Energy Trust of Oregon 2009-2011 New Homes Billing Analysis: Comparison of Modeled vs. Actual Energy Usage

Dan Rubado, Energy Trust of Oregon, Portland, OR

ABSTRACT

This paper describes a utility billing analysis of newly constructed homes that received performance-based incentives through Energy Trust of Oregon's New Homes (NH) program. Similar to many new residential construction programs, Energy Trust's NH program uses an Energy Performance Score (EPS™) to determine incentive amounts and energy savings to be claimed. The EPS is based on energy modeling to compare home performance versus a code baseline. In this study, we analyzed the differences between actual weather normalized and modeled annual energy usage for the first full year post-occupancy and subsequent years, for homes built from 2009 to 2011. We examined the distribution of differences and analyzed mean differences using paired t-tests. For gas heated homes, the average differences between normalized and modeled gas use were less than 10% and individual differences were within 25% of the modeled usage for roughly two-thirds of homes. The average differences for electric base load usage were also less than 10%, although variability was much higher. For electric heated homes, sample sizes were too small to provide reliable results. Analysis of energy usage over time showed that the energy models consistently underestimated average annual gas and electric use by a small amount. In conclusion, energy models used by the NH program appear to be relatively accurate, on average, particularly for gas use, although they may slightly underestimate actual usage. However, there are substantial deviations from modeled usage in individual homes.

Introduction

Energy Trust of Oregon's New Homes (NH) program has provided performance-based incentives to home builders for whole home efficiency upgrades through its Energy Performance Score (EPS™) track since 2009. To receive an EPS, a program verifier must inspect the home and model its energy usage with REM/Rate™ software (NORESCO, 2015). The modeled energy performance is compared to a baseline of what is required by State building code. The incentive provided to the builder is on a sliding scale, based on the estimated energy savings above code. Energy Trust developed the performance-based EPS track in 2008 in response to a more stringent State building code and the limitations of the prescriptive ENERGY STAR system. EPS was formally launched in mid-2009 along with an education and promotion campaign to recruit builders, verifiers and real estate professionals. Within the first six months of EPS, program builders were already exceeding the Energy Star specs (Stull & Youngblood, 2010).

This report describes a billing analysis that quantifies the average annual energy use of newly constructed, detached single family homes built in Oregon from 2009 to 2011. In particular, we analyzed the energy use of homes that received an EPS compared to their predicted energy use. Single family homes built from 2009 to 2011 were primarily constructed under Oregon's 2008 residential building code. We analyzed each year of home construction separately to account for some residual code differences, programmatic differences and changes in the market. The primary goal of this analysis was to determine how accurate the modeled energy use estimates were during these program years. Although similar analyses of REM/Rate's accuracy have been conducted in the past (Earth Advantage Institute, 2009; Hassel, Blasnik, & Hannas, 2009), there has been no assessment of its accuracy for new homes in Oregon since it was deployed by Energy Trust's NH program.

The findings from this analysis provide feedback about the accuracy of the modeling software used by the New Homes program to claim savings. This may help to better calibrate the models to improve energy use and savings estimates in the future. The results will provide feedback to the Northwest Energy Efficiency Alliance and Northwest utilities that are investigating similar performance-based incentive programs for new residential construction. The analysis also offers a rare glimpse into residential energy use over several years and how modeled estimates perform in real world conditions. A full report from Energy Trust, with additional details, is forthcoming.

From 2009 to 2011, according to market data that the NH program purchases from Construction Monitor (Construction Monitor, 2014), there were approximately 14,500 single family homes built in Energy Trust's service territory in Oregon and 2,130 of them received incentives from the New Homes program for whole home energy efficiency treatments. The number of homes that receive incentives through the New Homes program varies by year based on trends in home construction and the individual builders and subcontractors that are involved and active in the program. **Table 1** shows the number of homes constructed per year and the market share of program homes in the state.

Table 1. Overview of NH program activity: number of program homes, total program gas and electric savings, home characteristics, and program market share, 2009-2011

Year Built	Program Homes	Therm Savings Claimed	kWh Savings Claimed	% Gas Heat	% Electric Heat	Mean Sq.Ft.	Total New Homes in Market*	Program Market Share
2009	705	105,110	821,500	81%	18%	2,450	5,592	13%
2010	611	72,510	472,200	79%	21%	2,120	4,812	13%
2011	814	116,370	686,400	84%	16%	2,160	4,052	20%

Note: Numbers may not match official program results due to slight definitional differences.
* Numbers based on market data purchased by the New Homes program from Construction Monitor.

