The Ravina Project

Household Thermodynamics – July 2010

Gordon Fraser B.A.
Director - The Ravina Project
Toronto, Canada

gord@theravinaproject.org

2010/07/09

REV 06

Blank Page

Household Thermodynamics July 2010

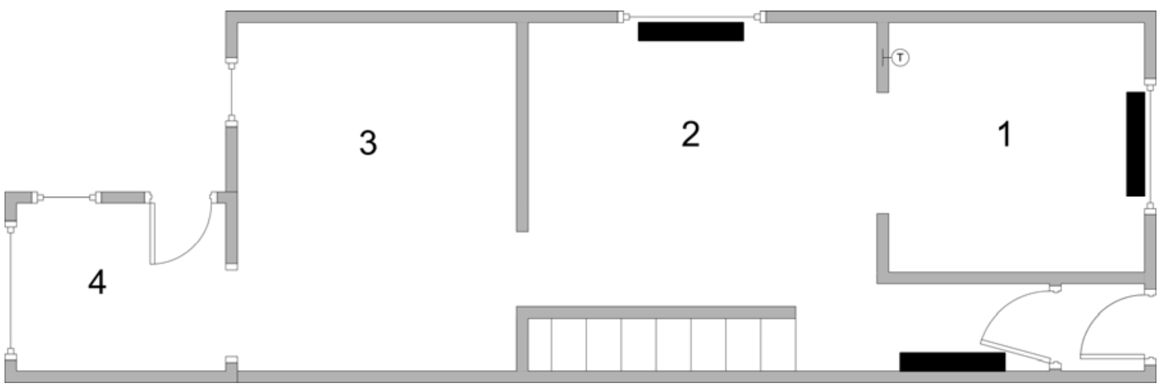
Introduction

This is the third of a series of papers we publish on the changing thermodynamics of our 80 year old house here in Toronto. Two years have gone by since we last published a version of this paper. We made some significant changes to the external surface of our house and the database of observations we have to draw upon and mine is about double in size.

We have converted exclusively to the efficiency metric; cubic meters of natural gas used per heating degree day or CM/HDD. We have updated our historical database on the house to reflect this new metric.

Household Layout at The Ravina Project

Layout of first floor



Consider the diagram above. The area labeled 1 is the living room and is at the front of the house. Area 2 is the dining room; area 3 is the kitchen and 4, the porch. All rooms except 4 have a second floor overhead. All rooms have an unheated basement below. The basement gets its heat from overhead pipes carrying hot water for heating.

Area 1

Area 1, the living room, has double brick external walls. It has a large new modern double pane window and a hot water radiator beneath it. The area also contains the thermostat marked as T. The opening between 1 and 2 consists of a set of double doors which are always open. The floor is covered with furniture and a rug.

Area 2

Area 2, the dining room has 2 external double brick walls. It has the same type of window as area 1 and another radiator. The three doorways are always open. The bottom right doorway leads to the bottom of the stairs to the upper floor and the hallway which has its own radiator.

Area 3

Area 3, the kitchen, has three external double brick walls. It has no radiator and must get its heat from other rooms at night and cooking during the day. The stove is natural gas powered. The window is a large modern double pane type.

Area 4

Area 4, an enclosed porch, has three wood frame exterior walls. It has no radiator and gets all its heat from area 3, the kitchen. It has two large modern double pane windows and a modern double door. It has no second floor and rests on a basement fruit cellar that is separated from the full basement by a door.

Analysis of Heat Flow

On the main floor in the winter the heat comes primarily from the three radiators located in area 1 and 2 and the hallway. Since area 3 the kitchen is unheated it will become a heat sink for the heat generated in the other heated areas. The heat will migrate through the open door way between 2 and 3. Area 4 has less insulation on its outside walls and ceiling. It will be the heat sink for any heat migrating into area 3.

So we can say in general that area 1 and 2 are the hottest with area 3 being cold and area 4 being the coldest.

From physics we know that heat flows 'down hill'. That is, heat flows from areas that are hotter to areas that are colder. The rate of heat flow is proportional to the difference in temperature (K) among the areas. Other variables are factors but the main idea is that the greater the difference in absolute temperature (K); the greater the rate of heat flow.

It follows then that any impediment to the heat flow between a warm area and cold area will affect the rate of heat movement. One way to slow the flow of heat is to place a barrier between the areas. We use doors to do this all the time … especially the external doors on our houses. They keep the heat in during the winter. Another way of doing the same thing is to modify the heat gradient between the hot area and the cold area by injecting heat into the cold area.

Modifications made to Internal Heat Flow

Modifications were made over the past winters to the internal heat flow in the house during winter. We were hoping that our analysis of the heat flow was correct. As well, we hoped that there would be a measurable change in household efficiency.

Winter 1 2004 - 2005 – no changes

The first winter had no modification to the household heat flow. It will be, for the purposes of this experiment, the baseline year.

Winter 2 2005 - 2006 – curtain and heater

Using the diagram above, notice that there is a doorway between the kitchen and the enclosed porch. Our analysis above strongly suggests that there will be a heat gradient between the better insulated kitchen which opens onto the hotter areas 1 and 2, and the enclosed porch. This doorway we believe is a pinch point for heat flow between the rooms.

We fabricated a curtain consisting of about $10 of corduroy material from a second hand store and purchased a rod and hanging brackets from the hardware store costing about $15. From a yard sale we purchased for $15 an electrical heater that looks like a radiator but is filled with oil. It has a thermostat on it plus three power settings of 500, 900 and 1200 watts. We purchased an outside alcohol filled thermometer from another yard sale for $1.

We hung the curtain in the doorway between areas 3 and 4. We placed the heater in area 4 and set it up so that the temperature in area 4 never dropped below 5-10 C even on the coldest night. Our Grid supplied electrical energy has about a 25% fossil carbon component to it. When we use heaters we are replacing natural gas which is 100% fossil carbon.

To complicate the experiment the enclosed porch has many semi-tropical plants that must not freeze. These plants are placed outside from the spring to the fall. This situation required a more extensive solution than just purchasing a door and closing it between the kitchen and the porch.

From a heat flow point of view, we speculate that heating the porch will reduce the magnitude of the gradient between the rooms and thereby reduce the rate of heat flow. The curtain will reduce the heat flow because it is a physical barrier between the rooms.

Winter 3 2006 – 2007 curtain and 2 heaters

We purchased a $65 heater of the same design as the one mentioned above. We placed it in the kitchen and set it to turn on when the temperature reached about 13 C. It ran on the 500 Watt setting. The goal here is to reduce the heat gradient between the dining room (area 2) and the kitchen. This would moderate the heat flow between the rooms.

Winter 4 2007 - 2008– New siding on one second story wall

The siding cost about $4,000. Included was the addition of R 2.81 foam and a heat reflector. This wall was the leakiest wall in the house and was judged to give the best return for our Green Dollars. It represents about 20% of the external surface area. The work was completed during the summer of 2007.

Winter 5 and 6 2008 - 2010– New siding on rest of second floor.

We finished off the siding on the second floor. The whole second floor is capped with siding / insulation plus the back porch during the summer of 2008. The basement windows were replaced with new high efficiency tightly fitted models.

Analysis of gas usage over the last 6 winters

The Databases we are using

The Ravina Project has kept detailed records of the household energy it has used since 2004. The database now contains six winters worth of natural gas usage. We have converted our database using historical data from Environment Canada to reflect the household efficiency in Cubic Meters of Natural Gas used per Heating Degree Day. Our period is the length of the Utility billing cycle. These data come from our utility bills.

We are introducing a second database for this paper. We have collected natural gas usage on a daily basis since January 1, 2007. This database contains daily readings for the past three heating seasons. These data allow us to crunch the household efficiency on a daily basis.

And lastly, we are introducing yet another database into this paper. We also record on a daily basis the amount of energy we collect from the sun using our solar array. However, it’s the data we push back to the Grid that is of interest. Last year we were fitted with a new bi-directional utility meter which gives us two readouts, the amount of energy we take from the Grid and the amount sent to the Grid. The readouts are in the form of non-resettable totals. Since this paper tracks energy from all metered sources entering our house to the eventual production of unusable, waste heat, we must account for the energy we push back to the Grid for the energy balance sheet to be correct.

