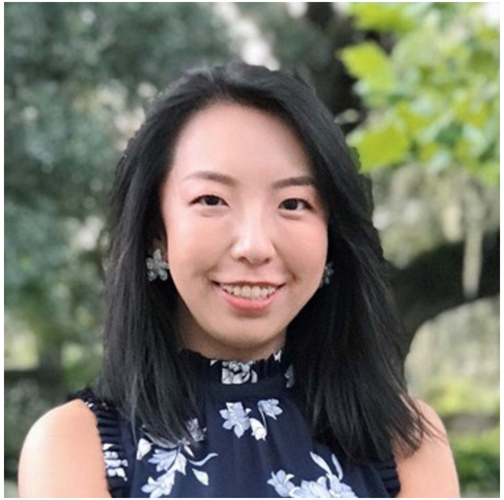
Questions and Further Discussion

George Stefopoulos
georgios.stefopoulos@ee.doe.gov

BIPV System Integration and Implementation

Dr. Marcus Bianchi, PE
National Renewable Energy Laboratory

Dr. Marcus Bianchi is a senior research engineer with the Building Technologies and Science Center at the National Renewable Energy Laboratory, where he also leads the business development activities to coordinate external funding, partnerships, and collaborations with corporations, government agencies, and other research institutes. Marcus was principal scientist at Johns Manville, performing insulation heat transfer research, and a professor in mechanical engineering at Universidade Federal do Rio Grande do Sul and at Purdue University.



Dr. Mengjie Li
University of Central Florida

Dr. Li is a research professor at the Florida Solar Energy Center and the University of Central Florida. She has a background of high efficiency solar cell fabrication and is currently focused on degradation pathway analysis of PV modules and improving energy and community resilience with renewable energy solutions. She will discuss the role of BIPV in improving energy resilience and the current state-of-art in BIPV durability and reliability characterization research.

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BREAK 2:45 - 3:15pm

Dr. 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.

Standards Requirements for Walls, Windows, and Roofs

Break-out Sessions

Walls

Source: Net Zero Envelope: Curtain Wall Retrofit at SMUD Headquarters | glassonweb.com

Windows

Source: Building-Integrated Photovoltaics Can Lead to Net-Positive Construction | ArchDaily

Roofs

Source: Solar Shingles for EPCs, Contractors & Installers | Targray

Breakout Group Assignments

DOE's RFI responses indicated that updating and the development of building performance standards is a critical necessity to remove barriers to greater market adoption of BIPV. Please address the following questions in your breakout groups.

1) Identify the top three to five standards or specifications that need to be improved that can have the biggest impact to reduce barriers to BIPV adoption?

2) What are the highest priorities of the identified standards and why?

3) For the top two priorities, what are the next steps needed to pursue the standard improvements and what is an estimated timeframe for them to be fully promulgated?

Thank you!

Thank you!

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NATIONAL RENEWABLE ENERGY LABORATORY

BIPV: Drivers, Benefits, Challenges, and the Holy Grail

Mary Werner

National Renewable Energy Laboratory
Solar Energy Technologies Program Manager

December 8, 2022

Topics:

Combining (i.e. Applied) vs. Integrating

Benefits & Drivers behind BIPV

Challenges to Integration

Holy Grail

Combining

1997: Birth of the Camera Phone

On June 11th, 1997, Philippe Kahn created the first camera phone solution to share pictures instantly on public networks. The impetus for this invention was the birth of Kahn's daughter, when he jerry-rigged a mobile phone with a digital camera and sent photos in real time. In 2016 Time Magazine included Kahn's first camera phone photo in their list of the 100 most influential photos of all time.

It is on exhibit at the San Francisco Museum of Modern Art.

Integrating

Drivers & Benefits

Why should the construction industry care about solar and BIPV?

- Solar's projected growth is >25% whereas the construction industry growth rate is projected at 3%
- There are serious drivers behind increasing solar and renewable generation that are going to drive increased adoption over the next decade
- BIPV can be much more aesthetically pleasing than rooftop solar, opening a much broader market base
- There are huge advantages to local generation (generation at the load) to avoid transmission expansion that are going to drive pressure to deploy local renewable generation, of which solar is the leading option
- Not only have solar costs dropped, but BIPV can cost substantially less than rooftop solar

Driver: Aesthetics Matter

Source: World Economic Forum

Source: PV Magazine

Driver: Transmission Expansion

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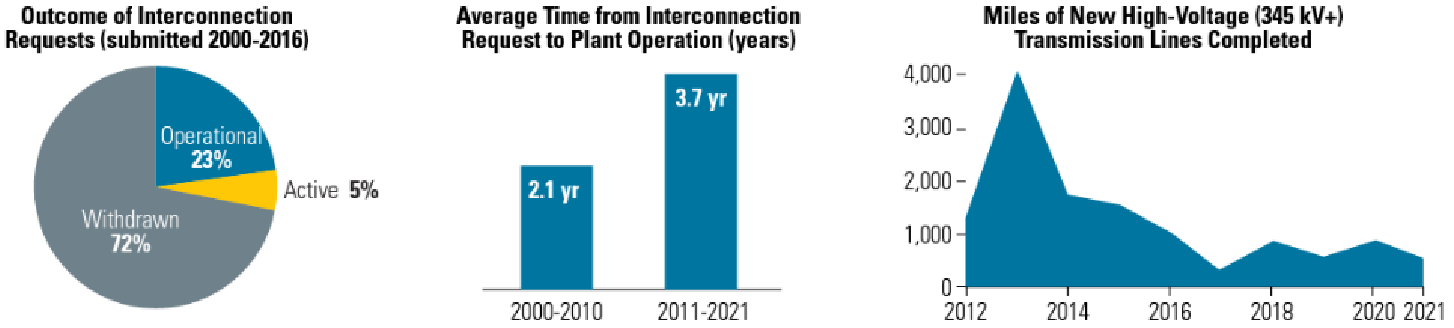
Figure 2. Indicators of the Challenges Facing Transmission Interconnection, Planning, and Construction



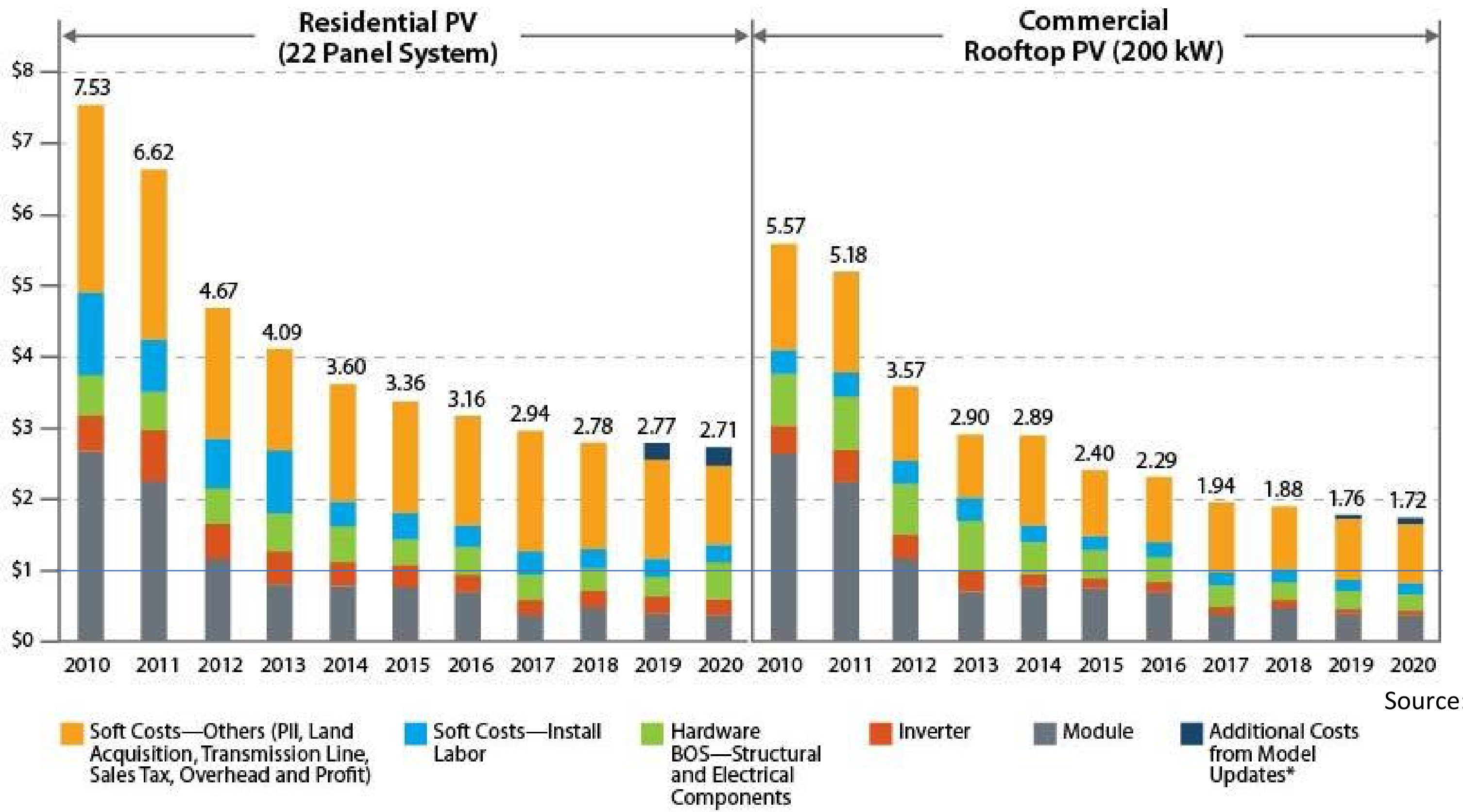
Independent estimates indicate that to meet our growing clean electricity demands, we'll need to **expand transmission systems by 60% by 2030** and may need to triple those systems by 2050.

Source: Queued Up… But in Need of Transmission; Department of Energy; April 2022

Depending on the scenarios, transmission expansion is estimated between 2X and 5X current levels.

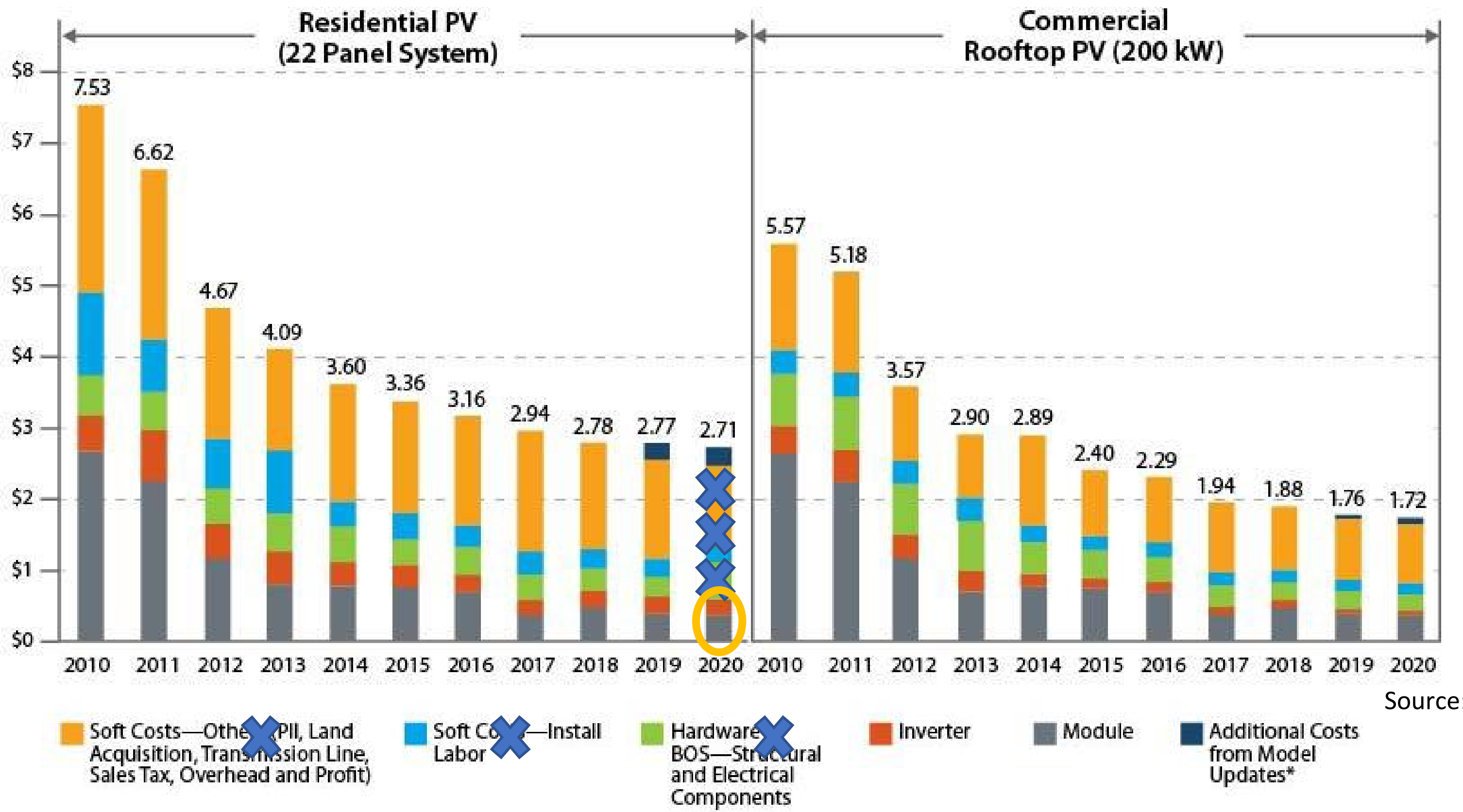
Co-locating Generation with Load through Rooftop PV and/or BIPV could provide over 2,000 TWh/yr, offering huge transmission expansion mitigation.

Driver: PV Costs have dramatically dropped



Source: NREL

Driver: BIPV Cuts Costs Even Further!



Source: NREL

Benefits

- Construction industry grows in revenues and labor
- Less raw materials are used overall
- Generation is produces at the load
- Integration of generation is more aesthetically pleasing than adding it on after the fact
- BIPV costs less than Building Applied PV

Challenges to Integration

Connecting the Construction Industry with the Solar Industry

Construction Industry

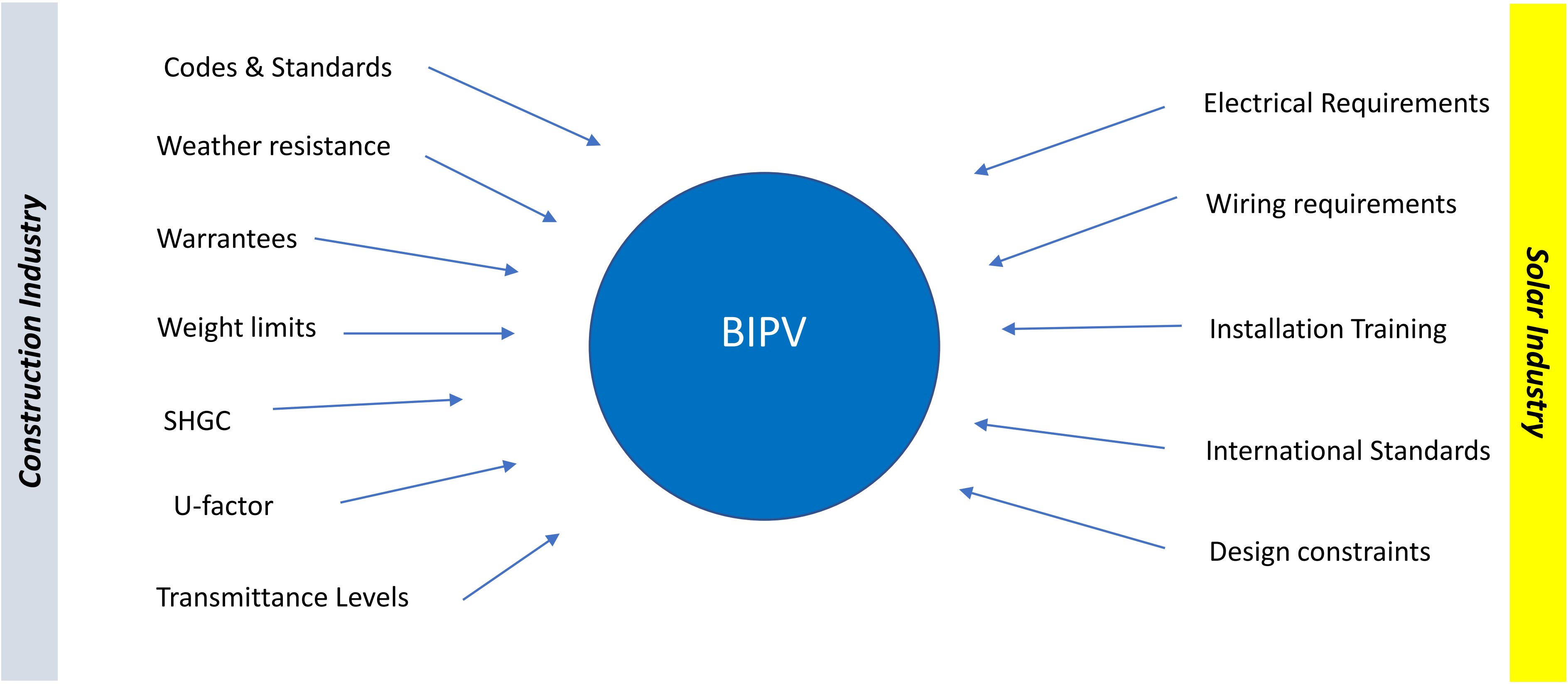
- The market size of the US construction sector was **$1.6 Trillion** U.S. Dollars in 2021 by the U.S. Census, accounting for ~4% of the US GDP
- There are nearly 4 Million construction businesses in the U.S. and ***over 10 million employees.***
- Construction industry:
  - Spends less than 1% of revenue each year on R&D
  - Is considered a low tech industry
  - Is one of the least digitally advanced sectors

Solar Industry

- The market size of the U.S. solar industry is **$16 Billion** U.S. Dollars
- There are approximately ***230,000 employees*** in the solar industry overall
- The market size of BIPV in the U.S. is estimated at **$1.6 Billion** in 2021.
- Solar Industry is:
  - Less mature, focusing more on R&D
  - Evolving and growing rapidly
  - Focused on reducing costs and time to install

Regardless of which industry develops the product, the product has to be accepted, regulated, and understood by the construction industry.

Finding the Integration Middle Ground



Mindset Challenge

At what price-point is optimal no longer needed

- Great is the enemy of Good
- Minor shading okay?
- PV in all four directions?
- Entire roof of PV?
- Angle no longer critical?

Holy Grail?

- Mainstream building materials with integrated solar generation technology
- Building designs automatically include wiring for BIPV
- Architects automatically include BIPV products just as they would a window or a roof
- The KISS Principle

Thank you

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NATIONAL RENEWABLE ENERGY LABORATORY

International markets current state and future projections

Jacob C. Jonsson

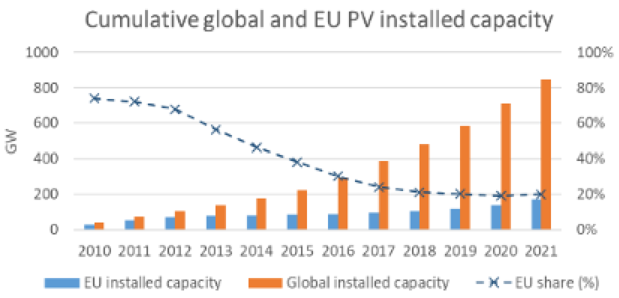
Yuan Gao

Windows and Envelope Material Group
Building Technology and Urban Systems

The grass is greener …

- A feeling that the US is late to the party, EU ahead
- Who is doing better that we can copy?
- BAPV is increasing but still a small fraction of US homes (2.7 Million homes in 2020), BIPV much smaller (1000? 10000? 100?)

