The Ravina Project

Household Thermodynamics – October 2011

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

gord@theravinaproject.org

Twitter: @ravinaproject

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Introduction

This is the third in an ongoing series of papers we publish on the changing thermodynamics of our now, 85 year old house, here in Toronto. Over the years we made changes to the heat flow within the house and to its structure. This paper uses several databases we populated over the years to help us understand statistically, the thermodynamic properties of our household. And further, we are curious to see statistically if the changes we make can affect energy efficiency. This is a tough calculation to make. We have been careful to construct large enough data sets to provide a credible foundation for any statistical conclusions we might make. Using a 'back of the envelope' calculation, we estimate we will have on December 31st, 2011 about 90,000 pieces of hand collected data in our various databases.

To understand our wintertime household efficiency better, we 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.

Note we use the term 'house' when we refer to the physical structure of the house and we use the term 'household' to include the house and the people living in it.

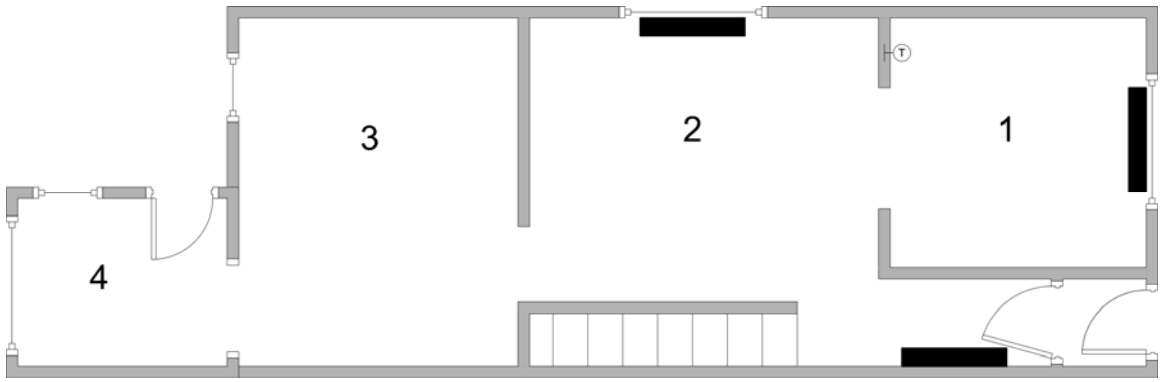
Wintertime efficiency at this latitude and geographic location is critical to reducing carbon emissions from heating. Hence this paper started out as being a wintertime efficiency paper, but Global Warming spurred us to make changes. We are introducing a new section based upon the thermodynamics of our household in the summertime. We know that heat mitigation in urban areas will make substantial demands upon city power supplies as Global Warming continues. We want to attempt to do the same for our electrical power usage as we have done for our carbon usage. That is, we want to calculate the household summertime efficiency for each summer and track it over a period of years. We use the metric kilowatt-hours used per Cooling Degree Day or kWh/CDD for our summertime efficiency calculation.

Note our method of data collection. We use the 'double-look' method. We record the meter reading on first look. We look away from the meter and then back again. We take another reading and verify our written value. We find this simple method catches errors especially when hurried outside readings are taken during inclement weather. Hehe, we've taken readings wearing almost everything including snowshoes, many times.

There are other standardized methods that require two observers to agree on a reading. We find it inconvenient for both of us to be out doing the same thing. The above method is our compromise position/method on this issue.

Original House 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 central heating.

Area 1

Area 1, the living room, has double brick external walls. It has a large new modern double pane window with a hot water radiator beneath it. The area also contains the furnace 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 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 stairs to the upper floor and the hallway which has its own radiator.

Area 3

Area 3, the kitchen, has 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 an unheated basement fruit cellar that is separated from the full basement by a door.

Analysis of Heat Flow

On the main floor in the winter heat is provided primarily by 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 heat generated in other areas. The heat will migrate through the open door 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 (heat pressure) 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 and in a real sense, the greater the heat pressure between hot and cold areas.

It follows then that any impediment to 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 areas. We use doors to do this all the time … especially the external doors on our houses. They keep the heat inside during the winter. Another way of slowing heat flow between areas is to modify the heat gradient between the hot area and the cold area by injecting heat into the cold area. This lowers the heat pressure between them.

Modifications made to Heat Flow

Modifications have been made over the past winters to the heat flow through the house during winter. We hope that our analysis of heat flow is correct such that there is, statistically, a demonstrable change in household efficiency using these ideas.

Winter 1 2004 - 2005 – no changes

The first winter had no modification to the household heat flow. It will be, for the purposes of The Ravina Project’s wintertime efficiency 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 which 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. Theoretically, when we use heaters we are replacing natural gas heating, which is 100% fossil carbon with 25% carbon electricity.

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 sophisticated 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

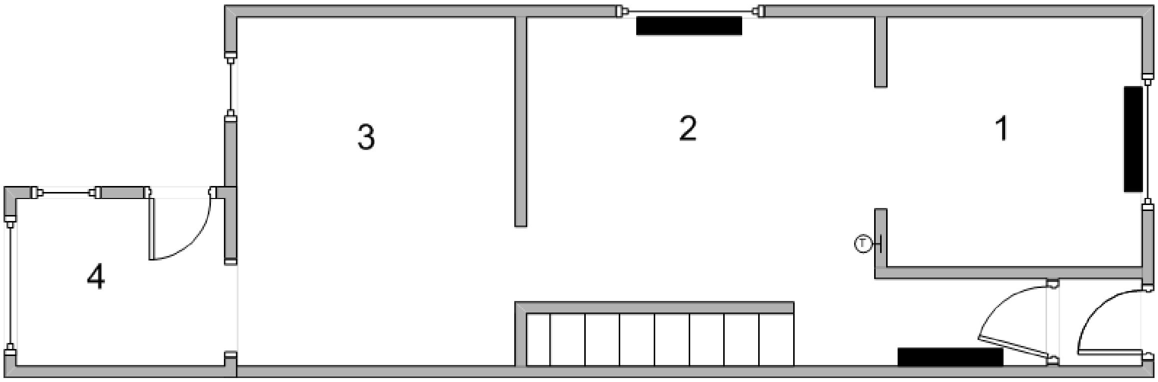
The siding cost about $4,000. Included was the addition of R 2.81 foam and a heat reflector. This wall was the leakiest wall in the house and was judged to give the best return for our Green Dollars. It represents about 20% of the external surface area. The work was completed during the summer of 2007.

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

We finished off the siding on the second floor at a cost of about $5,000.00. 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.

Winter 7 2010 – 2011 – Several household changes.

Here's the new house layout.



You will first notice that the thermostat is in a new location. The manual device was upgraded to a cheap computerized model. We really have no idea how this move will affect our data or the household heat flow over the long haul. What it does do for us is to give us steady unwavering daily heat regulation. There are no more days when we forget to turn down/up the thermostat or we set it to the wrong time-of-day temperature.

We placed a folding door between the kitchen and the enclosed porch. It provides much better seal for the doorway between areas 3 and 4, the kitchen and porch.

The curtain we had between areas 3 and 4 was relocated to the doorway between 2 and 3. Since this curtain isolates the kitchen from the rest of the house it allows us to keep hot air in the kitchen in the summer time and release hot air in the winter time. We have more to say about this below in our new section on summertime living here at The Ravina Project.

Area 1 became a bedroom for an adult family member. The double doors between area 1 and 2 are closed most of the time. This was the reason for the thermostat move.

All else remained the same; there was an electrically powered heater both in area 1 and area 2. The heater in area 1, the enclosed porch, was set to never let the temperature drop below 50F at 4 feet above the floor. We had a few hardier plants on the floor but most were on tables about 3-4 feet above the floor. This is the range we wanted to control and have been for several years.

Our thermostat settings for the Winter of 2010 – 2011 are below. They were never changed.

Winter 2010 - 2011 Thermostat Settings

Weekdays	Start time	Temp F
p1	7:50A	65
p2	9:00A	64
p3	5:00P	66
p4	8:50P	62
Weekends		
p1	7:50A	65
p2	9:00A	64
p3	5:00P	66
p4	9:10P	62

Note that the water filled radiators we are using guarantee temperature overshoot just because of the huge latent heat contained by water. A 64F daytime temperature for the house with two retired adults and a student seems to be quite low. However, the temperature is overshot several times during the day and the AM sun shines on the wall with the most windows on both floors. The house is well insulated and tends to keep the heat longer before it finds its way outside.

Bottom line, the house feels much warmer that what the thermostat settings suggest. Goes to demonstrate the physical location of windows to the sun in winter at this latitude is vital for lowering energy use plus of course, insulation. Note as well what this observation means for harvesting heat directly from the sun. Since we heat our houses with carbon release, any help with direct house heating is vital at this latitude to moderate wintertime carbon release. The sun is still powerful in the wintertime, it just does not get too high for too long. The development of wintertime heat harvesting technologies specifically designed to augment carbon based furnace heating is vital for carbon mitigation in older, well insulated houses.

The Databases we are using / creating

Data from Utility Bills

The Ravina Project has kept detailed monthly records of the household energy it has used since 2004 gleaned from our utility bills. 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.

Daily Readings from various meters

We collect on a daily basis meter readings from our natural gas utility meter and our bi-directional electrical utility meter. We also collect ‘end of generation day’ readings from our solar charge controller.

Solar data at various times during the day

This is our biggest database by far. We take readings at various times of the day: the time in standard time, the array angle, the storage battery voltage, the sun’s power being harvested, the accumulated energy harvested so far, for the day and a short report on the sun’s condition (thin cloud, overcast, etc.) when each reading was taken. We have averaged six readings a day since the project started so we’ll have by the end of this year a database of about 66,000 pieces of data in it.

Data provided by the Government

We collect daily average and median temperatures from the local weather office. We also collect daily sun rise and sun set times for our location. These data allow us to calculate the number of minutes in each day thereby helping us to crunch the solar array efficiency for the day. The average daily temperature for each day of the heating season allows us to calculate the Heating Degree Days generated each day and thereby allows us to calculate the house efficiency for that day.

Other comments

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 and proclivities of the householders as by the physical properties of the house.

We are focused on the house efficiency, which at this latitude is very important. Much of the year, even when faced with Global Warming, we have to deal as efficiently as possible with the cold. That cold can freeze our water pipes and make our old house a nasty place in which to live, very quickly.

Household heating dwarfs all other forms of carbon release we might have. Efficiency directly affects our household carbon footprint.

Analysis of household efficiency over the last 7 winters

Efficiency calculations based upon monthly gas utility bills

Consider the following baseline natural gas usage calculation :

Baseline Calculation
June 1st Through September 30th

Year	Days	CM used	Baseline CM/Day
2004	121	183	1.51
2005	121	187	1.55
2006	123	233	1.89
2007	123	220	1.79
2008	121	229	1.89
2009	121	239	1.98
2010	124	283	2.28

At this latitude and geographic location, wintertime heating is a monster energy load. We power our house by electricity but we heat our house via natural gas. Actually it would not be far from the truth if we described our situation as using natural gas to produce heat that we consume in one way or another. It is a huge carbon load.

At this latitude and geographic location, our carbon footprint is really determined by the thermodynamics of our house/household. Efficiency is really where it's at, so we'll be focusing on efficiencies of various kinds for the rest of this paper.

In order to calculate house efficiency we needed to know the amount of our baseline Natural Gas (NG) usage. By baseline we mean the amount of NG we use each day regardless of season. 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 NG usage we examined our database and calculated our summer time usage of NG. This amount is net of heating and to a large extent of clothes drying … we have a large clothesline which we use whenever possible.

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 by incorporating them 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. Of course it is not exact because the baseline is somewhat skewed at this latitude. Note we wash our clothes in cold water and we use the dryer much less in the summertime. We also noticed we take longer, hotter showers in the wintertime. We usually have hot and humid summers which encourages us to: take cool showers, eat cold meals, BBQ or visit neighbours ☺. Bottom line we don't use as much NG for summertime cooking/bathing/clothes drying as in the winter. This appears in our calculations as a reduction in house efficiency, which implies, we probably are slightly more efficient that what we calculate.

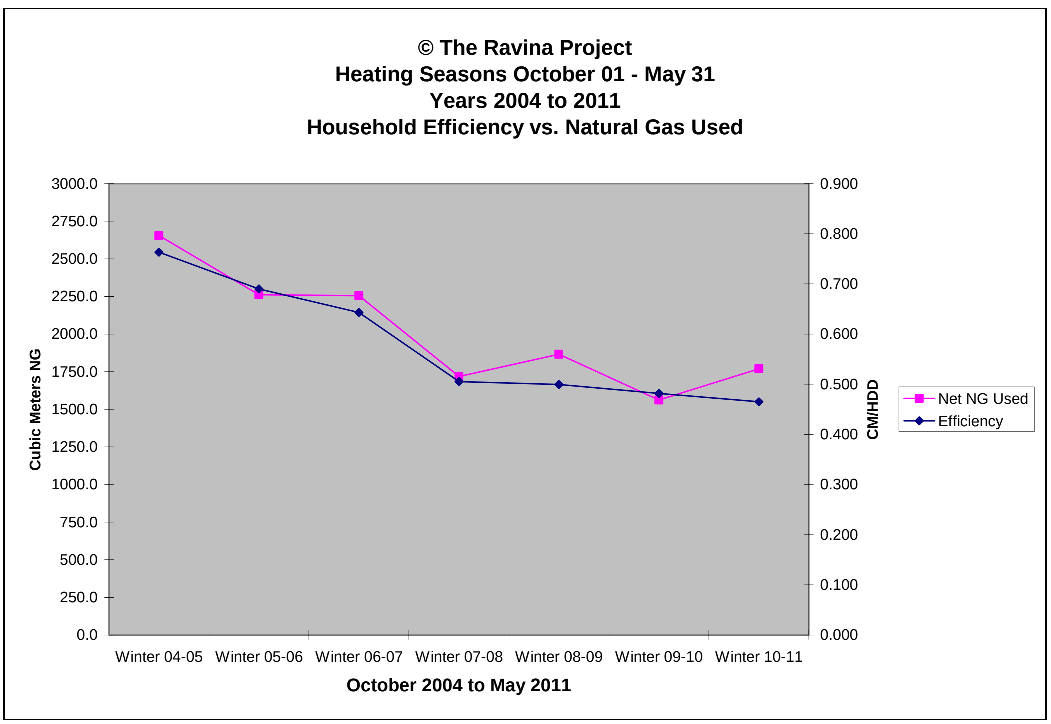
Household energy dynamics

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. More domestic hot water was required to support this person hygienically. Meals are larger so more gas was 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 spring 2010 another adult was added to our household. The baseline increased to 2.28 cubic meters of gas per day.

Consider the following chart constructed from the database that contains our monthly utility gas bills. We can calculate a monthly efficiency value for the house.



For each heating season the total baseline is subtracted from the Natural Gas used to compute the net NG used for the heating season. The seasonal efficiency is calculated by dividing the total net NG used by the total number of Heating Degree Days in that heating season.

The axis, which is labeled as CM/HDD is the household efficiency axis. It is an inverted axis in the sense that lower readings mean 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 ratio 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 ratio indicating increased efficiency. So bottom line, the smaller the value for this ratio; the more efficient the house.

Think about the house efficiency as being a measure of how difficult it is for heat to flow out of the house. This leads to some interesting observations. The house efficiency is temperature compensated because Heating Degree Days relate to an outside daily average temperature of 18C. The more heating degree days means it's colder outside. However, the number of net cubic meters (CM) of Natural Gas (NG) burned is proportional to the outside temperature and how efficient the house is during that winter season. So looking at the graphic above, during years where more net NG was burned but the efficiency of the house stayed the same, we conclude that the house is well insulated for that temperature range. If the house was not so well insulated, an up-tick in NG usage matched by a lowering of the household efficiency for that season means that the house is leaky. The key bit of physics here is that heat has a pressure that it exerts as it tries to find it's way through a structure. It looks for cracks or soft places poorly insulated to get through. As the difference between the inside temperature and the outside temperature of the structure increases in Kelvin (K) the pressure also increases.

