



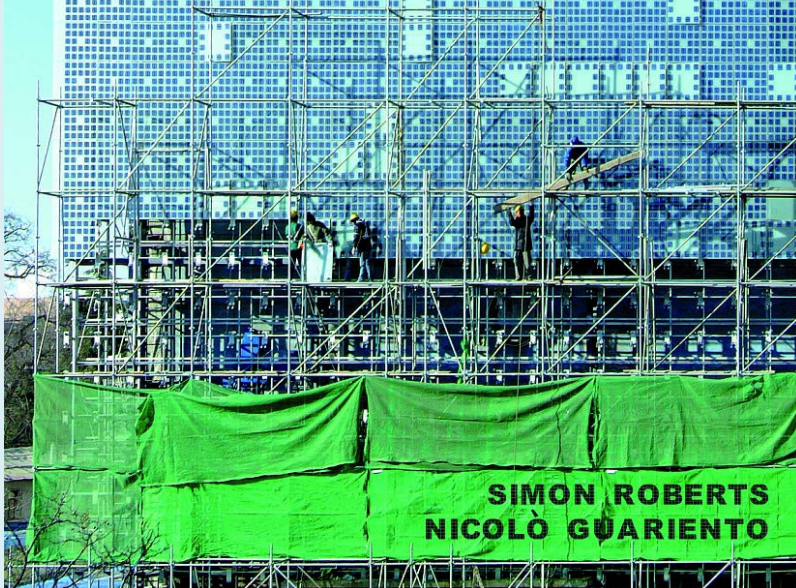
# **Renewable Energy Integration: Building Integrated Photovoltaic System**

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Ravin School of Architecture  
UNC Charlotte



BIRKHAUSER

# BUILDING INTEGRATED PHOTOVOLTAICS A HANDBOOK



**SIMON ROBERTS  
NICOLÒ GUARIENTO**



## *Photovoltaics* in Buildings



A Design Handbook  
for Architects and  
Engineers

Editors:  
Friedrich Sick and Thomas Erge



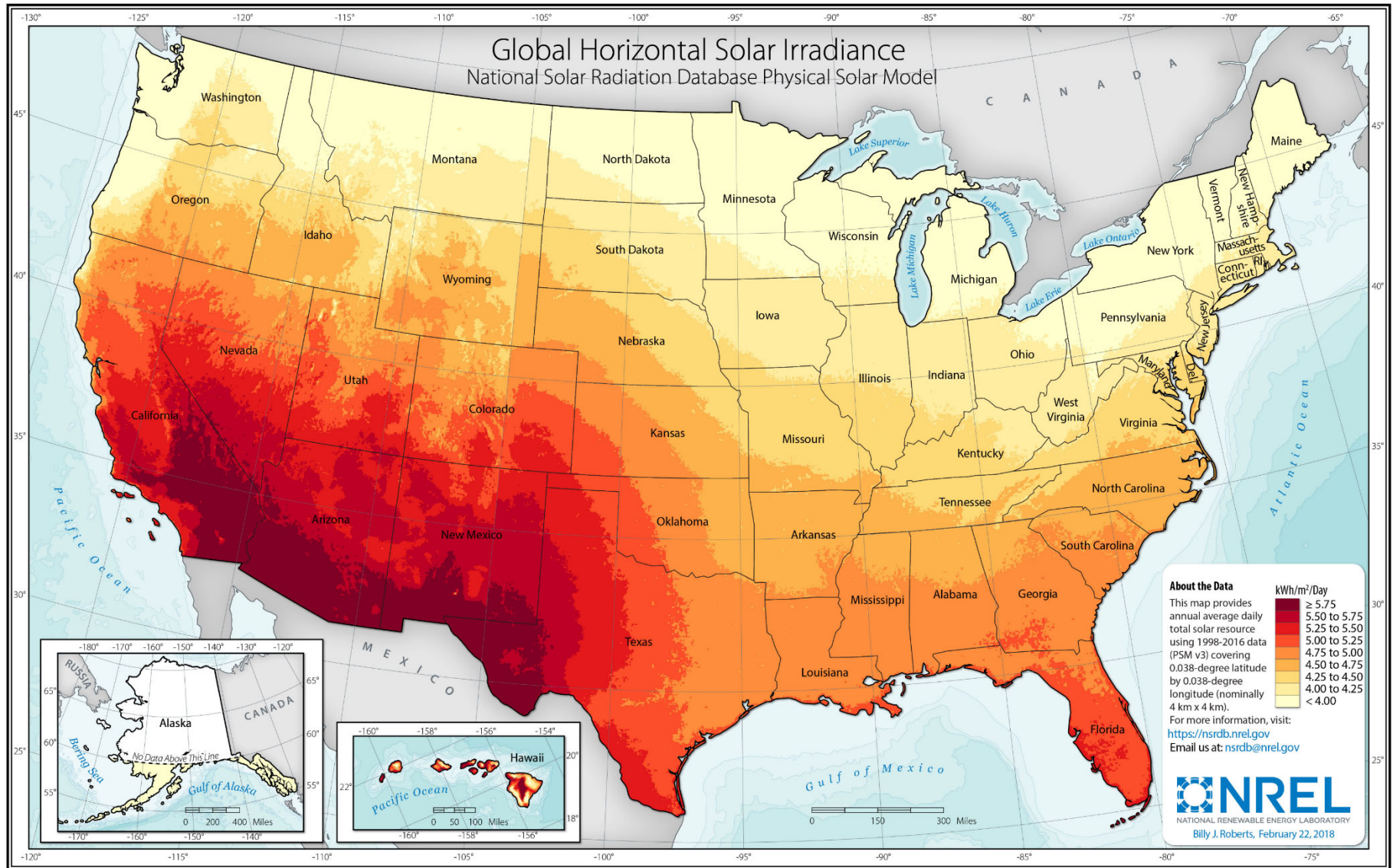
Task 16



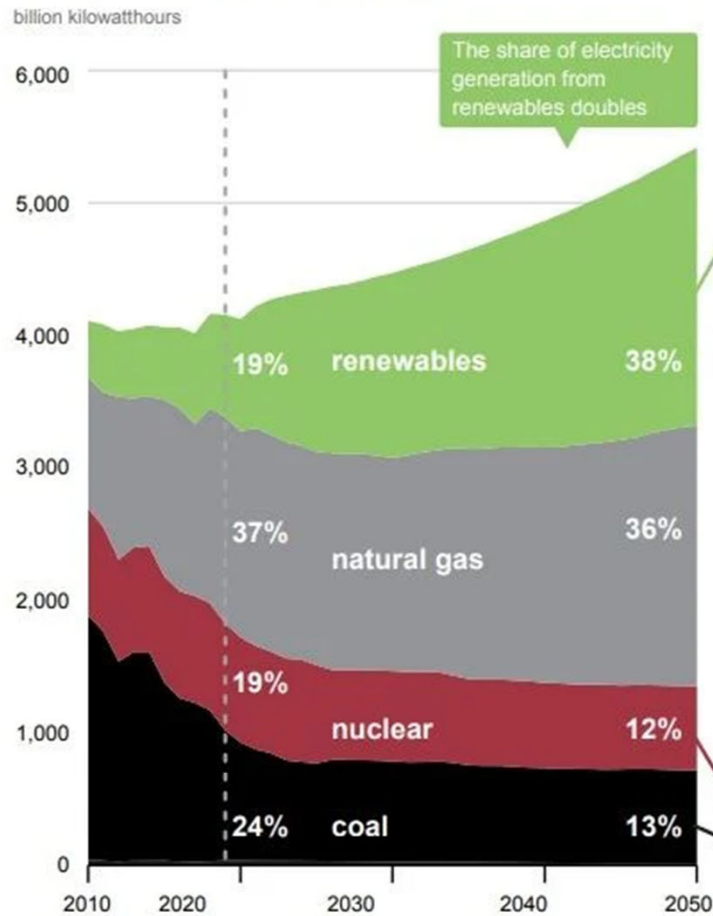
International Energy Agency



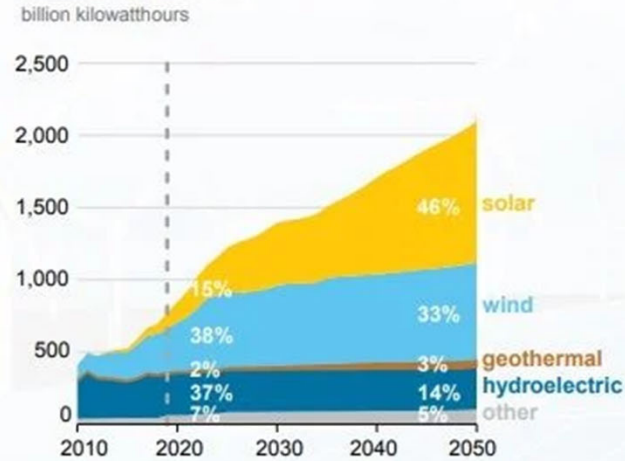
# Renewable Energy: Solar Resource Available on Horizontal Surface



# Solar Outlook



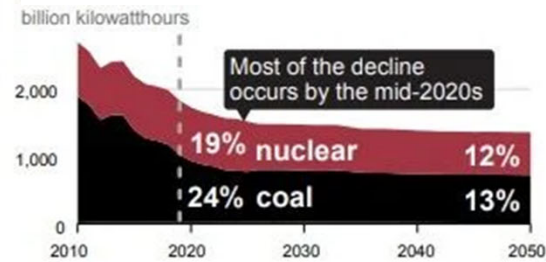
## Renewable electricity generation, including end use



Most of the growth in renewable electricity generation is from solar and wind.



Continued declines in the capital costs for solar and wind are supported by federal tax credits and higher state-level renewables targets.



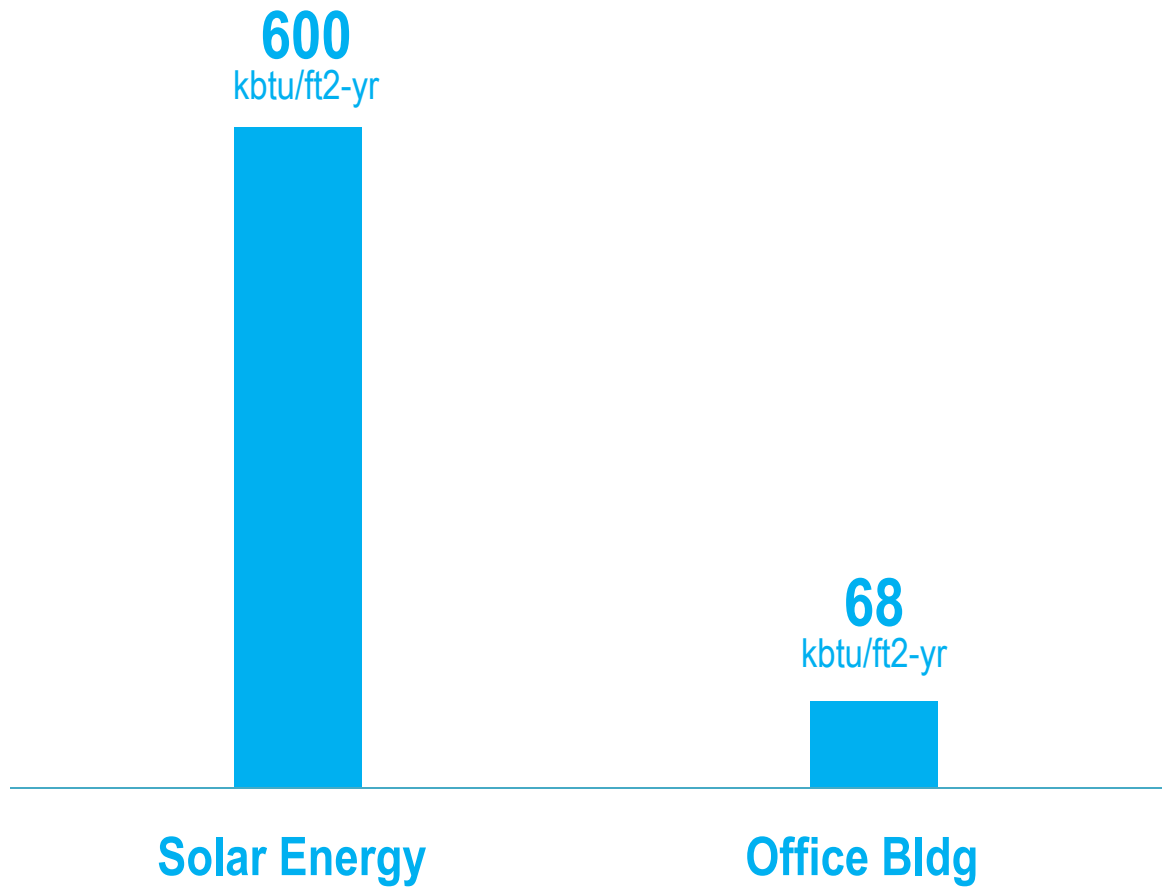
The share of coal-fired electricity generation falls from 24% to 13%.



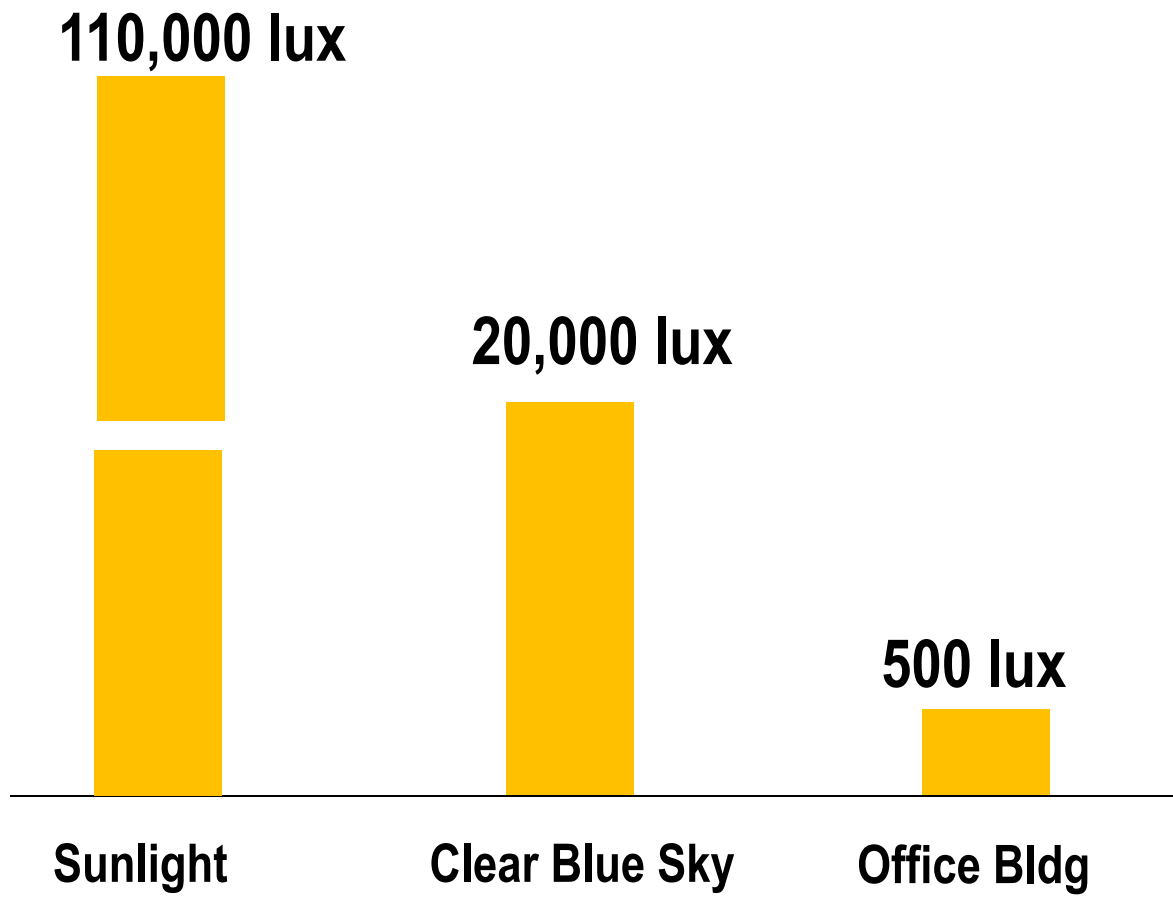
The share of nuclear generation falls from 19% to 12%.



