IoT Powering

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The Abdus Salam International Centre for Theoretical Physics (ICTP)

UNESCO
United Nations Educational, Scientific and Cultural Organization

Goals

- Examine some of the alternative energy sources that can be used for off-grid powering.
- Realize that to calculate the electrical power consumption of IoT devices all the possible states must be considered
- Analyze the components of a photovoltaic system and estimate the requirements to supply a given load.

IoT Powering considerations

- Gateways can be grid connected.
- End devices normally off-grid, battery powered, but can use energy scavenging.
- Keep node sleeping as much as possible.
- Photovoltaic is widely used. We will cover it in detail.
- Many other sources of energy can be harvested.
- Most alternative energy sources are intermittent and will require storage devices like batteries or supercapacitors.

Energy harvesting sources

Energy harvesting is the process by which light, thermal, kinetic, chemical and radio frequency energy can be converted into electrical energy to power some device.

Kinetic energy in the form of wind, vibration, ambient noise, piezoelectric, electrostatic, fluid flow, magnetic induction, wave and tides is used in many applications.

Energy harvesting sources

While Solar, Hydraulics and wind energy are the predominant renewable sources of energy, for IoT applications the most widely used are:

- Photovoltaic
- Piezoelectric
- Thermoelectric
- Radiofrequency

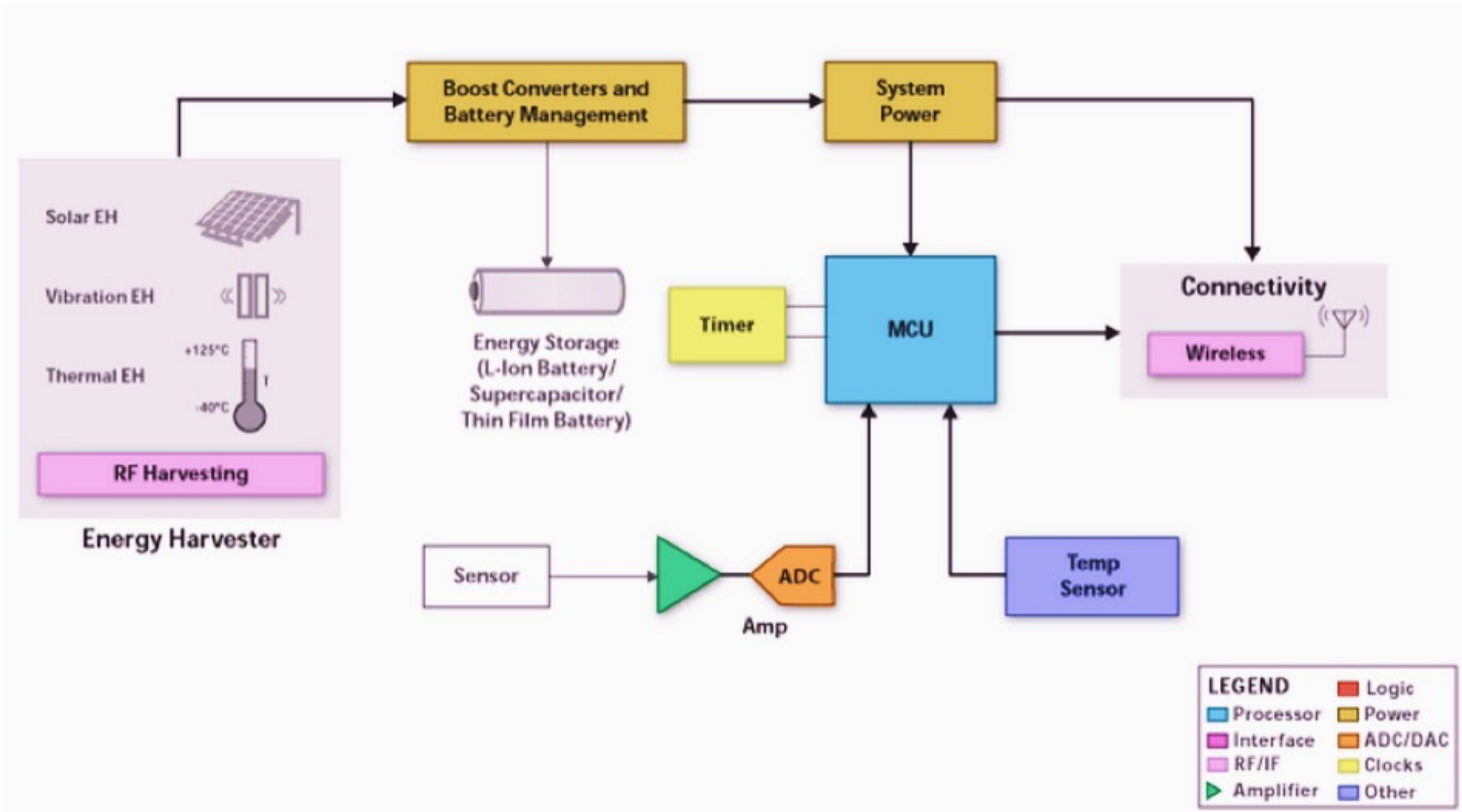
Energy harvesting system

Many energy sources are intermittent, so energy storage devices might be required, the most common are batteries and (super) capacitors.

Some of the sources produce a very small voltage that must be transformed into a higher voltage before it can be utilized.

Wind and solar generators in Galapagos

Energy harvesting for IoT



http://eu.mouser.com/applications/benefits_energy_harvesting/

RF Energy

RF energy has been leveraged in RFID in which the reader transmits a powerful enough wave so that a passive tag can use it to power its receiver and transmitters stages.

This idea has been applied to other RF sources like WiFi with discouraging results, due to the quadratic decay of RF power with distance.

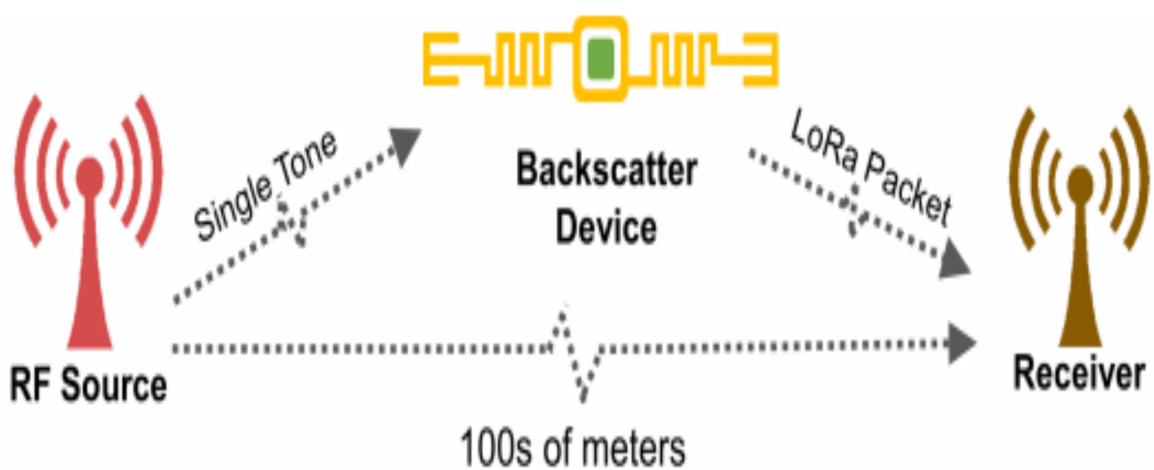
An interesting twisting of this concept will be presented next.

Backscatter

- Backscatter modulates information by reflecting existing wireless signals.
- Signal reflection only consumes microwatts of power since it only changes the information that modulates the carrier.
- But the reflected signal is very low power and can be interfered.
- Shifting the carrier frequency at the reflector addresses this issue

LoRa Backscatter Implementation

- Piggybacking data on an existing RF signal with very low power backscattering device
- Self interference handled by frequency shifting and harmonic cancellation

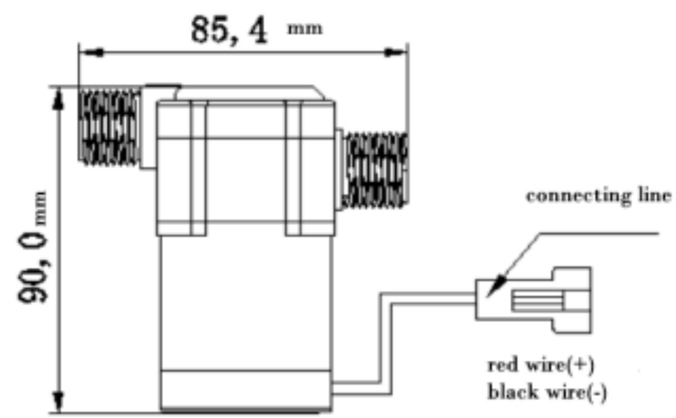


https://arxiv.org/pdf/1705.05953.pdf 16 May 2017

Micro hydro generator

Introduction

Micro hydro power is clean, renewable energy. Here is a micro hydro generator which can supply stably output voltage and output current with the help of one voltage stabilizing circuit and one rechargeable battery.
We can install it at home to save household energy, like using spray shower to light LEDs etc.



