PV TECH

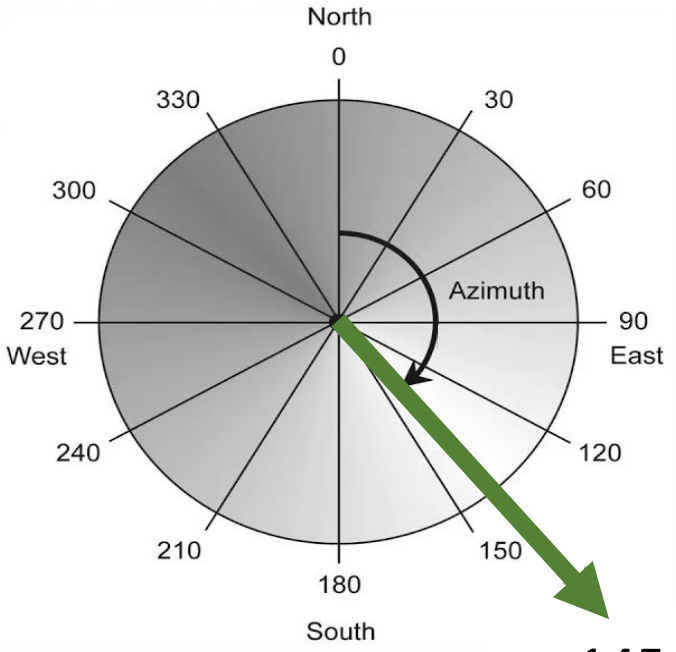
PV module

DC electricity

solar module
solar panel

Azimuth

The direction faced, relative to the north direction.

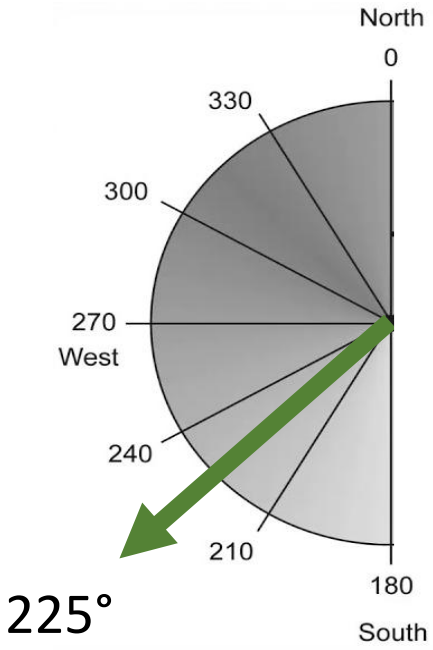


145 ° azimuth

Image: Stan Gibilisco

Southwest azimuth in degrees?

Southwest azimuth in degrees?



225°

Roof face

One surface of a building’s overall roof, with a particular azimuth and tilt.

roof plane

Roof eave and ridge

The eave runs along the bottom. The ridge runs along the top.

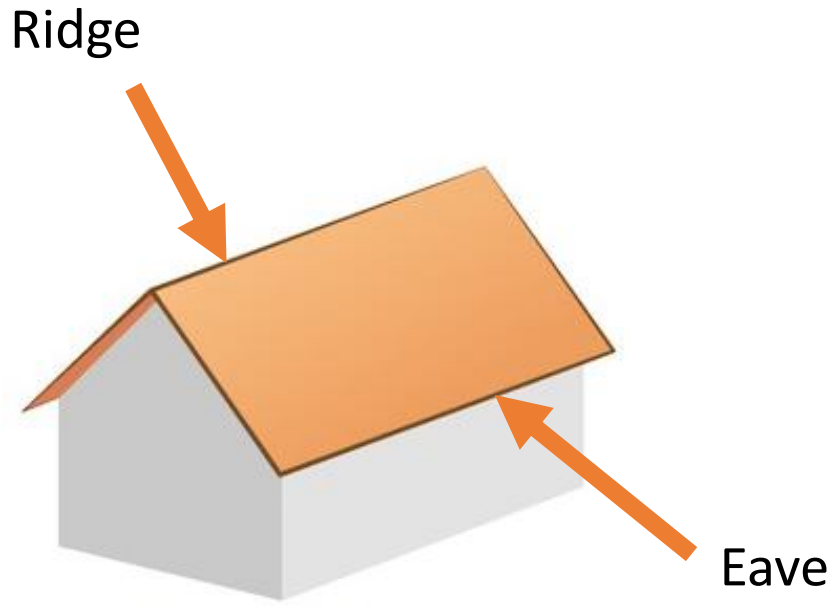
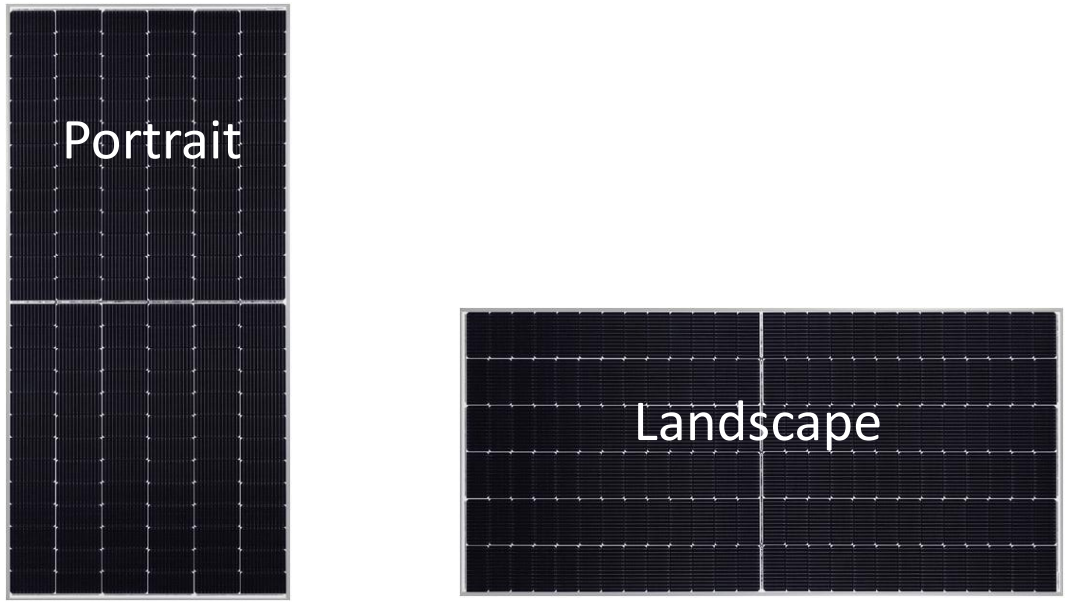


Image: homedit

PV module orientation

Modules can be in portrait or landscape orientation

The roof ridge



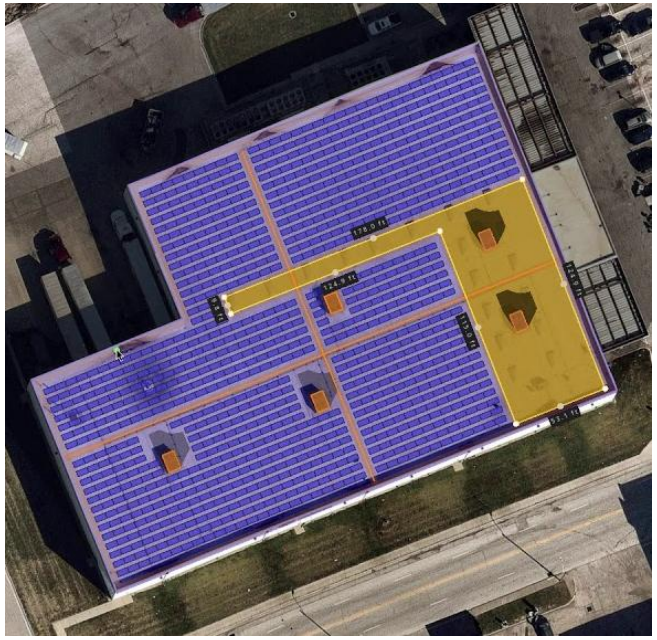
The roof eave

PV array

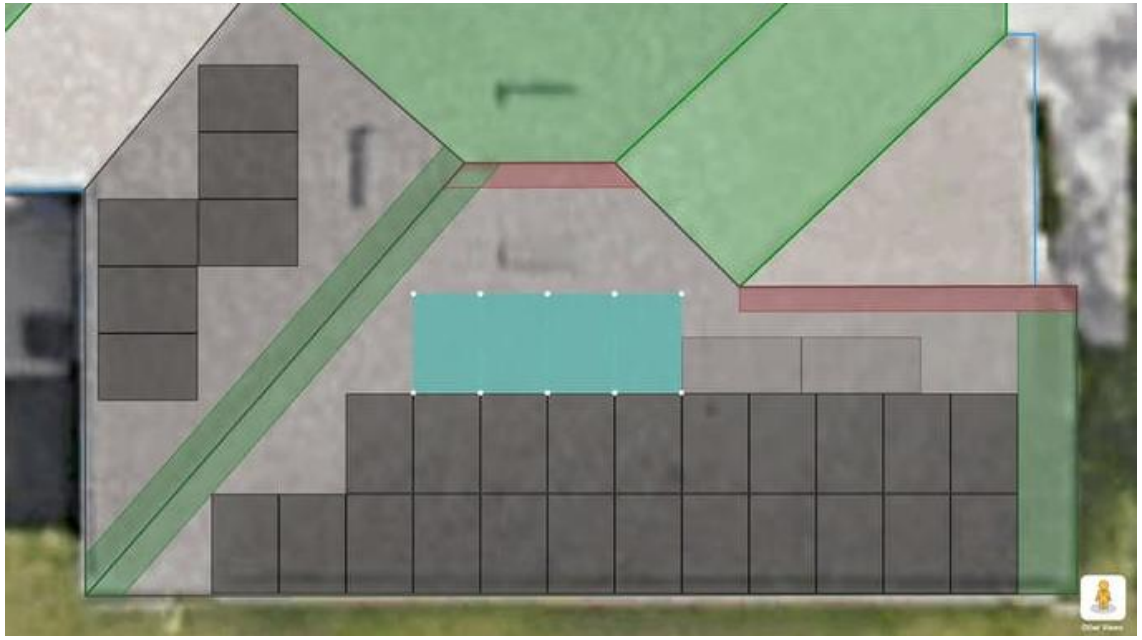
A group of adjacent PV modules, with shared racking.

