The Ravina Project

Household Thermodynamics – July 2008 04

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Introduction

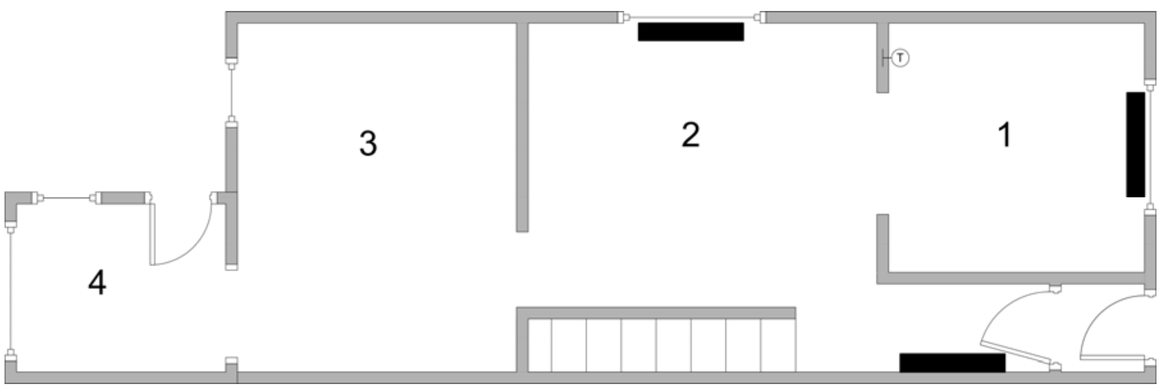
This is the second of a series of papers we will publish on the thermodynamics of our 80 year old house here in Toronto. The last paper "*The Ravina Project – Household Thermodynamics August 2007 07"* presented the data and the changes to our house up to August 2007. Another year has gone by. We made some significant changes to the external surface of our house. We will describe the changes and present the data in this paper.

Over the past year 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.

During last summer we placed siding and R-5 insulation on the poorest external wall of our house. The house's surface area covered is about 20% of the total surface area.

Household design 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 domestic hot water and 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) between 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. We know that the steeper the heat gradient between the areas the greater the rate of heat flow. If we modify this gradient the rate of heat flow will change thereby changing the total amount of heat flowing at each instant.

Modifications made to internal heat flow

Modifications were made over the past winters to the internal heat flow in the household 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 the amount of natural gas used over those winters.

Winter 1 – 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. The thermostat was set for a night time temperature of 16 C and a daytime temp of 20 C for visitors. 18C was usual.

Winter 2 – 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.

A curtain was fabricated consisting of about $10 of corduroy material from a second hand store and a rod and hanging brackets from the hardware 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.

The curtain was hung in the doorway between 3 and 4. The heater was placed in area 4 and set up so that the temperature in area 4 never dropped below 10 C even on the coldest night. It ran on its 500 Watt setting.

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

From a heat flow point of view, 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 – 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 – New siding on one second story wall

The siding cost about $4,000. Included was the addition of foam and a heat reflector to give the stucco wall an R5 rating. 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.

Analysis of gas bills over the last 4 winters

The Ravina Project has kept detailed records of the household energy it has used over the last four years. The database now contains four 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.

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.

Consider the following:

<u>Baseline Calculation</u>

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

To calculate our Net NG usage we actually use two numbers. In our first set of calculations we use the average baseline and in the second we use the latest baseline. We do that because our lifestyles may have changed. Those changes may be reflected by using the latest baseline.

Consider the following analysis for the winter months between October 2004 and May 2005. The value for CM/HDD was calculated for each of the eight months. The statistics shown below are the analysis of those monthly values.

Stats Oct/04 - May/05	
CM/HDD using average baseline	
Average	0.69
Median	0.78
Stdev	0.17
CM/HDD using most recent baseline	
Average	0.68
Median	0.77
Stdev	0.18

First off you can see that using different baselines result in very marginal differences in the statistics. The data are virtually identical between using the average and latest baseline NG usage.