Features

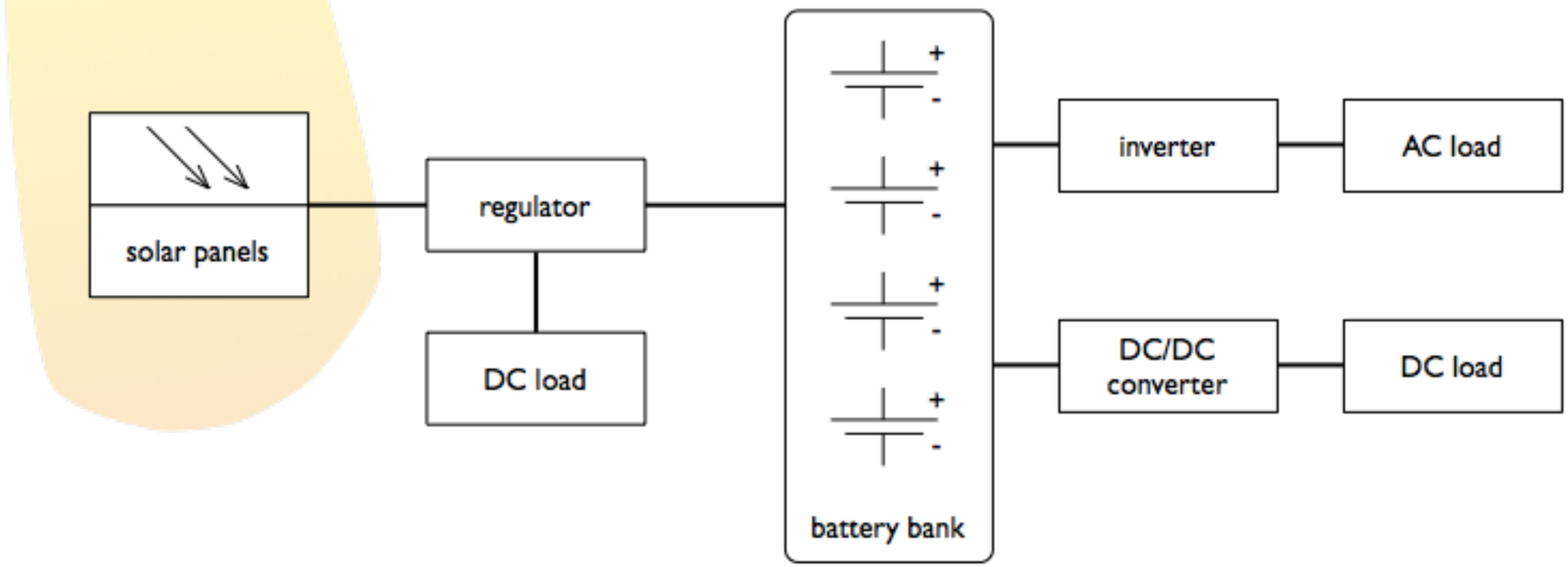
Weight	165 g
Output voltage	3.6V
Output current	300mA
Maximum working pressure	1.75 MPa
Working pressure	0 ~ 1.75MPa

Power availability from some common sources

Energy Source	Power Density and Performance
Acoustic noise	3 nW/cm^3 @ 75 dB, 0.96 $\mu W/cm^3$ at 100 dB
Airflow	1$\mu W/cm^2$
Ambient Light	100 mW/cm^2 (sun), 100 $\mu W/cm^2$ (office)
Ambient Radiofrequency	1 $\mu W/cm^2$
Hand Generators	30 W/kg
Heel Strike	7 W/cm^2
Push Button	50 J/N
Shoe Inserts	330 $\mu W/cm^2$
Temperature Variation	10 $\mu W/cm^2$
Thermoelectric	60 $\mu W/cm^2$
Vibration (micro generator)	4 $\mu W/cm^3$ (human, Hz), 800 $\mu W/cm^3$ (machine, kHz)
Vibration (Piezoelectric)	200 $\mu W/cm^3$

Photovoltaic system

A basic photovoltaic system consists of five main components: the **sun**, the ***solar panel***, the ***regulator***, the ***batteries***, and the ***load***. Many systems also include a ***voltage converter*** to allow use of loads with different voltage requirements.



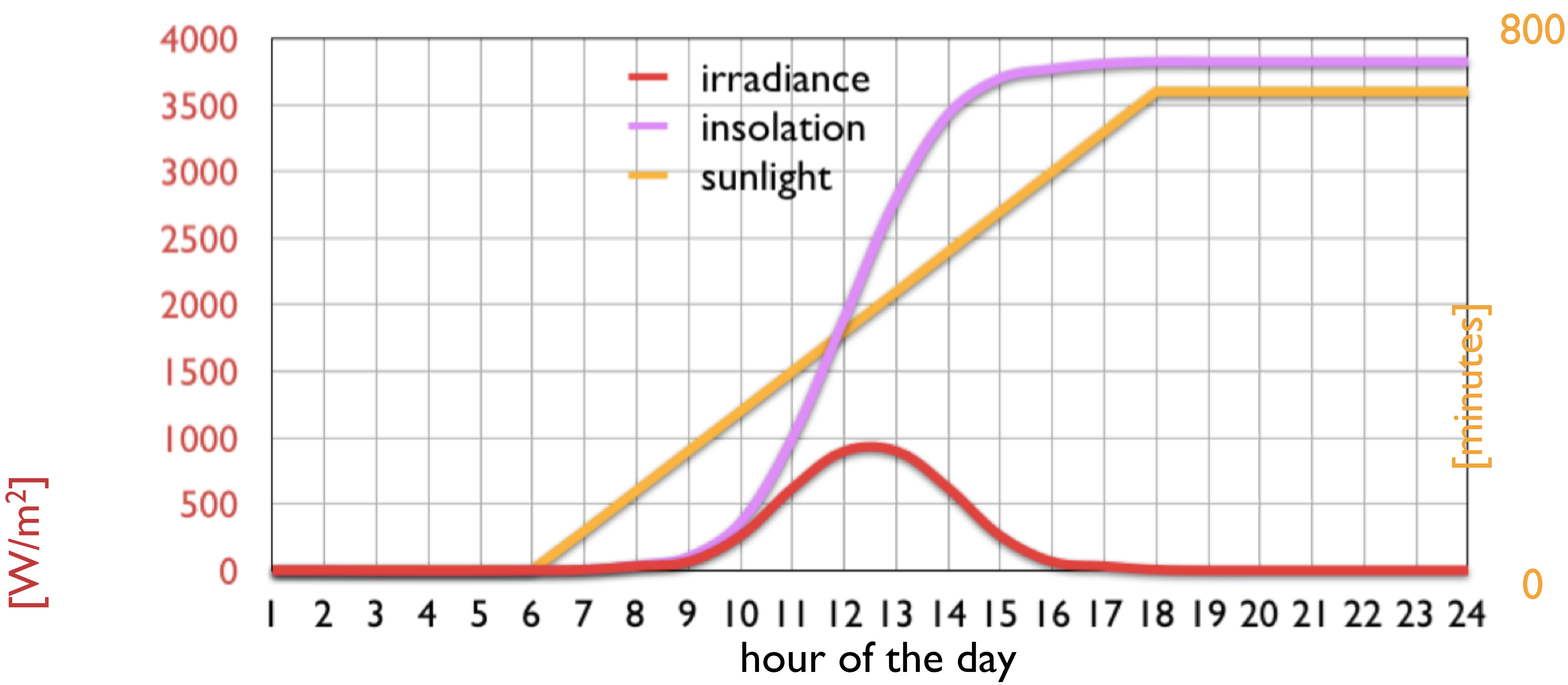
Solar power

A photovoltaic system is based on the ability of certain materials to convert the electromagnetic energy of the sun into electrical energy. The total amount of solar power that lights a given area is known as ***irradiance*** and it is measured in ***watts per square meter*** (***W/m***^{2}).

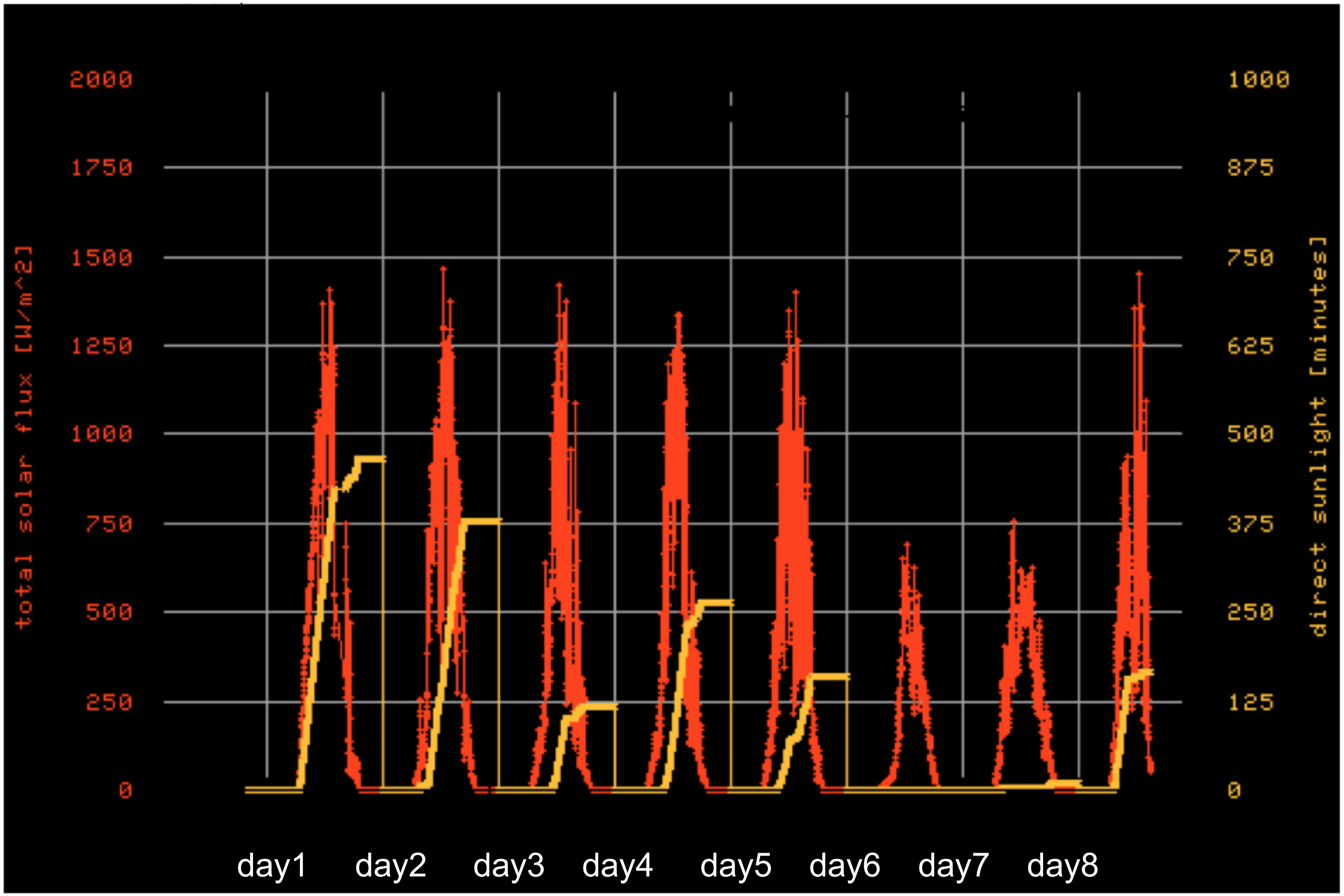
The accumulated power over certain time is called ***insolation***, measured in ***Wh/m***^{2} . We then talk about total insolation per hour, day, month or year.

