



Running the Electric Meter Backwards: Real-Life Experience with a Residential Solar Power System

Brooks Martner
Lafayette, Colorado

University of Toledo
Spring 2014
PHYS 4400 - Principles and Varieties of Solar Energy

Our Solar Photovoltaic (PV) System



Our Solar PV System

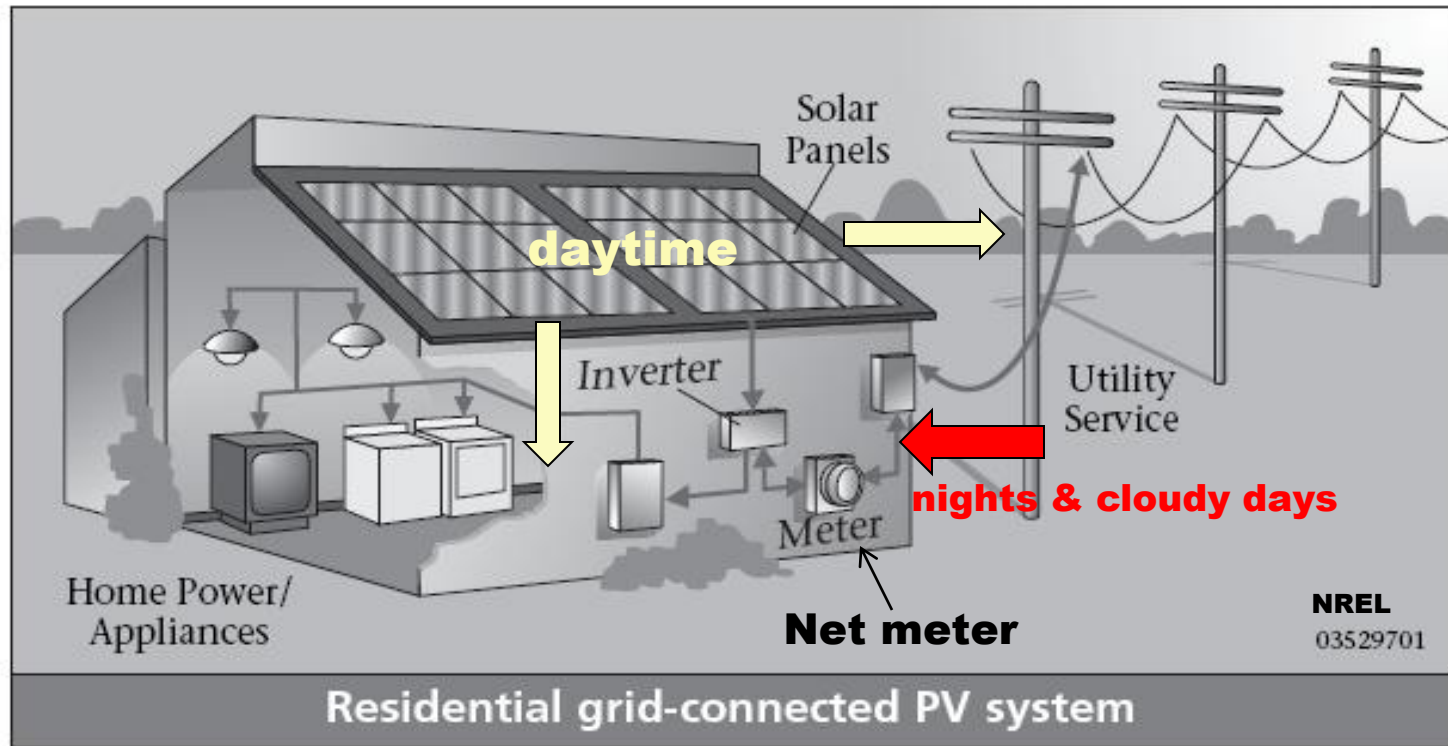
- Near Boulder, Colorado (latitude = 40 deg., alt. = 5300 ft)
- Ground-mounted
- South-facing
- Fixed-tilt at 35 degrees (no moving parts)
- Silicon polycrystalline cells
- Grid-tied with net-metering (no batteries)
- 5.1 kilowatts (DC rating)
- 30 modules (panels) of 170 watts each
- Area = 39.3 m² (approx. 52 ft x 8 ft)
- Predicted annual AC energy production ~ 7400 kWh

How much is a kilowatt-hour worth?

Answer: about 11½ cents
in Colorado and Ohio*

* state-wide average residential retail rate in 2012
according to Energy Information Admin., U.S. Dept. of Energy

What Do You Do for Electricity When the Sun Isn't Shining (like at night)?



With a “grid-tied” PV system, your back-up is already in place in the form of the utility company’s grid.

Jump-Starting the Arrival of Renewable Energy

Renewable Portfolio Standards

- **Colorado** – It's the law:
30% Renewables by 2020*
* applies to investor-owned utilities,
10% renewables for municipal and co-op utilities
- **Ohio** – It's the law:
12.5% Renewables by 2024
including 0.5% from solar.

Primary Factors Involved PV-System Design & Purchase

- ☀ Electrical Consumption of the Home
- ☀ Solar Radiation Climatology of Region
- ☀ Sun Exposure of the Site
- ☀ “Eco-karma” Benefits
- ☀ Financial Costs/Benefits



Electrical Consumption

PUBLIC SERVICE COMPANY OF COLORADO
P O BOX 840
DENVER, CO. 80201
(800) 895-4999

Customer Name	Service Address	Due Date	Account No.	Amount Due
	LAFAYETTE, CO	Dec 18, 2007		\$168.11

Account Activity				
Date of Bill	Dec 3, 2007	Previous Balance		\$103.32
Number of Payments Received	1	Total Payments		(\$103.32)
Number of Days in Billing Period	31	Balance Forward		\$0.00
Statement Number		+ Current Bill		\$168.11
Premise Number	001000007	Current Balance		\$168.11

Electric Service - Account Summary

Invoice Number	0201132727	Residential General		\$33.02
Meter No.	000035889617	GRSA		\$4.19
Rate	R Residential General	Air Quality Imp		\$0.72
Current Reading	22579 Actual 11/30/2007	Elec Commodity Adj		\$23.88
Previous Reading	21730 Actual 10/30/2007	Demand Side Mgmt Cost		\$1.10
Kilowatt-Hours Used	849	Purch Cap Cost Adj		\$11.57
		Renew. Energy Std Adj		\$0.44
		Franchise Fee		\$2.25
		Sales Tax		\$2.71
		Subtotal		\$79.88

Gas Service - Account Summary

Invoice Number	0095836510	Residential		
Meter No.	00000R519496	Usage Charge	114.00 x 0.08868	\$10.10
Rate	RG-T Residential	Interstate Pipeline	114.00 x 0.06110	\$6.97
Current Reading	2218 Actual 11/30/2007	Natural Gas - Nov	110.23 x 0.48350	\$53.30
Previous Reading	2085 Actual 10/30/2007	Natural Gas - Oct	3.77 x 0.31600	\$1.19
Measured Usage	133	Service & Facility		\$11.20
Therm Multiplier	0.8598	Franchise Fee		\$2.49
Therms Used	114.00	Sales Tax		\$2.98
		Subtotal		\$88.23

Comparison Information

			Billing Period	Kwh Usage/Month	Therm Usage	Avg. Daily Temp.
Gas	\$88.23 per month	\$2.85 per day	This Year	849	114	43°
Electric	\$79.88 per month	\$2.58 per day	Last Year	755	127	42°

Residential Electrical Consumption - 2007

	Consumption (kWh/year)	Electric Bill (\$/year)
• Our house:	7,400	781
• U.S. Average	11,232	1196

**will require approx. a 5-kW
PV system in Boulder, Colorado
to offset 100% of this annual
electric consumption**

Data source:
Energy Information Admin.,
U.S. Dept. of Energy

Climatology of Sunshine

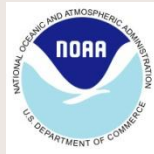


Landscape

Carolyn Ellingson '76

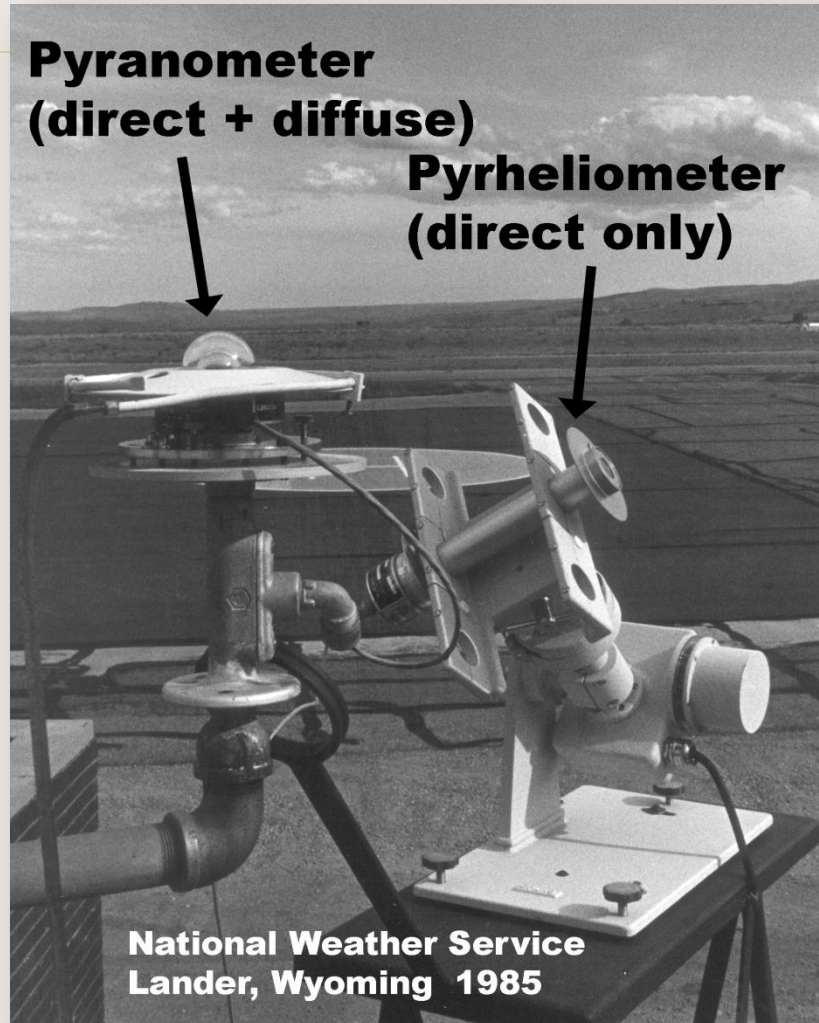
Solar Radiation Measurements:

Long-term, hourly measurements at 44 National Weather Service (NWS) sites ended 1990.



