The Ravina Project

The Ravina Project Update 2009 07

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Project Update January 2009

Introduction

At the end of October 2008 The Ravina Project completed two years of data collection. Now, in February 2009, we would like both, to provide an update on the project and to discuss the data / trends we have observed. In the pages that follow, we want to present our data and highlight many of the things we learned and discovered. As always, and this is true for all our on-line efforts, we hope to help people spend their **green dollars** wisely by making information and data freely available to all. Several of our databases containing our raw data are now on-line and published in Excel format. We hope that others who are doing research can make use of our published data.

Project Goals

From our WEB site here's a list of questions The Ravina Project wants to answer.

How much energy can a homeowner realistically expect to generate with a 1.5 kW solar array?

Here are a few charts and graphs of our solar energy generation broken out on a monthly basis.

2007 Monthly Generation Totals in kWh

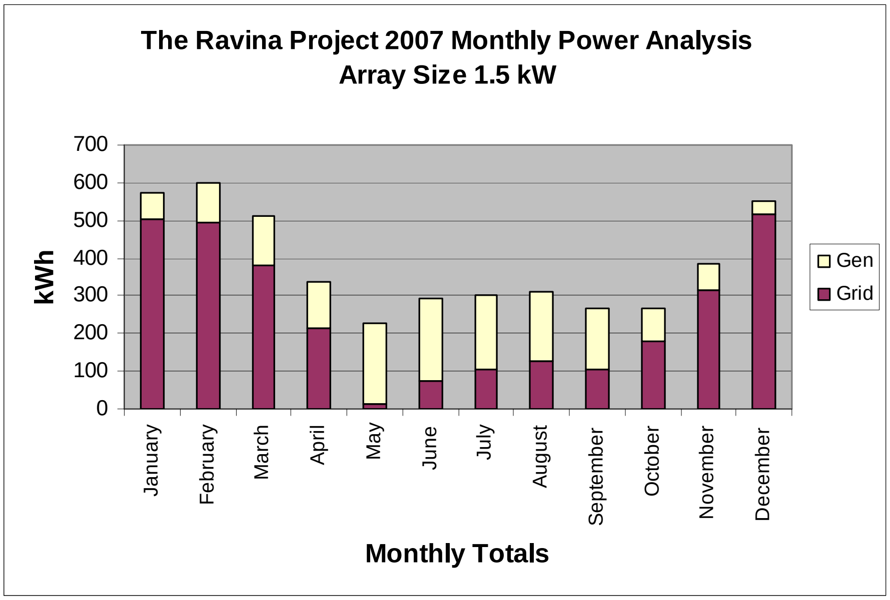
Month	Gen	Grid	% Gen
January	69.9	505.2	12.2
February	107.7	493.1	17.9
March	134.7	378.6	26.2
April	123.4	214.1	36.6
May	215.4	12.4	94.6
June	218.9	72.8	75.0
July	193.2	106.9	64.4
August	182.4	128.4	58.7
September	161.9	106.0	60.4
October	87.8	180.5	32.7
November	70.5	314.0	18.3
December	37.6	500.1	7.0
Total:	**1603.4**	**3027.0**	**34.6**

The heading **Gen** indicates the number of kWh we generated that month. **Grid** indicates the amount of energy we used from the electrical utility for the month. Finally, **% Gen** indicates the total energy we generated as a percentage of total electrical energy we used that month.

For the year 2007 we generated 34.6 percent of the electrical energy we used.

In total the house used 4,630.4 kWh of electrical energy in 2007.

Here's the same data in the sheet above but expressed in a graph.



2008 Monthly Generation Totals in kWh

Month	Gen	Grid	% Gen
January	66.4	462.1	12.6
February	91.7	476.1	16.2
March	154.8	338.7	31.4
April	196.4	97.7	66.8
May	187.0	109.4	63.1
June	173.3	195.8	47.0
July	197.9	205.4	49.1
August	170.5	129.3	56.9
September	134.6	195.2	40.8
October	124.9	263.8	32.1
November	75.0	420.2	15.1
December	57.5	567.8	9.2

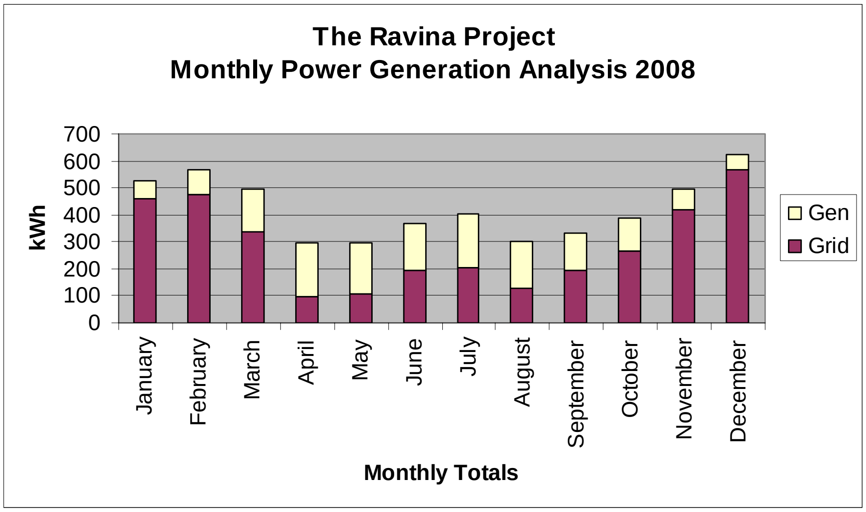
Total: 1630.0 3461.5 32.0%

The heading **Gen** indicates the number of kWh we generated that month. **Grid** indicates the amount of power we used from the electrical utility for the month. Finally, **% Gen** indicates the total power we generated as a percentage of total electrical energy we used that month.

For the year 2008 we generated 32.0 percent of the electrical energy we used.

In total the house used 5,091.5 kWh of electrical energy in 2007.

Here's the same data in the sheet above but expressed in a graph.



Will the off-the-shelf components used by The Ravina Project stay reliable for the length of the project?

The components we have in operation have worked very well. We have not sustained any days of down time due to component failure nor have we had to place any components 'off line'. We had a lightning strike nearby that induced current in the connection box on the back of one of the panels. Clearly there had been a fire in the box. All the usually shiny metal was darkened. We replaced the burned parts with new to prevent the build up of resistance. The panel is operating fine after the incident.

How much maintenance will be required to keep the components in proper working order?

We have done no maintenance to components that collect, store and transform power for the house and sent it to the grid. We have done work to ensure that the angles we set the array to are verified and correct. We have also done work on the aiming technology we have used. This extra work on our part has nothing to do with maintenance that a regular user of solar electric generation would require. It has everything to do with us using our dynamic solar array as a scientific instrument.

What is the cost of a realistic maintenance program for any household that installs solar power generation components?

We have not accumulated enough data to estimate these costs. So far we have had two calls to manufacturers and four calls to our installation technician. All this in two years. None of these consultations concerned themselves with our equipment. They were centered upon the voltage the utility provided when we were drawing a large current from he grid.

Are the industry standard solar array angles to the sun in the summertime the correct angles to use?

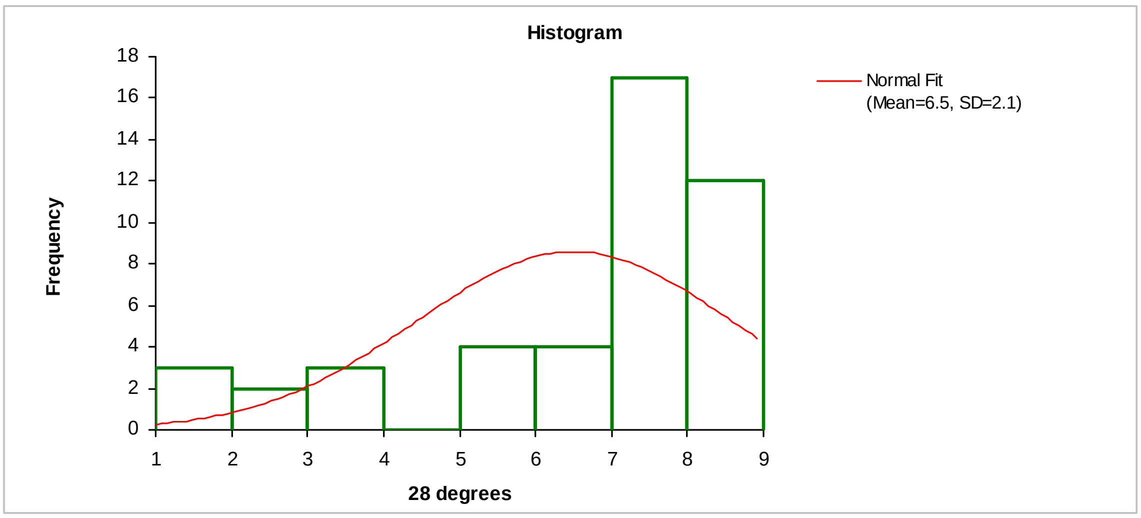
Our first summer data run suggests that the best orientation for a solar array is to lay it flat for May, June and July. The data is available on our WEB site. There are caveats to this recommendation. The solar array must have good summertime access to early morning and late afternoon sun because the sun spends those times of the day behind the array's east-west axis. If such sun access is not available at a certain site then the beneficial affects of a horizontal orientation are diminished or eliminated.

