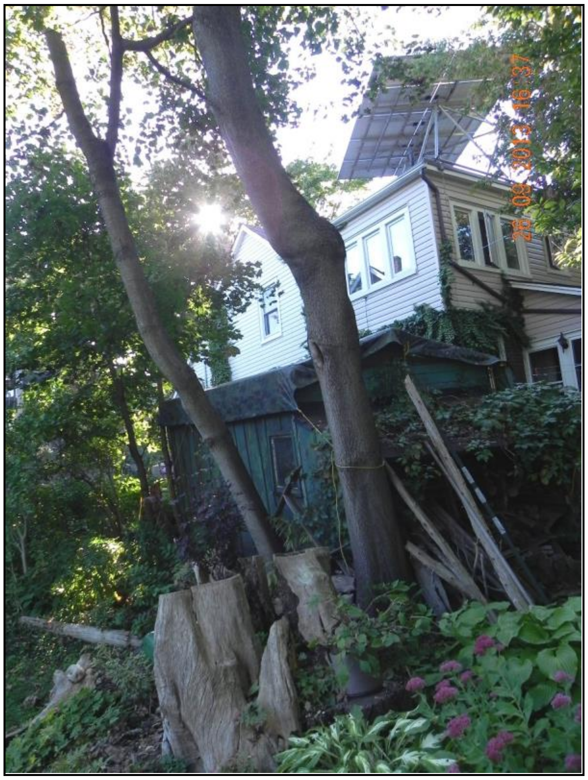
The Ravina Project

Improving Household Carbon Efficiency

Reducing Household Carbon Release per Heating Degree Day



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The Ravina Project - Goals

The Ravina Project consists of several projects all proceeding concurrently. If we were to rename our project today we probably would name it, “The Ravina Projects”.

Our project goals page allows our readers to understand the scope and depth of the various areas of inquiry focused totally on the household.

See the Project Goals page on our WEB site at:

www.theravinaproject.org/project_goals.htm

Improving Household Carbon Efficiency

Abstract

Electrical space heating has the potential to reduce the total carbon footprint when used in households that use fossil gas for heating.

Introduction

In many households the high efficiency, fossil gas powered heating system is too new to replace with an electrical heat pump. Many of these households have completed all the other modifications to the house structure that will make it much more efficient to heat and cool. In their cases, in the short term there is really nothing further to be done to reduce fossil gas usage for heating.

Several years ago we decided to tackle this assumption by answering this question. Is it possible to reduce further the carbon footprint of a well insulated house without major investment?

The most straightforward method of reducing our heating carbon footprint is to leverage the very low carbon overhead of our Grid electricity. We used space heaters in colder areas of the house to raise the wintertime average internal house temperature by impeding the flow of heat from warm areas to colder areas. Theoretically, this small rise in temperature will tend to keep our fossil gas powered high efficiency boiler OFF for longer periods of time thereby reducing carbon release.

Being theoretically possible is one thing. Having the data to show a significant difference is quite another. This paper uses daily data starting with the 2007-2008 heating season and ending with the 2021-2022 heating season. For the last three heating seasons, net the current one we are in at this time of writing, we have carried out the experiment with space heaters.

Method

Normally when evaluating a household for its heating efficiency with fossil gas we use the standard: cubic meters of fossil gas used per Heating Degree Day (m^3 gas / HDD). This brute force method typically involves adding up the heating season's fossil gas usage and dividing that total by the total number of Heating Degree Days generated that season. The heating season here starts on October 1^{st} and ends May 31^{st} in the next year … 243 days long except for leap years.

For this paper we are introducing a new metric … at least a new one to us. Instead of cubic meters of fossil gas used we substitute kilograms of CO_2 release. We convert the volume of gas used to kilograms of CO_2. We also convert the Grid energy used to kilograms of CO_2. The new metric is, kilograms of CO_2 released per Heating Degree Day (kg CO_2 / HDD). The brute force seasonal method is totally inadequate for spotting changes in the daily data. We use the commercial statistics analysis package "***<u>Analyse-it</u>***" that integrates into our Excel spreadsheets.