New-site measurements in progress by various agencies, especially DOE.

Interpolated-modeled hourly data are now available for **222 U.S. locations.**



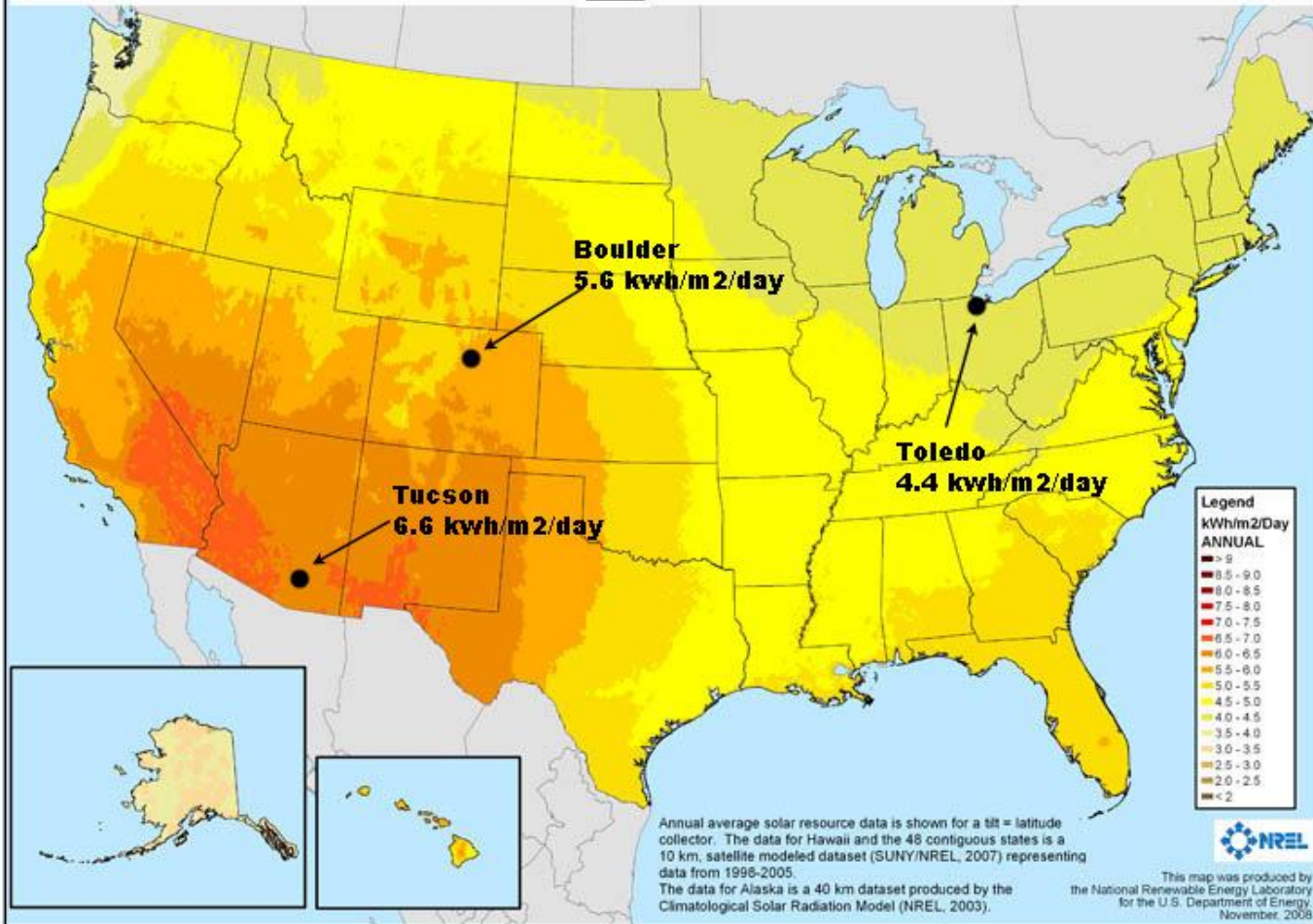
**Pyranometer
(direct + diffuse)**

**Pyrliometer
(direct only)**

**National Weather Service
Lander, Wyoming 1985**

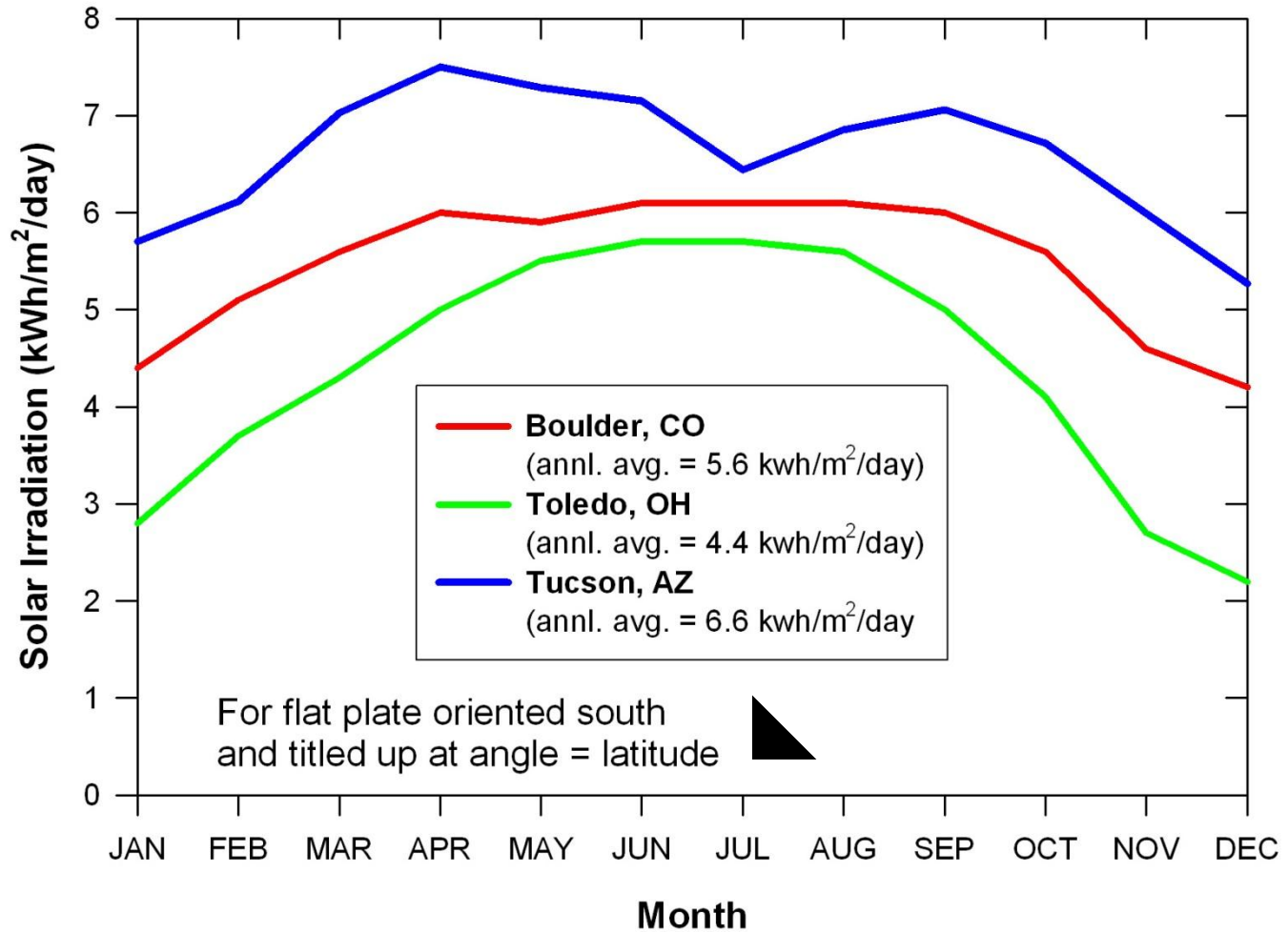
Photovoltaic Solar Resource:
Flat Plate Tilted South at Latitude