So, even if more NG is burned but the house efficiency remains unchanged, the impedance the house structure presents to heat flow through it remains unchanged.

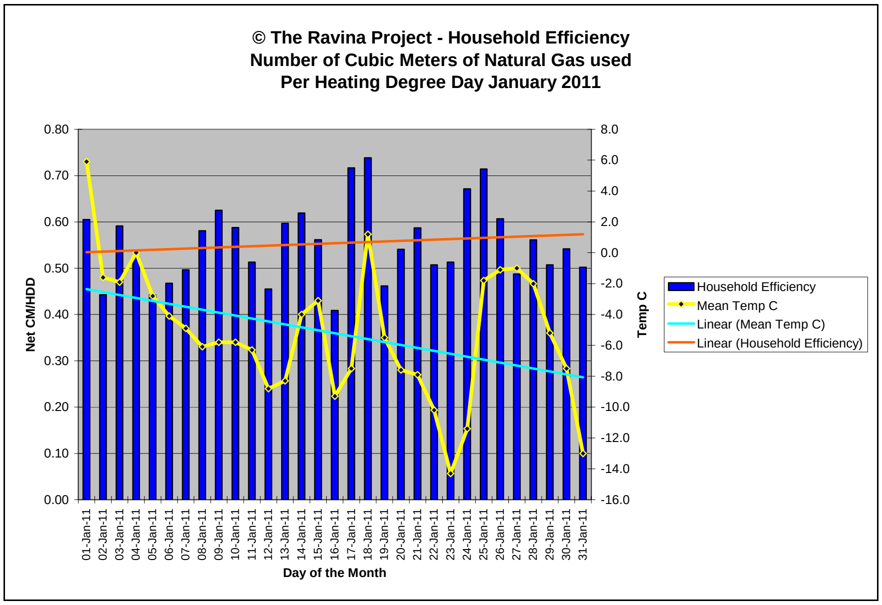
Before we discuss each year in particular let's look at the whole graph above and spot trends. The first trend is seen in the first three winters. The first winter is the baseline. The second and third winter's improvement in efficiency show that simple changes to the rate of internal heat flow can make a measurable difference in efficiency. Annually, quite apart from the boost in efficiency, our household use of natural gas decreased from about 2,700 to about 2,250 cubic meters.

The most obvious trend is the substantial increase in efficiency from the winter 06-07 to the winter 07-08. During the intervening summer we covered our coldest outside second story wall with foam insulation and siding. The area covered was 20% of the house's external surface. As you can see on the chart, that upgrade was a game changer for the house's efficiency … it is a pivot point in the chart. The chart has two sections; before this upgrade and after. We will explore further these two groups of wintertime results below.

Daily efficiencies and data management issues

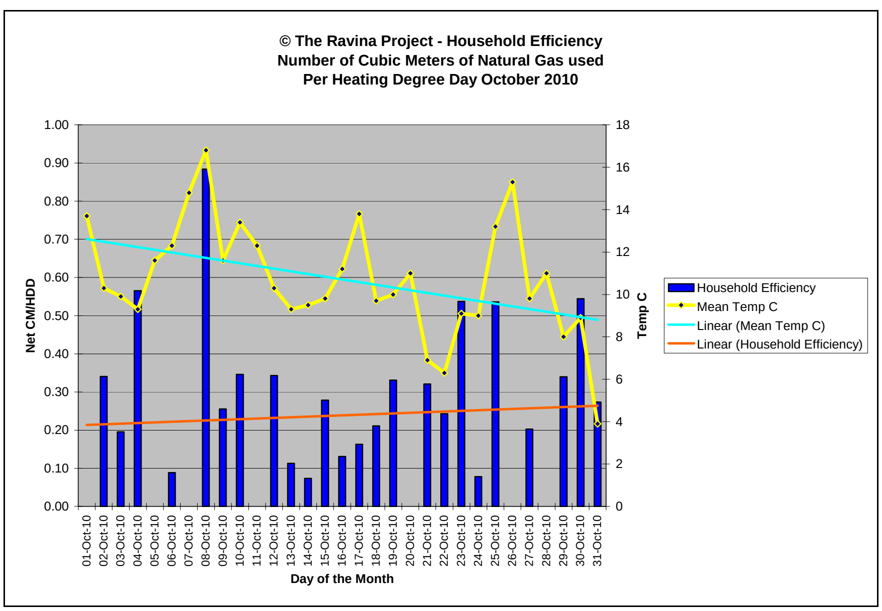
What does efficiency look like on a daily basis? At this level of detail the efficiency is all over the place. It's very probably chaotic.

Here's a chart for January 2011.



There is a problem that comes up statistically when crunching daily efficiency numbers that does not have an analog when dealing with monthly totals. I want to highlight it here.

Consider the following efficiency chart. October is a heating month here.



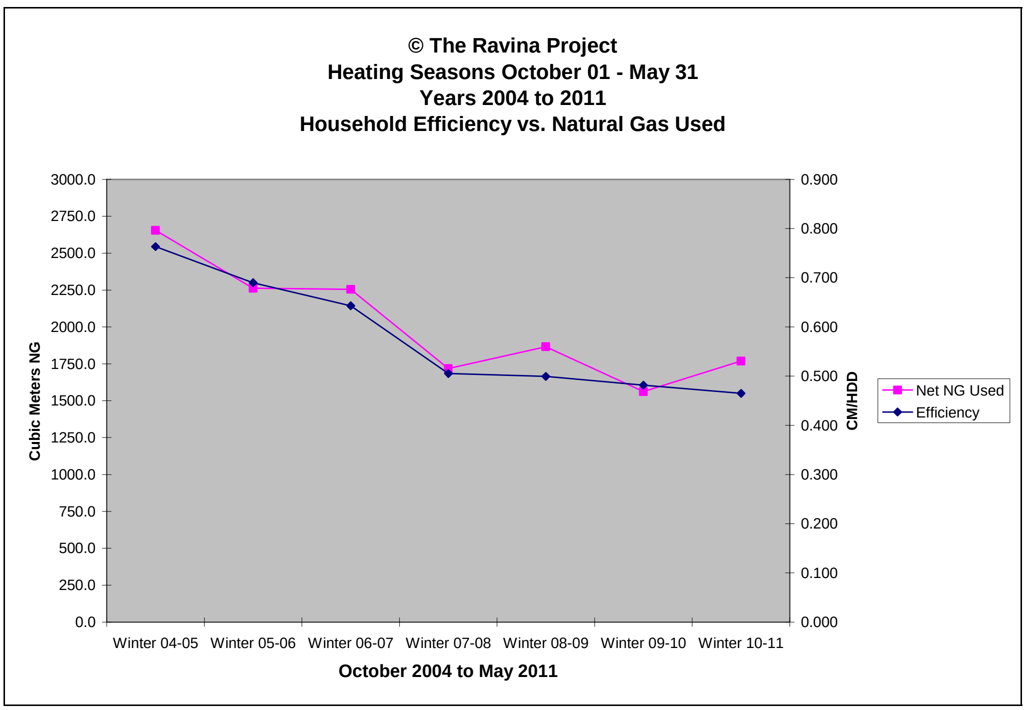
So what does having an efficiency below zero or equal to zero mean? It means that these values are end point outliers. October (and May) can have surprising weather, pushing the net gas usage calculation into negative territory. On these rare days we use less NG than our baseline which makes the value for net NG usage a negative number. On other, much more common days, the number of Heating Degree Days for that day is negative … which means of course the day is really a Cooling Degree Day (CDD) day. Seasonal end point data are tough to manage.

When we look at the household efficiency we discard all outliers greater than .99 and less that 0.01. These outliers accumulate at the beginning and end of the heating season. There are usually between 5 and 15 of these anomalous daily calculations in each heating season of over 220 daily observations.

We will be looking at the house using our daily data below but first let us look at the house efficiency over a much longer period using our monthly utility bills.

Efficiency calculations from Utility bills

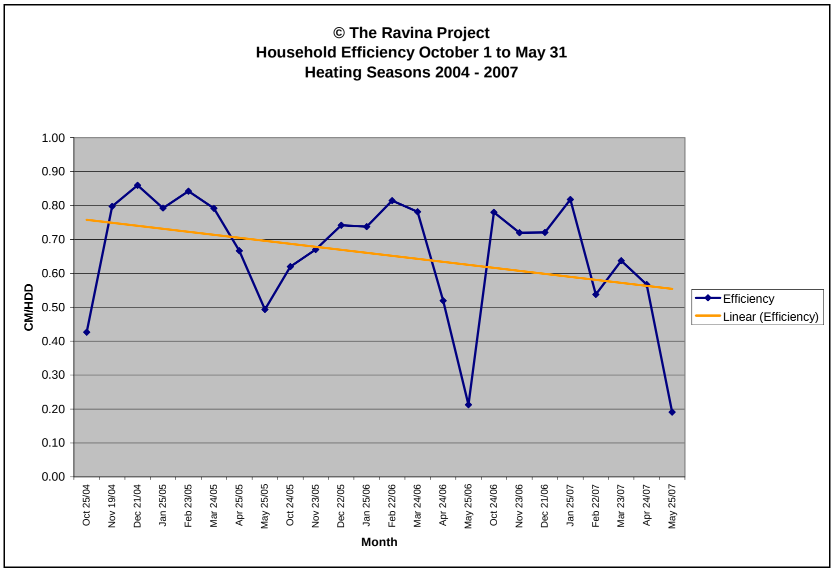
Let's look again at the chart we included above.



Notice that the chart divides easily into two parts; the first three winters and the last four. If we plot each section, independently, we get noisier graphs shown below.

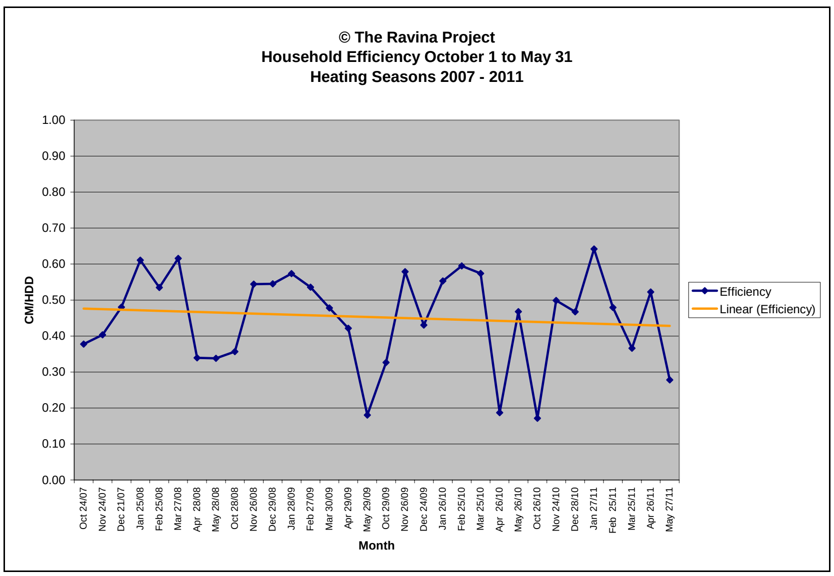
Heating seasons 2004 to 2007

This graphic has much more information on it and allows us to get a better idea of the changes in monthly household efficiency in the three year time frame. Note the changes we made during this time frame were internal changes to the house heat flow. Our efforts were successful; our household efficiency increased.



Heating seasons 2007 – 2011

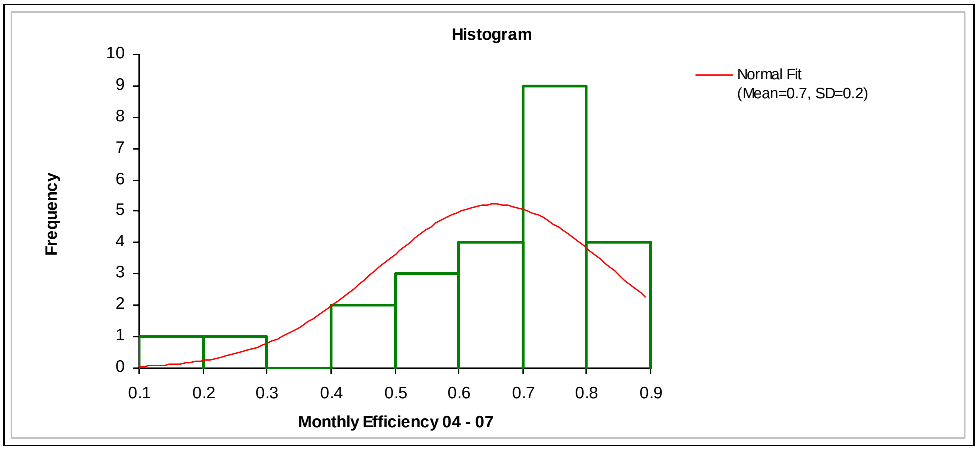
We see a substantial change in the next four seasons. Note the changes in efficiency were the result of changes to the structure of the house plus more internal heat flow modifications.

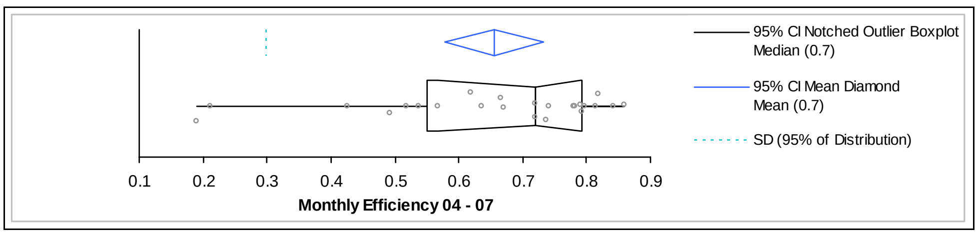


Let’s crunch these data statistically and see that’s happening over these two groups of heating seasons.

Winters 04-07

We unleash our purchased stats package from **Analyse-it** on these 24 months of data to give us a better understanding.



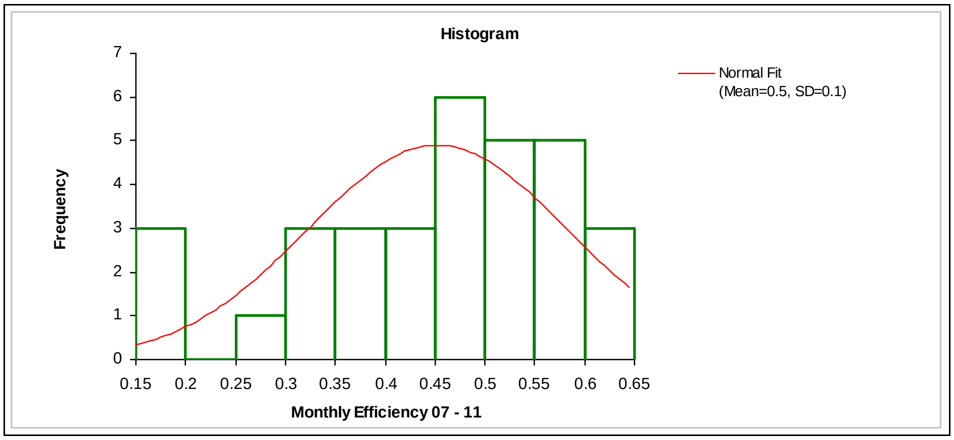


n	24				
Mean	0.656		Median	0.720	
95% CI	0.578	to 0.733	97.7% CI	0.567	to 0.792
SE	0.0374				
			Range	0.67	
Variance	0.034		IQR	0.242	
SD	0.183				
95% CI	0.142	to 0.257	Percentile		
			0th	0.191	(minimum)
CV	27.9%		2.5th	-	
			25th	0.550	(1st quartile)
Skewness	-1.33		50th	0.720	(median)
Kurtosis	1.34		75th	0.792	(3rd quartile)
			97.5th	-	
Shapiro-Wilk W	0.86		100th	0.860	(maximum)
p	0.003				

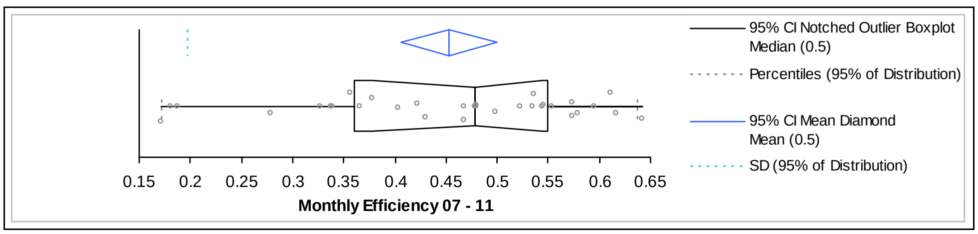
We see the data is skewed (-1.33) to the top end with the median higher than the mean. The mean efficiency for these three heating seasons is 0.656 with a Confidence Interval of 95% between values of 0.578 and 0.733. That is, there is only one chance in 20 that the 'true' mean value lies outside this range.