# Renewable Energy: Solar Resource



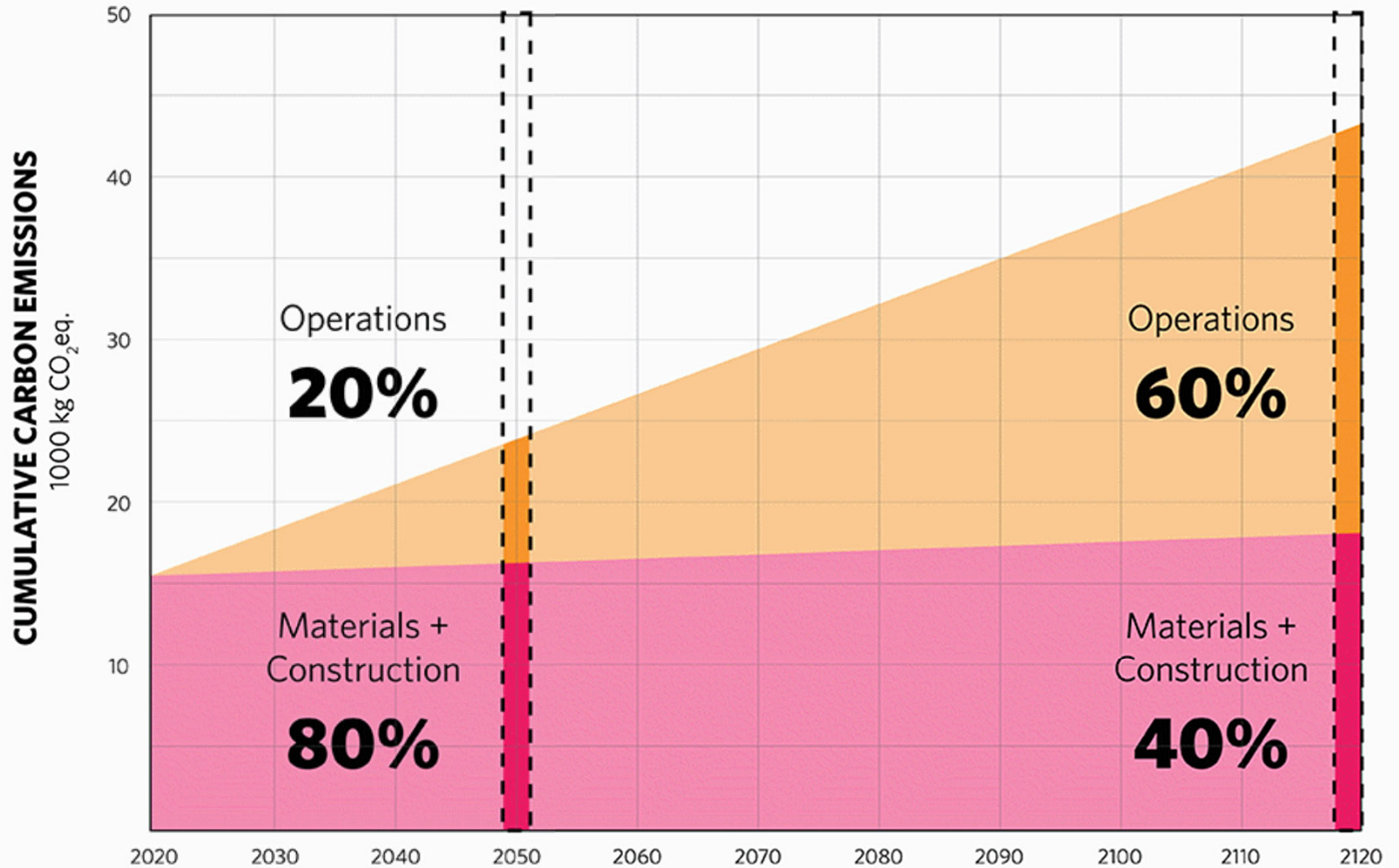
# Renewable Energy: Solar Resource





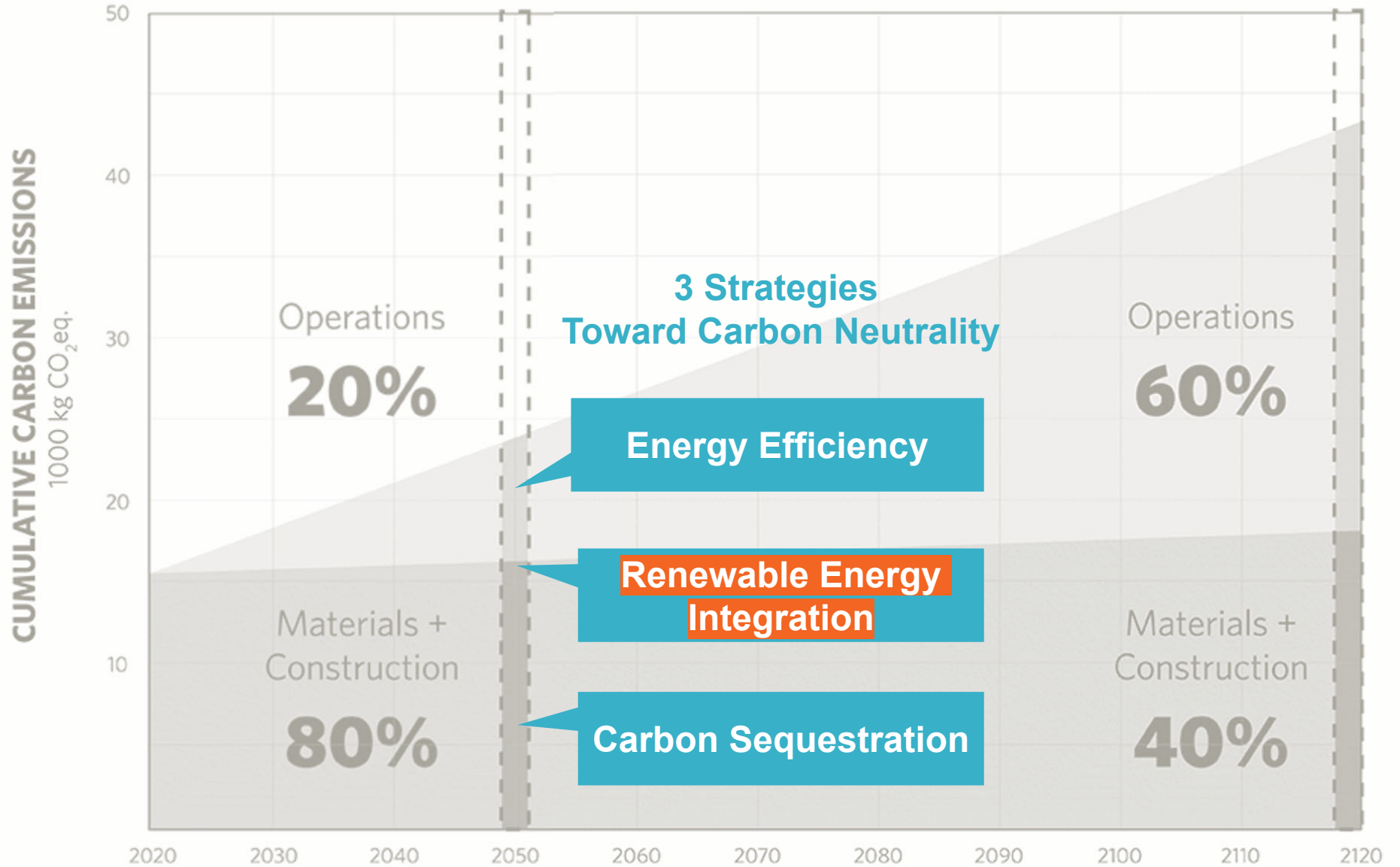
# CARBON EMISSIONS

Typical High Performance Commercial Building



# CARBON EMISSIONS

Typical High Performance Commercial Building



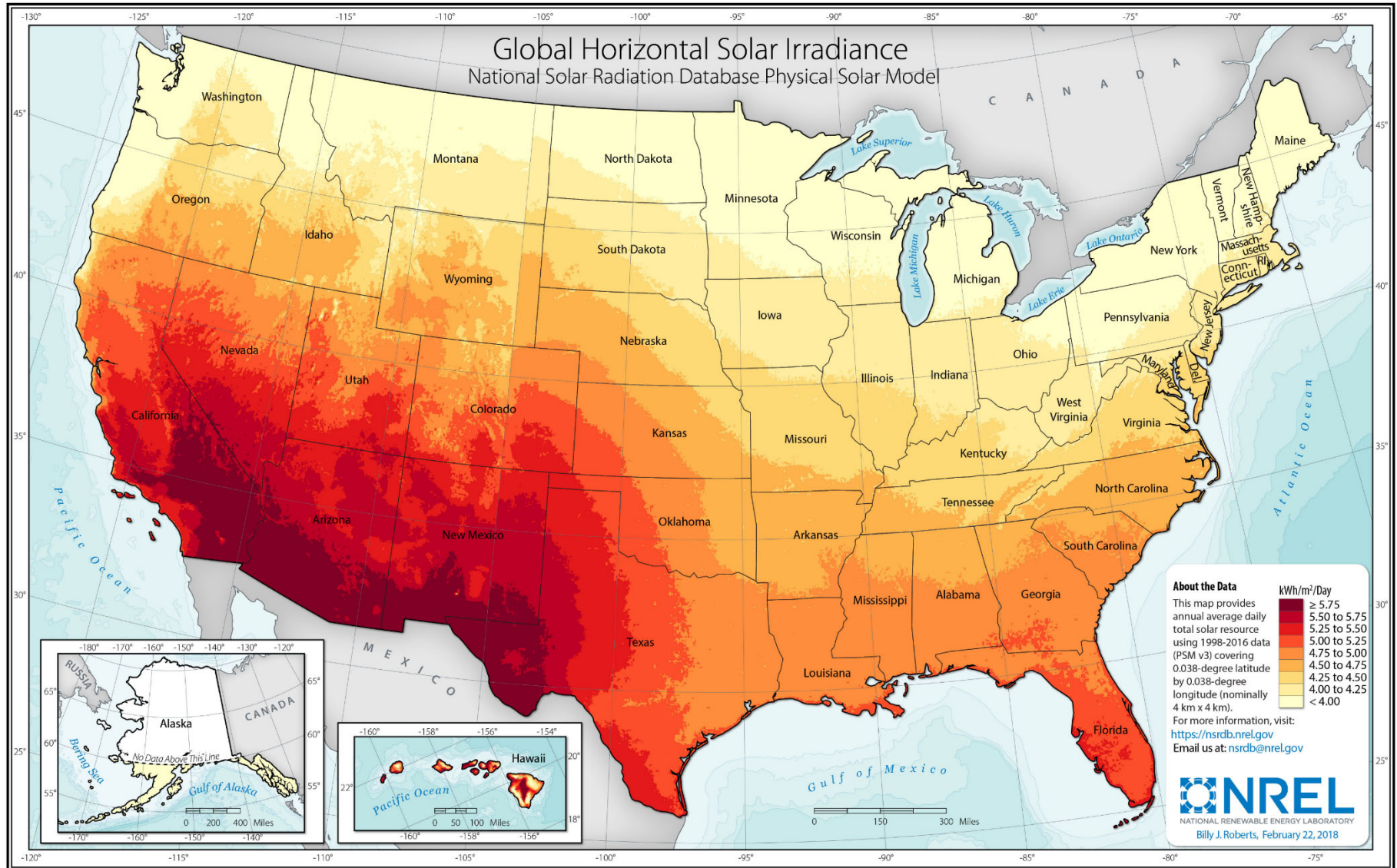




# Solar Architecture Basics

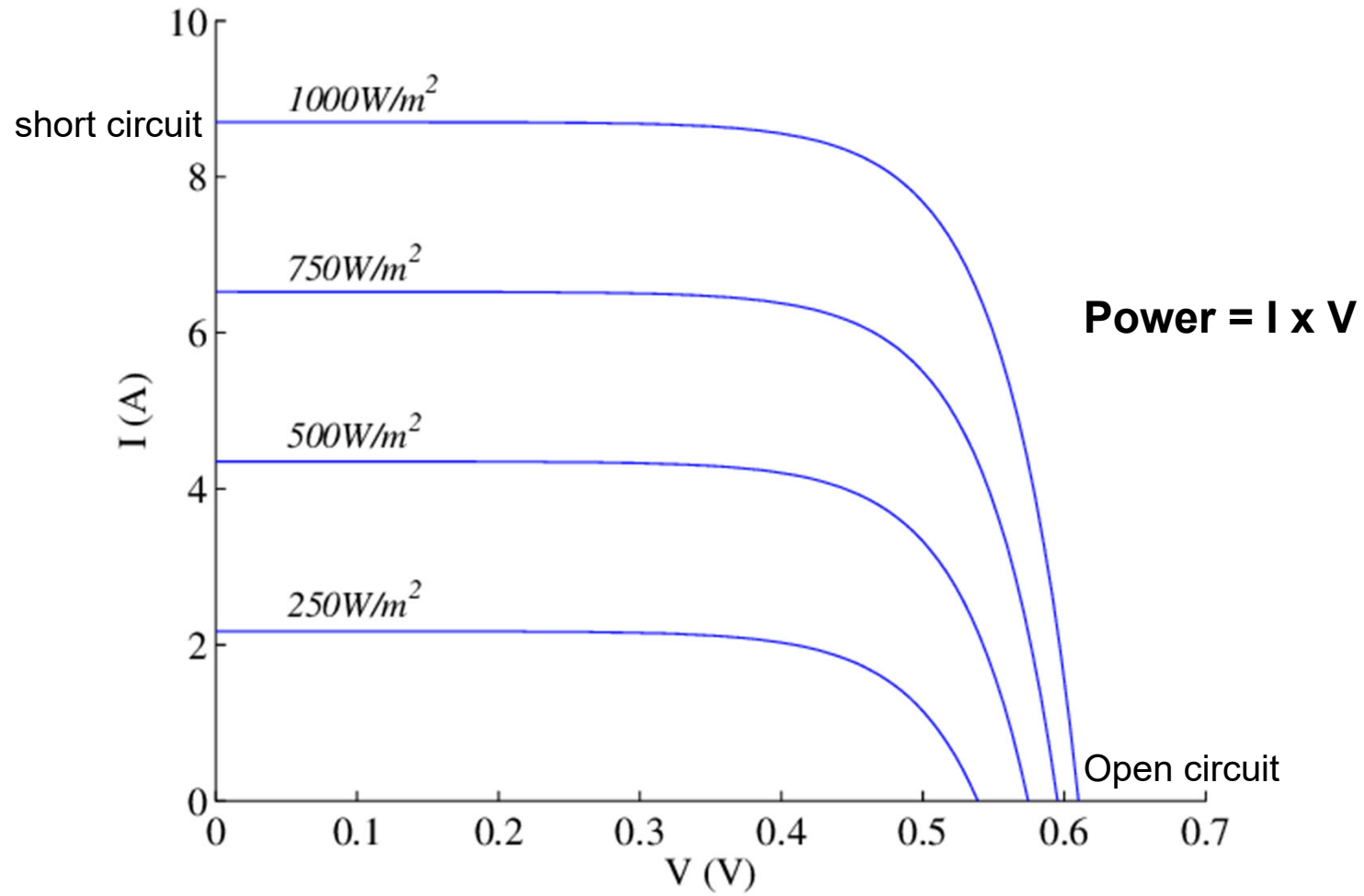


# Effect of Location

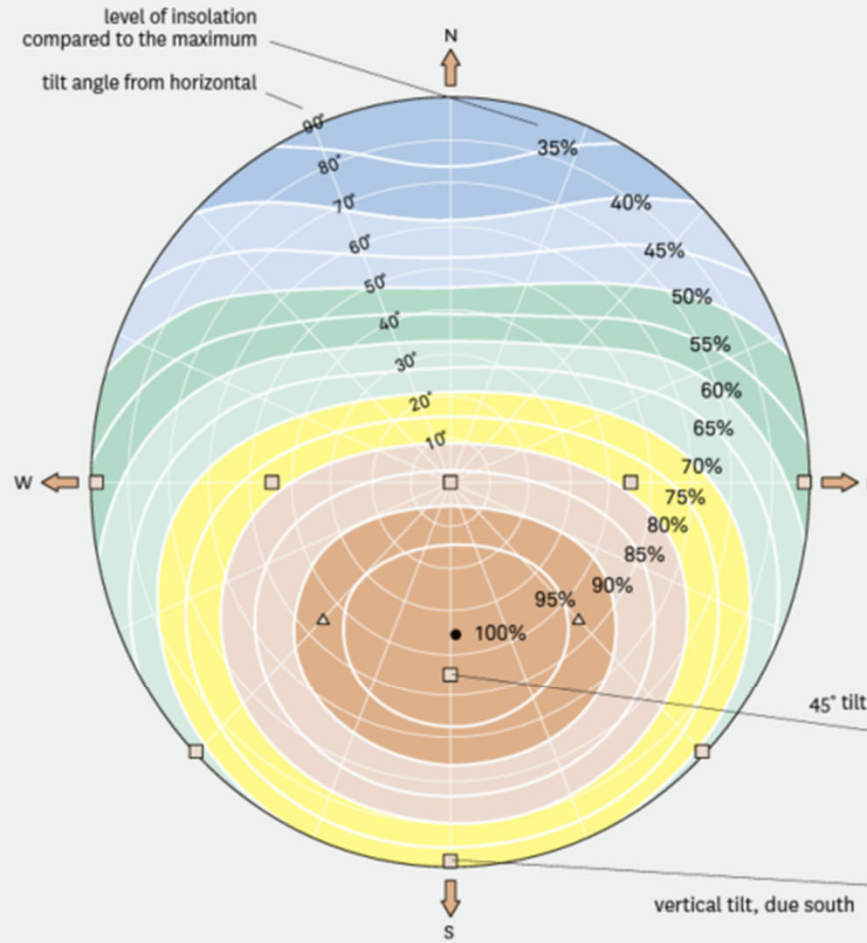




## Effect of Location

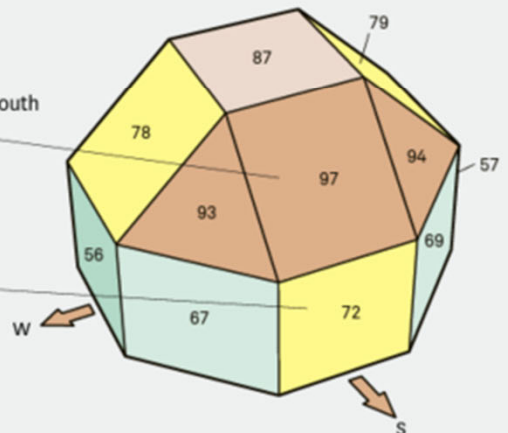


# Effect of Orientation



**Fig. 3.5** Chart of comparative total insolation over one year for all angles of tilt from horizontal and orientation, at Freiburg, Germany (latitude +50.9°, longitude +13.3°). The actual value of maximum insolation is 1,278 kWh/m<sup>2</sup> at the 100% point that is positioned with a tilt of 35° and oriented 2° east of due south. (The position slightly to east follows from mornings being a little less cloudy than afternoons.)

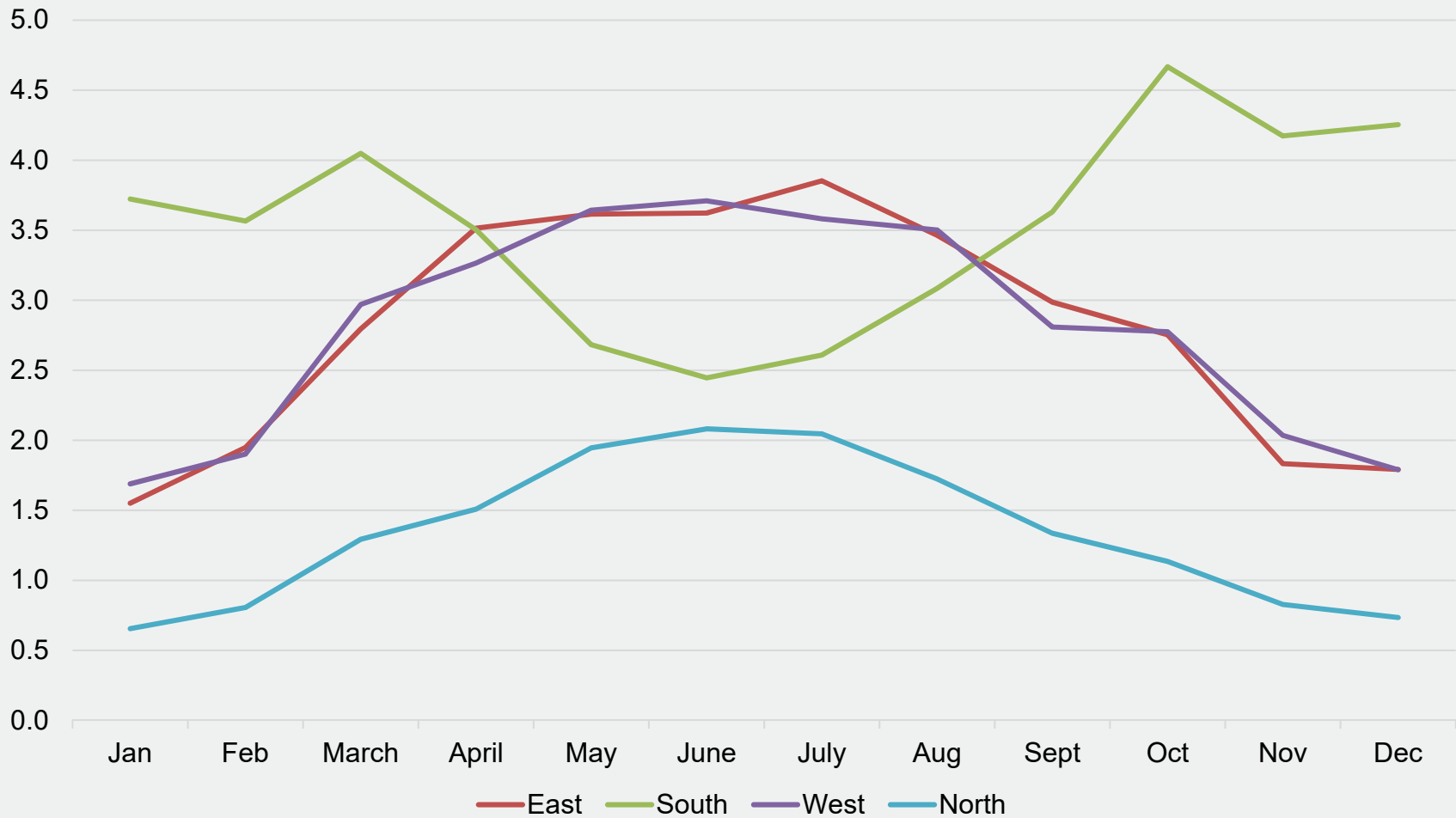
**Fig. 3.6** Selected values from Fig. 3.5 for 45° facets of a building. Colour shading of the facets relates to the bands of insolation in Fig. 3.5.





