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

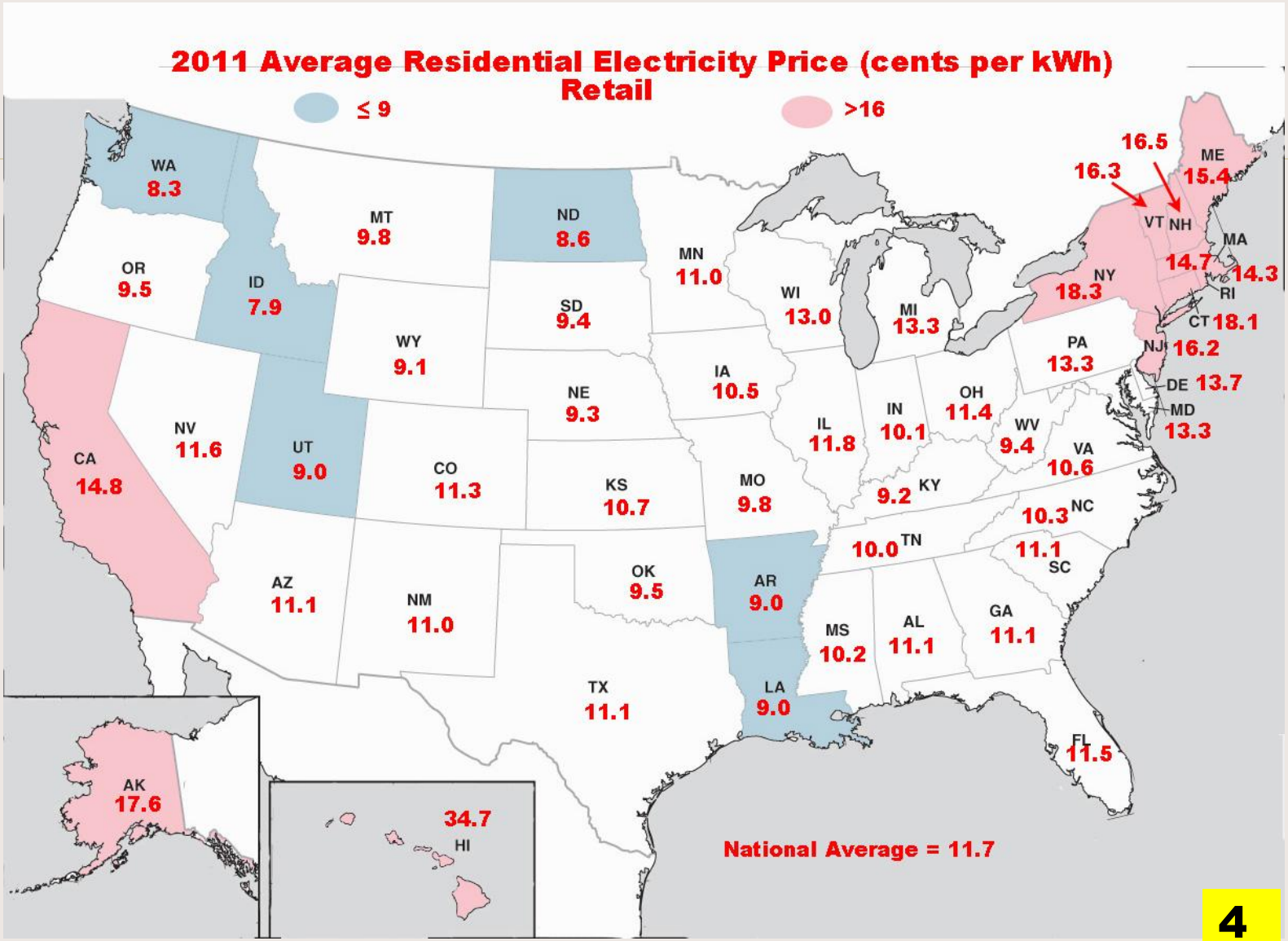
Brooks Martner
Lafayette, Colorado

University of Toledo
Spring 2013
PHYS 4400 - Principles and Varieties of Solar Energy

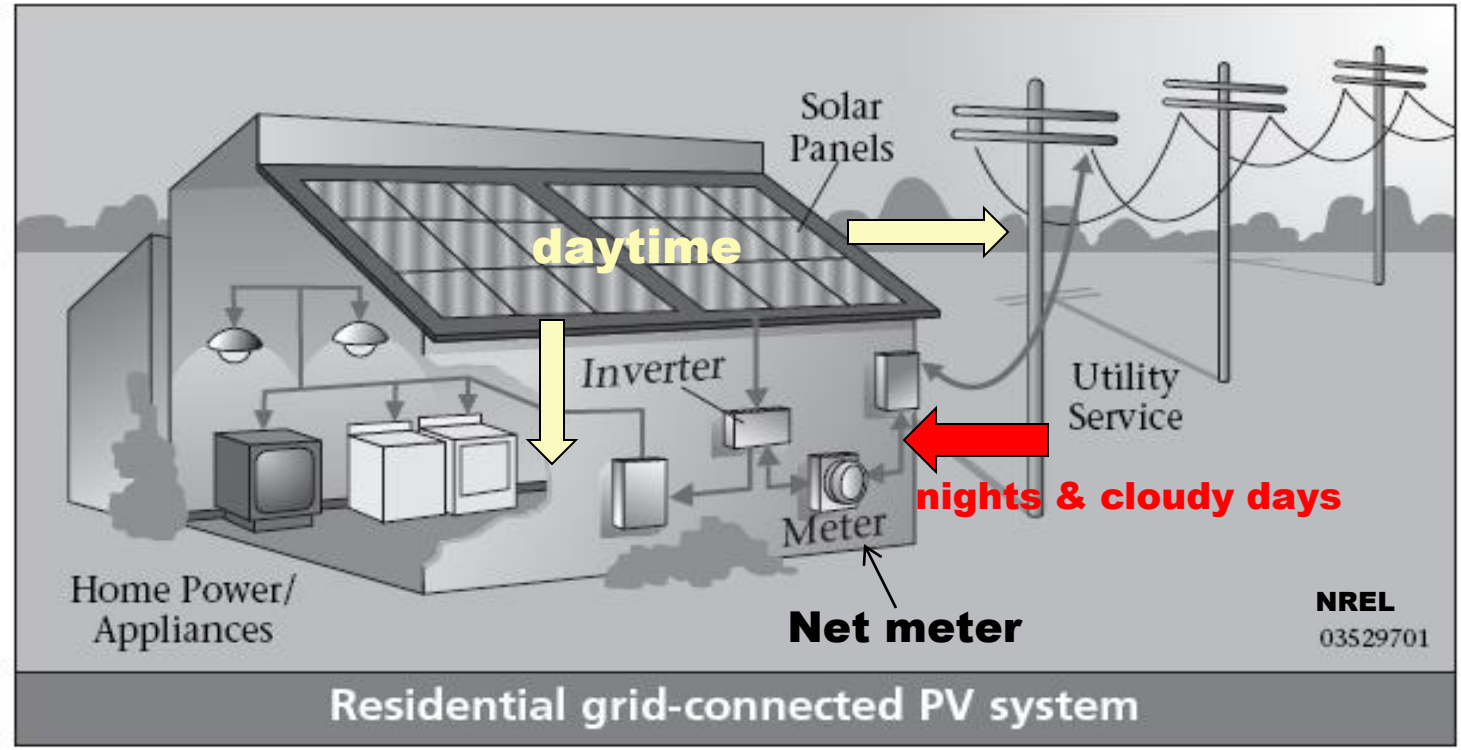
Our Solar Photovoltaic (PV) System

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 m^2 (approx. 52 ft x 8 ft)
- Predicted annual AC energy production ~ 7400 kWh


2011 Average Residential Electricity Price (cents per kWh)
Retail
≤ 9
>16
WA 8.3
OR 9.5
CA 14.8
ID 7.9
NV 11.6
MT 9.8
WY 9.1
UT 9.0
AZ 11.1
CO 11.3
NM 11.0
ND 8.6
SD 9.4
NE 9.3
KS 10.7
OK 9.5
TX 11.1
MN 11.0
IA 10.5
MO 9.8
AR 9.0
LA 9.0
WI 13.0
IL 11.8
MS 10.2
MI 13.3
IN 10.1
KY 9.2
TN 10.0
AL 11.1
OH 11.4
WV 9.4
VA 10.6
NC 10.3
SC 11.1
GA 11.1
FL 11.5
PA 13.3
NY 18.3
16.3
16.5
VT
NH
ME 15.4
MA 14.7
RI 14.3
CT 18.1
NJ 16.2
DE 13.7
MD 13.3
AK 17.6
34.7
HI
National Average = 11.7

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 in System Design

- Electrical Consumption of the Home
- Solar Radiation Climatology of Region
- Sun Exposure of the Site
- Cost of System (parts + labor + sales tax)
  - Rebates
  - Tax Credits
  - Monthly Savings on Energy Bill
  - = Pay-back Time

Electrical Consumption

Xcel Energy®

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

Page 1 of 1

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
Number of Payments Received	1
Number of Days in Billing Period	31
Statement Number	
Premise Number	

Previous Balance	$103.32
Total Payments	($103.32)
Balance Forward	$0.00
+ Current Bill	$168.11
Current Balance	$168.11

