The Ravina Project

Household Thermodynamics – August 2007

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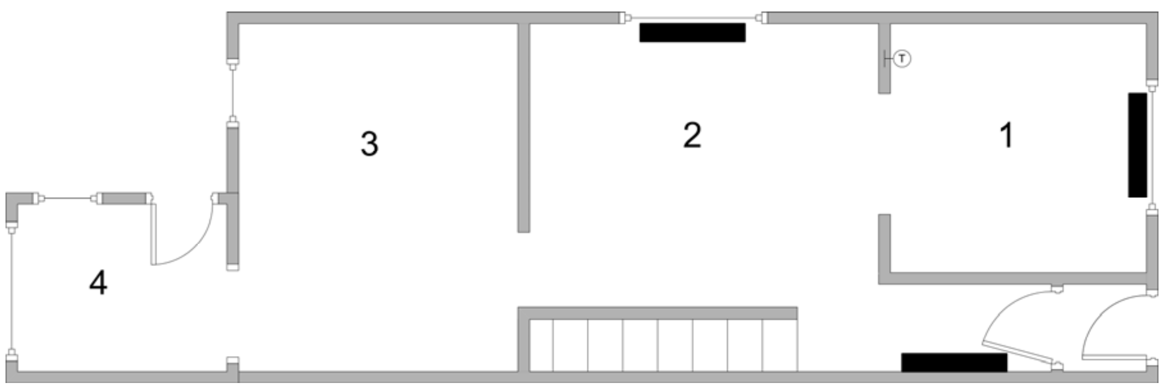
Introduction

We have made changes to the internal heat flow of our 80 year old house over the last two winters. Our gas bills for the periods detail the energy use. We will examine the data from several points of view. Finally, we will make conclusions and explore their energy policy implications.

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.

We had two goals

The first goal was to reduce the household carbon footprint by reducing the consumption of natural gas. This goal has two parts to it. Firstly, we want to reduce our absolute number of cubic meters of natural gas consumed. Secondly, we wanted to try to displace the carbon of natural gas with cleaner electricity.

The second goal was to save money by reducing our use of natural gas.

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

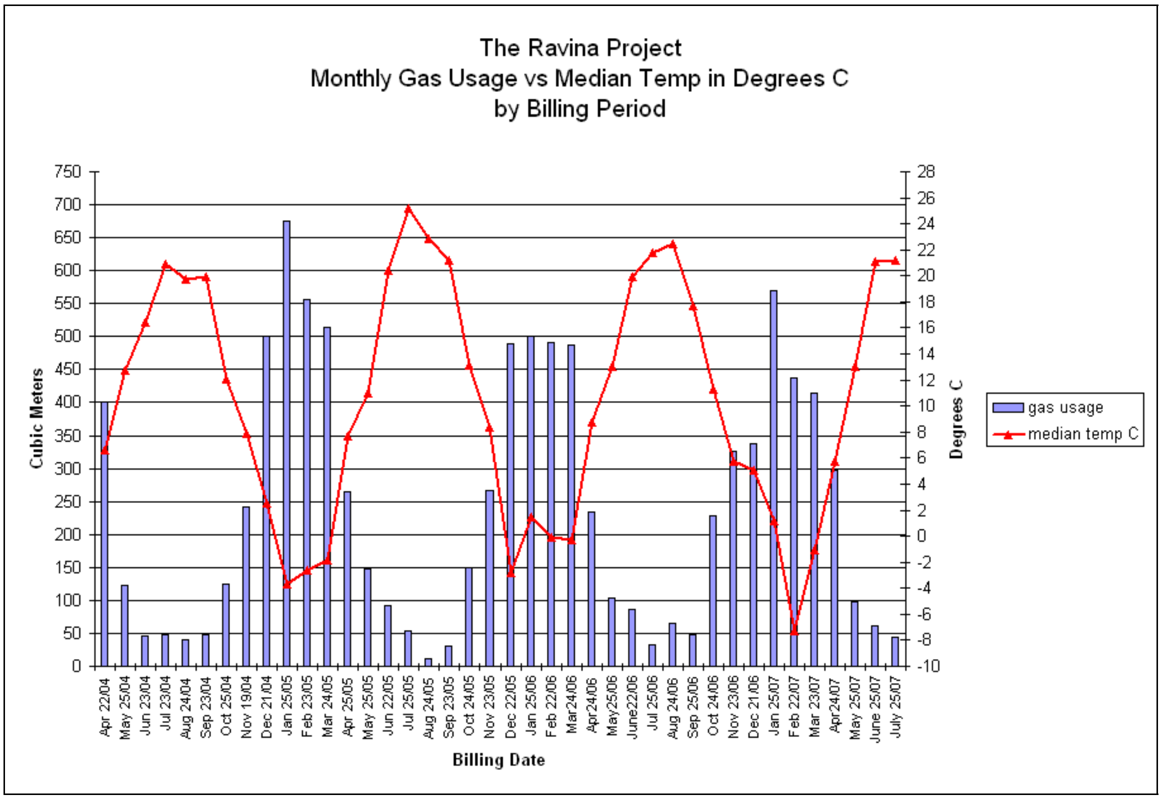
We purchased a $65 heater of the same design as the one mentioned above. We placed it in the kitchen and set it to turn on when the temperature reached about 13 C. It ran on the 500 Watt setting. The goal here is to reduce the heat gradient between the dining room (area 2) and the kitchen. This would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

Winter 4 – New siding on one outside Second Story wall

This data is yet to be collected. The siding cost about $4,000. Included was the addition of foam and a heat reflector to give the stucco wall an extra R5 rating boost. This wall was the leakiest wall in the house and was judged to give the best return for our Green Dollars. Data from this modification will be available when this paper is updated next year.

