The Ravina Project

Solar Research - Theory and Practice

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Executive Summary

A solar array is an antenna.

We normally associate an antenna with the reception and transmission of radio signals. To compare an array of solar panels to a radio antenna seems to be off the mark in some ways.

However consider the following similarities:

- They both intercept streams of photons.
- They both require photons to be at or very near a particular energy to be useful.
- They both reject photons at different or unusable energies.
- They both use photons to create electrical voltage and current in the antenna. In the case of radio the induced current and voltage is amplified and filtered by the radio receiver's front end so that the modulated signal placed upon the photons by the transmitting modulator can be demodulated as it travels further into the receiver circuitry. In the case of the solar array, the photons are directly harvested by materials that will emit electrons over a range of voltages.
- They both receive maximum signal when their collecting surfaces are set at an angle of 90 degrees (perpendicular) to the intercepted stream of photons.

It is our opinion that these similarities cannot be ignored. Some of the ideas we get from radio antennae design and use, should therefore be useful in the quest to get as much power out of an array of solar panels as possible. We have built a dynamic, programmable 1,500 watt solar array for research purposes to test out our hypothesis regarding the similarities between a solar array and radio antenna. This paper uses ideas taken from radio antennae usage to detail the theory and methods used for maximizing the power output of solar panels. Further, the paper outlines the ongoing 60 month research program here at The Ravina Project.

Assumptions used in this paper

There are a few assumptions used in this paper. We want to acquaint the reader with them up front.

- We are considering a solar panel as an antenna during this whole paper. Everything we discuss will assume that a solar panel has an aperture just like a radio antenna.
- As a corollary of the above assumption, maximum power is obtained from a signal when the signal's photons intercept the antenna's aperture at 90 degrees, that is, at an angle perpendicular (normal) to the aperture.
- When we mention photons we will be limiting our meaning to the kind found in direct sunlight. This type of photon is the kind that stimulates maximum current in a solar panel. Other photons from diffuse light are ignored.
- We assume that direct sunlight photons reach the solar panel on a path that is in parallel with all other photons of a similar energy.
- The Ravina Project is located at 43.68 degrees Latitude and -79.34 degrees Longitude at a height above sea level of 120 meters.

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- The dynamic solar array used by the Ravina Project faces 150 degrees azimuth. It favours the morning sun. However, it is at a disadvantage during the afternoon and evening sun. If there is an anomaly such that at this location there is an advantage to this orientation, that is, there is more sun available during the year in the morning than at other times, then the 30 degree offset will affect the data collected. We discount this possibility and assume that the offset will not compromise the statistical validity of the collected data.
- All times are expressed using a 24 hour clock in Sun Time which has an offset in minutes from Eastern Standard Time (EST).

The Sun's Altitude and Azimuth

For every hour of the day the sun is above the horizon; it has a position in the sky. The position is actually a combination of two factors. The sun has an elevation above the horizon measured in degrees; the sun has a direction measured by a compass on a circle of 360 degrees. The first factor is called the sun's altitude and second, its azimuth.

Altitude

Suppose we are standing so we can see the horizon clearly. We are located at the above latitude and longitude (lat/long) and it is April 8th at 11:00. We take two rulers. We sight along one pointing it at the sun and sight the other on the horizon. We make a measurement of the angle so formed between the two rulers. It turns out to be about 50 degrees. We therefore can say that for that time and date at our location on the surface of the earth, the sun has an altitude of 50 degrees above the horizon.

Azimuth

Continuing with the thought experiment started above, let's take out our compass and use it. We draw the shortest line in the sky between sun and the horizon so that when the line reaches the horizon it is perpendicular with it. We now use that point on the horizon as a target for our compass. We take the bearing of that point which turns out to be about 150 degrees.

The important thing to remember is that every location of the sun in the sky can be deconstructed into two variables: its altitude above the horizon and its compass bearing.

It's also interesting to note that these variables vary only slightly from decade to decade. The implication of course is that a 'sun finder' machine could be constructed to find the location of the sun using only a look-up table in it's memory. The table would be valid for a particular location on the surface of the earth for many years.

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Time

We have to address the issue of time considering so much of the following paper concerns itself with events that occur at a particular time of day.

Sir Sanford Fleming proposed in the late 1870s that the world be divided up into 24 time zones that would each be 15 degrees in width. This ingenious idea was adopted for use in 1884. (http://wwp.greenwichmeantime.com/info/time-zones-history.htm) The idea simply was that all the clocks in a time zone would show 12:00 noon on their faces when the sun's azimuth is at 180 degrees at the far eastern edge of the time zone. For each minute of the day, all the clocks in the time zone will mimic the time on the faces of the clocks at the extreme eastern end of the time zone.

So what happens if your location is 500 km to the west of the eastern edge of the time zone? Your clock will be the same as all the other clocks in your time zone and mimic the eastern clocks. But, and here's where it becomes complicated, what happens if you are trying to aim a device precisely at the sun? Given the time of day the sun should be at a certain location in the sky. When in practice the aiming procedure takes place, the sky at that location is empty at that time for most of the year. So what happened?

Actually to understand this anomaly we must go back to first principles. Here at our lat/long the sun passes through 180 degrees, due south at exactly noon sun time. That fact is always the case. However, during the year our clocks might agree with sun time and at others they may be off by tens of minutes. Why does this happen?

Let's do a thought experiment. We locate ourselves looking south at the far eastern edge of our local time zone. We see the sun cross 180 degrees due south and we look at our watch and it says 12:00 noon. So far so good. Now let's beam over 500 km due west of our location and look at our watch. Since we are in the same time zone we see 12:00 on our watch face. However when we take the azimuth of the sun we see that it does not have an azimuth of 180 degrees. It is short of 180 degrees and we have to wait minutes before it arrives at 180 degrees azimuth. On June 5th here, we have to wait 15 minutes before the sun is at 180 degrees azimuth. Our local clock will say 12:15! The sun time and our local clock will vary depending on where we are located east-west in the time zone.

One can reconcile this anomaly if one remembers that we live on the outer surface of a sphere that is rotating once about every 23 hours and 56 minutes or so. If sun time could be frozen at noon 'somewhere', there exists a line connecting the north and south poles through 'somewhere' that has a very specific property. All places on that line including 'somewhere' will either see the sun at an azimuth of 180, 0 (if the sun's azimuth is viewed from south of the equator) or directly overhead (on the equator). As each minute of the day passes and it is, in turn frozen, a different line for noon sun time can be drawn between the poles. This line progresses from east to west … or the line stays the same and the earth moves under it … whatever. From the surface of the Earth the illusion is the same.

Now we understand why our local time is different from the sun's noontime appearance 500 km east of us at the eastern edge of our time zone. The line that represents the sun's noon has not traveled across 500 km of the earth's surface to us yet.

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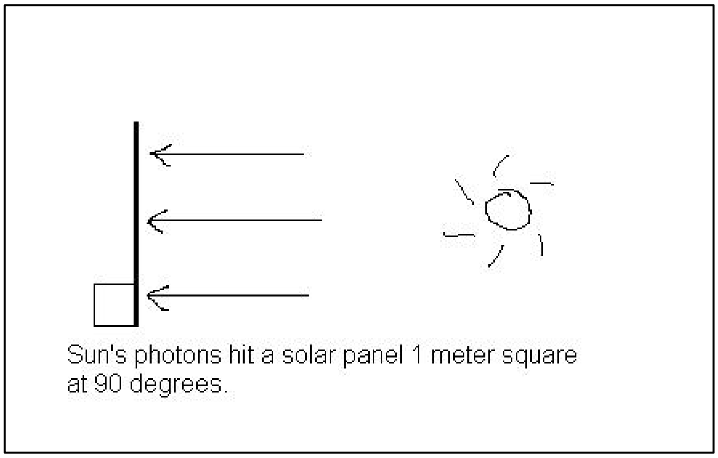
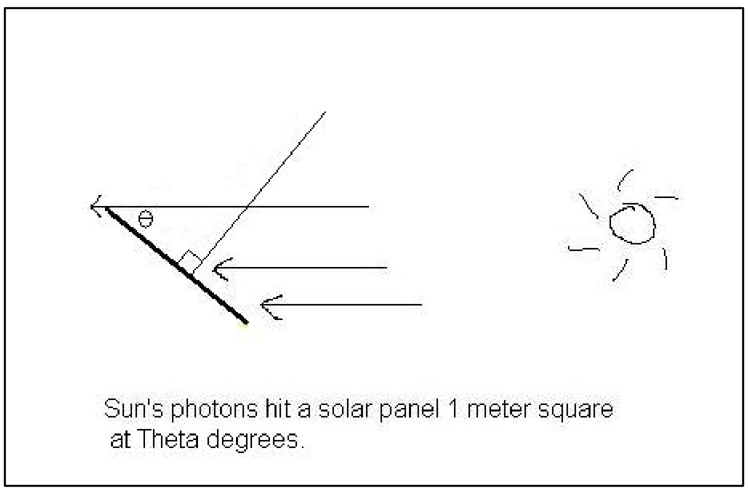
Effective Aperture of a Solar Array

Consider the following diagram.



The point of view is from the side of the array. The sun's rays (photons) hit the array in parallel lines. One of the assumptions above is that when solar radiation hits the aperture of the array at 90 degrees the number of photons intercepted is at a maximum. Hence the signal power received is at a maximum. The solar array will generate maximum power in this orientation to the sun.



Consider the next diagram above.

Here's the same array but this time the sun's rays are hitting it at **theta** degrees. Note the following. The incident ray is offset from 90 degrees, the maximum power angle for the aperture, by (90 – theta) degrees. Note that at the latitude of The Ravina Project the sun will never be at the zenith or 90 degrees overhead. The best we can do here is about 70 degrees of elevation on the 21st of June at noon sun time.