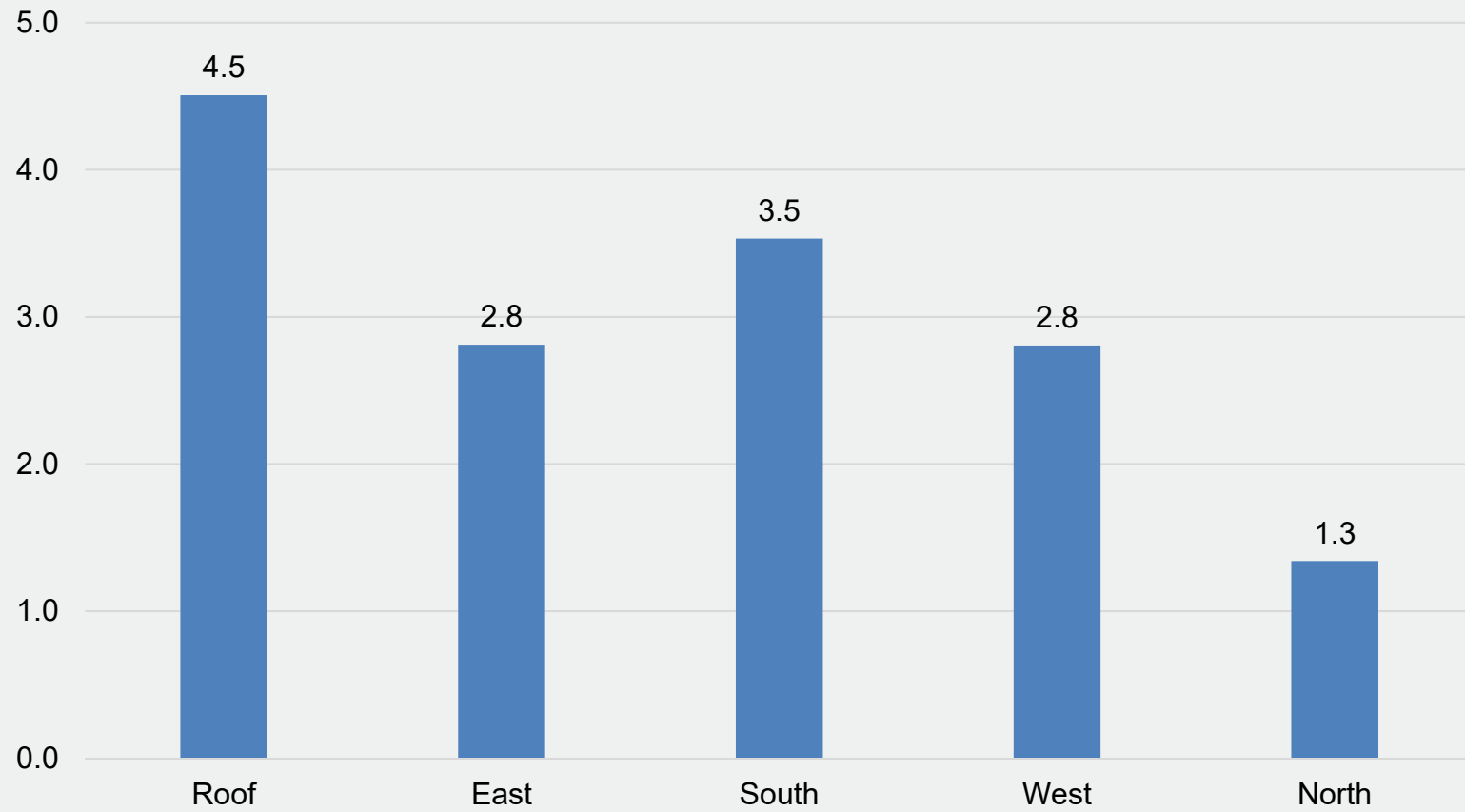
# Effect of Orientation

## Daily Insolation (kWh/m<sup>2</sup>-day)



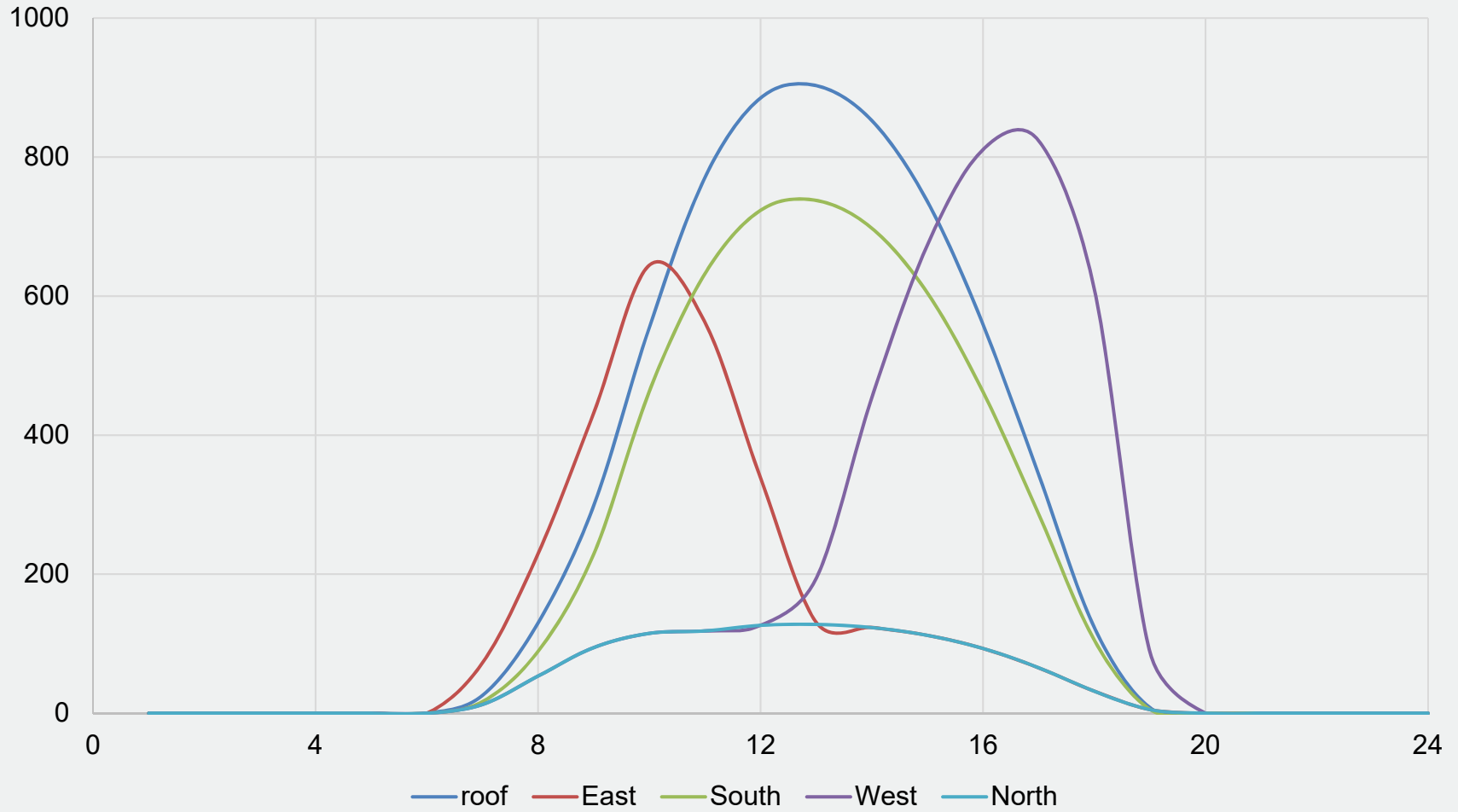
## Effect of Orientation

Daily insolation comparisons (kWh/m<sup>2</sup>-day)



# Effect of Orientation

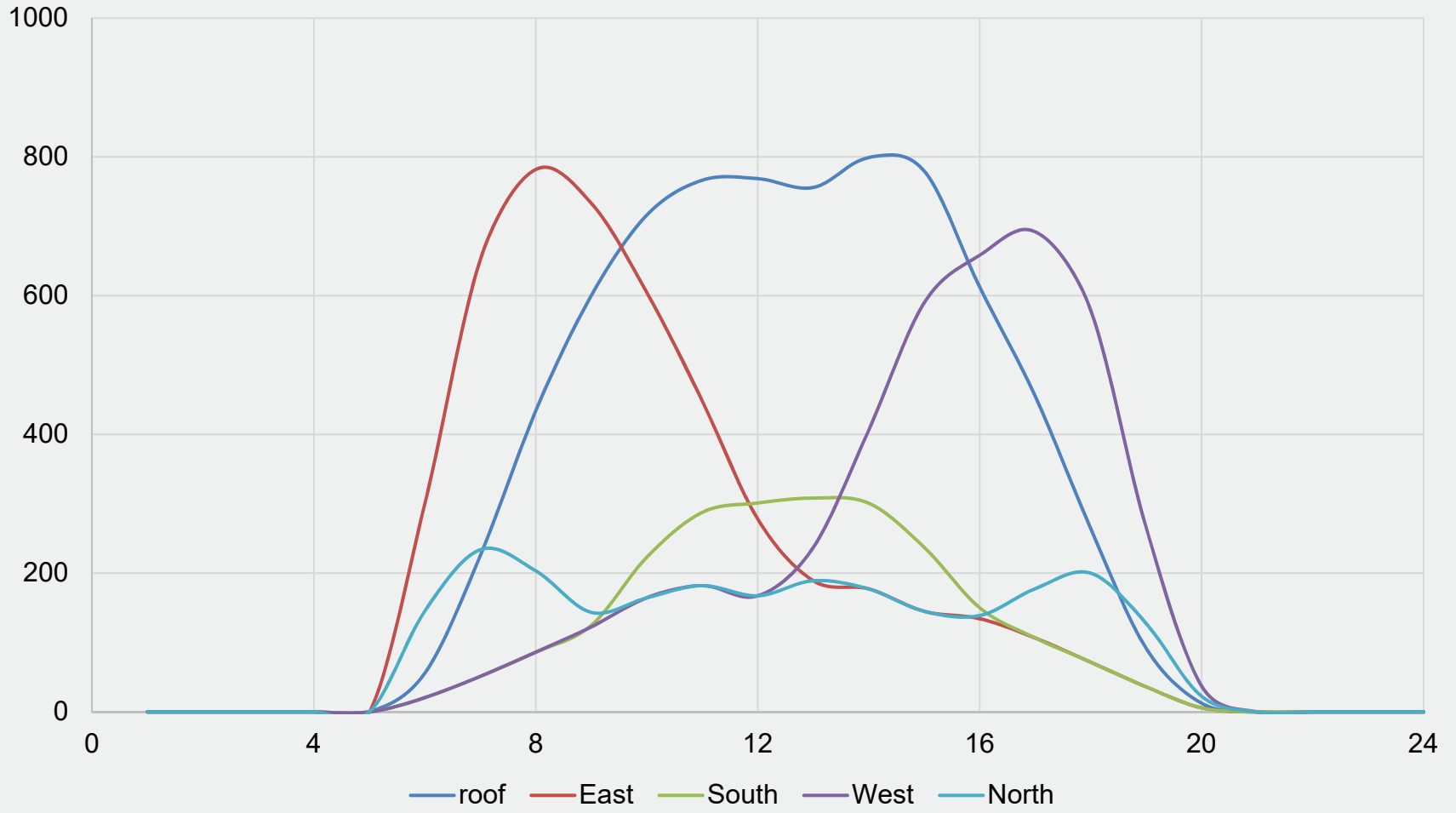
## Hourly insolation (Wh/m2) on March 21