PV layout

The arrangement of: PV modules in an array, and arrays on a roof face.



non-residential example



residential example

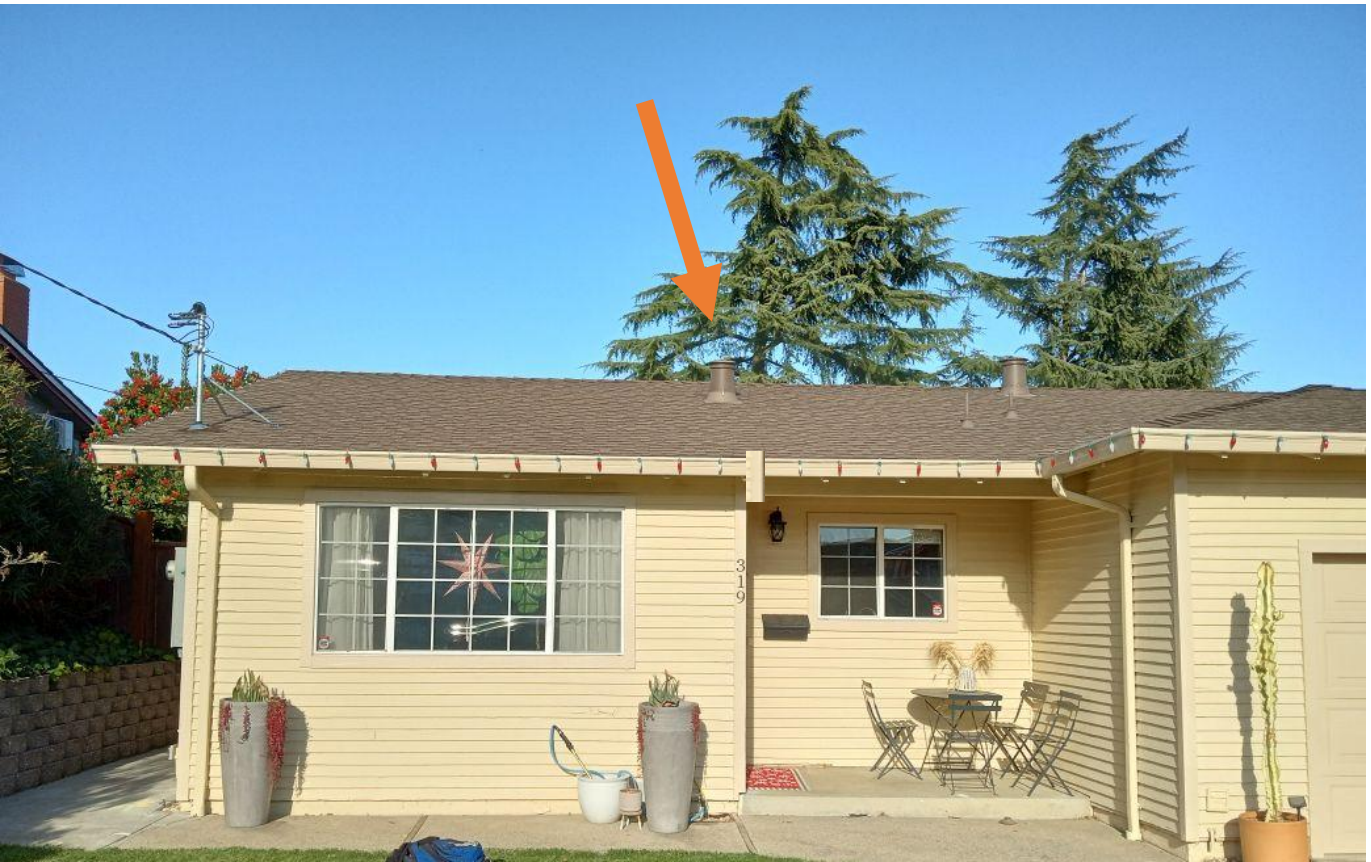
Images: Folsom Labs and Lyra

Roof obstructions

Passive plumbing vents, natural-gas exhaust vents, skylights, etc.

Mike moved an exhaust vent

...to the north side of the ridge.



Mike did some HVAC work.

...carefully.

Remote site analysis

Analyze sites from your office.

Blurry satellite imagery is no fun

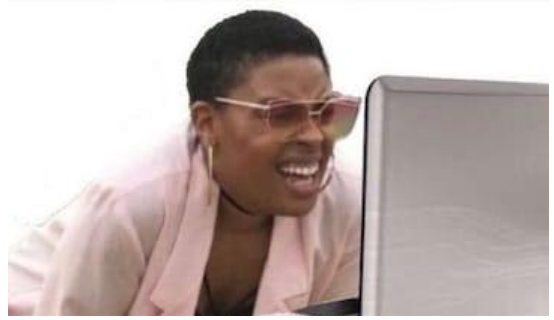


Image: iRoofing

High-resolution imagery

...From an airplane or a drone.

Top-down (“orthogonal”) view:

From-an-angle (“oblique”) view:

Roof measurement

We need to get the lengths of roof-face sides.

We need to get obstruction locations.

Going on the roof with a tape measure... is tedious.

Automated roof measurement

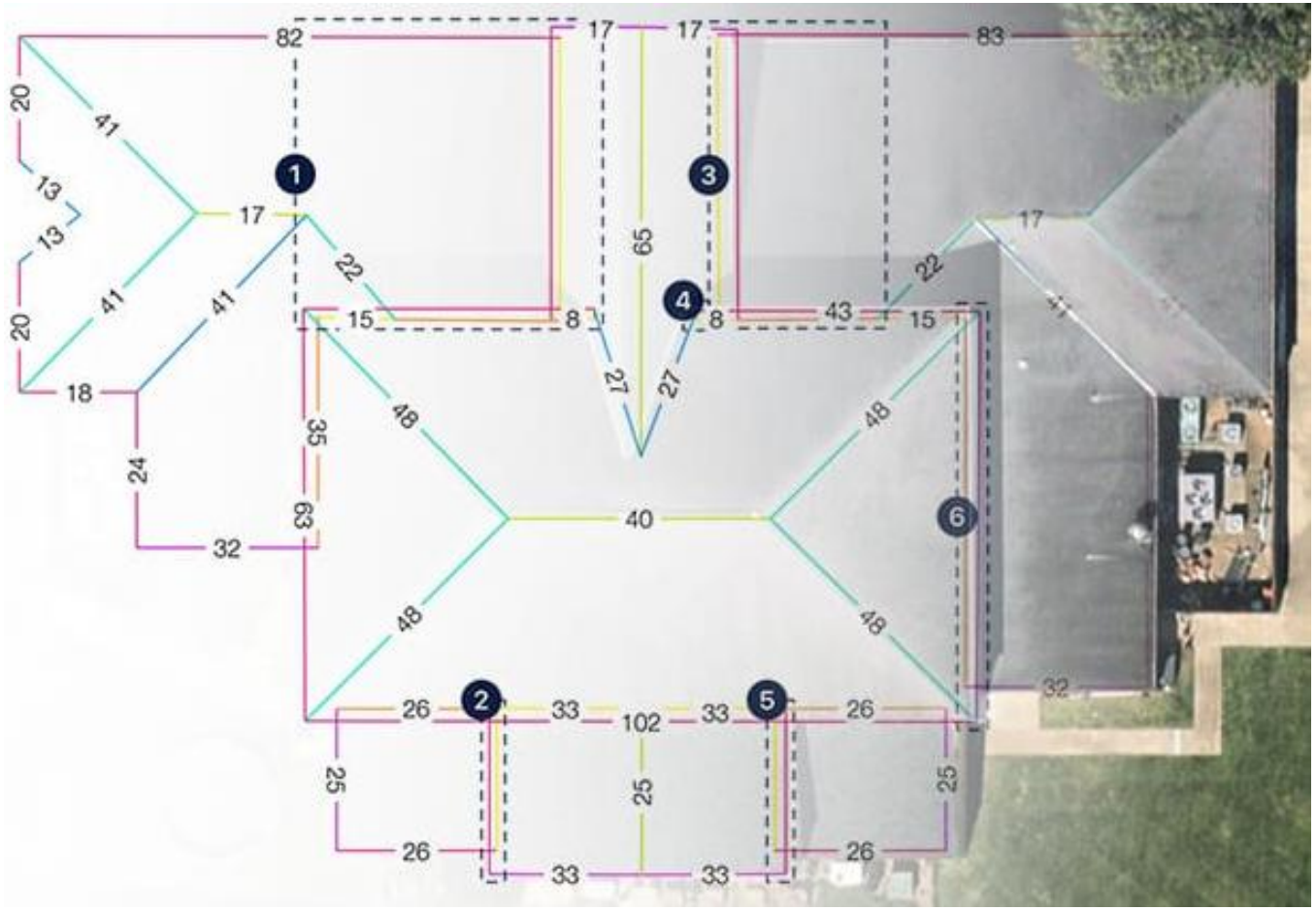


Image: [iRoofing]