Irradiance, insolation and sunlight

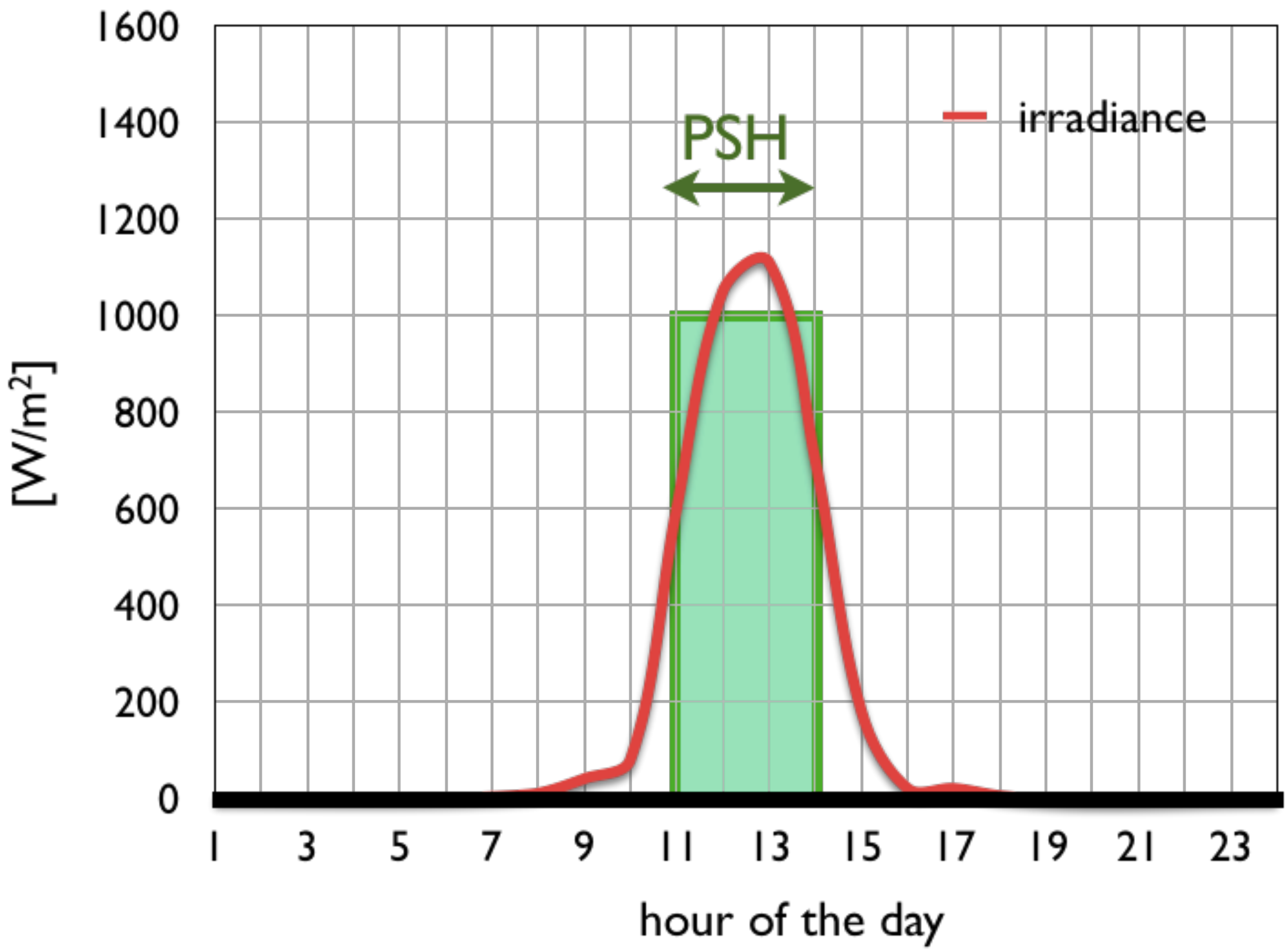
This graph shows **solar irradiance** (in W/m^2), **insolation** (cumulative irradiance) and **sunlight** (in minutes):