Annual



<http://www.nrel.gov/gis/solar.html>

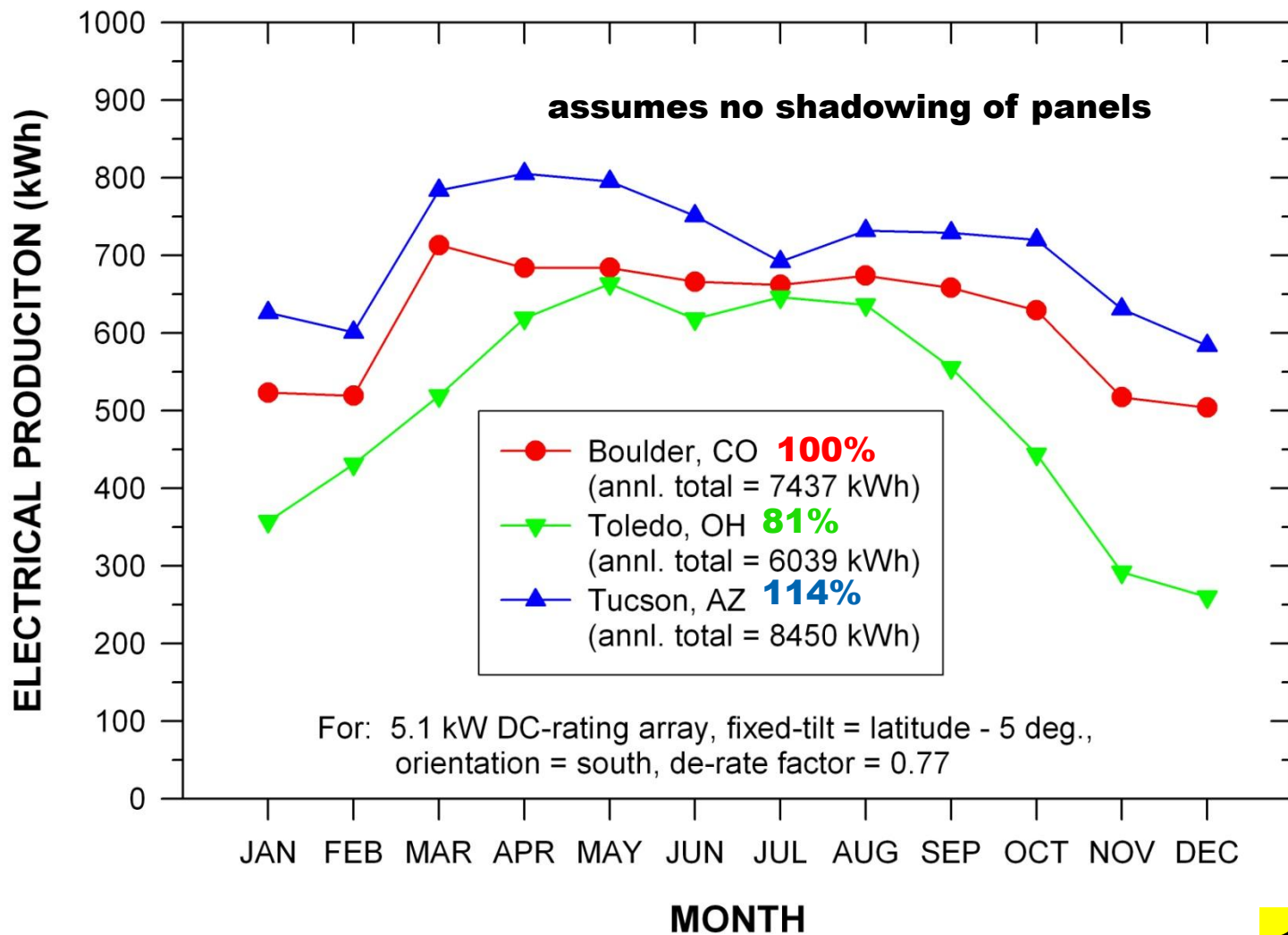
Mean Monthly Solar Radiation Long-term Averages



Calculating a PV System's Expected Electrical Production

- Using NREL's **PV-Watts** on-line calculator
<http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/>
- Input:
 - Geographic location **Boulder, Colorado**
 - DC rating of array **5.1 kW**
 - Type of array **fixed tilt**
 - Tilt **35 deg.**
 - Orientation **south**
- Output:
 - Avg. electric production for each month of the year:
Jan = 523 kWh, Feb = 519 kWh, Mar = 713 kWh, ... etc.