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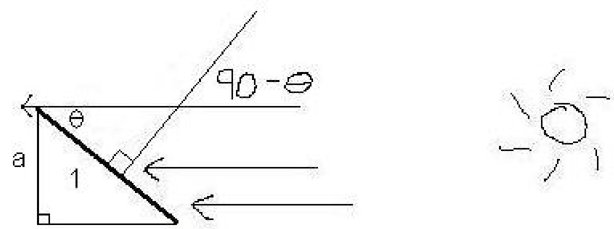
This diagram also gives insight into the solar designer's dilemma of the proper angle to set the solar array at with respect to the sun's seasonal angles. Traditionally we are always dealing with compromises with respect to the proper orientation of the solar arrays we put up.

Consider this next diagram.

The effective size of an array dimension shrinks when the photons hit the array at any angle other than 90 degrees. In fact the effective size of the array is proportional to the sine of the angle of incidence, **theta**. Note as well that the length 'a' expressed in proportion to the offset of the incident angle from normal, (90 minus theta), is COS(90-theta).



Effective size of array 1 meter in length is "a" when angle of sun's rays hit the array at theta degrees. Effective length "a" is calculated as Sin (theta).

We therefore have two ways of calculating the effective length of a dimension of the array. We can either use the angle offset from 90 degrees or the actual angle of the incident ray on the surface of the array.

Note that as the angle theta approaches zero the dimension "a" approaches zero. Note as well that as the angle theta approaches 90 degrees the dimension 'a' approaches unity which is the physical length of the array. Furthermore, this approach to calculating an effective dimension of the array can work for both the array's effective width and its effective height. This allows for the calculation of the array's effective aperture.

Calculating Effective Array Aperture

As we have seen above the array's effective collecting dimensions can be affected greatly by the photon's angle of incidence upon the plane of the array.

Since the sun's altitude starts at the horizon, zero degrees and increases to some maximum before decreasing at the end of day, the sun's daily motion can be understood, on the vertical axis, as an up and down motion. The effective array height can be calculated using the methods described above and the sun's altitude.

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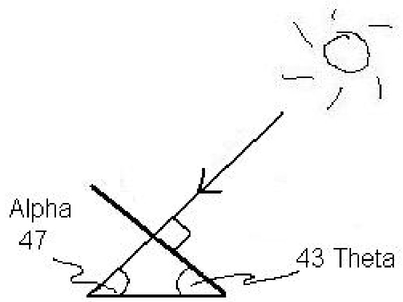
Consider an array 1 meter square that is fixed at a tilt of 43 degrees from horizontal and its north-south centerline is 150 degrees … exactly like the array at The Ravina Project.



Array raised to an angle of 43 degrees from horizontal. Sun's rays hit the array at 90 degrees when sun is at 47 degrees altitude.

If the sun is at an azimuth of 150 degrees and an altitude of 47 degrees the sun's rays will hit the array at an angle of 90 degrees in both the horizontal and vertical axes.

Keeping the same azimuth, let's say that the altitude of the sun is 30 degrees. As we can see from the diagram alpha and theta must add up to 90 degrees if the 90 degree incident angle is to be maintained. However, the array angle theta is fixed at 43 degrees but alpha decreases to 30 degrees. Since the triangle contains 180 degrees the third angle, once normal at 90 degrees now must now become obtuse. When alpha decreases by 17 degrees to become 30, the right angle must increase by 17 degrees to compensate. The sun's ray hits at an offset of 17 degrees from normal on the vertical axis. From above we know that the effective vertical dimension of the array varies as the cosine of the offset which in this case would be COS (17) or .96m.

Can we calculate the width of the array?

Yes we can.

Since the azimuth of the sun is a compass bearing we can understand the sun's motion as a sweeping motion starting in the east and moving to the west through south each day. What I mean by sweep is that once the sun is above the horizon it sweeps through all intervening points of the compass until it sets. It's motion is horizontal. The sun therefore illuminates a fixed azimuth array at various angles throughout the day. The effective width of the array is entirely due to the sun's azimuth. This phenomenon becomes a huge problem for array designers because there are times of the day when the sun is quite high in the sky yet the sun is unusable by tilted solar panels.

We will explore this topic below.

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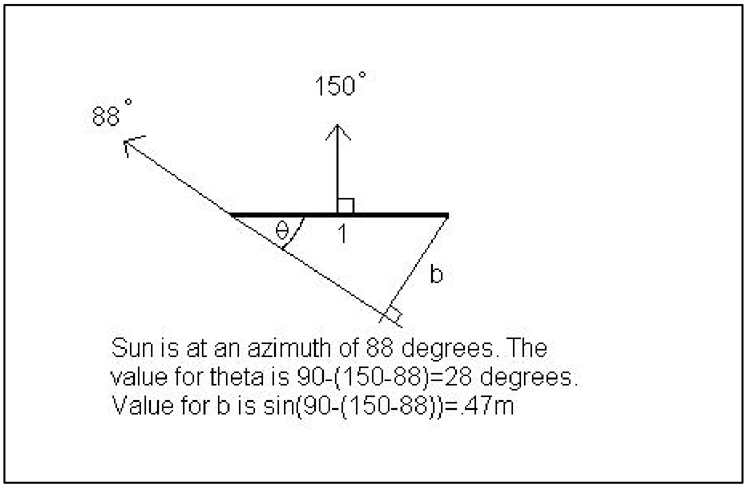
We can use the above techniques to calculate the effective width of the array using the azimuth of the sun.



Consider the illustration above.

The array here at The Ravina Project has an azimuth of 150 degrees. Suppose the sun is located at azimuth of 88 degrees. What is the effective width 'b' of the array? As you can see the angle formed by the array surface and the incident ray is **theta** or 28 degrees. The length 'b' is the SINE of 90 degrees minus the offset or .47m .

Let's do a practical calculation based upon sun angles and industry standard fixed angles for solar panels.

The fixed angle for solar panels this time of year is 43 degrees. At 7:00 the altitude of the sun is 16 degrees and its azimuth is 96 degrees on April 8th at our lat/long.

What is the effective size of the aperture for the 1 meter square array?

The vertical axis offset is calculated by 90-(16+43) equals an offset of 31 degrees. We know from above that knowing the offset allows us to calculate the effective height of the array as COS (offset) or COS (31) or .86 meters.

For the width we also know that the sun's ray hits the array at a horizontal axis incidence angle of 90-(150-96) or 36 degrees. The effective width of the array is SIN (36) or .59 meters.

The effective array aperture is .86m (height) times .59m (width) which is .51 square meters.

To give you some idea of where we are going with this paper, suppose we eliminate the effects of the altitude of the sun? Then only the width will be the determining factor in the

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size of the array aperture. Note we get an immediate increase of 16 percent in the size of our aperture … .51 sq m vs. .59 sq m.

Here's another calculation showing the limits of fixed array angles. See the April 8th sun chart below.

Solar Time of Day	Sun Azimuth	Effective Width	Sun Altitude
6	85	0.42	5
7	96	0.59	16
8	107	0.73	26
9	118	0.85	36
10	135	0.97	45
11	156	0.99	51
12	180	0.87	53
13	204	0.59	51
14	225	0.26	45
15	241	-0.02	36
16	253	-0.22	26
17	265	-0.42	16
18	275	-0.57	5

We have the same setup and date (April 8th) as above. We want to calculate the effective aperture of the array at 15:00. The sun's altitude is 36 degrees and its azimuth is 241 degrees. The effective height is 90-(43+30) = 11. COS (11) = .98 meters. The effective offset is 90-(241-150) = -1. The effective width SIN (-1) is -.02 meters. The sun is off the end of the array and power starts a relatively rapid decline. The effective aperture has a value quickly approaching zero.

Ok let's look at the situation earlier in the day, at 14:00. The altitude is 45 degrees and the azimuth is 225 degrees. The height calculation is COS (90-(43+45)) = .99 meters. The width calculation is SIN (90-(150-225)) = .26m . Our effective area is .99m times .26m which is .26 sq m. As we see above the aperture of the array is on its way to zero very quickly.

The sun is at 14:00, it does not set for another 4 hours but as we can see once the sun gets behind or at a highly acute angle to the array, power will diminish rapidly.

This is all pretty dismal but these calculations demonstrate how much of a power killer azimuth is for an array which has a fixed seasonal angle.

Let's generalize on what we have discovered.

For the effective height the generalized formula we have used is: COS (90-(array angle from horizontal + sun's altitude)). Note some interesting trends in the formula. As the array's angle from the horizontal decreases to zero, the sun's altitude becomes the only determining factor in calculating the effective height of the array.

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For the effective width, the generalized formula we have used is: SIN (90-(azimuth of the array – azimuth of the sun)). There is one exception to this formula. When the array is laying flat, horizontal with the ground, the effects of azimuth disappear. Why?

Do this experiment. Take a saucer and hold it at arms length parallel with the ground. Close one eye and view the saucer from a point of view, say 30 or so degrees above the plane of the saucer. Rotate the saucer keeping it in its plane and at the same angle to your eye. Pay attention to any difference in the shape or the amount of saucer you can see as you rotate it through 360 degrees.

You will see no difference at all. The effective area of the saucer is unaffected by its rotation through 360 degrees.

Let's assume that the top of the saucer is the energy collection surface of a solar array. We saw that the effective area of the saucer was unchanged, hence the aperture of the array is unchanged. When the array is made to lie flat the azimuth drops out and has no effect on the size of the array aperture.

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As you can see the effective aperture of the saucer does not change no matter what the azimuth of the observer. Note that the point of view of the camera is fixed but the structure which supports the saucer was moved through 360 degrees in these photos as evidenced by the relative position of the cork.

This fact has profound consequences and is one of the main reasons The Ravina Project built a dynamic array. We are, over the next 5 years going to explore exactly what these presumed consequences have for daily power generation.

