DTU

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Building integrated photovoltaics

Contents

Part 1 - Sune

- Introduction to BIPV
- Financial feasibility of BIPV
- Typical BIPV architypes
- Challenges for BIPV systems

Part 2 – Markus

- Appearance
- Glare

Dansk solenergi

Use of PV

PV applications

- **Grid Connected**
  - BAPV
    - Commercial Roof top
    - Residential
  - BIPV
    - Roof
    - Facade
    - Accessories
  - Utility scale
    - Farms
    - Hybrid Farms
    - Floating PV
    - Agro PV
- **Off Grid**
  - Island systems
  - Product Specific:
    - PIPV
    - Leasure

This session

Application of Photovoltaics in buildings

- **Building attached PV (BAPV)**
  - Traditional PV panels Attached to the building
- **Building integrated PV (BIPV)**
  - The PV module serves as a building component
  - **Architecturally integrated**
    - Building Hidden PV (BHPV)
      - PV is hidden and typically integrated

Where is the PV?

https://www.ecowatch.com/solar-facade-denmark-school-2263274993.html

What is BIPV

- IEA PVPS T 15 recommends the following definition:
  - https://iea-pvps.org/wp-content/uploads/2020/02/IEA-PVPS_Task_15_Report_C0_International_definitions_of_BIPV_hrw_180823.pdf (pp 16)

- A BIPV module is a **PV module and a construction product together**, **designed to be a component of the building.** A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system which retains building-related functionality. **If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product.**
- **A BIPV system is a photovoltaic system in which the PV modules satisfy the definition above for BIPV products.** It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building.

BIPV panels are thus…

- BIPV is both a construction product and a power generator for
  - Facades
  - Roofs
  - Misc (canopies, sunshades …)
- Needs to meet several requirements:
  - Construction product functionalities
  - Electrical safety and durability
  - Architectural/ aesthetics demands

https://www.ebay.co.uk/itm/312239942183

https://www.ecowatch.com/solar-facade-denmark-school-2263274993.html

https://www.nhpr.org/post/solar-roof-shingles

Why BIPV?

Overall

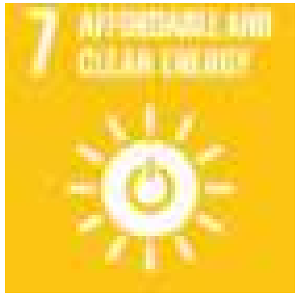
- Optimized use of area
- Energy close to its consumption (reduced need for grid expansion) (reduction of transmission losses)
- ***Free energy*** (marginally) is in the horizon
- Savings on conventional building materials

Regulatory advantages

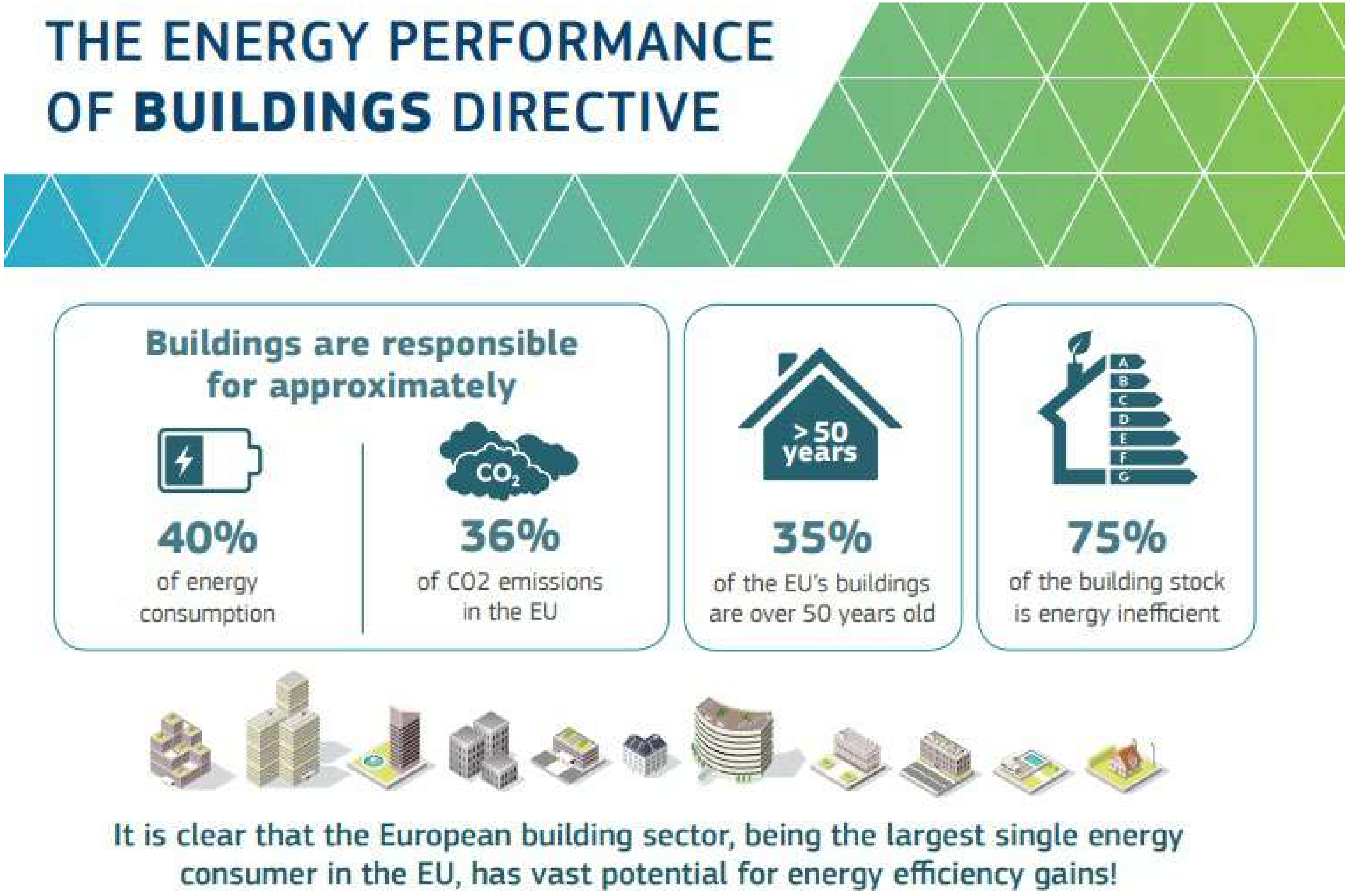
- Location dependent

Challenges:

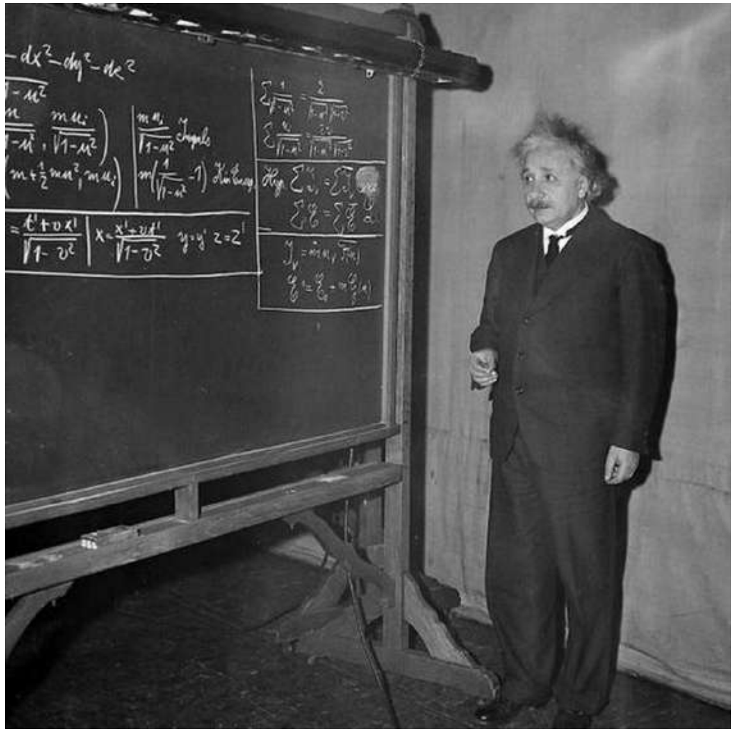
- Aesthetics – getting solved
- Storage
- Price
- Knowledge of availability



Energy in buildings



BIPV Challenge



Physicist

Architect (https://big.dk/about)

Can we make aesthetic durable solutions that satisfies both?

NIMBY

From English:

Not In My Back Yard:

Renewable energy is great among most people:

Though only as long as its not in the backyard.

- Wind turbine and a solar park in your backyard?
- Aesthetic BIPV solutions exists and can convert Nimby to Yimby ☺

Nimby / Yimby example

https://textbook-photovoltaics.org/figures.html

Dansk solenergi

Which is your favorite?

Which one of these is a BIPV roof?

This one!