Consider the following analysis for the winter months between October 2005 and May 2006:

Stats Oct/05 - May/06	
CM/HDD using average baseline	
Average	0.66
Median	0.72
Stdev	0.19
CM/HDD using most recent baseline	
Average	0.65
Median	0.71
Stdev	0.19

The data are virtually identical again however notice that there is improvement in the efficiency of the household between years especially in the median value. This means that the data has fewer larger numbers in it. This corresponds to the changes in heat flow we made to the household.

Consider the following analysis for the winter months between October 2006 and May 2007:

Stats Oct/06 - May/07	
CM/HDD using average baseline	
Average	0.64
Median	0.69
Stdev	0.20
CM/HDD using most recent baseline	
Average	0.63
Median	0.69
Stdev	0.20

Again the baseline seems irrelevant however a small change is apparent especially in the median value. From Oct/04 until May/07 the monthly average CM/HDD has been reduced from .69 to .64 which is an improvement of about 7%. The median has shown much more change going from .78 to .69, an improvement of about 12%. This shows that the changes we made to the internal heat flow of the household resulted in a reduction of days that consumed a larger number of cubic meters of NG per HDD.

Consider the following analysis for the winter months between October 2007 and May 2008:

Stats Oct/07 - May/08	
CM/HDD using average baseline	
Average	0.47
Median	0.45
Stdev	0.11
CM/HDD using most recent baseline	
Average	0.46
Median	0.44
Stdev	0.11

This data is new and is the result of our house getting 20% of its external surface covered with siding and R-5 insulation.

Notice that for the first time the median is below the average which means that there were more smaller numbers than larger ones in the data base. Note that the different baselines are, again, not a factor. And finally note that the average household efficiency as measured in CM/HDD fell by about 27% from the previous year and, as well, the median usage dropped by a whopping 38%.

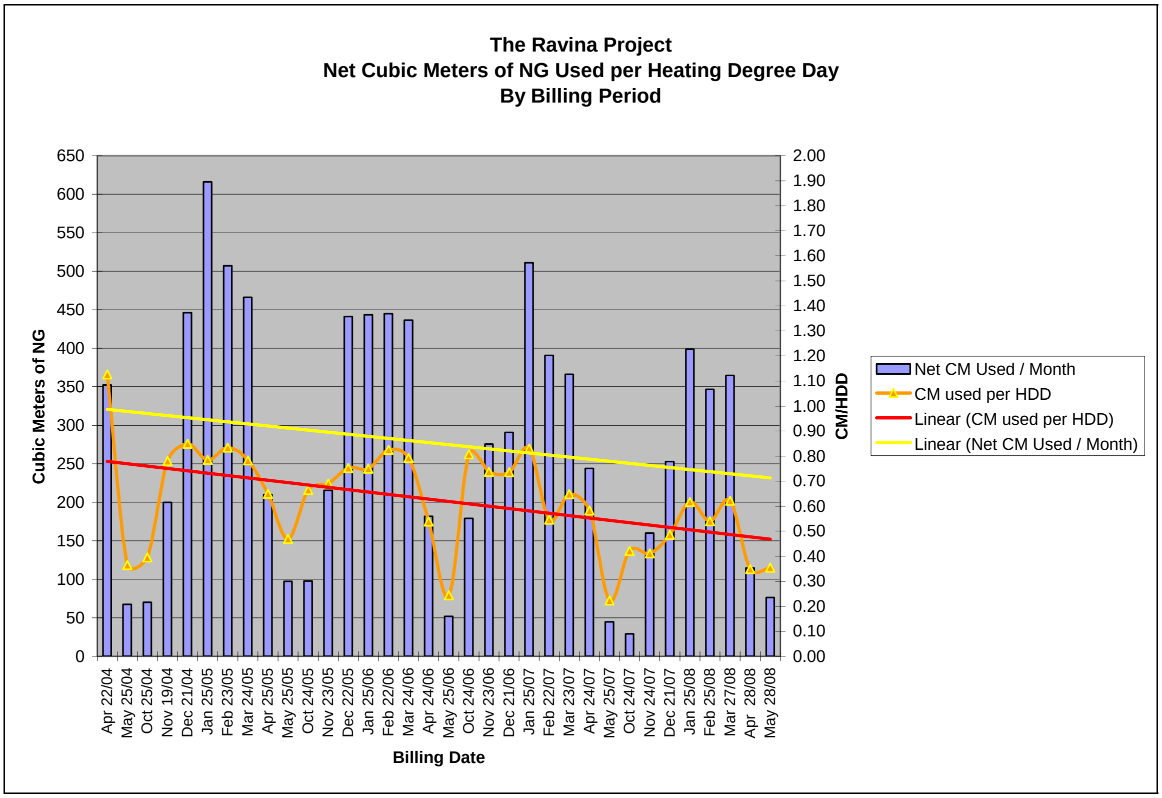
To sum up here's a chart and a graph showing the data.