Winters 07-11

Consider the following look at the stats for the next 32 months of data.



There is a dramatic change in the shape of the histogram.



n	32				
Mean	0.452		Median	0.479	
95% CI	0.405	to 0.499	98.0% CI	0.378	to 0.544
SE	0.0230				
			Range	0.47	
Variance	0.017		IQR	0.189	
SD	0.130				
95% CI	0.104	to 0.173	Percentile		
			0th	0.172	(minimum)
CV	28.8%		2.5th	0.173	
			25th	0.361	(1st quartile)
Skewness	-0.71		50th	0.479	(median)
Kurtosis	-0.26		75th	0.550	(3rd quartile)
			97.5th	0.638	
Shapiro-Wilk W	0.93		100th	0.642	(maximum)
p	0.050				

This is an entirely different set of data. We are making progress in our quest to make the house more efficient.

Let's consider the change in mean efficiency. The 95% Confidence Interval for the mean in the first group of 24 months runs between .578 and .733. For the last 32 months the mean lies between .405 and .499 with a 1 in 20 error possibiliy, two standard deviations away. As you can see these two data sets are so far apart the possible values for the means do not overlap, even 2 standard deviations (95%) away.

Statistically, from our monthly utility bills we have been successful in placing the house on quite a different efficiency pathway. All our efforts contributed in a variety of ways.

We thought that the efficiency was problematic by being 'over the top' during the winter of 07-08. We re-checked our numbers. However, upon reflection we believe that wind chill played a role too.

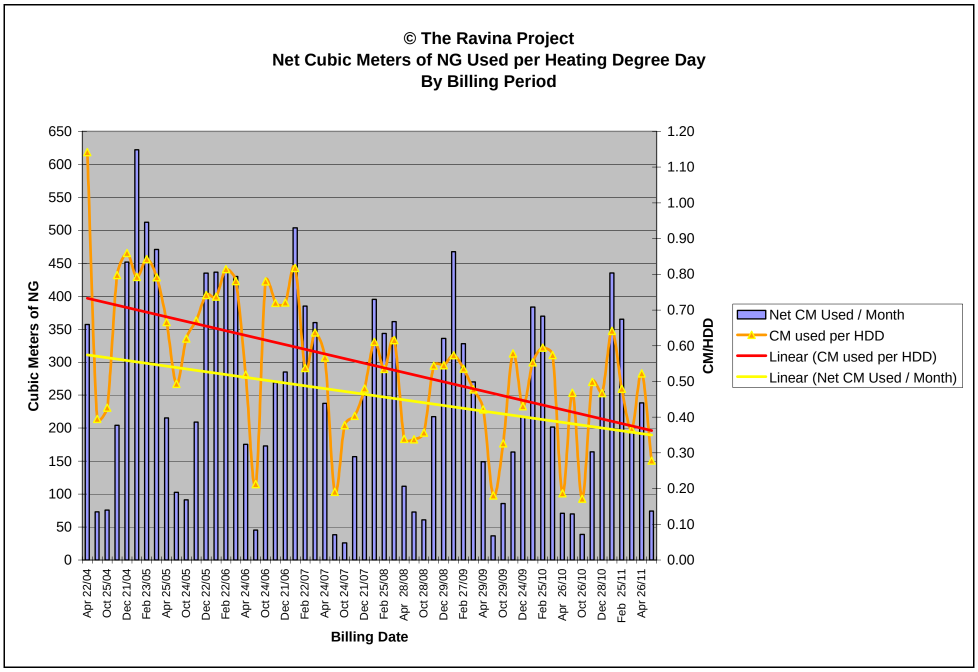
In the picture our house on the left has the siding and the neighbour's house has the brick. The distance between the houses at the back is about 1.5 meters at the most which is shown in the picture. At their front, the houses are at most 25 cm apart. The space between the houses is a long wedge shape. This closeness provides an avenue for air to travel whenever the air pressure is different between the backs of the houses and their fronts. The prevailing winds come from the rear. Our second floor at the back of our house had the coldest wall.

It is our hypothesis that the Venturi Effect is in operation, increasing the incidence of wind chill in the wintertime over our least insulated wall. Adding, more or less, air proof siding over foam insulation minimized heat loss due to wind chill.

This minimized wind chill effect, which we have no way to measure or to capture in our data, provides us at least theoretically, with some explanation as to why covering only 20% of the house's surface returns about a 20% gain in efficiency. Sure it was a leaky wall, that's why we covered it first, but it was a leaky wall constantly exposed to higher winter wind speeds, a condition unlike any other wall.

We are not sure how much the fellow on the right was involved to boost wintertime efficiencies. But we do know that he's a great foot warmer on those cold nights. ☺

This chart below pulls it all together.



Let's unpack this chart.

The **vertical blue** lines represent our net natural gas usage, that is, our monthly gas usage minus our baseline usage for cooking etc. Use the scale on the left side of the chart to read their individual values.

The **orange** line represents our monthly efficiency based upon Heating Degree Days. Use the right side scale to read the individual values. Note the efficiency scale is 'inverted' in that a lower value represents better efficiency than a higher value.

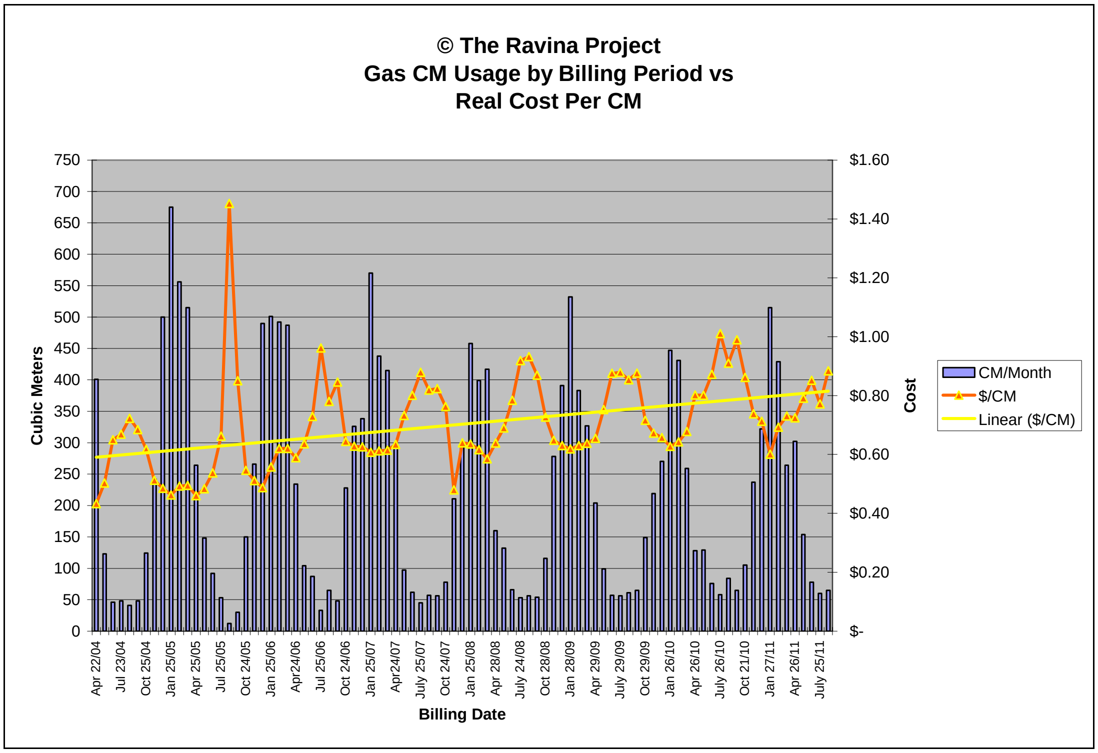
The **red** line represents a linear curve fit to the efficiency curve.

The **yellow** line does the same for the monthly net use of natural gas.

Eyeballing the chart above, it is obvious that we are using less natural gas and the house is becoming more efficient.

It also highlights a curious anomaly. We all know about making bulk purchases. If we purchase more we get a per unit price break. And as you can see below there is a huge penalty for conserving natural gas consumption. In the same season unit gas prices can vary from below $0.20 to about $0.65. This is a huge premium to pay for conservation.

As Global Warming starts biting us even more than today, carbon release will migrate to the top of the list for the world wide community to deal with. Some serious thought should be given to how people will be incentivised on a per unit basis to reduce their carbon release for heating at this latitude.

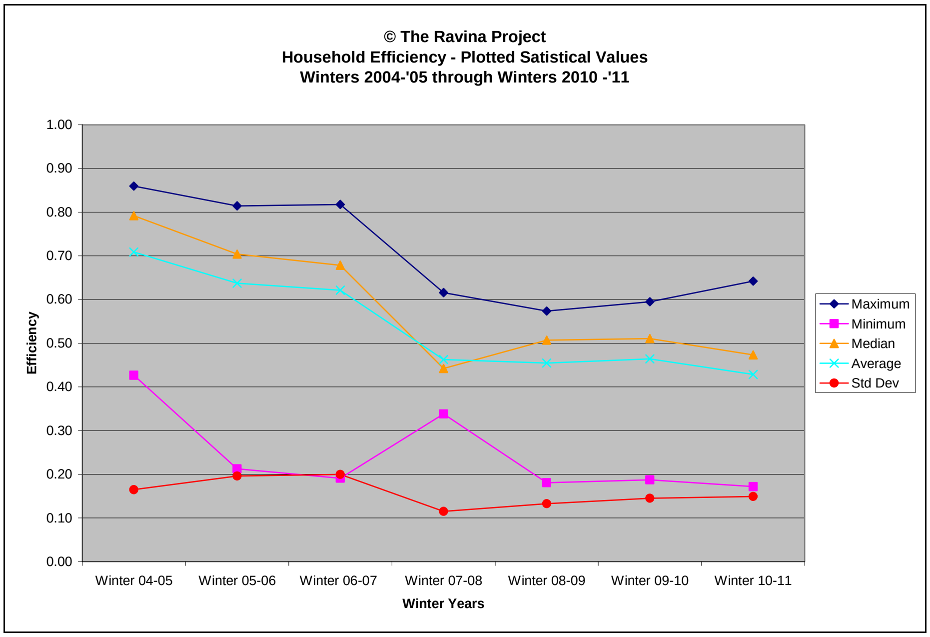


This should be inverted. That is, as the household saves CM usage the cost per unit to the user should decrease. What's the standard that each household should be measured by to determine their savings? Your utility has a very good understanding of your household energy usage. In fact here, our NG utility only reads the meters every two months but bills us every month. The month in which there is no actual reading taken, their estimate of our usage is really close to actual usage. The point being that the utility has all your household data in its databases.

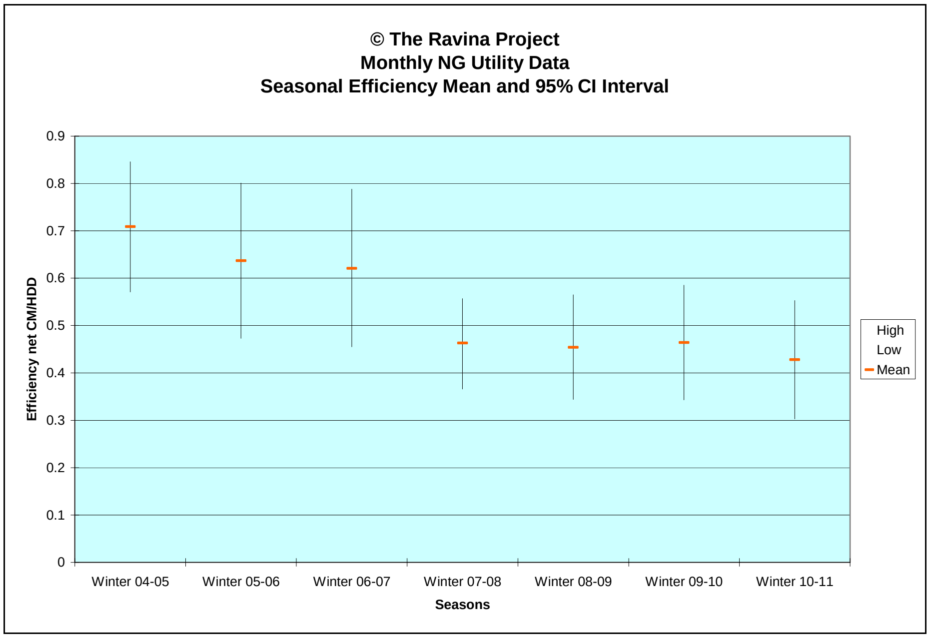
It becomes trivial to calculate any savings over a baseline your household may make.

There are many other ways to tackle this issue fairly as well.

Here is a graphic that plots five stats for each year of data.



In this graphic below, each winter's mean is plotted with its 95% Confidence Interval.



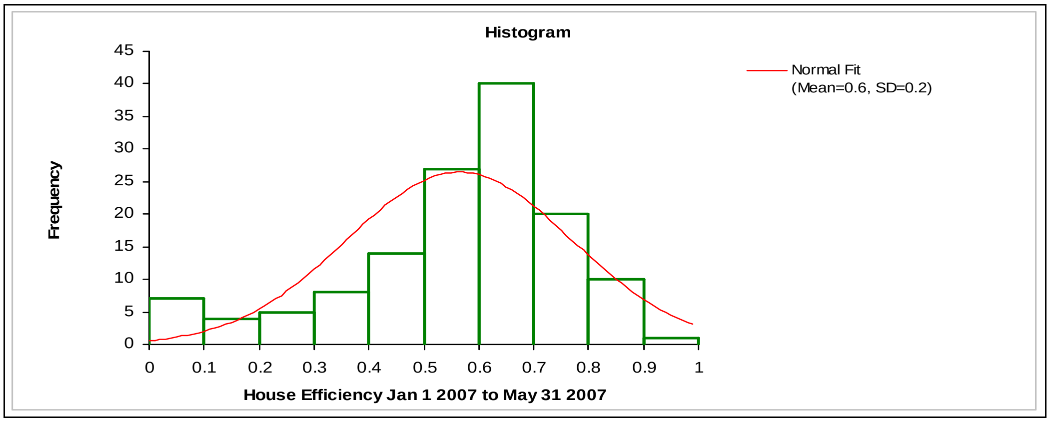
All in all, we have placed our household on a different wintertime efficiency trajectory going forward. Note how far the baseline year (04-05) is away, statistically, from winters since 2007 – 2008.

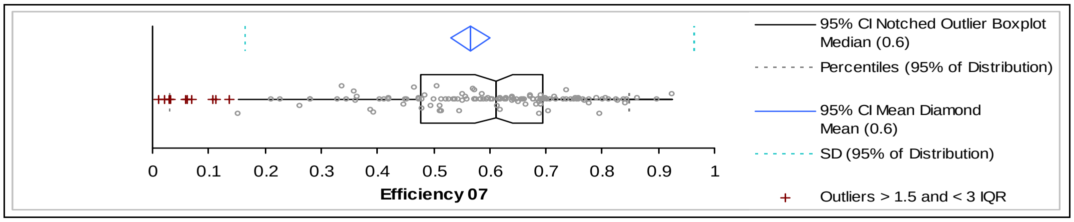
This ends our efficiency analysis using monthly utility data. The next section uses our daily data, a different and totally separate data set, to statistically evaluate the changes in our wintertime household efficiency.

