Building integrated PhotoVoltaics (BiPV)

Lecture 1: Introduction to BiPV

Building integrated photovoltaics

Erasmus+

Course material developed in collaboration with Utrecht University, Fachhochschule Technikum Wien, University of Cyprus, Deloitte, WIP

with support from Erasmus+

Content BiPV-material

- 2 weeks

- 4 lectures
  - Introduction & PV-principles
  - Influence on electricity performance
  - BiPV vs. conventional constructions & LCA
  - Market development & Aesthetics

- 4 corresponding tutorials

Content of the lecture

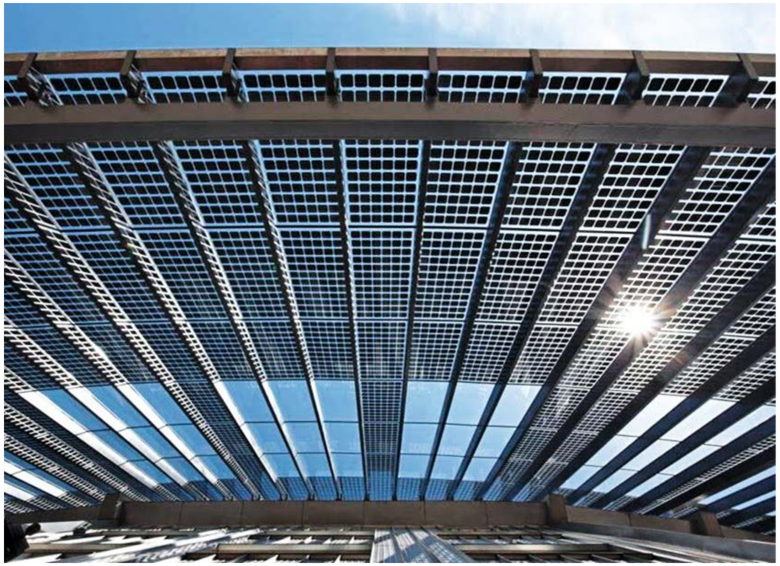
1. **Introduction**
    a. **What is BiPV**
    b. Examples
    c. Advantages and barriers
2. Photovoltaic solar energy
    a. Solar Energy
    b. Photovoltaic effect
    c. Solar cells
    d. PV systems

What is BiPV?

PV-system integrated in the building envelope.

The system converts solar energy into electricity and it takes over (part of) the functions of the initial construction material.

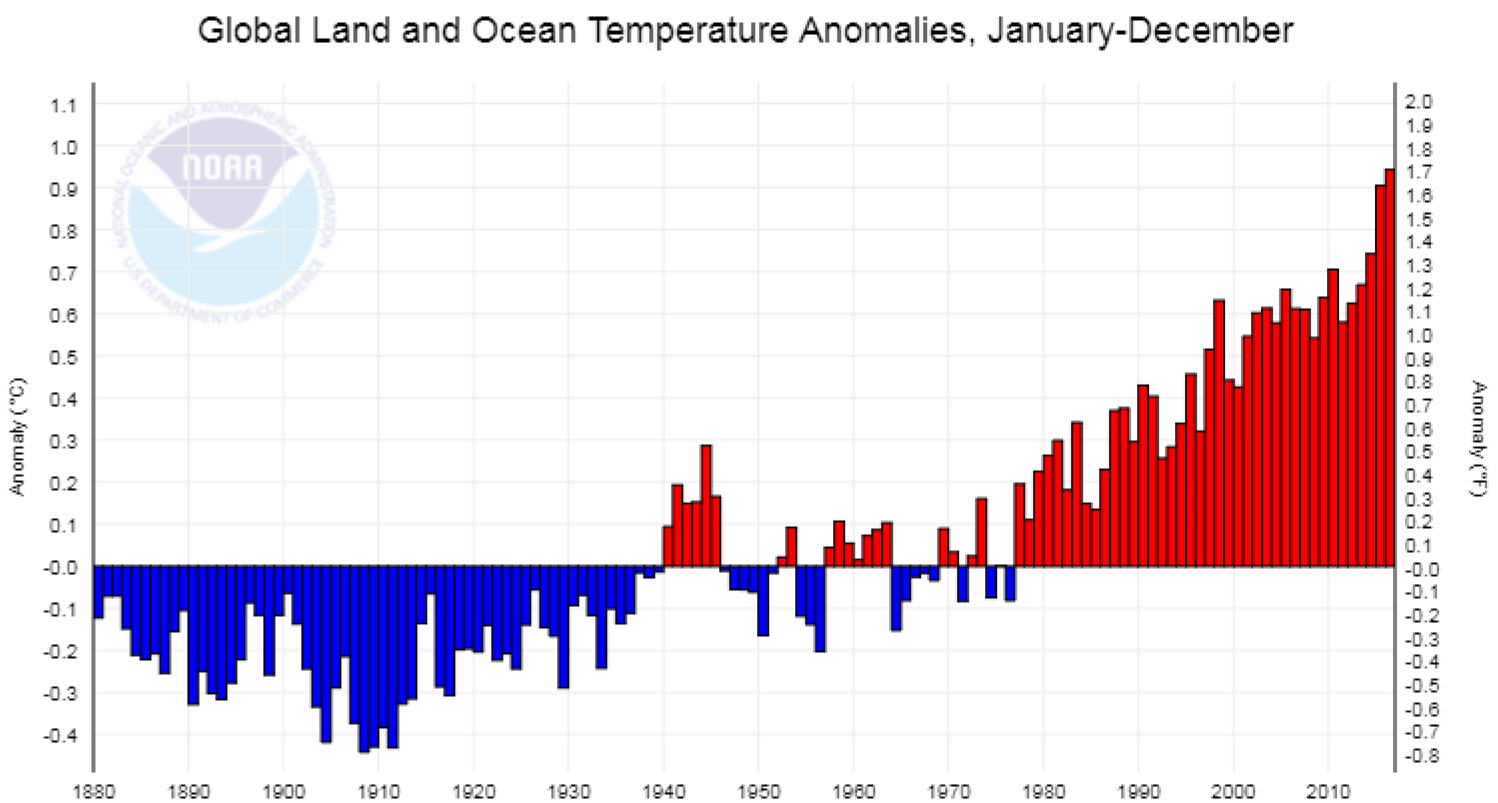
This can be either on the roof or as facades.



SolarBuildingTech, n.d.; Schüco, 2014

Relevance

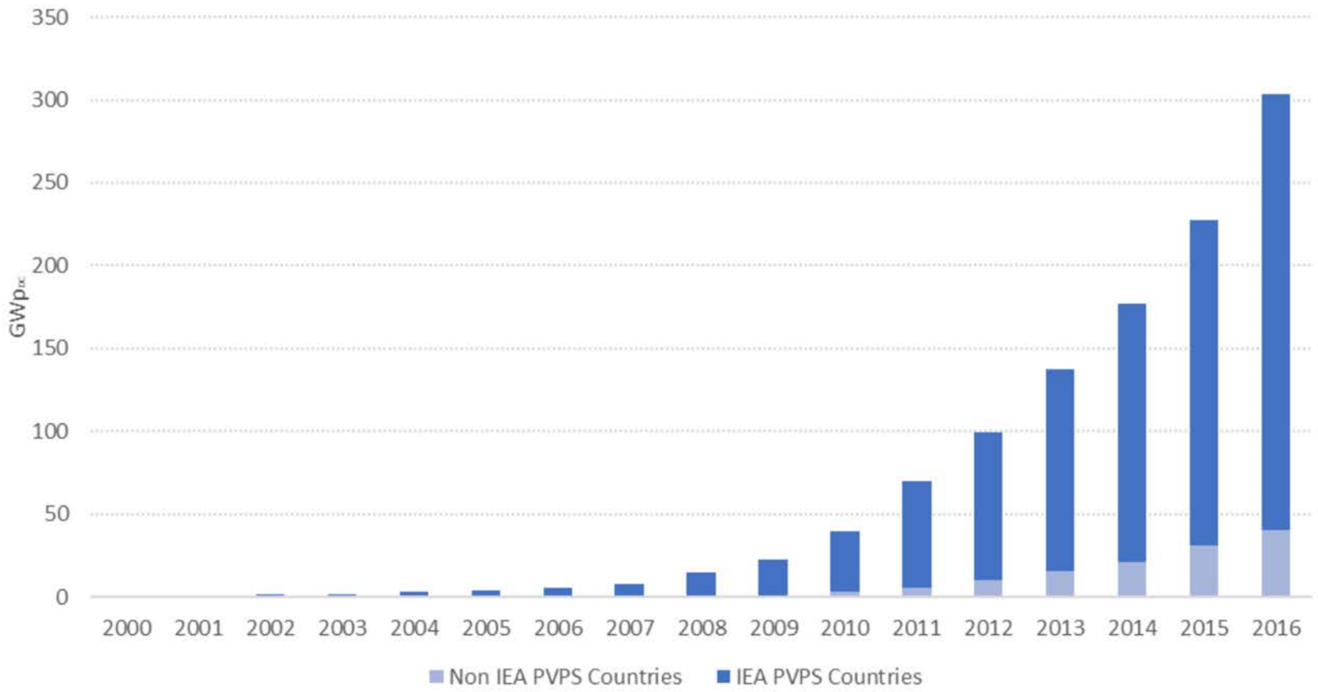
Cli



NOAA, 2018

Relevance

Photovoltaic electricity generation:



IEA PVPS, 2016

Relevance

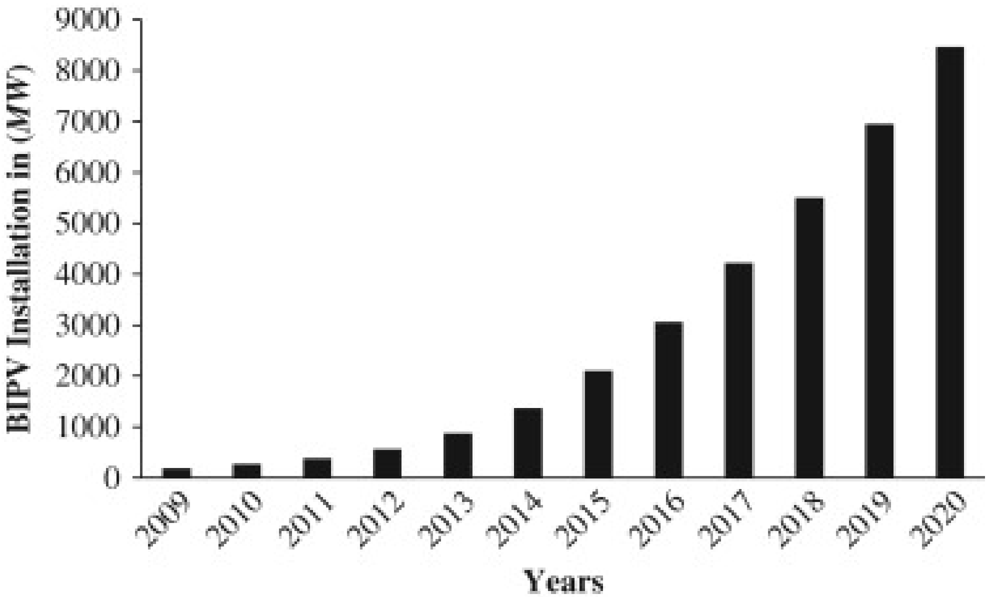
BIPV:

Logistic reasons:

- Lack of available area (densely populated areas)
- No/less dependence on the electricity grid

Regulatory reasons:

- European Commission: nZEB – directives
  - All new buildings must be near Zero-Energy Buildings by 31 dec. 2020
- Dutch government: Energielabel
  - All Dutch offices will have at least an ‘energielabel C’ (scale A-G) in 2023



Tripathy et al., 2016

These new regulations caused more optimistic forecasts for BIPV-generation.