Note that we use the words ‘house’ and ‘household’ to mean different things. When we use the word ‘house’ we are talking about the physical structure of our house. We attach siding to our house or the house has certain radiative properties. The term ‘household’ incorporates both the house and the people living here. In many ways the thermodynamic properties of a house are governed as much by the activities of the householders as by the physical properties of the house.

Data From Billed Natural Gas Usage

Baseline Usage Calculation

Consider the following:

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

Baseline calc for June through September 2009		
days=	121	
CM NG used	239	
Baseline	1.98	CM/day

One of the first calculations we had to make was to get some idea of the baseline gas usage. We use gas to heat the house, make domestic hot water, cook, and dry our clothes. In order to get some idea of the baseline Natural Gas (NG) usage we examined our database and calculated our summer time usage of NG. This amount would be net of heating and to a large extent clothes drying … we have a large clothesline which we use whenever possible. For each of the summers we calculate our baseline usage for that summer.

To calculate our Net wintertime NG usage we use the baseline from the previous summer. This method allows us to compensate for changes in our lifestyle or household to be incorporated into our database. We are trying to eliminate as much as possible changes in lifestyle or household being reflected in our data as actual changes in the thermodynamic properties of the house.

In practical terms we subtract the baseline from each daily NG usage total during the heating season. This net amount is used to calculate our household efficiency. Using this method we try to eliminate the gas used for domestic hot water production, cooking, and the drying of clothes from our efficiency calculation. Note we wash our clothes in cold water. Of course it is not exact because the cooking baseline is somewhat skewed at this latitude. We usually have rather hot summers which encourages us to eat cold meals, BBQ or visit neighbours ☺. Bottom line we don't use as much NG for summertime cooking as in the winter.

If you look closely at the baseline numbers above, you will notice a jump in baseline daily NG usage from 1.55 a day in 2005 to 1.89 a day in 2006. Further, if you look at the subsequent numbers you will notice that they are all about the same value varying about by 0.10 cubic meters on average per day. This value is grouped around about 1.89 CM a day.

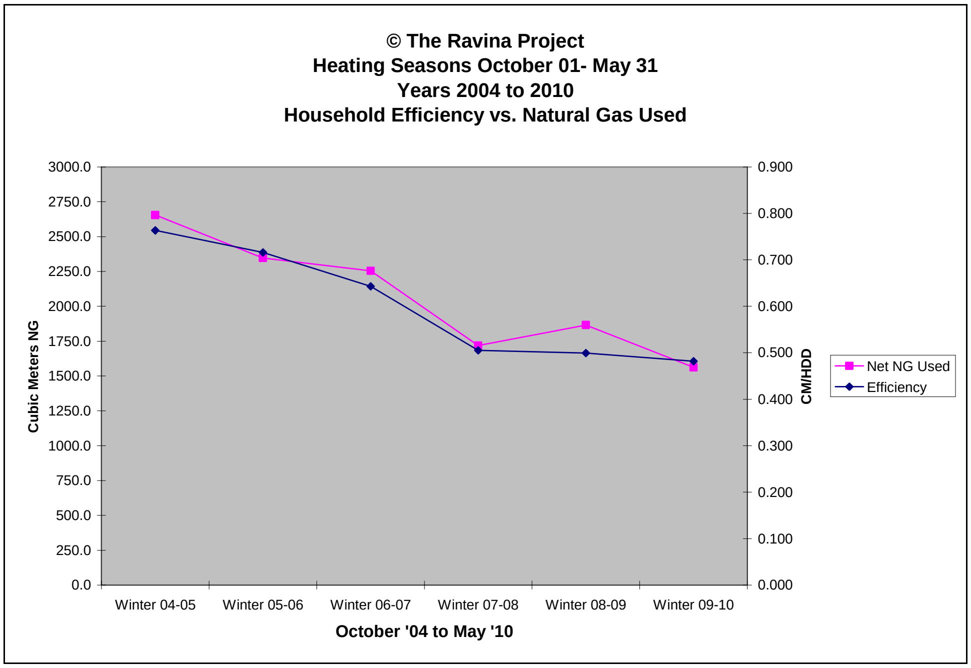
What happened here?

This is a very nice example of a change in household causing a change in the thermodynamics of the household. As a matter of fact the household grew by one adult person before the summer of June through September 2006. The new adult placed a load upon the household's energy flow such that more energy was used to support that individual.

More washing was done requiring more gas for clothes drying when it is raining. More domestic hot water was required to support this person hygienically. Meals are larger so more gas is used to cook them. All in all, more energy is used when a person is added to the household. The summertime baseline calculation should show this increase in value.

Late this spring another adult was added to our household. It will be interesting to see the effects this has upon the energy use by the household during the baseline summer of 2010.

Consider the following chart. It is constructed from the database that contains our utility gas bills.



For each heating season the net Natural Gas used is totaled and the efficiency is calculated by dividing the total NG used by the total number of Heating Degree Days in that heating season.

The axis which is marked as CM/HDD is the household efficiency axis. It is an inverted axis in the sense that lower readings means that efficiency is better. The axis is a ratio between the number of cubic meters of gas used and the number of heating degree days. Less gas used for the same number of heating degree days will give a smaller number which means the house is more efficient. Similarly, the same number of cubic meters of gas used for an increased number of heating degree days will also return a smaller number indicating increased efficiency. So bottom line, the smaller the value for this ratio; the more efficient the house.

Note the big increase in efficiency from the winter 06-07 to the winter 07-08. During the summer of 2007 we had siding and R 2.81 foam insulation placed on our coldest second story wall. The efficiency went from 0.643 to 0.505 CM/HDD. This increase in efficiency is about 21% over the winter of 06-07. That was just one second floor outside wall being covered. It was very instructive for us because the next summer we completed the rest of the second floor and as you can plainly see, we got only a 3.4% boost (0.499 and 0.482). That was a cold wall!!

Let's examine the heating season of '08 – '09. The efficiency stayed virtually unchanged yet more NG was used. What's going on here? This was the first winter where the second floor was completely capped by insulation and siding. The amount of NG used increased. What does that tell us? It means it was colder and/or it means that the thermostat may have been set a bit higher.

In any case, more gas was used.

But the efficiency, what happened with it? It did not move. How can this be justified if we only have two parameters that can be modified to increase gas usage … higher thermostat and/or colder temperatures over the winter.

The average daily temperature during the winter of ’07 – ’08 was 4.48 degrees C. The average daily temperature during the winter of ’08 – ’09 was 3.52 degrees C. Let’s round the difference to 1 degree C difference on average every day. There are about 242 days in each sample and the household was working at a constant efficiency during this time of just under 0.50 CM/HDD. On average then there was one extra heating degree day every day for 242 days because of the extra 1 degree C cooler average daily temperature during this time. Since the household used about 0.50 CM of gas for every Heating Degree Day it follows that the household used about 121 CM of extra gas during the winter of ’08 – ’09.

