# PV 101 Basic PV

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# Presentation Overview

- Introductions, agenda, goals
- Resources, definitions
- PV Basics
- System types, virtual tour
- Movement of the sun, solar window, SPF
- Ohms Law, general math, load profiles
- Energy efficiency
- Sizing systems
- System pricing

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# Resources

Books

- Photovoltaics Design and Installation Manual, SEI
- Photovoltaic Systems, American Technical Publishers
- Power from the Sun, Dan Chiras
- The Homeowner's Guide to Renewable Energy, Dan Chiras

# Resources

Periodicals

- Home Power Magazine
- Solar Today
- Solar Pro
- Sun & Wind Energy

# Resources

Websites

- dsireusa.org
- http://www.quickmountpv.com/training/webinars/index.html?cur=0
- renewwisconsin.org
- midwestrenew.org
- http://pvwatts.nrel.gov/
- the-solarfoundation.org
- http://openpv.nrel.gov/index
- http://www.rbisolar.com/solar-calculator/
- http://solar-estimate.org/?page=estimatoroverview
- http://design.unirac.com/tool/project_info/solarmount/?pitched=true#max-span-help
- http://www.energyperiscope.com/

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# Definitions

Watt (W)

- Watts is a measure of power.
- Volts X Amps = Watts
- Indicates amount of power a module or PV system can produce or the amount of energy a device will consume

# Definitions

kiloWatt (kW)

•One thousand Watts (W) of power.

• W / 1000 = kiloWatts

# Definitions

kilo Watt hour (kWh)

- Units in which power is bought and/or sold
- kilo Watts X time = kilo Watt hour
- 1 kW X 3 hours = 3 kWh

# Definitions

Grid/Utility Grid

- Network of wires that run up and down the streets and highways of the US used for electrical distribution

- Can be used to store excess electrons generated by a renewable source for future use.

# Definitions

Net Metering
Investor owned utilities are required by law to credit customer accounts for their over production of RE electricity at retail rates.

- Maximum output varies from state to state

- Amount of over production is usually based on nameplate output not kilowatt-hours/year

# Definitions

Net Metering

- WI - 20 kW
- IL - 40 kW
- NE – 25 kW (credited at avoided cost on next bill)
- OK - 100 kW or 25,000 kWh/yr of production whichever is less
- IA - 500 kW
- ON - 500 kW
- WV – 25 kW residential, 50 kW commercial

# Definitions

Net Metering

- Maximum allowable system size, based on rated output

REI

960 W PV

1,200 W PV

2,000 W PV

2,200 W PV

<u>3600 W Wind</u>

9,960 W rated output

10,040 W to go

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# Irradiance, Irradiation, and Insolation

Solar irradiance – the power of solar radiation per unit surface area. It is expressed in $W/m^2$

Power (rate)

Solar irradiation – the energy of solar radiation over a given period of time. It is expressed in $kWh/m^2$

Energy (quantity)

Insolation– the measure of solar radiation energy received on a given surface area in a given time. It is commonly expressed as average irradiance in kilowatt-hours per square meter per day, $kWh/m^2/day$

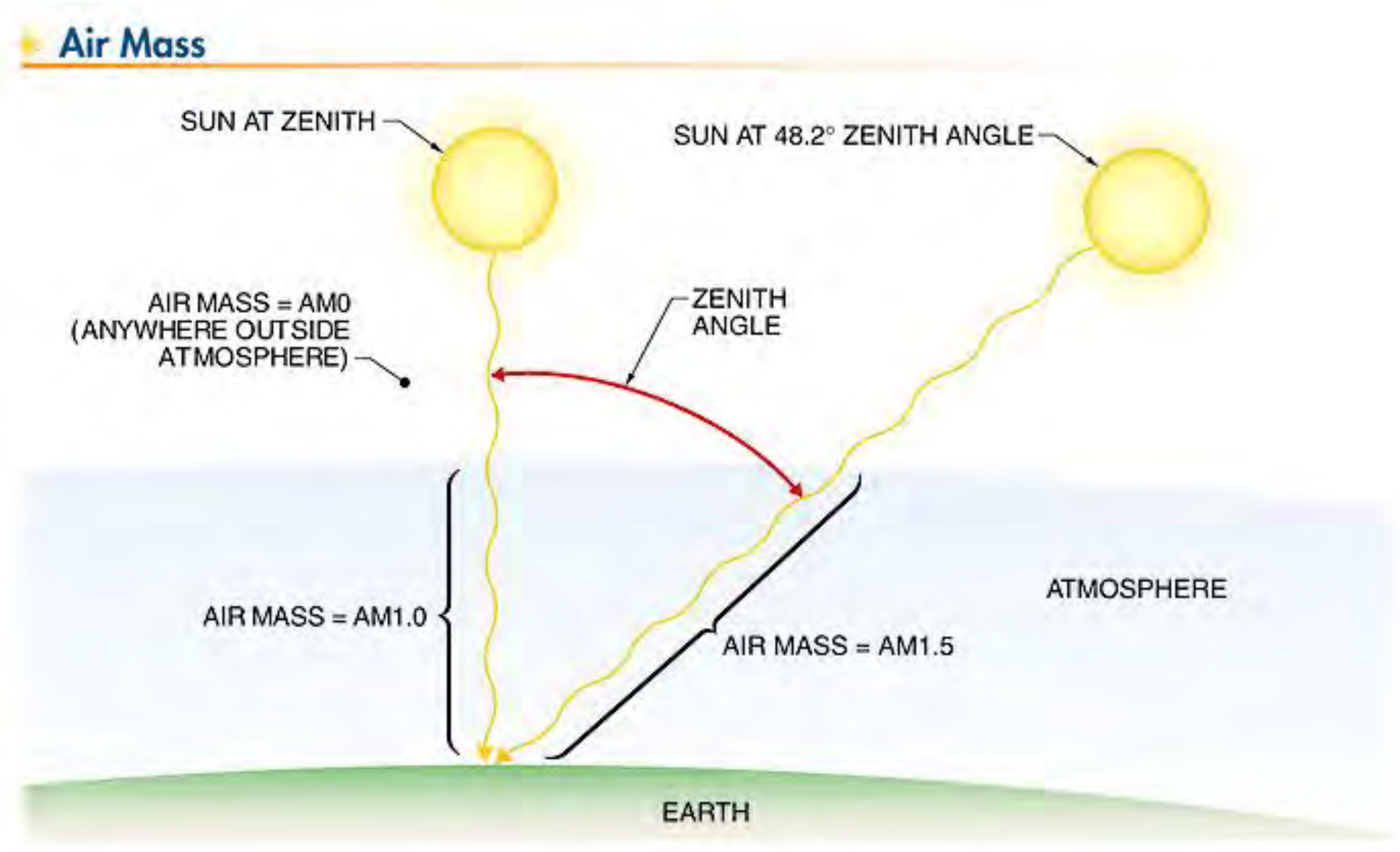
Peak Sun Hours

# Definitions

Standard Test Conditions (STC)
- Manufactures specification for power output of a PV module.

- Predicts output under ideal test conditions.
  - 25° C (77°F)
  - 1000 $W/M^2$
  - 1.5 AM (Sea level)

# Air Mass



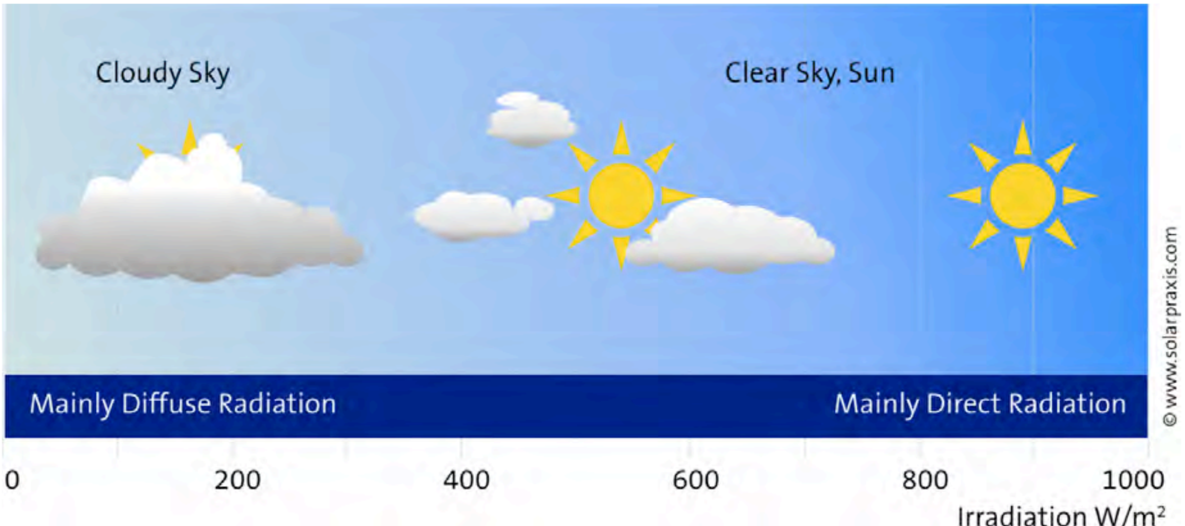

Source: Dunlop, Jim. *Photovoltaic Systems*.

# Definitions

Rated Output
Maximum amount of power a PV system will produce in full sun

- Expressed in watts or kiloWatts
- ten 100 W modules wired together would equal a 1000 Watt system
- May also be called Nameplate Rating

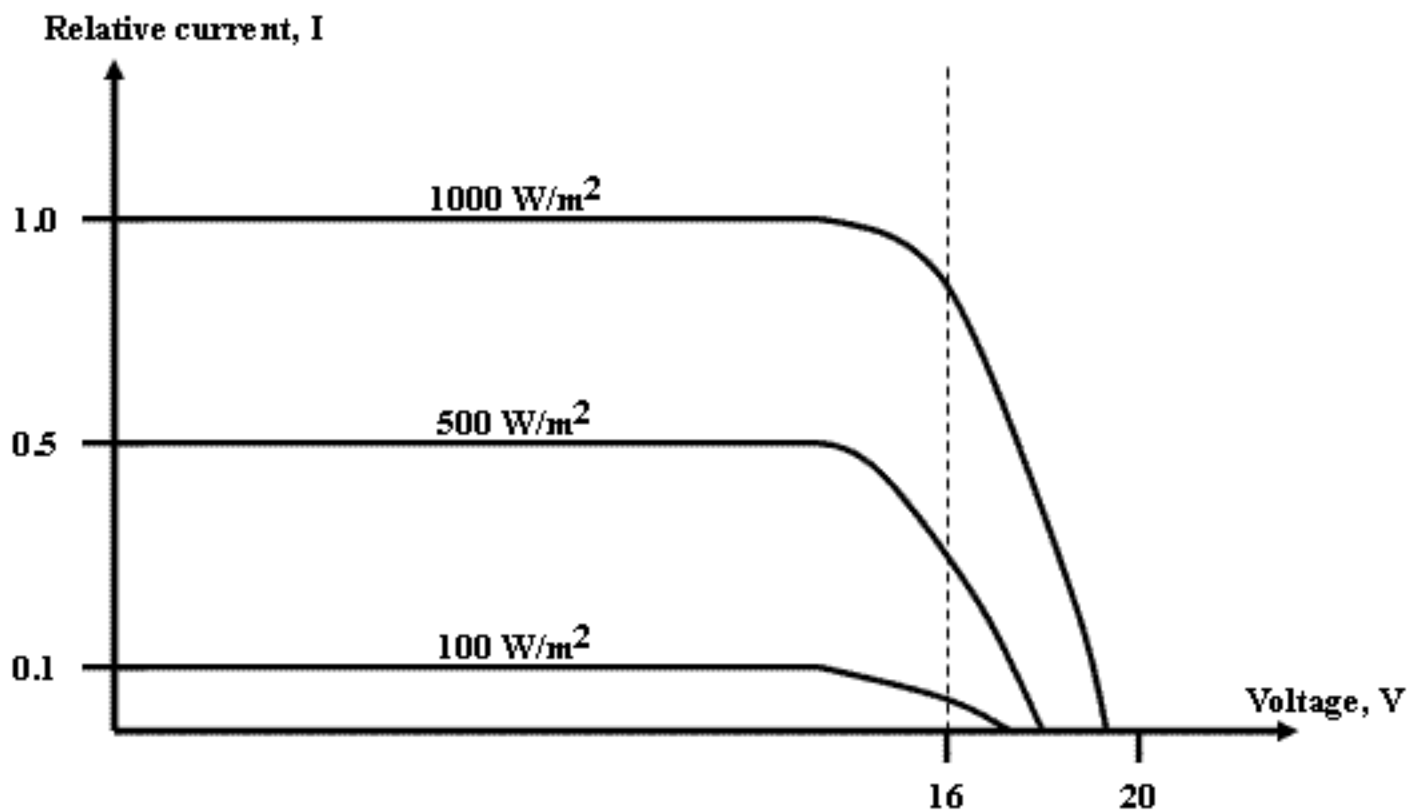
# Solar Irradiation as a Function of Weather




- This graph shows the approximate global solar irradiation values on a horizontal plane as a function of the weather. On clear days, there are very high levels of irradiance, which can be in the order of 800 to 1000 W/m2, while on completely overcast days, only 200 W/m2 or less are obtained. Seasons can also have an effect on irradiance levels.

Source: Peuser, Felix A., Remmers, Karl-Heinz, and Schnauss, Martin. 2002. Solar Thermal Systems: Successful Planning and Construction. Earthscan: Frieberg, Germany.

# Output as a Function of Solar Irradiation

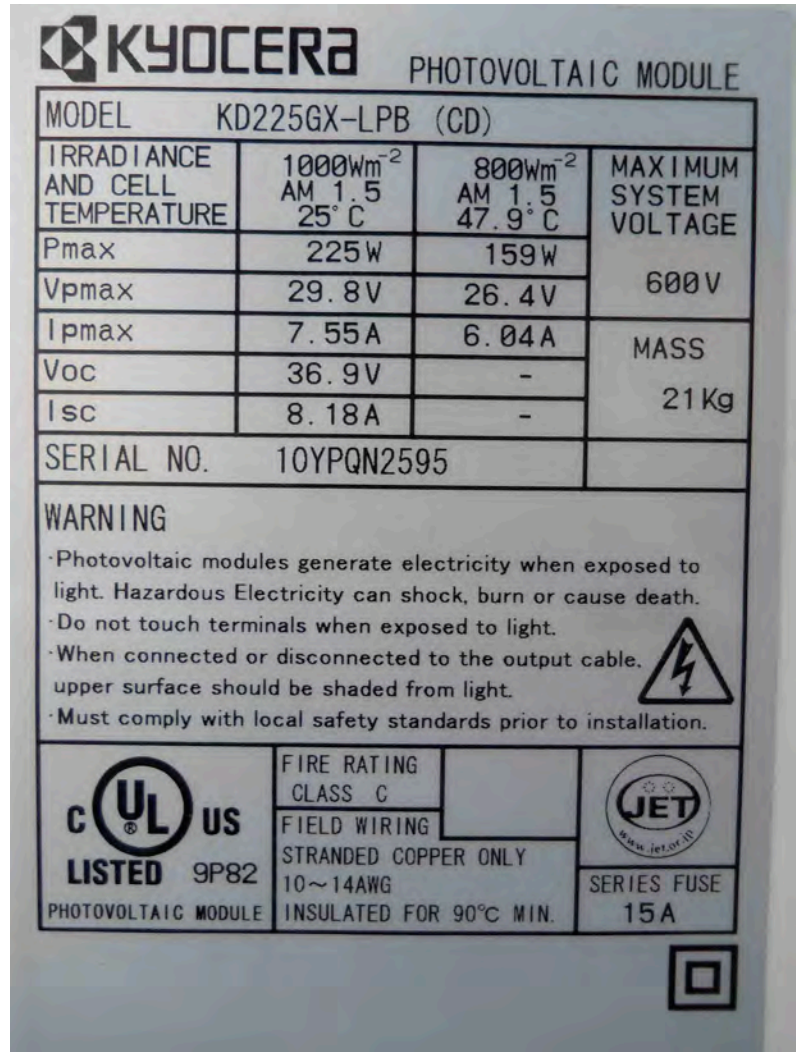



Source: Solar Fast Track. IV Curve Temp. solarfasttrack.com.

# Module Label

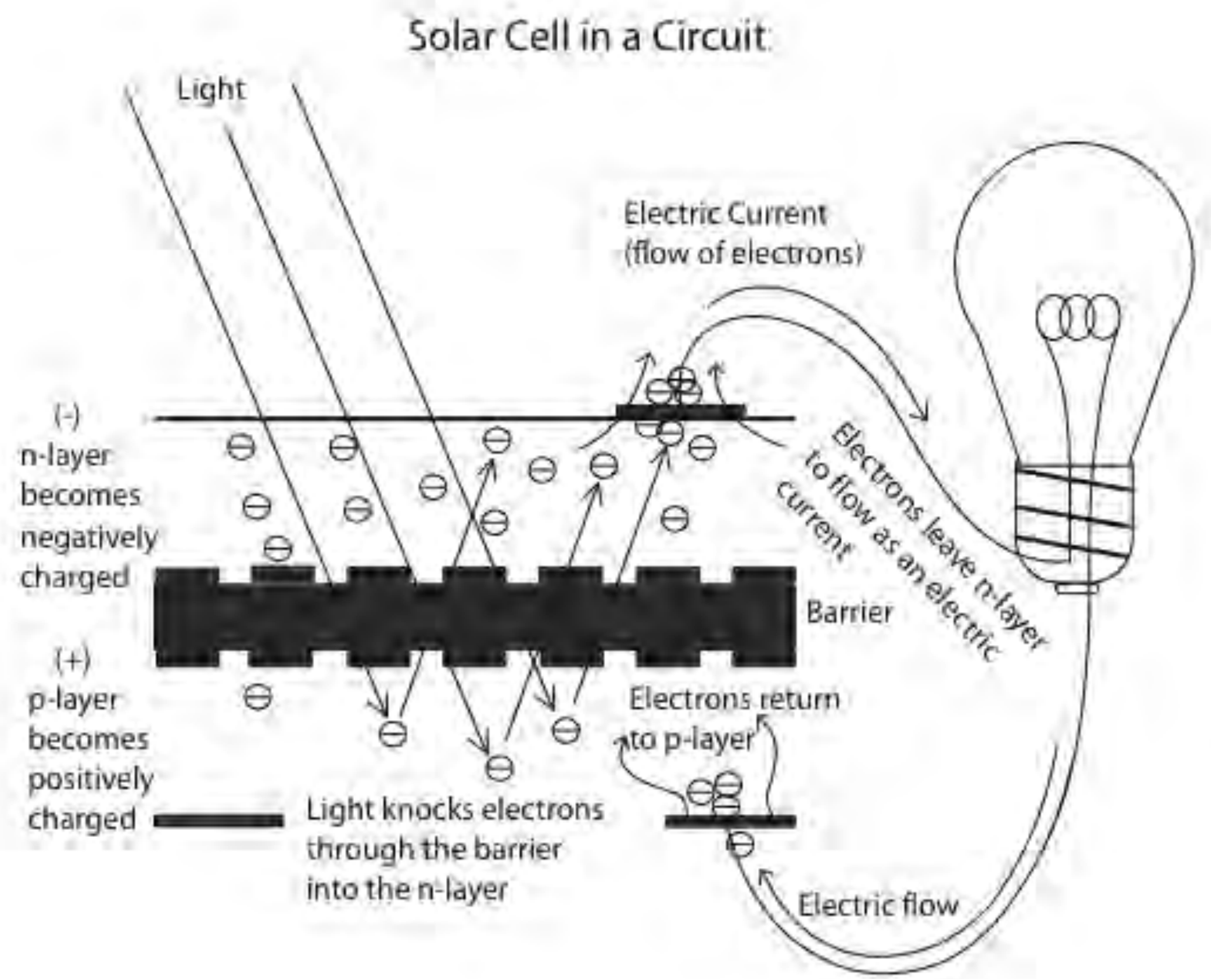
PTC
Performance Test Conditions
Or
PVUSA

- 800 W/M$^2$
- Sea level (1.5 AM)
- 50°C (122°F)



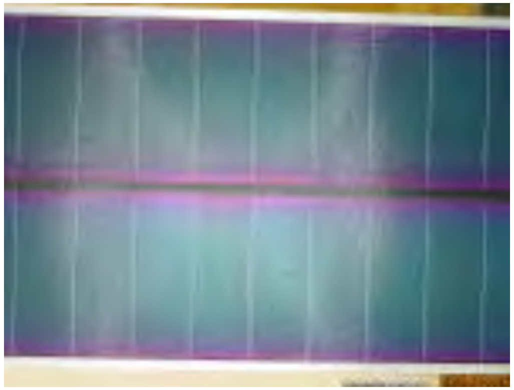

Source: Sterling, Clay. KC Module Label Midwest Renewable Energy Association.

# Photovoltaic Cell



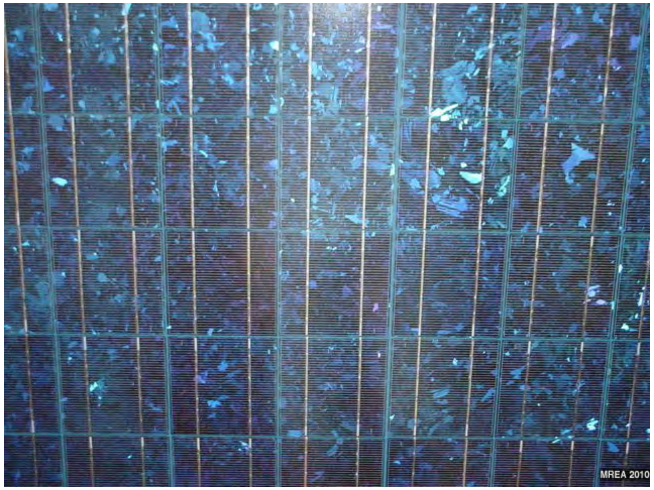

Source: Photovoltaic Effect. Clay Sterling, 2005.

# Photovoltaic Module

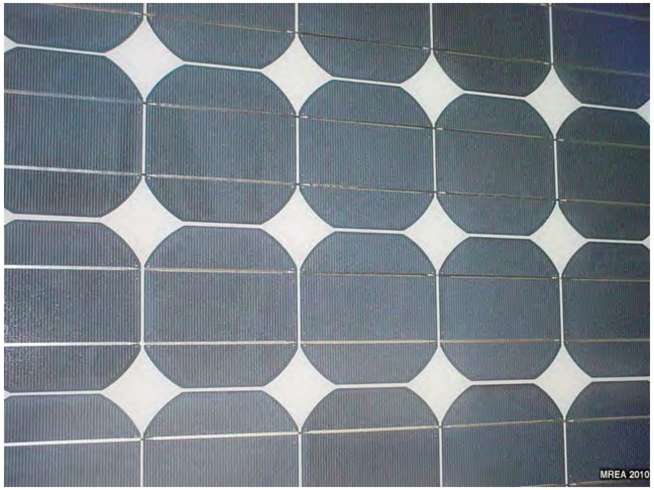


Amorphous

String Ribbon

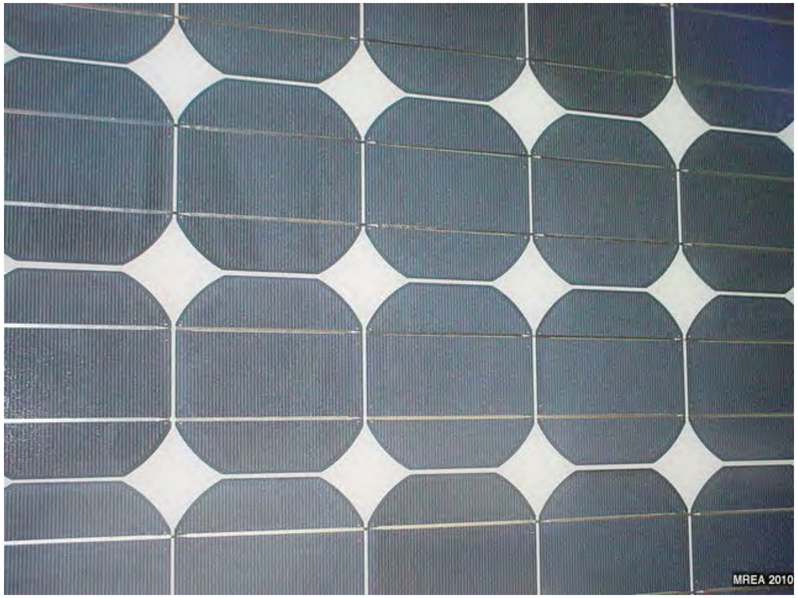



Multicrystal



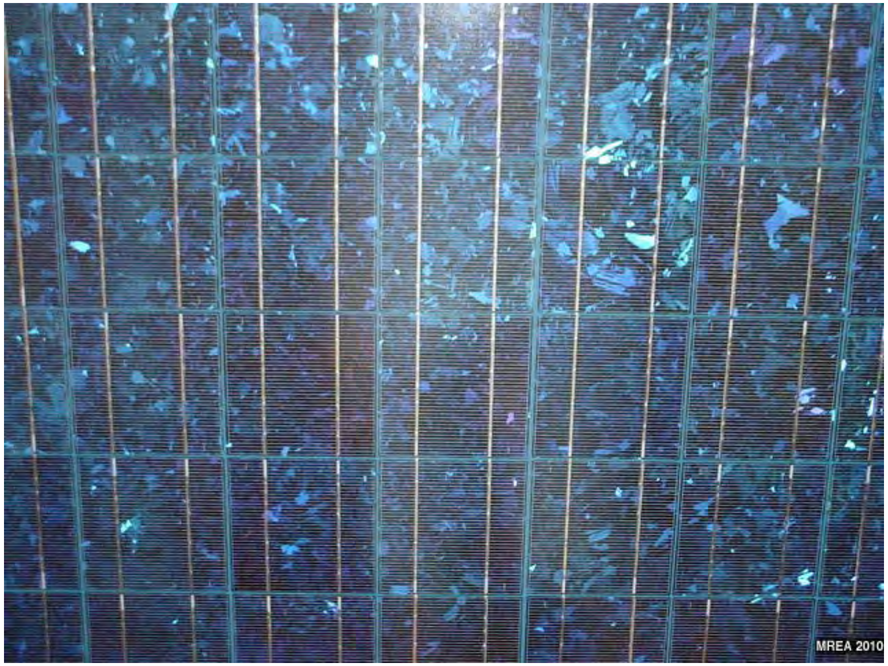

Monocrystal

# Photovoltaic Module




Monocrystal
- Single crystal grown
- Silicon based
- Most expensive process
- Most efficient cell (18%)
- Solid navy blue color

# Photovoltaic Module




Multicrystal

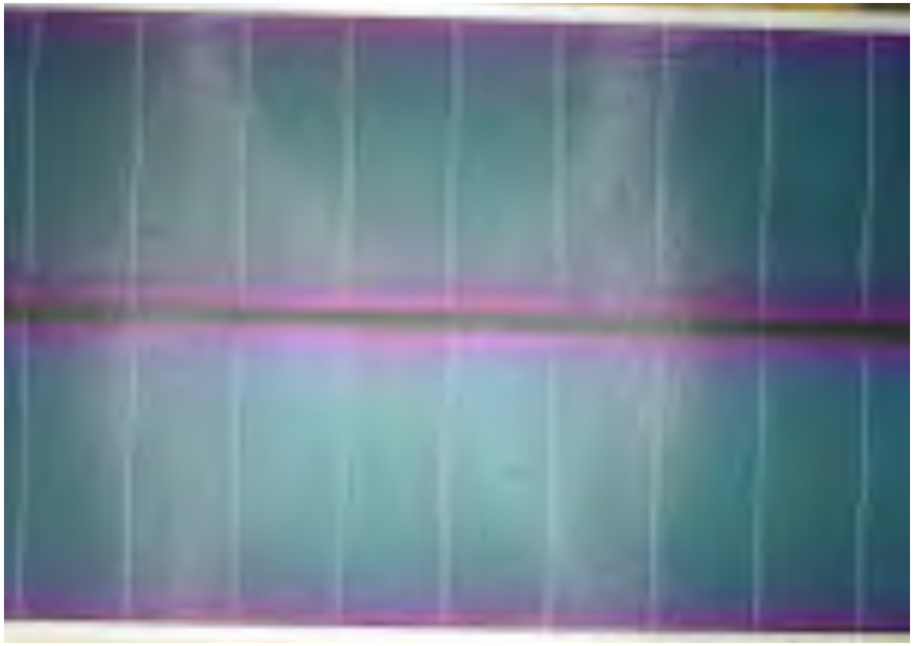
- Silicon based
- Molten silicon is cast into mold
- Cheaper manufacturing process
- Cell efficiency up to 14%
- More efficient use of surface area

# Photovoltaic Module

String Ribbon

- Silicon based
- least expensive manufacturing process
- Cell efficiency up to13%

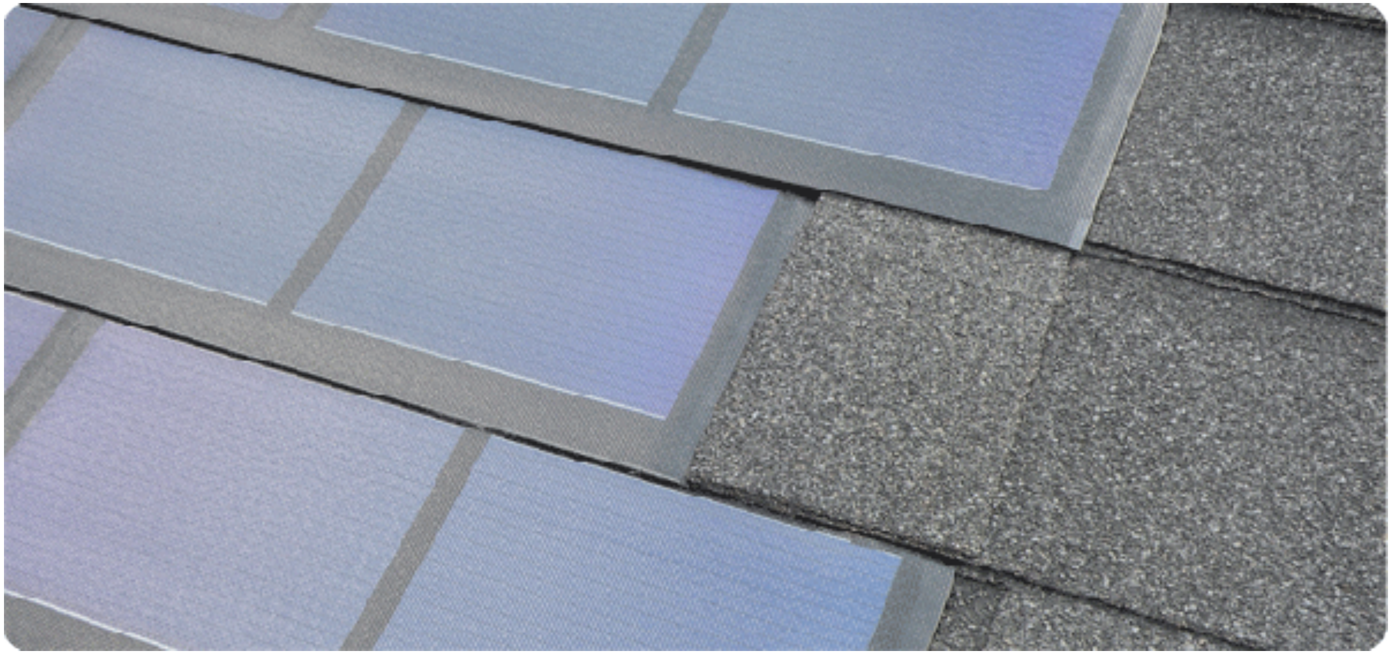
# Photovoltaic Module



Amorphous
- Some are silicon based
- Can be flexible
- Inexpensive
- Efficiency up to 9%
- Poor track record

# Photovoltaic Module

- Building Integrated



Source: Uni-Solar. "Power shingle." uni-solar.com/products/residential-products powershingle-2/.