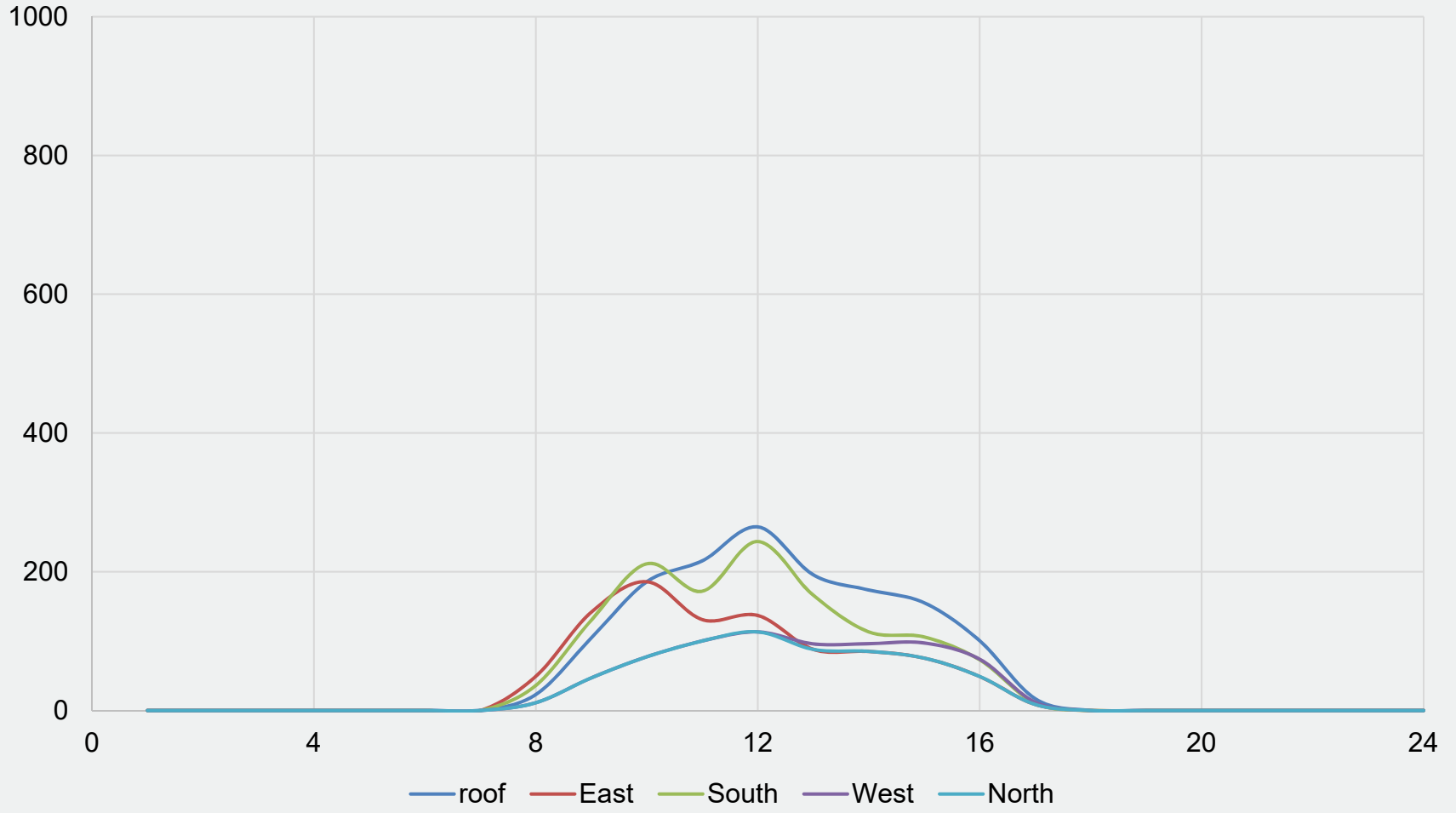
# Effect of Orientation

## Hourly insolation (Wh/m2) on June 21

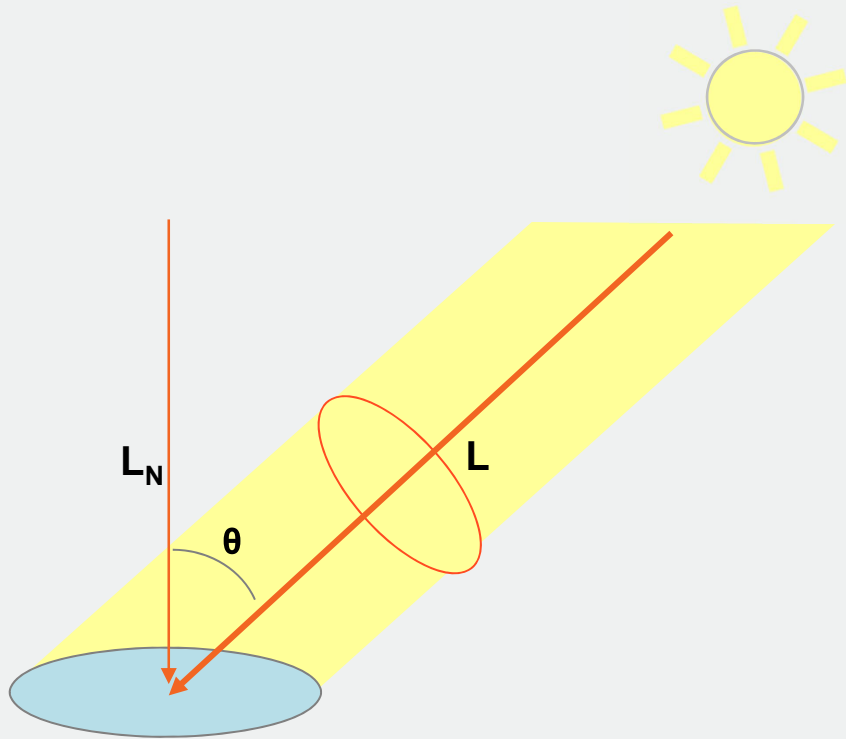


# Effect of Orientation

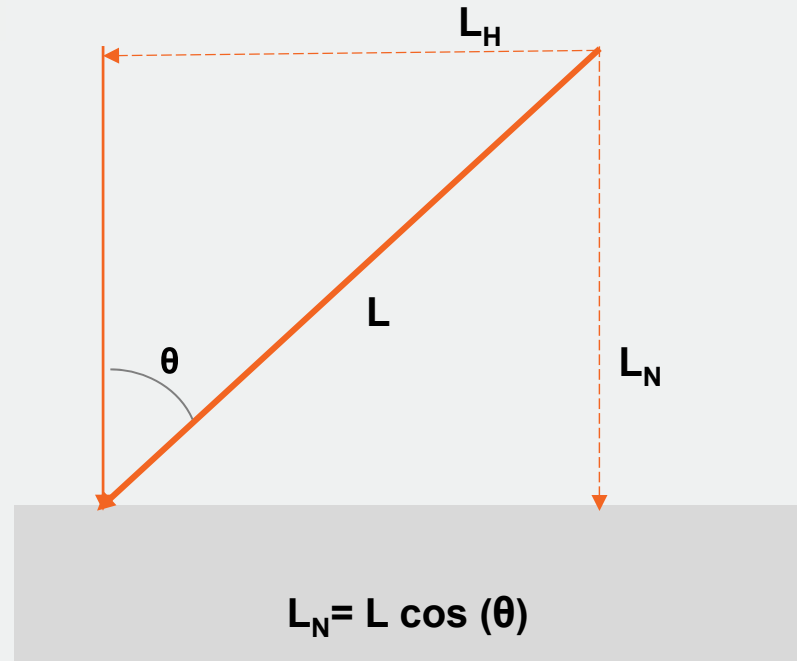
## Hourly insolation (Wh/m2) on Dec 21



# Effect of Tilting



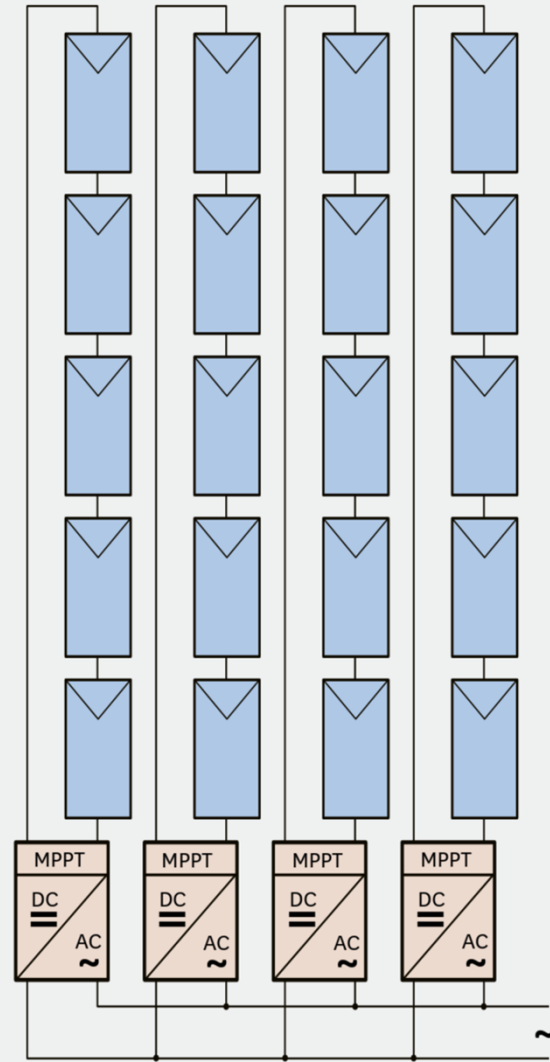
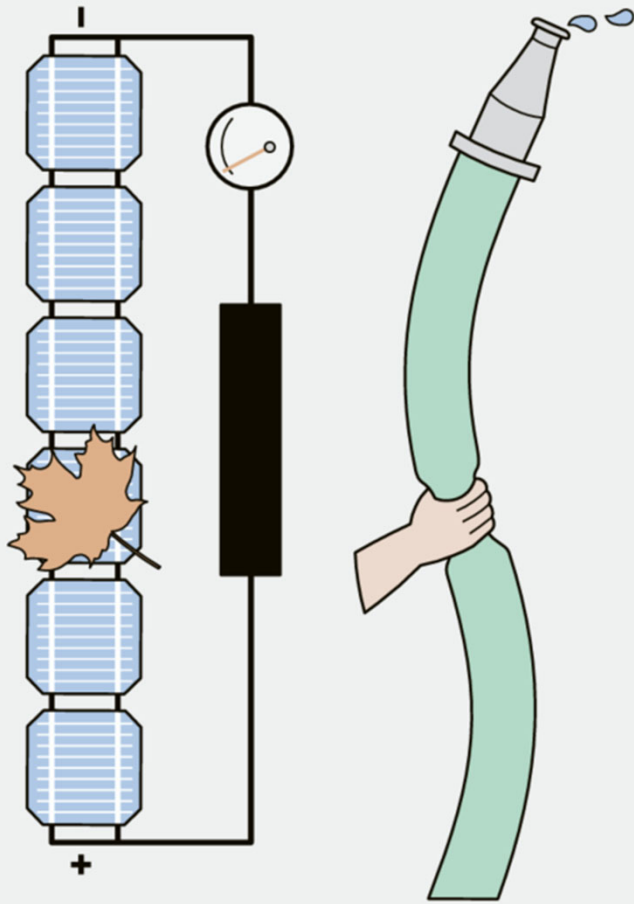
$$L_N = L \cos(\theta)$$



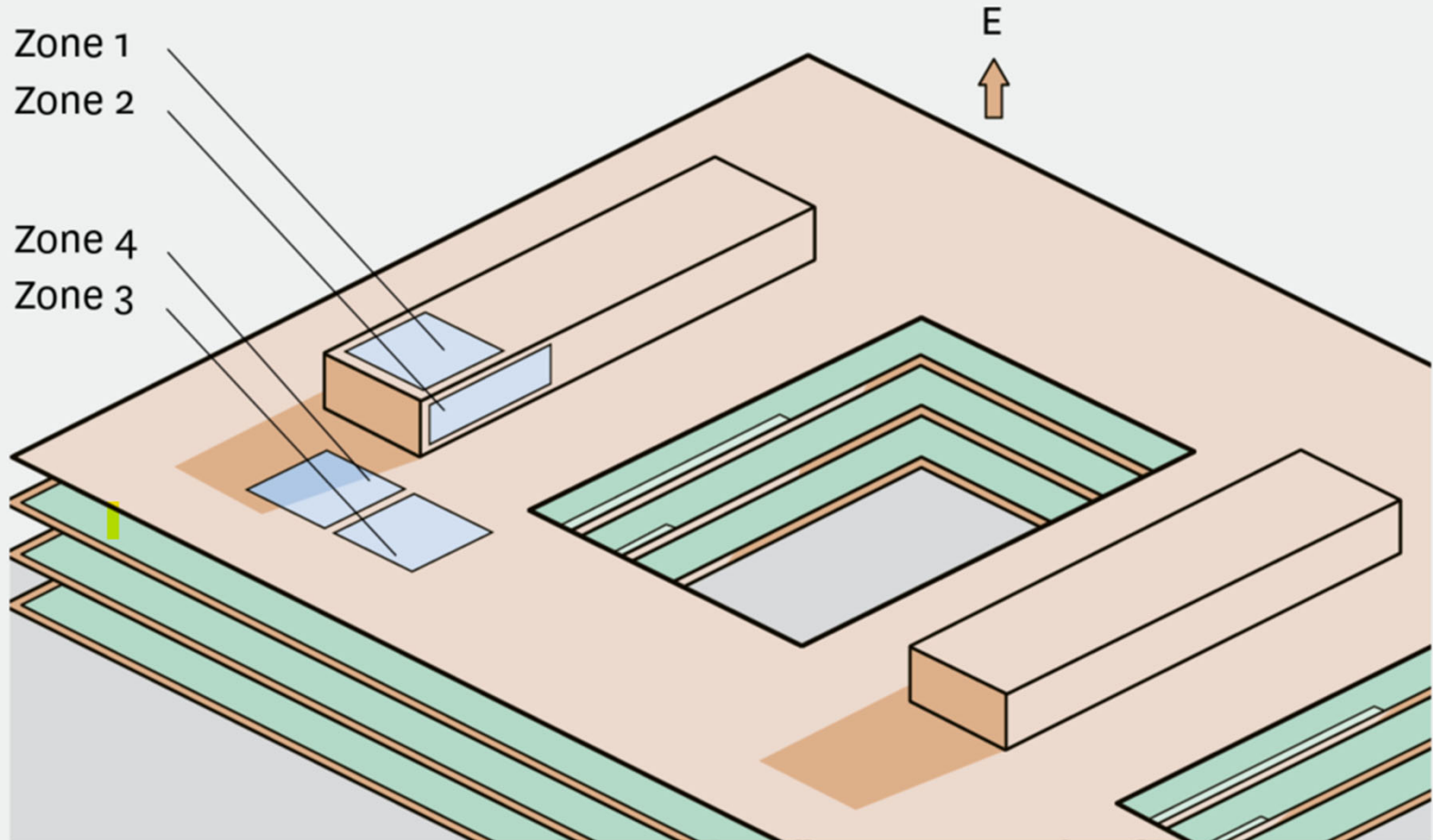
$$L_N = L \cos(\theta)$$



# Effect of Shading

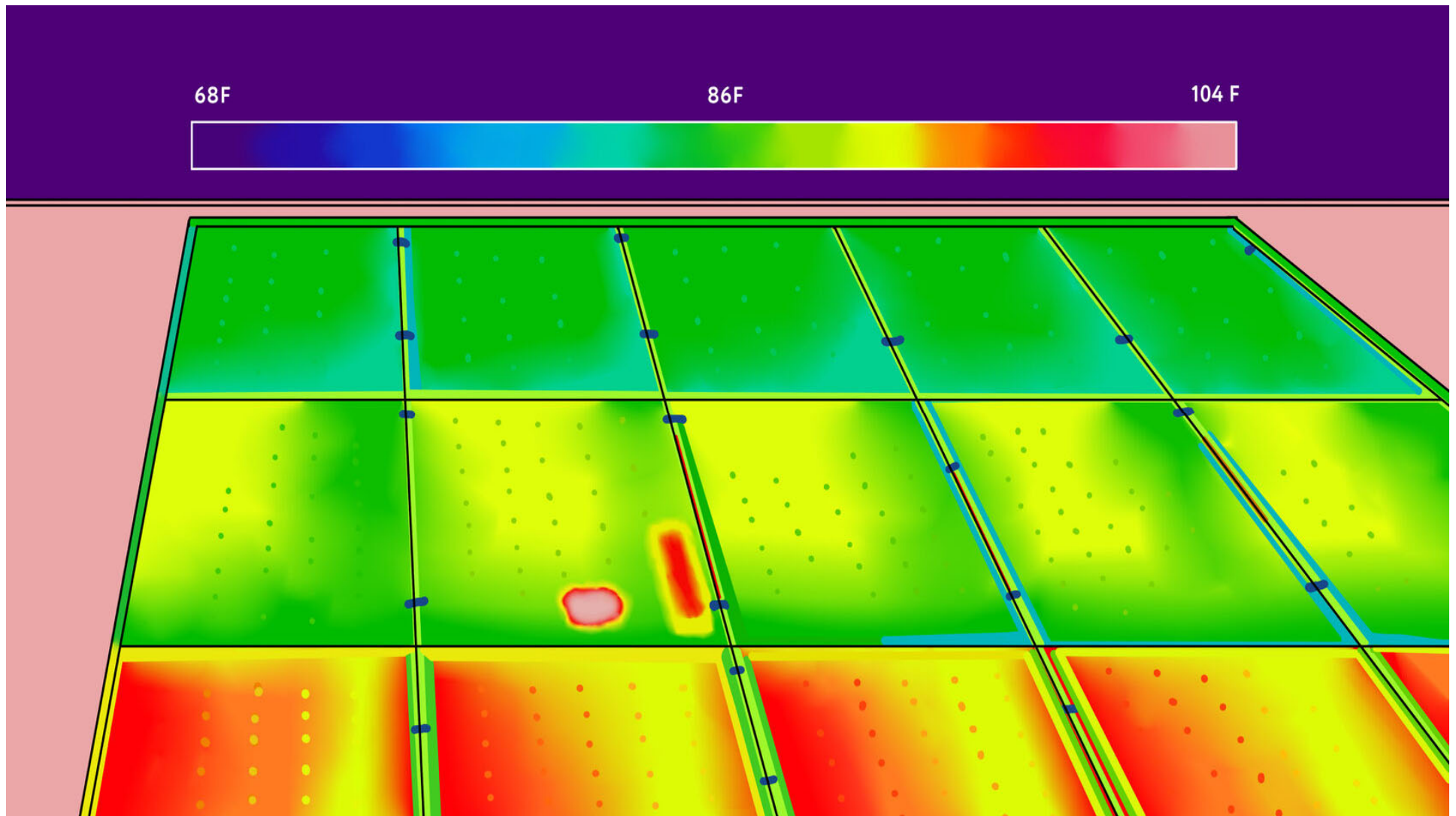


# Effect of Shadowing



## Effect of Temperature/Ventilation

For crystalline silicon cells, the efficiency drop by  $-0.4\%$  for every degree rise in temperature; reference temp is  $20\text{degC}$ .



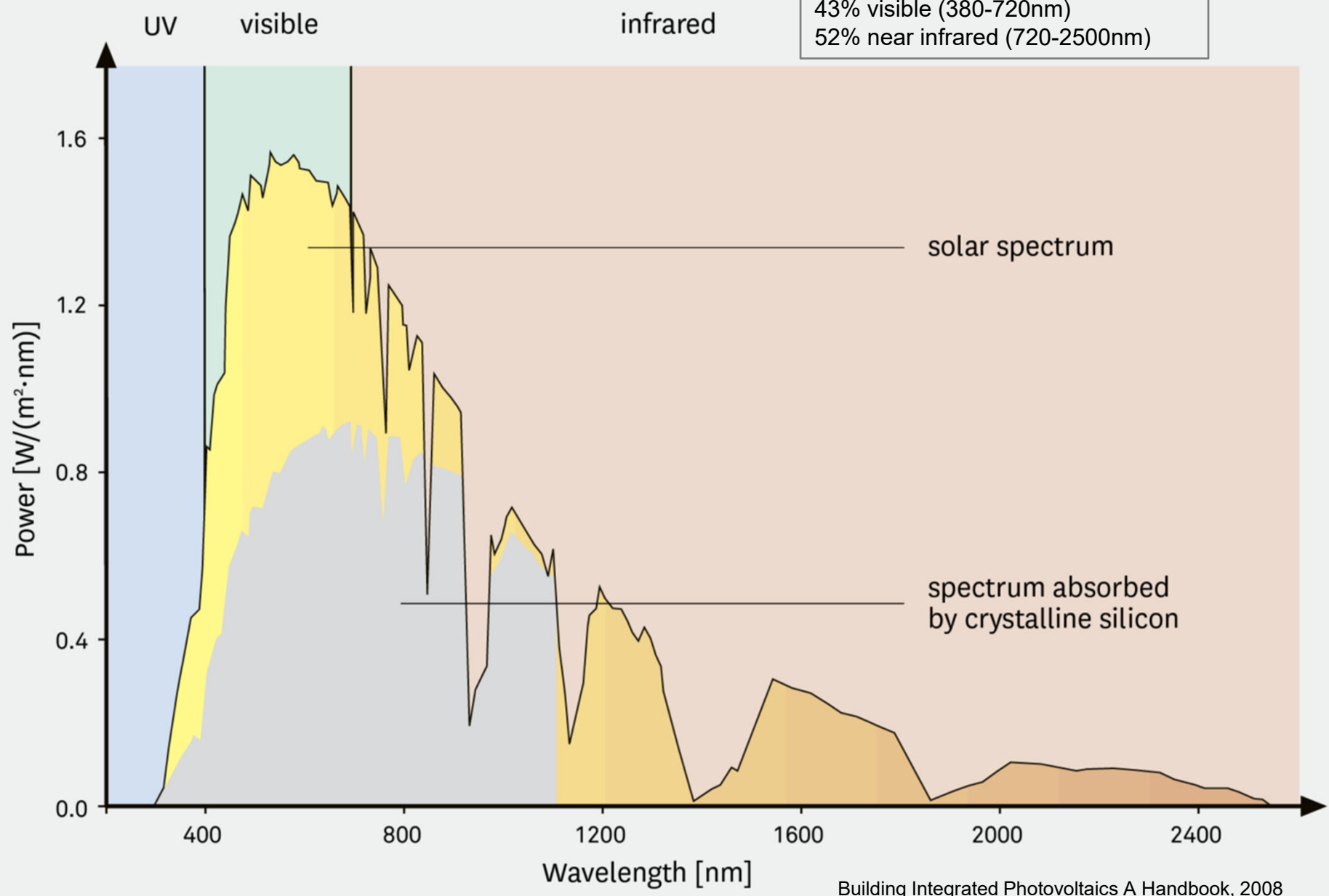


A microscopic image of a BIPV solar cell surface. The image shows a repeating hexagonal pattern of cells. Each cell contains a complex network of fine, light-colored electrical traces. The cells are separated by darker, recessed channels. The overall appearance is that of a highly structured, multi-layered material.