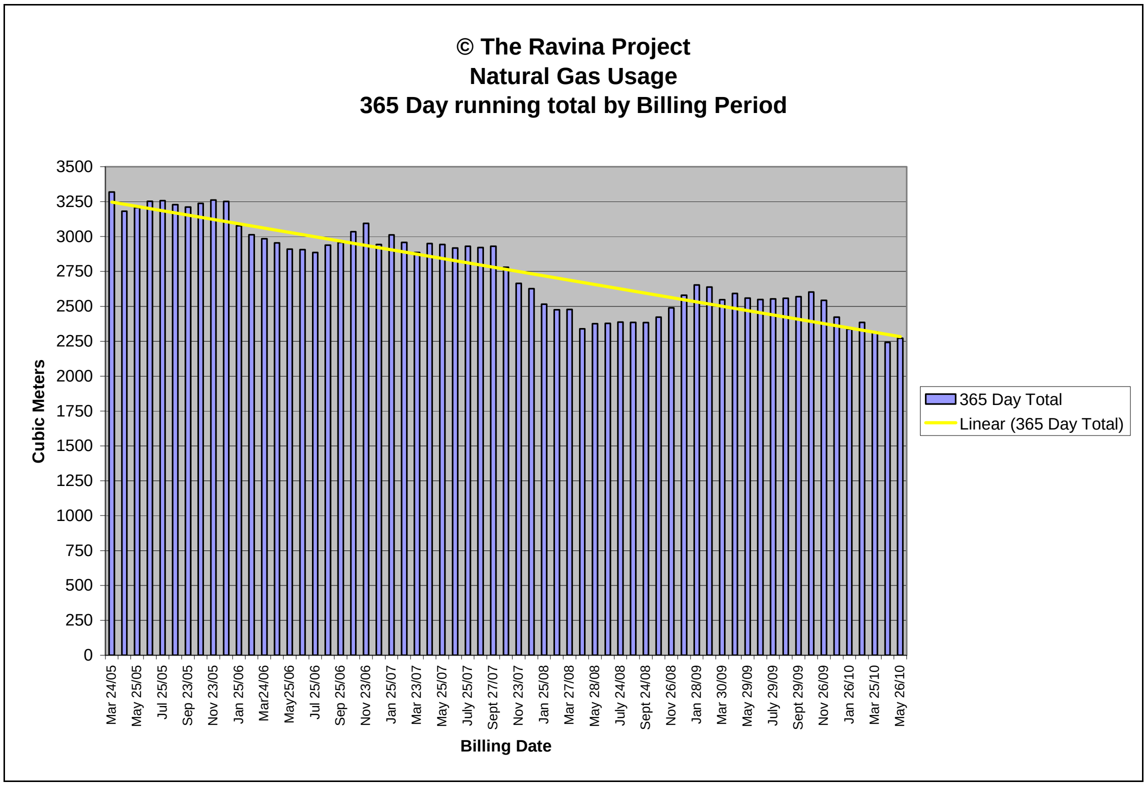
From the database the real value is: 1,718.2 CM of NG used during the complete heating season of ’07 – ’08. For the next year the value is: 1,866.3. The difference from the database is about 148.1 CM of NG. So there is about 47 CM of natural gas unaccounted for. Different thermostat settings (lifestyle) could account for some of it.

The heating season of ’09 – ’10 had NG usage of 1,562.9 CM with an efficiency about 0.48 CM/HDD. The average daily temperature during this season was 5.47 degrees C. This is 1 degree C on average every day warmer than the winter of ’07 – ’08. As you can see in the chart above there is little difference between the NG used for the heating season of ’07 – ’08 and for ’09 – ’10 nor is there any significant difference in the efficiency of the household.

From the inside of the house, the thermostat is set to a certain level. The furnace will cycle on and off to keep the internal temperature of the house at the set temperature. Cubic Meters of gas are consumed to maintain these set temperatures. In a sense, heat leaving the house is defined by Heating Degree Days (HDD) and heat entering the house is defined by NG used. The radiative properties of the house are defined by the ratio of injected heat (cubic meters [CM] of NG) divided by the radiative heat (HDD). If the ratio of CM/HDD is unchanged the resistance to heat passing through the walls of the house is unchanged no matter what the ambient heat the house finds itself in. The data should indicate that even though we burned more NG because it was colder outside, the impedance the house presents to heat passing through it should stay more or less constant indicating that the house is well insulated for that ambient temperature range.

This is what we see in the data.

Let's take a look at the same data when a 365 day running total is charted.



This chart ignores the household efficiency. It focuses only on natural gas usage but breaks it out by totaling the 365 day usage. Each bar represents a year of natural gas usage. The chart starts out with a gas usage of 3,319 cubic meters for the 365 day period ending on March 24, 2005. On March 25, 2010 the 365 day period has a gas usage of 2,317 cubic meters. The household improvements represent a gas savings of 1,002 CM a year over a span of exactly 60 months.

This is an improvement of 30.2% over 60 months.

In total this savings consists of 0.5 multiplied by 1,002 multiplied by 5 years which works out to be about 2,505 CM saved over 5 years in total.

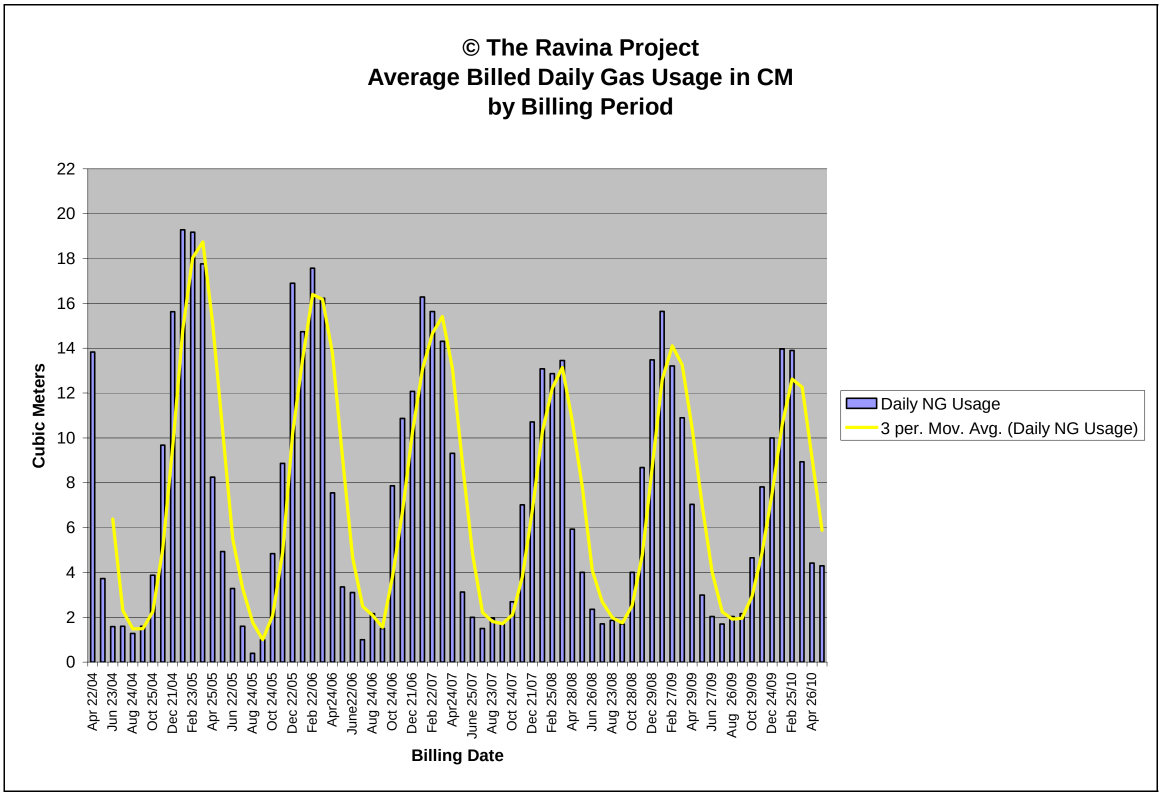
Totals for NG

Billed Days		2249
Cubic Meters used		16789.6
Total Billed	$	10,177.37
Cost per M3	$	0.61
M3/day Average		7.47
Billed per day	**$**	**4.53**

Our database above indicates that this savings of 2,505 translates into 2,505 times $0.61 which is $1,528.05 over 5 years or $305.61 a year. That's tax free!!!

This chart has to be taken with a caveat. This is a 'brute force' chart. It does not take into consideration whether the weather was colder. Weather itself could account for some of the savings in gas usage. The chart does not use net gas usage where the baseline is subtracted from the charted amount. And further, the chart includes the summertime months which are not heating months at this latitude. However, the summertime contributes very little to the yearly total so any changes should be primarily those accrued in the winter time.

We can look at the average daily NG usage per billing period. Six winters can be clearly seen. The shape of the curve demonstrates a savings of some kind is under way.