Each day since January 1st 2007, we record:

- the amount of fossil gas used (meter reading),
- grid energy imported (meter reading),
- generated energy from the solar panels (meter reading),
- energy exported to the grid (meter reading),
- date / time of the observation,
- energy placed into our EV (on-line meter reading),
- the number of Heating Degree Days accrued for the day from Environment Canada's weather office, Toronto Center (on-line data).

These daily data form the basis for this paper.

Total CO_2 release Calculation / Conversions

Each of the energy sources we use has a carbon footprint. We have a carbon accounting model developed in a previous paper. We will use that model to produce a total carbon release for each day. The various energy sources are assigned a carbon overhead:

- Ontario Grid energy emits 55 grams CO_2 per kWh on average,
- Heating season solar energy harvested is so low it falls into the noise, that is, it is inconsequential,
- Electrical energy placed in the Electric Vehicle is subtracted from the daily electrical energy total because it is impossible for this energy to be used to heat the house,
- Electrical energy sent back to the Grid is subtracted because it too is impossible to be used to heat the house,
- Fossil Gas emits 1.915 kilograms of CO_2 per cubic meter burned or about 180 grams of CO_2 per kilowatt-hour.

Note we do not include the global warming potential effects expressed in CO_2e of Fugitive Methane from the fossil gas distribution system in our fossil gas calculation. If calculated using this value for fossil gas the values for the last 3 years would make an island of values farther away from the other yearly values. The greater the carbon footprint from burning fossil gas the greater the effect of using a much cleaner energy source for heating.

Data Preparation

Data collection is one thing. Data preparation is another. How do we know which kWh is used for the space heaters and which is used for the fridge? How do we know that a kWh from fossil gas is used for household heating and not for cooking or clothes drying or hot water which have nothing to do with heating? We have had to deal with these questions since our first papers on household efficiency.

There are lifestyle changes that occur. For instance my son lived with us for about 2 years. Did his presence change our non-heating electrical usage and fossil gas consumption … yes it did. So the question becomes, how do we prepare our data to ignore the extra energy used for his extra load on the system?

Fossil Gas

Our standard procedure is to look at the non-heating season, from June 1st to September 31st preceding the heating season we want to graph. From the daily data over those 122 summer days we develop baselines for energy usage. During this time our boiler's furnace function is off-line. All the fossil gas used during this time is used for clothes drying, domestic hot water production and cooking. We total this usage and compute the average daily usage which becomes our baseline non-heating usage for the following heating season. The heating season of 243 days therefore has a daily non-heating usage component. We multiply the daily non-heating usage by 243 to get the total number of cubic meters of wintertime non-heating fossil gas used. Our net gas usage for heating is the difference.

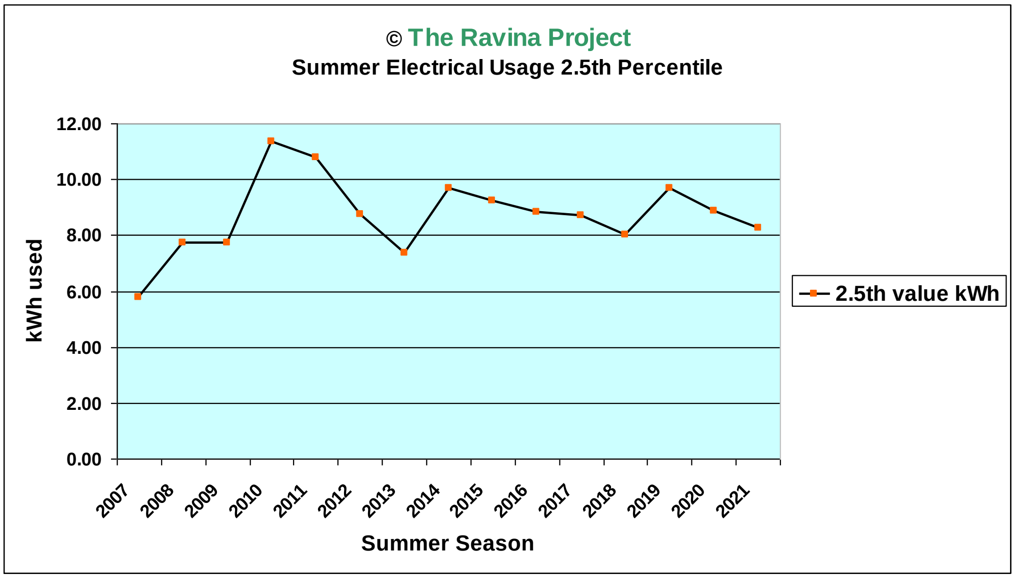
This is an approximation because the summertime usage of fossil gas is less than wintertime. Showers are cooler, lots of cold food is consumed, hot foods are cooked on the BBQ, laundry is air dried on a line and the like. Bottom line, the value of the baseline for fossil gas derived from summertime data is guaranteed to be less than the actual non-heating wintertime usage. However, it is the best we can do. Note that if fossil gas is used for non-heating but is accounted for as being used for heating, the metric 'gas used per Heating Degree Day' will be larger, which means the heating efficiency of the household will be calculated to be less than it actually is.