Analysis of gas bills over the last 3 winters

The Ravina Project has kept detailed records of the household energy it has used over the last three years. The database contains three winters worth of natural gas usage. Consider the following graph, also available on our Web site at: http://www.theravinaproject.org/house_data_gas_usage.htm .



Notice the months of December through March for the last three years. Notice as well the median temperature for each of these months. Obviously colder months will have larger usage and will skew the consumption of natural gas. Notice that there is no obvious ‘warm’ winter and the coldest month on the chart is February 2007 even though the last two Januarys have been slightly above zero.

Impact on Fossil Fuel Use

Consider the table below.

The Ravina Project Natural Gas Usage in Cubic Meters						
	2004/05	2005/06	Saving 1	2006/07	Saving 2	Total
December	500	490	**10**	338	**152**	**162**
January	675	501	**174**	570	**-69**	**105**
February	556	492	**64**	438	**54**	**118**
March	515	487	**28**	415	**72**	**100**
	Season Totals		**276**		**209**	**485**

As the graph above suggests the savings in natural gas usage over these four months has been dramatic. The initial investment of the old heater and curtain saved 276 cubic meters of natural gas. The further investment of the new heater saved another 209 cubic meters of natural gas over the baseline of the winter of 2004/05.

Can we put a price on these savings? We here at The Ravina Project calculate our monthly natural gas rate by dividing the total dollars paid each month by the number of cubic meters of natural gas used. For instance, in December 2005 we paid $238.97 for 490 cubic meters of gas. Our per cubic meter rate for that month was 48.77 cents.

We can redo the table above using dollar figures.

The Ravina Project Natural Gas Usage in Dollars						
	2004/05	2005/06	Saving 1	2006/07	Saving 2	Total
December	$242.45	$238.97	$3.48	$211.67	$27.30	$30.78
January	$312.14	$279.36	$32.78	$346.16	-$66.80	-$34.02
February	$274.06	$305.14	-$31.08	$268.43	$36.71	$5.63
March	$254.93	$302.18	-$47.25	$255.09	$47.09	-$0.16
	Total Savings		-$42.07		$44.30	$2.23

What?

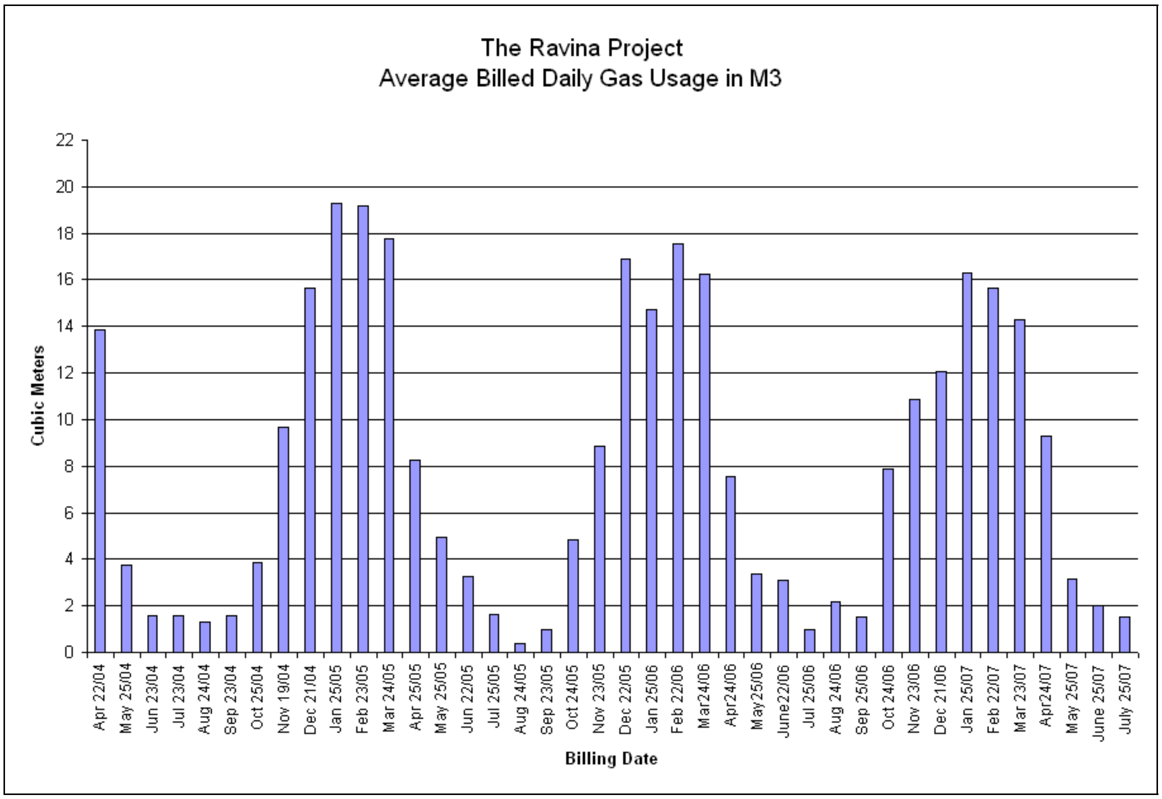
Yes, we lost money! In the first period we used a total of 276 cubic meters less in natural gas and had to pay $42.07 more. At $2.23 total savings for the project so far we have not paid for really anything.