Before we leave this topic, take the saucer and tilt it so that it is not parallel with the ground but is face on from your point of view 30 or so degrees above it. Now carefully rotate the saucer through 360 degrees yet maintaining the fixed angle and notice if the surface area of the saucer varies. If you are doing it right, the saucer will look like one of those radar antennas turning around in a circle. You will see the front full on, then the side edge on and then the back. The surface area of the saucer you see varies from all to none. See the pictures below.

The sun's azimuth affects a fixed angle solar array the same way. At times during the day the sun is full on the array. At other times of the day the sun is behind the array or off its end.

The sun is face on the tilted array. The effective aperture is very close to unity which means it is at its maximum.

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Here the tilted array is close to being end on the sun. As you can see the effective aperture is much less than the picture above and as the sun continues increasing its azimuth, the effective aperture approaches zero.

The effective aperture is at zero. No sun can hit the front of the array.

The sun is almost end on and the effective aperture is near zero.

Again we stress, aperture variation due to sun azimuth is a huge power killer for any fixed angle solar power generator.

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Using the Dynamic Solar Array

The picture shows the tilting mechanism and tilting geometry. The support structure, designed by Ben Rodgers of Solsmart Energy Solutions Inc., consists of three interlocked tetrahedra. Each strut is 7 feet 6 inches (2.286 m) long consisting of 2 3/8 inch (60.33 mm) OD schedule 40 steel pipe.

The dynamic solar array has been in use since the start of the project (November 2006) over 5 months ago.

The array is operated remotely from the Power Room in the basement and viewed from the Power Room in real time using an external 802.11b IP camera and a laptop. The angle can vary from laying flat, parallel with the ground to plus 70 degrees. The array can also be programmed for time of day movement for a two week period. This allows for consistent array behaviour over a period of time and reduces operator errors.

As you can see the array has one degree of freedom. It can move vertically so it has the capability of compensating for the sun's altitude or it can lay flat and compensate for the sun's azimuth each hour for the entire day. The ability to double compensate for the sun's location in the sky is its defining feature. The data we collect will determine its value.

Array Programming Calculations

The array for it to be used must have data calculated for it. It must have, at minimum, an angle and time of day. In theory an angle can be calculated for each hour of the day with little effort. However, at times of the year when the apparent motion of the sun in the sky, from day to day, is sluggish at best, few calculations need to be made. This slow movement occurs in the summer (May to July) and winter months (November to January).

During the transition months the sun is very active moving upwards or downwards very quickly each day. More frequent calculations need to be made during these times of the year. See the sun chart on page 23 below.

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We want to take you through one day's calculations in order to show you the method and models used to generate the daily angles for the array.

Effective Width Calculations

The first part of the spreadsheet deals with the calculation of the effective width of the array based upon the sun's azimuth. Refer to the chart below on page 14 to verify these angles. The effective width is calculated using our derived formula above. The column entitled "Effective Width" has the following formula for the column. Note that this formula, **"=+SIN((90-(C22-B5))*PI()/180)"** has a constant **C22** associated with it. The **C22** stands for the fixed azimuth of the array. Here at the Ravina Project our array is pointing to 150 degrees rather than 180. Changing **C22** to a different value allows us to evaluate the array angle to find whether there is a theoretical advantage in using other array azimuths. **B5** is the value of the sun's azimuth read directly from the sun chart below.

Array Programming for April 8th

Solar Time of Day	Sun Azimuth	Effective Width
6	85	0.42
7	95	0.57
8	106	0.72
9	119	0.86
10	135	0.97
11	156	0.99
12	180	0.87
13	204	0.59
14	225	0.26
15	241	-0.02
16	254	-0.24
17	265	-0.42
18	275	-0.57

Note from the sheet above that at 15:00 the sun goes behind the array. At 15:00 the array is effectively shutting down with four hours of sunlight to go in the day. Note as well, that the 'effective width' calculation is only valid for an array that is raised at some angle from the horizontal.

This is a simple minded calculation because there are some orientations where the sun just peaks over the back of the array even though the sun is behind the east – west line running through the array. For instance, the array is tilted at 28 degrees and the sun is behind it but 35 degrees in altitude. The effective height of the sun is somewhere around 7 degrees. It is our opinion that no significant on-going power is being generated with this orientation even though the geometry is possible. We acknowledge this possibility but we chose to ignore it in our calculations for effective width.

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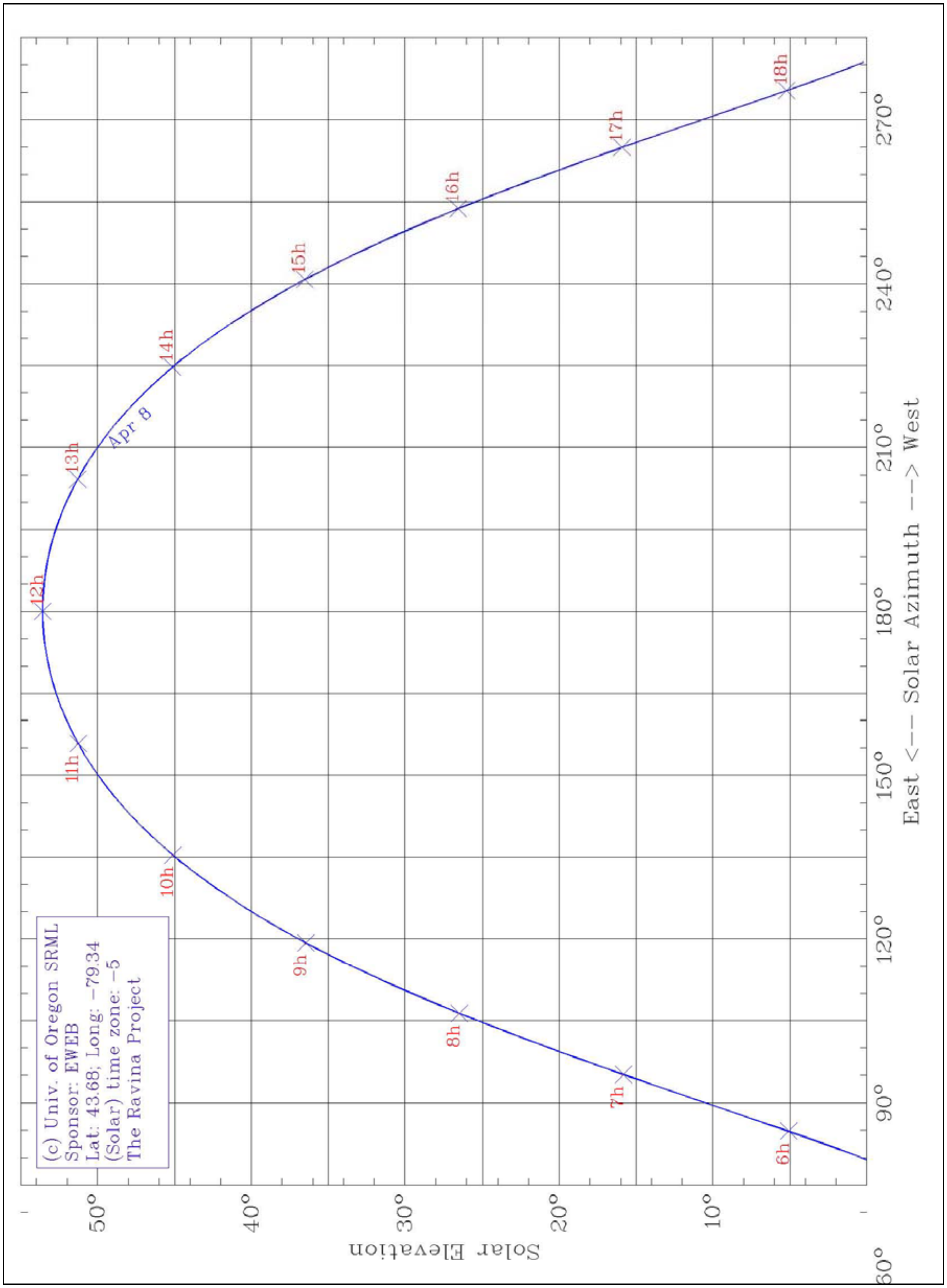

The solar chart for the day of April 8th, 2007.

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Effective Height Calculations

The array's effective height calculation is somewhat more complex than the effective width calculation. Whereas the effective width deals with the array at a fixed azimuth and only the sun's azimuth is a variable, when working with the array's effective height both the angles of the array and sun are variable.

To make this whole process more useful, we make a calculation for each hour of the day based upon three different array angle models. These models are the only ones possible for an array with the articulation of the one here at The Ravina Project.

Flat Plate Model

The array may be laying flat and parallel with the ground. In this model the sun rises and sets but only the altitude of the sun determines the effective hourly aperture of the array.

Industry Standard Angle Model

The array is set at an angle with respect to the ground as defined by the solar industry for this latitude. The angle here is 43 degrees at this time of year during the transition months. In the winter the angle is set at 58 degrees and in the summer it is set at 28 degrees. Both sun azimuth and altitude combine to form the effective hourly array aperture in this model.

Sun Tracking Angle Model

The array is programmed to track the altitude of the sun so that all effects of the sun's altitude are eliminated. That is, the sun's rays are hitting the array aperture at 90 degrees on the vertical axis. This effect is like having the sun overhead all day long with respect to the sun's altitude but the affects of azimuth are still taken into consideration when the effective hourly aperture of the array is calculated for this model.

For each of these models we calculate the aperture available during each hour of the sun day. At the end of the day we add up the aperture-hours generated for each model. That total provides us with a basis for comparison among the three theoretical models.

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We have found that each of these three models, surprisingly, has its strengths and weaknesses when evaluated over an entire year of sun angles.