https://freesuns.com/en/project?ferlens-listed-building-in-ferlens

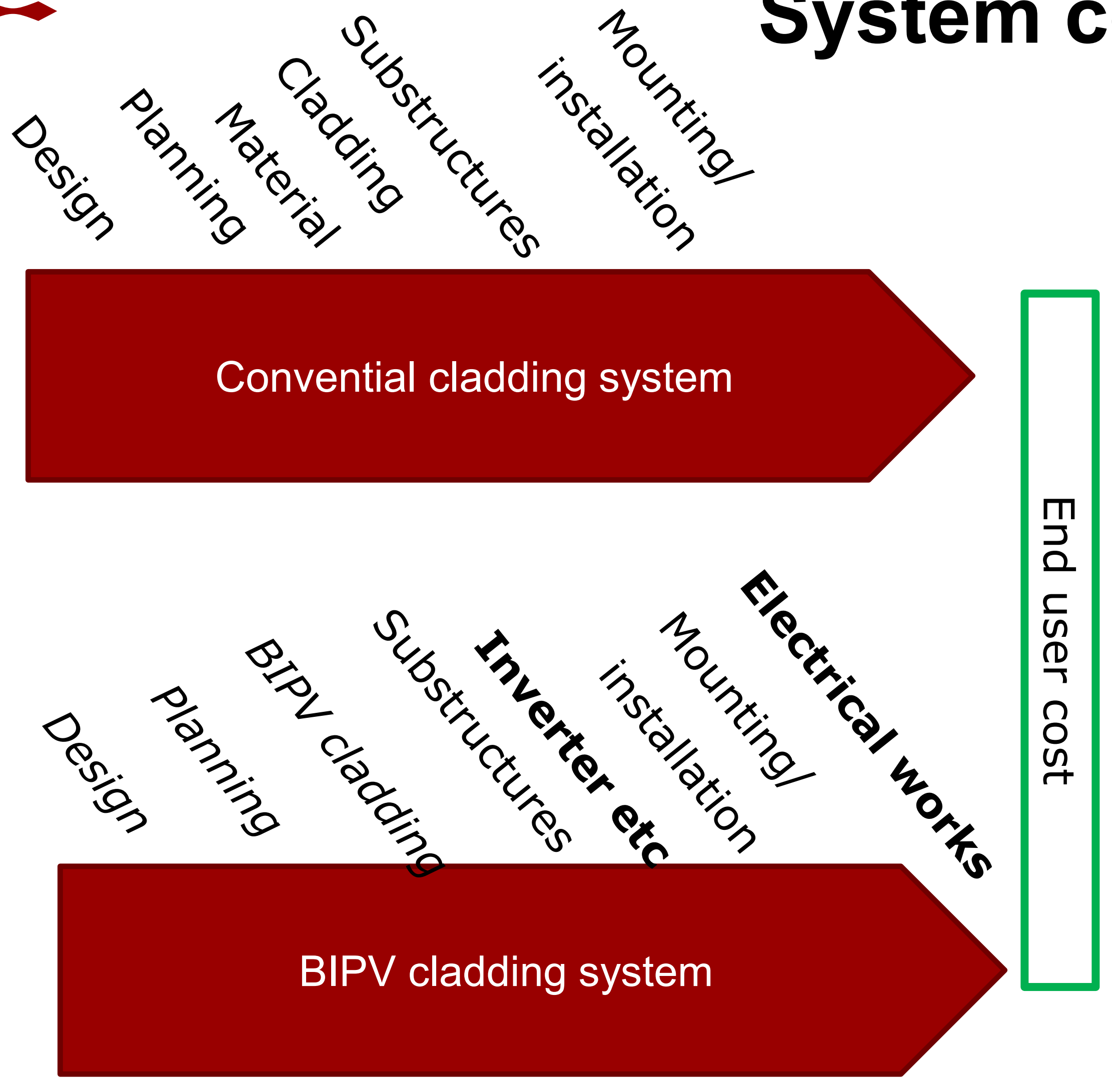
Financial feasibility of BIPV systems

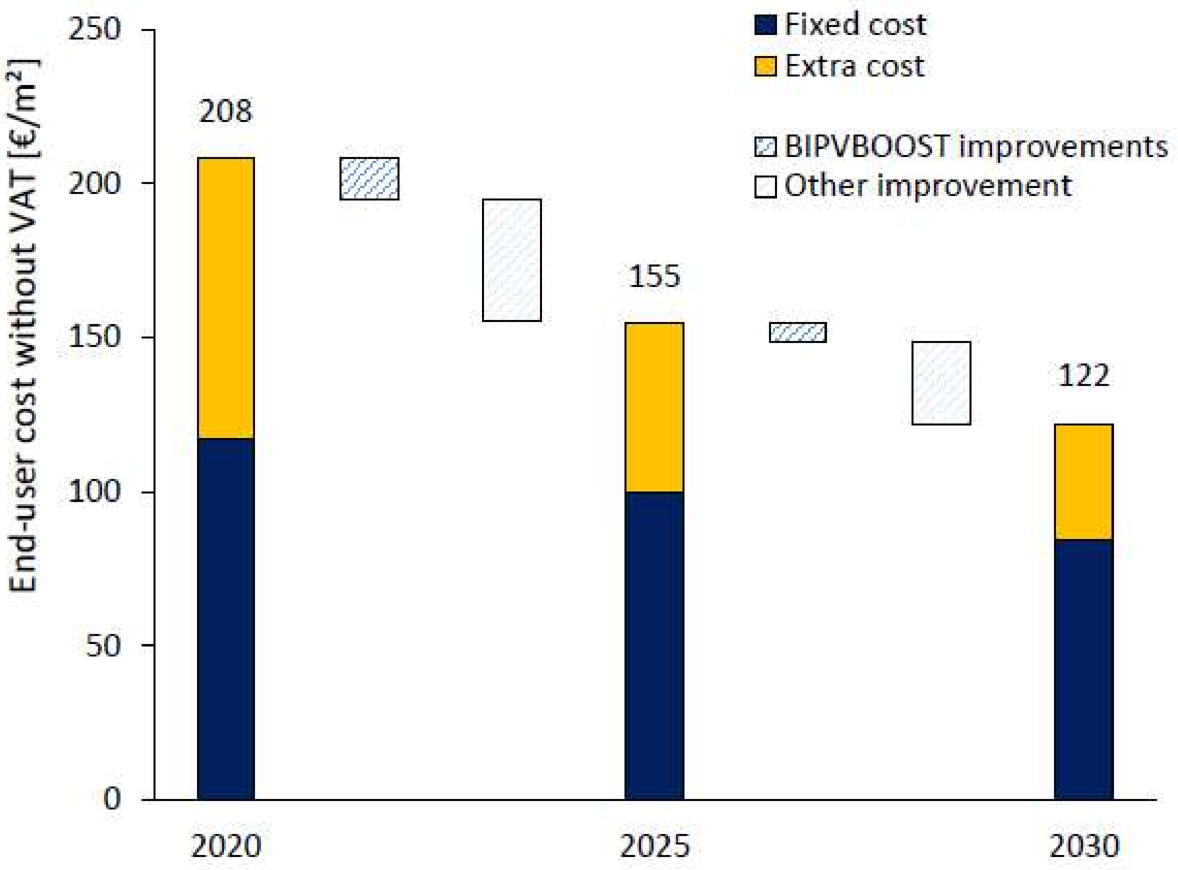
BIPV make sense for new builds or renovations

- Marginal/extra cost approach:
  - only the extra cost of the BIPV system is considered.
  - evaluate the feasibility of the BIPV system
    - Is the energy produced financing the extra cost?
- Total cost
  - What you will pay (and needs to be financed)
- Competitive parameters
  - Both €/m2 and (marginal) €/kWh

VS

System cost





https://bipvboost.eu/public-reports/download/bipv-solutions-in-europe-competitiveness-status-ro

Extra Cost approach - Example

Example

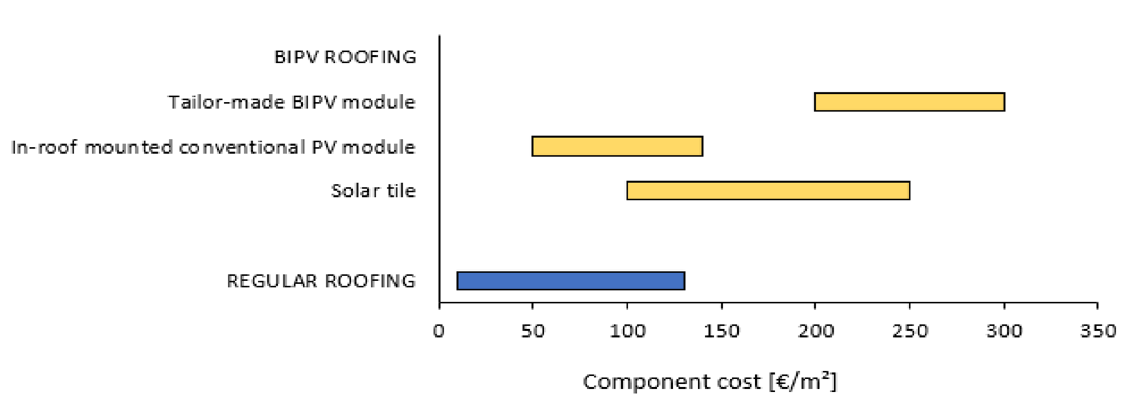
- Roof has reached end of life
- The roof needs replacement:
  - Case 1
    - Replace the roof with fiber cement ~100 €/m^2
  - Case 2
    - Replace the roof with a BIPV solution -~270 €/m^2
  - (Marginal) cost of PV 170 €/m^2
    - The 170 €/m^2 needs to be justified financially
      - not the 270 €/m^2 because you anyway need a new roof to (at least 100 €/m^2)

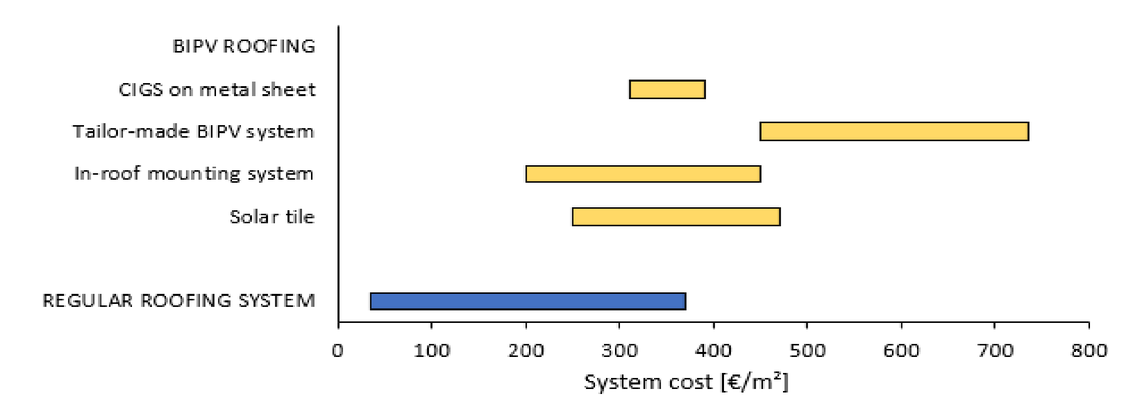
https://www.sj-tagteknik.dk/galleri/

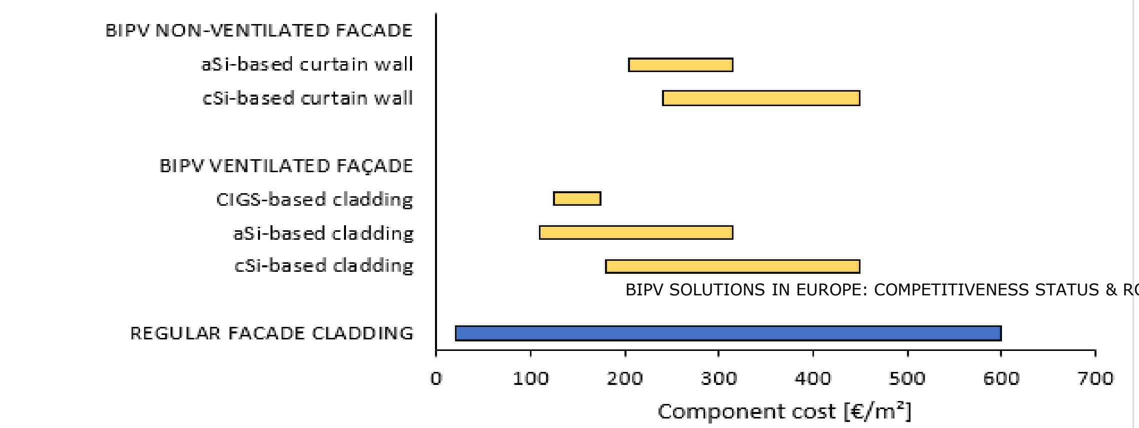
Pricing structure EU 2021

Imagine (in a wild dream):

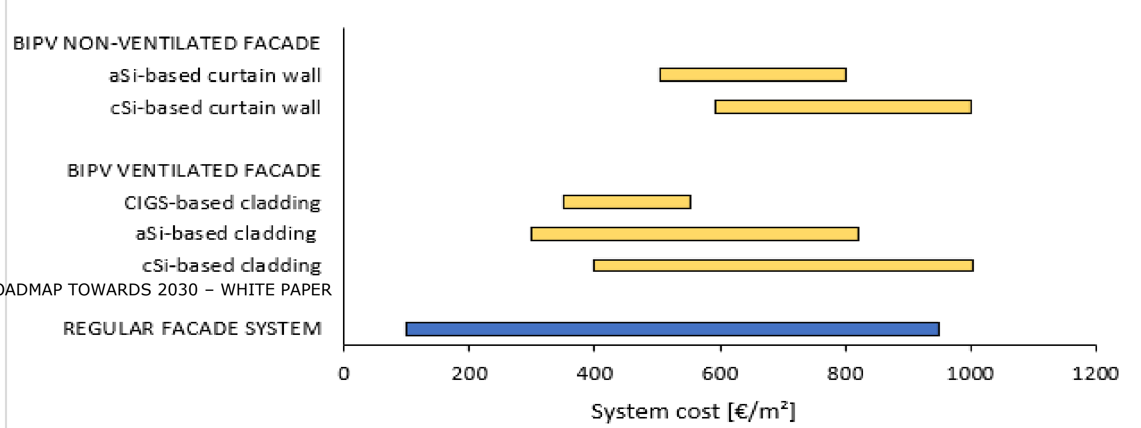
BIPV price cheaper than the cost of replaced material.