BiPV vs. BaPV

Building integrated PV vs. Building applied PV

BiPV replaces the initial construction material and thereby BiPV takes over its functions, BaPV is installed on top of the initial material and its function are thus limited to solar energy production only.

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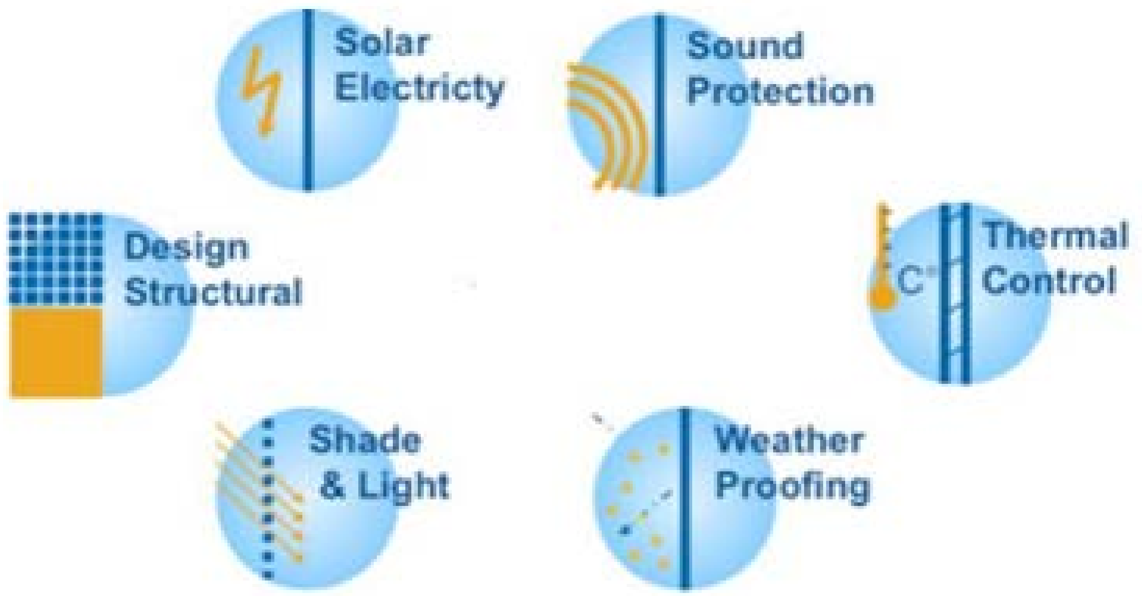
Functions of BiPV

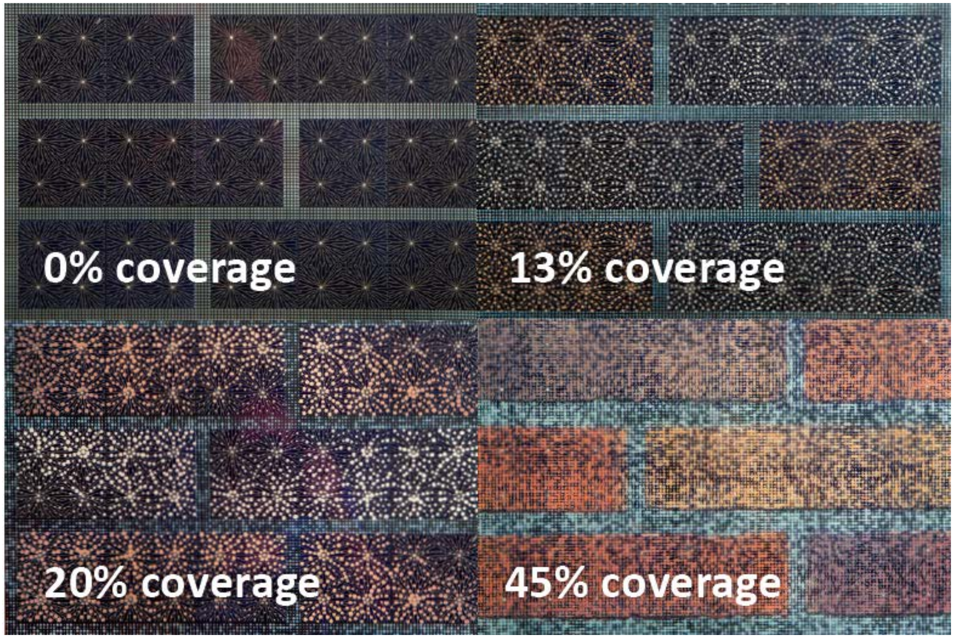


University of Cyprus

Shading & Light

PV-sunscreen (BISEM, 2012)

Aesthetics



DSD PV: PV modules partly covered with a full color print (ECN).

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Examples

Full Roof Solution

Zanetti et al., 2017

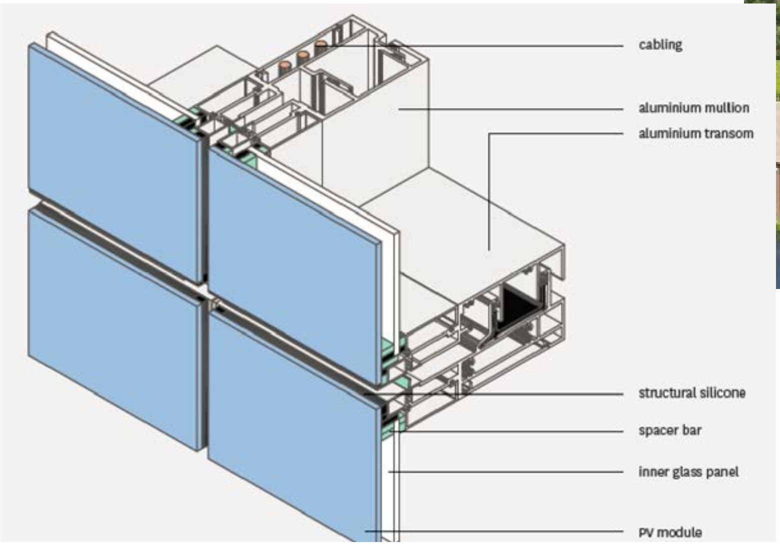
Examples

PV roof tiles

Zanetti et al., 2017

Examples

Curtain Wall (warm facade)

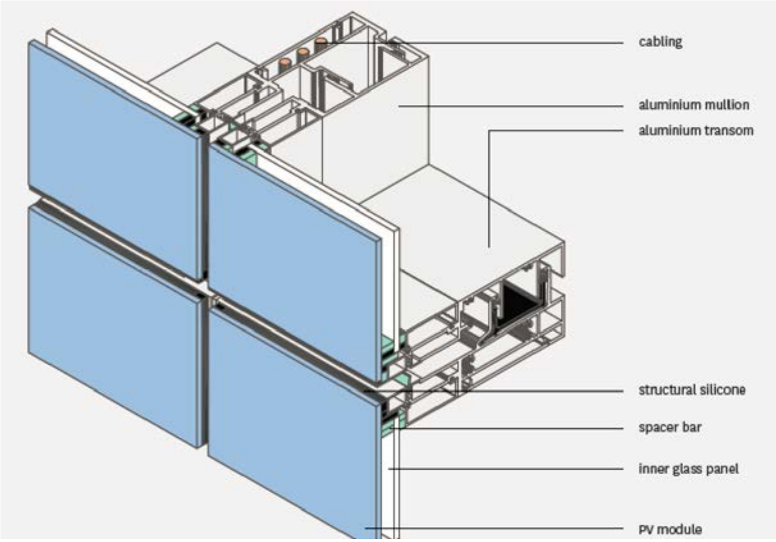


Onyx, 2017

Examples

Curtain Wall (warm facade)

- PV modules can be **integrated** into unitised curtain wall systems either **in the vision** area or **in the spandrel area** of the facade.
- Single or double-glazed units can be **replaced** by **clear** or **opaque**, **single-** or **double-glazed PV** modules. Installation for PV is comparable as for ordinary glass.



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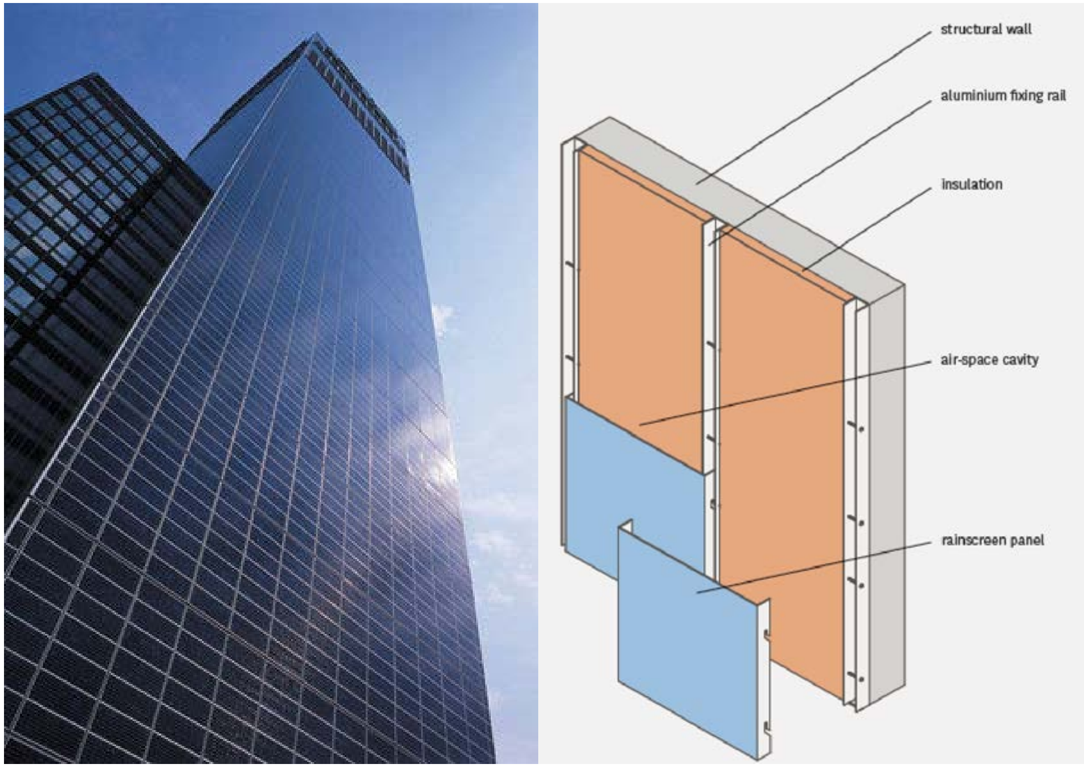
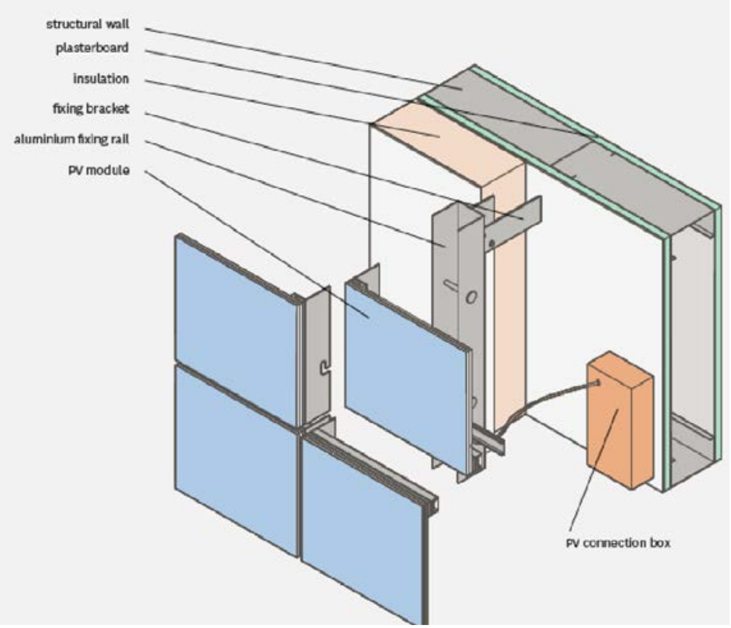
Examples

