Power Alternatives for the Off-The-Grid Radar

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Outline

- Introduction
- Photovoltaic Technology (PV)
- PV-Considerations
- Other Available Technologies-WIND
- WIND-Considerations
- General PV Design
- Homework

Introduction

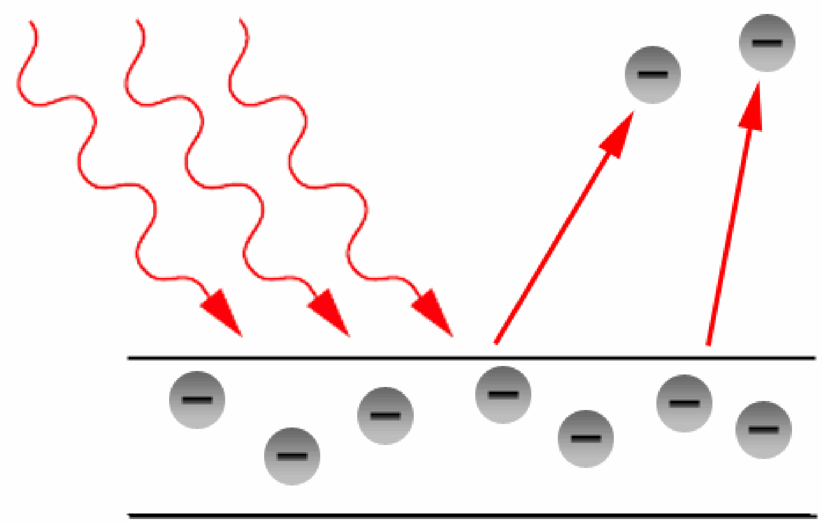
- Off-The Grid radar (OTG) important part of DCAS
- Will be deploy by end user needs
- Power generated on site
- Should generate using renewable sources
- Renewable sources are:
  - Clean
  - Natural
  - Reliable
  - Theoretically endless
  - Exists everywhere, especially in remote places
- The later is why the OTG needs to be powered by a renewable energy alternative.

Photovoltaic Technology-PV

- Based on photoelectric effect
  – Einstein's Noble Prize
- Light photons
  – Energy proportional to its wavelength

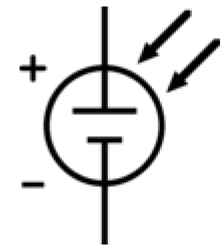
$$hf = hf_0 + \frac{1}{2} m {v_m}^2$$

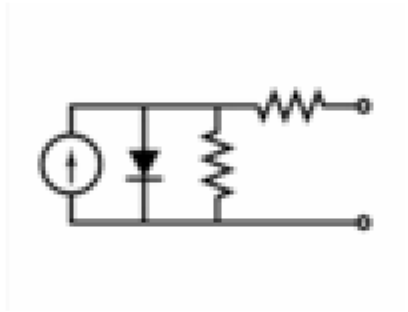
$$hf = \phi + E_k$$

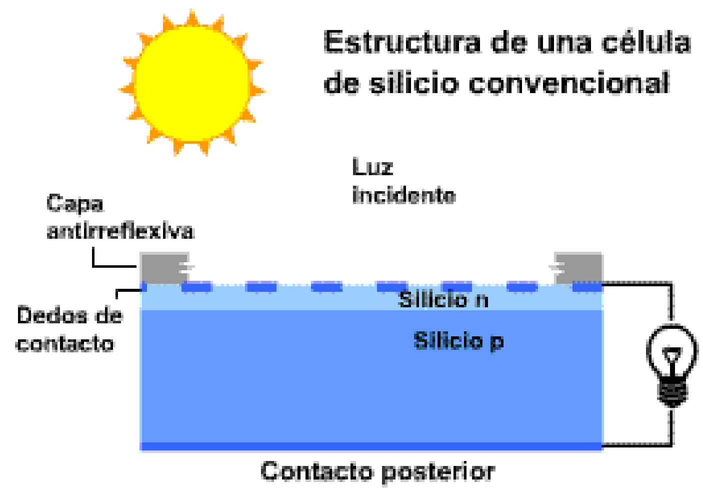


Photovoltaic Technology-PV

- PV Cell, basic building block
  - Semiconductors
  - PN junction-photodiode
  - By photoelectric effect generates current