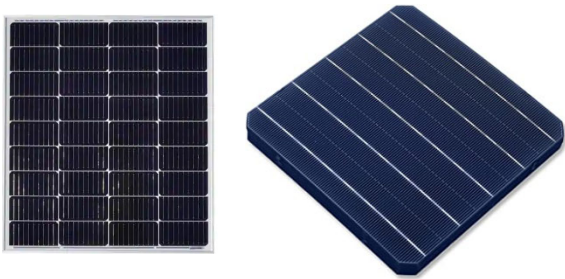
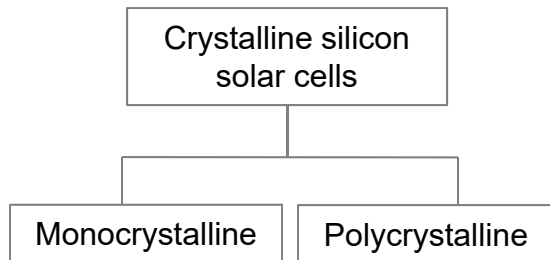
# BIPV Solar Cells



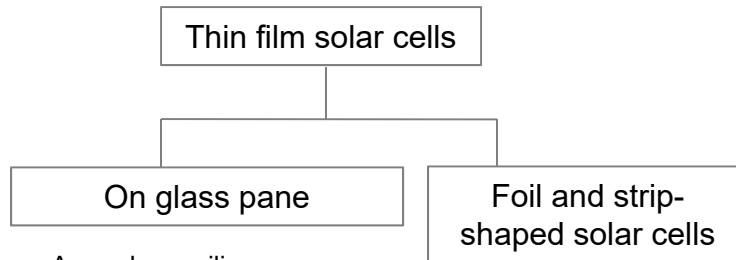
Solar Energy (insolation) Distribution  
5% UV (300-380nm)  
43% visible (380-720nm)  
52% near infrared (720-2500nm)



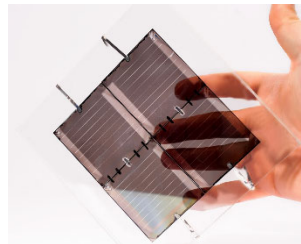
# Solar Cell Technology



- Wafer technology; individual slices
- Opaque
- Approx. 85% market share
- Mature technology
- 14~20% cell efficiency (mono)
- 13~17% cell efficiency (poly)



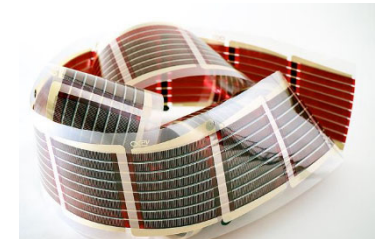
- Amorphous silicon
- CdTe
- Micromorph silicon
- CIS, CIGS



- Vacuum technology; full-surface substrate layering
- Opaque/translucent
- Approx. 15% market share
- Mature technology
- 6~14% module efficiency

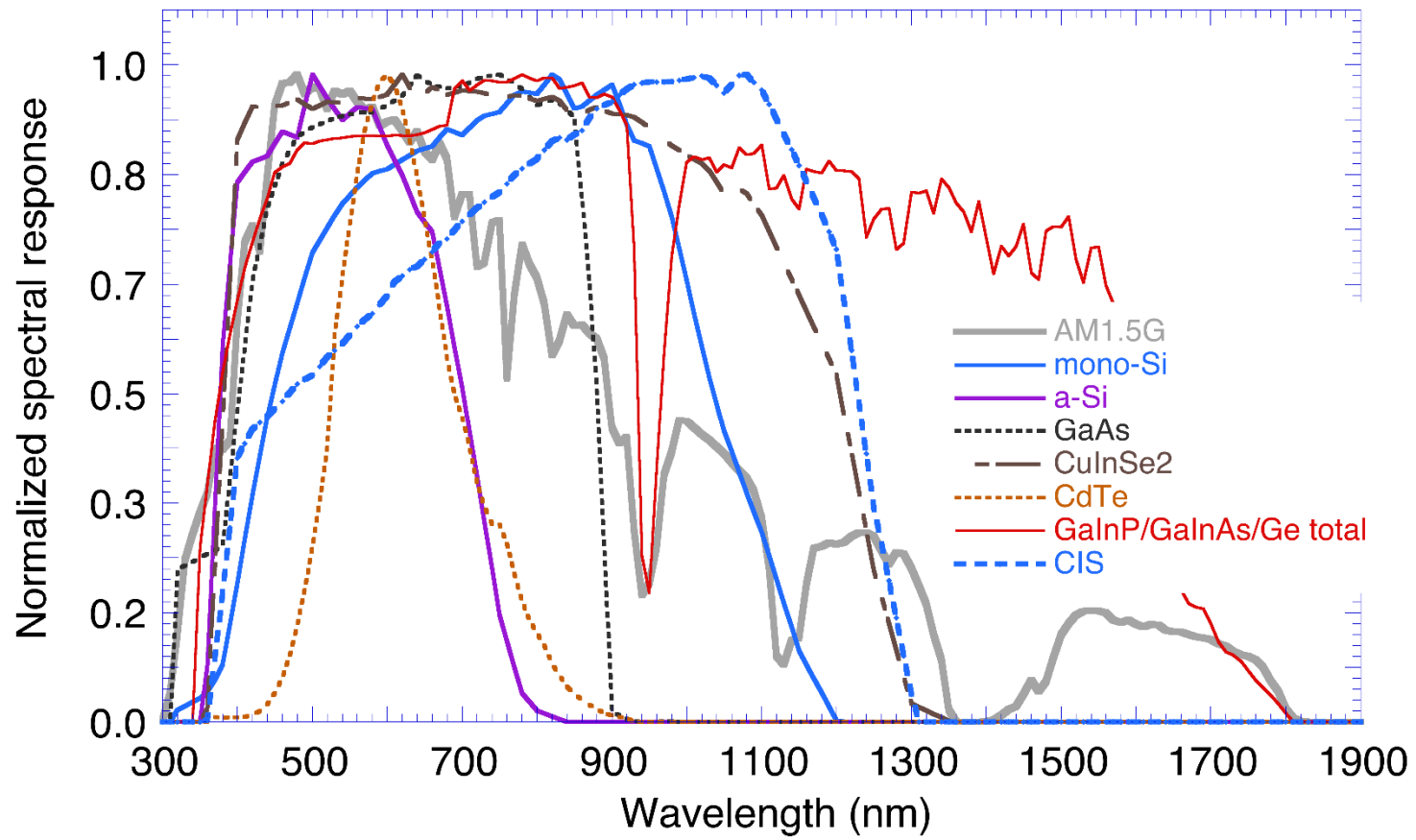
Organic solar cells

Foil/glass substrate



- Printing process
- Nanostructure
- Pilot stage
- 2~3% efficiency

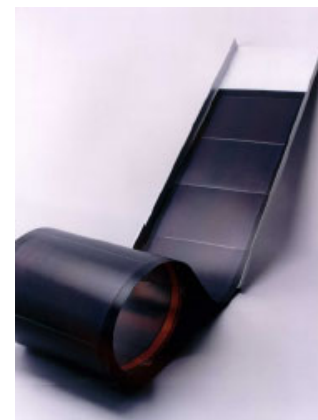
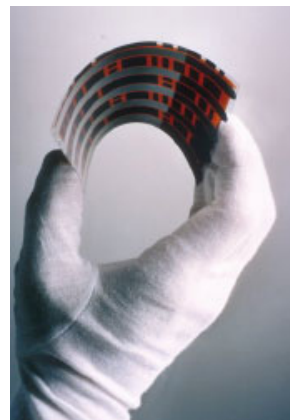
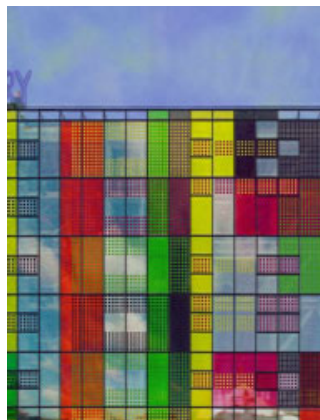
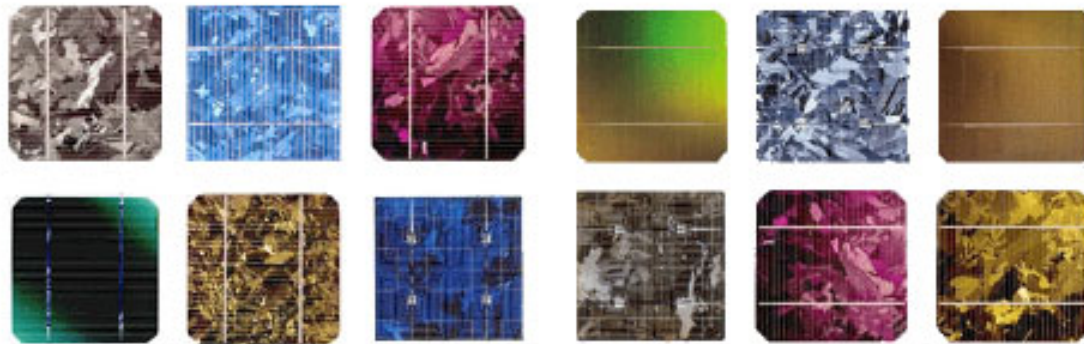
# Solar Spectrum Use for Different Solar Cell Technology



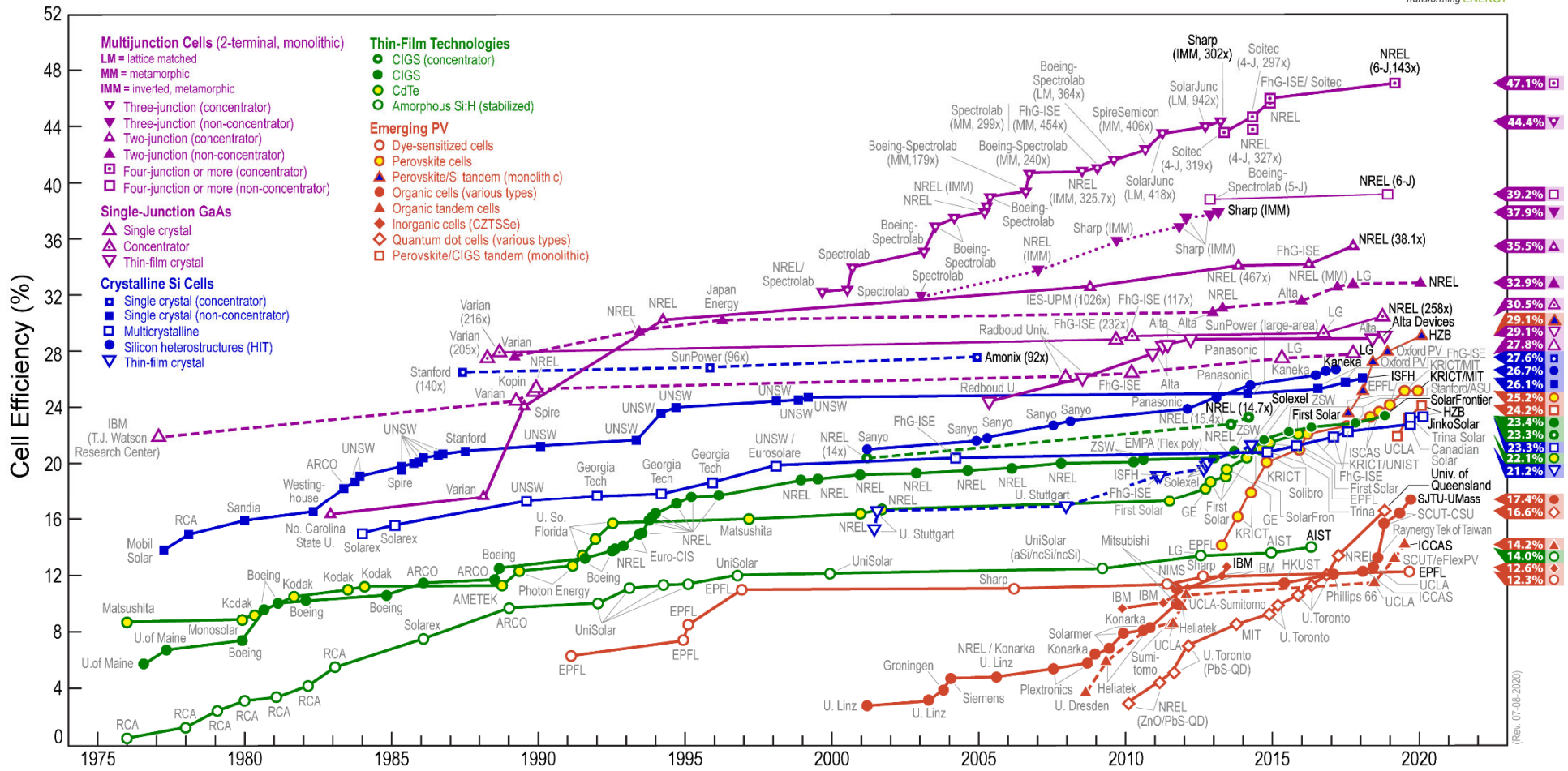


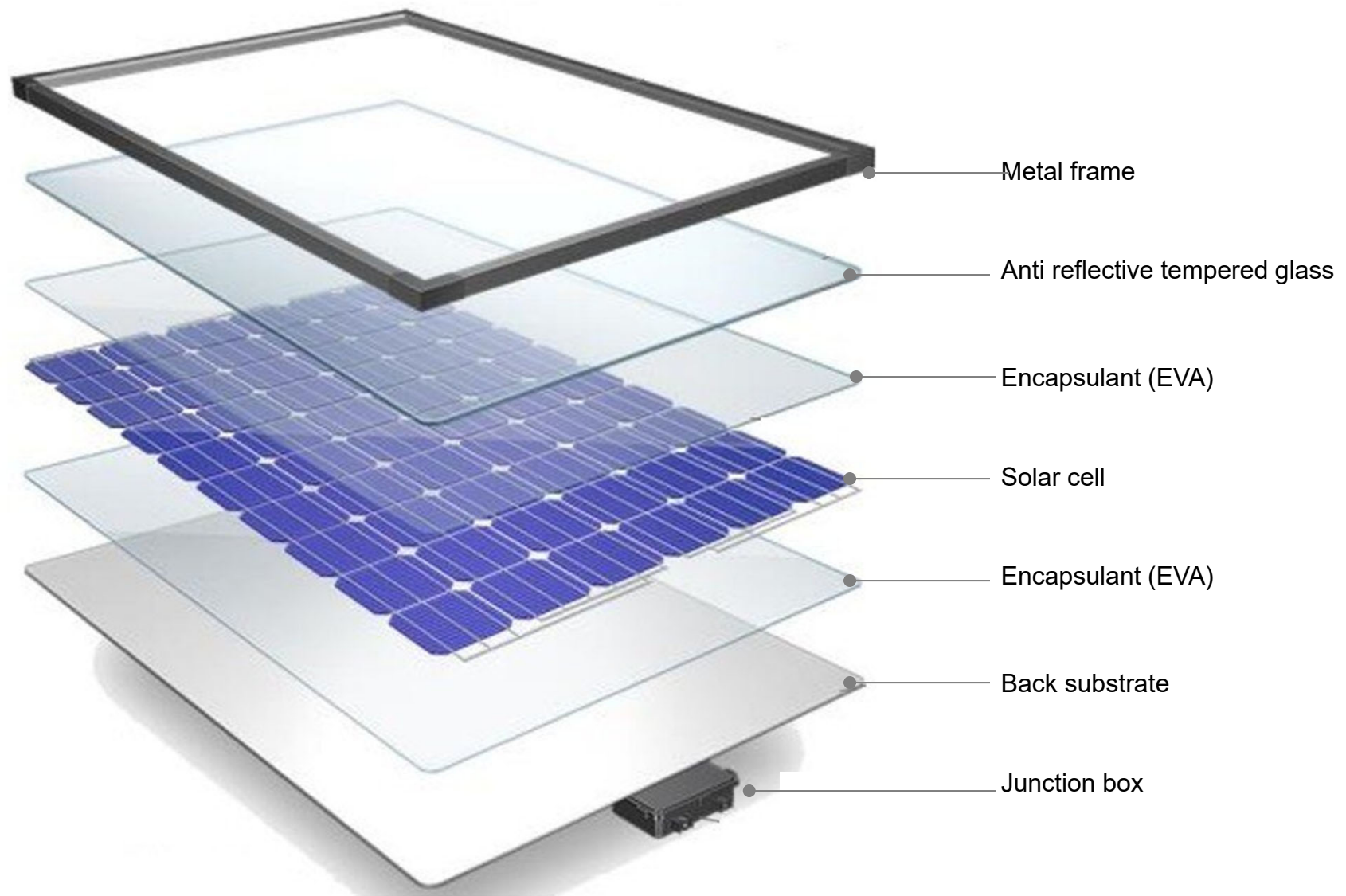
# Solar Cell Technology

- The renewable energy integration is required to offset the energy use by active building systems.
- The integration of renewable energy system involves variables such as available renewable energy resources, energy economics, energy requirements, building constraints, and site constraints.
- Renewable energy resources for site energy could include: sun, wind, hydro, geothermal, biomass, hydrogen, and fuel cell.



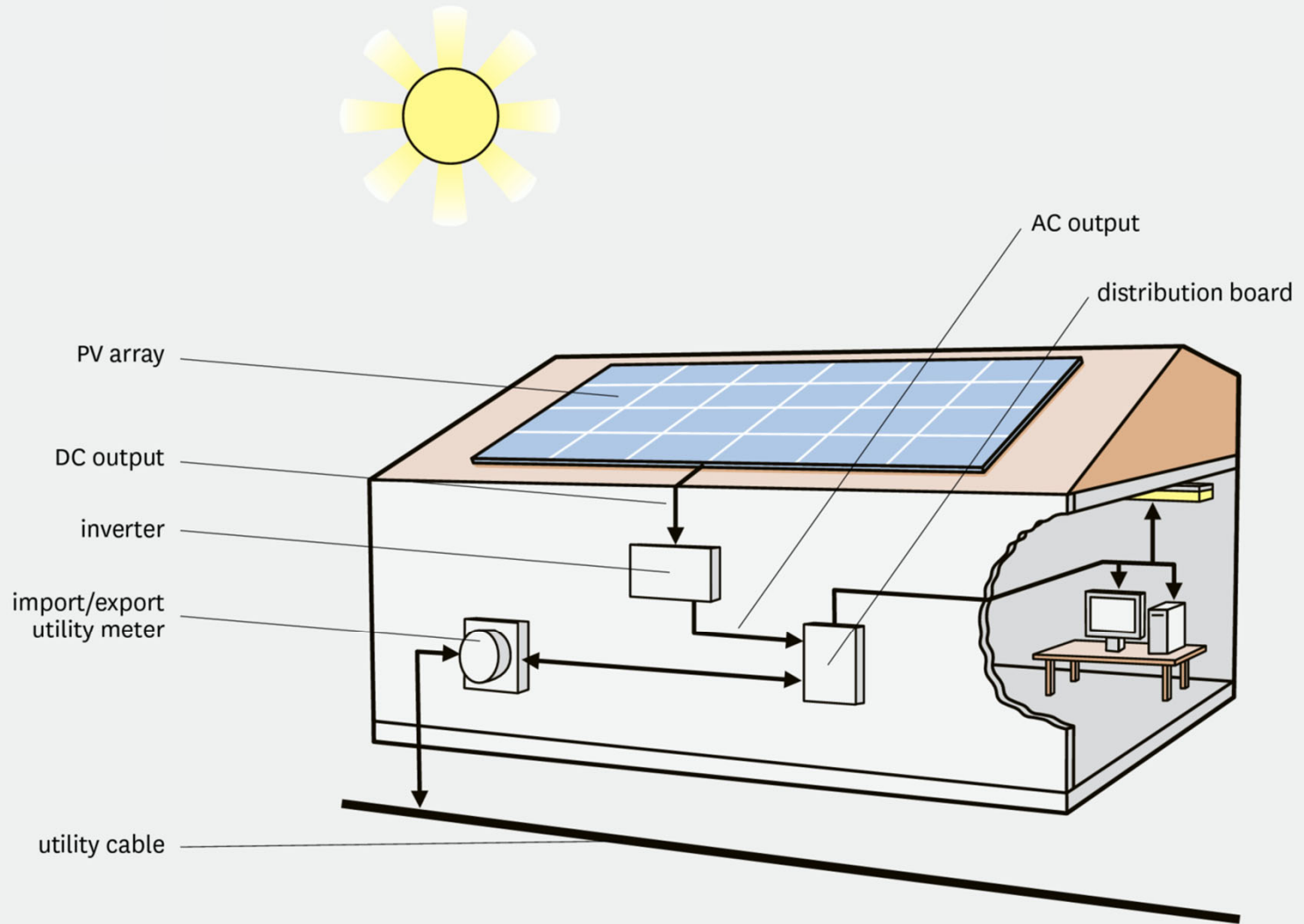
# Best Research-Cell Efficiencies







# Solar Systems Integration



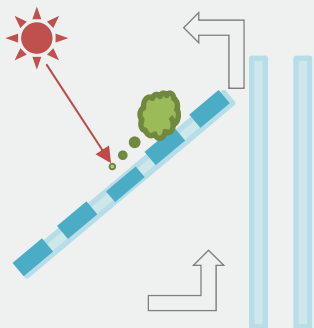




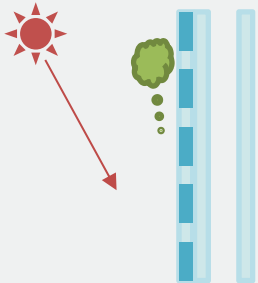
# BIPV Integration

# BIPV Typology

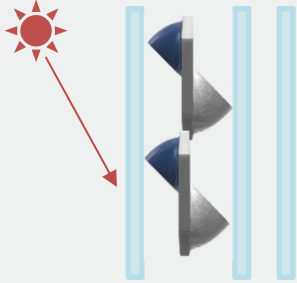
## Glazing application



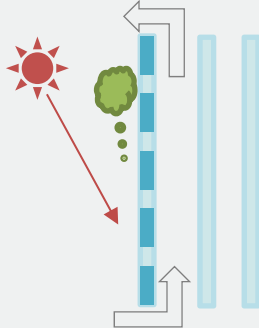
Shading device



Curtainwall

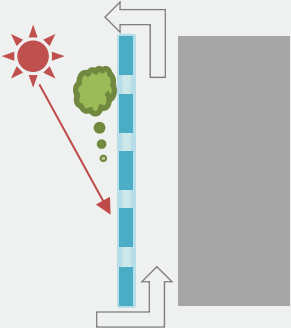
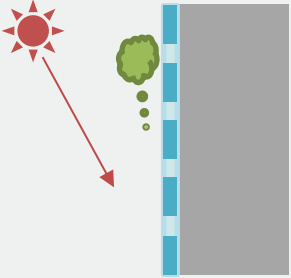


