The effect of shape on energy generation by photovoltaic panels

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Background

This project was motivated by the fact that climate change is caused by man, in large part due to the burning of fossils fuels releasing carbon-based gas emissions into the atmosphere. The greater use of solar energy generation is one mode of energy generation that can reduce the dependence on fossil fuels.

As CSIRO explains:

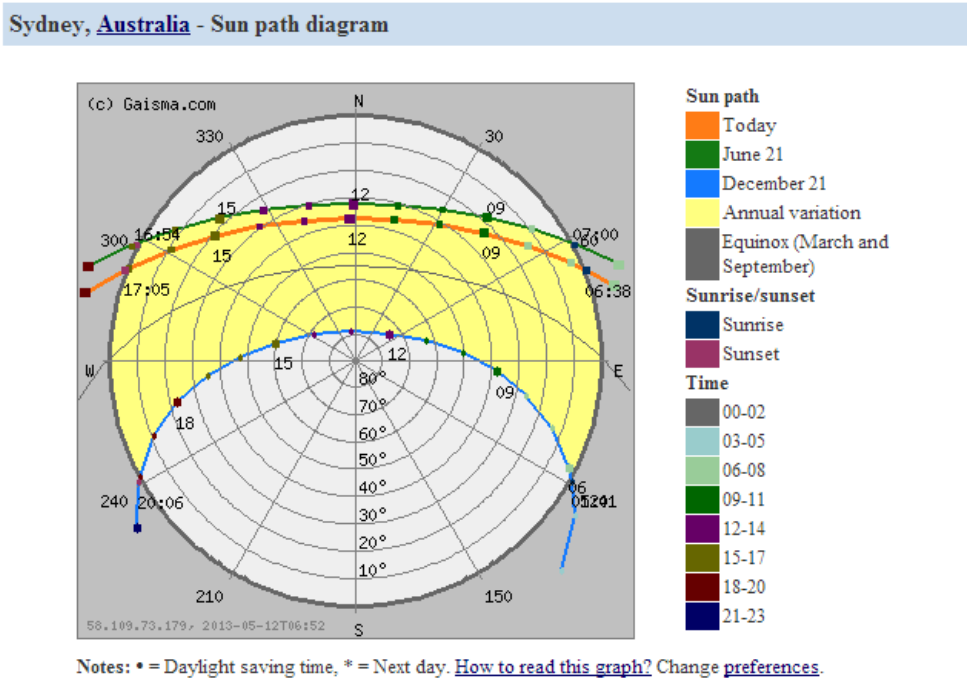
> *'Photovoltaics (PVs) involve the conversion of light into electricity at the atomic level. Materials are selected or designed to absorb photons of light and release electrons. When these electrons are captured, electricity is created.'* [1]

Considerable research has been done in terms of PV **materials**. Perhaps there is a more basic question to ask about PV devices? The vast majority of such devices are in the form of rectilinear flat panels. Is this the best shape? What about curved or domed shapes?

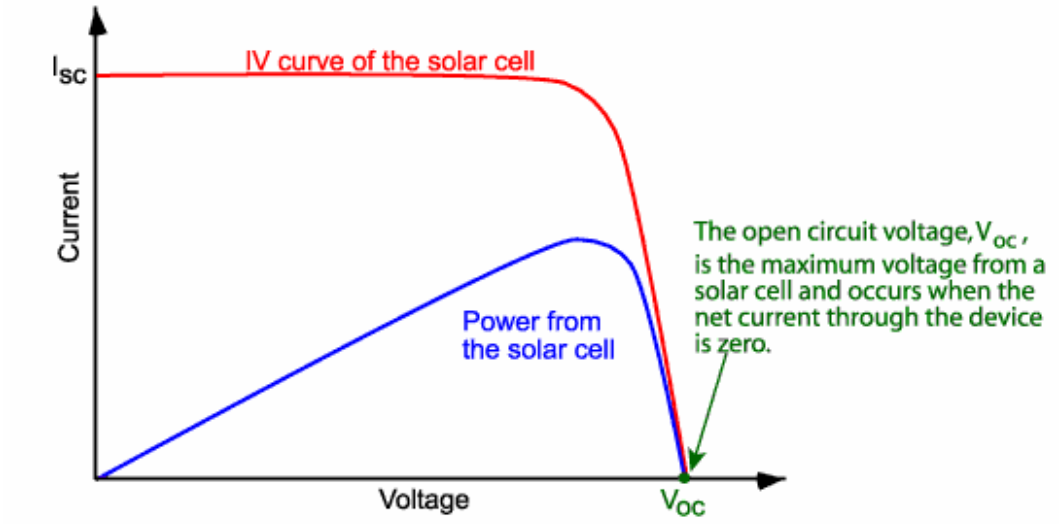
The underlying science includes an understanding of the variation of solar radiation through the day, as the sun travels across the sky, and the conversion efficiency of PV panels as the angle of incidence changes.

