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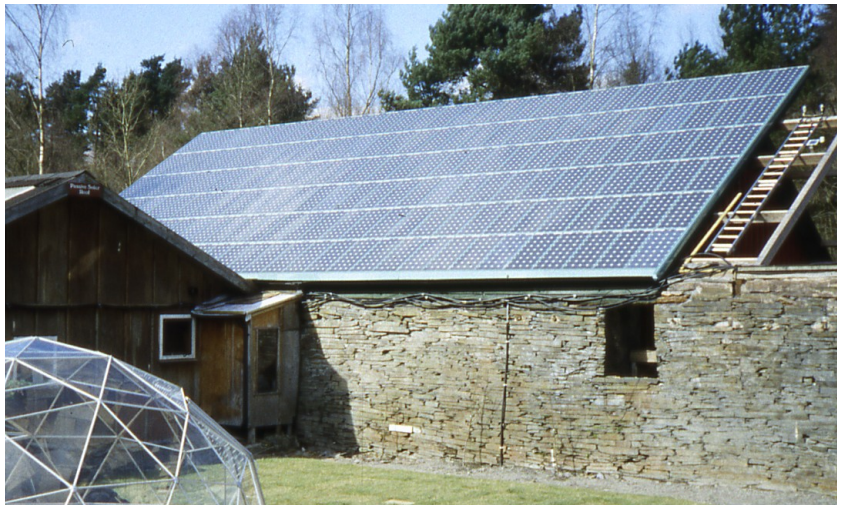

Centre for Alternative Technology, Wales

PHOTOVOLTAIC MODULES FOR OFF-GRID APPLICATIONS

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Main themes

- Photovoltaic cell
- Photovoltaic module
- Types of modules
- Output / radiation
- Effect of shade
- Effect of temperature
- Open circuit voltage
- Short circuit current

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The photovoltaic effect

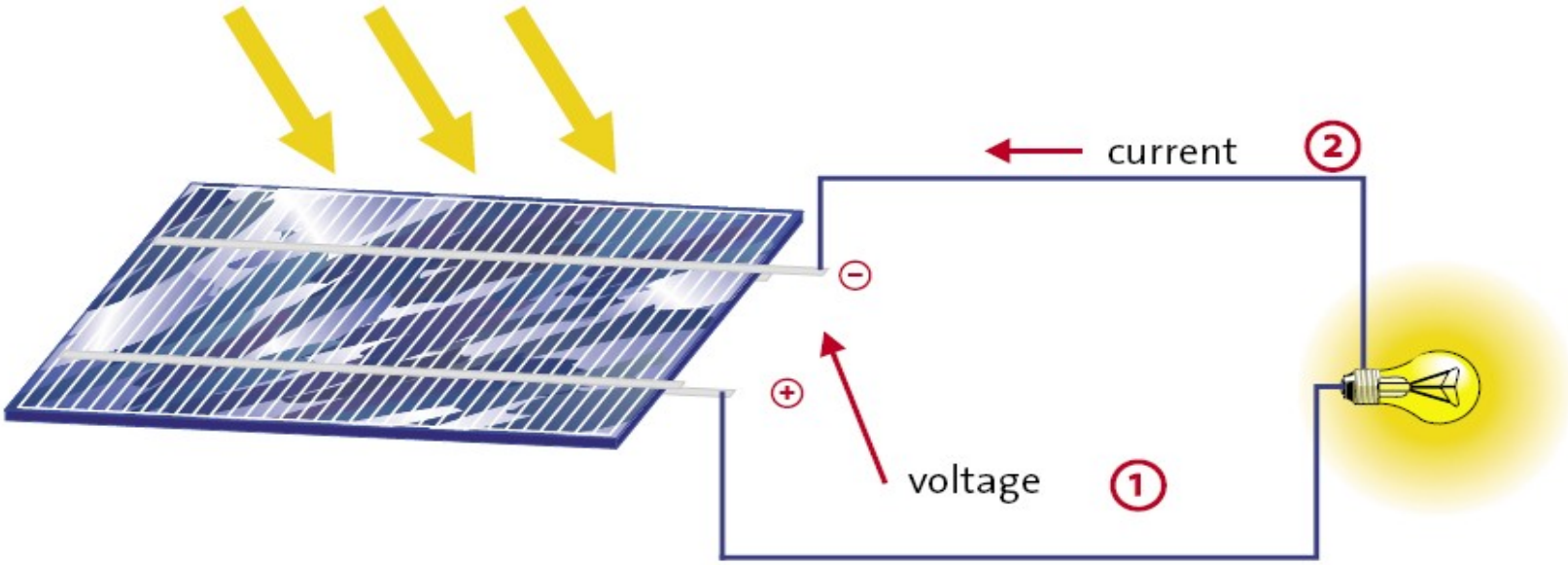

Figure 2.6: When exposed to light a voltage difference (1) occurs between the side of the cell exposed to the light and its underside. If a circuit is completed, electrical current will flow (2)

Photovoltaics for Professionals
Recommended first book for engineers, electricians, builders ad architects interested in grid-tied photovoltaics

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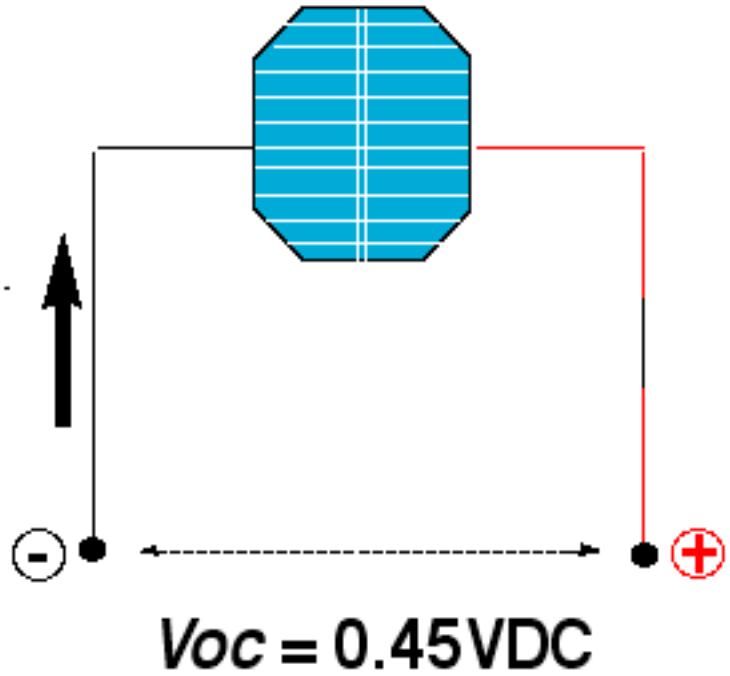
The photovoltaic cell