Electric Service - Account Summary

Invoice Number	0201132727		
Meter No.	000035889617		
Rate	R	Residential General	
Current Reading	22579	Actual	11/30/2007
Previous Reading	21730	Actual	10/30/2007
Kilowatt-Hours Used	849		

Residential General	$33.02
GRSA	$4.19
Air Quality Imp	$0.72
Elec Commodity Adj	$23.88
Demand Side Mgmt Cost	$1.10
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		
Meter No.	00000R519496		
Rate	RG-T	Residential	
Current Reading	2218	Actual	11/30/2007
Previous Reading	2085	Actual	10/30/2007
Measured Usage	133		
Therm Multiplier	0.8598		
Therms Used	114.00		

Residential			
Usage Charge	114.00 x	0.08868	$10.10
Interstate Pipeline	114.00 x	0.06110	$6.97
Natural Gas - Nov	110.23 x	0.48350	$53.30
Natural Gas - Oct	3.77 x	0.31600	$1.19
Service & Facility			$11.20
Franchise Fee			$2.49
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
• Colorado Average	8,520	789
• Ohio Average	11,112	1063
• U.S. Average	11,232	1196

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

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

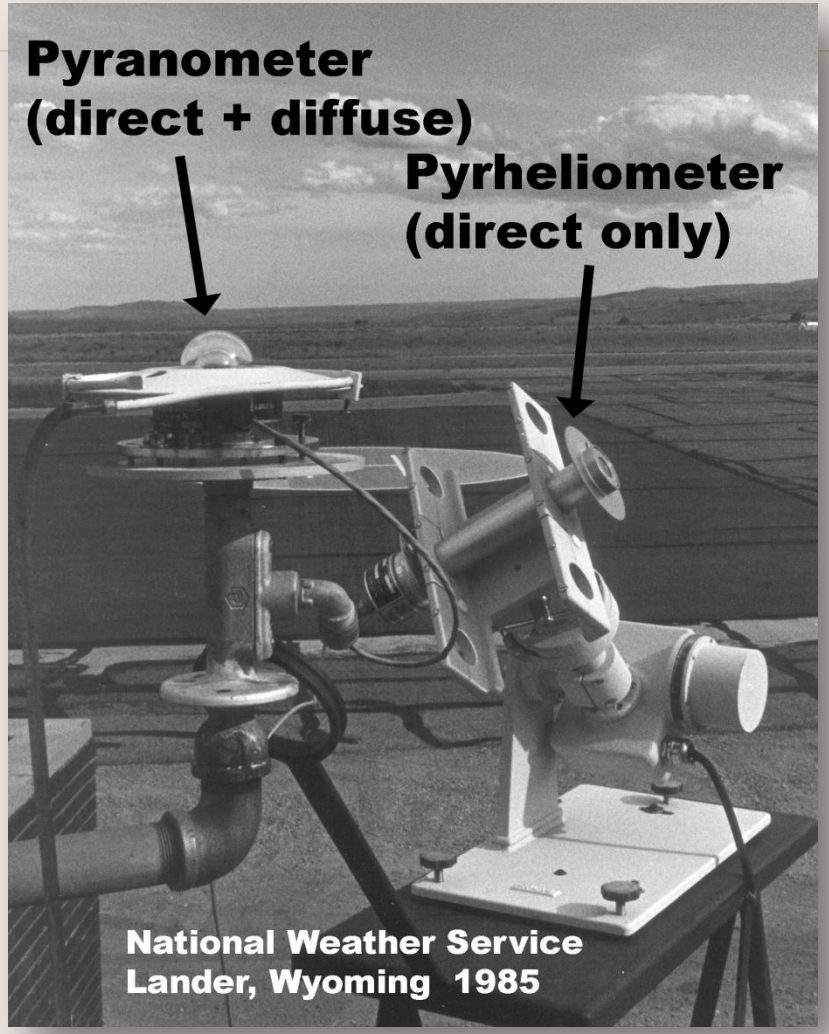
Climatology of Sunshine

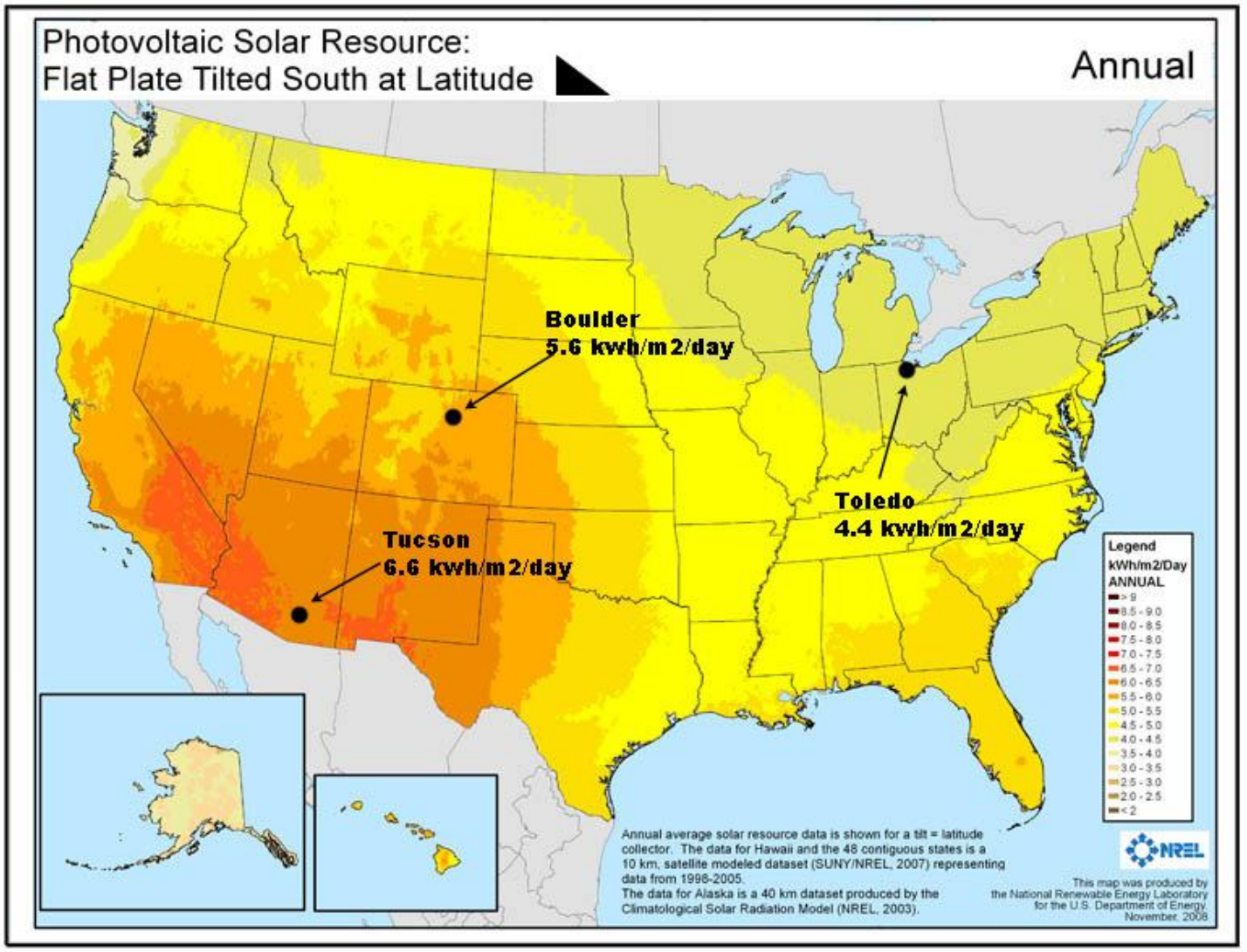
Solar Radiation Measurements:

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

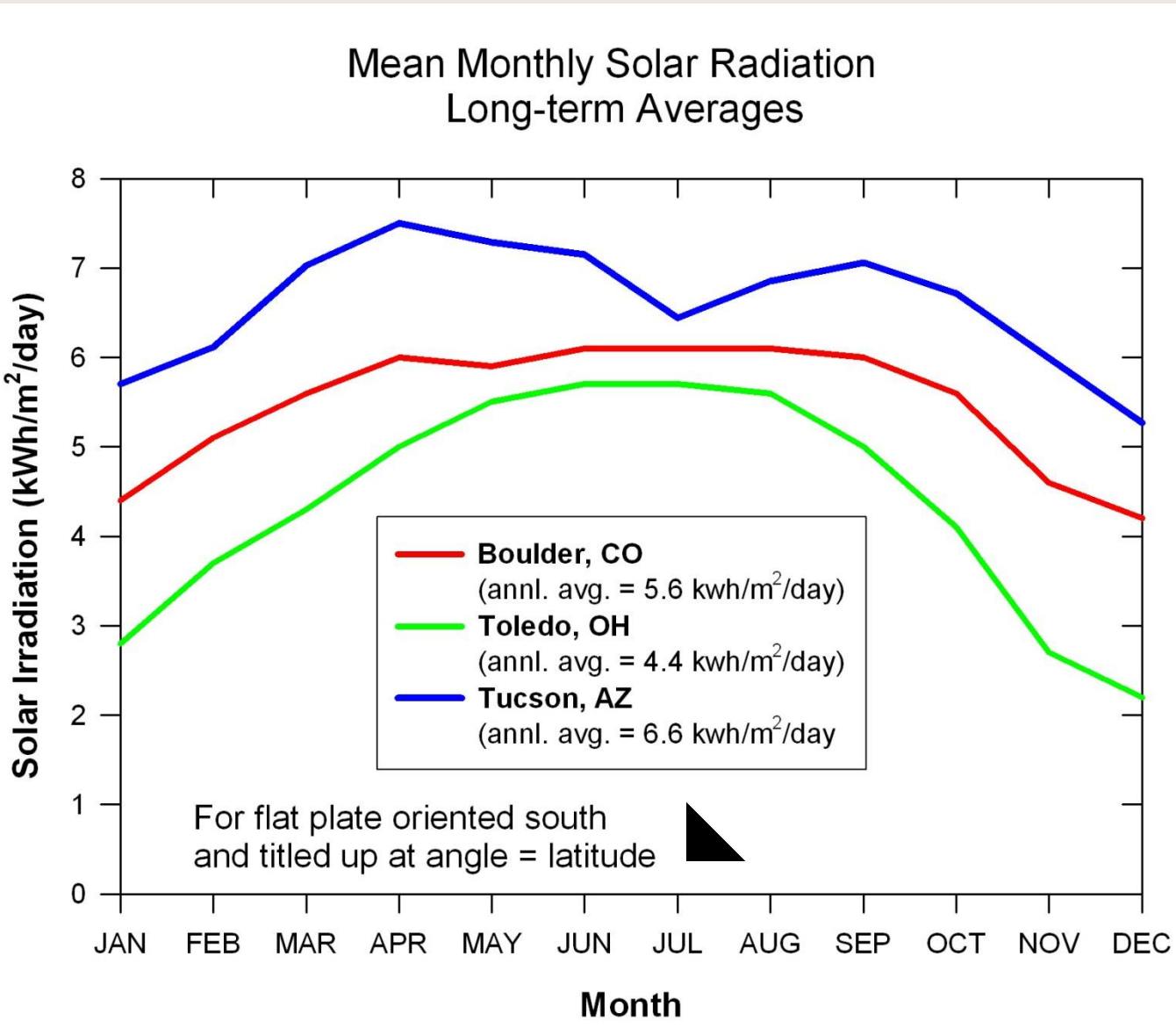
New-site measurements in progress by various agencies, especially DOE.

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





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


Mean Monthly Solar Radiation
Long-term Averages
Solar Irradiation (kWh/m²/day)
0
1
2
3
4
5
6
7
8
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Boulder, CO
(annl. avg. = 5.6 kwh/m²/day)
Toledo, OH
(annl. avg. = 4.4 kwh/m²/day)
Tucson, AZ
(annl. avg. = 6.6 kwh/m²/day
For flat plate oriented south
and titled up at angle = latitude

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.**

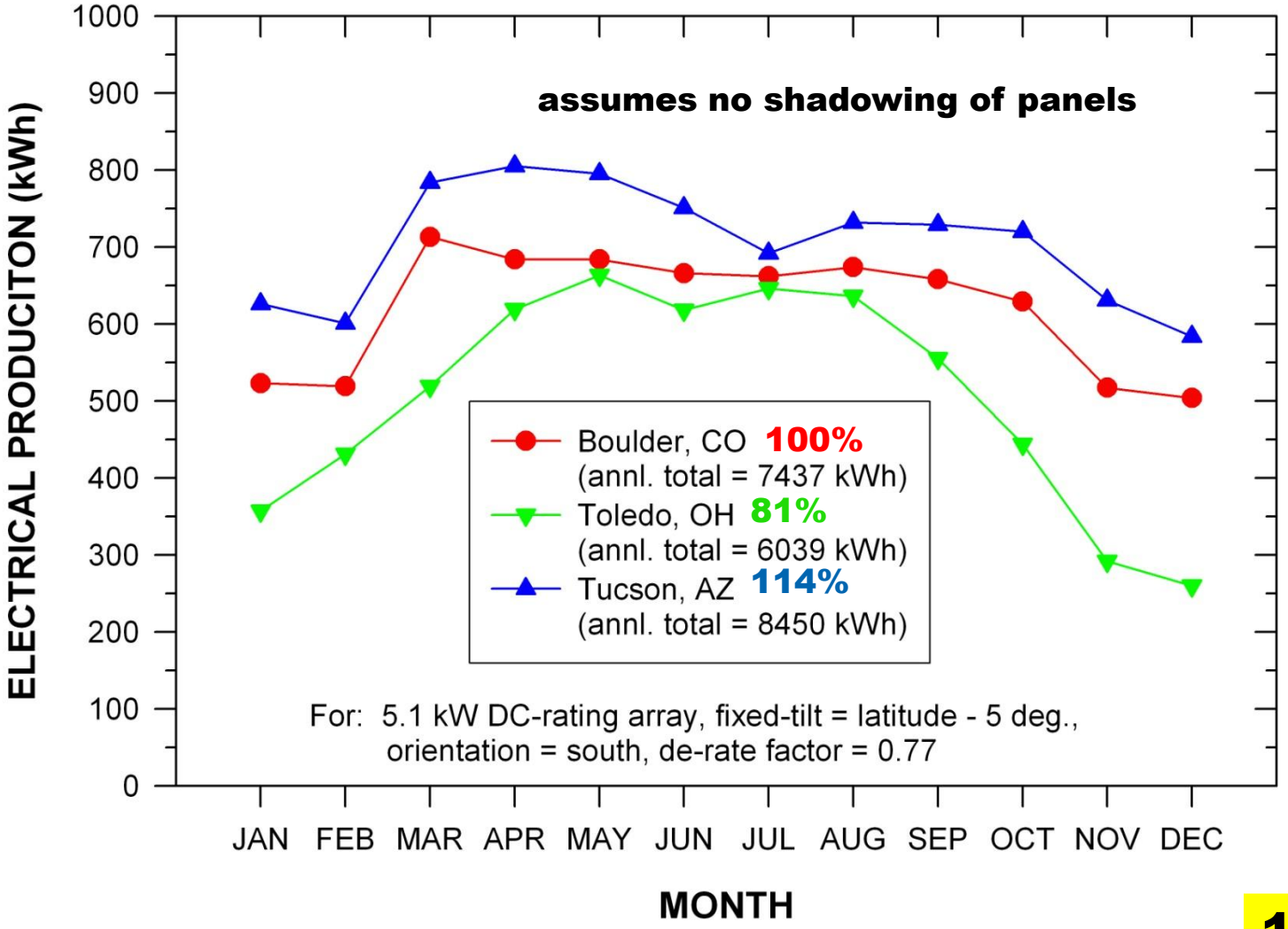
  Orientation **south**

- Output:

  Avg. electric production for each month of the year:

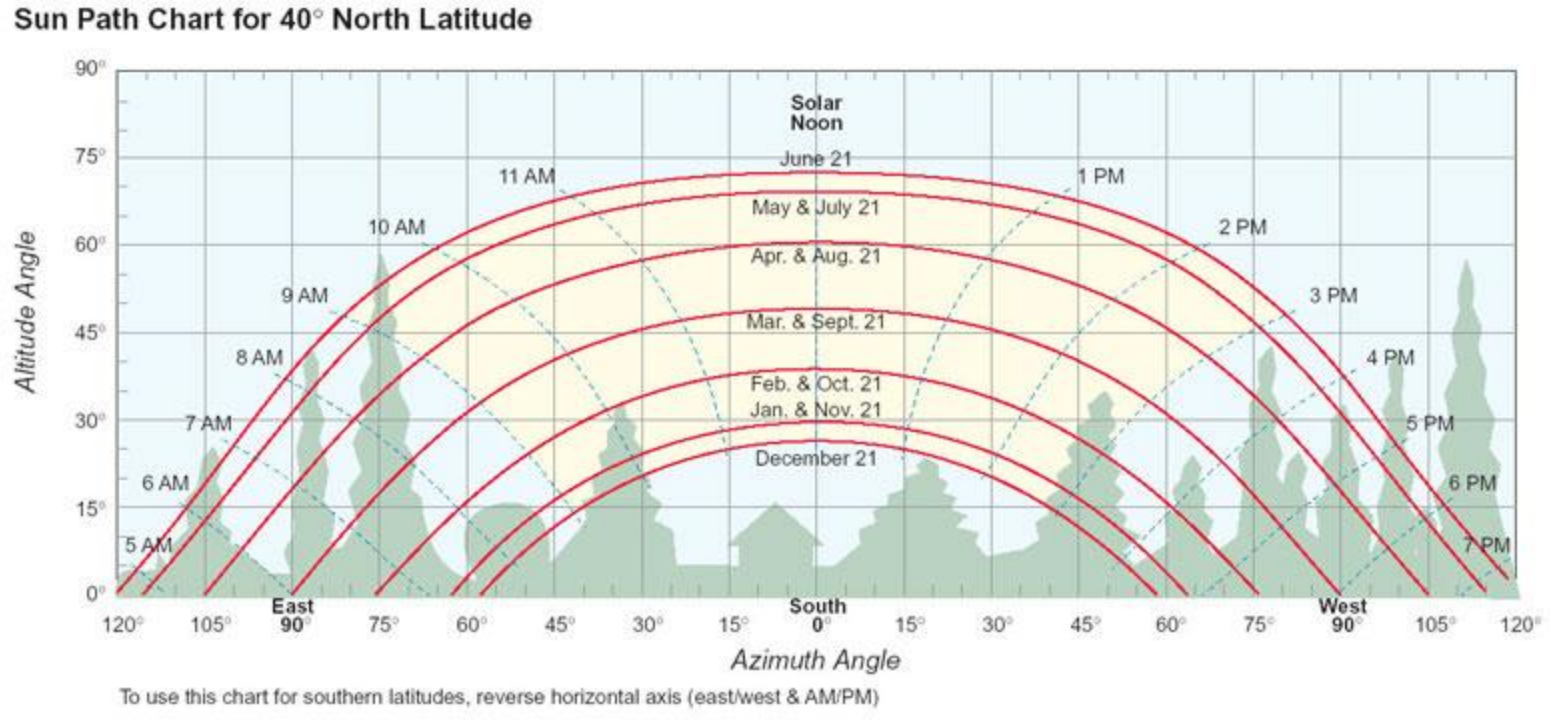
  Jan = 523 kWh, Feb = 519 kWh, Mar = 713 kWh, … etc.