Figure 8. Cumulative global and EU PV installed capacity with EU share for the period 2010-2021.

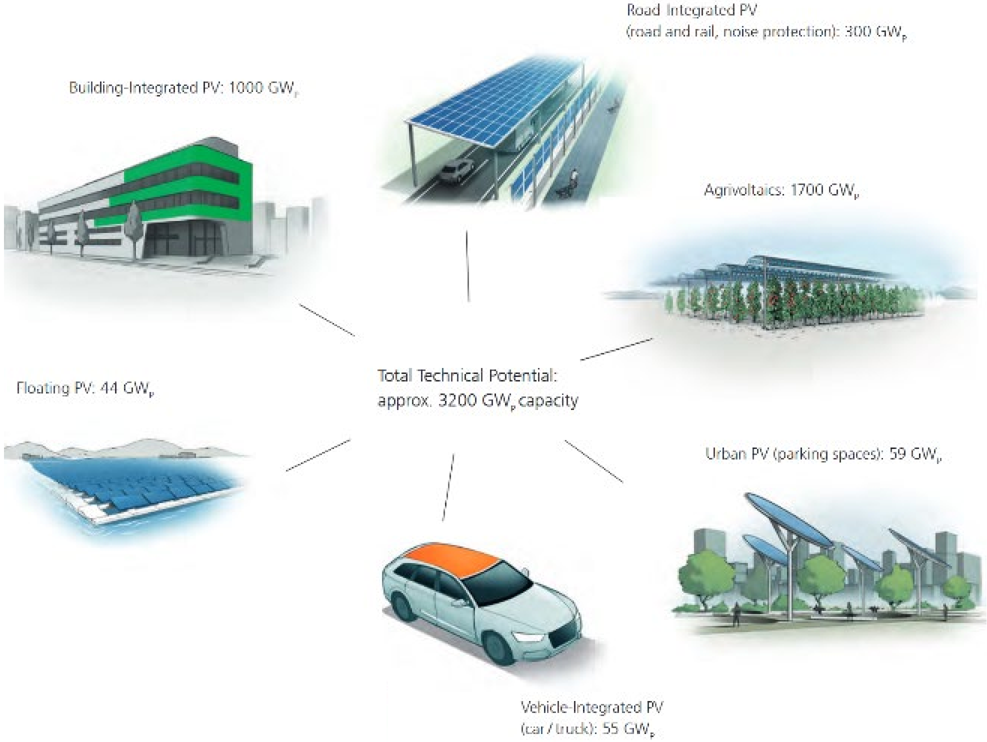


Source: JRC analysis based on Eurostat, IRENA and (Jäger-Waldau, 2022)

Source: Chatzipanagi, A., Jaeger-Waldau, A., Cleret de Langavant, C., Letout, S., Latunussa, C., Mountraki, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/812610, JRC130720

Room to grow in Germany

- Numbers from end of 2021
- 59 GW installed in Germany, mostly road related
- Potential for buildings in Germany 1000GW
- Source: Fraunhofer ISE



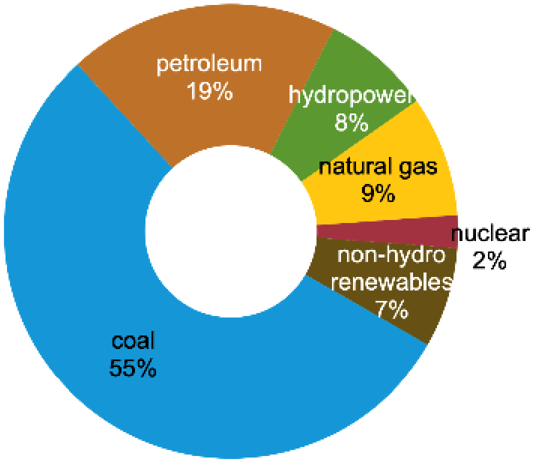
Similar story in Singapore

- SERIS and NUS provided 2020 update that provides a conservative estimate of > 50km^2 usable façade area limiting themselves to the top 5 floors of existing buildings
- Potential of > 500 kWh/m^2/yr
- For comparison rooftop area was calculated to 13.2 km^2 with a potential of > 1000 kWh/m^2/yr
- Installed square footage < 1% of potential

BIPV in China

- China’s solar manufacturing association expects China to add between 75 GW to 90 GW of solar capacity in 2022.
- Building PV (BAPV + BIPV) accounts for 15% of the total PV capacity in China (data in 2020)
- Increasing building energy efficiency and green building development, primarily through installed capacity of building integrated photovoltaics (BIPV) on new buildings to exceed 50 gigawatts (GW) by 2025.

Figure 1. Total primary energy consumption in China by fuel type, 2021



Data source: BP Statistical Review of World Energy 2022
Note: Total may not equal 100% because of independent rounding.
Includes only commercial fuel sources and does not account for

BIPV & BAPV in Japan 2021

- Installed PV capacity: BAPV > Utility scale
- Goals for new construction help push adoption
- Source: IEA PVPS report 2021

Table 2: PV power installed during calendar year 2021

			Installed PV capacity in 2021 [MW] DC value
Grid-connected	BAPV	(1) Residential (< 10 kW)	805
		(2) Commercial (< 50 kW, including ground-mounted)	1,664
		(3) Industrial (50 kW - 1 MW, including ground-mounted)	1,037
		(4) Total of BAPV	3,506
	BIPV	(5) Residential (< 10 kW)	25
		(6) Commercial (10 - 250 kW)	20
		(7) Industrial (> 250 kW)	
		(8) Total of BIPV	45
	Utility-scale	(9) Ground-mounted (1 MW ~)	2,572
		(10) Floating PV systems	120
		(11) Agricultural PV systems	300 (including small-scale systems)
		(12) Total of utility-scale	2,992

Table 20: Ideal vision for housing and buildings in 2050 and 2030

2050	The energy conservation performance of the ZEH/ZEB standard level is secured on average in the stocks, and the introduction of renewable energy such as PV systems becomes common in houses and buildings where the introduction is reasonable.
2030	Energy conservation performance at the level of ZEH/ZEB standards shall be ensured for newly constructed houses and buildings, and 60 % of newly constructed detached houses shall be equipped with PV systems.

BIPV in Spain

- IEA report 2022
- BIPV knowledge development has sufficient quality
- Mainly scientific and academic fields, dissemination is hard
- Large company 350+ projects

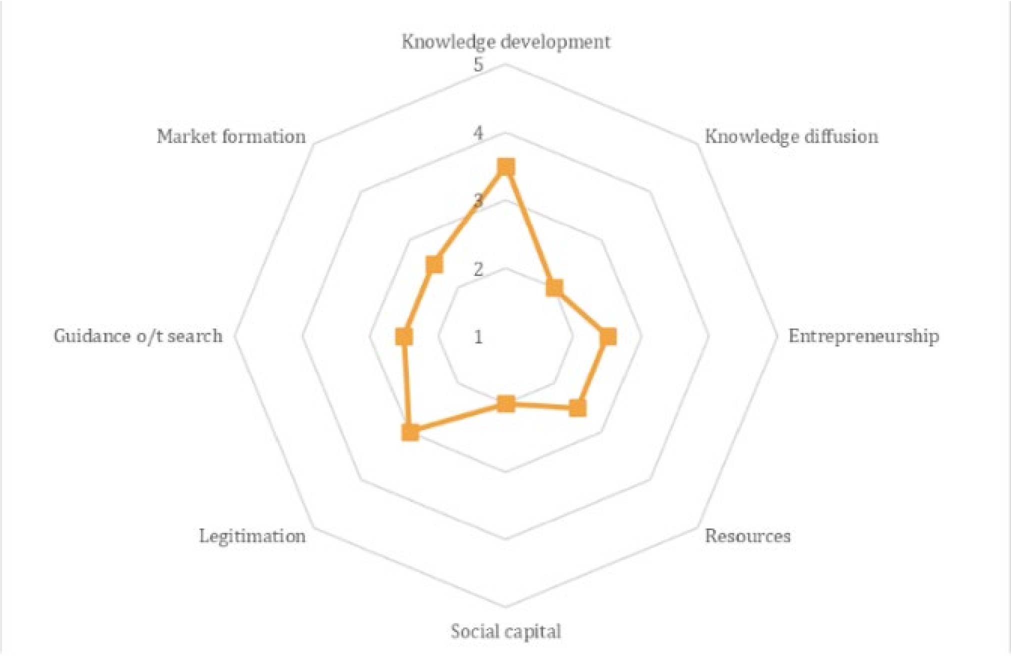


Figure 6 Results of the fulfilment assessment of the TIS functions. Numbers indicate the degree of fulfilment: 1 – absent; 2 – weak; 3 – moderate; 4 – strong; 5 – excellent.

Sweden – mostly harmless

- 86 page IEA report about the state of PV in 2021
- 3.2.5 BIPV development measures: There were no specific BIPV measures in Sweden in 2021
- Appartment complex Uppsala
- Demand is not a barrier

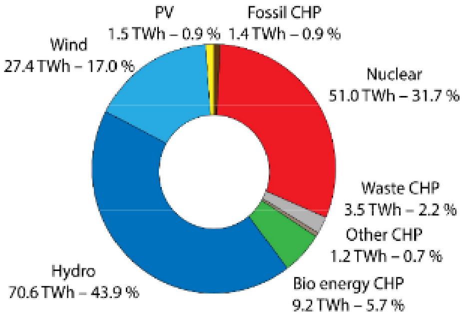
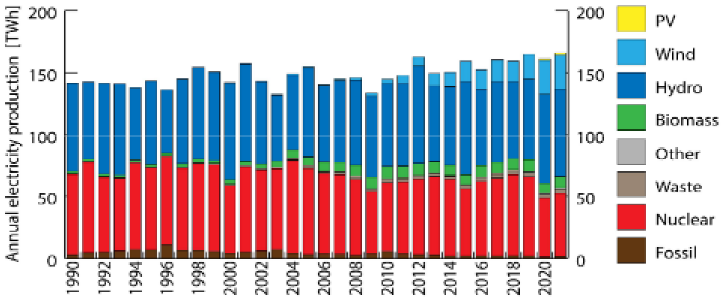


Figure 7. Total electricity production in Sweden in 2021.



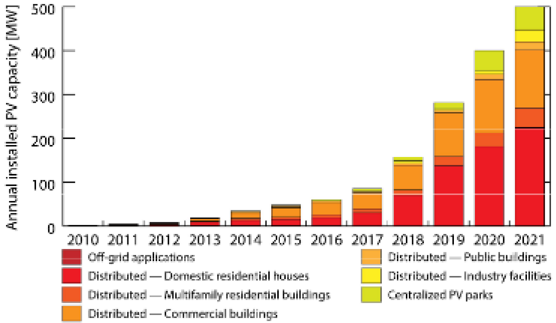


Figure 1: Annual installed PV capacity in Sweden

What do we know now? Discuss

- No market has solved all the barriers identified at these workshops
- Hard problem to accelerate niche product to mainstream, things that are easier to imagine
  - Incentives (e.g. Tax rebate) reduces cost for early adopters
  - Demonstration projects and field tests give real world data and validate software tools to give planners more confidence
  - Work on standardization to increase potential for interoperability
- Things that are more like fantasies
  - Growing a company from making 20 to 2000 projects a year
  - Removing inertia in a conservative building industry (humans in general)

IEA PVPS Task 15 review

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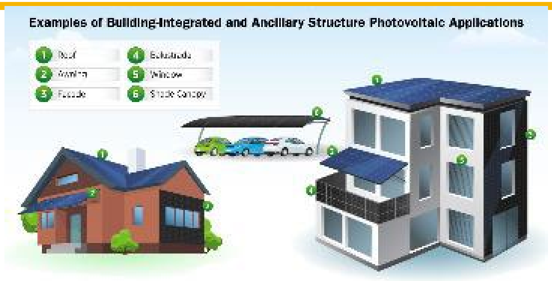
Enabling Framework for the Development of BIPV

- The International Energy Agency started PVPS task 15 in 2016 and has studied a lot of topics identified as important in the DOE RFI
  - Phase I (16-19) Project database, business models, international specifications, environmental benefits, demonstration
  - Phase II (20-23) Tech innovation system analysis, cross-section analysis – lessons learned, BIPV guidelines, digitalization, characterization methods
  - Phase III (24-27) Scope in development, life-cycle analysis and recycling of components
- Great collection of public reports: https://iea-pvps.org/research-tasks/enabling-framework-for-the-development-of-bipv/



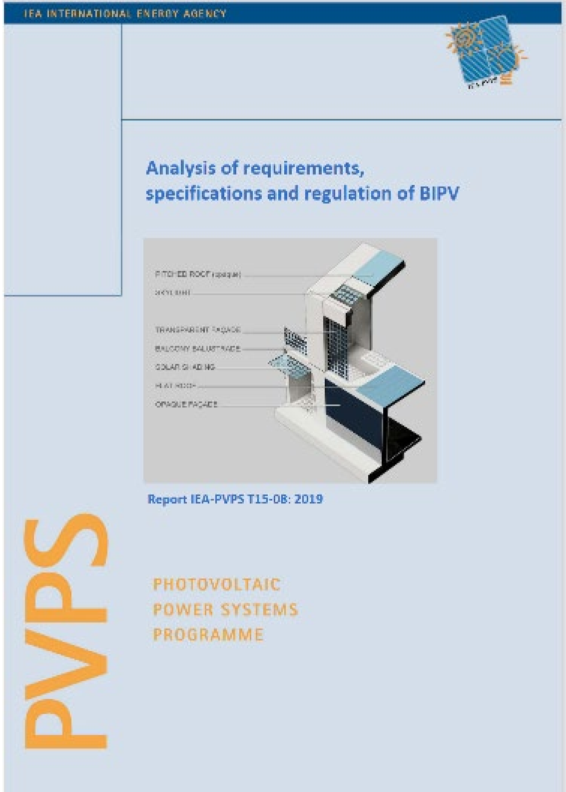
Credit: DOE DE-FOA-0002685 RFI

International standards

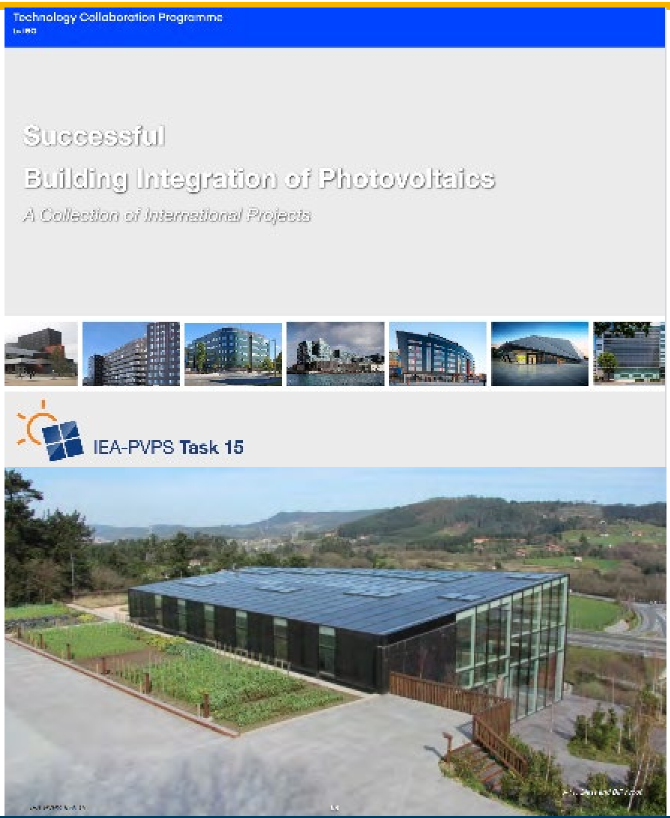
- Inherent challenge for products that do two things
- IEC 63092-1 Photovoltaics in buildings – Part 1: Requirements for building-integrated photovoltaic modules
  - More focused on what than how unless another standard exists
  - Extensive list of normative references
  - Mechanical durability, fire safety, hygiene, accessibility, noise protection, energy economy/insulation, sustainability
- IEC 63092-2 Photovoltaics in buildings – Part 2: Requirements for building-integrated photovoltaic systems
  - Annex on wind driven rain testing
- EN 50583-1 Photovoltaics in buildings - Part 1: BIPV modules
- EN 50583-2 Photovoltaics in buildings - Part 2: BIPV systems

How to avoid reinventing the wheel?

- A commonly recurring phrase is the need to adhere to local codes. True in the US between states, EU between members, and internationally
- IEA report matrixed standards and tried to index which where overlapping or not, as well as if they were mandatory, useful for design or useful for characterization
- Do these standards need to provide more guidance on where to find those local regulations?
- Would an online repository be useful or get outdated too quick?