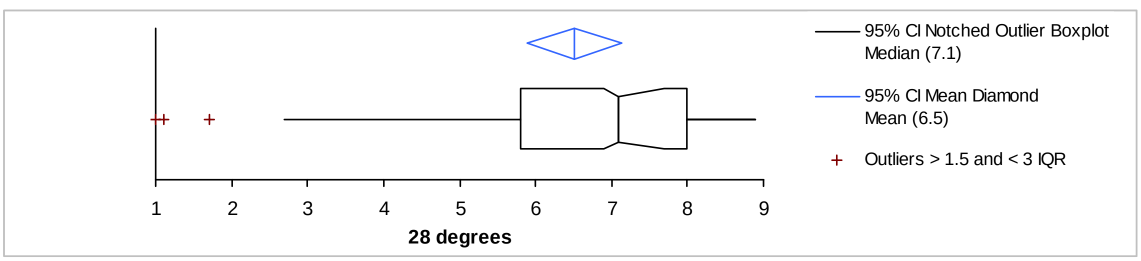
The summer time, at this latitude, is the main production time for power. Even a 10% increase in the amount of power generated would translate into lots of kWh over the course of the summer.

Here's the stats on the summer 2007 run.

Firstly we have the 28 degree angle statistics.

			Analyse-it v2.08
Test	**Describe - Summary**		
	Comparison between 28 degree and zero Degree Array Angles		
	28 degrees		
Performed by	Gordon Fraser	Date	11 March 2008



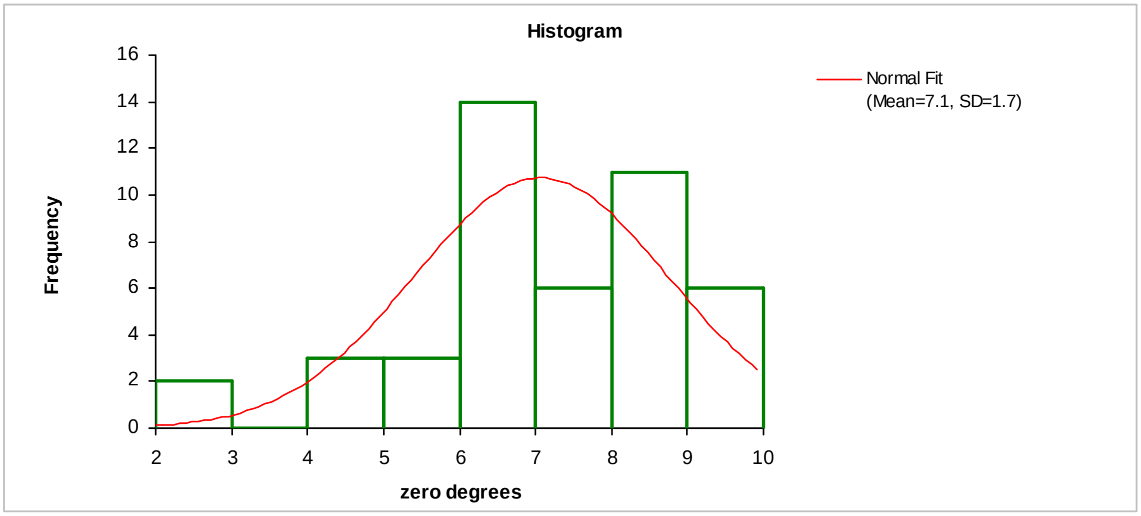


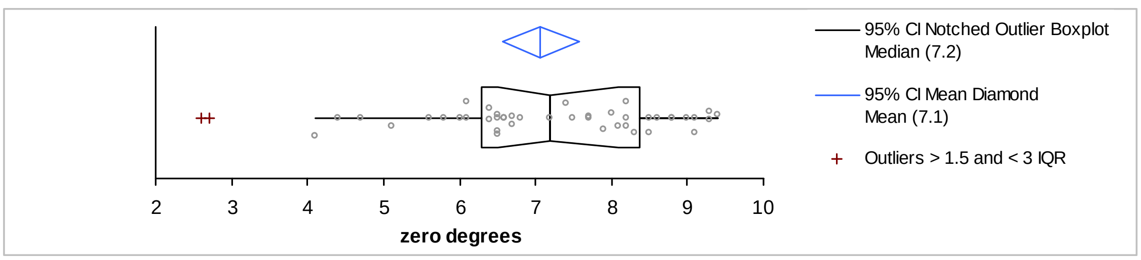
The method for collecting this data consisted of identifying a 90 day period centered upon June 21st as a mid point which, at this latitude, provides us with sun angles that are very similar day in and day out over this trial period. We had two orientations of the array, flat or at an elevation of 28 degrees. 28 degrees is the industry standard elevation for solar panels in the summer time at this latitude of 43 degrees North.

We wanted to eliminated weather trends and other issues as much as possible by choosing a method that would tend to cancel out statistical weather related anomalies over the course of the experiment. The best way to do that would be to alternate the array setting each day. At the end of the experiment we had 45 generation numbers for 'flat' days and another 45 numbers for 'raised' days.

Secondly we have the zero degree angle statistics.

Test	**Describe - Summary**		v2.08
	Comparison between 28 degree and zero Degree Array Angles		
	zero degrees		
Performed by	Gordon Fraser	Date	11 March 2008





Here's a summary of the season.

Firstly here's the 28 degree elevation summer generation totals over 45 data points.

average	6.5	kWh
median	7.1	kWh
standard dev	2.1	kWh

Total	292.9	kWh

Here's the zero degree elevation summer generation totals over 45 data points.

average	7.1	kWh
median	7.2	kWh
standard dev	1.7	kWh
Total	318.2	kWh

It looks like you get an 8.6 percent boost if the panels are parallel with the ground for the three summer months. That corresponds to the addition of another 8.6 percent of solar generation capacity to our array if we insist in keeping the angle at 23 degrees for the summer time.

How much would that extra capacity cost? We will use a cost of $13.50 per Watt installed. The extra capacity would be 8.6% of 1,500 Watts (the size of our collector) which is 129 Watts. That corresponds to us running another panel in the array. The cost for that panel installed is about $1741.50.

We get something for nothing. Nice.

Active sun azimuth tracking is the preferred method of collecting solar energy however azimuth tracking is not compatible with urban rooftops. Will active tracking of the sun's altitude provide better results than passive collectors and be more roof friendly than the azimuth trackers?

At this latitude industry specialists plan for a daily average of 3.0 kWh for each kW of solar collectors installed. We averaged about 4.5 kWh a day which would be the standard for a 1.5 kW installation. Large trees shade the panels after 2 PM from October through April. This impediment to our generation potential is overcome entirely by: the active use of solar altitude tracking during the transition months of February to April and August to October and the ability of our panel to lay flat in the summer season. We are still gathering data. In the summer time the ability to drop the panels to horizontal provides a tangible boost during the best generation days.

If active sun altitude tracking is better, by how much is it better?

We are still gathering data. However, given we generate, on a yearly basis, somewhat less than we should, yet get an 8% boost over the most productive months means that we are making the best out of the sun we get. We have afternoon shade issues for 6 months of the year starting at about 14:00.

Will the support structure that provides active sun altitude tracking be hardy enough to survive Canadian winters and other weather related events?

So far so good; we have not seen any problems with the mechanical workings of the array or its support structure. It has been placed in the 70 degree angle since the fall. This winter we are trying to get the best generation numbers. The only way we can achieve that goal is to constantly be at angle of 70 degrees. So far the support structure has gone through two winters and two summers with no other issues.

Will the support structure be roof friendly over the test period of 60 months?

We seem to be on the right track. More data is required for a complete answer to this question. There seem to be no markings around each pad that would indicate that the roof membrane is in any distress.