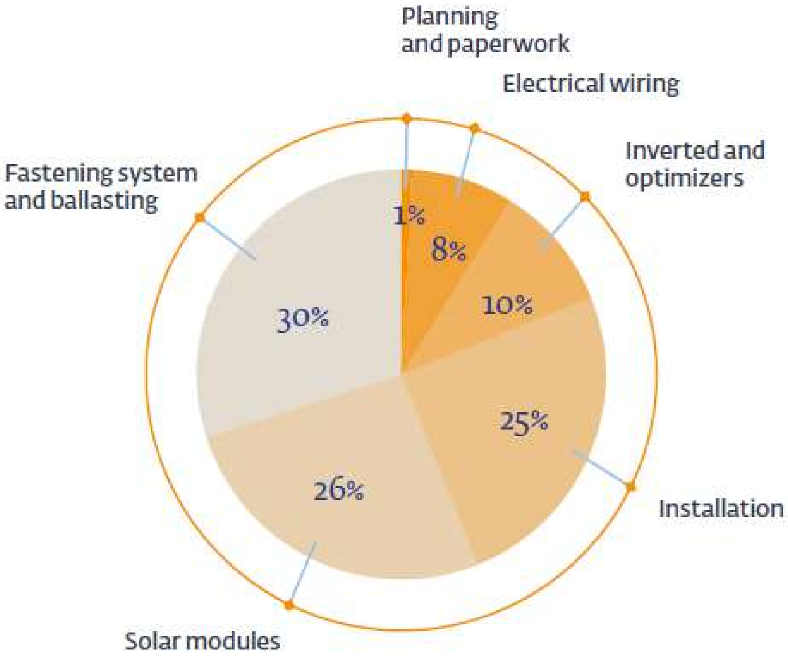
BIPV SOLUTIONS IN EUROPE: COMPETITIVENESS STATUS & ROADMAP TOWARDS 2030 – WHITE PAPER



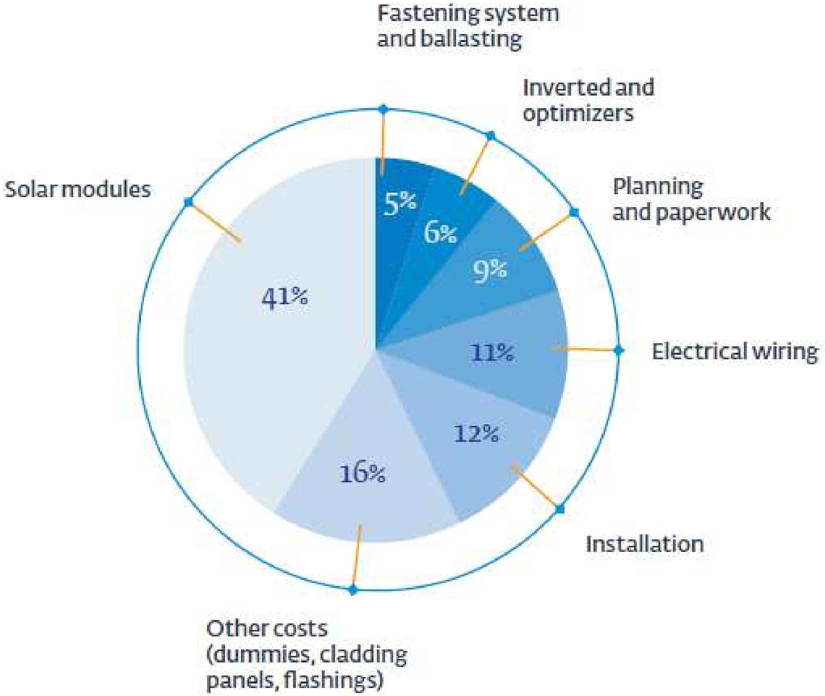
BIPV boost

Cost distributions

RESIDENTIAL BUILDING
FAÇADE PRODUCTS



SINGLE-FAMILY HOUSE
ROOF PRODUCTS



CHF/m²:
410 (reference cost, excl. VAT)

2017 survey (BIPV boost)

CHF/m²:
360 (reference cost, excl. VAT)

BIPV industry

90's

Demonstration of BIPV concepts
Customized individual projects
- Price pr Watt

2010+

Flagship demonstration projects

2020

Standardized
Energy producing
building materials
- Scaling
- Price pr m^2

Market forecast

Status report 2020 Bequerel Institue

Market drivers and obstacles

BIPV Boost Stakeholder Analysis 2019

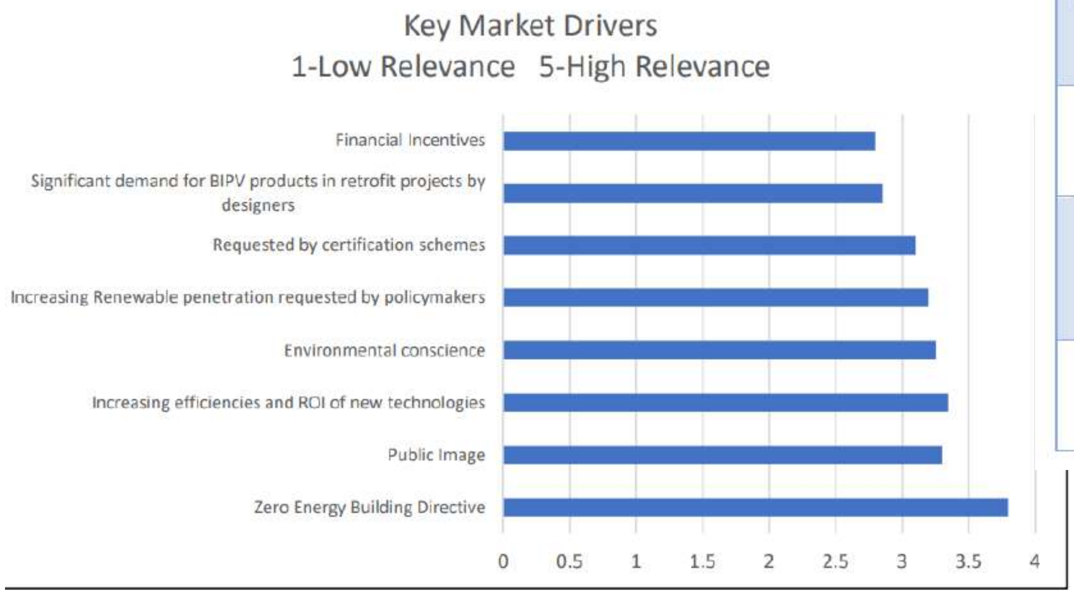


Table 3.2 Summary of barriers to the deployment of BIPV solutions (Source: Becquerel Institute)

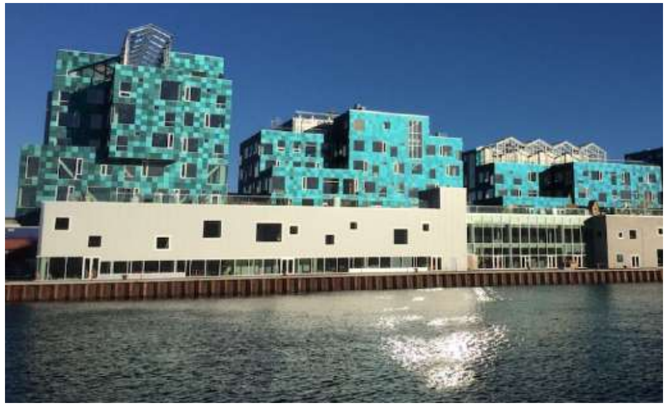
Structural & Regulatory	Economic	Technical	Socio-Psychological
Lack of collaboration between stakeholders: PV, construction and real estate sectors do not communicate enough	Additional cost of BIPV compared to BAPV and regular construction material which can be discouraging	Lack of field data on degradation level and system performances	Lack of knowledge among professionals of the construction sector
Complex and inappropriate regulatory framework	Lack of possibilities to monetize PV electricity production	Lack of standardized products (e.g. mounting systems)	Lack of awareness among the public
Unstable regulatory environment, such as unexpected modifications and retroactive measures	Lack of valorization of renewables in the built environment	Lack of clearly defined maintenance procedures	Aesthetical possibilities of BIPV elements are still too limiting for some architects
Lack of standards and codes combining PV and building requirements	High up-front cost and long-term payback	Ability of some buildings' structures is insufficient to carry BIPV elements' weight	

Break

BIPV application in more details

BIPV Use

- Cladding material
    - Roofs
    - Facades
    - Accesories



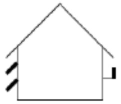
https://www.ecowatch.com/solar-facade-denmark-school-2263274993.html

https://freesuns.com/en/project?ferlens-listed-building-in-ferlens

https://www.solarinnova.net/en/services/installations/photovoltaic/railings

The 5 overall BIPV categories (Standards and IEA T 15)

Table 3. BIPV Application categories in Standard IEC 63092-1

Category A:	**Sloping, roof-integrated, not accessible from within the building** The BIPV modules are installed at a tilt angle between 0° and 75° from the horizontal plane [0°, 75°], see Fig.1, with another building product installed underneath (see NOTE).	
Category B:	**Sloping, roof-integrated, accessible from within the building** The BIPV modules are installed at a tilt angle between 0°and 75° from the horizontal plane [0°, 75°], see Fig.1.	
Category C:	**Non-sloping (vertically) envelope-integrated, not accessible from within the building** The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°,90°], see Fig. 1, with another building product installed behind (see NOTE).	
Category D:	**Non-sloping (vertically), envelope-integrated, accessible from within the building** The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°, 90°], see Fig. 1.	
Category E:	**Externally-integrated, accessible or not accessible from within the building** The BIPV modules are installed to form an additional functional layer that provides a building requirement as defined in 4.1. E.g. balcony balustrades, shutters, awnings, louvers, brise soleil etc.	