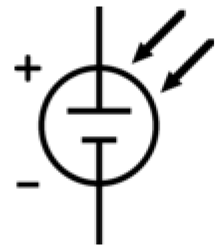


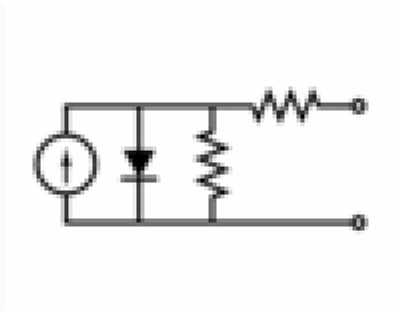


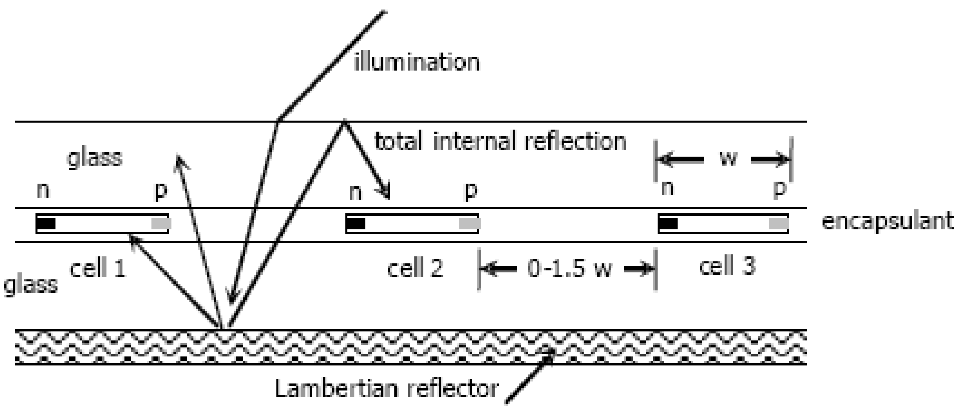


Photovoltaic Technology-PV

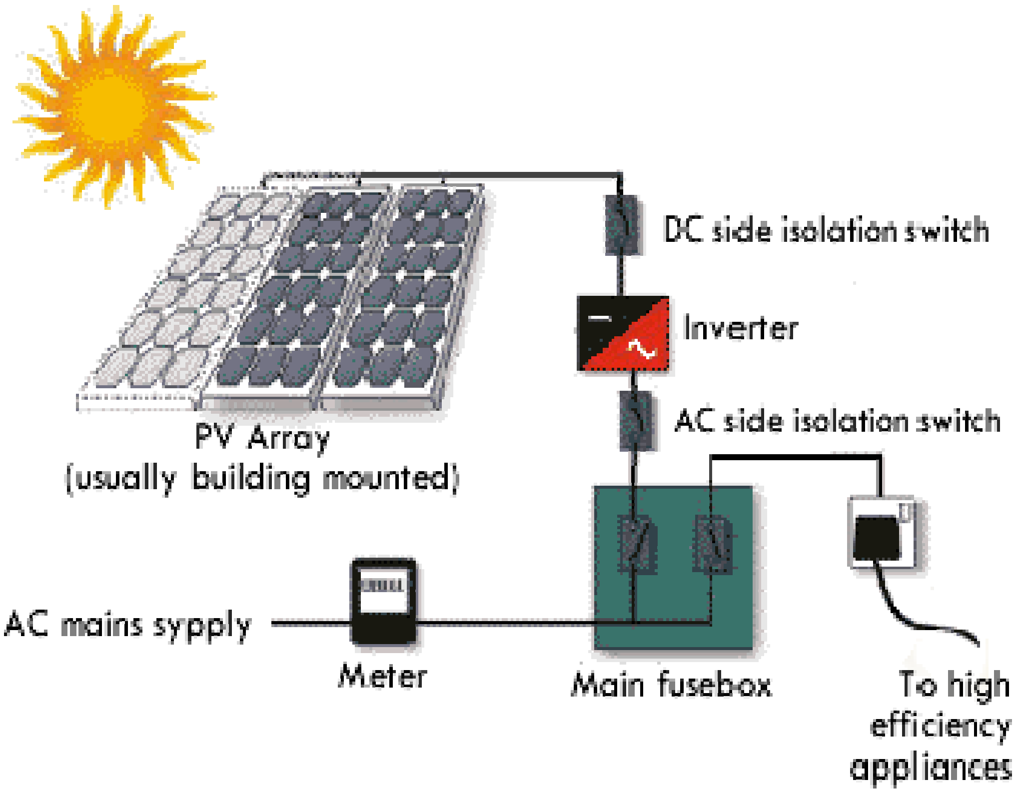
- PV Module
  - Hundreds of cells
  - Increase power output
- 1st Generation
  - Single silicon based pn-junction
- 2nd Generation
  - Multiple silicon based pn-junctions
  - Each junction absorbs a wavelength
- 3rd Generation
  - Different structure, enhance absorption