Closed cavity facade (CCF)

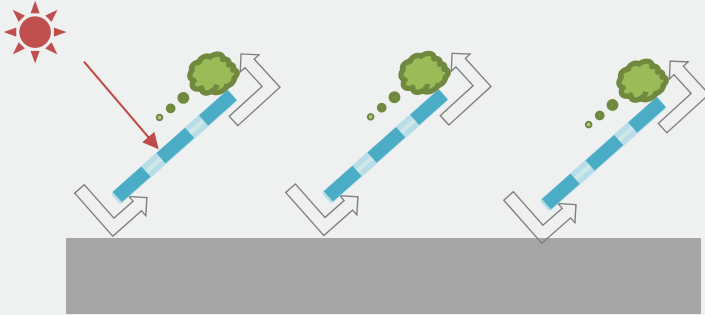


Double facade

## Opaque wall application (rain screen system)



## Roof top application





# Roof Top Installation



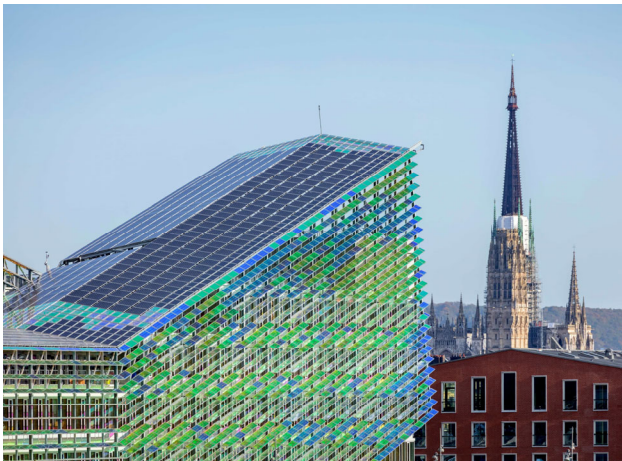
Powerhouse Brattørkaia – Sloping



Google HQ – Dragon Scale



Google HQ – Flat



Métropole Rouen Normandie HQ - Sloping



LAD HQ-Veiling



School in port-Undulating



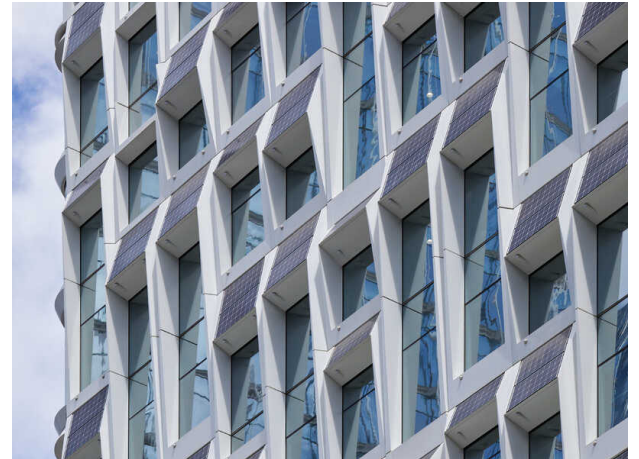
# BIPV Curtainwall



Federation of Korean Industry –  
Folded (Horizontal)



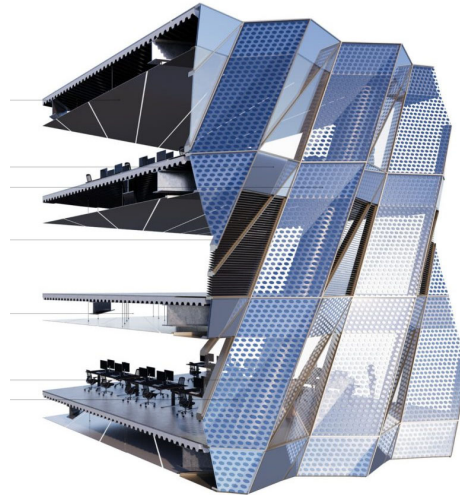
Doctors without Borders HQ–  
Flat



HanHwa HQ– Modular



Solar Skin Tower – Folded (Vertical)

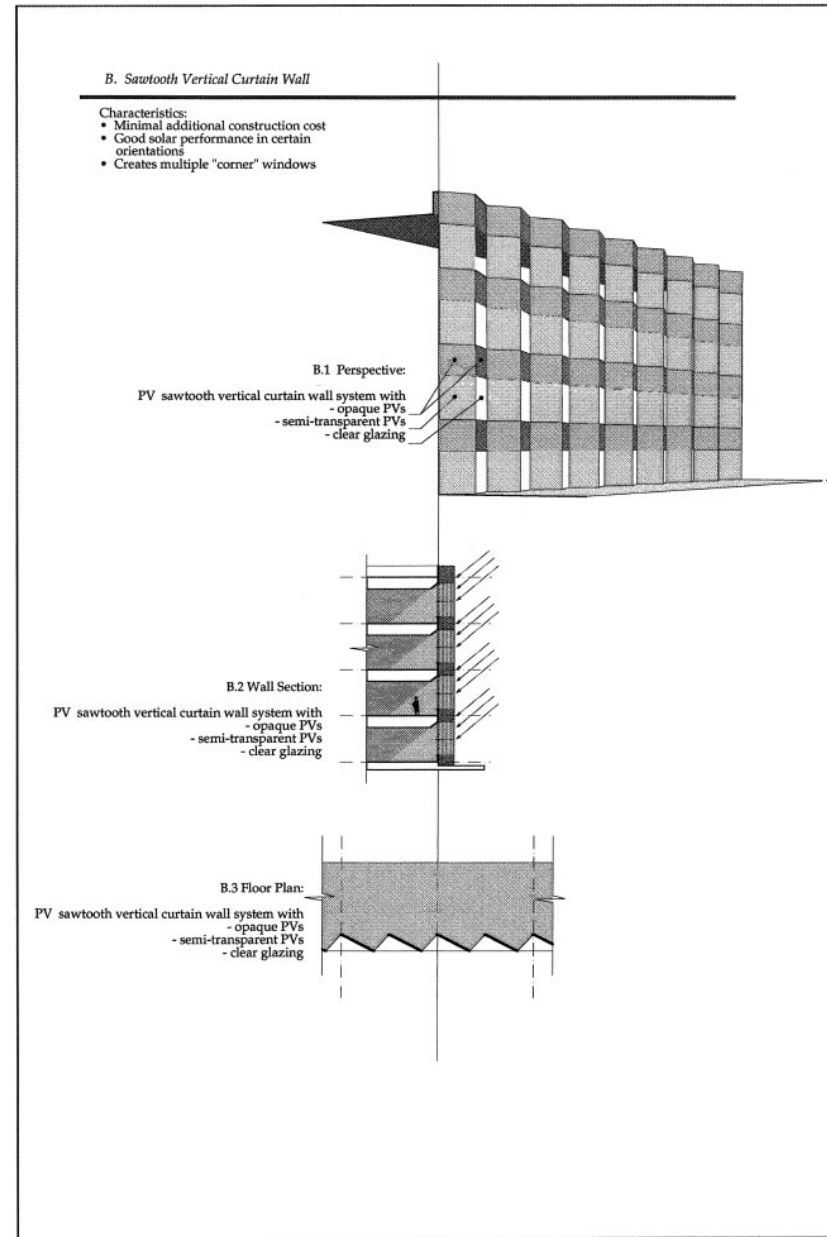
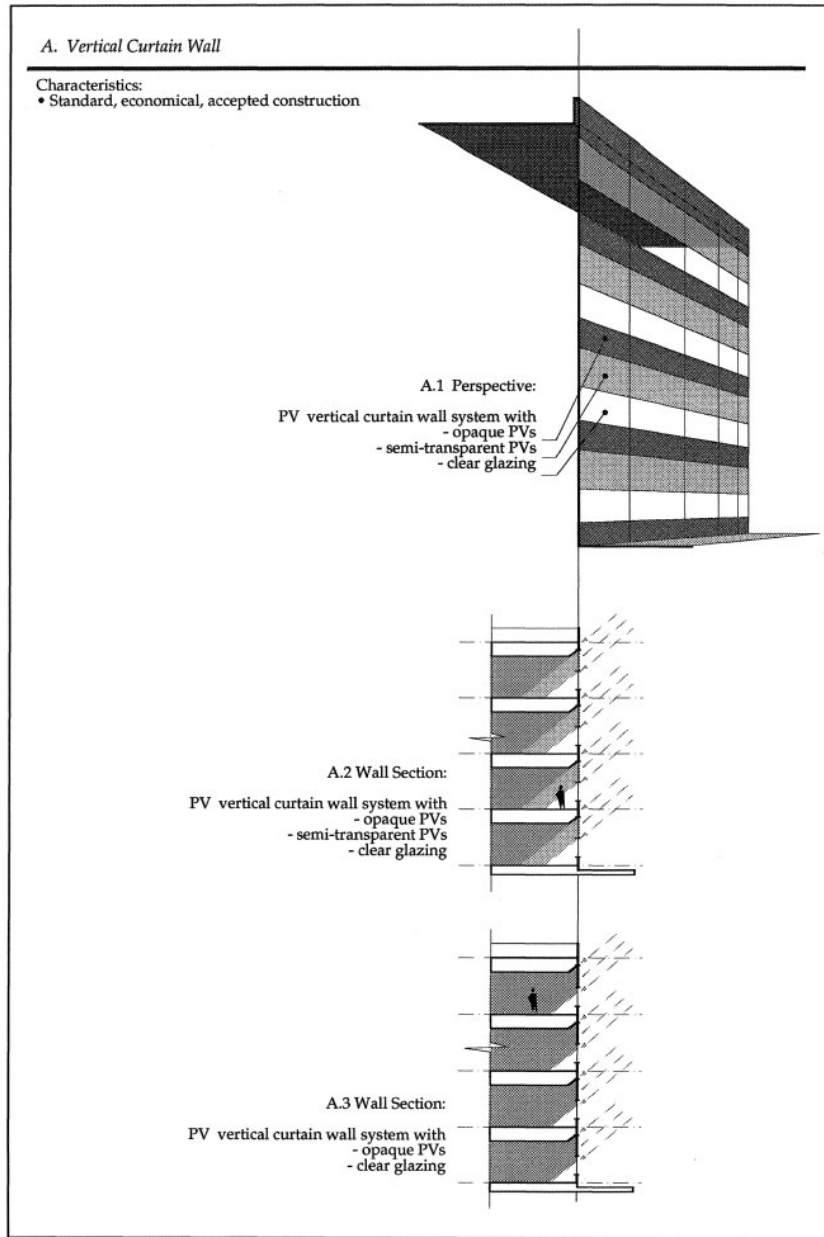


East Park Tower (Tilted)



The Blauhaus - Woven

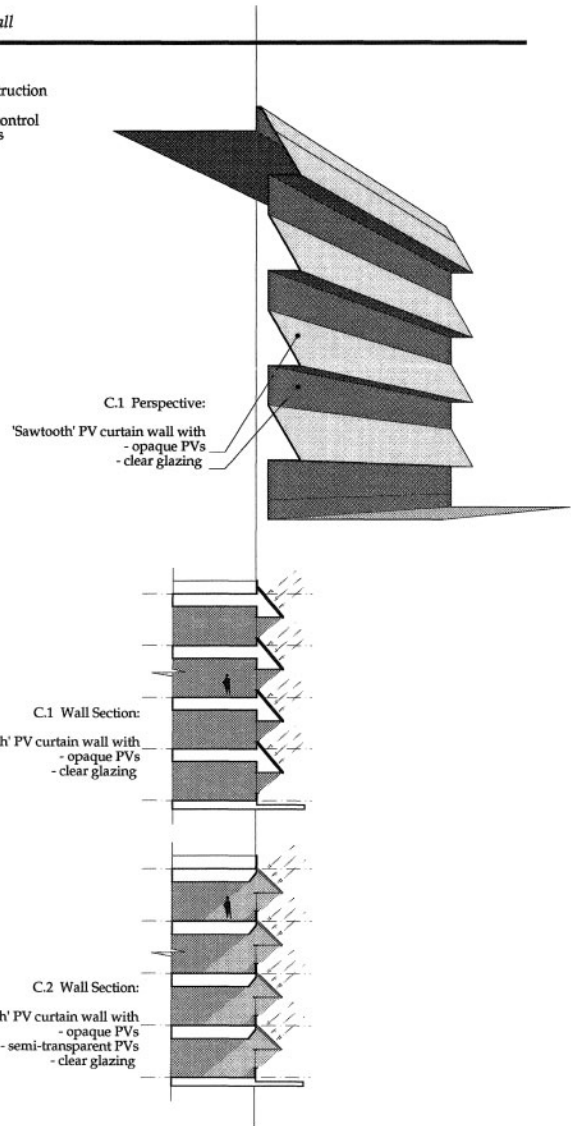
# BIPV Design



# BIPV Design

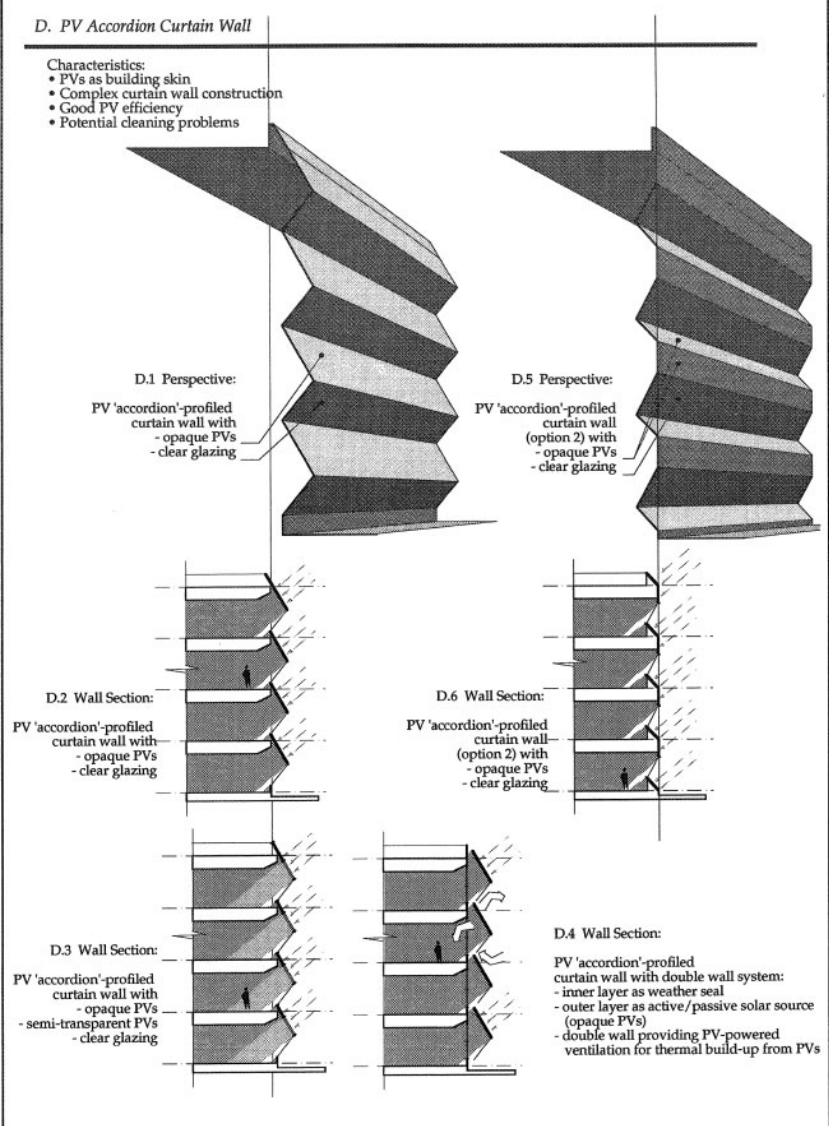
## C. PV Sawtooth Curtain Wall

- Characteristics:
- PVs as building skin
  - Complex curtain wall construction
  - Good PV efficiency
  - Passive shading/daylight control
  - Potential cleaning problems