Curtain Wall (cold facade)





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Cameron, 2007

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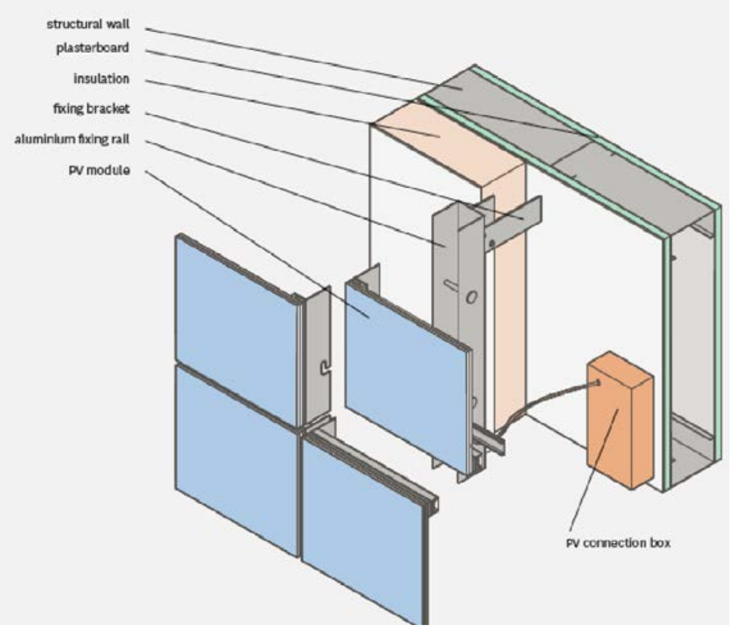
Examples

Curtain Wall (cold facade)

- **Rainscreen over-cladding** systems offer a very good opportunity for the **integration** of PV modules.
- In the case of existing cladding technology, **no major modification** would be needed to incorporate solar modules.
- Furthermore the **ventilated cavity** contained within the system would help to keep the **operating temperatures** of the PV cells down to some degree



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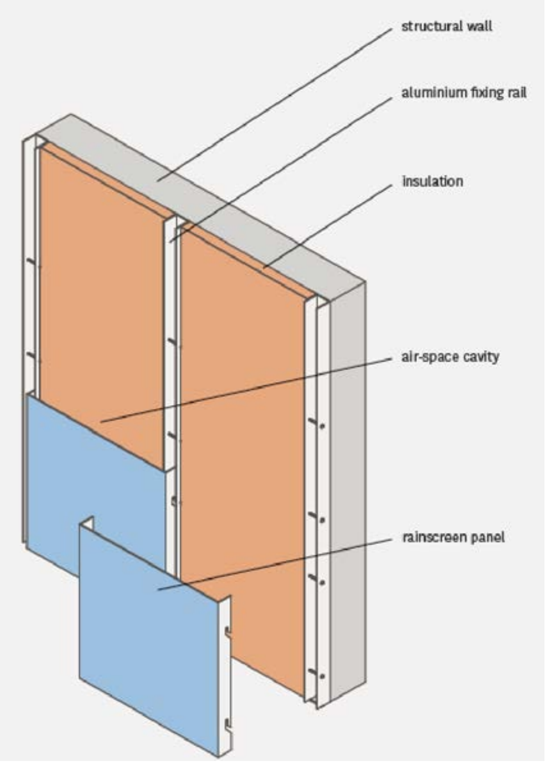
Examples

Curtain Wall (cold facade)

- The **inner** structural leaf or **backing wall** can be built of any material, for example concrete or brickwork.
- A **layer of insulation** is provided on the outside of the backing wall, finished off with a vapour barrier on the warm side (on the inside in a typical) and possibly a **breather-type waterproofing membrane** on the cold side of the insulation (on the outside).
- **Vertical cladding rails** or fixing **brackets** are bolted onto the backing wall ready to receive the outer rainscreen panels.



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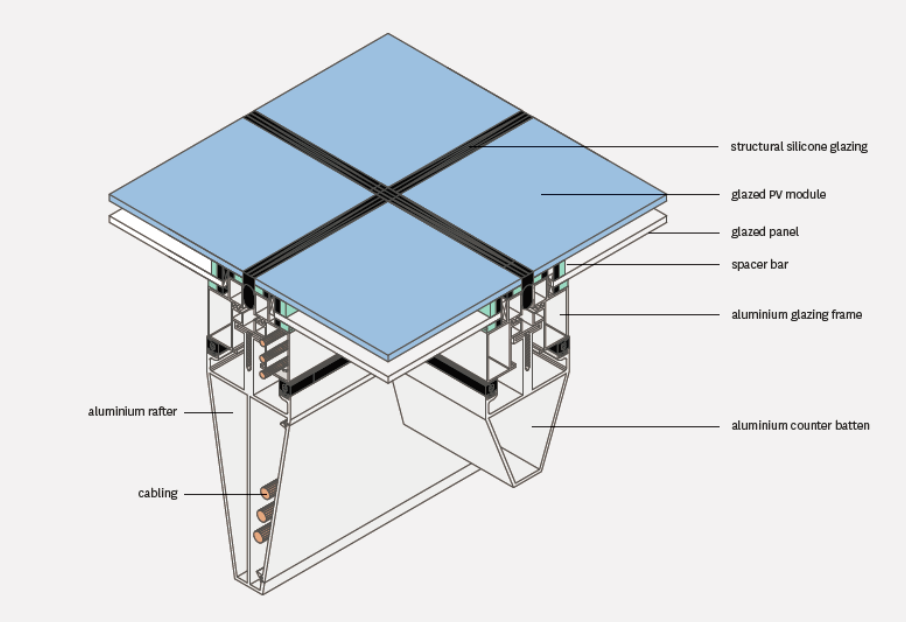
Examples

Skylight/Canopy

Onyx, 2017



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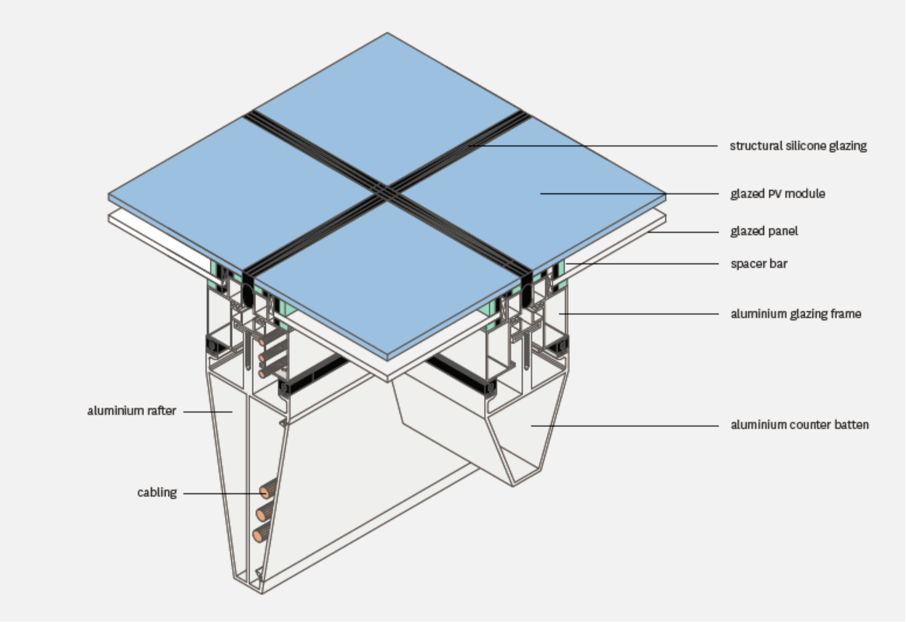
Examples

Skylight/Canopy

- Construction of glazed skylights can **be based on stick curtain wall system** and **unitised curtain** wall system.
- The **double-glazed units** can be **replaced** by **clear** or **opaque PV modules**, preferably double-glazed. An additional outer lite can be installed for solar control, high performance coatings and low emissivity
- The **mullions** acting as rafters and the transoms acting as counter battens **transfer the vertical loads** (dead load, wind, snow, maintenance) to the main structure.



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1. Introduction
    a. What is BiPV
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    a. Solar Energy
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2 questions:

What are potential advantages of BiPV?

What could be the disadvantages/barriers for BiPV?

Advantages:

- Lower costs
- No rural/unoccupied area required
- Electrically self-sufficient
- Lower electricity losses
- Increased aesthetics
- Decreased heat-transmittance
- Decreased harmful irradiance
- Internal shading
- Creating awareness for BiPV
- Interesting marketing-strategy

Improved internal environment

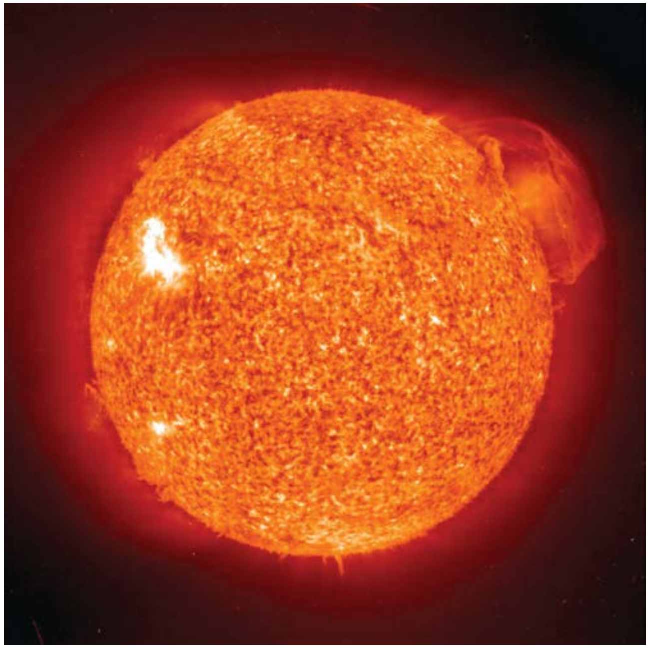
Disadvantages/Barriers

- Lower electricity performance
  - Cell-efficiency fetish
- (Partial)-shading
- BiPV is experienced as ‘too difficult’
  - Shortage of specialists
- Critics on aesthetics