Electricity

We use a similar method for calculating the extra electricity used for heating but we believe it is not as accurate. In the summertime we use electricity for the fridge, exhaust fans used for cooling, air conditioning, clothes washing, basement dehumidifier, lighting, electronics, grass cutting, charging the EV, floating our batteries, appliances and the like. It's quite a list … much more complex than those devices consuming fossil gas. We know that the fridge takes about 4 kWh a day in the summertime … it works harder because of warmer ambient temperatures. Our air conditioning is a basic 5000 BTU window unit in the master bedroom which cools and dehumidifies the whole house except on very humid days when we also operate a basement dehumidifier. Our extra insulation and the local microclimate created by shade trees allows us to keep the AC unit OFF except on the hottest days. We rarely use it at night.

What do these facts tell us? They tell us that we can never know the actual baseline electrical usage. However, we can use our stats package to find the value of the 2.5th percentile of electrical usage over the 122 days of the summertime in question. We reason that the baseline will be a low value but not the lowest value. It can't be the average value because of all the appliances and cooling we use in the summertime makes the average larger. But there are many days when the windows are open, the fridge is operating, with no air conditioning, few if any fans are in use except for the fan in the bedroom window bringing in cool overnight air. These days are as close to the baseline as we can get. We assume that the data for these days will fall quite close to the 2.5th percentile

Consider the following chart.



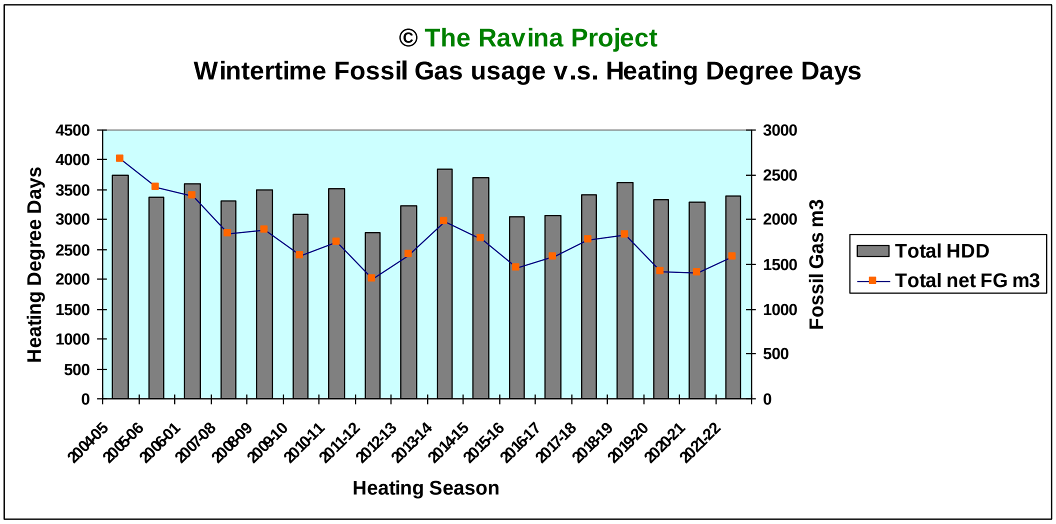
Note that the values of 9 of the 15 seasons are between 8 and 10 kWhs and 3 of the 15 are just below 8 kWh. Note as well the outliers, 2007 is just below 6 and 2 back-to-back summers where the values are substantially above 10. The reason these two years are outliers is the fact that my son was living with us. The excess power he used is reflected in the data. This is a good example of why we use the previous summer's data to calculate baselines for the subsequent winter. This method accounts … or tries to account, for changes in lifestyle and/or living conditions.