Wind Project goals

The next group of goals we cannot achieve because we have reconsidered the advisability of our wind project. The trees are just too high here in this neighbourhood. The self supporting tower required to support a horizontal axis wind turbine would be massive at its base in order to withstand the torque exerted on it by a wind turbine 3.7 meters in diameter at 23 meters in height. That is a long lever. It is really only at this height that the wind turbine would be in anything near laminar air flow. Even painted green the support structure would be out of place in the neighbourhood. Wind generation here would have to use vertical axis wind turbines which allow for use in turbulent air and hence require support structures at half the height.

The wind project goals were:

- What is the power density of wind at 25 meters in Toronto if a state of the art wind turbine is used at that height on a day by day and month by month basis?
- Is the wind power density enough so that wind power should be considered by the urban householder as a clean source of power?
- Furthermore, is the wind power density enough for local municipal governments to lift zoning laws regarding tower heights in neighbourhoods?
- The complementarity of wind and solar power are well established in the mythology of clean power generation. What exactly is this complementarity in real data terms on a month by month basis in a dense urban area?
- How much does the wind turbine and its associated technologies cost to install and maintain over 60 months of use?
- How reliable is the wind turbine and its associated technologies?
- 25 meters is about the hub height for a wind turbine that could be installed on a school or municipal building. Does the amount of power generated by a small turbine indicate that wind power should be considered for those types of buildings?

Can an old but upgraded house in Toronto using a reasonably sized solar power collector and a reasonably sized wind turbine at 25 meters generate enough power to go off-grid?

We have a partial answer to this question. During the months April, May, June, July and August in 2007, we could, from solar generation alone, have gone off grid for extended periods of many days. In May we generated 94.6% of our power. In June it was 75 %. If we had larger batteries, that is, if we doubled the size of our current capacity of 14.5 kWh (usable) to something around 28 kWh, we could have gone off grid using just solar for about 4 months continuously.

In 2008 it was a different story. The summer generating numbers were disappointing and our power usage was larger. April was the best month in 2008 but generated only about 66% of our power. We generated more power in 2008 but less as a percent of our used power.

In either case we could have gone off grid for selected periods in each year.

Using commonly accepted energy use practices, can the increase in efficiency of an 80 year old house be large enough to be measured?

Yes it can. Note that efficiency gets better as the number of cubic meters (CM) of natural gas burned per heating degree day (CM/HDD ratio) gets smaller. Notice as well the big jump between winter 3 and winter 4. We covered one, second floor exterior wall, our leakiest (coldest) wall, with R 2.81 foam and siding. The area was about 20% of the total house external surface. A gain in efficiency of 14 points represents about a 20% change.

The baseline daily usage of Natural Gas is calculated during the non-heating months of June, July, August and September. We have calculated this baseline over the last five summers.

Baseline Calculation			
Baseline calc for June through September 2004			
	days=	121	
	CM NG used	183	
	Baseline	1.51	CM/day

Baseline calc for June through September 2005			
	days=	121	
	CM NG used	187	
	Baseline	1.55	CM/day
Baseline calc for June through September 2006			
	days=	123	
	CM NG used	233	
	Baseline	1.89	CM/day
Baseline calc for June through September 2007			
	days=	123	
	CM NG used	220	
	Baseline	1.79	CM/day
Baseline calc for June through September 2008			
	days=	121	
	CM NG used	229	
	Baseline	1.89	CM/day

The following table calculates household efficiency using the median baseline of the four calculated above.

Efficiency Analysis Using Median Baseline

Median Baseline **1.79** **CM of NG used per day**

	Winter 1 Oct/04 - May/05	**Winter 2 Oct/05 - May/06**	**Winter 3 Oct/06 - May/07**	**Winter 4 Oct/07 - May/08**
Total NG Used (CM)	3024	2724	2710	2154.6
Total Baseline Used (CM)	436.4	436.4	432.8	436.4
Net NG Used (CM)	2587.6	2287.6	2277.2	1718.2
Total HDD	3478.5	3277.7	3507.3	3400.3
Efficiency CM/HDD	**0.74**	**0.70**	**0.65**	**0.51**

Let's unpack this table. Each heating season we use a gross amount of natural gas. Mixed in with that total is natural gas usage for hot water, cooking and the like. In order to get an idea of the natural gas we use only for heating we subtract the daily amount we use for everything but heating. This leaves us with a net amount of natural gas used over the heating season. Environment Canada publishes the number of accumulated heating degree days (HDD) for each day of the heating season. The **total HDD** represents the total accumulated heating degree days for the entire heating season. The efficiency simply is the total cubic meters of natural gas used divided by the total number of heating degree days in the season.

The efficiency of our house has improved by about one third since the first winter of 2004 -2005. Every summer we write a paper called, "***Household Thermodynamics***" in which we document the changes and upgrades we have made to our house. The same calculation is made below except that the most recent baseline is used.

Efficiency Analysis Using Most Recent Baseline

Most Recent Baseline **1.89** **CM of NG used per day**

	Winter 1 Oct/04 - May/05	Winter 2 Oct/05 - May/06	Winter 3 Oct/06 - May/07	Winter 4 Oct/07 - May/08
Total NG Used (CM)	3024	2724	2710	2154.6
Total Baseline Used (CM)	369.0	377.1	455.4	436.4
Net NG Used (CM)	2655.0	2346.9	2254.6	1718.2
Total HDD	3478.5	3277.7	3507.3	3400.3
Efficiency CM/HDD	**0.76**	**0.72**	**0.64**	**0.51**

The answer to this question is, Yes. We can make changes to the house and measure the benefits.

Is it possible to place a dollar figure on this increase in efficiency? If so, what is it?

It is difficult to put a dollar figure on the increase in efficiency because the price of gas changed and one winter was colder than the other. These data are the best we can generate. Winter 1 is the baseline winter. Changes were made to the house internal heat flow and to the house heat radiation characteristics in each of the winters 2 until 4. Winter 4 is the first winter to have the new siding/insulation installed.

Based upon the use of natural gas, the total savings, since the baseline heating season of '04, '05 are 1041.4 cubic meters. Based upon our cost per cubic meter delivered to our door, the savings since, over the baseline year, have been 1014.4 times our standard cost for gas. From the chart below where we have tracked our total gas usage and the total amount we have paid for gas, our cost for each delivered cubic meter of natural gas is $0.58.

Our total savings since the baseline year are $604.01.

Our database covers 1674 days.

Totals for NG

Billed Days		1674
Cubic Meters used		12304.6
Total Billed	$	7,184.69
Cost per M3	$	0.58
M3/day Average		7.35
Billed per day	$	4.29

Based upon our natural gas cost from our database we saved (559.0 times $0.58) = $324.22 over the last heating season.

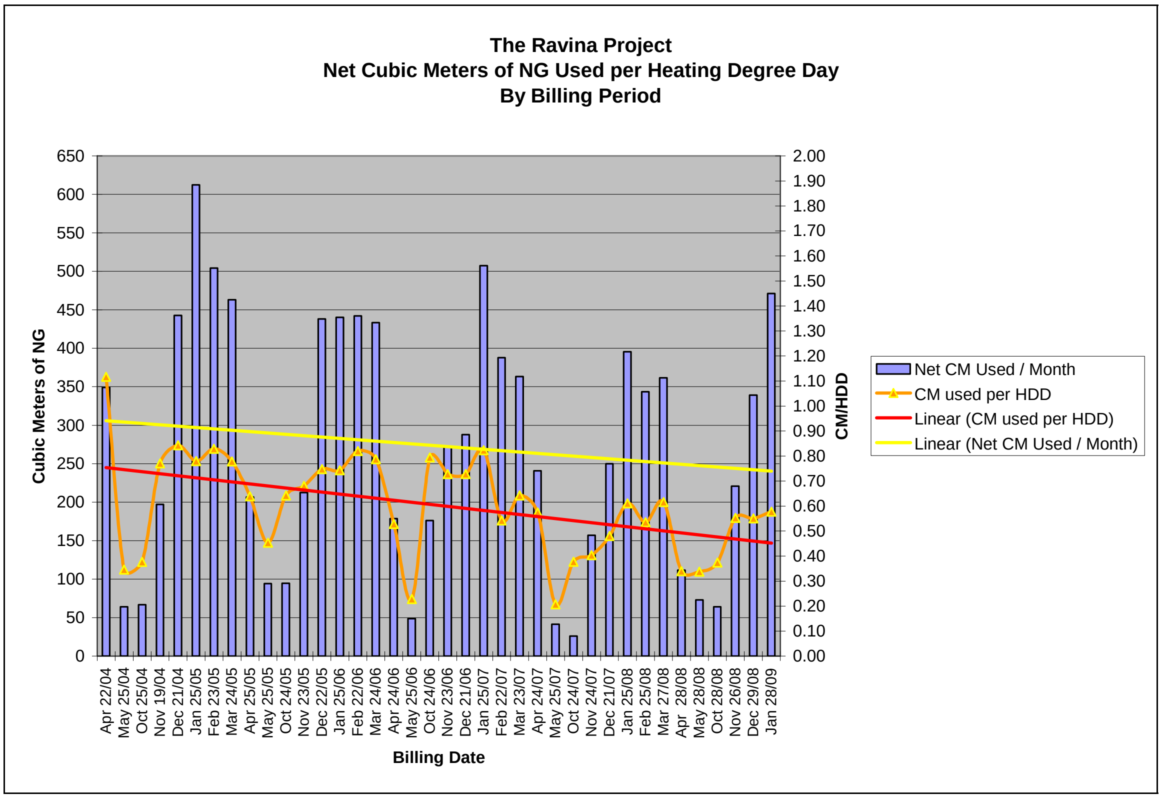
Because we have used less gas our carbon footprint has been reduced.