# Photovoltaic Module

- Field applied

Source: Uni-Solar. “Field applied.” soldonsun.com

# Photovoltaic Module

- Building block of an array
- Each cell .47 V
- Each cell linked series/parallel
- Rated output at STC in Watts

# Make Up of a Module

- Frame
- Glass
- Cells
- Backer
- J Box
- Connections

# Module Variations

Curb Appeal

- Clear glass with an uncolored aluminum frame
- Black frame with tinted glass
- Shapes vary
- Peel-and-stick amorphous modules
- Translucent modules for carport, walkway roof, awning, etc.

# Module Variations

Module Choices

- Clear backsheet

Source: Sharp Solar. "Clear module."sustainablesolutionscorporation.com.

# Module Variations

Module Choices

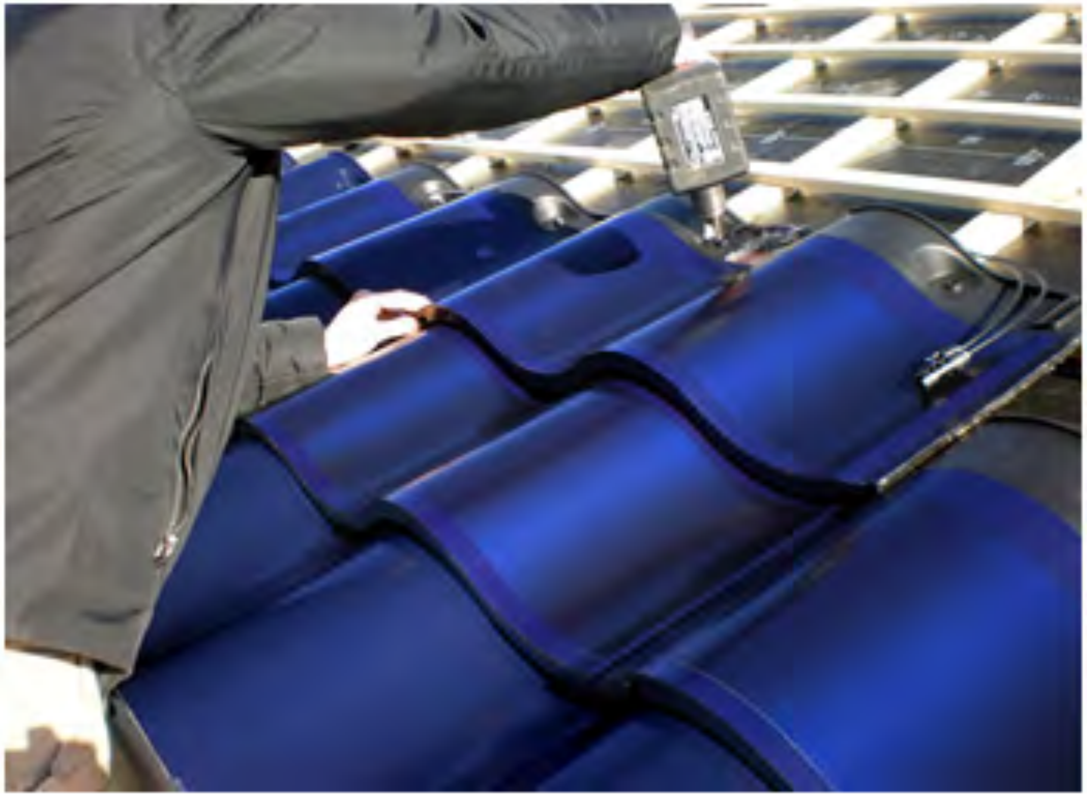
- Black frame
- Black backsheet

Source: Sharp Solar. “Black frame module.” www.wholesalesolar.com

# Module Variations

Module Choices

- Roof tile



Source: Sole Power Tile, “Roof tile.” solarenergygreenlifestyleforyou.com.

# Module Variations

Module Choices

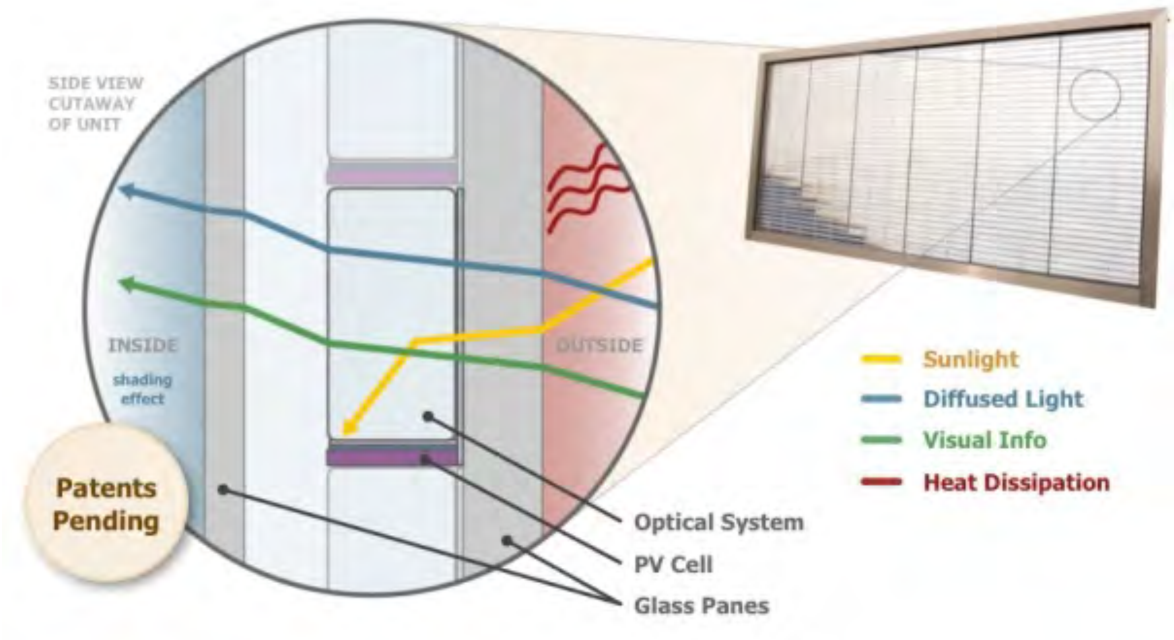
- Slate roof tile

Source: Solar Slate Ltd, "Roof slate." solarslate-ltd.com.

# Module Variations

Module Choices

- Solar window




Source: Pythagoras Solar Windows, “Solar window.” gigaom.com/cleantech/the-vision-for-solar-windows/.

# Photovoltaic Array

# PV Mounting

# PV Mounting

Mounting

- L-foot mounted on deck with lots of silicone

Source: Sterling, Clay. “L-foot.” Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Stanchion on roof deck without protection

Source: Sterling, Clay. "Stanchion." Midwest Renewable Energy Association.

# PV Mounting

# PV Mounting

Rail

Source: Sterling, Clay. “Rail.” Midwest Renewable Energy Association.

# PV Mounting

Rail

Source: Sterling, Clay. “Rail.” Midwest Renewable Energy Association.

# PV Mounting

End

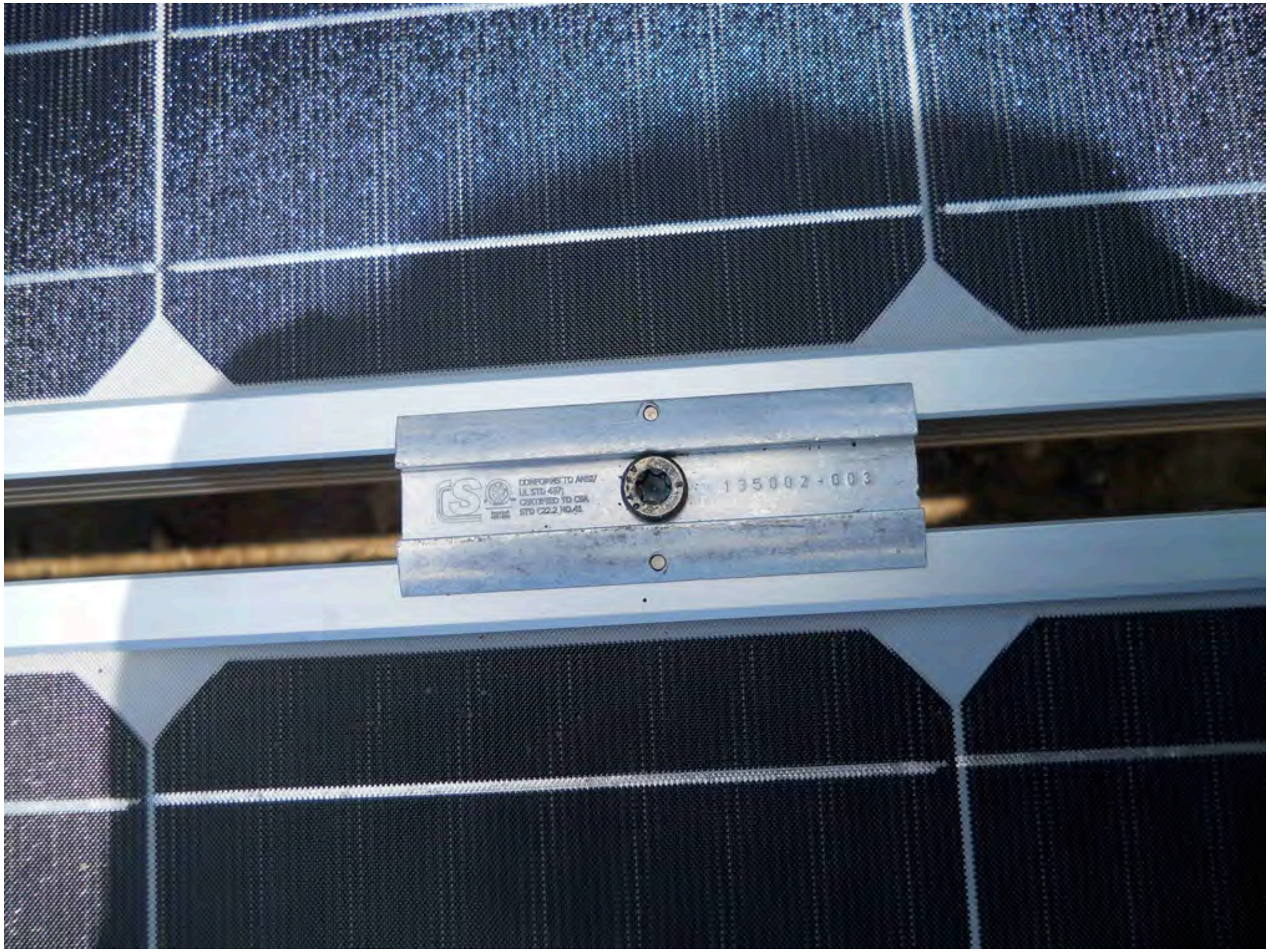
Clamp

Source: Sterling, Clay. “End Clamp.” Midwest Renewable Energy Association.

# PV Mounting

Mid

Clamp




Source: Sterling, Clay. “Mid Clamp.” Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Based on many factors:
  - Visibility
  - Space constraints
  - Shading
  - Performance optimization
  - Security
  - Cost
  - Integrated architecture designs

# PV Mounting

Mounting

- Quick mount
  - Stainless steel 12” x 12” flashing
  - Stainless steel hardware
  - 2,554 lbs. av. pullout

Source: Quick Mount. “Classic compost mount.” quickmountpv.com.

# PV Mounting

Mounting

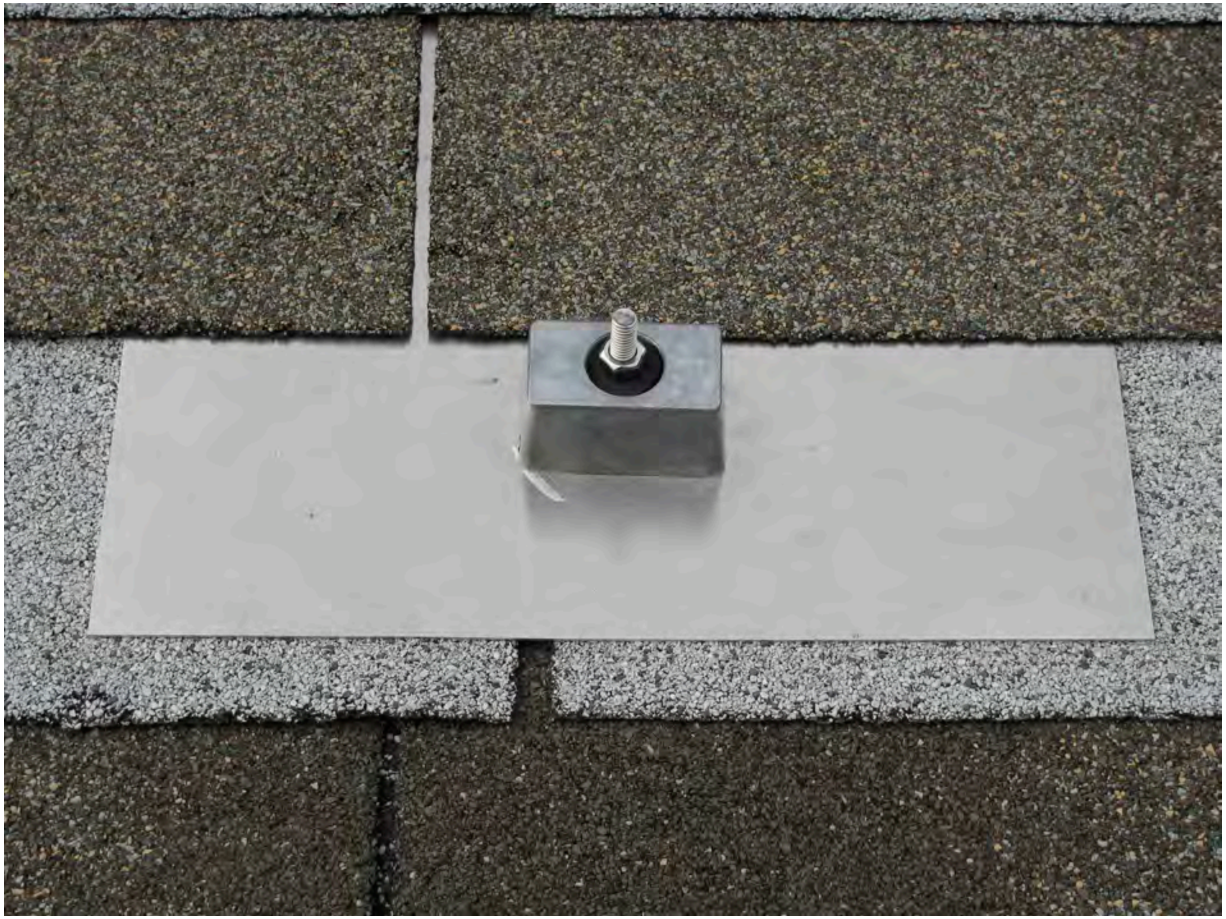
- Quick mount

Source: Sterling, Clay. “Quick Mount install.” Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Quick mount



Source: Sterling, Clay. "Quick Mount install." Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Quick mount

Source: Sterling, Clay. “Quick Mount install.” Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Fast Jack
  - Single bolt
  - Proper flashing
  - Variable height stanchion


Source: Solar Power Planet. "Fast Jack install." solarpowerplanetearth.com.

# PV Mounting

Mounting

- Fast Jack

Source: Sterling, Clay. "Fast Jack install." Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Fast Jack

Source: Sterling, Clay. "Fast Jack install." Midwest Renewable Energy Association.

# PV Mounting

- Mounting
  - Fast Jack

Source: Sterling, Clay. "Fast Jack install." Midwest Renewable Energy Association.

# PV Mounting

- Mounting
  - Fast Jack

Source: Sterling, Clay. “Fast Jack install.” Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Fast Jack


Source: Sterling, Clay. “Fast Jack install.” Midwest Renewable Energy Association.

# PV Mounting

Mounting

- Fast Jack

Source: Sterling, Clay. "Fast Jack install." Midwest Renewable Energy Association.

# PV Mounting

Mounting

- S-5 clamp
- Standing seam

Source: S-5. "S-5-E." s-5.com.

# PV Mounting

Flush-mount

- Subtle, low cost
- Requires adequate roof space facing a southerly direction and no shading from adjacent structures

Source: Sterling, Clay. “Flush-roof mounting.” Midwest Renewable Energy Association.

# PV Mounting

Pole-mount

- Good choice where the array size is larger than available roof space
- Easy to change tilt angle
- Easy for snow removal
- Requires trenching

Source: Ammond, Chuck. "Pole mount."

# PV Mounting

Ground Racking

- Simple structure
- Structural integrity
- Ease of access
- Simple foundation
- Easy to change the tilt angle for seasonal optimization

Source: Ammond, Chuck. “Ground racking.”

# PV Mounting

Flat Roof Racking

- Able to use ballasted racks to avoid roof penetrations for mounting
- Ability to remove snow or dirt easily
- Modules in a secure location
- Hidden from outside view
- Only one penetration – conduit with the wiring

Source: Ammond, Chuck. “Flat roof racking.”

# PV Mounting

Integrated Architecture Designs

- Awnings – take advantage of passive solar
- Carport – used as primary roof
- Translucent – allow sunlight to filter in

Source: Ammond, Chuck. "Integrated Architecture, PV Awnings."

# PV Mounting

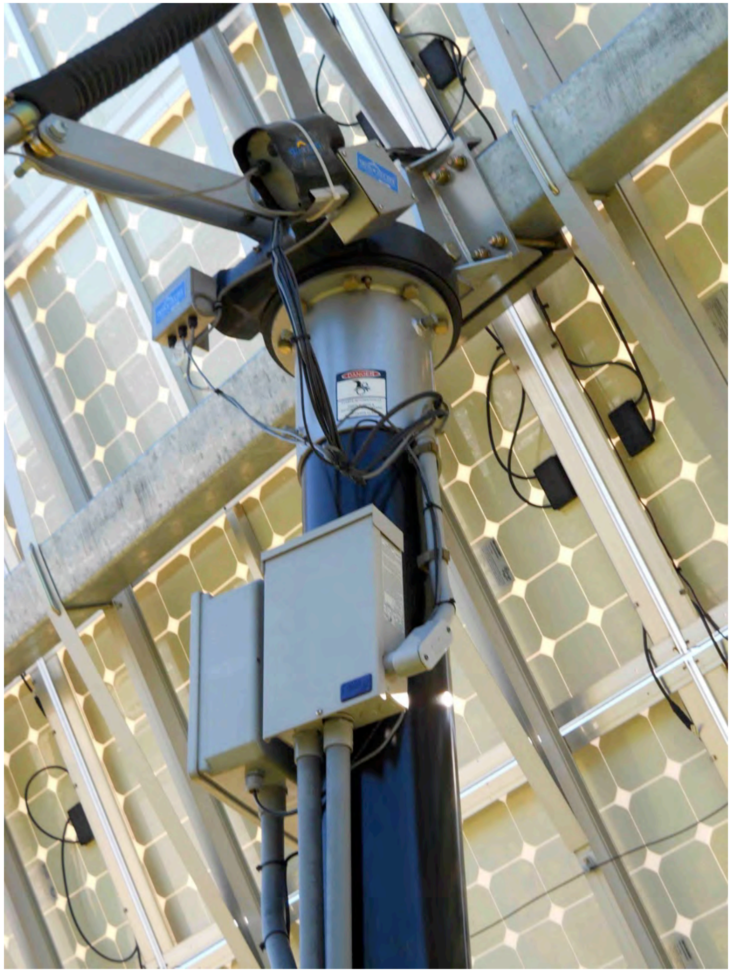
Tracker

- Single or dual axis
- Tracks sun daily
- Adjusts for seasonal change in sun angle
- 25 – 30% more production

Source: Sterling, Clay. "Dual axis trackers." Midwest Renewable Energy Association.

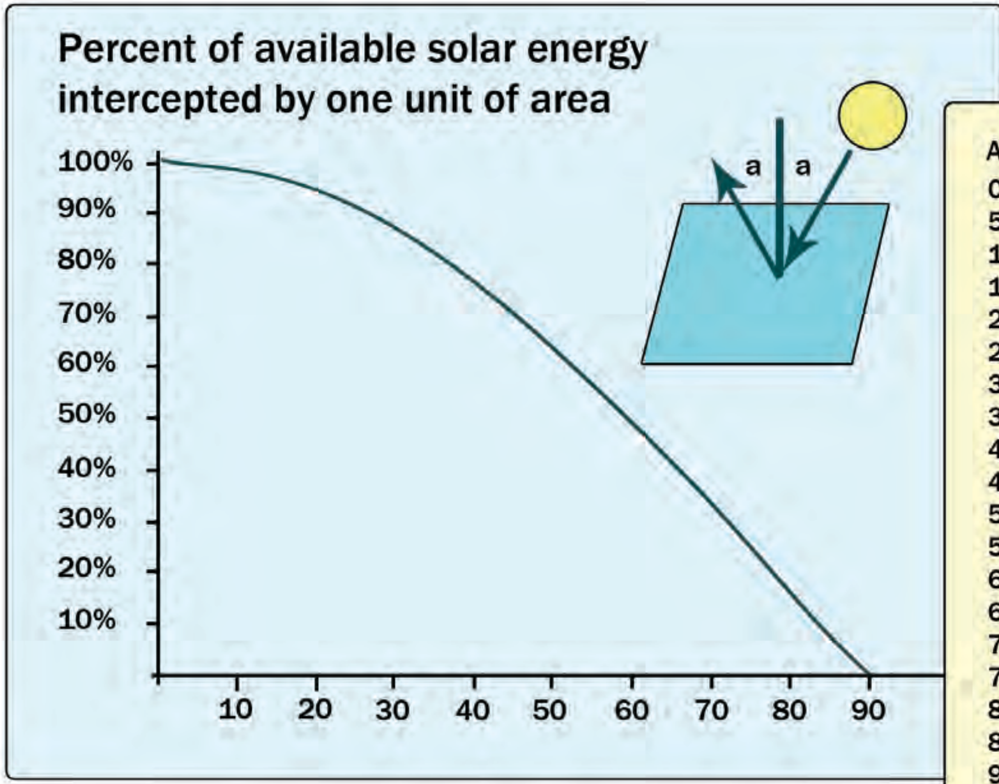
# PV Mounting

Tracker



Source: Sterling, Clay. “Dual axis trackers.” Midwest Renewable Energy Association.