Fossil Gas Usage and Heating Degree Days

The Heating Degree Day (HDD) value tells us how cold the day in question was. It is a number calculated using the Mean, 24-hour, daily temperature in relation to 18 degrees C. Suppose a day has a Mean 24-hour temperature of 10C. On that day 8 Heating Degree Days would be generated (18 minus 10). One can go to the Environment Canada WEB site and download the HDD value for every day in the heating season.

In a general way one can think of the number of Heating Degree Days in a season as a value telling us how cold a particular season was.

Consider the following chart.

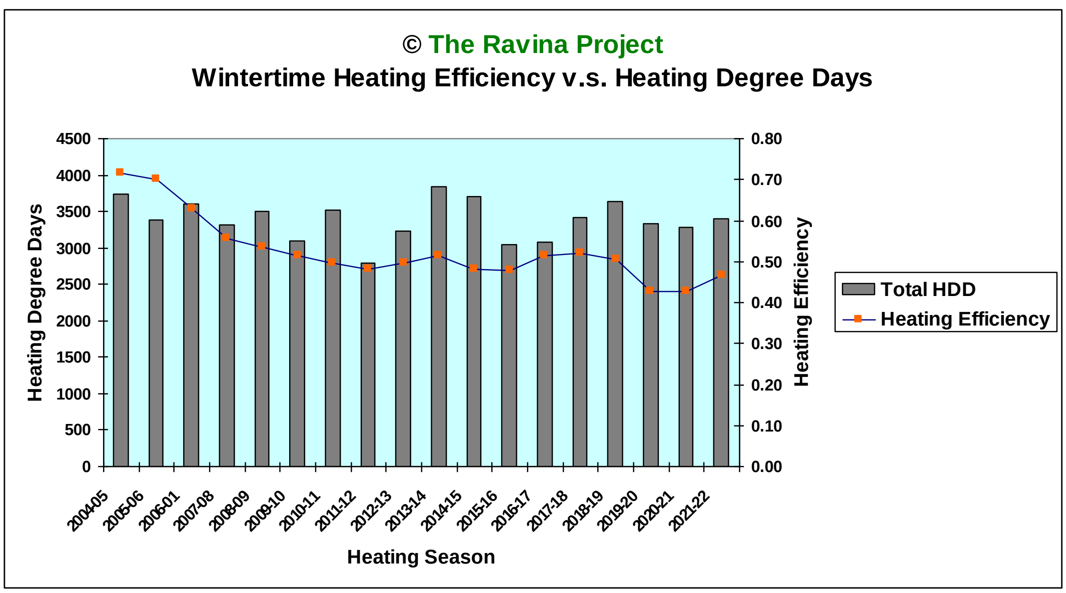


We plot the seasonal total HDD against the number of cubic meters of net fossil gas usage. For the seasons 2004 to 2006 we use data from our 2018 paper on household heating found at:

http://www.theravinaproject.org/The%20Ravina%20Project%20-%20Household%20Heating%20Efficiency.pdf

As you can see there is an association between the number of seasonal heating degree days and the total amount of fossil gas consumed. We produce this chart to assure the reader that any results we demonstrate are not the results of quirky values from the weather and the like.

Consider the following chart:



This chart compares the heating efficiency of the household measured in cubic meters of fossil gas used per heating degree day. This is the classic way of measuring heating efficiency. We have used this metric in all our previous papers. It gives the reader a snapshot of the seasonal heating efficiency especially when evaluating upgrades to the house. We went from about 0.71 cubic meters of fossil gas used per HDD to about 0.48 in the heating season of 2011-12 an increase in efficiency of about 32%. These numbers reflect the upgrades we made to the house structure: new windows, new doors, attic insulation, encapsulating the second floor, sealing the basement headers and the like.

Note the last 3 years the efficiency has improved getting down to 0.43 cubic meters of fossil gas used per HDD. This has nothing to do with the improved thermodynamic properties of our house structure but they are a bonus result of our efforts to reduce the carbon release from our household heating which is the focus of this experiment.