Methods

Weather Normalization of Usage Data

Electric and gas utility billing data from Energy Trust's participating utilities were obtained for all Oregon residences. The usage for every billing period was divided by the number of days in the period to arrive at the daily average usage. Data on daily average temperature were collected from the National Climatic Data Center for 13 weather stations dispersed across Energy Trust's service territory and matched to home addresses. Weather normalization was conducted using a method similar to the PRInceton Score-keeping Method (PRISM) (Fels, 1986), where average daily energy use is a function of heating requirements of the home. The algorithm decomposes energy use into estimated heating and base load components. To do this, an optimum "set-point", or reference temperature, is found below which energy use for heating is detected. Reference temperatures ranging from 30 to 90 degrees Fahrenheit were calculated for each gas/electric billing period and a regression was run for each of the 61 possible reference temperatures. The regression for the reference temperature with the best fit and explanatory power (maximum R-squared) was used to calculate the weather normalized annual usage using the latest typical meteorological year (TMY3) long run heating degree-days.

Comparison of Modeled and Normalized Annual Energy Usage

The goal of this analysis was to determine the accuracy of the NH program's modeled energy usage estimates, which are used to calculate energy savings above code-level performance. We selected single family detached EPS homes that were built in Oregon from 2009 through 2011 from Energy Trust's project tracking database. Homes east of the Cascades were dropped from the analysis, due to the relatively low project volumes and lower availability of billing data. Next, we matched EPS homes to their normalized annual energy usage data based on address. To ensure that we only analyzed post-occupancy energy usage, we matched the energy data to homes beginning with the year of data following the completion year. The analysis was separated by year built, year of energy data, and primary heating fuel, which was determined for each home using the billing data and weather normalization regression results. To specify the main heating fuel, we picked the fuel with a regression heating signature (positive HDD regression coefficient, HDD R-squared value greater than 0.5, greater than 80 therms or 2,000 kWh normalized annual heating load). Homes that indicated heating with both gas and electricity were not analyzed.

For gas heated homes, we first analyzed gas usage and then analyzed the base load electric usage for homes where electric data were available. For electric heated homes, we analyzed electric usage only. Homes that could not be matched to billing data were dropped from the sample. When analyzing electric use, all homes with known solar photovoltaic (PV) systems were dropped. Homes with solar PV systems are difficult to use in electric billing analysis because the amount of on-site generation is not recorded by the utility meter. Homes that had incomplete or unreliable gas or electric billing data in a given year, and those that were outliers in usage (top or bottom 1%), were dropped from the sample. We directly compared the normalized annual energy usage to the modeled annual usage for each EPS home. We started by analyzing the energy data from the first full year of occupancy post-construction, then, each subsequent year of energy use data was analyzed through 2012. We then computed the differences between the normalized and the modeled annual gas and electric use for each home. Summary statistics and graphs were used to assess the distribution of differences. Paired, two-tailed t-tests were used to determine the magnitude and statistical significance (from p-values) of the mean differences for each construction year, fuel and year of billing data. A p-value of less than or equal to 0.05 is equivalent to statistical confidence of greater than or equal to 95% and was selected as our threshold to determine statistical significance for this analysis.

To model the annual energy use of an EPS homes with REM/Rate, a number of standards and assumptions are used. The NH program follows the Residential Energy Services Network (RESNET) Ratings Standards (RESNET, 2013) when modeling energy usage in REM/Rate, which includes guidelines related to housing characteristics, HVAC systems, water heating, lighting, appliances and assumptions about other end uses, such as TVs, refrigerators, cooking ranges, clothes washers and dryers, dishwashers, mechanical ventilation, ceiling fans and plug loads. One key assumption used in modeling is occupancy, which is set equal to the number of bedrooms plus one. Each version of REM/Rate contains updates and changes, some of which impact the modeled energy use estimates. Since the deployment of EPS, there have been several updates to REM/Rate. This analysis does not attempt to account for any of the inputs or assumptions used to model energy use in REM/Rate. We simply compared the modeled energy usage with normalized annual energy usage and did not attempt to determine the cause of any differences.

Results

The results of this billing analysis are organized into sections pertaining to gas heated homes and electric heated homes. Within each section, sub-sections discuss the comparisons of modeled and first

year normalized energy usage and the comparison of modeled and normalized annual energy use over time. **Table 2** summarizes the results of our analysis to determine the heating system fuel for each EPS home in western Oregon. Six-hundred three homes out of 1,635 total could not be matched to energy usage data, particularly those built in 2011, due to missing data in Energy Trust's billing database. These homes could not be further analyzed and were removed during the attrition analysis described below.

Table 2. Heating fuel for new EPS homes determined using energy usage data, 2009-2011

Year Built	Heating System Fuel				Total*
	Electric	Gas	Both	No billing data	
2009	35	377	16	115	557
2010	31	314	12	95	452
2011	48	147	2	393	626

* Total program homes shown here are restricted to western Oregon and thus are lower than the totals shown in Table 1.

Attrition occurred during our analysis primarily due to missing or insufficient billing data. For both gas and electric heated homes, more than half of homes in the population were lost during the attrition steps. For both gas and electric heated homes, the large amount of attrition due to missing energy usage data may have introduced bias into the study. Although the results are indicative of the sample we analyzed, they may not be quantitatively representative of the entire population of homes in Energy Trust's territory. The final sample sizes are shown in each section below.