Will improvements to the house's insulation be reflected in the efficiency numbers expressed in cubic meters of natural gas usage per Heating Degree Day during the heating season?

Here is a chart from our natural gas usage database. The red line trends the number of cubic meters of natural gas used from April '04 to January '09. Our conservation efforts seem to be paying off. See our latest paper on **household thermodynamics** for a more in depth discussion of our efforts.

Note the dramatic change in efficiency last winter (07-08). We added external siding and R 2.81 foam over top of the coldest second floor wall. This year is starting out to look good as well.

Consider the graph below.



This graph is complicated so let's unpack it. Notice that 4 months of every year are missing. These are not heating months so are not included because the furnace is off.

The **blue bars** represent the amount of natural gas we have used per billing period net of the baseline amount used for domestic hot water, cooking and the like. This amount is the closest we get to isolating our natural gas usage for heating. Use the scale on the left of the chart to read the values on these bars.

The yellow line represents the linear trend in our natural gas usage. We seem to be using less.

The **orange squiggly line** represents the efficiency of our house and is the point this graph is trying to make. We divide the monthly total number of cubic meters of natural gas used by the total monthly number of heating degree days as published by Environment Canada for Central Toronto. The result is a ratio which indicates the monthly efficiency. As the house gets more efficiency it will use less natural gas per heating degree day. Notice the downward trend of this line. The scale used to read the vales for this line is on the right hand side of the graph.

The **red line** traces the linear trend of the orange line. The house is getting more efficient. We are being rewarded for our efforts to control heat loss.

Solar Energy Production

Solar Panels

The solar panels required no maintenance. As an experiment we hosed them down after they were laying flat for half the summer (2007). We noticed that rainfall washed them off so much so that when we checked them at the end of the summer they were surprisingly free of any buildup of dust. Bird poop did not wash off easily but the buildup covered such a small area of the 12 square meters of panels that any attenuation would be, in our opinion, immeasurable.

Peak power analysis

As you know if you have been looking at our solar data we record a short weather report, the peak power recorded for the day and the total energy generated in kWh. It has been accepted that at this latitude (43 degrees north) that the sun in the winter time would have less power that at other times of the year.

The explanation about why this occurs centers upon the geometry of the sun's angles upon the earth at this location. In the winter time the sun's altitude is about 24 degrees at noon sun time. This noon time angle persists for most of the winter (November, December and January). This angle forces the sun's rays to travel through much more atmosphere than at other times of the year before hitting the solar panels. The argument concludes with a prediction that the intensity of the sun at this time of year is less than at other times and hence less peak power will be recorded.

The data we have collected show little in the way of a decrease in the peak power generated by the array during the winter months.

What does this mean? Firstly it is best to understand how peak power is generated and recorded. Our MX-60 ™ solar charge controller keeps track of the maximum or peak power recorded during the day. At the end of the day that maximum or peak can be accessed via the push buttons on the front panel. We record that peak value on our daily data sheet.

How are peaks generated? This is a more complex question. On days that have cloudless skies there will be a peak value recorded but it is important to note that these peaks will correspond closely with the peak in sustained power generation. For a cloudless winter day we expect to see that peak about 1250 – 1350 watts which corresponds to the sustained power that we would record on our daily power log. In the summer time on a cloudless day we expect to log about 1060 watts for our sustained power and the corresponding peak power.

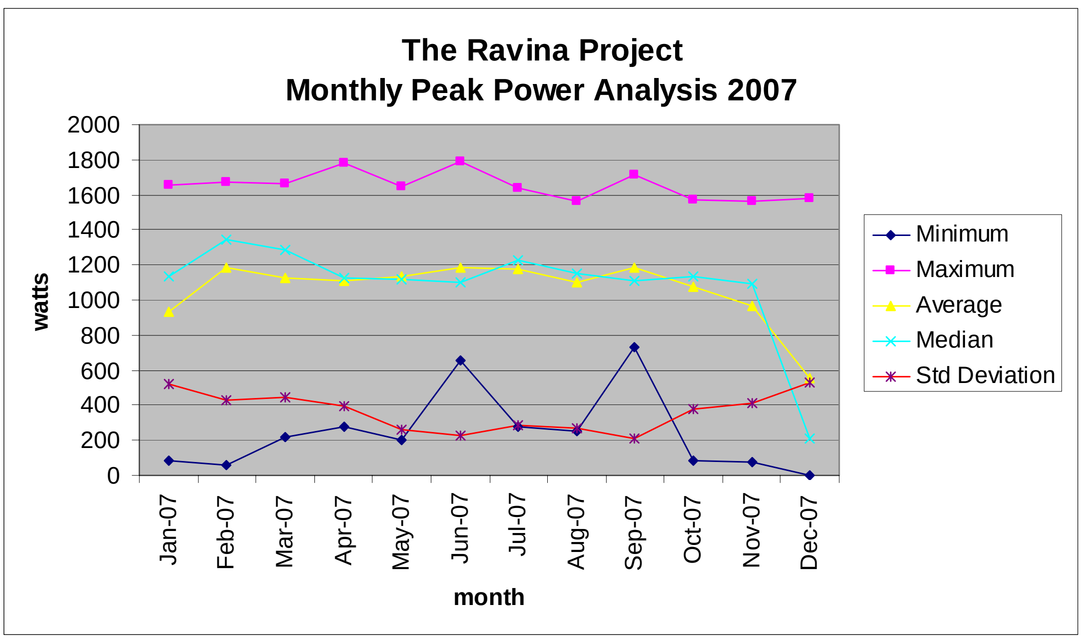
The days that produce peak powers above 1500 watts, the theoretical capacity of our array, are days that are partly cloudy. When a cloud covers the sun for a time the internal temperature of the solar panels falls to air temperature. When the sun again strikes the panels, they are cool and much cooler than they are when under sustained sunshine. Solar panels are very sensitive to heat because of the materials used in their construction. The hotter they get the more internal resistance they have to electrons flowing through them which, in turn, decreases the amount of current and voltage they produce. If one looks at the voltage generated within the panel, the specifications indicate that the fall off in voltage is actually several times greater than the reduction in current. This reduction is in proportion to the reduction in power generated at any particular time of day.

However, then the sun comes from behind a cloud, the array gets a chance for a short time, to produce power unhindered by heat buildup.

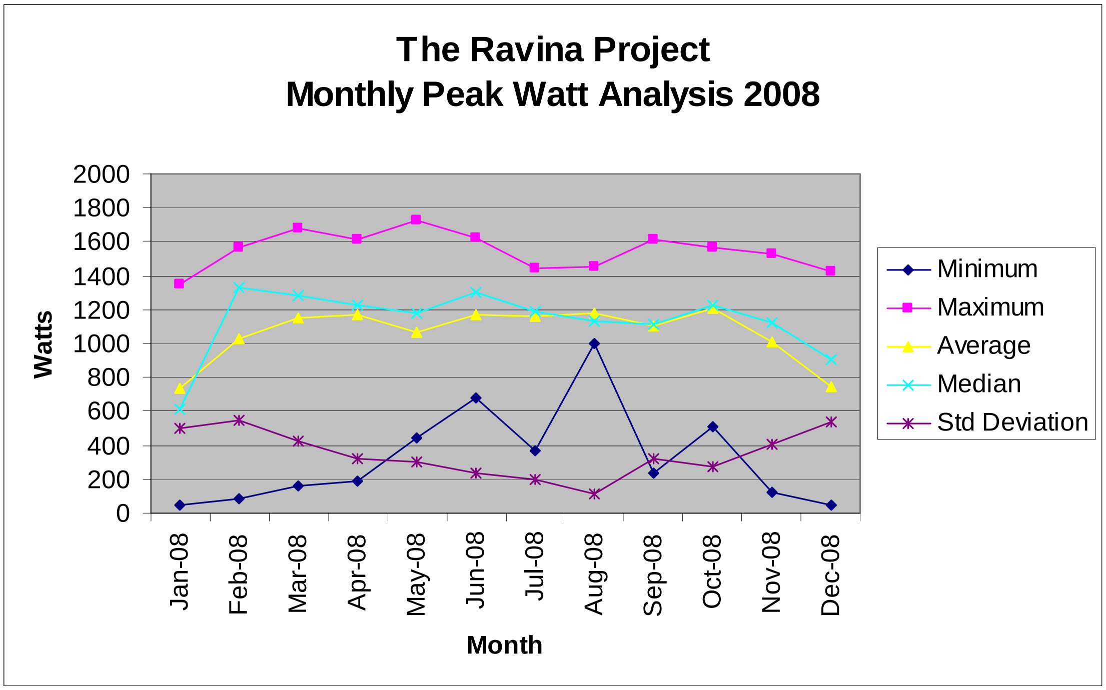
This phenomenon, in a sense, allows the solar panels to measure the sun's power in a more accurate way. We have seen this phenomenon many times and watched as the power slowly decreases as the panels heat up internally. In the winter time the power decreases to a level higher than in the summer time because the panels are cooled by the ambient temperature of the surrounding air. We have lots of ventilation for the backs of the panels at all orientations of our array to the sun.