Effective Width	Sun Altitude	Flat Plate	Fixed Angle	Sun Tracking
0.42	5	0.09	0.31	0.41
0.59	16	0.28	0.50	0.59
0.73	26	0.44	0.68	0.73
0.85	36	0.59	0.83	0.85
0.97	45	0.71	0.97	0.96
0.99	51	0.78	0.99	0.99
0.87	53	0.80	0.86	0.86
0.59	51	0.78	0.59	0.59
0.26	45	0.71	0.26	0.26
-0.02	36	0.59	0.00	0.00
-0.22	26	0.44	0.00	0.00
-0.42	16	0.28	0.00	0.00
-0.57	5	0.09	0.00	0.00

Let's unpack this sheet.

We know about the effective width calculation based upon the sun's azimuth calculated above. The sun's altitude for each hour of the day is read directly from the sun chart for April 8th above.

Let's focus firstly on the **flat plate** model calculations. Since there are no influences from azimuth the formula is: " **=+COS((90-D5)*PI()/180)". D5** is the value of the sun's altitude. The effective width is not a factor. The numbers produced give a value for the effective aperture of the array for each hour of daylight on the hour. The assumption made for each model is that the effective aperture value is constant over the course of the hour. The value 0.09 means that the effective aperture has a value of 0.09 of its maximum (1) for an hour. The totals at the bottom add up the effective aperture-hours for the day. Or another interpretation would be that a total for flat plate of 6.55 means that the same collection ability would be achieved by 6.55 apertures working in parallel for an hour. Or still another would be one aperture collecting power for 6.55 hours.

Let's focus on the **fixed array** model calculations. Here, at this time of the year, during the transition months, the industry standard array angle is 43 degrees, identical with our latitude here in Toronto. Azimuth will influence our calculations. We use the following formula to calculate the effective aperture of the array each hour: "**=IF(C6>0,+COS((90-(C23+D6))*PI()/180)*C6,0)**". The value **C23** is a constant which represents the angle of the array, 43 degrees. We made this a variable so that various other angles (latitudes) / times of year could be investigated theoretically. **D6** is the value of the sun's altitude. **C6** is the value of the effective width of the array due to azimuth of the sun. Notice that there can be zeros in the column. During these times when the sun is behind the array the aperture is turned away from the signal. Little power is collected.

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Let's focus on the **sun tracking** model calculations. In this column the sun's altitude is tracked slavishly by the model. Even if the sun is behind the array, the sun's altitude is compensated for. The array is never flat because the sun is never directly overhead. The angle of the array is limited to 10 degree increments. The goal is to have the sun's vertical axis angle on the array equal to 5 degrees or less from normal due to the sun's altitude for every hour of the day. This offset value is well within the 1.00 rounded value for the effective height for the hour. We use the following formula: "**=IF(C6>0,+COS((90-(70+D6))*PI()/180)*C6,0)**". Note the constant **70**. This value is entered by hand. Its value is determined by the altitude of the sun for that hour and the array angle that best compensates for it. Since early in the day the sun is barely above the horizon and the maximum angle of the array is +70 degrees, the maximum ray incidence to the array can be as great as about 18 degrees. However that incident angle still has an effective height of .95. Note that the sun does get behind the array so that zero aperture-hours can occur.

Let's revisit the whole table with a focus on the last columns.

Array Programming for April 8th

Solar Time of Day	Sun Azimuth	Effective Width	Sun Altitude	Flat Plate	Fixed Angle	Sun Tracking	**Best angle**	Best Aperture
6	85	0.42	5	0.09	0.31	0.41	**70**	0.41
7	96	0.59	16	0.28	0.50	0.59	**70**	0.59
8	107	0.73	26	0.44	0.68	0.73	**60**	0.73
9	118	0.85	36	0.59	0.83	0.85	**50**	0.85
10	135	0.97	45	0.71	0.97	0.96	**40**	0.97
11	156	0.99	51	0.78	0.99	0.99	**40**	0.99
12	180	0.87	53	0.80	0.86	0.86	**40**	0.86
13	204	0.59	51	0.78	0.59	0.59	**0**	0.78
14	225	0.26	45	0.71	0.26	0.26	**0**	0.71
15	241	-0.02	36	0.59	0.00	0.00	**0**	0.59
16	253	-0.22	26	0.44	0.00	0.00	**0**	0.44
17	265	-0.42	16	0.28	0.00	0.00	**0**	0.28
18	275	-0.57	5	0.09	0.00	0.00	**0**	0.09
		Totals:		6.55	6.00	6.24		8.27
Time	EST offset	19 min				% Over Flat		126.32
Array	Azimuth	150				% Over Fixed		137.87
	Fixed Angle	43				% Over Sun Track		132.56

As we indicated when we started this explanation, each of the possible models for the array must be considered and evaluated for the number of aperture-hours each can generate for each hour of the day. The last two columns 'cherry pick' the best angle and aperture-hours for each hour of the day.

Notice that the **sun tracking** model works best for each hour right up to the end of the 12th. After that it falls off dramatically due to the sun's azimuth each hour thereafter. The **fixed array** model suffers a similar fate. Sun azimuth is a killer for tilted arrays.

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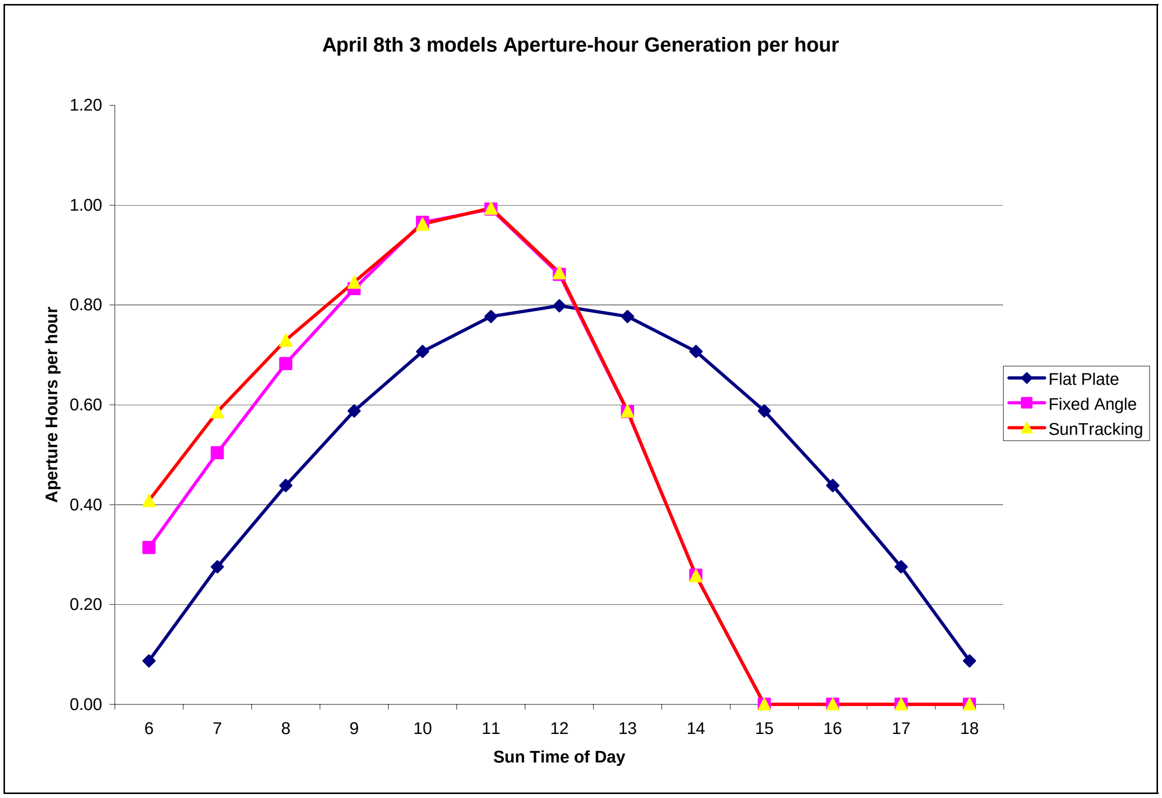

Note the Flat Plate. It's like the, '*Little Engine that Could*". It just keeps delivering aperture-hours long after the others are finished.

The column entitled, "**Best Angle**" provides the time of day programming for the dynamic array for this day plus or minus one week. During the transition months the calculations should be done every 2 weeks for maximum aperture-hour generation.

The **EST Offset** is the time difference between the times on the left column given as Solar Time of Day and the actual local clock time. If the dynamic array moves to a new angle, it will have to move not on the hour but on the hour plus 15 minutes.

The percentages on the lower right corner of the sheet compare various total aperture-hours to the Best Aperture column. Each of the totals generated by the three models are compared to the total of the last column. At various times of the year this comparison is quite remarkable. On this date these numbers suggest that the dynamic array can generate at least 20% more aperture-hours than its nearest rival.

In conclusion, the above calculations form the heart of the theoretical analysis of The Ravina Project's solar projects. Practically, the array programming resulting from the calculations will drive the array angle each hour. It is these new angles and the power generated by them that will be compared with the industry standard angles and their resultant power generation.

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Research Method

The solar industry in North America has guidelines for the tilting of solar panels according to the time of year and the lat/long of the installation. Briefly, these guidelines specify that the year should be broken up into four seasons. Each season has its own recommended tilt angle. We have mentioned this regimen above.

The Ravina Project divides the year up into three parts rather than four. We divide up the year according to the speed of the sun's weekly movement in the sky. See the sun chart below that tracks the sun's movement for 6 months. The summer months and the winter months are both quite different so they account for two of the three parts. The transition months, February, March, April and August, September and October are basically inversely identical from the point of view of the sun's motion.

Here's the argument. Refer to the sun chart on page 23 below.