Gas Heated Homes

Table 3 summarizes the average characteristics of the final sample of gas heated EPS homes. The mean home size hovered around 2,000 square, but increased slightly from 2009 to 2011. EPS, first year gas heating and total gas usage also increased slightly over time. The mean heating reference temperature, the point below which gas heating was used, also appeared to increase slightly over time.

Table 3. Characteristics of final sample of gas heated EPS home built from 2009-2011

Year Built	Analysis Year	N	Mean Sq.Ft.	Mean EPS	Mean Heating Reference Temp (^{o}F)*	Mean Heating Usage (Therms)**	Mean Total Usage (Therms)
2009	2010	176	1,990	71	56	344	485
2010	2011	299	2,160	72	57	360	515
2011	2012	135	2,250	75	58	394	547

* Mean heating reference temperature refers to the best fit HDD reference temperature selected for each home during the PRISM analysis.
** Mean annual heating usage calculated from the weather normalization regression coefficients.

Comparison of Modeled and First Year Normalized Energy Use. Table 4 summarizes the results of the comparison between modeled and first year normalized gas use for gas heated EPS homes. The mean modeled gas use was very close to the mean normalized first year usage in all three years, with mean differences ranging from three therms higher than first year usage to 30 therms lower. These

differences amount to less than 10% of the mean first year gas use. However, using the p-values from our paired t-tests, we found that the models significantly underestimated gas use for 2011 homes (p=0.023), on average, although the difference was slight (5.5%). **Figure 1** displays the mean differences between the modeled and first year gas use graphically. **Table 5** provides a summary of the variation between homes in the differences between modeled and first year gas use. For roughly one-third of homes modeled gas use was within 10% of first year usage and about two-thirds of homes were within 25%. This relatively low band of variability around the mean differences is illustrated in the scatterplots presented in **Figure 4**.

Table 4. Comparison of mean modeled vs. first year normalized gas use (in therms) in gas heated EPS homes built from 2009-2011

Year Built	Analysis Year	N	Mean Modeled Usage	Mean Normalized Usage	Mean Difference	90% CI LB*	90% CI UB*	p-value
2009	2010	176	488	485	3	-15	21	0.797
2010	2011	299	504	515	-10	-24	3	0.211
2011	2012	135	517	547	-30	-52	-9	0.023**

* Lower and upper bounds of the 90% confidence interval for the mean difference.
** Statistically significant at the 0.05 level.

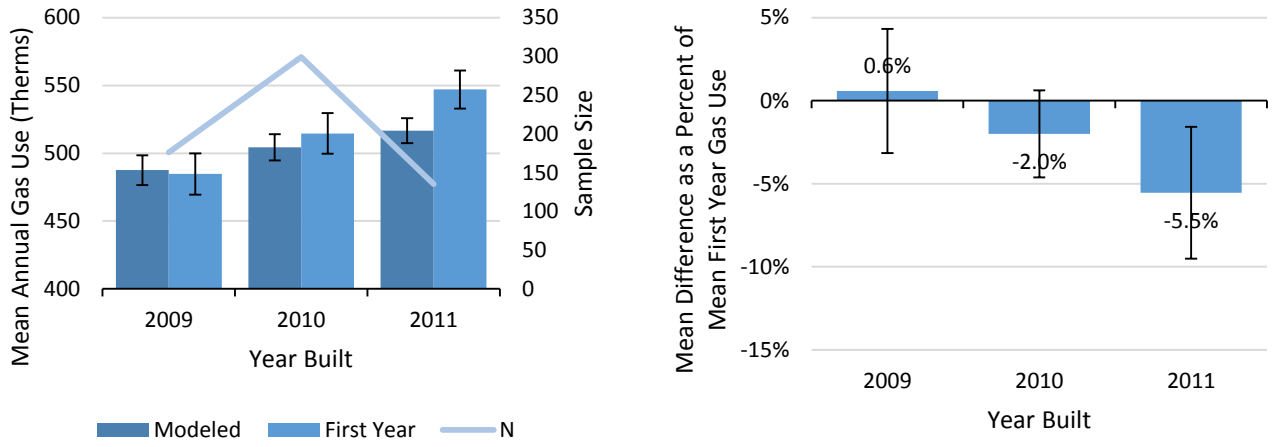

Figure 1. Comparison of mean modeled vs. first year normalized gas use (in therms) and mean differences as a percent of mean annual usage in gas heated EPS homes built from 2009-2011.
Note: positive values in the graph of differences indicate that models overestimated usage, on average, while negative values indicate that they underestimated it.