NOTE: A BIPV module is considered to be "not accessible" when another building product (represented by a dashed line in the pictograms) is present, which among other functions prevents: (i) the interior surface of the module from being touched and (ii) large pieces falling onto adjacent accessible areas within the building.

”Standard” roof with insolation under neath

”(Semi transparent)” roof No insolation

- overhangs etc

”Standard” rain screen insulation behind

- Cold Facade

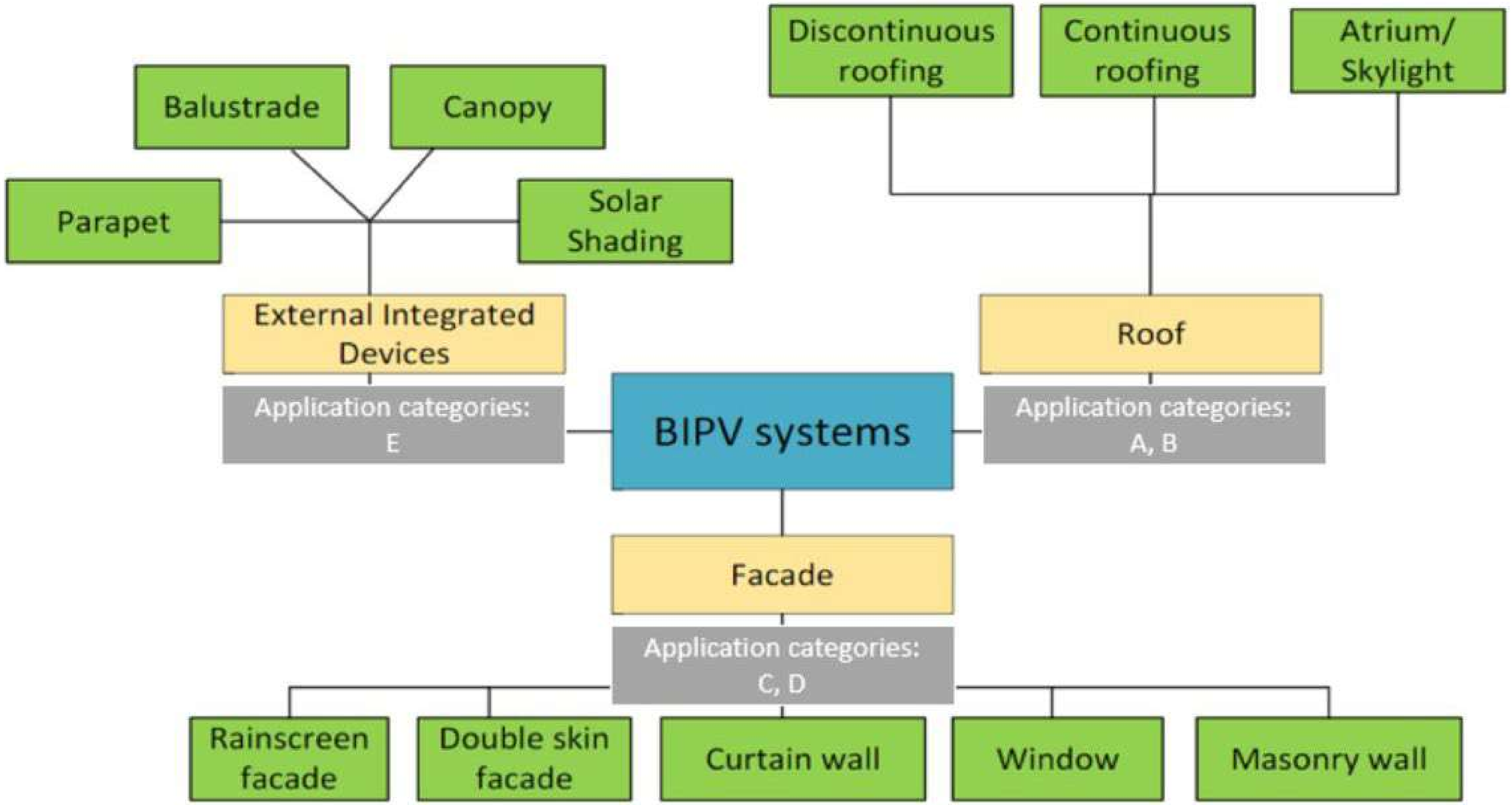
Rain screen and insulation within the PV

- Warm facade (Curtain wall)

Accessories.

- Sunshades, fences, louvers …

Examplified component categorization



(Brick wall)

IEA PVPS Task 15

BIPV applications Roofs

- **Roofing**
  - Roof tiles
  - Integrated standard PV
  - Glazings/skylights

BIPV Facades and roofs

What about windows, exhuast, doors, dormers etc.

- You can’t cut PV panels
- Passive dummies used for adaption

Available area VS energy production:

- Available area larger than energy need
- “Dummies” are used for non active area
- Energy Production target=annual consumption

https://www.nhpr.org/post/solar-roof-shingles

Caution!

Lets have a more detailed look at typical solution

The next slides will highlight commonly used construction principles (used in Europe) however it is not exhaustive, and you might find many other examples that the one that are shown.

- In other parts of the world there might be different building traditions and practices

Category A - Roof not accessible from the inside

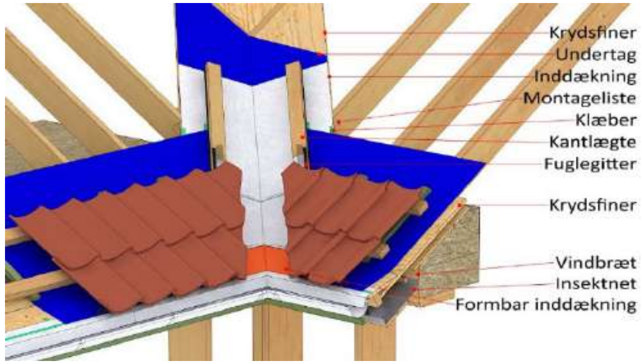
- 3 overall Concepts:
  - **Discontinuous roof**
    - Special “crate” for the PV
    - Standard roofing material for remaining area
      - https://www.gseintegration.com/en/solutions/gse-in-roof-system/
  - **Continuous roof**
    - PV slates same form factor and appearance as the passives
    - Uniform appearance
  - **Misc. types**
    - Panels with insulation on the back
    - Full roof standard panels special frame
      - Solrif
  - Roof underlay is generally always needed
    - Standing seem sheet metal

https://energitaget.dk

https://solartag.eu/referencer/

Category A - Roof not accessible from the inside

- General (Danish) construction
  - As a ”standard roof”
  - From top
    - Roof tiles/slates/PV tiles/PV-slates
    - Battens (73 mm*38mm)
    - ”Fixing list”
    - Roof underlay (water barrier)
    - Rafters
    - Optional insulation with appropriate vapor barrier and inside cladding



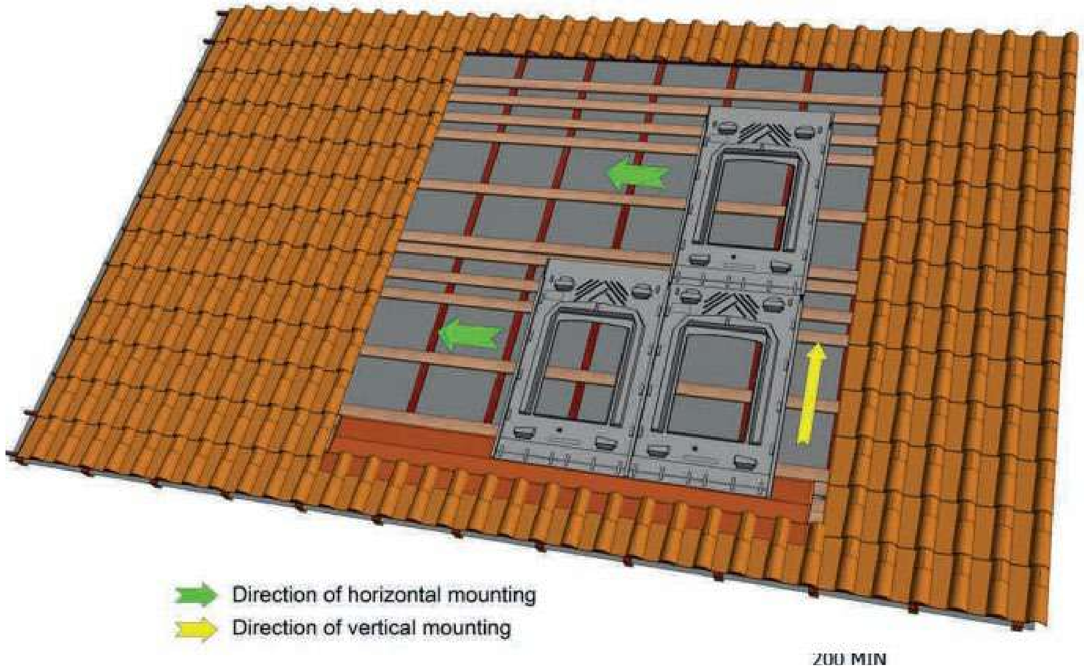
https://membran-erfa.dk/forsaenket-skotrende-ved-tagfod

https://byggeri-arkitektur.dk/article/Phonix-Tagmaterialer/Derfor-er-denne-type-undertag-det-sikreste-valg

https://www.profiltech.dk/product/undertag/

Discontinous roof

- Crate for the (Standard) PV panels
- Rubber ”Gaskets” for water management
- Mounting with module clamps on the frame
- Flexible zinc flashings for integration with remaining roof