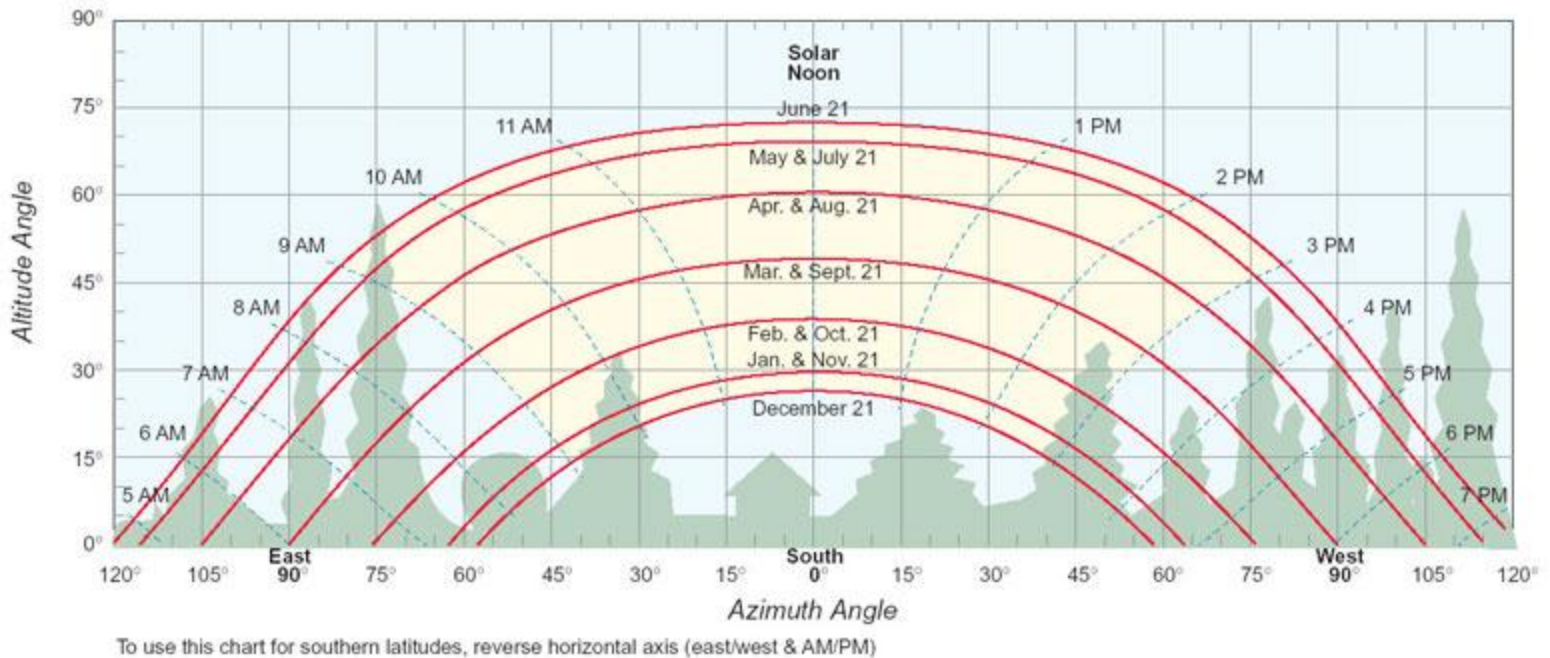
MEAN MONTHLY ELECTRICAL PRODUCTION PREDICTED BY NREL'S PV-WATTS

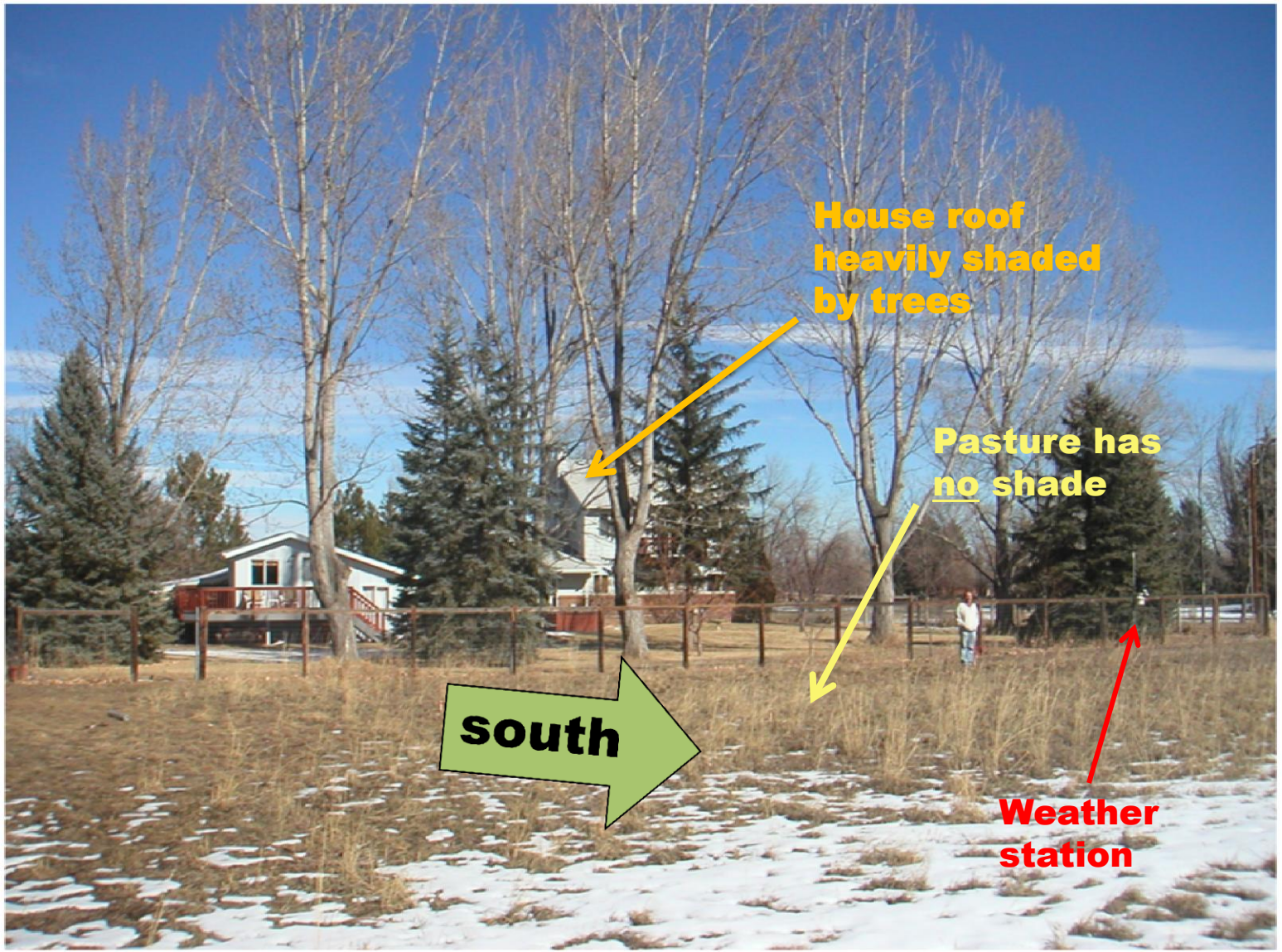


Sun Exposure of Site

Selecting a site that has little of no shading year-long

Sun Path Chart for 40° North Latitude





House roof heavily shaded by trees

Pasture has no shade

south

Weather station



Namaste Solar
— Electric —

Customer: Brooks Martner
Address: Lafayette, CO

Drawn by: Dan Yechout

Date: 06 February 2008

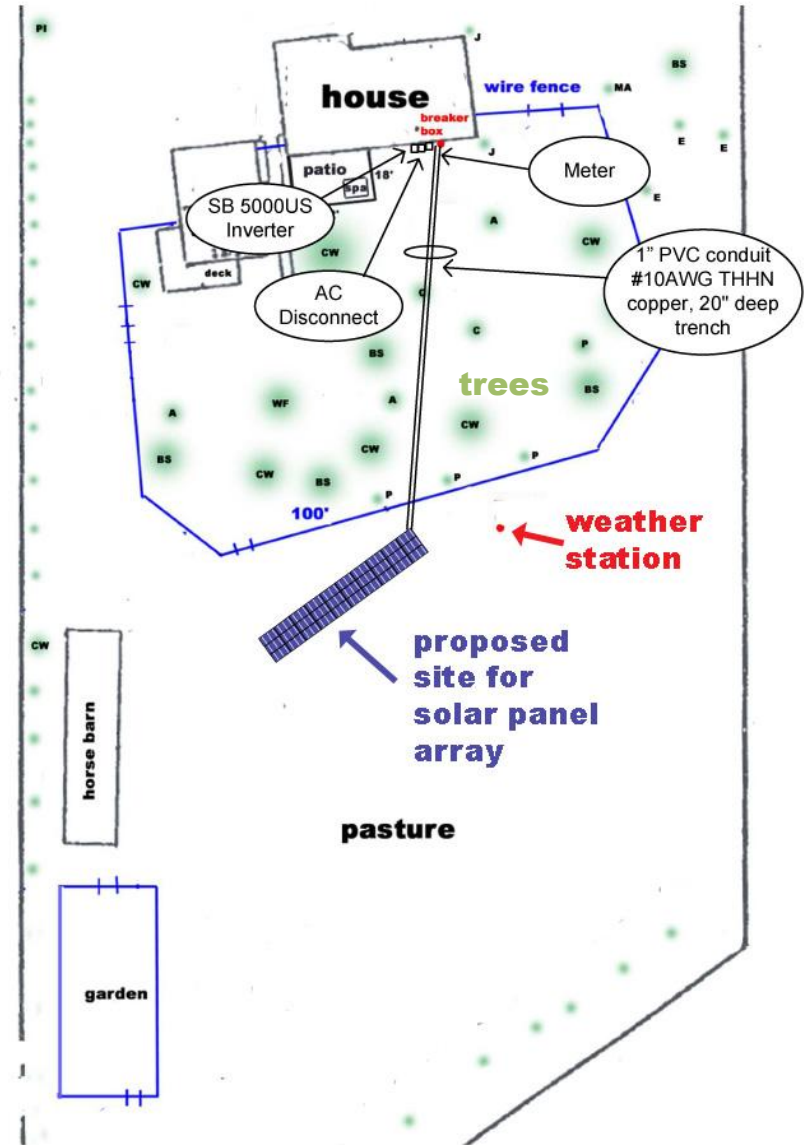
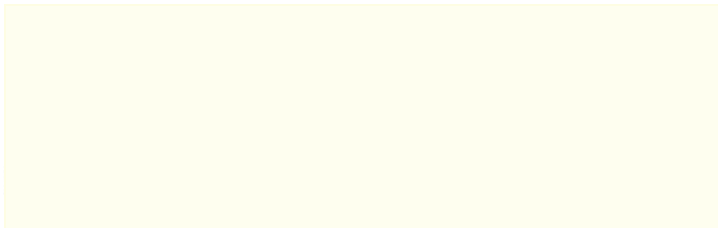
Scale : Drawn to Scale

Project type : Solar PV

Scale:
50 feet



● = Trees



Estimated “Eco-Karma” Benefits

Every year:

Clean energy production	7440 kWh
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CO ₂ emissions averted*	7 tons
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Other pollutants averted*

(e.g., NO_x, SO₂, particulates)

EPA limits

* = compared with a coal-fired electric plant

Financial: Bottom Line

In 2008:

Our out-of-pocket total cost
(after rebates and tax credit) was \$16,701
(= \$3.27/Watt)

Estimated pay-back time from
savings on monthly electric bills 14 years

In 2013:

Buying the same system would cost less today in the long run, but rebates would pay out over the first ten years, instead at the start.

Estimated pay-back time ~ 9 years.

What's new since 2008 in Colorado solar finances?

- Most home-owners don't buy solar PV systems any more; they lease instead.
- The cost of solar modules has nose-dived.
- Rebates from utility companies have also nose-dived.
- Federal tax credit is better now (but may soon disappear).
- Solar gardens are available to some electric customers.

Factors We Weighed in Our Decision to Go Solar (or not)

Buy:

- * **Very good sunshine climate**
- * **Excellent rebates from utility company**
- * **Good tax credits**
- * **Good “eco-karma”**
- * **Increases re-sale value of home?**
- * **Ideal un-shaded site**

Don't Buy:

- * **High initial cost**
- * **Long pay-back time**



**The
Beginning**

Installation



Installation



Installation



Installation



Installation



Installation



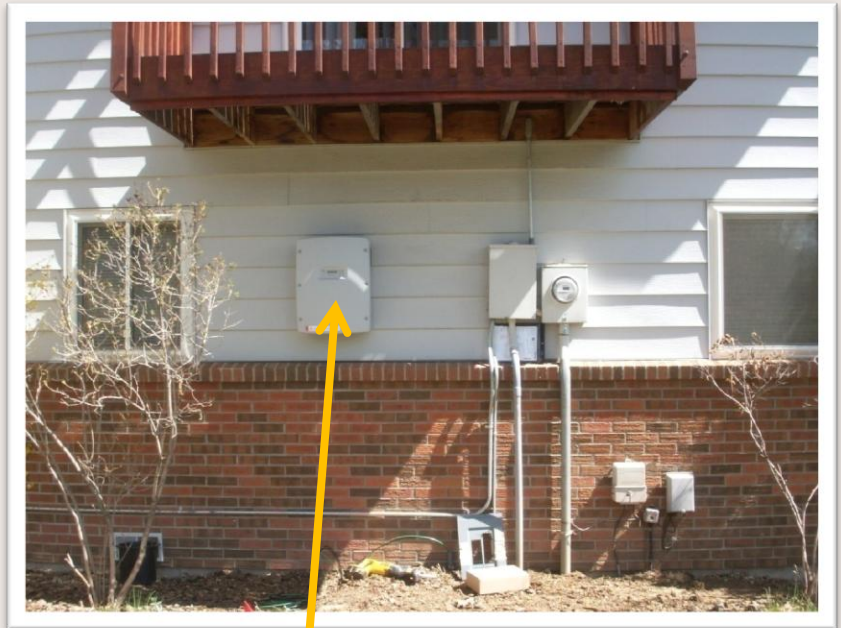
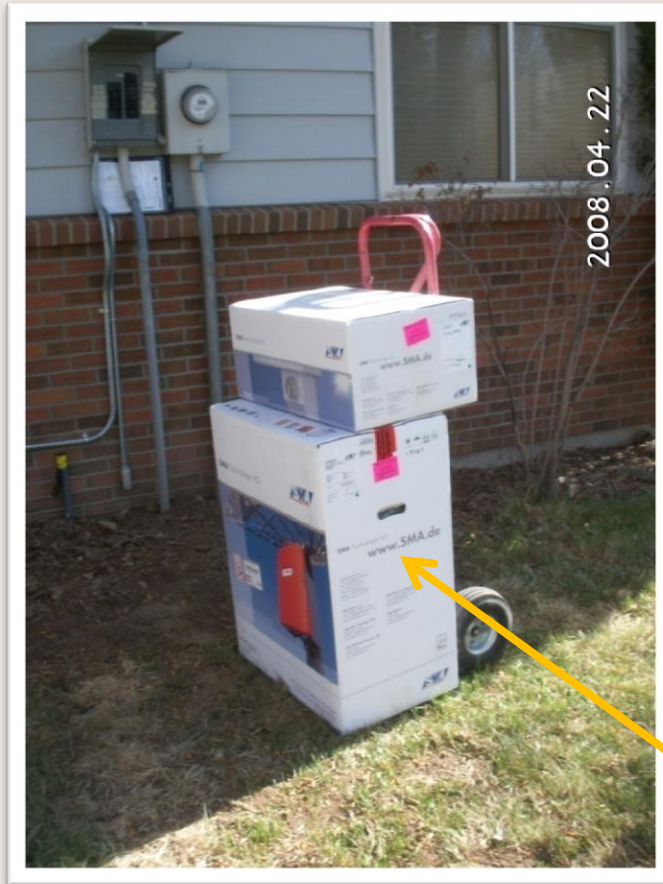
Installation