3D layout design

Installing with AR glasses

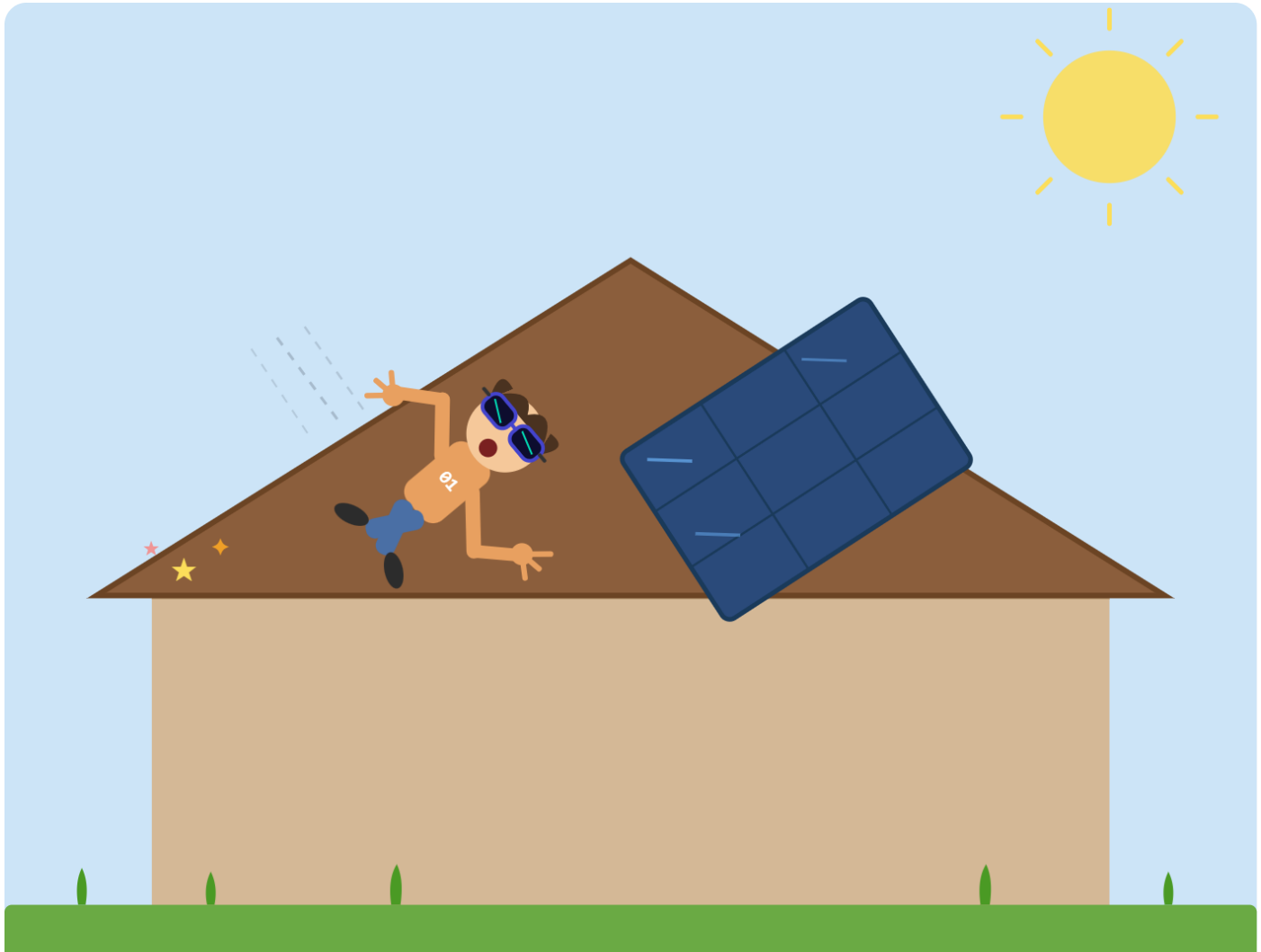


Image: Claude, 2026-03

Solar irradiance

Power per unit of area.

…Watts per square meter.

Solar insolation

The total irradiance that hits a surface over a period of time.

Often measured in kWh per square meter per day.

A bottle of sunshine

Irradiation

Sun hour

One hour with average solar irradiance of 1,000 watts per square meter.

…Or the equivalent at a different level over a different period of time.

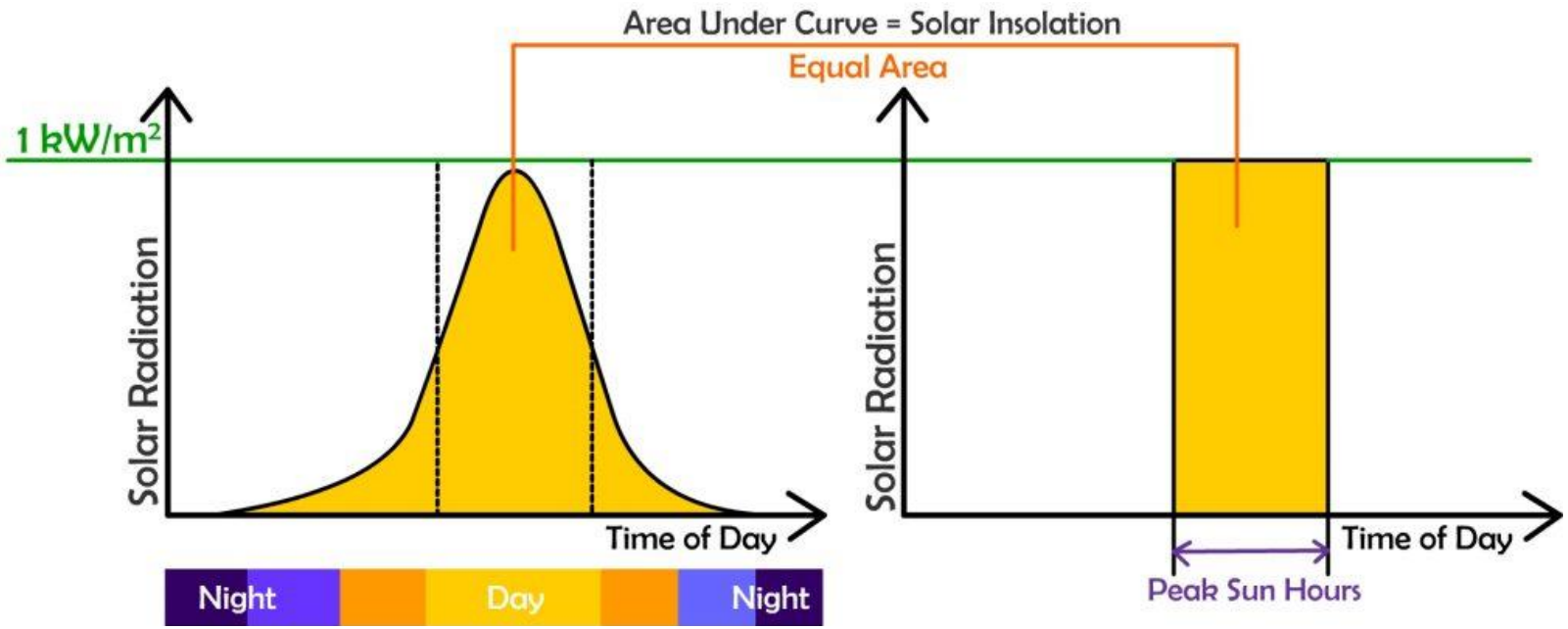
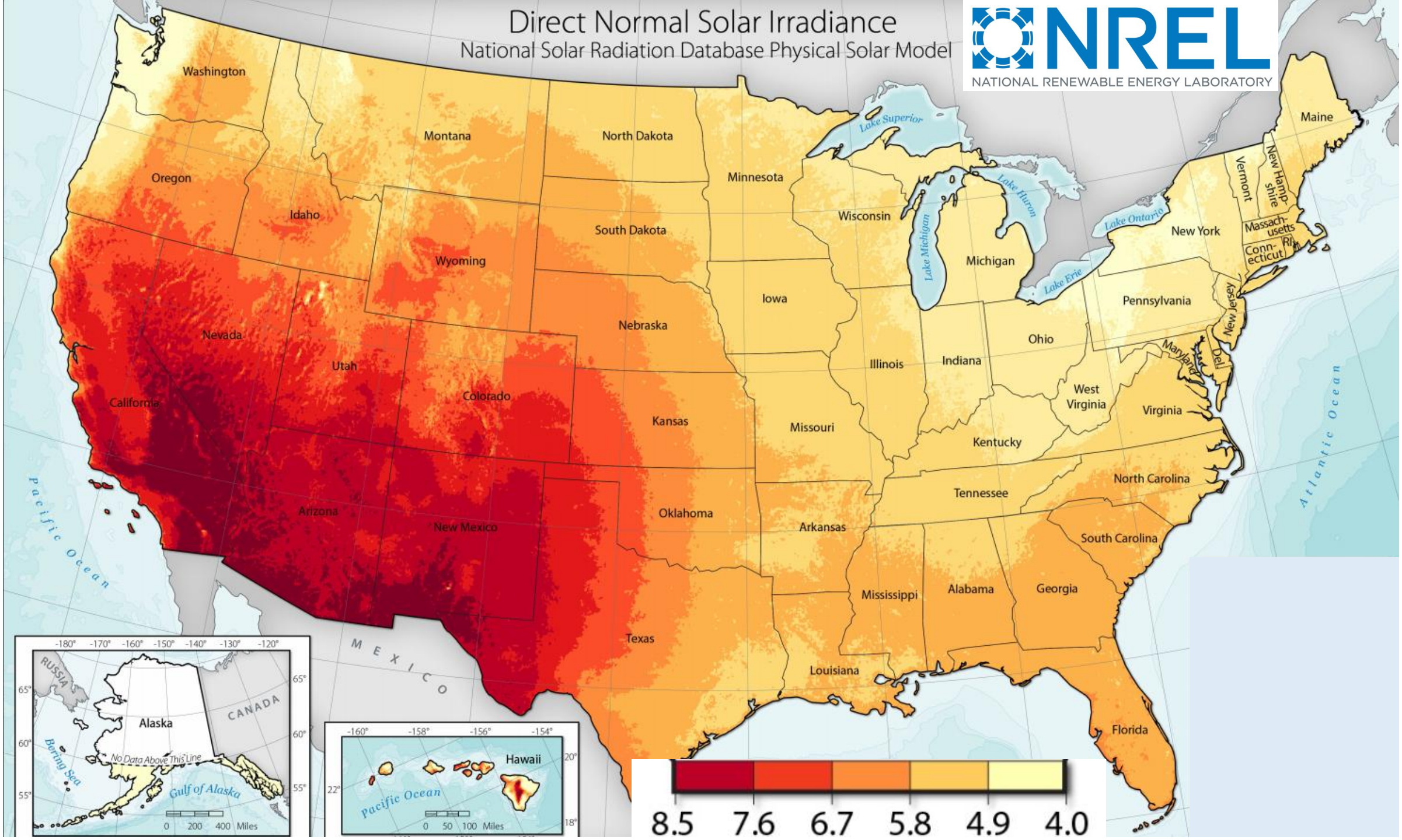