As seen below, the Sun's path follows an envelope through the period of a year (depending upon latitude), and that envelope should be the optimal path for the collection of energy.[2] Therefore, a curved PV panel is selected as a possible advantageous shape. A comparison will be made with two other (flat) panel shapes: one square and one rectangular.

[1] CSIRO http://www.csiro.au/en/Outcomes/Energy/Renewables-and-Smart-Systems/solar-power/Photovoltaics.aspx
[2] Gaisma http://www.gaisma.com/en/location/sydney-au.html

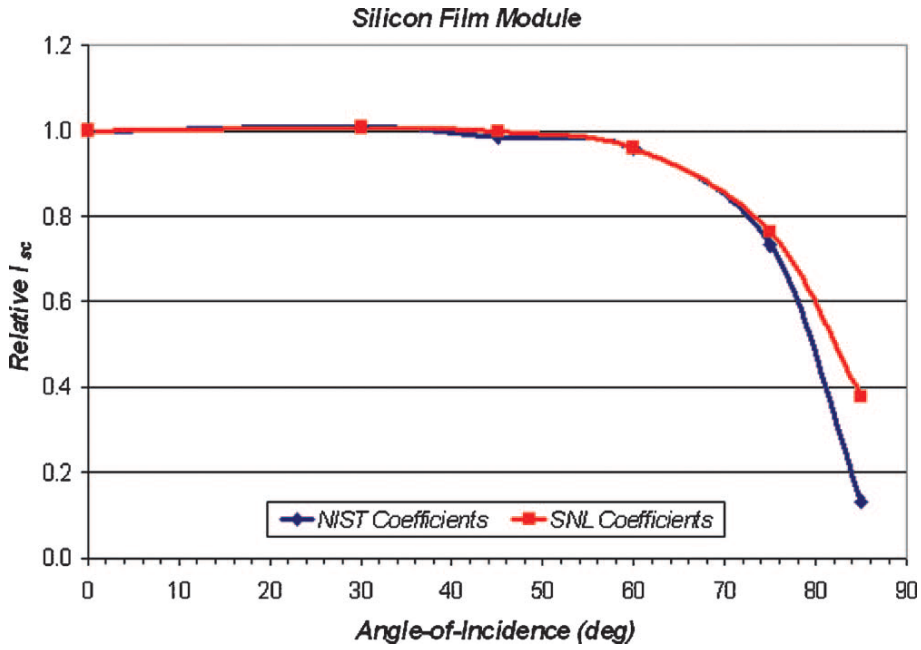


The diagram below shows that current is constant with voltage up to almost the maximum voltage.[3] Since power = voltage x current, then power is directly proportional to voltage. Therefore, voltage can be used as a proxy for power.



A panel's conversion efficiency varied with angle of incidence.[4]

[3] Curtin University
http://bauhaus.ece.curtin.edu.au/~rep301/Lecture/Lect%202%20_PV_Power%20Systems_1.pdf



The Sun's radiation changes according to the time of day:

> *'The combination of both forms of solar energy incident on a horizontal plane at the Earth's surface is referred to as global solar energy and all three quantities (specifically their rate or irradiance) are linked mathematically by the following expression:*
>
> $E_g = E_d + E_b \cos(z)$
>
> *where: E_g = global irradiance on a horizontal surface, E_d = diffuse irradiance, E_b = direct beam irradiance on a surface perpendicular to the direct beam, z = Sun's zenith angle.'* [5]

This equation is the basis of the popular wisdom that 'the sun is strongest in the middle of the day'.