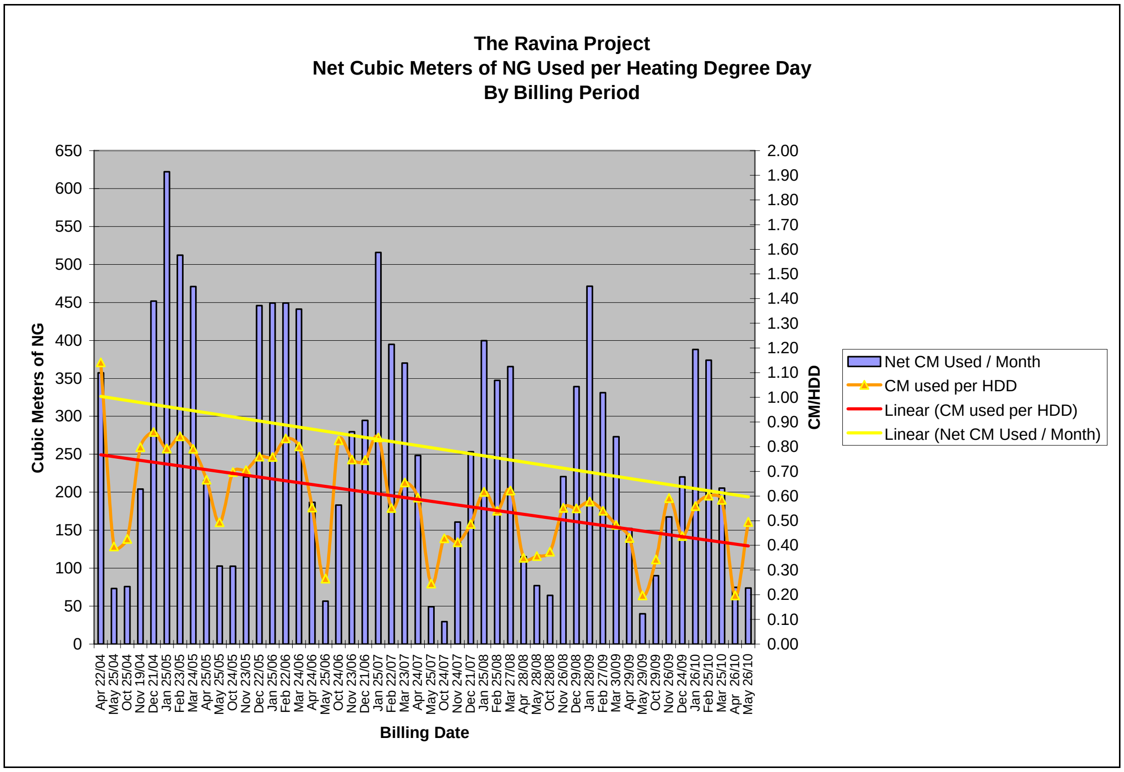
Our discussion above looked closely at the heating season of '08 – '09. From this chart we can see the cross section of the extra gas usage broken out by average day per month. The efficiency remained the same throughout all three of these months. The insulation did not fail during this time. It provided the same resistance to heat flow even if the average external temperature was 1 degree K lower on average.

This is not active insulation that adds to its heat flow-through resistance as the temperature gradient across it increases. That would be a great idea for an engineering project.

The best we can ask of our regular inert insulation is that it provide the same heat flow resistance across a range of heat gradients.

Clearly our new insulation did the trick.

Let's see if we can view these improvements in household efficiency using our monthly gas bills.



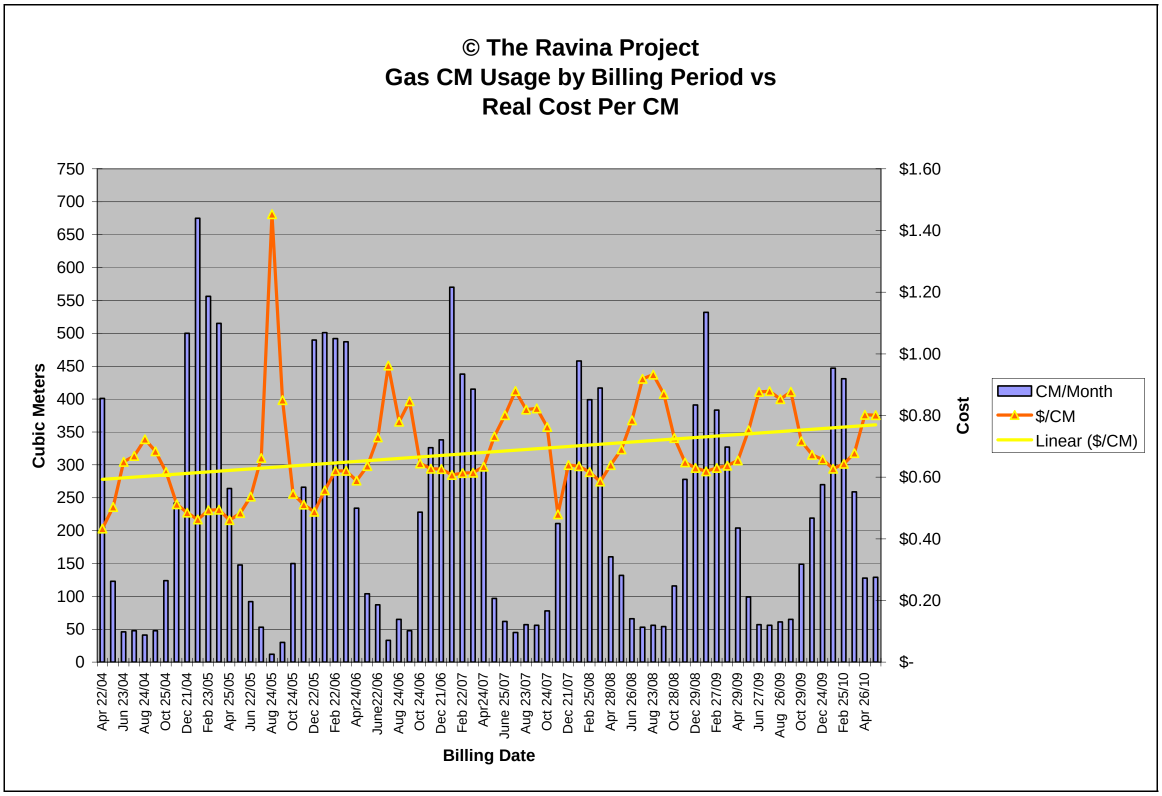
This chart uses a somewhat different calculation for its values as compared to the above gas usage charts. The months represented here are only heating months, which at this latitude start on October 1 and run until May 31. There may be some changes to this tradition because of Global Warming. We had our first wave of hot weather this year in March with more or less continuous warm weather in April and May. The monthly NG amounts are net amounts, they have had the baseline subtracted from them.

Each of the heating seasons can plainly be seen. The efficiency and total gas usage for the months represented on the chart clearly shows improvement.

Look closely at the heating season of 2007-2008. The length of the bars for this heating season are obviously shorter that the previous three heating seasons. In fact the downward trend is pronounced between the group of the first three heating seasons and the last group of three.

Again we see the heating season of '08 – '09 which has the largest use of NG among the last three heating seasons. We also see the month by month calculation of house efficiency. It stays between 0.55 and 0.60 for the three heating seasons unresponsive to the colder temperatures and increased NG usage.

Let's look at the savings from our house upgrades. Consider the following chart.



Savings occur but the savings per unit used are not there. The price per unit increases dramatically as usage decreases. This pricing policy, where reduced use prompts higher per unit prices is not encouraging to those who want to conserve.

Note as well that we changed our gas supplier from our local supplier to another one that locked in our prices for several years. We took a gamble that the price of gas would increase. As you can plainly see our gas bill did increase but not as a result of the cost of gas. The increase is artificial because the increase is a result of a high price charged for gas by our new supplier. However, it is a constant added to the curve drawn on the chart. The shape of the curve will not change, just its relative position on the cost axis.

However, as stated above the overall unit price rises occur as the household decreases its use of NG. Did we ever think we would be paying about $1.50 per cubic meter of gas delivered to our door? Or how about sustained prices above $.80 a cubic meter for several seasons in a row? Doh!!