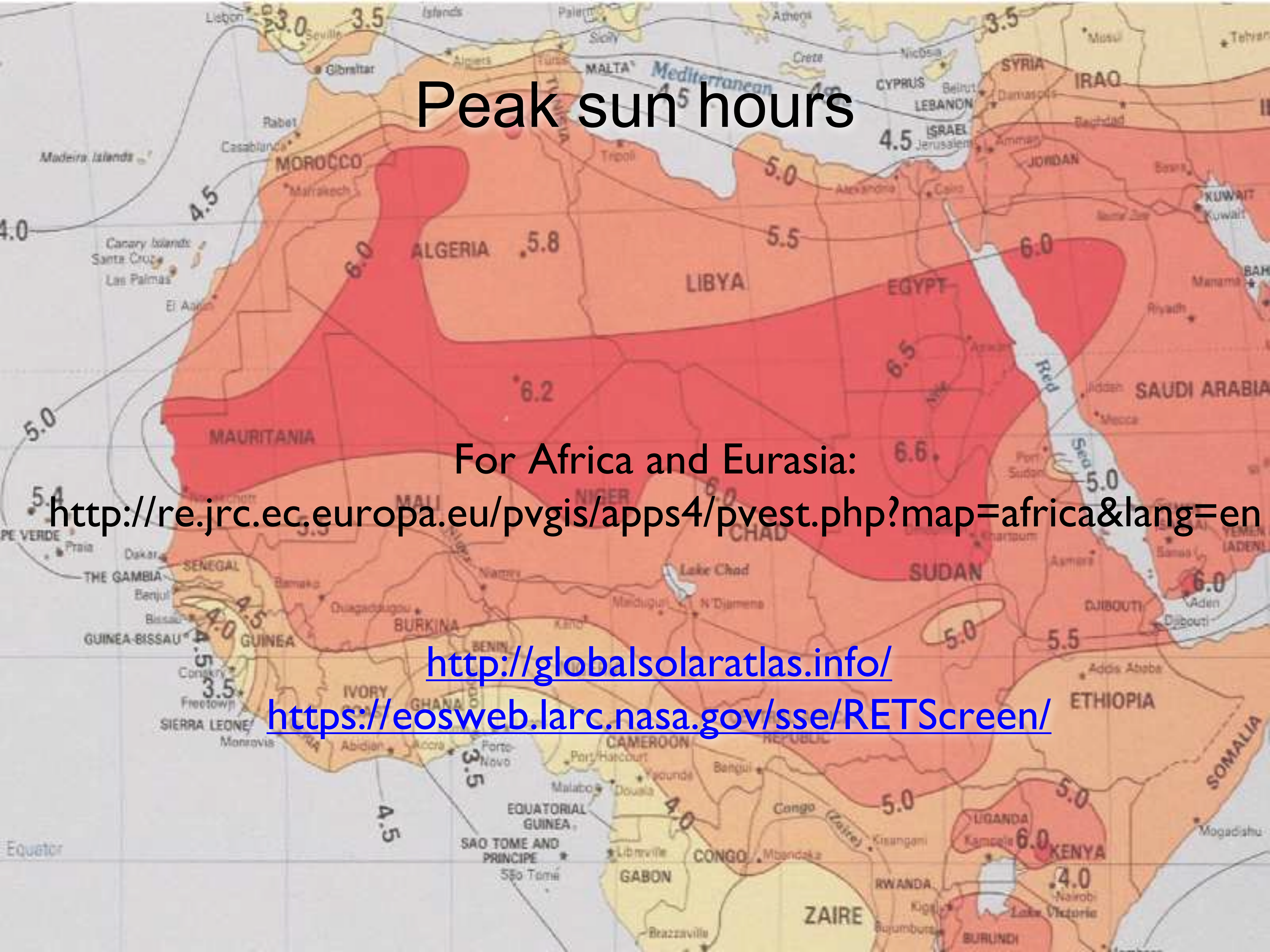
Real data: irradiance and sunlight



Peak Sun Hours = kWh/m^2 per day



Peak sun hours



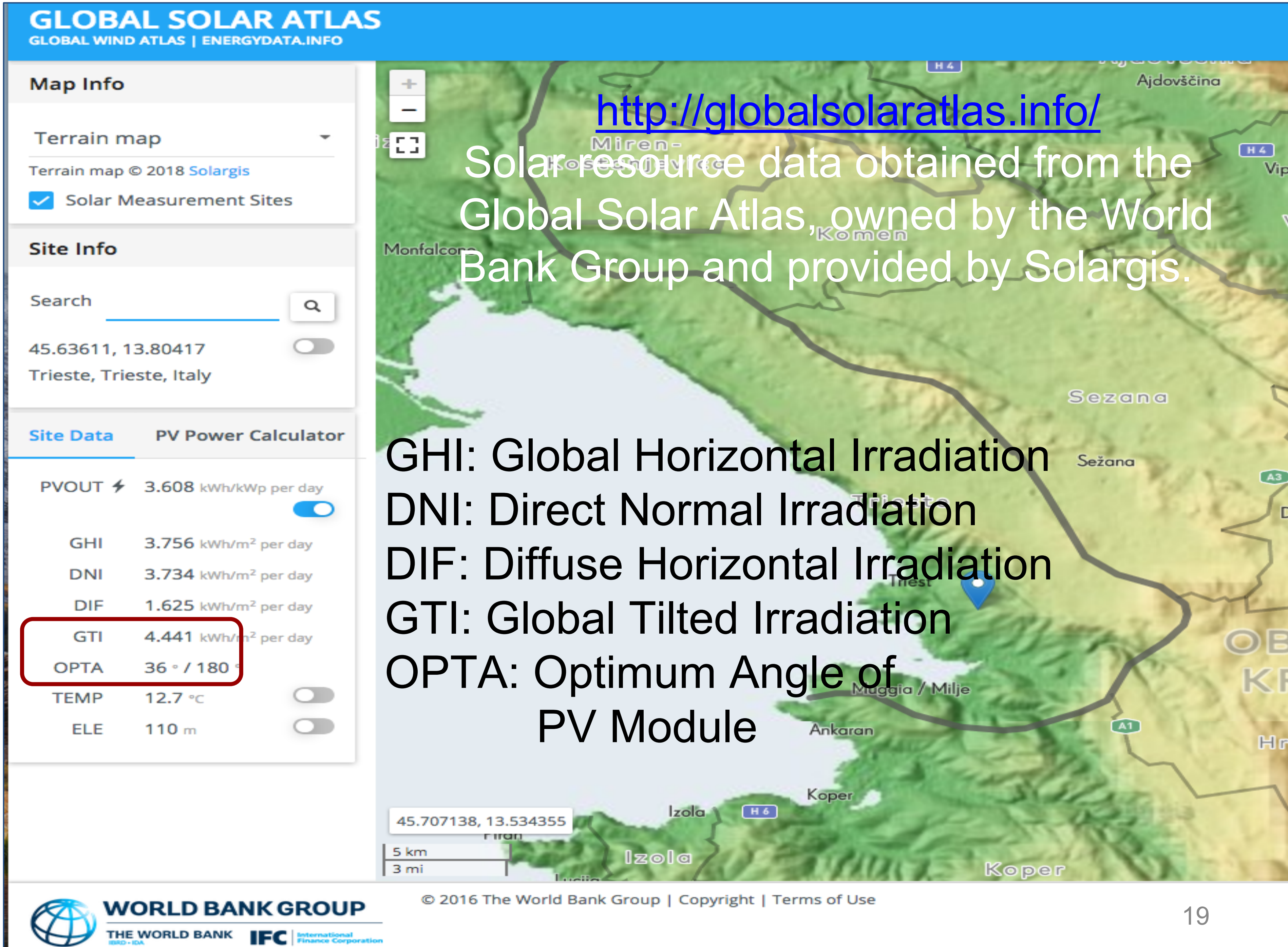
For Africa and Eurasia:
http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en

http://globalsolaratlas.info/
https://eosweb.larc.nasa.gov/sse/RETScreen/

http://globalsolaratlas.info/

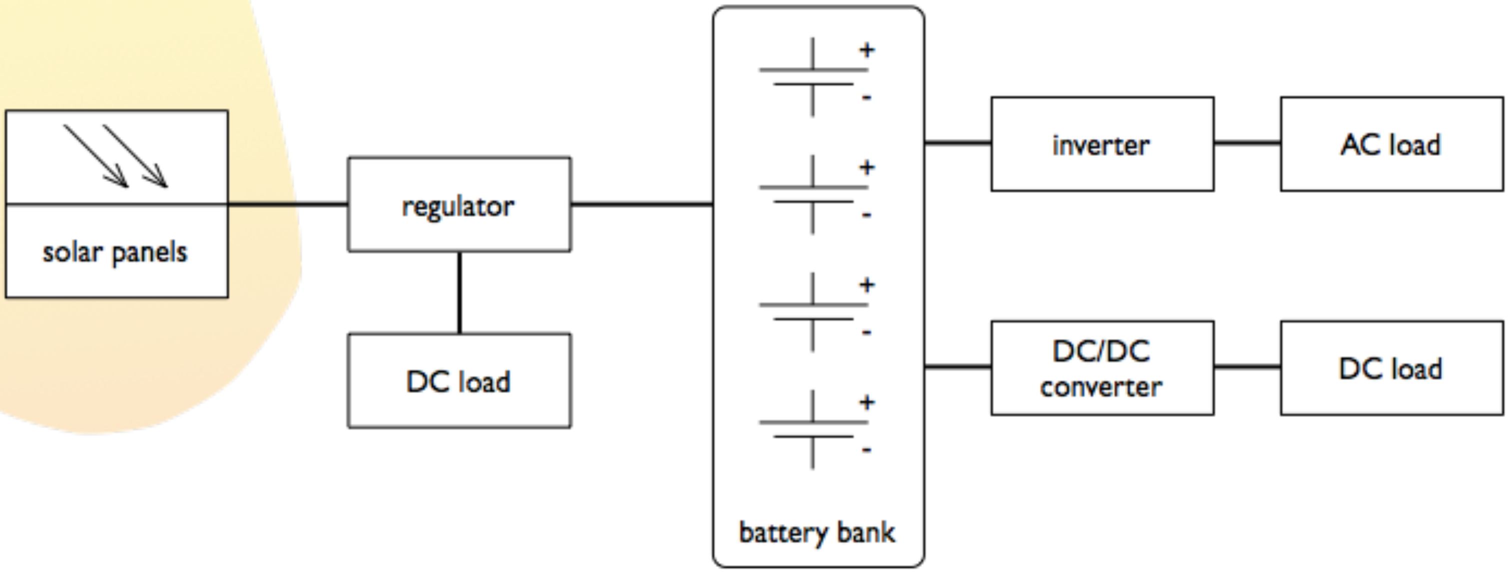
Solar resource data obtained from the Global Solar Atlas, owned by the World Bank Group and provided by Solargis.

GHI: Global Horizontal Irradiation
DNI: Direct Normal Irradiation
DIF: Diffuse Horizontal Irradiation
GTI: Global Tilted Irradiation
OPTA: Optimum Angle of PV Module



Solar Panel

The most obvious component of a photovoltaic system are the ***solar panels***.