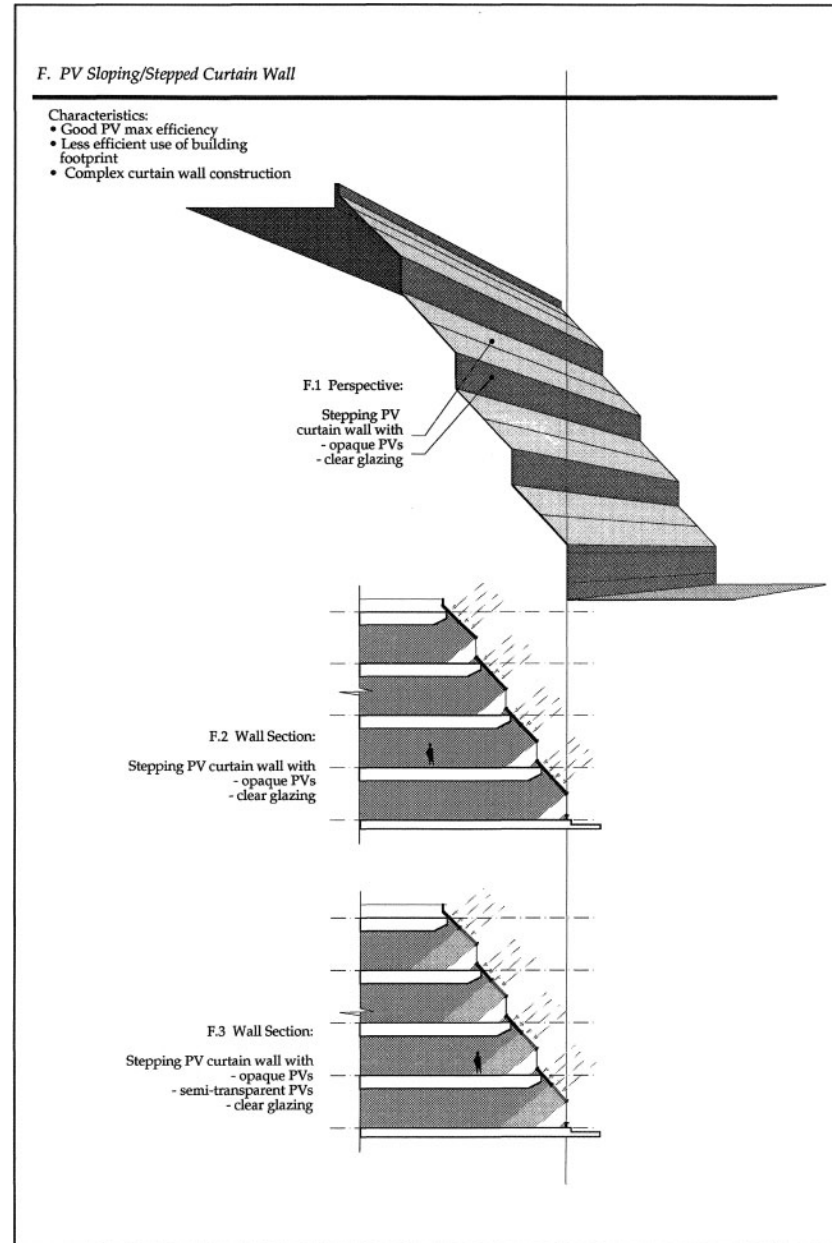
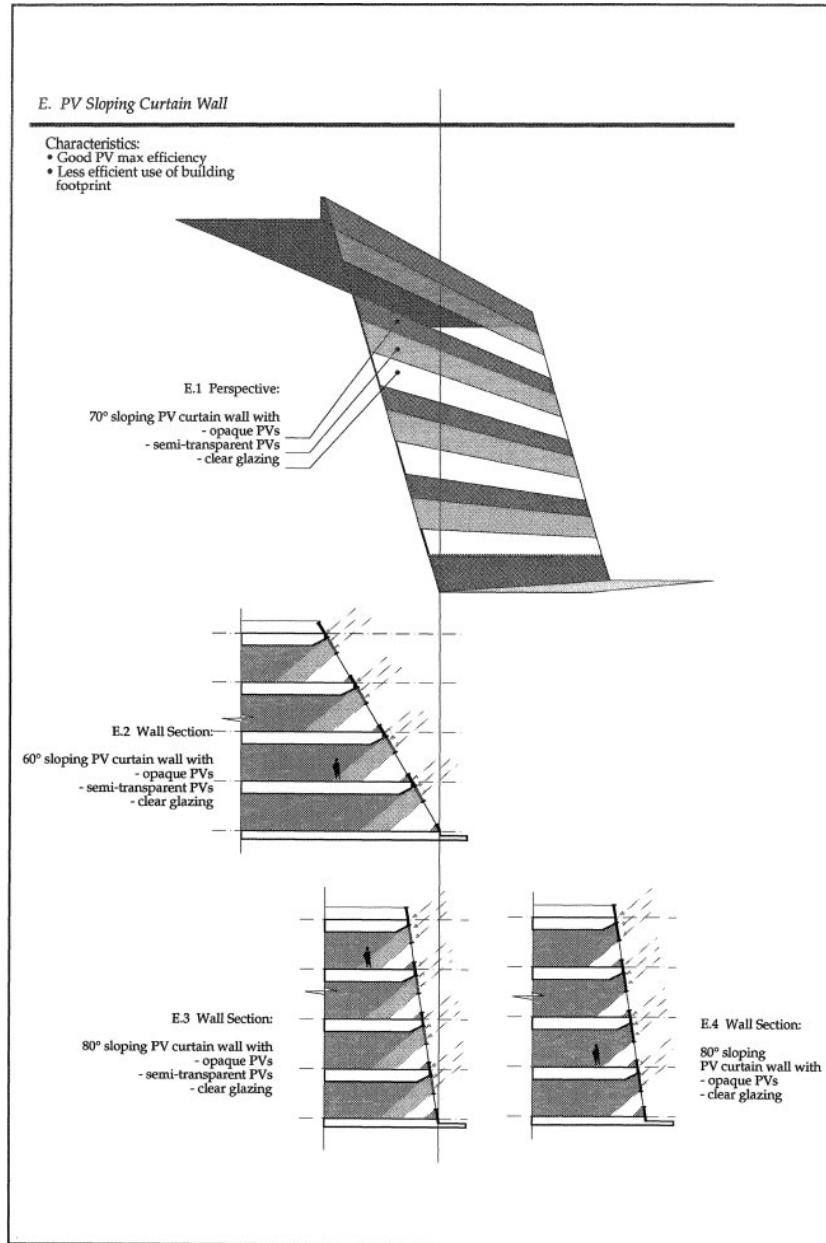


## D. PV Accordion Curtain Wall

- Characteristics:
- PVs as building skin
  - Complex curtain wall construction
  - Good PV efficiency
  - Potential cleaning problems



# BIPV Design





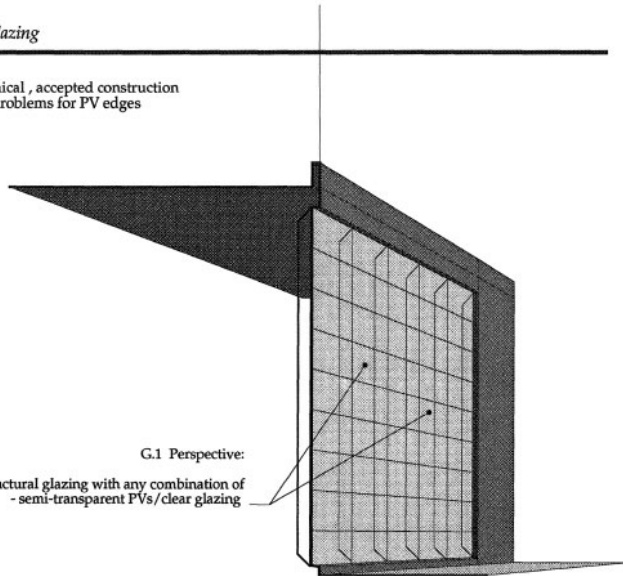
# BIPV Design

## G. PV Structural Glazing

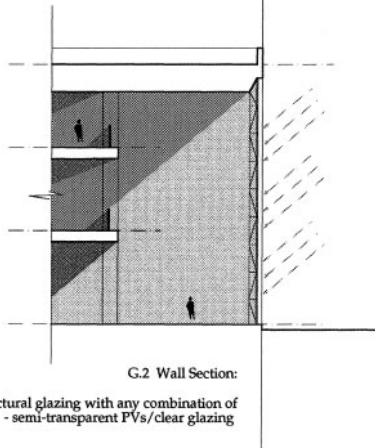
Characteristics:

- Standard, economical, accepted construction
- Difficult sealing problems for PV edges

G.1 Perspective:  
Vertical PV structural glazing with any combination of  
- semi-transparent PVs/clear glazing



G.2 Wall Section:  
Vertical PV structural glazing with any combination of  
- semi-transparent PVs/clear glazing

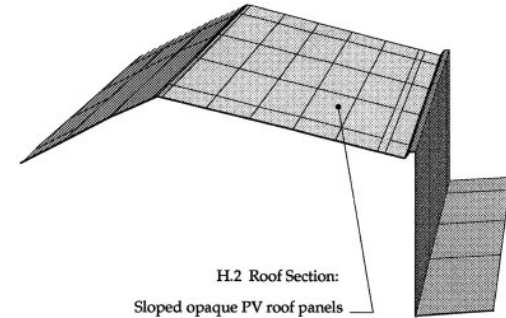


## H. PV Roof Panels

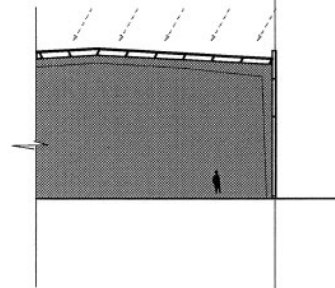
Characteristics:

- PVs as building skin
- Combined with rooftop structural system (panelized units with insulation, fastened directly to roof structure)
- Weatherproofing and structural issues must be carefully resolved
- Snow accumulation considerations

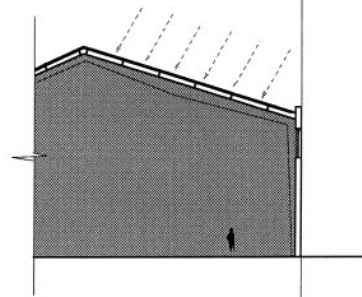
H.2 Roof Section:  
Sloped opaque PV roof panels



H.2 Roof Section:  
Horizontal opaque PV roof panels

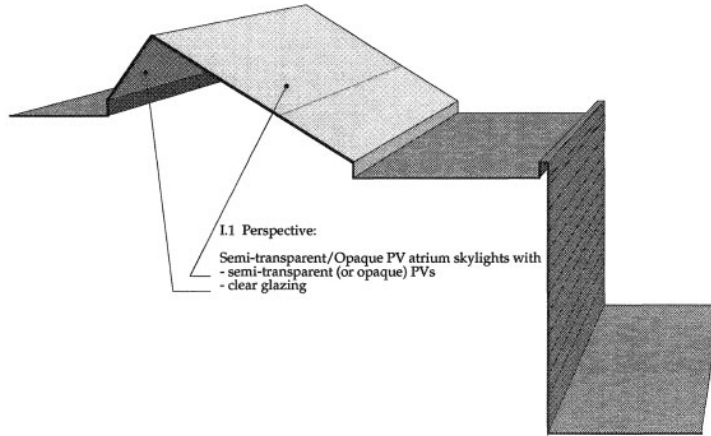


H.3 Roof Section:  
Sloped opaque PV roof panels

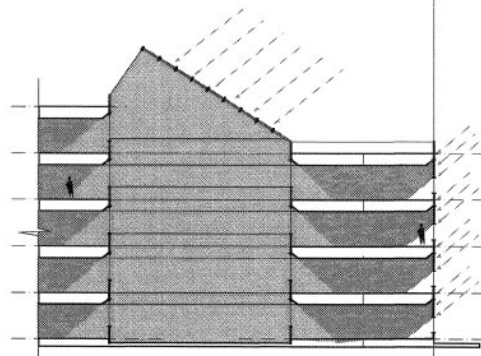


# BIPV Design

## I. PV Atriums



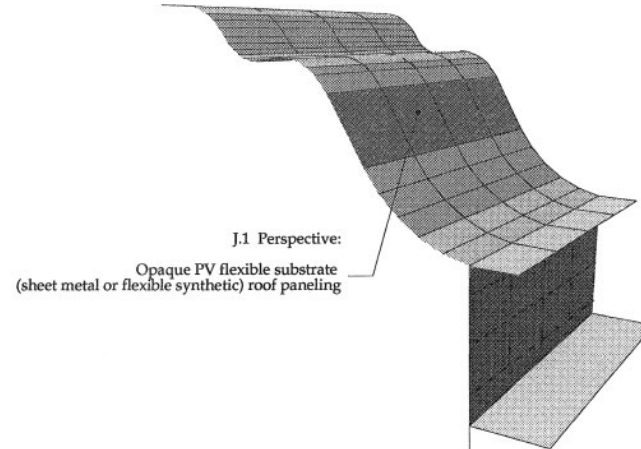
I.1 Perspective:  
Semi-transparent/Opaque PV atrium skylights with  
- semi-transparent (or opaque) PVs  
- clear glazing



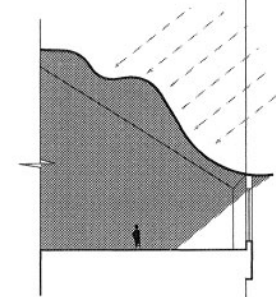
I.2 Roof /Wall Section:  
Opaque &/ or transparent PV atrium skylights with  
- semi-transparent (or opaque) PVs  
- clear glazing

## J. Flexible/ Metal PV Substrates

- Characteristics:
- For roofs and/or wall applications
  - Good design flexibility
  - Light-weight
  - Possible integral weather barrier



J.1 Perspective:  
Opaque PV flexible substrate  
(sheet metal or flexible synthetic) roof paneling



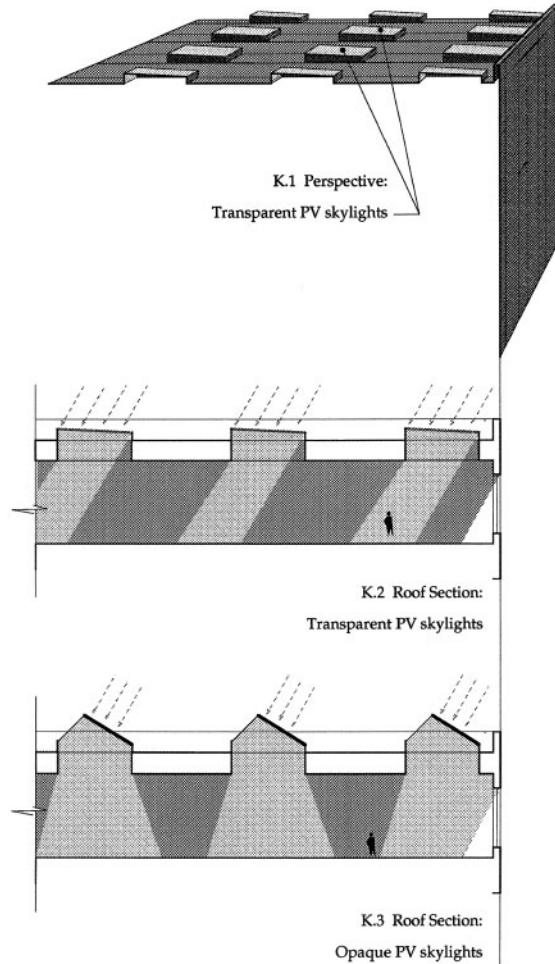
J.2 Wall Section:  
Opaque PV flexible substrate  
(sheet metal or flexible synthetic) roof paneling

# BIPV Design

## K. PV Skylights

**Characteristics:**

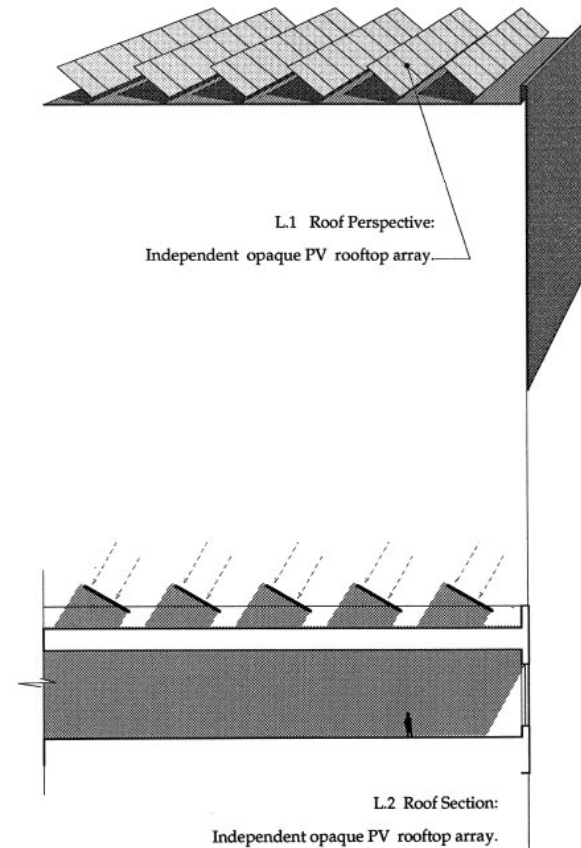
- PV system as indiv. roof openings
- New construction or retrofit
- Tilted or horizontal orientation
- Numerous configurations possible
- Daylighting benefits
- Snow accumulation considerations



## L. Independent PV Rooftop Array

**Characteristics:**

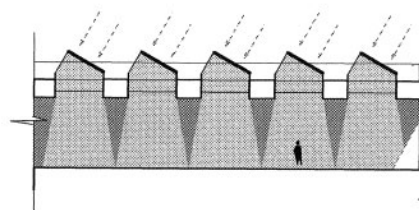
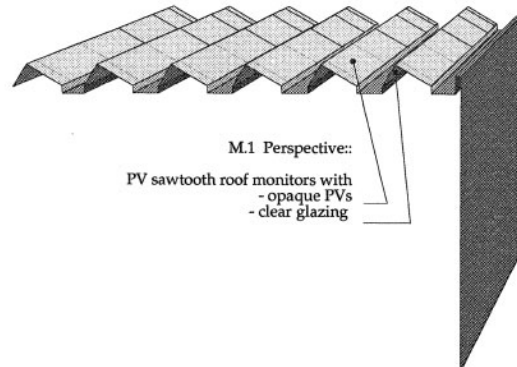
- PV system independent of bldg skin
- conventional array configuration installed on rooftop
- Maximal efficiency
- New construction or retrofit
- Potential passive benefit from reduced heat load
- Potential structural costs
- Water proofing issues at roof/structure



# BIPV Design

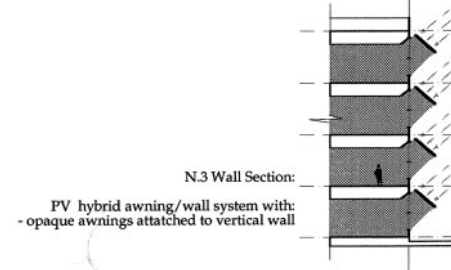
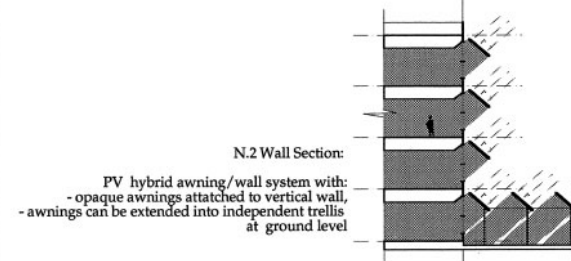
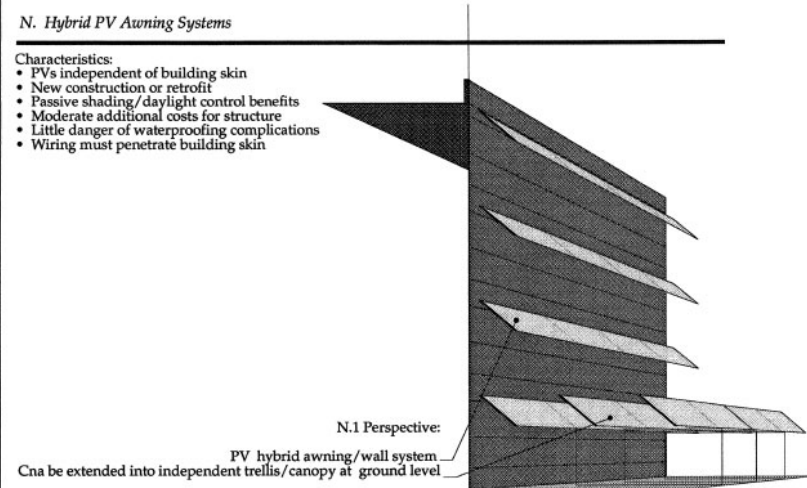
## M. PV Sawtooth Roof Monitors

- Characteristics:
- PV system as building skin
  - Retrofit to exist. industrial buildings
  - Good PV efficiency
  - Good daylight benefits



## N. Hybrid PV Awning Systems

- Characteristics:
- PVs independent of building skin
  - New construction or retrofit
  - Passive shading/daylight control benefits
  - Moderate additional costs for structure
  - Little danger of waterproofing complications
  - Wiring must penetrate building skin