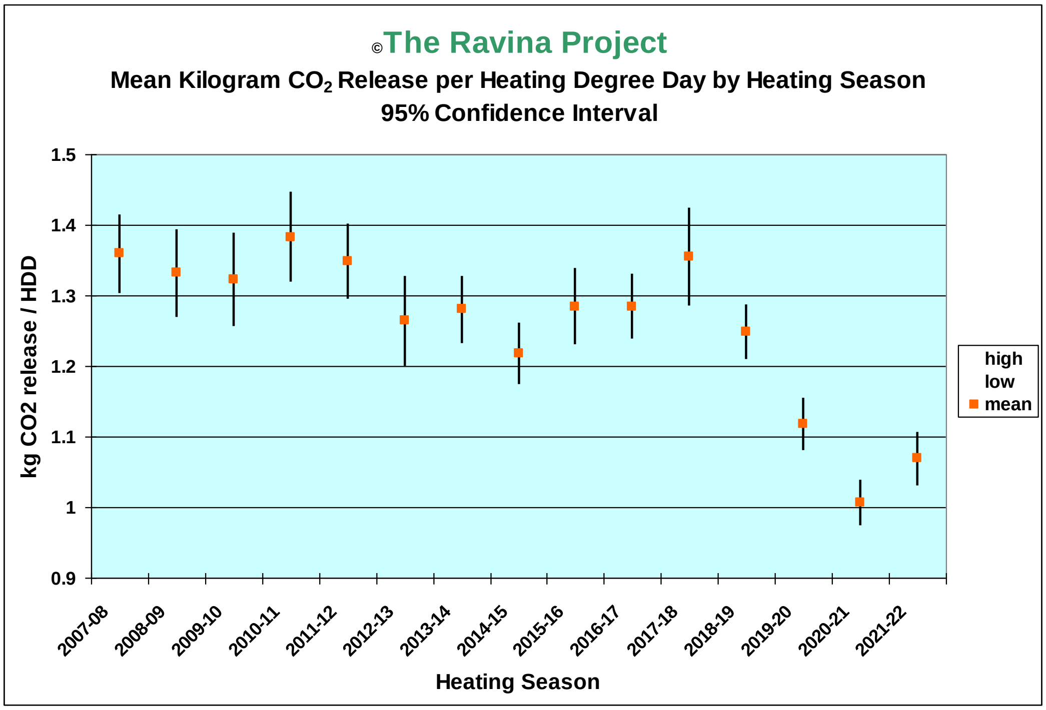
Data Presentation

We use our stats package to crunch our daily data to provide insight into the carbon release trends over the 243 day heating seasons. Each day we calculate our total energy used from all sources, calculate the carbon release from each of those sources, calculate a daily total for carbon release from all sources and then divide the result by the HDDs generated for the day. The result is CO_2 released per HDD for the day … the carbon efficiency of heating for the day.

We generate a daily average or Mean for the seasonal daily carbon release by analyzing each season of 243 daily values. The result for each heating season is the Mean value plus the 95% Confidence Interval of values grouped around the mean. You can see lines going up and down in the chart below from the Mean plotted in orange.

The Confidence Interval allows us to expand our observations to other houses. If let's say, there are 100 other houses which have gone through the same upgrades and have similar thermodynamic properties as our house, the CI allows us to speculate with a degree of confidence that their CO_2 overhead would be similar to ours. That is, the chance their carbon overhead would fall into the Confidence Interval range of values our house generated would be 19 times out of 20. That 5% chance means that among these 100 other houses 5 would have carbon overhead values outside of the confidence range.

Consider the following chart:



The Means for each heating season seem to group themselves into two groups. The last 3 years seem to be in their own group with more similar yearly Mean daily kg CO_2/HDD to each other than to the rest of the years.

In our view these data strongly suggest that a reduction in total CO_2 emissions from all heating sources can be reduced by substituting a cleaner energy source for some of the household heating.