https://www.gseintegration.com/wp-content/uploads/2021/03/IR_EN_GU.pdf

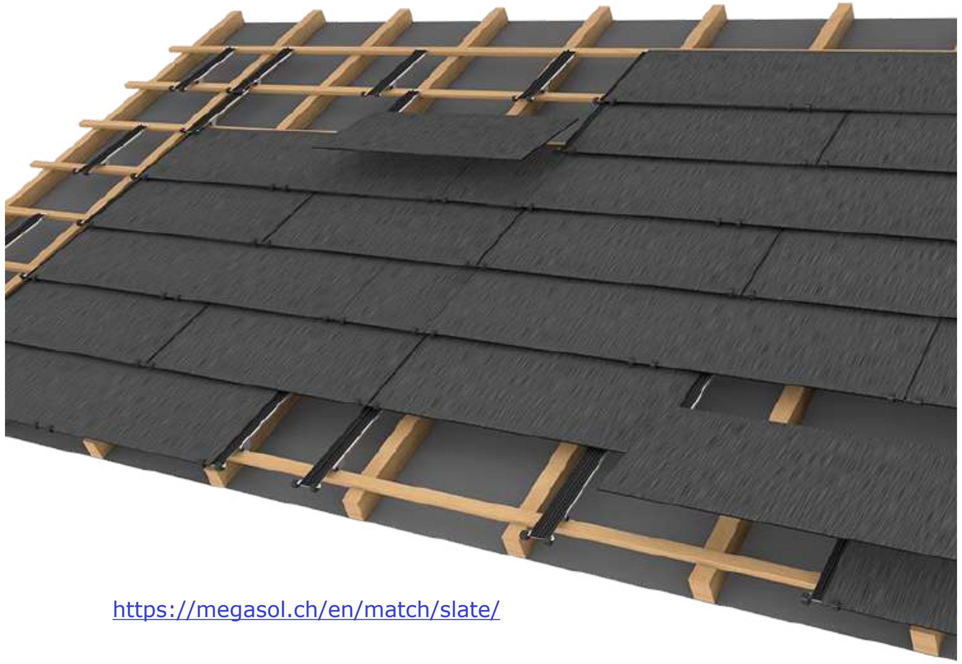
Module clamp

https://www.dreamstime.com/stock-photo-solar-pv-panel-clamp-spacer-image72927002

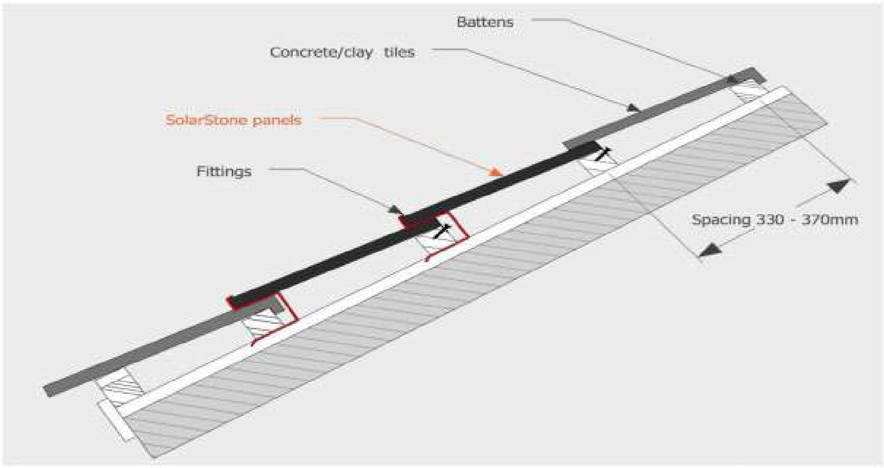
Continuous Roof

- PV slates have almost same form factor and appearance as the passives
- Often mounted with ”hooks” directly on the battens
  - ”Screw-less installation”
  - Mounted with top screws hidden by overlay
- Rubber ”gasket” optional for flexibility

Solartag.eu



https://megasol.ch/en/match/slate/



Side view. Solarstone modules and fittings

https://solarstone.ee/wp-content/uploads/2020/01/SolarStone-Installation-Guide.pdf

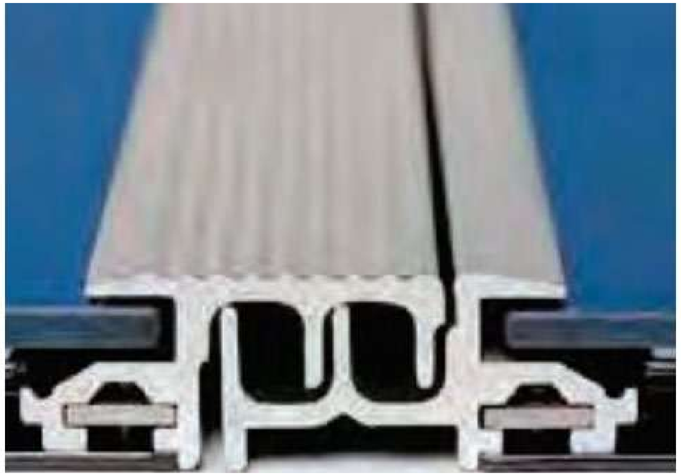
Water-tight frame system

Solrif System (Mostly standardish panels)

- Water management in the frame
  - Sides:
    - Left: Double water ridge
    - Right “lid”
  - Top/ bottom:
    - Overlay/Shingling
- Mounting system with water management and flashings.
- Subroof needed

Details:

https://en.solrif.com/solrif-dach-der-zukunft



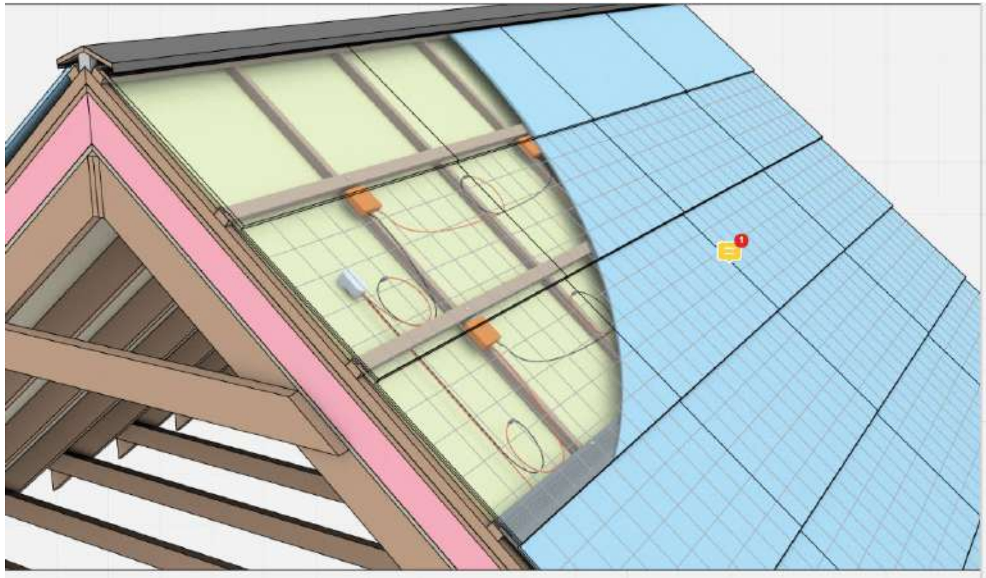
Solitek.eu

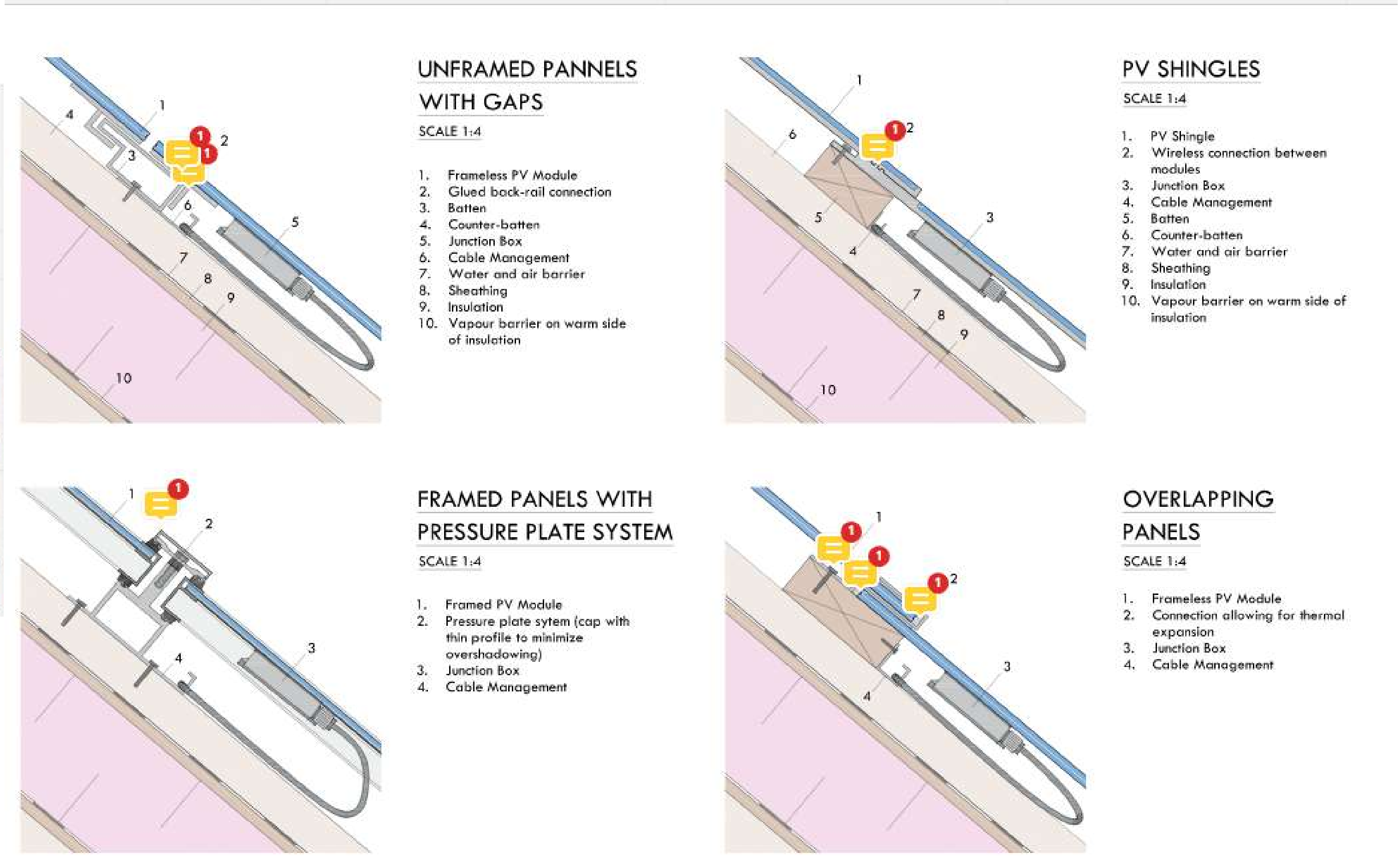
https://solarchitecture.ch/product-solrif-xl/

https://solarim.net/solrif-roof/

Category A - Roof not accessible from the inside

Generic consruction details





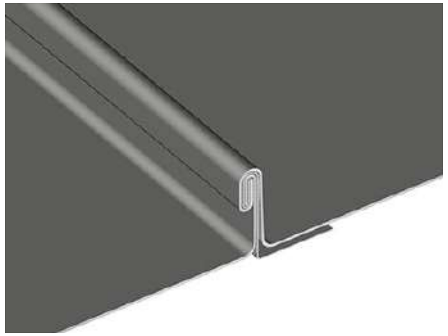
IEA PVPS task 15 work

Standing Seem Metal PV-roofs

- Metal sheets
  - PV glued to the metal sheet
  - Lower power density (Lindab 83 W/m^2 (2021)) (thinfilm)
- Water tightness from hook like wrap around in the joints
- Roof underlay battens etc also generally needed

Details:
https://katalog.lindab.dk/Byggekomponenter/Brochure/solarroof-teknisk-information-20004/?page=40

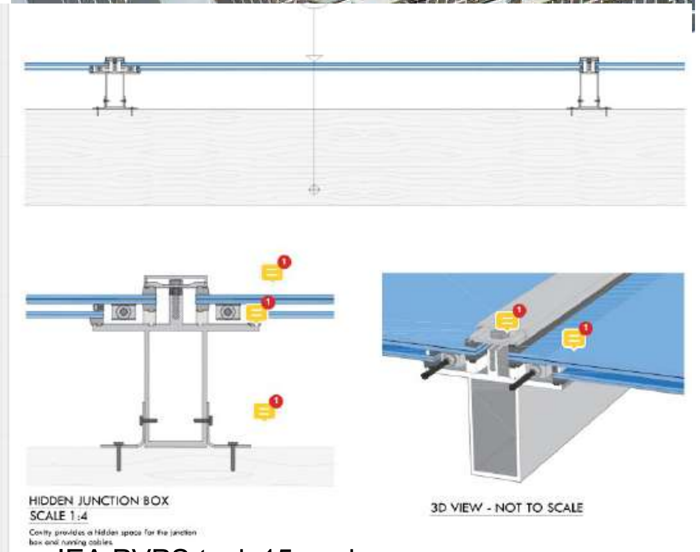
Lindab



Technically this is not a BIPV system according to the IEA definition?