# Angle of Incidence

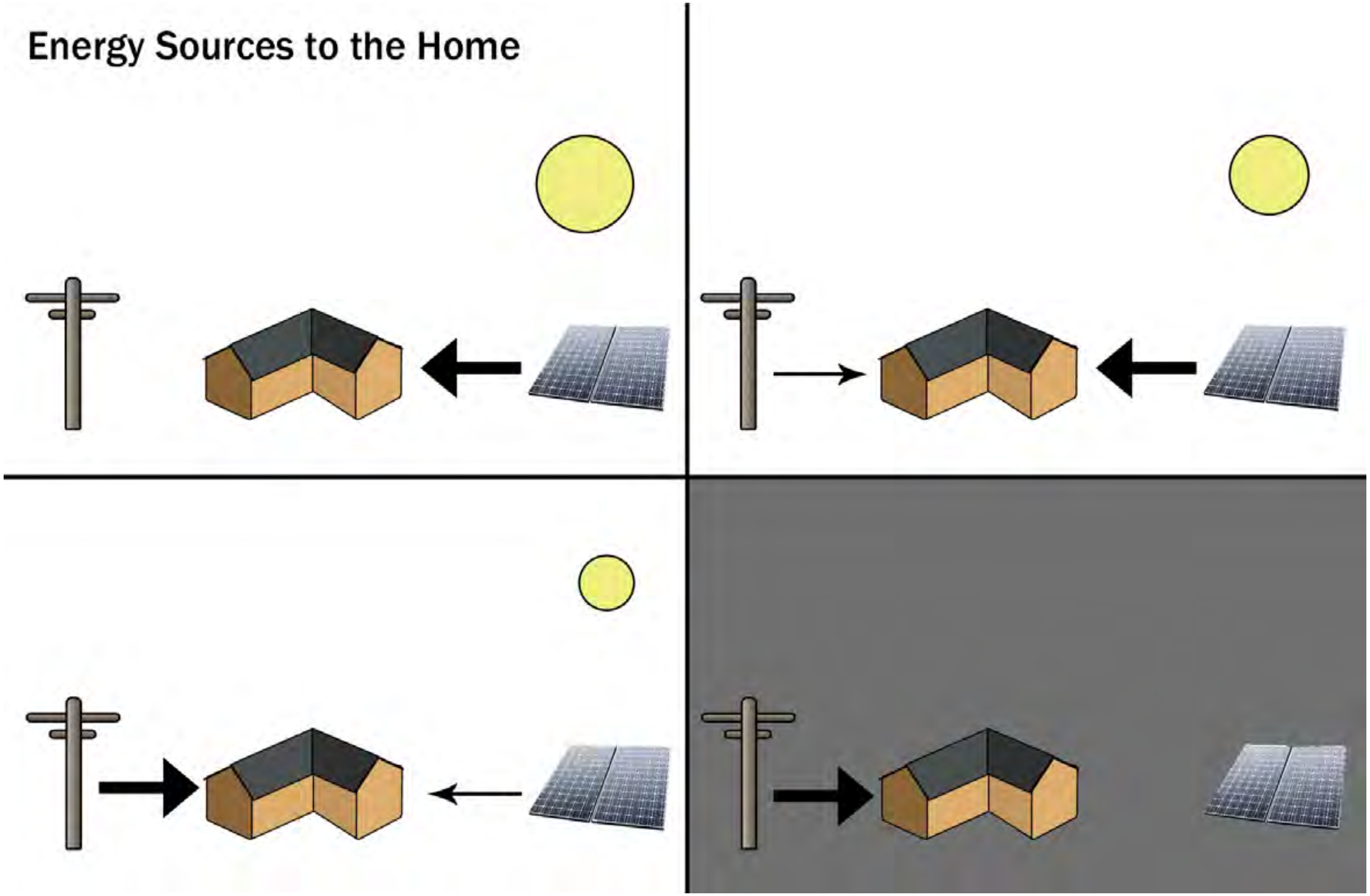



| Angle | Density |
|---|---|
| 0 | 100.0% |
| 5 | 99.6% |
| 10 | 98.5% |
| 15 | 96.6% |
| 20 | 94.0% |
| 25 | 90.6% |
| 30 | 86.6% |
| 35 | 81.9% |
| 40 | 76.6% |
| 45 | 70.7% |
| 50 | 64.3% |
| 55 | 57.4% |
| 60 | 50.0% |
| 65 | 42.3% |
| 70 | 34.2% |
| 75 | 25.9% |
| 80 | 17.4% |
| 85 | 8.7% |
| 90 | 0.0% |

# System Types

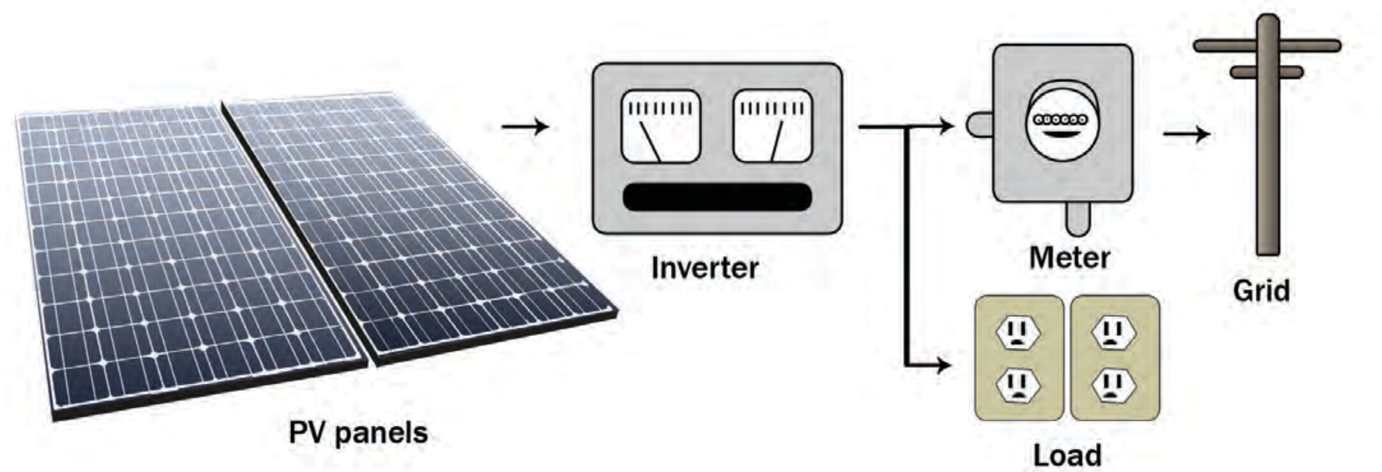
- Utility Interactive System
  - AKA: Utility Intertied without Batteries
  - Simplest System
- Bimodal System
  - AKA: Utility Intertied with Batteries
  - Power all the time
- PV Direct System
  - Power only when needed
- Stand-Alone System
  - You are your own utility

# Utility Interaction




Source: Talbot-Heindl Chris. “Utility Interactive Systems.” Midwest Renewable Energy Association

# Utility Interactive



# Utility Interactive

Array

- Collection of modules
- Produce DC electricity
- Sized for needs or goals
- Generally, high-voltage configuration (250 – 400+ VDC)

Source: "PV Array at The Center for Energy Education Laboratory." Sinclair Community College Energy Education Center.

# Utility Interactive

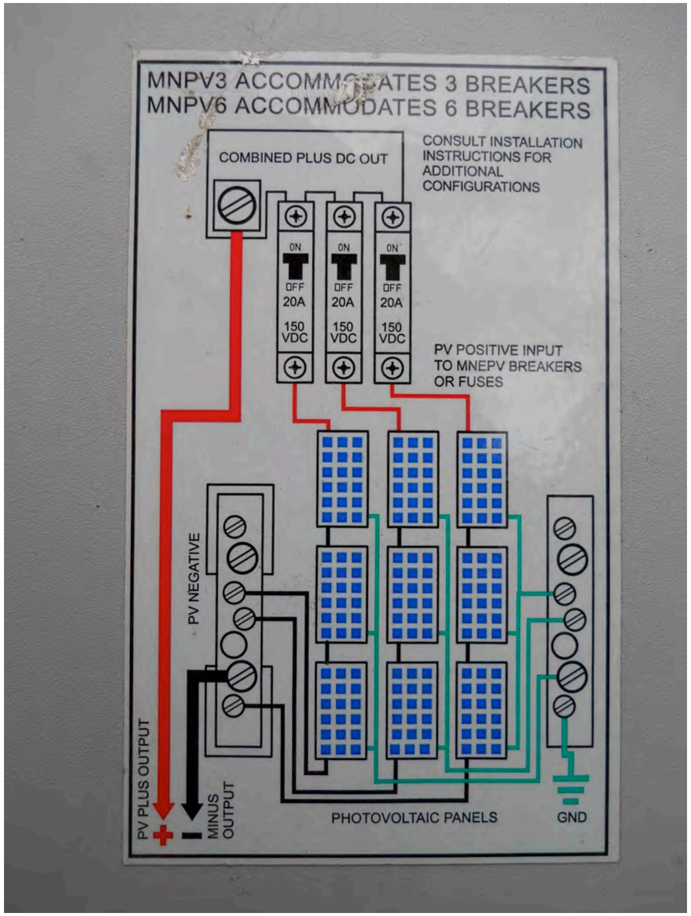
Combiner Box

- Located at the array
- Combines strings of sub arrays to form one large array
- Allows one set of wires to go to the balance of system instead of multiple sets of wires in series/parallel strings


Source: Sterling, Clay. "Combiner Box ." Midwest Renewable Energy Association.

# Utility Interactive

- Watertight electrical box that contain touch safe fuses or breakers
- Circuits are collected and connected in parallel
- Circuits exit at a higher amperage through a single, larger conductor where it connects to the BOS




Source: Sterling, Clay. "Combiner Box Lid." Midwest Renewable Energy Association.

# Utility Interactive

Inverter

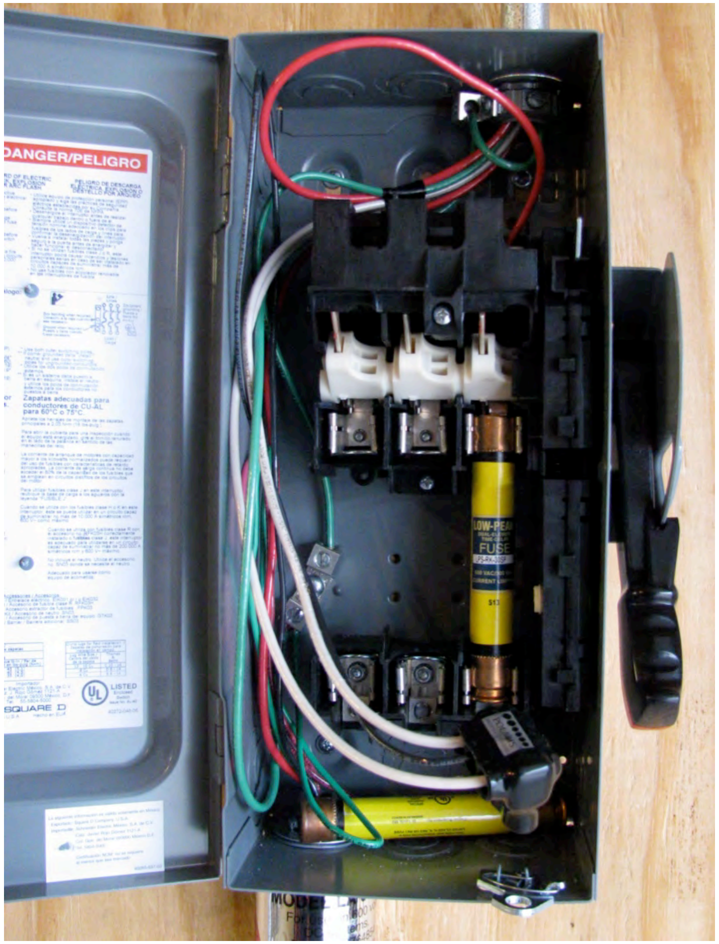
- Converts high-voltage DC electricity to utility-grade AC
- Maximum power point tracking of array
- Monitor utility match the array voltage and Hertz to utility
- Disconnect from utility during utility outage (anti-islanding)
- Sine wave


Source: Sterling, Clay. "Inverter on a PV Training Lab." Midwest Renewable Energy Association.

# Utility Interactive

Disconnects

- Isolation of components to safely service of equipment
- Provide overcurrent protection of system




Source: Sterling, Clay. “DC Disconnect on a PV Training Lab.” Midwest Renewable Energy Association.

# Utility Interactive

Lightning Arrestors

- Provide some protection of electronics of a system from lightning
- Required by most insurance companies
- Cheap form of protection, may or may not prevent all damage


Source: Sterling, Clay. “Lightning arrestor on a PV Training Lab.” Midwest Renewable Energy Association.

# Utility Interactive

Load Center

- Conventional breaker panel
- Location where renewable energy system will physically meet the utility


Source: Sterling, Clay. "Load center on a PV Training Lab." Midwest Renewable Energy Association.

# Utility Interactive

Utility Meter

- Accountant of consumption and/or production
- Interconnection Agreement


Source: Sterling, Clay. "Utility meter on a PV Training Lab." Midwest Renewable Energy Association.

# Utility Interactive – System Cost

Installed Cost

- Simple utility interactive, fixed mount - $4-6/watt
- Simple utility interactive, tracking array - $5-7/watt

Prices change as the industry changes

Check The Open PV Project for updated costs:

http://openpv.nrel.gov/

# Utility Interactive – System Cost

Installed Cost

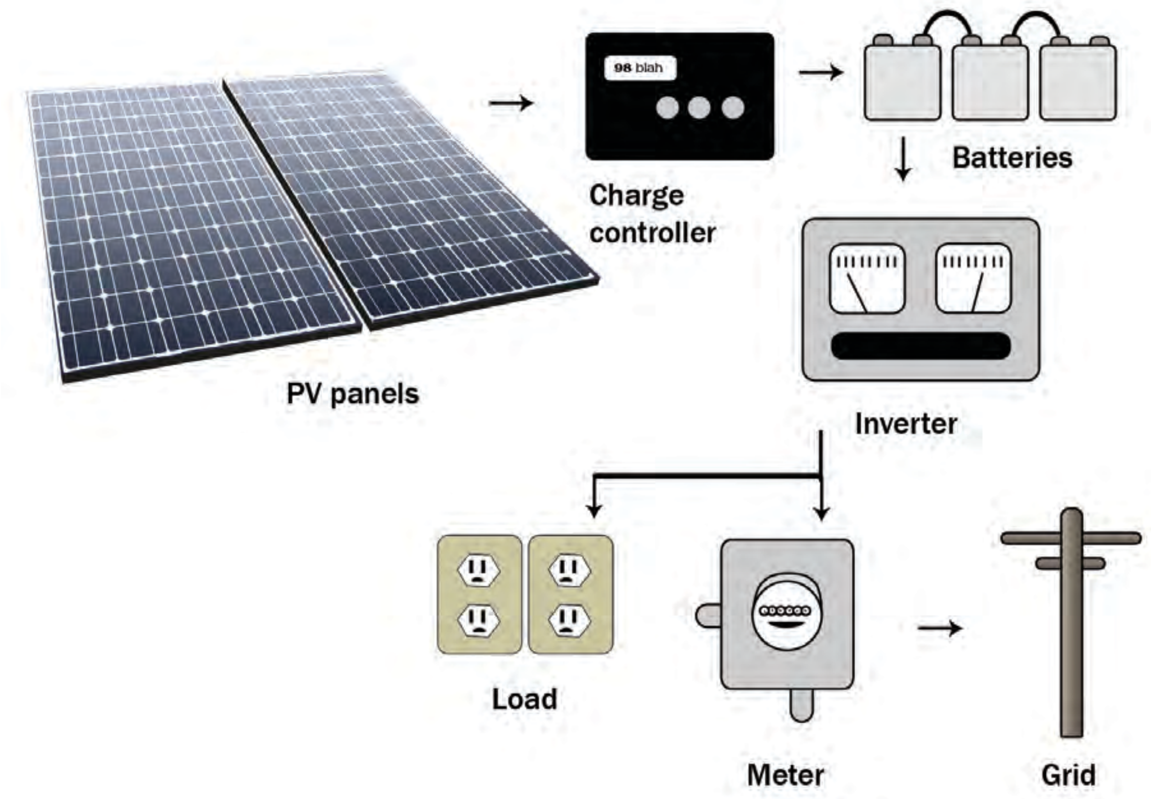
- Building Integrated simple utility interactive - $8-11/watt
- Simple utility interactive, fixed mount - $7-10/watt
- Simple utility interactive, tracking array - $8-12/watt

Prices change as the industry changes

Check The Open PV Project for updated costs:

http://openpv.nrel.gov/

# Bimodal


98 blah
PV panels
Charge
controller
Batteries
Inverter
Load
Meter
Grid

# Bimodal System - Components

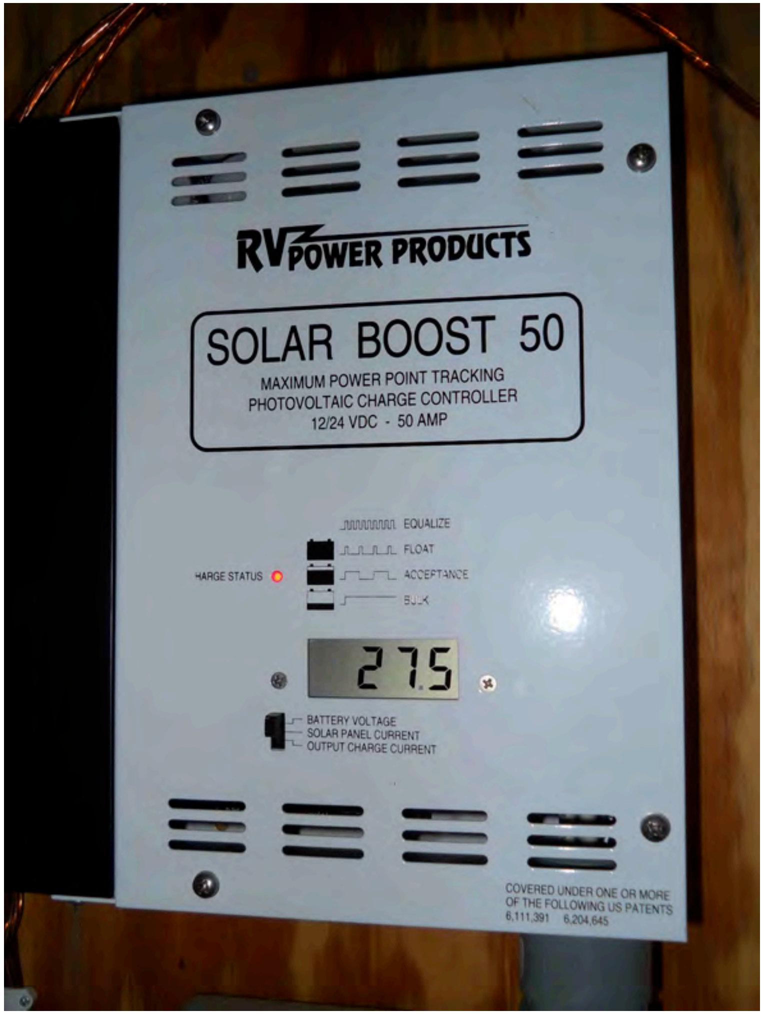
Array

- Produces DC electricity
- May be low- or high-voltage (24 or 48 VDC or greater)
- Sized for the loads or goals of the owner

Source: “PV Array at The Center for Energy Education Laboratory.” Sinclair Community College Energy Education Center.

# Bimodal System - Components

- Charge Controller
  - Regulates battery voltage during charging process
  - Protects batteries from overcharge, maintains battery at 100%, can initiate equalizing cycle
  - Can transform array high-voltage to battery low-voltage
  - Can maximum power point tracking
  - Can be simple to very complex
  - Brain of a system



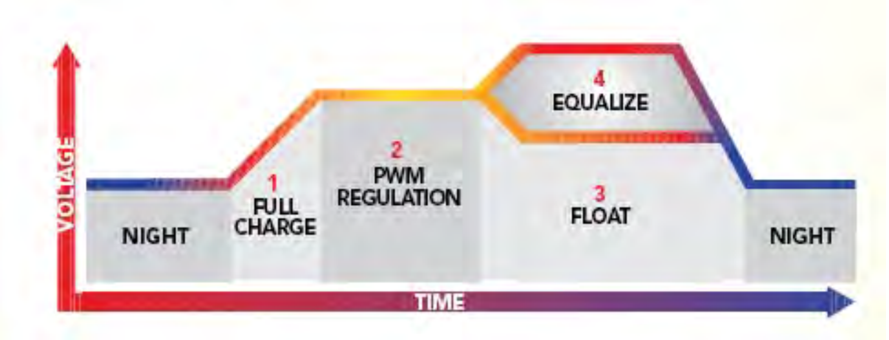

Source: Sterling, Clay. “Charge controller.” Midwest Renewable Energy Association.

# Bimodal System - Components

Battery Charging

PWM (pulse width modulation)

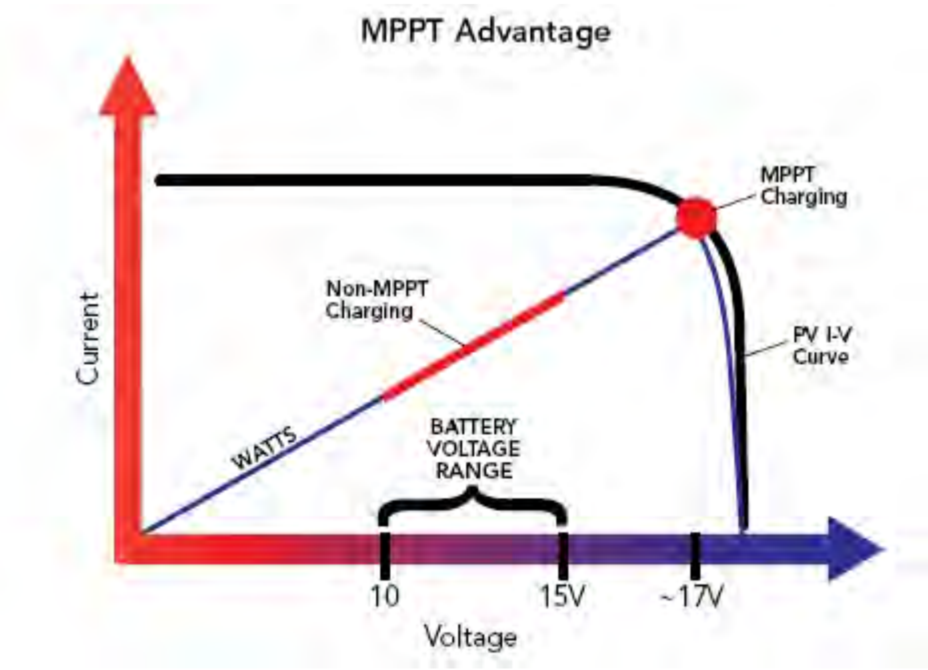
- High speed connection and disconnection between batteries and charging source
- A series of short charging pulses are sent to battery depending on state of charge
- Low battery long pulse, charged battery short pulse
- Juggling electrons




Source: RV Solar. “PWM charge profile.” Rvsolarnow.com.

# Maximum Power Point Tracking-MPPT

MPPT charge controllers trick PV module, by adding resistance to the circuit, to increase maximum voltage output




Source: Ecodirect. “MPPT Chart.” ecodirect.com.

# Bimodal System - Components

Batteries

- Storage of electrons for critical loads
- Maintained at 100%
- Usually flooded lead acid
- Needs venting for hydrogen
- Large footprint, spill containment, significant owner participation

Source: Sterling, Clay. “Battery bank.” Midwest Renewable Energy Association.

# Bimodal System - Components

Inverter

- More sophisticated, must interact with utility and as stand-alone during power outage
- Sine wave
- Will charge batteries off of utility when solar resource not available
- Anti-islanding


Source: Sterling, Clay. "OutBacks." Midwest Renewable Energy Association.

# Bimodal System - Components

Load Center and Critical Load Center

- Critical load center
- Loads you need to run during a typical power outage
- Need a transfer switch to manually disconnect from utility panels to critical loads panel

# Bimodal System - Components

Other Components

- Lightning arrestors
- AC and DC Disconnects
- Combiner Boxes
- Interconnection agreement

# Bimodal System - Components

Installed Cost

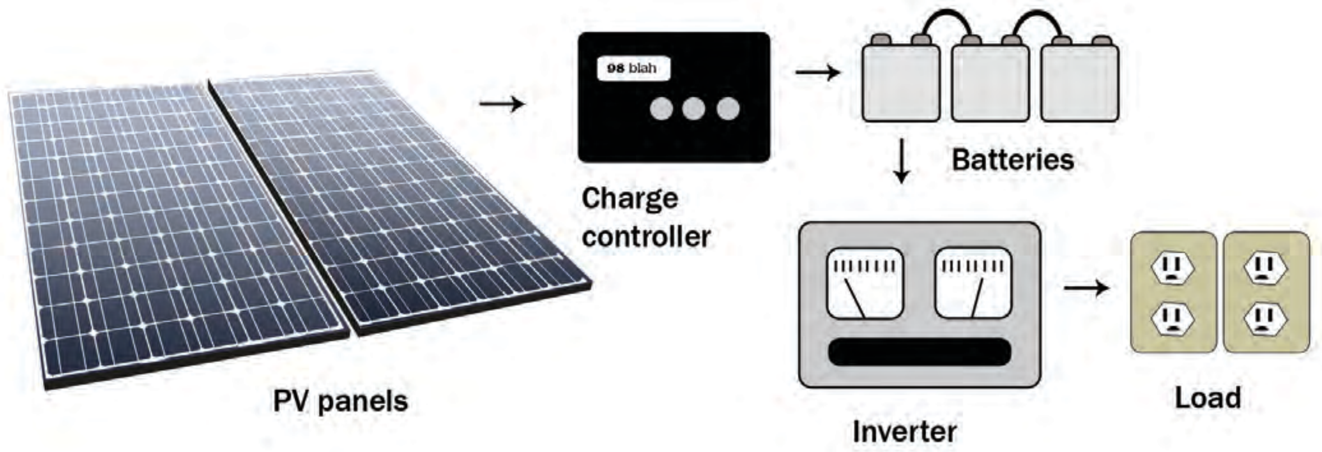
- Bimodal, fixed mount - $9-12/watt
- Bimodal tracking, - $10-13/watt

Prices change as the industry changes

Check The Open PV Project for updated costs:

http://openpv.nrel.gov/

# Stand Alone



98 blah
Charge controller
Batteries
PV panels
Inverter
Load

# Stand Alone – Components

Array

Sized for needs of the home, sized different than other system types

Seasonal tilt angle is critical

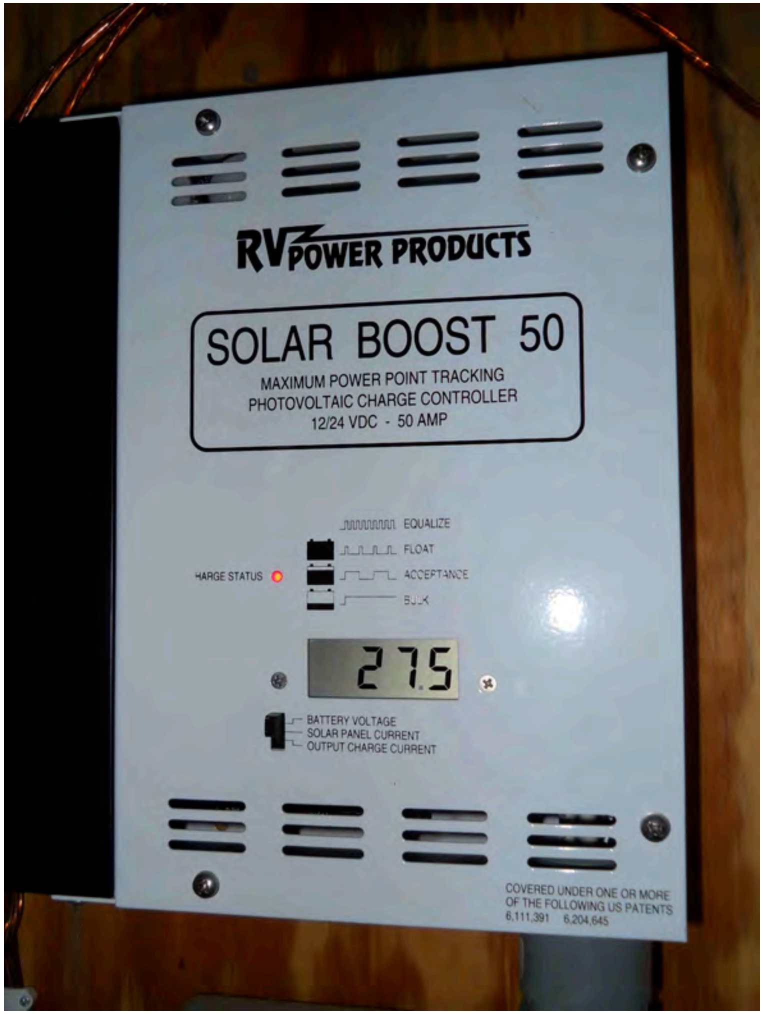
Array voltage generally matches battery voltage, can be high-voltage

Source: Sterling, Clay, Dawson Array. Midwest Renewable Energy Association.

# Stand Alone – Components

Charge Controller

- Charges, regulates, and protects batteries
- Regulates battery voltage during charging process
- Can maximum power point tracking
- Can be simple to very complex
- Brain of a system




Source: Sterling, Clay. "Charge controller." Midwest Renewable Energy Association.

# Stand Alone – Components

Batteries

- Sized for three-five days of autonomy
- Usually flooded lead acid batteries
- Always require back-up

Source: Sterling, Clay. "Battery bank." Midwest Renewable Energy Association.

# Stand Alone – Components

Batteries Metering

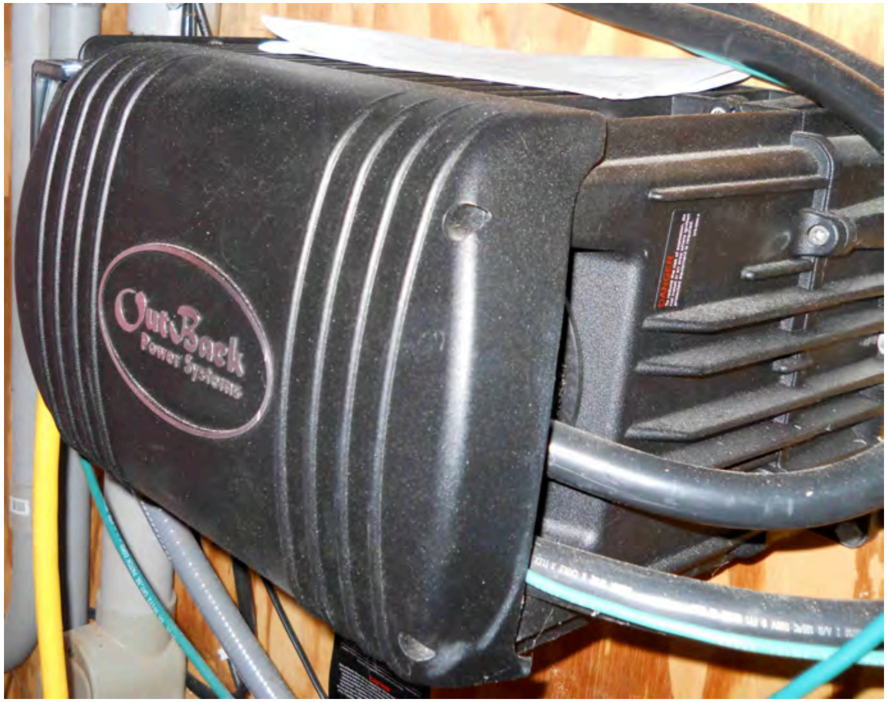
- Gas gauge of system
- Real time readings
- Historic information


Source: Sterling, Clay. "Trimetric." Midwest Renewable Energy Association.