So what happened? Let’s look at the real rate we pay for natural gas. We calculate our real rate per cubic meter as **the total gas bill in dollars divided by the number of cubic meters we used** of natural gas.

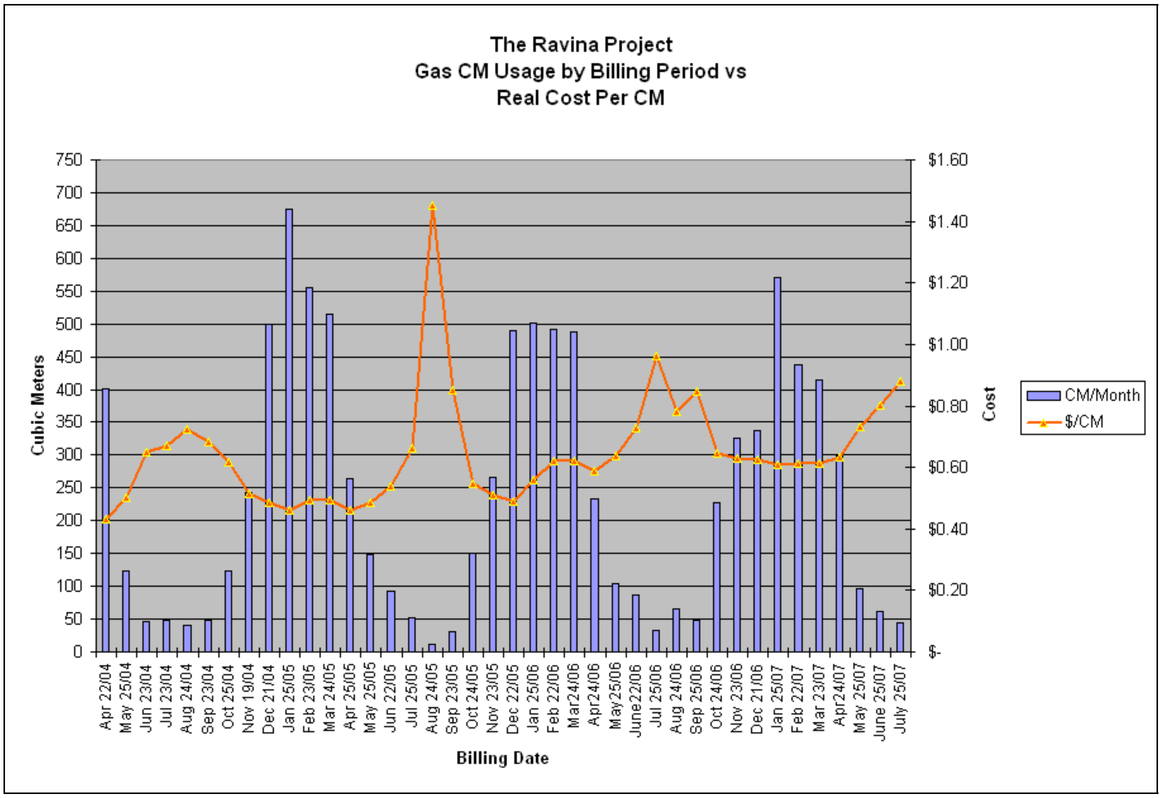
The Ravina Project Natural Gas Cost per Cubic Meter

	2004/05	2005/06	Change %	2006/07	Change %	Total
December	$0.48	$0.49	2.08%	$0.63	28.57%	30.65%
January	$0.46	$0.56	21.74%	$0.61	8.93%	30.67%
February	$0.49	$0.62	26.53%	$0.61	-1.61%	24.92%
March	$0.50	$0.62	24.00%	$0.61	-1.61%	22.39%
	Average Change		18.59%		8.57%	27.16%

The January 2007 billing period is a very long 35 days. Compared to the months around it like February and December both with a 28 day billing period, January sticks out. However, when you look at January 2007 on an average cubic meter usage per day it does not stand out and indeed, the daily usage graph shows the savings in gas usage.