Current (*I*) depends on the level of solar insolation and the area of the cell



Open circuit voltage (*Voc*) remains fairly constant

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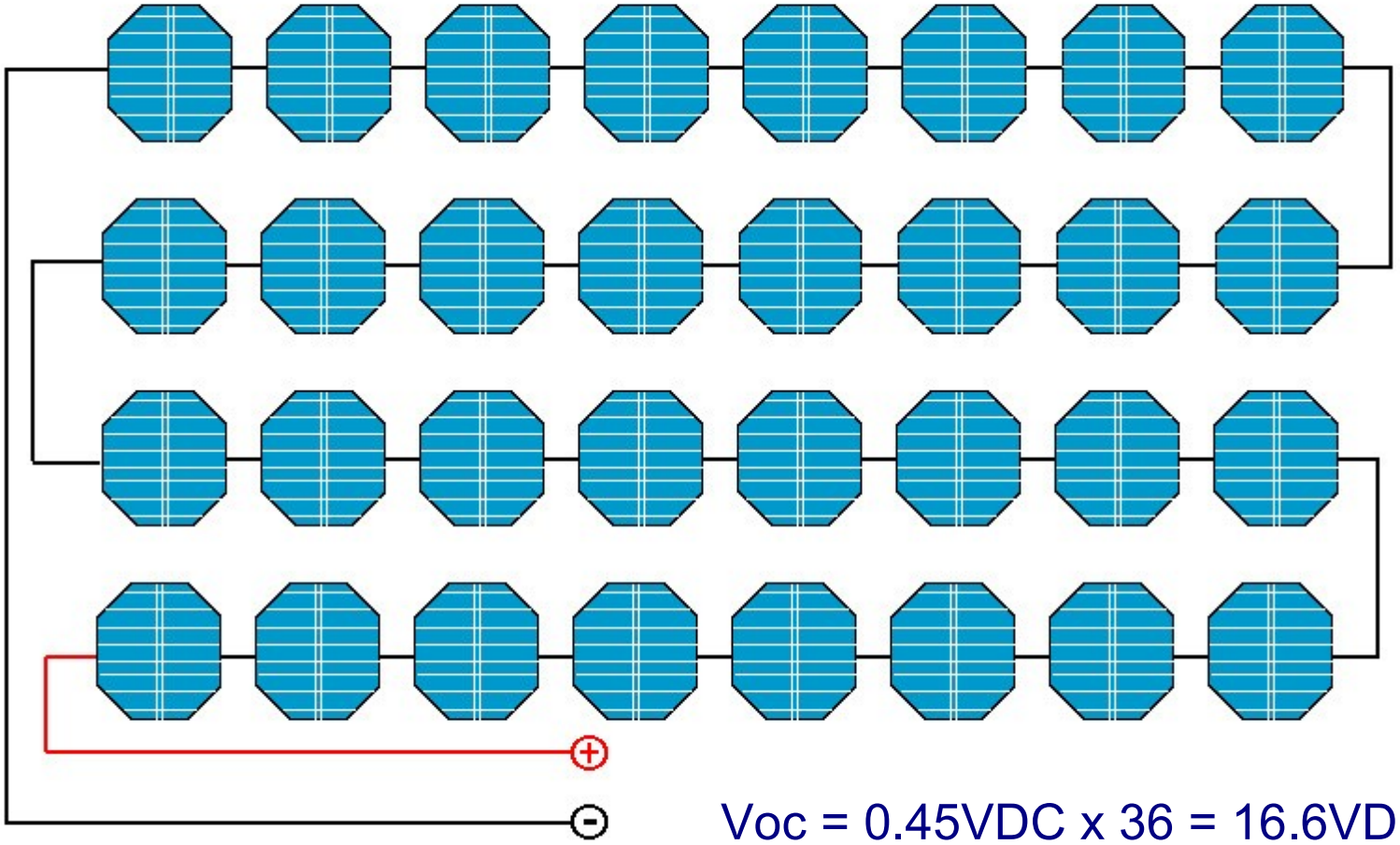
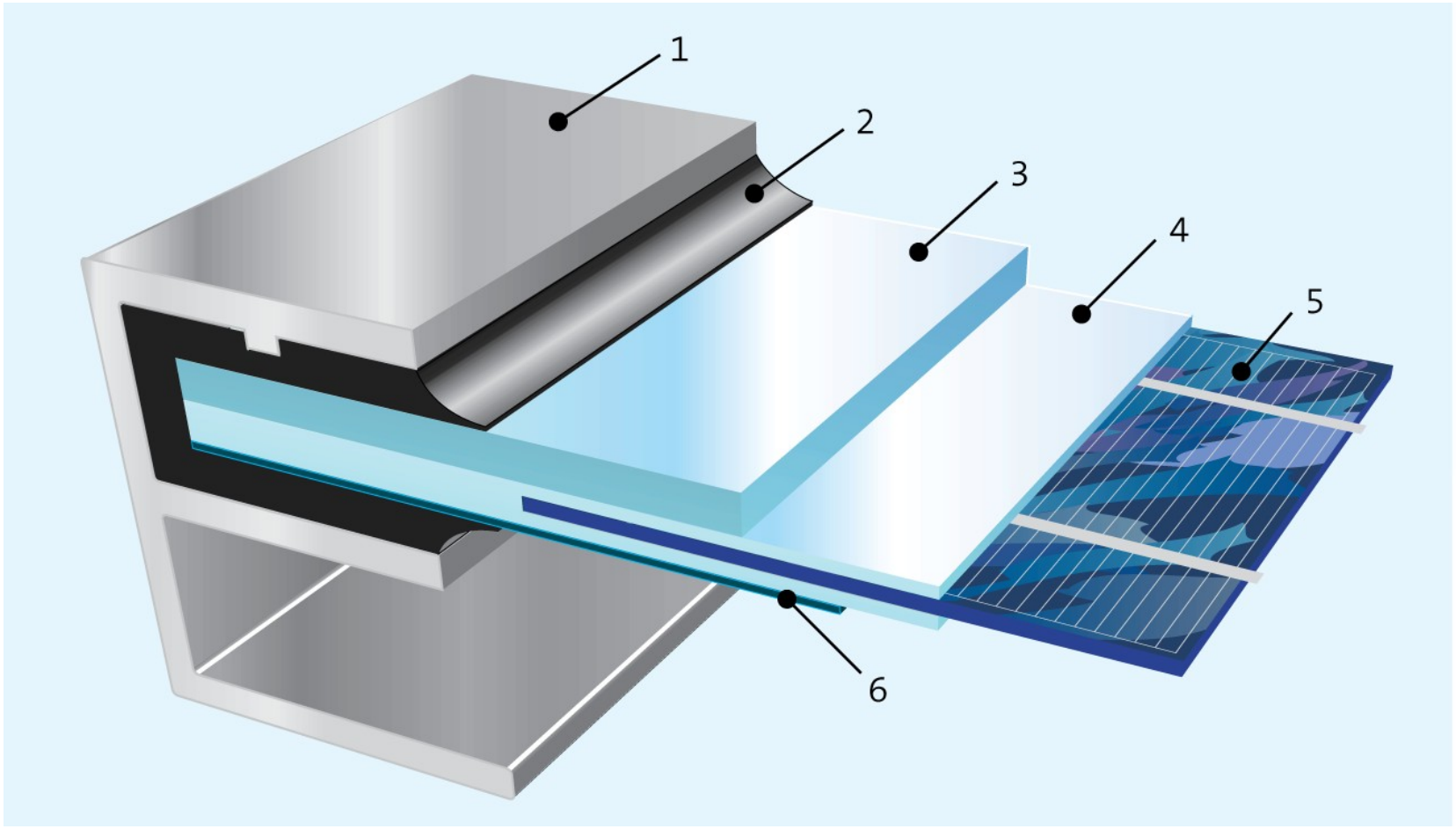
Solar cells in series in a solar module