Installation

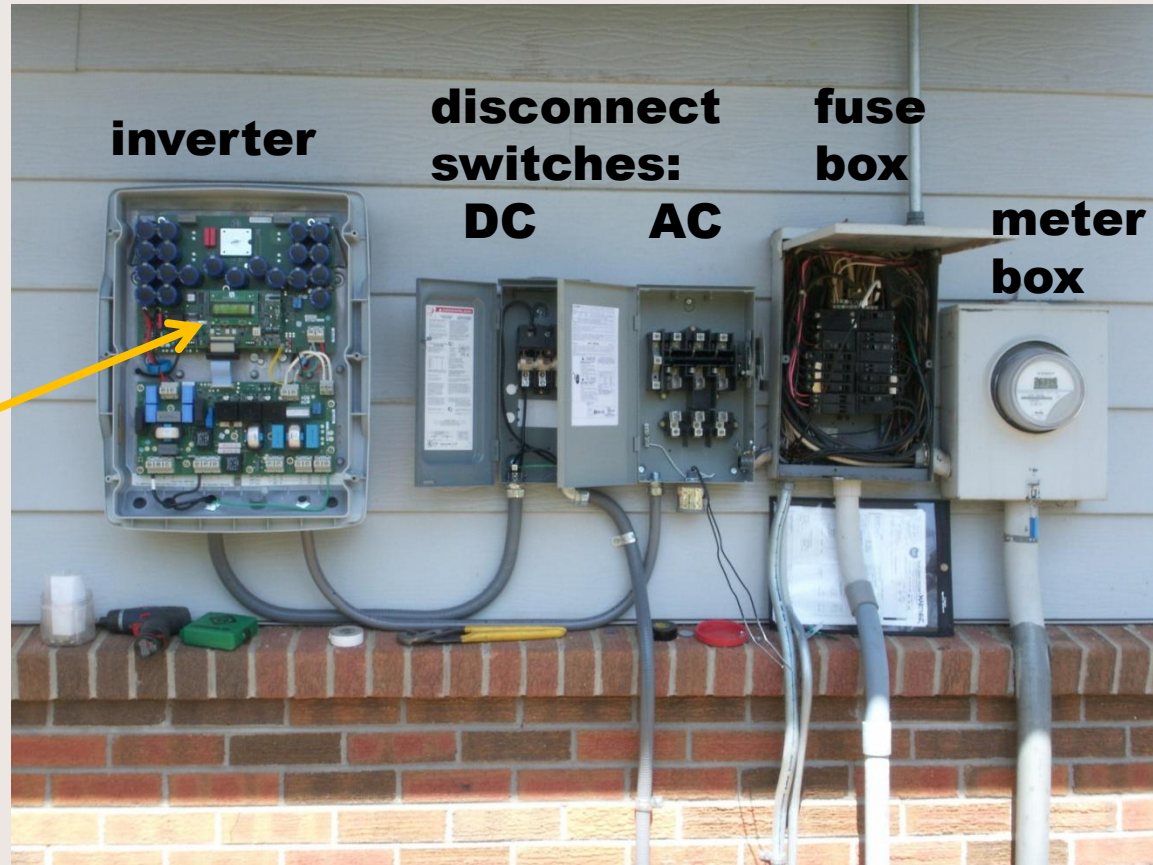


Installation



inverter

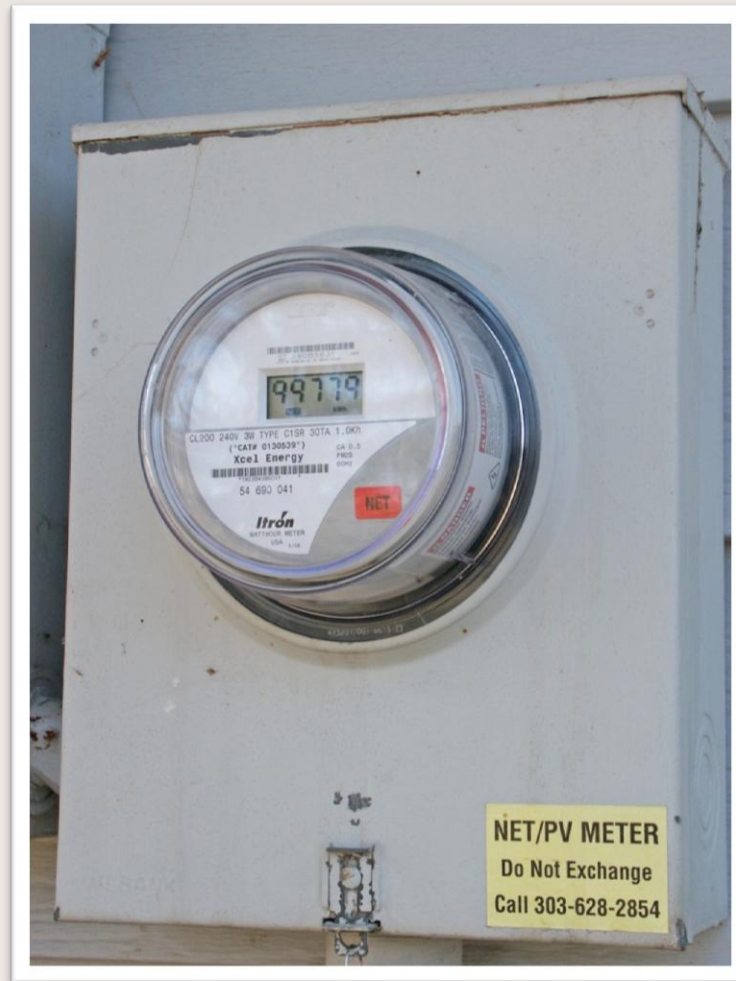
Installation



**display shows:
watts
kwh
volts
hours
etc.**

Installation

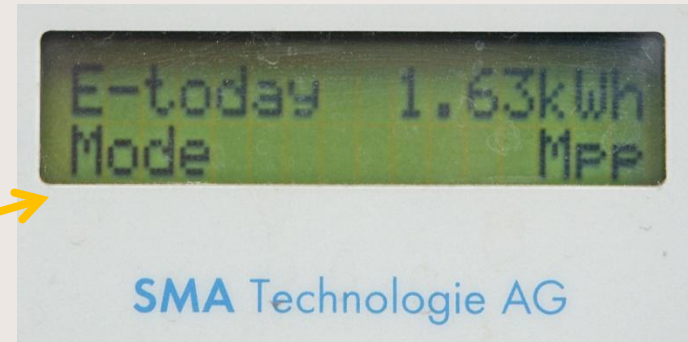
The Net Meter



**Start-up
date:
9MAY08**

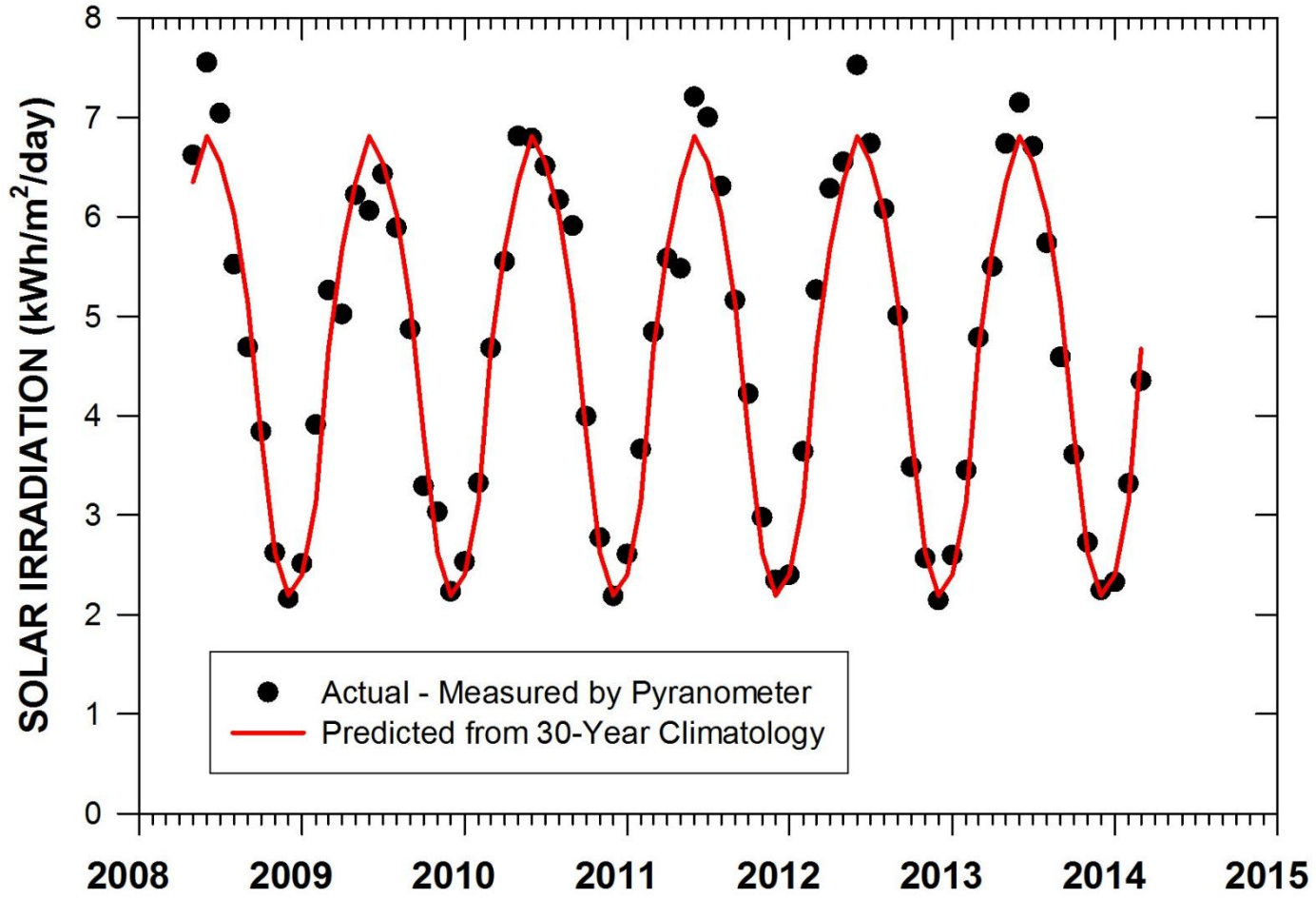
Performance in the First 6 Years

Tracking the electricity production of the solar panels with daily readings of the inverter's data display