Efficiency Analysis Using Most Recent Baseline

Most Recent Baseline **1.79** **CM of NG used per day**

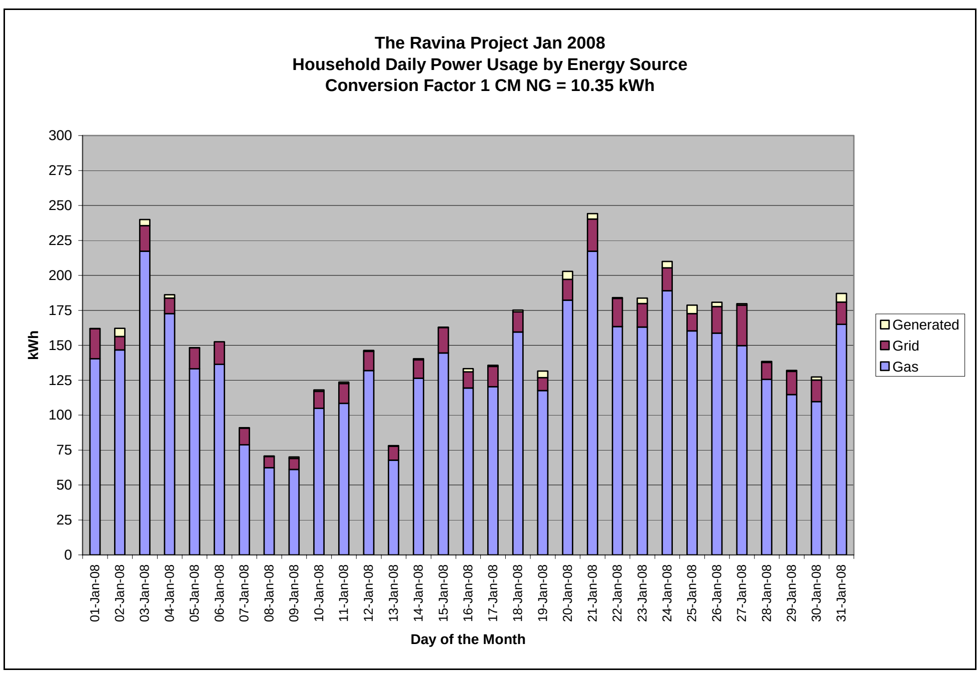
	Winter 1 Oct/04 - May/05	**Winter 2 Oct/05 - May/06**	**Winter 3 Oct/06 - May/07**	**Winter 4 Oct/07 - May/08**
Total NG Used (CM)	3024	2724	2710	2154.6
Total Baseline Used (CM)	436.8	436.8	433.2	436.8
Net NG Used (CM)	2587.2	2287.2	2276.8	1717.8
Total HDD	3478.5	3277.7	3507.3	3400.3
Efficiency CM/HDD	**0.74**	**0.70**	**0.65**	**0.51**
Overall Efficiency	**0.65**			

When we process the total numbers for each winter we get a somewhat less spectacular improvement in household efficiency. Using seasonal numbers the increase from winter 3 to winter 4 is about 22%. We covered 20% of the house and we got a boost in efficiency of 22%.