Panel elevation (from the horizontal) also affects performance:

> *'For stand-alone PV systems, where winter operation is crucial, the angle should be the latitude plus 15 degrees.'*
>
> *'For grid connected systems the angle should be latitude minus 10 degrees to maximise the amount of energy produced annually.'* [6]

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[4] Fanney et al http://fire.nist.gov/bfrlpubs/build05/PDF/b05047.pdf
[5] Bureau of Meteorology http://www.bom.gov.au/climate/austmaps/solar-radiation-glossary.shtml

The implication, therefore, is that there may not be much energy to be collected by a curved PV panel in the mornings and afternoons, and that valuable surface area isn't oriented in the most-useful direction during the middle of the day.

[6] Australian Government http://yourhome.gov.au/technical/fs67.html page 208

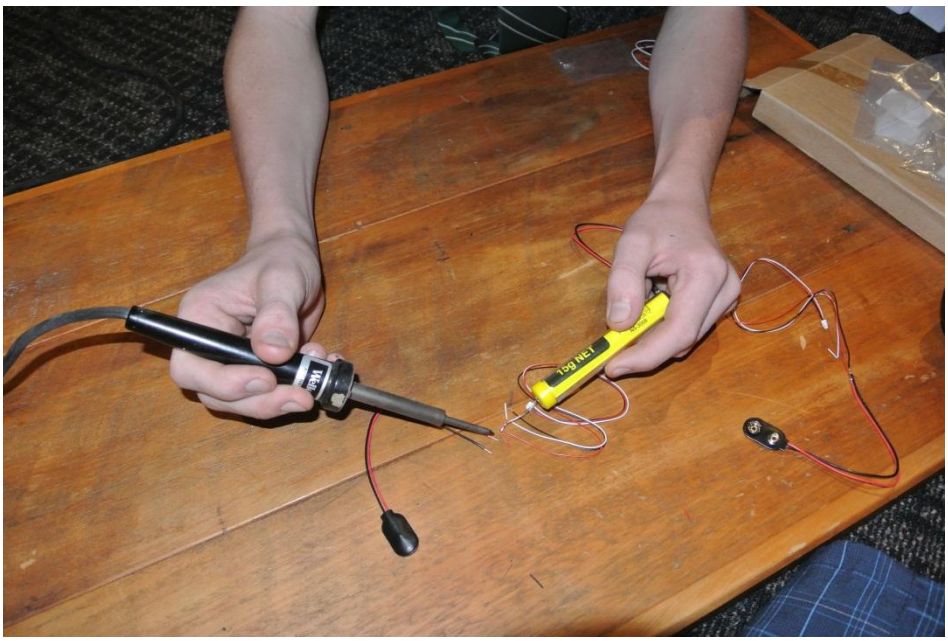
Experiment

Three experimental models were constructed. The principal components were:

- 6 x Flexible “PowerFilm” photovoltaic panels, model no. MP7.2-150 (200mA @ 7.2V)
- 3 x “Powertech” digital DC power meters, model no. MS6170
- 1 x “Powertech” data adaptor, model no. MS6174
- 3 x 5V 100Ω resistors