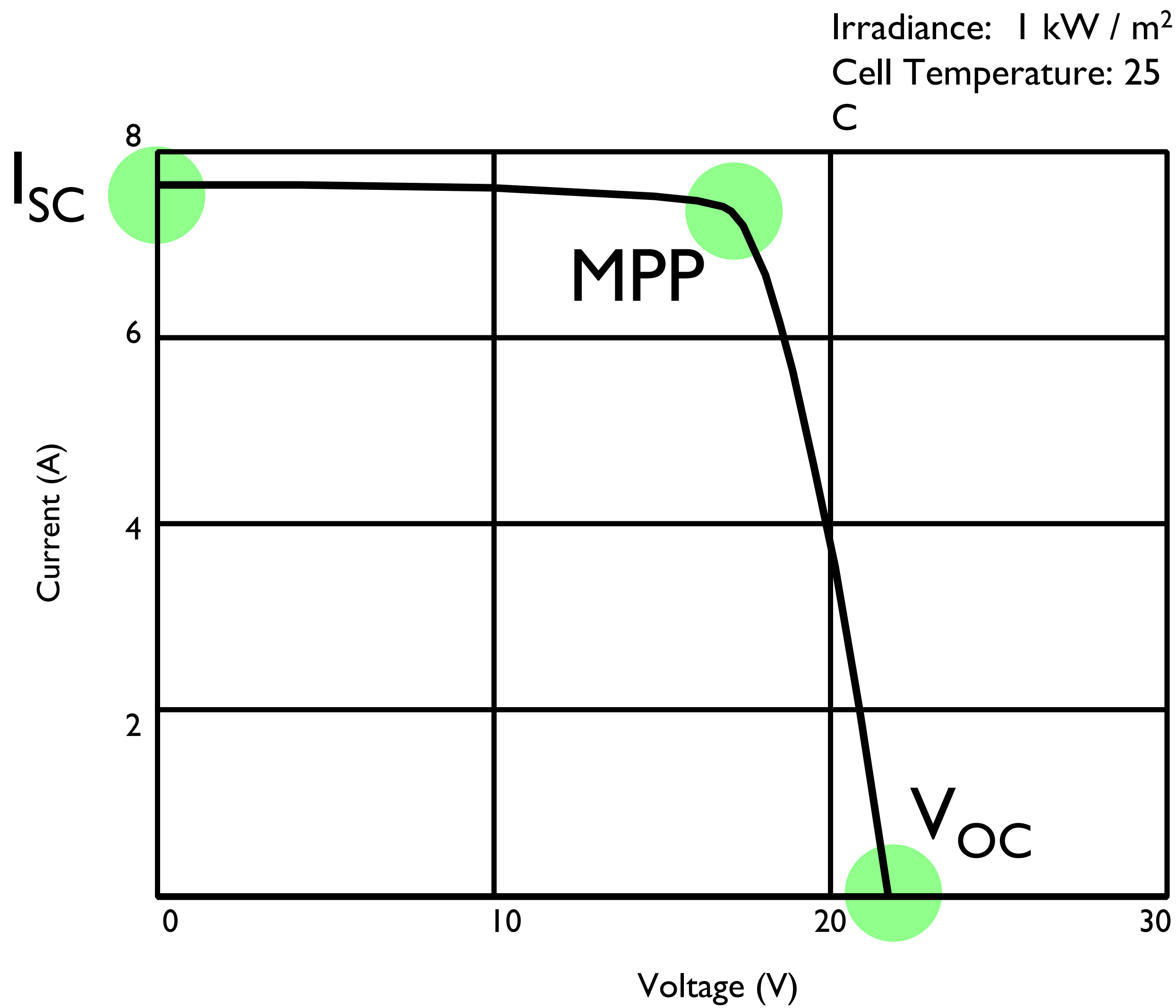
Solar panels

A solar panel is made of many solar **cells**

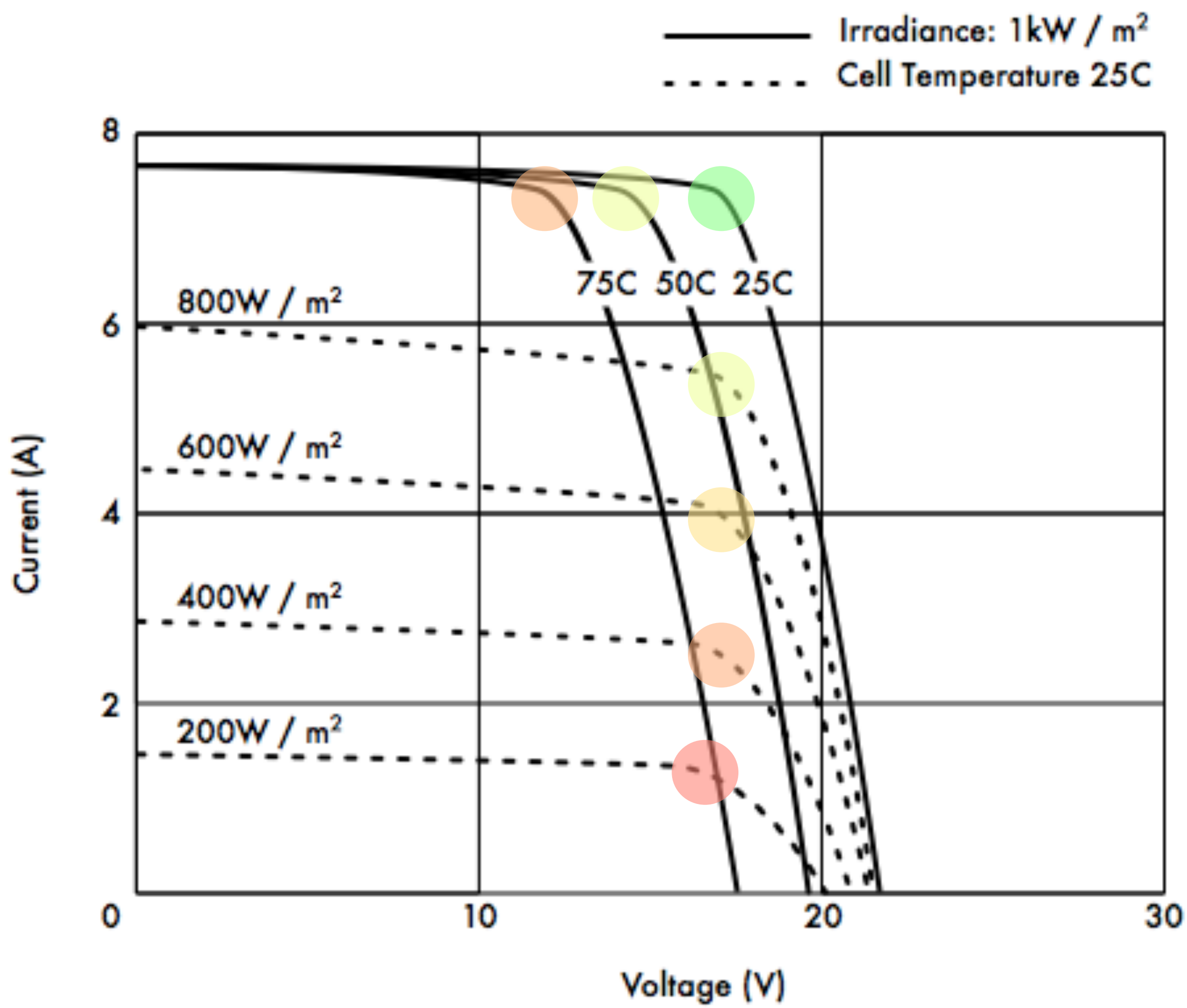
There are many types of solar panel:

- **Monocrystalline**: expensive, best efficiency
- **Polycrystalline**: cheaper, less efficient
- **Amorphous**: the cheapest, worst efficiency, short lifespan
- **Thin-film**: inexpensive, flexible, low efficiency,
- **CIGS**: Copper Indium Gallium Selenide

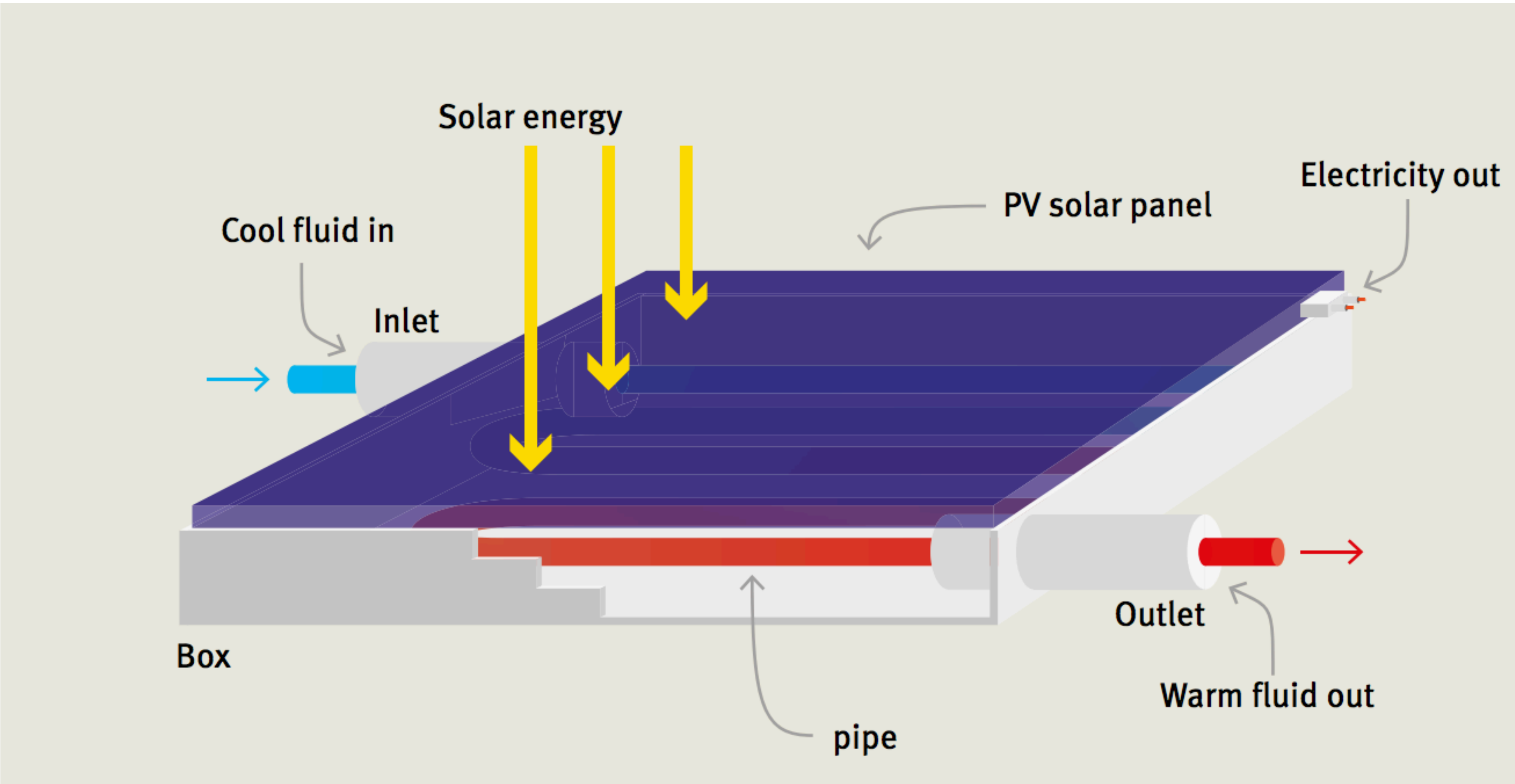
Solar panel IV curve



Solar panel IV curve for different amounts of irradiance and temperature



Photovoltaic and thermal harvesting



https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/2679_Briefing-P-22-Solar-heat_web.pdf

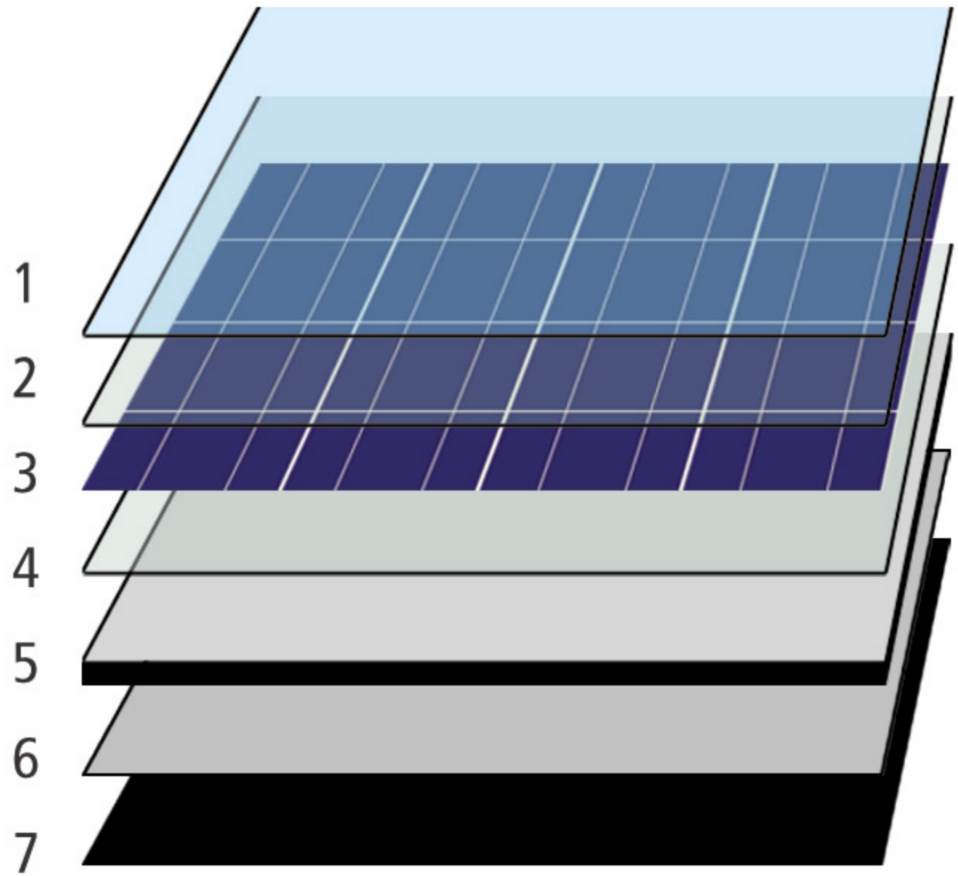
Photovoltaic Thermal hybrid

PVT, are systems that

convert solar radiation into thermal and electrical energy.