Efficiency calculations from our daily observations

House Efficiency for Heating season January 1st, 2007 to May 31st, 2007

Consider the following analysis of 136 daily observations between January 1st, 2007 and May 31st, 2007. These data consist of 5/8ths of the 2006 – 2007 heating season at this latitude. They represent the start of our ability to calculate our daily household efficiency. Prior to this we could only calculate monthly household efficiencies based upon our utility bills.





n	136				
Mean	0.564		Median	0.610	
95% CI	0.530	to 0.599	95.2% CI	0.574	to 0.642
SE	0.0176				
			Range	0.91	
Variance	0.042		IQR	0.217	
SD	0.205				
95% CI	0.183	to 0.233	Percentile		
			0th	0.011	(minimum)
CV	36.3%		2.5th	0.031	
			25th	0.477	(1st quartile)
Skewness	-1.02		50th	0.610	(median)
Kurtosis	0.67		75th	0.695	(3rd quartile)
			97.5th	0.850	
Shapiro-Wilk W	0.92		100th	0.926	(maximum)
p	<0.0001				

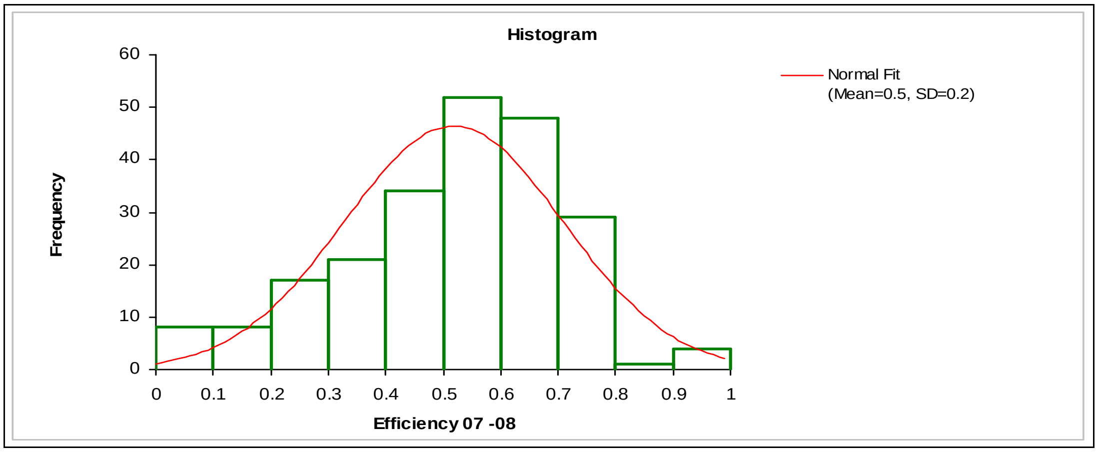
The mean's 95% CI is between 0.530 and 0.599. In a sense this is our baseline year going forward in time with this data set.

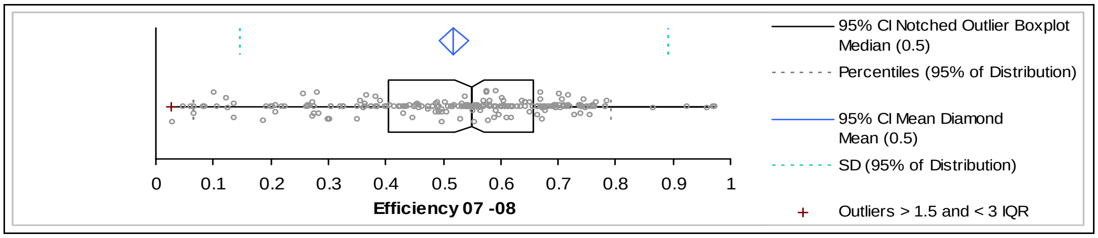
The data values recorded during this period are the only daily data we have in our database gathered before we put insulation and siding on our coldest wall. Our internal changes to the house to that point consisted of the curtain between the kitchen and the porch plus the two electric heaters, one on the porch and the other in the kitchen.

Note as well the number of days with gas usage equal to or over 15.0 CM is 34 out of a database of 151 days or about 22.5% of the days. That corresponds to at least 155.3 kWh per day net of any other energy used. We used more because this total does not include electrical energy and baseline NG usage. Anyway, we just want to make the point that 155 (plus) kWh is a lot of energy to use in a house this small. So days when we use 155 or more are significant.

House Efficiency for Heating season October 1st, 2007 to May 31st, 2008

Consider the following chart of 222 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.





n	222				
Mean	0.518		Median	0.549	
95% CI	0.493	to 0.543	96.3% CI	0.520	to 0.572
SE	0.0128				
			Range	0.95	
Variance	0.036		IQR	0.251	
SD	0.191				
95% CI	0.175	to 0.210	Percentile		
			0th	0.027	(minimum)
CV	36.8%		2.5th	0.068	
			25th	0.406	(1st quartile)
Skewness	-0.55		50th	0.549	(median)
Kurtosis	0.12		75th	0.657	(3rd quartile)
			97.5th	0.795	
Shapiro-Wilk W	0.97		100th	0.973	(maximum)
p	<0.0001				

We gathered data over the heating season when all the internal household modifications like the curtain and heaters were in place. These 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.

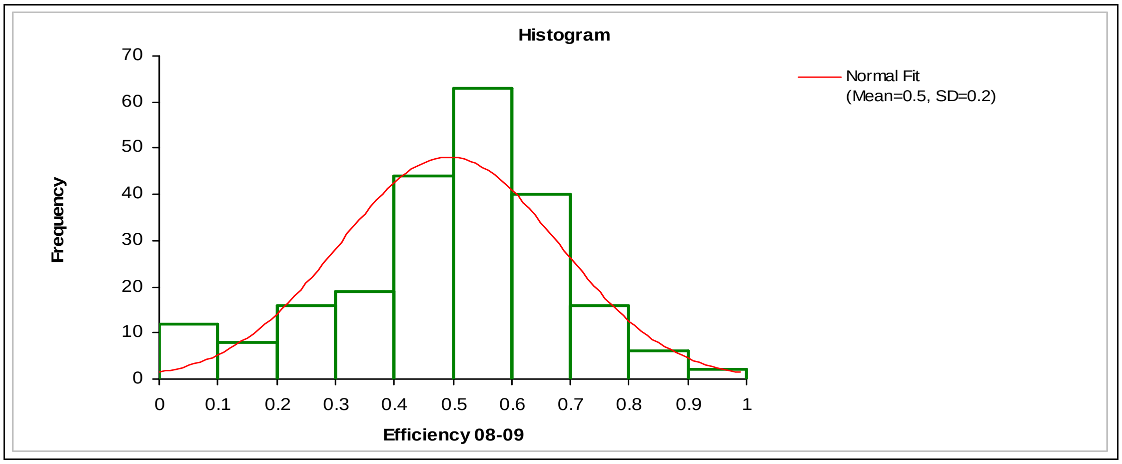
From the raw data the number of days with net gas usage greater or equal to 15.0 drops from 34 over 140 days to 13 over 223 days. Or in percentage terms the number of days which usage is greater or equal to 15.0 CM drops from about 30% to about 5.8 %. This is a dramatic fall.

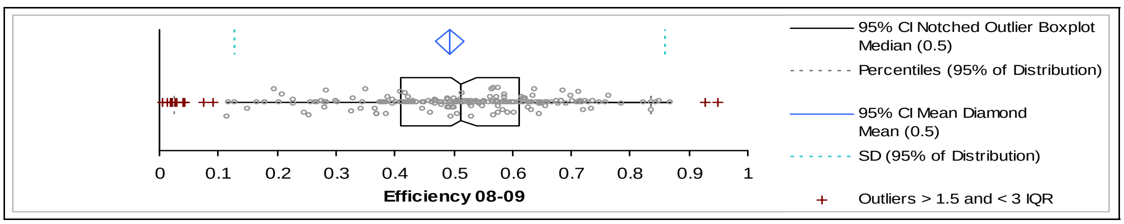
The covered wall accounted for about 20% of the outer surface area of the house. This dramatic change, all else being equal, demonstrates just how much heat loss occurred from the house through that poorly insulated wall. The wall was original, had fallen into disrepair and unmodified since the house was constructed.

The mean's 95% CI falls to between 0.493 and 0.543 CM/HDD. Note that this CI just barely overlaps the previous heating season's values of between, 0.530 and 0.599. This is a huge change. The data in general are skewed more toward the center as seen in the histogram (from -1.02 to -0.55).

House Efficiency for Heating season October 1st, 2008 to May 31st, 2009

Consider the following chart of 226 daily observations over the heating season 2008 and 2009. During the summer of 2008 we covered the rest of the second story in R 2.81 foam insulation and siding over it.



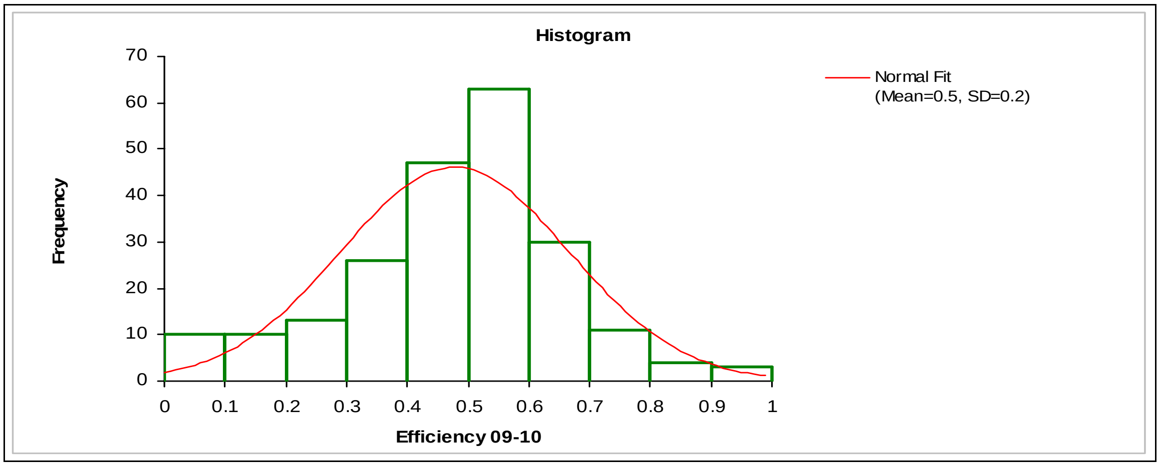


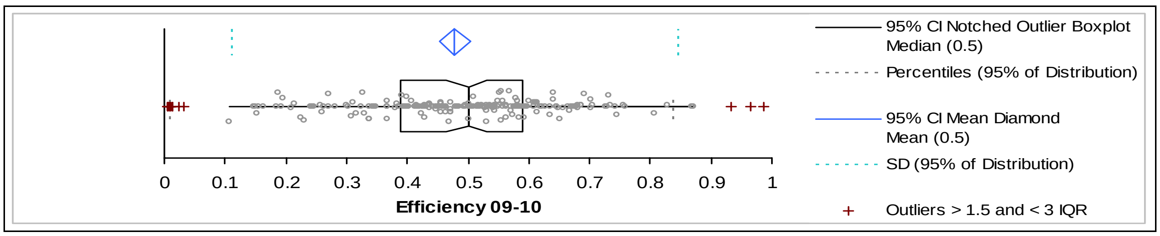
n	226				
Mean	0.493		Median	0.512	
95% CI	0.469	to 0.518	96.1% CI	0.497	to 0.538
SE	0.0125				
			Range	0.94	
Variance	0.035		IQR	0.202	
SD	0.187				
95% CI	0.171	to 0.206	Percentile		
			0th	0.006	(minimum)
CV	38.0%		2.5th	0.028	
			25th	0.411	(1st quartile)
Skewness	-0.64		50th	0.512	(median)
Kurtosis	0.49		75th	0.612	(3rd quartile)
			97.5th	0.837	
Shapiro-Wilk W	0.96		100th	0.950	(maximum)
p	<0.0001				

The mean falls to 0.493 CM/HDD with the 95% CI between 0.469 and 0.518. We have left far behind any overlap with the baseline 95% CI range of between 0.530 and 0.599.

House Efficiency for Heating season October 1st, 2009 to May 31st, 2010

Consider the following chart of 217 daily observations over the heating season 2009 and 2010.



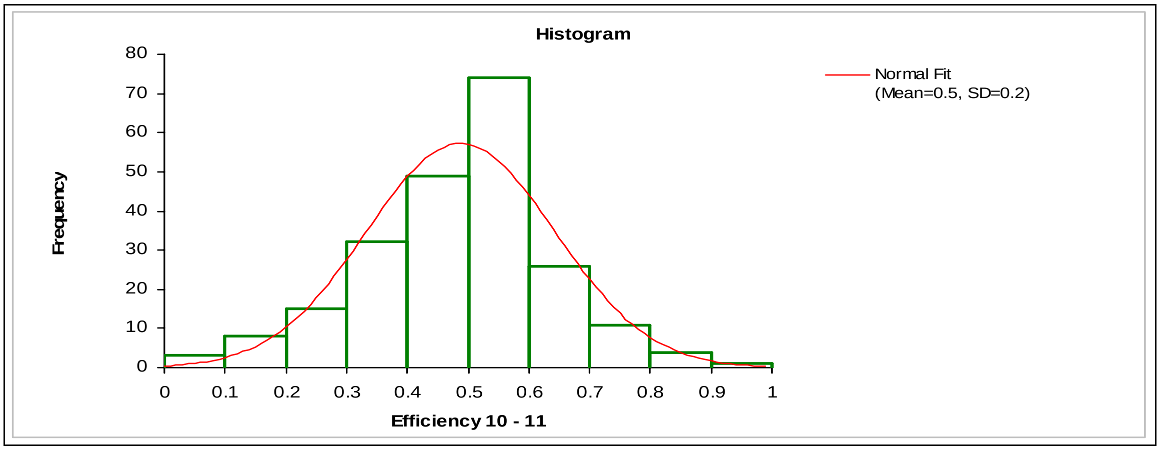


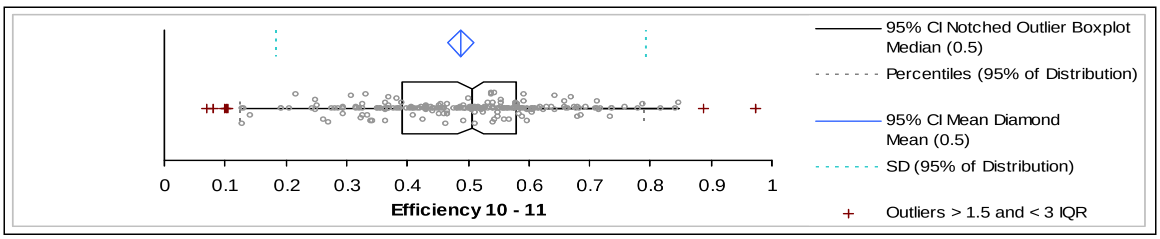
n	217				
Mean	0.478		Median	0.501	
95% CI	0.453	to 0.503	95.9% CI	0.465	to 0.530
SE	0.0127				
			Range	0.98	
Variance	0.035		IQR	0.199	
SD	0.188				
95% CI	0.172	to 0.207	Percentile		
			0th	0.006	(minimum)
CV	39.3%		2.5th	0.011	
			25th	0.390	(1st quartile)
Skewness	-0.45		50th	0.501	(median)
Kurtosis	0.55		75th	0.589	(3rd quartile)
			97.5th	0.839	
Shapiro-Wilk W	0.97		100th	0.985	(maximum)
p	0.000				

The mean and its 95% Confidence Interval retreats even further from baseline values.