# Stand Alone – Components

Inverter

- Can be of lesser quality wave form
- Can have auto functions to turn on generator or divert loads
- Sized for maximum loads and start-up

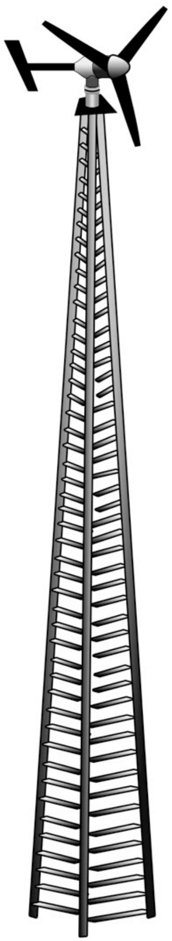



Source: Sterling, Clay. "Inverter." Midwest Renewable Energy Association.

# Stand Alone – Components

Back-Up

- Gas generator
- Wind machine
- Micro-hydro



Source: Talbot-Heindl, Chris. "Wind Turbine on Tower." Midwest Renewable Energy Association.

# Stand Alone – Components

Other Components

- Standard issue load center
- Lightning arrestors
- AC and DC Disconnects
- Combiner Boxes

# Stand Alone – System Costs

Installed Cost

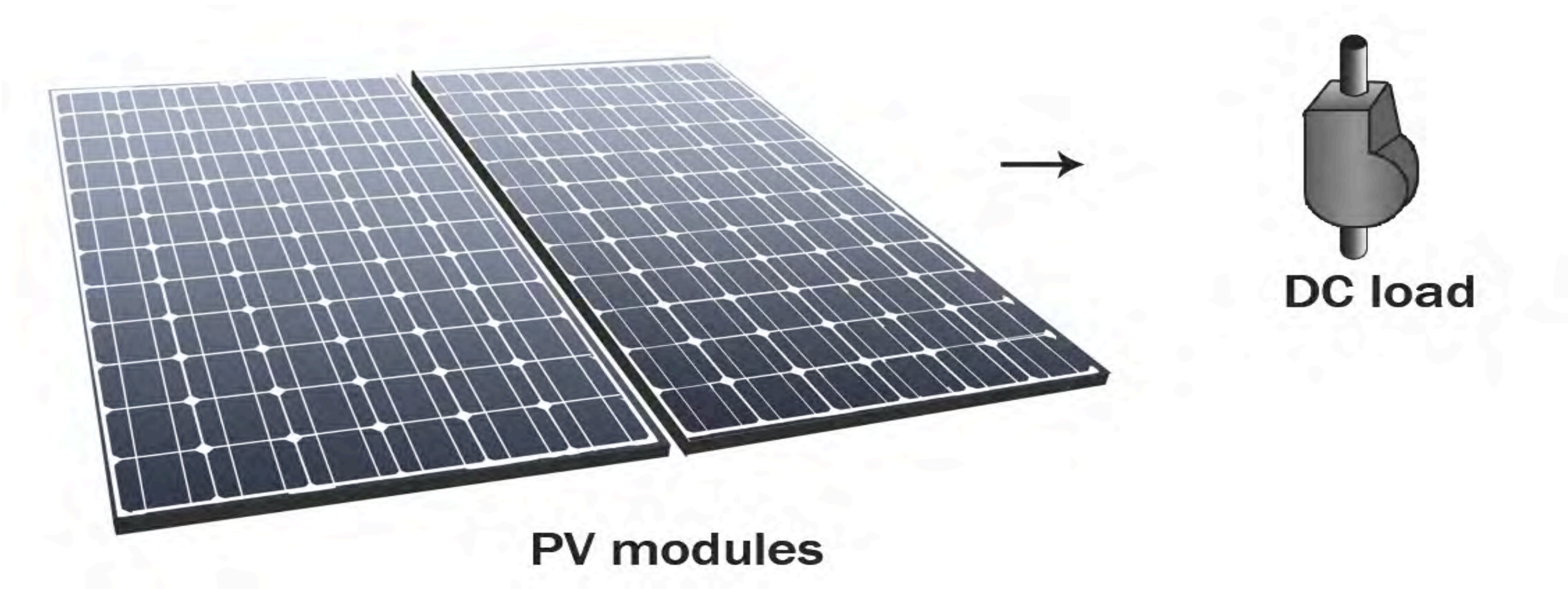
- Stand-alone, fixed array - $12-16/watt

Prices change as the industry changes

Check The Open PV Project for updated costs:

http://openpv.nrel.gov/

# PV Direct System




Source: Talbot-Heindl, Chris. "PV Direct System." Midwest Renewable Energy Association.

# PV Direct System - Components

Array

- Sized for function

Source: Grid Be Gone. “Attic fan.” gridbegone.com.

# PV Direct System - Components

Device or Appliance

- Fans
- Lights
- Circulation pumps

# PV Direct - System Cost

Prices change as the industry changes

Check The Open PV Project for updated costs:

http://openpv.nrel.gov/

## Virtual Tour

# MREA Carport

10 – 230 W MAGE Solar

Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# Virtual Tour

# MREA Carport

10 – 230 W MAGE Solar

Rated output?

Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# MREA Carport

10 – 230 W MAGE Solar

10 x 230 = 2,300 W

Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

## Virtual Tour

# MREA Carport

10 – 230 W MAGE Solar

10 x 230 = 2,300 W

Source: Sterling, Clay. "Car port array." Midwest Renewable Energy Association.

# Virtual Tour
# MREA Carport

Solar Edge Optimizer

- DC to DC converter
- Tune individual module output to the array
- Any fault goes to 1 volt


Source: Sterling, Clay. "Car port array." Midwest Renewable Energy Association.

# Virtual Tour

## MREA Carport

Solar Edge Inverter

- 3,300 W


Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# Virtual Tour

## MREA Carport

Load Center


Source: Sterling, Clay. "Car port array." Midwest Renewable Energy Association.

# MREA Training Roof

10 – 225 W Kyocera

Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# MREA Training Roof

10 – 225 W Kyocera

Rated output?

Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# MREA Training Roof

10 – 225 W Kyocera

10 x 225 = 2,250 Watts

Source: Sterling, Clay. "Car port array." Midwest Renewable Energy Association.

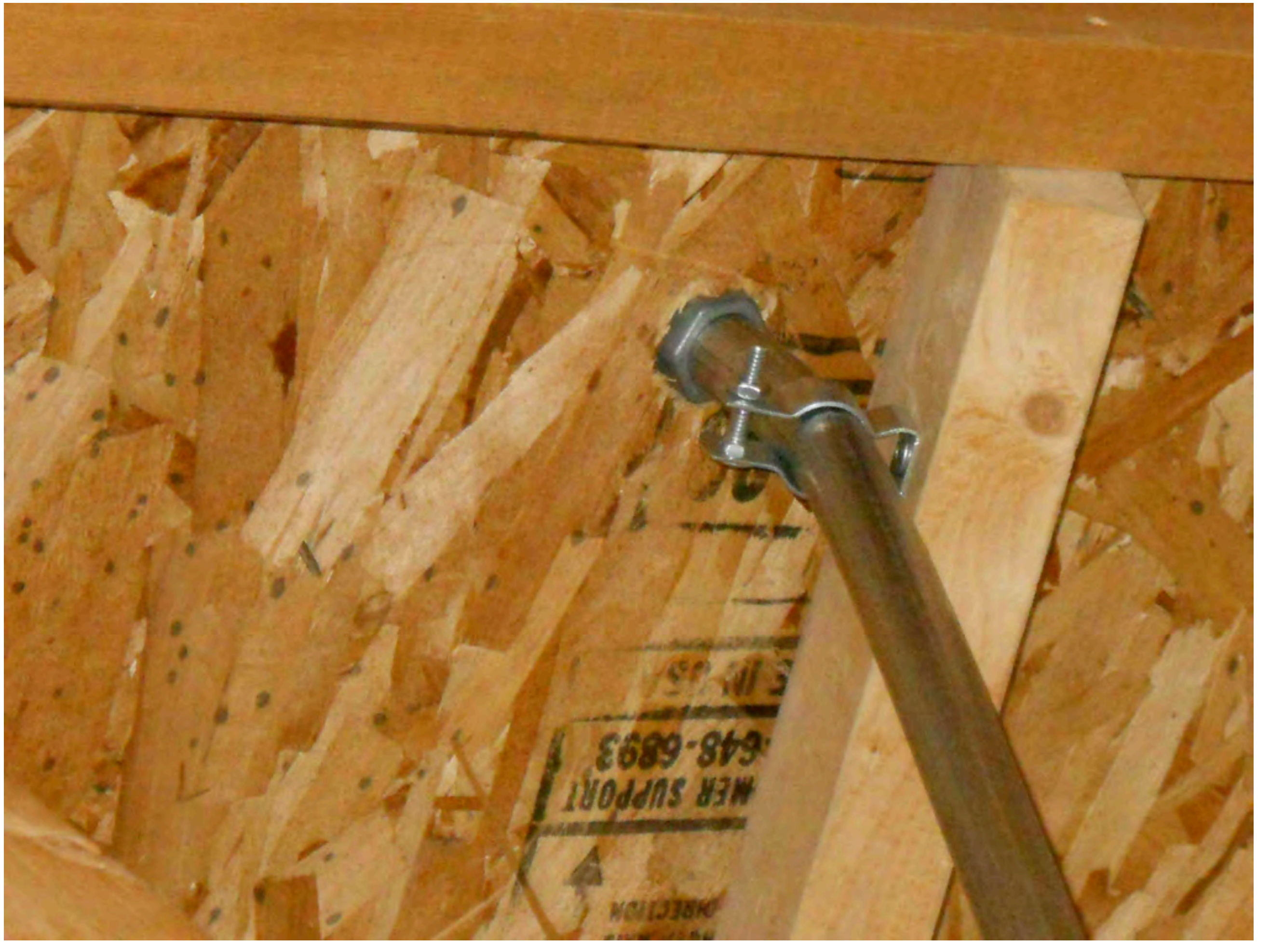
# MREA Training Roof

SolaDeck

Source: Sterling, Clay. “SolaDeck.” Midwest Renewable Energy Association.

# MREA Training Roof

SolaDeck



Source: Sterling, Clay. “SolaDeck.” Midwest Renewable Energy Association.

# MREA Training Roof

DC Disconnect


Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# MREA Training Roof

Inverter – Magnatek (Power One)


Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# MREA Training Roof

Utility Disconnect


Source: Sterling, Clay. “Car port array.” Midwest Renewable Energy Association.

# MREA Training Roof

Load Center

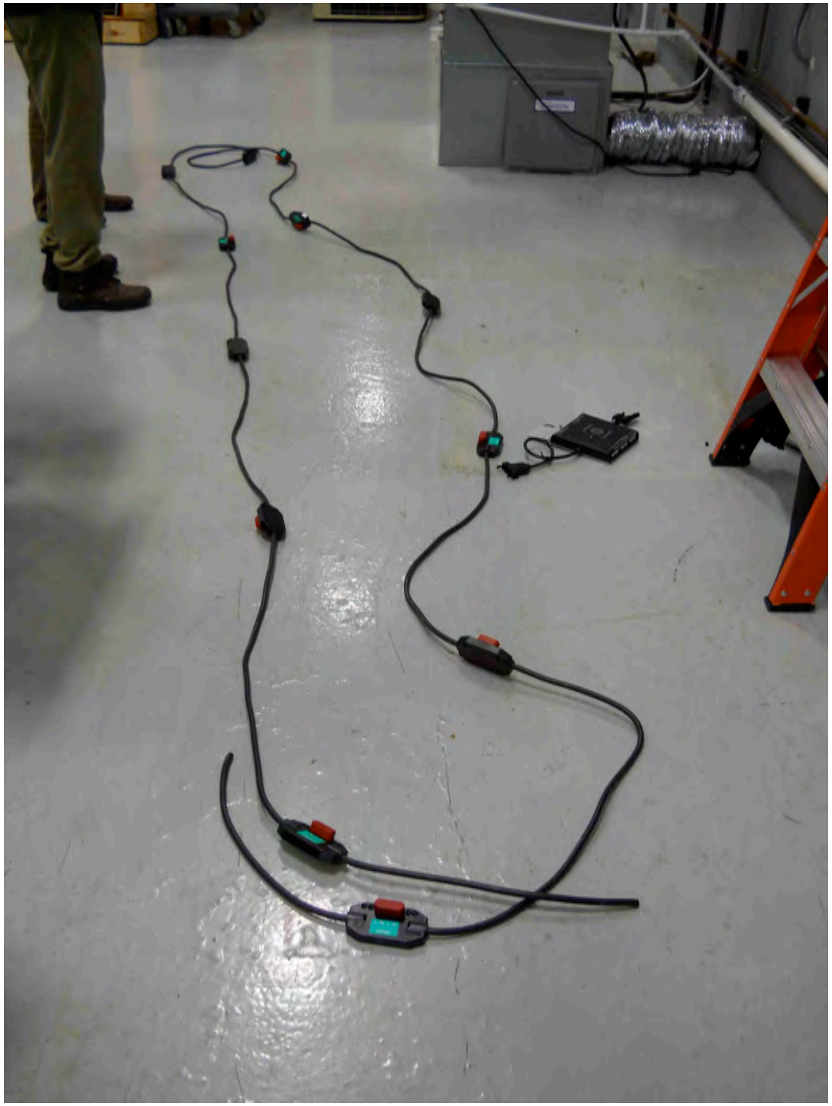

Source: Sterling, Clay. "Car port array." Midwest Renewable Energy Association.


13 kW Central Waters Brewery

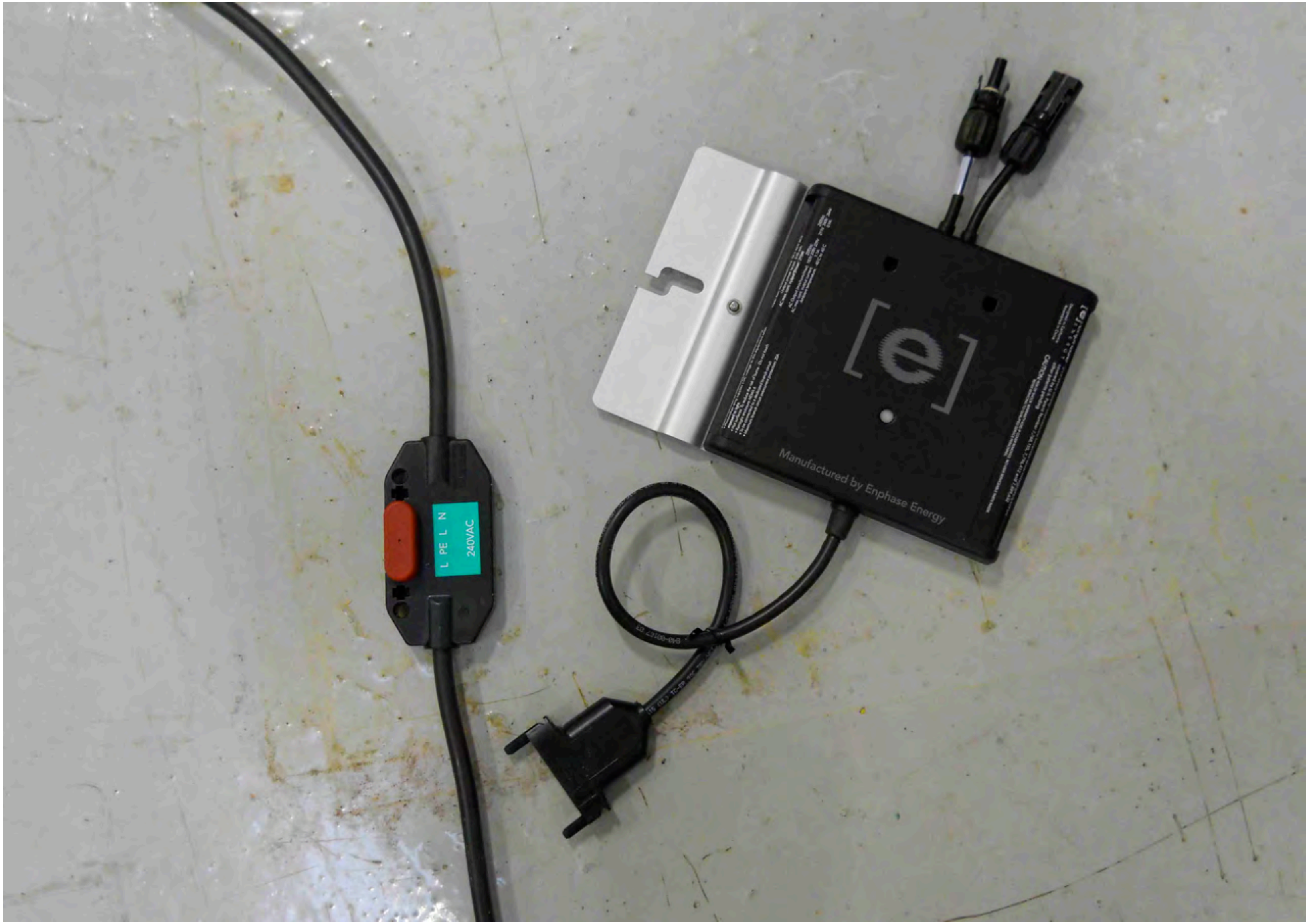

13 kW Central Waters Brewery


13 kW Central Waters Brewery


NWMC Enphase Install

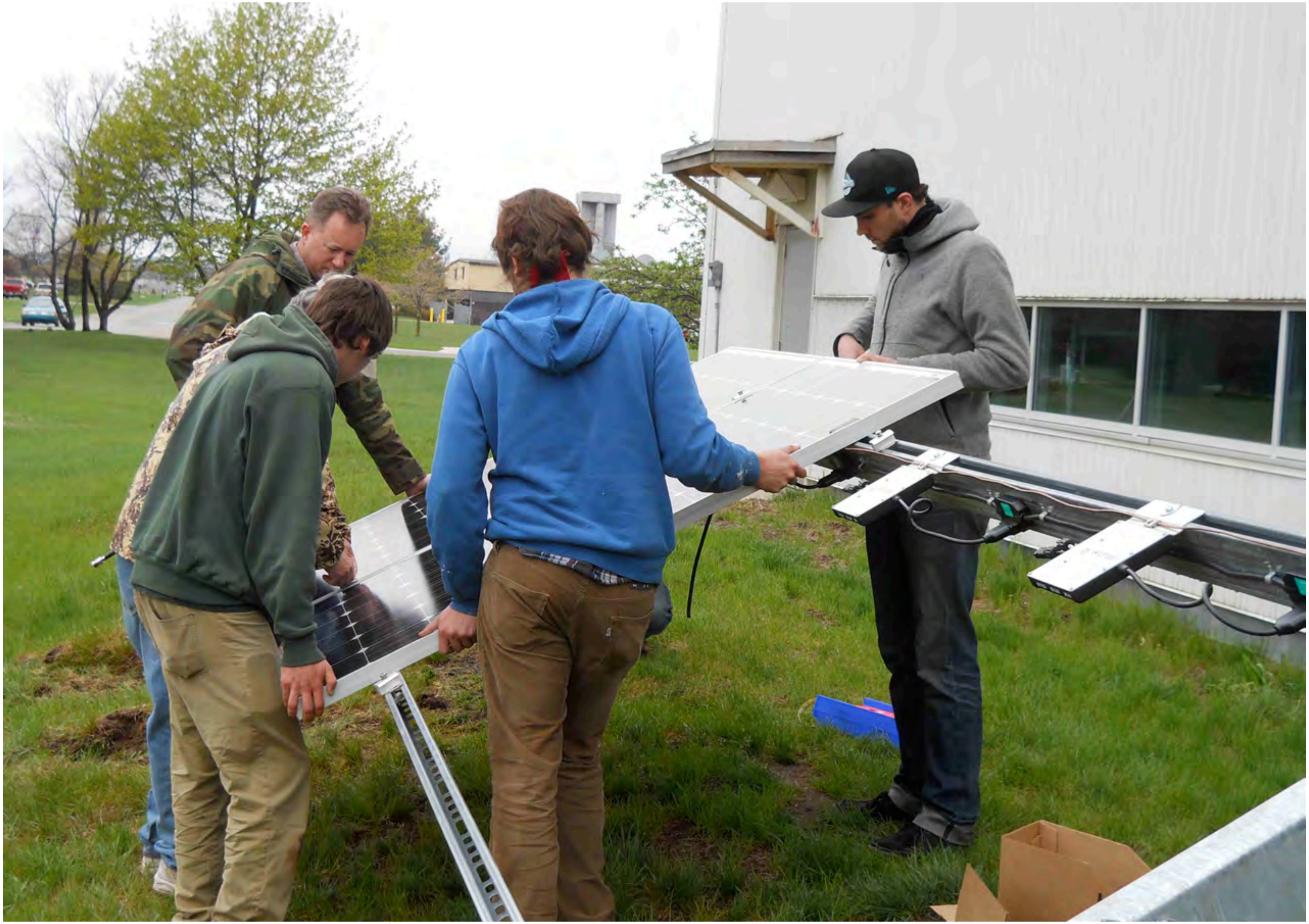


NWMC Enphase Install




NWMC Enphase Install

NWMC Enphase Install



NWMC Enphase Install

Van Meter Inc Iowa City

Van Meter Inc Iowa City

Van Meter Inc Iowa City

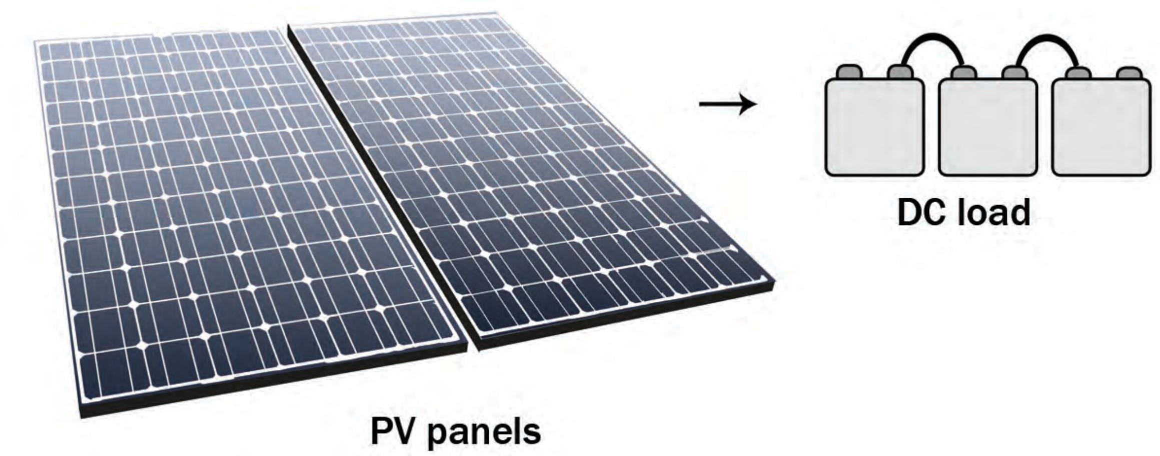
1000 W, 30-32 W Arco modules


Battery Pack


Low Voltage BOS

Load Center

# PV Direct

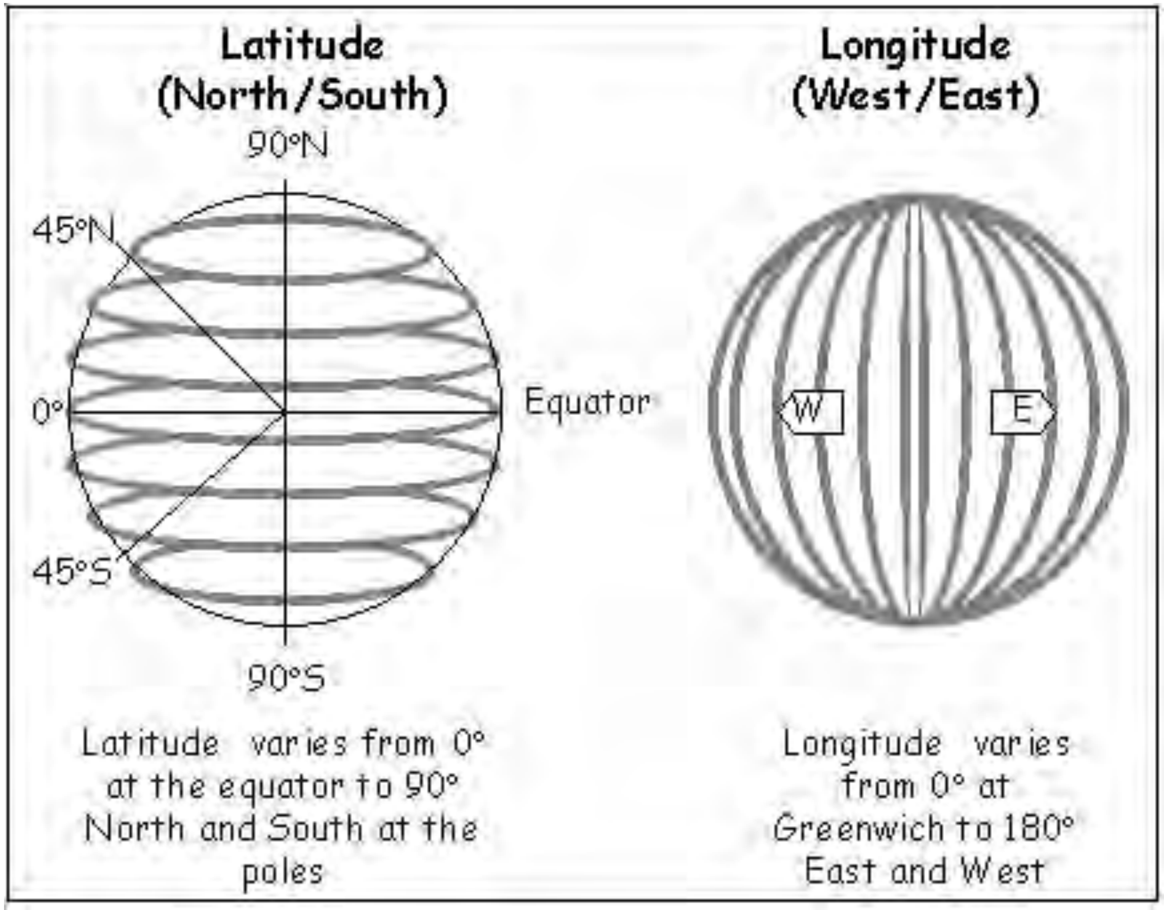



BIPV, Exelon Pavilion, Millennium Park Chicago

459 – 75 W modules, 34.5 kW array est. 16,175 kWh/yr, actual 2,967 kWh 10 months 2009

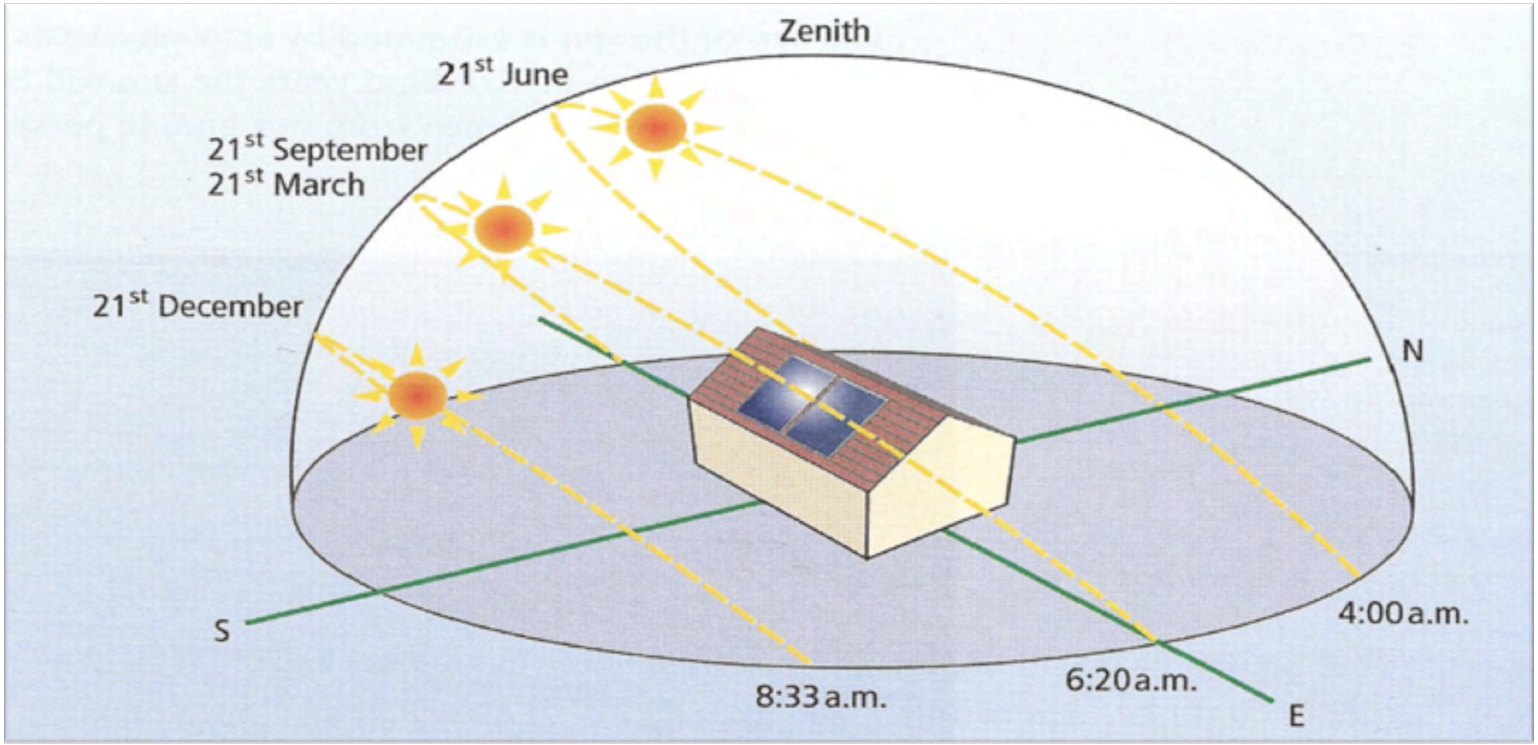
http://www.illinoissolarschools.org/solar-projects/exelon-pavilions-randolph/