Photovoltaic Technology-PV



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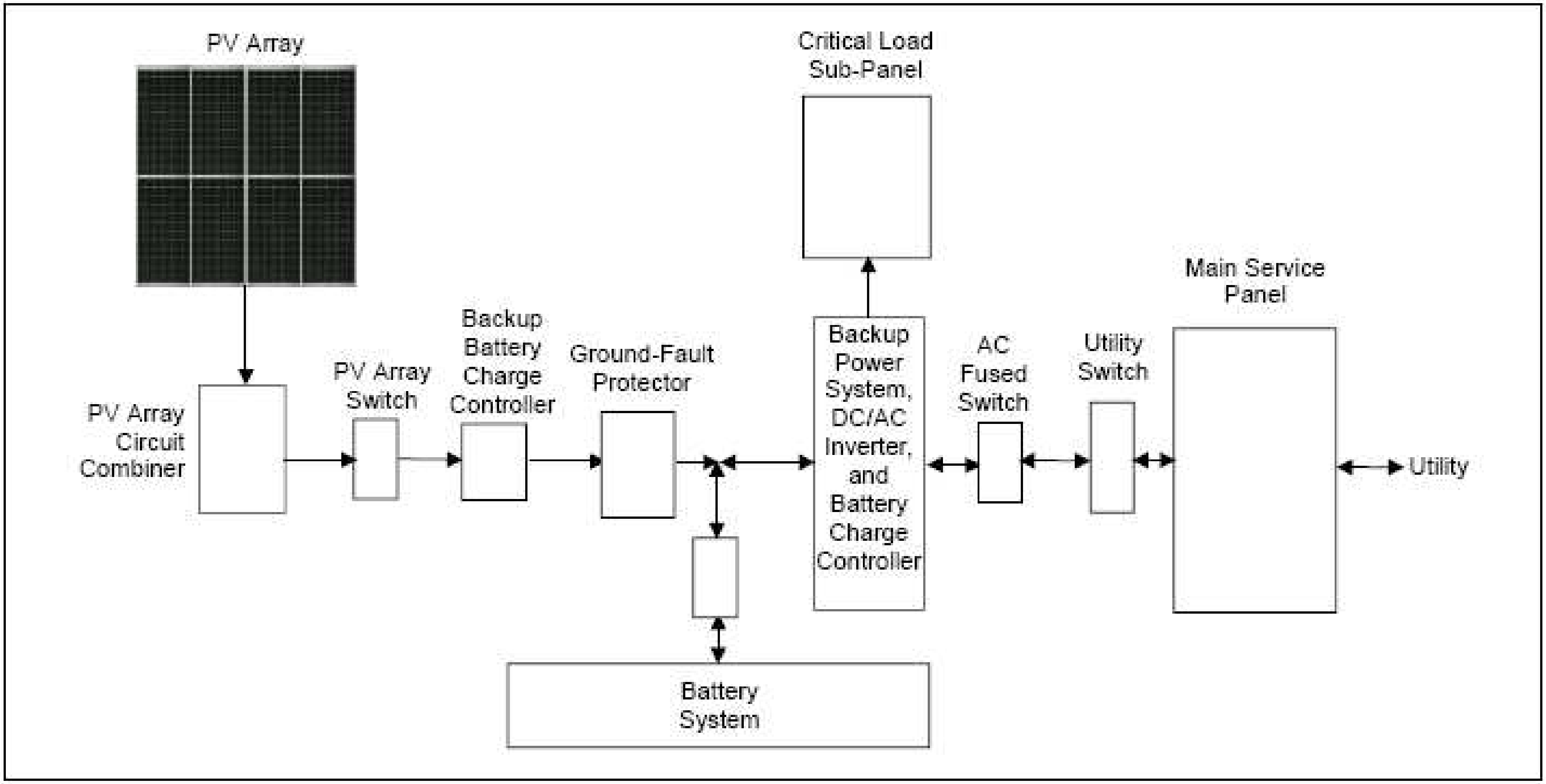
Photovoltaic Technology-PV



PV-Considerations

- Power vs. Energy

$$P(t) = I(t) \cdot V(t)$$

$$P = \frac{dE}{dt} = \frac{dW}{dt}$$

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = \lim_{\Delta t \to 0} P_{\mathrm{avg}}$$

$$P = \frac{W}{t} = \frac{E}{t}$$

In a DC System:

•Power = Voltage x Current

•Energy = Power x Time of use

Example:

V=12V, I=6A, t=5hr

•P=V x I=12Vx6A=72Watts

•E=P x t=72Wx5hr=360Wh=0.36kWh

PV-Considerations

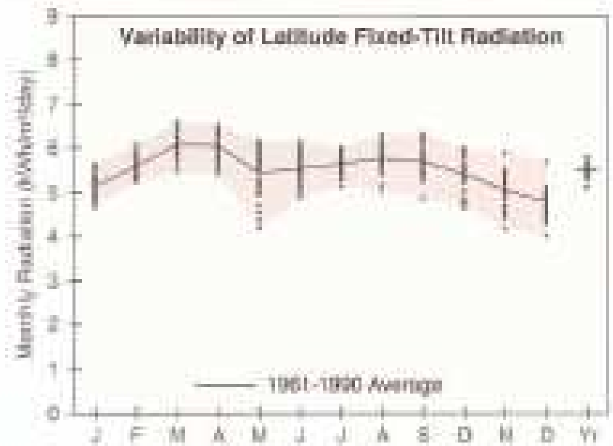
- Radiation is an issue

San Juan, PR

WBAN NO. 11641

LATITUDE: 18.43° N
LONGITUDE: 66.00° W
ELEVATION: 19 meters
MEAN PRESSURE: 1014 millibars