Schematic of a hybrid (PVT) solar collector:

1 - Anti-reflective glass
2 - EVA-encapsulant
3 - Solar PV cells
4 - EVA-encapsulant
5 - Backsheet (PVF)
6 - Heat exchanger (copper)
7 - Insulation (polyurethane)



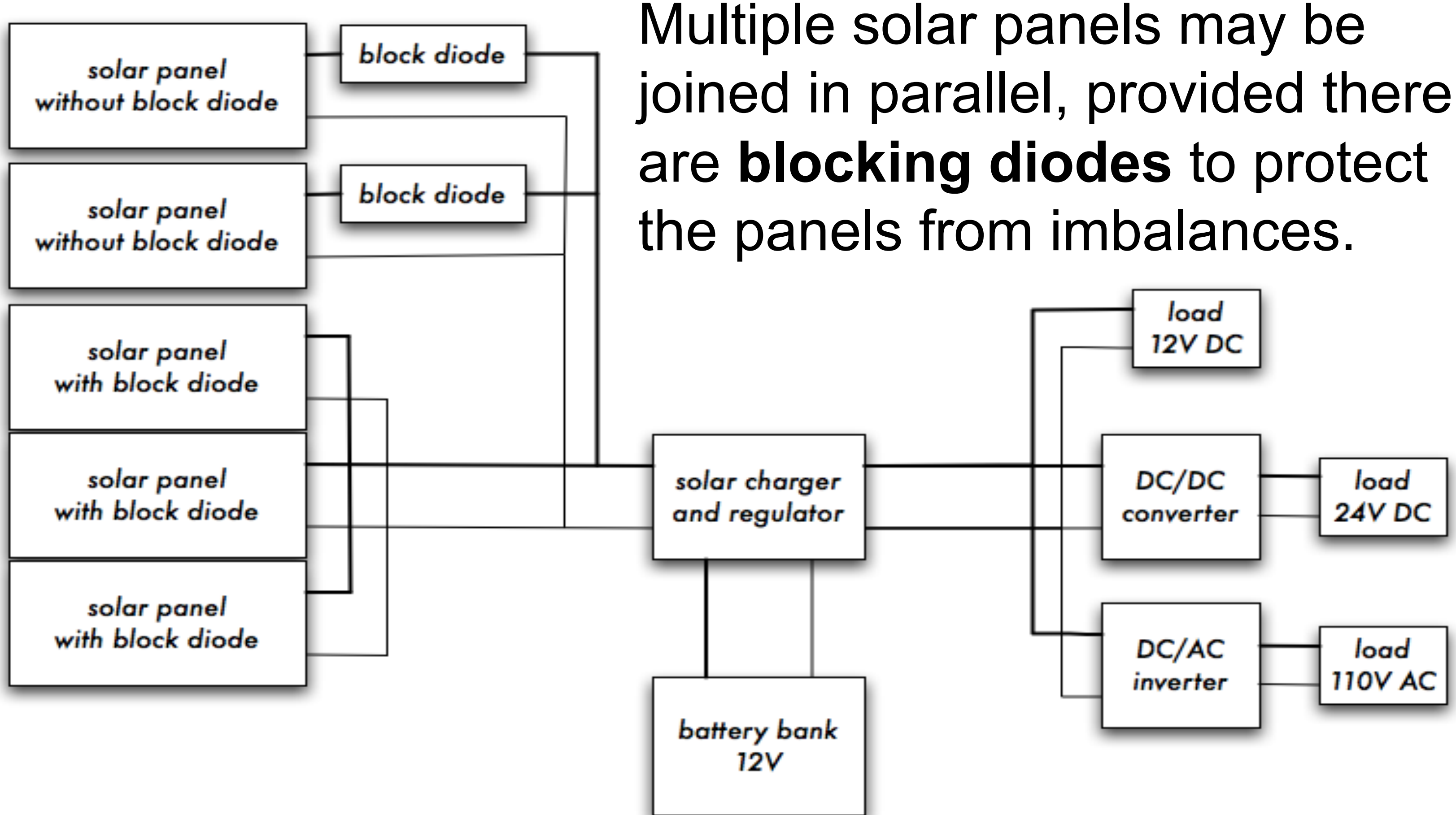
https://commons.wikimedia.org/w/index.php?curid=12014094

Optimizing panel performance

Optimal elevation angle = Latitude + 5°

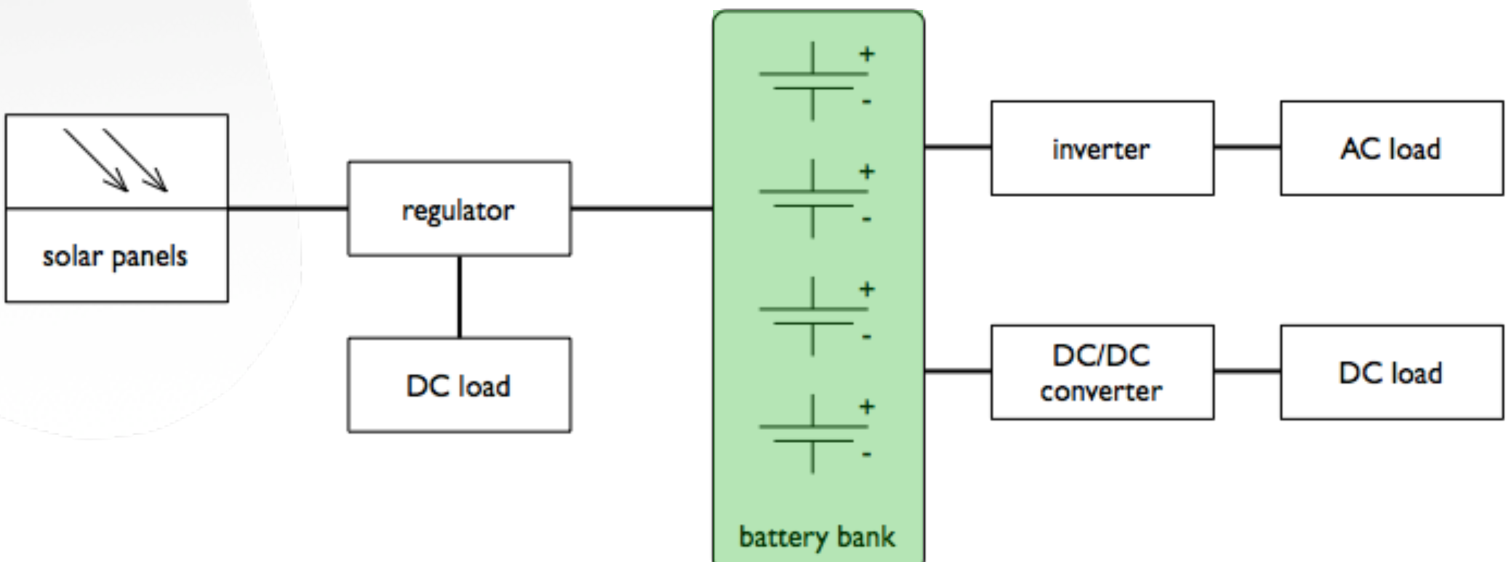
Photovoltaic system

Multiple solar panels may be joined in parallel, provided there are **blocking diodes** to protect the panels from imbalances.



Batteries

Batteries are at the heart of the photovoltaic system, and determine the operating voltage.



Batteries

The ***battery*** stores the energy produced by the panels that is not immediately consumed by the load. This stored energy can then be used during periods of low solar irradiation (at night, or when it is cloudy) called n-sun days.

Batteries

The most common type of batteries used in solar applications are maintenance-free lead-acid batteries, also called **recombinant** or **VRLA** (valve regulated lead acid) batteries. They belong to the class of deep cycle or stationary batteries, often used for backup power in telephone exchanges.

They determine the ***operating voltage*** of your installation, for best efficiency all other devices should be designed to work at the same voltage of the batteries.

Designing a battery bank

The size of your battery bank will depend upon:

- the storage capacity required
- the maximum discharge rate
- the storage temperature of the batteries .

The storage capacity of a battery (amount of electrical energy it can hold) is usually expressed in amp-hours (Ah) rather than in Wh or joules.

A battery bank in a PV system should have sufficient capacity to supply needed power during the longest expected period of cloudy weather.

Monitoring the state of charge

There are two special states of charge that can occur during the cyclic charge and discharge of the battery. They should both be avoided in order to preserve the useful life of the battery.

Overcharge takes place when the battery arrives at the limit of its capacity. If energy is applied to a battery beyond its point of maximum charge, the electrolyte begins to break down. This produces bubbles of oxygen and hydrogen, a loss of water, oxidation on the positive electrode, and in extreme cases, a danger of explosion.

Monitoring the state of charge

- ***Over discharge*** occurs when there is a load demand on a discharged battery. Discharging beyond the battery's limit will result in deterioration of the battery. When the battery drops below the voltage that corresponds to a 50% discharge, the regulator should prevent extracting any more energy from from the battery.
- The proper values to prevent over charging and over discharging should be programmed into your charge controller to match the requirements of your battery bank.

Maximizing battery life

Lead acid batteries degrade quickly if they are discharged completely. A battery from a truck will lose 50% of its design capacity within 50 -100 cycles if it is fully charged and discharged during each cycle.Never discharge a 12 Volt lead acid battery below 11.6 volts, or it will forfeit a huge amount of storage capacity. In cyclic use it is not advisable to discharge a truck battery below 70%. Keeping the charge to 80% or more will significantly increase the battery’s useful lifespan. For example, a 170 Ah truck battery has a usable capacity of only 34 to 51 Ah.