There are about 120 days between noon January 21st and noon May 21st. During that time the sun moves through about 40 degrees in total. This rate of movement is about a third of a degree a day at noon sun time. If the signs are reversed and the sun's noontime altitude is decreasing then the months from August to October have the same relative daily motion. From our discussion above, sun altitude and azimuth play a huge role in collecting solar power. The months where the sun is moving rapidly at noon from day to day we call the Transition Months. Except for the sign on the movement these two sub-groups of months are treated in our data as being identical. The array programming and calculations are therefore identical for each group.

The Research projects

The Ravina Project has two solar research projects and one household thermodynamic tracking project currently underway.

Summer Months Project

This project focuses on the power generation of a fixed array during the summer months. Our calculations using the models we elaborated above strongly suggest that the power generated using summer array angles can be improved upon. This project will gather data for 5 consecutive summers between 2007 and 2011.

A 90 day period starting May 7th at 00:01 EST and ending August 4th at 23:59 EST will be used to collect total power generation data on a daily basis. Since the array can assume any angle between zero degrees and plus 70 degrees, it will assume two distinct angles during the test period. The angles will change on alternate days. The industry standard angle of 28 degrees will be duplicated by the array on odd numbered days starting from project day one through project day 89. The new angle suggested by our calculations will be adopted on project day two through project day 90. The total power generated for each day will be recorded and at the end of the project 90 totals will be in the database, 45 for each regimen.

At the end of the project in August 2011, 450 data points will be in the database. We believe that if there is a better angle for summertime power generation we will have

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enough data to demonstrate it. As well, we should be able to predict the percentage amount of summertime increase in power expected from a solar array if the new angle is adopted.

This research project is directed at the small but growing household solar power market. Solar panels are expensive so the householder would like to get as much from them as possible. Overall, society at large also wants the householder to generate as much power as possible. If by using a different angle in the summertime, the maximum solar power generation period for the entire year, they get an increase in excess of 10% over industry norms, then that translates into substantial dollars and cents.

Here's why.

Solar panels cost between $10,000 and $12,000 per kW. Installation costs are over and above this number. Let's say a homeowner has 1 kW of solar on his roof. He/she has paid $10 per watt, right? No, his/her real cost per watt is the total paid for the racking plus the panels plus installation of the panels divided by the maximum sustained output of the panels. So the 1 kW of panels cost $15k rather than $10k, so the cost is now $15 per watt. The real maximum sustained output of the 1 kW array is, based upon our experience here, about 830 watts more or less. The real cost per watt is therefore $15k divided by 830 which is $18 a watt, or $17k divided by 830 which is $20 a watt.

Suppose that through our research we discover that a small change in the summertime angle of an installed array can result in a 10% boost in generated power. That increase would correspond to an increase of 100 watts for a 1 kW installation. If solar panels were added to the installation to make up for another 100 watts then it would cost the homeowner between $1,500 and $2,000 more for that modification all else being equal.

This is a forced argument because of course there are lots of other factors. The point is that the homeowner can generate more power with no marginal expense. As well, some kind of fair value for that extra power generation can be estimated. For instance, since only 90 days in the summertime are covered by this new angle, only .25 of the year is affected. The value then to the home owner is only 25% of the totals cited above or $375 to $500 per year. However, we might discover that the regimen is good for 120 days or 1/3 of the year. So now the value of the new angles is between $500 and $657 per year.

In any case, the idea is, that the installed base of household solar power generation may be increased by at least 10% if our hypothesis holds up under the harsh light of real data and its analysis. Note as well that this whole discussion is based upon an increase of 10%. What happens if the real increase is 20% or 30%?

The data collected and statistically processed will provide us with some interesting trends.

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Transition Months Project

The transition months project will begin the next day after the summer months project described above. It will proceed for 90 days in 2007 and 180 days for each year thereafter. Our calculations based upon the models discussed above, strongly suggest that a substantial increase in power output can be achieved using a dynamic array. A dynamic array changes its angle automatically to the sun several times during the day.

The method is similar to the summer months project. The data collection period lasts for 90 days twice a year during the transition months. The static industry standard angle will be used on the odd days of the project; day 1 through day 89. The array will be dynamic during the even days of the project; day 2 through day 90. Each day the total power generated will be recorded. Each year 180 data points will be collected.

Statistical analysis should tell us whether there is an increase in the power output using a dynamic array. It may be possible to determine the magnitude of the power output increase.

This research is directed to large commercial solar installations on the rooftops of large commercial, government or school buildings. They may have an installed base of 10 or more kW. It may be possible to increase their output by as much as 20% over the course of the summer and transition months by making their arrays dynamic at a fraction of the cost of putting up more solar panels.

The value of such a boost would be huge in real dollar terms.

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Household Thermodynamic Tracking Project

Each day data is recorded from the household:

- Electrical utility meter reading - kWh,
- Gas utility meter reading - CM,
- Power generated by the solar array - kWh,
- Peak power generated by the array – W,
- Sky conditions.

The data is entered into a spread sheet. Along with this data, data from the weather office is entered:

- Daily Mean temperature
- Daily Mean Wind speed
- Daily Mean Wind Chill.

The output numbers provide the following data:

- kWh used per hour,
- kWh used per day,
- kWh uploaded to grid per day,
- CM used per hour,
- CM used per day,
- CM daily usage converted to kWh,
- Total household daily energy usage in kWh
- Wind in m/sec,
- Wind power in Watts (based upon manual lookup table for Skystream 3.7)
- Totals, mean, median and standard deviation of many columns for each month
- To date totals,
- Monthly Correlation between Temperature and total energy usage, gas usage and electrical usage,
- Monthly Correlation between Wind speed and total energy usage, gas usage and electrical usage,
- Monthly Correlation between Wind chill and total energy usage, gas usage and electrical usage.

This meticulous data is collected in the hopes that it provides insight into many household energy dynamics.

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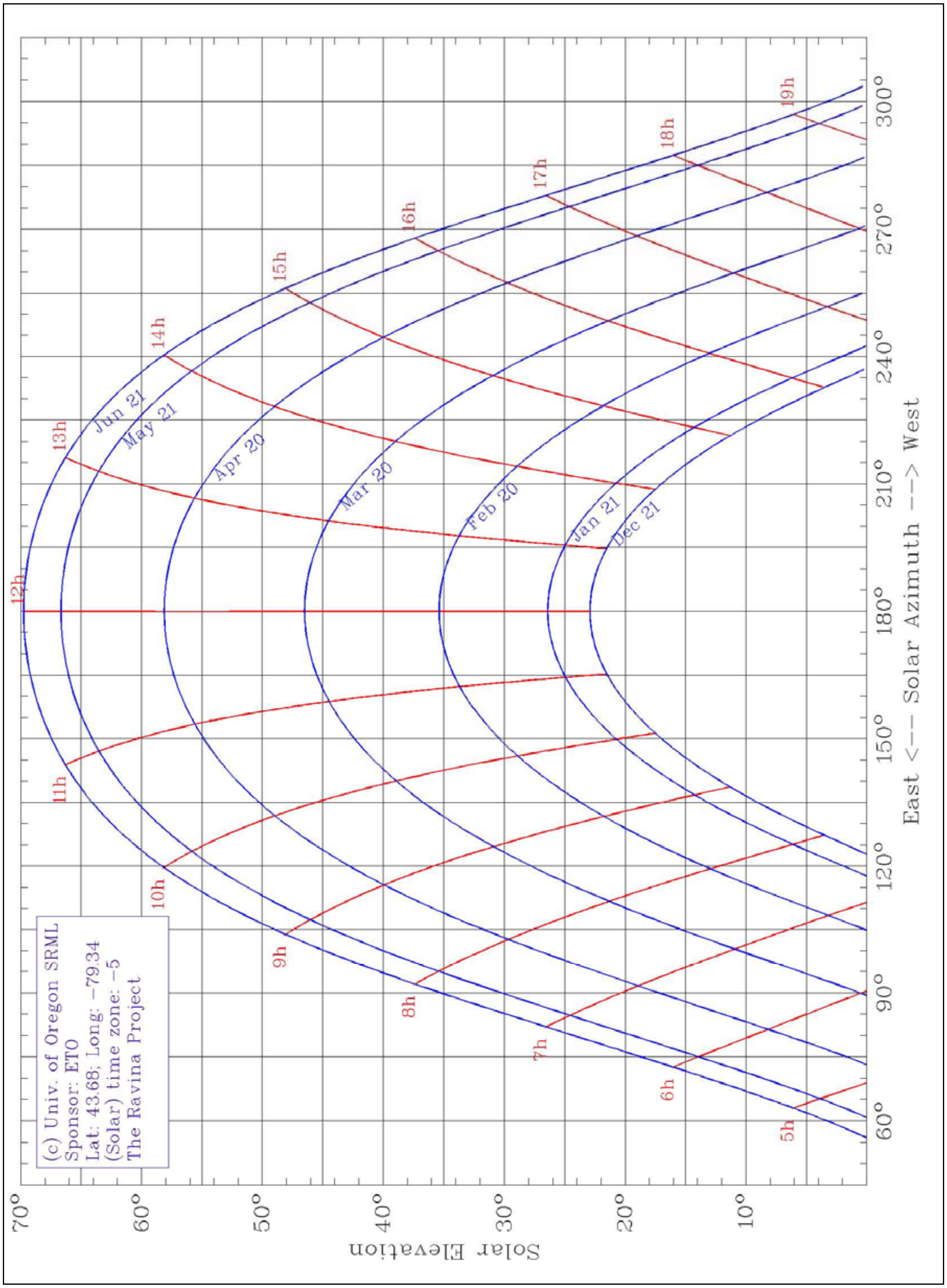

Sun chart showing transition months and rapid daily movement of noon sun altitude during those months.

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Dynamic Array Evaluation Project

An astute reader, knowing the current technology in solar panel support structures, would, quite rightly, question why such a big fuss is being made over the dynamic array described above.