House Efficiency for Heating season October 1st, 2010 to May 31st, 2011

Consider the following chart of 223 daily observations over the heating season 2010 and 2011.





n	223				
Mean	0.488		Median	0.506	
95% CI	0.467	to 0.508	95.6% CI	0.482	to 0.526
SE	0.0104				
			Range	0.90	
Variance	0.024		IQR	0.190	
SD	0.156				
95% CI	0.142	to 0.171	Percentile		
			0th	0.071	(minimum)
CV	31.9%		2.5th	0.126	
			25th	0.390	(1st quartile)
Skewness	-0.22		50th	0.506	(median)
Kurtosis	0.51		75th	0.580	(3rd quartile)
			97.5th	0.790	
Shapiro-Wilk W	0.99		100th	0.972	(maximum)
p	0.027				

The mean actually increases in value over the previous year but notice the SE value decreases indicating that the mean's 95% CI values are grouped closer around the mean. The big changes to internal heat flow were many: the repositioning of the thermostat, the use of a computer based thermostat rather than a manual one, the use of a curtain between area 2 and area 3 and the use of a folding door between areas 3 and 4. The changes are too radical to get a complete understanding with only one year of data. We will run unchanged for the heating season 2011 – 2012 and for several years thereafter. We believe we have finished modifying our wintertime internal heat flow or, to put it better, we are out of ideas for internal heat flow modifications. ☺

This ends our efficiency analysis using our daily data set.

Grid Support

The household thermodynamics part of our project has meant that we only 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 as electrical energy. In the summer of 2009 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 tables.

Monthly Energy Generation Analysis 2010 © The Ravina Project

Month	Gen	Used Grid	Used Gen	% Gen	To Grid
January	71.9	587.1	62.9	11.1	9.0
February	77.2	575.3	67.2	12.0	10.0
March	157.8	407.5	112.8	30.3	45.0
April	198.7	164.6	131.7	67.1	67.0
May	204.4	336.1	155.4	41.6	49.0
June	182.3	240.0	138.3	48.2	44.0
July	212.5	424.0	183.5	35.0	29.0
August	183.9	439.9	166.9	30.3	17.0
September	123.2	394.5	101.2	24.9	22.0
October	109.7	409.2	83.7	22.3	26.0
November	96.6	660.8	84.6	13.0	12.0
December	57.2	905.4	54.2	6.0	3.0
Total:	**1675.4**	**5544.3**	**1342.4**	**24.3**	**333.0**

Monthly Energy Generation Analysis 2011 © The Ravina Project					
Month	**Gen**	**Used Grid**	**Used Gen**	**% Gen**	**To Grid**
January	53.8	997.8	50.8	5.1	3.0
February	83.6	840.1	74.6	9.1	9.0
March	150.2	764.0	130.2	16.8	20.0
April	134.1	486.7	113.1	22.4	21.0
May	157.7	303.3	125.7	36.8	32.0
June	200.7	256.1	168.7	47.2	32.0
July	211.2	447.1	186.2	33.4	25.0
August	173.9	330.9	143.9	36.6	30.0
September	136.0	320.6	108.0	31.7	28.0
October					
November					
December					
Total:	**1301.2**	**4746.6**	**1101.2**	**22.3**	**200.0**

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.

We can't use any Watts pushed back to the grid. 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 switch back to using Grid power, the Watts we have placed on the Grid have been used by, most probably, one of our neighbours.

Summertime at the Ravina Project

We are adding this new section to our paper because of Global Warming. Summertime heat is an issue now and will be more of an issue going forward. Just as we have concentrated on reducing our reliance on carbon to heat our home we hope, in this section, to explore efficient ways to make our home cooler. Since most places have a carbon component to their electrical Grid power, we are searching for ways to reduce our electrical energy use for cooling and pass on those ideas in this new section.

We will attempt to calculate a meaningful household efficiency but instead of our wintertime efficiency, measured in net cubic meters of natural gas used per Heating Degree Day (CM/HDD), we will use a different metric. The local weather office publishes a daily total called Cooling Degree Days, which are calculated by subtracting 18C from each summertime 24 hour daily mean temperature. It then is possible to construct a summertime efficiency for the household by calculating the net energy used each day, i.e. daily energy use minus a baseline, and then use the resulting value in the daily efficiency calculation.

There is more discussion below on that and other related topics.

Inventory of cooling technologies we employ

Here's an exhaustive list of the technologies we use to keep our house cool in the summertime.

- **Basement dehumidifier** – This is an 'energy star' appliance built to work efficiently.
- **Basement low velocity, high volume oscillating fan** – This fan is on a timer and ON for 12 hours a day to mix up the air in the basement during certain kinds of weather so that humid air pockets do not form.
- **Exhaust fans in both the kitchen and second floor office** – these double fans are placed at the highest points in both rooms/floors. They expel the least dense air that accumulates near the ceiling.
- **Window reflectors** – We constructed sun reflectors to be placed in the windows which receive the most morning sun. They are light and are removed when the sun changes its angles upon the house. See the Appendix for more info.
- **Master bedroom 5000 BTU in-window air conditioner** – This is an Energy Star appliance. It is very efficient in cooling and dehumidifying air.
- **Master bedroom overhead fan** – This fan moves the air in the master bedroom allowing for better sleep in hotter weather.
- **Master bedroom input fan** – This is a small 10 inch low velocity (quiet), high volume fan placed in the window to draw in cooler, denser night time air to the bedroom and to flush out hotter bedroom air.
- **Portable 10,000+ BTU air conditioner on first floor** – This is portable (on wheels) air conditioner that is very powerful at both cooling and dehumidifying air.

The Physics of household summertime cooling

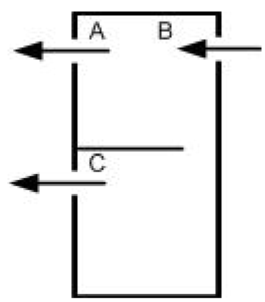
There are two ideas to keep in mind when looking at your own house and trying to understand the summertime heat flow through it:

- dry air is more dense that humid air, and
- cool air is more dense than warm air.

Left to its own a parcel of dry air will settle through a volume of humid air just because it is heavier than the humid air. The same activity occurs between a parcel of cool air and a volume of hot air. The interesting thing about air conditioners is that they produce both cooler and dryer air, doubling up on the air's potential density increase.

Our house as a chimney

Our analysis of heat flow in the summertime is very different than that done in the wintertime. We want to keep heat and humidity out of our house in the summer time. We want the exact opposite in the winter. Our wintertime insulation keeps heat out but unlike the wintertime, the summertime windows are open for much of the day for weeks at a time in some years. A good description of the household heat dynamic / efficiency is totally different and much more challenging than the wintertime analysis.



Our heat analysis has convinced us that our house acts like a giant chimney such that dense air gathers at the bottom and less dense air gathers at the top on each floor and throughout the house as a whole.

Consider a simplified diagram of our house. The house is two boxes attached together with a staircase providing the opening for air movement between floors. In the kitchen we have a set of exhaust fans running to expel less dense air from the room, marked as 'C'.

The kitchen is a hot spot even when cold meals are prepared. The refrigerator dumps the heat it takes from its insides into the room. I can reach behind my fridge to touch a rather hot radiator. It's probably true that the fridge works harder, that is its radiator is hotter during the summer months. That's probably because the ambient air temperature surrounding the fridge is hotter than in the wintertime. As well, other appliances/electronics like the toaster/kitchen TV and the like add to the kitchen heat load presented by heat sources in the kitchen that have nothing to do with using the stove.

The exhaust fan at 'C' is very important because it is in a location which is a constant heat generator for the household during the cooling months. It can be separated from the rest of the house by a drawn, thick curtain. The heat tends to stay in the kitchen when it is drawn. In the wintertime the curtain is opened to allow for cooking heat migration into the rest of the house.

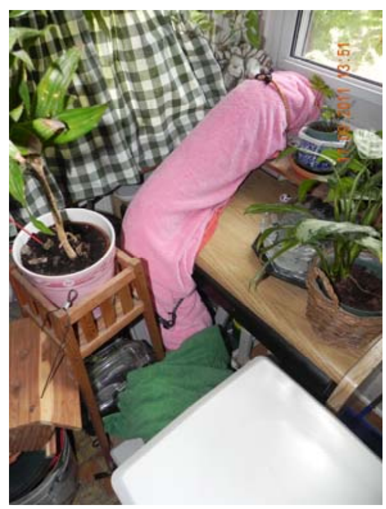
Here's a picture above of our exhaust fans in the kitchen. They have hand IR controls that allow for independent fan control of its speed and direction. On this day, and for the majority this summer, the ambient heat/humidity was such that it was cooler in the kitchen if fresh air was brought in and the hot air on the ceiling, exhausted. Note the open window.

Some of the hotter and wetter air gets out of the kitchen and travels up the stairwell. It rises to the tops of the rooms and gets picked off by the exhaust fan on that floor at location 'A'.

At location 'B', on hotter, muggy days, all windows in the house are closed, the exhaust fans are running on their high setting and the in-window 5000 BTU air conditioner is pumping out cool, dry air that sinks to the floor on the second story, goes down the stairwell and displaces the less dense hotter/wetter air. On these days, the force of cool, dry air from that small AC unit is felt on the main floor within an hour of the house being closed and it being turned ON.

On days, few in number, where the Humidex air temperature is well in excess of 100 F or 38 C the 5000 BTU window unit just can't keep up with the heat and humidity. During these intense days, which may last for a week, we engage the downstairs 10,000 BTU air conditioner.

This is a monster unit. Its cooling and dehumidifying abilities are huge. We hook it up to the window where it uses a large diameter flexible hose to flush hot air from its condenser fins to the outside. There are two downsides when using this kind of AC that you should know about.



Firstly, the unit uses inside air to cool its condenser fins which means air is constantly being taken from the inside of the house and pumped as hot air to the outside. The unit therefore gives the house a slightly negative internal air pressure as compared to outside. This means of course that hot, humid outside air will tend to be sucked into the house. We tried this AC unit on the second floor and found that it did not cool because the hot humid air sucked into the house quickly rose to the second floor negating the cooling effects. Using this unit on the first floor in conjunction with the exhaust fans and second floor 5000 BTU unit, we had no problem with this effect.

Secondly, the flexible tube carrying the hot air from the unit to the outside is very hot and radiates a huge amount of heat over its length. We found we had to wrap this length of tube in towels in order to insulate it and keep the heat out of the house.

Once the modification was made the unit worked extremely well. We only needed it for a few days all summertime. If you haven't already noticed we use a layered approach to make our summertime house a fun place to live. As the weather makes more demands upon the house's cooling abilities, we engage more and more technology to offset those demands. We believe that this approach allows us to use the cooling technology we have in the most efficient ways. A house too warm/humid is not a fun place to be. One too cold and dry is not fun either and besides energy is being wasted. Our layered approach is one that we believe allows us to tailor our energy expenditure to the thermodynamic demands placed upon us by the weather.

Anyway back to our discussion.

So this is the chimney effect. Dense dry/cool air fills up the chimney from the bottom and displaces the thinner hotter/humid air which rises and gets picked off by the exhaust fans on both floors.

The important thing to note is that the fans seem to work quite well by themselves without AC help across many ambient heat environments. In fact it's only when humidity gets involved in the ambient conditions, that technology other than fans are required, for the most part.

The very base of the chimney is the basement. On very humid days the basement windows are closed. They are all modern double pane windows. On other days the windows are opened to allow the room to air out. On very hot and humid stretches of time the basement is closed and the basement dehumidifier is activated. The level of humidity that is set as a limit on the dehumidifier is important when energy is considered. The dehumidifier takes about a half a kW in power. It has a refrigeration unit in it. If we run our basement too dry we use a huge amount of energy for no purpose. And of course, the other thing that gets lost is that the compressor has a hot side, as all compressors do. The hot side has a fan the blows the heat off the condenser fins and into the basement. The dehumidifier is a heat source in a house optimized for cooling! There are times when I have been shocked at how warm the basement had become when the unit was set to maintain a 'too dry' basement.

Ground floor cooling issues are basically solved with cooling the kitchen properly. The kitchen has the greatest sources of heat, is separated as required from the rest of the house with a curtain and has its own double exhaust fans plus lots of modern windows that can open wide. When the curtain is open and the exhaust fans working, less dense air from all across the first floor travels into the kitchen and out the fan.

The second story exhaust fan is placed critically because it cools a room that has a big tube monitor in it. This monitor is a significant heat source. It's mine … and I'm looking at it right now as I write this …I love CRTs, hehe.

There are other second floor cooling issues.

This is the warmest floor. If the outside air is not too humid there is a good chance that it is as cool or noticeably cooler than the internal temperature on the second floor. We are surrounded with large 57 foot, or so, trees which shade the house from afternoon sun and provide a cooler microclimate via their transpiration.

As well, keep in mind that hotter parcels of air migrate up the staircase from the first floor to the second floor ceiling and eventually find their way into the computer room only to be expelled by the fan. It does make a substantial difference on an overwhelming number of summer days we have here in Toronto. See our monthly electrical energy charts on our WEB site: www.theravinaproject.org .

So what happens during the evenings when we are trying to sleep? The fans cool the first floor as much as they can and do well … on the first floor, but still many nights are warm on the second floor … to warm to sleep.

How do we deal with that?

We like to run an overhead fan plus, on still nights that are too warm inside, a fan that brings air into the room from outside. From the picture we fit a small fan in the open window and run the overhead fan. The combination provides much cooling at a fraction of the energy cost of AC being used.

We think that having a cool room during the day to retire to or to nap or even to cool off in is a good thing to have on very hot and humid days. Many times a cool shower and a few minutes spent in a room that is cooler and has much less humidity can revive one to the point that going back into the heat and humidity and doing limited work is not stressful. We call it our Cool Room. We cool off and nap in it. We use this strategy on days that are on the verge of being major cooling days when we engage the large downstairs AC unit.

The interesting thing about using a cool room is that the AC unit, once the room has reached the temperature on the AC's thermostat, begins to cycle its compressor on and off. This occurs because the bedroom door is closed. At this point the AC unit starts drawing much less total electrical energy over say an hour. It settles into an energy drain such that its fan is ON all the time and the compressor is ON for 1 out of five minutes (I've timed it). The fan draws about 80 Watts and the compressor draws about 500 Watts. This cycling saves energy use. The room kept cool yet the energy draw falls to only about 20% of normal full blast AC.

Note that on days where we use the exhaust fans and the AC pictured above to cool the house in the chimney scenario described above, we do not want the compressor to cycle ON and OFF like it does in our cool room scenario. We want the compressor ON all the time because the unit is dehumidifying and cooling the complete house, a job way above its rated cooling potential. It works well in this regard with the help of the exhaust fans picking off the least dense air and changing the mix of the air left behind to favour denser air. In order to ensure the compressor does not stop we set the AC's thermostat at an unreasonably cool setting like 15C.

It's hard to imagine that such a small air conditioner in a second floor bedroom can make any kind of difference on a hot summertime day. We tried an experiment one day. We opened up the house and got it quite warm and humid inside … hard to do with the amount of insulation we have now. We closed the house up, turned ON the fans and the upstairs AC. I was working on this paper in the dining room on the main floor. It was so hot I was wearing just shorts. I was damp with sweat. It was a good setup though, because I wanted to feel when the lower part of the house started filling up with denser air. Within 30 minutes I felt cool and within an hour I had to change into more clothes. I was getting cold. The house is a chimney, and physics works. Hehe

Calculation of summer time kWh usage baseline

We have to devise a method which allows us to account, thermodynamically, for the summertime operation of the house. How many electrons does the house use just to run itself? Included in the house 'running itself' are all the electrically powered amenities we assume will be in operation day and night. Some of these amenities are labeled 'appliances', which seems to suggest that they are entirely optional. For instance, we install a fridge and it keeps stuff cold for us … especially the beer … hehe, but it has to work without fail every day. That performance requirement puts the fridge in the same class as the furnace which few would argue is not part of the house's infrastructure. Computers, DSL routers, data switches and WiFi Access Points fall into this same infrastructure class along with phones and lighting.

So the question is, how much do we use as a household when the only electrical energy being used by the house powers the house's infrastructure?

We know from our wintertime stats that changes in the household can affect the wintertime household thermodynamics. In the case of the wintertime, we calculate our baseline using data collected during the previous summer. We see this method as accounting for baseline usage changes brought about by changes in the household.