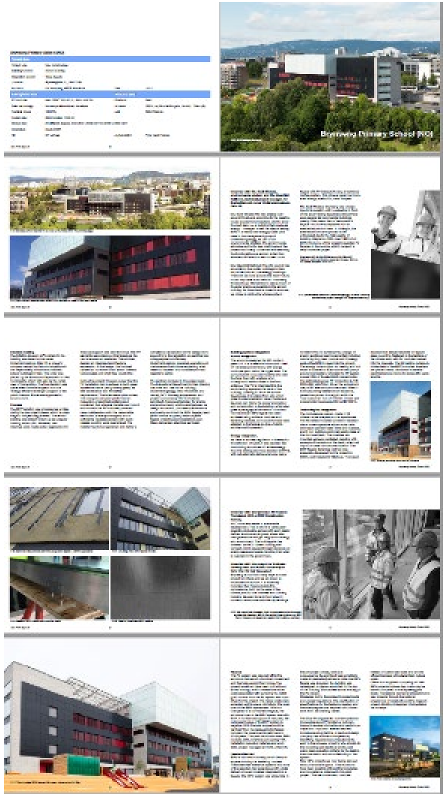
Demonstrations



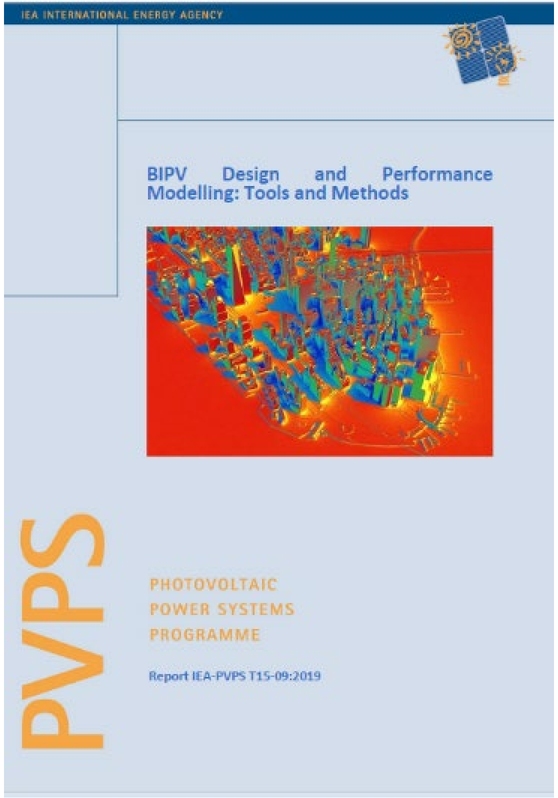
- Every workshop has listed the need for more demonstration projects and validations
- How can it be made sure demonstrations are collected and added to a database of examples?
- What is the half-life of a document like this?
- Nice with a standard format

Demonstration template

- Project type detailing new construction or retrofit and building type
- BIPV details on what product was used
- Decision making and process highlighting challenges and aesthetics
- Building Integration
- Interviews with architect, construction company, and owner
- Financing and lessons learned

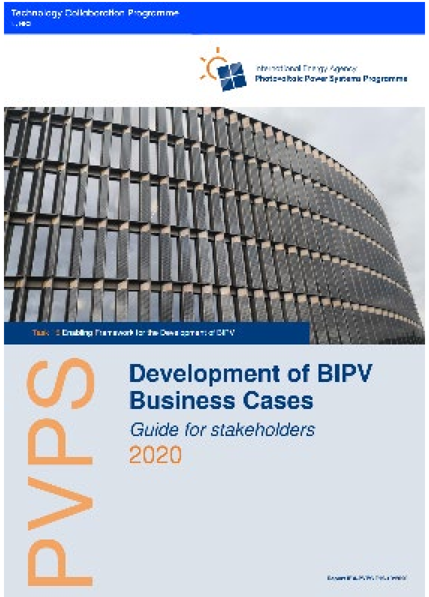


Software tools

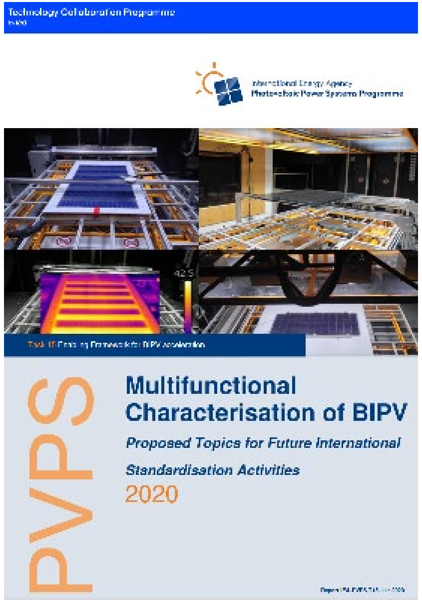


- Do we need more than SAM and EnergyPlus?
- A reference counted 200 design tools the report drills down to 40 of the most popular
- 15 domains including geophysical, economical, technical, and environmental
- Different problems solved in different tools

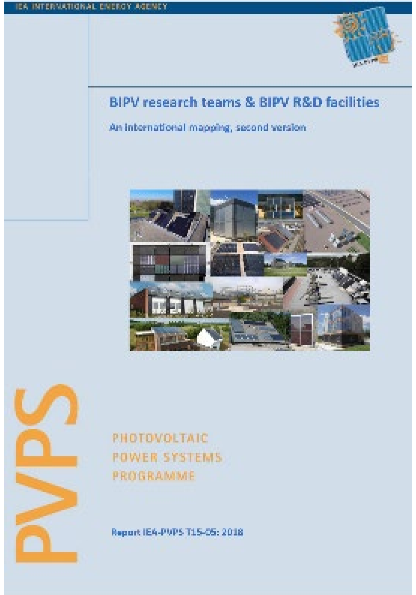
More reports



Going beyond kWh and payback time



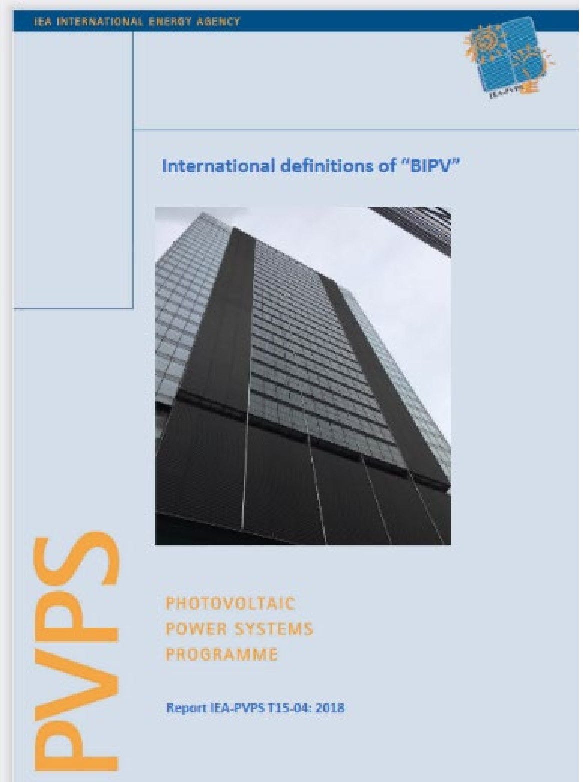
Suggest modification of existing tests to accommodate BIPV



Find collaborators or contact experts

US involvement in Phase III?

- Set the scope
- Increase manufacturer influence
- Improve collaboration on simulation tools
- Life-cycle analysis and maintenance issues
- Typical IEA setup: In person meeting every 6 months, 3rd day workshop. ~60 people in the room and more online.



Monitoring BIPV Durability and Reliability

- Imaging techniques

Mengjie Li

Florida Solar Energy Center, UCF

Resilient, Intelligent and Sustainable Energy Systems (RISES) Cluster, UCF

Department of Materials Science and Engineering, UCF

Overview

- [00:00 - 00:30] Introduction
- [00:30 - 05:00] What is BIPV Resilience and Why it's Important
- [05:00 - 12:00] Imaging Techniques
- [12:00 - 15:00] Discussion: Challenges and Opportunities

What is BIPV resilience, reliability and durability

Energy Resilience ⇄ BIPV Resilience

Extreme weather scenario

- BIPV can improve community energy resilience, by providing power, particularly during the response and recovery period
- Challenge of severe weather
  - Wind
  - Hail
  - Hurricane
  - Fire
  - Heavy snow
  - Cold & Heat shock

Normal weather scenario

- BIPV modules – only effective when deployed in direct sunlight
- Inherently harsh service environment
  - Damaging solar radiation (especially UV)
  - Heat
  - Humidity
  - Biological factors (mildew, algae, bird's dropping...)
  - Mechanical factors (sand abrasion, hail ...)

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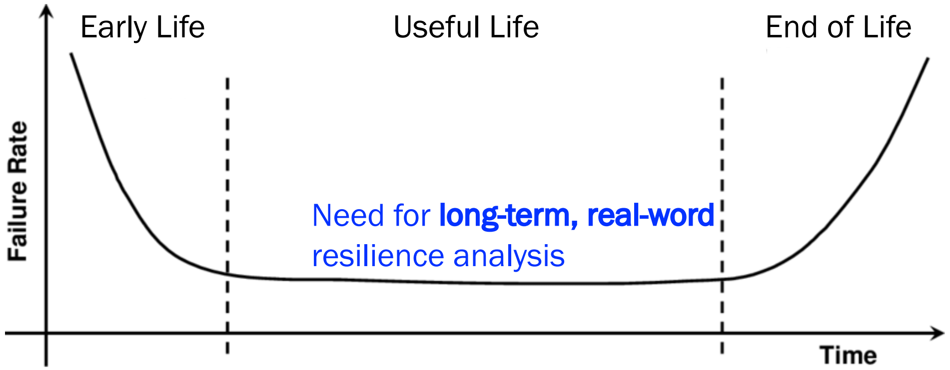
What is BIPV resilience analysis

Combining **long-term field inspection** and **lab degradation characterizations** to perform a multi-scale **qualitative** and **quantitative** analysis to understand the BIPV behavior (degradation pathway) as both a **building material** and **PV system**



BIPV vs. BAPV vs. BIPVT ⇄ PV

Least integrated (Open rack-mounted PV) | **More integrated** (Close roof rack-mounted PV) | **Fully integrated** (Direct-mounted BIPV, multifunctional)

Detect

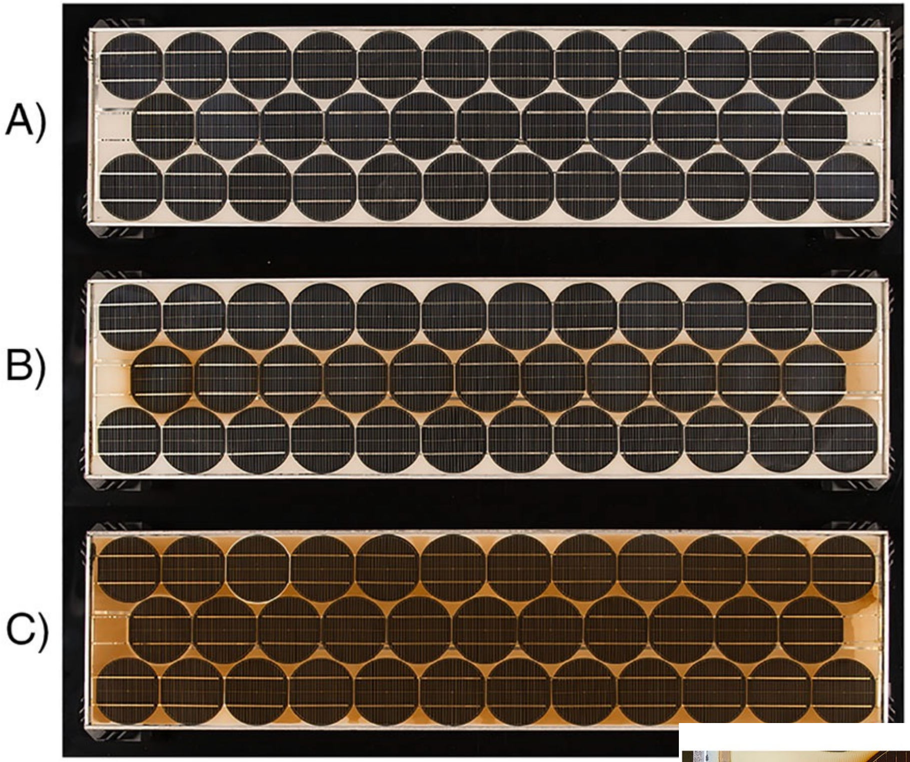
Understanding the **root cause** of different failure mode

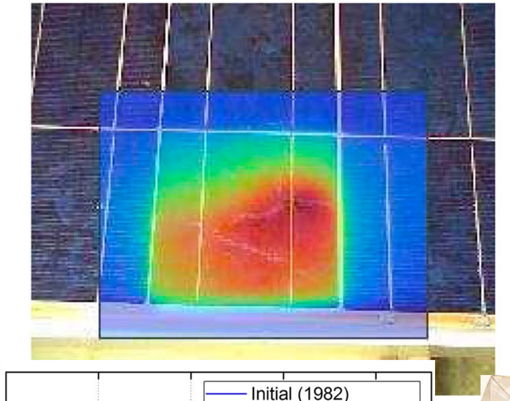
Understanding the different **degradation pathway**

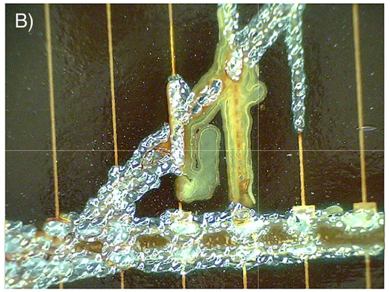
Predict ↔ Improve

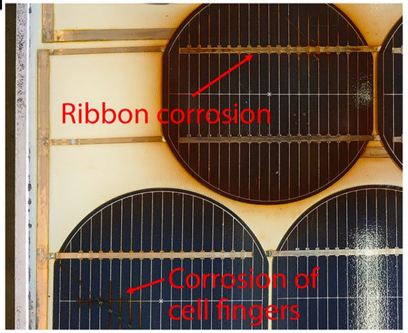
Improving **accuracy** of energy yield prediction, degradation rate calculation and provide input for techno-economic analysis, ultimately **de-risk** the investment and support **market growth**

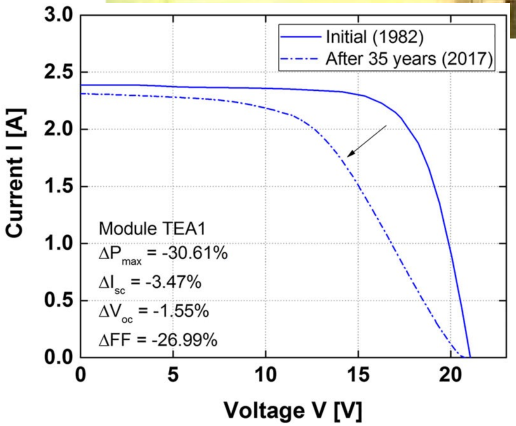
PV product field degradation

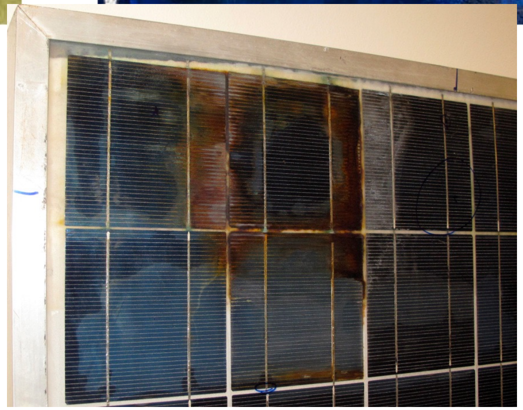










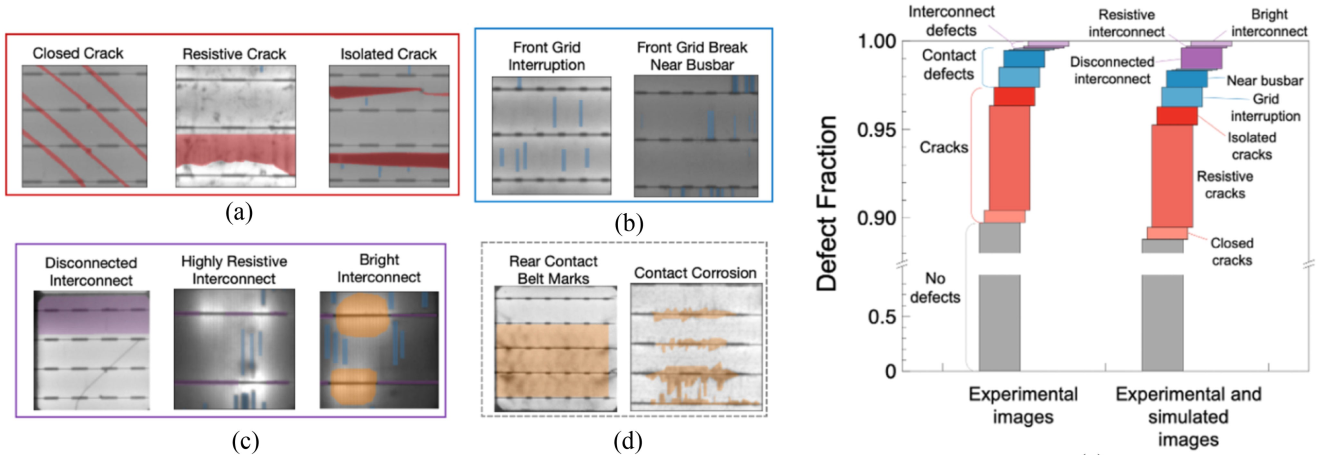


Annigoni et al. "35 years of photovoltaics Analysis of the TISO-10", progress in photovoltaics, DOI: 10.1002/pip.3146, 2019
Davis et al. "Multi-pronged analysis of degradation rates of photovoltaic modules and arrays deployed in Florida", Progress in photovoltaics, DOI: 10.1002/pip.2154, 2013

Imaging Techniques

What information we can get from images?

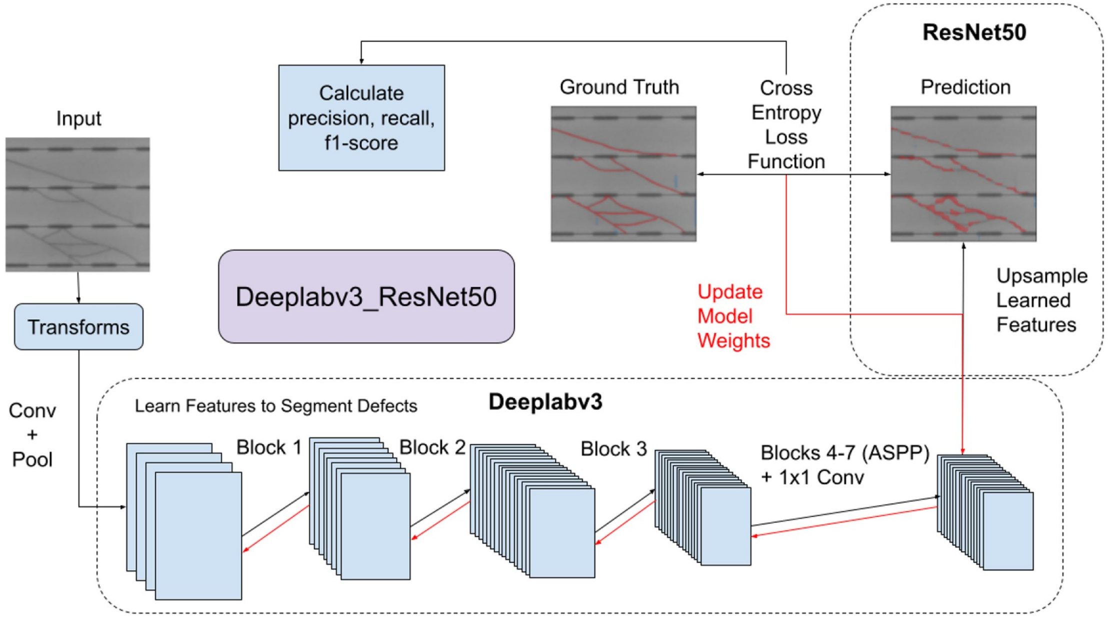
Degradation Analysis – EL imaging



(a) (b) (c) (d) (e)

Automatic defect detection using semantic segmentation

- Input of module EL images
- Indexing each individual cells within the module
- Output percentage of cells with certain type of defect



Defect	Modules with Defect	Percent of Total
Backsheet bubbling	2	1.3
Front delamination	156	100
Backsheet burn marks	10	6.4
Backsheet bumps	27	17.3
ARC corrosion	80	51.3
Snail trails	30	19.2

J. Fioresi, D. Colvin, R. Frota, R. Gupta, **M. Li**, H. Seigneur, S. Vyas, M. Shah, K. O. Davis, "Automated Defect Detection and Localization in Photovoltaic Cells using Semantic Segmentation of Electroluminescence Images",*IEEE Journal of Photovoltaics*, vol. 12, issue 1, pp. 53-61, 2021.