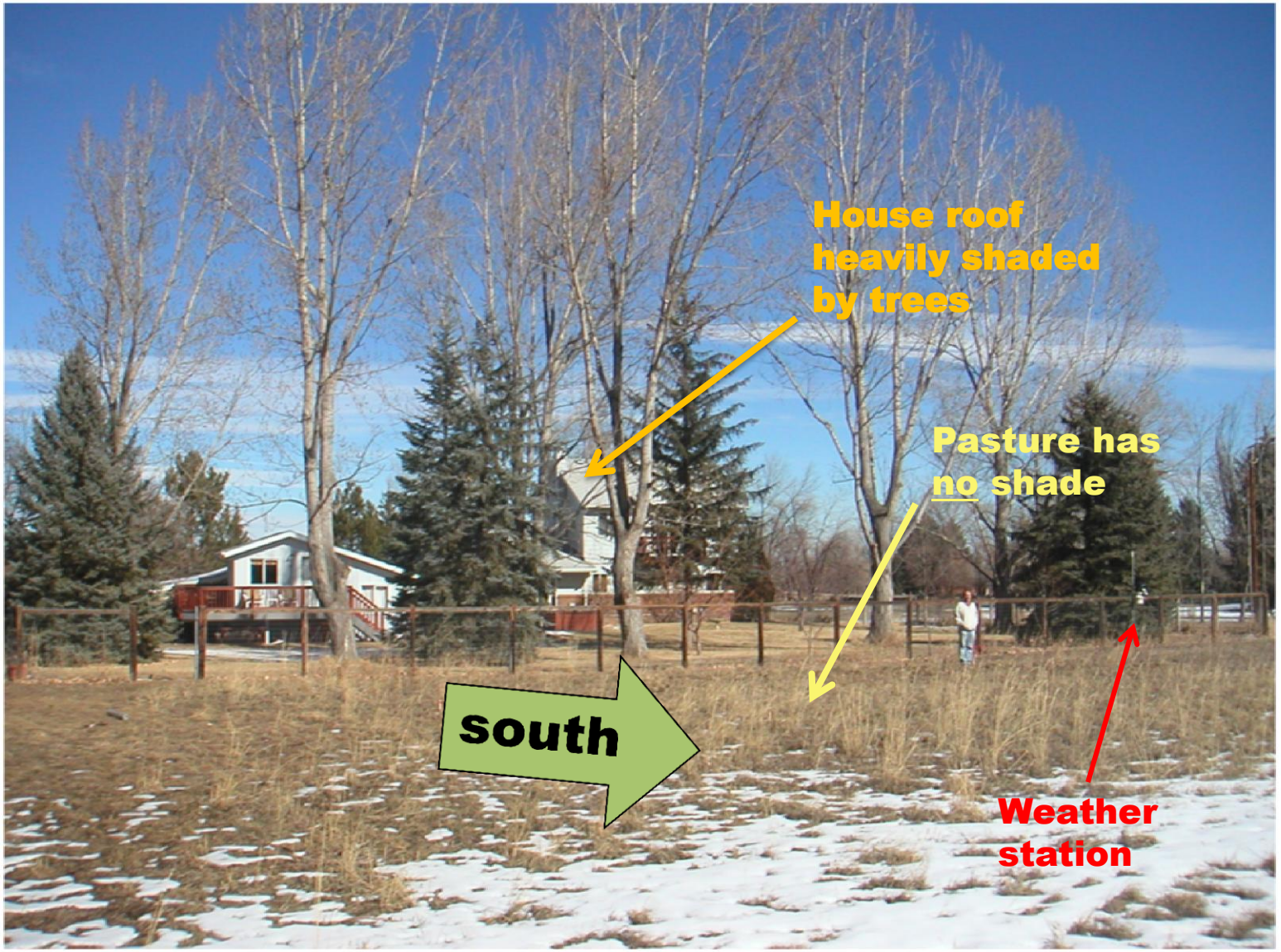
MEAN MONTHLY ELECTRICAL PRODUCTION PREDICTED BY NREL'S PV-WATTS



Sun Exposure of Site

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

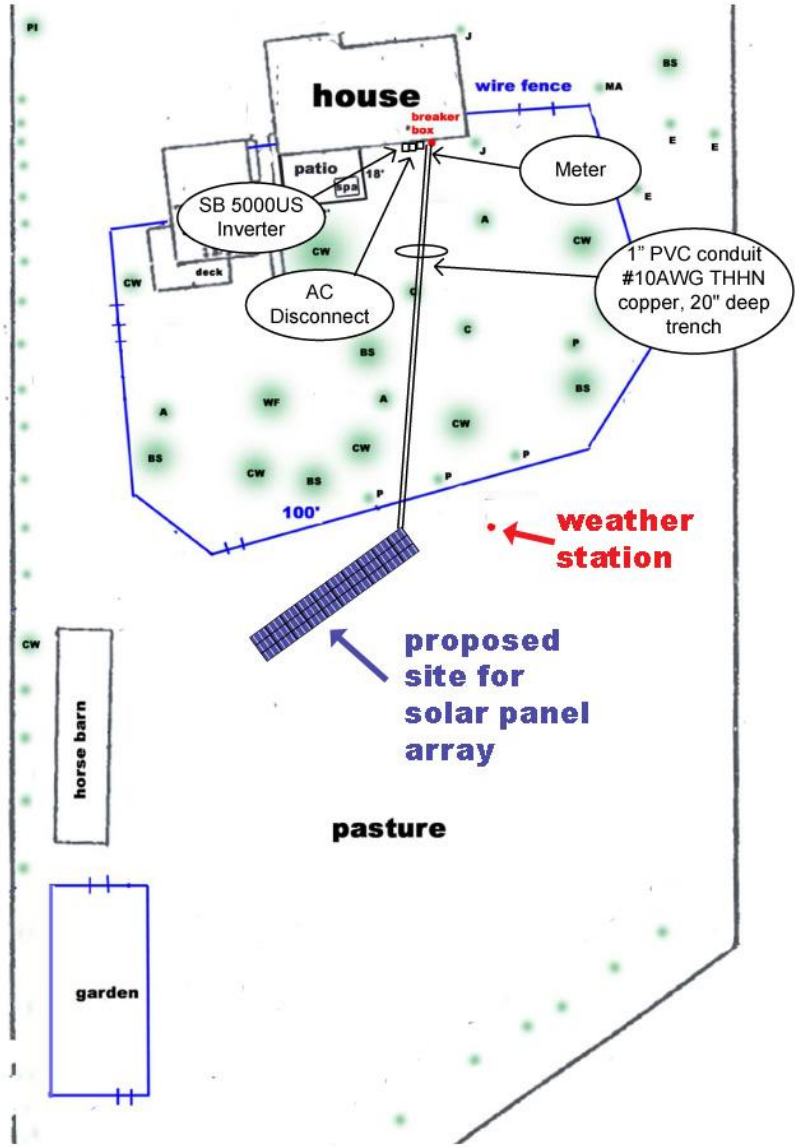



House roof
heavily shaded
by trees
Pasture has
no shade
south
Weather
station

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



Financial: Costs

Colorado - 2008

• PV system equipment costs:	
Solar panels (30 Sharp 170-watt)	$24,097
Inverter (5-kW Sunny Boy)	3,008
Rack for ground-mounting panels (ULA)	1,837
Other electrical components	165
• Civil works (pylon & trench digging, concrete)	3,663
• Installation labor	8,198
• County sales tax	1,382
• Total Value	$42,350

Financial: Rebates, etc.