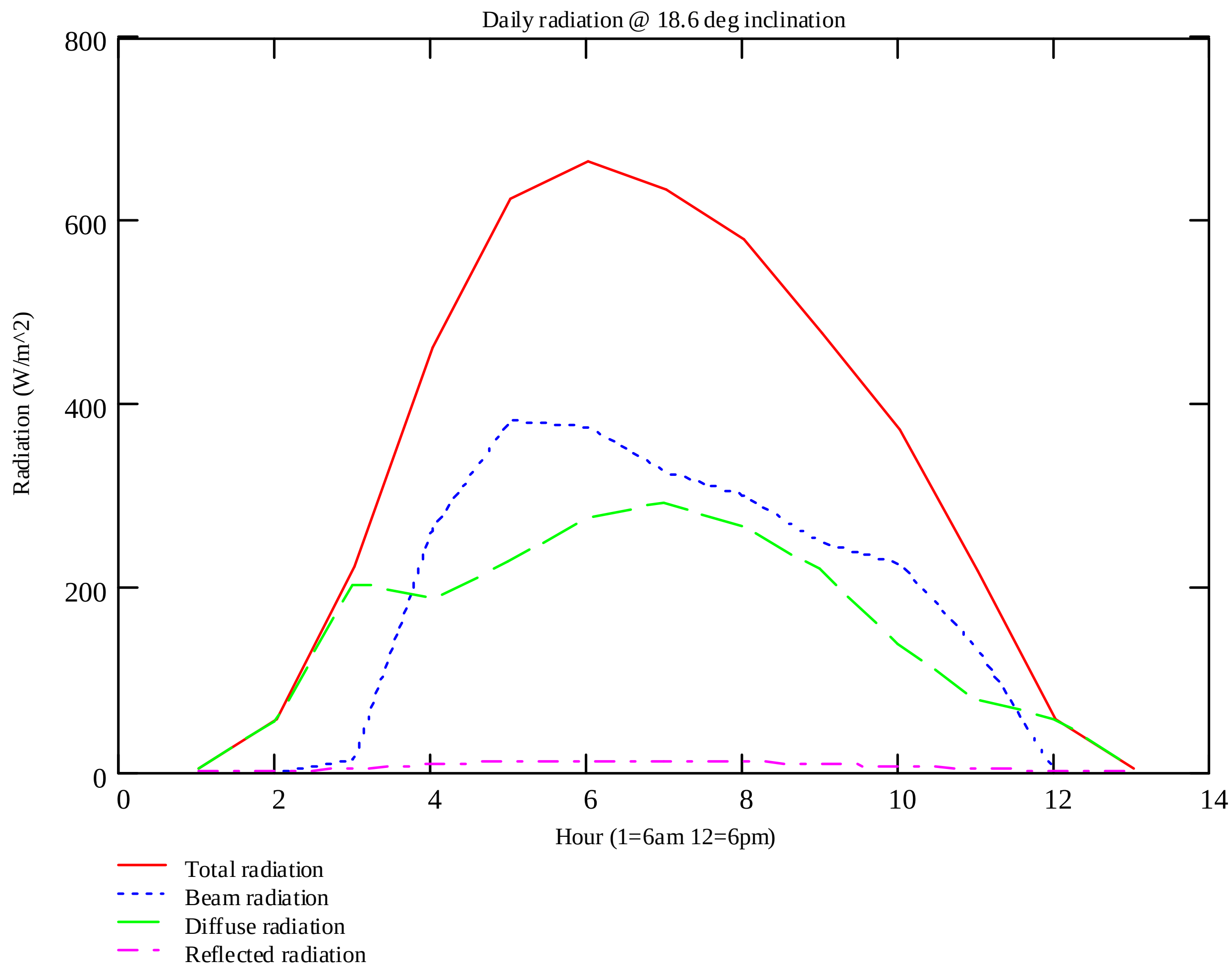
STATION TYPE: Primary



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

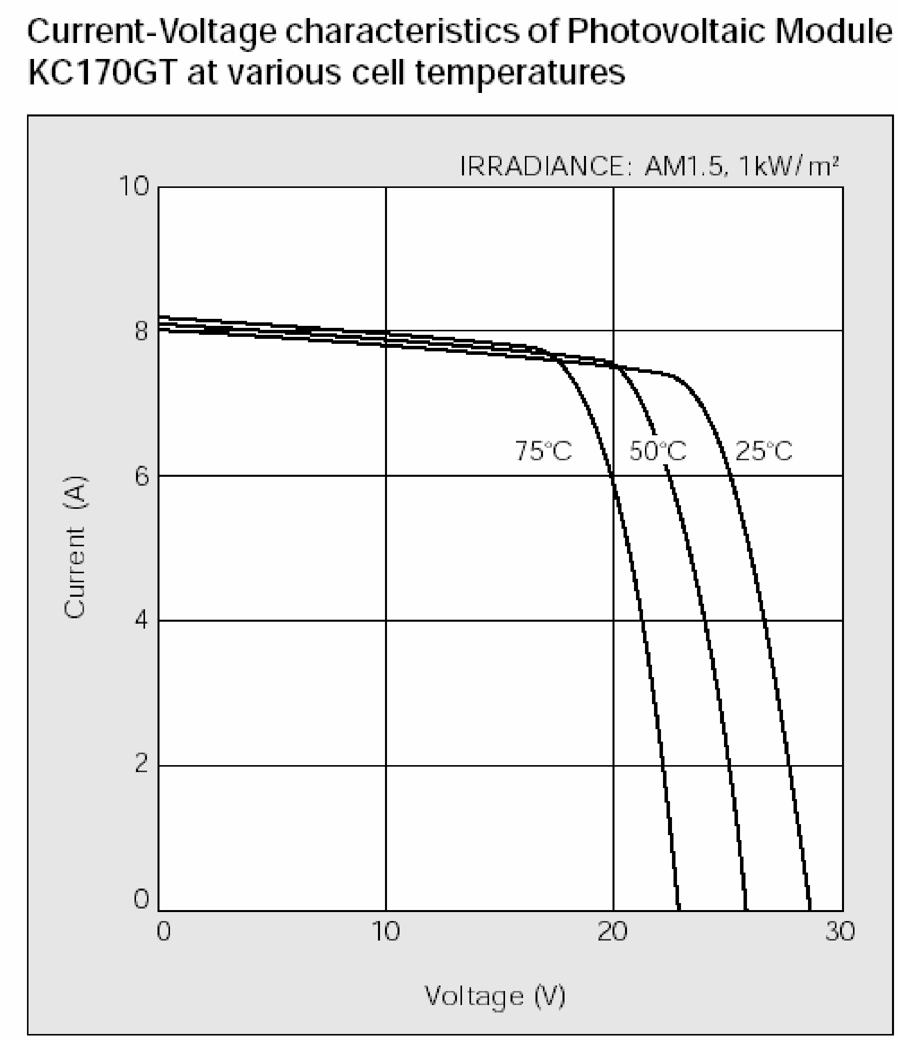
Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	4.3	4.9	5.7	6.1	5.8	6.1	6.1	6.0	5.5	4.9	4.3	4.0	5.3
	Min/Max	4.0/4.6	4.7/5.3	5.2/6.2	5.4/6.5	4.4/6.6	5.3/6.8	5.5/6.5	5.2/6.5	4.8/6.1	4.3/5.4	3.7/4.9	3.4/4.5	4.9/5.5
Latitude -15	Average	4.5	5.1	5.8	6.1	5.7	6.0	6.0	6.0	5.6	5.0	4.5	4.1	5.4
	Min/Max	4.1/4.8	4.8/5.5	5.3/6.3	5.5/6.6	4.4/6.5	5.2/6.7	5.5/6.4	5.2/6.5	4.8/6.2	4.4/5.5	3.8/5.1	3.5/4.8	5.0/5.6