We want to duplicate this effort using our summertime numbers. But it is not obvious how to do it. In the summertime we are not using carbon to heat the house so statistically the carbon use for heating can be isolated; not so with electricity use! We use electricity during all seasons.

What we have done is to make an executive decision here. We figure that the house running without any kind of cooling like our exhaust fans are rare times. And indeed they are. They usually occur very early (and late) in the summer cooling season at this latitude and geographic location when the outside temperature is optimal both day and night. Every window is open on the house and it remains like that for several days. It's during these times we argue we probably are using the baseline amount of electrical energy per day.

We argue that, statistically, the baseline value is a rare, low end value because there are so few days in the summertime in which we use none of our cooling appliances. Looking over our data for each summer and our experience of hand logging our data for five summers, our intuition tells us that the real value for the household baseline electrical energy usage is at the very bottom end of our data. We have to be careful though and inspect our data. If we are off-grid for a period of time, the data gets skewed to the low end because we have no ability to measure how much the house uses independently of the utility and solar charge controller meters. So our data will have to go through a 'cleaning' cycle. More on that below.

We have decided a strategy: now what is the method?

We'll follow the method we use when calculating wintertime household efficiency but with a twist. Instead of calculating the baseline on the previous summertime usage, we will calculate the baseline on the current summertime usage. This paper will become a 'Fall' paper because we have to incorporate the summer data which has just passed. Other than that we'll follow the same method.

But there's a wrinkle in all this logic. How do we know that the minimum value for the daily summertime kWh usage is the correct value to use for the calculation of net kWh usage for that summer? Well we don't have another method to ensure this value is correct. Note that if we choose a baseline data value that is too small, the household efficiency calculation (Net kWh/CDD) shows a poorer result (less efficient) because the numerator is larger than it should be. Conversely, if the baseline value is too large, the household efficiency calculation will be too small (more efficient).

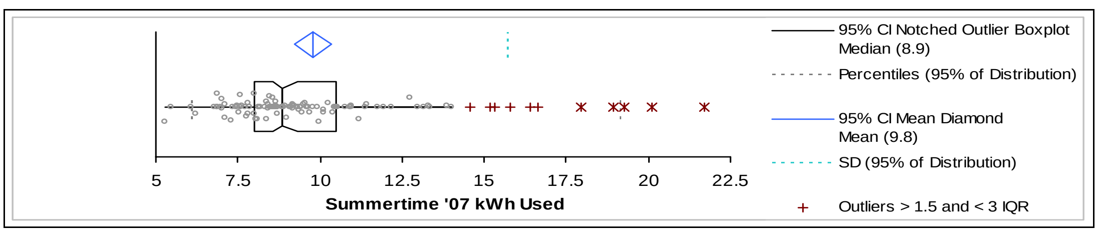
So what do we do? What do we know for certain when thinking about this issue? We know for certain that the value we want for baseline is located at the very bottom end of the stack of values for the summertime if we were to sort them with the lowest values on the bottom of the stack. The question is how far up the stack should we go to pick another value in order to have a reasonable likelihood that the 'real' or 'correct' value for the household's baseline is contained between those two values? If we look at the daily statistics for each of the summer cooling seasons we will find the lowest daily value and a value at 2.5% percentile. If we had 1000 sorted data values, we would select the value located at the 25th item from the bottom of the sorted stack as our high value.

What we are trying to do is generate a plausible range in which the 'correct' value lies. We can use this range to provide error bars in our charts. This is a statistical kluge and we admit it as such. However, if we do not make some kind of range choice here, we can't continue with our argument because we have not isolated our baseline value to a range. This is far more difficult to do than the wintertime baselines we have isolated. We do not want to pull a baseline value 'out of thin air' as it were. We see our developing a plausible baseline range of values as a better alternative. We believe that there is merit in continuing in this way; so we introduce this kluge, hold our noses and carry on. Hehe

So let's look at each of our summers and calculate these values.

Note we use our own commercial statistics package called: Analyse-it for our statistics work.

Here's a plot of the 2007 summertime kWh usage data:



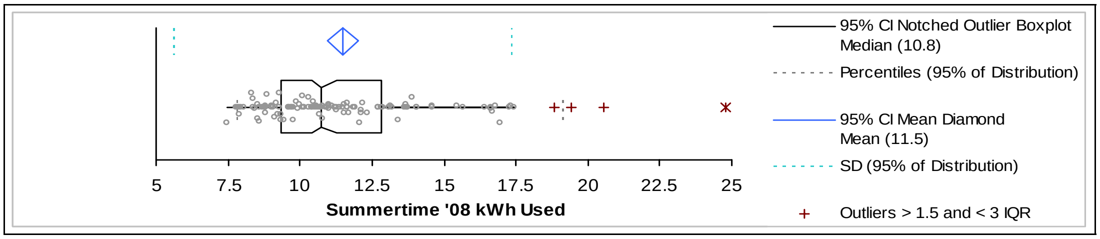
As you can see the bottom end contains just a few data values. See those big kWh values? Yup your are right … the 10K was ON or, the 5k and the dehumidifier put in quite a few hours those days.

If we look at the percentiles we get the following values:

Percentile		
0th	5.30	(minimum)
2.5th	6.12	
25th	8.00	(1st quartile)
50th	8.87	(median)
75th	10.47	(3rd quartile)
97.5th	19.16	
100th	21.72	(maximum)

So for 2007 we will use the range between 5.30 kWh and 6.12 kWh in which we are optimistic of finding the true baseline value for that summer.

The summer of 2008 looks like this:

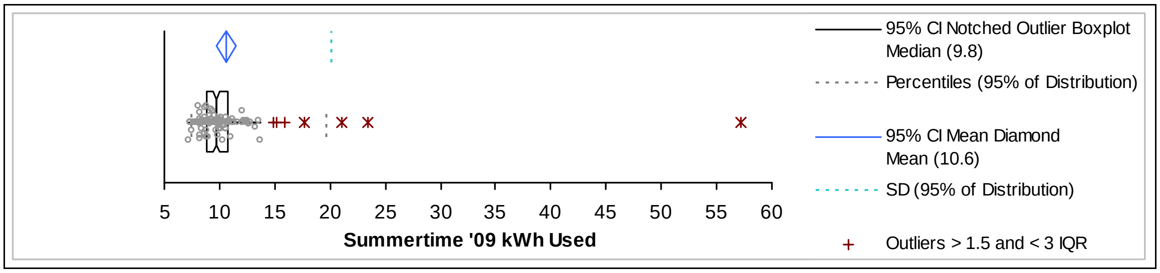


And the percentiles:

Percentile		
0th	7.452	(minimum)
2.5th	7.843	
25th	9.323	(1st quartile)
50th	10.758	(median)
75th	12.826	(3rd quartile)
97.5th	19.179	
100th	24.782	(maximum)

Our daily baseline range for 2008 is between 7.45 and 7.84 kWh.

The summer of 2009 looks like this:



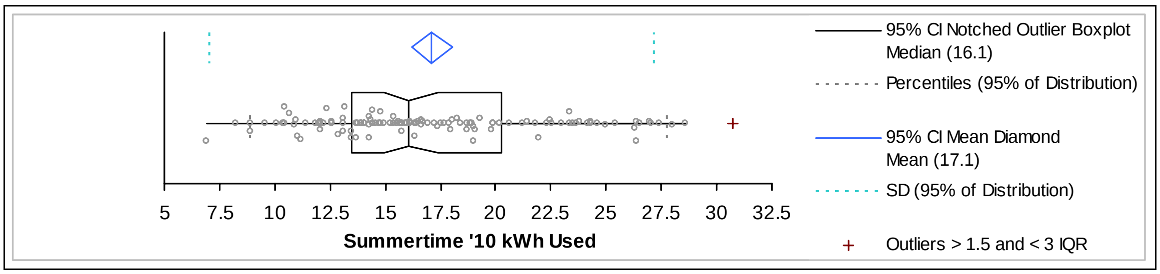
On one particular day it looks like we had everything ON … 57.3 kWh! … Yikes!!

The 2009 percentiles look like this:

Percentile		
0th	7.20	(minimum)
2.5th	7.45	
25th	8.82	(1st quartile)
50th	9.76	(median)
75th	10.79	(3rd quartile)
97.5th	19.71	
100th	57.26	(maximum)

The range of daily baseline values we will use for 2009 is between 7.20 and 7.45 kWh.

The summer of 2010 looks like this:

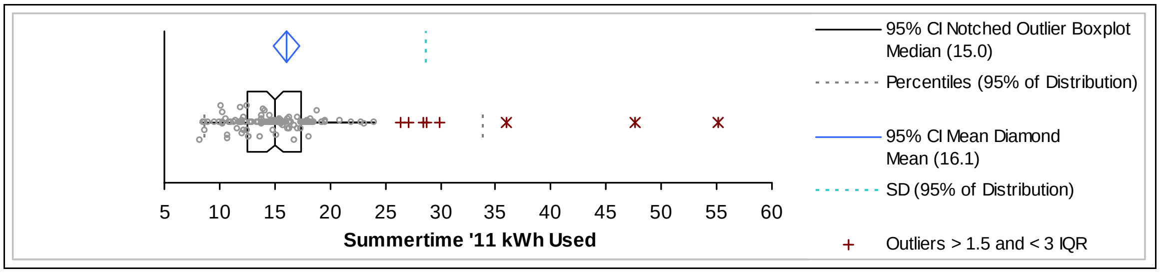


And the percentiles are as follows:

Percentile		
0th	6.90	(minimum)
2.5th	8.93	
25th	13.45	(1st quartile)
50th	16.06	(median)
75th	20.23	(3rd quartile)
97.5th	27.76	
100th	30.77	(maximum)

The range of daily baseline values we will use for 2010 is between 6.90 and 8.93 kWh

The summer of 2011 looks like this:

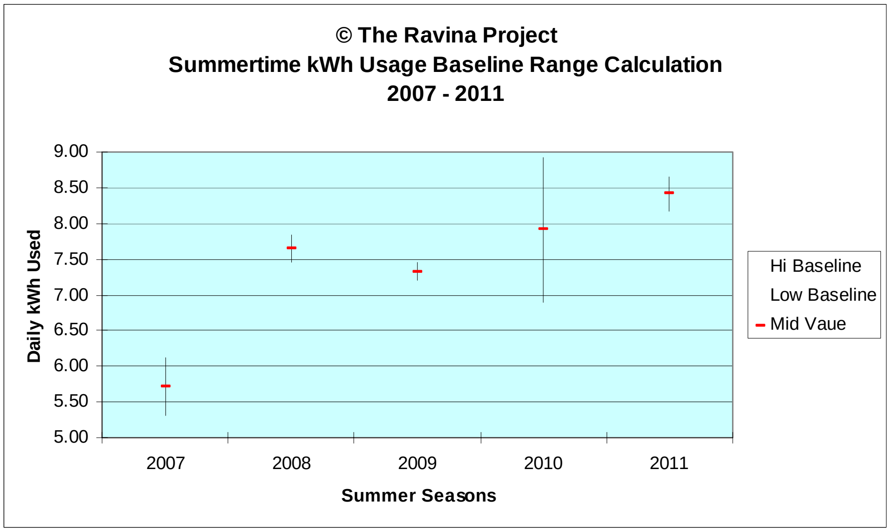


And the percentiles are as follows:

Percentile		
0th	8.17	(minimum)
2.5th	8.66	
25th	12.55	(1st quartile)
50th	14.97	(median)
75th	17.46	(3rd quartile)
97.5th	33.84	
100th	55.19	(maximum)

The range of daily baseline values we will use for 2011 is between 8.17 and 8.66 kWh

Here's the above data ranges in graphic form.



Data cleaning issues

In order to calculate our household efficiency which we describe as the ratio of net kWh used per Cooling Degree Day, we follow the same methods we used to calculate household efficiency using Heating Degree Days. We subtract the baseline from the actual daily recorded kWh used.

What happens to our data when we subtract the baseline from our daily kWh usage?

If we subtract our lowest baseline amount from the daily readings we will get at least one value of zero in the data set. If we use the value at the 2.5% percentile we will get several resulting values less than or equal to zero. What does it mean to use a negative number of kWh in a day to cool the house?

Note that these values are interim values. The next step in the process is to generate the number of Cooling Degree Days for each day of the summer. Just like in calculating the number of Heating Degree Days in the winter by subtracting the average (mean) daily temperature from 18 Centigrade, we use 18 C in a slightly different manner. We subtract 18 C from each 24 hour daily mean temperature for the whole summer. The result produces the Cooling Degree Days (CDD) generated for each day in the summertime. For instance, if the mean temperature for the day is 24.5 C, we calculate the CDD value as follows: 24.5 minus 18 equals 6.5 CDDs.

So let's calculate the house efficiency using 6.5 CDDs. Suppose we use 13.0 net kWh that day. Our efficiency is calculated as net kWh/CDD or 13.0 divided by 6.5 equals an efficiency of 2.0 kWh/CDD.

So far so good … what could possible go wrong with simple subtraction followed by simple division? Well, evidently lots!! Consider a day which has a negative number of CDDs. On these days the mean temperature for the 24 hour day is less than 18 C. This is a problem because the day is technically a Heating Degree Day but it is within the time of the year which we associate with Cooling Degree Days (CDDs).

What do we do with negative numbers?

As well, there are other issues. The denominator may be positive but it may approach zero. In this case the resulting fraction with any kind of positive number as the numerator may get very large. We are left with monstrously large numbers for efficiency. What does it mean to have an efficiency of 5 kWh for every CDD … especially when the efficiency data is grouped around, let's say, 1.7?

So we have two situations (negative numbers and large positive numbers) where anomalous data can play havoc with our analysis. There really does not seem to be any way to make these outliers 'fit' into the data set. They are real data but their outlier status will colour our statistical results.

We will eliminate all this data from our data sets. Our efficiency calculations will be completed with existing data but any value of zero or less and any value of 4.0 or more will be eliminated. Still 4.0 kWh per a 1 degree C mean temperature is a lot of energy to cool that 1 degree. It may be too large but we'll go with it in the paper and in subsequent papers we may revise it.

So our data cleaning method is as follows:

- Delete all negative or zero efficiencies
- Delete all efficiencies over or equal to 4.00

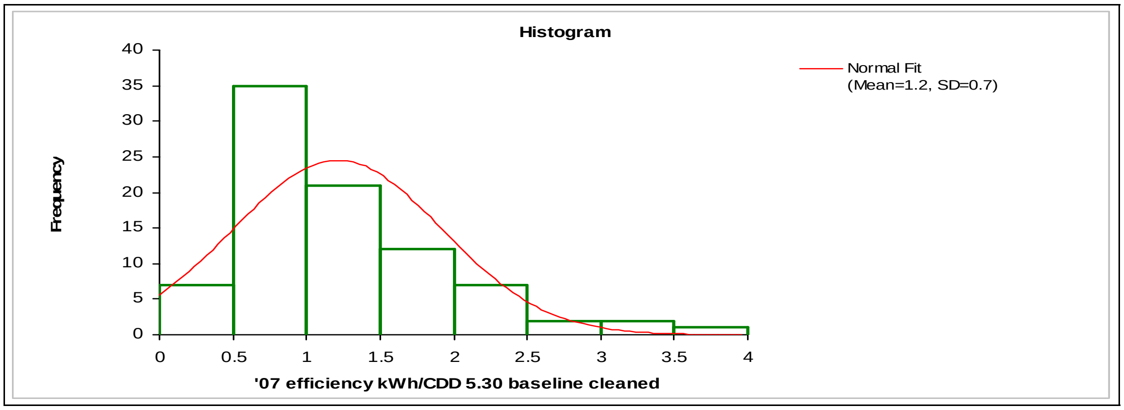
Calculating Efficiencies

We use the following steps to calculate daily efficiencies for each of the 5 summers in our database:

- Assemble the values for each 24 hour day the kWh used and, from the weather office, the mean temperature
- Calculate the Cooling Degree Days for each day
- Subtract the high baseline value from each daily used kWh value to calculate the high baseline daily net kWh used
- Subtract the low baseline value from each daily used kWh value to calculate the low baseline daily net kWh used
- Using these two net kWh lists described above, for each calculate a daily net kWh/CDD efficiency.
- Sort and clean each of the efficiency lists according to the rules above.
- Use our stats package to generate reports by cooling season.