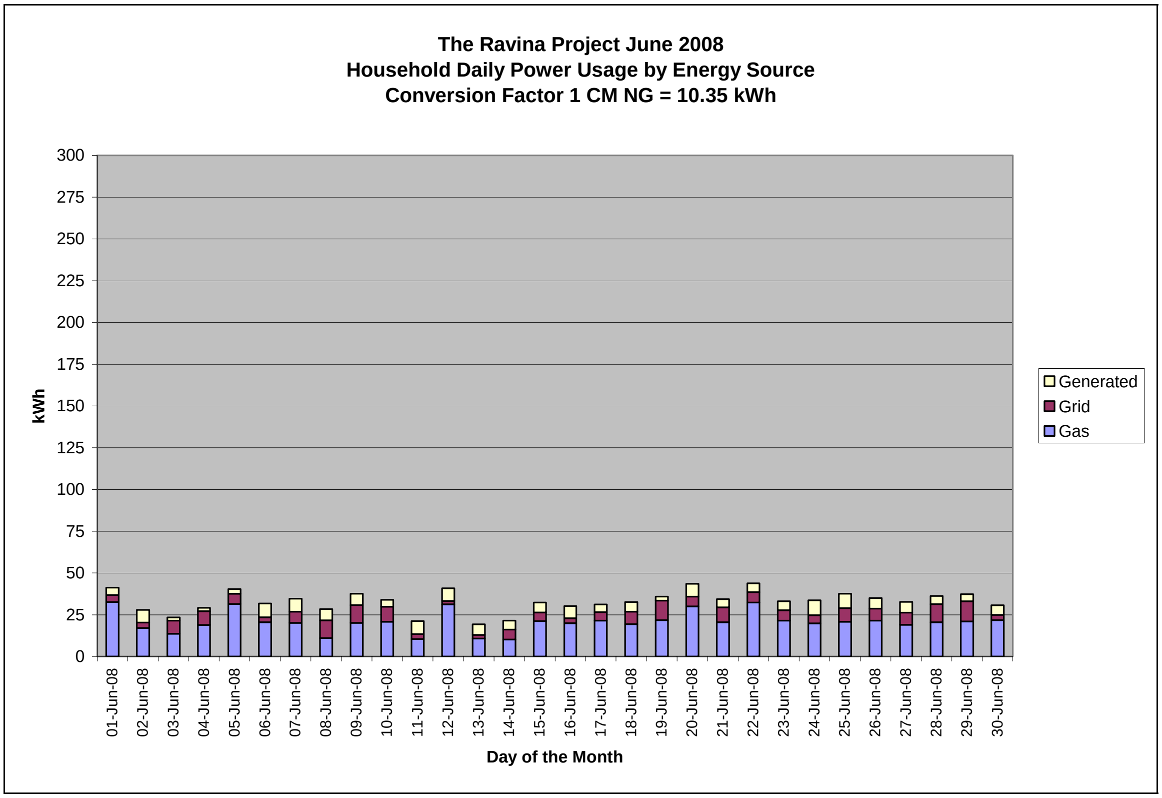


The graph (above) for the years in the database shows the increase in household efficiency over the past year (orange line).

Natural Gas is the workhorse. Natural Gas is 100% fossilized carbon.