Latitude	Average	5.1	5.6	6.1	6.1	5.4	5.5	5.6	5.8	5.7	5.4	5.1	4.8	5.5
	Min/Max	4.7/5.6	5.3/6.1	5.5/6.6	5.4/6.5	4.5/6.2	4.9/6.2	5.1/6.0	5.1/6.3	4.8/6.3	4.7/6.0	4.2/5.9	4.0/5.7	5.3/5.8
Latitude +15	Average	5.5	5.8	6.0	5.7	4.9	4.8	5.0	5.3	5.5	5.5	5.4	5.2	5.4
	Min/Max	5.0/6.1	5.4/6.3	5.4/6.5	5.1/6.1	3.8/5.5	4.3/5.3	4.5/5.3	4.6/5.8	4.7/6.1	4.7/6.1	4.3/6.3	4.3/6.3	5.0/5.7
90	Average	4.2	3.9	3.1	2.0	1.5	1.5	1.5	1.7	2.5	3.3	3.9	4.1	2.8
	Min/Max	3.8/4.8	3.6/4.2	2.8/3.5	1.9/2.1	1.4/1.6	1.4/1.5	1.4/1.5	1.6/1.7	2.3/2.7	2.8/3.7	3.1/4.7	3.3/5.1	2.7/3.0