Introduction to Photovoltaic Solar Energy

From

To



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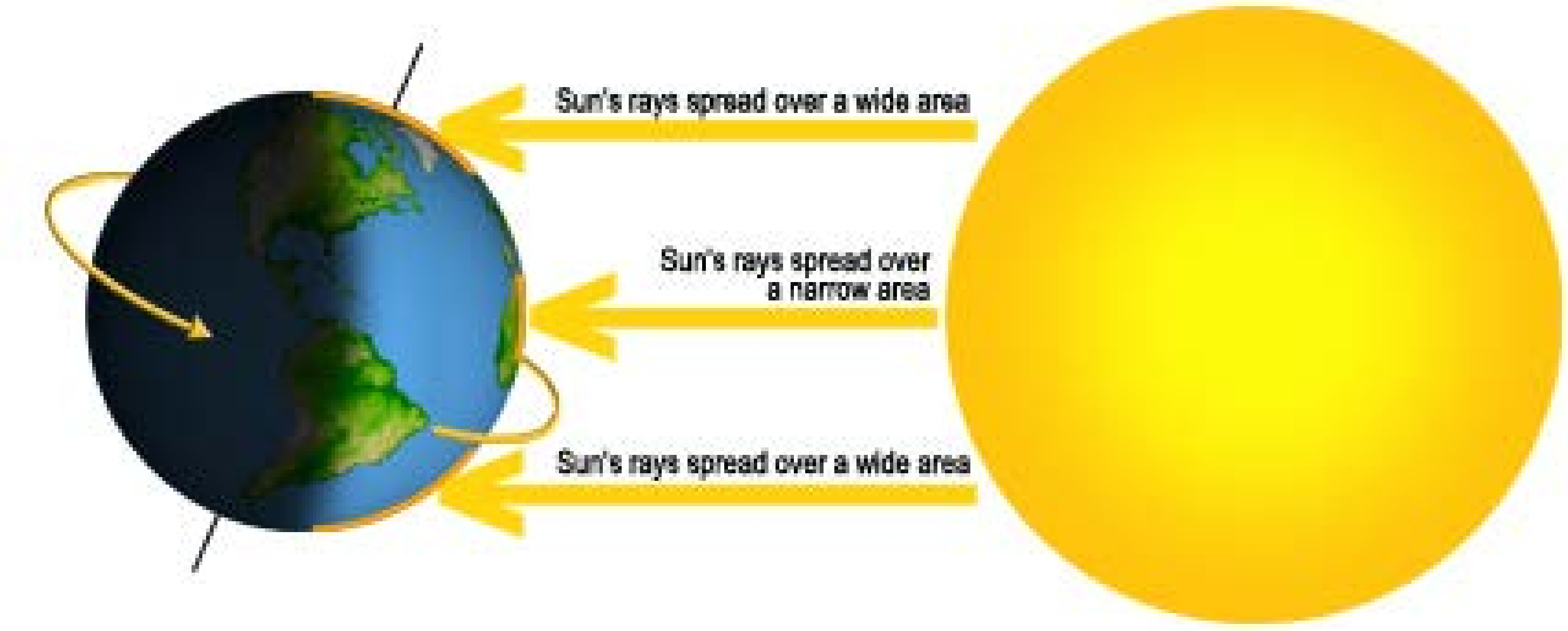
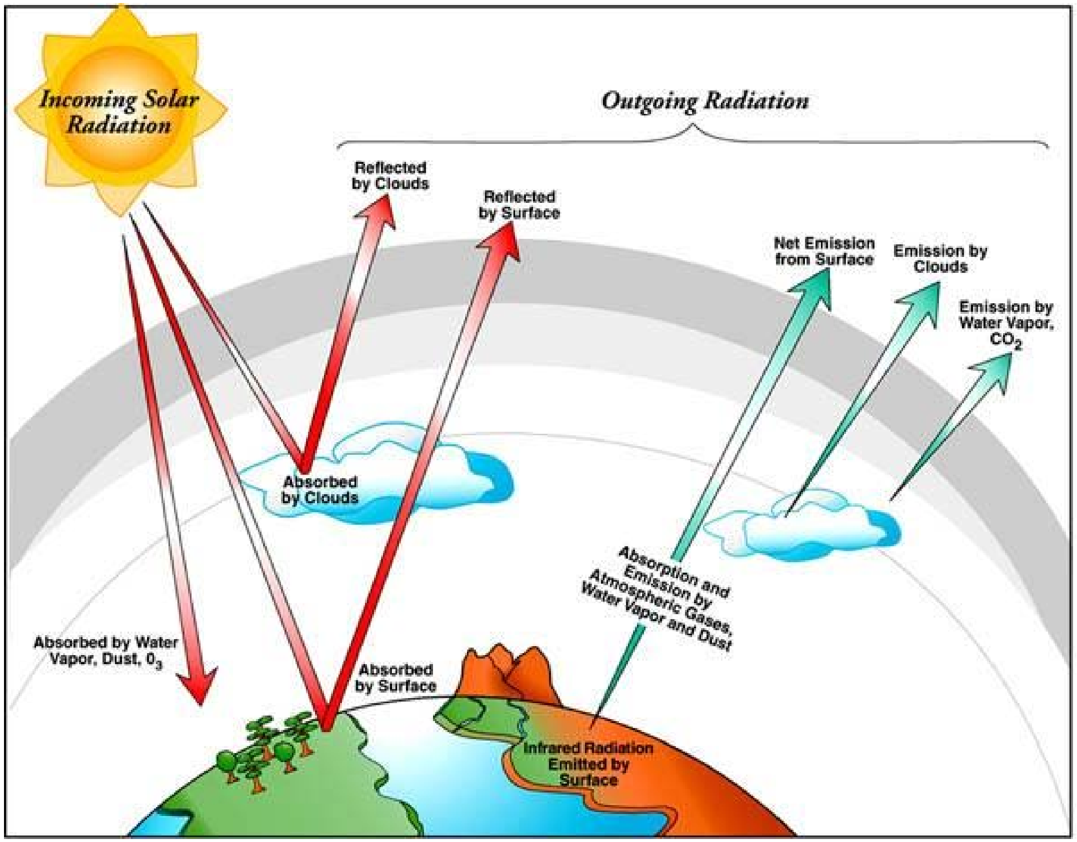
Solar Energy- Seasonal differences



USRA, 2018

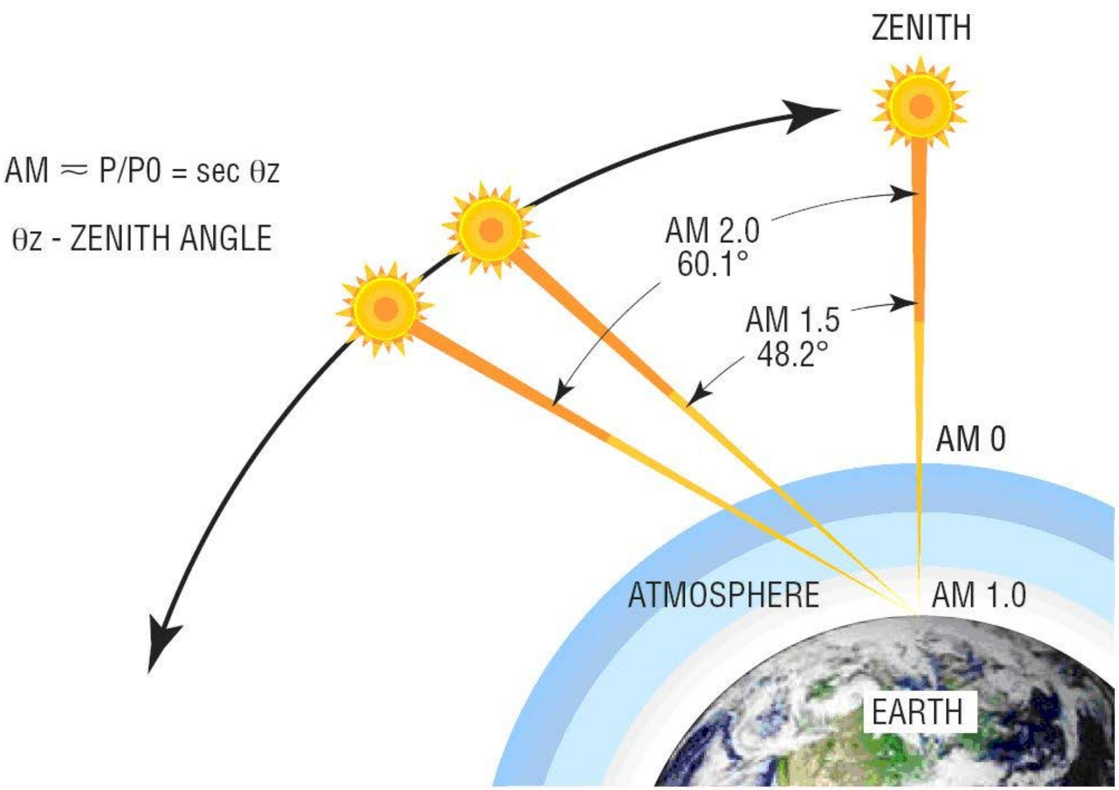
Solar Energy - Effect of Atmosphere



- Solar energy passes through a certain amount of Air Mass before it reaches the earth's surface

Source: Steve Ackerman and John Knox. US Department of Energy (ARM)

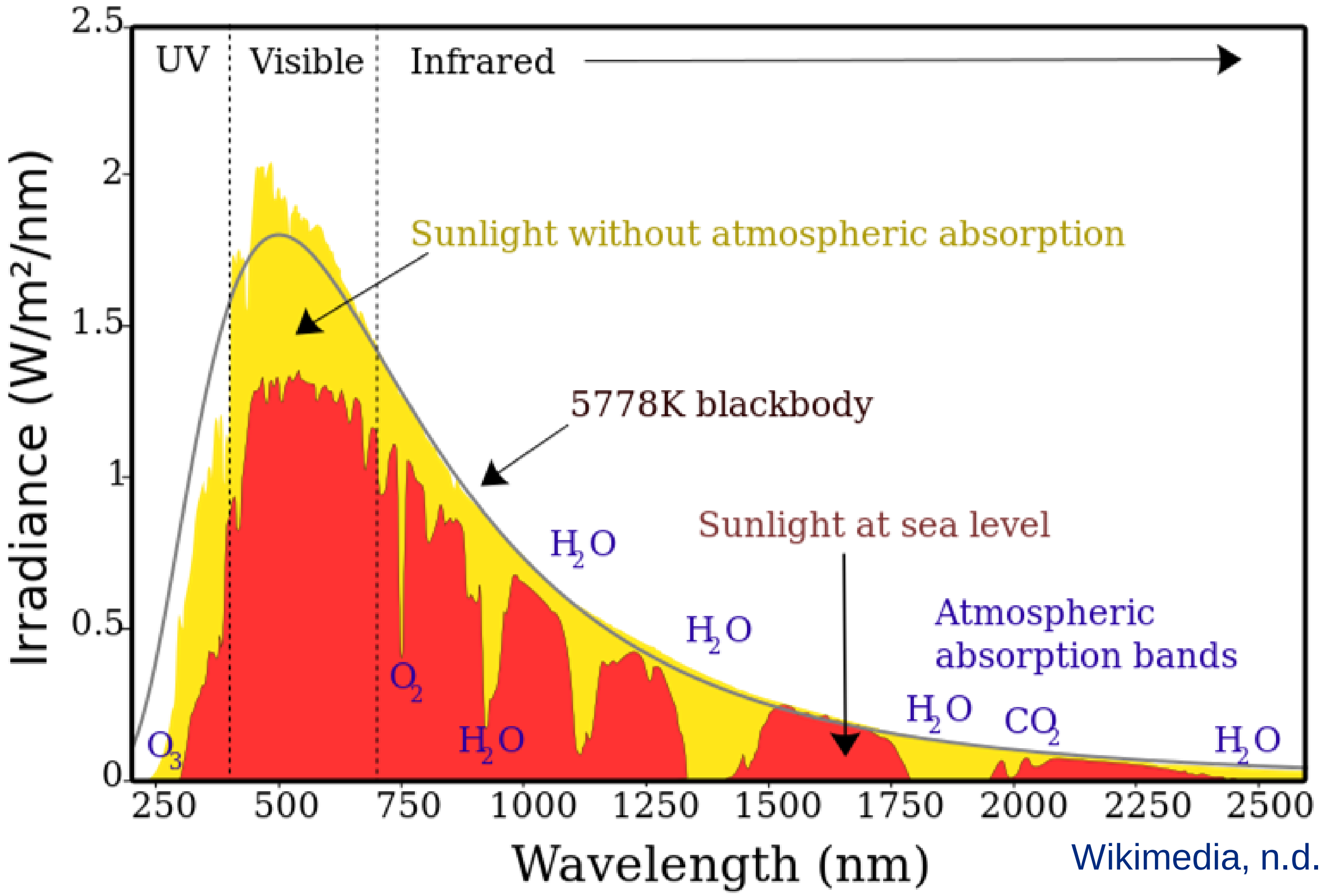
Solar Energy - Effect of Atmosphere



- Straight to the equator = AM 1
- Europe in summer ≈ AM 1.5 = Standard Test Condition (STC)

