Energy Efficiency

Energy Use of the Eco House

Ben Francis

Introduction:

Three years ago one of the small houses owned by the college was altered with the goal of being more energy efficient. Among the changes to 200 Vernon Street was the installation of insulation the replacement of several appliances as well as a solar preheat to the water used in the house. Now we wish to determine how efficient the house actually is. Down the street from the now Eco House is the Japanese House. This house (176 Vernon) is similar to the Eco House in many ways including number of people living in the house as well as the time of construction. However, the Japanese House did not get upgraded to be more energy efficient. In my analysis, I will use the Japanese House as a base case.

Data:

To determine the efficiency of the Eco House I acquired the electricity bills for 200 and 176 Vernon Street from the past three years. For each billing period I have data on how much electricity and natural gas was used as well as the cost of each energy source. In addition, I have data on how many heating degree days were in each billing period and how many days were in each billing period. The length of a billing period is roughly a month and thankfully is the same for each house.

Natural Gas Use:

To begin my analysis of natural gas use I explored how natural gas use varies with the number of heating degree days in a billing period. Using the number of days in each billing period, I translated total natural gas, electricity, and heating degree days into an average per day for each month. With these three new data fields, I modeled the natural gas use of each house.

Linear Model:

Therms per Day ~ HDD per Day + KWH per Day

Eco House

Variable	Estimate	Std. Error	P Value
Intercept	-0.154237	0.137482	0.270
HDDperDay	0.118895	0.003572	$<2e^{-16}$
kWhperDay	0.011250	0.010250	0.281

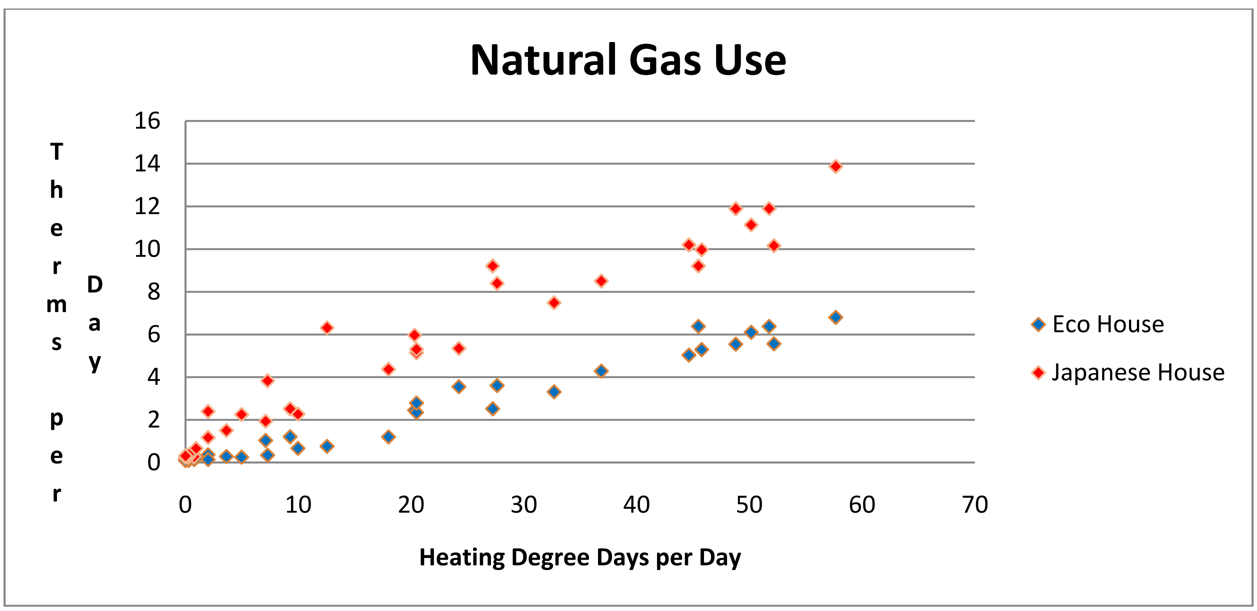
Japanese House

Variable	Estimate	Std. Error	P Value
Intercept	0.64593	0.30116	0.0397
HDDperDay	0.20711	0.01052	$<2e^{-16}$
kWhperDay	0.01615	0.01608	0.3225

This model attempts to use the number of average number of heating degree days each month and the average amount of electricity used per month to explain the variation in the amount of natural gas used, measured here in therms. Electricity use is included in the model because most electricity use, such as using a light bulb, generates heat.