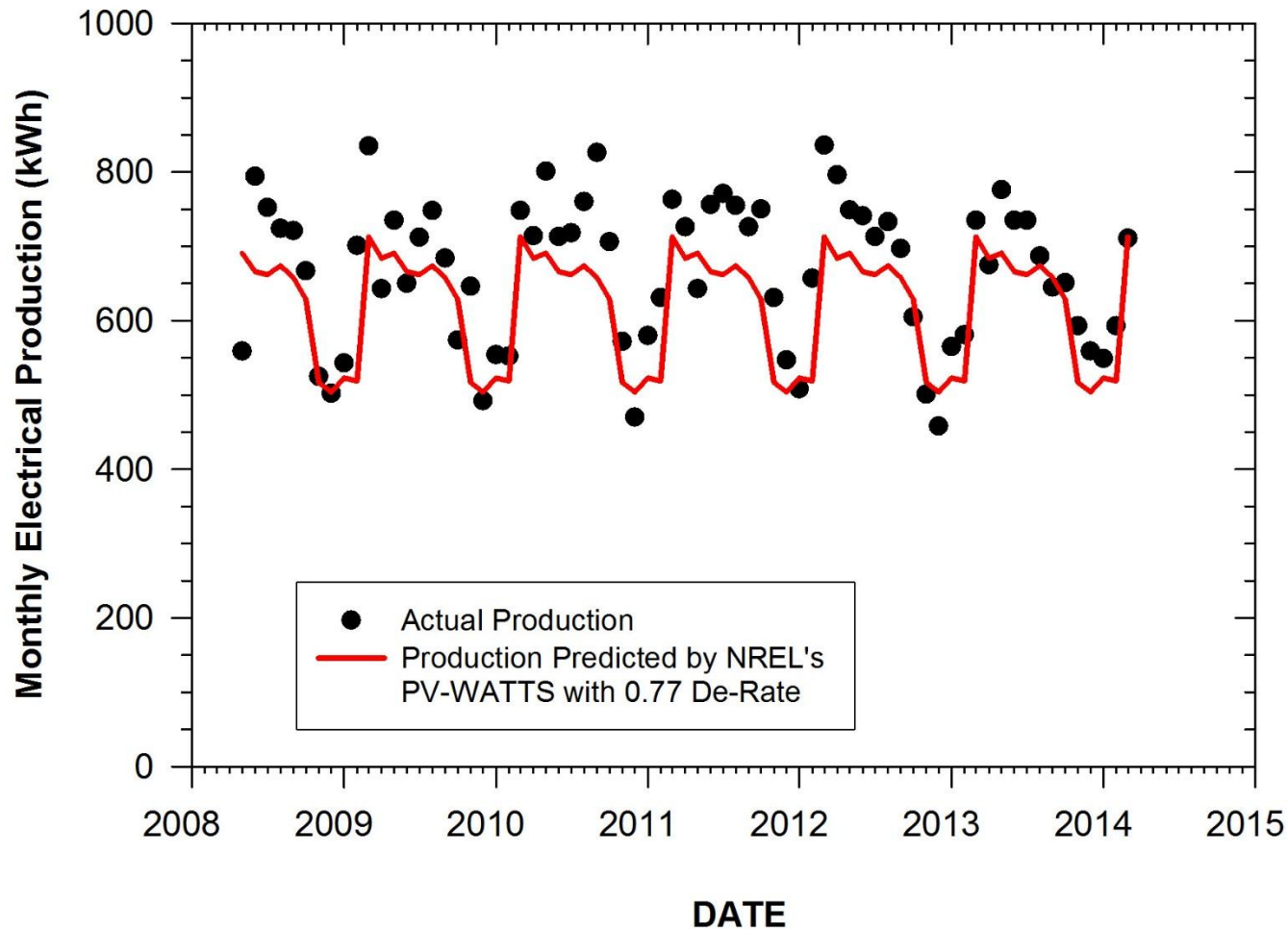
Correlating with meteorological data from our home weather station located beside the panels