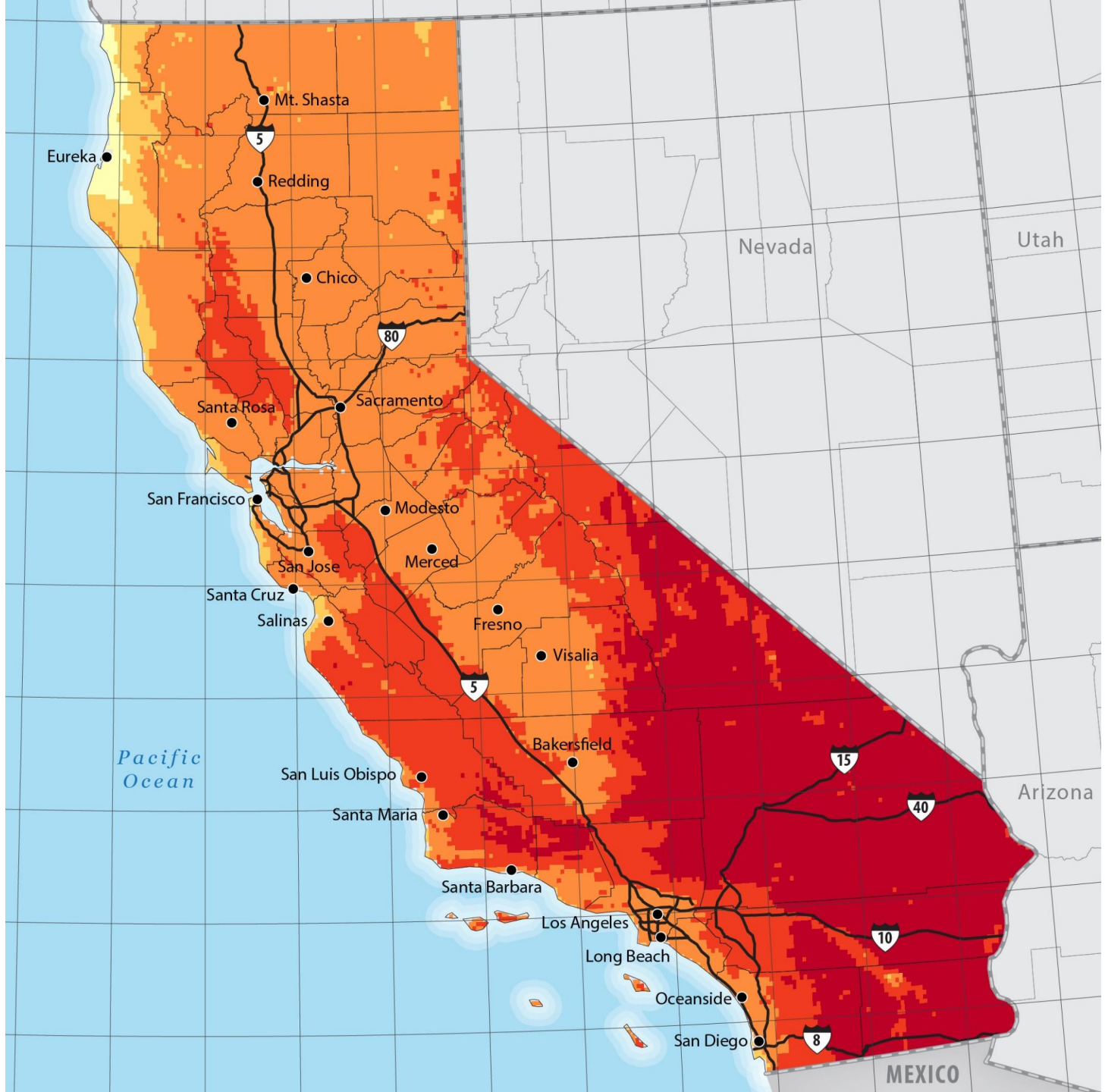
Image: Green Sarawak

Direct Normal Solar Irradiance

National Solar Radiation Database Physical Solar Model

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



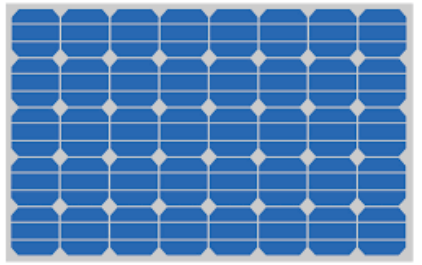


NREL

NATIONAL RENEWABLE ENERGY LABORATORY

8.5 7.6 6.7 5.8 4.9 4.0

Standard Test Conditions (STC) rating



Power output in controlled (lab) conditions:

1,000 watts-per-square-meter solar irradiance

1.5 air mass

25° celsius ***cell*** temperature (77° F)

Module Data Sheet M60

ELECTRICAL SPECIFICATION (STC)

Model	SEAM60-250	SEAM60-260	SEAM60-270	SEAM60-280
Rated Power (Pmpp)	250W	260W	270W	280W

Nameplate rating

Temperature coefficient

Recall that the STC rating uses a 25° C cell temperature...

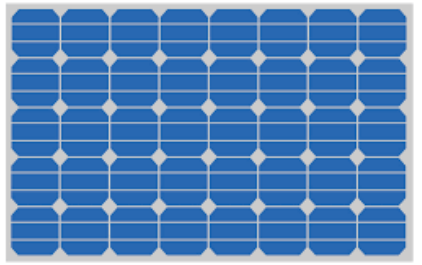
If the module's temperature is over 25° C…

…its power output will be less than the STC-rated power output.

This power-output decrease (or increase, if under 25° C) is linear:

Different modules have different temperature coefficients... check the spec sheet.

Temperature coefficient



ELECTRICAL SPECIFICATIONS

Model	VBHN330SA17
Rated Power (Pmax)[1]	330W
Maximum Power Voltage (Vpm)	58.0V
Maximum Power Current (Ipm)	5.70A
Open Circuit Voltage (Voc)	69.7V
Short Circuit Current (Isc)	6.07A
Temperature Coefficient (Pmax)	-0.258%/°C
Temperature Coefficient (Voc)	-0.16V/°C
Temperature Coefficient (Isc)	3.34mA/°C
NOCT	44.0°C
CEC PTC Rating (Tentative)	307.1W
Cell Efficiency	22.09%
Module Efficiency	19.7%
Watts per Ft.^{2}	18.3W
Maximum System Voltage	600V
Series Fuse Rating	15A
Warranted Tolerance (-/+)	+10%/-0%*

Spec sheet for Panasonic HIT N330

Inverter

Converts DC electricity to AC electricity.