Category B Roof acessible from the inside

- PV as the outer glazing
  - Optional semi transparent modules
  - Used in Atriums as skylight
    - Water tightness achieved with construction similar to glazed roof (rubber gaskets, and pressure plates (list) etc)
    - Might be a member of a double (tripple) glass construction
    - Vary the transparency with solar cell density
    - Cables can be hidden in construction profiles



IEA PVPS task 15 work

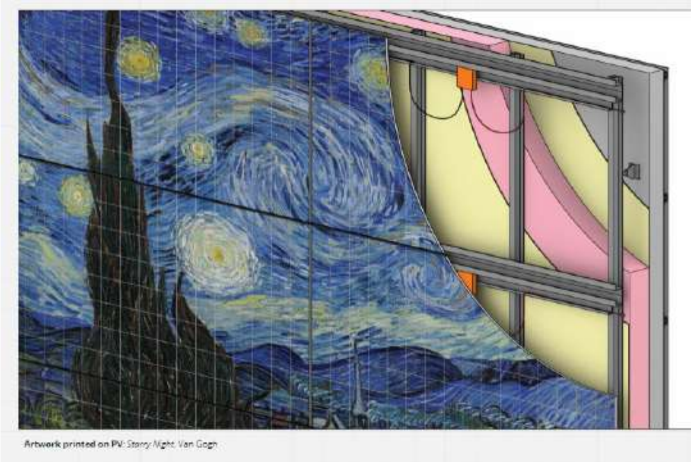
BIPV applications Facades

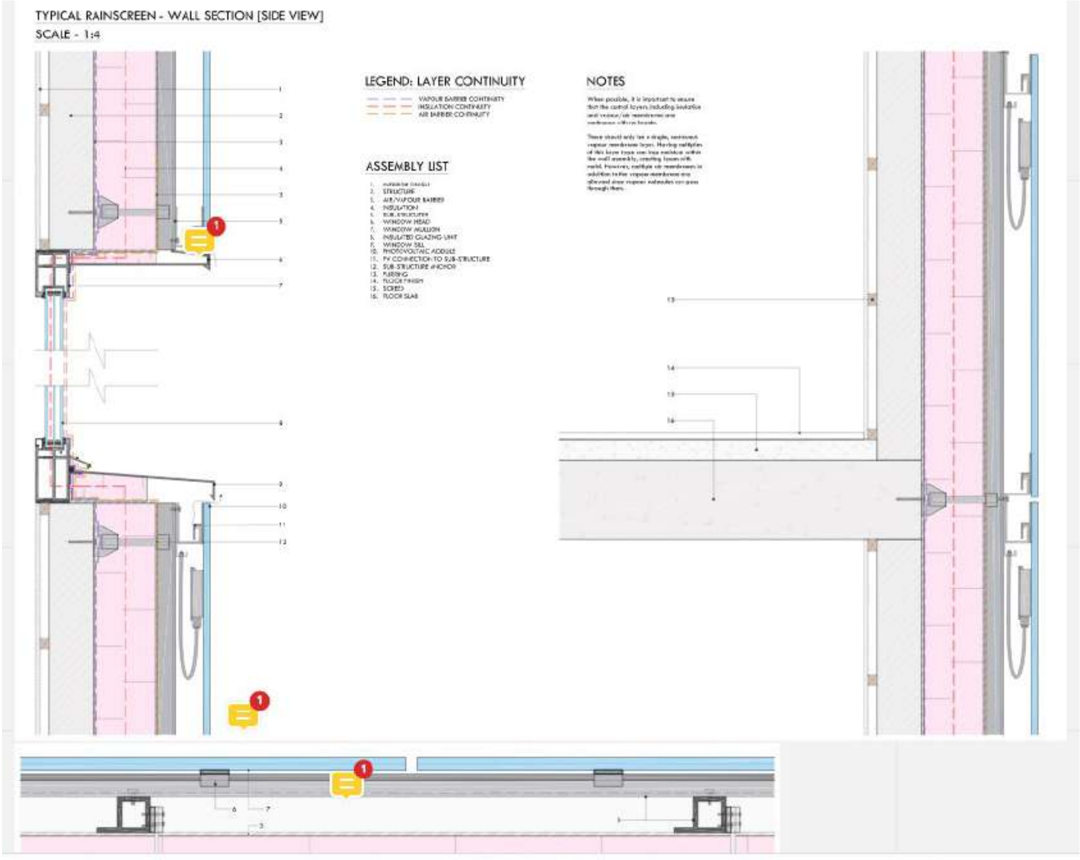
- **Facades**
  - Cold facades
  - Warm facades (Curtain walls)

https://www.ecowatch.com/solar-facade-denmark-school-2263274993.html

Category C Facade not accessible from the inside

- PV is the outer cladding
  - Rainscreen
    - Ventilated facade
    - Load bearing sub structure
    - PV is integrated similar to conventional materials
  - Modules glued or ”hooked” (preferred)
  - Mansony wall
    - Massive wall
    - Non ventilated
    - Moisture barrier

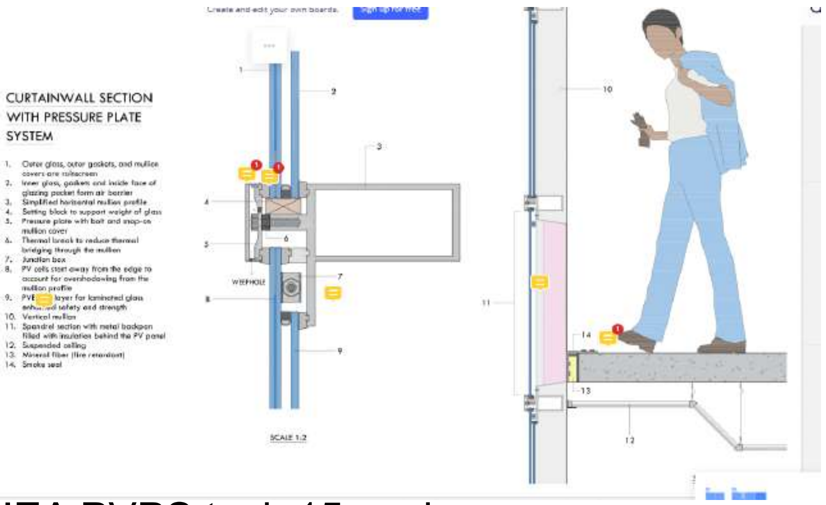




IEA PVPS task 15 work

Category D Facade accessible from the inside

- Mostly certain Curtain Walls
  - Glazed (or non glazed)
  - Often double or 3 x glazed
  - Can be Loadbearing
  - Sound and thermal insulation
    - Alu profiles thermally disconnected with plastic sheets
  - Can be pre fabricated
  - Opacity can be adjusted with cell density



IEA PVPS task 15 work

https://www.seniorarchitectural.co.uk/senior-adds-strength-to-its-range-with-new-sf62-curtain-wall/

Category E Misc

- Fences/Balustrates/Parapets
  - Compliance to standards
    - Withstand sufficient force
- Canopies/ ”Open roofs”
  - Opacity is often adjusted with cell density
  - Substructure provides mechanical strength
- Sunshades
- Misc (What is not mentioned here ☺)

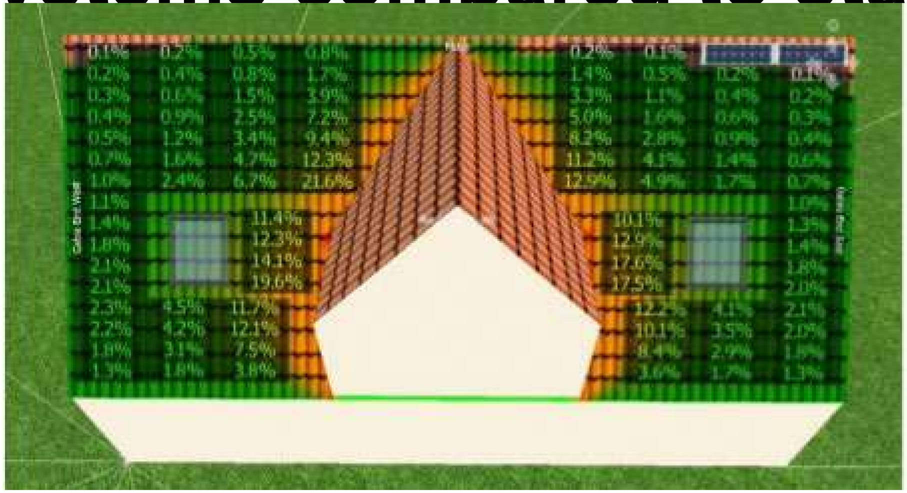
https://www.solarinnova.net/en/services/installations/photovoltaic/rail

https://www.mornglass.com/solar-glass-photovoltaic-glass-classification.html

https://www.researchgate.net/publication/273025092_Building_integration_of_solar_renewable_energy_systems_towards_zero_or_nearly_zero_energy_buildings/figures?lo=1

Challenges of BIPV systems compared to standard PV systems

- Partial shading
- Temperatures
- Lifetime
  - Construction product
  - Electricity generator



Partial Shading

BIPV systems:

- Often placed in non optimal orientations
- Often with partial shading

Power electronics solutions handling partial shading is needed:

- Module level power electronics

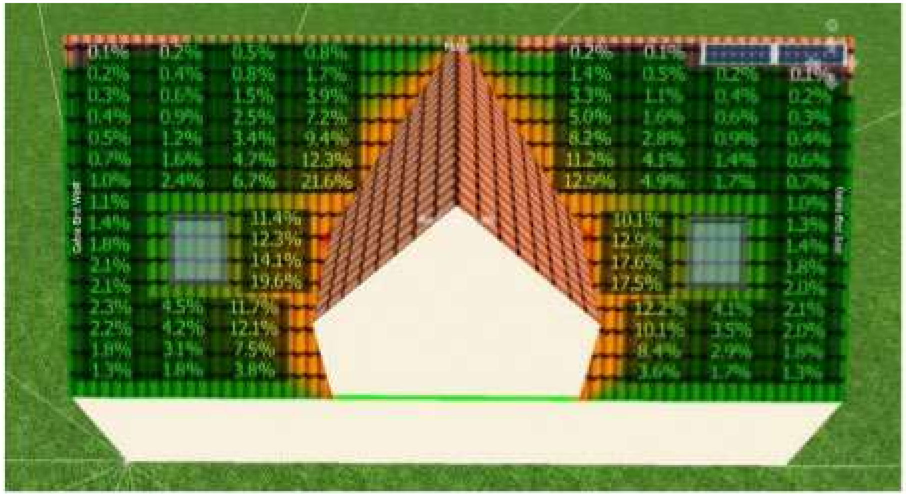


Figure 9: South side panel shading.