LiPO (Lithium-Polymer) battery

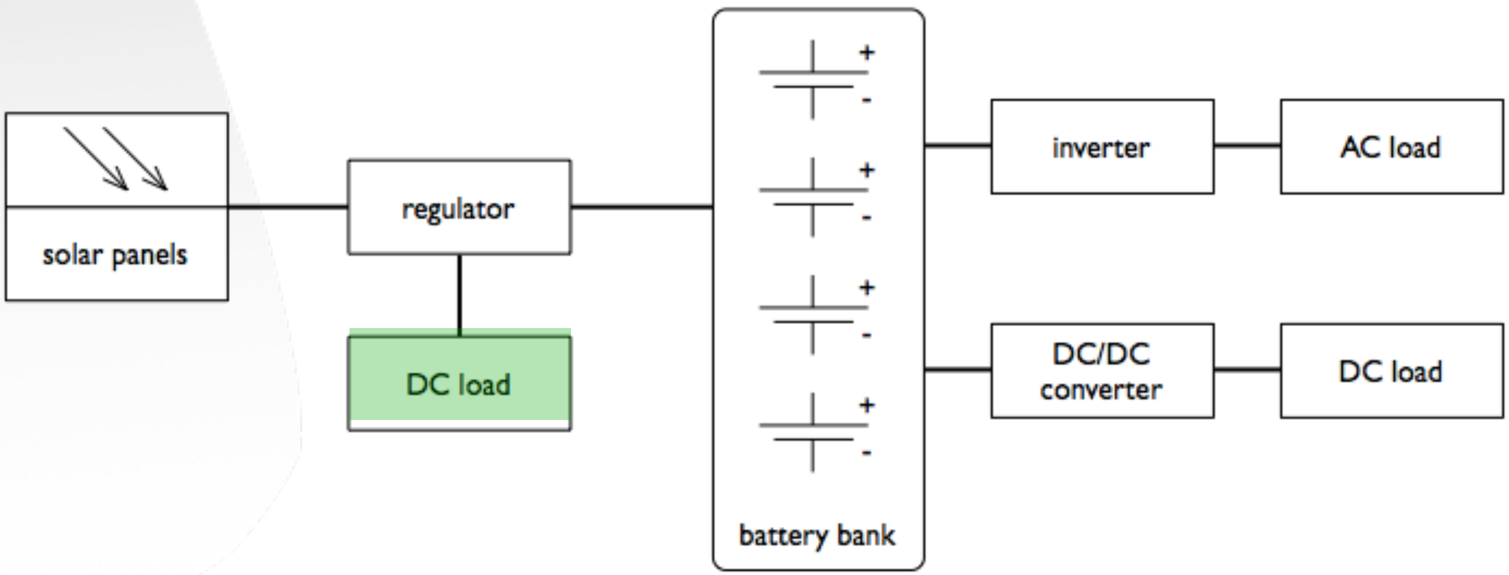
- Each cell will be around 3.7 V when fully charged
- The minimum voltage is around 3 V per cell
- Capacity expressed in mA/h, amount of energy storable
- Handle with precaution, lithium can explode
- Can be attached directly to a small solar panel, but for bigger ones a voltage regulator is required to protect the battery

Supercapacitors

- High capacity device with capacitance much higher than normal capacitors but with lower voltage ratings.
- They bridge the gap between rechargeable batteries and electrolytic capacitors
- Store up to 100 times more energy per mass or volume than electrolytic capacitors, charge and discharge much faster than batteries and tolerate more C/D cycles than batteries

Regulator

The ***regulator*** is the interface between the solar panels and the battery, and provides power for moderate DC loads.



IoT devices often have a voltage regulator built in

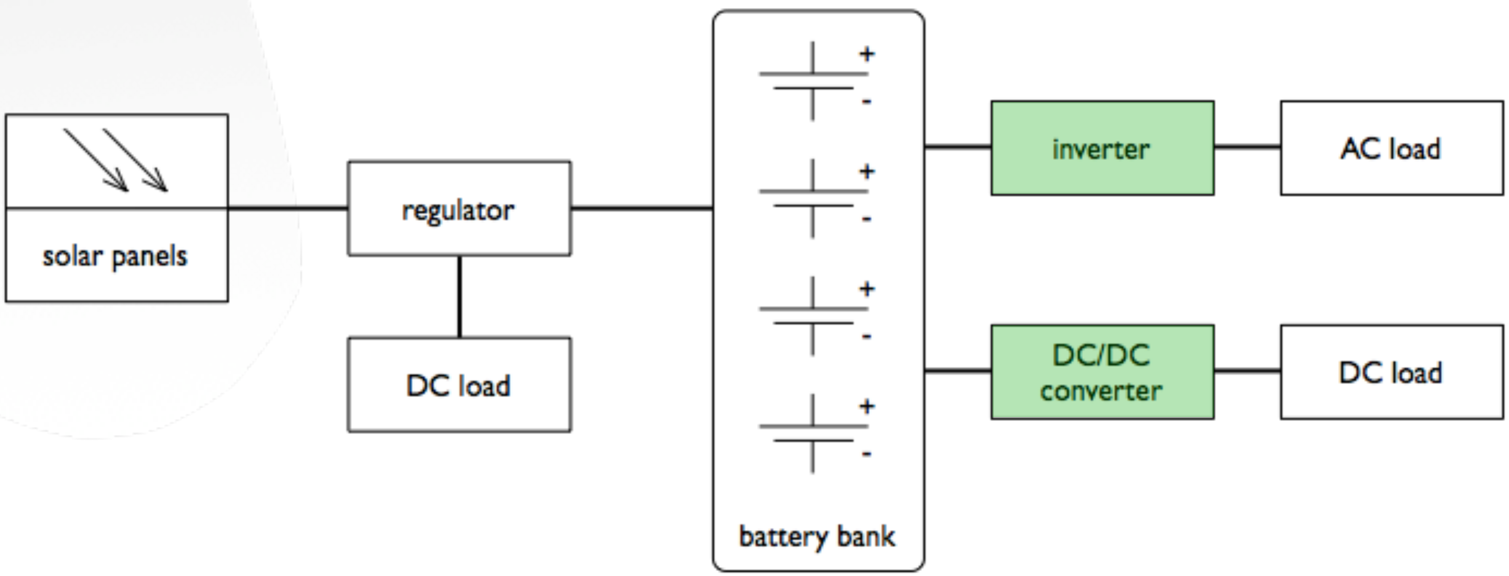
Regulator

PROSTAR
PROSTAR-30
SOLAR CHARGE CONTROLLER
VERSION: PS-30
MORNINGSTAR
corporation
CHARGING
TEMP. SENSOR
BATTERY STATUS
BLINK: LOW
ON: LVD
BATTERY TYPE
1 - GEL
2 - SEALED
3 - FLOODED
SOLAR
BATTERY
LOAD
SENSE

Voltage converters

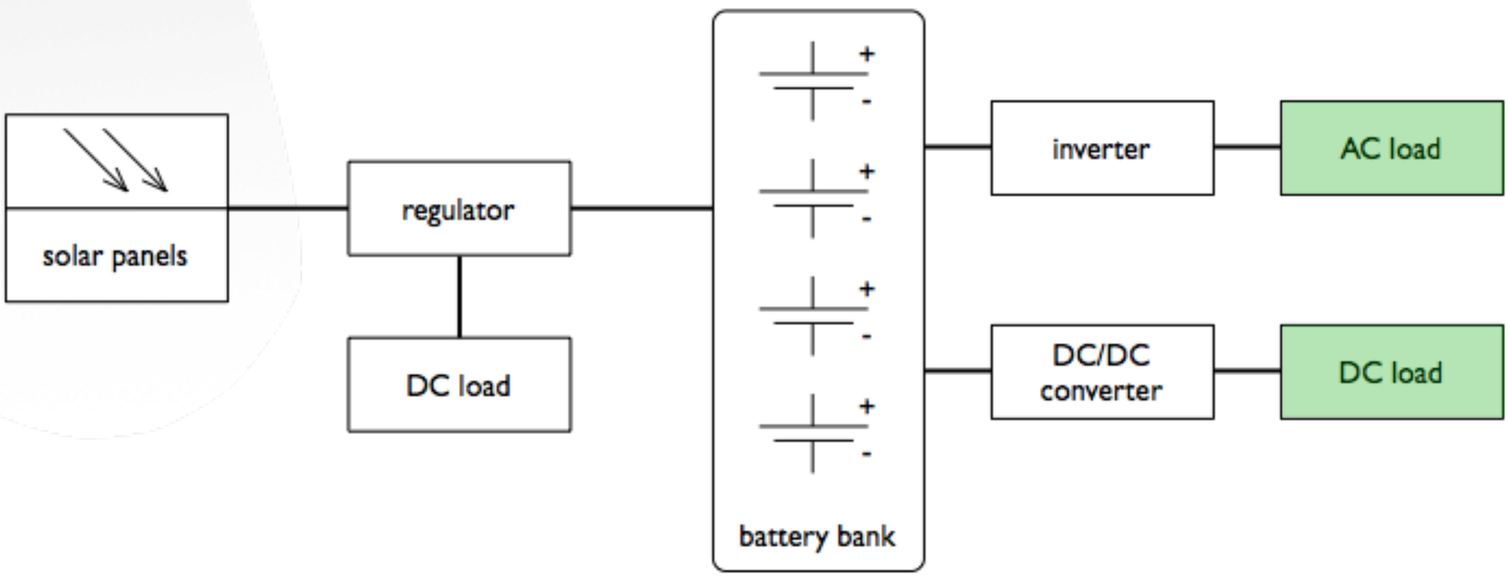
An ***inverter*** turns DC into AC, usually at 110 V or 220 V.

A ***DC/DC converter*** changes the input DC voltage into a desired value.



The load

The ***load*** is the usable energy that the solar system must supply.



The Load

The ***load*** is the equipment that consumes the power generated by your energy system.

The load is expressed in watts, which are

$$\text{watts} = \text{volts} * \text{amperes}$$

If the voltage is already defined, the load can be expressed in amperes.

The Load: IoT Example

The ***load*** is the equipment that consumes the power generated by your energy system.

The load is expressed in watts, which are

watts = volts X amperes

If the voltage is already defined, the load can be expressed in amperes.