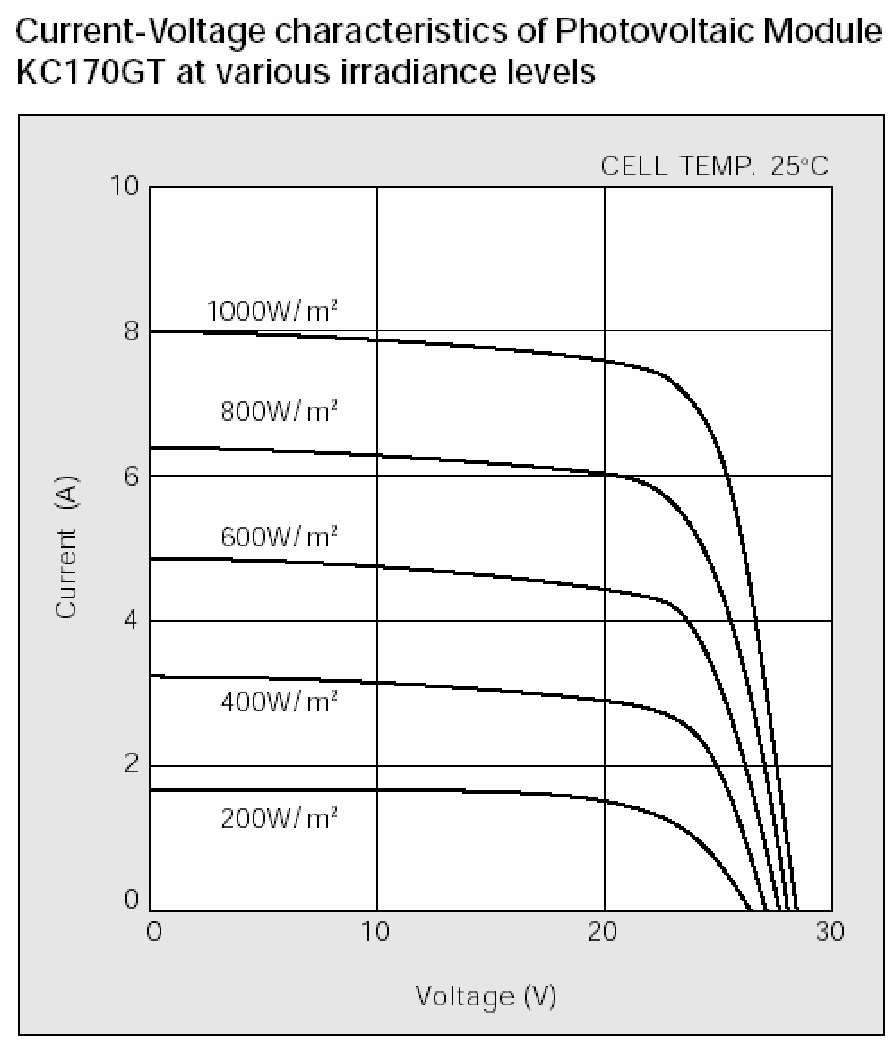
PV-Considerations



Mayagüez Area Daily radiation @ 18.6 degrees for January

Why is the radiation important?
Kyocera Model KC170GT





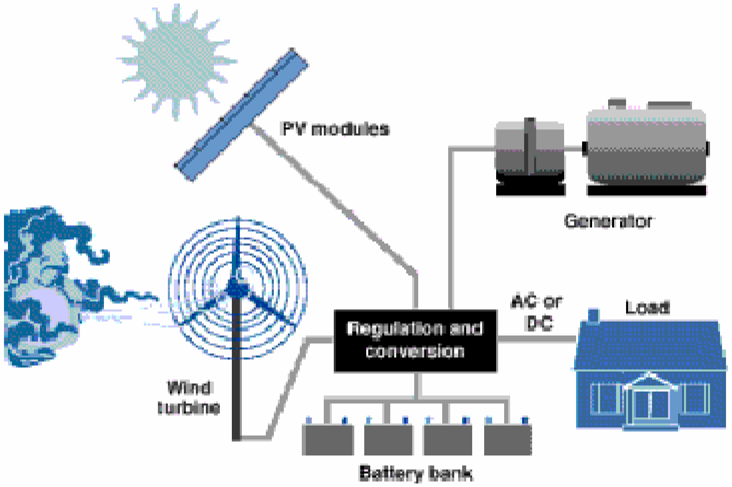
PV-Considerations

Hourly Horizontal Radiation (W/m²) for the city of Mayagüez P.R.									
Month/Hour	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	Monthly Average (Kwh/m²)	Yearly Avarege(Kwh/m²)
Jan	5.1	59.0	22.1	412.3	552.4	594.6	572.6	3.47	4.09
Feb	8.8	75.1	269.1	471.3	602.5	626.5	567.2	3.96	
Mar	16.4	117.0	348.3	552.4	669.1	658.1	628.1	4.39	
Apr	26.8	183.0	404.4	586.8	684.2	683.9	652.1	4.61	
May	48.0	215.5	400.3	549.9	613.3	608.2	584.6	4.26	
Jun	51.1	216.1	407.4	589.0	679.2	634.7	574.8	4.50	
Jul	38.8	204.7	397.8	581.4	672.6	640.7	547.6	4.19	
Aug	29.0	192.8	403.8	593.9	711.7	692.4	589.6	4.40	
Sep	24.3	155.5	383.6	566.3	684.6	678.9	631.2	4.27	
Oct	15.1	132.5	356.2	540.4	645.4	655.5	579.8	3.91	
Nov	9.5	101.6	304.4	477.3	605.7	637.9	575.4	3.77	
Dec	2.5	66.6	242.0	405.4	542.3	573.2	531.9	3.37	

Month/Hour	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM
Jan	524.6	431.6	328.7	192.1	58.0	4.4
Feb	559.0	467.8	346.4	209.2	80.2	8.8
Mar	615.8	482.0	352.1	212.3	90.5	13.6
Apr	600.6	479.2	338.5	224.3	111.7	20.8
May	510.4	425.6	316.4	210.1	106.3	24.3
Jun	556.2	450.2	324.6	227.8	126.2	36.3
Jul	450.8	372.6	269.4	201.0	122.4	36.6
Aug	489.6	416.7	293.4	206.9	117.4	31.6
Sep	526.2	407.3	287.7	174.1	89.6	13.3
Oct	507.6	361.2	253.3	136.0	48.3	3.2
Nov	504.4	411.4	278.6	142.6	29.0	2.5
Dec	472.6	368.8	268.5	141.3	33.1	1.9