# Solar Window



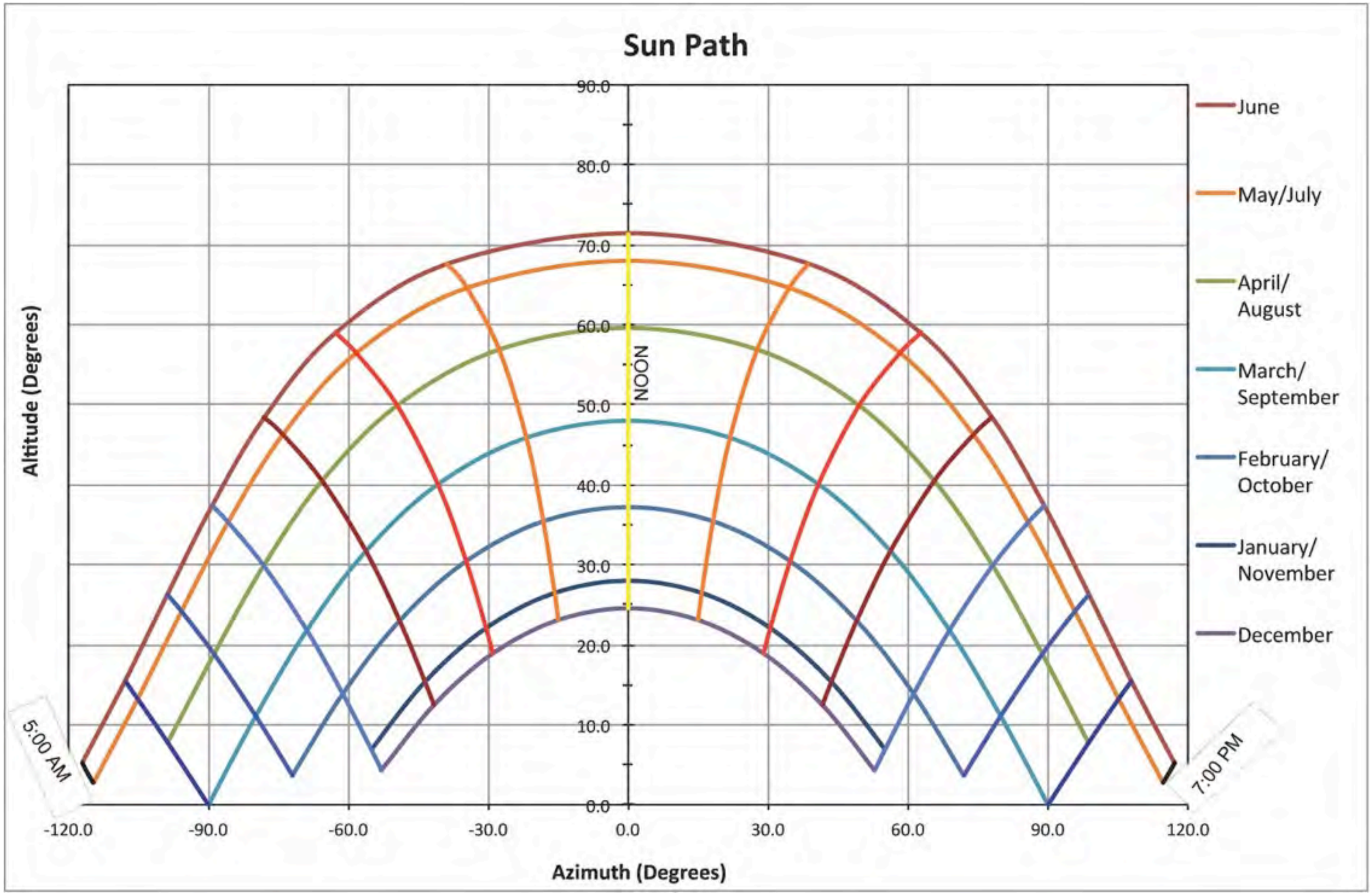
# Solar Window

Seasonal Changes



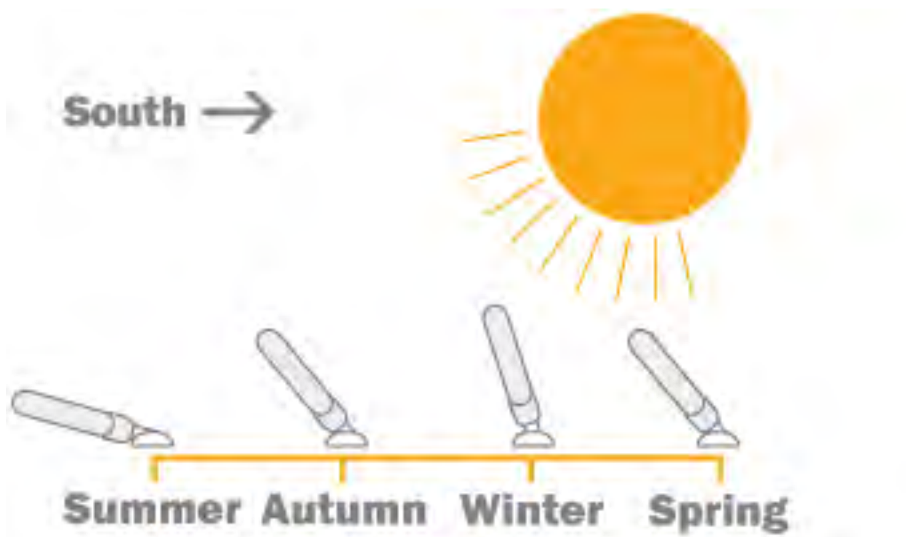

Source: The German Solar Energy Society. 2005. Planning and Installing Solar thermal Systems: A Guide for Installers, Architects, and Engineers. Frieburg: Earthscan.

# Solar Window




Source: Foreman, Claudia. *1989 ASHRAE Fundamentals*. Atlanta: American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. 1989. 27.21.

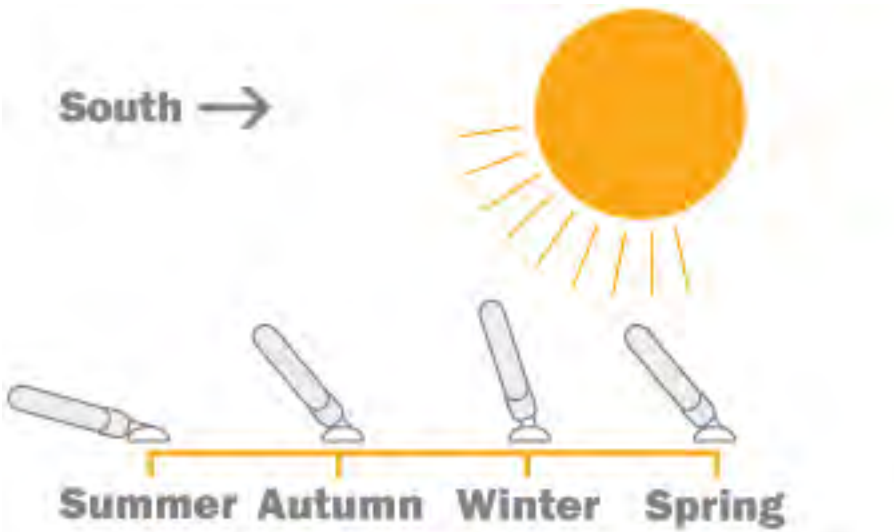
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Custer WI Latitude = 45 deg N
Fall/Spring = 45 deg, Summer = 30 deg, Winter = 60 deg

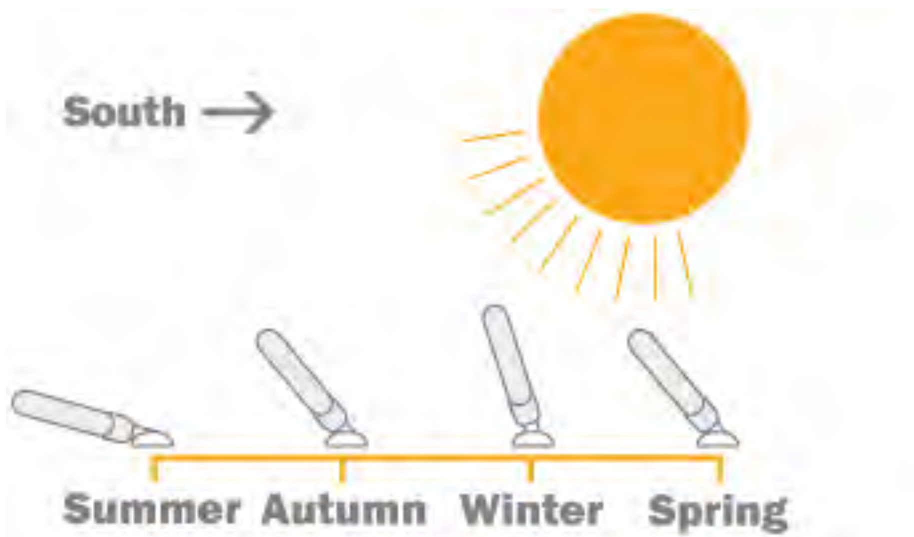
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Iowa City, IA Latitude = 41 deg N
Fall/Spring = 41 deg, Summer = 26 deg, Winter = 56 deg

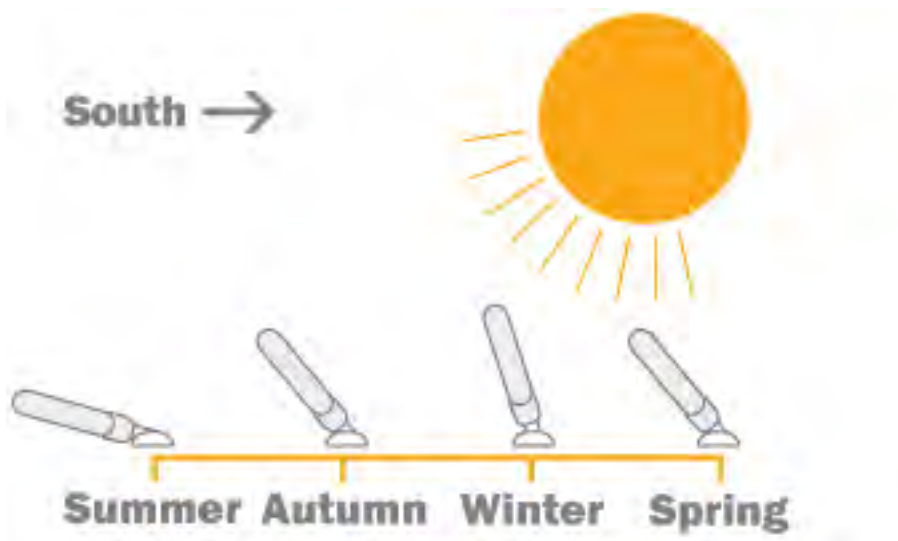
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Traverse City, MI Latitude = 45 deg N
Fall/Spring = 45 deg, Summer = 30 deg, Winter = 60 deg

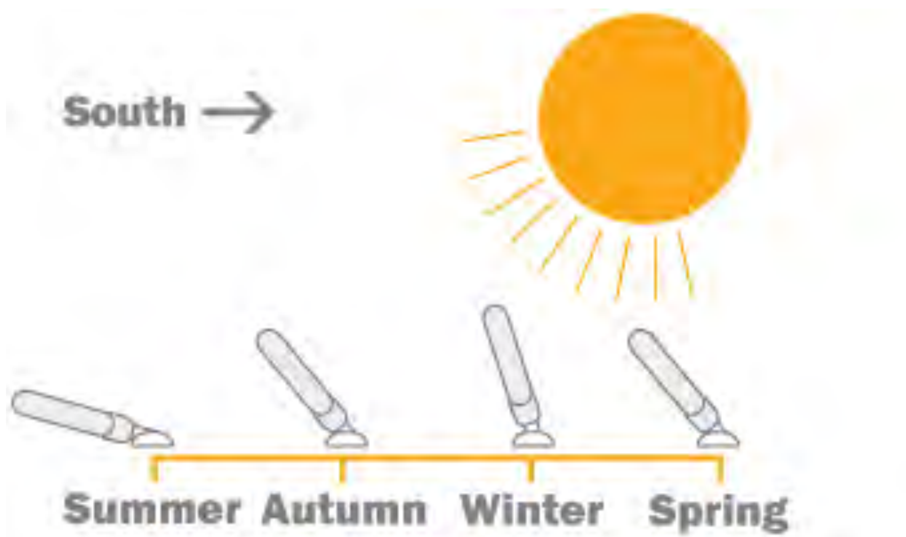
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Parkersburg, WV  Latitude = 39 deg N
Fall/Spring = 39 deg, Summer = 24 deg, Winter = 54 deg

# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Decatur, IL  Latitude = 40 deg N
Fall/Spring = 40 deg, Summer = 25 deg, Winter = 55 deg

# Solar Window PV

Optimal tilt angle year round fixed mount: Custer, WI
Outputs for a 1 kW array at various angles
30 deg = 1127 kWh/year summer angle
31 deg = 1129 kWh/year
32 deg = 1130 kWh/year
33 deg = 1130 kWh/year
34 deg = 1131 kWh/year
35 deg = 1131 kWh/year
36 deg = 1131 kWh/year
37 deg = 1130 kWh/year
38 deg = 1129 kWh/year
39 deg = 1128 kWh/year
40 deg = 1127 kWh/year
45 deg = 1116 kWh/year fall/spring angle
60 deg = 1046 kWh/year winter angle

# Solar Window PV

Optimal tilt angle year round fixed mount: Custer, WI
Outputs for a 1 kW array at various angles 4.0 SH

30 deg = 1127 kWh/year  Lat – 15 deg (summer angle)

37 deg = 1130 kWh/year Lat – 8 deg Optimal year round angle

45 deg = 1117 kWh/year Latitude (fall/spring angle)

60 deg = 1046 kWh/year Lat + 15 (winter angle)

# Solar Window PV

Optimal tilt angle year round fixed mount: Traverse City, MI
Outputs for a 1 kW array at various angles 4.0 SH

30 deg = 1,137 kWh/year  Lat – 15 deg (summer angle)

37 deg = 1,134 kWh/year Lat – 8 deg (Optimal year round angle Custer)

45 deg = 1,116 kWh/year Latitude (fall/spring angle)

60 deg = 1,034 kWh/year Lat + 15 (winter angle)

# Solar Window PV

Optimal tilt angle year round fixed mount: Iowa City, IA
Outputs for a 1 kW array at various angles

5/12, 22 deg = 1,225 kWh/year flush mount

27 deg = 1,240 kWh/year Lat – 15 (summer angle)

34 deg = 1,247 kWh/year Lat – 8 deg Optimal year round angle

42 deg = 1,237 kWh/year Latitude

57 deg = 1,165 kWh/year Lat + 15 (winter angle)

# Solar Window PV

Optimal azimuth angle year round fixed mount: Iowa City, IA
Outputs for a 1 kW array at various angles

E 90, 5/12, @ 22 deg = 1,015 kWh/year flush mount

S 180, @ 22 deg = 1,225 kWh/year

W 270, @ 22 deg = 1,030 kWh/year

# Solar Window PV

Optimal tilt angle year round fixed mount: Traverse City MI
Outputs for a 1 kW array at various angles

E 90, 5/12, @ 22 deg = 954 kWh/year flush mount

165, 5/12, @ 22 deg = 1,117 kWh/year

S 180, @ 22 deg = 1,124 kWh/year

195, 5/12, @ 22 deg = 1,121 kWh/year

W 270, @ 22 deg = 963 kWh/year

# Solar Window PV

Optimal tilt angle year round fixed mount: Decatur, IL
Outputs for a 1 kW array at various angles 4.8 SH

25 deg = 1262 kWh/year  Lat – 15 deg (summer angle)

32 deg = 1271 kWh/year Lat – 8 deg Optimal year round angle

40 deg = 1269 kWh/year Latitude (fall/spring angle)

54 deg = 1193 kWh/year Lat + 15 (winter angle)

# Solar Window PV

Optimal tilt angle year round fixed mount: Tucson AZ
Outputs for a 1 kW array at various angles
17 deg = 1613 kWh/year summer angle
18 deg = 1619 kWh/year
19 deg = 1625 kWh/year

29 deg = 1660 kWh/year
30 deg = 1662 kWh/year
31 deg = 1662 kWh/year
32 deg = 1663 kWh/year fall/spring angle
33 deg = 1663 kWh/year
34 deg = 1662 kWh/year

45 deg = 1626 kWh/year
46 deg = 1620 kWh/year
47 deg = 1614 kWh/year winter angle

# Solar Window PV

Optimal tilt angle year round fixed mount: Charleston SC
Outputs for a 1 kW array at various angles
17 deg = 1304 kWh/year summer angle
18 deg = 1308 kWh/year
19 deg = 1313 kWh/year

28 deg = 1335 kWh/year
29 deg = 1336 kWh/year
30 deg = 1336 kWh/year
31 deg = 1336 kWh/year
32 deg = 1336 kWh/year fall/spring angle
33 deg = 1336 kWh/year
34 deg = 1335 kWh/year

45 deg = 1303 kWh/year
46 deg = 1299 kWh/year
47 deg = 1293 kWh/year winter angle

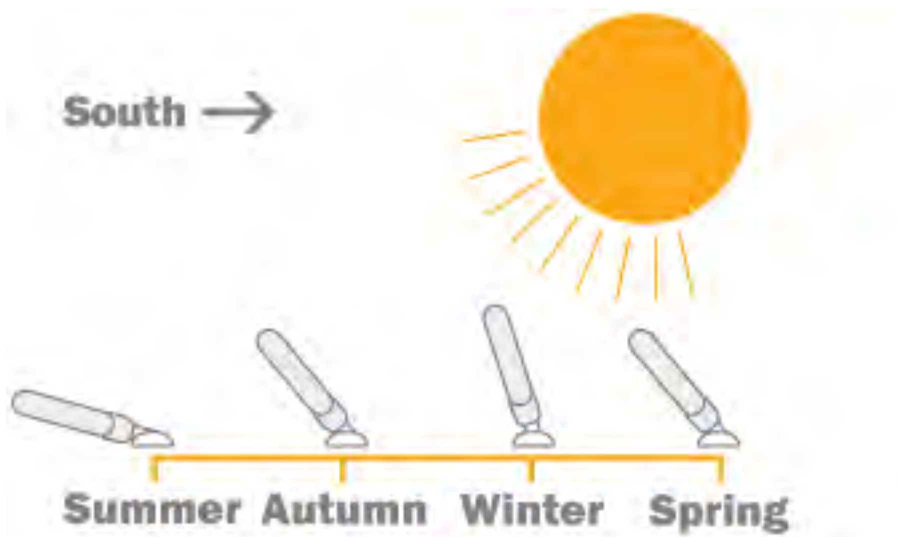
# Solar Window PV

Optimal tilt angle year round fixed mount: Charlotte NC
Outputs for a 1 kW array at various angles
20 deg = 1293 kWh/year summer angle
21 deg = 1297 kWh/year
22 deg = 1301 kWh/year

30 deg = 1318 kWh/year
31 deg = 1319 kWh/year
32 deg = 1319 kWh/year
33 deg = 1319 kWh/year
34 deg = 1319 kWh/year
35 deg = 1318 kWh/year fall/spring angle
36 deg = 1317 kWh/year

48 deg = 1280 kWh/year
49 deg = 1275 kWh/year
50 deg = 1269 kWh/year winter angle

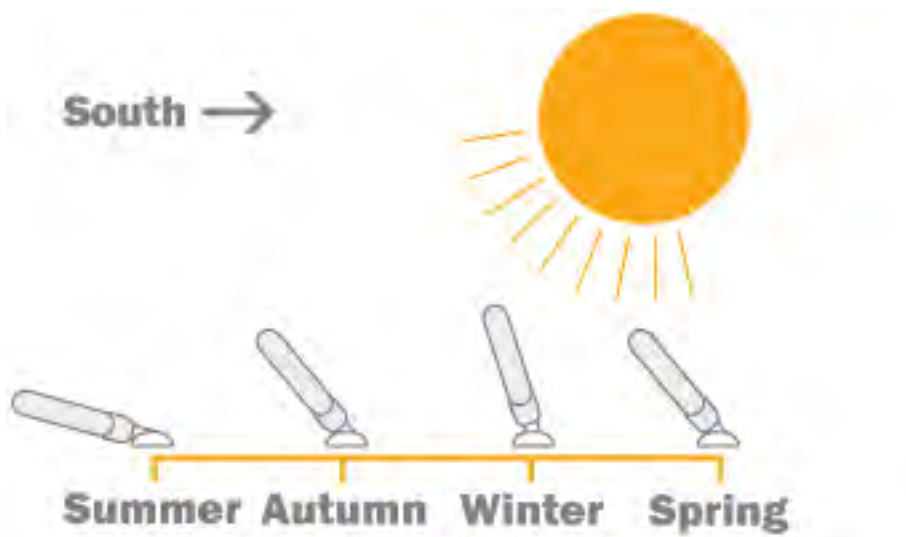
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Lac du Flambeau WI Latitude = 46 deg N
Fall/Spring = 46 deg, Summer = 35 deg, Winter = 61 deg

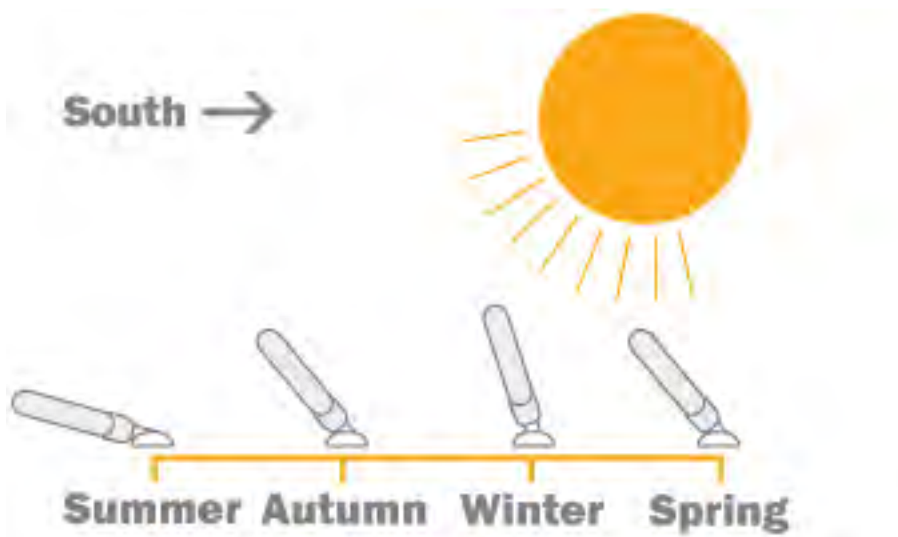
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Charlotte NC Latitude = 35 deg N
Fall/Spring = 35 deg, Summer = 20 deg, Winter = 50 deg

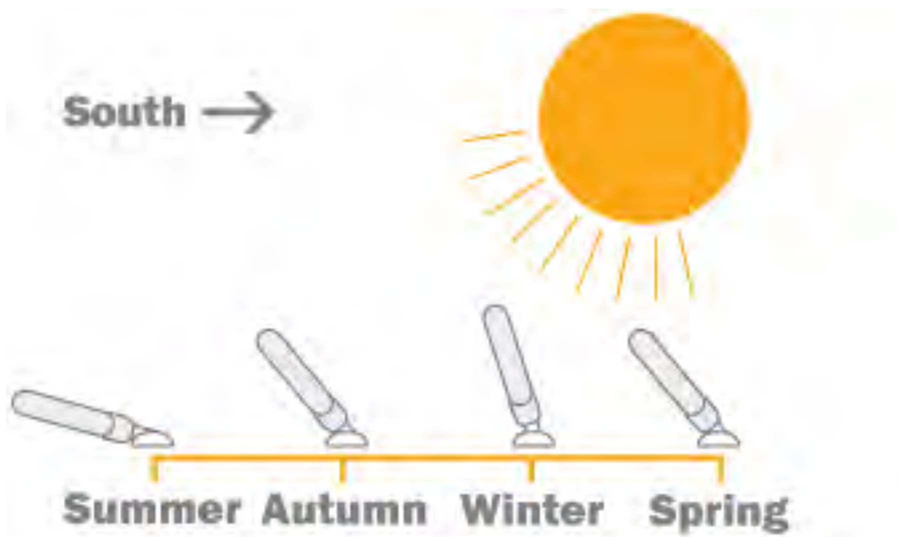
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

Ex. Charleston SC Latitude = 32 deg N
Fall/Spring = 32 deg, Summer = 17 deg, Winter = 47 deg

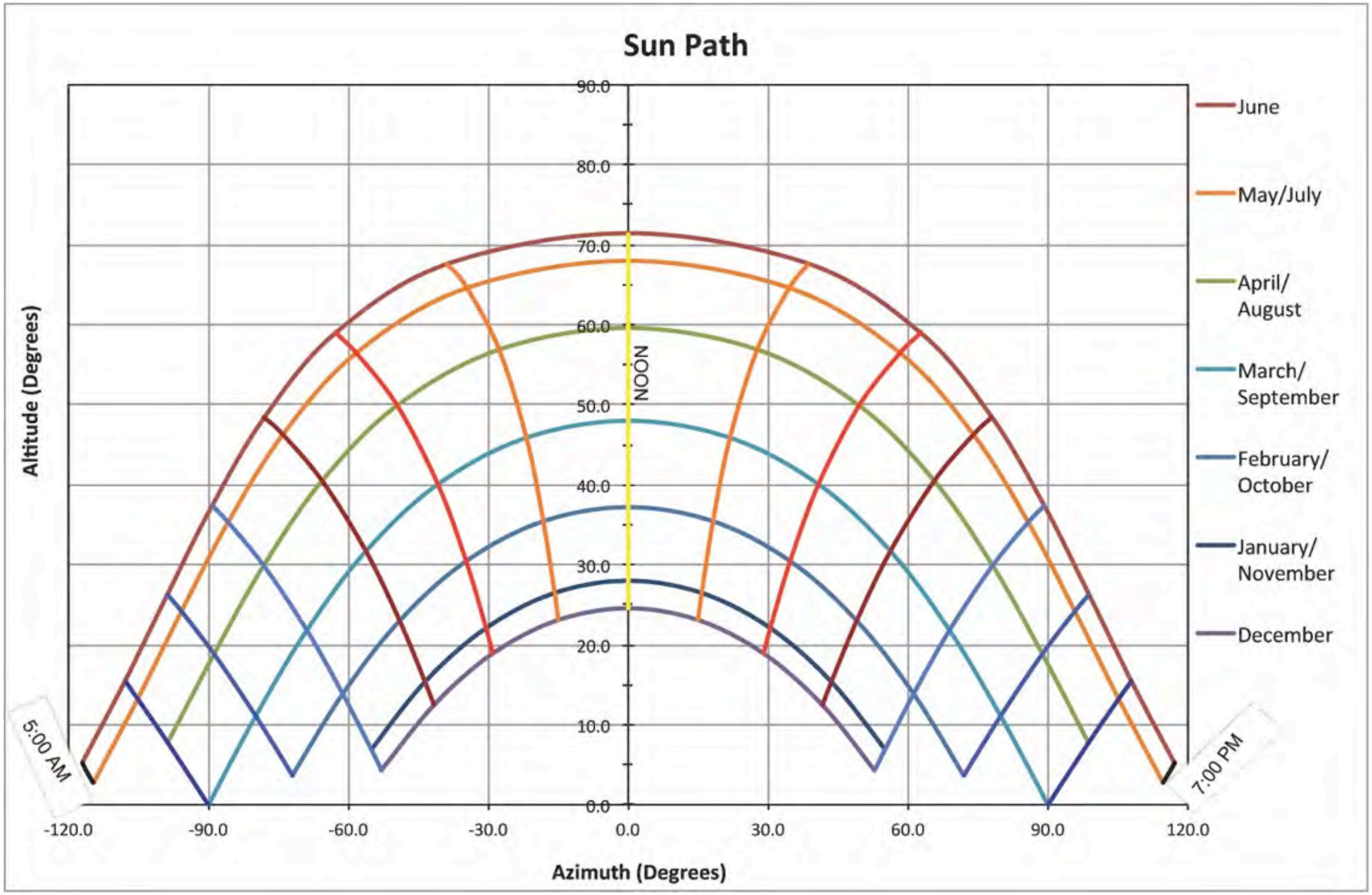
# Solar Window




Seasonal Tilt Angles:
Summer = Lat – 15 deg, Winter = Lat + 15 deg, Fall/Spring = Lat