Voc = 0.45VDC x 36 = 16.6VDC



1 Aluminium frame, 2 Seal, 3 Glass, 4 Encapsulating EVA, 5 Crystalline cell, 6 Tedlar sheet

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Photovoltaic modules are rated in

Peak Watts (Wp)

The peak wattage of a solar module is

the number of watts it will produce under

Standard Test Conditions (STC) (in ideal conditions)

Standard Test Conditions (STC) are

1kW/m^2 of solar radiation (1 PSH)

at a temperature of 25º C

in an Air Mass 1.5

Ideal conditions never exist outside the laboratory

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Solar module output @ STC

Wh = Wp x PSH

@ Standard Test Conditions

(Ideal conditions)

but in reality

Wh = Wp x PSH x **performance ratio**

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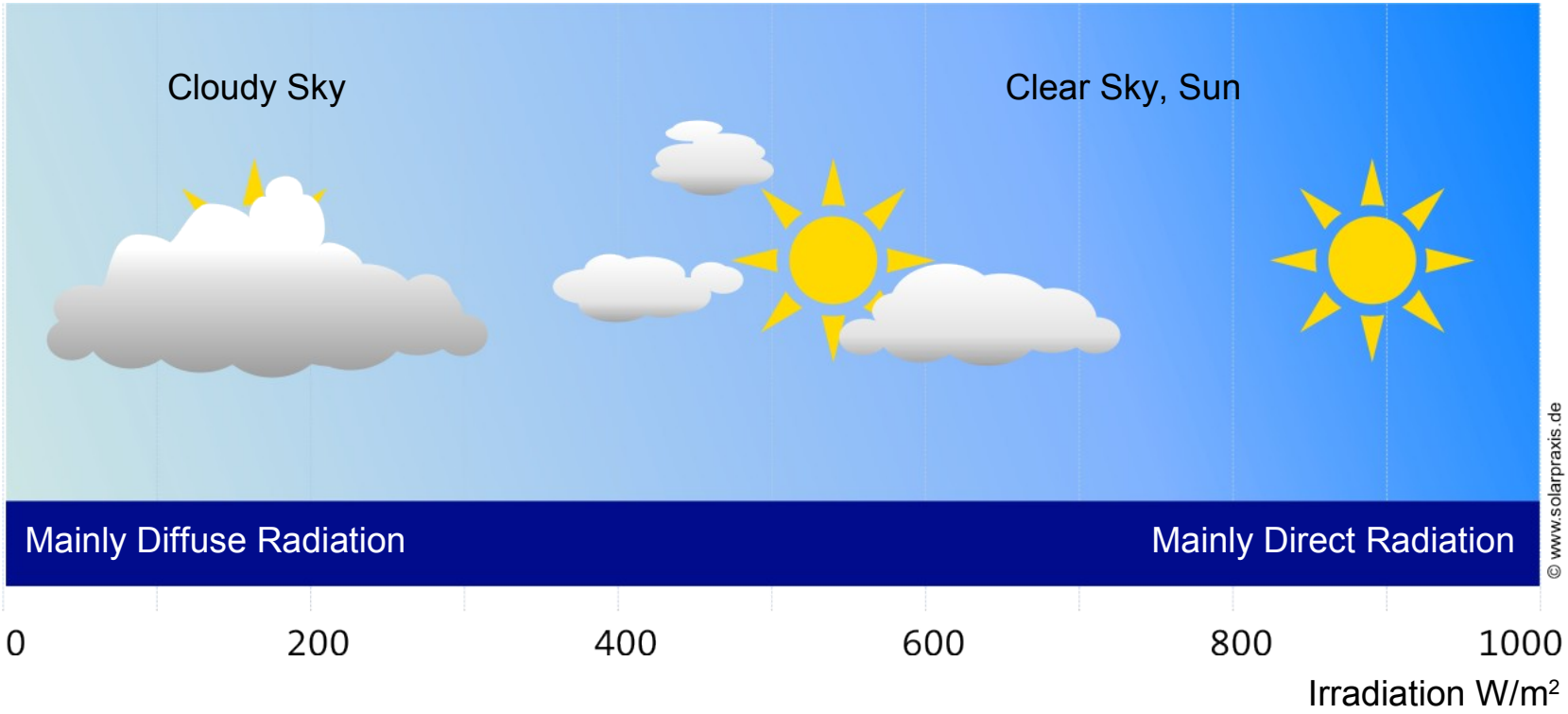
Irradiation dependence on weather