This is an excellent question and deserves a section of this paper to explain fully.

Consider the following sheet based upon the April 8th data seen above.

Sun Azimuth	Effective Width	Sun Altitude	Flat Plate	Fixed Angle	1 axis Tracker	Sun Tracking	**Best angle**	Best Aperture
85	0.42	5	0.09	0.36	0.85	0.41	**70**	0.41
96	0.59	16	0.28	0.55	0.93	0.59	**70**	0.59
107	0.73	26	0.44	0.72	0.98	0.73	**60**	0.73
118	0.85	36	0.59	0.85	1.00	0.85	**50**	0.85
135	0.97	45	0.71	0.96	0.99	0.96	**40**	0.96
156	0.99	51	0.78	0.96	0.97	0.99	**40**	0.99
180	0.87	53	0.80	0.83	0.96	0.86	**40**	0.86
204	0.59	51	0.78	0.57	0.97	0.59	**0**	0.78
225	0.26	45	0.71	0.26	0.99	0.26	**0**	0.71
241	-0.02	36	0.59	0.00	1.00	0.00	**0**	0.59
253	-0.22	26	0.44	0.00	0.98	0.00	**0**	0.44
265	-0.42	16	0.28	0.00	0.93	0.00	**0**	0.28
275	-0.57	5	0.09	0.00	0.85	0.00	**0**	0.09
	Totals:		6.55	6.05	12.41	6.24		8.27

Note the new column entitled, “1 axis Tracker”. This column represents the aperture-hours generated by a solar array support device which moves a fixed angle array east to west on a minute by minute bases. By moving in an east-west direction it compensates for the azimuth of the sun. The aperture hours delivered by this kind of dynamic support structure are more than 50% greater than the best our dynamic array has to offer.

Why does this occur?

Consider the azimuth of the sun. We have mentioned many times the devastating effects of azimuth upon a fixed azimuth solar collector. Our dynamic array tries to compensate for these effects by becoming a flat plate during the time of day when azimuth cuts into the aperture-hour production. Our dynamic array compensates for the elevation of the sun that on this day above we see travels through a range between zero and 53 degrees. However, the azimuth travels through a range between 275 minus 85 equals 190 degrees. Compared with the sun’s elevation this is a huge range and it is quite natural for array support structure designers to compensate for this sun movement range on the azimuth and ignore it on the elevation.

We see that such compensation is rewarded with a huge bonus over the fixed array angle of 100% and 50% over the best our dynamic array has to offer.

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You might question why we built our dynamic array structure when we here at The Ravina Project know of this better support and aiming technology. We will try to explain to you why we built our present structure and what we want to learn from its performance over the next 60 months.

Here's a short overview of what's available in tracking technology for solar arrays.

Dual Axis Tracking Mount

Here is a picture from the WATTSUN AZ-225 installation manual for their dual axis tracker. A single axis tracker also can have this exact design except that the elevation is set manually.

Note the following.

The array is mounted on a pedestal. This is required because the array will tilt east and west as well as up and down to track the sun. It swivels on one point of attachment. This particular model has a sun sensor feedback system that tracks the sun's motion both in the azimuth and in the altitude.

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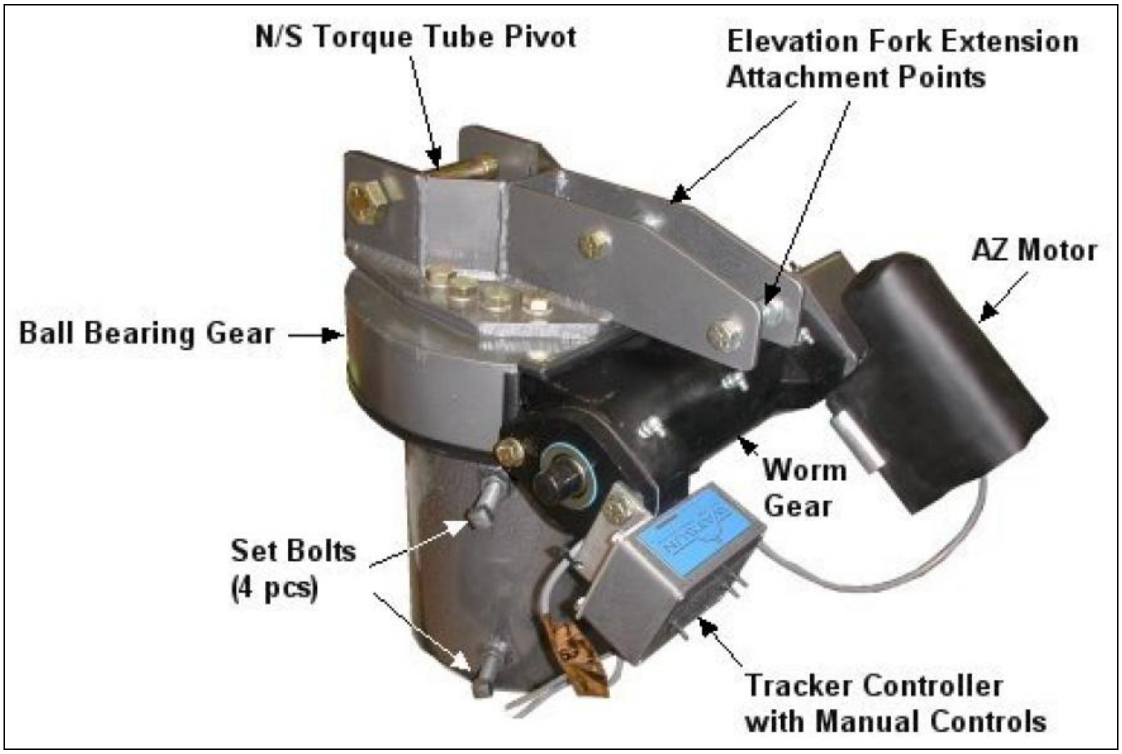
Here's a view of the tilting mechanism.



This tracking and movement mechanism allows the array to follow the sun in both axes. Note the controller is exposed to the elements.

Here's a view showing the mount, the pedestal and the mechanism in perspective.

This picture above also shows the kind to terrain this tracker is used in. We will have more on this point later below.

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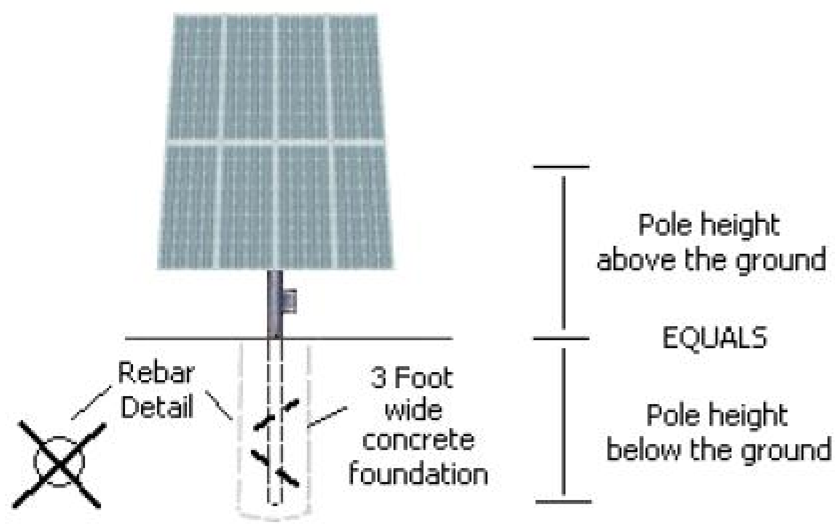
The pedestal mount, if mounted on the ground can have a concrete base like the one shown above or have an extended pole mount deep in the ground.



Both the size of the mounting pole and its depth in the ground plus the concrete and rebar demonstrate to the reader the huge torque anticipated by this design. The solar panels will act as a huge sail multiplied by the mechanical advantage of the length of pole between its attachment to the base/ground and the pivot point.

Obviously, the designers realize that the pedestal mount must be substantially over engineered to withstand the forces that may present themselves to the structure. Note that the force of wind increases as the cube of its speed.

It would be interesting to calculate the increase in the size of the mount if the designers were to take into consideration 100 km per hour gusts and 1 cm of ice buildup which may increase the weight of the structure by several hundreds of kilos.

In summary, the design shown above can produce prodigious amounts of power from the sun given the analysis of aperture-hours above for a single axis tracker.

From a Canadian urban perspective the design has some points of interest.

- Weather is a huge issue in Canada for any structure placed outdoors all year long. How this structure would react to being coated with ice and in substantial wind gusts is a matter of concern. The torque on the base in these conditions must be huge.
- How this structure would translate to a roof top where the only attachment is via roof penetrating bolts is also a matter of concern.
- What would happen if several of these structures were attached to the same roof? Would the torque literally pull off the roof causing major damage to the structure?

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- If they were pole mounted, where, in Canada's urban setting with small lot sizes and large trees, would they be installed except on large/tall poles above the shading effects of buildings and trees?
- The tracker's controls are subject to the weather and are located by several manufacturers on the pedestal mount on the pole. Manual override may have some operational problems in freak weather when the unit is mounted on roof tops or on tall poles. Getting to it would be a problem.

The Ravina Project's Dynamic Array

The above solutions were not an option for The Ravina Project.

Here's why.

- The house is 80 years old and the flat roof portion of the house is only 18 by 17 feet in area. To put a pedestal based system on such a roof would require many roof penetrating bolts over a large area. There is no guarantee that such an old roof and building structure could withstand the torque generated in a wind storm using this kind of system.
- All the intelligence and control must come from the power room in the basement.
- Ice, high winds or a combination of both should not impede the array operation nor should such conditions harm the house.
- The array must be removable. That is, it must be able to be cleared from the roof of the house in no more that two days.
- The support structure must not use roof penetrating bolts to hold it down yet must be strong enough to withstand high winds, snow and ice buildup.
- The support structure must move in such a way as to eliminate either the effects of sun azimuth or altitude.
- The technology used to move the array should be off the shelf, inexpensive, well tested in commercial use, extremely simple in its mechanical movement and use.
- The support structure must be scalable such that the same shape of structure could grow to support a larger array or shrink to support a smaller array. All the technology and simplicity of use must also translate to the new sizes.
- The design should allow for useful solar research work to be accomplished.