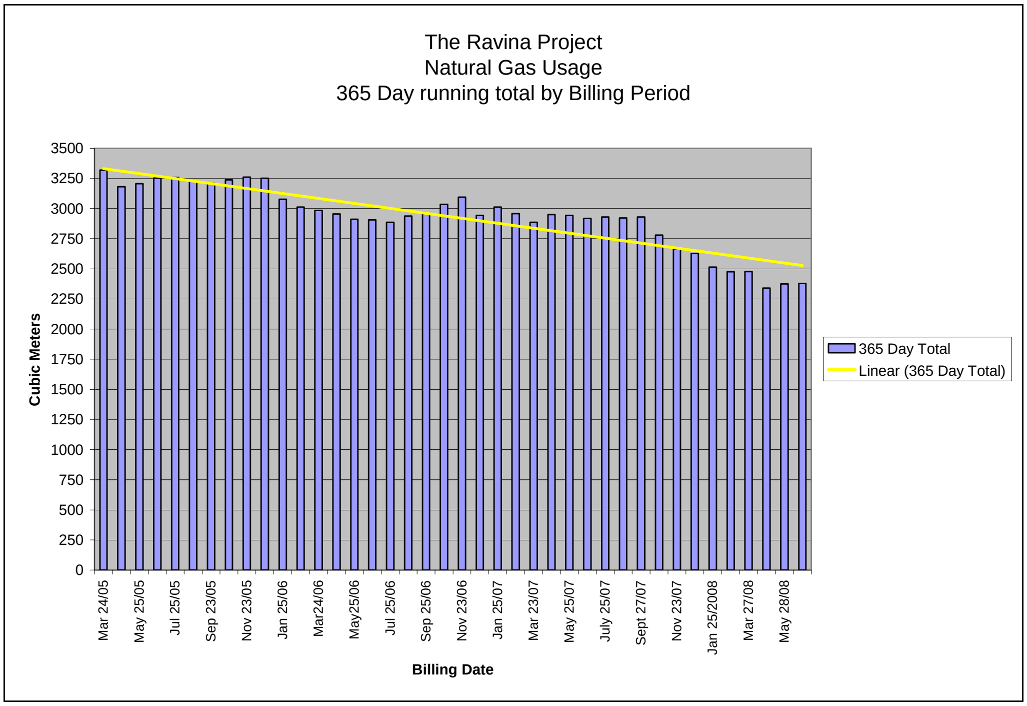
As we can see the main power source for our house at The Ravina Project is natural gas. On the graph above each bar represents the total amount of power used by our house expressed in kWh. The value is read on the left side of the graph. Natural Gas is converted to kWh and is coded with a blue colour. Electrical power coming in from the utility is encoded in dark red and generated energy is encoded in yellow. The January graph (above) shows the energy usage during one of the coldest months here in Toronto.



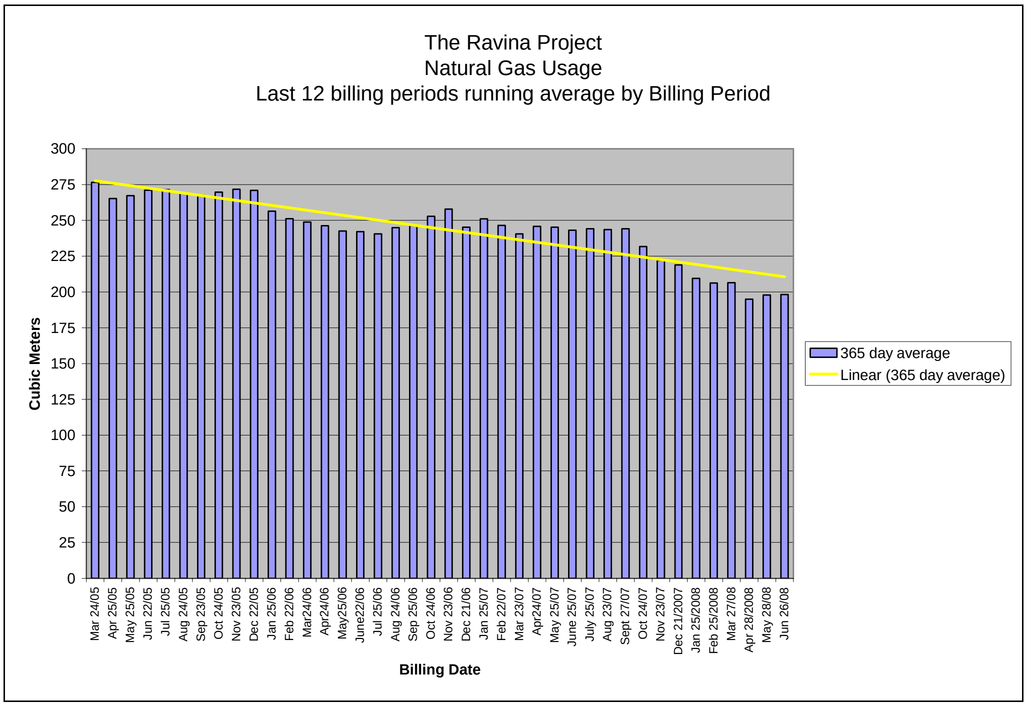
The graph above is encoded the same way as the January graph, however it is for the month of June which is typically a warm month in which no air conditioning is used. One can see the NG usage as ‘base level’ with none being used for heating and little for clothes drying.