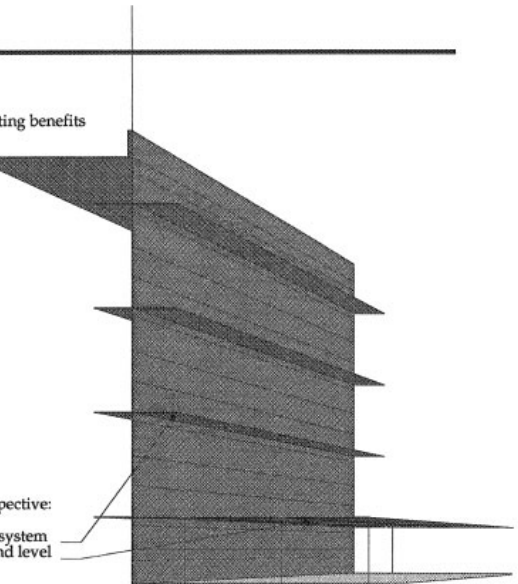
# BIPV Design

## O. Hybrid PV Awning/Light Shelf Systems

- Characteristics:
- PVs independent of building skin
  - New construction or retrofit
  - Passive shading/daylight control/daylighting benefits
  - Potentially significant structural and weatherproofing costs

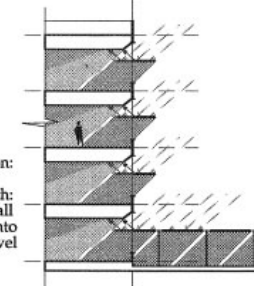
O.1 Perspective:

Hybrid PV light shelf/wall system  
Can be extended into independent trellis at ground level



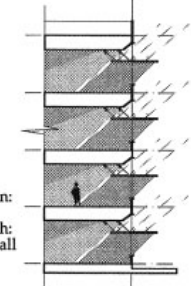
O.2 Wall Section:

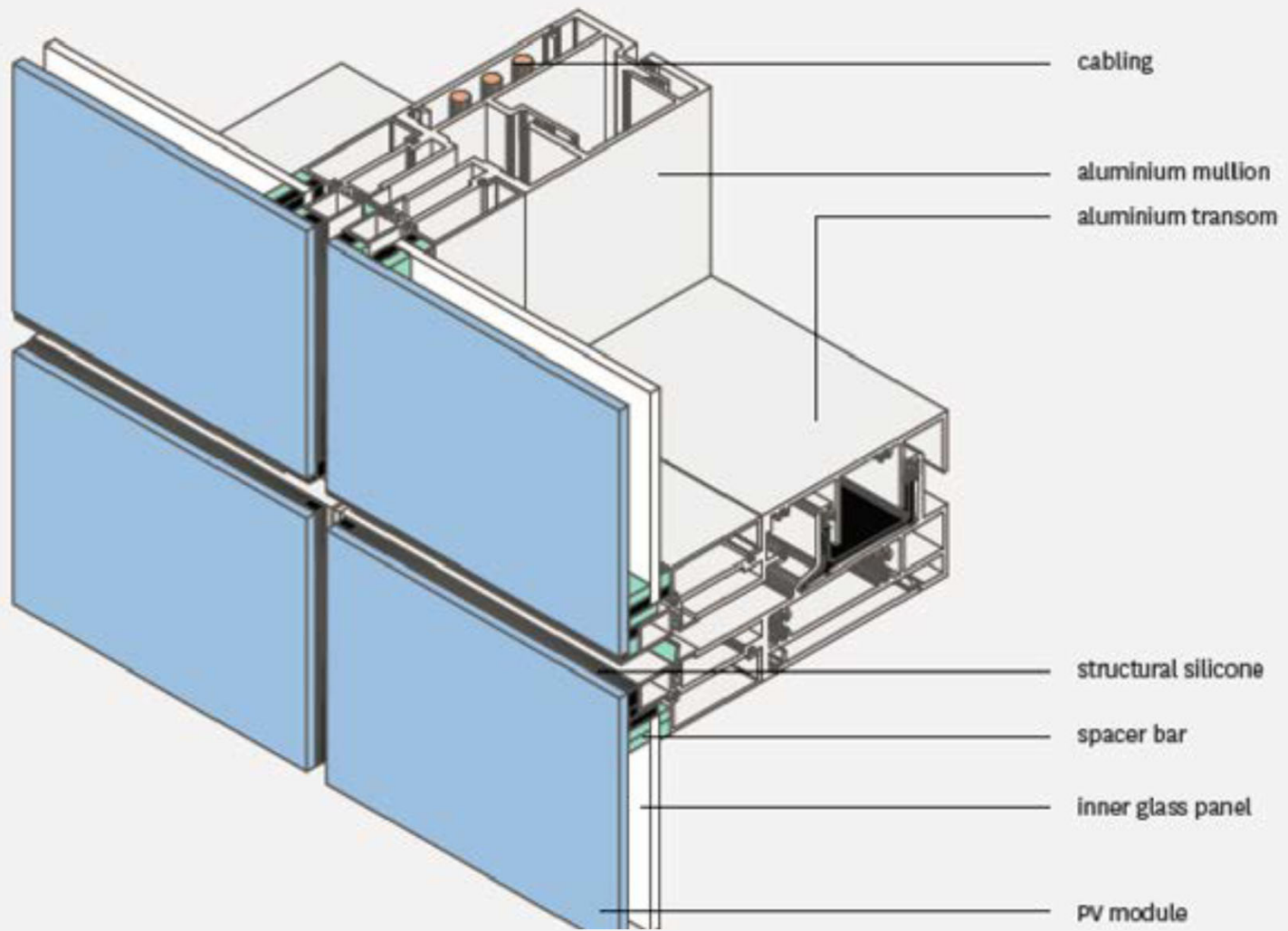
Hybrid PV light shelf/wall system with:  
- opaque PV light shelves attached to vertical wall  
- horizontal PVs which can be extended into independent trellis at ground level



O.3 Wall Section:

Hybrid PV light shelf/wall system with:  
- opaque PV light shelves attached to vertical wall









07771 3603118 86701











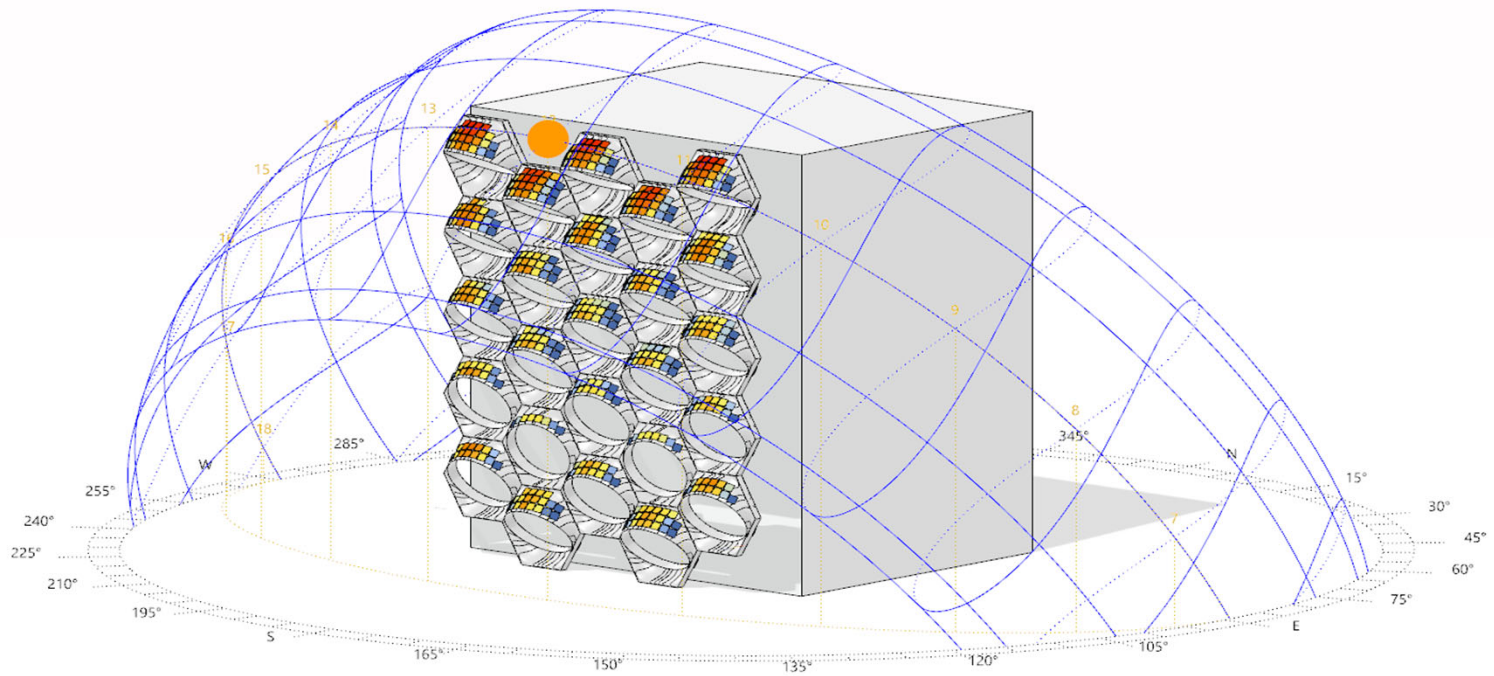
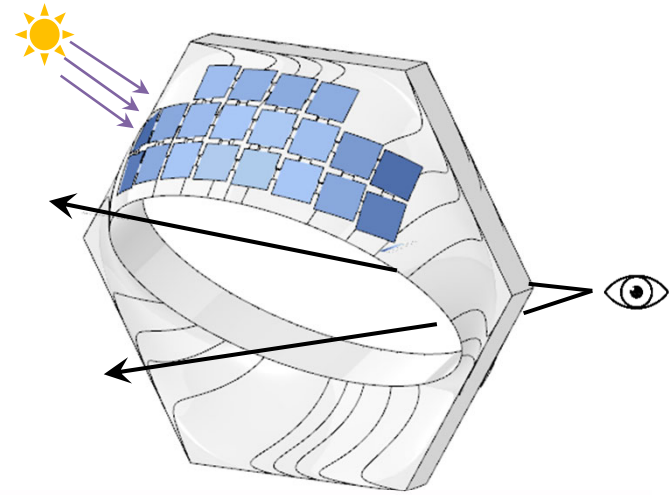
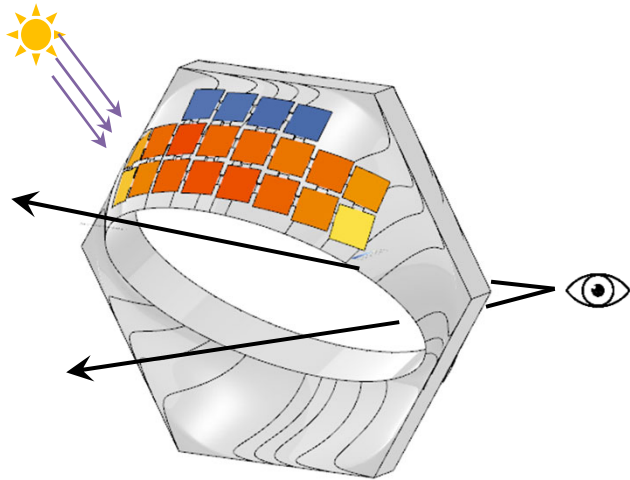
The image shows a top-down view of a printed circuit board (PCB) with a complex, symmetrical layout. The board is dark, and the traces are highlighted in a bright, glowing white or light grey. The layout features a central hexagonal pattern of circular cutouts, with intricate circuit traces connecting them. The overall appearance is that of a high-tech, precision-engineered component.

# Circuit Connection

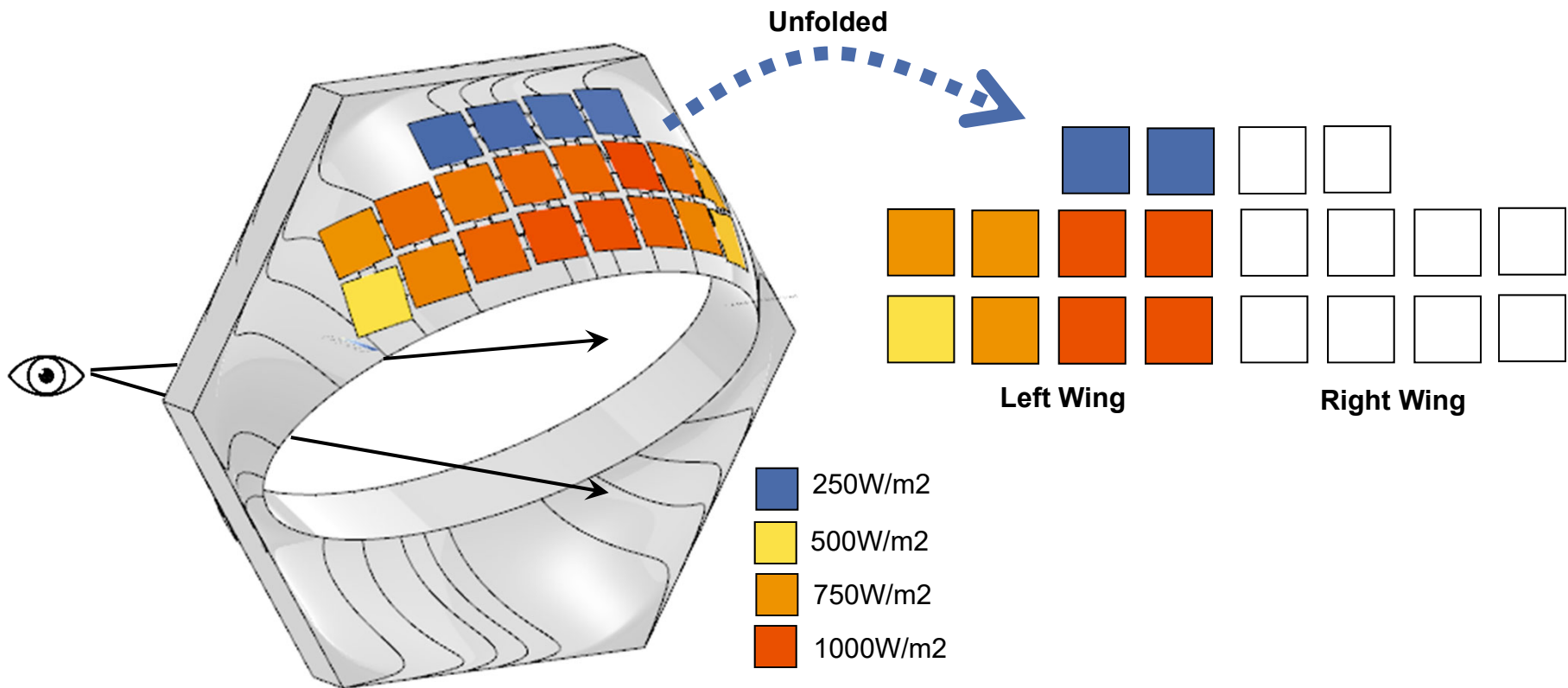






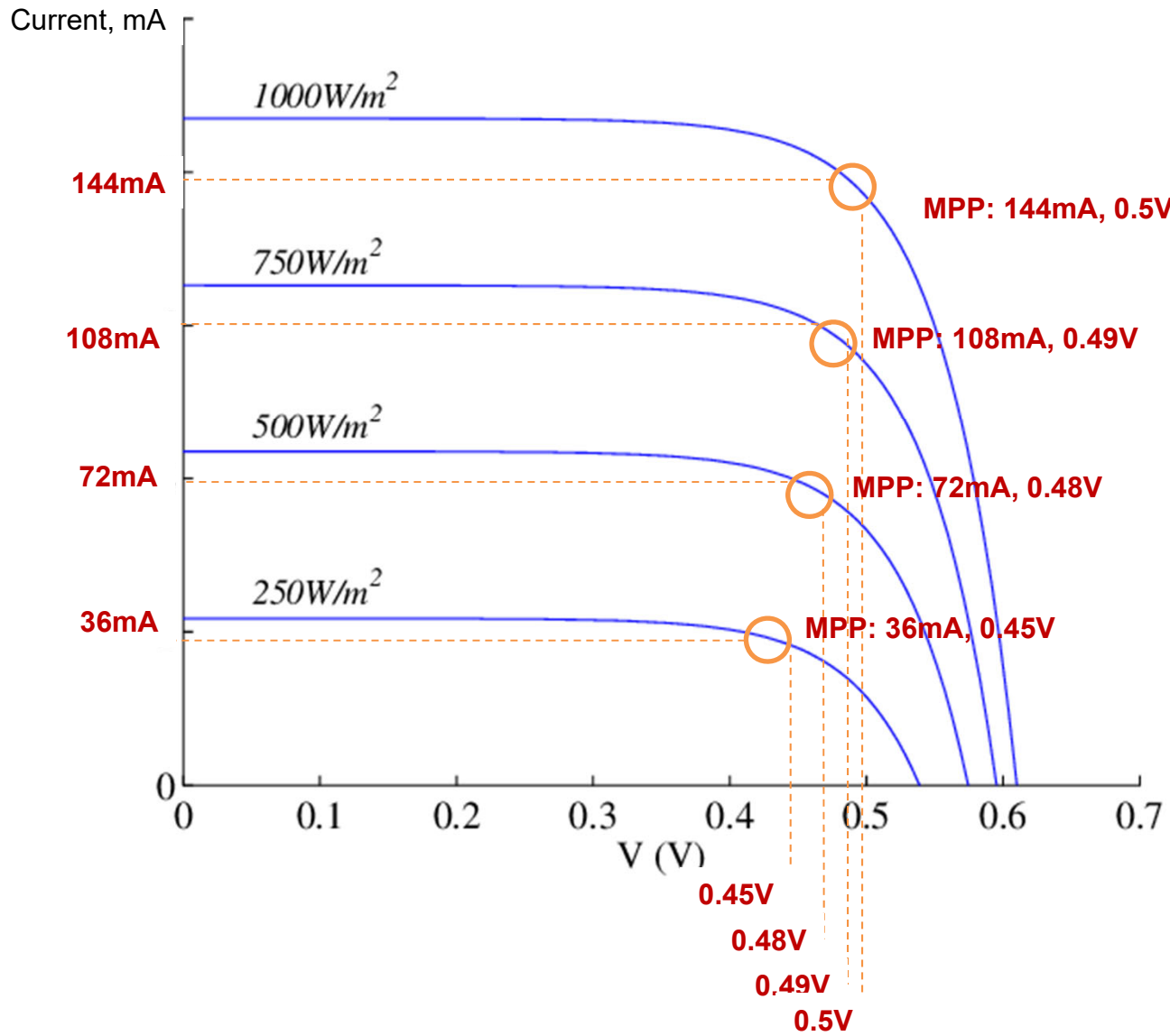


- Using irradiance color coding at 1pm, summer solstice, which cell connection is better for the left-wing? series, parallel or hybrid? Draw lines between cells representing cell connection.
- What is the maximum theoretical power output based on the I-V curve data?



Solar Cell spec: 0.5V, 160MA measured at lab setting under 1000W/m<sup>2</sup> light source. Use the following I-V graph.  
[https://www.amazon.com/dp/B087TK7T7T?ref\\_=cm\\_sw\\_r\\_apin\\_dp\\_4MBC3S0RF81E1Z0TY456](https://www.amazon.com/dp/B087TK7T7T?ref_=cm_sw_r_apin_dp_4MBC3S0RF81E1Z0TY456)

### I-V curve







3:29 4/6 par voltage



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