Solutions

μ-inverter

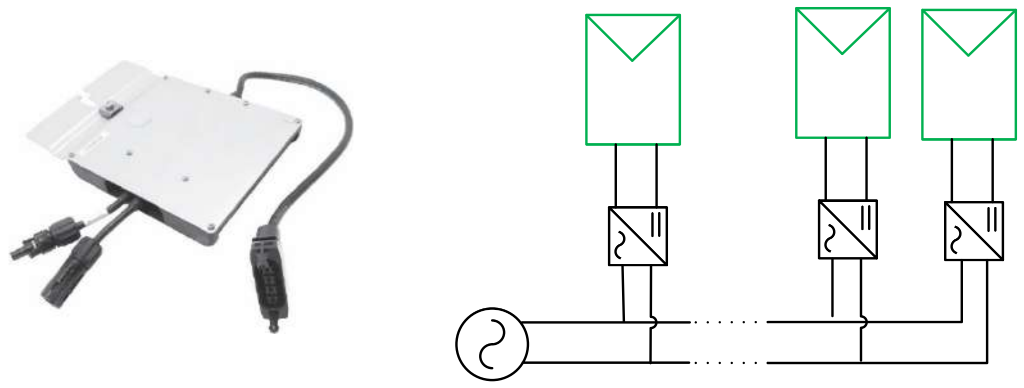
- One small inverter pr module
- Expensive
- Plant control management

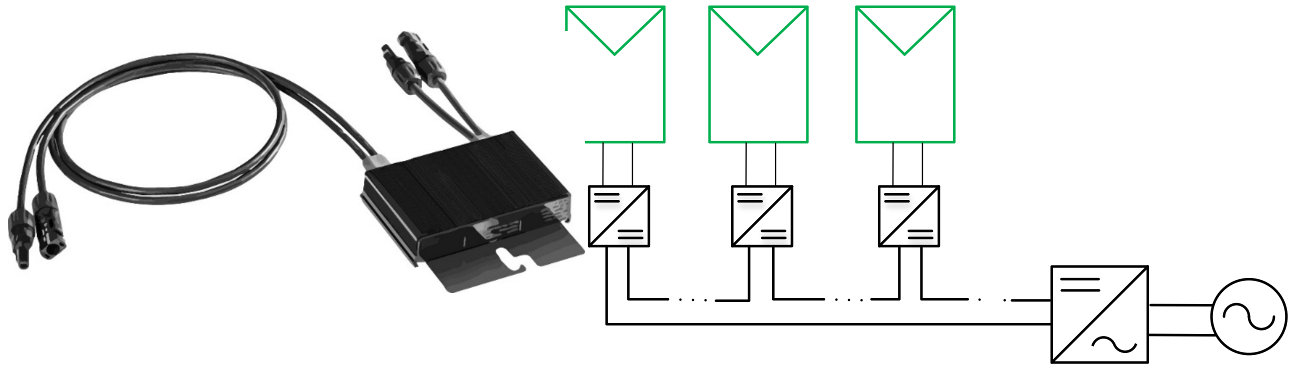
DC optimizers

- Mpp+DC converter pr moduler
- Output connected to an inverter
- Open and closed configurations

Challenges:

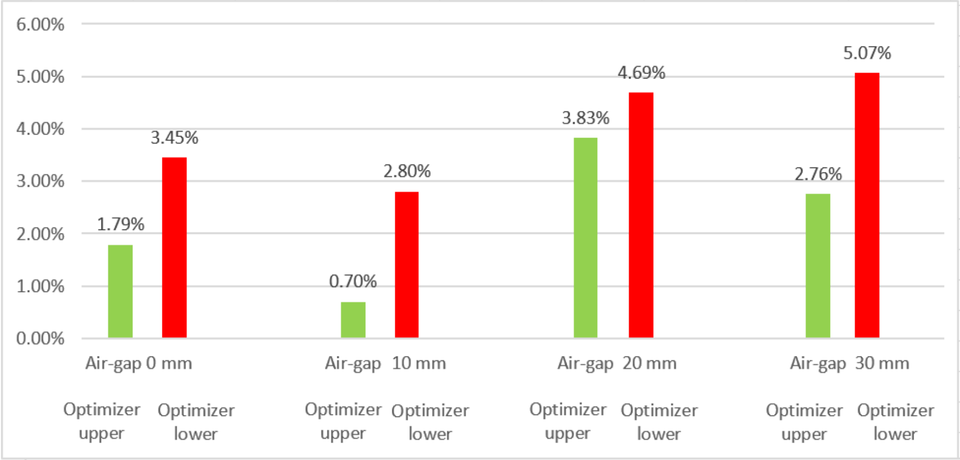
- How are the performing in real installations?

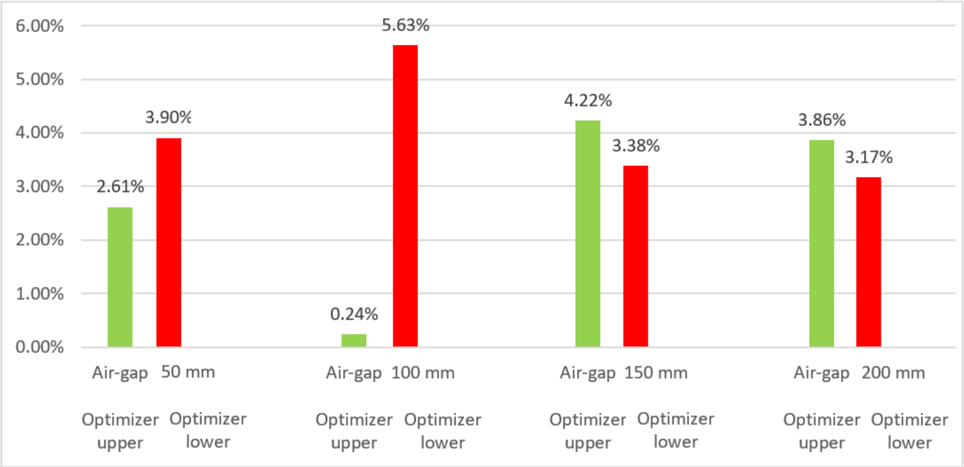


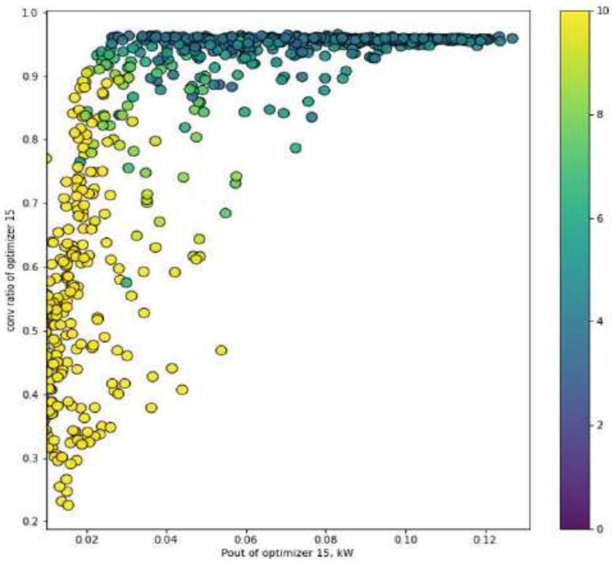


Preliminary analysis og optimizers from field test

- Performance of power optimizers
  - Datasheet efficiency 99 %
  - Measured Energy loss from test side up to 5%
  - Real performance depends on
    - conversion ratio and input power
  - More investigations ongoing



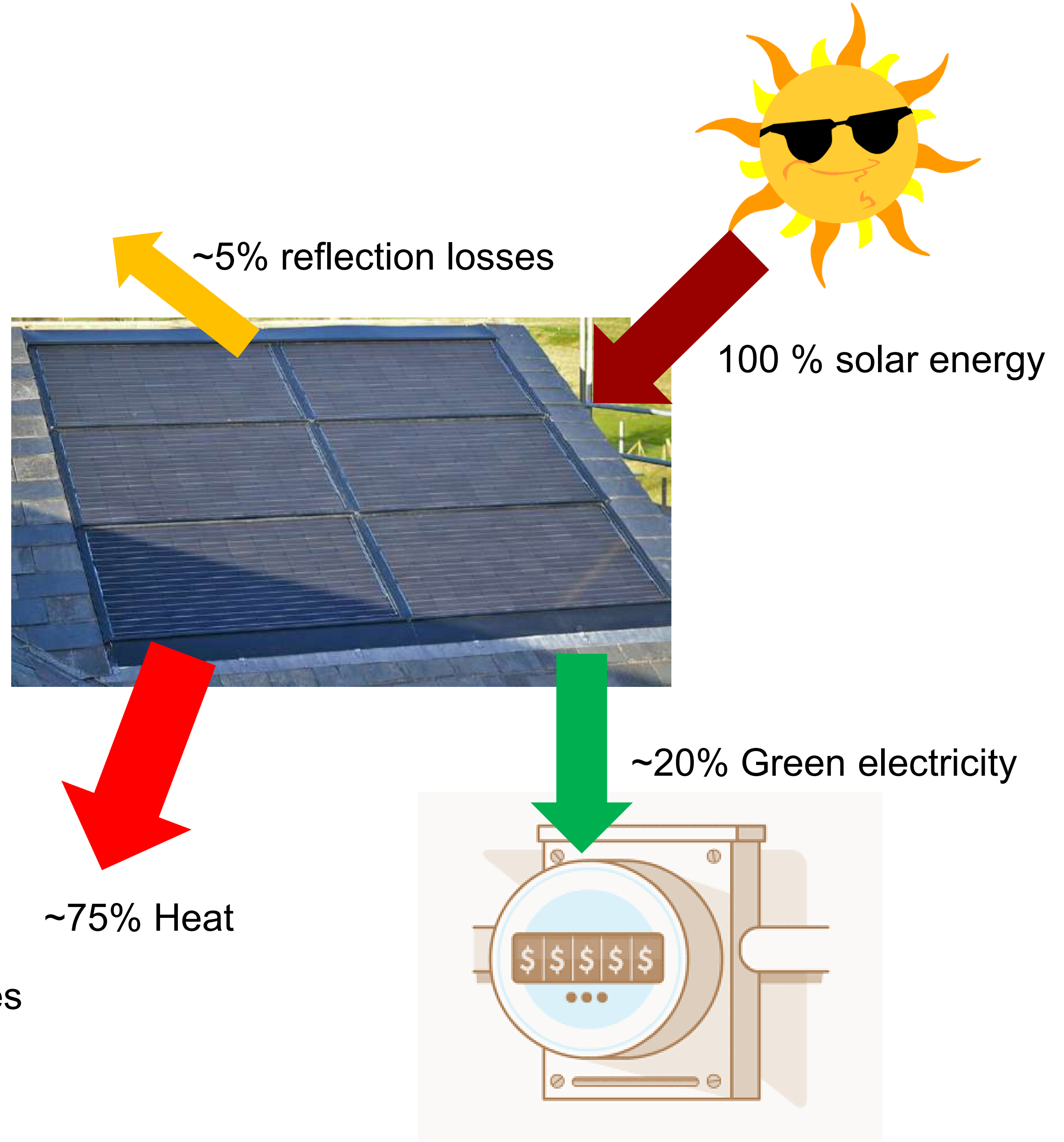




Operating temperatures

PV module temperatures

- Higher than ambient T
    - Convective heat transfer
    - (Radiative heat transfer)
- Depends on:
    - Irradiance
    - Wind speed
    - Airgap behind the module
    - (Module Efficiency)
- Increasing Temperatures
    - Reduces power
    - Stresses materials
        - Fabric based materials
            - Wind and moisture membranes
        - Softens adhesives