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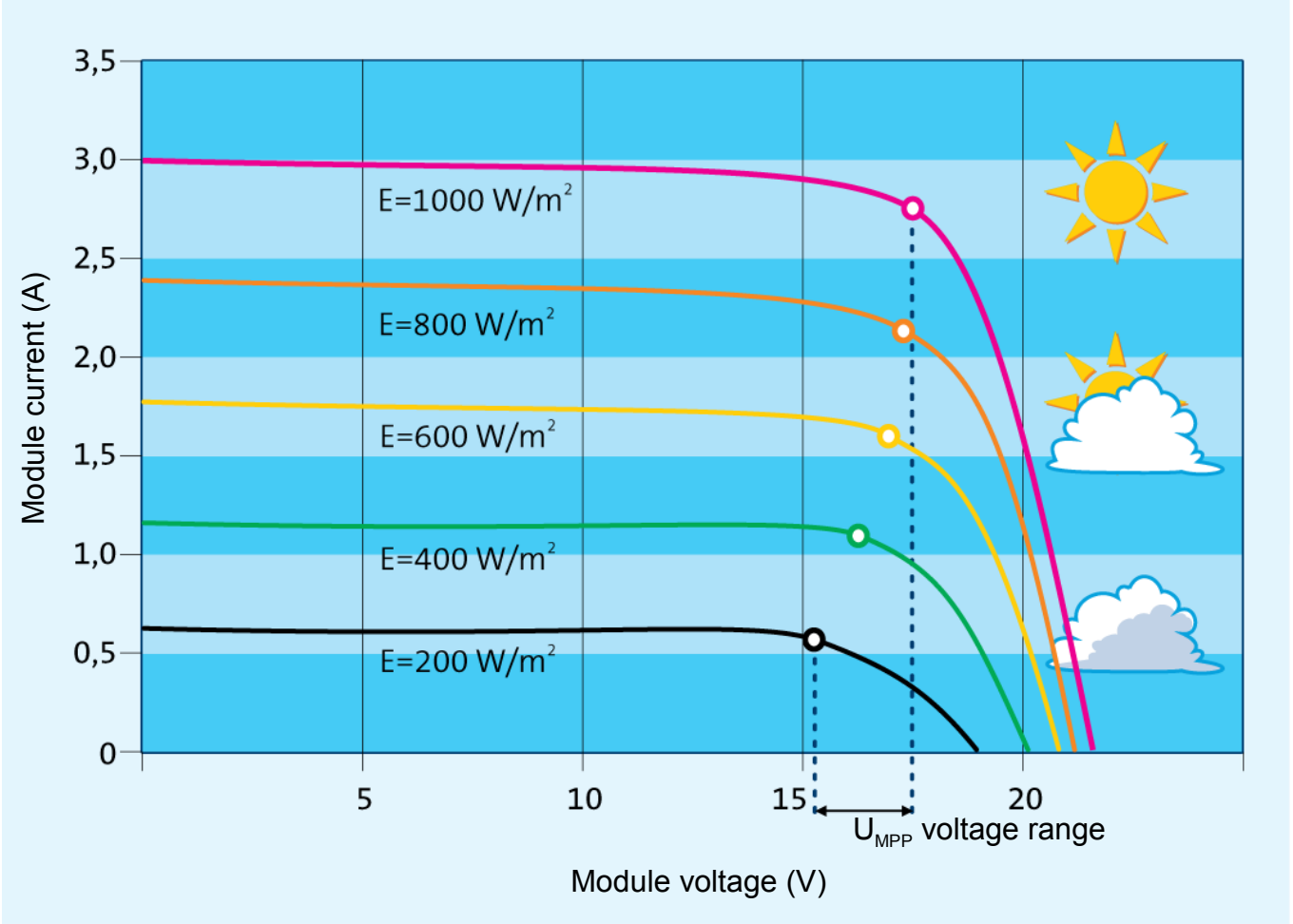
Effect of irradiation on silicon crystalline solar modules



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Solar module output – stand-alone

The unit of electrical energy used is
the **watt-hour (Wh)**

To calculate *approximately* how many Wh a module will produce on an average day *in a stand-alone system*, the following formula can be used:

Units of energy produced (Wh) = Module Peak Watts (Wp) x Peak Sun Hours (PSH) x (**0.60 - 0.70**)

Solar modules are rated in **peak watts (Wp)**
This will be on label on the back of the modules

Assumption : module is near optimum angle and orientation
Battery/system inefficiency needs to be added - 20%
(More exact to use module current)

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Solar module output example - off-grid

A 75 Wp solar module is installed in Devon in a stand-alone solar system. Approximately how much energy will it produce on one day in September when the average daily insolation available is 4.63 PSH?

Units of energy produced (Wh) = 75 Wp x 4.63 PSH x 0.7 =243Wh

The amount of electrical energy produced by the module would be approximately 243 Wh

Assumption : module is near optimum angle and orientation
Battery/system inefficiency needs to be added - 20%

(More exact to use module current)

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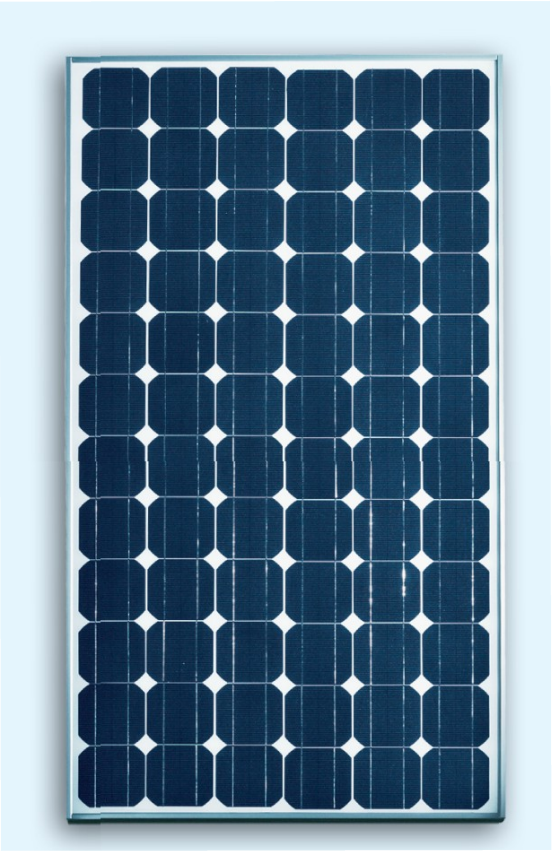
Monocrystalline modules

- Cells manufactured from wafers cut from an ingot of a single silicon crystal
- Field efficiencies of 10 - 15%
- Guarantee: 80% of rated at the end of 20/25 years
- Suitable for most applications, high quality



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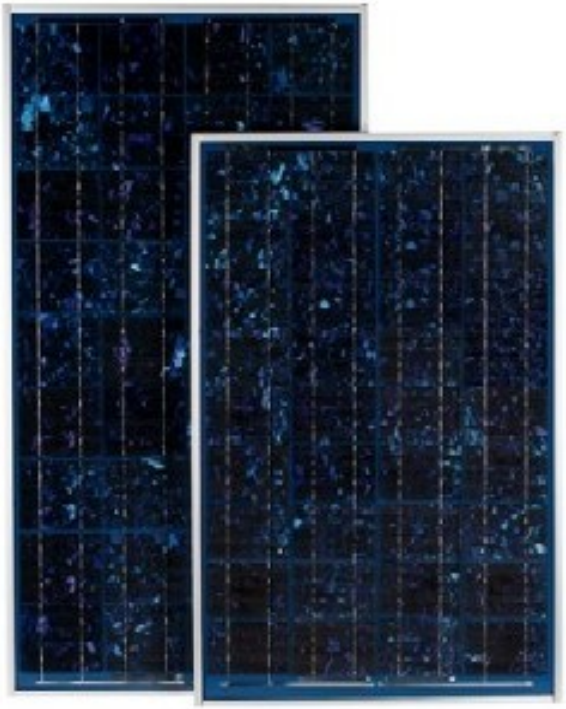
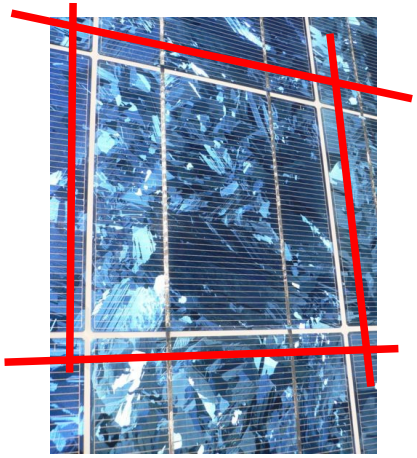
Polycrystalline modules