We believe that these peak power readings are like readings from a simple photometer. We can take these maximum power readings and compare the intensity of the winter sun with the summer sun. We find that there is little difference among them. What we do find is that over the past year the standard deviation decreases over the months that have good sun most of the time. This stands to reason.

Peak power analysis is accomplished by recording each day the peak power recorded on our MX-60 ™ Outback solar charge controller. Each month therefore will have a maximum, minimum, average and median daily peak power recorded. The standard deviation for each month is calculated using all the peak power values for that month.



The graph above is set up to show the value of the maximum and minimum peak power recorded for each month. During poor months the minimum peak power might only be 100 watts or less, even zero. These are very poor days with the sky in dull overcast all day long. ☹



Over the two years the relative curves seem to be similar.

Bottom line on this exercise is that we expected to see a very pronounced difference between the sun's power in the winter and summer, with the summer being the champ. The conventional wisdom comes out on the side of summertime when the sun angles are such that the amount of atmosphere traversed by the sun's rays is at a minimum. From the physics of the workings of the solar collectors, there is a counter argument expressed as follows: since the solar collectors are cooler in the winter time they have less internal loss associated with heat. This increase in efficiency would tend to offset any losses associated with the increased atmospheric mass transit of the sun's rays.

We have no answer but our data suggest there might be a subtle interplay between the trends.

Earth Week April 2008

The Ravina Project went off grid for **Earth Week** 2008. On Sunday night at about 10:30 EST we cut the 100 amp circuit breaker to the street. From that point on until Monday April 28th, the day after **Earth Week** concluded we were off grid.

Here are the stats for the week expressed in kWh.

Total	43.4
Daily Ave	6.2
Daily Median	6.1

The daily average was a little light. Our house uses about 300 to 350 watts averaged over 24 hours for a total of 7.2 to 8.4 kWh per day in the spring, fall and other times during the summer when auxiliary heating and cooling are not required. As you can see we came up short that week. The house used between 50.4 and 58.8 kWh that week. We were down anywhere between 7.0 and 15.4 kWh. That is, the batteries made up the difference as their charge migrated into the house to make up the difference. We did not get enough sun for 4 of the 7 days of the week. When we reconnected to the grid we used over 16 kWh of power in the first 24 hour period which is about 8 kWh more than what we would expect. The batteries needed that extra energy to recharge.

Here are the individual days' generation numbers for **Earth Week**.

21-Apr	6.1	kWh
22-Apr	8.5	kWh
23-Apr	4.9	kWh
24-Apr	8.4	kWh
25-Apr	3.3	kWh
26-Apr	4.1	kWh
27-Apr	8.1	kWh

So you can see where the power went.

Why did we cut the power at night rather than in the morning?

We reasoned this way.

The goal was to collect data but also we wanted to last for the whole week without using grid power. There are two rates at work which could determine whether we would be successful. Firstly, our burn rate could not increase substantially beyond its normal range and secondly the amount of energy harvested from the sun must replace the amount we burn. There is some latitude in this exercise.

On a good day we can replace all the energy we burn and that means that the battery is, more or less, recharged completely in the 24 hour period.

On a poor day we do not replace the power we use from the battery so that the battery is in some degree of discharge at the end of the 24 hour period.

Several poor days back to back will drop the battery charge as each 24 hour period passes. The limit to battery discharge is -14.0 kWh. At that point the battery is 80% discharged and cannot be discharged further without harming the battery permanently. Given we have about $5,000.00 worth of battery, we don't want this to happen.

Solar energy is harvested and travels to the battery to charge it. Typically a daytime power generation number is somewhere in the 1150 Watt range however the house only uses about 350 Watts. Normally the extra power goes to the grid and turns our utility meter backwards. Off grid means this pathway for power is closed. However, when off grid and if the battery is full, the solar charge controller shuts down the solar panels to a level where they are generating only enough power to run the house no matter how bright the sun is. The excess power is lost.

To get back to our question about when to isolate us from the grid, we had a choice of going off grid in the morning or in the evening.

If in the morning we would be generating power all day long but our battery would be full. We would generate only as much power as the house would use for the daytime hours. Let's suppose there are 12 usable hours in the day at this latitude and time of year. We would limit ourselves to generating about 4.2 kWh in that first 24 hour period no matter how much sun energy was available during that period. As you can see from the generation statistics for the week 4.2 kWhs of power would put that first day next to last in generation numbers for the week.

If we isolated ourselves in the evening then the batteries would be in some state of discharge the next morning. The sun would charge the battery and run the house at the same time for the entire day. The charge controller would not shut down or reduce the power output from the solar panels because the extra load provided by the battery recharge is available.

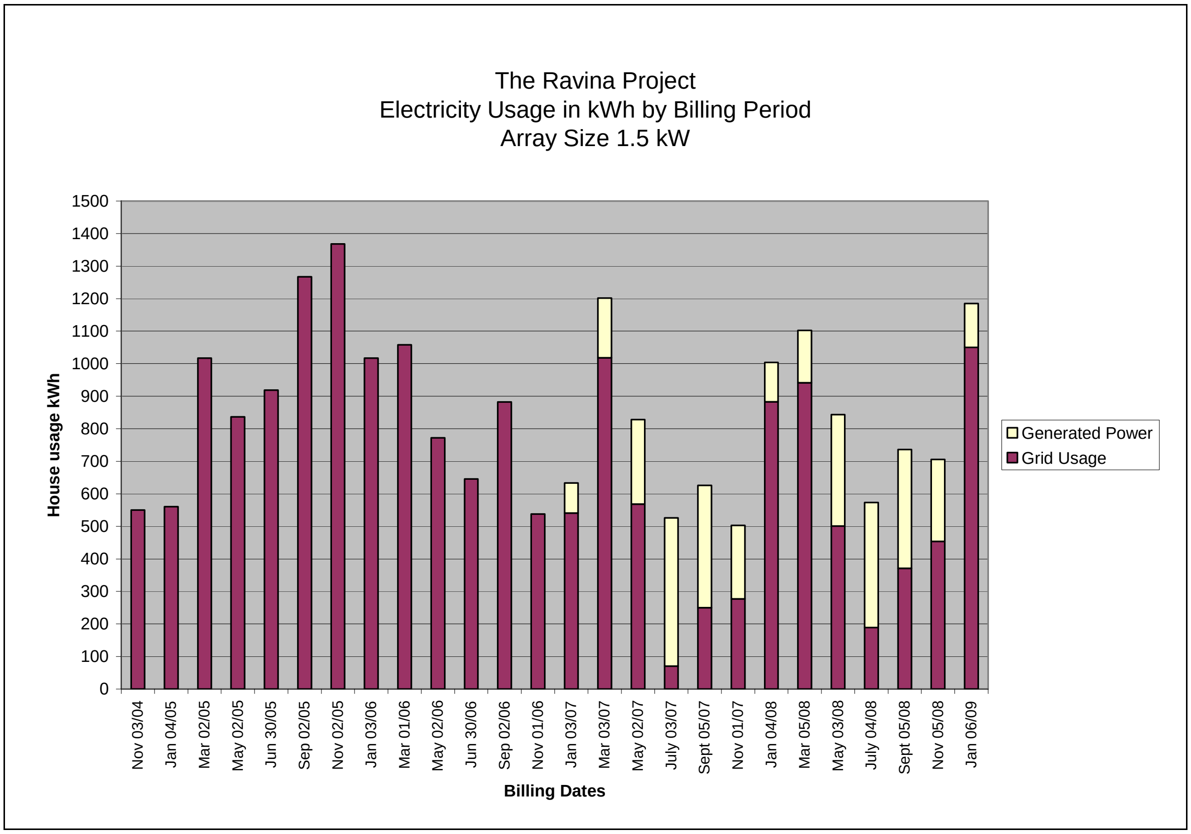
The records we kept for the 21st of April 2008 indicate that the sun was hazy for the entire day. The generated amount of 6.1 kWh was the best we could do that day given the atmospheric conditions. However, the energy we harvested was still more than what we would have needed if we had started the day with a full battery by about 2 kWh. So in the greater scheme of things, we harvested 2 kWh more energy than what we would have if we started the day with a full battery and, and this is important, we ran the house for an extra night.