Method

1) Construct electronic circuits

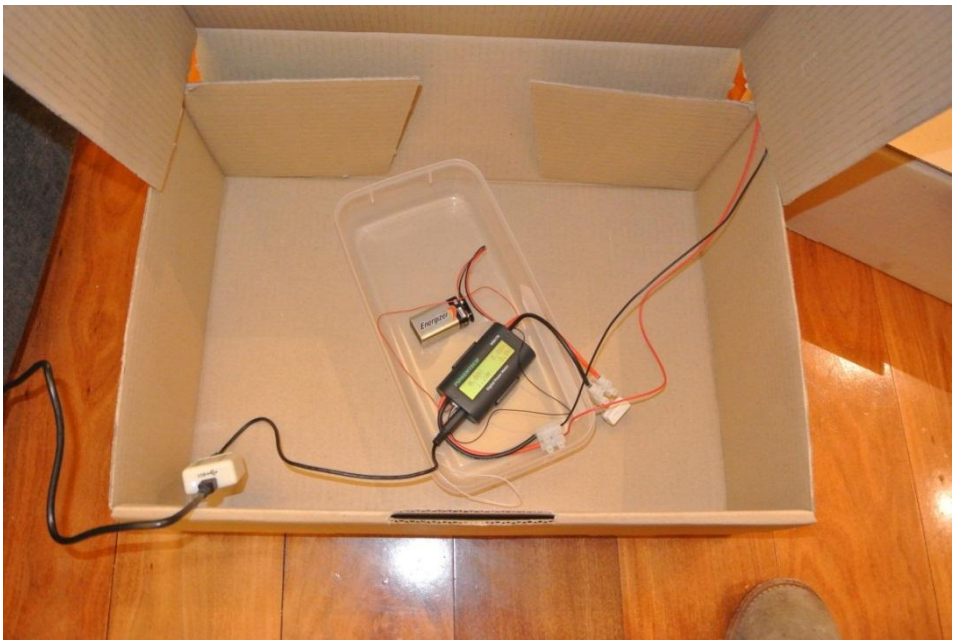


2) Construct experimental solar panels mounted on cardboard boxes

3) Locate boxes at first test position at ground level, facing North at 33 degrees from horizontal

4) Place boxes at second position (on roof, North facing at 45 degrees) for whole of daytime