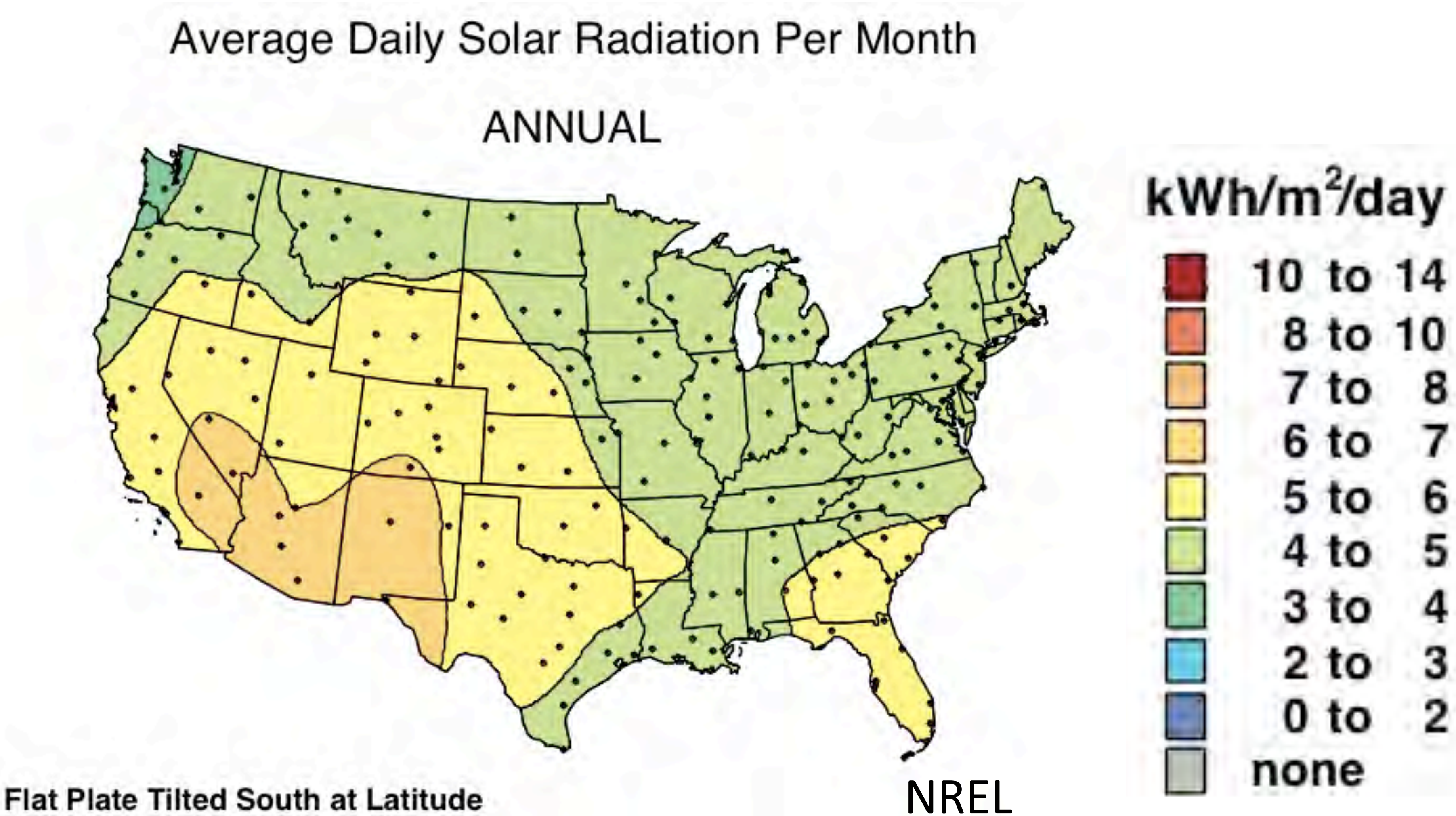
Ex. Tucson AZ Latitude = 32 deg N
Fall/Spring = 32 deg, Summer = 17 deg, Winter = 47 deg

# Solar Window




Source: Foreman, Claudia. *1989 ASHRAE Fundamentals*. Atlanta: American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. 1989. 27.21.

# Solar Window




NREL
2010

# Solar Window

Sun Hours/Day

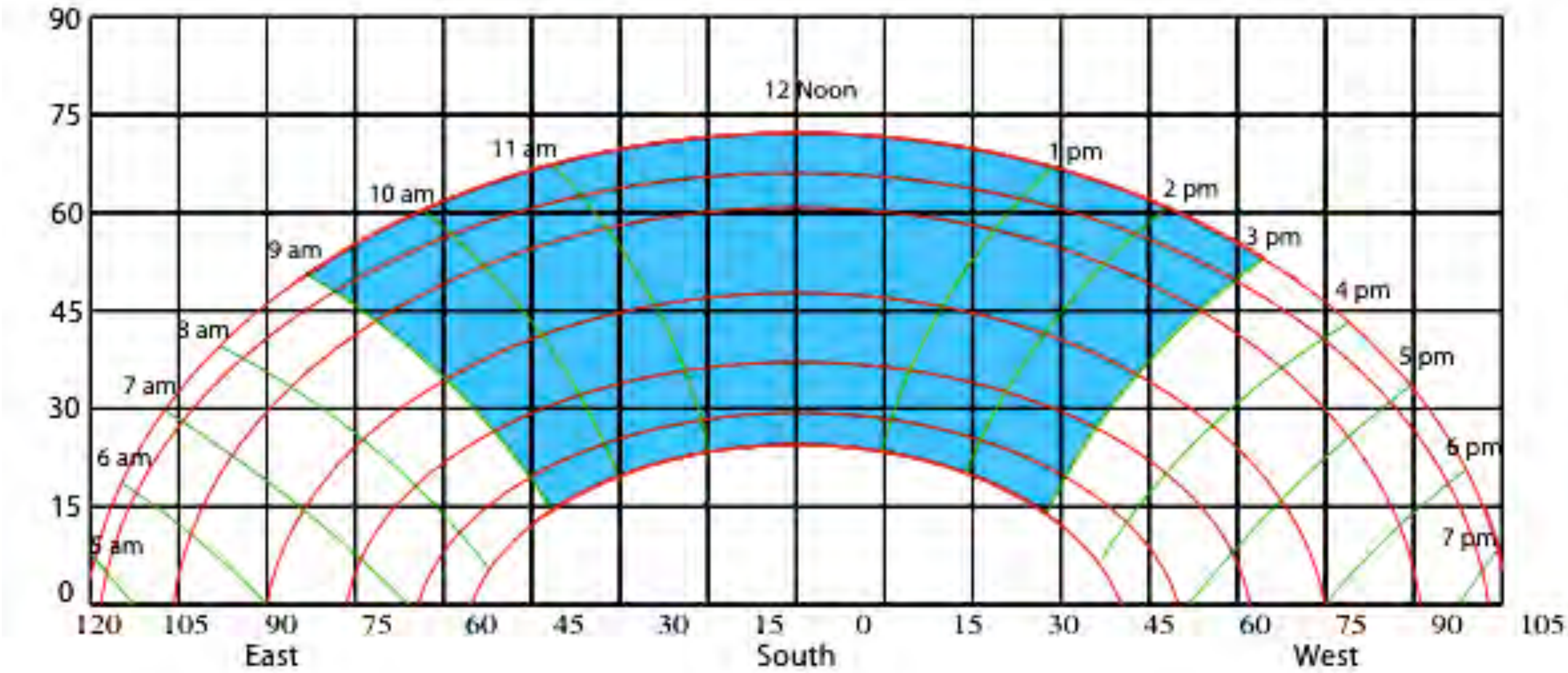
| State | City | High | Low | Avg |
|---|---|---|---|---|
| AK | Fairbanks | 5.87 | 2.12 | 3.99 |
| AZ | Tucson | 7.42 | 6.01 | 6.57 |
| CO | Boulder | 5.72 | 4.44 | 4.87 |
| DC | Washington | 4.69 | 3.37 | 4.23 |
| FL | Miami | 6.26 | 5.05 | 5.62 |
| GA | Atlanta | 5.16 | 4.09 | 4.74 |
| IA | Ames | 4.80 | 3.73 | 4.40 |
| IL | Chicago | 4.08 | 1.47 | 3.14 |
| IN | Indianapolis | 5.02 | 2.55 | 4.21 |
| MN | St. Cloud | 5.43 | 3.53 | 4.53 |
| MO | St. Louis | 4.87 | 3.24 | 4.38 |
| NC | Greensboro | 5.05 | 4.00 | 4.71 |
| NE | Omaha | 5.28 | 4.26 | 4.90 |
| NV | Las Vegas | 7.13 | 5.84 | 6.41 |
| NY | Schenetady | 3.92 | 2.53 | 3.55 |
| NY | New York City | 4.97 | 3.03 | 4.08 |
| OH | Cleveland | 4.79 | 2.69 | 3.94 |
| SC | Charleston | 5.72 | 4.23 | 5.06 |
| SD | Rapid City | 5.91 | 4.56 | 5.23 |
| WI | Madison | 4.82 | 3.28 | 4.29 |
| WY | Lander | 6.81 | 5.50 | 6.06 |
| WV | Charleston | 4.12 | 2.47 | 3.65 |

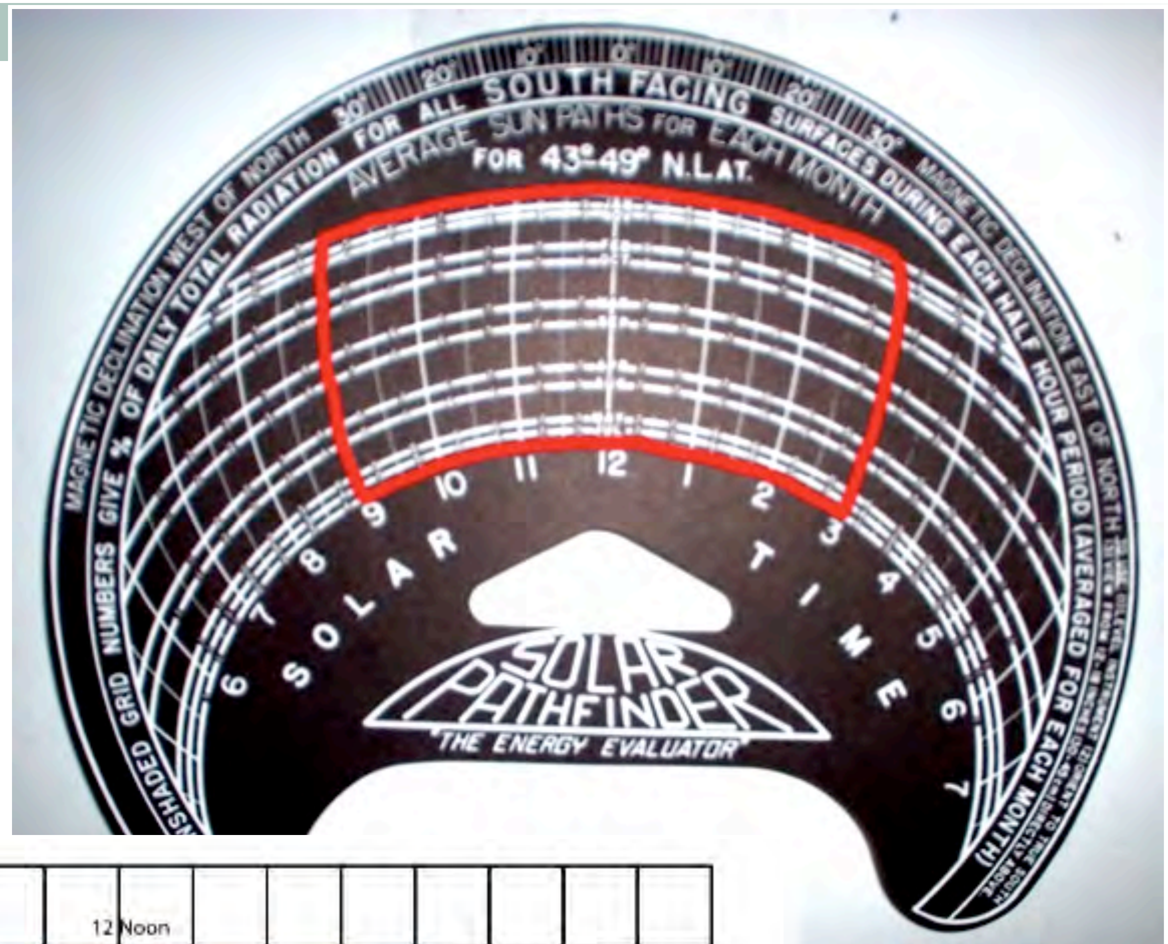
# Site Assessment Tools

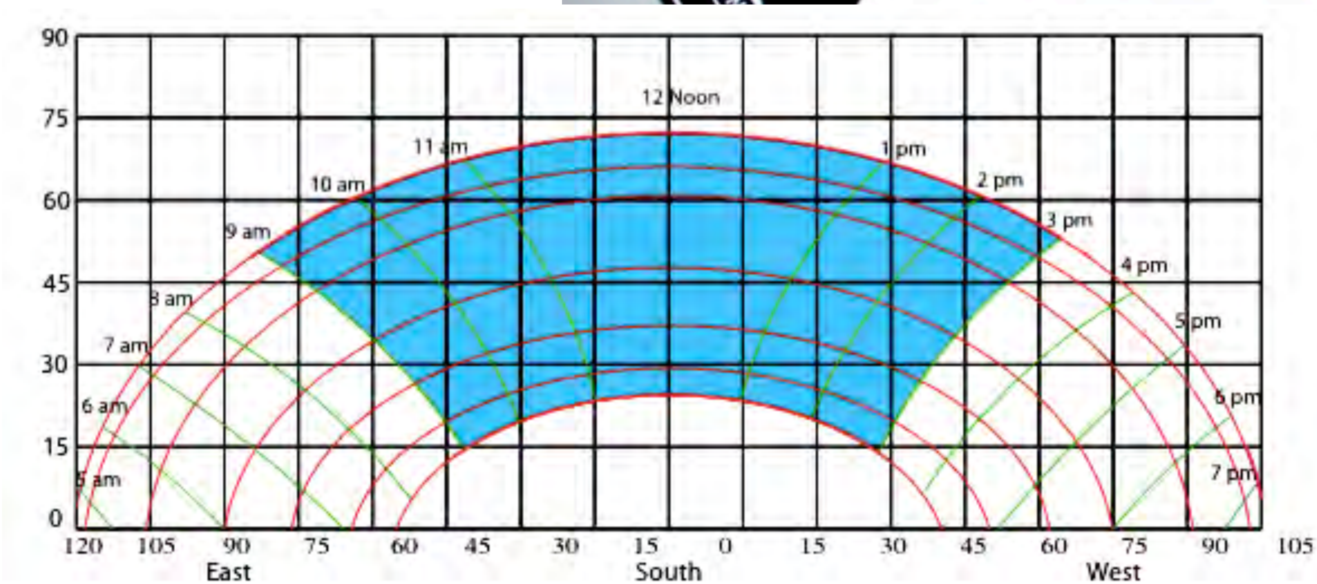
Solar Pathfinder ~ $290

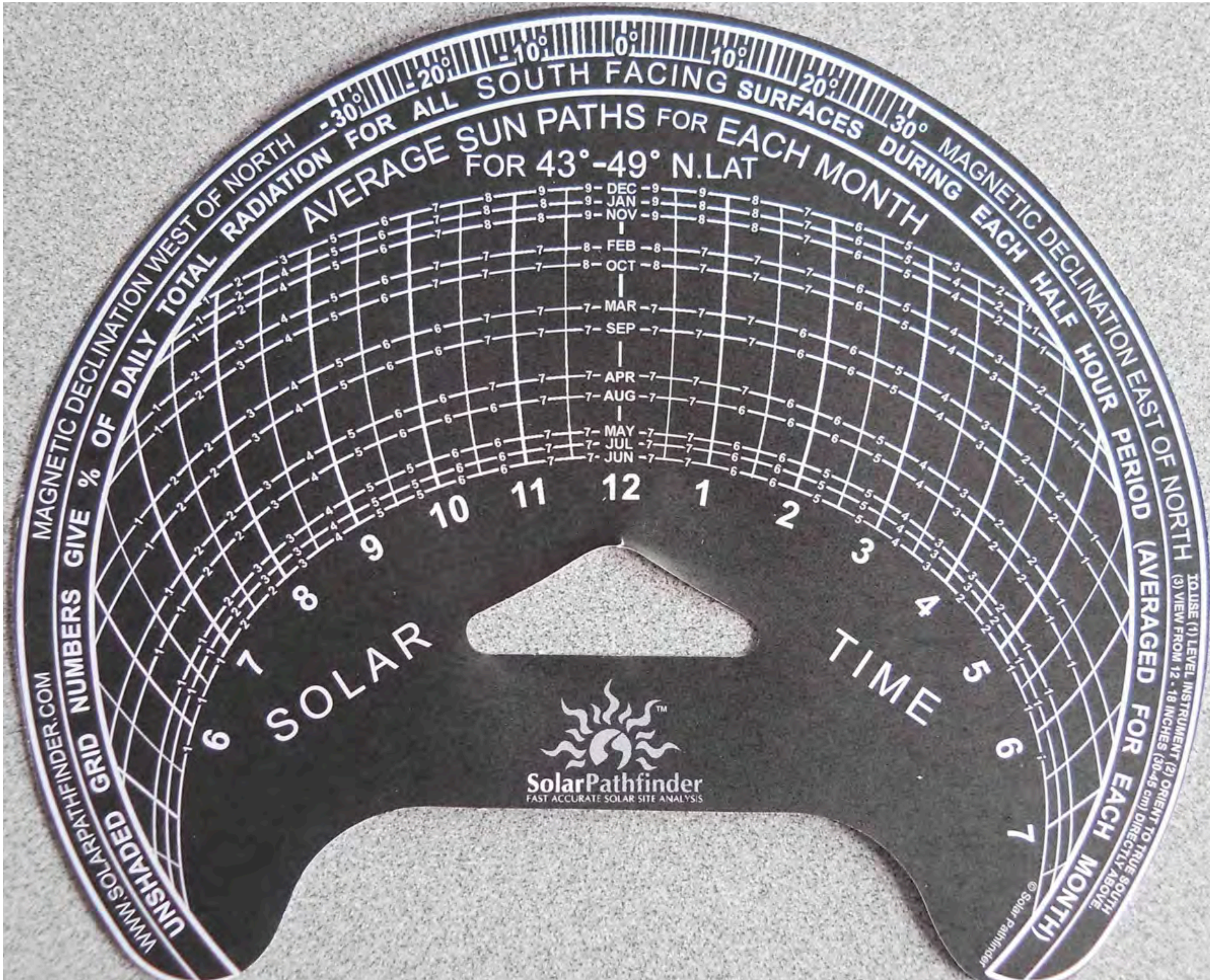
Solmetric ~ $2200

# Solar Window

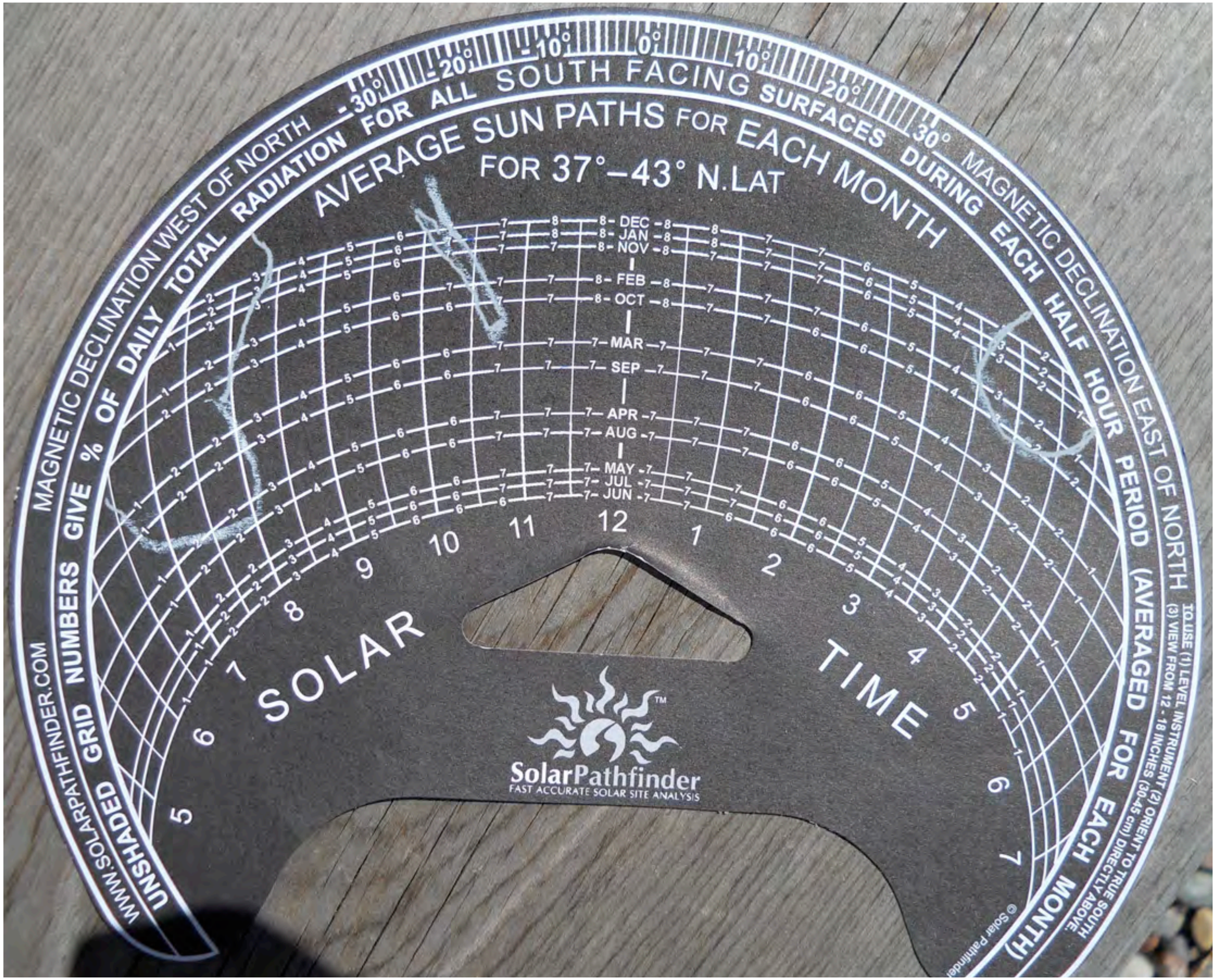



MAGNETIC DECLINATION WEST OF NORTH
30° 20° 10° 0° 10° 20° 30°
UNSHADED GRID NUMBERS GIVE % OF DAILY TOTAL RADIATION FOR ALL SOUTH FACING SURFACES DURING EACH HALF HOUR PERIOD (AVERAGED FOR EACH MONTH)
MAGNETIC DECLINATION EAST OF NORTH
AVERAGE SUN PATHS FOR EACH MONTH
FOR 43°-49° N.LAT.
6 7 8 9 10 11 12 1 2 3 4 5 6 7
SOLAR TIME
SOLAR PATHFINDER
"THE ENERGY EVALUATOR"

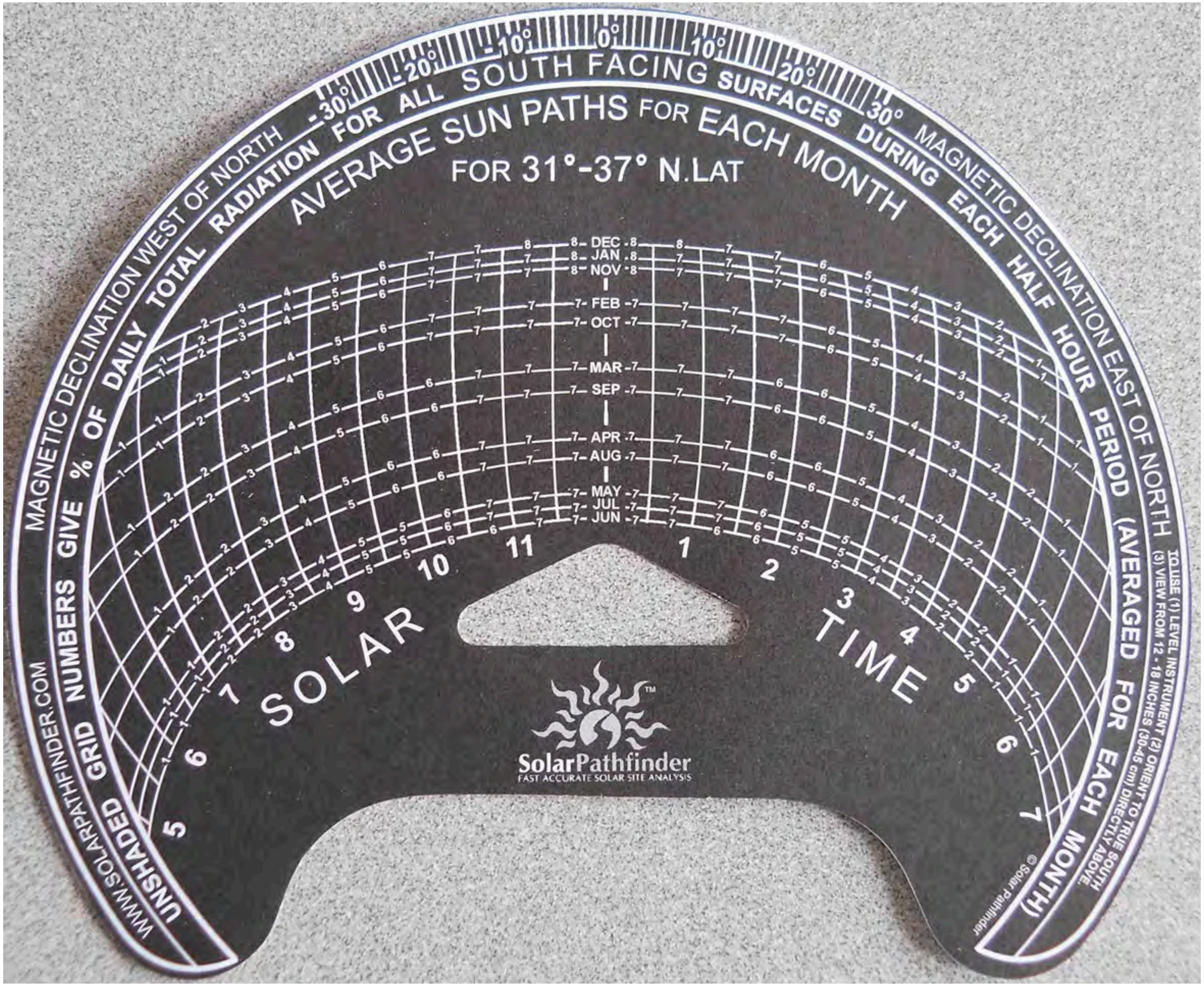

90
75
60
45
30
15
0
12 Noon
11 am
10 am
9 am
8 am
7 am
6 am
5 am
1 pm
2 pm
3 pm
4 pm
5 pm
6 pm
7 pm
120 105 90 75 60 45 30 15 0 15 30 45 60 75 90 105
East
South
West