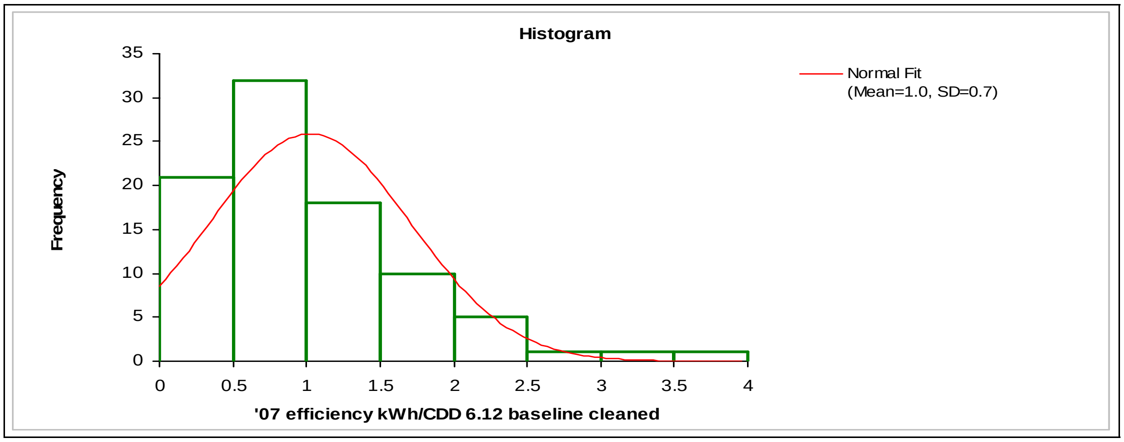
The results are produced below.

Summer of 2007 using low baseline of 5.30 kWh per day



n	87	
Mean	1.211	
95% CI	1.060	to 1.361
SE	0.0758	

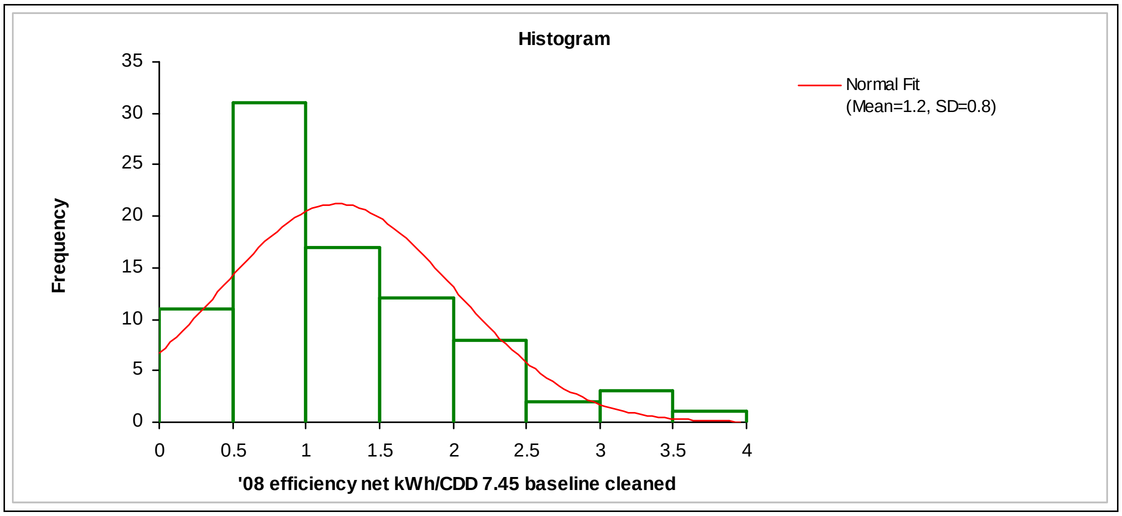
Summer of 2007 using High baseline of 6.12 kWh per day



n	89	
Mean	1.023	
95% CI	0.878	to 1.168
SE	0.0728	

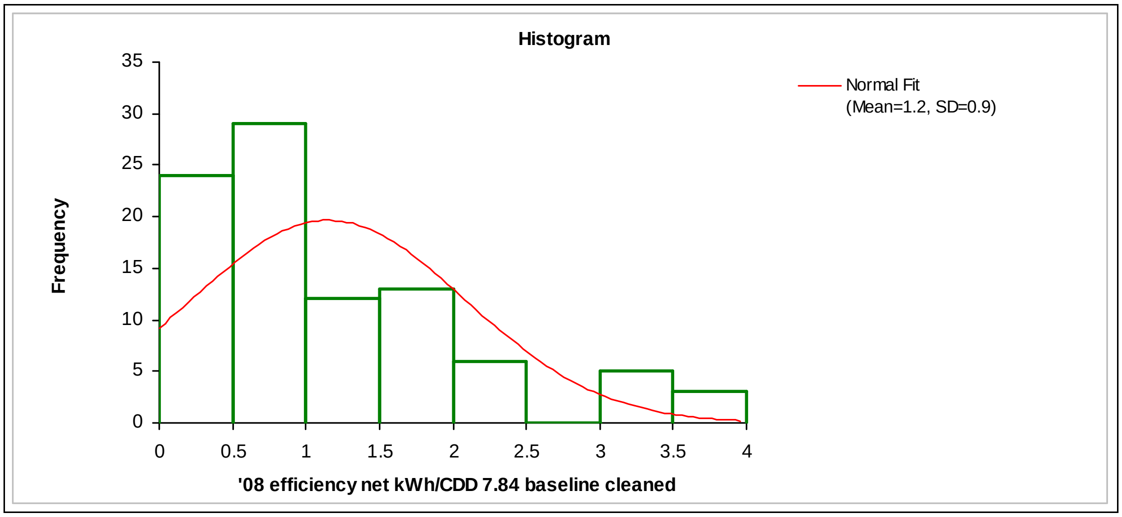
As you can see using a slightly larger value for the baseline makes the household look more efficient.

Summer of 2008 using Low baseline of 7.45 kWh per day



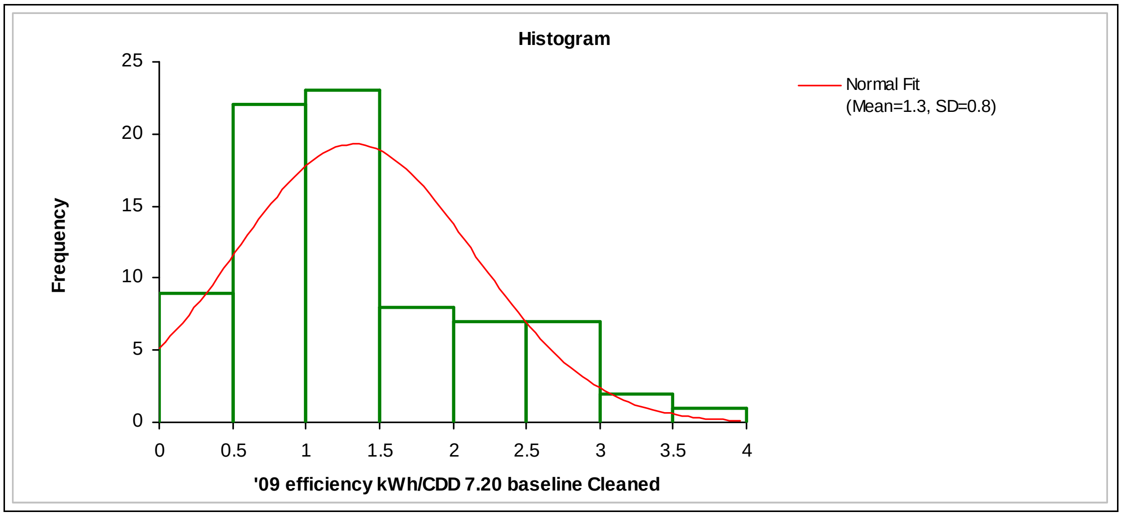
n	85	
Mean	1.214	
95% CI	1.041	to 1.386
SE	0.0867	

Summer of 2008 using High baseline of 7.84 kWh per day



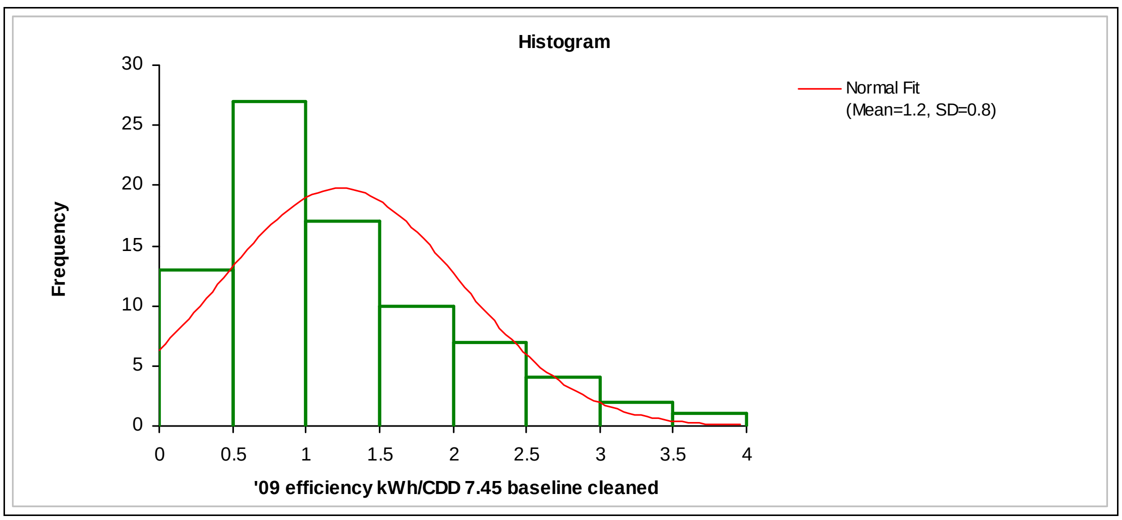
n	92	
Mean	1.151	
95% CI	0.958	to 1.345
SE	0.0974	

Summer of 2009 using Low baseline of 7.20 kWh per day



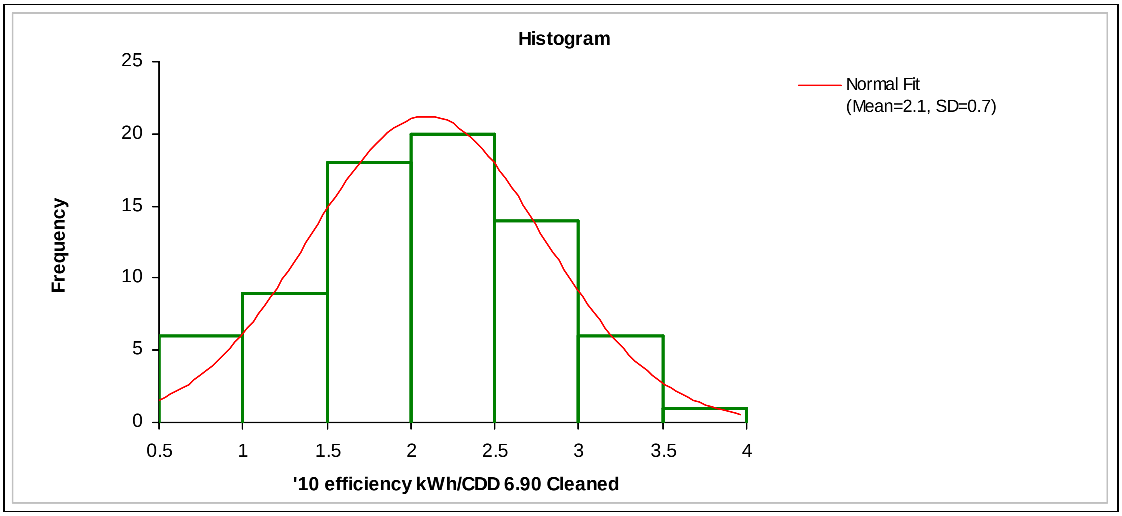
n	79	
Mean	1.330	
95% CI	1.147	to 1.513
SE	0.0919	

Summer of 2009 using High baseline of 7.45 kWh per day



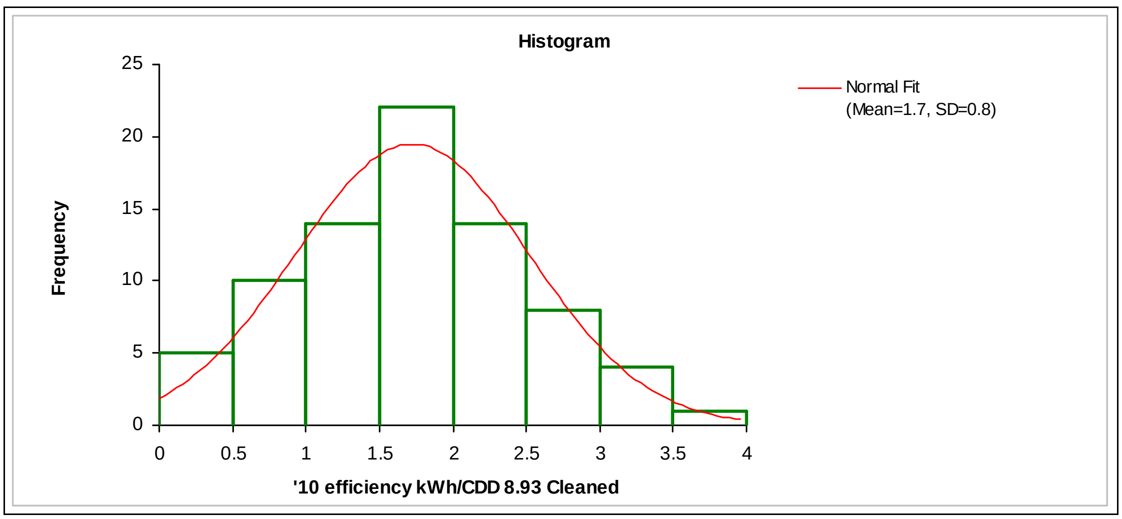
n	81	
Mean	1.234	
95% CI	1.053	to 1.415
SE	0.0909	

Summer of 2010 Using Low baseline of 6.90 kWh per day



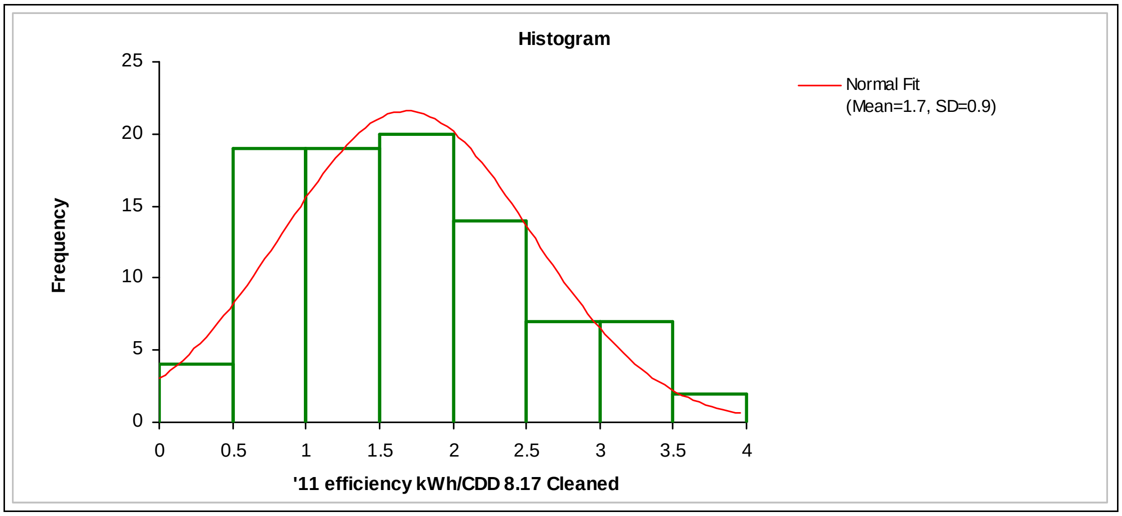
n	74	
Mean	2.094	
95% CI	1.932	to 2.255
SE	0.0808	