- Cells manufactured from wafers cut from an ingot of a several silicon crystals
- Field efficiencies of 9 - 13%
- Guarantee: 80% of rated output for 20/25 years
- Suitable for most applications, high quality



Polycrystalline modules



Polycrystalline cell

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Amorphous multi-junction modules

- Silicon deposited by gaseous deposition method in several layers, creating multi-junction cells which are sensitive to a wider light spectrum.
- Field efficiencies of 8 - 10%
- Guarantee: 80% of rated output for 10/20 years. Less for flexible models
- Most expensive type. Can be advantageous in conditions of diffuse radiation i.e. northern latitudes

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Amorphous silicon thin film modules

- Silicon deposited by gaseous deposition
- Field efficiencies of 3 - 6%
- Guarantee: depends very much on the manufacturer
- Least expensive type. generally more suitable for small applications. Quality depends very much on manufacturer. Can be fragile.
- Degrades 10% in first 3 months

Cell material	Module efficiency	Surface area need for 1 kWp
Monocrystalline silicon	11–16%	7–9 m^2
Polycrystalline silicon (EFG)	10–14%	8–9 m^2
Polycrystalline silicon	8–10%	9–11 m^2
Thin film copper-indium-diselenide	6–8%	11–13 m^2
Amorphous silicon	4–7%	16–20 m^2

Figure 2.2: Cells made from different materials have different efficiencies. PV array surface area depends on the type of cell used. EFG (Edge-Defined Film-Fed Growth Technique) is a more efficient production process for polycrystalline cells

Source: ***Photovoltaics for Professionals***

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Type of cell	Construction	Cell Efficiency *	Module Efficiency	Current stage of development
Monocrystalline silicon	Uniform crystalline structure – single crystal	24 %	13–17 %	Industrial production
Polycrystalline (multi-crystalline) silicon	Multi-crystalline structure – different crystals visible	18 %	11–15 %	Industrial production
Amorphous silicon	Atoms irregularly arranged. Thin film technology	11–12%	5–8 %	Industrial production
Gallium-arsenide	Crystalline cells	25 %	**	Produced exclusively for special applications (e.g. space craft)

** Cell efficiency is based on laboratory samples, and is invariably higher than module efficiency. From the practical point of view of evaluating systems, the module efficiency should be used.*

*** Not available in module form.*

Source: ***Photovoltaics for Professionals***

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Type of cell	Construction	Cell Efficiency *	Module Efficiency	Current stage of development
Gallium-arsenide, gallium-antimony & others	Tandem (multi-junction) cells, different layers sensitive to different light wavelengths	25–31 %	**	Research and development stage
Copper-indium-diselenide	Thin film, various deposition methods	18 %	10 –12 %	Industrial production
Cadmium-telluride & others	Thin film technology	17 %	9 –10 %	Ready to go into production
Organic solar cells	Electrochemical principle based	5–8 %	**	Research and development stage – not commercially available

Source: ***Photovoltaics for Professionals***

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Module data sheets

SHARP

NE-80E2E

Multi-Crystalline Silicon Photovoltaic Module
with 80W Maximum Power

GENERAL DESCRIPTION

SHARP's NE-80E2E photovoltaic module is designed for large electrical power requirements. Based on the technology of crystal silicon solar cells cultivated for over 35 years, this module has superb durability to withstand rigorous operating conditions and is suitable for grid connected systems.

FEATURES

1. High-power module (80W) using 125mm square multi-crystal silicon solar cells with 12.6% module conversion efficiency.
2. Photovoltaic module with bypass diode minimizes the power drop caused by shade.
   Anti Reflection Corting and BSF (Back Surface Field) structure to improve cell conversion efficiency: 14%.
3. Using white tempered glass, EVA resin, and a weatherproof film along with an aluminum frame for extended outdoor use
4. DC 12V system
5. Output terminal: Lead wire with waterproof connector

SHARP

NT-R5E3E

Single-Crystalline Silicon
Photovoltaic Module
with 175W Maximum Power

GENERAL DESCRIPTION

SHARP's NT-R5E3E photovoltaic module is designed for large electrical power requirements. Based on the technology of crystal silicon solar cells cultivated for over 35 years, this module has superb durability to withstand rigorous operating conditions and is suitable for grid connected systems.

FEATURES

1. High-power module (175W) using 125mm square single-crystal silicon solar cells with 13.5% module conversion efficiency.
2. Photovoltaic module with bypass diode minimizes the power drop caused by shade.
   Textured cell surface to reduce the reflection of sunlight and BSF (Back Surface Field) structure to improve cell conversion efficiency: 16.4%.
3. Using white tempered glass, EVA resin, and a weatherproof film along with an aluminum frame for extended outdoor use
4. DC 24V system and high-voltage output for grid-connected system
5. Output terminal: Lead wire with waterproof connector

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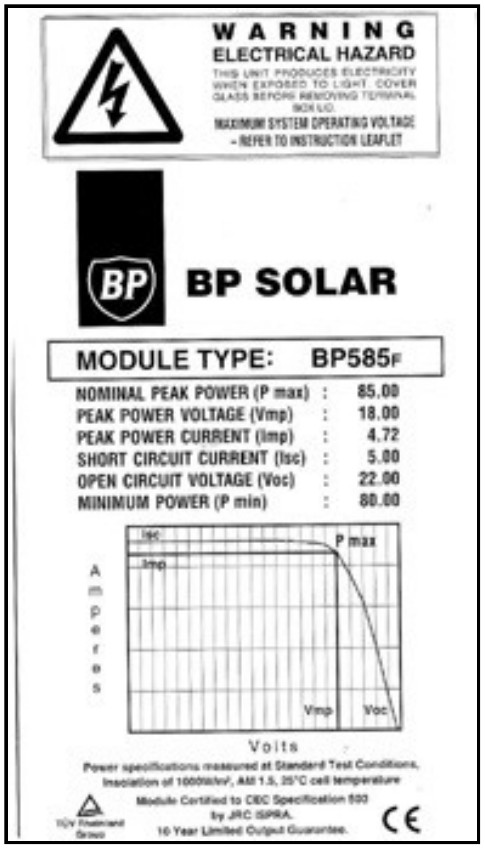
Module labels