Allow me to explain this model. First, the intercept term is the base natural gas use for each house. For example, if the temperature outside is the same as the temperature inside is the same, causing the number of heating degree days to be zero, the Eco house will use essentially zero therms of natural gas where the Japanese House will use around 0.65 therms of natural gas. Second, the HDD per Day term shows how natural gas varies with outside temperature. This shows that for each degree difference between indoor and outdoor temperature the Eco House will use about 0.12 more therms of natural gas. The same is true for the Japanese House except that it uses about 0.21 more therms for each degree. For example, if the temperature outside is 50^{O}F and the temperature inside is 70^{O}F, a difference of 20^{O}F, we will expect that the Eco House will use 2.4 therms of natural gas to heat the house that day where the Japanese House will use 4.1 therms. Finally, the main goal of the KWH per Day is to reduce the residuals in the model. However, one would expect the estimate to be negative. Notice that each variable also has a standard error and a P value. These two values show us how statistically significant each variable is; the smaller each is, the more significant the variable is. As can be seen the most significant variable for each model is the HDD per Day variable.

Since electricity use is not significant, we can safely graph natural gas use verses heating degree days with lossing only statistically insignificant bits of data.



Comparing Houses:

As far as the uses of natural gas the Eco and Japanese houses are similar. Both have a stove that is run on natural gas. The Eco House has an oven that runs on natural gas where the Japanese house doesn't. However, a resident of the Eco House stated that the oven is rarely used. Both have water heaters that are essentially identical except that the Eco House has a system that preheats the water before it is heated with natural gas. As far a heating, the Japanese House has a boiler where the Eco House has a forced air system. I did some research online but I could not find good information on which tends to be more efficient. I only found a bit of information that mentioned in passing that boilers tend to be more efficient. However, for simplicity, I shall assume that boilers and forced air systems are similar in base efficiency.

Sensitivity Analysis:

Even though both houses are similar they are not identical. The Japanese House may take more natural gas to heat for reasons other than the lack of weather proofing that the Eco House got. To explore this, I took the natural gas use of the Eco House and increased it by 20%. This helps to simulate the possible poor heat capacity of the Japanese house. I then constructed the same model that I constructed above on this modified data.

Variable	Estimate	Std. Error	P Value
Intercept	-0.185084	0.164978	0.270
HDDperDay	0.142675	0.004286	$<2e^{-16}$
kWhperDay	0.013500	0.012300	0.281

As can be seen, the 20% increase in natural gas use increases the heating degree days per day variable from 0.118895 to 0.142675.

Conclusions:

Ignoring natural gas heating for a moment, I can make some concrete conclusions about non-heating natural gas use such as water heating and cooking. This is captured in the intercept turn in the first two models. For the Eco House base natural gas use is essentially zero. In contrast, the Japanese house has a base use of 0.6 therms per day. I will assume that the majority of this base natural gas use goes to heating water since the water heater is on all of the time where the stove will only be on for maybe an hour each day. Thus, it is logical to conclude that the solar preheat in the Eco House is responsible for a reduction of about 0.6 therms per day of natural gas use.

As mentioned above, since the heating physics of each house are not identical, it is impossible to quantify how much the Eco House saves on natural gas heating without data from before the Eco House became the Eco House. We can say, however, that the Eco House uses 57% of the natural gas that the Japanese House uses for the same amount of heating. From my sensitivity analysis, I simulate a situation where the heating physics of the Eco House were worse. If this was the case the Eco House would use 68% of the Japanese Houses' use. Thus, I will guess that the actual natural gas use reduction for the Eco House is somewhere between 55% and 70%.

Electricity Use:

In modeling Electricity use, I was unable to create a model that was statistically significant. Part of the reason for this is that electricity use most strongly varies with personal use. Since there are no automated uses of electricity in either the Eco House or the Japanese House (automated uses being water heaters or central heating), the only variable the effects electricity use is how much the residents choose to uses electrical items in the house. This, as one can guess, cannot easily be quantified. With the data I have I cannot quantify this "resident use" variable.

Comparing Houses:

As mentioned above, I could not create any model that was statistically significant. One would think that modeling one house's electricity use against the others would create a good model. However, this is not the case. When one thinks about, it makes sense: Would the use of a toaster in the Eco House affect the use of a toaster in the Japanese House? No. The best I can do is present the averages from each month.