5) Collect results

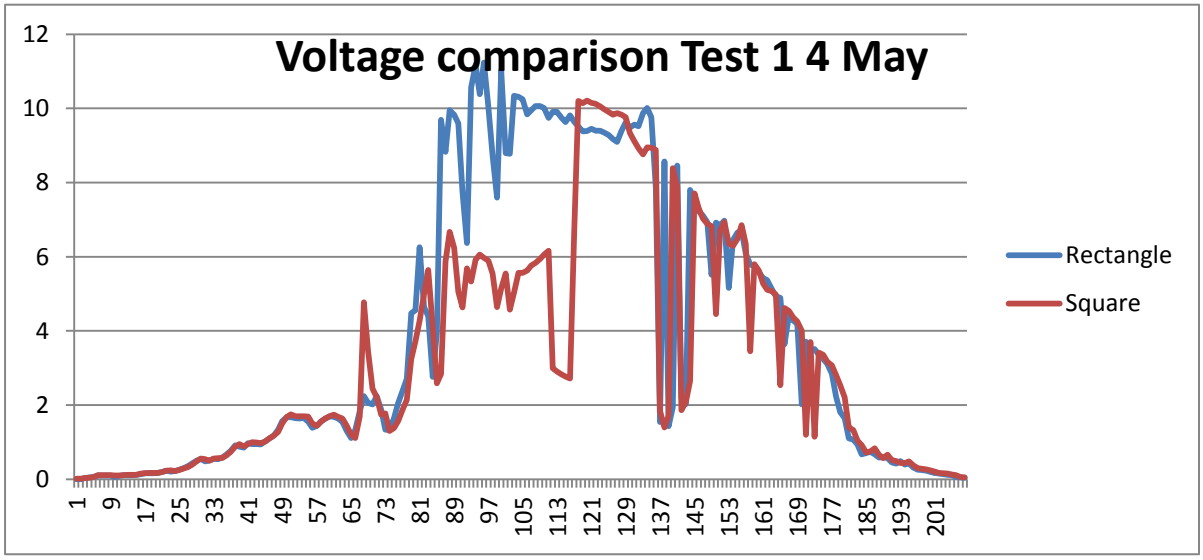


6) Repeat steps 7-8 twice for increased data measurements

Results

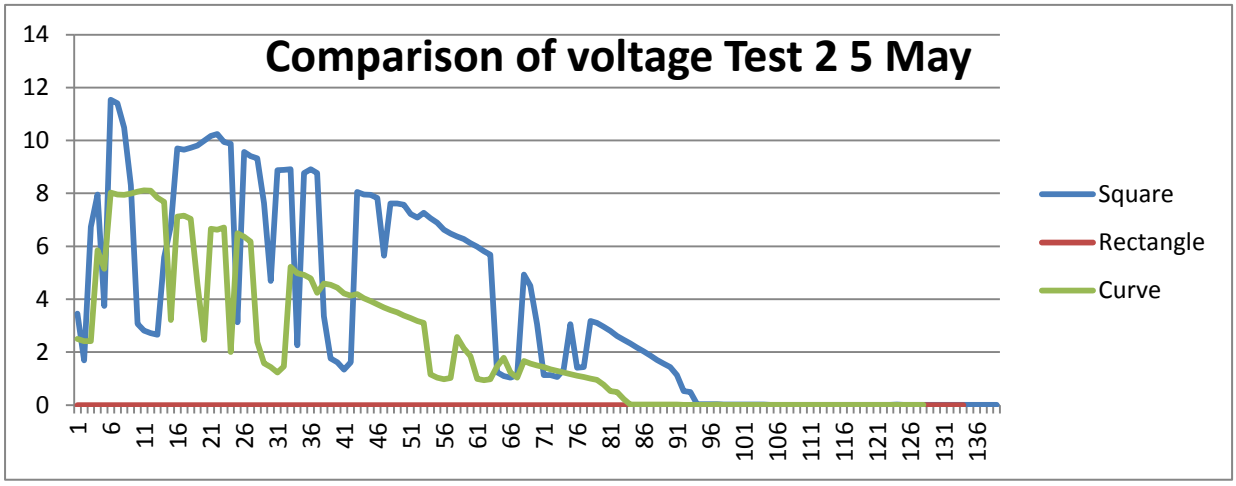
Tests 1 and 2 were intended to check the instrumentation was working correctly. The data is unreliable.

Test 1 – part-day only



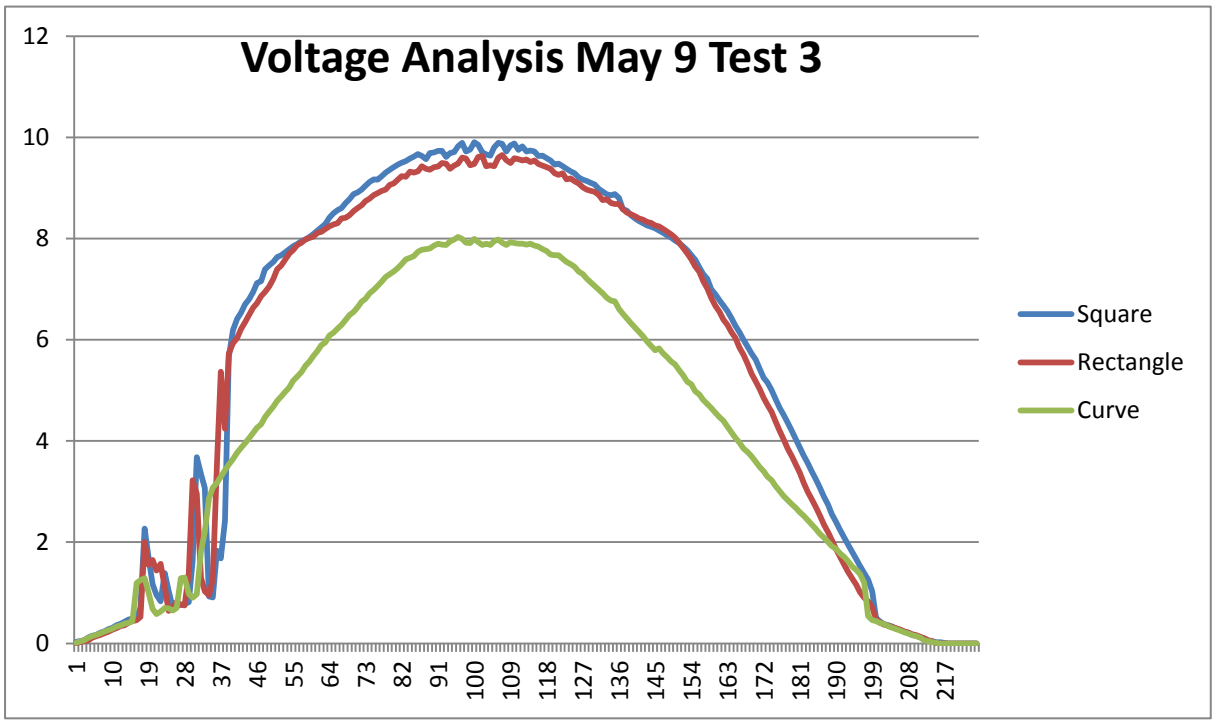
The large dip in the rectangle curve was due to the lid of the box blowing open.