DC

AC

a DC power source

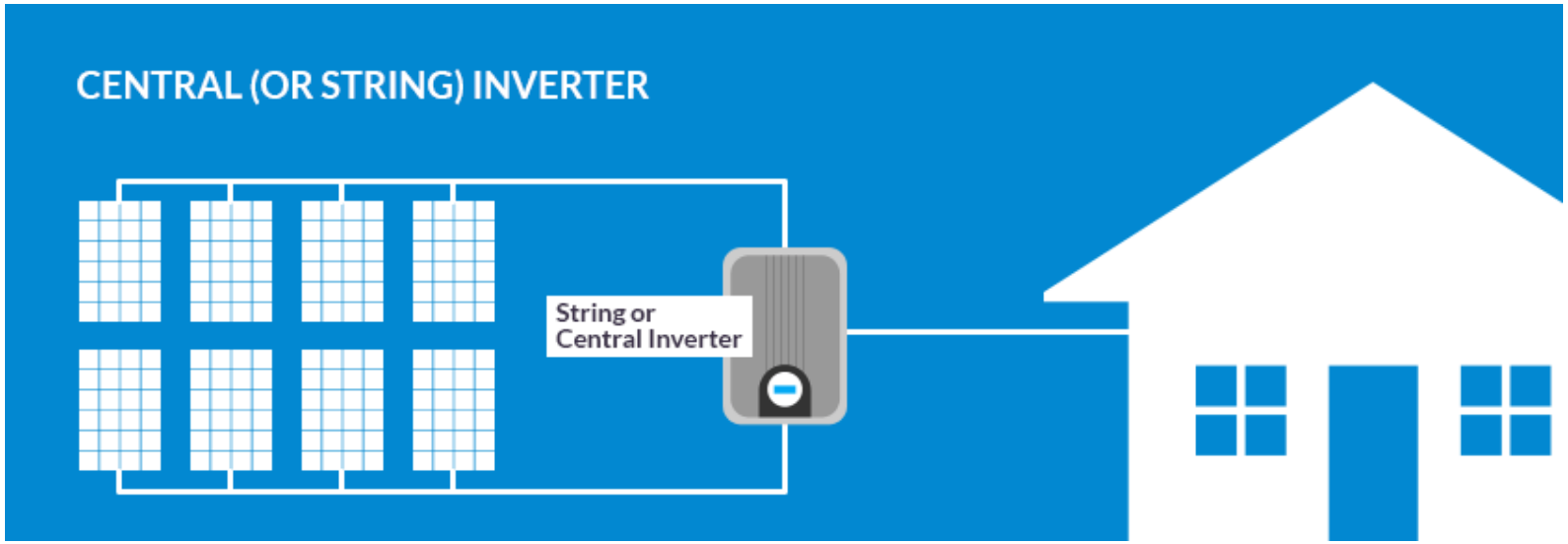
inverter

an AC load

String inverter

An inverter, that converts electricity from all connected modules.

It’s typically mounted on a wall.



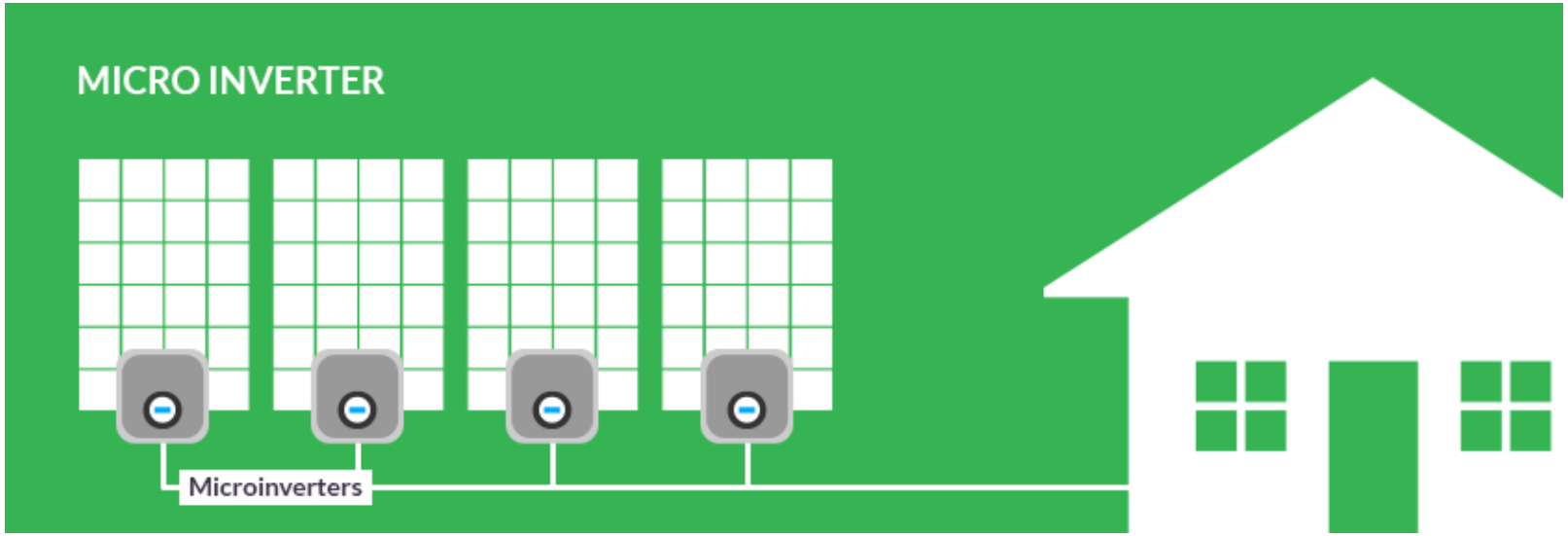
Central inverter

Image: Let’s Go Solar

Microinverter

An inverter that’s dedicated to one* PV module.

The inverter is installed underneath the module.



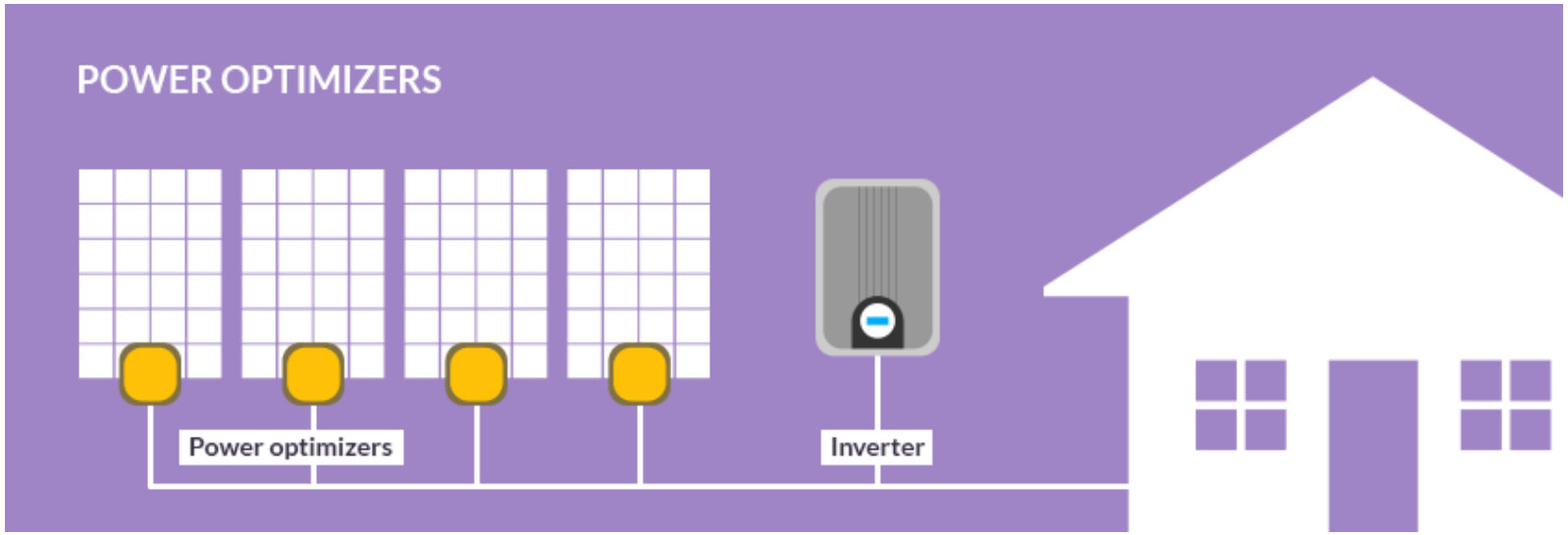
* Some microinverter models support two or four modules.

Image: Let’s Go Solar

Power optimizer

An electronic device that optimizes the voltage of one PV module.

The power optimizer is installed underneath the module.