WI SPF Chart. Midwest Renewable Energy Association. February 2011



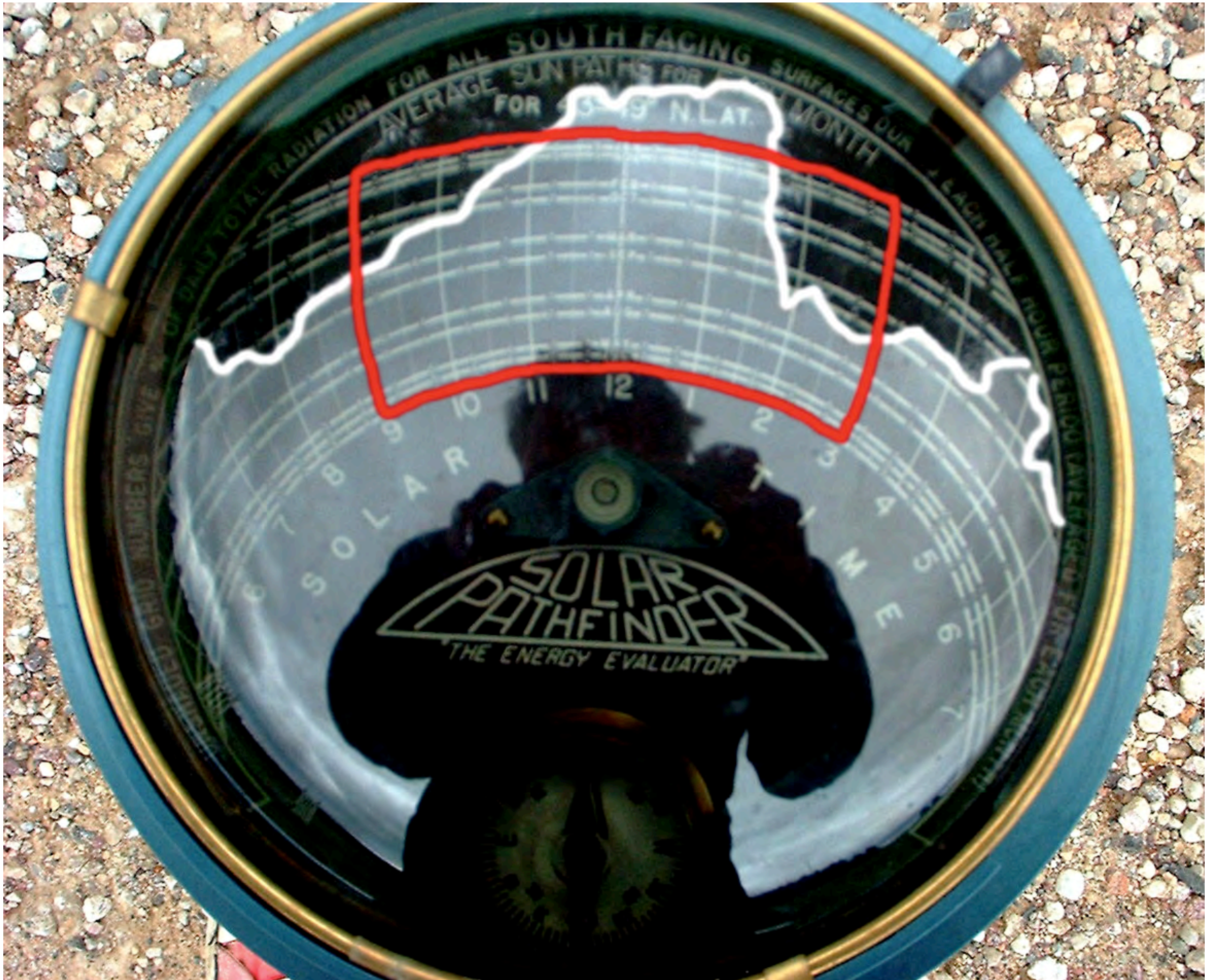

WI SPF Chart. Midwest Renewable Energy Association. February 2011




NC, SC, AZ SPF Chart. Midwest Renewable Energy Association. February 2011

# Performing a Site Assessment

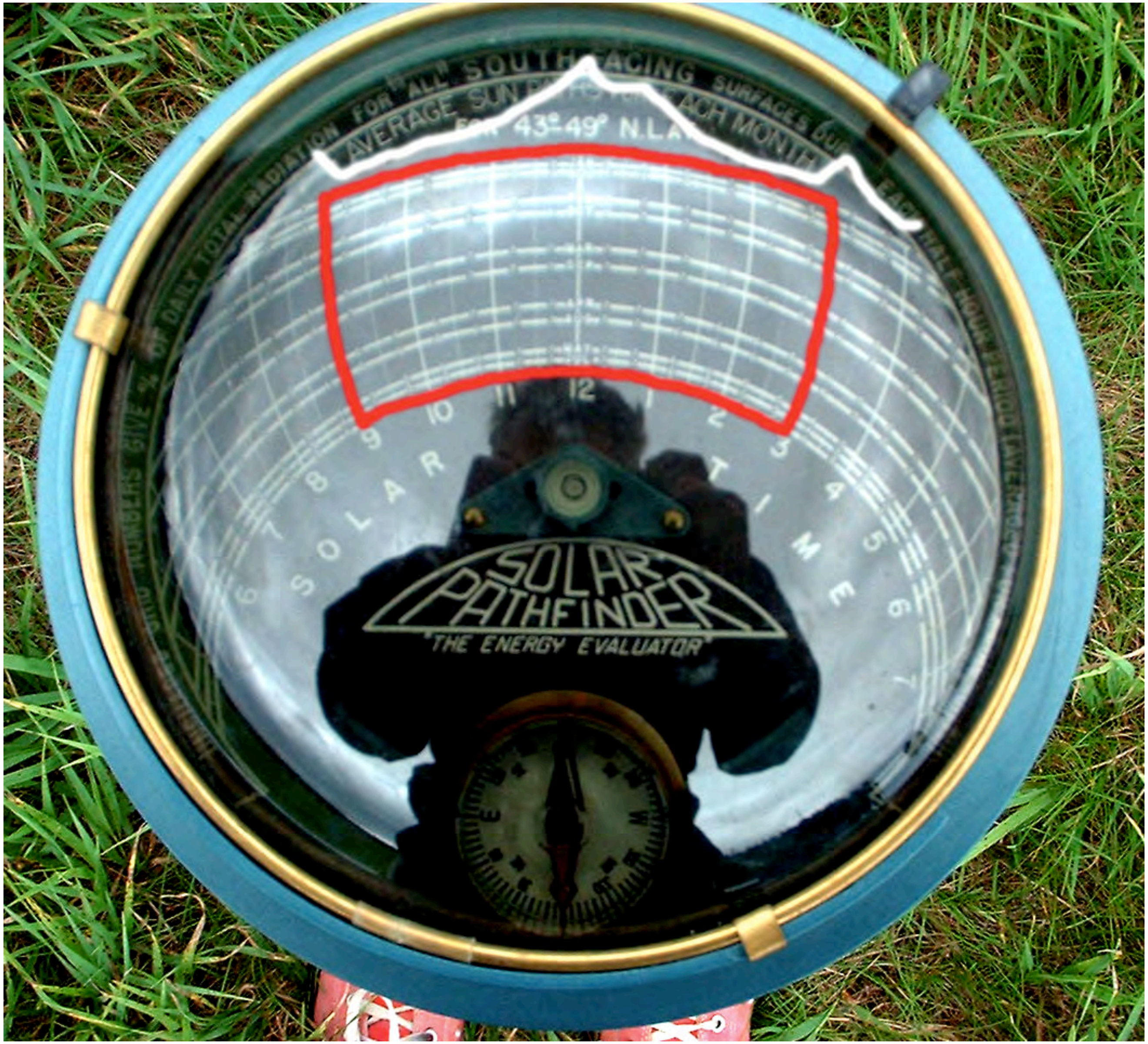
## Starting Point



# 20 ft. (from starting point)

# 40 ft. (from starting point)

# 60 ft. From starting point



# Sighting Considerations

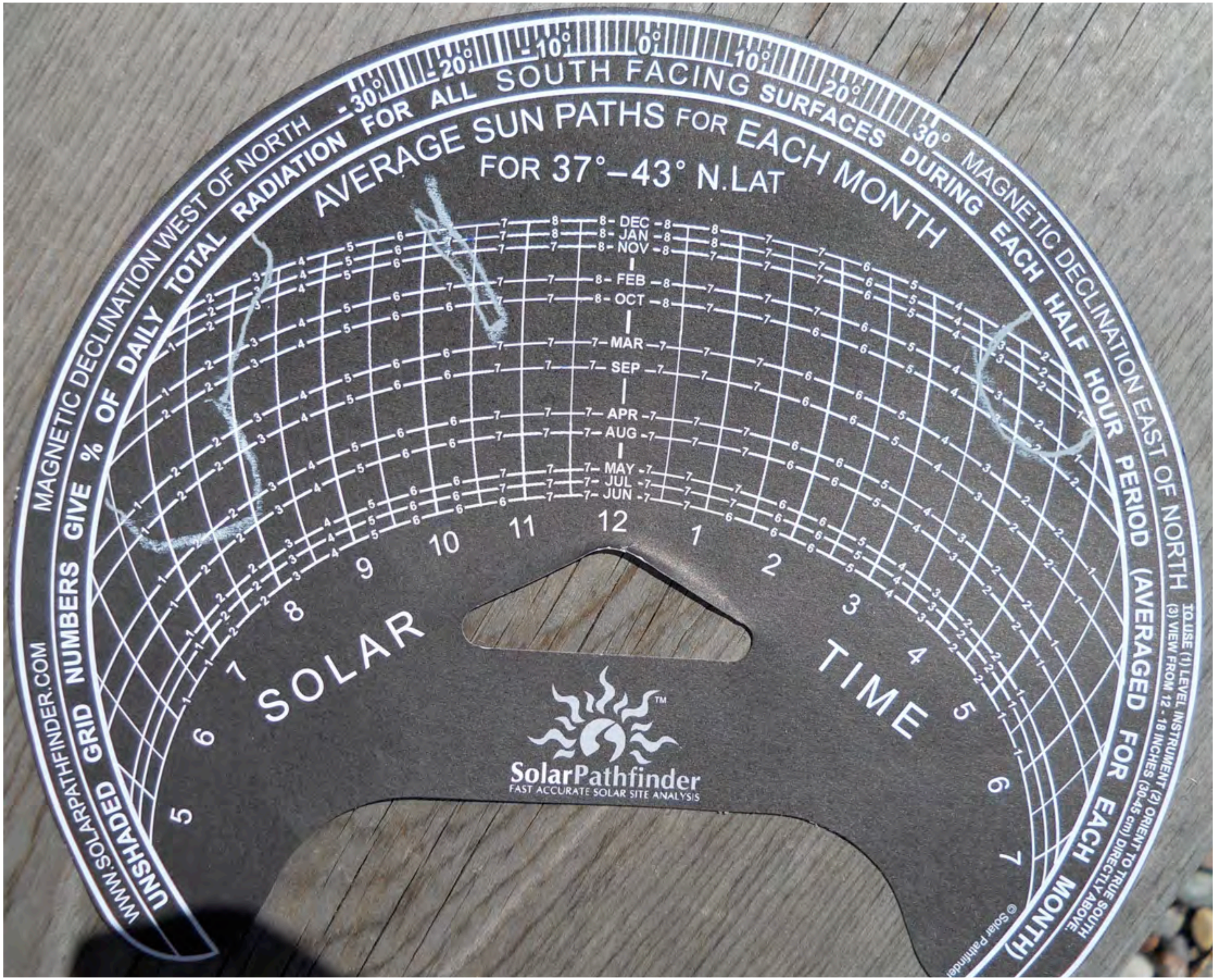
•Neighbors

• Distance to BOS

• Future construction

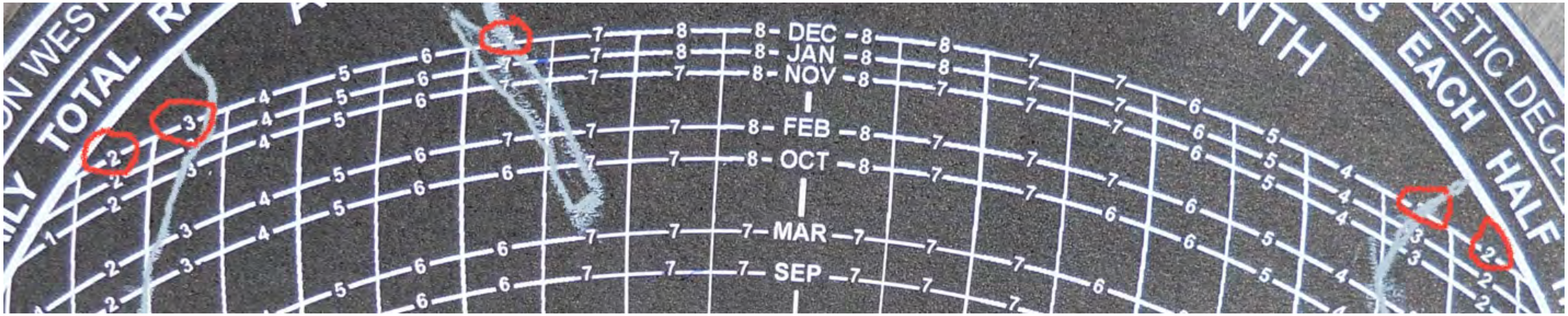
• Aesthetics

• Vegetative growth

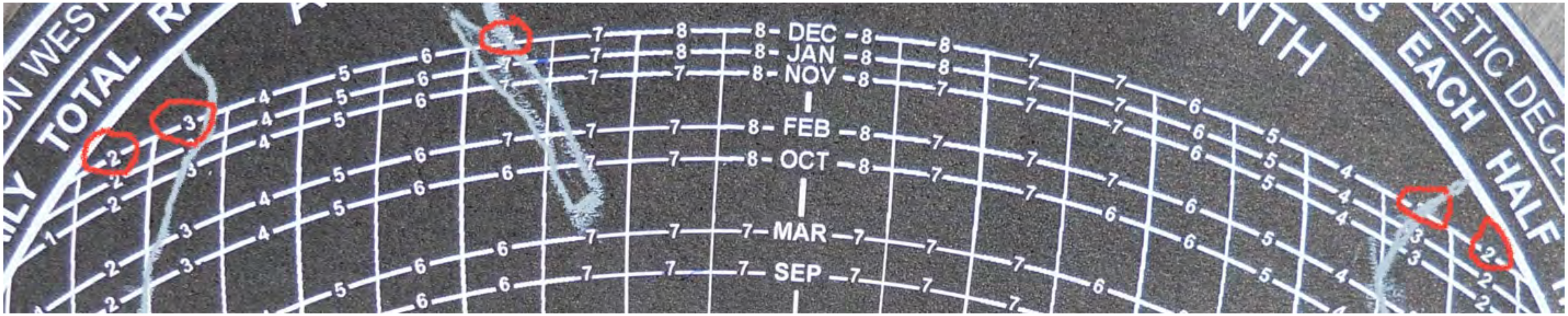



WI SPF Chart. Midwest Renewable Energy Association. February 2011

# SPF Exercise

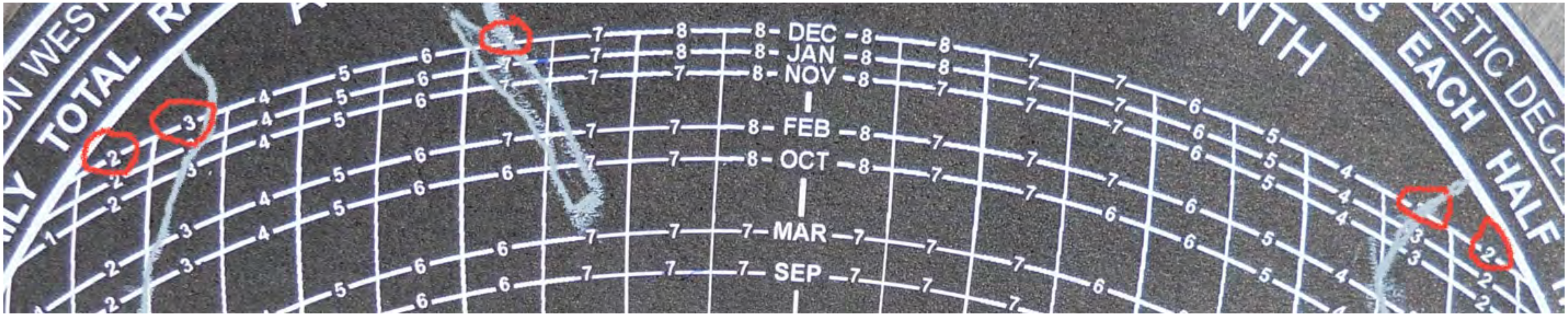


# SPF Exercise




Dec. 2+3+7+3+2= 17% Shade = 100-17=83% Sun

# SPF Exercise




Dec. 2+3+7+3+2= 17% Shade = 100-17=83% Sun
Jan. 2+3+7+3+2=17% Shade = 100-17= 83% Sun
Nov. 1+2+3+7+3+2+1= 19% Shade = 100-19 = 81% Sun
Feb. 1+2+3+7+7+3+2+1=25% Shade = 100-25=75% Sun

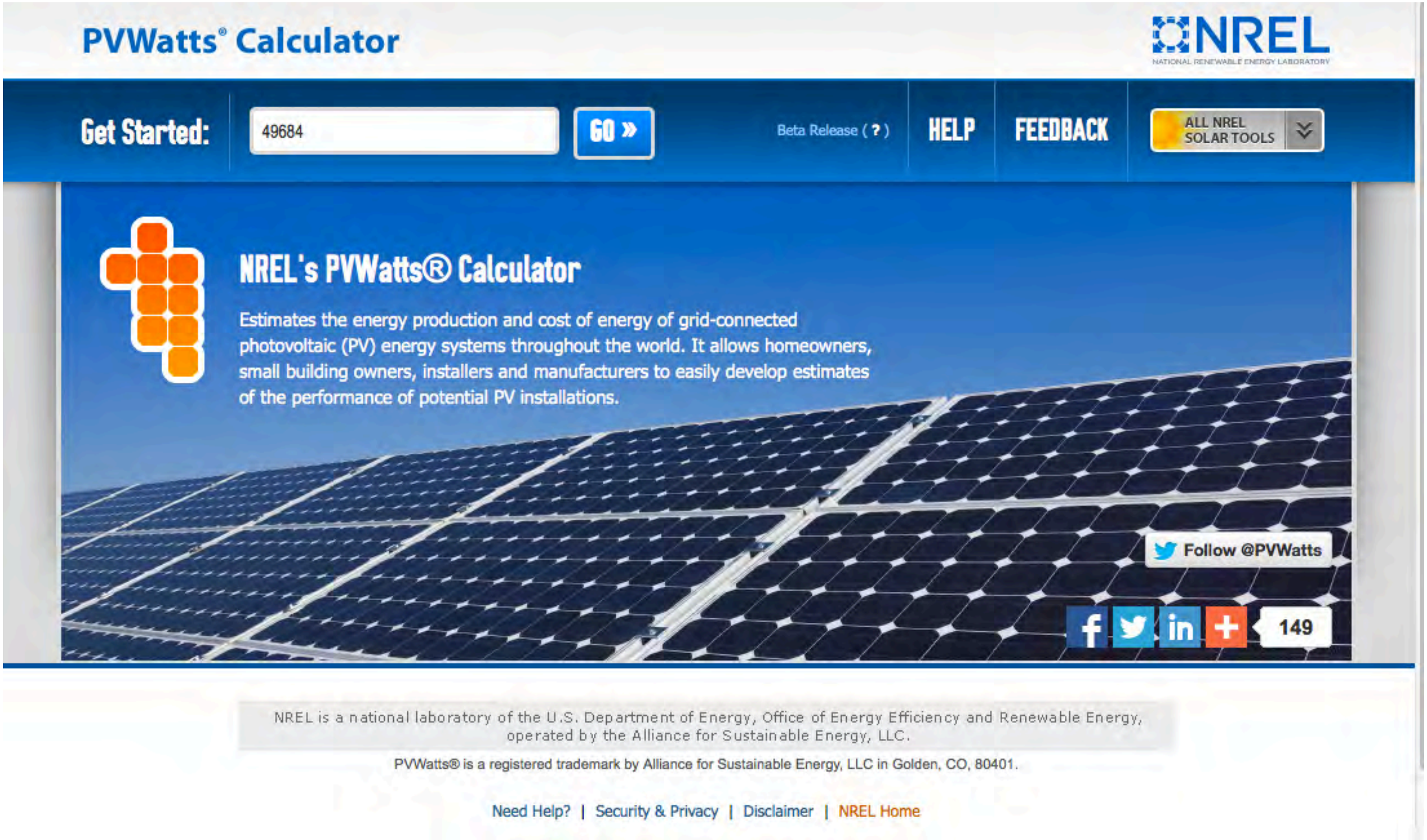
# SPF Exercise

# Using PVWatts

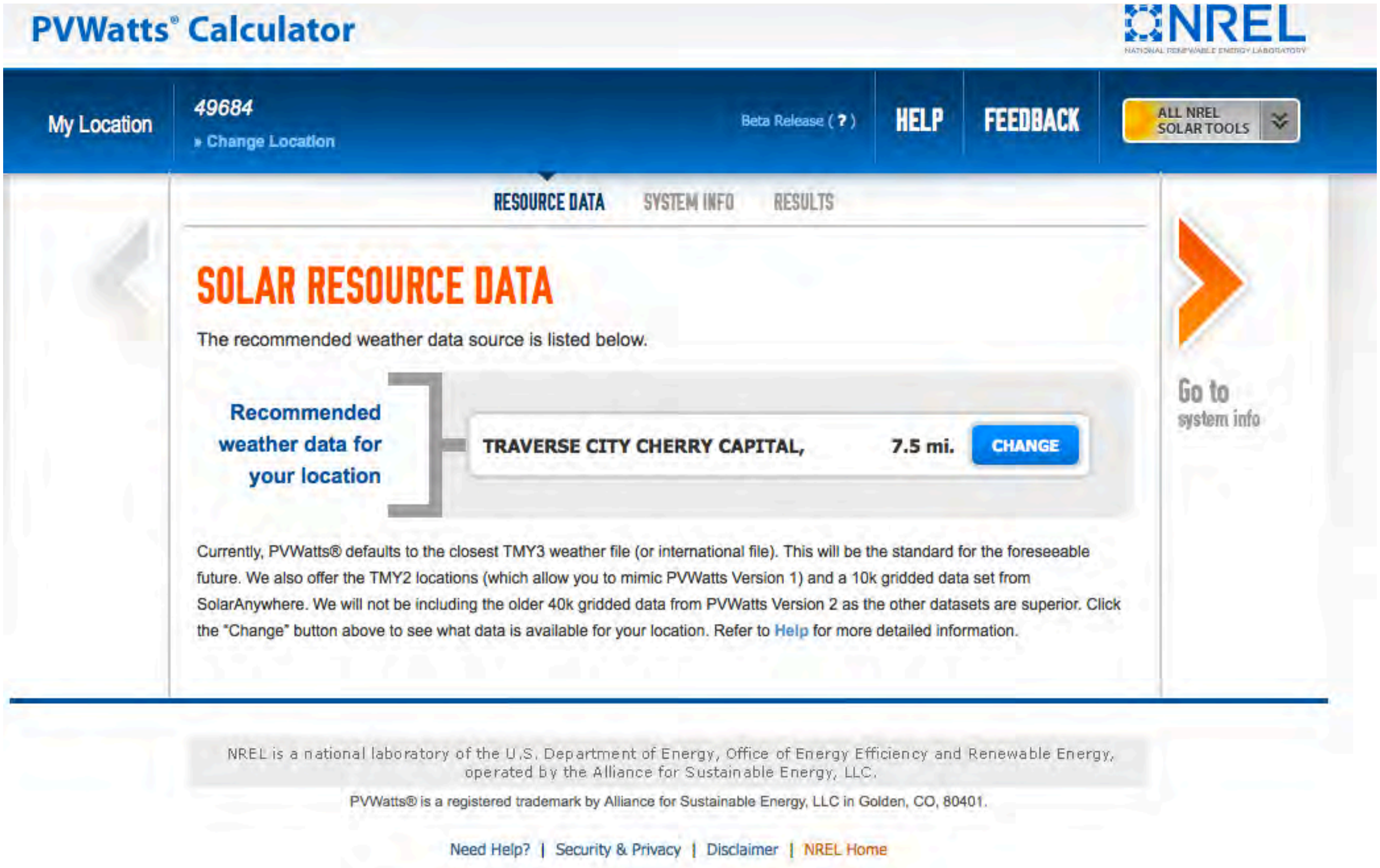
Online, free software from National Renewable Energy Lab (NREL)

- Calculates the output of a PV array of essentially any wattage and any elevation angle, at any azimuth angle
- Generates a report that gives production numbers for every month of the year
- Does not account for snow shading
- Helps size an array to meet the load requirements and site conditions

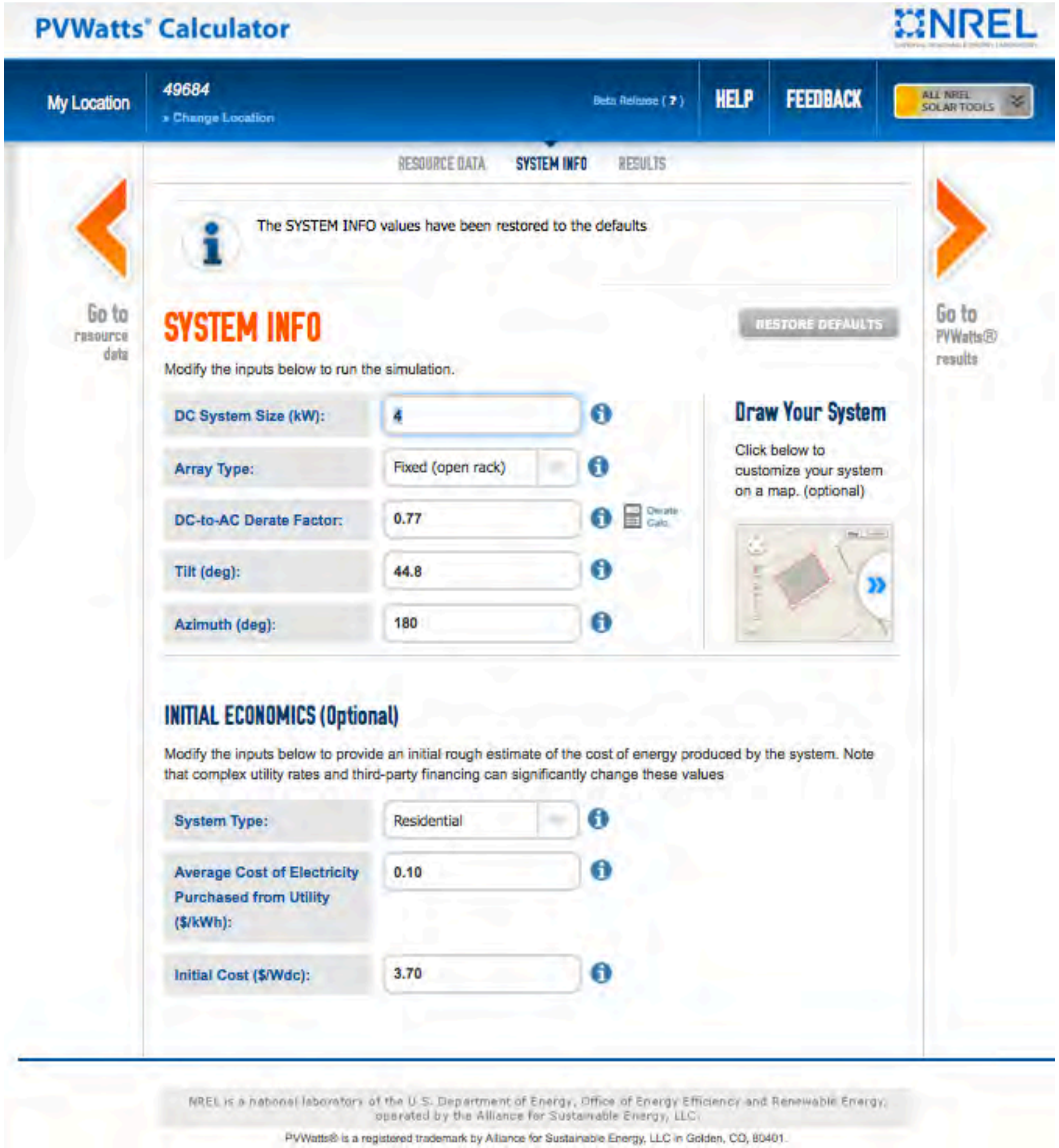
# Using PVWatts



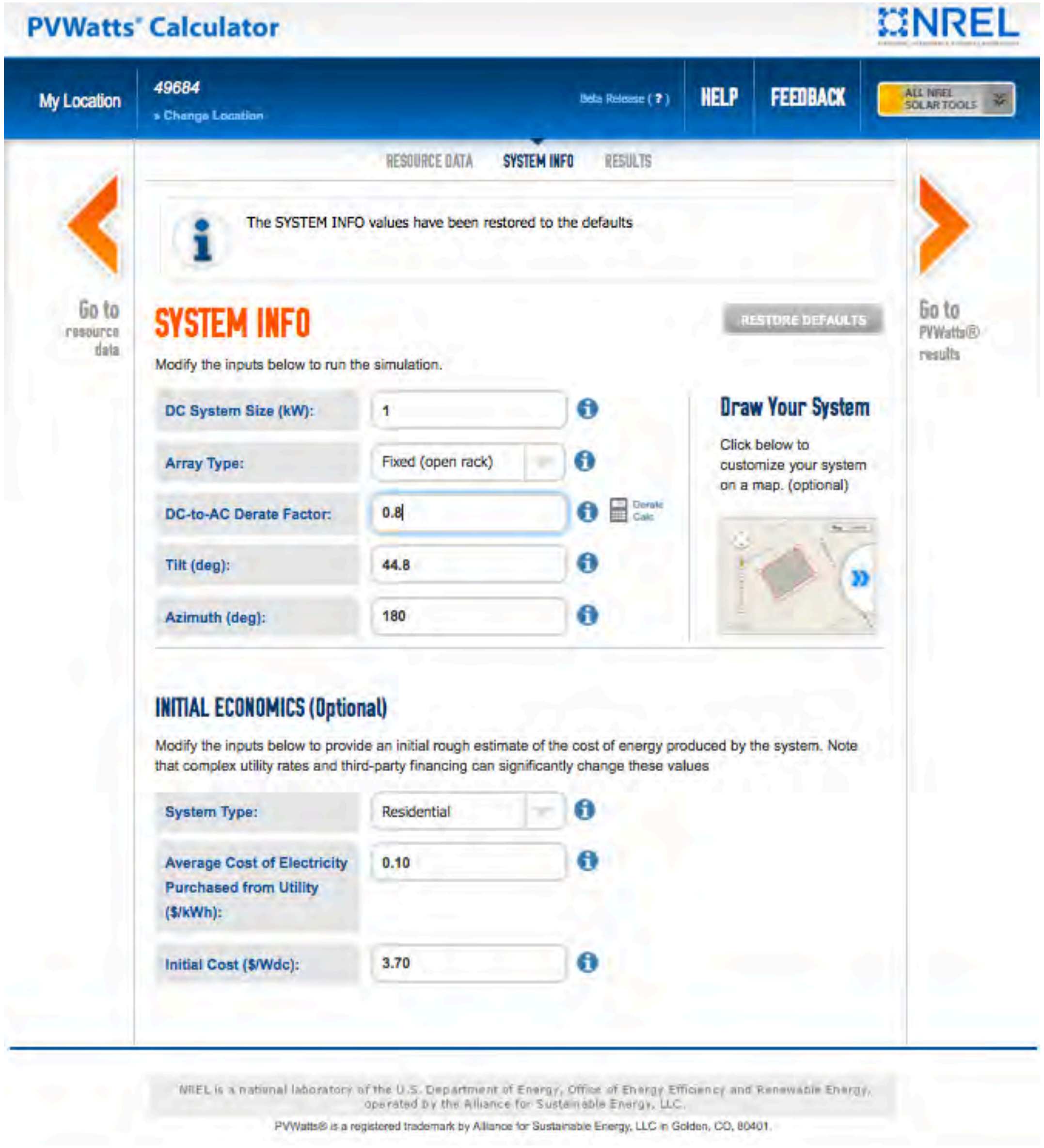
# Using PVWatts



# Using PVWatts



# Using PVWatts



# Using PVWatts

PVWatts® Calculator

NREL

My Location 49684

» Change Location

Beta Release ( ? ) HELP FEEDBACK ALL NREL SOLAR TOOLS

RESOURCE DATA SYSTEM INFO RESULTS

Go to system info

## RESULTS

Print Results

**1,116** kWh per Year

| Month | Solar Radiation ( $kWh / m^2 / day$ ) | AC Energy ( kWh ) | Energy Value ( $ ) |
|---|---|---|---|
| January | 2.22 | 57 | 5 |
| February | 3.44 | 81 | 8 |
| March | 4.41 | 111 | 11 |
| April | 4.58 | 106 | 10 |
| May | 5.58 | 130 | 12 |
| June | 5.70 | 125 | 12 |
| July | 5.54 | 122 | 12 |
| August | 4.99 | 112 | 11 |
| September | 4.66 | 104 | 10 |
| October | 3.30 | 78 | 7 |
| November | 2.18 | 51 | 5 |
| December | 1.61 | 40 | 4 |
| Annual | 4.02 | 1,116 | $ 106 |