Electrical Energy Usage vs. Generated Energy

In this section we want to discuss our use of electrical energy with reference to our historical data.

We read our gas and electrical utility meters at the end of every day. We have kept old bills from the utilities which allows us to generate databases of usage going back several years.

Consider the following graph.

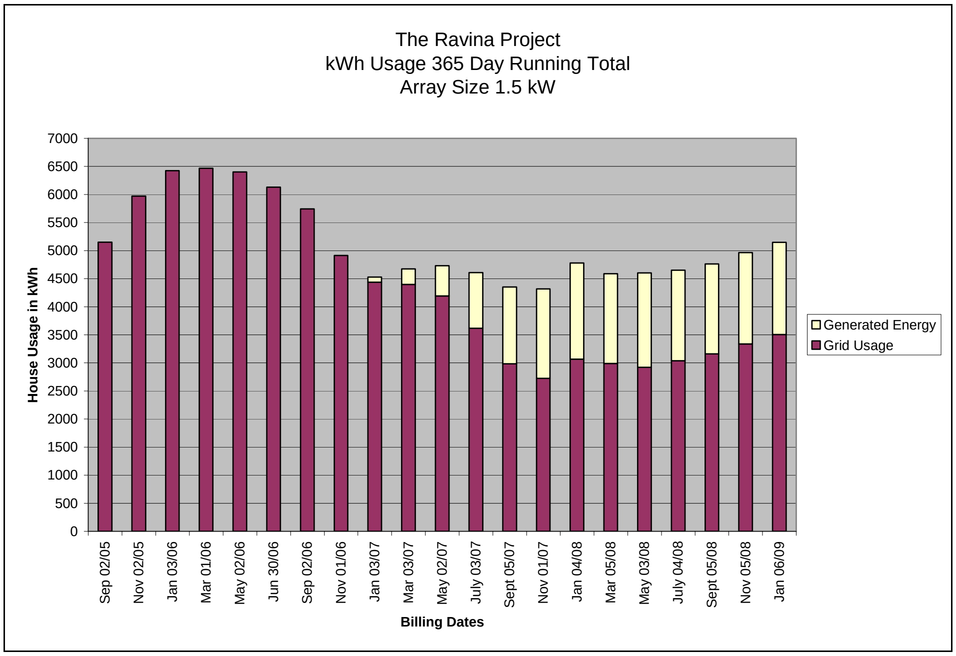


Using our old utility bills and combining them with our daily readings for energy generation we can produce a graph showing exactly the effect our solar array is having upon the demands the house is making upon the electrical grid.

The **rust** coloured parts of the columns correspond to the electrical energy we use from the utility.

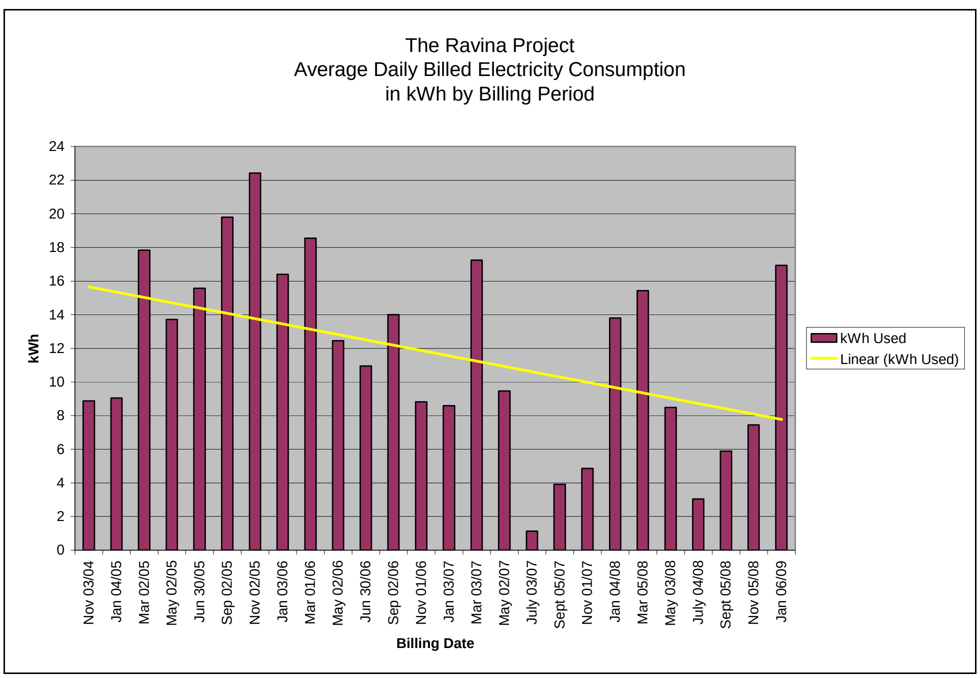
The yellow parts correspond to the generated energy.

Consider the following graph.



This graph takes the database and expresses it as a 365 day running total of electrical energy usage in each bar. For instance by November 2005 we had used about 6000 kWh from the grid in the previous 365 days. As we generate more and more this visual representation look like we are generating about one third of our needs on an ongoing basis.

Consider the next graph.



This graph brings grid usage down to the daily level. The fall off in daily grid usage is dramatic especially in the summer time, the peak generation time of the year.

Power generation vs. maximum air temperature

We were curious to find out whether there was a correlation between the maximum air temperature for the day and the array efficiency. See the paper, "*Solar Array Efficiency – A Simple Standard*".

From that paper we include the chart below.

2007	Average Efficiency	Average Temp		Maximum Efficiency	Maximum Temp
January	**5.7**	**1.2**	January	**7.5**	**-4.6**
February	**7.5**	**-5.0**	February	**7.9**	**-1.8**
March	**7.8**	**1.7**	March	**8.5**	**-10.9**
April	**6.8**	**16.9**	April	**7.6**	**11.8**
May	**6.8**	**15.4**	May	**7.1**	**12.4**
June	**6.5**	**22.5**	June	**6.7**	**22.0**
July	**5.8**	**23.3**	July	**6.2**	**24.3**
August	**6.1**	**27.1**	August	**6.3**	**32.9**
September	**6.2**	**21.1**	September	**6.6**	**21.2**
October	**5.6**	**18.5**	October	**6.0**	**18.1**
November	**6.1**	**5.3**	November	**7.1**	**-3.2**
December	**4.3**	**-0.8**	December	**5.8**	**4.1**

Correlation between average efficiency and average temperature:	**-0.104**
Correlation between maximum efficiency and average temperature:	**-0.508**
Correlation between maximum efficiency and maximum temperature:	**-0.688**
Correlation without December Values.	
Correlation between average efficiency and average temperature:	**-0.506**
Correlation between maximum efficiency and average temperature:	**-0.803**
Correlation between maximum efficiency and maximum temperature:	**-0.845**

Average Efficiency for year:	**3.8**	Wh/kW/min
Maximum Efficiency for year:	**8.5**	Wh/kW/min
Median Efficiency for year:	**4.2**	Wh/kW/min
Average Daily Generation:	**4.4**	kWh
Maximum Daily Generation:	**9.4**	kWh
Median Daily Generation:	**4.4**	kWh
Kilowatt-hours generated per kilowatt of installed base:	**1069.0**	

The data for this chart was gathered over the year 2007. **Average efficiency** is the daily average for the month. **Average temp** is the daily average temperature for the month. **Maximum efficiency** is the best daily reading for the month. **Maximum temp** is the maximum temperature on the day the Maximum efficiency was recorded.

Efficiency has a lot to do with the number of minutes available in the day when the sun is above the horizon. Shorter days will deliver less energy on average but the array is not necessarily less efficient. In order to make the shorter and longer days compete evenly we divide the number of

Watt-hours generated in a day by the number of minutes of sun in the day. This solves the problem of day length however the capacity of the solar panels must also be taken into consideration. Using this calculation a one kW installation would always be less efficient than a 3 kW installation. To eliminate this disparity we divide the total again by the number of kilowatts of installed base.