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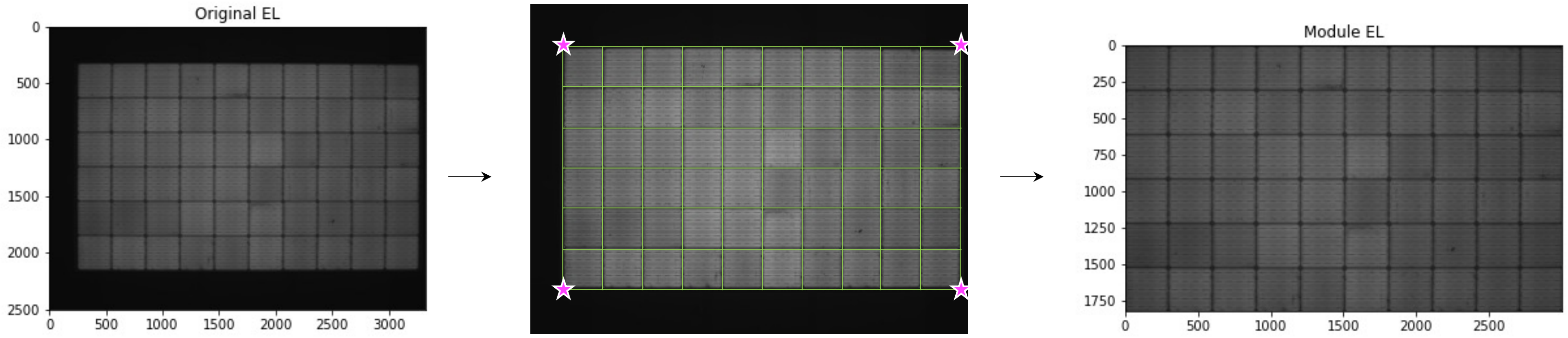
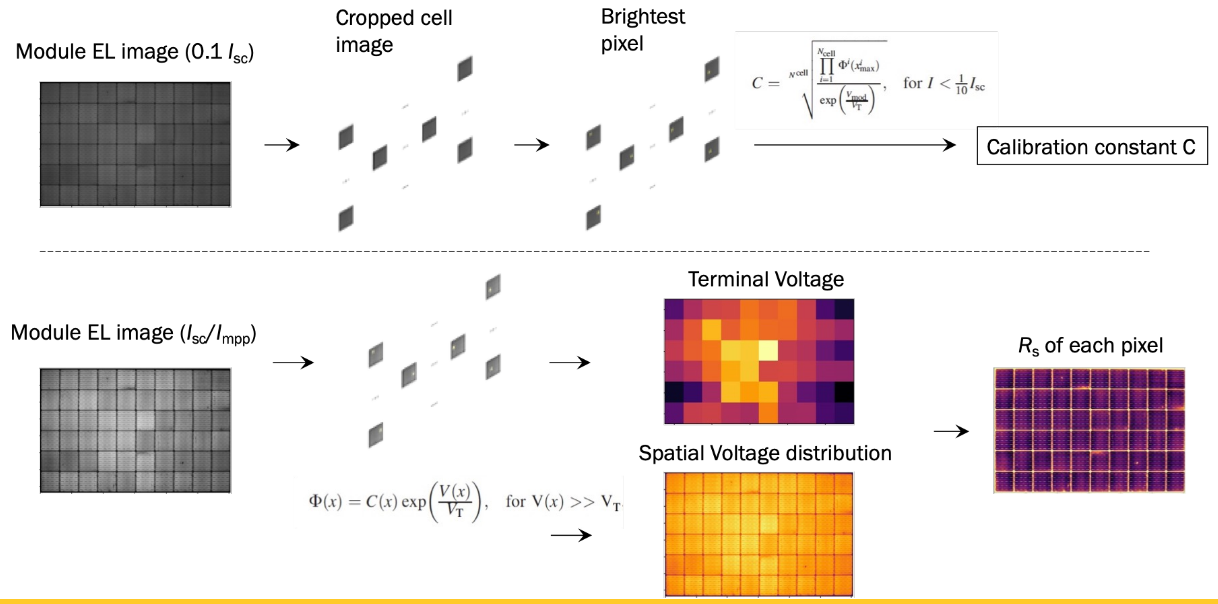
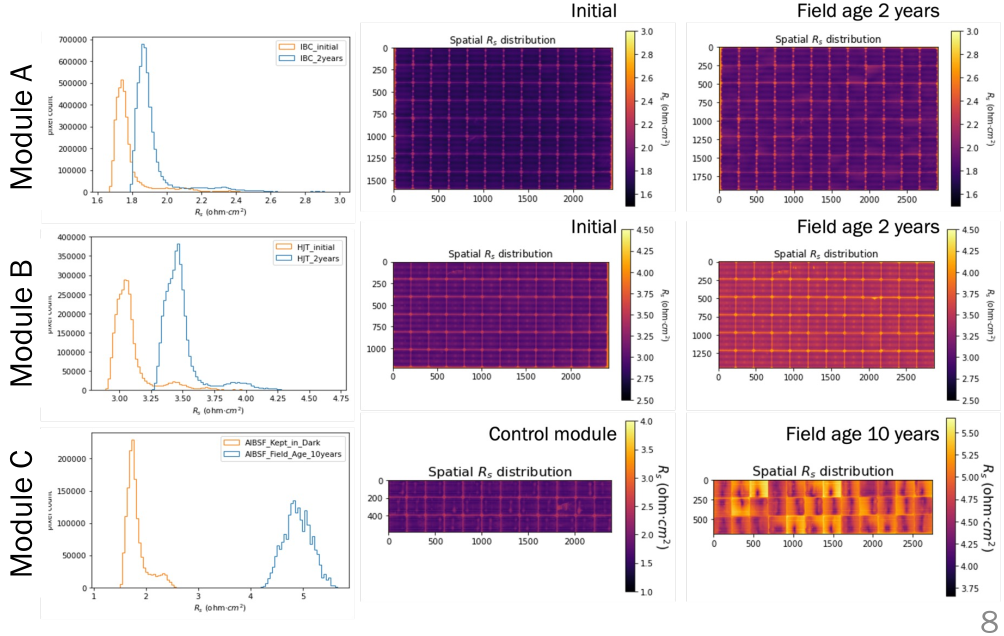
Degradation Analysis – EL imaging

Streamline series resistance imaging

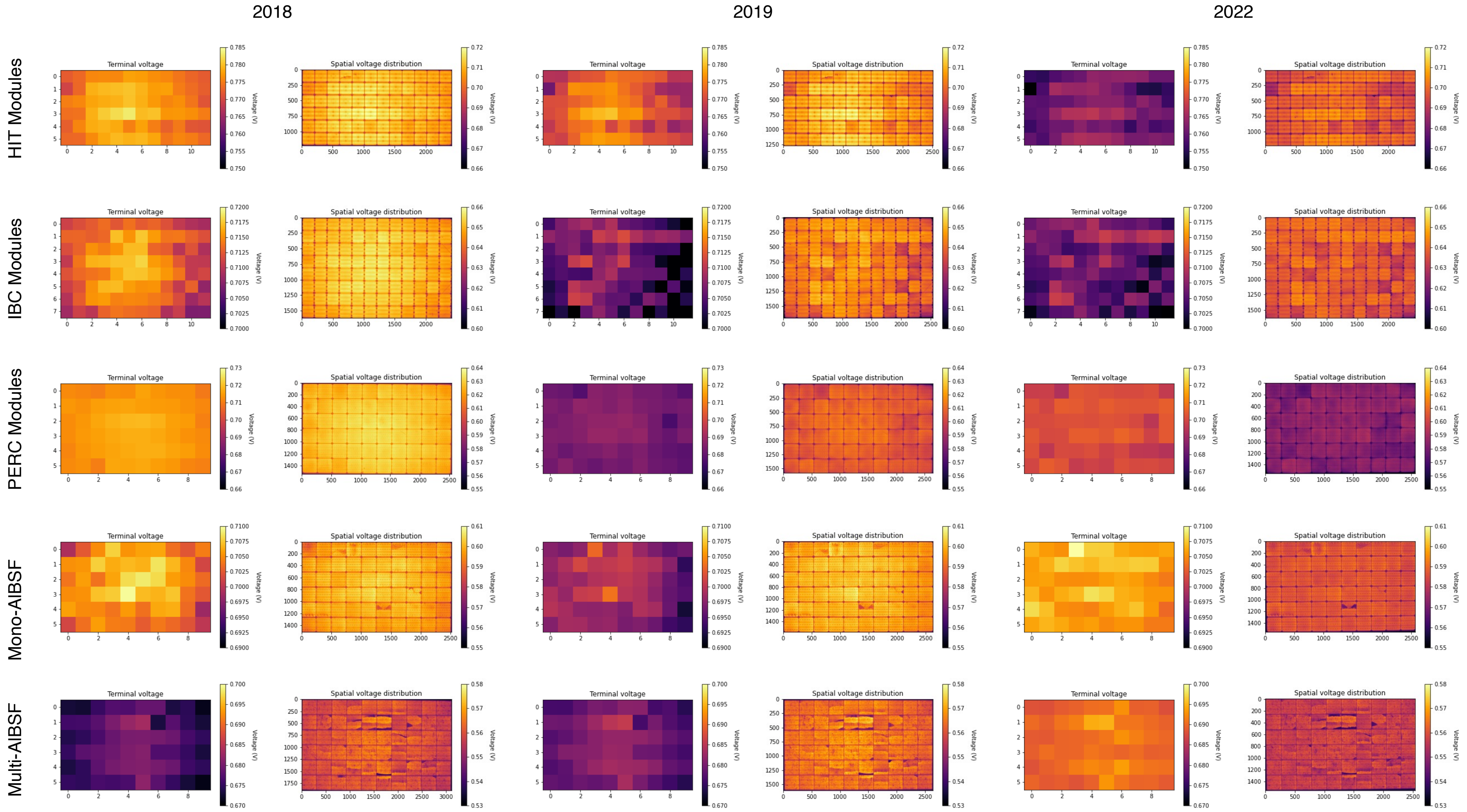
- Input of minimum of 2 EL images
- Automatically calculate terminal voltage and spatial voltage distribution at pixel level
- Output module R_s images