Table 5. Summary of differences for individual homes between modeled and first year normalized gas use as a percent of annual usage, in gas heated EPS homes built from 2009-2011

Year Built	Analysis Year	% Homes with <10% Difference	% Homes with <25% Difference	% Homes with <50% Difference
2009	2010	27%	65%	87%
2010	2011	28%	64%	92%
2011	2012	34%	75%	90%

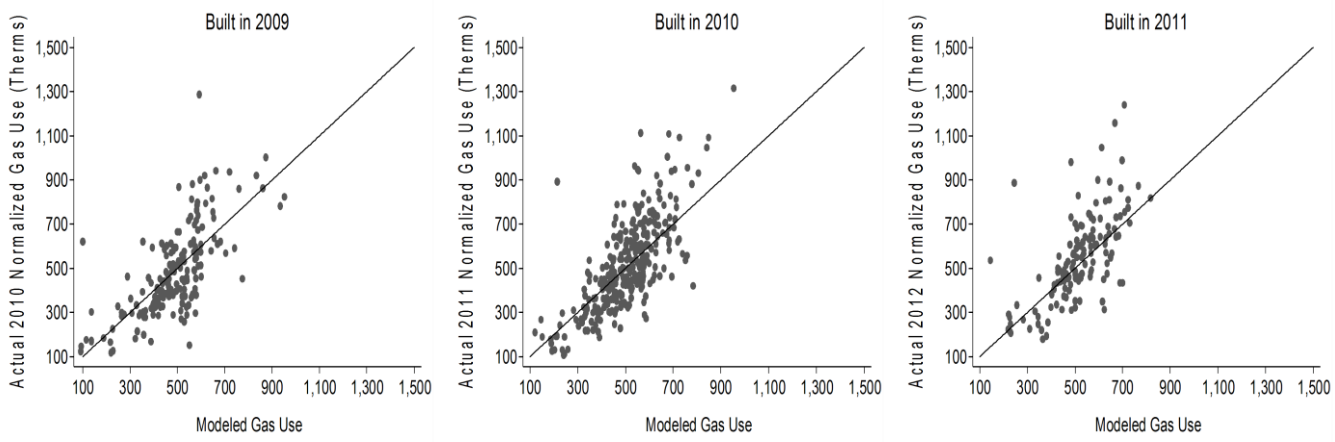

Figure 2. Scatterplots of modeled gas usage versus the deviation in first year normalized gas use from modeled usage (in therms) for individual gas heated EPS homes built from 2009-2011.
Note: the reference line indicates where first year and modeled gas use are equivalent; points above the line indicate homes where actual usage was higher than estimated and vice versa.

Table 6 shows the results of the comparison between the modeled and first year normalized electric base load usage for gas heated homes. In all three years, the models underestimated first year electric use, on average, by 140 to 530 kWh. These differences are relatively small and represent less than 10% of the mean first year electric use. There were no statistically significant differences. **Figure 3** displays the mean differences between modeled and first year usage graphically. **Table 7** provides a summary of the variation between homes in the differences between modeled and first year electric use. Only about one-third of homes had modeled electric use within 50% of first year usage, indicating substantial variability around the mean differences in all three years. This relatively wide scatter is illustrated in the scatterplots presented in **Figure 4**.

Table 6. Comparison of mean modeled vs. first year normalized electric use (in kWh) in gas heated EPS homes built from 2009-2011

Year Built	Analysis Year	N	Mean Modeled Usage	Mean Normalized Usage	Mean Difference	90% CI LB*	90% CI UB*	p-value
2009	2010	75	6,210	6,550	-340	-900	230	0.334
2010	2011	105	6,360	6,500	-140	-550	270	0.568
2011	2012	49	6,340	6,870	-530	-1,140	90	0.167

* Lower and upper bounds of the 90% confidence interval for the mean difference.

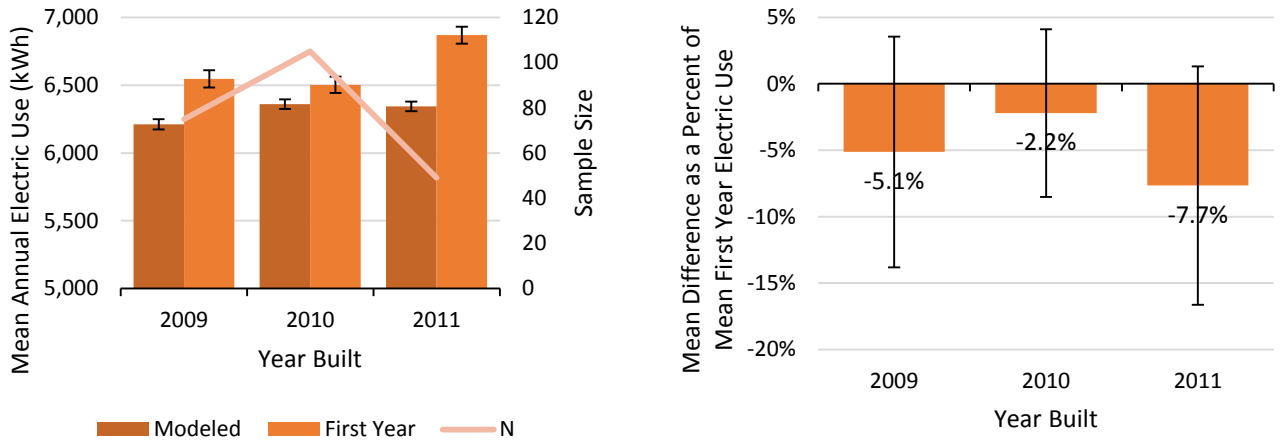

Figure 3. Comparison of mean modeled vs. first year normalized electric use (in kWh) and mean differences as a percent of mean annual usage in gas heated EPS homes built from 2009-2011.
Note: positive values in the graph of differences indicate that models overestimated usage, on average, while negative values indicate that they underestimated it.