DC-to-DC converter

Image: [Let's Go Solar]

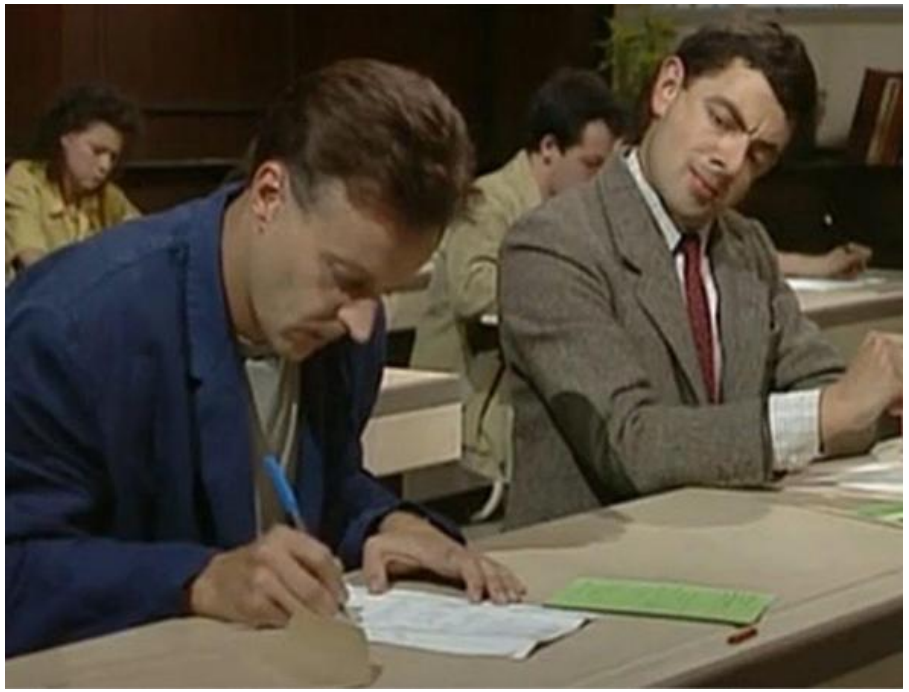
Module-level power electronics (MLPE)

MLPEs include:

- microinverters
- power optimizers
- rapid-shutdown devices

Grid-following inverter

Syncs with an existing grid’s voltage and frequency.



Grid-interactive inverter

Grid-forming inverter

Can make its own grid. Can maintain its own stable voltage and frequency.

Off-grid inverter

Multi-mode inverter

Can follow a larger grid or make its own grid.

Hybrid inverter

Accepts multiple power sources.

Grid profile

Pre-defined “smart” inverter settings, that support grid stability.

Voltage limits (when to ramp down or disconnect)

Frequency limits

Volt-VAR and Volt-Watt response curves

Power factor requirements

Ride-through settings

Reconnect delays

IEEE 1547-2018

A national technical standard for how DERs interact with the grid.

California’s Rule 21 grid profile

California’s implementation of IEEE 1547-2018.

Including: The inverter must be able to receive utility control signals.

This network of modern inverters supports a cleaner / more stable grid.

PV system losses

Calculate System Losses Breakdown

Modify the parameters below to change the overall System Losses percentage for your system.

Soiling (%):	2
Shading (%):	3
Snow (%):	0
Mismatch (%):	2
Wiring (%):	2
Connections (%):	0.5
Light-Induced Degradation (%):	1.5
Nameplate Rating (%):	1
Age (%):	0
Availability (%):	3

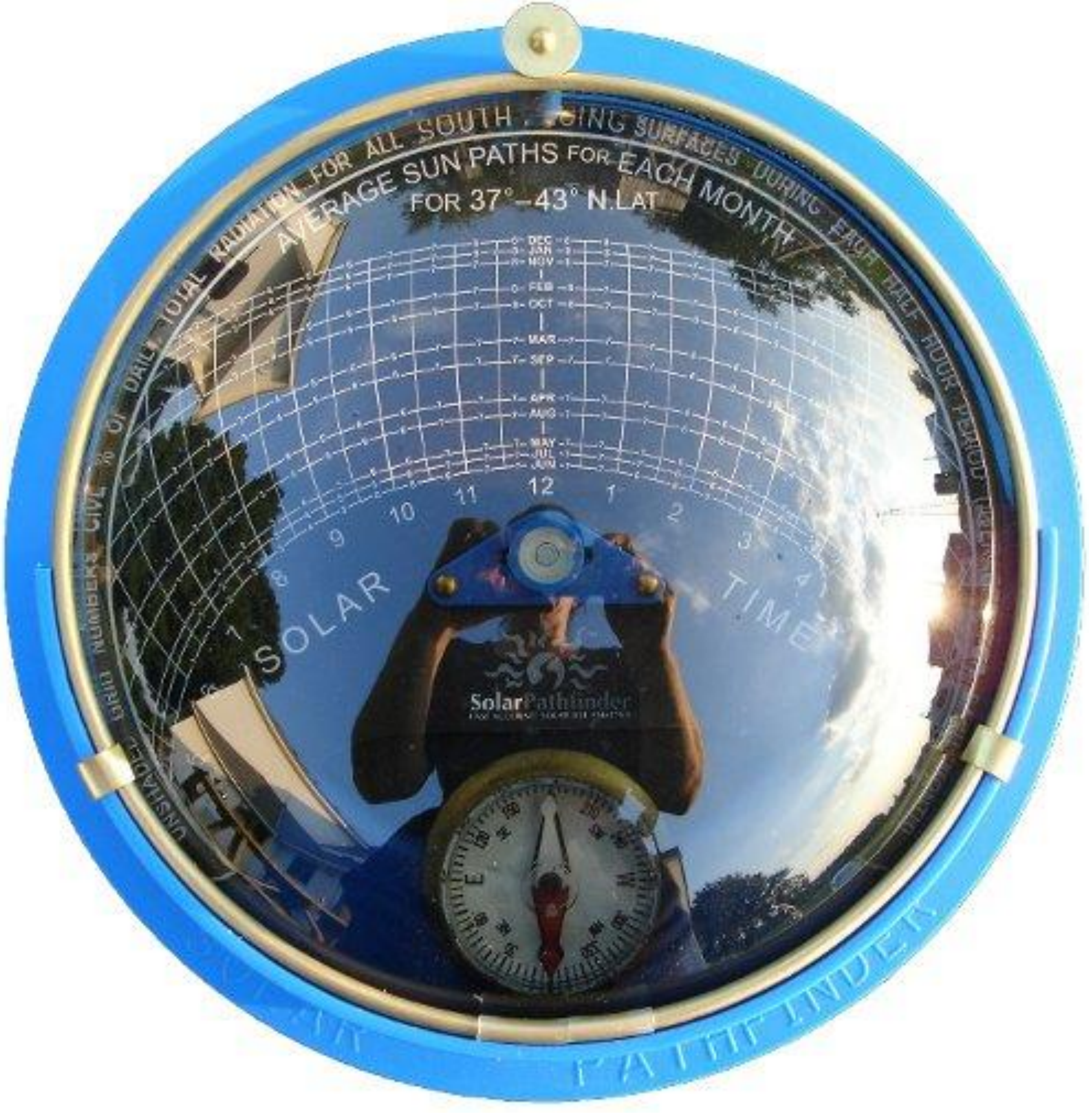
Estimated System Losses:

14.08%

Shading

Image: Solar Builder

Physical shade-measurement tools


AVERAGE SUN PATHS FOR EACH MONTH
FOR 37°–43° N.LAT
DEC
JAN
NOV
FEB
OCT
MAR
SEP
APR
AUG
MAY
JUL
JUN
8 9 10 11 12 1 2 3 4
SOLAR
TIME
SolarPathfinder
PATHFINDER