A Further Question

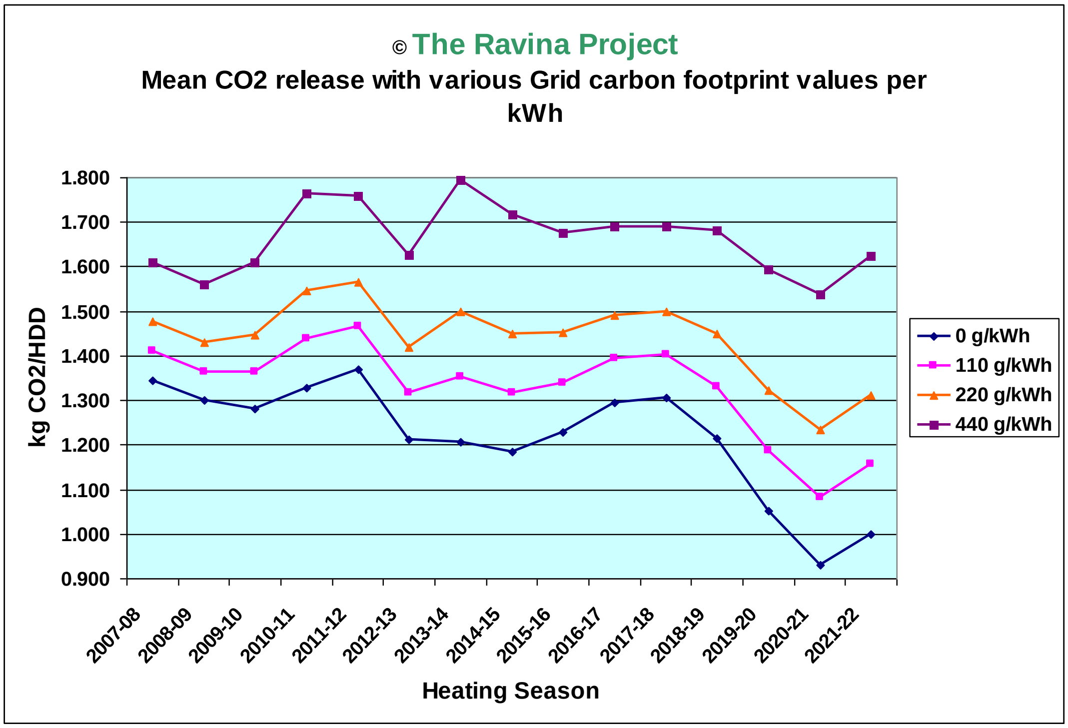
What affect does the Grid's carbon overhead have upon the total kg CO_2 per Heating Degree Day?

Our initial calculations were done with an assumed Grid carbon overhead of 0.055 kg CO_2/kWh.

What happens when the Grid's overhead expands to 0.440 kg of CO_2/kWh?

Note that the carbon footprint of fossil gas per kWh of energy is about 180 grams. If the Grid's footprint is about 180 grams per kWh then from a carbon release point of view, it basically is a trade off between the energy sources. In the chart below we see the shape change between the lowest and highest Grid footprint. That 180 gram curve is not charted but if it were plotted it would appear between the 220 grams and the 110 grams per kWh curve.

Consider the following chart:



We have calculated the Mean CO_2 release per HDD for every heating season. What we have done is to change the carbon intensity of the Grid from zero kilograms to 110 grams (France), 220 grams (England) and 440 grams (Germany). We see the changes in the benefits of Grid powered space heating.

From our data we saw that the last three years have been quite different in their total carbon release. We saw that even the 95% CI intervals for those years did not overlap the others. That means of the 100 houses with our thermodynamic characteristics, the 5 houses that are not within our 95% CI range, very few if any would be within the nearest 95% CI range (2014-15). Some of those houses may have Mean carbon releases per HDD lower than the bottom end of our 95% CI range. The point is, the last 3 years are a statistical island unto themselves.

Note how this islanding changes as the Grid's carbon overhead increases. At zero grams per kWh the effect is amplified and as the Grid gets dirtier this effect gets more and more muted to the point where it disappears when the Grid gets to be as dirty as Germany's.

Conclusion

When the household has completed all its upgrades both to the physical structure of the house as well as changes to heat flow and lifestyle, and the Grid is providing low carbon energy below about 180 grams of CO_2 release per kilowatt-hour, adding Grid powered heating to the house will reduce the household carbon footprint. On cleaner Grids the advantage gained by using this method is amplified.

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

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Friends of the Ravina Project

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