Did Our Heaters and Curtains Work?

This is an interesting question to try to answer because so much of this paper has been devoted to large scale expensive changes to the house. Did the cheap changes in the internal heat flow get reflected in the efficiency numbers for the house in the winters of 05-06 and 06-07 with the baseline year as 04-05? The following tables are stats based upon monthly calculations. The average efficiency below is the average of the 8 months in the heating season.

Here are the stats for the reference winter of ’04-’05.

CM/HDD using most recent CM baseline. Winter of ’04-‘05	
Average	0.71
Median	0.79
Stdev	0.16
High	0.86
Low	0.43

Let’s unpack this table. Firstly, the baseline referred to as the ‘CM baseline’ is the amount calculated the summer before to isolate the amount of gas we use to cook and for domestic hot water and the like.

The above table shows the stats of the reference year of ‘04-’05. The standard deviation is tight so the data are grouped nicely. Note the median is higher than the average so there seems to be more months in this season which have higher values (are less efficient) than the average of .71 CM/HDD efficiency.

Here are the stats for the first winter after the baseline year.

CM/HDD using most recent baseline Winter of ’05-‘06	
Average	0.67
Median	0.73
Stdev	0.19
High	0.83
Low	0.26

The daily NG baseline stays the same as we explained above. The average falls by 5.6%; the median falls by 7.6%, the high falls by 3.5% and finally the lows fall by 40.0%. All values except the lows (highest efficiency) are marginal but in the right direction, that is, increasing efficiency. The distance between the median and average decreases from 0.08 to 0.06. The change at the highest efficiency is huge. This is a big signal and represents the ability of the house to better maintain its internal temperature by being better able to resist the flow of heat from it. The standard deviation says the data are grouped nicely and the slight increase in efficiency as measured by the other stats indicates something significant resulted from adding the curtain and heater in the unheated porch.

Here's the stats for the next year.

CM/HDD using most recent baseline Winter of '06-'07	
Average	0.62
Median	0.68
Stdev	0.20
High	0.82
Low	0.19

As above we see the downward trend continuing.

Over the baseline heating season '04-'05, the average falls by 12.7%; the median falls by 13.9%, the highs fall by 4.7% and finally the lows fall by 55.8%. The distance between the median and average falls to 0.05. The change at the highest efficiency is huge gaining another 15% over the last year. This is a huge signal and represents the ability of the house to better maintain its internal temperature by being better able to resist the flow of heat from the house. The change in these efficiency numbers is partly determined by the addition of the second heater.

So just by adding a curtain in a critical spot as determined by an analysis of the heat flow in the house, and two heaters to further impede the heat flow through the house and out to the world, every aspect of the statistical description of the data fell over 2 winters by at least 10% except for the worst efficiency. The best efficiency skyrocketed by 55.8% over base. This efficiency describes the house is at its best in an external ambient temperature range where the internal modifications provide maximum impedance to heat.

Everything above concerns itself with the analysis of the internal changes in the house. Basically they were all geared to making the kitchen and porch areas more difficult for heat to travel through. We were successful in two ways: we achieved our goals by making the house more efficient using primitive means and our analysis of heat flow is demonstrated to be correct.

The reader may want to look with new eyes at the heat flow of their own house in order to make internal modifications for the winter time. We have shown that substantial energy reductions are possible with low tech solutions.

We continue with this analysis over subsequent years. The summer of 2007 marked the addition of the external insulation and siding to our coldest second story wall. Since we have the numbers let's see how this compares with our mods to internal heat flow. We won't carry out the percentage analysis … we'll leave that as a homework exercise for the reader.

CM/HDD using most recent baseline. Winter ’07-‘08	
Average	0.46
Median	0.44
Stdev	0.11
High	0.62
Low	0.34

We will still use the baseline year to compare our values. We see immediately above that the average and median are virtually identical which means the data values are well distributed. The standard deviation is small so the data values are grouped together nicely. Every description of the data is radically better although the best efficiency is quite a bit lower than the year before. We have no explanation for this anomaly.

CM/HDD using most recent baseline. Winter ’08-‘09	
Average	0.45
Median	0.51
Stdev	0.13
High	0.57
Low	0.18

During the summer of 2008 we finished the rest of the second floor insulation. The numbers seem to ‘settle in’ although the highest efficiency returns to the former high levels from two years previous.

In the summer of 2009 we replace three leaky basement windows with modern well sealed modern windows.

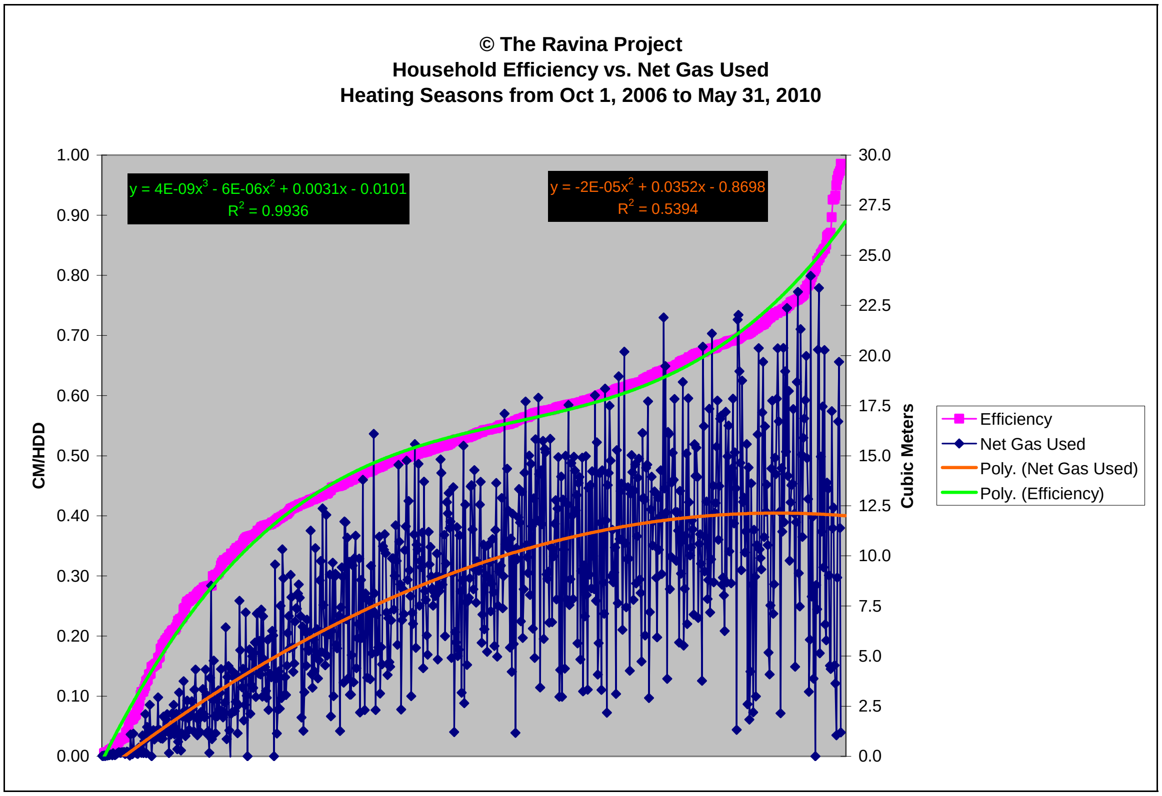
CM/HDD using most recent baseline. Winter ’09-‘10	
Average	0.46
Median	0.51
Stdev	0.14
High	0.59
Low	0.19

The numbers remained unchanged from the previous year.

Data From Daily Observations

We have been taking daily observations as part of the Ravina Project's goal of tracking the thermodynamics of the house, making upgrades to the house and then seeing if the effects of the upgrades are evident in the change in household efficiency.

Consider the following chart of 814 days from the start of the heating season October 1, 2006 until the end of the last heating season here, May 31, 2010. Only days within a heating season are in the database. The amount of NG used is net of the baseline amount.