Compare with 5.5 (yearly average) & 4.8 (monthly average) at LMM Inter. Airport

Other Available Technologies-WIND



The power *P* available in the wind is given by:

$$P = \frac{1}{2}\rho\pi R^2 v^3$$

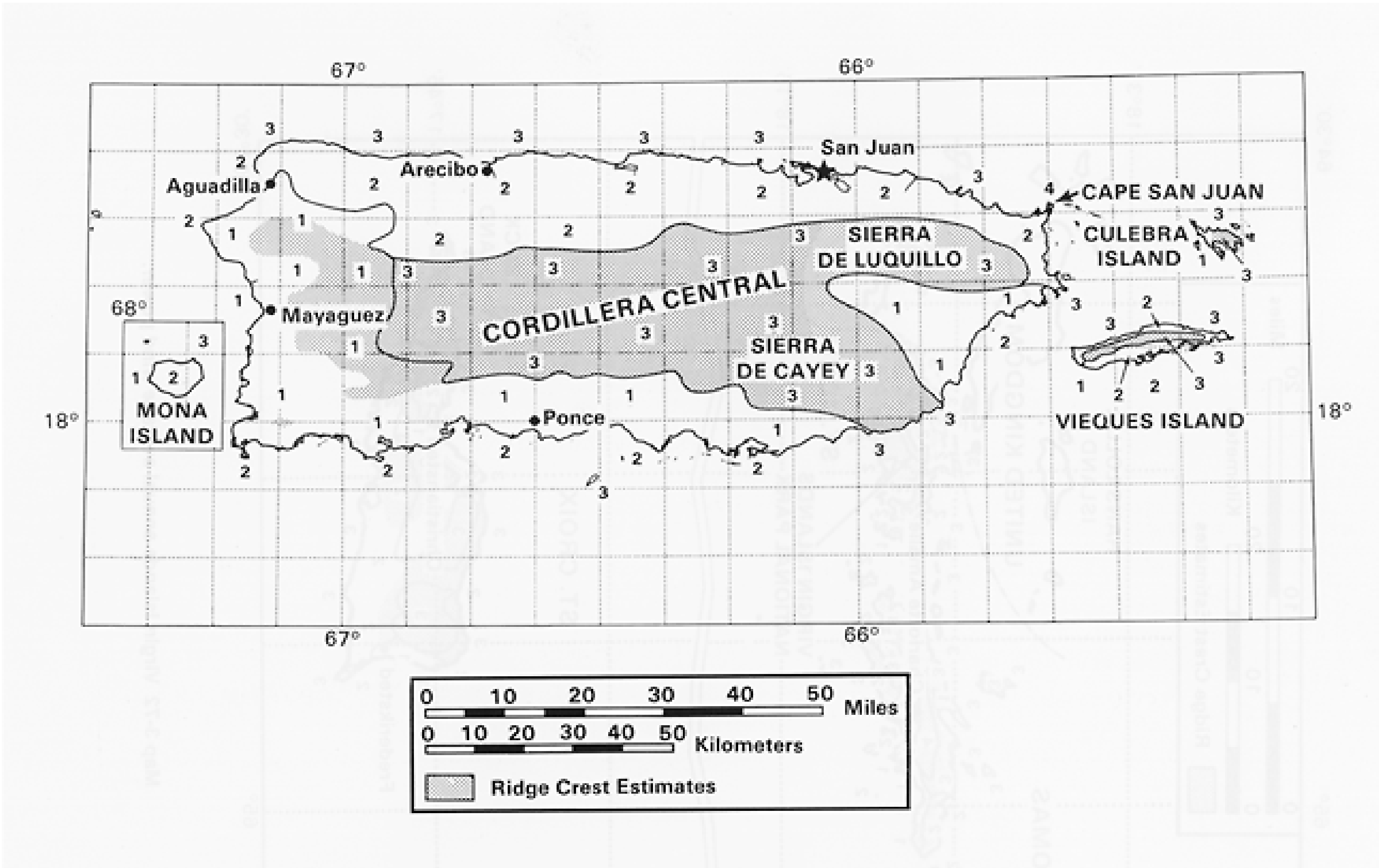
where *P* is in watts, ρ (density of air) is measured in kg/m³, *R* (rotor radius) is in m, and *v* (wind speed) is in m/s.

WIND-Considerations

Wind Classes for US-DOE Wind Maps
Classes of wind power density at 10 m and 50 m (a)

Wind Power Class*	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed (b) m/s (mph)	Wind Power Density (W/m^2)	Speed (b) m/s (mph)
1	0	0	0	0
2	100	4.4 (9.8)	200	5.6 (12.5)
3	150	5.1 (11.5)	300	6.4 (14.3)
4	200	5.6 (12.5)	400	7.0 (15.7)
5	250	6.0 (13.4)	500	7.5 (16.8)
6	300	6.4 (14.3)	600	8.0 (17.9)
7	400	7.0 (15.7)	800	8.8 (19.7)
	1000	9.4 (21.1)	2000	11.9 (26.6)

WIND-Considerations



Bergey 1000W Specifications:

- **Rotor Diameter:** 2.5 m (8.2 ft.)
- **Start-up Wind Speed:** 3m/s (6.7 mph)
- **Rated Wind Speed:** 11m/s (24.6 mph)
- **Rated Power:** 1000 Watts
- **Net Weight:** 75lbs

Predicted Energy Production

Wind Speeds Taken at Top of Tower

Annual Average Wind Speed (m/s)		3.5	4	4.5	5	5.5	6	6.5
Annual Average Wind Speed (mph)		7.8	8.9	10.1	11.2	12.3	13.4	14.5
Production in kWh (24 VDC)	Daily	1.9	2.8	3.9	5.1	6.4	7.7	8.9
	Monthly	55	85	115	155	195	235	270
	Annually	680	1,010	1,410	1,850	2,320	2,790	3,260