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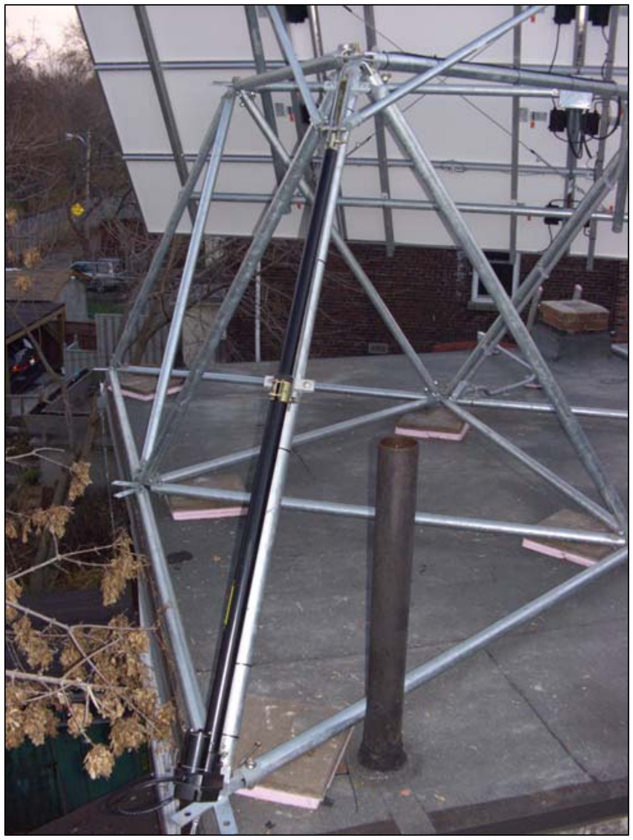

The picture above shows the design elements that solve the project limitations listed above. Note that the support structure rests on soft pads which themselves lay upon the roof. The Saginaw Gear 36 inch actuator arm has been in use commercially for decades to move large solid communications dishes. It will move comfortably 1800 lbs. of load and is over engineered to move the array under any circumstances including the ice and wind of the Canadian Winter. It locks to withstand 6000 lbs. of force. It moves in a rectilinear manner with enough force to crush any ice or other foreign matter interfering with its motion. The support structure consists of three interlocked tetrahedra. This type of structure, is extremely rigid and strong and forms the basis of many natural structures including molecules.

The whole structure is tethered to the roof with four anchors fabricated from ¼ inch diameter aircraft wire. These are attached to 7/8 inch stainless steel bolts that run through the basement walls.

The structure is totally portable and no holes were made in the roof to support it.

As you can see from the picture above the load is distributed over the whole roof under the structure on six one foot square pads. The torque on the roof is minimal because the strategically placed guy wires transfer the forces to the basement walls. The structure itself does not impede wind traveling through it with only the sail effect of the array creating shear forces. A flat array has no or very minimal wind resistance.

The design is totally scalable such that a smaller array can be constructed using smaller tetrahedra consisting of shorter struts. The reverse is true. The design is portable in the sense that it can be implemented upon any flat roof. Other roofs may be newer allowing

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for anchor bolts to be used in conjunction with the pads. In such a configuration the torque is spread out over a huge area with the wide bases of the tetrahedra providing the structure with mechanical advantage to resist the forces that may either try to move or overturn it. No wire strapping would be required.

We ended up with a flat roof friendly support structure that can't be moved on its azimuth. The dynamic part of the array has only one degree of freedom allowing it to compensate for the sun's elevation in real time. Since the array can be lowered to a flat position it can compensate, somewhat, for the sun's azimuth.

The Ravina Project believes this design is far more Canadian weather and urban friendly than other designs. It is a prototype for other future designs that can make good use of the available flat urban roof acreage.

The science done here at The Ravina Project should be understood in the context of this design.

The first two projects outlined above use the dynamic array to generate data that will be useful to two different markets. Both of these markets are described above. This last project focuses on the array structure itself. Several questions will be answered including: How good is this design in the context of its reliability, ruggedness and solar power generation capability?

Our research indicates that this design using interlocked tetrahedra and compensating for sun elevation is new, both in design and method. If successfully tested this design will provide the urban real estate owner, both commercial and not, with options far more efficient than the usual roof top racking. The Ravina Project's dynamic array technology is not in competition with the tracker technology described above. It merely extends the use of compensating / sun tracking technology to the large urban rooftop market which cannot use the traditional trackers.

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Conclusion

We have made lots of assumptions in the paper.

The biggest one, of course, is the one about aperture-hours. Is this value a predictor for array performance? Does it have anything to do with anything? Is a solar array like a radio antenna such that it does have an aperture? And etc.

This whole project could be off in the wilderness and we're too ignorant and too data poor to know we are lost. It's the worst nightmare for anyone doing research ... especially when they are using their own money to finance the project.

To balance that feeling, The Ravina Project has generated some very interesting numbers to this point. As I sit here writing this paper on Easter Sunday, April 08, 2007 at 12:55 EST I look at my computer monitor. It has the output upon it of several wireless IP cameras focused on the array from the outside and the MX-60 front panel in our Power Room. The day started with such great hope for good sun but quickly became cloudy with sunny breaks and now is overcast but brightly diffuse. I had the array at about 40 degrees. It was generating about 215 watts. I have learned that the array's aperture does not like looking at the surrounding houses on diffuse days … it likes looking at the entire sky. I dropped it to horizontal and got a boost to a decent 400 watts (a high of 540 watts and a low of 360 watts since then). We have already generated 3.2 kWh so far and we have lots of hours of light left. At 400 watts average we can generate another kWh in 2.5 hours. So we'll end up today with more than 4.0 kWh (we actually did 4.4 kWh - gf). The 400 or so watts are running the house entirely right now. We are only drawing about 200 watts when the fridge is off and about 400 when its compressor is on.

We have had some good days. Some days have defied description given that some of the totals seem to be beyond the theoretical daily maximum for fixed array output. The dynamic array seems to be able to generate outstanding numbers on good sun days and good numbers on marginal days, like today generating 400 watts out of diffuse overcast.

So what are the numbers?

Here's part of a PPT presentation we gave to some VIP visitors to The Ravina Project a few days ago.

Using a 1500 watt dynamic array the following solar power maximums have been generated:

- *December 24th '06 – 5.3 kWh (hours away from the shortest day of the year)*
- *January 20th '07 – 6.4 kWh*
- *February 23rd '07 – 8.2 kWh*
- *March 6th – 8.8 kWh*
- *March 11th – 8.1 kWh*
- *March 20th – 8.9 kWh*
- *March 28th – 8.4 kWh*
- *March 29th – 9.0 kWh!!*
- *Total power generated to date: 357.6 kWh (November 1st '06 - March 31st '07)*
- *Total power uploaded to Grid: 74.44 kWh*

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That 9.0 kWh gets a lot of attention but it is in a context. It's not an orphan value. It's tenths of a kWh away from 4 other totals in the month of March, and one total in February. February? Not a month with great sun angles. The sun at that time of the year still has to contend with lots of atmosphere to cut through, for most of the day, before it gets here.

The days in the sevens are as follows:

- March 18th – 7.3
- March 9th – 7.9
- February 24th – 7.8
- February 18th – 7.2
- February 15th – 7.5

What do these numbers mean?

Our solar array consists of 12, 125 watt Centennial Solar CS-125 crystalline panels wired in three groups of 4, each with a total Voc of 88.0. We've watched the output for many hours over the last 5 months. We get a sustained power output in the best sun of about 1250 watts. In fact we use 1250 in all our calculations for maximums. On very cold days it has been 1450 for some lengths of time but over time, heat takes its toll in rising resistances. We've seen daily power maximums at 1,760 watts.

Array Programming for March 29th

Solar Time of Day	Sun Azimuth	Effective Width	Sun Altitude	Flat Plate	Fixed Angle	Sun Tracking	**Best angle**	Best Aperture
6	88	0.47	2	0.03	0.41	0.45	**70**	0.45
7	98	0.62	13	0.22	0.58	0.61	**70**	0.61
8	109	0.75	24	0.41	0.75	0.75	**60**	0.75
9	122	0.88	33	0.54	0.88	0.88	**50**	0.88
10	138	0.98	42	0.67	0.96	0.97	**40**	0.97
11	157	0.99	48	0.74	0.95	0.99	**40**	0.99
12	180	0.87	50	0.77	0.82	0.87	**40**	0.87
13	203	0.60	48	0.74	0.58	0.60	**0**	0.74
14	222	0.31	42	0.67	0.30	0.31	**0**	0.67
15	238	0.03	33	0.54	0.03	0.03	**0**	0.54
16	251	-0.19	24	0.41	0.00	0.00	**0**	0.41
17	262	-0.37	13	0.22	0.00	0.00	**0**	0.22
18	272	-0.53	2	0.03	0.00	0.00	**0**	0.03
		Totals:		6.01	6.28	6.46		8.14
	Sun Rise	6:02						
Time	EST offset	22 min				% Over flat		135.39
Array	Azimuth	150				% Over Fixed		129.68
	Fixed Angle	58				% Over Sun Track		126.10