Choose your shade-measurement roof points

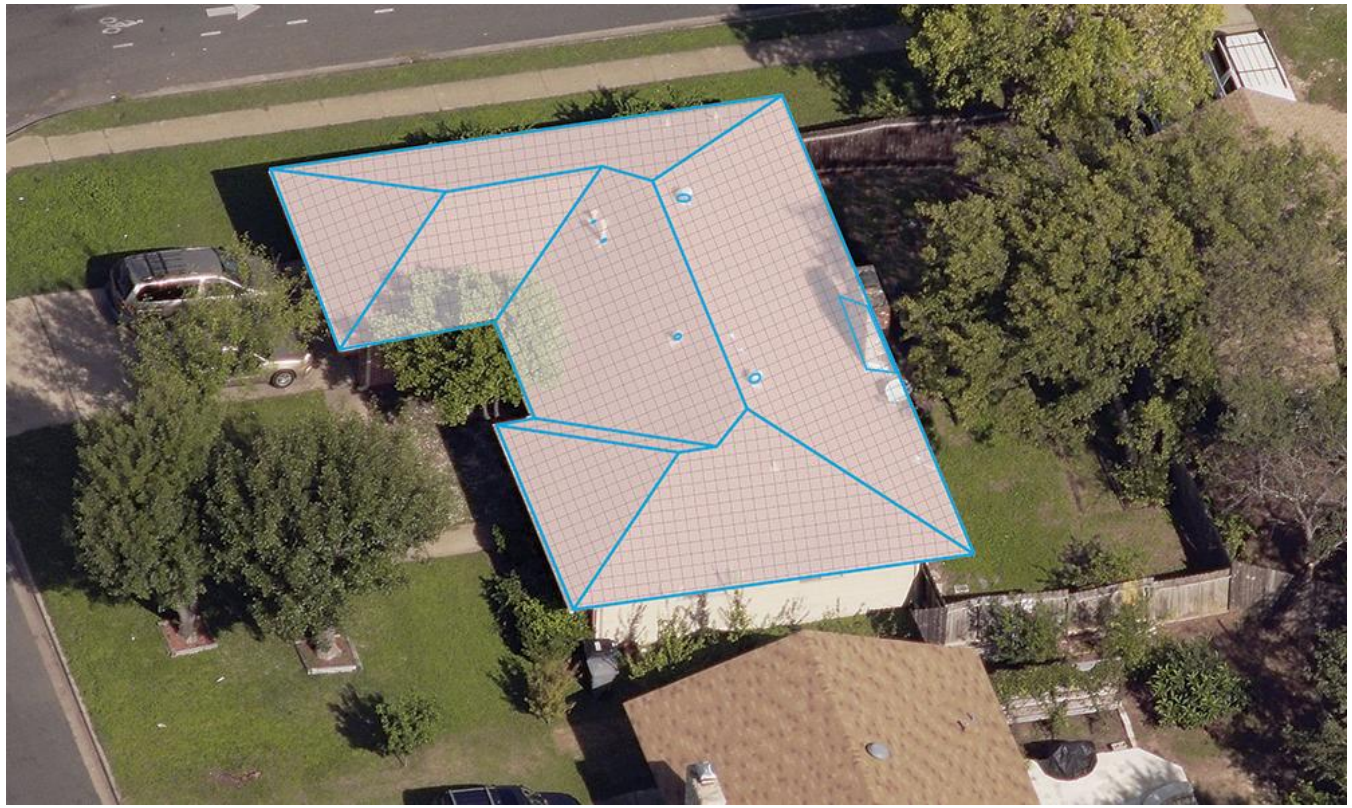
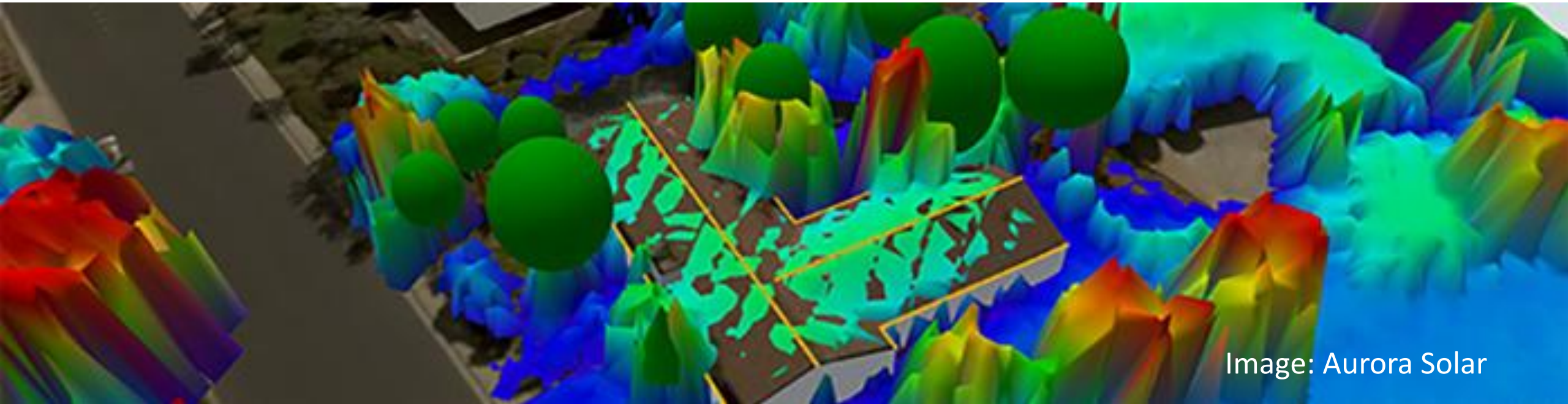


Image: EagleView

Remote shade analysis

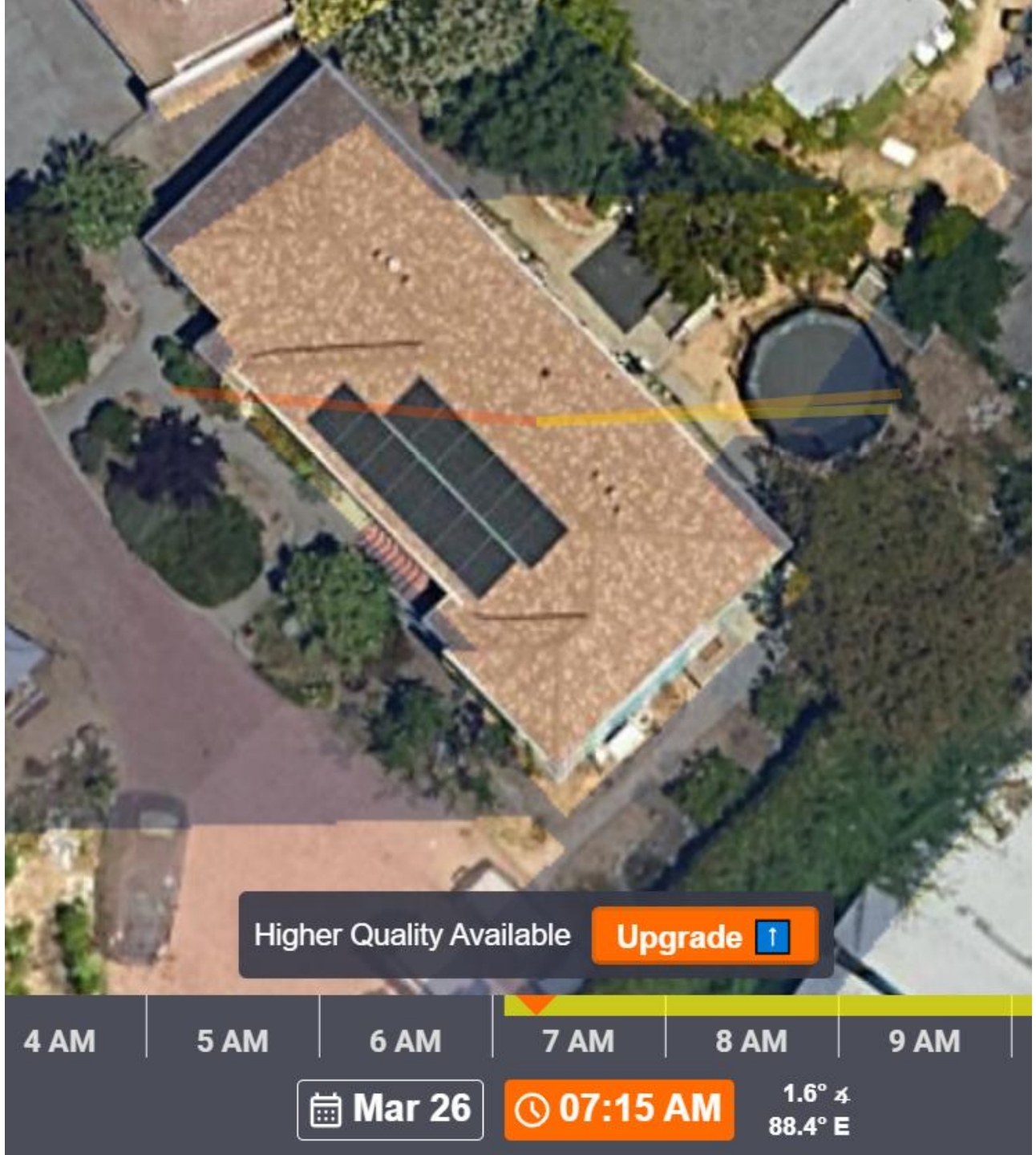
Get an hour-by-hour shade analysis for every point on a roof face.

The shade loss is adjusted automatically as the array design is updated.



ShadeMap

A free online shade app

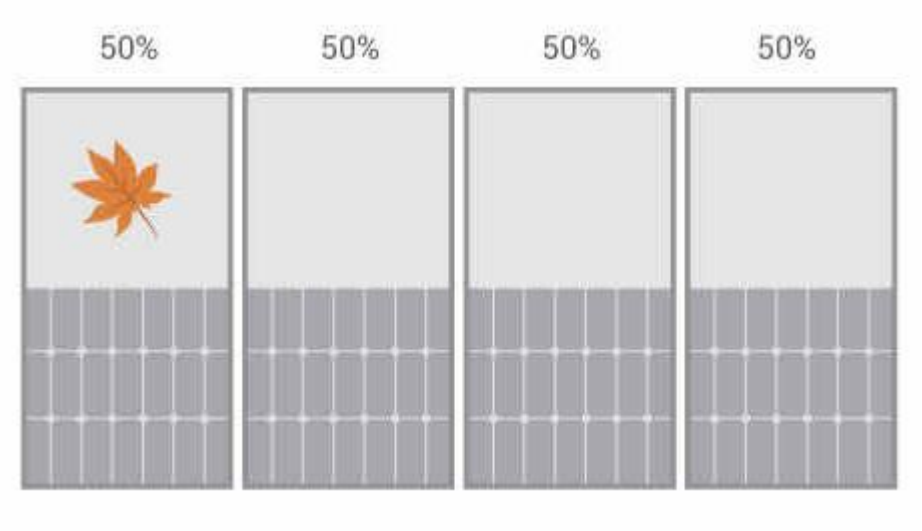


Are nearby trees deciduous or evergreen?