Table 7. Summary of differences for individual homes between modeled and first year normalized electric use as a percent of annual usage, in gas heated EPS homes built from 2009-2011

Year Built	Analysis Year	% Homes with <10% Difference	% Homes with <25% Difference	% Homes with <50% Difference
2009	2010	10%	21%	32%
2010	2011	8.4%	20%	28%
2011	2012	4.4%	16%	31%

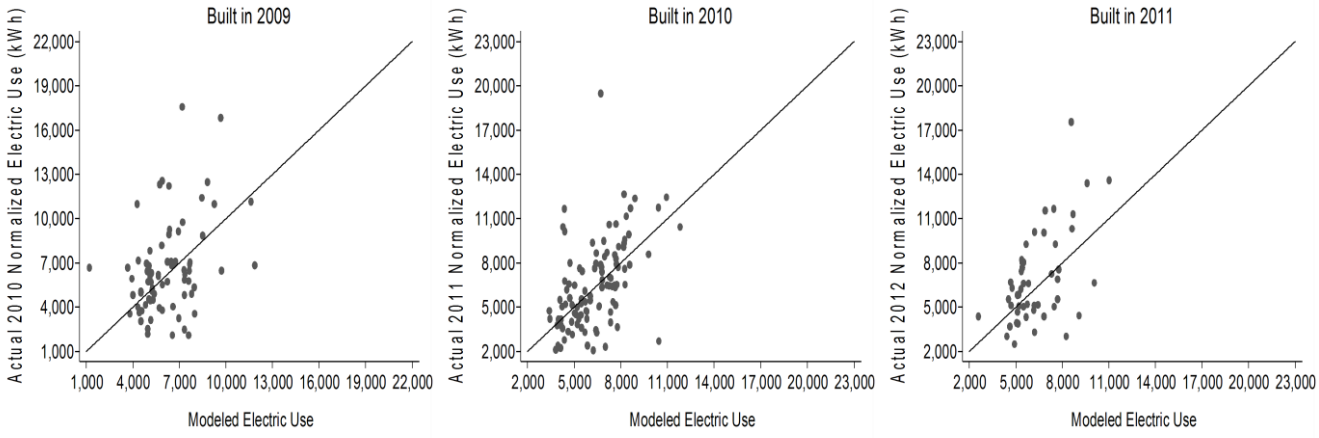

Figure 4. Scatterplots of modeled electric usage versus the deviation in first year normalized electric use from modeled usage (in kWh) in gas heated EPS homes built from 2009-2011.
Note: the reference line indicates where first year and modeled electric use are equivalent; points above the line indicate homes where actual usage was higher than estimated and vice versa.

Comparison of Modeled and Normalized Annual Energy Use over Time. We analyzed additional years of energy data for each year of gas heated home construction to see if any trends

appeared. **Figure 5** displays the mean differences over time between modeled and normalized annual gas use as a percent of annual usage. Although the differences between mean modeled and first year gas use were relatively small, the gap appears to widen over time. This analysis does not cover enough years of energy data to identify whether there are any significant trends, but there is a consistent pattern of modeled usage slightly underestimating annual gas use, on average. Several years of usage data show mean differences where modeled gas use was significantly lower than the annual gas use. However, all of these differences are well below 10% of mean annual usage, so there is not a strong bias, on average.

Figure 6 displays the mean differences over time between the modeled and annual electric base load as a percent of annual usage. Modeled usage appeared to consistently underestimate annual electric usage, on average. The mean difference was only statistically significant for one year of energy data, but there was a clear pattern across all years. However, the differences were relatively small, on average, and were well below 10% of annual usage. **Appendix B** contains the tables of results for the comparisons of modeled and normalized annual energy use over time associated with the figures below.