In 2008:

• Utility company rebate + RE credit ($4.50/watt)	-$22,950
• State sales tax rebate	- 699
• Federal income tax credit	- 2,000
• Total incentives	-$25,649

Financial: Bottom Line

• Total value of system	$42,350
• Total rebates, etc.	- 25,649
• Buyer's grand total cost	$16,701

= $3.27/watt

Estimated Energy-Bill Savings and Pay-Back Period

Assuming:

- Initial cost = $16,700
- Solar production = 7446 kWh per year
- Initial electric rate = $0.10 per kWh
- Average annual increase (expected) in the utility company's price for electricity

~ 14 years →

	Pay-back in:	**Net savings in 25 years:**
0%	22 years	$1,900
5%	15 years	$18,800
10%	12 years	$56,500
15 %	10½ years	$141,700

Estimated “Eco-Karma” Benefits

Every year:

Clean energy production	7440 kWh
CO_2 emissions averted*	7 tons

* = compared with coal-fired electric plant

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

Installation

Installation

Installation

Installation

Installation

Installation

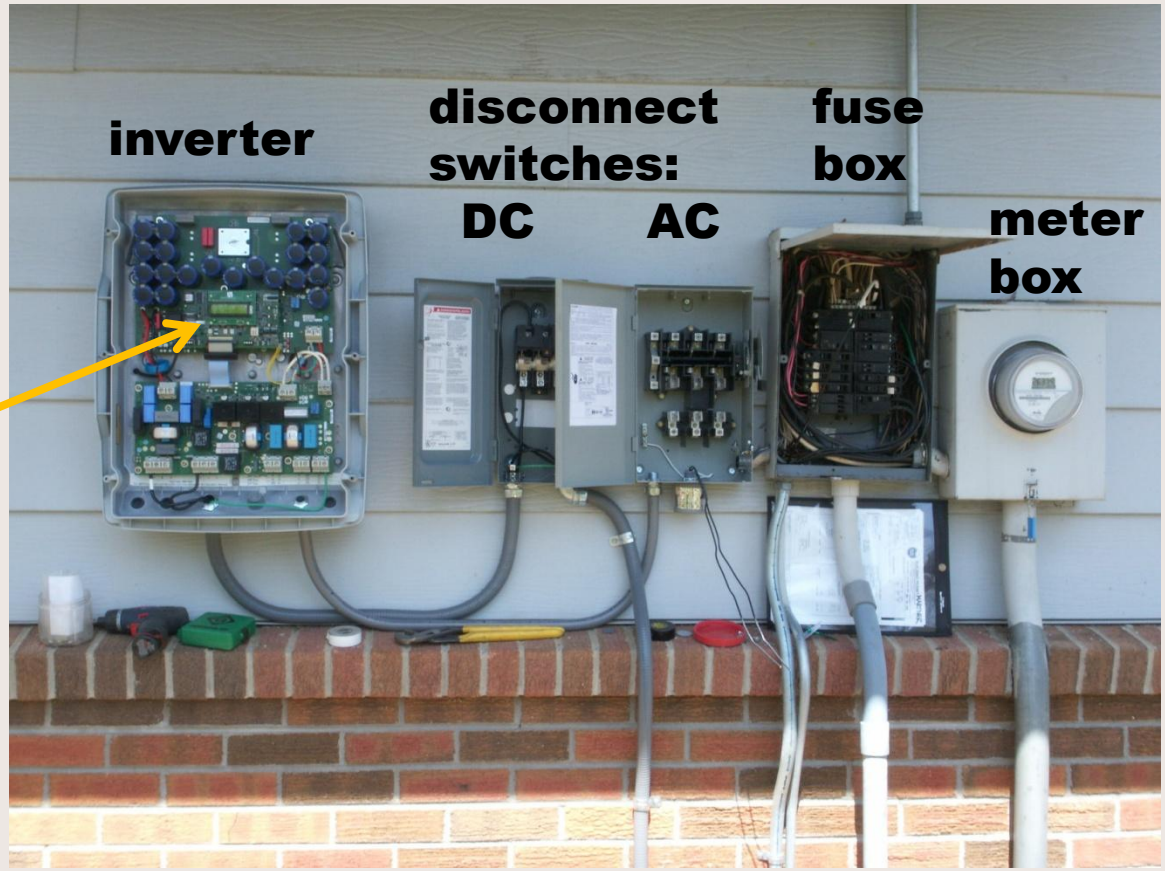
Installation

Installation

Installation

inverter

Installation



Installation

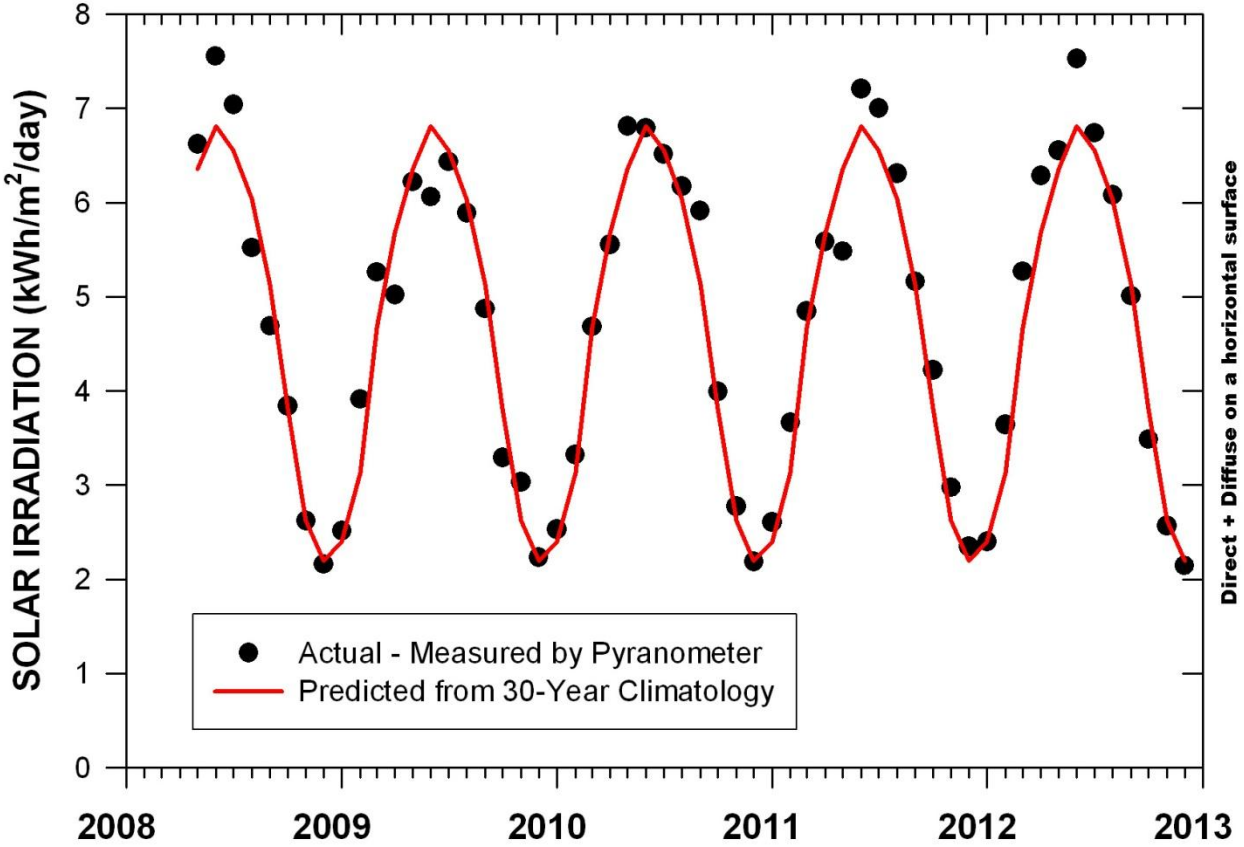
The Net Meter

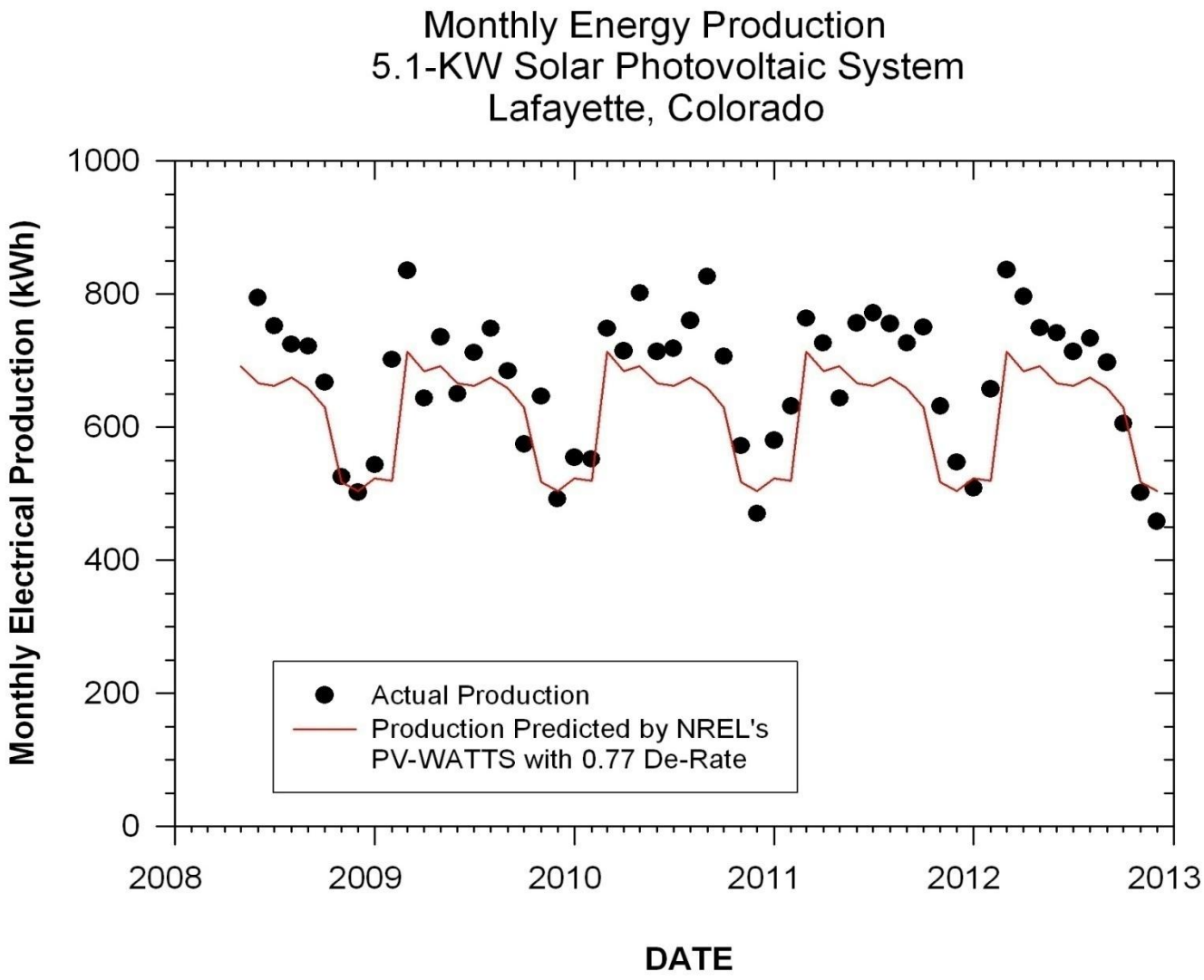
Start-up date: 9MAY08

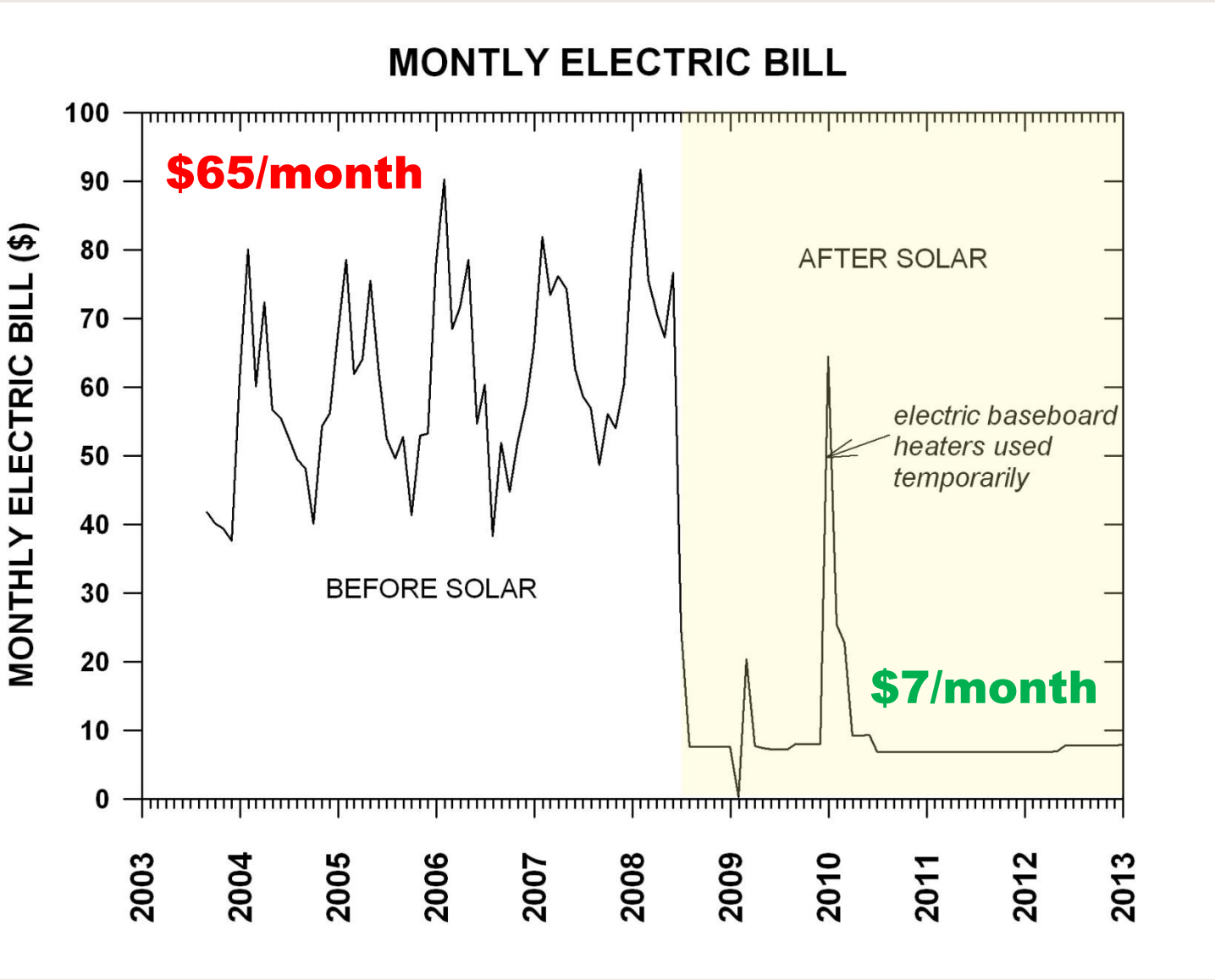
Performance in the First 5 Years

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

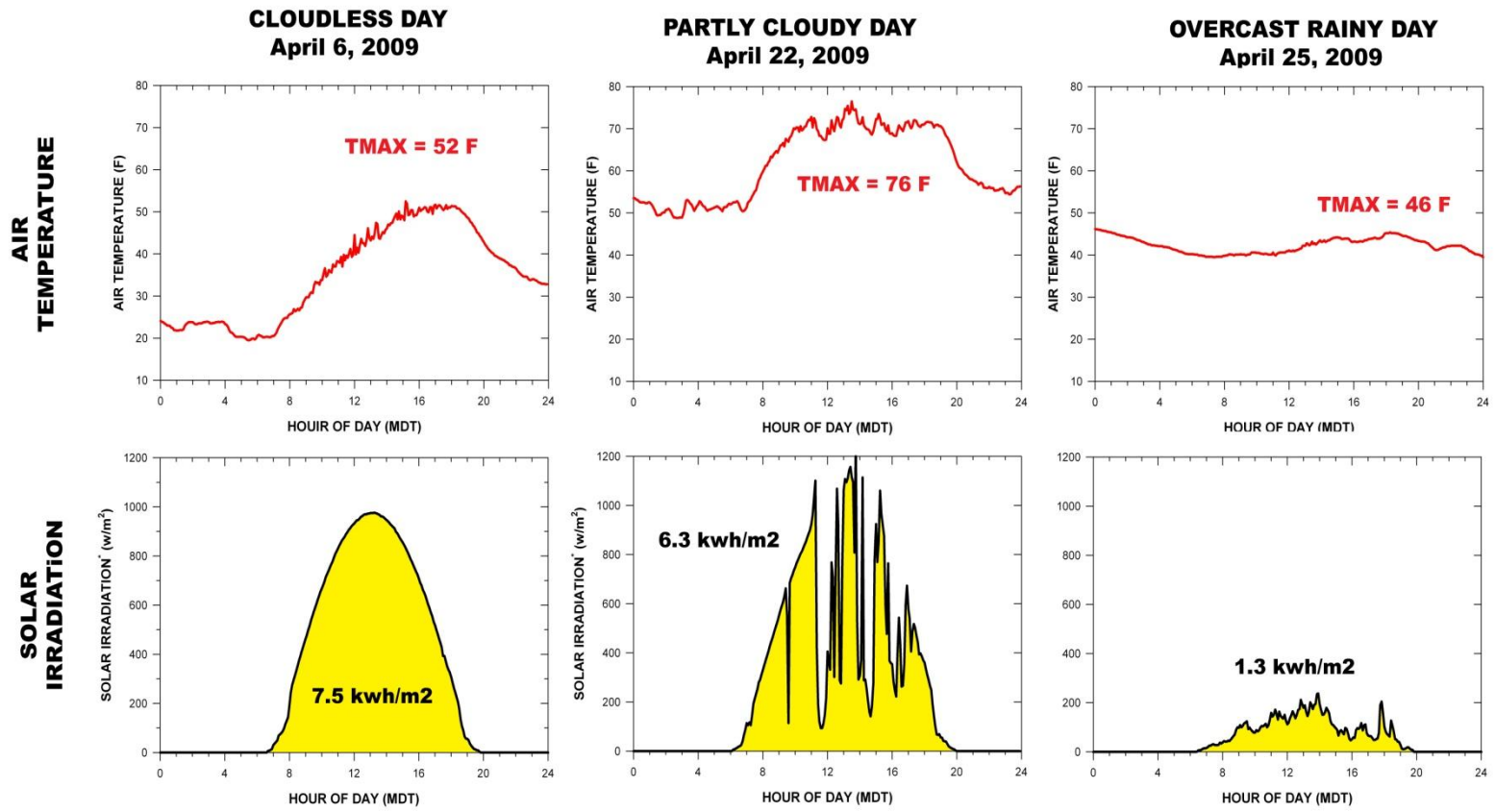
Correlating with meteorological data from our home weather station located beside the panels


INCOMING SOLAR IRRADIATION
Lafayette, Colorado
SOLAR IRRADIATION (kWh/m²/day)
0
1
2
3
4
5
6
7
8
2008
2009
2010
2011
2012
2013
Actual - Measured by Pyranometer
Predicted from 30-Year Climatology
Direct + Diffuse on a horizontal surface