Power consumption

The amount of power consumed can be calculated with this formula:

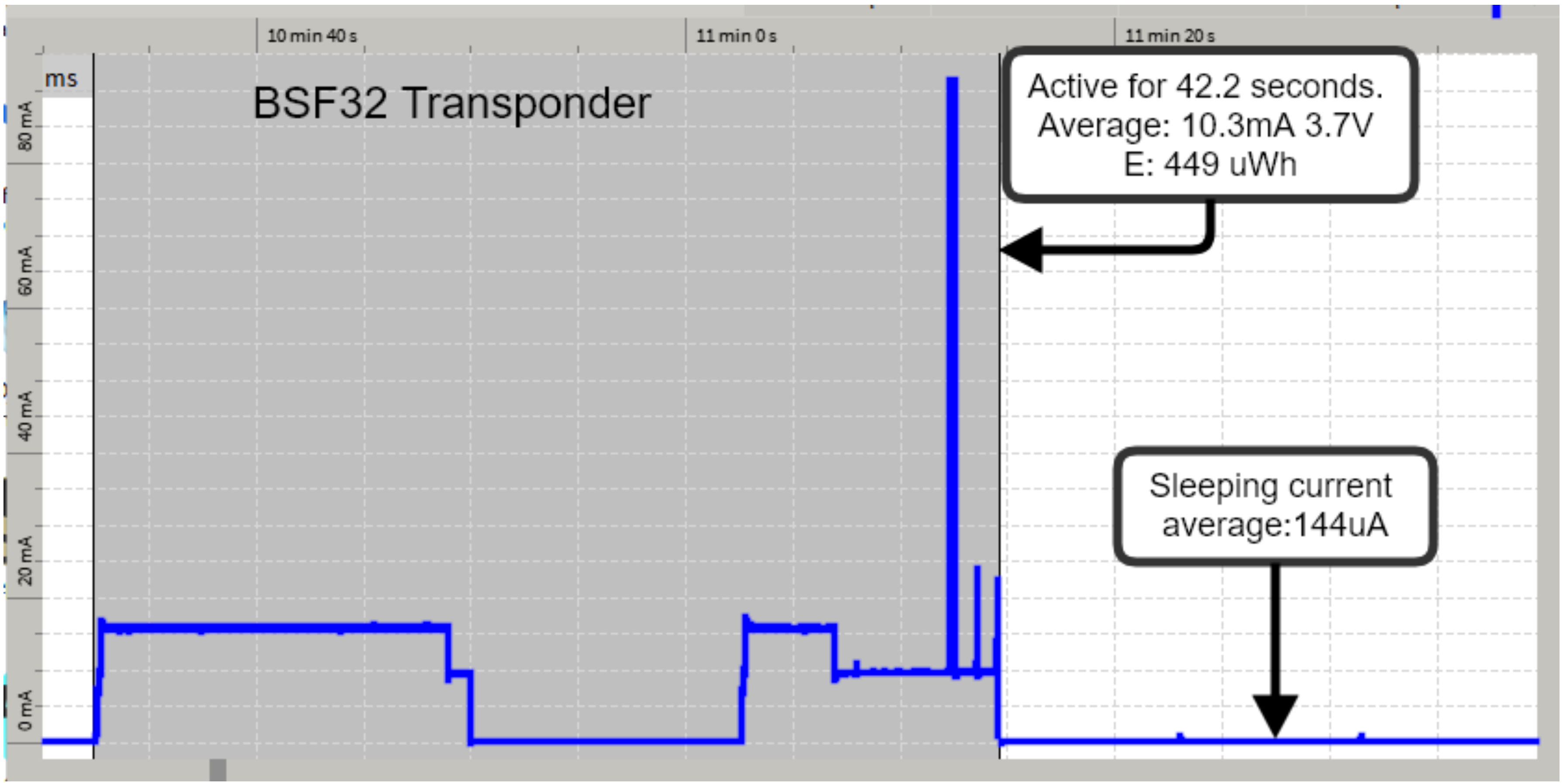
$$P = V \times I$$

P is the power in Watts, ***V*** is voltage in volts, and ***I*** is the current in amperes. For example:

$$6 \text{ watts} = 12 \text{ volts} \times 0.5 \text{ ampere}$$

If this device is operating for an hour it will consume 6 watt-hours (Wh), or 0.5 ampere-hours (Ah) at 12V. Thus the device will draw 144 Wh or 12 Ah per day.

Example of IoT device consumption



Spreadsheet for consumption calc.

Input data framed in red			Intermediate results framed in blue			Final results framed in green			

IoT Electrical power consumption calculator

Radio		duration, ms	# per hour	Current, mA	mA per day	mA per year	mA per hour	Wh per year	Battery usage,%
	Transmit	70	12	38	0.2128	77.672	0.008866666667		21.68
	Receive	80	12	15	0.096	35.04	0.004		9.78
Sensor					0	0	0		
	Temperature	20	12	15	0.024	8.76	0.001		2.45
	Humidity	20	12	15	0.024	8.76	0.001		2.45
	GPS	60	12	130	0.624	227.76	0.026		63.58
	Other				0	0	0		0
Microcontroller					0	0	0		
	Active	200			0	0	0		0
	Sleeping	1000	12	0.008	0.00064	0.2336	0.000026666666		0.07
	Idle				0	0	0		0
Total					0.98	358	0.04	1290	100
Battery Voltage	volts	3.6							
Battery Capacity	mAh	800							
Battery self discharge per year		15.00%		Battery self discharge depends on the material and type of battery					
	mWh	2880							
Battery duration	years	1.90							

Spreadsheet for PV dimensioning

Simplified spreadsheet for photovoltaic calculations

Solar radiation data for a given site available from:

https://eosweb.larc.nasa.gov/sse/RETScreen/ , Worldwide coverage

http://globalsolaratlas.info/ , Worldwide coverage

http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en, Africa and Eurasia coverage

Input data framed in red | Intermediate results framed in blue | Final results framed in green

Electrical Load Calculation

Device	Consumption,W	Hours/day	Energy/day, Wh
GPS	1.5	24	36
WiFi Client	8	24	192
Laptop	15	12	180
WiFi AP	3	24	72
Ethernet Switch	4	24	96
Total energy consumption/day, Wh			36

Battery capacity calculation, considering the number of no-sun days and the allowed depth of discharge

Required autonomy, days	Depth of Discharge	Battery capacity,Wh	Battery voltage,V	Battery Capacity, Ah	Number of batteries
4	0.5	288	12	24.0	2

Panel capacity calculation

Panel Peak power, Wp
10

Load energy,Wh	Battery charging allowance	Energy /d, Wh	PSH	Daily Photovoltaic power, W	Number of panels
36	1.5	54	5.5	9.8	1

Wind power

A ***wind generator*** is an option for an autonomous system on a hill or mountain.

The average wind speed over the year should be at least 3 to 4 meters per second.

Hint: locate the generator as high as possible

Wind power

The maximum available wind power is given by:

$$P = 0.5\,\rho\, v^3\ [W/m^2]$$

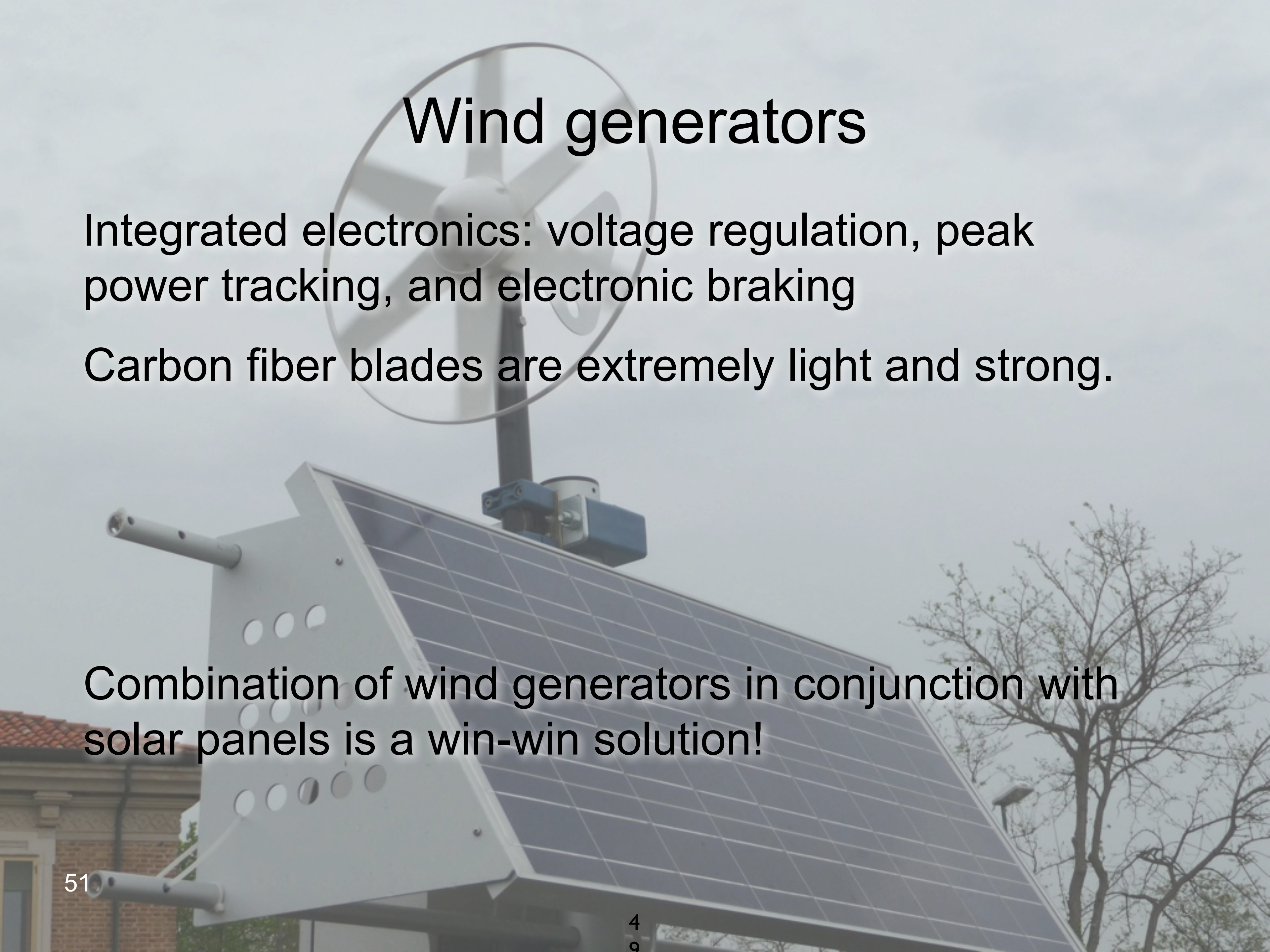
where v is velocity in m/s,
$\boldsymbol{\rho}$ is air density (around 1.2 kg/m^3 at sea level).
The efficiency range of wind generators is between 20 and 40%

Wind generators

Integrated electronics: voltage regulation, peak power tracking, and electronic braking

Carbon fiber blades are extremely light and strong.

Combination of wind generators in conjunction with solar panels is a win-win solution!



Conclusions

- Many forms of ambient energy can be harvested and leveraged for powering IoT devices
- Turning off non essential services is key for energy saving
- Solar or wind power are mature technologies to provide energy
- Batteries for energy storage and proper charge regulators are required for most intermittent energy sources