INCOMING SOLAR IRRADIATION Lafayette, Colorado

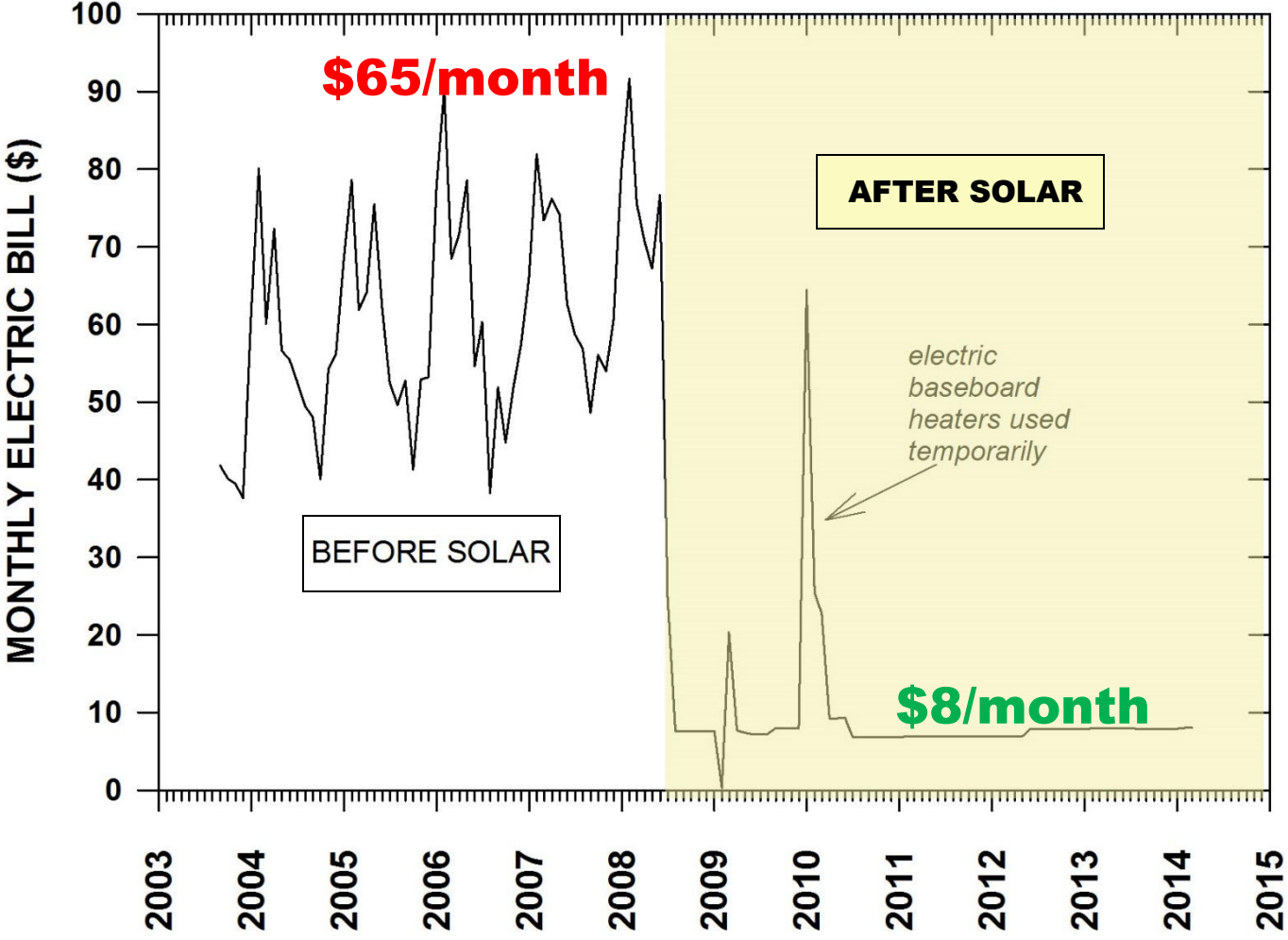


Direct + diffuse on horizontal surface

Monthly Energy Production 5.1-KW Solar Photovoltaic System Lafayette, Colorado



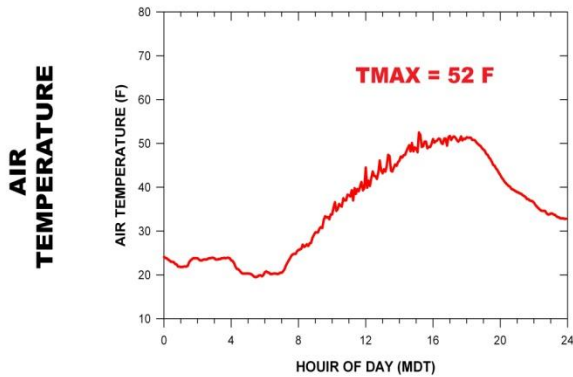
MONTHLY ELECTRIC BILL



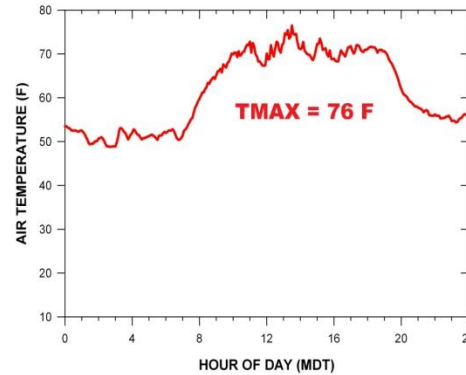
The Effect of Clouds

Three Example Days

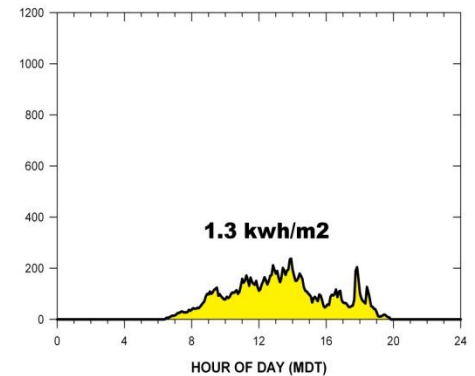
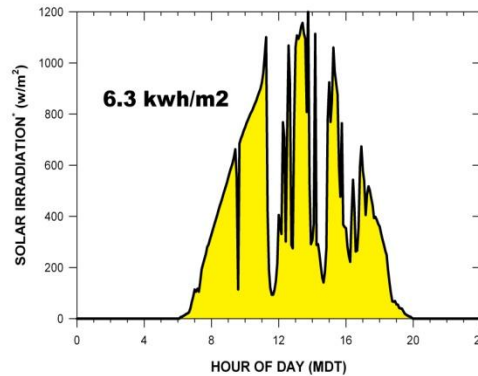
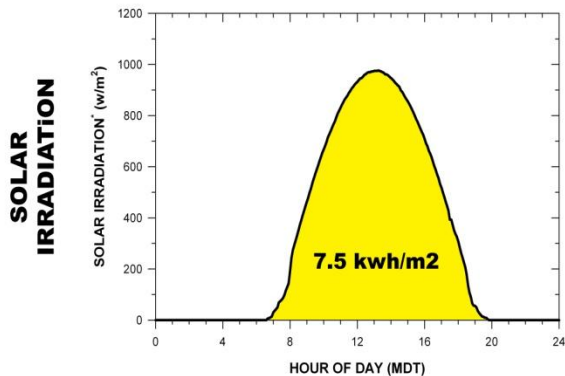
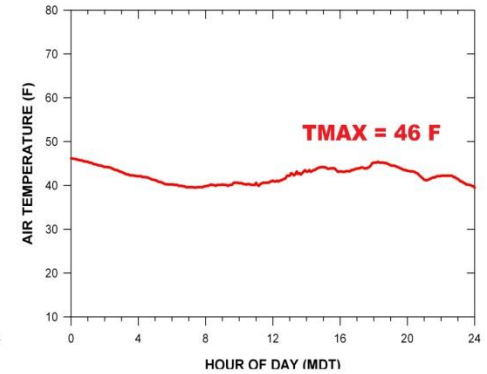
CLOUDLESS DAY
April 6, 2009



PARTLY CLOUDY DAY
April 22, 2009



OVERCAST RAINY DAY
April 25, 2009



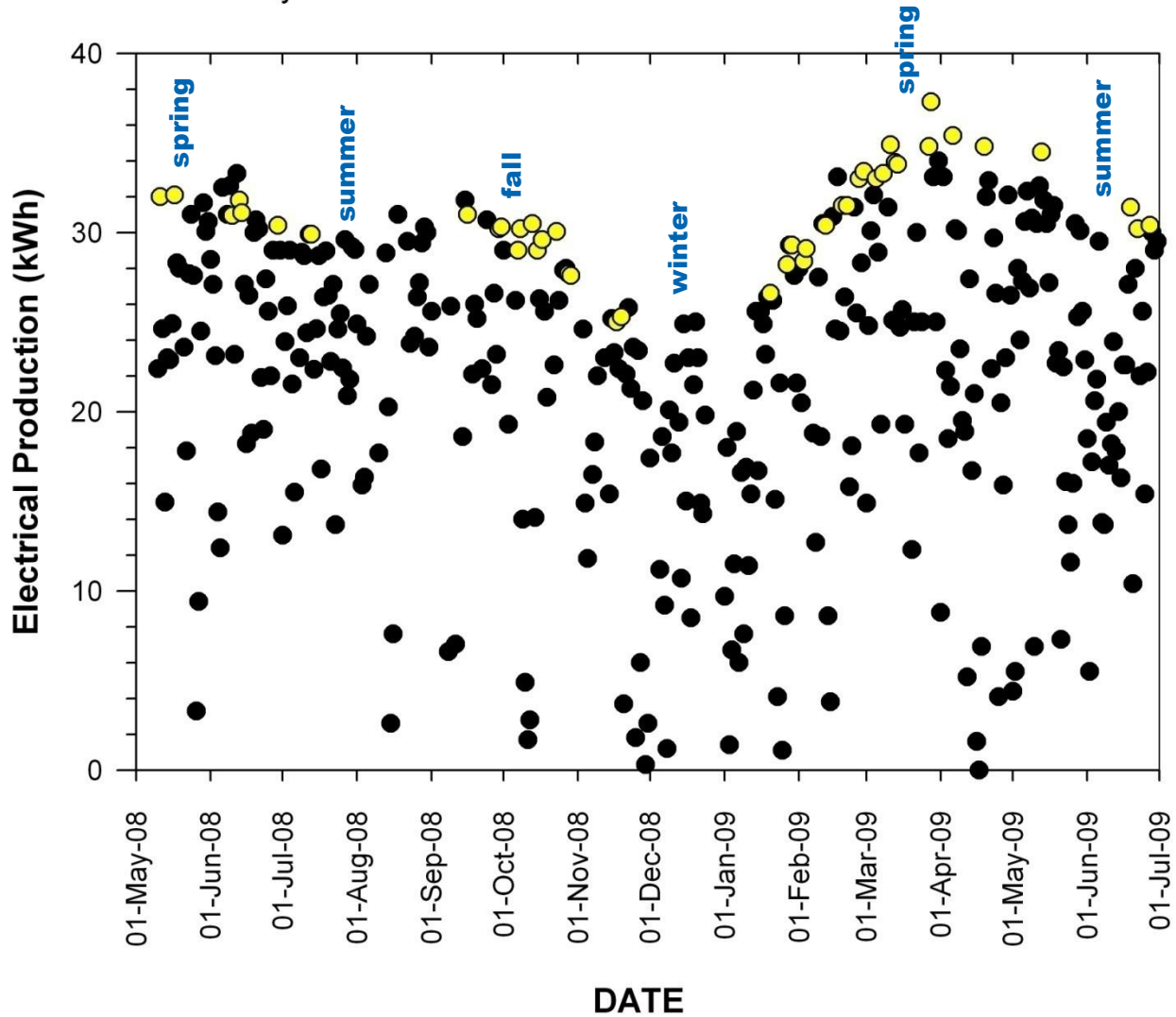
**Solar Electric
Production: 35.5 kWh**

22.4 kWh

4.1 kWh

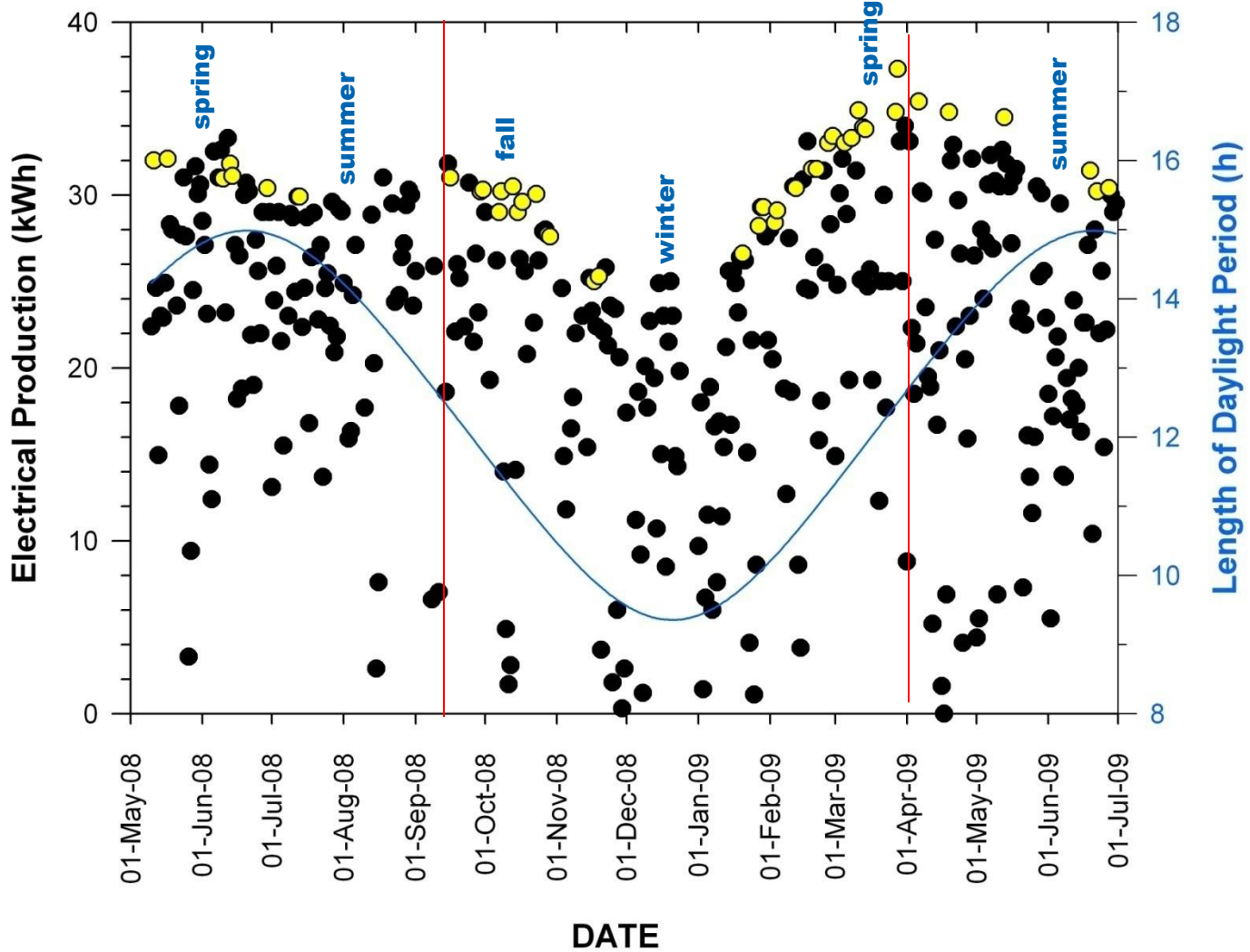
Solar PV System
Lafayette, Colorado
10May08 - 30Jun09