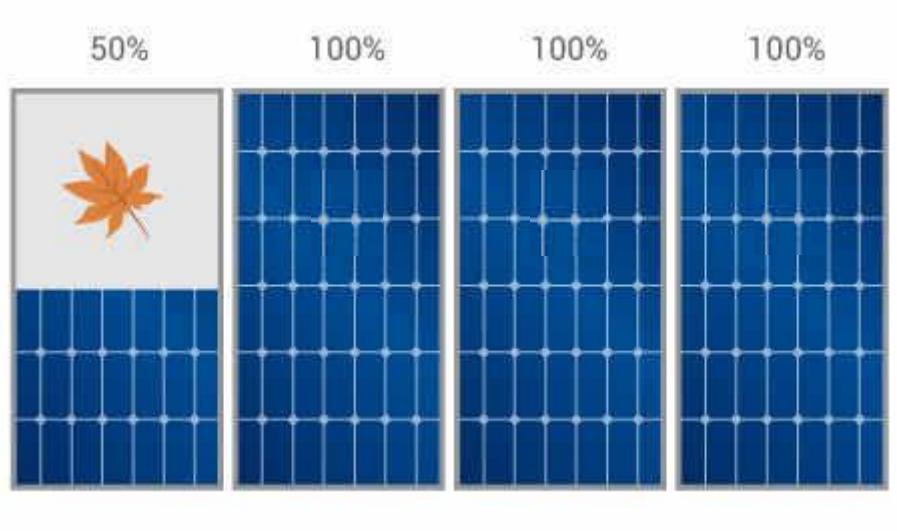
Image: Gardenerdy

Inverters and shade

Once reality, now a myth...



with a string inverter



with MLPEs

Inverter types and shading

Eddy May monitored side-by-side microinverter and string arrays.

Images: NRG Solar video

Eddy's conclusion:

String-inverter output was within a few percent.

This was consistent across several shade scenarios.

	Days	Enphase kWh	Fronius kWh	Percent Diff.
Chimney	13	122	118	103.5%
Pipe	4	57	55	102.5%
Unshaded	27	291	285	102%
Total		469	458	102.5%

Source: NRG Solar video, 2021-08

Module-level monitoring

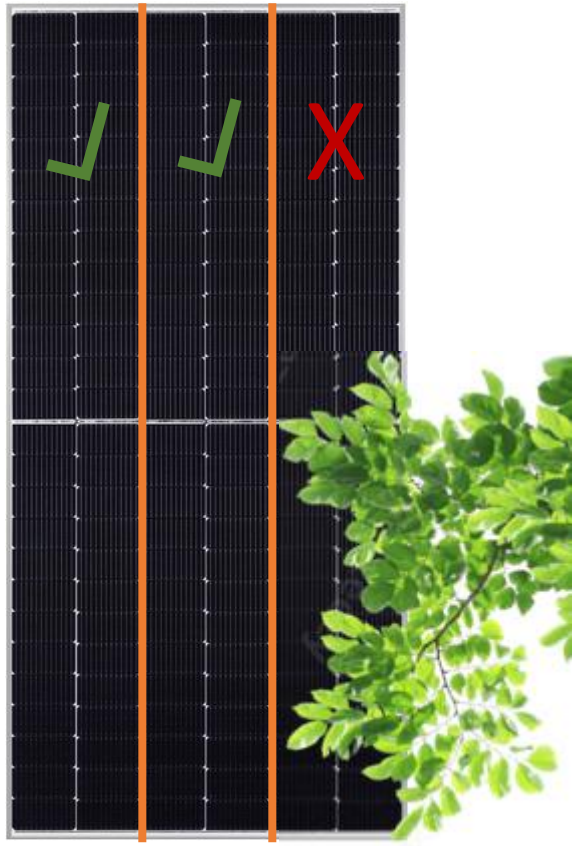
MLPEs make this possible.

Image: Solar Power World

Bypass diodes

Splits a module into three portrait sections.

Heavily-shaded sections are bypassed, for higher overall production.

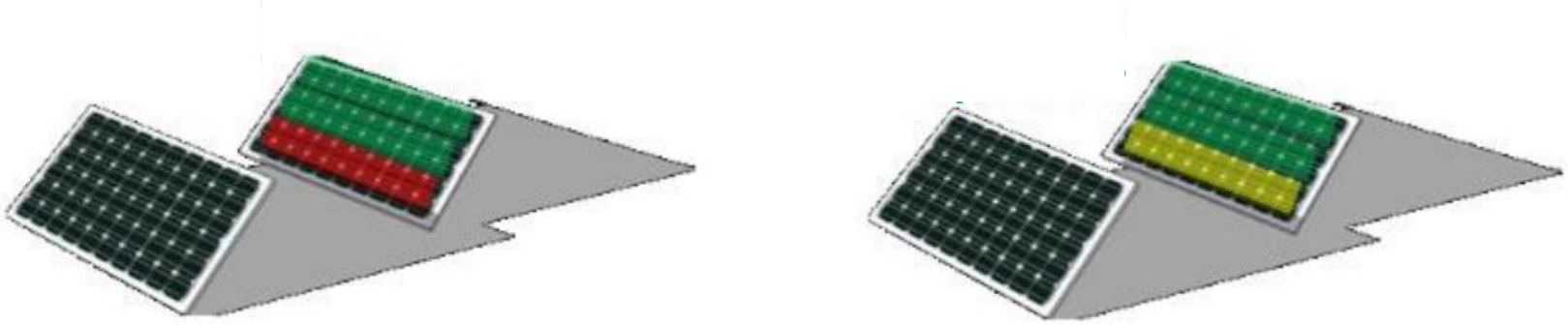


Submodule power optimizer

An optimizer dedicated to a module sub-string (one of three in the module).

This device replaces the bypass diode.

(This isn’t currently available.)

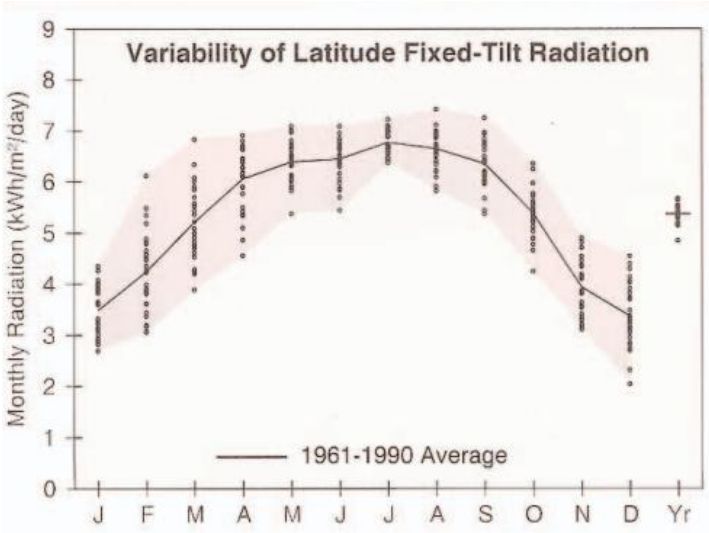


Images: Maxim Integrated

PV Sizing

Monthly production estimate

Module count x STC rating x (1 – losses) x daily sun hours x days per month



San Francisco, CA

WBAN NO. 23234

LATITUDE: 37.62° N
LONGITUDE: 122.38° W
ELEVATION: 5 meters
MEAN PRESSURE: 1017 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.2	3.0	4.2	5.7	6.7	7.2	7.3	6.5	5.4	3.9	2.5	2.0	4.7
	Min/Max	1.8/2.5	2.3/3.9	3.3/5.3	4.4/6.4	5.7/7.4	6.1/7.9	6.9/7.9	5.7/7.3	4.7/6.0	3.2/4.4	2.1/2.9	1.4/2.4	4.4/4.9
Latitude -15	Average	3.1	3.9	5.0	6.2	6.8	7.0	7.3	6.9	6.2	5.0	3.5	2.9	5.3
	Min/Max	2.4/3.8	2.9/5.5	3.8/6.5	4.7/7.0	5.7/7.5	5.9/7.7	6.9/7.8	6.0/7.7	5.3/7.1	4.0/5.8	2.8/4.3	1.9/3.9	4.9/5.6
Latitude	Average	3.5	4.2	5.2	6.1	6.4	6.5	6.8	6.7	6.4	5.4	3.9	3.4	5.4
	Min/Max	2.7/4.3	3.1/6.1	3.9/6.8	4.6/6.9	5.4/7.1	5.4/7.1	6.4/7.2	5.8/7.4	5.4/7.3	4.3/6.4	3.1/4.9	2.0/4.6	4.9/5.7
Latitude +15	Average	3.7	4.4	5.1	5.6	5.7	5.6	5.9	6.1	6.1	5.5	4.1	3.6	5.1
	Min/Max	2.8/4.7	3.1/6.4	3.8/6.8	4.2/6.4	4.8/6.3	4.7/6.1	5.6/6.3	5.3/6.7	5.2/7.0	4.3/6.5	3.2/5.2	2.1/5.0	4.6/5.5
90	Average	3.3	3.6	3.7	3.4	2.8	2.5	2.7	3.3	4.1	4.3	3.6	3.3	3.4

Hourly production estimates

…Or one of many proprietary software options.

...Or your spreadsheet.

No roof space? No ground-mount space?

No problem. Install on a wall.

Floating PV

Image: BayWa r.e.

Agrivoltaics

Image: BayWa r.e.

WIND ENERGY

NUCLEAR FUSION

One million amps. 100 million degrees celsius. 18k miles per second.

Lex Fridman Podcast: episode # 485 with David Kirtley

PV TECH