Test 2 – partly cloudy



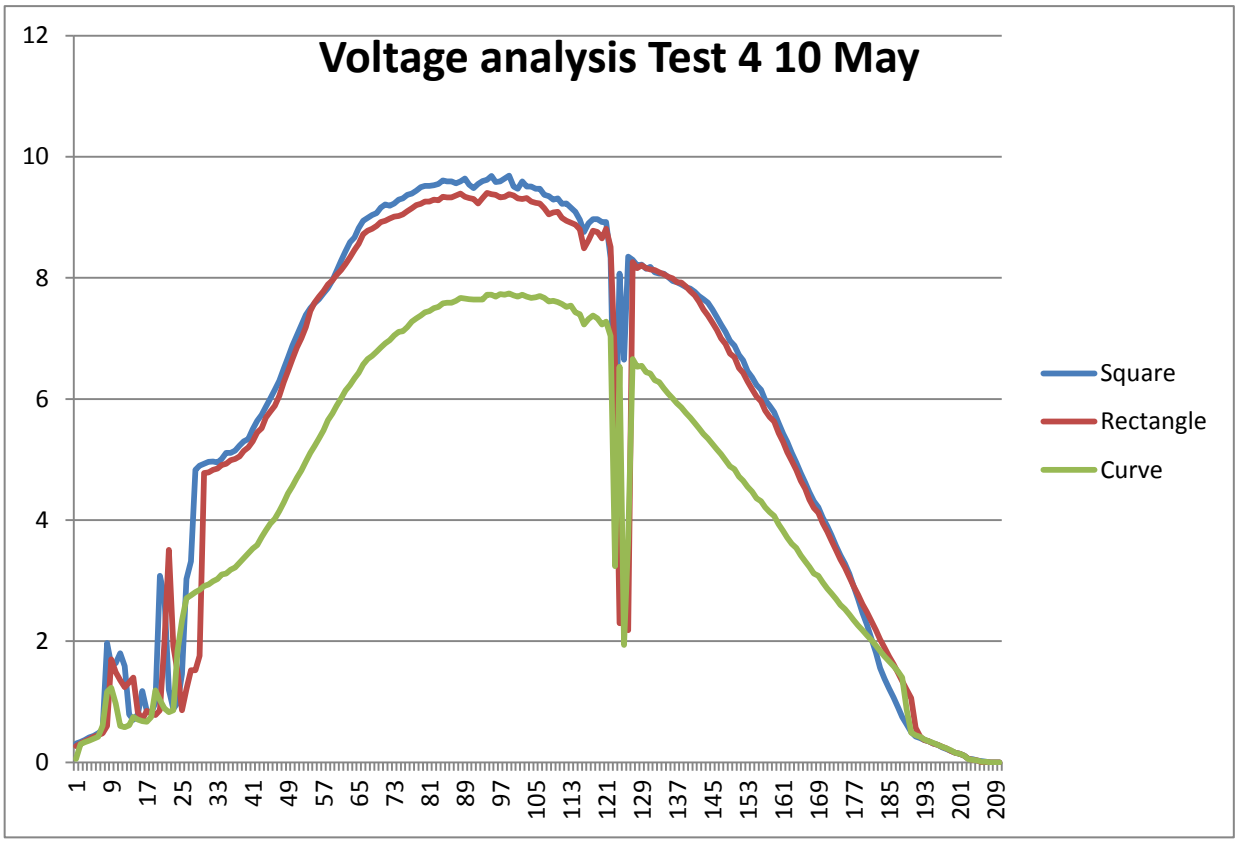
The rectangular panel malfunctioned due to a lead coming loose.