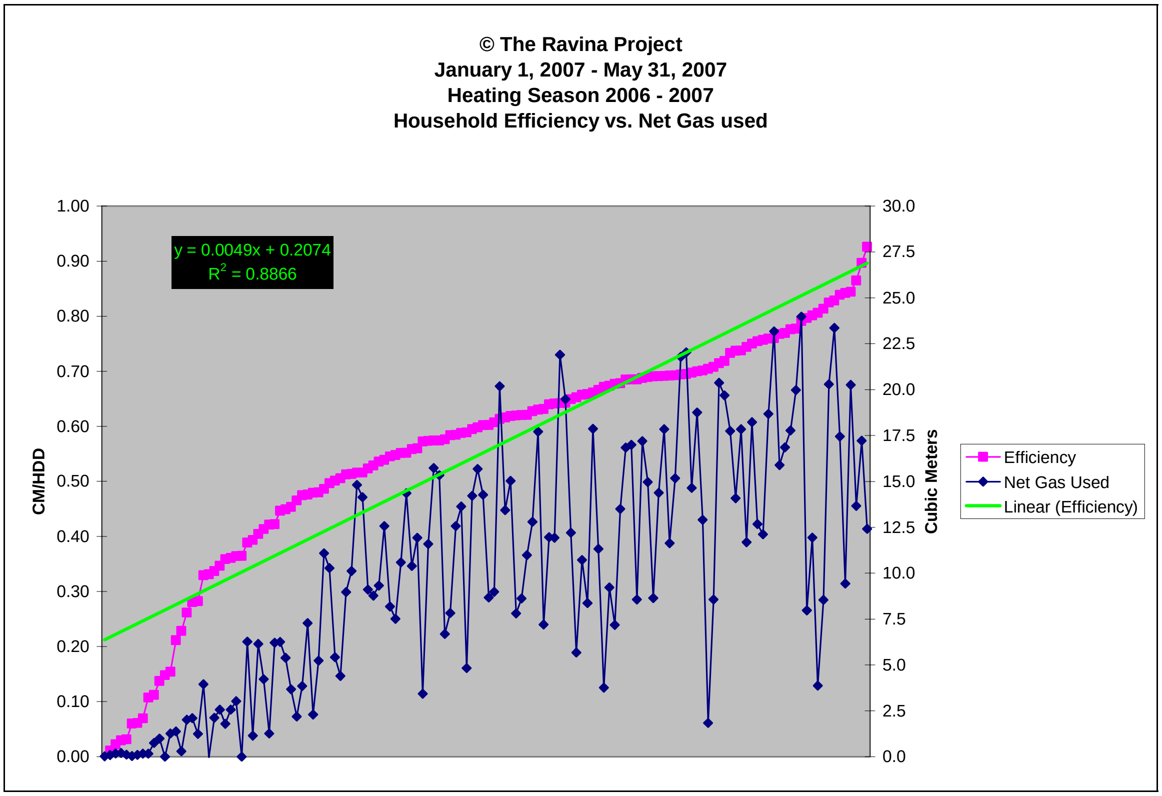
These data come from our daily and historical Heating Degree Day records from the local weather office. The efficiency is better as the CM/HDD ratio assumes smaller values. If a fixed number of cubic meters of natural gas is used from day to day but the number of heating degree days increases, the ratio will get smaller.

The above chart really does not show us anything really interesting other than showing us the complete database.

We are interested in getting an understanding about the changes in household efficiency when we upgrade the structure of the house. With all the data accumulated together the various heating seasons cannot be compared.

Let's separate out the various heating seasons and look at the results.

Consider the following chart for the winter months between January 1, 2007 and May 31, 2007.



These data come from our daily data collection. We collect the gas meter reading and the HDD data from our local weather office. We crunched the efficiency number and Net NG amount for each day. We started our daily data collection on January 1, 2007.

These data, comprised of 140 daily observations, are for the last 5 months of the 2006-2007 heating season. They are cold weather compensated because the efficiency is based upon heating degree days which are in turn based upon the average temperature.

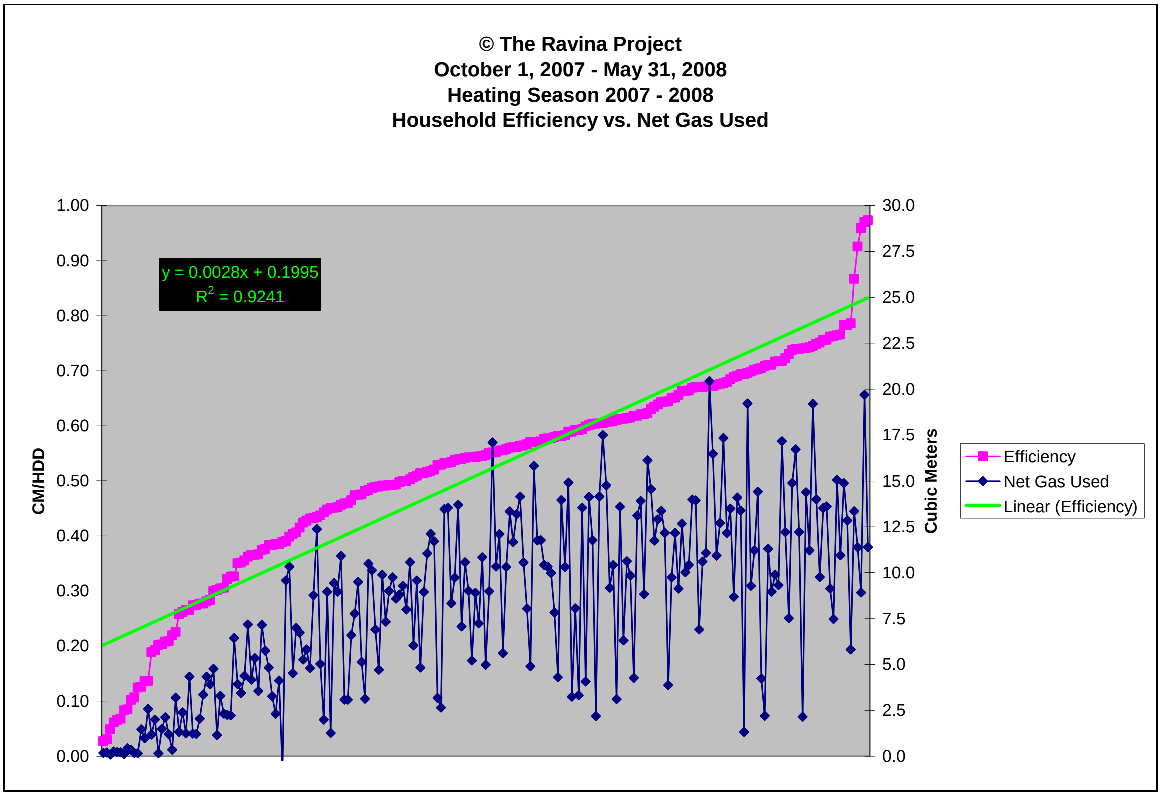
We gathered data before the insulation and siding was affixed to our coldest wall. The changes to the internal workings of the house, the heaters and the curtain, were already in place.

Note that the slope of the efficiency curve fit line is 0.0049 and the fit is 0.89.

Note as well the number of days with gas usage equal to or over 15.0 CM is 34 out of a database of 140 days or about 24.3% of the days. That corresponds to at least 155.3 kWh net of any other energy used. Obviously we used more because this total does not include electrical energy. Anyway, we just want to make the point that 155 kWh is a lot of energy to use in a house this small. So days when we use 155 or more are significant.

Since the efficiencies are temperature compensated any change in efficiency will occur because the thermodynamic properties of the house have changed and not the outside temperature.

Consider the following chart of 223 daily observations over the heating season 2007 and 2008. During the summer of 2007 we covered our coldest second story wall with R 2.81 foam insulation under siding.



We gathered data over the heating season when all the internal household modifications like the curtain and heaters were in place. The data span the whole heating season from October 1, 2007 until May 31, 2008.