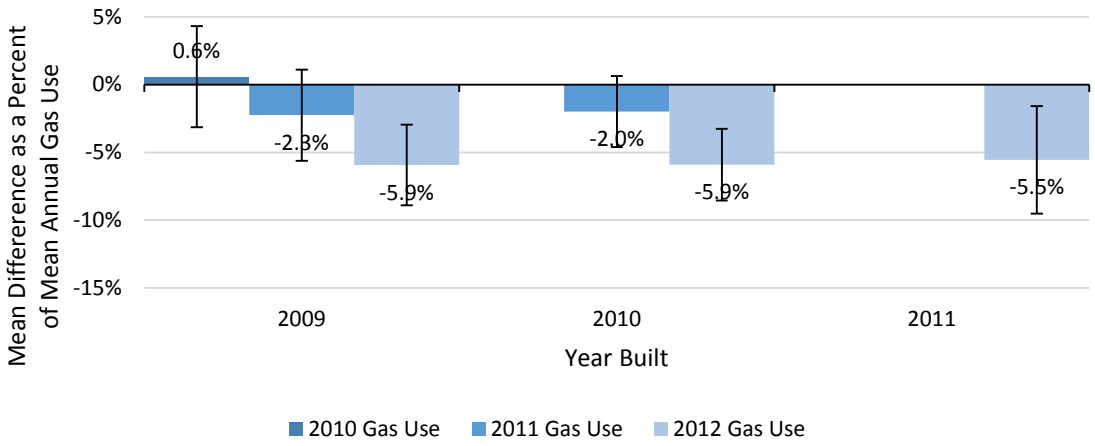

Figure 5. Mean differences in modeled vs. normalized annual gas use as a percent of mean annual usage over time, in gas heated EPS homes built from 2009-2011.
Note: positive values indicate that models overestimated usage, on average, while negative values indicate that they underestimated it.

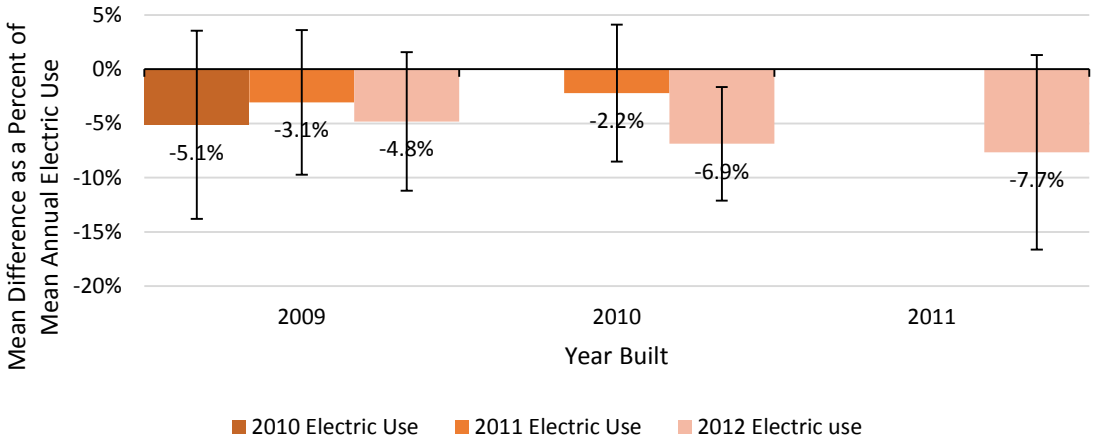

Figure 6. Mean differences in modeled vs. normalized annual electric use over time as a percent of mean annual usage, in gas heated EPS homes built from 2009-2011.

Note: positive values indicate that models overestimated usage, on average, while negative values indicate that they underestimated it.

Electrically Heated Homes

Table 8 summarizes the average characteristics of the final sample of electrically heated EPS homes. Mean square footage hovered around 2,000 square feet, but appeared to decrease over time. The mean EPS hovered around 53 and mean normalized annual electric use was around 12,000 kWh, with heating usage of about 4,000 kWh. Similar to gas heated homes, the mean heating reference temperature increased slightly from 54 to 56 degrees over time.

Table 8. Characteristics of final sample of electrically heated EPS homes

Year Built	Analysis Year	N	Mean Sq.Ft.	Mean EPS	Mean Heating Reference Temp (^{o}F)*	Mean Heating Usage (kWh)**	Mean Total Usage (kWh)
2009	2010	22	2,270	53	54	4,090	12,770
2010	2011	23	2,090	52	55	4,530	11,680
2011	2012	36	1,980	53	56	3,580	12,140

* The mean heating reference temperature refers to the best fit HDD reference temperature selected for each home during the PRISM analysis.
** Mean annual heating usage calculated from the weather normalization regression coefficients.

Comparison of Modeled and First Year Normalized Energy Use. Table 9 shows the results of the comparison between the modeled and first year electric use for electric heated homes. The mean differences for 2009 and 2010 homes were small and insignificant, less than 2% of first year electric use. However, for 2011 homes, the modeled usage underestimated first year electric use by 1,450 kWh, on average, or nearly 12% of usage. Using the p-values from our paired t-tests, we determined that this difference was statistically significant (p=0.036). **Figure 7** shows the mean differences graphically. However, due to the small sample sizes, these results may not be reliable. **Table 10** provides a summary of the variation between homes in their differences between modeled and first year electric use. Less than half of homes overall had modeled electric use within 50% of first year usage, indicating a large amount of variability. This relatively wide scatter is illustrated in **Figure 8** and is not surprising given the small sample sizes. It also appears that a few homes with large differences may have skewed the results for 2011 homes.