Let’s expand on these costs and see if there is a relationship between saving gas and the real cost of gas on a per cubic meter basis. We have enough data to build a graph showing this relationship.



So we see clearly what the charts above hinted at. As we conserve gas our cost per cubic meter of gas … the money we take out of our pockets to pay for each cubic meter … increases. So where is the incentive to save natural gas? The more you save the more you spend on a per cubic meter of natural gas usage.

Our experiment displaces fossil fuel, which we burn in our boiler to produce heat for the house, with electricity. The electricity from the grid here in Toronto contains let’s say 20% fossil fuel. Our boiler heats the house using 100% fossil fuel. We displace the 100% with the 20% and net out positive. Our carbon footprint thereby fell accordingly during the winter of 2005/06. The actual numbers here in Toronto may be different. Note that if all Grid electricity were generated by coal or NG then it can’t displace the NG consumed by us.

With the Solar array in action this last winter we generated much if not all of the extra power that was used to provide heat in areas 3 and 4. The fossil fuel accounting changes dramatically. We displaced many CM of natural gas with absolutely clean electricity.

This is as good as it gets. But we needed solar power at $12k - $14k per installed kW to do it! There is just no reason for investing that kind of money in solar power. One will never live long enough to get a payback either through paying less for electricity or a combination of that and saving on natural gas.

Policy Implications

If you were head of a profit making corporation, would you take steps to ensure that your revenues were guaranteed to fall? Utilities have huge debt both long term and short term. It is not in their best interest to really put their hearts into any kind of reduction in their revenues. If my money were invested in a utility that tried to be altruistic and beat the conservation bandwagon in a way that produced actual reductions in revenue then I'd sell the stock.

I'd expect them to go to the regulator and get a rate increase every time conservation practiced by customers took revenues below a critical level. If they didn't do that then I'd bail.

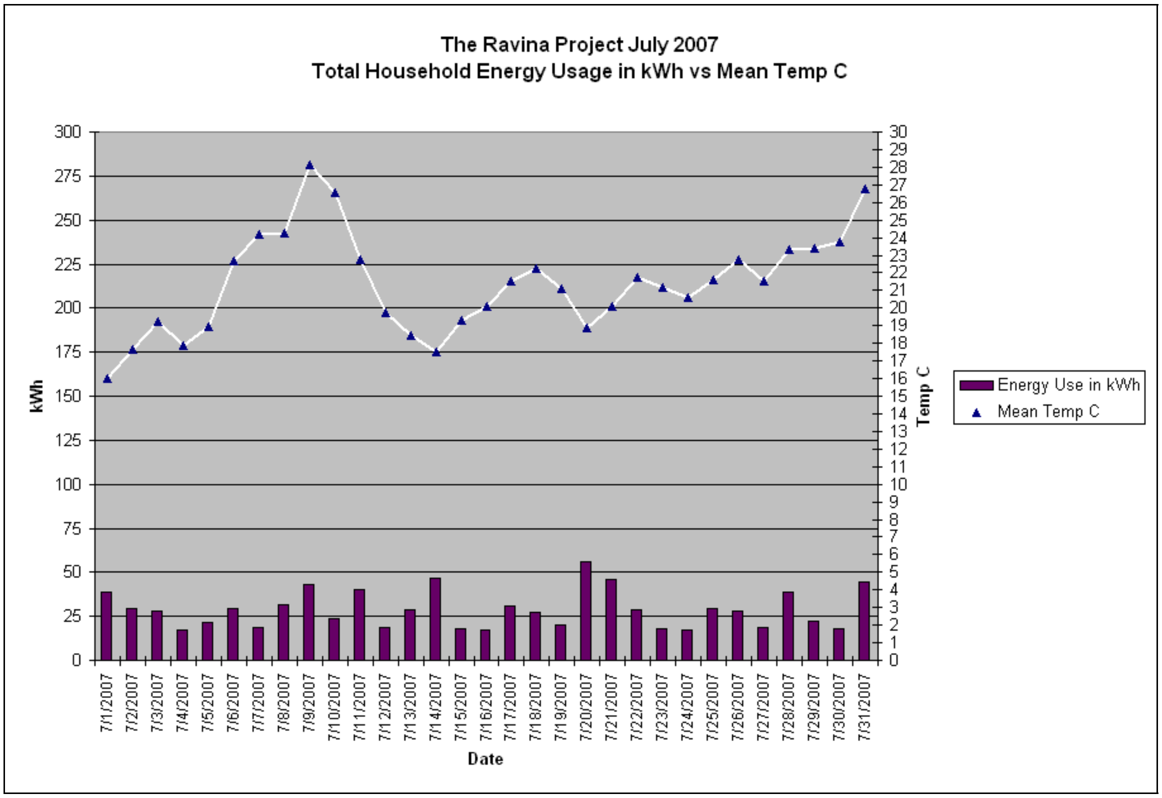
I see the conservation efforts of the local utility as compromised in the following ways. I believe their projections demonstrate that the demand curve will exceed the supply in the medium term. This for one thing will cost them money because they will have to import expensive energy. Along with this projection they also know the sensitivity of their distribution system to overload. Knowing this and to save their corporate reputation, because they cannot match the increase in demand, they must push 'conservation' efforts. This activity allows them to market themselves as 'green' over the medium term. Furthermore, since every corporation wants to be seen as being 'green', the utilities want to be on the bandwagon like everyone else. However If they were not in a supply and/or delivery (infrastructure) crunch there would be no reason for them to get on the conservation bandwagon. Their efforts can be seen as disingenuous yet be entirely reasonable and responsible.