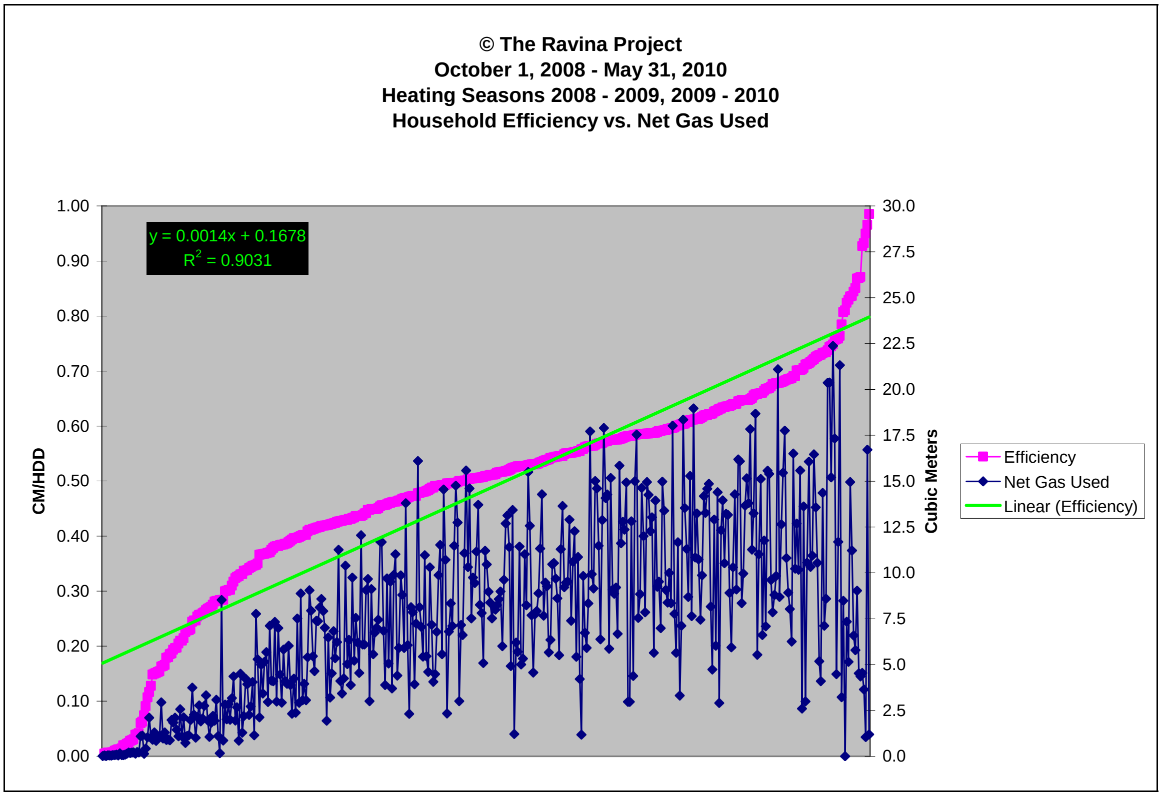
So let's take a look at this chart and compare it to the one above.

The slope of the efficiency curve changed from 0.0049 to 0.0028, a change of about 43%. The fit increased to 0.92.

The number of days with net gas usage greater or equal to 15.0 drops from 34 over 140 days to 13 over 223 days. Or in percentage terms the number of days which usage is greater or equal to 15.0 drops from about 30% to about 5.8 %. This is a dramatic fall. However, this may be the result of a change in temperatures over this particular heating season; we have more about this argument below.

The wall that was covered accounted for about 20% of the outer surface area of the house. This dramatic change, all else being equal, demonstrates just how much heat was radiating from the house through that poorly insulated wall.

Consider the following chart of 446 daily observations over the heating season 2008 and 2009 plus the heating season 2009 and 2010. During the summer of 2008 we covered the rest of the second story in R 2.81 foam insulation and siding over it.



These data were gathered over the heating seasons when all the internal household modifications like the curtain and heaters were in place. These data span the heating seasons from October 1, 2008 until May 31, 2010.

Let's take a look at this chart and compare it to the one on the above page.

The slope of the efficiency curve changed from 0.0028 to 0.0014, a change of about 50%. The fit dropped slightly to 0.90.

The number of days with gas usage greater than or equal to 15.0 CM is 35 over a database of 446 daily observations for a percentage of about 7.8%. The dramatic fall in this category, seen on the above page, remains for this database over two more heating seasons. So we can observe that for a part of one heating season we have a 30% chance of a day using 15.0 cubic meters of gas or more. Three heating seasons in a row after the application of extra insulation under siding we have a fairly constant rate of between about 6 and 8 percent of the days requiring 15.0 or more net cubic meters of gas. It would be unlikely that the first heating season in our records would be so much colder that it would have 30% more days with gas usage equal to or over 15.0 CM.

Let's compare the average daily temperatures for the same number of days in the four heating seasons. Since the first recorded heating season starts on January 1 and ends on May 31, we will look that these same days in the subsequent 3 heating seasons. We will take the average of the average daily temperatures for the whole season. The results are:

- January 1 – May 31 2007 3.16 C
- January 1 – May 31 2008 3.21 C
- January 1 – May 31 2009 3.07 C
- January 1 – May 31 2010 5.57 C

There was nothing anomalous about the average daily temperature for January 1 to May 31 2007 as compared to 2008 and even 2009. Since the 2009 and 2010 data are combined one might say that the resulting database was not representative because 2010 was so hot. We'll let the argument stand as it is. The change in slope plus the huge drop in days with gas usage equal to or over 15.0 CM are just too dramatic to be explained by such a small change in average daily temperature.

Grid Support

The household thermodynamics part of our project up until this year, has meant that we track heat as it enters the house as useful energy. It has been a one way street as it were. However, we now can track the energy we push out of the house, not as heat but as electrical energy. Last year the local utility installed a bi-directional electrical utility meter. We read it every day to get two totals. Both are running totals, one total keeps track of the energy we use from the Grid; the other, energy we push back to the Grid.

At times of the day with the right sun conditions, The Ravina Project becomes a net exporter of energy to the Grid. We become an electrical power generator.

Since we are tracking energy as it moves through the house, we want to add another section to this paper which covers off our electrical generation. Energy being energy whether waste or usable, this new energy flow must be accounted for in this paper to balance our energy budget.

Consider the following table.

Monthly Energy Generation Analysis 2010 © The Ravina Project

Month	Gen	Used Grid	Used Gen	% Gen	To Grid
January	71.9	587.1	62.9	9.7	9.0
February	77.2	575.3	67.2	10.5	10.0
March	157.8	407.5	112.8	21.7	45.0
April	198.7	164.6	131.7	44.4	67.0
May	204.4	336.1	155.4	31.6	49.0
June					
July					
August					
September					
October					
November					
December					
Total:	**710.0**	**2070.6**	**530.0**	**20.4**	**180.0**

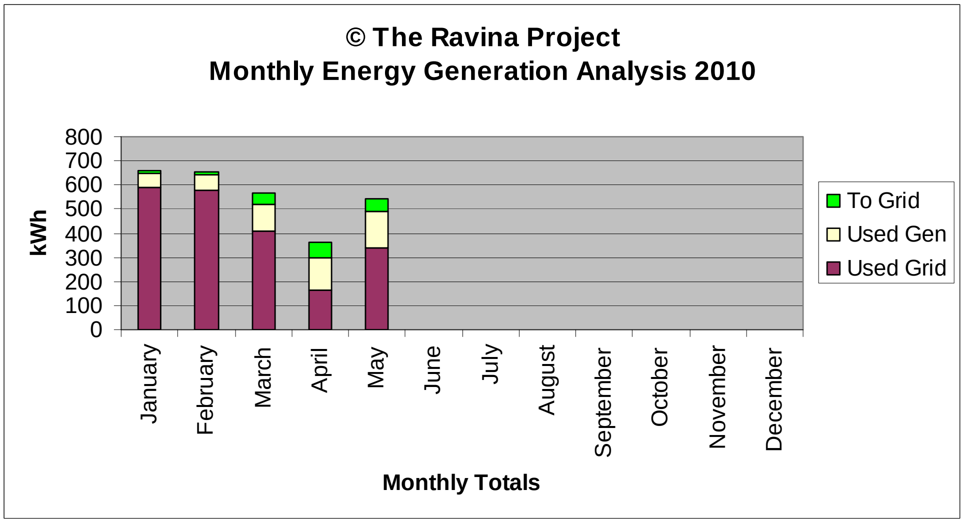
Let's unpack the table to understand the columns.