We can track power usage over the length of the database in blocks of 365 days.

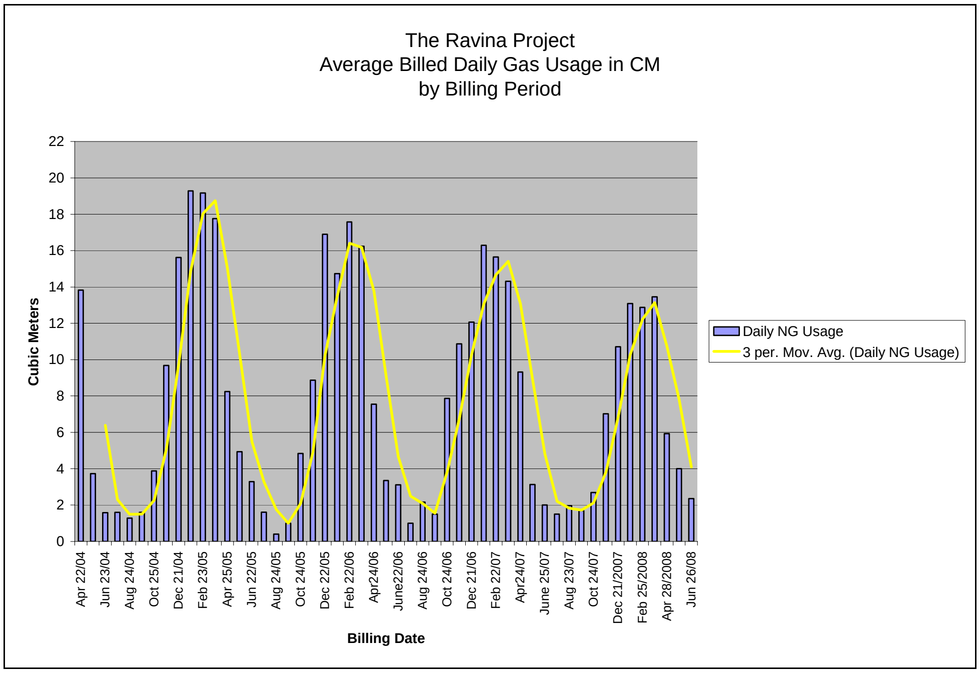
For instance we can keep track of the 365 day running total for NG usage.