What should the policy be that will stimulate conservation?

What's a good fossil fuel conservation stimulation policy?

Note that 31% of fossil carbon emission comes from households and that they are the greatest single emitter when compared to industry: cars, trucks and etc. In Canada, our weather makes great demands upon our heating fuels.

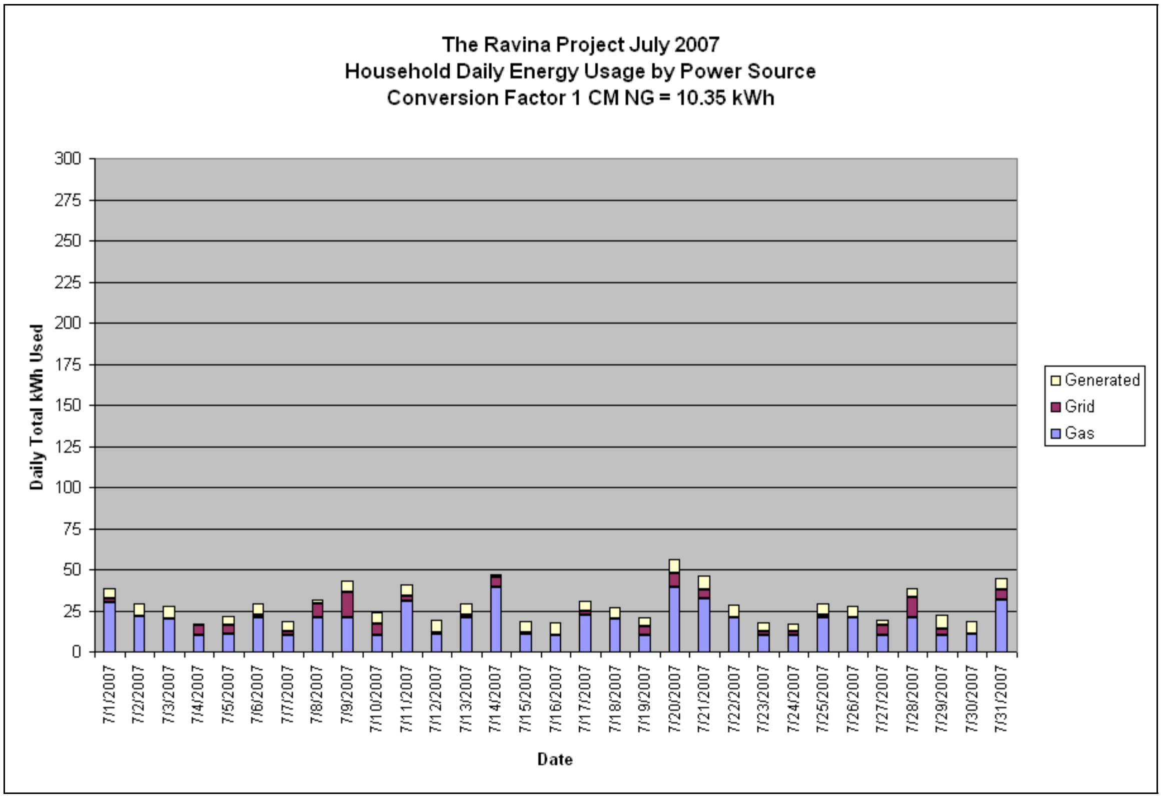
Consider the following chart for July 2007 that tracks the total usage of our house at The Ravina Project.



This chart has been prepared by converting energy from all sources used by the house into kWh. Grid power comes in as kWh and so does generated power. Natural Gas is converted to kWh at the ratio of 10.35 to 1. The Natural Gas in this chart is used for domestic hot water and cooking. In other words, the NG used here is the 'base' level of usage. We can't use any less than what is shown here unless we modify our lifestyle in a dramatic fashion. We have no intentions of doing so.

One of the assumptions of The Ravina Project is the idea that we as occupants of our house go about our daily business in the lifestyle we are comfortable with. We are conscious about our usage of power and govern ourselves accordingly. We are not zealots in this regard though.

The graph below shows the break out of energy usage by power source for July 2007.