- The label on the back of the module contains important information
  - peak power (*Wp*)
  - operating current
  - open circuit voltage (*Voc*)
  - closed circuit current (*Isc*)
  - the *IV* curve



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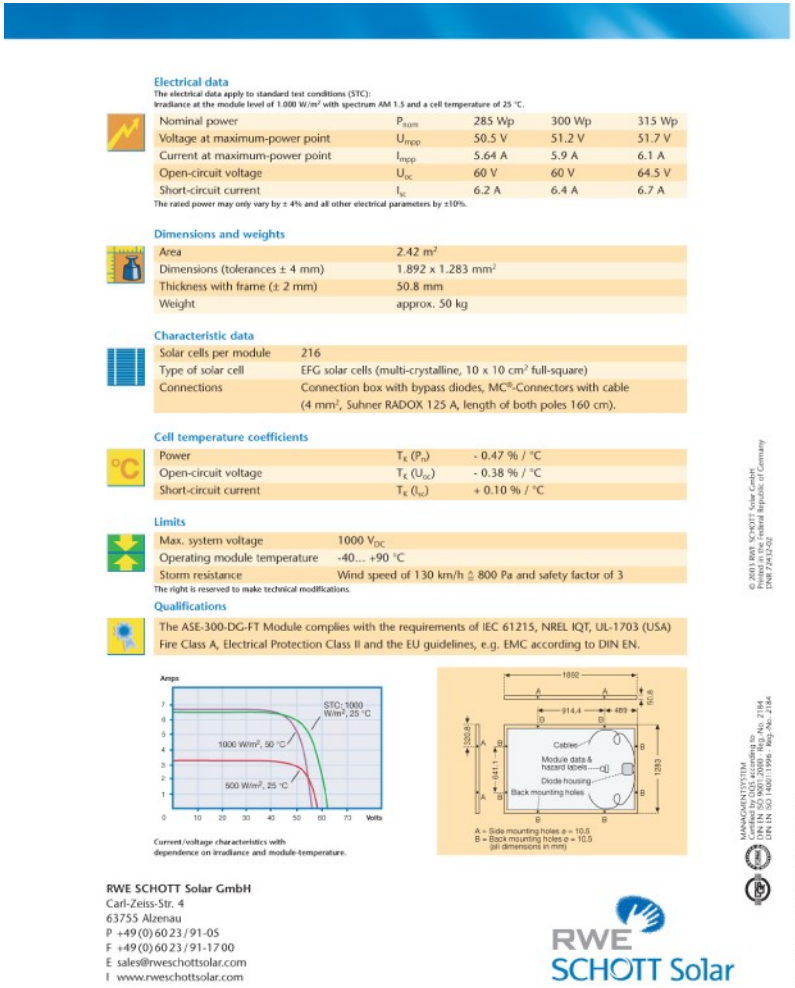
Datasheet specifications of a module



Electrical data

The electrical data apply to standard test conditions (STC):
Irradiance at the module level of 1.000 W/m² with spectrum AM 1.5 and a cell temperature of 25 °C.

Nominal power	P_{nom}	285 Wp	300 Wp	315 Wp
Voltage at maximum-power point	U_{mpp}	50.5 V	51.2 V	51.7 V
Current at maximum-power point	I_{mpp}	5.64 A	5.9 A	6.1 A
Open-circuit voltage	U_{oc}	60 V	60 V	64.5 V
Short-circuit current	I_{sc}	6.2 A	6.4 A	6.7 A

The rated power may only vary by ± 4% and all other electrical parameters by ±10%.

Dimensions and weights

Area	2.42 m²
Dimensions (tolerances ± 4 mm)	1.892 x 1.283 mm²
Thickness with frame (± 2 mm)	50.8 mm
Weight	approx. 50 kg

Characteristic data

Solar cells per module	216
Type of solar cell	EFG solar cells (multi-crystalline, 10 x 10 cm² full-square)
Connections	Connection box with bypass diodes, MC®-Connectors with cable (4 mm², Suhner RADOX 125 A, length of both poles 160 cm).

Cell temperature coefficients

Power	T_K (P_n)	- 0.47 % / °C
Open-circuit voltage	T_K (U_{OC})	- 0.38 % / °C
Short-circuit current	T_K (I_{sc})	+ 0.10 % / °C

Limits

Max. system voltage	1000 V_{DC}
Operating module temperature	-40... +90 °C
Storm resistance	Wind speed of 130 km/h ≙ 800 Pa and safety factor of 3

The right is reserved to make technical modifications.

Qualifications

The ASE-300-DG-FT Module complies with the requirements of IEC 61215, NREL IQT, UL-1703 (USA) Fire Class A, Electrical Protection Class II and the EU guidelines, e.g. EMC according to DIN EN.

Current/voltage characteristics with dependence on irradiance and module-temperature.

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RWE SCHOTT Solar

MANAGEMENTSYSTEM
Certified by DQS according to
DIN EN ISO 9001:2000 Reg.-No.: 2184
DIN EN ISO 14001:1996 Reg.-No.: 2184

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12V & 24V modules

- Originally most modules were so-called 12 V modules, designed to charge batteries – used mainly in off-grid systems
- Modules for grid-connect are usually 24 V these days – they are larger so less are needed
- Module junction boxes – in modules for grid connect there are usually plug/socket leads instead, for easier string connection. Proper junction box preferable for stand-alone