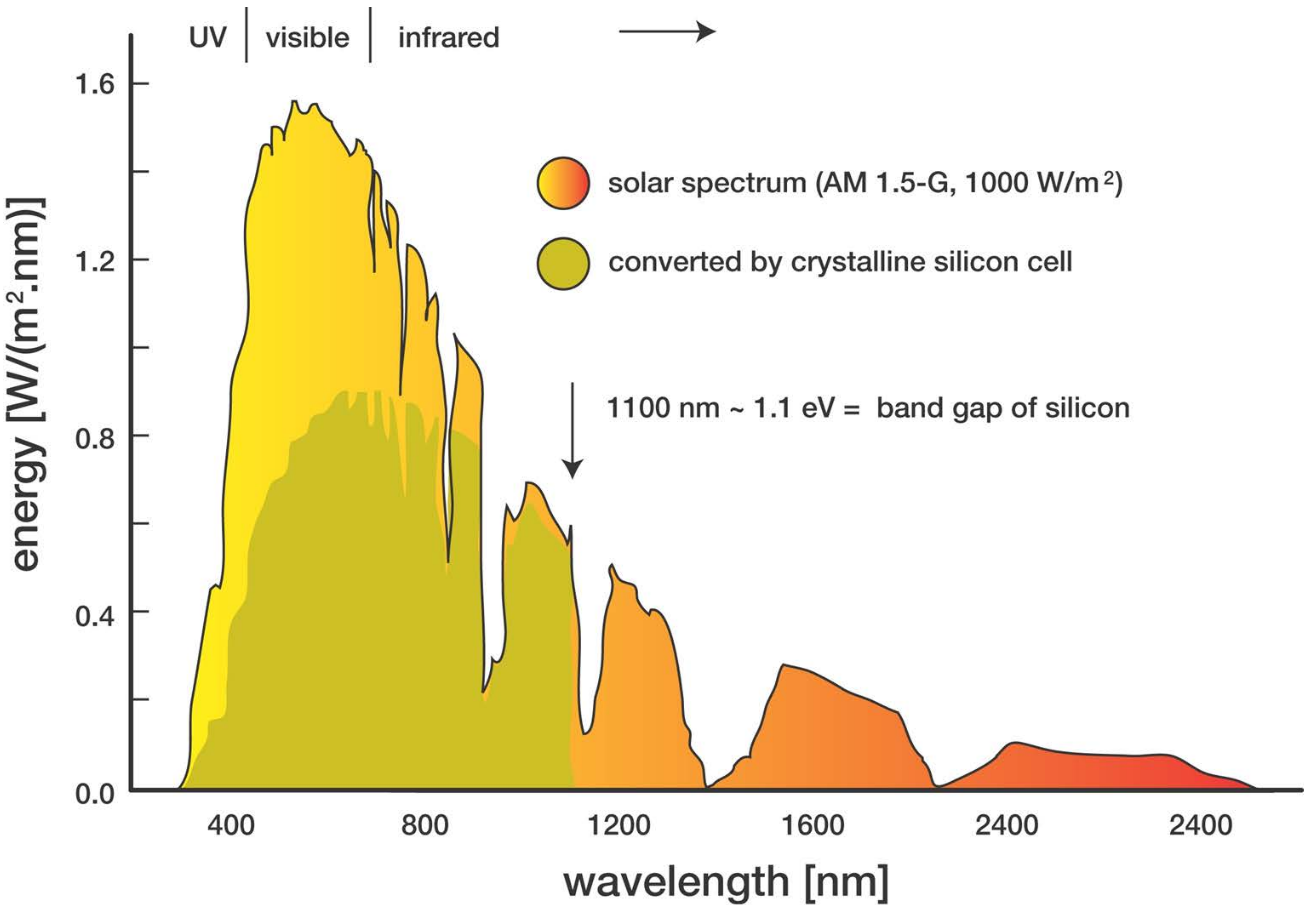
Jeong, 2014

Spectrum of solar irradiation



Wikimedia, n.d.

Available for cSi PV



Wu et al., 2011

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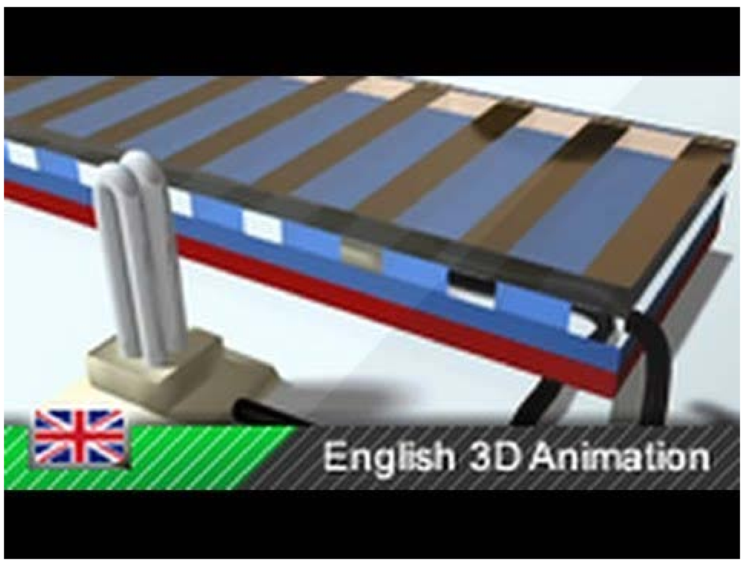
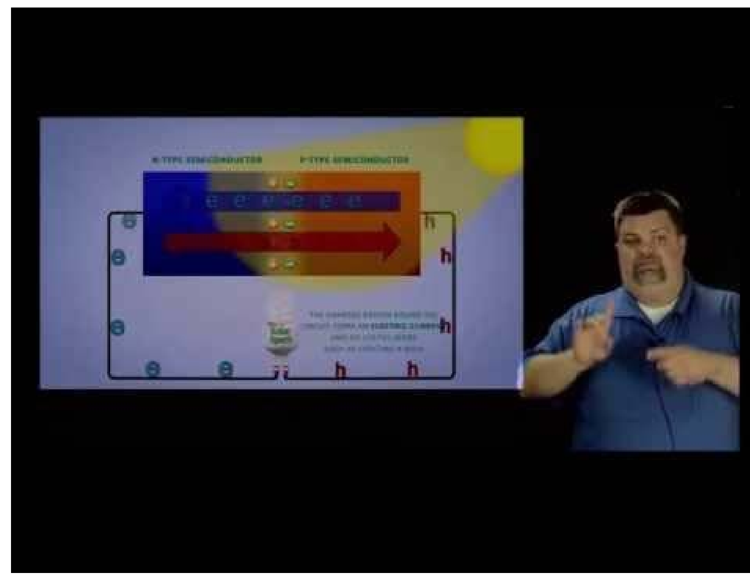
Photovoltaic effect basics

Watch the following video’s to understand semiconductors and the photovoltaic effect.