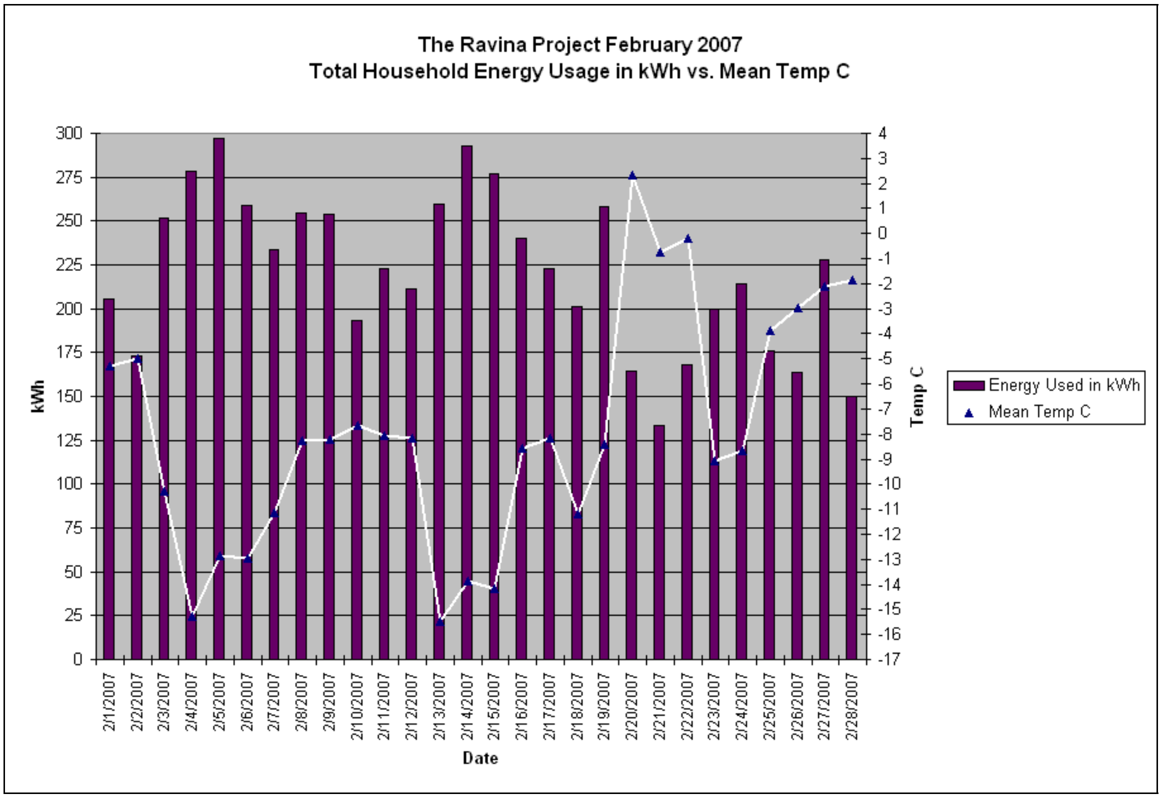


As you can see above, the NG usage in blue still provides more energy than the other sources combined. Parenthetically, on some days the generated power used is greater than grid power supplied. On other days no grid power is used and all electrical power is generated.

Again these graphs are included to give the reader an idea of the base level energy usage for the household especially in the usage of natural gas.

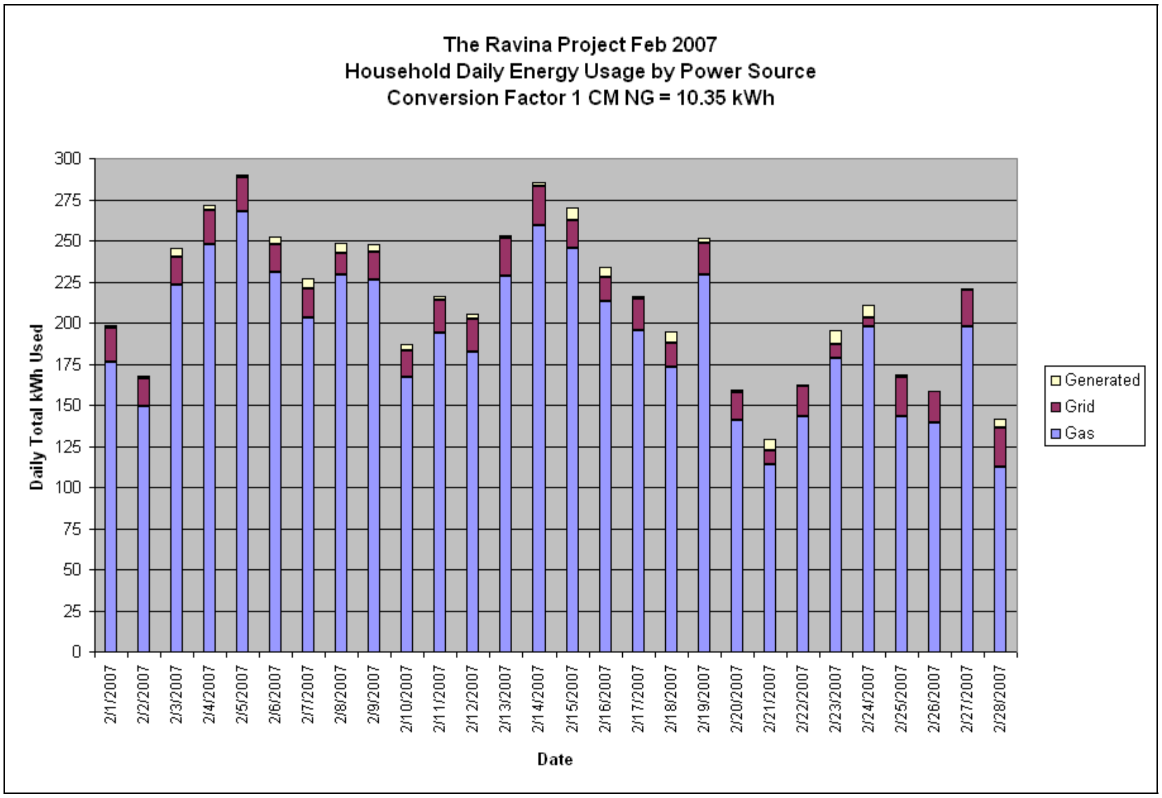
Note that the scale from zero to 300 is preserved among all charts. This is done to amplify the perceived difference in gas consumption between seasons.