The complete formula is, (number of Watt-hours generated per day) divided by (number of minutes in the day) divided by (the size of the array in kilowatts).

We wanted to determine if there was a correlation between heat and array efficiency.

You notice that correlation is calculated with and without December's values. The values were deemed to be outliers. Leaving them out seemed to perk up the correlation values.

The statistic "kilowatt-hours generated per kilowatt of installed base" is a solar industry standard measurement.

Solar Panel Specifications regarding heat

The specifications for our solar panels from Centennial Solar have a specification for heat which is of interest in this discussion. Let's examine the specs on our panels.

Consider the picture below.

CentennialSolar

SPECIFICATIONS OF CRYSTALLINE SOLAR MODULES

Electrical Data

The electrical data applies to standard test conditions (STC):
Irradiance at the module level of 1,000W/m^2 with spectrum AM1.5 and cell temperature of 25^{0}C

Electrical Parameters		CS125	CS130	CS135	CS140
Power (max.)	P_p (watts)	125W	130W	135W	140W
Voltage at maximum power point	V_p (volts)	17.4V	17.6V	17.9V	17.9V
Current at maximum power point	I_p (amps)	7.18A	7.39A	7.54A	7.82A
Open-circuit voltage	V_{oc} (volts)	22.0V	22.0V	22.0V	22.0V
Short-circuit current	I_{sc} (amps)	7.6A	8.0A	8.1A	8.4A

The quoted technical data refers to the usual series cell configuration
All electrical parameters may vary by ±10%
Contact us for warranty details

The panels we have are CS125s. Note that the panel temperature during the testing is 25 degrees Centigrade which corresponds to 298 degrees Kelvin. Since not all light is the same with certain frequencies (colours) providing more power than others the kind of light is specified in the spectrum parameter. In this case it is AM1.5 which is a short form for saying that the sun light has traveled through an air mass (AM) of 1.5. This air mass is calculated as that which sun light would travel through if the sun were about 42 degrees above the horizon and the solar panel on the surface of the earth was tilted to the sun at about 37 degrees.

The sun's power, its irradiance, is expressed in watts per square meter.

If all these conditions are met then the panel should turn out 125 watts of power plus or minus 10%.

So what happens when the panels get hot, that is, they get hotter than 298 K?

Consider the following picture:

Cell temperature coefficients			**Limits**	
Power	$T_K(P_p)$	$-0.55\%/^0K$	Maximum system voltage	1000V DC
Open-circuit voltage	$T_K(V_{oc})$	$-0.33\%/^0K$	Operating module temperature	-40 to $+90^0$ C
Short-circuit current	$T_K(I_{sc})$	$+0.05\%/^0K$	Tested wind resistance	Wind speed 192km/h
Certifications: IEC61215				

Note: The specifications are subject to change without notice

Since all the specifications have been generated when the cell temperature is 298 degrees K, there must be some specification as to how the cells will react when the temperature gets hotter than that. In this specification above we see that the power will decrease 0.55% for each degree Kelvin the cell is above 298 degrees.

For example, let's say that the air temperature is 30 degrees C, the noon sun is clear and powerful. The cell temperature is 55 degrees Centigrade. We know the characteristics of the cells at 25 degrees C, what happens when they are 30 degrees over and above that temperature? We see from the specifications above that the power generated by the cell will be 30 times .55% or 16.5% less than if the cells were at 25 degrees.

This corresponds to our readings of sustained summertime vs. springtime power readings. Our sustained hot summertime readings are about 1050 watts versus a springtime reading of 1250 watts. This corresponds to about a 16% difference.

Our recorded data also point to another interesting fact. When the cell temperatures fall to air temperature because the sun is behind a cloud for enough time, the peak power generated by the cells do not vary by much over the course of the year through all seasons. The chart below shows the monthly peak power maximums for 2007.

	Minimum	**Maximum**
Jan-07	82	1652
Feb-07	60	1675
Mar-07	220	1664
Apr-07	279	1782
May-07	202	1645
Jun-07	653	1787
Jul-07	274	1639
Aug-07	251	1561
Sep-07	727	1715
Oct-07	87	1572
Nov-07	76	1561
Dec-07	0	1578

The variation between the maximum monthly peak power is about 13%. However, and this is important, it seems to have little correlation with the months that are cold. Maximums in the 1700's occur in April, June and September. Maximums in the 1500's, the lows for the year occur in the months of August, October, November and December. Other than August these months are not known for their hot daytime temperatures.

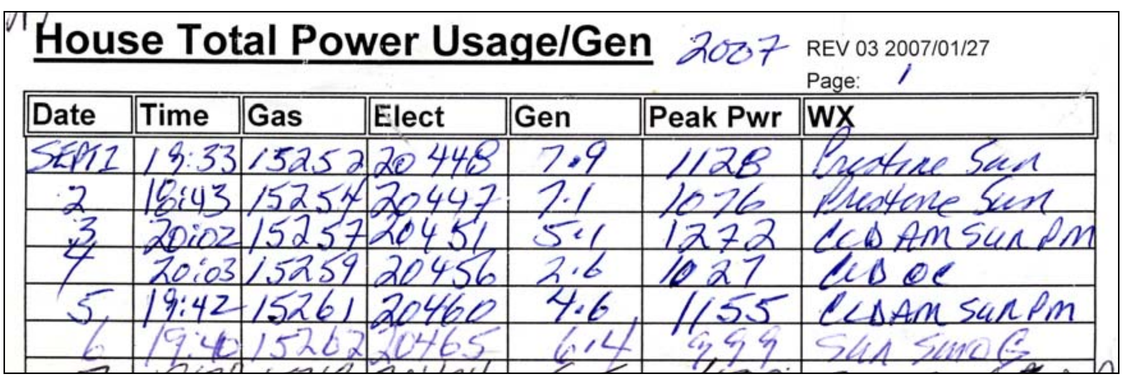
The chart below shows the monthly peak power maximums for 2008. A similar analysis can be made.

	Minimum	Maximum
Jan-08	49.0	1351.0
Feb-08	88.0	1567.0
Mar-08	160.0	1677.0
Apr-08	188.0	1617.0
May-08	443.0	1727.0
Jun-08	675.0	1622.0
Jul-08	372.0	1444.0
Aug-08	1004.0	1457.0
Sep-08	237.0	1615.0
Oct-08	508.0	1562.0
Nov-08	121.0	1531.0
Dec-08	44.0	1424.0

Data Collection

At the end of each day we collect several pieces of data. We call it "doing the numbers". We read the gas meter, the electrical meter and, from the Outback MX-60 ™ solar charge controller, we get the peak power and total generation in kWh.

Below is a sample of the numbers taken at the start of September 2007.



House Total Power Usage/Gen 2007 REV 03 2007/01/27

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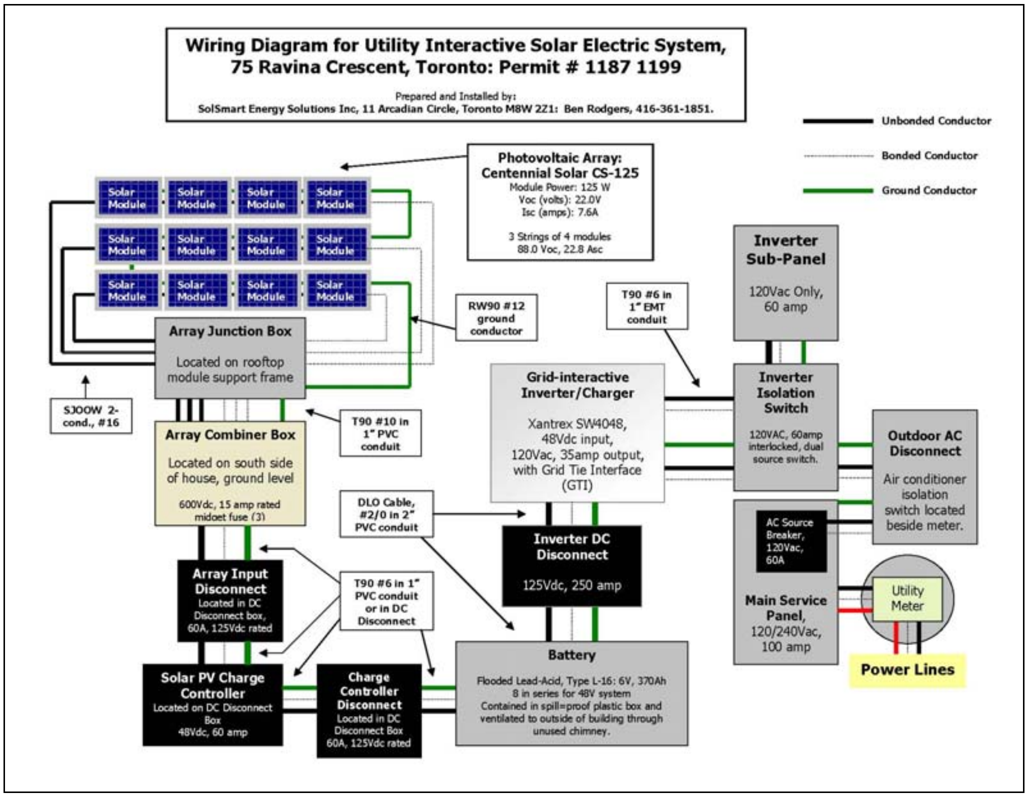
Date	Time	Gas	Elect	Gen	Peak Pwr	WX
SEPT 1	19:33	15252	20448	7.9	1128	Pristine Sun
2	18:43	15254	20447	7.1	1076	Pristine Sun
3	20:02	15257	20451	5.1	1272	CLD AM Sun PM
4	20:03	15259	20456	2.6	1027	CLD OC
5	19:42	15261	20460	4.6	1155	CLD AM Sun PM
6	19:40	15262	20465	6.14	999	Sun [illegible]