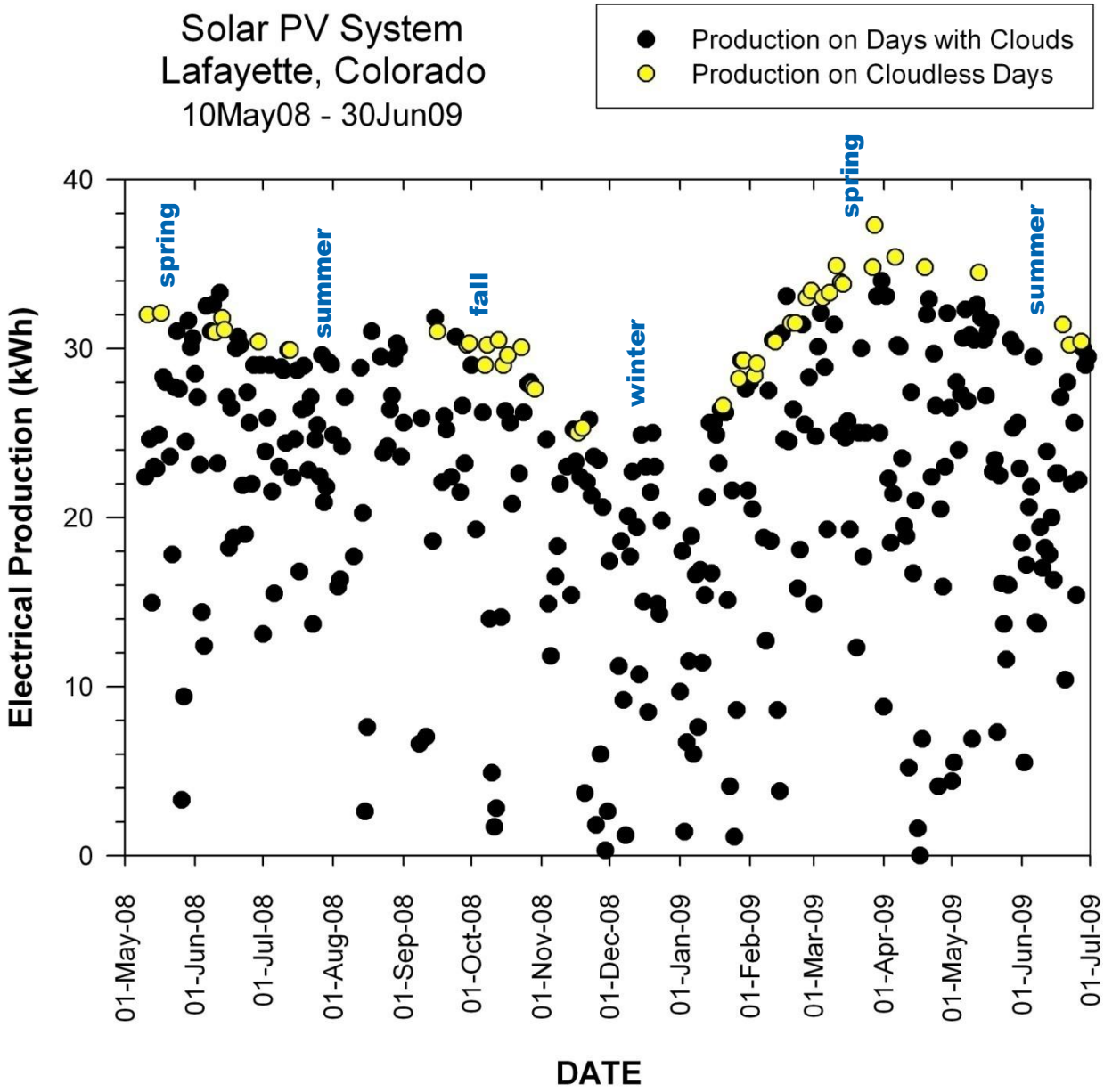

Monthly Energy Production
5.1-KW Solar Photovoltaic System
Lafayette, Colorado
Monthly Electrical Production (kWh)
1000
800
600
400
200
0
2008
2009
2010
2011
2012
2013
DATE
Actual Production
Production Predicted by NREL's
PV-WATTS with 0.77 De-Rate

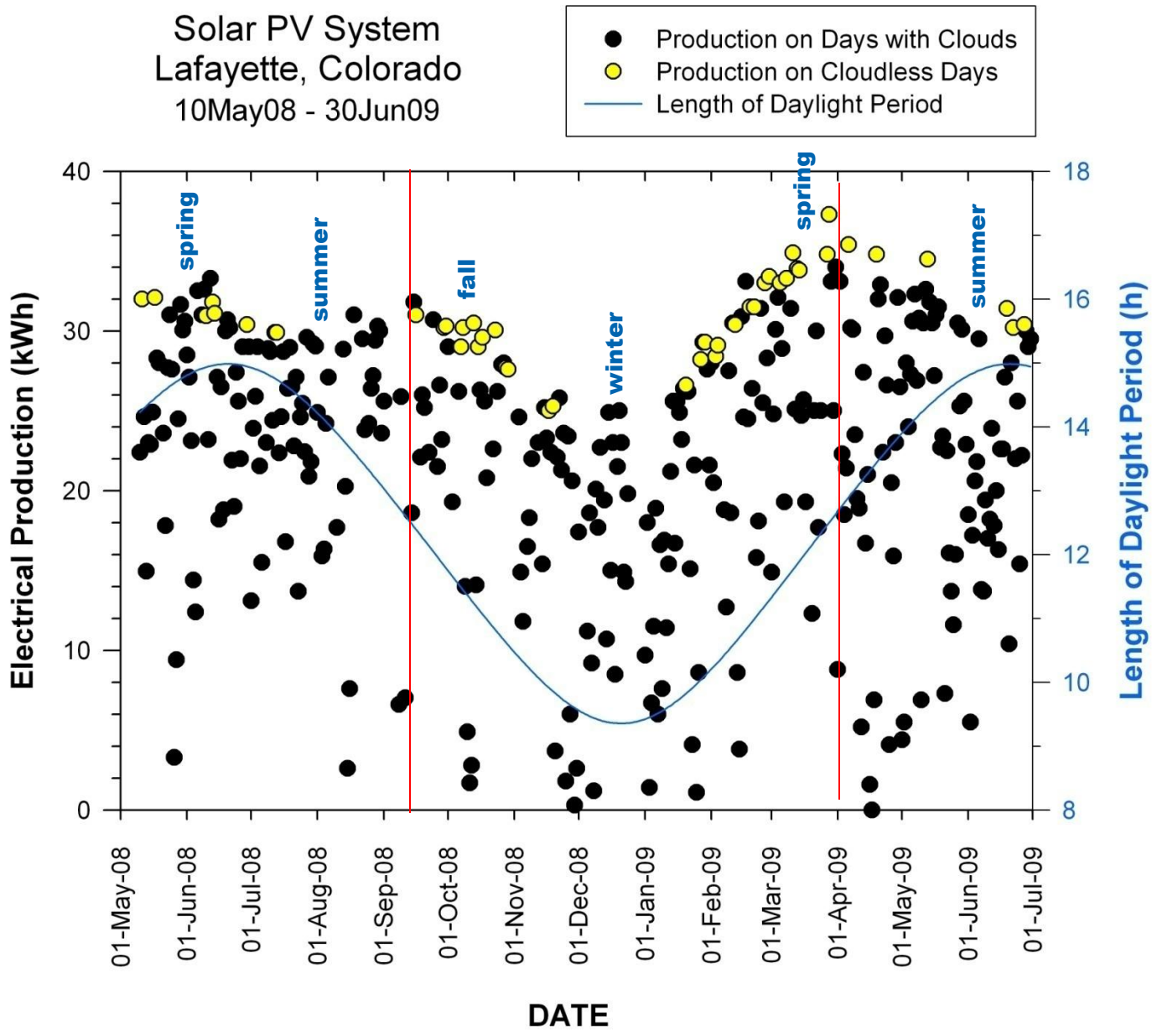

MONTLY ELECTRIC BILL
MONTHLY ELECTRIC BILL ($)
100
90
80
70
60
50
40
30
20
10
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
$65/month
BEFORE SOLAR
AFTER SOLAR
electric baseboard heaters used temporarily
$7/month