Consider the chart below.



Notice the huge increase in the energy used each day in relation to the mean temperature for the day. Since the only difference between this chart and its counterpart above is the outside temperature, one can conclude that the difference in energy usage is caused by extra heating demands.

We see the breakout by power source in the chart below.



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

These graphs tell us that our old house is a sieve for heat. Yet the house has been upgraded better than most in its age class. It still isn't good enough. Our boiler is 95% efficient when it operates yet it takes a huge amount of NG to heat the house. Our thermostat is set cooler than most and we have the heaters and curtain in areas 3 and 4. But we still burn NG like there is no tomorrow. Our grid usage is up slightly because of the heaters.

What does all this mean for energy policy?

For one thing the charts demonstrate that upgraded houses don't cut it when their NG usage is taken into consideration. The house must be encased in a new outer 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 less grid power is used both for air conditioning in the summer and heating in the winter. It will guarantee that the solar array generates a much larger share of the total energy requirements of the household.

This summer we put siding on our worst wall above the brick. It included R5 insulation. We were not aware of any rebate program at the time of the installation.

Our charts demonstrate that our house, like many others, requires more insulation to really make a difference. Our solar array cost us about $18,000.00 for 1.5 kW of generation capacity. We reached our 1,000,000th Wh generated in July of this year (2007). We probably will generate about 1,700 kWh of electricity this year from the sun. We can convert this total to cubic meters of natural gas. It amounts to about 164 cubic meters.

We saved more than this amount using our curtain and heaters!

Imagine what could be saved by enclosing our house in a blanket of R5 insulation? It would save far more than our efforts with a curtain and a couple of heaters. We saved over 400 cubic meters of natural gas usage. House enclosure would save several times that amount.

It's obvious then what the policy should be if governments are serious about reducing the consumption of fossil fuels and electricity.

Take for example the ECOENERGY Retrofit for Homes program sponsored by Natural Resources Canada. I have their brochure (ISBN 978-0-662-45546-2). We recently had one of our walls insulated with R5 under new siding. Our house has double brick first floor walls and frame second story walls. We insulated our leakiest frame wall. The wall area as a percentage of the total is about 20%. The brochure indicates that we would receive $180 in total for our $4,000.00 expenditure or about 4.5% which does not cover the taxes.

For the record we spent just overt $22,000.00 several years ago upgrading: the heating / hot water system to the boiler, crawl space insulation, doors and windows, basement header insulation and air sealing. With all of this expenditure our house is still lacking. The external wall insulation looks like it is critical for the program to get real results. But how critical is it?

At this time we have no real answers because we need at least one winter of data to show if there is a difference and by how much..

We'll upgrade this paper in 2008.

Conclusions

As you can see there have been some wins, losses and interesting revelations when we look at the data.

- **Win** - A simple analysis of heat flow in the house during the winter and the resulting mitigation efforts on our part realized a savings of 485 cubic meters of gas over the benchmark year of 2004/05. Since burning natural gas releases 100% fossilized carbon we came out ahead in this area.
- **Loss** - We did not save money, so there is no payback except in altruism.
- **Revelations** – Our house needs insulation even after all the upgrades. Our 'all up' cost for each cubic meter of natural gas skyrockets as we use less and less during the summer months. From a cost per cubic meter point-of-view there is no incentive to conserve.

We covered our worst and leakiest wall with siding and R5 insulation as a partial mitigation for the heat loss. We need more data to understand the implications for this action on our part.

Some ideas seem to be implied by our experiment.

Data Mining Utility Customer Accounts

From the point-of-view of natural gas conservation, it seems that a mechanism should be in place that rewards those who save. Ditto for electrical consumption. I know that the utilities have extensive records of the usage for each subscriber. They use this database to predict consumption for each customer based on the air temperature. This explains why the utility's estimation of usage is so accurate when they don't get out to read your meter.