Summer of 2010 using High baseline of 8.93 kWh per day



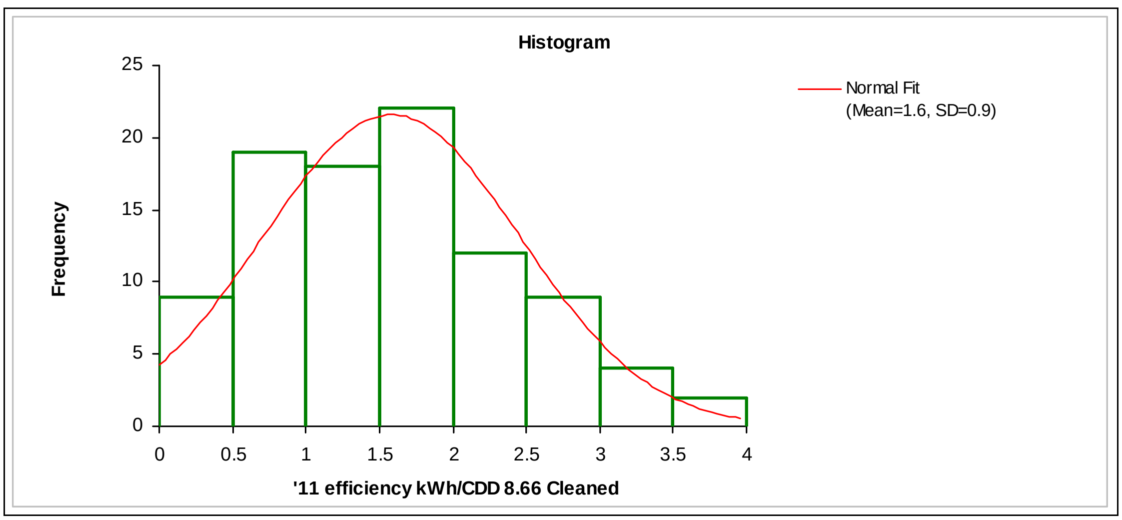
n	78	
Mean	1.723	
95% CI	1.543	to 1.903
SE	0.0904	

Summer of 2011 using Low baseline of 8.17 kWh per day



n	92	
Mean	1.686	
95% CI	1.510	to 1.862
SE	0.0887	

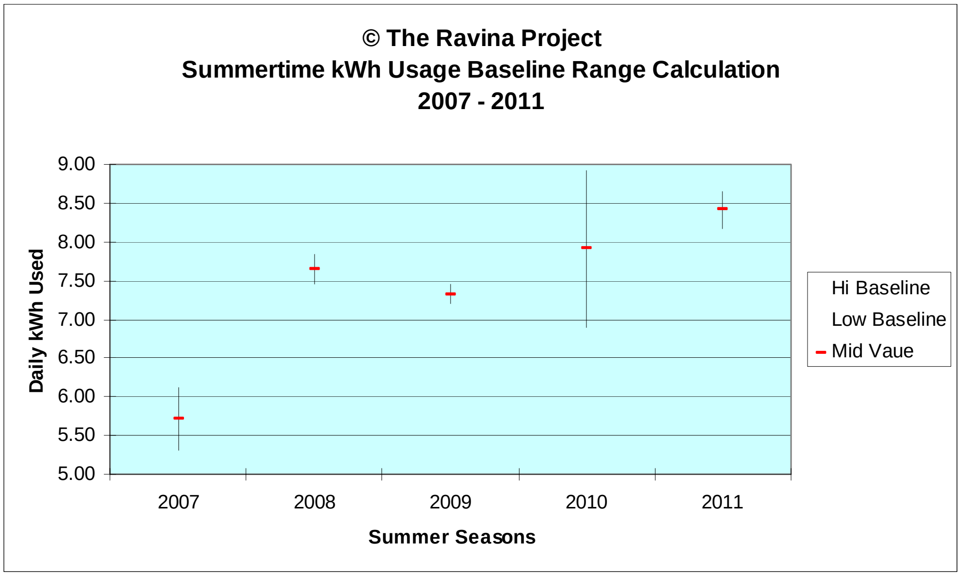
Summer of 2011 using High baseline of 8.66 kWh per day



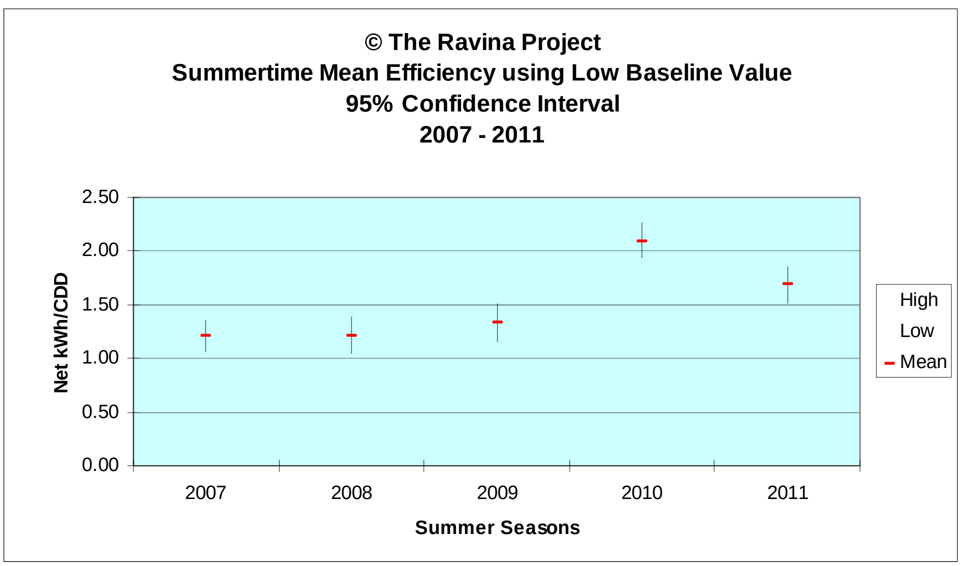
n	95	
Mean	1.582	
95% CI	1.404	to 1.761
SE	0.0900	

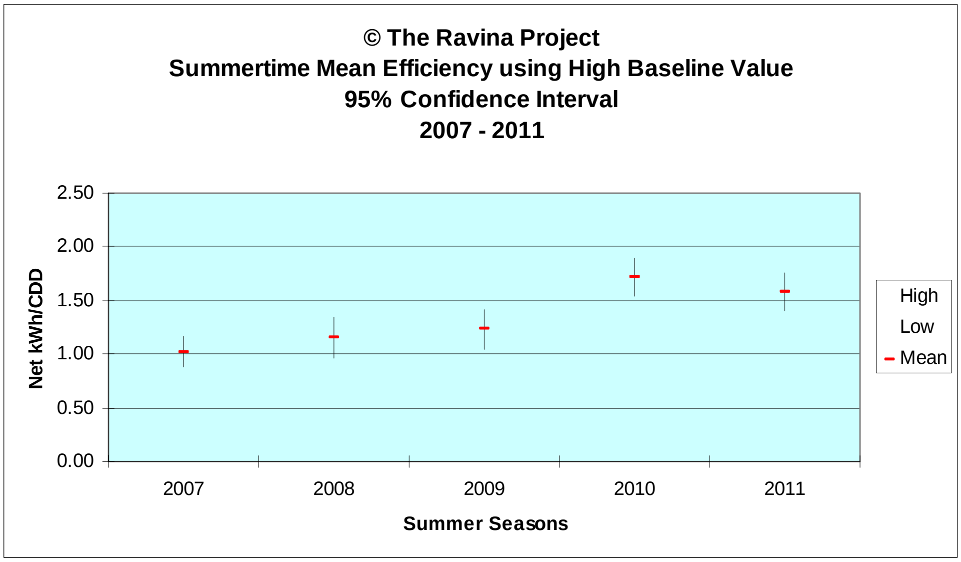
Five Year summary Charts

As you recall from above we used the minimum daily kWh usage value for each season as our low baseline value and the value at the 2.5% percentile as the high baseline value. This graphic below shows each of these seasonal values in a range.



So all this work comes down to the following two charts. Each chart is based upon a different baseline value. The mean value for each season is the red bar and the 95% Confidence Interval is plotted as a range around it.





There seems to be a decrease in the summer season household efficiency as compared to the summers of 2007 to 2009. We are using more and more kWh to cool the household.

How do we account for these numbers?

As the project has matured we have worked hard to understand and control the household summertime heat gain using various methods. In parallel, our use of electrically powered cooling/dehumidifying devices has increased. Our philosophy has been to employ the minimum amount of energy to fill the house with dense air. So what happened in 2010 and 2011? We had an adult join our household at the beginning of summer 2010.

The summertime cooling has been a work in progress in a sense that each year we try to do a better job. The sun shields were new this year.

We are surprised that our data shows some consistency from year to year. We believe we have found a household 'sweet spot' in our efforts to increase our air density without using excessive energy. More summertime data is needed to show any trends.

Bottom line, with the data we have today, our cooling efficiency lies between a low value of 2.26 kWh/CDD and a high efficiency value of 1.40 kWh/CDD for the last two summers (with a stable household) across all baselines.

There is definitely more work to do in this area. We need more data which only time and effort will give us. Our electrical utility bills are of no help because they are issued bi-monthly over a four month cooling season. Data values are too few. Daily data collection is our only option going forward with summertime efficiency calculations.

Conclusion

What does all this mean for energy policy in general?

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

An old house encased in an insulating skin that will seal and insulate it much more effectively can show real efficiency increases. Such an upgrade plus others will guarantee a cut in energy use as we have demonstrated. Energy generated (Watt-hours) and energy not used (NegaWatt-hours) are very similar. In both cases, the external energy supply requirements for the house are reduced. From an energy supply point of view our 5 year savings were 25.9 MWh in gas (10.35 kWh equals 1 cubic meter of gas) just from increased insulation and changes to the internal heat flow in the house. We calculate that over that same period we could harvest about 8.25 MWh of PV energy. The insulation/house upgrades and the PV solar generator cost about the same to install with the insulation coming in a little less than the PV. Note that our PV installation is not typical and cost about 40% over what an installation would cost. That being noted, we still agree with the comment directly below.

As you can see we got three times the effective energy decrease in perpetuity from the insulation. And this is net of any energy savings we received in the summertime by living in a better insulated house.

This is a significant finding for energy policy … before anything else, insulate.

Policy for Individuals

We encourage people to read this paper and analyze their own house according to the methods we have demonstrated. As well we have an Appendix with information about constructing sun shields from scrap materials.

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 summertime by requiring less energy to cool. Insulation can be as effective in keeping heat out of a house as keeping it in.

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

Furnace augmentation via solar heat harvesting

The development of a technology specific to the augmentation of household heating that harvests in the most efficient way, heat from the sun is necessary and essential. This technology should be designed to use harvested heat to augment household heating during the heating season. Our understanding of the power of the sun in the spring and fall informs us about this potential. With this technology in operation the carbon based furnace will be used less frequently or not at all during these transition seasons. This augmentation directly translates into reduction of the household carbon footprint by taking some of the heating load off the carbon based furnace or in places that are electrically heated, taking some load off the kWh used for household heating. In many places in North America, local Grid supplied electricity is produced by coal fired generation. The electrons used to heat these houses have a 100% carbon component. Harvesting heat from the sun using a specifically optimized technology for this job will reduce the carbon footprint of the house. Note we do not envision this technology being some kind of re-jigged solar hot water heater technology but something new.

Global Warming is taking a toll on our infrastructure which includes our Grid distribution of electrical power. A well designed heat harvester should be able to inject some heat into the house without the use of Grid energy. Some freak weather, like ice storms and sub-tropical storms can destroy Grid networks for days / weeks. At the higher latitudes, the ability to inject heat into a cold, freezing unpowered house could very well make the difference between having huge repair bills or not.

Thermodynamic description of a common building type

It may be, in the future, that CO2 reduction by any available means is required; our data will give good numbers for our building type. Our building type is very common example of the housing infrastructure built in Toronto from the late 19th century. Here in Toronto huge deposits of clay were found close to the surface. Normally, these deposits were buried under many tens of meters of overburden. However, Toronto has several ancient rivers that have cut through the overburden to expose the clay. As a result, many brick works sprang up in the river valleys. Clay bricks are indeed even today a wonder material. They were good insulators especially when used in double brick construction with an air pocket between walls. They are able to support huge compressive loads. Double brick construction properly interlocked is notorious for being tough and long lasting. Our house at 85 years old needs no work on its brick exterior.

The point of this polemic on bricks is that here in Toronto, as in many other places where bricks were cheap, brick construction was the main form of housing type. As a result Toronto like many other places has a huge housing stock made from this material. In our section of town the dominant mode is double brick main floor and frame second floor or double brick main floor with a mixture of double brick and frame for the second floor. These buildings are everywhere and are so common that a frame building is an anomaly. So the data we are collecting and putting on-line are critical to understanding the thermodynamics of a whole class of legacy housing stock here in Toronto.

So bottom line on this issue, the government should pay attention to our data regarding this housing type.

Comments regarding household energy requirements and CO2 emissions

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 PV solar generation. The reason of course is, as we have demonstrated, for certain structures savings per invested dollar are greater with insulation than with PV solar and those saving continue in perpetuity.
- Enforce rules that would mandate all newly constructed houses be very efficient and self powered in some way.
- Some existing newer homes may be well insulated. They should proceed to some kind of generation straightaway.
- However, as the CO2 problem increases, new home designs must be mandated to minimize their CO2 footprint even more. In this case, designing and building houses that self power in a way that maximizes their reduction of CO2 is hugely important.
- We see well publicized contests by house designers for livable, affordable, self-powered houses being 'voted' upon by the public. We envision builders bragging about the new designs they provide in their new housing sub-divisions.
- As well, we see other designers promoting 're-do' designs for the existing housing stock, again with huge efficiency and self power capability.
- Devise and use a mechanism that gangs together demonstrable per household energy savings and a rate cut for those utility customers who quality. When less is used the real cost per unit should decrease. See the above graph on page 17 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.

Masses of people, properly motivated, are extremely powerful. They can do wonders.

Don't play politics; it will alienate the masses from the issues. The masses are a power center so should not be alienated from any problems government and the governed may seek to solve together.

The masses MUST be involved as partners in any global CO2 solution we seek.

Appendix 1

Making a Sun Shield

We found that using sun shields kept lots of heat out of the house.

We cut a large box and laid it out flat.

We coated it with wood glue.

We pressed some foil on it shiny side up. We used the wide thick stuff made for cooking turkeys and roasts. Leave some foil extra because it will fold over to be glued onto the back.

Note we did not want to stop all sunshine from entering the house. We wanted to reflect back about 60% in each window. We have all kinds of indoor plants that require the sun. And of course the shields had to be light enough to remove quickly to enjoy afternoon and evening illumination in the house.

We glued some scrap wood to reinforce and stiffen the cardboard. We made a handle out of a folded over piece of duct tape … Canadian eh?

Here's a shield being used in the upstairs office at area 'A' on the chimney diagram on page 28 above. The exhaust fans are in operation.

The shields being used in the dining room.

The shields in the plant room.

The shields on the back porch.

Blistering sun shine late morning with several hours to go.

You can see why shields help us out.

Must be a hot/humid day, the house is totally sealed up.

Note we take the shields down and store them in the room where they are used when they are not in use. They are light weight and just sit in the window out of reach for small children or pets. The porch door was the most difficult. Susan got a couple of magnetic hooks allowing us to hang the shield on the door as can be seen above.

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

Project Directors

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

The Ravina Project,
Toronto, Ontario,
Canada M4J3L9

gord@theravinaproject.org

Twitter: @ravinaproject

Friends of the Ravina Project

Ben Rodgers B.A., M.A.,
NABCEP Certified Solar PV Installer™
Designer of our sun altitude compensating, solar array structure