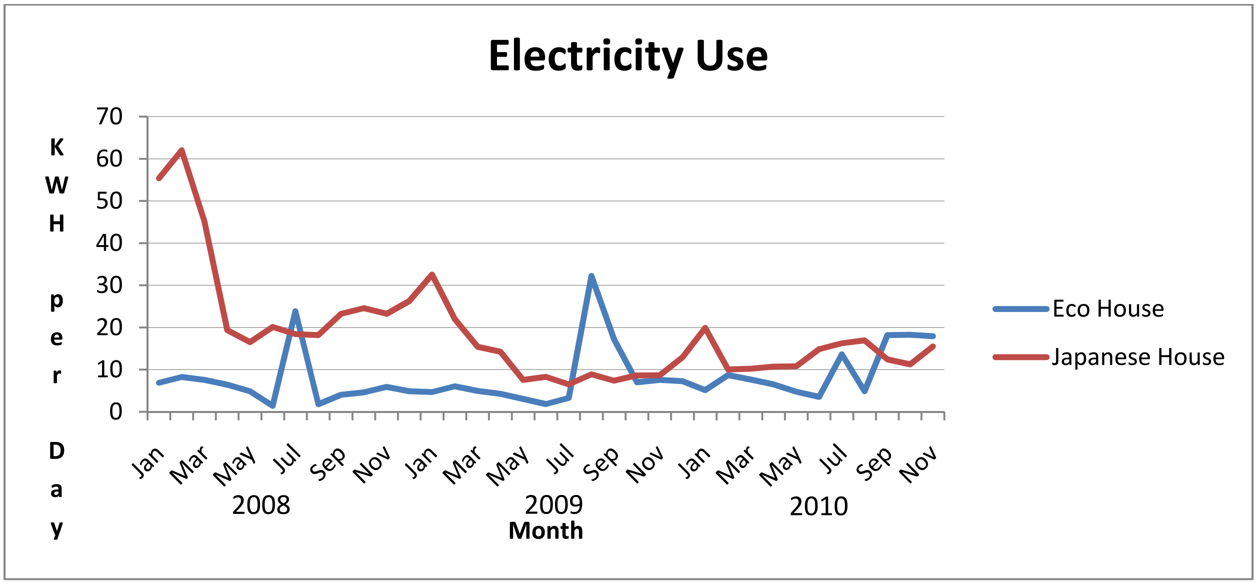
Each average only considers three separate data points. Thus these should only be taken as a long term average in the loosest sense of the word.

Units are in kWh per Day

	Eco House	Japanese House
January	5.563	35.935
February	7.654	31.356
March	6.728	23.592
April	5.733	14.779
May	4.229	11.630
June	2.268	14.419
July	13.581	13.724
August	12.966	14.678
September	13.114	14.352
October	9.966	14.816
November	10.460	15.808
December*	6.058	19.594

*Average of two points instead of three

This graph shows the energy use for each month over the entire data set.



Even though the Eco House has appliances that use less electricity than ones in the Japanese house, this cannot account for differences in energy use at the end of the 2007-2008 year or the 2008-2009 year. Note how the graph of the Japanese House's energy use is much lower in the 2009-2010 year. There were no changes to appliances in the Japanese house to explain this difference. The only explanation is that resident habits were different.

Dehumidifier:

One aspect of the above graph that I would like to draw your attention to is the spike in Eco House energy use in the summer. There are no students living in Eco House during the summer. Why is there an energy use spike?

In the basement of the Eco House is a dehumidifier. It only runs in the summer to help deal the mold problems in the basement of the Eco House. Out of curiosity I tested the energy use of the dehumidifier. It drew 0.05 KWH in 10 minutes. This multiplies out to 7.2 KWH over an entire day. Due to the in accuracies of the measurement device, I calculated how much it would draw at 0.06 KWH and 0.04 KWH. It multiplies out to be 8.64 KWH and 5.76 KWH respectively. Due to the low number of trials (one) this data does not show exactly how much the device draws. I took measurements from the dehumidifier when after it had been off for a while and while the basement was relatively dry. It is reasonable to guess that in a damper environment the dehumidifier may draw as much as 0.1 KWH in 10 minutes (14.4 KWH in a day). Even with the number that I took, the dehumidifier draws as much as the entire house does on a typical day during the school year.

Note: A member of facilities noted that the dehumidifier, while normally on only during the summer, was not turned off until January of 2011 this year. This most likely is the reason August to November of 2010 appears to have a higher energy draw than normal.

As it turns out, the Japanese House also has a dehumidifier in its basement. While the Eco House dehumidifier had an instantaneous draw of about 311 watts, the Japanese House dehumidifier had and instantaneous draw of only about 65 watts. This shows that this Japanese House dehumidifier draws about 20% of the energy that the Eco House dehumidifier draws. This better dehumidifier also has an auto shutoff that kicks in when it is not needed. The Eco House dehumidifier has no such system.

Conclusions/Recommendations:

As far as gas use is concerned it is clear that the Eco House has managed to reduce consumption of natural gas. However, it is impossible to determine exactly how much natural gas was saved. When we look at electricity use, it appears that the Eco House is much more energy efficient. One must keep in mind, though, that it is impossible to know how much of this is due to good habits and how much is due to use of better appliances. In addition, we can safety guess that the energy use of the Eco House in the summer is due to the inefficiency of the dehumidifier in the basement.

From this study I have three recommendations. First, the dehumidifier in the basement of the Eco House needs to be replaced. It is very likely that an "energy star" dehumidifier will pay for itself quickly. Second, people must be made aware that the best way to reduce energy use is to change habits. Avoid wasteful energy use; only leave items on if they are actively being used. Third, with this project I had to work with limited amounts of data. From a statistician's point of view, 35 points of data from each house (one for each month) is hardly any data. The fact that I was able to get a statistically significant model for natural gas out of so little data is a testament to how strong the effect is. If the college intends for people to study the energy use of the college in the future, it would be very beneficial if data is collected and saved. Said plainly: save my data for future projects.