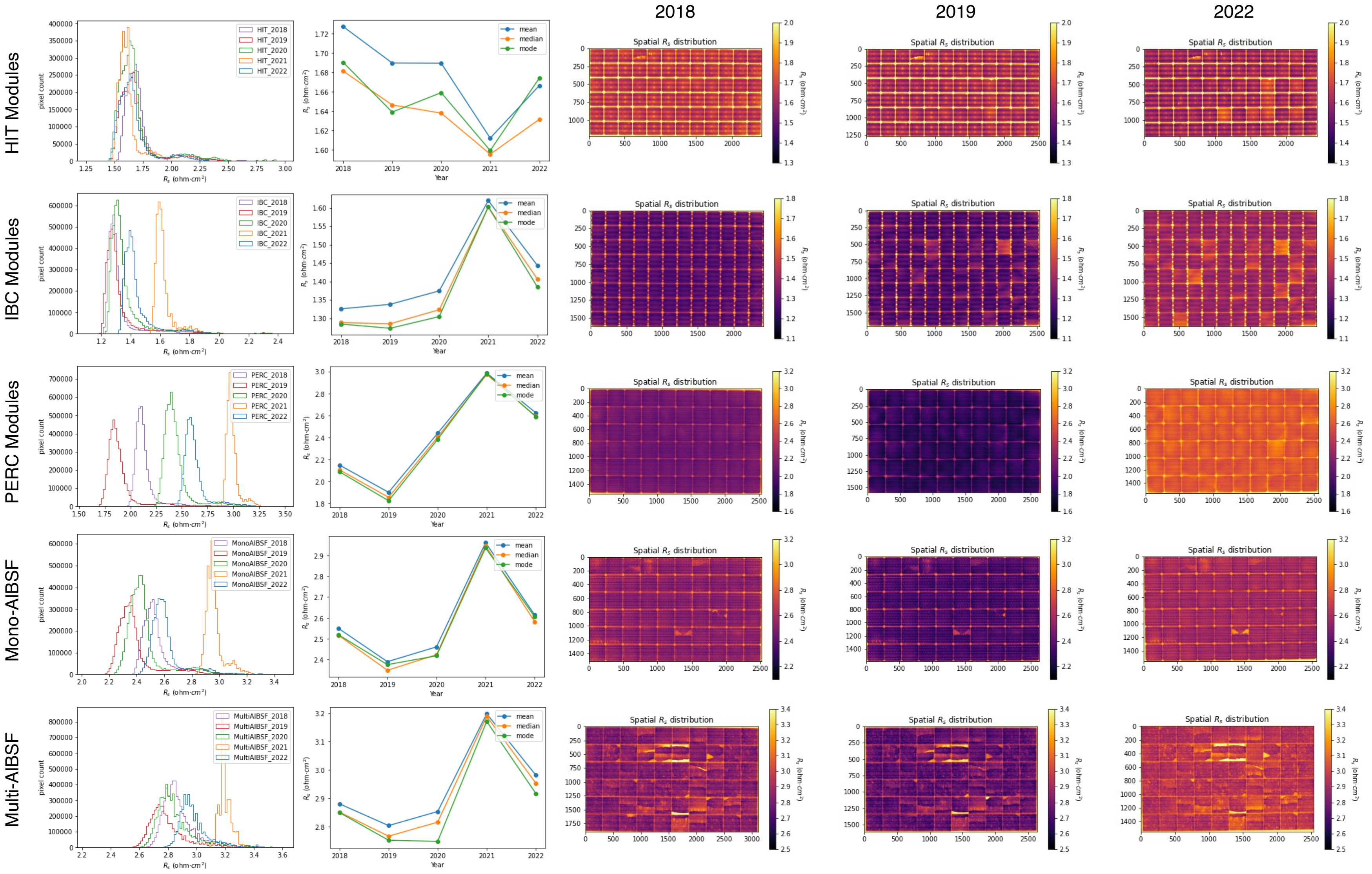


Degradation Analysis – EL imaging



https://github.com/ucf-photovoltaics/PVRs

Degradation Analysis – EL imaging

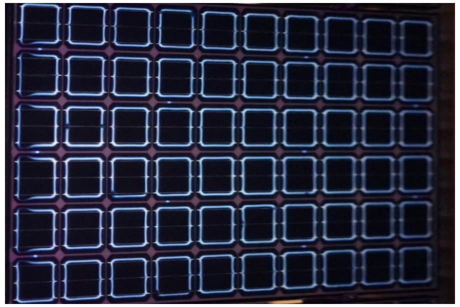


https://github.com/ucf-photovoltaics/PVRs

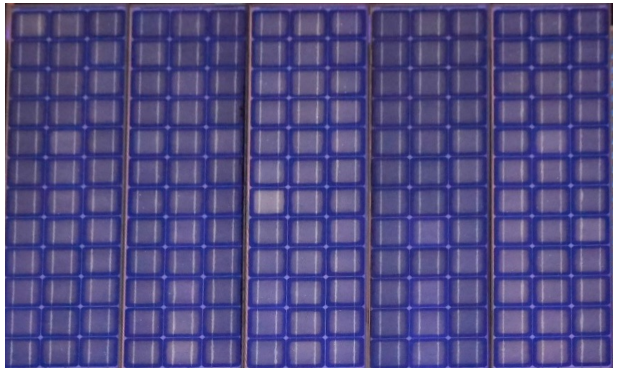
Degradation Analysis – UVF imaging

Mono AlBSF, System age = 4 years

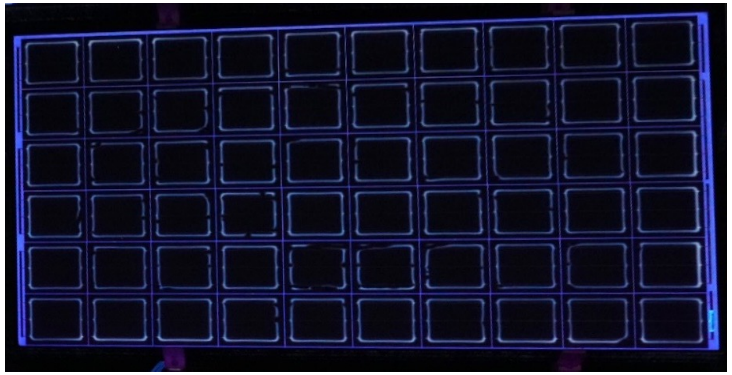
Mono AlBSF, System age = 10 years



Mono AlBSF, System age = 20 years

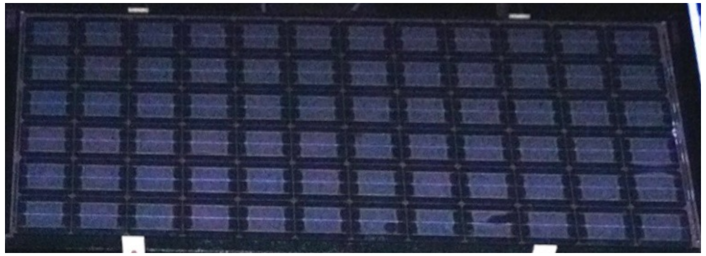


Multi AlBSF, System age = 4 years

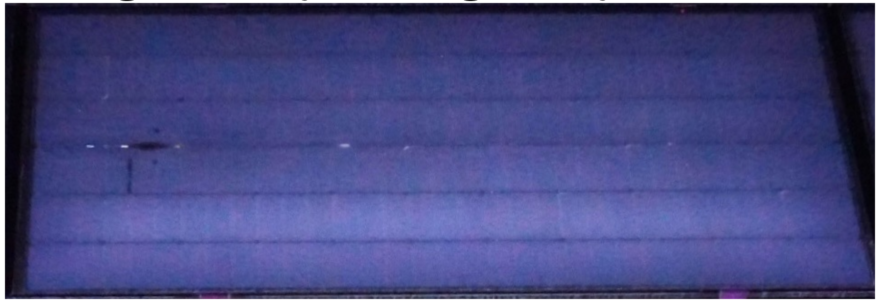


Mono PERC, System age = 4 years

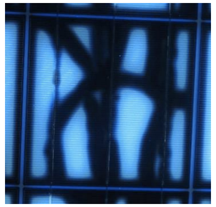
HIT, System age = 4 years



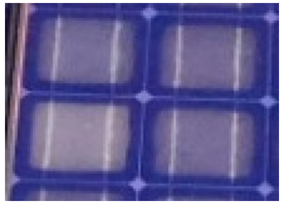
Shingle HIT, System age = 6 years



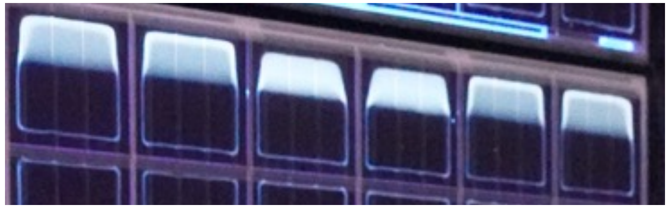
- Cracks



- Hot cells



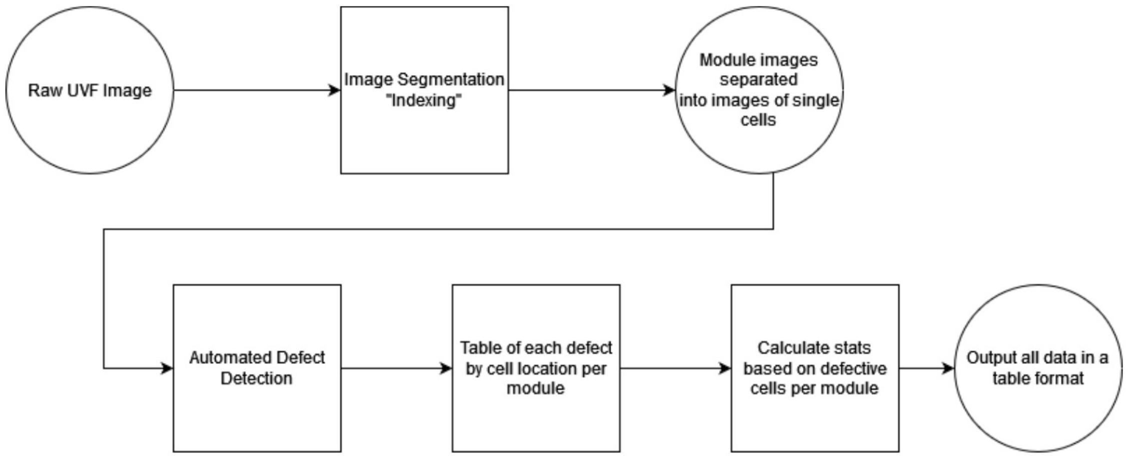
- Different BOM

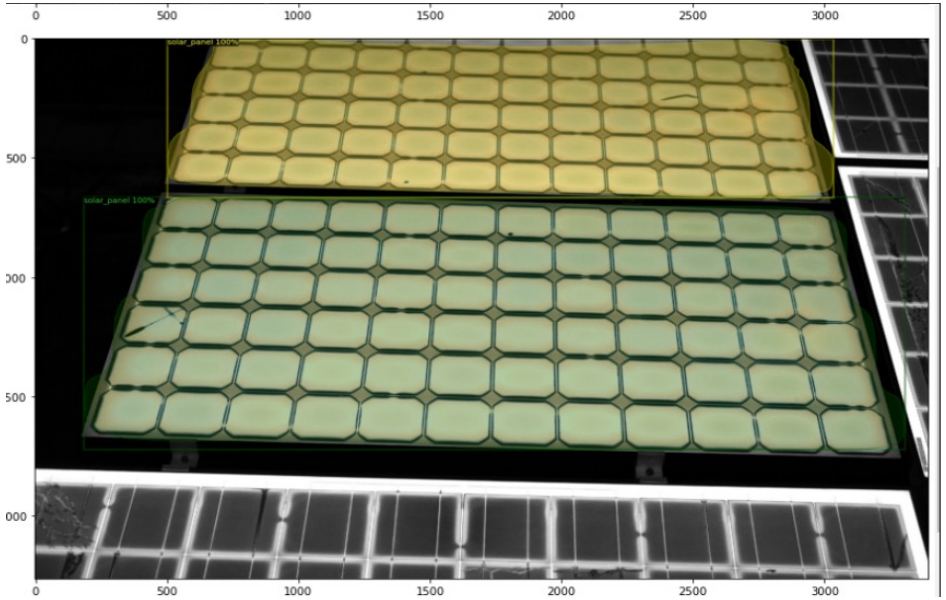


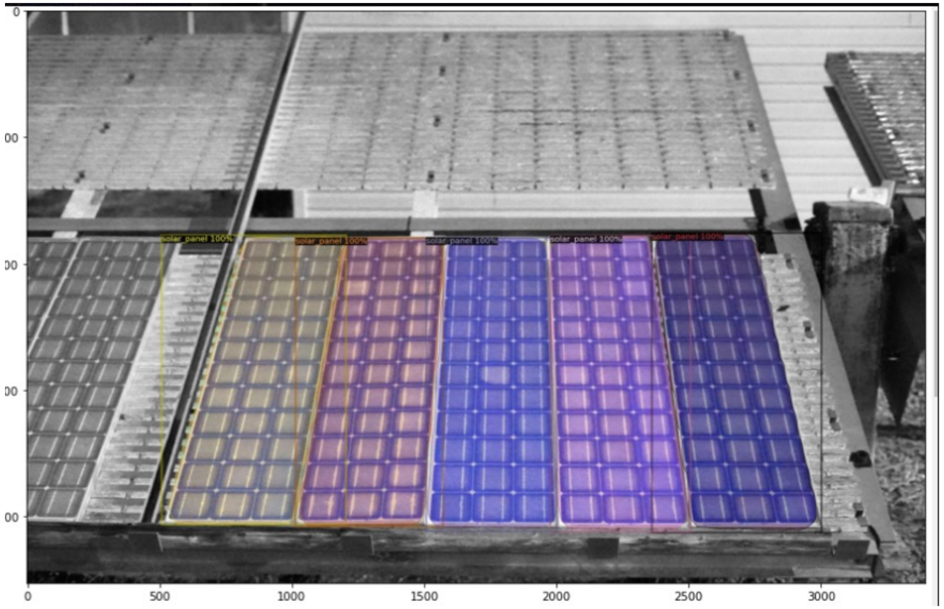
Degradation Analysis – UVF imaging

Automatic module detection and indexing

- Building PV degradation ontology model
- Automatically link IV, EL, UVF to specific module under investigation
- Statistical analysis of PV module degradation behavior







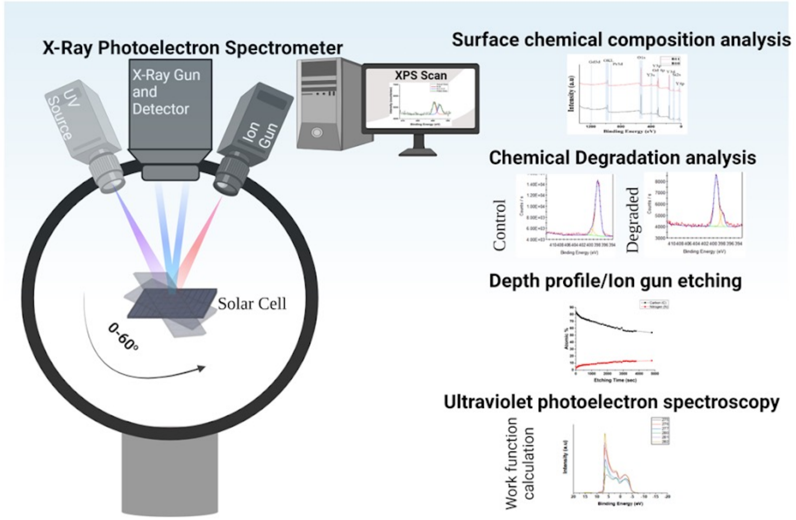
Degradation Analysis – Materials Characterization

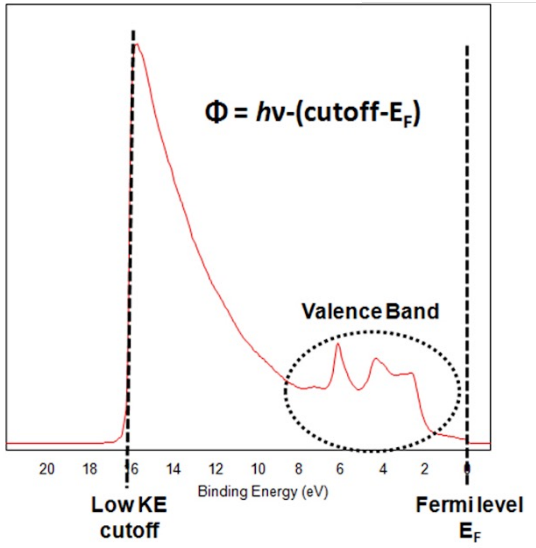
Cored out sample

Front

Back

XPS

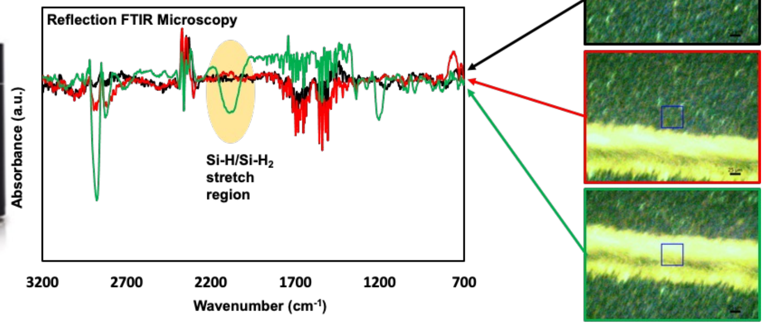




Objective-Determine degradation processes as work function changes

Methods-XPS surface analysis, XPS etching and UPS analysis

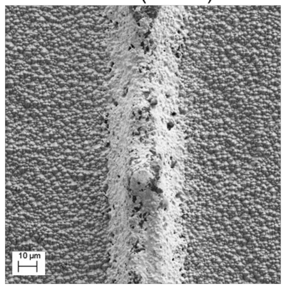
FTIR



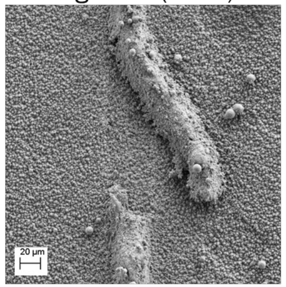
The Shimadzu AIM-9000 Infrared Microscope system

SEM

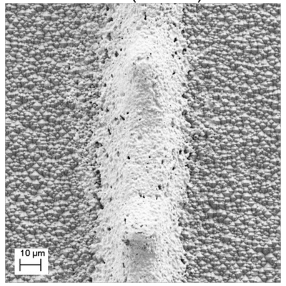
G1 Control (Front)



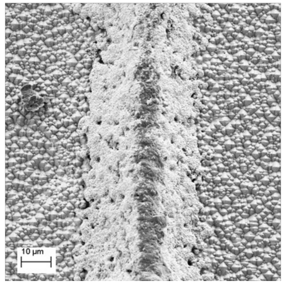
G1 Degraded (Front)



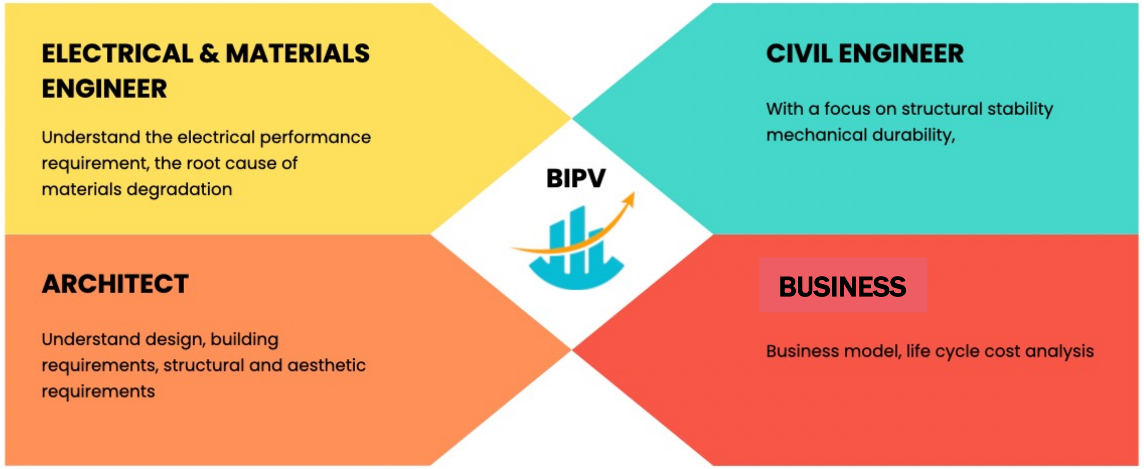
G2 Control (Front)



G2 Degraded (Front)



Challenges and Opportunities



- Challenges with performance monitoring in a building integrated/applied scenario
- Understanding root cause vs. global degradation rate estimation
- Challenge with long-term field testing

Thanks! Questions?

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Funding

SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

Award number: DE-EE-0009347
DE-EE-0008155

UCF

RENOVEERIMISMARATON

En-ActivETICS

OPEN LAB

DRIVE

European perspectives regarding BIPV

energy performance, technical solutions, building physics, circularity

Targo Kalamees,

Tallinn University of Technology, Estonia

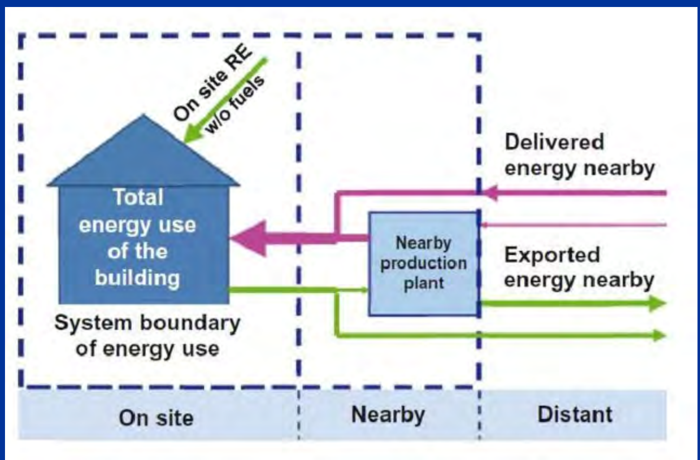
Thanks to Martin Talvik (TalTech), Roofit, Solarstone, Naps Solar, Go Vertic, Timbeco

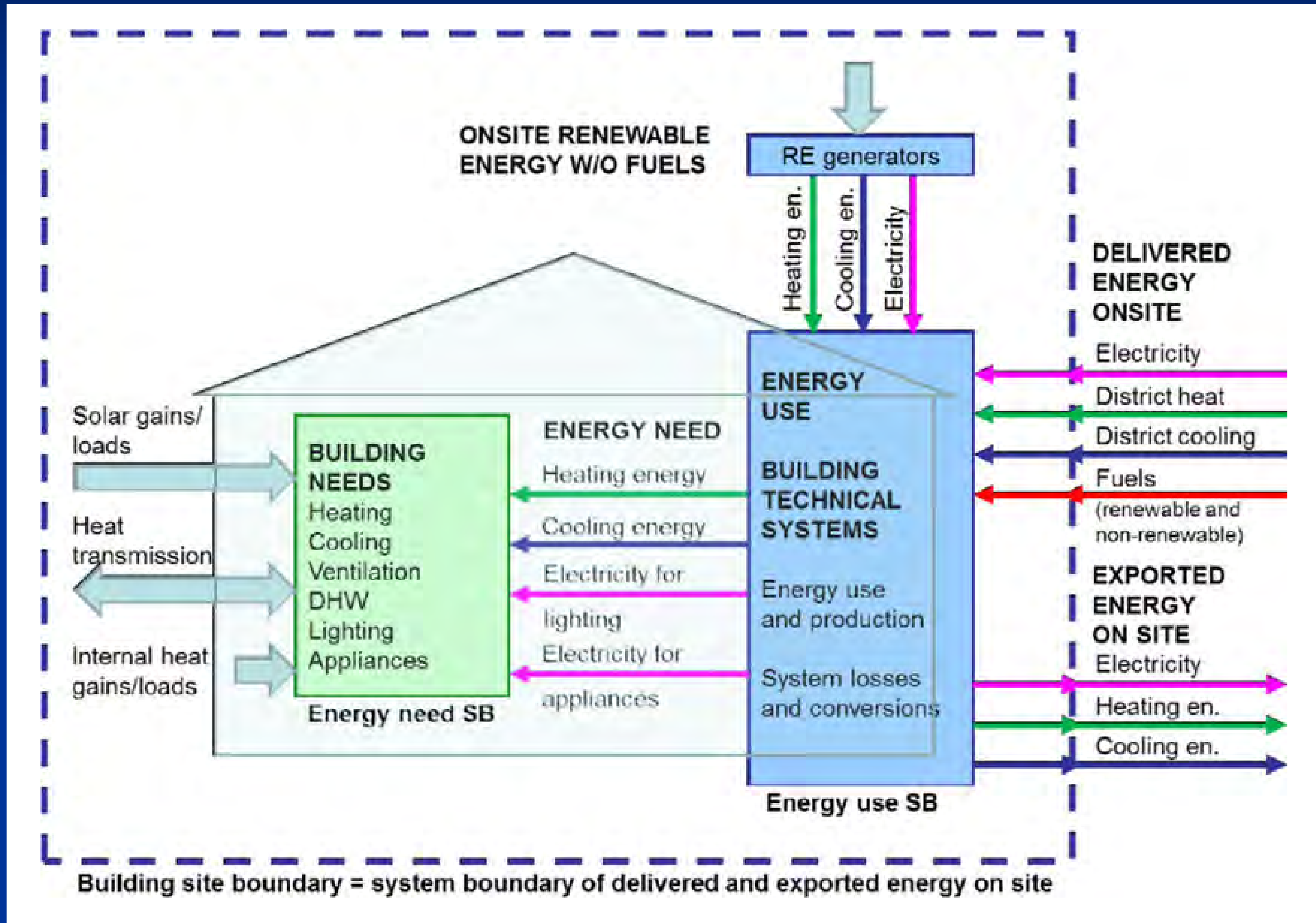
Targo Kalamees

- 2009, Professor of Building Physics at Tallinn University of Technology, Estonia
- 2006, PhD “Hygrothermal criteria for design and simulation of buildings”
- Nearly Zero Energy Buildings research group
  - Staff: 39 persons
    - 3 (4) professor, 15 senior researchers (PhD)
    - 11 early stage researchers (PhD candidates)
  - Research topics:
    - Building physics
    - Energy performance of buildings
    - Indoor climate
    - Building services
    - Renovation of buildings
    - Some architectural elements like acoustics, solar shading, and daylight

Energy performance of buildings

- Buildings need
- Energy need
- Energy use
- Delivered energy
- Heat loss and gains
- Onsite renewable energy w/o fuels
- Energy export





Energy performance indicator, kWh/(m²·a)

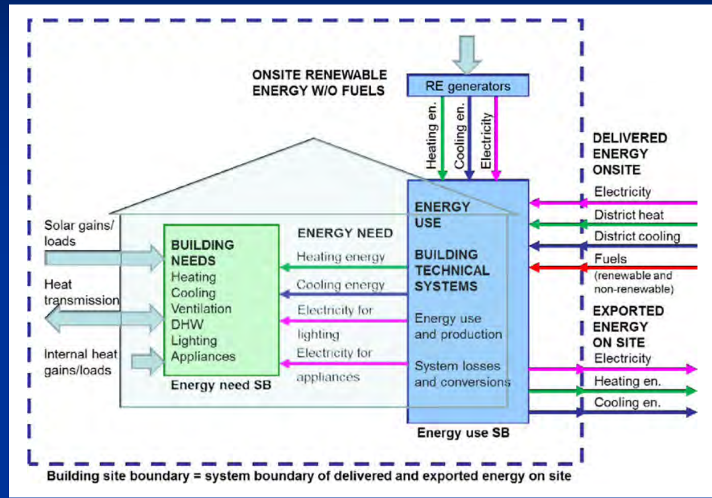
- EPBD → primary energy use, kWh/(m²·a)
  - Heating
  - Cooling
  - Ventilation
  - Domestic hot water
  - Appliances
  - Lighting
  - Service systems

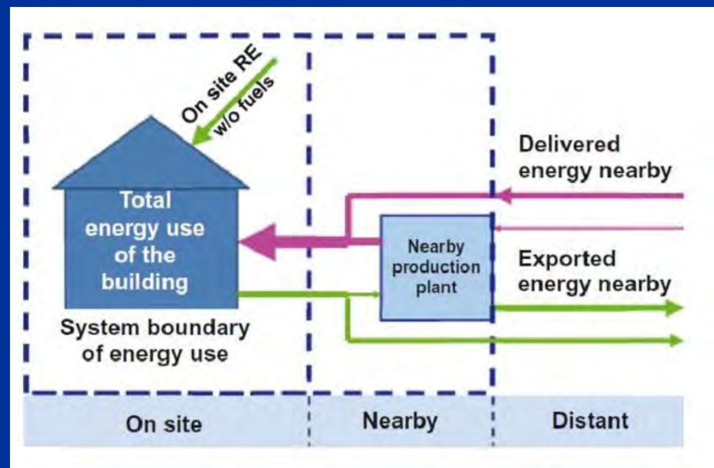
Heat

Electricity

$$EPI = \frac{\sum_i (Q_i \cdot f_i)}{A_{net}}$$

Energy carrier	PE factors, -			
	EC	DK	EE	FI
Electricity	2.3	1.9	2.0	1.2
District heating	1.3	0.85	0.65	0.5
Natural gas	1.1	1.0	1.0	1.0





Energy performance indicator, kWh/(m²·a)