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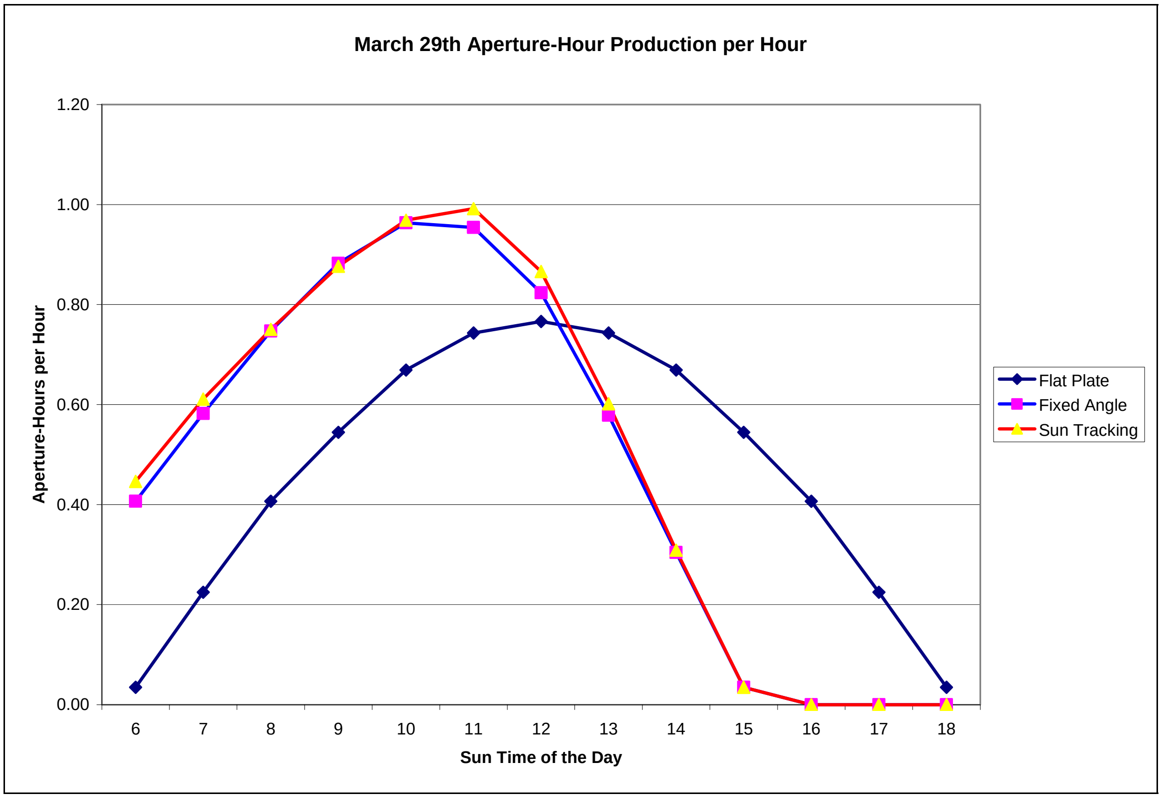

Let's try to give these numbers some context. Included is a graph of the day above.

Lets assume that we have our 1,500 watt array locked in at the industry standard 58 degrees for this time of year.

Lets assume 1,250 watts of sustained output for our calculation. At 58 degrees, we see from the spreadsheets above on the 29th of March (nine days ago) the sun goes behind a tilted array such that it starts going off-line by about 14:30 (14:52 EST). It has 9 hours (I'm being generous here) to harvest 9.0 kWh of power. It's output must average 1 kW for nine hours straight!

And for all the numbers in the eights … ditto … for the most part. In February??

We don't think a tilted array at 58 degrees can generate that kind of sustained power even in totally pristine sun conditions. March 29th here was pristine, no question.

Let's say that the fixed angle array generates on average 1250 watts for 5 hours and averages 500 watts for the rest of the 9 hour day. That gives us 8.25 kWh. Even with these sky high (puns?) estimations, the fixed array comes up short of 9.0 kWh and several other daily totals.

It just so happened that March 29th was a holiday for me (gf). I saw that the sun was great so I spent the day logging data. I generally log as much as I can on good sun days but typically not as much as on this day. As it turned out I could not have logged intensively on a better day.

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The array maintained an average power output of 720 watts over the 12.5 hour day!

To calculate a baseline for the relationship between our aperture-hours and actual power output let's make the following calculation. From our spreadsheets the dynamic array generated 8.14 aperture-hours on March 29th. Power generation was 9000 watt-hours for a generation capacity of 1106 watt-hours per full aperture-hour.

Let's apply that aperture power number to the fixed angle array.

Looking at the sheet for March 29th, we see the fixed array generated 6.28 aperture-hours and would have generated 6.28 times 1106 equals 7,543 watt-hours.

We are still missing 1,500 watt-hours at the same rate for the array.

We can conclude that it is highly improbable that a fixed angled, 1,500 watt array could generate 9,000 watt-hours on March 29th. We also can conclude that it is only the dynamic array that has the capability to generate these kinds of numbers.

Let's look at the daily log for March 29th, 2007 below.

Looking at the log we noticed how many hours were spent over 900 watts (6 hours), how quickly the power came on in the morning (1 kWh by 8:33 EST), and finally, the end of day performance which generated power to within an hour of the actual setting of the sun.

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Solar Array Daily Log

REV 01
2006/12/04
Page:

Date	Time EST	WX	Power	kWh	Angle	Comments
Mar 29/07	6:50	Hi Cirrus	182	0.0	70	Tree branch shadows
	6:53	Hi Cirrus	210	0.0		Tree branch shadows
	6:56	Hi Cirrus	220	0.0		Tree branch shadows
	7:00	Hi Cirrus	232	0.0		Tree branch shadows
	7:23	Hi Cirrus	364	0.2		Tree branch shadows
	7:25	Hi Cirrus	375	0.2		Tree branch shadows
	7:27	Hi Cirrus	326	0.2		Tree branch shadows
	7:42	Clear	492	0.3		
	7:48		497	0.3		
	7:50		551	0.3		
	7:52		634	0.4		
	7:55		706	0.4		
	7:58		765	0.4		
	8:04		834	0.5		
	8:22		962	0.8		
	8:26		973	0.8		
	8:29		995	0.9		
	8:33		1010	1.0		
	8:37		1030	1.1		
	8:39		1028	1.1		
	8:45		1054	1.2		
	9:00		1074	1.4		
	9:14		1089	1.7		
	9:27		1168	1.9	60	
	9:29		1177	2.0		very stable power output
	9:45		1208	2.3		very stable power output
	9:49		1222	2.3		very stable power output
	9:53		1219	2.4		very stable power output
	9:55		1234	2.5		very stable power output
	10:04		1242	2.7	50	very stable power output
	10:09		1260	2.8		very stable power output
	10:19		1255	3.0		very stable power output
	11:01		1280	3.8		very stable power output
	11:02		1275	3.9		very stable power output
	11:11		1277	4.1		very stable power output
	12:00		1225	5.1		
	12:04		1227	5.1	40	
	12:05		1224	5.2		
	12:13		1211	5.3		
	12:28		1200	5.6		
	12:45		1159	6.0		
	13:55		990	7.2		
	14:00		975	7.3		
	14:09		931	7.4		
	14:12		918	7.5		

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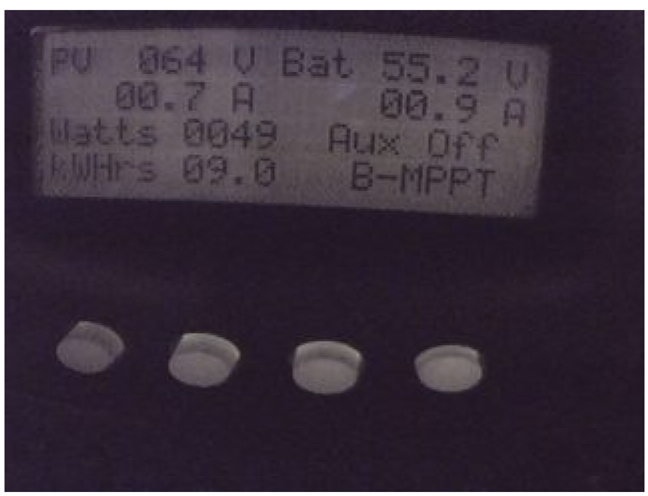
14:14	949	7.5		
14:22	910	7.6		
14:23	915	7.7		
14:29	885	7.8		
14:34	870	7.8		
14:37	820	7.9	Flat	
14:40	815	7.9		
14:44	810	8.0		
14:49	796	8.0		
14:53	785	8.1		
15:02	760	8.2		
15:13	724	8.3		
15:17	707	8.4		
15:25	666	8.5		
15:38	570	8.6		
16:00	292	8.7		
16:04	264	8.8		
16:21	220	8.8		
16:32	198	8.9		
17:01	143	8.9		
17:22	60	9.0		WOW !!

The March 29th end of day view from the IP Camera trained on the Outback MX-60 in the Power Room.



The above numbers seem to imply that the dynamic array configured according to the models and method discussed above is showing some promise. Several years of data collection will demonstrate for us whether we are being teased by anomalous data or whether we are on to something interesting and commercially valuable.

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The picture above shows the set up in the Power Room. The Power Room laptop displays the real time picture of the array from an external 802.11b IP camera. As you can see the other IP camera is located so that it can relay the readings from the front panel display of the Outback MX-60 solar power charge controller. See the still picture taken on March 29th above showing what this camera observes.

All computers in the household can monitor these cameras in real time. It is handy to view the sun angles on the array and, on the same screen, see the real time power output of the array. It also allows for logging the progress of power generation from any computer. The log on March 29th was recorded mostly from another wireless LAN based laptop in the kitchen and the main desktop in the second floor computer room which is hard wired via 802.3u into the 802.11b Access Point switch/router. The RF network uses DBPSK for its superiour structural penetration characteristics.

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"If we knew what we were doing, it would not be called research."
- A. Einstein

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