Table 9. Comparison of mean modeled vs. first year normalized electric use (in kWh) in electric heated EPS homes built from 2009-2011

Year Built	Analysis Year	N	Mean Modeled Usage	Mean Normalized Usage	Mean Difference	90% CI LB*	90% CI UB*	p-value
2009	2010	22	12,930	12,770	160	-1,280	1,610	0.853
2010	2011	23	11,870	11,680	190	-1,710	2,090	0.870
2011	2012	36	10,690	12,140	-1,450	-2,540	-360	0.036**

* Lower and upper bounds of the 90% confidence interval for the mean difference.
** Statistically significant at the 0.05 level.

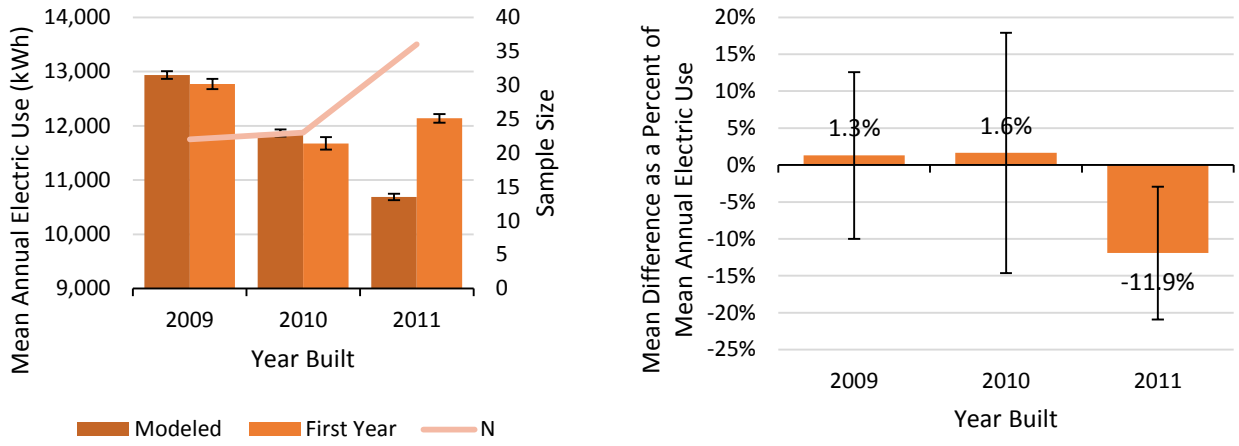

Figure 7. Comparison of mean modeled vs. first year normalized electric use (in kWh) and mean differences as a percent of mean annual usage in electric heated EPS homes built from 2009-2011. Note: positive values indicate that models overestimated usage, on average, while negative values indicate that they underestimated it.

Table 10. Summary of differences for individual homes between modeled and first year normalized electric use as a percent of annual usage in electric heated EPS homes built from 2009-2011

Year Built	Analysis Year	% Homes with <10% Difference	% Homes with <25% Difference	% Homes with <50% Difference
2009	2010	14%	50%	82%
2010	2011	9%	22%	70%
2011	2012	25%	61%	86%

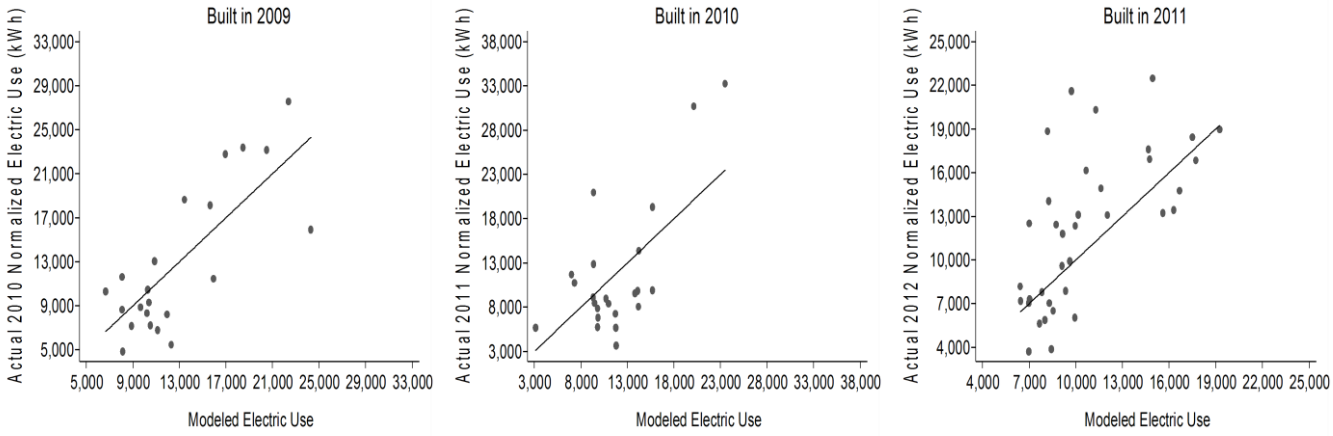

Figure 8. Scatterplots of modeled electric usage versus the deviation in first year normalized electric usage from modeled usage in electric heated EPS homes built from 2009-2011.
Note: the reference line indicates where first year and modeled electric use are equivalent; points above the line indicate homes where actual usage was higher than estimated and vice versa.