The customer database could be put to another use. It could track customer conservation efforts so that some meaningful benefit could accrue to the customer in recognition of their conservation.

Where to Spend the Green Dollar?

We define the Green Dollar ($) as a dollar that was purposefully spent to consume a green product or service. The dollars I spend to upgrade all my light bulbs to more efficient models are Green Dollars ($).

The Green Dollar market is growing and will continue to grow into the foreseeable future. At this time people are interested in alternative forms of power generation; solar (PV and heat), wind and geothermal. Both governments and individuals are looking closely at what they can do to generate power in alternative, clean ways.

The question becomes, "Where to spend the Green Dollar?".

This is a two pronged question because the householder and government have quite different takes on the answers to this question.

Householder's Green Dollars

When it comes to power the household can, in the broadest sense; decrease consumption, increase efficiency and generate. Any household can be evaluated using these three criteria.

Let's look at The Ravina Project through the eyes of these three criteria. We have decreased consumption by all the house upgrades. We have increased efficiency by using light bulbs that cast the same illumination yet use a fraction of the power. Our boiler takes over the domestic hot water and house heating tasks yet works at an amazing 95%. We generate our own electrical power and send it out to the street during every sunny day time.

When we look at our data we see that the vast majority of green dollars should be spent by the individual householder on decreasing consumption and increasing efficiency. We thought when we began this project that there could be a case made for using Green

Dollars to purchase electrical generation capacity. We based our argument on the idea of diminishing returns when more and more money is spent to save less and less. At some point we thought that it would make good economic sense for the householder to start generating power.

Our data, so far, suggests otherwise.

Our house is very typical of the houses designed and built before 1985 when the effects of the 70s oil shock reached the house designer's desk. Unfortunately, of the installed base of houses there is a huge percentage built before 1985. Our house is in that group. We are, in some cases, better built with thick double brick walls with insulating dead air between them. Our original equipment has been upgraded just like everyone else's.

We know from the charts above that our house burns much NG in the winter. We know that we spent money to generate power at the rate of $12k per kilowatt or about $18k. However, we also know that the power we generate will only account for an offset of a small amount of fossilized carbon compared to the fossilized carbon we release by burning Natural Gas. If we had spent the money on cocooning the house in R5 grade insulation our NG usage would have been dramatically less.

We know this to be the case because of our little experiment with the drape and heaters. This is a very small change in the heat flow in the house but actually saved lots of NG combustion.

We will confirm this trend with the coming of this next winter. Those numbers will spell out for us what happens when insulation is applied to only 20% of the leakiest outside wall surface area. From there we might be able to extrapolate how much might be saved if the entire house were encased in R5 insulation and new siding.

So the bottom line for people in houses built before 1985 is to invest in insulation and forget about power generation. In our case, we use domestic hot water all year but in the summer time no heat is required. Our natural gas usage plummets during the late spring, summer and early fall. The difference is heating the house during cold days.

Insulation directly attacks this consumption.

The householder's Green Dollar should be spent on insulation.

Government's Green Dollars

It's obvious where the energy is used during the winter time in the vast majority of homes build before 1985. It goes to heating. The government can leverage this fact by making house insulation substantially cheaper. Note that $15K spent on insulation saves year after year. The home owner may not get $15k in saving. The initial cost of insulating the home may never be paid off given the costs involved. However, if the government's policy was set up to ensure that householders get their money back in, let's say, 10 years, then householders have something to aim for. What I mean by this, is the government would add to the energy dollar savings that the household realized over the first 10 years after the insulation upgrade. The amount added would be to the extent that the house insulation would be paid for completely.

House Insulation Program	
Cost of Insulation	12,000.00
Savings per year	900.00
Savings after 10 years with rate increase	9,540.00
Government Rebate	2,460.00

Let's say that the insulation costs $12,000. Over the years there is an average dollar savings of $900.00 a year from all utilities which allows the house owner to pocket $9,540.00 after 10 years. A rate increase in included in the calculation. At the end of the 10th year the rebate check is delivered to the current home owner covering the cost outstanding between the amount saved and the original cost. Whether that cost covers 50% or 90% of the original cost outstanding is not at issue here … that's ultimately a political question. The idea is to get the homeowner involved quickly in this program. Safeguards will have to be built in to avoid fraud and etc.

This idea has several good points about it.

On of the best is the fact that cash strapped governments can start the program using the homeowner's cash. The homeowner finances the whole roll out right up to the end of the 10th year. The rebate program is attached to the property and not to the owner because the insulation is placed on the property and the savings are calculated using statistics generated by the property's energy consumption.

The municipal government may be the best level to administer this program. They will have to get some resources to deliver the program from other levels of government.

Such an agreement would serve to encourage people to upgrade their houses, prompt the creation of private business dedicated to the installation of insulation, promote development of new insulation techniques and save huge amounts of natural gas (fossil carbon release). Seems that this policy, if implemented, would be both business friendly and green.

It just doesn't get any better.

The government's Green Dollar should be spent on assisting home owners to insulate their houses.

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

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

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