Gen means the amount in kWh generated from the solar array. **Used Grid** is the amount of Grid energy we used in kWh. **Used Gen** is the amount of the generated energy in kWh we used. **% Gen** is the monthly **Used Gen**eration divided by the total monthly energy used by the household multiplied by 100%. And finally, **To Grid** is the amount of energy in kWh we pushed back to the Grid that month.

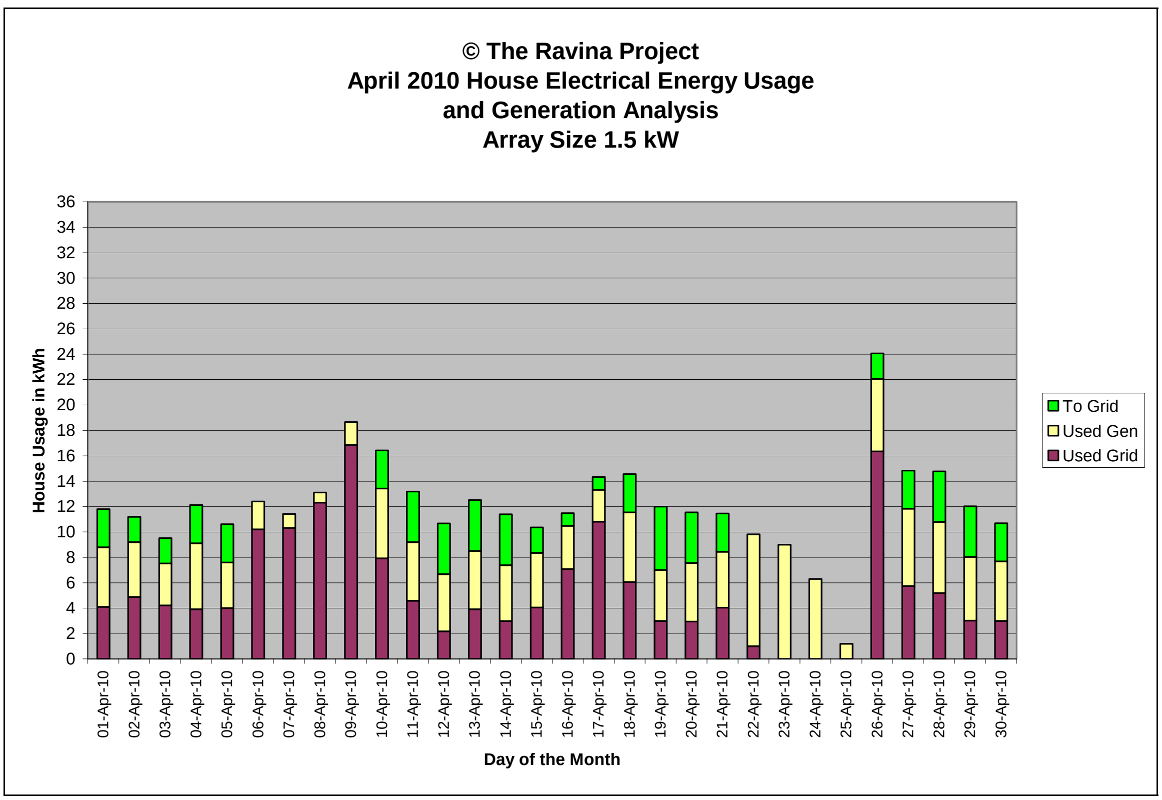
A Watt pushed back to the grid is impossible to use by us. They don't 'hang around' waiting to be used. They are used by others immediately. The Grid is not elastic in its ability to store power in anything but the most fleeting of ways. The reason for our inability to use our pushed back energy is that our connection to the Grid is half-duplex. We can receive power from the grid or we can send power to the grid but we can't do both at the same time. Our relationship to the Grid on this physical level is logically, exclusive OR (XOR). By the time we are switched back to using Grid power, the Watts we have placed on the Grid have been used by, most probably, one of our neighbours.

Looking at the totals for the year so far, we have generated 710 kWh of which we have used 530 kWh. We have brought in another 2,070.6 kWh from the Grid and exported 180 kWh to the Grid. In all, we have generated 20.4 % of the electrical energy we have used this year.

Here is a chart which shows the data presented above in a graphic form.



The chart below shows the daily totals for the month of April in the above chart. You can see quite clearly when we were off grid for a few days from April 22 until April 26. During those days we used little or no energy from the Grid. On April 26th we refilled our battery from the Grid and the sun.



Conclusion

What does all this mean for energy policy?

We have demonstrated that Insulation makes a huge difference at this latitude.

An older house may be encased in a skin that will seal and insulate it much more effectively. Such an upgrade will guarantee a cut in energy use. Energy generated (Watt-hours) and energy not used (negaWatt-hours) are very similar. In both cases the external energy supply requirements of the house are reduced.

From an energy supply point of view our 5 year savings was 25.9 MWh in gas (10.35 kWh equals 1 cubic meter of gas) just from increased insulation and changes to the internal heart flow in the house. We calculate that over that same period we could generate about 8.25 MWh of energy. The insulation and the PV solar generator cost about the same to install with the insulation coming in a little less than the PV.

As you can see we got three times the effective energy savings in perpetuity from the insulation.

This is a significant finding for energy policy.

Policy for Individuals

Before you spend your marginal Green Dollar on any high tech energy generation solution for your house, your house must be insulated to a reasonable maximum. You will get better return for your money than virtually any other kind of investment into your house infrastructure. With Global Warming, a well insulated house will help in the summer time by requiring less energy to cool. Insulation can be as effective in keeping heat out of a house as keeping it in.

There is one caveat we will add to this recommendation and that has to do with harvesting the sun's energy using solar powered hot water heaters. For a young family with several kids the domestic hot water demands are substantial. The pay back time on solar hot water systems, the type that can operate all year round, decreases as the number of people, especially kids, are in the household. It is our view the 'bang for the buck' is the best for solar hot water. We believe that both insulation and solar hot water should be pursued if the household consists of people of the right age and numbers.

Don't invest in heat pumps that harvest heat from the ground or wind turbines unless you have taken care of your household insulation.

Do analyze the heat flow in your house and compensate for it!

Policy for Government

Household heating is one of the largest single sources of carbon emission in Canada. Encourage on a massive scale the encapsulation of houses that qualify. Provide an incentive program better than the one for electrical solar generation. The reason of course is that savings per invested dollar are greater with insulation than with PV solar. Enforce rules that would mandate all newly constructed houses be very efficient. Some existing newer homes may be well insulated. They should proceed to some kind of generation straightaway.

Devise and use a mechanism that gangs together demonstrable energy savings and a rate cut for those customers who quality. When less is used the real cost per unit should decrease. See the above graph for our real costs per unit used.

People should see a monthly dividend on their energy avarice. This will allow them to become emotionally involved in their reduced consumption. It is well known that an emotionally engaged populous can accomplish much over time.

Don’t play politics; it will alienate the population from the issues.

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

Project Directors

Susan Laffier B.SW., M.SW.
Gordon Fraser B.A., MCSE, CCDP

The Ravina Project,
Toronto, Ontario,
Canada M4J3L9

gord@theravinaproject.org

Friends of the Ravina Project

Ben Rodgers B.A., M.A.,
NABCEP Certified Solar PV Installer™
Designer of the Dynamic Array structure

Prof. Fraser Bleasdale Ph.D.
Department of Psychology
Otonabee College
Trent University

Ken Traynor
Community Solar Advocate
Our Power Project Manager
Toronto Renewable Energy Cooperative