The Green Translation Service, 2011

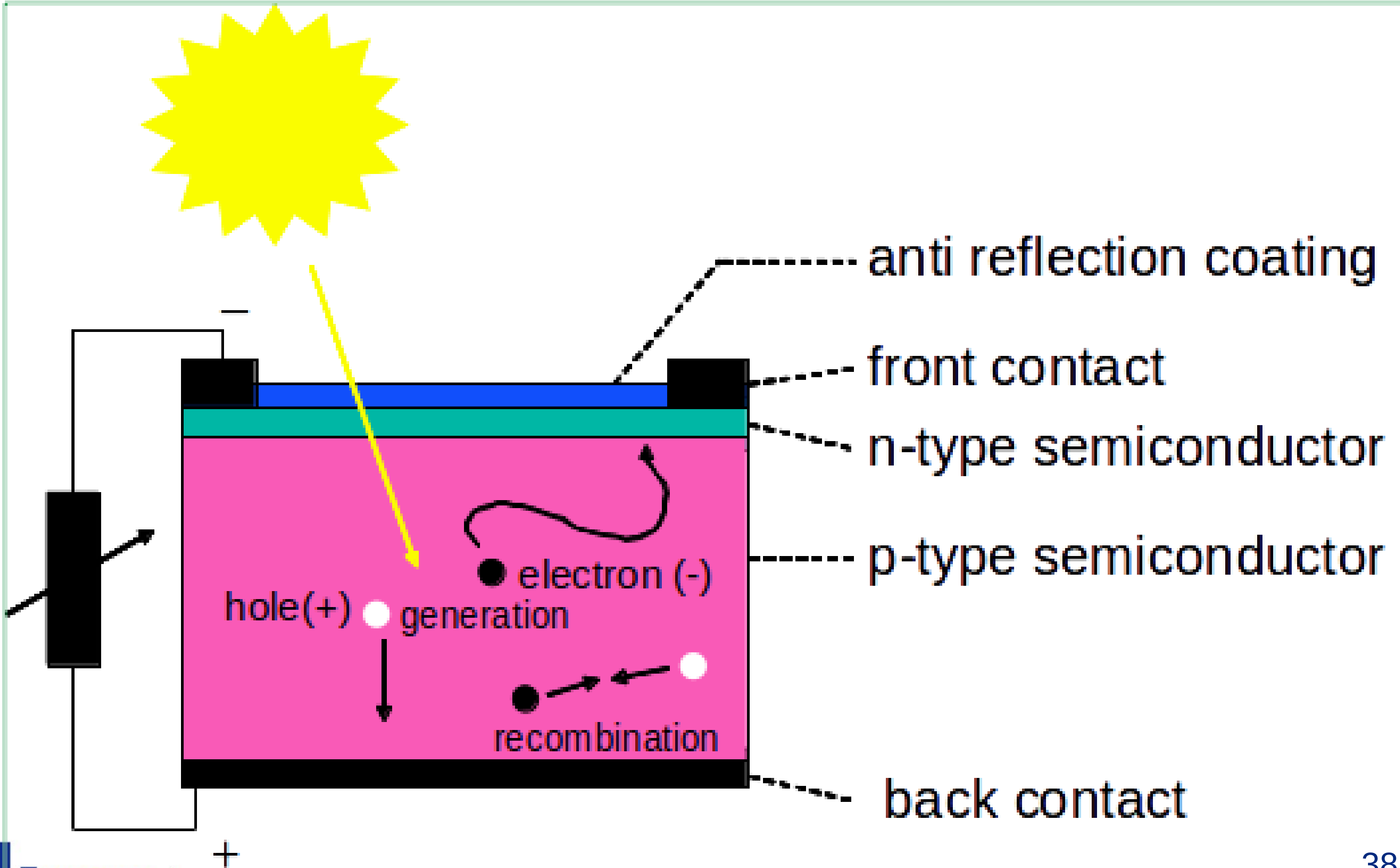


Adams, 2014

Photovoltaic effect basics

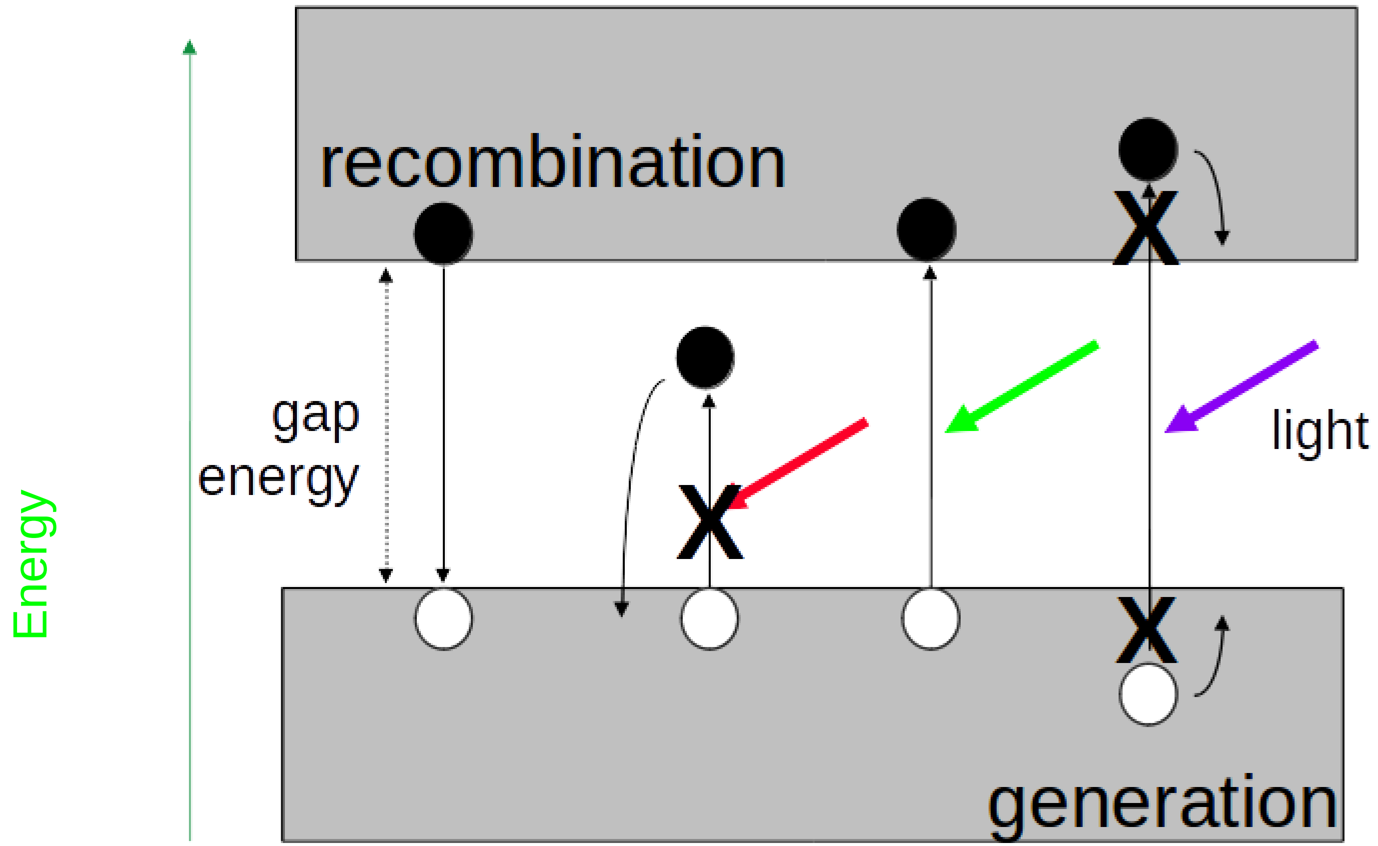
- Material used is a semiconductor (commonly Silicon)
- Using light, electrons are released from their atoms and become mobile carriers (electron - hole pairs)
- Electrons have to cross an energy gap (band-gap, material specific)
- By making additions to the pure semiconductor, an electronic structure is created that separates and directs mobile carriers
- Electron - hole pairs recombine after flowing through an external circuit

Basic process of photovoltaic conversion



gap
energy

Losses in photovoltaic conversion



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Solar cell operation

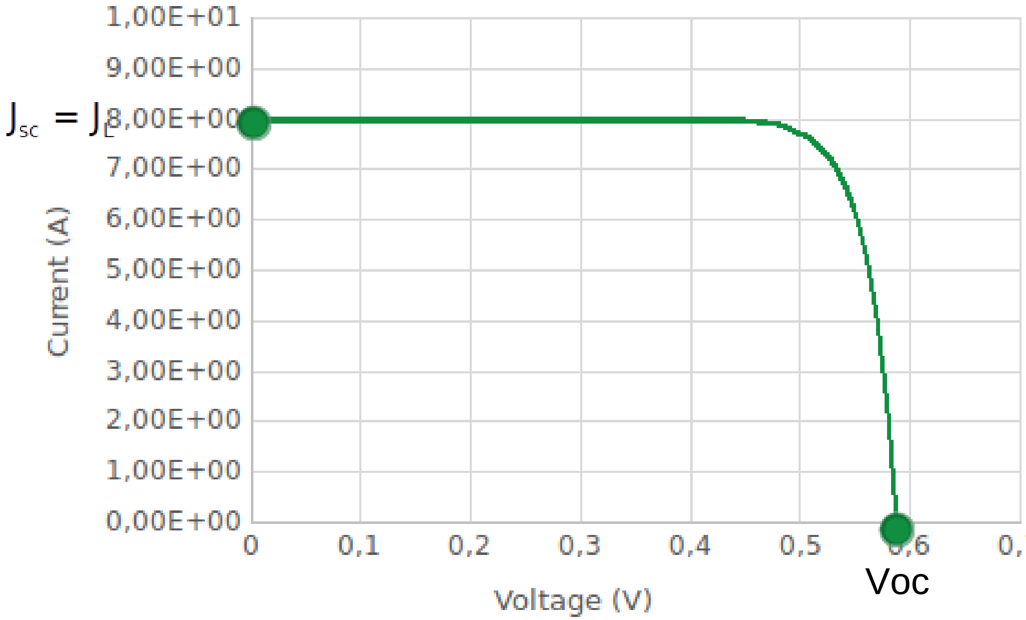
- Under illumination solar cells generate electrical current
- Cells have a built-in voltage due to the electronic structure (p-type and n-type)
- Current is mostly linear with light intensity
- Voltage is logarithmic and affected by temperature

Solar cell operation

Operation described by:

$$J = J_0\left(e^{qV/kT} - 1\right) - J_L$$

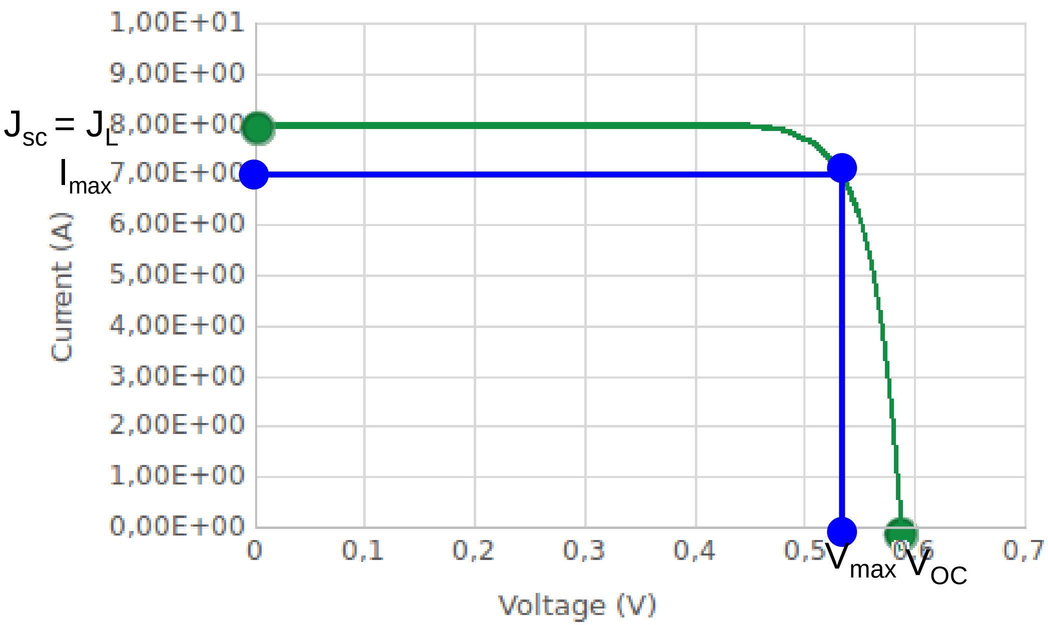
$$V_{OC} = \frac{kT}{q}\ln\left(\frac{J_L}{J_0} + 1\right) < E_{gap}$$



Utrecht University

IV-curve of typical Si cell

- $P_{max} = I_{max} * V_{max}$
- Varies with cell temperature, irradiance etc.
- MPPT to operate the cell at maximum efficiency



Utrecht University

From Cell to Panel (or module)

A typical cSi solar cell has an output voltage of around 0.5 V at its maximum power point.

How do we get from here to a solar panel?

Typical solar panel

JA Solar JAP6-60 270

- 60 Cells (6 x 10)
- Rated maximum power @STC: 270 W
- Max Power Voltage (Vmp): 31.21 V
- Max Power Current (Imp): 8.65 A
- Open Circuit Voltage (Voc): 38.30V
- Short Circuit Current (Isc): 9.16 A