Operating temperatures

Our Measurements on vertical panels:

- Curtainwalls ~15 % eff cells
- Glass-Glass modules
- Back of module temp - not cell temp

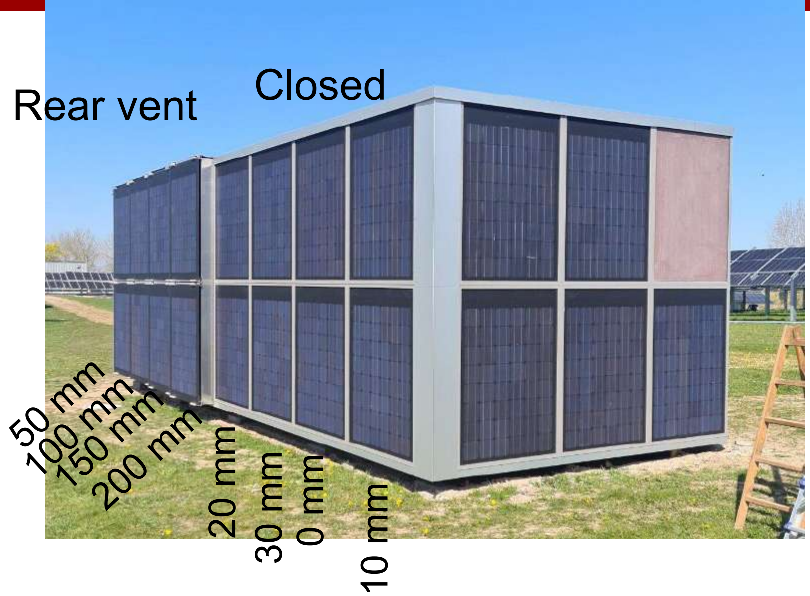
Results:

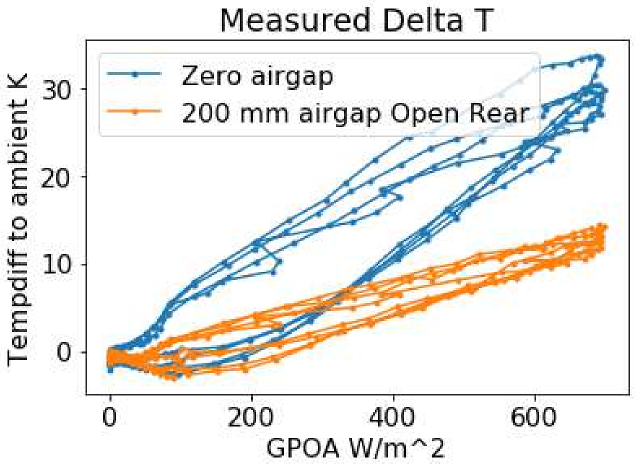
- Open rear side reduces Temperature
- Temperatures builds up through the column
- Closed airspace - same Temp
- Hysteresis from thermal mass

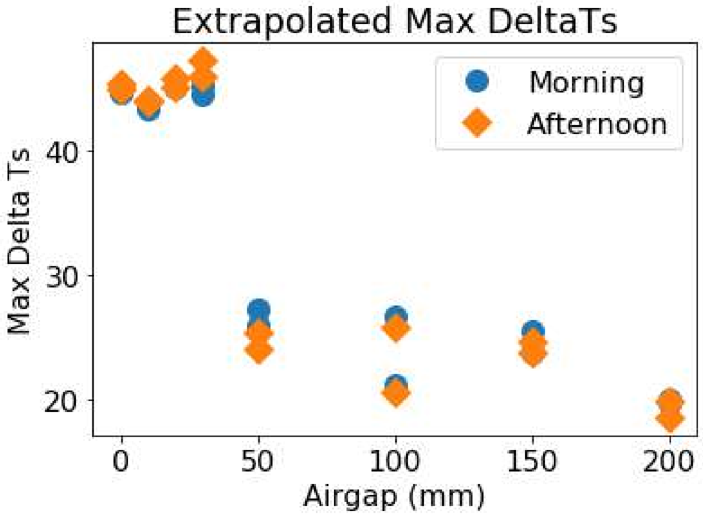
Delta T measurements

- E.g. T ambient 40°C
- Tmax without airgap=40+~47=87°C
- Could challenge inner materials

Different results on tilted panels







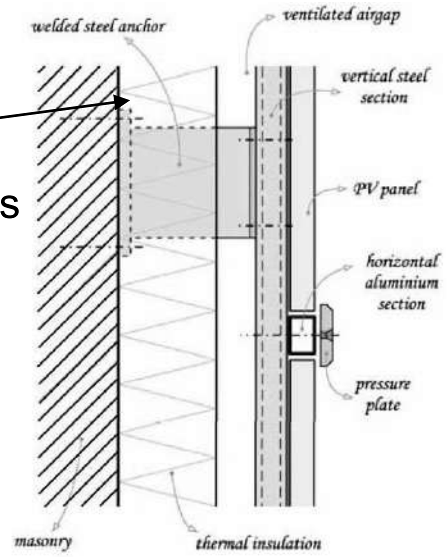
Construction and temperatures

Robust BIPV construction

- Temperature capabilities of rear construction
  - Thermal expansion
  - Degradation of fastners
    - Degradation of adhesives
    - Corrosion (also galvanic)
  - Fastening also for many years
    - On Facades: use metal for vertical mounted PVs
    - Adhesives exposed to wheather for 30-50 years!

Elevated temperatures behind the panel

Large temperature variations



Building process

Idea phase

Detailed Design phase

Permitting

Construction phase

Key delivery

Think BIPV from the start

Contract with arhcitect

Specification and design of subparts

Contract negotiations with main contractor

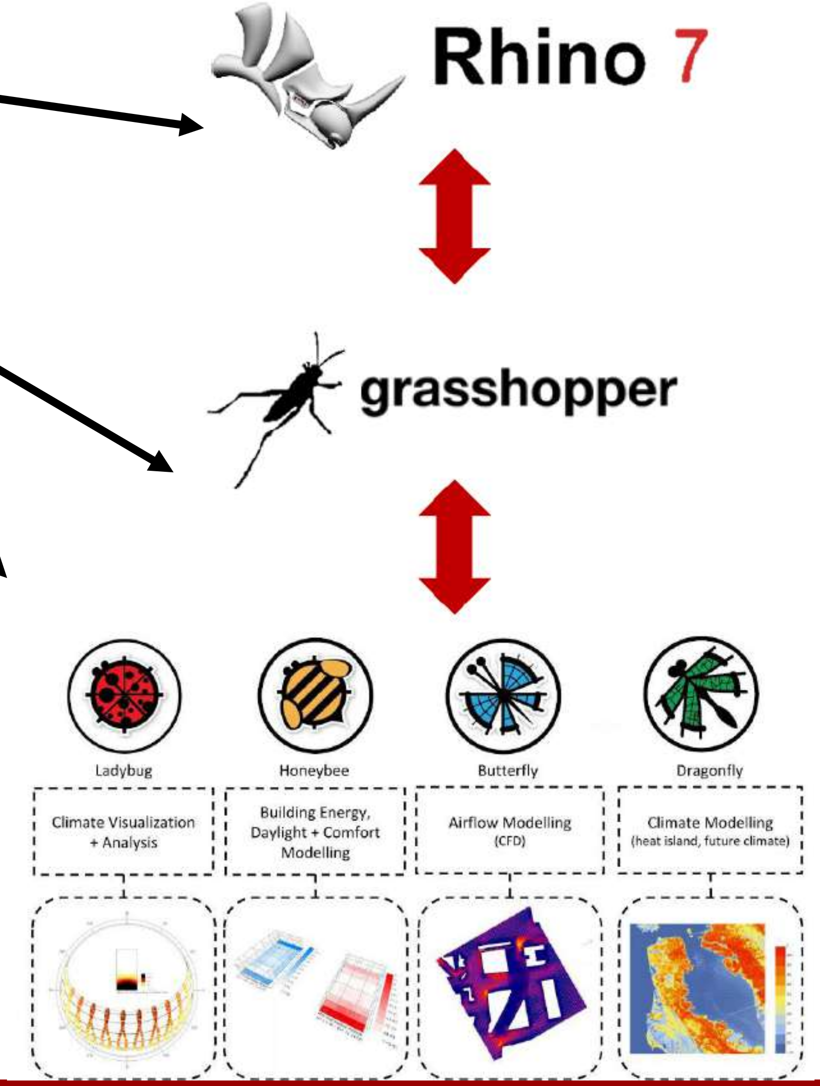
Construction phase planning

Subcontractor negotiation

Ordering parts - some made on special order

Building designers workspace

- **Drawing programs with used for building design:**
  - Sublayer with construction details:
  - Plugins for performance modelling
    - Building
    - Parts
  - So aim is collect everything in one program
- **PV data to be incorporated:**
    - Mechanical /geometric info
    - Electric parameters
    - Energy yield prediction
    - Appearance parameters
  - Ladybug uses mostly Pvlib (from NREL)
    - Uses CEC databases
    - Messy implementation
    - Limited model validation



Lifetime for BIPV

Two life times:

Construction product lifetime

- When does a the PV panel its function as construction product:
  - E.G water tightness
  - A glass plate – long lifetime, if fixings proper engineered

Electrical Lifetime:

- Also BIPV products are sold with the standard warranty
- Will likely produce elektricity longer

Conclusion

- BIPV is both a construction product and a power generator
- Marginal cost and absolute cost
- BIPV system topologies
  - 5 catagories
  - Dummies for adaption and passive areas
- Special challenges of BIPV
  - Temperatures
  - Partial shading
  - 2 lifetimes