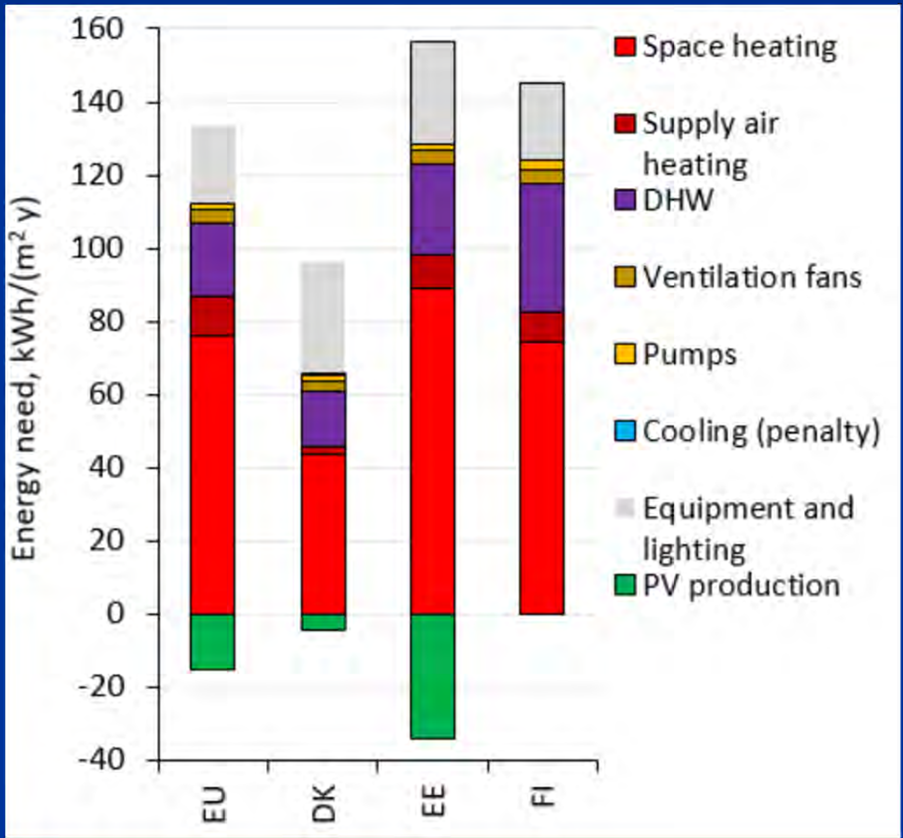
Building type	A (with PV) nZEB	B (w/o PV) LEB	C Major renovation	D	E
Detached house <120 m²	**145**	165	185		
Detached house 120–220 m²	**120**	140	160		
Detached house >220 m²	**100**	120	140		
Apartment building	**105**	125	150		
Office building	**100**	130			
Hotel	**145**	170			
School	**100**	120			
Kindergarten	**100**	120			
Hospital	**100**	130			

Building code requirement for new building **in Estonia:**

- EPC ”B” ≤ without **PV**
- EPC ”A” ≤ with **PV**

A comparative analysis of nZEB requirements

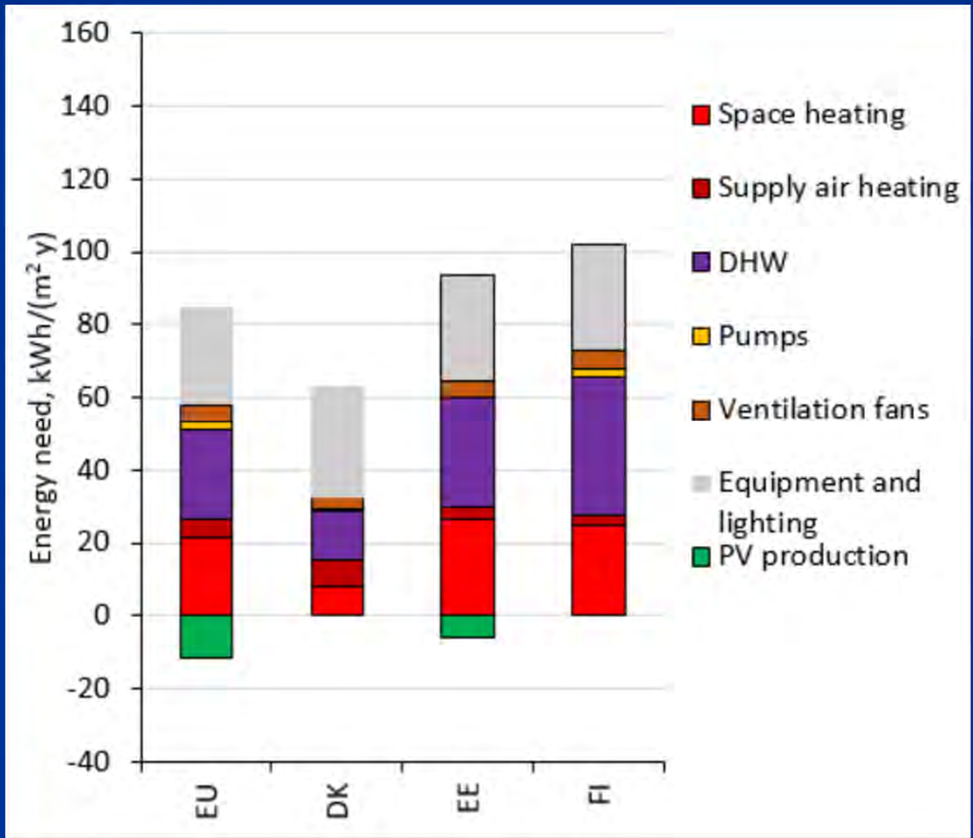
- Detached house



Simson et.al 2021

A comparative analysis of nZEB requirements

- Apartment building

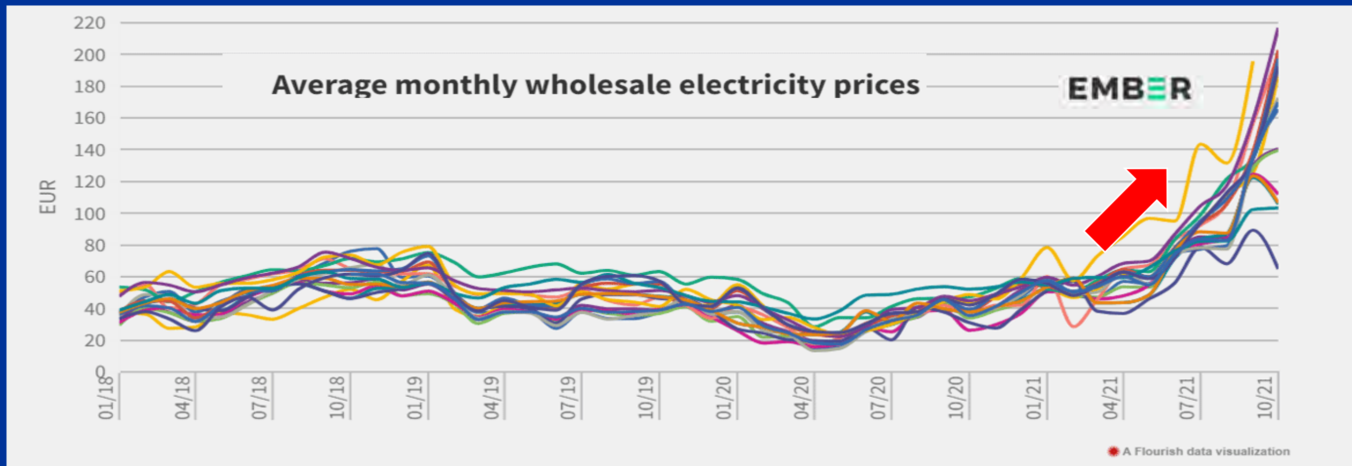


Electricity use in standard conditions

Building type	Use time h/24h	Use time d/7d	Use rate	Lighting W/m²	Appliances W/m²
Detached house <120 m²	24	7	0.6	6	3
Detached house 120–220 m²	24	7	0.6	6	2.4
Detached house >220 m²	24	7	0.6	6	2
Apartment building	24	7	0.6	8	3
Office building	11	5	0.55	10	12
Hotel	24	7	0.4	10	1
School	8	5	0.5	12	8
Kindergarten	12	5	0.4	12	4
Hospital	13	5	0.6	10	4

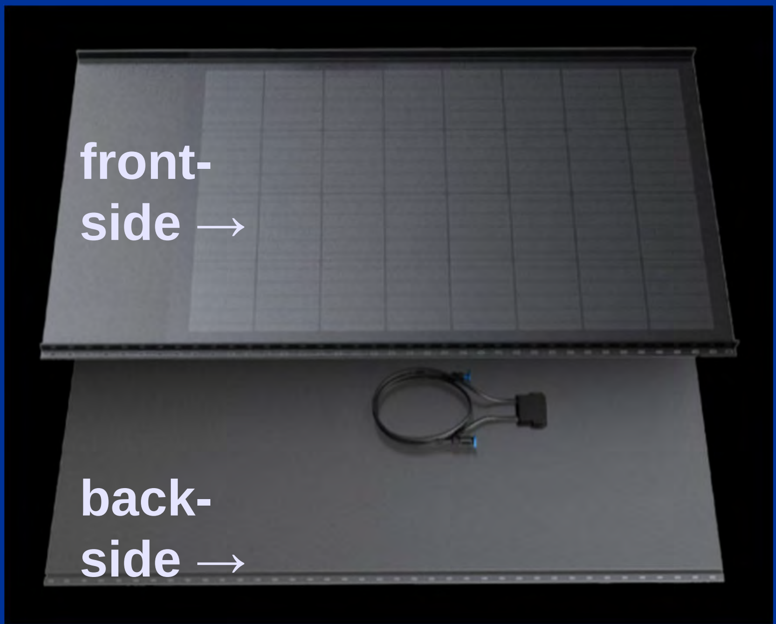
Need for PV

- **nZEB** means a building that has a very high energy performance.
  The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including RES on-site or nearby;
- Electricity price;
- Energy security;
- Energy resilience



Examples of BIPV

- **Roofit Solar**
  - Looks like a regular steel roof.
  - Suitable for historical and protected buildings.



Examples of BIPV

- **Roofit Solar**
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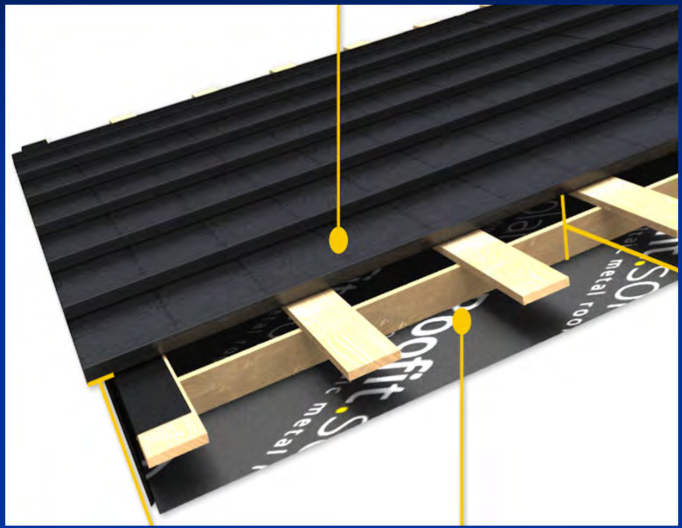
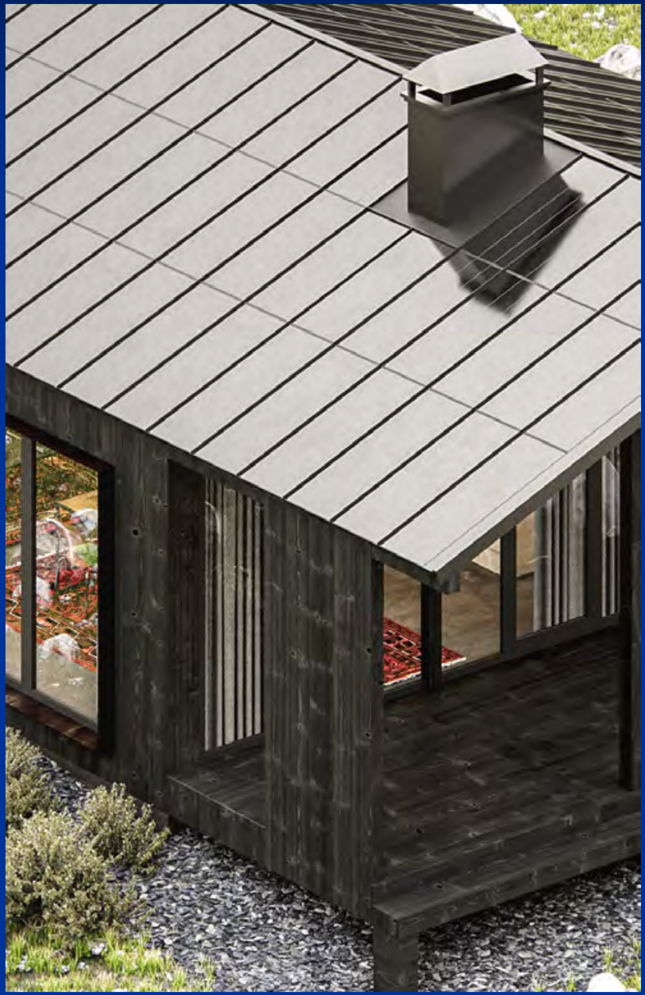
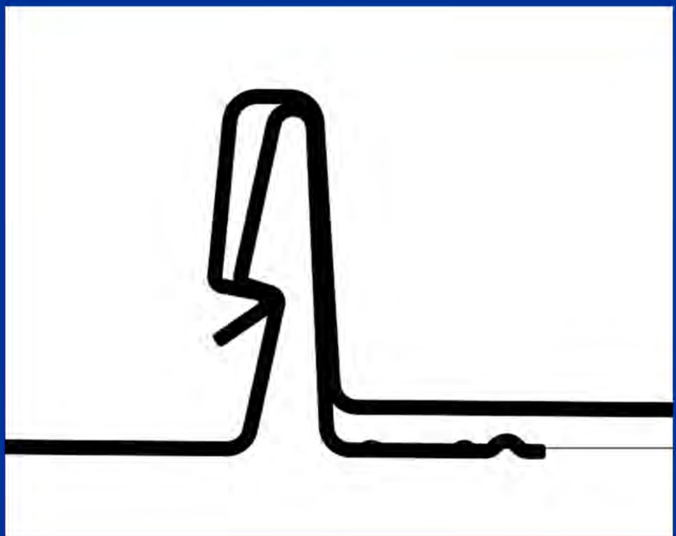




	Double Seam solar roof module	Click solar roof module
Rated power	110W / 135W / 160W	155W / 235W
Technology	Mono PERC	Mono PERC
Efficiency	150 W/m²	160 W/m²
Fire rating	Class A (Highest)	Class A (Highest)
Seaming	Double Seam	Click

Examples of BIPV

- **Roofit Solar**
  - Looks like a regular roof.
  - Suitable for historical and protected buildings.

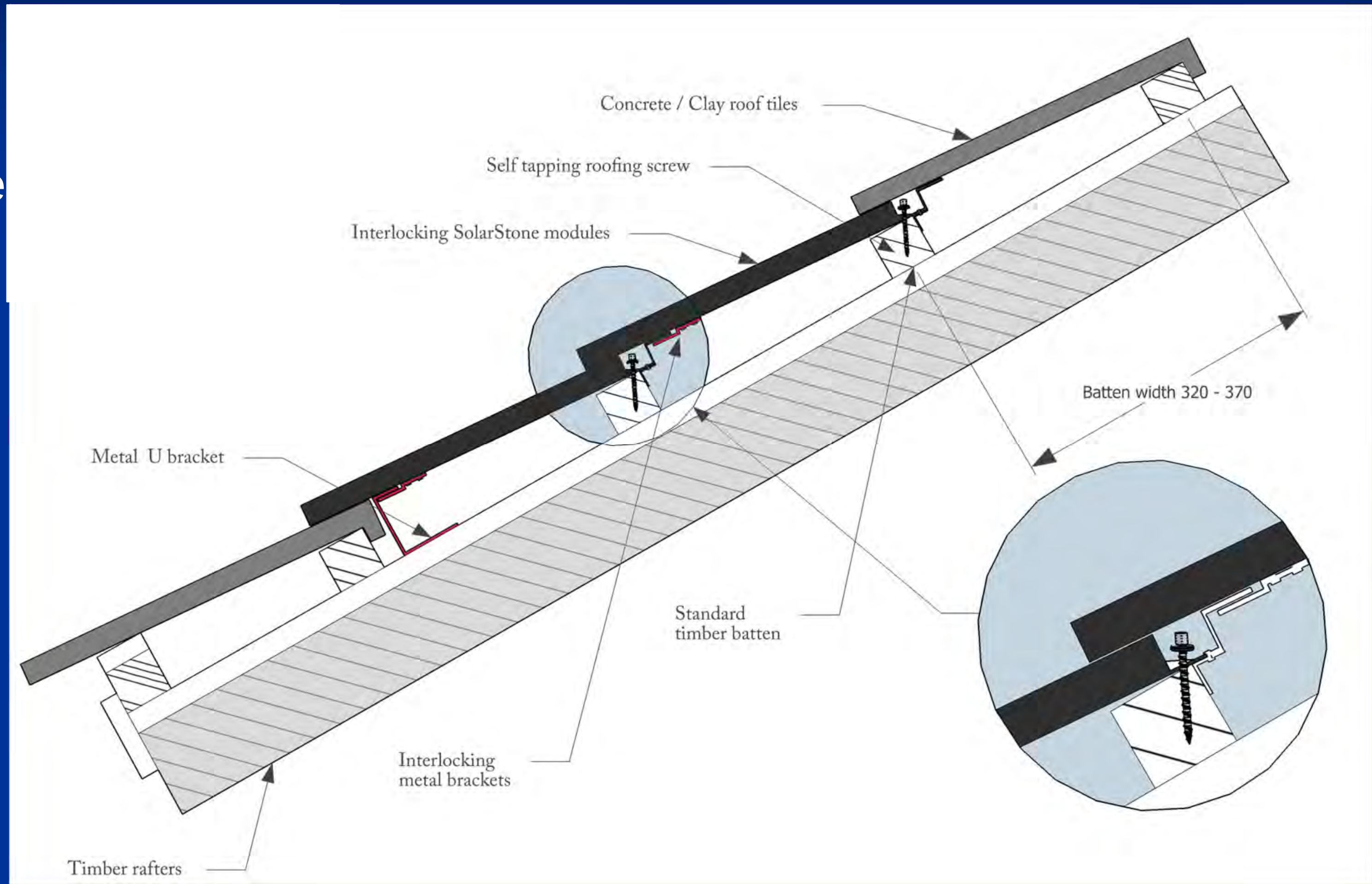


Examples of BIPV

- **SolarStone**
  - Solar Tiled Roof
  - Looks like a regular stone roof.