STC

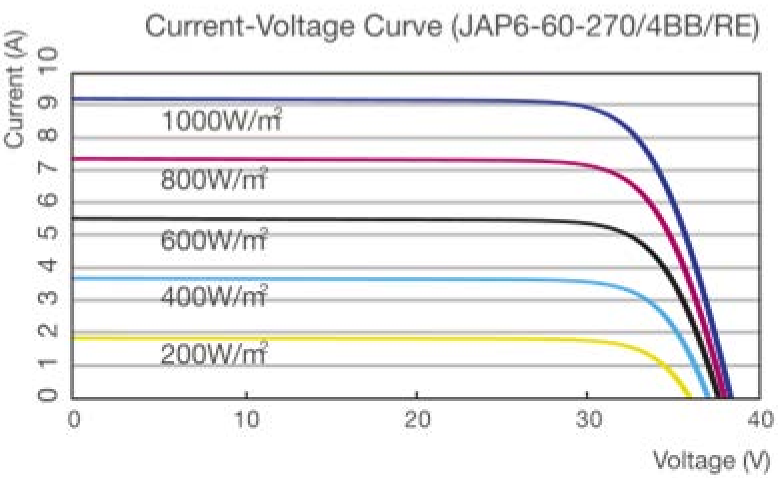
Irradiance of 1000 W/m^2

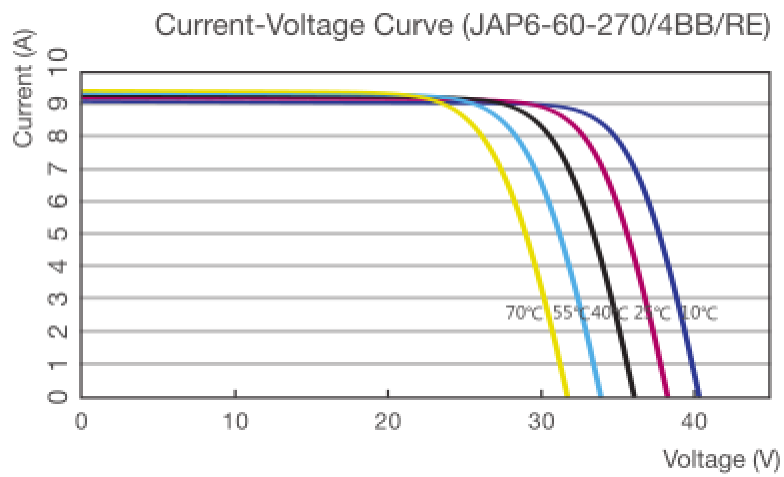
Cell temperature of 25 C

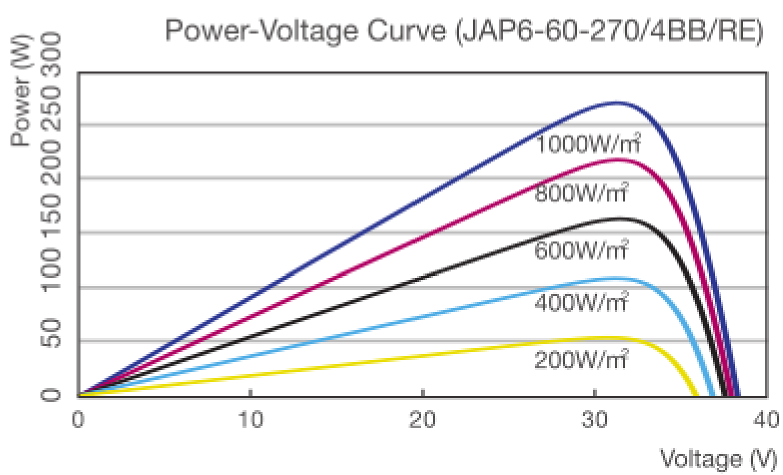
Air Mass 1.5

Source: JAsolar, 2016

IV-characteristics of solar panel







JASolar, 2016

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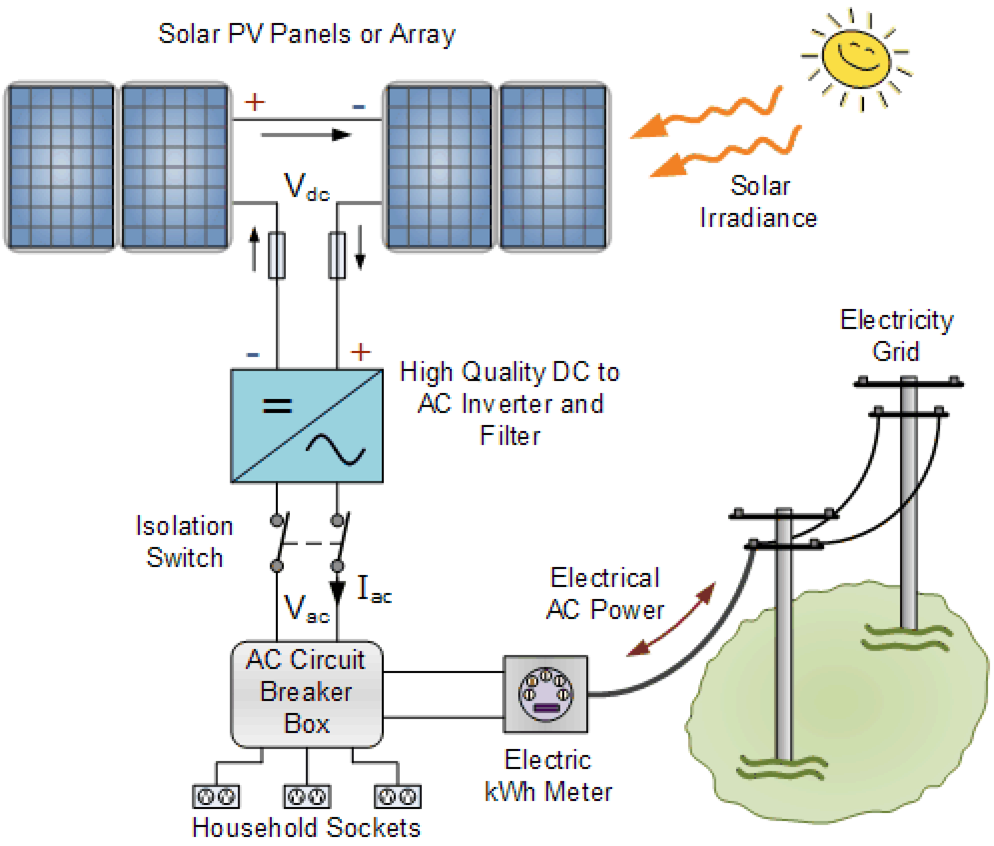
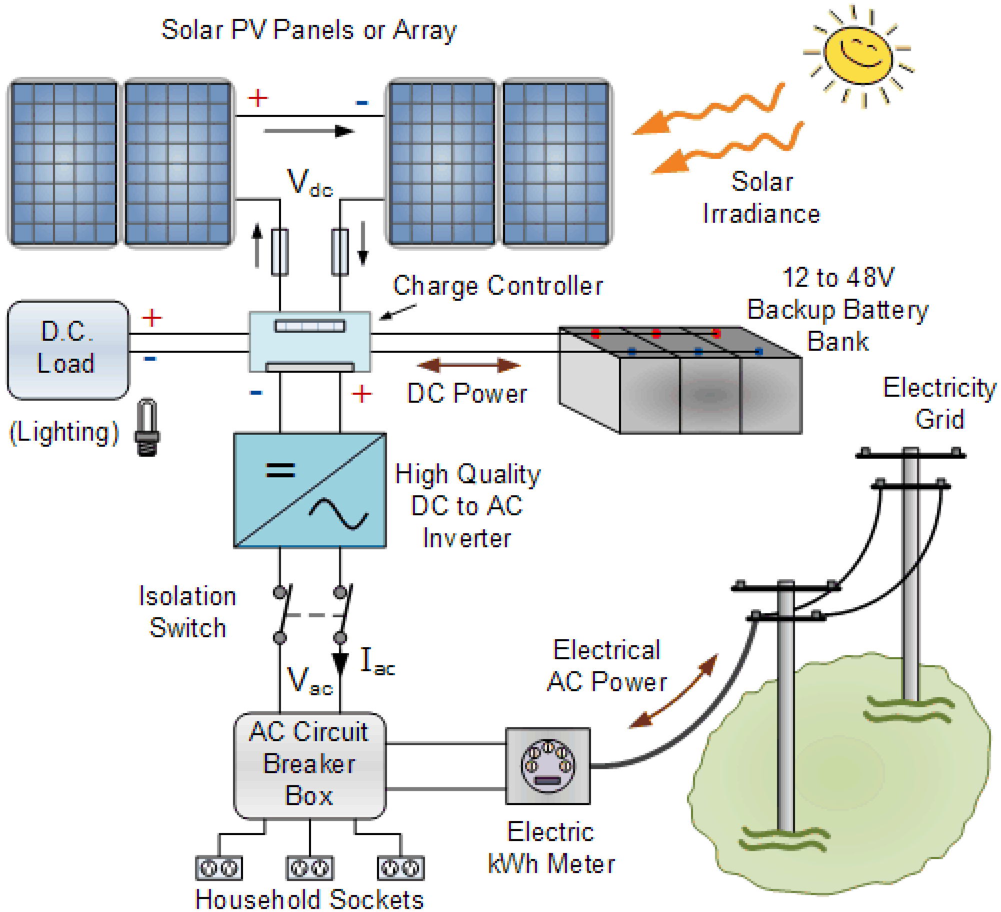
Grid connected PV System



Alternative Energy Tutorials, 2013

Grid Connected PV System with battery storage



Alternative Energy Tutorials, 2013

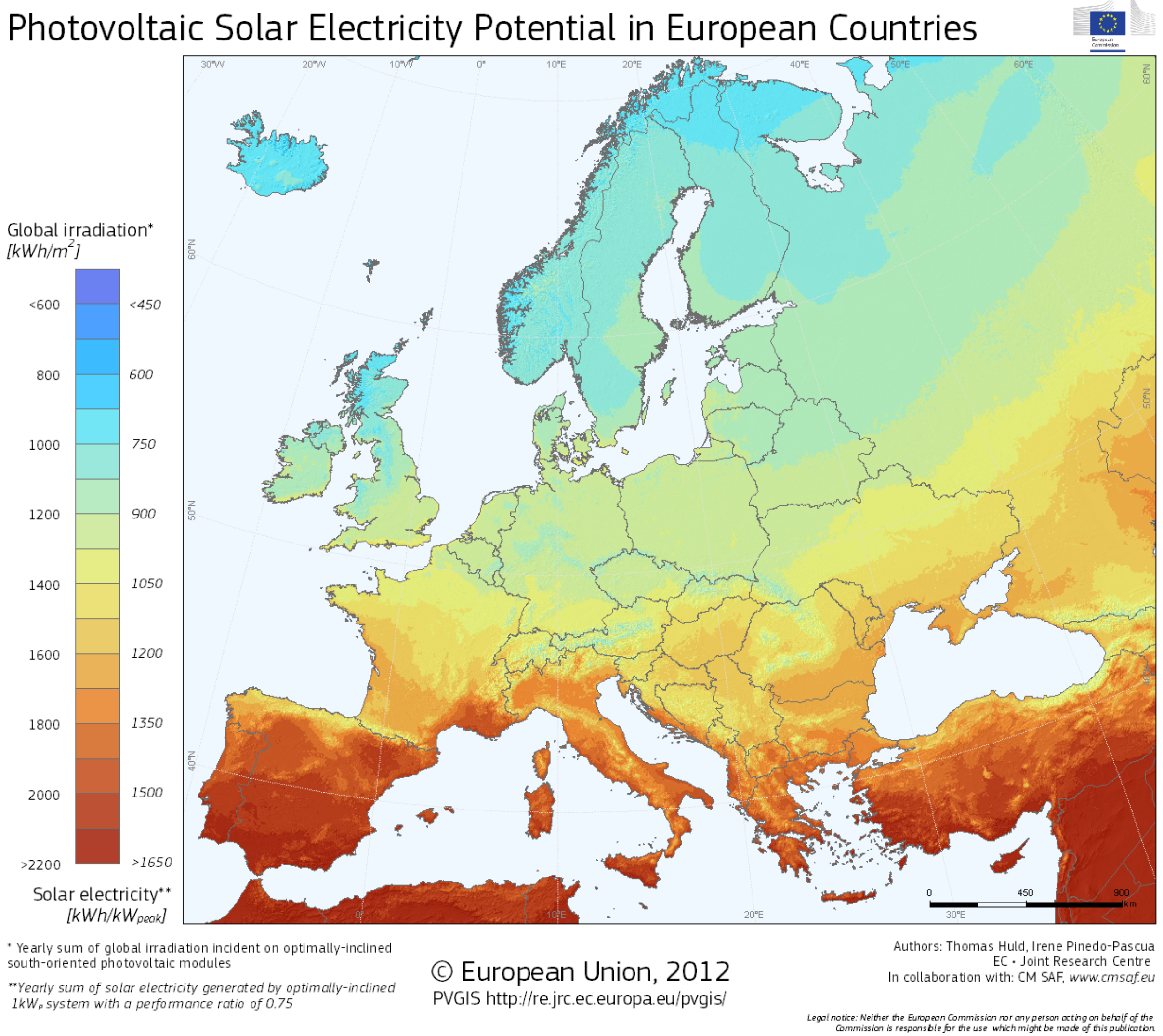
Modelling software

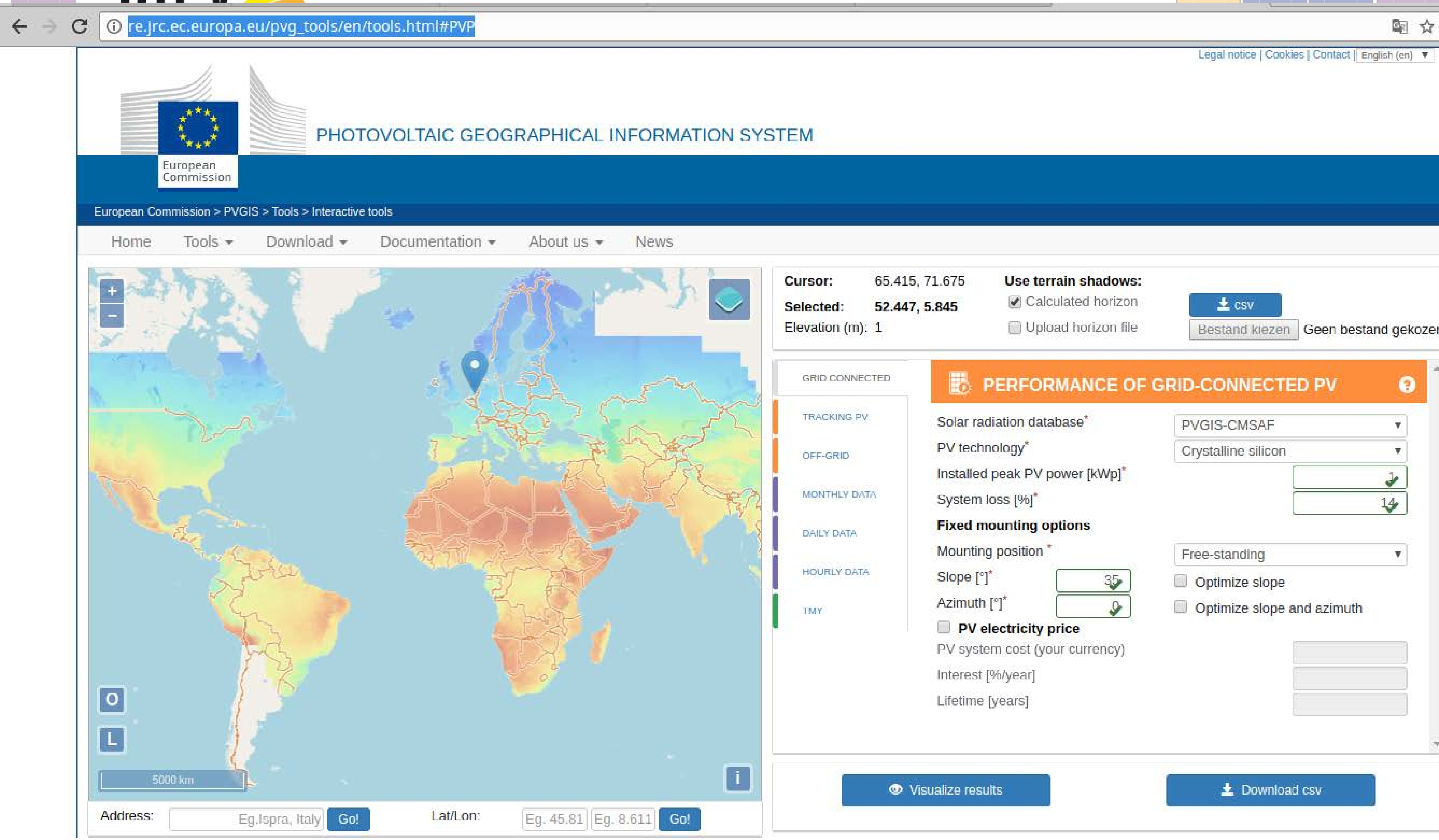
- For a quick performance check of a PV system
  - PVGIS (online tool)