- Production on Days with Clouds
- Production on Cloudless Days

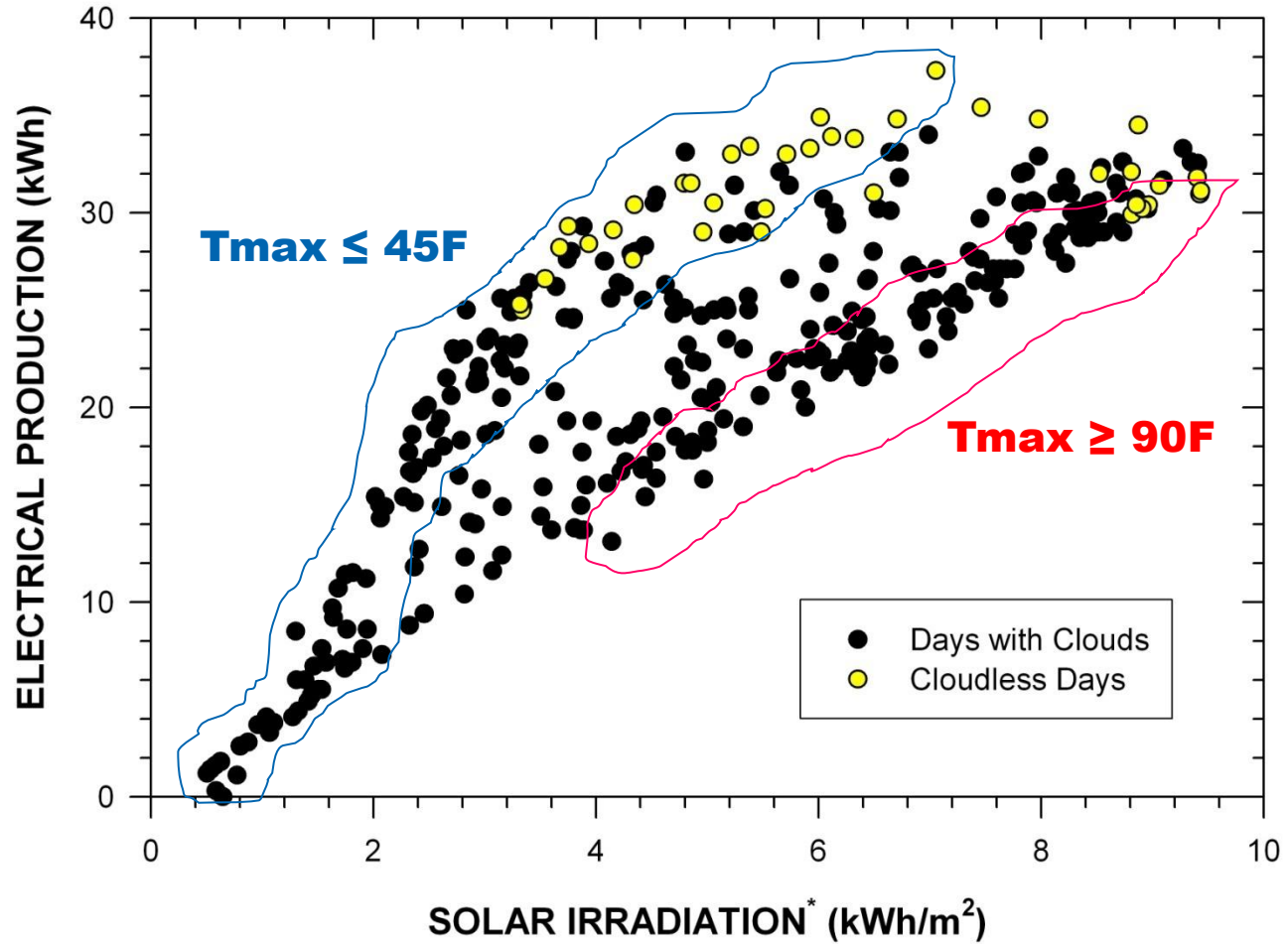


Solar PV System
Lafayette, Colorado
10May08 - 30Jun09

- Production on Days with Clouds
- Production on Cloudless Days
- Length of Daylight Period

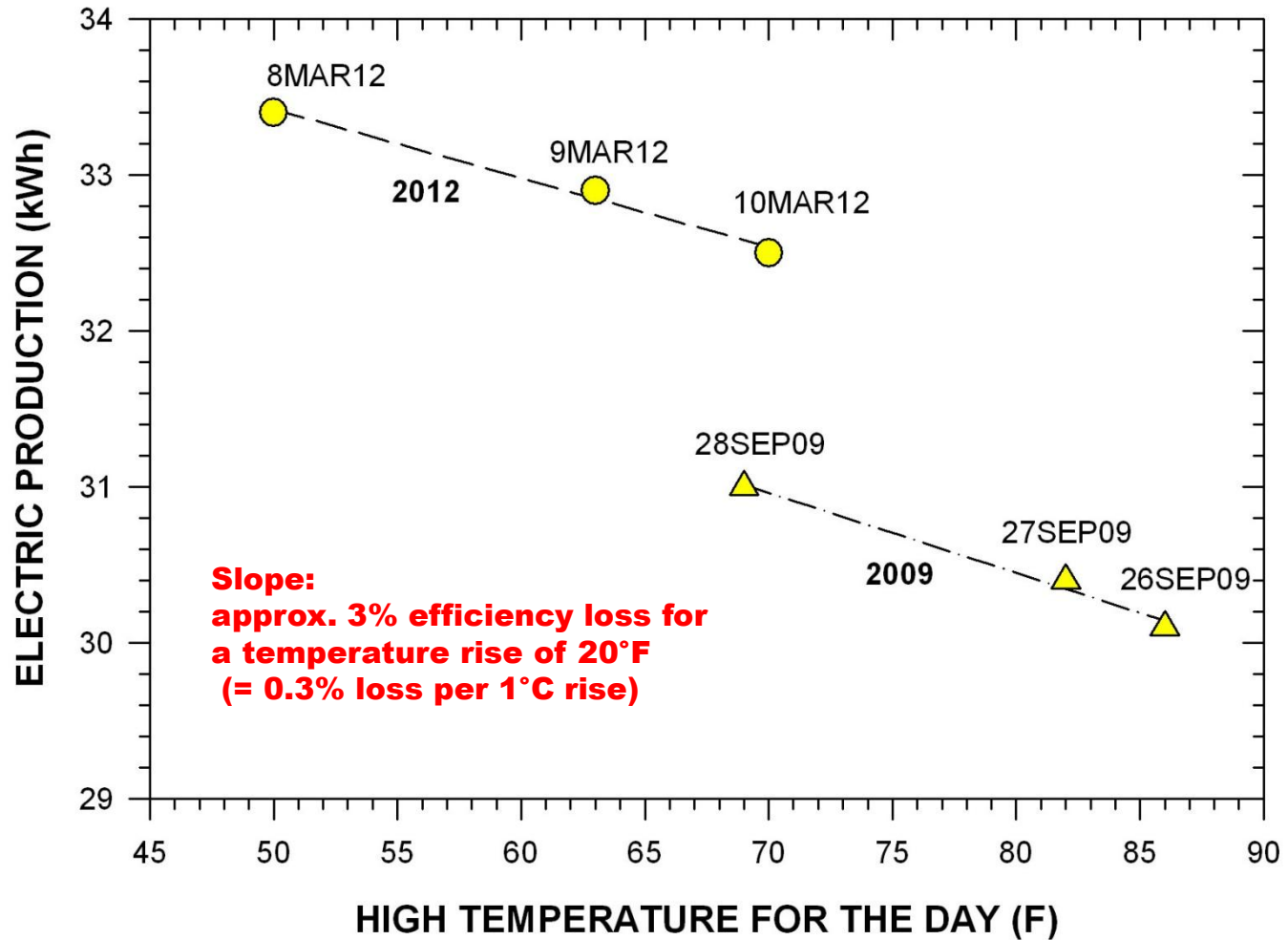


Solar PV System and Weather Station Data
Lafayette, Colorado
Daily Totals 10May08 - 30Jun09



* = direct + diffuse on horizontal surface

TWO TRIOS OF CONSECUTIVE CLEAR-SKY DAYS WITH DIFFERING TEMPERATURES 5.1-kW Solar PV System in Lafayette, CO



Less than 1 inch of **snow** cover can completely shut down the panels' electrical production



**Don't try this with
roof-mounted solar panels!**

Summary of Primary Environmental Factors (Weather and Sun-Geometry) that Reduce Our Solar-Panel Electrical Production

decreasing importance
↓

- ☀ Cloudiness
 - sky coverage
 - thickness
 - timing
- ☀ Sun angle departure from perpendicular
- ☀ Short daylight period
- ☀ Snow cover
- ☀ Hot days

Our Solar-PV Experience So Far?

- ☀ Zero problems with the system.
- ☀ Our typical monthly electric bill is 88% lower now.
- ☀ We have produced 47 Megawatt-hours of clean electricity.
- ☀ We have elevated our “eco-karma” and reduced our carbon footprint by:
 - 40 tons of CO₂ emissions
 - = 106,000 fewer miles driven
 - = 3,750 trees planted.



The dawn of solar ?

www.cloudphotos.net

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