Wind Speeds Taken at 10 meters (per standard wind resource maps)

US-DOE Wind Power Class			1	2	3	4	5	6	7
Annual Average Wind Speed (mph)			~ 8.9	~ 10.7	~ 12.1	~ 13.0	~ 13.9	~ 15.0	~ 18.8
Annual Average Wind Speed (m/s)			~ 4.0	~ 4.8	~ 5.4	~ 5.8	~ 6.2	~ 6.7	~ 8.4
Production in kWh (24 VDC)	30 ft (9m) Tower	Daily	2.6	4.3	5.8	6.8	7.8	9.1	12.7
		Monthly	80	130	175	205	240	275	385
	64 ft (20m) Tower	Daily	4.1	6.4	8.2	9.3	10.4	11.7	14.7
		Monthly	125	195	250	285	320	355	445
	104 ft (32m) Tower	Daily	5.2	7.8	9.7	10.9	12.0	13.1	15.4
		Monthly	160	235	295	330	365	400	465

Assumptions: Inland site, Rayliegh Wind Distrubution, Shear Exponent = 0.20, Altitude = 1000ft (300m).

Note: Battery charge regulation (batteries full) and wire run losses will reduce actual XL.1 performance.

Your Performance May Vary.

General PV Design

- **Energy Audit of the Load-Daily kWh of use**
  - *Power rating of each electrical load*
  - *Total time of use for each load*
- **Solar Array Sizing**
  - *How many PV modules are needed*
- **Battery Sizing**
  - *How many batteries are needed*
- **Inverter Specification (if needed)**
  - *For AC loads*

Energy Audit-Room BNF8

BNF 8						
Equipo	Voltaje (V)	Amperes (A)	Potencia (VA)	Tiempo Enscendido (hr./dias)	Rango	Potencia BNF8 (KVA)
Precision Low Temperature Incubator (nevera)	115	5	575	24	5	6.86
Controlador de temperatura de nevera	115	8	920	24	5	
Nevera Whirpool	115	6.5	747.5	24	5	
Nevera General Electric	115	7	805	24	5	
Nevera Westing House	115	4.75	546.25	24	5	
Edge Card Hood Blower/luces	115/115	9.4/2.9	1415			
Heat Lab-Line	120	1.25	150			
Precision Thelco Model 6	120	2.7	324			
Bacti-cinerator	120	1.1	132			
Fisher Scientific	115	0.7	80.5			
2 Computadoras			610			
1 Printer			14			
4 sets de luces fluorescente de 4 tubos			544			

Potencia Total (KVA)
88.71

Total power rating of the building. →

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Energy Audit-Total for building's critical loads

Load Evaluation Form														
Appliance	AC	DC	Qty	VA	Watts (VA) Mult. by 1.15 for AC	Hrs.	Hrs. Per Day	Days	Days Per Week	/	Avg. Watt Hrs./Day	Total watt-hr per day	Load correction factor	Corrected watt-hr per day
Refrigerator	x		10	300	3,450	24	82,800	7	**579,600**	7	82,800	124,849	1.25	156,061
Lights Column	x		1	647	744	12	8,929	7	**62,500**	7	8,929			
Freezers	x		4	300	1,380	24	33,120	7	**231,840**	7	33,120			

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Solar Array Sizing

Solar Array Sizing Worksheet		
Winter	Yearly Average	# modules
3.37	4.09	126
156,060.75	156,060.75	
46,321.27	38,150.26	
370	370	
125.36	103.25	

Minimum value of solar radiation

Corrected load in Watt-hrs per day

Watts needed to be generated at maximum Sun capacity

Power produced by each PV module

Minimum amount of modules needed for the application

Amount of modules needed for the application

Yearly average of solar radiation

Battery Bank Sizing

Battery Sizing Worksheet	
124,848.60	# batteries
7	356
873,940.20	
1,747,880.40	
1,747,880.40	
4920	
355.26	

- Amount of Watt-hrs per day from pag19
- Total days of energy needed from batteries
- Watt-hrs needed during the days needing batteries
- To maintain life expectancy of batteries, preceeding number is divided by 50%
- Preceeding number is multiplied by a temperature factor affecting battery capacity (1.0 in Puerto Rico)
- Selected batteries watt-hr capacity
- Minimum number of batteries required
- Number of batteries required

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Main Equipment Cost

These are some examples of devices specified for the application on the example.

Battery Model	V	A*hr @ 20 hr	Price	Cost
6CS-25PS	6	820	$927.0	$330,012.0

PV Module	Watts	Price for quantity			Cost	Cost/w
		1	2	4	126	
Kyrocera 130 W	130	$595.0	$1,250.0	$2,500.0	$74,970.0	$4.6

Inverter/Charger Module	Watts	Volts	Price	Cost
SW4048 Series II	4,000	48	$2,179.0	$4,358.0

Total Equipment Cost
$409,340.00

Homework

- Using the example tables above specify the amount of PV modules and batteries needed to power the whole CLiMMATE Lab.
- How much it would cost to power the Lab?