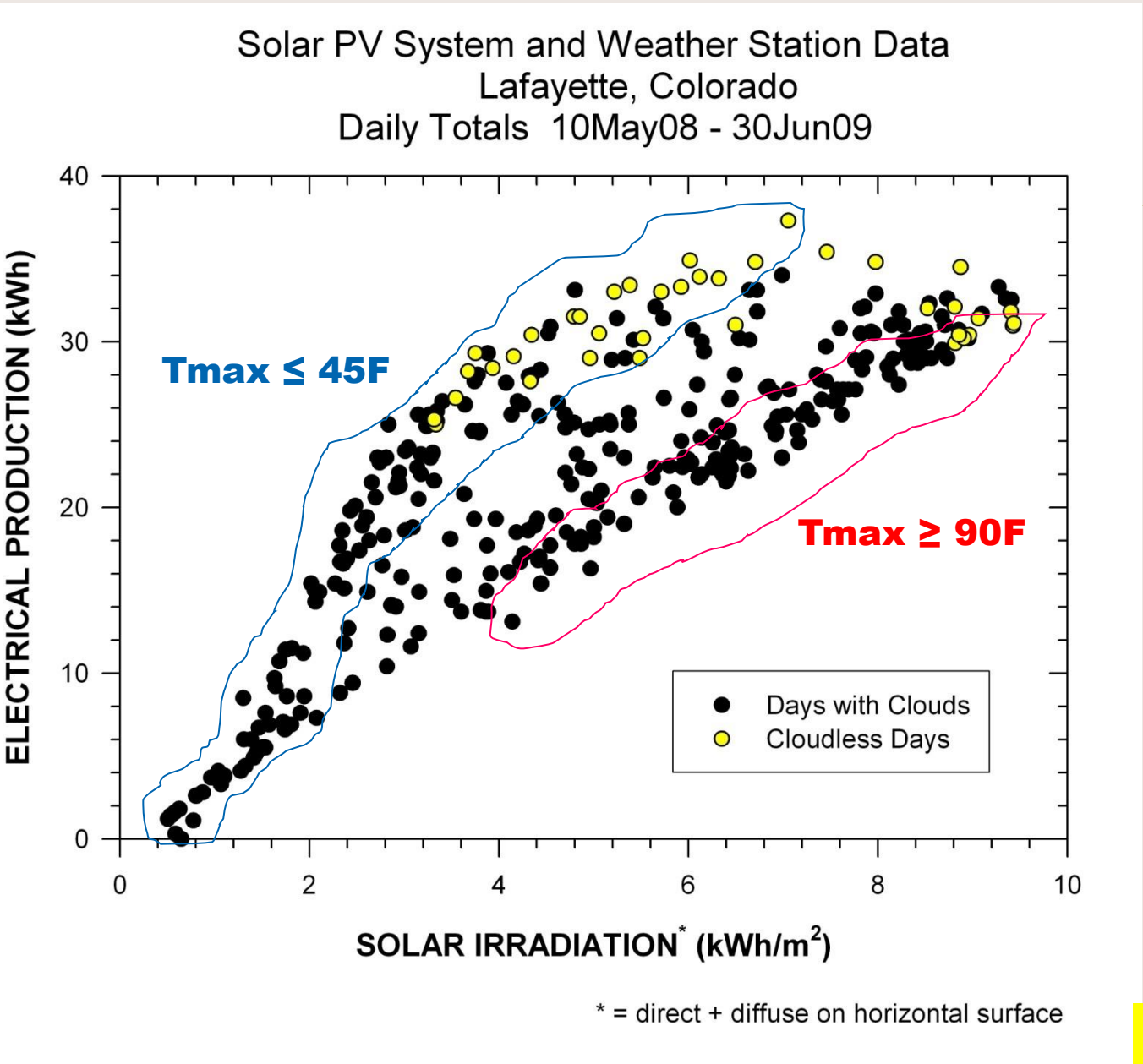
The Effect of Clouds
Three Example Days

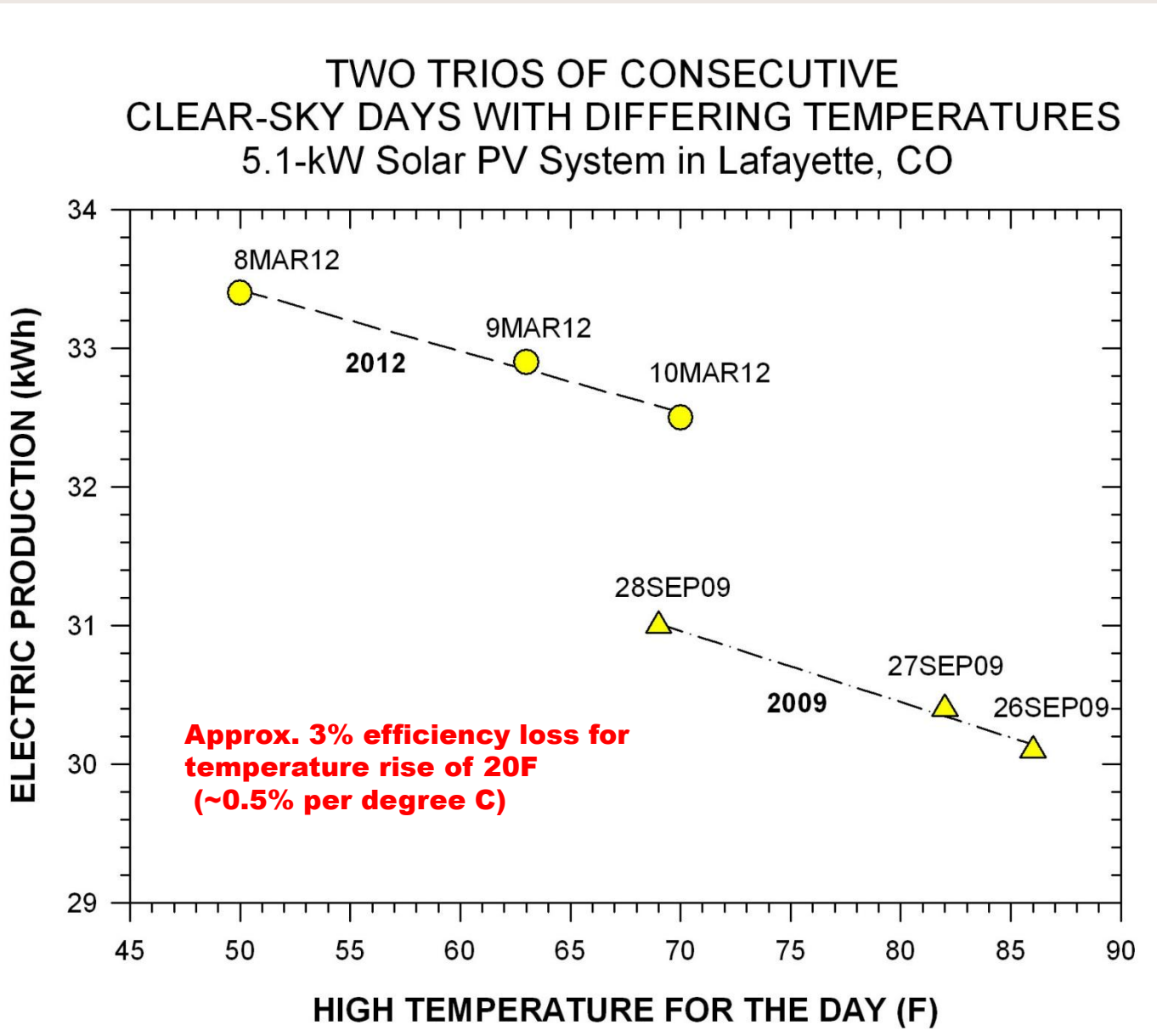


Solar Electric Production: 35.5 kWh | 22.4 kWh | 4.1 kWh


Solar PV System
Lafayette, Colorado
10May08 - 30Jun09
Production on Days with Clouds
Production on Cloudless Days
Electrical Production (kWh)
0
10
20
30
40
spring
summer
fall
winter
spring
summer
01-May-08
01-Jun-08
01-Jul-08
01-Aug-08
01-Sep-08
01-Oct-08
01-Nov-08
01-Dec-08
01-Jan-09
01-Feb-09
01-Mar-09
01-Apr-09
01-May-09
01-Jun-09
01-Jul-09
DATE


Solar PV System
Lafayette, Colorado
10May08 - 30Jun09
Production on Days with Clouds
Production on Cloudless Days
Length of Daylight Period
spring
summer
fall
winter
spring
summer
Electrical Production (kWh)
Length of Daylight Period (h)
DATE
0
10
20
30
40
8
10
12
14
16
18
01-May-08
01-Jun-08
01-Jul-08
01-Aug-08
01-Sep-08
01-Oct-08
01-Nov-08
01-Dec-08
01-Jan-09
01-Feb-09
01-Mar-09
01-Apr-09
01-May-09
01-Jun-09
01-Jul-09


Solar PV System and Weather Station Data
Lafayette, Colorado
Daily Totals 10May08 - 30Jun09
ELECTRICAL PRODUCTION (kWh)
SOLAR IRRADIATION* (kWh/m2)
Tmax ≤ 45F
Tmax ≥ 90F
Days with Clouds
Cloudless Days
0
10
20
30
40
0
2
4
6
8
10
* = direct + diffuse on horizontal surface


TWO TRIOS OF CONSECUTIVE
CLEAR-SKY DAYS WITH DIFFERING TEMPERATURES
5.1-kW Solar PV System in Lafayette, CO
ELECTRIC PRODUCTION (kWh)
34
33
32
31
30
29
8MAR12
9MAR12
10MAR12
2012
28SEP09
27SEP09
26SEP09
2009
Approx. 3% efficiency loss for
temperature rise of 20F
(~0.5% per degree C)
45
50
55
60
65
70
75
80
85
90
HIGH TEMPERATURE FOR THE DAY (F)

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

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

- ☼ 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 85-90% lower now.
- ☼ We have produced almost 40 Megawatt-hours of clean electricity.
- ☼ We have elevated our "eco-karma" and reduced our carbon footprint by:

  32 tons of CO_2 emissions

  = 85,000 fewer miles driven

  = 3,000 trees planted.
- ☼ The sun-scorched Colorado drought is not all bad.


The dawn of solar ?
www.cloudphotos.net
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