Comparison of Modeled and Normalized Annual Energy Use over Time. For each year of home construction, we analyzed additional years of electric data through 2012. **Figure 9** displays the

mean differences over time between modeled and normalized annual electric use as a percent of annual usage. Although these differences varied from year to year, there is a discernable pattern of modeled usage slightly underestimating annual electric use, on average. All but one of the mean differences from modeled usage were less than 10%. For 2011 homes, the mean difference of 12%, as noted above, was statistically significant. Due to the small sample sizes, these results have a high degree of variability and uncertainty. **Appendix B** contains the table of results for the comparisons of modeled and normalized annual electric use over time associated with the figure below.

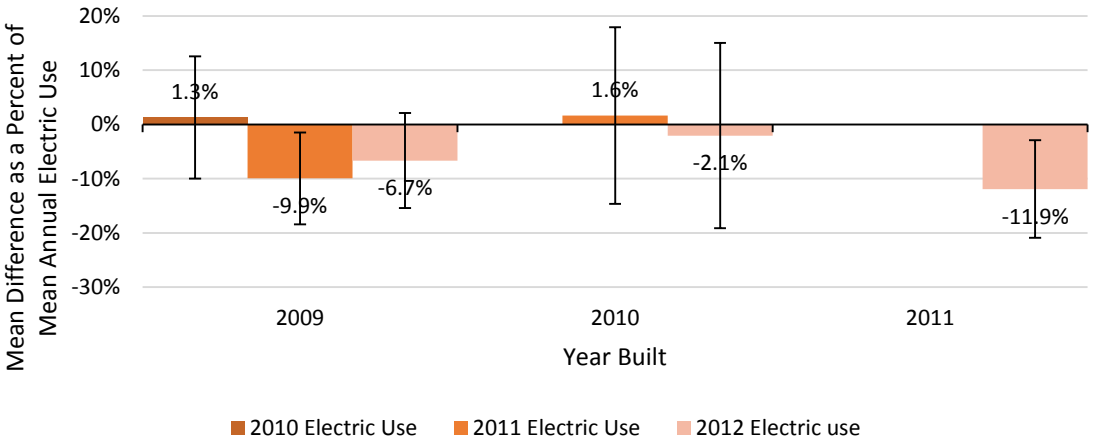

Figure 9. Mean differences in modeled vs. normalized annual electric use over time as a percent of mean annual usage, in electric heated EPS homes built from 2009-2011.
Note: positive values indicate that models overestimated usage, on average, while negative values indicate that they underestimated it.

Conclusions

Energy Trust's NH program appears to have modeled annual energy use with relatively good accuracy, on average, for EPS homes built from 2009 to 2011. Differences in modeled versus normalized annual energy usage were less than 10% for gas heated homes on average, and within 25% of the modeled usage for roughly two-thirds of homes. For electric heated homes, differences in modeled versus normalized annual electric use were between 1% and 12%, on average, with wide confidence intervals due to the small sample sizes. Slightly less than half of electric heated homes had normalized usage within 25% of the modeled usage value. Across the board, there was a consistent pattern of modeled gas and electric use being slightly underestimated, on average, although most of these differences were not statistically significant. The accuracy of modeled electric base loads, which are influenced more by human factors such as behavior and plug loads, varied substantially between homes. However, it is difficult to draw any conclusions from the limited number of electric heated homes in our sample. Further analysis with a larger sample of electric heated homes would be required to better understand the accuracy of modeled electric use.

There were several limitations to this analysis. We were not able to obtain energy usage data for all program homes and saw attrition of greater than half the original sample. Therefore, the results are indicative but may not be quantitatively representative of the population of homes in Energy Trust territory. Although we weather normalized the energy data for each home using standard methods, it is possible that there were residual weather effects, particularly because we used monthly data with only 12 data points per home on which to run the weather regression models. This could have factored into the small differences in results we observed between years of construction and energy data. In addition,

because we were only able to analyze whole home gas and electric use, we were unable to identify the source of any deviations from modeled usage or assess how accurately different end uses were modeled.

In spite of these limitations, the findings of this analysis validate that REM/Rate is a reliable tool, on average, for estimating energy use in gas heated EPS new homes and provides a sound basis for calculating energy savings. Small calibrations may further improve modeled usage estimates. However, the variability we observed in the accuracy of modeled usage means that the models frequently miss the mark for individual homes. This analysis does not provide information about how accurately the NH program estimates energy savings for EPS homes. We are currently undertaking a follow up analysis to evaluate NH program energy savings claims by comparing normalized annual energy use between EPS homes and similar homes built to code that did not receive incentives from the program.

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