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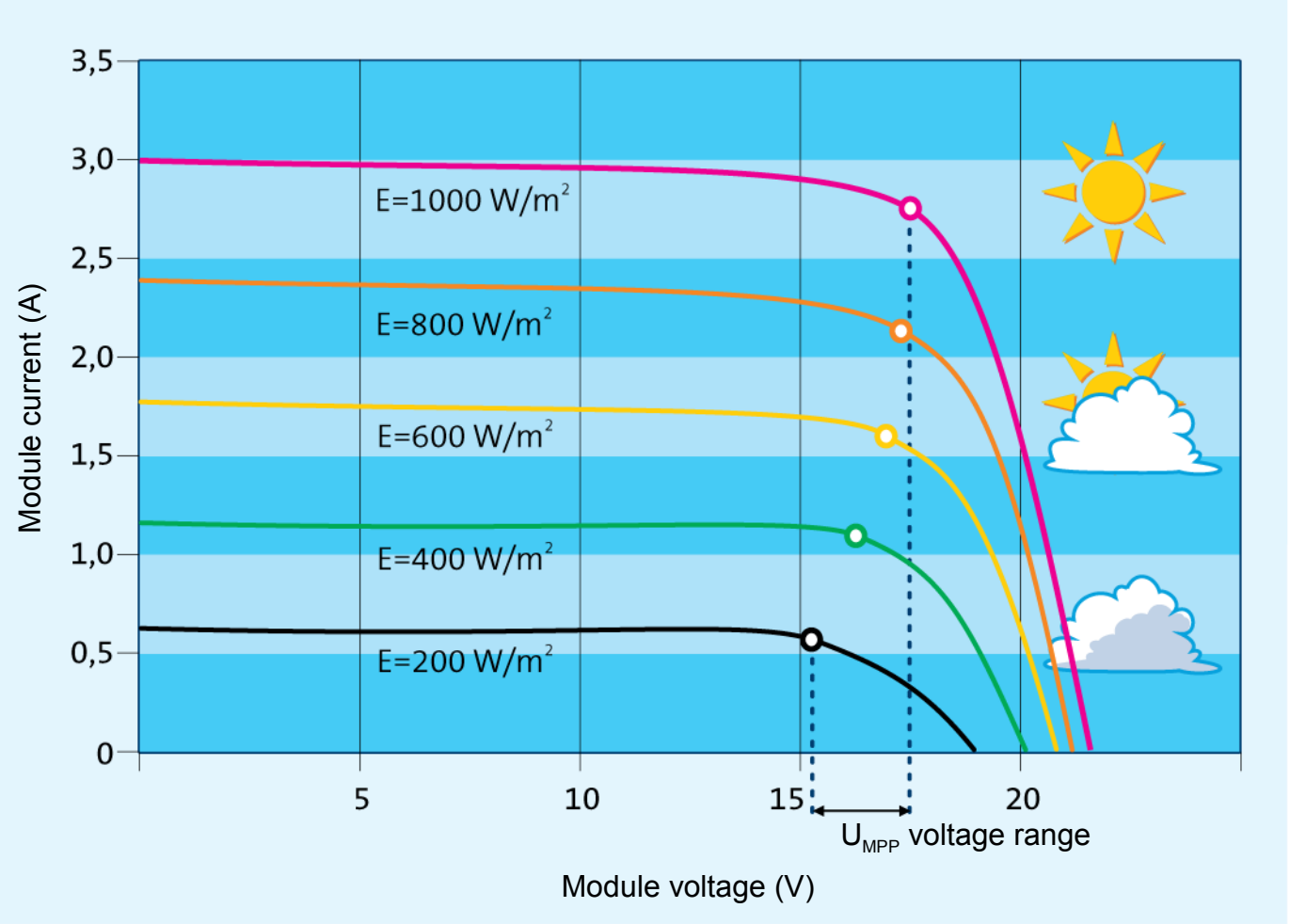
IV - Curves



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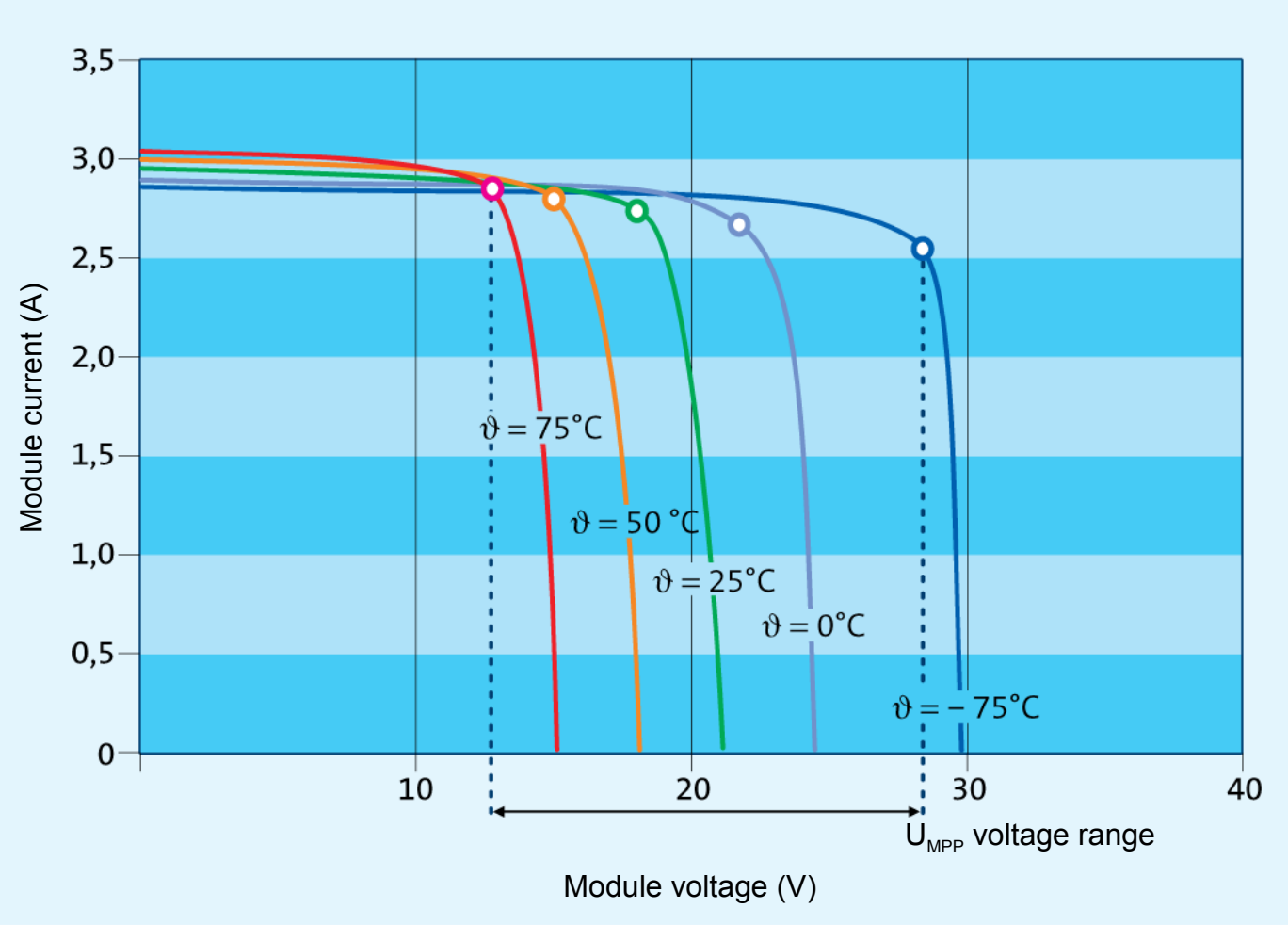
Effect of temperature on the operation of crystalline solar modules