- For more elaborate simulations several software packages available.
  - PVSites for our assignment

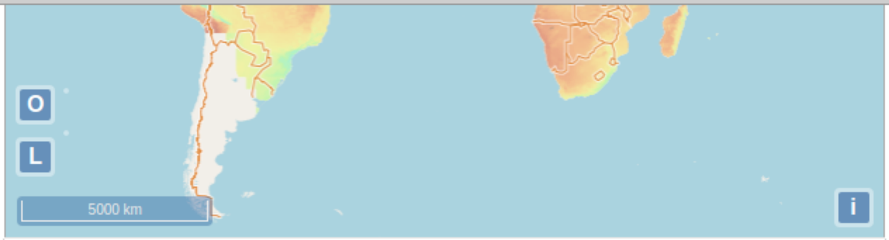
PVGIS

- Photovoltaic Geographical Information System





http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP



Address: Eg.Ispra, Italy Go!   Lat/Lon: Eg. 45.81 Eg. 8.611 Go!

PV electricity price

PV system cost (your currency)

Interest [%/year]

Lifetime [years]

Visualize results   Download csv

Location changed. Click to refresh figures

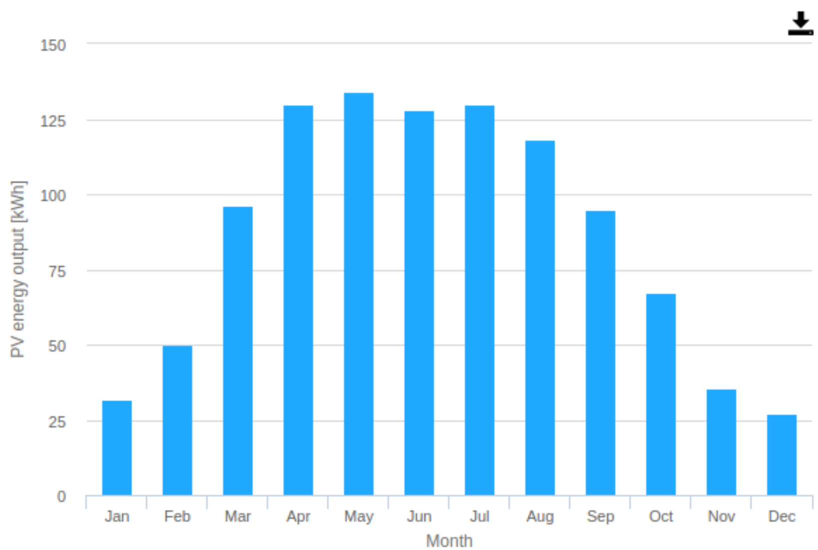
PERFORMANCE OF GRID-CONNECTED PV: RESULTS

PV output | Radiation | Info | PDF

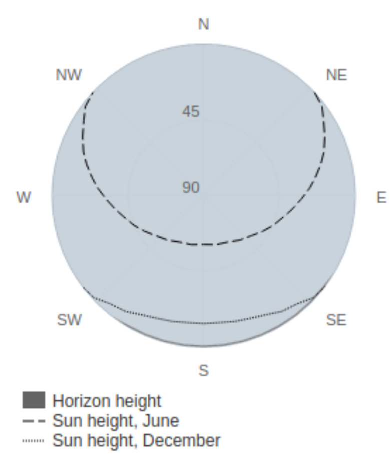
Summary

Provided inputs:	
Location [Lat/Lon]:	52.447, 5.845
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	35
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	1040
Yearly in-plane irradiation [kWh/m²]:	1280
Year to year variability [kWh]:	37.20
Changes in output due to:	
Angle of incidence [%]:	-3.1
Spectral effects [%]:	1.9
Temperature and low irradiance [%]:	-4.4
Total loss [%]:	-18.8

Monthly energy output from fix-angle PV system



Outline of horizon



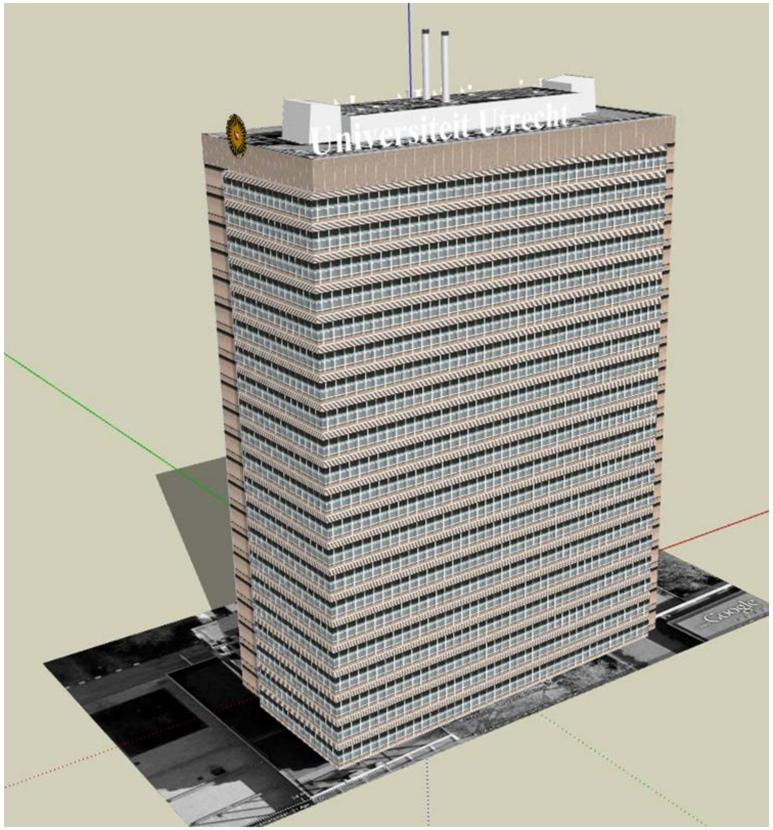
Last update: 21/09/2017 Top

Assignment

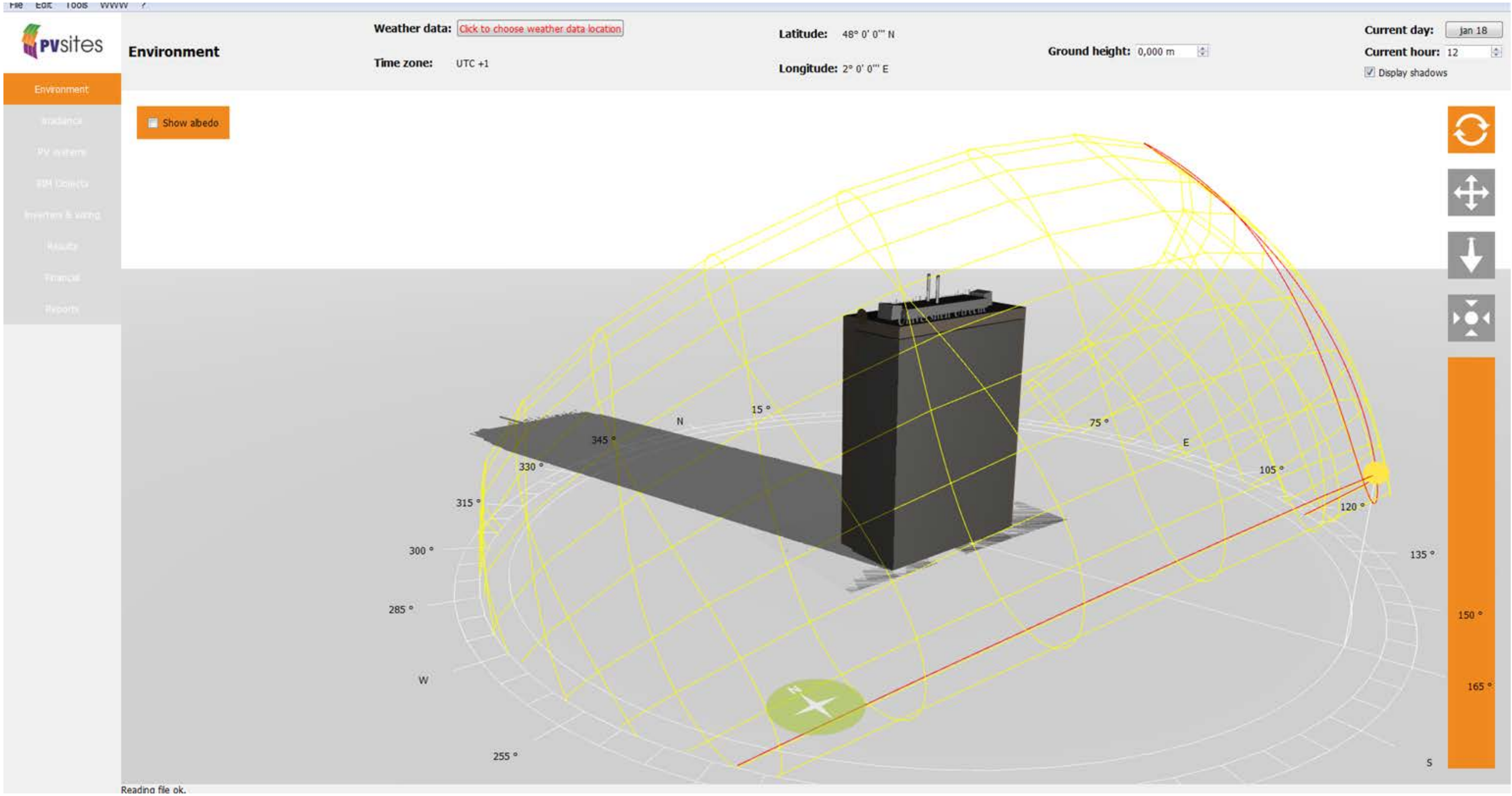
PVsites

Assignment

The ‘Willem C. Unnik-building’ - Utrecht University



Assignment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PVsites
Environment
Weather data:
Click to choose weather data location
Time zone:
UTC +1
Latitude:
48° 0' 0'' N
Longitude:
2° 0' 0'' E
Ground height:
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Current day:
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12
Display shadows
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Reading file ok.

Thank you for Your Attention

www.dem4bipv.eu

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