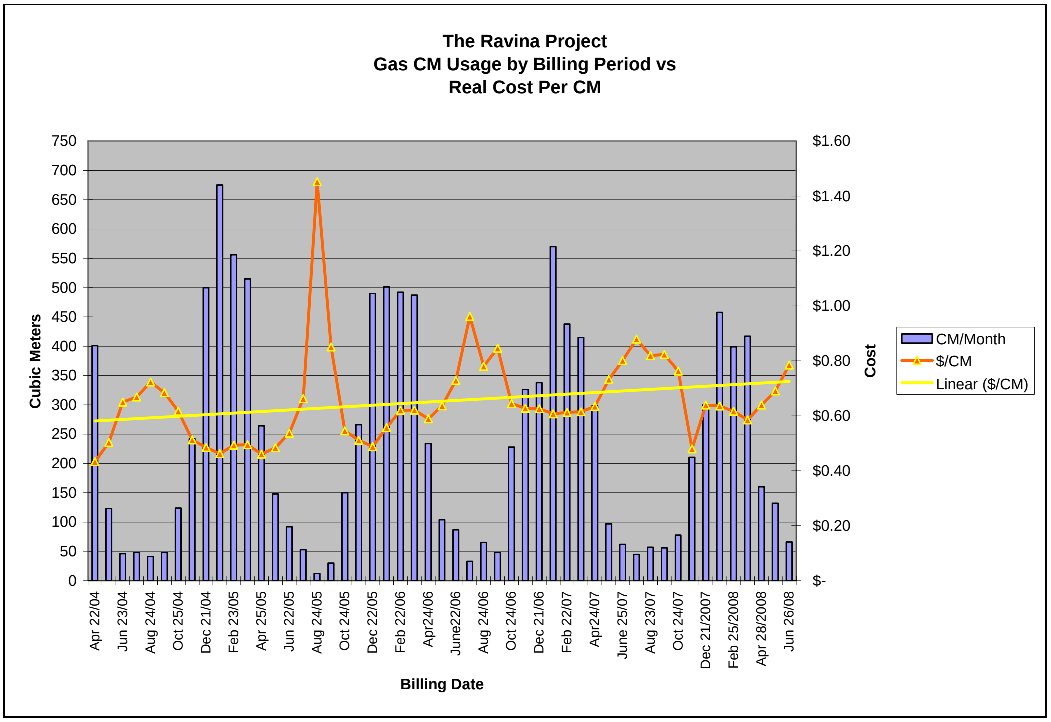
We can track the 365 day running average of NG used per billing period. The graph below shows that the average monthly billed usage over the last 12 billing periods is falling.



And finally we can look at the average daily NG usage per billing period. The four winters in question stand out. The shape of the curve demonstrates a savings of some kind is under way.



Savings occur but the savings per unit used are not there. The price per unit increases dramatically as usage decreases.



What does all this mean for energy policy?

Insulation makes a huge difference. The house must be encased thermodynamically in a skin that will insulate it much more effectively. Such an upgrade will guarantee a huge cut in NG burned and hence a huge cut in fossil CO2 gas emissions. It will also guarantee that less grid power is used both for air conditioning in the summer and heating in the winter. It will guarantee that the solar array effectiveness will be amplified because the solar array will generate a much larger share of the total energy requirements of the household. Actually, when you think of it, such insulation will amplify any generation in a similar way. The insulation cuts back on power usage and if the household has a generation facility, the remaining power used by the household has a larger clean energy component.

This next summer we are planning to put siding and R-5 insulation on the remaining portion of the upper floor of the house.

Conclusion

Our conclusion does not vary from the one we had in our paper last year.

Policy for Individuals

Before your marginal Green Dollar is spent on any high tech energy generation solution for your house, your house must be insulated to the maximum. You will get better return for your money than virtually any other kind of investment into your house infrastructure.

Don't bother with generating your own power or harvesting heat from the sun with solar hot water systems.

Don't invest in heat pumps that harvest heat from the ground or wind turbines.

All these high tech solutions can and should be considered but ONLY after you have maxed out your insulation on your house.

Next summer we will publish a version of this paper taking into account another year's worth of data.

Policy for Government

Household heating is the largest single source of carbon emission in Canada.

Encourage on a massive scale, heat encapsulation of houses that qualify. This may be done using the mechanism outlined in last year's paper.

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.

Don't play politics with this issue.

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

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