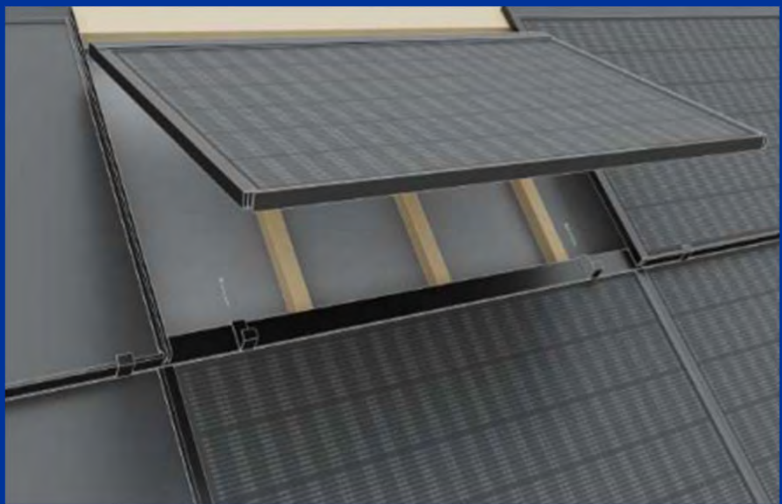
Examples of BIPV

- **SolarStone**
  - Solar Tiled Roof
  - Looks like a regular stone



Examples of BIPV

- **SolarStone**
  - Solar Full Roof

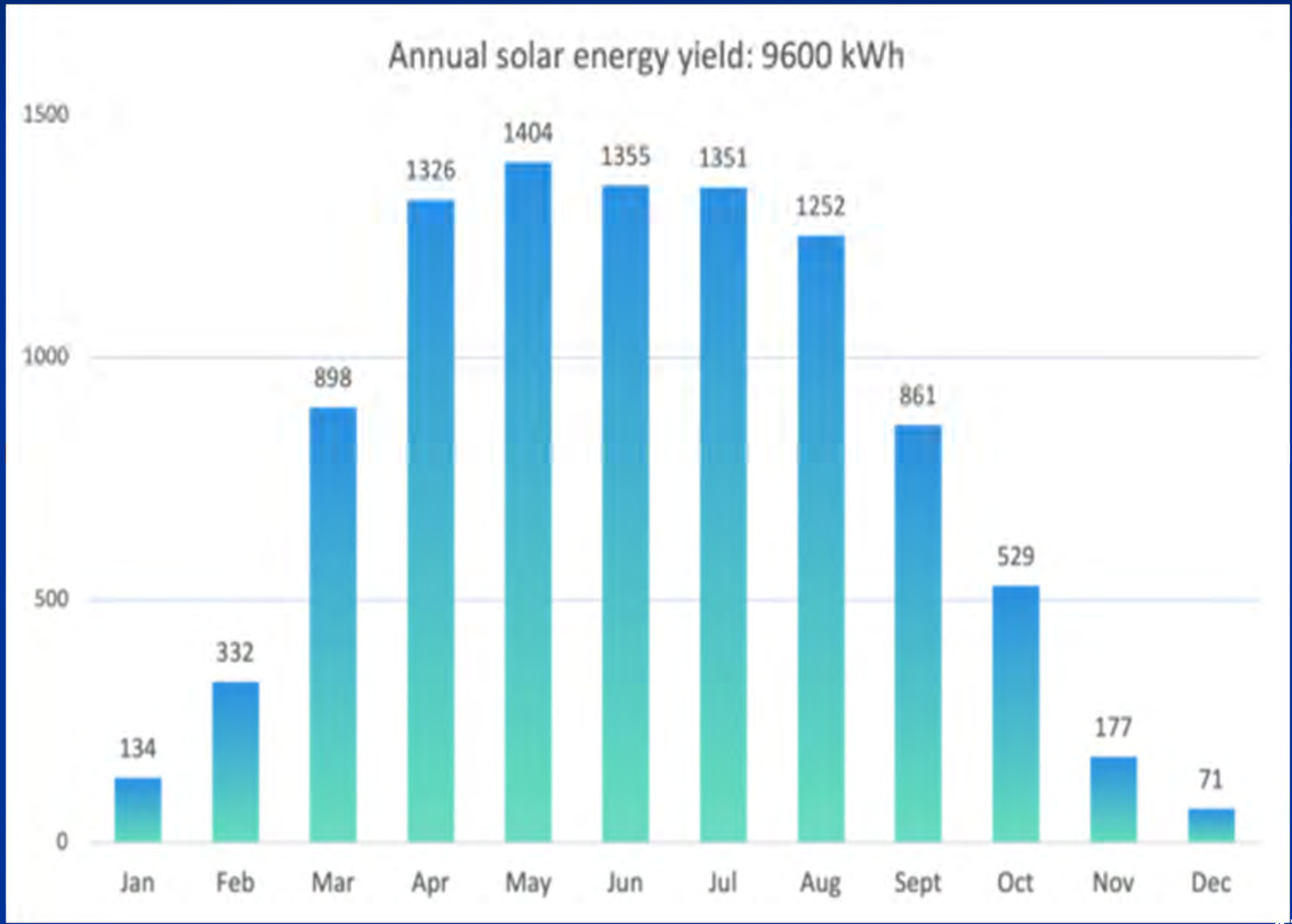


Examples of BIPV

- **SolarStone**
  - Solar Full Roof

Examples of BIPV

- **SolarStone**
  - 10.6 kWp roof
  - 9600 kWh per year (real data 2020)



Examples of BIPV

- **Go Vertic**
  - 850 € / kWp
  - 16 kg/m²

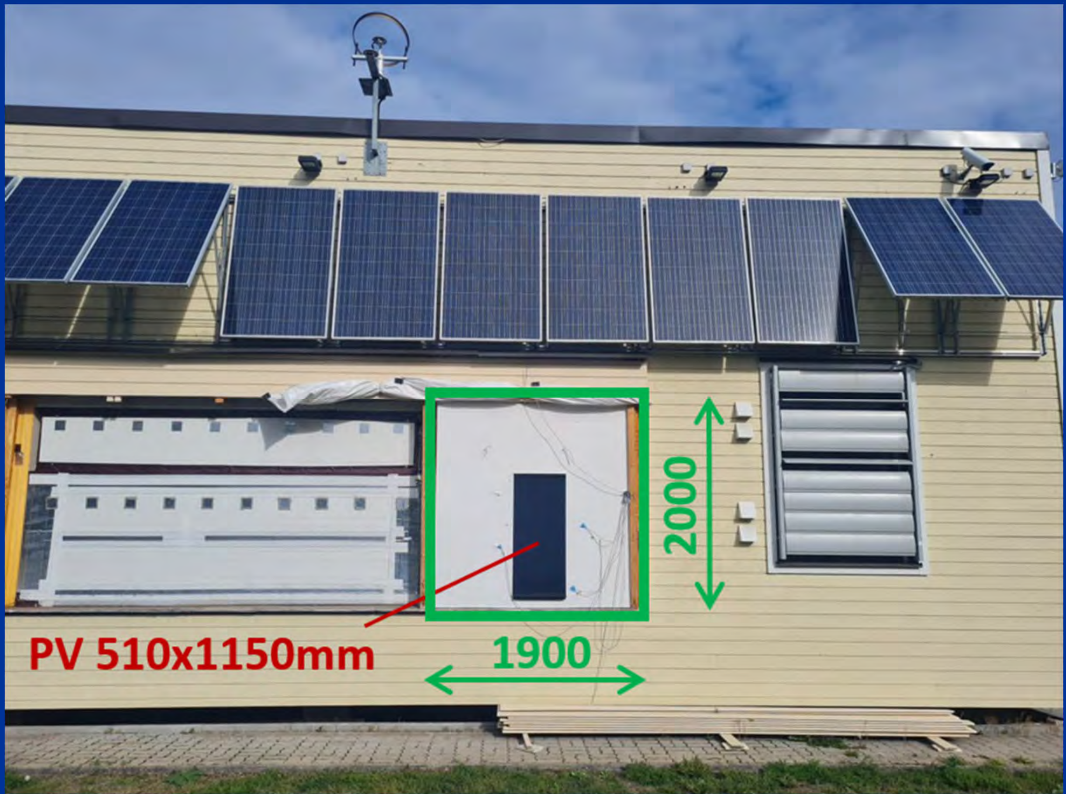
Examples of BIPV

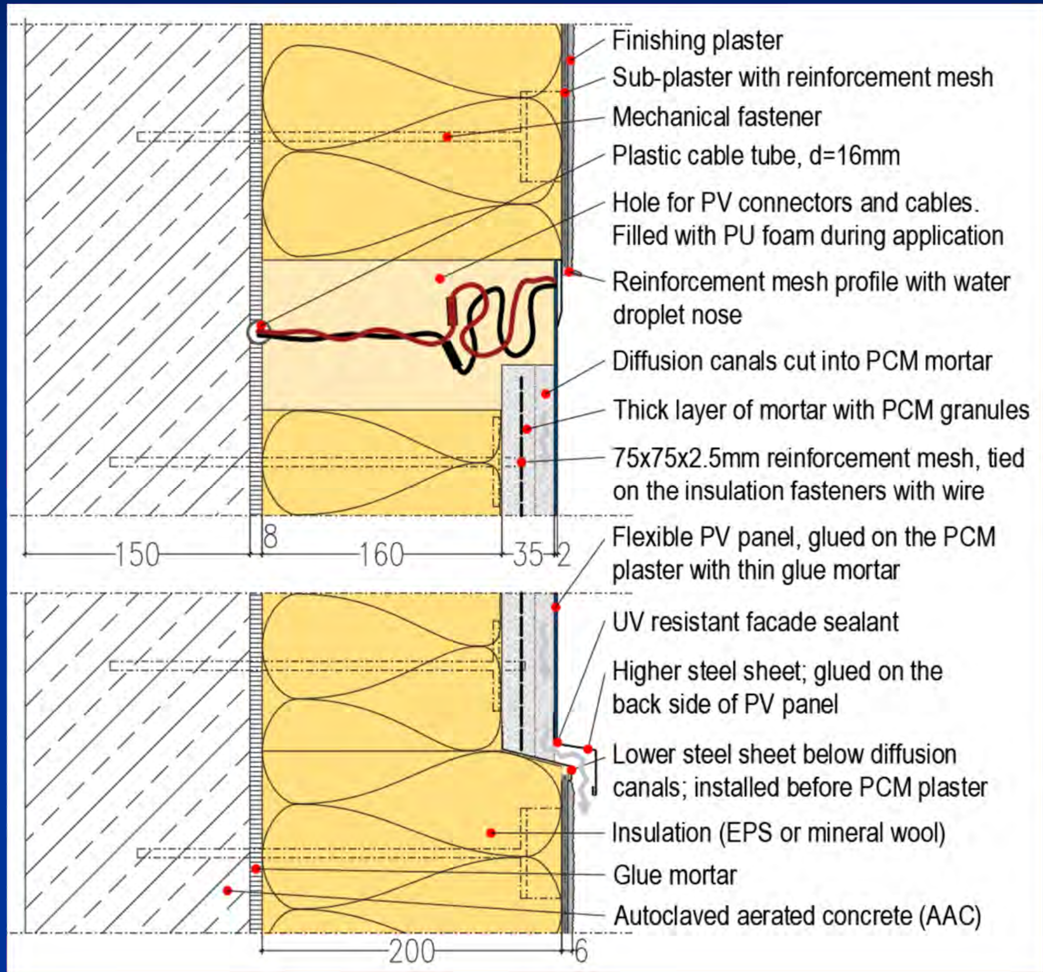
En-Activ ETICS

- **EnActive ETICS**
  - Energy activating traditional ETICS/EIFS with flexible PV panels and PCM
  - Both for renovation and new buildings
  - Overheating of PV panels
    - Using PCM for passive cooling
  - Vapor tight outer layer (flexible PV panel)
    - Diffusion channels for drying out excess moisture

Examples of BIPV

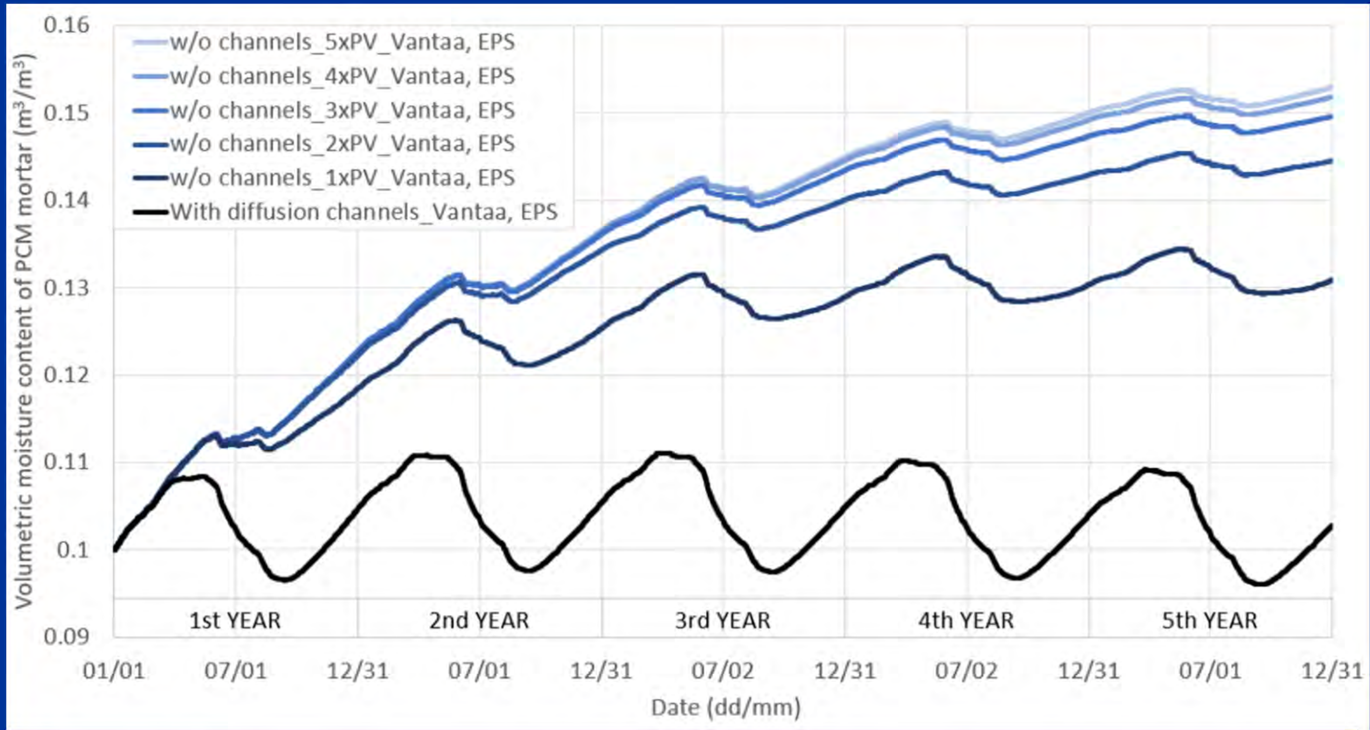
- **EnActive ETICS concept**





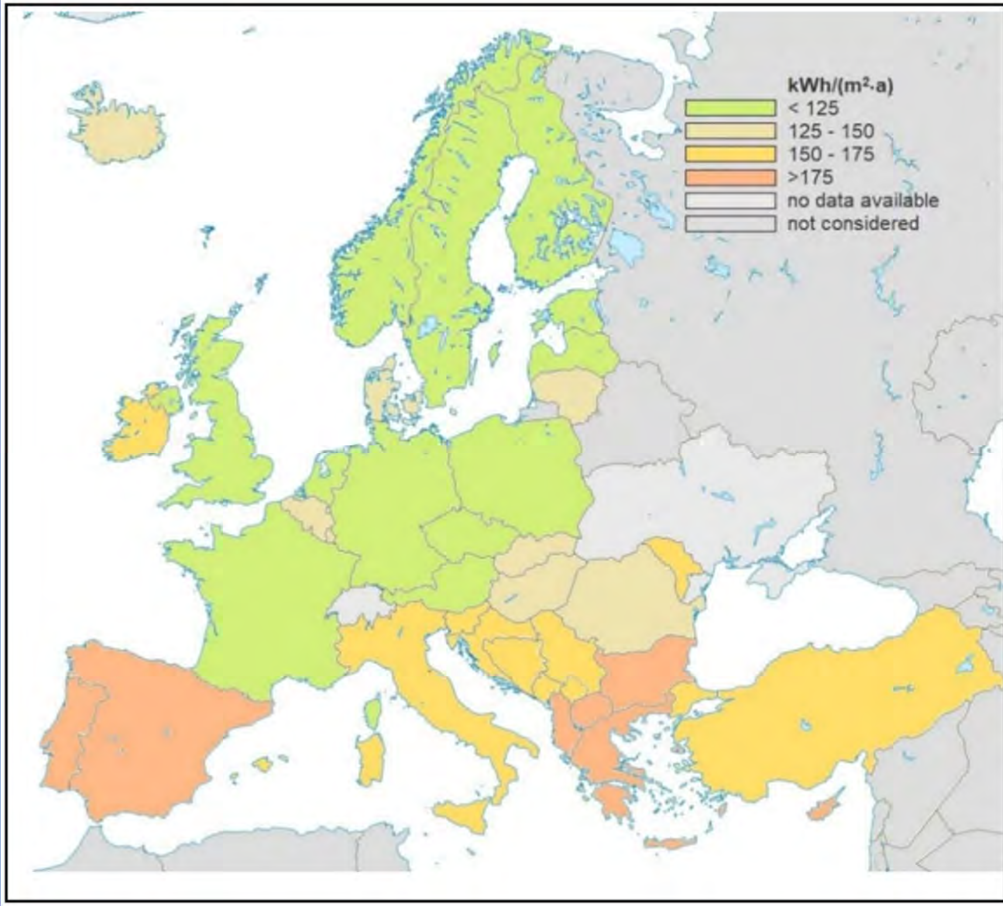
Examples of BIPV

- **EnActive ETICS**
  - Importance of diffusion channels
    - Modelled results with and without diffusion channels
    - Using diffusion channels makes it possible to apply multiple PV panels side-by-side.