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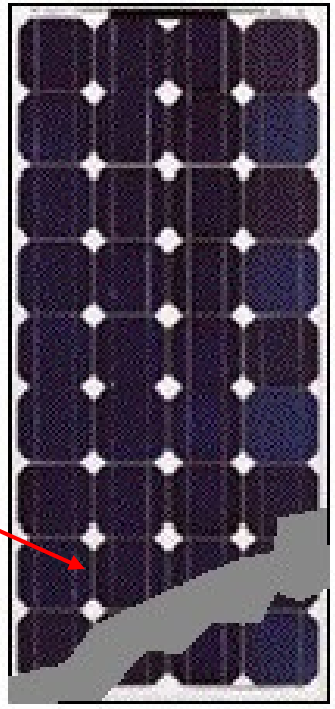
Effect of shade on solar modules

Even a small shadow like this can reduce the amount of electricity a module produces by 80-90%,



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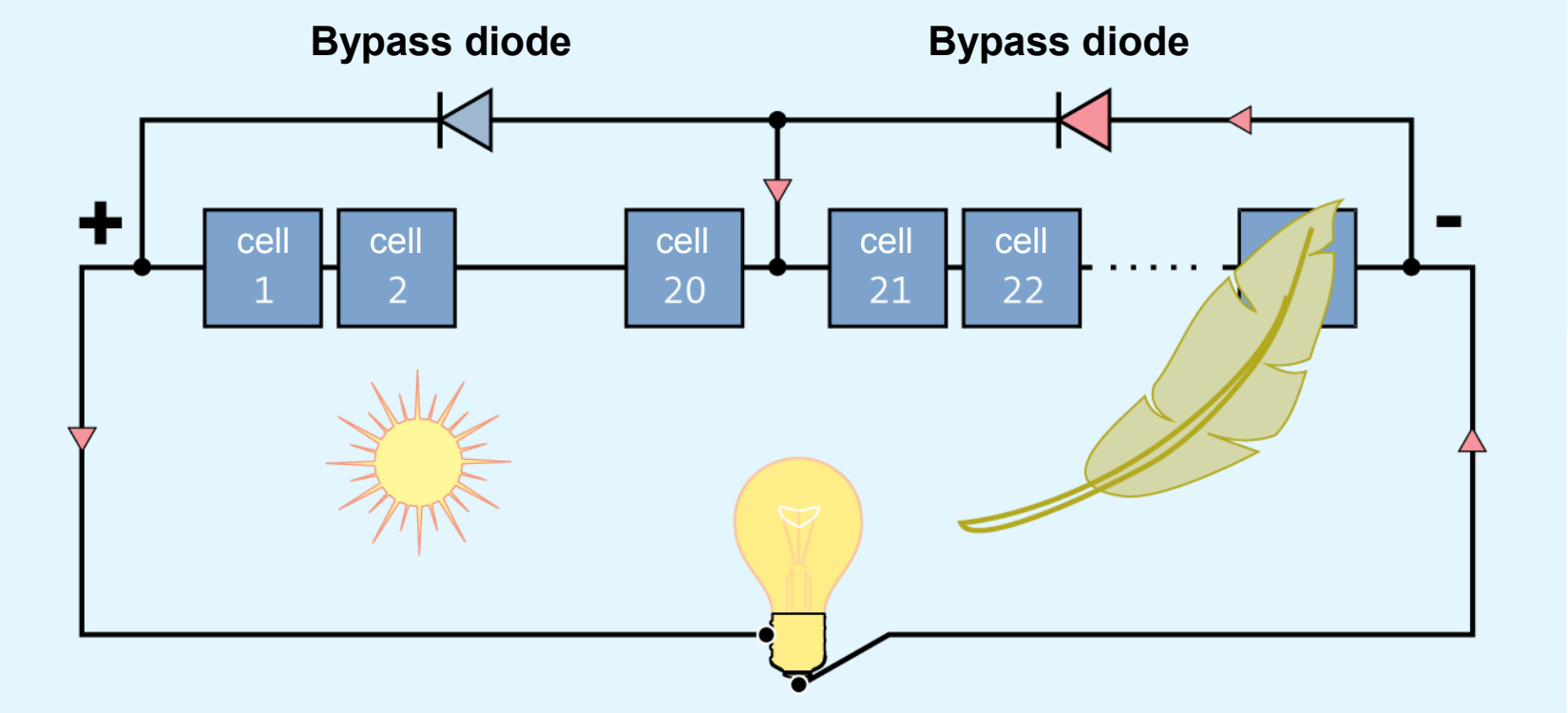
Functioning of bypass diodes



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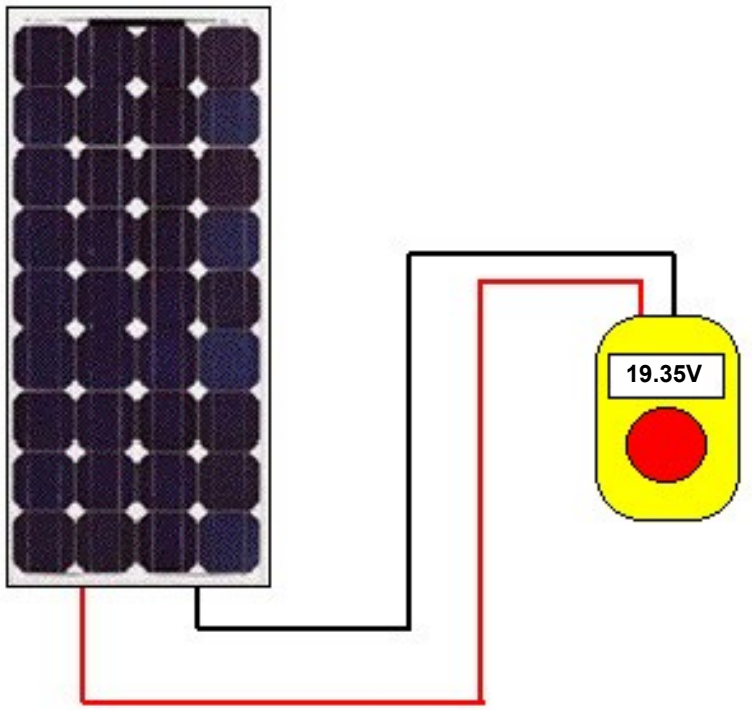
Open circuit voltage (*Voc*)

- The open circuit voltage (***Voc***) of a solar module remains fairly constant over a range of sunlight levels



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Short circuit current (*Isc*)

- The short circuit current (***Isc***) of a solar module varies with the level of sunlight