Description technical

Below you will find a schematic of our setup here at The Ravina Project. This whole design and setup has been hassle free. This demonstrates that a well designed system using off-the-shelf components is the best way to go without a doubt. As well, Ben Rodgers and the team from Solsmart Energy Solutions Inc. produced a fully integrated package for us in response to our Request for Proposal.



Daily Solar log

The daily log is recorded on an ad hoc basis. We have WiFi cameras focused on the array from an external source and one focused on the MX-60™. These camera outputs are displayed on any of 3 computers in the household. We fill in this form as the day progresses. If the day is very promising as this one below was, we take some extra time in the morning … extra cup of coffee … and record more thoroughly than at other times.

Solar Array Daily Log 2008 REV 03 2008/01/17

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Date	Time	WX	Power	kWh	Angle	Batt V
JAN20	10:11	Clear Sun	1201	1.1	+70	55.2
	10:31		1230	1.4		
	10:34		1244	1.5		
	10:40		1253	1.6		
	10:44		1250	1.7		
	10:58		1268	2.0		
	11:11		1269	2.2		
	11:12		1261	2.3		
	11:22		1260	2.5		
	11:47		1253	3.0		

In the late fall, winter and early spring, getting 4 kWh by noon EST means that it will be a very good day. This day looks promising with more than 3.0 kWh generated by noon and with power levels over 1200 watts. We ended the day with 5.7 kWh … a good winter time number. The log indicated that clouds moved in later in the PM.

Heating with hot water

Central heating using hot water has to be one of the most efficient ways to heat a house bar none. The heat capacity of water is huge. The radiators in our house are early 1900’s vintage but they work just fine. We understand that modern houses use water heating in the floors to the same effect.

Thermostat settings

We have a simple thermostat located in the living room. See our paper on **household thermodynamics** for a layout of our house. One of us (Gord) has owned houses with forced air heating. There is quite a difference between using thermostats with the two heating methods.

Forced air heating starts when the temperature falls and the thermostat keys the furnace. The furnace stops when the temperature reaches the preset level and the furnace is unkeyed. The forced air fan usually stays on until the furnace heat exchanger reaches some preset temperature. When the furnace fan stops no more heat is transferred from the furnace to the house at large.

Hot water heating is quite different. When the thermostat unkeys the furnace there is still lots of heat in the radiators. In fact the radiators are full of water at their hottest temperature and they will remain hot for an hour or more. During this time the ambient temperature of the house will increase well above the setting on the thermostat. This is quite different than heating with forced air. This extra heat in the house is wasted heat … that is, it is heat that was not called for by the thermostat setting. It is unwanted heat.

To counter this waste we do the following. In the morning we turn up the thermostat to a setting a few degrees lower than the ambient temperature we desire. We had to play around with this setting to find one to fit our needs and comfort level. The radiators fill with hot water until the thermostat keys the furnace off. The house continues to get hotter as the heat in the radiators is transferred to the air. We found that the house spends much of the day at a higher temperature and for longer periods than what would be expected just by looking at the thermostat setting. The house became quite comfortable and stayed that way for the day.

Electrical Energy Usage

Here’s a section of our household database of 1,219 days of electrical billing.

Totals for Electricity		
Days		1219
kWh billed		15039
Total Billed	$	2,150.59
cost per kWh	$	0.14
kWh/day		12.34

On the **Totals for Electricity** chart above, we kept our electrical bills for many years so the numbers there are accumulative. The cost for each kWh of electrical energy is just a gross division of the total used by the number of days in the database. The daily usage is again a gross division between the total billed kWh divided by the number of days.

Other yearly statistics

Yearly 2007 totals and other stats:

yearly solar generation efficiency	4.0	Wh/min/kW
total solar generation per kW of collector	1069.0	kWh/kW
average solar energy generation per day	4.4	kWh/day
total energy generation	1603.5	kWh
total grid energy used	3036.0	kWh
percentage of total energy generated	34.6%	
house total electrical energy consumption	4639.5	kWh
total gas used	2691	cubic meters
yearly average gas usage / day	7.37	cubic meters
average gas usage / day for heating	8.41	cubic meters
total yearly energy consumption from all sources	32.59	mWh
house efficiency - cm used per HDD	0.58	cubic meters

Yearly 2008 totals and other stats:

yearly solar generation efficiency	4.1	Wh/min/kW
total solar generation per kW of collector	1086.7	kWh/kW
average solar energy generation per day	4.5	kWh/day
total energy generation	1630.0	kWh
total grid energy used	3461.5	kWh
percentage of total energy generated	32.0%	
house total electrical energy consumption	5091.5	kWh
total gas used	2591	cubic meters
yearly average gas usage / day	7.10	cubic meters
average gas usage / day for heating	7.92	cubic meters
total yearly energy consumption from all sources	31.90	mWh
house efficiency - cm used per HDD	0.54	cubic meters

Conclusion

As the months go by, we are getting a better picture of what it takes to energize a household in Toronto. We get our energy from two distribution systems, natural gas pipes and the electrical grid. The natural gas, averaging about 2,600 cubic meters per year, is used to provide heat in one form or another. The electricity, averaging about 4,800 kWh per year is used to energize appliances (we consider light bulbs as appliances) and to produce more heat for the household. In total and from all sources we use just over 32 mWh of energy if all sources are converted to kilowatts or just below 3,100 cubic meters of natural gas if all sources are converted to natural gas. These data have been a revelation to us. We're sure there are 'test houses' where similar data are generated. It would be interesting to see how we compare to these houses.

The absolute sublime nature of creating electrons from photons, that is, creating usable electrical energy from the sun, still astounds us. I (Gord) remember as a child going to the Canadian National Exhibition in Toronto. In one booth in the Better Living Building, one found a stationary bike hooked up to a generator which in turn powered a TV set. The goal for the youngsters who participated was to pedal the bike with enough force to power the TV set. As I sat there working very, very hard to keep the set lit, the experience became an indelible memory of just how much power there is in a lowly Watt. And how much effort one has to put out to generate just a few tens of Watts. When I look at the solar charge controller and see that the array is generating electrical energy at a rate of 1250 Watts, I think of how much effort it would take to generate the same amount of power by hand. The panels just sit there. They don't require any maintenance. They are like a hi-tech pet rock: they are the ultimate low maintenance power source.

We would like the accounting gurus of the world to put their heads together and come up with a new way of accounting that incorporates carbon into the traditional methods. For instance everyone can have a carbon balance sheet assigned to them where their carbon footprint is constantly re-calculated. It could be very much like a bank account? We don't know.

One of the burning (no pun intended) questions we here at the Project would like answered has to do with second hand things we purchase. It is obvious that purchasing something new requires the purchaser to assume the total carbon debt of the purchased product. We can understand that accounting but what happens if the new thing purchased is second hand? Does the first owner take all the carbon debt on their balance sheet? Or is there a split in carbon debt between the first and second owners? If there is a split then how much carbon debt gets apportioned to each of the owners?

A proper answer to this question would help those who are constantly faced with the decision: new or used?

We are in month 28 of our 60 month Ravina Project. The house upgrade part of the project is much older than that by several years. However, The Ravina Project is formally only 28 months old.

I (Gord) read the log files from the WEB site on a more or less regular basis. We get hits from all over the world. We have had several suggestions from visitors to the site. We thank you all for your valuable input.

We hope to author several more 'update' papers like this one between now and when the project terminates.

Regards to all,

Susan and Gord

"Live simply so that others may simply live."
- Mahatma Gandhi

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