Examples of BIPV

- **EnActive ETICS**
  - Electricity output of PV façade
    - **South facing facade**

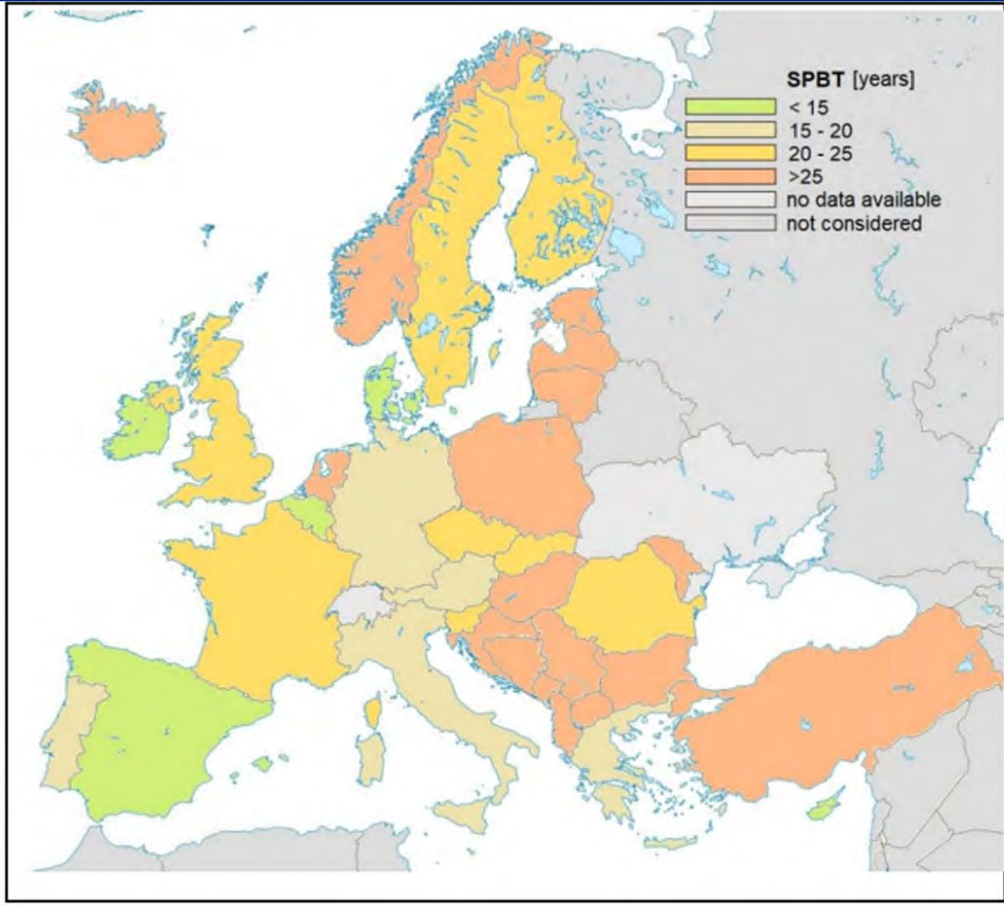


PV production

Contry	City	kWh/(m^2·a)
Albania	Tirana	187.2
Austria	Vienna	122.8
Belgium	Brussels	146.4
Bosnia and Herzegovina	Sarajevo	165.0
Bulgaria	Sofia	181.6
Croatia	Zagreb	163.9
Cyprus	Nicosia	195.8
Czechia	Prague	103.4
Denmark	Copenhagen	149.5
Estonia	Tallinn	119.4
Finland	Helsinki	122.1
France	Paris	116.8
Germany	Berlin	113.3
Greece	Tanagra	179.9
Hungary	Debrecen	133.3
Iceland	Reykjavik	125.9
Ireland	Dublin	157.0
Italy	Rome	154.6
Latvia	Riga	116.4
Liechtenstein	Vaduz	174.4
Lithuania	Vilnius	132.4
Luxembourg	Luxemburg	141.7
Malta	Luqua	189.3
Moldova	Chisinau	156.5
Montenegro	Podgorica	170.9
Netherlands	Amsterdam	118.0
North Macedonia	Skopje	177.1
Norway	Bergen	88.3
Poland	Lodz	109.4
Portugal	Lisboa	175.0
Romania	Bucharest	149.9
Serbia	Belgrade	166.0
Slovakia	Bratislava	132.8
Slovenia	Ljubkjana	158.9
Spain	Madrit	180.3
Sweden	Stockholm	124.4
Türkiye	Istanbul	168.5
United Kingdom	London	118.3

Examples of BIPV

- **EnActive ETICS**
  - Simple payback time is highly dependant of electricity price



Simple PayBack Time

Contry	City	Years
Albania	Tirana	32
Austria	Vienna	21
Belgium	Brussels	13
Bosnia and Herzegovina	Sarajevo	38
Bulgaria	Sofia	30
Croatia	Zagreb	26
Cyprus	Nicosia	13
Czechia	Prague	29
Denmark	Copenhagen	12
Estonia	Tallinn	32
Finland	Helsinki	25
France	Paris	25
Germany	Berlin	16
Greece	Tanagra	18
Hungary	Debrecen	40
Iceland	Reykjavik	32
Ireland	Dublin	14
Italy	Rome	16
Latvia	Riga	30
Liechtenstein	Vaduz	15
Lithuania	Vilnius	31
Luxembourg	Luxemburg	20
Malta	Luqua	22
Moldova	Chisinau	37
Montenegro	Podgorica	32
Netherlands	Amsterdam	29
North Macedonia	Skopje	38
Norway	Bergen	36
Poland	Lodz	34
Portugal	Lisboa	15
Romania	Bucharest	25
Serbia	Belgrade	44
Slovakia	Bratislava	25
Slovenia	Ljubkjana	21
Spain	Madrit	13
Sweden	Stockholm	21
Türkiye	Istanbul	37
United Kingdom	London	21

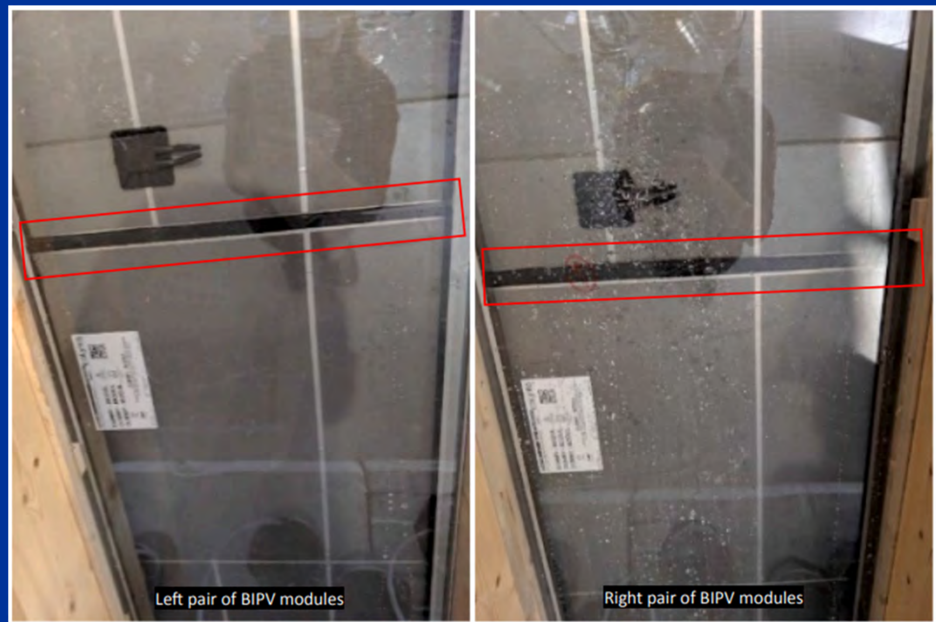
Examples of BIPV

- **EnActive ETICS - CONCLUSIONS**
  - Adding vapour-tight PV panel as an outermost layer of ETICS facade promises to be hygrothermally safe only if there are diffusion channels created behind the PV panel.
  - PCM managed to reduce PV panel peak temperatures below 80°C
  - Integrating PV panels into ETICS facades makes economical sense.
    However, payback time calculations are hugely dependent of electricity prices.
  - Besides PV, most expensive component is PCM mortar

Roof-integrated PV – building physical challenges

Gullbrekken et.al. 2015

- Rain tightness of BIPV systems, see Breivik et.al 2013 Large-scale experimental wind-driven rain exposure investigations of building integrated photovoltaics; Solar Energy, 2013;900:179-187; Fedorova et.al 2021 Quantification of wind-driven rain intrusion in building-integrated photovoltaic systems Solar Energy 2021,230:376-389



Roof-integrated PV – building physical challenges

Gullbrekken et.al. 2015

- Rain tightness of BIPV systems,
- Snow and ice: ~3% loss in power production

At the Regional Test Center in Williston, Vermont, researchers are examining how framed (in the background) and frameless (in the foreground) solar photovoltaic modules handle snowy conditions. | Photo Courtesy: Sandia National Laboratories

Roof-integrated PV – building physical challenges

Gullbrekken et.al. 2015

- Rain tightness of BIPV systems
- Snow and ice
- Condensation on the rear side of a PV: ventilation of the air gap between the modules and the underlayer roof is necessary in order to dry out the water;
- Underlayer roof: s_d-value of a wind barrier should be less than 0,5m (SINTEF)

B. Figgis et al.

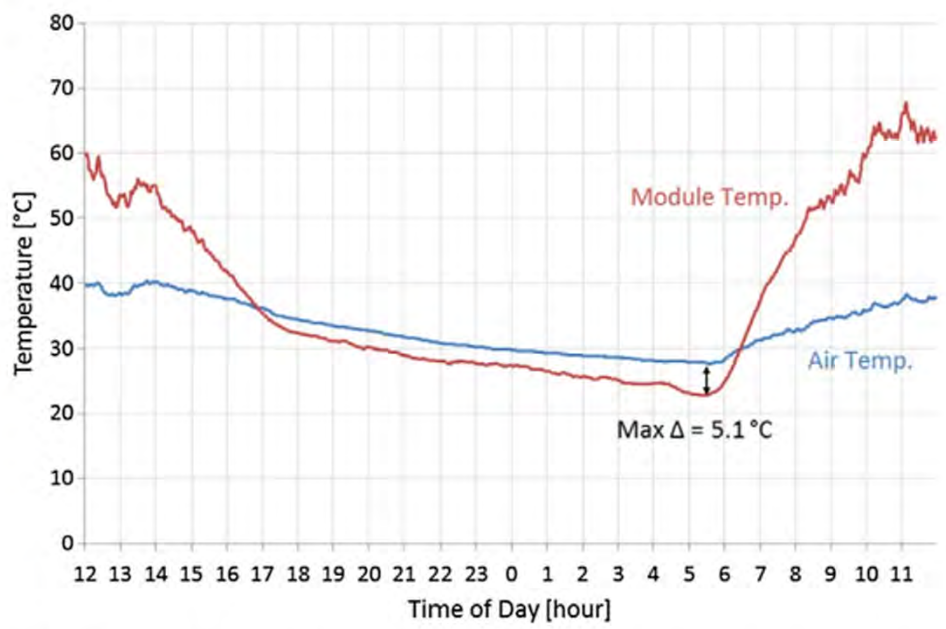
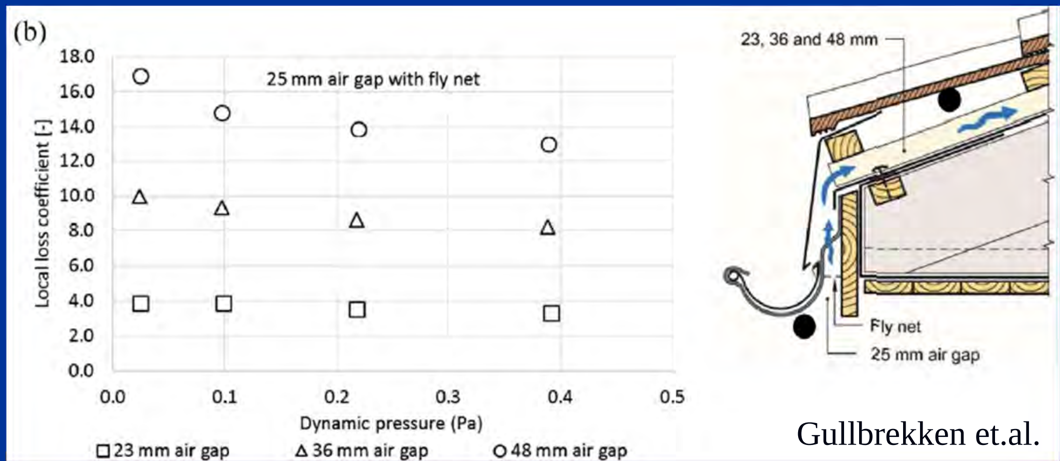


Fig. 2. Example of a PV module cooling to below air temperature during the night in Doha. Blue line = air temperature, red line = module back-surface temperature.

Roof-integrated PV – building physical challenges

Gullbrekken et.al. 2015

- Rain tightness of BIPV systems
- Snow and ice
- Condensation
- Underlayer roof
- Venting below the BIPV:
  - The inclination (25°, 45°, 70°, 90°)
  - the air gap of the roof was varied (0.23m, 0.115m and 0.06m);



Gullbrekken et.al.

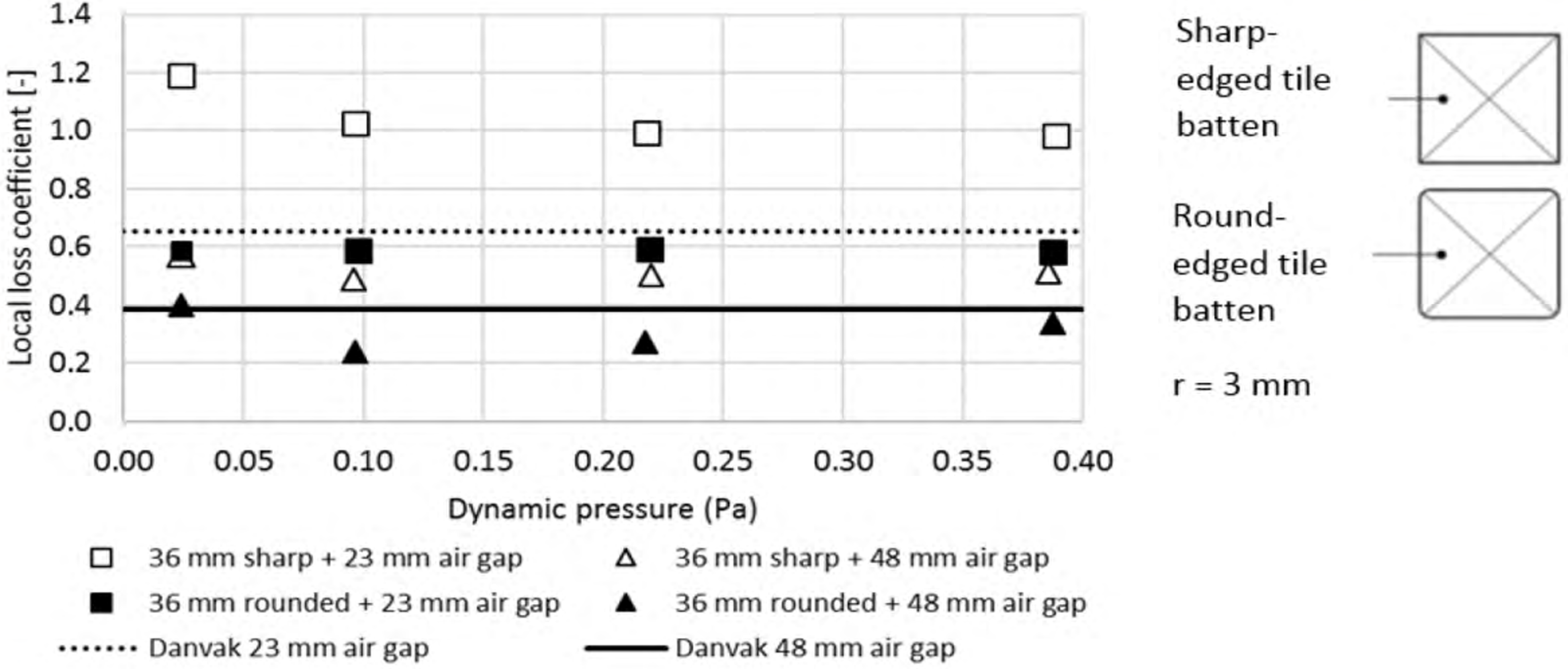


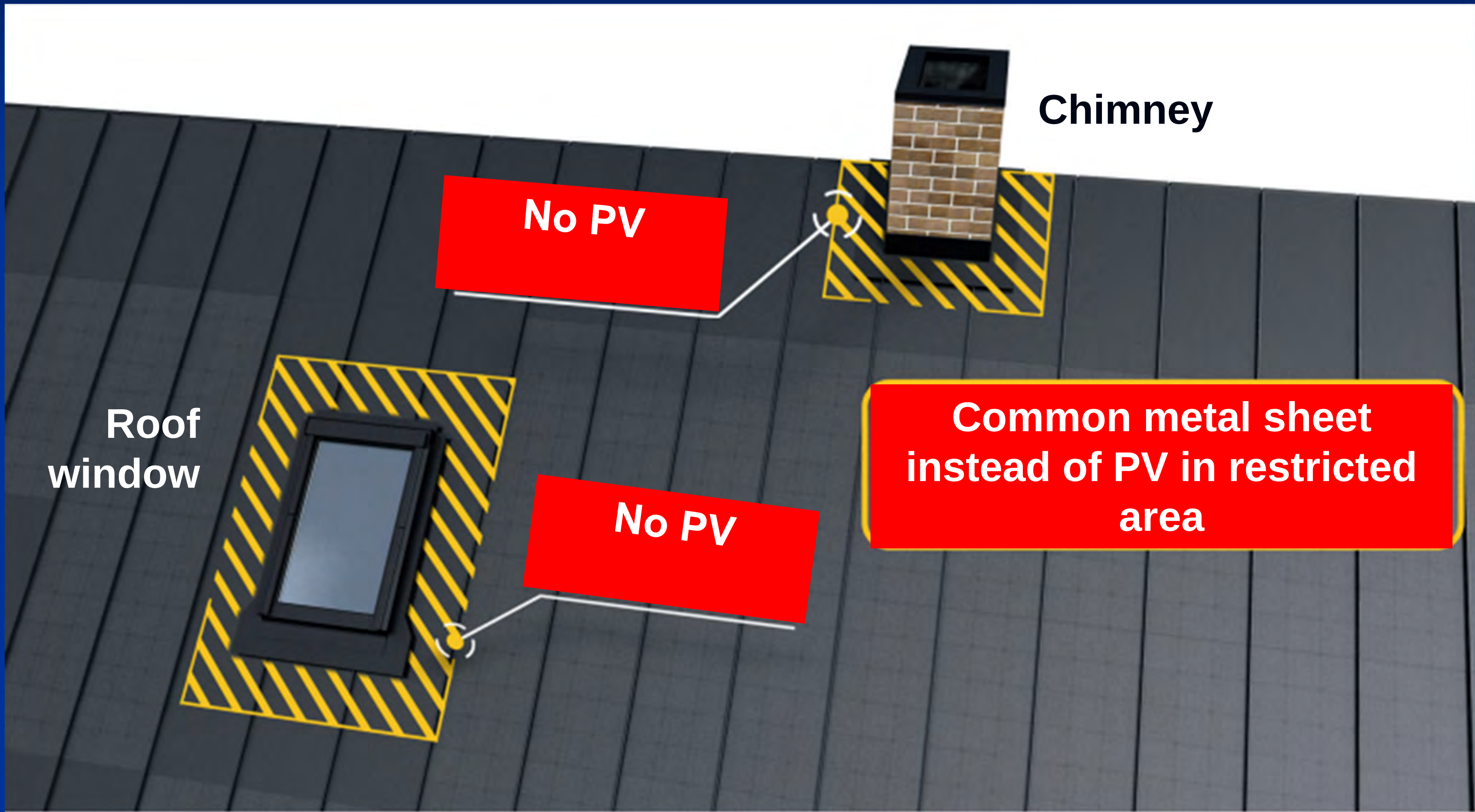
Figure 22. Local loss coefficient for sharp-edged and round-edged battens with different air gaps and dynamic air pressure of the airflow passing the tile batten. "Danvak" means values calculated from Hansen et al. (2013).

Gullbrekken et.al.

Roof length		m	7.5	10	15	20	30	60
Britain	Inlet/outlet	mm	25	25	25	25	25	25
	Height channel	mm	50	50	50	50	50	50
Germany	Inlet/outlet	mm	40	50	75	100	150	300
	Height channel	mm	40	50	75	100	150	300
Canada	Inlet	mm	50	70	100	135	200	400
	Height channel	mm	50	70	100	135	200	400
USA	Inlet	mm	50	70	100	135	200	400
	Height channel	mm	50	70	100	135	200	400
Finland	Inlet	mm	15	20	30	40	60	120
	Height channel	mm	100	100	100	100	100	120
Norway	Inlet/outlet	mm	36	72	98	-	-	-
	Height channel	mm	36	72	98	-	-	-
New guidelines for Norway	Inlet	mm	23	36	73	98	148+11	-
	Height channel	mm	23	36	73	98	148+11	-

Gullbrekken et.al.

Fire safety


Chimney
No PV
Roof window
No PV
Common metal sheet instead of PV in restricted area

BIPV on prefabricated insulation element


DRIVE
TIMBECO


OPEN LAB


oPEN LAB

Q / A

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