# Using PVWatts

Go to
system info

Download Results: Monthly | Hourly

Find A Local Installer

**Caution:** Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Similarly, the "Energy Value" column simply multiplies the utility-average electricity price by production. Complex utility rates and financing can significantly impact the energy value. See Help for additional guidance.

## Location and Station Identification

| | |
|---|---|
| Requested Location | 49684 |
| Weather Data Source | TRAVERSE CITY CHERRY CAPITAL, MICHIGAN (TMY3) |
| Latitude | 44.73° N |
| Longitude | 85.58° W |

## PV System Specifications *(Residential)*

| | |
|---|---|
| DC Rating | 1 kW |
| DC to AC Derate Factor | 0.8 |
| Array Type | Fixed (open rack) |
| Array Tilt | 44.8° |
| Array Azimuth | 180° |

## Initial Economic Comparison

| | |
|---|---|
| Average Cost of Electricity Purchased from Utility | 0.10 $/kWh |
| Cost of Electricity Generated by System | 0.27 $/kWh |

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

# Using PVWatts

| Month | Solar Radiation ( kWh / $m^2$ / day ) | AC Energy ( kWh ) |
|---|---|---|
| January | 2.22 | 57 |
| February | 3.44 | 81 |
| March | 4.41 | 111 |
| April | 4.58 | 106 |
| May | 5.58 | 130 |
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| July | 5.54 | 122 |
| August | 4.99 | 112 |
| September | 4.66 | 104 |
| October | 3.30 | 78 |
| November | 2.18 | 51 |
| December | 1.61 | 40 |
| Annual | 4.02 | 1,116 |

# Using PVWatts

| Month | Solar Radiation ( kWh / $m^2$ / day ) | AC Energy ( kWh ) |
|---|---|---|
| January | 2.22 | 57 |
| February | 3.44 | 81 |
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| July | 5.54 | 122 |
| August | 4.99 | 112 |
| September | 4.66 | 104 |
| October | 3.30 | 78 |
| November | 2.18 | 51 |
| December | 1.61 | 40 |
| Annual | 4.02 | 1,116 |

Dec = 83% Sun

.83 x 40 = 33.2 kWh

# Using PVWatts

| Month | Solar Radiation ( kWh / m² / day ) | AC Energy ( kWh ) |
|---|---|---|
| January | 2.22 | 57 |
| February | 3.44 | 81 |
| March | 4.41 | 111 |
| April | 4.58 | 106 |
| May | 5.58 | 130 |
| June | 5.70 | 125 |
| July | 5.54 | 122 |
| August | 4.99 | 112 |
| September | 4.66 | 104 |
| October | 3.30 | 78 |
| November | 2.18 | 51 |
| December | 1.61 | 40 |
| Annual | 4.02 | 1,116 |

.83 x 57 = 47.3
.75 x 81 = 60.8

.81 x 51 = 41.3
.83 x 40 = 33.2

# Using PVWatts

| Month | Solar Radiation ( kWh / m² / day ) | AC Energy ( kWh ) | |
|---|---|---|---|
| January | 2.22 | 57 | .83 x 57 = 47.3 |
| February | 3.44 | 81 | .75 x 81 = 60.8 |
| March | 4.41 | 111 | |
| April | 4.58 | 106 | |
| May | 5.58 | 130 | |
| June | 5.70 | 125 | |
| July | 5.54 | 122 | |
| August | 4.99 | 112 | |
| September | 4.66 | 104 | |
| October | 3.30 | 78 | |
| November | 2.18 | 51 | .81 x 51 = 41.3 |
| December | 1.61 | 40 | .83 x 40 = 33.2 |
| Annual | 4.02 | 1,116 | 1,070.6 |

# General Math

General Math Problems

24 V (E) X 15 A (I) = ____360____ Watts

__360__ Watts X 12 hours/day run time = __4320__ Watt hours/day

__4320__ Watt hours/day X 7 days/week = __30,240__ Watt hours/week

__30,240__ Watt hours/week X 4 weeks/month = Watt hours/month

120,960__ Watt/hours/Mo / 1000 = __120.96__ kWh/month

kWh/Mo. X $0.16 = $__19.35__ to operate device/ month

# General Math

1. 115 V (E) 5 A (I) 2.5 hours/day run time. Find:

___575___ W ___1437.5___ Wh/d

2. 75 W 115 V (E) Find:

___.65___ A (I)

3. 110 V (E) 15 A (I) 12 hours run time Find:

___1,650___ Watts ___19,800___ Watt hours/day ___594,000___ Watt hours/month

4. 120 Wh/d 2 A (I) 3 hrs/day Find:

___40___ W ___20___ V (E)

5. 2 – 60 watt incandescent lights run 5 hours per day. Find:

___600___ Wh/day ___4200___ Wh/week

# General Math

1. 115 V (E) 5 (I) 2.5 hours/day run time. Find:

__________ W __________Wh/d

2. 75 W 115 V (E) Find:

__________ A (I)

3. 110 V (E) 15 A (I) 12 hours run time Find:

__________ Watts __________ Watt hours/day __________ Watt hours/month

4. 120 Wh/d 2 A (I) 3 hrs/day Find:

__________ W __________ V (E)

5. 2 – 60 watt incandescent lights run 5 hours per day. Find:

__________ Wh/day __________ Wh/week

# General Math

6. 4 – 40 watt incandescent lights run 3 hours per day. Find:

__480__ Wh/day __3,360__ Wh/week

7. 3 – 75 watt incandescent lights run 3 hours per day. Find:

__675__ Wh/day __4,725__ Wh/week

8. A pop machine has a label that says: 115 V 12 A. We know that the machine operates 12 hours per day. Calculate:

__1,380__ Watts __16,560__ Watt hours/day __16.6__ kWh/d

$ __2.65__ /day to operate @ $0.16/kWh

# General Math

6. 4 – 40 watt incandescent lights run 3 hours per day. Find:

___________ Wh/day ___________ Wh/week

7. 3 – 75 watt incandescent lights run 3 hours per day. Find:

___________ Wh/day ___________ Wh/week

8. A pop machine has a label that says: 115 V 12 A. We know that the machine operates 12 hours per day. Calculate:

___________ Watts ___________ Watt hours/day ___________ kWh/d

$ ___________ /day to operate @ $0.12/kWh

# General Math

9. A swimming pool has a pump that operates 24 hours/day during the summer months. The nameplate on the motor says: 220 V 16 A. Calculate:

__3,520__ Watts __84,480__ Watt hours/day __84.48__ kWh/d

__2,534.4__ kWh/month $__405.50__/month to operate @ $0.12/kWh

2,534.4 x 2 = 5,068.8 kWh/month

10. A refrigerator nameplate says: 115 V 6 A. We know that the refrigerator runs time is 10 hours each day. Calculate:

__690__ Watts __6900__ Watt hours/day __6.9__ kWh/d

$__1.10__ /day to operate @ $0.12/kWh

11. A 40 gallon electric water heater data sheet indicates that it consumes 4828 kWh per year and operates on a 220 V circuit. Calculate:

__13.2__ kWh/day consumption __13,200__ Wh/day consumption

# General Math

9. A swimming pool has a pump that operates 24 hours/day during the summer months. The nameplate on the motor says: 220 V  16 A. Calculate:

__________ Watts  __________ Watt hours/day  __________ kWh/d

__________ kWh/month $__________ /month to operate @ $0.12/kWh

10. A refrigerator nameplate says: 115 V  6 A. We know that the refrigerator runs time is 10 hours each day. Calculate:

__________ Watts  __________ Watt hours/day  __________ kWh/d

$__________ /day to operate @ $0.12/kWh

11. A 40 gallon electric water heater data sheet indicates that it consumes 4828 kWh per year and operates on a 220 V circuit. Calculate:

__________ kWh/day consumption  __________ Wh/day consumption

# General Math

12. A 80 gallon electric water heater data sheet indicates that is consumes 5047 kWh per year and operates on a 220 V circuit. Calculate:

__13.8__ kWh/day consumption _13,800_ Wh/day consumption

13. An 840 Watt wash machine does 6 loads per week .5 hours per load. Calculate:

__420__ Wh/load _2,520_ Wh/load

14. Average the following monthly kWh consumption and find the following:

_429.2_ Average kWh/month __14.1__ kWh/day

_14,100_ Wh/day

| | | | |
|---|---|---|---|
| Jun 410 kWh | May 420 kWh | Aug 620 kWh | Jul 340 kWh |
| Sep 490 kWh | Oct 350 kWh | Nov 400 kWh | Dec 350 kWh |
| Feb 440 kWh | Jan 500 kWh | Apr 370 kWh | Mar 460 kWh |

# General Math

12. A 80 gallon electric water heater data sheet indicates that is consumes 5047 kWh per year and operates on a 220 V circuit. Calculate:

__________ kWh/day consumption     __________ Wh/day consumption

13. An 840 Watt wash machine does 6 loads per week .5 hours per load. Calculate:

__________ Wh/load     __________ Wh/load

14. Average the following monthly kWh consumption and find the following:

__________ Average kWh/month     __________ kWh/day

__________ Wh/day

| | | | |
|---|---|---|---|
| Jun 410 kWh | May 420 kWh | Aug 620 kWh | Jul 340 kWh |
| Sep 490 kWh | Oct 350 kWh | Nov 400 kWh | Dec 350 kWh |
| Feb 440 kWh | Jan 500 kWh | Apr 370 kWh | Mar 460 kWh |

# General Math

15. Average the following monthly kWh consumption and find the following:

450.9 Average kWh/month     14.8 kWh/day

14,800 Wh/day

| | | | |
|---|---|---|---|
| Jan 353 kWh | Feb 428 kWh | Mar 550 kWh | Apr 431 kWh |
| May 431 kWh | Jun 444 kWh | Jul 475 kWh | Aug 311 kWh |
| Sep 484 kWh | Oct 518 kWh | Nov 335 kWh | Dec 651 kWh |

# General Math

15. Average the following monthly kWh consumption and find the following:

__________ Average kWh/month    __________ kWh/day

__________ Wh/day

| | | | |
|---|---|---|---|
| Jan 353 kWh | Feb 428 kWh | Mar 550 kWh | Apr 431 kWh |
| May 431 kWh | Jun 444 kWh | Jul 475 kWh | Aug 311 kWh |
| Sep 484 kWh | Oct 518 kWh | Nov 335 kWh | Dec 651 kWh |

# Load Profiles

6-60 W ___360___ W X 3hrs/d ___1080___ X 7 days = ___7560___ Wh/wk

1 -25 W ___25___ W X 1 hrs/d ___25___ X 7 days = ___175___ Wh/wk

2 – 65 W ___130___ W X 15 min/d ___32.5___ X 7 days = ___227.5___ Wh/wk

5 – 60 W ___300___ W X 1 hrs/d ___300___ X 7 days = ___2100___ Wh/wk

1 – 100 W ___100___ W X 6 hrs/d ___600___ X 7 days = ___4200___ Wh/wk

1 – 100 W ___100___ W X 6 hrs/d ___600___ X 7 days = ___4200___ Wh/wk

4 – 60 W ___240___ W X 1 hrs/d ___240___ X 7 days = ___1680___ Wh/wk

4 – 60 W ___240___ W X 6 hrs/week = ___1440___ Wh/wk

4 – 60 W ___240___ W X 2 hrs/d ___480___ X 7 days = ___3360___ Wh/wk

1 – 100 W ___100___ w X 6 hrs/d ___600___ X 7 days = ___4200___ Wh/wk

= ___29,142.5___ total Wh/week

# Load Profiles

6-60 W ___________ W X 3hrs/d ___________ X 7 days = _______________ Wh/wk

1 -25 W __________ W X 1 hrs/d __________ X 7 days = _______________ Wh/wk

2 – 65 W __________ W X 15 min/d __________ X 7 days = _______________ Wh/wk

5 – 60 W __________ W X 1 hrs/d __________ X 7 days = _______________ Wh/wk

1 – 100 W __________ W X 6 hrs/d __________ X 7 days = _______________ Wh/wk

1 – 100 W __________ W X 6 hrs/d __________ X 7 days = _______________ Wh/wk

4 – 60 W __________ W X 1 hrs/d __________ X 7 days = _______________ Wh/wk

4 – 60 W __________ W X 6 hrs/week = _______________ Wh/wk

4 – 60 W __________ W X 2 hrs/d __________ X 7 days = _______________ Wh/wk

1 – 100 W __________ w X 6 hrs/d __________ X 7 days = _______________ Wh/wk

= _______________ total Wh/week

# System Sizing Basics

- Add 12 months electrical bills = kWh/year
- Divide by 365 days = kWh/day
- kWh/day divided by solar resource for location = system size in kW
- Divide system size by .80 (derate factor) = system size corrected for inefficiencies

# Load Profiles

= 29,142.5 total Wh/week

$\frac{29{,}142.5 \text{ Wh/week}}{7 \text{ days}}$ = 4163 Wh/d

$\frac{4163 \text{ Wh/d}}{4 \text{ Sun Hours}}$ = 1040.7 W system

1041 W System /.80 (derating factor 20%)

= 1301.3 W system size

# Load Profiles

= _______________ total Wh/week

_________________________ Wh/week
7 days

= _________________________ Wh/d

________________________ Wh/d
4 Sun Hours

= _________________________ W system

_________________________W System /.80 (derating factor 20%)

= _________________________ W system size

# Load Profiles

Phantom Load Profile

| | | | | |
|---|---|---|---|---|
| Cell phone charger | 10 watts | 24 hrs/day X 7 days = | 1680 | Wh/wk |
| Cordless phone transformer | 5 Watts | 24 hrs/day X 7 days = | 840 | Wh/wk |
| Answering machine | 10 Watts | 24 hrs/day X 7 days = | 1680 | Wh/wk |
| Radio battery charger | 6 Watts | 24 hrs/day X 7 days = | 1008 | Wh/wk |
| Fax transformer | 6 Watts | 24 hrs/day X 7 days = | 1008 | Wh/wk |
| Cable box | 5 Watts | 24 hrs/day X 7 days = | 840 | Wh/wk |
| Wall clock | 4 Watts | 24 hrs/day X 7 days = | 672 | Wh/wk |
| Wall clock | 4 Watts | 24 hrs/day X 7 days = | 672 | Wh/wk |
| Alarm clock | 4 Watts | 24 hrs/day X 7 days = | 672 | Wh/wk |
| | | = | 9072 | total Wh/wk |

# Load Profiles

Phantom Load Profile

| | | |
|---|---|---|
| Cell phone charger | 10 watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Cordless phone transformer | 5 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Answering machine | 10 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Radio battery charger | 6 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Fax transformer | 6 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Cable box | 5 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Wall clock | 4 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Wall clock | 4 Watts | 24 hrs/day X 7 days = __________ Wh/wk |
| Alarm clock | 4 Watts | 24 hrs/day X 7 days = __________ Wh/wk |

= _______________ total Wh/wk

# Load Profiles

Phantom Load Profile

= 9,072 total Wh/wk

9,072 Wh/wk / 7 days = 1,296 Wh/d

1,296 Wh/d / 4 Sun Hours = 324 W system

324 W system /.80 (derate factor 20%)

= 405 W system size

Energy Efficiency recommendations:

# Load Profiles

Phantom Load Profile

= _______________ total Wh/wk

_______________ Wh/wk
7 days = _______________ Wh/d

_______________ Wh/d
4 Sun Hours = ________________ W system

_______________ W system /.80 (derate factor 20%)

= _______________ W system size

Energy Efficiency recommendations:

# Energy Efficiency

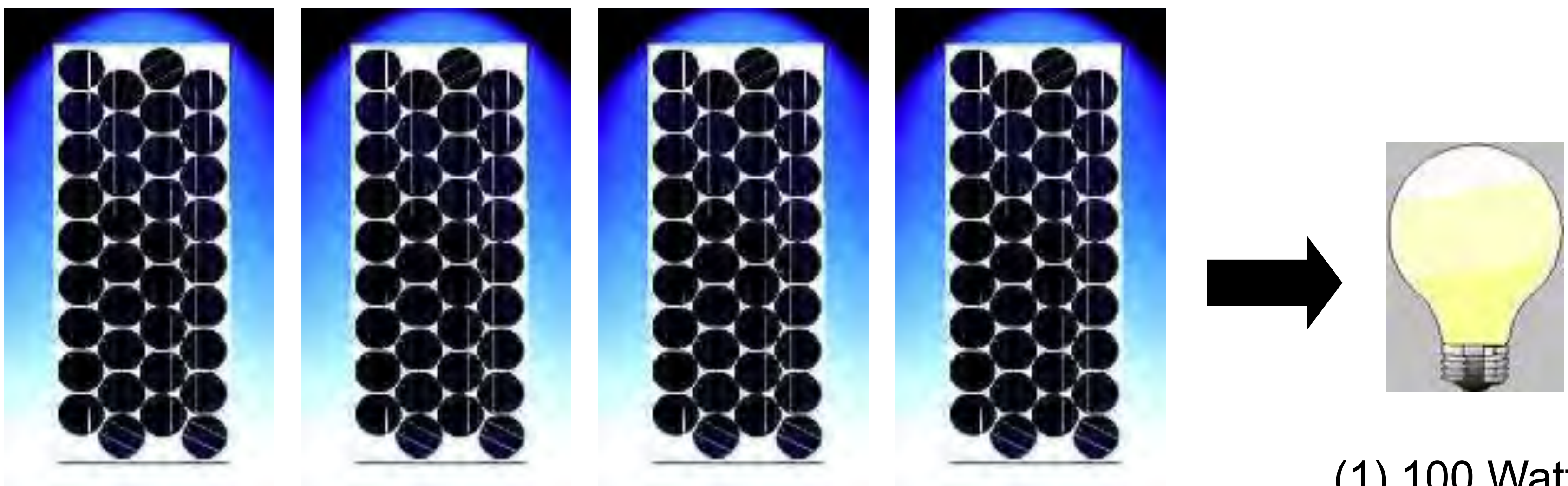
Energy Efficiency =

Doing the *same* work …

with *less* energy

# Energy Efficiency

## Cost-Effectiveness of Efficiency

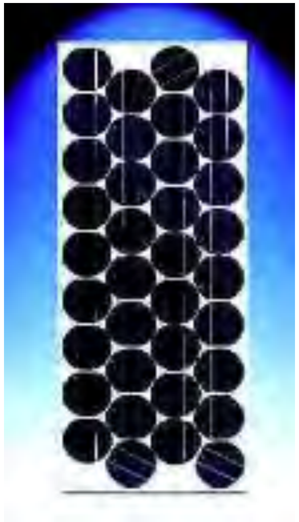


(4) 25 Watt PV panels

(1) 100 Watt
Incandescent bulb

# Energy Efficiency

Cost-Effectiveness of Efficiency



(1) 25 Watt PV Panel

(1) 25 Watt CFL
(100 W Equivalent)

# Energy Efficiency

## Cost-Effectiveness of Efficiency

### EQUAL LUMENS (light output)

<u>100 Watt Incandescent</u>

4 - 25 W PV panels
4 X $150 = $600
1 – 100 W bulb = $0.25

Total: $600.25

<u>25 Watt CFL</u>

1 - 25 W PV panel
1 X $150 = $150
1 CF bulb = $5

Total: $155.00

# Energy Efficiency

Cost-Effectiveness of Efficiency

(2) Refrigerators - one old, one new
Both 18 cubic ft

Old
3.6 kWh/day X $0.11/kWh = $0.40/day X 365 = $146/ year

New
1.3 kWh/day X $0.11/kWh = $0.14/day X 365 = $ 51.10/year

# Energy Efficiency

## Cost-Effectiveness of Efficiency

Refrigerator scenario - PV System Size

### Old

3.6 kWh/day X $0.11/kWh = $0.40/day X 365 = $146/ year

3600 Wh/day / 4 SunHrs = 900 W X $10/W = $9000 PV system

### New

1.3 kWh/day X $0.11/kWh = $0.14/day X 365 = $ 51.10/ year

1300 Wh/day / 4 SunHrs = 325 W X $10/W = $3250 PV system

# Energy Efficiency

## Cost-Effectiveness of Efficiency

Every $1 spent on energy efficiency

can reduce system cost by $3 - $5!

# Energy Efficiency

## Cost-Effectiveness of Efficiency

### Opportunities for Energy Efficiency

- Water heating - 9% to 50% of load (varies greatly)
- Refrigeration - typically 13% of load)
- Lighting - 9% of load

# Energy Efficiency

## Phantom Loads

Appliances that are turned off,
but are not *really* off!

# Energy Efficiency

## Phantom Loads

Computer
TV
Stereo
DVD player
CD player
Cell phone chargers

# Energy Efficiency

## Phantom Loads

| | |
|---|---|
| Stereo | 3 w |
| DVD player | 2 w |
| CD player | 2 w |
| TV | 3 w |
| Computer | 21 w |
| Cell phone charger | 1 w |
| | 32 w |

# Energy Efficiency

## Phantom Loads

32 W x 24 hrs/day = 768 Watt hours/day
0.768 kWh x 365 days = 280 kWh/year

280 kWh/yr x 30 people = 8,400 kWh!

Enough to power one WI home for 8 months

***… free!***

# Energy Efficiency

## Fuel Switching

Running an appliance with a cheaper fuel source

# Energy Efficiency

## Fuel Switching

- Electric water heater to gas or gas and solar water
- Electric stove to gas stove
- Electric space heating to gas and/or wood heat
- Electric dryer to gas dryer or clothes line

# System Sizing Basics

- Add 12 months electrical bills = kWh/year
- Divide by 365 days = kWh/day
- kWh/day divided by solar resource for location = system size in kW
- Divide system size by .80 (derate factor) = system size corrected for inefficiencies

# System Sizing Basics Example

Traverse City, MI sun resource = 4.0 Sun Hours/day
Annual load = 5,876 kWh/year

5,876 kWh/year
365 = 16 kWh/day

16 kWh/day
4.0 sun hours/day = 4 kW system

4 kW
.80 derate factor = 5.0 kW system
or
5,000 Watt system

# System Sizing Basics Example

Custer WI sun resource = 4.5 Sun Hours/day (use 4)
Annual load = 5,876 kWh/year

$$\frac{5{,}876 \text{ kWh/year}}{365} = 16 \text{ kWh/day}$$

$$\frac{16 \text{ kWh/day}}{4.0 \text{ sun hours/day}} = 4 \text{ kW system}$$

$$\frac{4 \text{ kW}}{.80 \text{ derate factor}} = 5.0 \text{ kW system}$$

or

5,000 Watt system

# Estimated Residential Install Costs

Utility Intertied Battery Free, Fixed Mount $7-10/W

Utility Intertied Battery Free, Tracking $8-12/W

Utility Intertied with Batteries, Fixed $9-12

Utility Intertied with Batteries, Tracking $10-13/W

Stand Alone $12-16/W

* Summer 2010, FOE

# Estimated Residential Install Costs

Utility Intertied Battery Free, Fixed Mount $7-10/W

Utility Intertied Battery Free, Tracking $8-12/W

Utility Intertied with Batteries, Fixed $9-12

Utility Intertied with Batteries, Tracking $10-13/W

Stand Alone $12-16/W

# Estimated Residential Install Costs

Utility Intertied Battery Free, Fixed Mount $4-6/W

Utility Intertied Battery Free, Tracking $5-8/W

Utility Intertied with Batteries, Fixed $6-10/W

Utility Intertied with Batteries, Tracking $7-12/W

Stand Alone $8-12/W

# System Pricing Basics

System Size = 5,000 W

Utility Intertied Battery Free, Fixed Mount $7-10/W
Utility Intertied Battery Free, Tracking $8-12/W
Utility Intertied with Batteries, Fixed $9-12
Utility Intertied with Batteries, Tracking $10-13/W
Stand Alone $12-16/W

System size X $/W install cost

Ex. 6,000 W X $10/W - $50,000 installed

# System Pricing Basics

System Size = 5,000 W

Utility Intertied Battery Free, Fixed Mount $4-6/W
Utility Intertied Battery Free, Tracking $5-8/W
Bimodal, Fixed $6-10/W
Bimodal, Tracking $7-12/W
Stand Alone $12-16/W

System size X $/W install cost

Ex. 5,000 W X $5/W - $25,000 installed

# PV Sizing - Exercise

Add 12 months of utility bills

Jan 720 kWh
Feb 550
Mar 540
Apr 327
May 390
Jun 357
Jul 363
Aug 402
Sep 560
Oct 446
Nov 623
Dec 598
Total: ???

# PV Sizing - Exercise

Add 12 months of utility bills

Jan 720 kWh
Feb 550
Mar 540
Apr 327
May 390
Jun 357
Jul 363
Aug 402
Sep 560
Oct 446
Nov 623
Dec 598
Total: 5,876 kWh/year