Test 3 – partially cloudy conditions



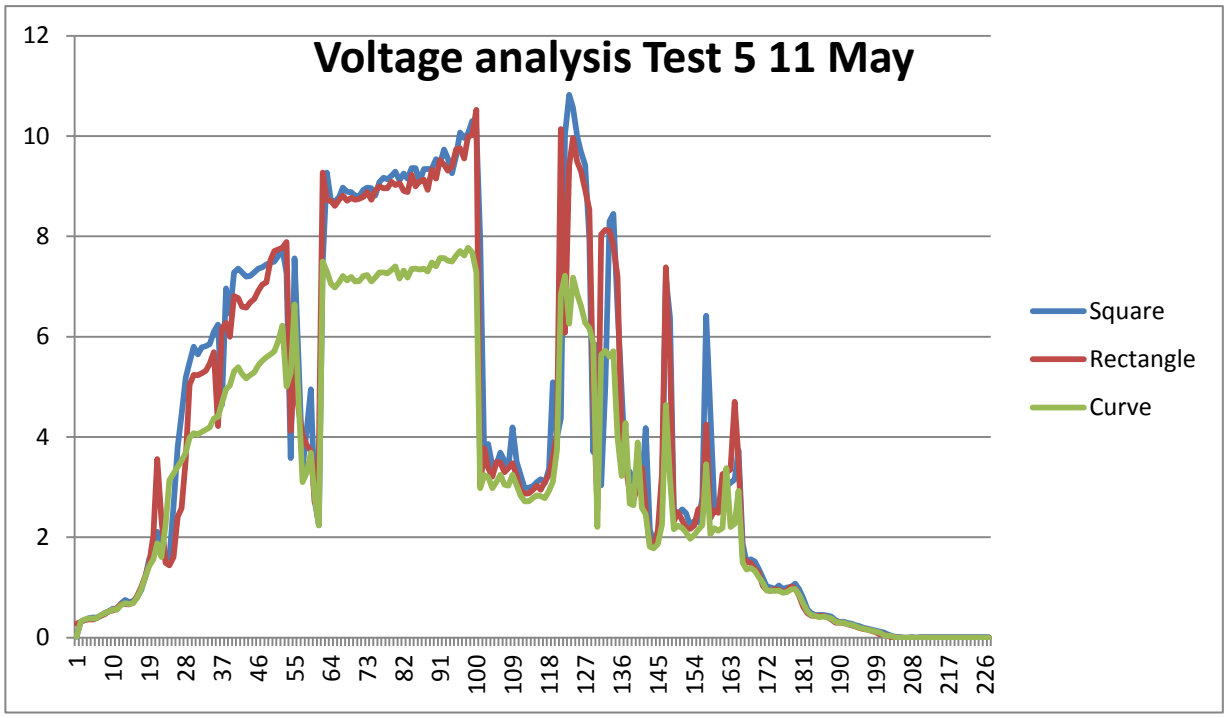
Shape	Vp	Wp	Wh	Ah
Square	9.93	0.9	4.5	0.5
Rectangle	9.66	0.9	4.0	0.5
Curve	8.05	0.6	2.0	0.3

Test 4 – sunny conditions



Shape	Vp	Wp	Wh	Ah
Square	9.69	0.9	3.9	0.5
Rectangle	9.43	0.8	3.5	0.5
Curve	7.77	0.5	1.8	0.3

Test 5 – partially cloudy conditions



Shape	Vp	Wp	Wh	Ah
Square	11.28	1.2	2.7	0.4
Rectangle	11.03	1.1	2.4	0.3
Curve	7.88	0.6	1.3	0.2

Comparative analysis between Tests 3-5

The weather was different on each of the five days that data sets were collected (i.e. the solar load varied), but comparisons can be made between the respective data sets in relative terms.

Wh/Wh	Square vs Curve	Square vs Rectangle	Rectangle vs Curve
Test 3	225%	113%	200%
Test 4	217%	109%	194%
Test 5	208%	113%	185%

These figures agree within the experimental error.

Discussion of results and conclusion

The flat (square and rectangular) panels produced significantly more energy than the curved panel. Curiously, the square panel produced more energy than the rectangular panel, yet both had the same surface area.

As predicted by the underlying science, the square and rectangular panels produced more energy than the curved panel. It is a flat world afterall!

An interesting side observation is the dramatic effect clouds have on energy generation. For example, in Test 4 the clouds reduced the output voltage by 75% (8V down to 2V).

Further study

It would be interesting to investigate why the square panel performed better than the rectangular panel. The load resistors could be swapped in case their actual resistance values have some effect. There might be variation in the characteristics of the panels too. The square panel could be reconfigured as a rectangle, and the rectangular panel as a square and measurements taken.

Acknowledgments

I want to thank my mother and father for their help and encouragement. I also discussed the project with my brother Angus who is an engineering student at Sydney University, and was helpful in checking the method.