APR 13, 2018

EPS-HES Comparison Analysis

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MEMO

Date: June 25, 2018
To: Board of Directors
From: Andrew Shepard, Residential Senior Project Manager
Dan Rubado, Evaluation Project Manager
Subject: Staff Response to the EPS-HES Comparison Analysis Report

This staff response addresses the findings of the EPS-HES Comparison Analysis Report, which compared Energy Trust of Oregon's Energy Performance Score to the U.S. Department of Energy's Home Energy Score.

Recent changes in the home energy scoring landscape in Oregon have resulted in Energy Trust of Oregon ending its use of the Energy Performance Score (EPS™) in existing homes and re-assessing EPS in newly constructed homes. In addition, the rise of the U.S. Department of Energy's Home Energy Score (HES) necessitated an updated comparison of the EPS and HES and their relative accuracy in predicting energy consumption in Oregon homes.

This study shows that Energy Trust's EPS and energy consumption estimates align with HES in some cases, but diverge for many home types. In particular, differences between the two systems appear to stem from how they handle home size and water heating fuel. There are also differences in the scores based on heating fuel. The study found that EPS is a better tool for assessing the efficiency of new homes, primarily because HES uses a 10-point scale and new homes cluster at the top of the range, even those built to the code baseline. This is partly why Energy Trust's Residential program (previously the New Homes program) will continue using the EPS for new homes.

In certain scenarios, both EPS and HES have significant issues with the accuracy of their energy usage estimates. EPS appears to estimate energy usage for gas-heated new homes more accurately, while HES appears to estimate energy usage for gas-heated existing homes more accurately. Both scoring systems performed poorly with electric-heated existing homes. To address inaccuracies in new homes, especially electric heated homes, Energy Trust will review its modelling assumptions in REM/Rate for EPS in new homes. In addition, Energy Trust will conduct an analysis to corroborate modeled energy usage with actual consumption of real code baseline homes (not just simulated ones), which were not included in this analysis, by the end of 2018. The inaccuracies in EPS for existing homes are no longer relevant, since Energy Trust stopped using EPS in existing homes in 2017.

The National Renewable Energy Laboratory is currently in the process of calibrating the DOE2 building simulation engine that underlies HES to improve its accuracy. Energy Trust will share the results of the EPS-HES Comparison Analysis Report with NREL and the Department of Energy to support their work on calibrating DOE2. In addition to calibration, Energy Trust recommends NREL consider making changes to its HES modelling assumptions, particularly for electric-heated existing homes and gas-heated new homes, where modelling errors appear to be large.

Executive Summary

Portland City Code Chapter 17.108 states that after January 1, 2018, all home sellers in the city of Portland, Oregon must disclose a score and energy consumption estimate from the Home Energy Score (HES) scoring tool. Before 2018, Energy Trust of Oregon (Energy Trust), had been using its own home scoring system, the Energy Performance Score (EPS), to rate homes as part of its New Homes and Existing Homes programs. After this transition, Energy Trust expects that many Portland homes previously scored with EPS will require rescoring with HES when they are sold to comply with the new ordinance. To prepare for these changes to the energy scoring landscape and to prevent customer confusion, Energy Trust contracted with Cadeo to conduct a study to compare the HES and EPS scores and validate them against actual energy usage data.

This document represents the final deliverable from Cadeo's study of HES and EPS scores for both new and existing homes in Energy Trust of Oregon's service territory and is divided into two sections:

- Phase 1: Compare EPS and HES Home Score Data
- Phase 2: Validate EPS and HES Energy Usage Estimates with Utility Billing Data

In this study, Cadeo found that

- HES scores are clustered at the top of the 10 point-scale in new homes, and are distributed more uniformly across the 10 point-scale for existing homes.
- EPS annual energy consumption estimates do not effectively predict the HES annual energy consumption estimates without adjusting for building characteristics (i.e., building, vintage, size)
- Both EPS and HES scores improve when simulating energy-efficient retrofits.
- Billing analysis indicates that both EPS and HES energy consumption estimates are inaccurate for many segments of homes, though the magnitude and direction of the differences vary by home vintage, heating fuel, and home size.
- In gas-heated existing homes, HES and EPS have offsetting differences in their electric and gas energy consumption. The net result of the offset is that the HES reports and EPS reports will show similar annual energy costs.

Background

A recent ordinance, Portland City Code Chapter 17.108, passed in Portland, Oregon will require all homes being sold to receive a US Department of Energy (USDOE) Home Energy Score (HES). In addition, the Oregon Department of Energy (ODOE) has adopted rules for home energy rating that support the use of the HES across the state. This represents a shift away from Energy Trust's Energy Performance Score (EPS), which has been used to rate the energy performance of new and existing homes across Oregon over the past nine years. Energy Trust is still using the EPS scoring system for efficient new homes across Oregon, as part of Energy Trust's New Homes program. For existing homes, Energy Trust has changed its scoring

system to use the HES and align with state and local regulations and efforts to promote home energy scoring.

Both HES and EPS are asset-based energy scores that communicate the energy-efficiency level of a home to homeowners and homebuyers. HES scores are shown on a simple, unit-less 1-to-10 scale, where a score of 10 is most energy efficient. EPS scores range from 200 to 0, and are more closely tied to actual energy consumption. Each EPS score unit represents one million BTU of energy consumption per year. Therefore, for any given home, a lower EPS score is more energy efficient.

Due to the promotion of HES, Energy Trust and other stakeholders are concerned about the potential market impact of a new score that provides homeowners with a different result. In the city of Portland, Energy Trust expects that many homes previously scored with the EPS will require rescoring using the HES when they are sold, to comply with the new city ordinance. These inadvertent comparisons between scoring systems could uncover systematic differences between the scores and their outputs and introduce some inconsistency and confusion into the market.

To prepare for these changes to the energy scoring landscape and prevent customer confusion, Energy Trust contracted with Cadeo to conduct a study to compare the HES and EPS scores and validate them against actual energy usage data.

Phase 1: Compare EPS and HES Home Score Data

Supporting Data

As part of this study, Energy Trust provided a sample of new and existing homes that received EPS scores in 2015 and 2016 to the National Renewable Energy Lab (NREL), who converted the characteristics of these homes into appropriate inputs for the HES scoring tool and computed the HES scores and associated outputs for each home. Both HES and EPS scores and associated outputs are building-simulation driven:

- HES uses the DOE2 building simulation engine,
- EPS scores were originally produced using REM/Rate v14.6.1 for new homes and CakeSystems SIMPLE home energy tool for existing homes[1]. However, for new homes using REM/Rate v14.6.1, NREL re-ran the models using REM/Rate v15.4, so that the EPS scores and outputs would be consistent with the most recent version of REM/Rate used by the New Homes program.

Energy Trust and Earth Advantage provided Cadeo with scores and energy consumption estimates from each scoring system for this analysis. The available data and data preparation steps that Cadeo used for new and existing homes differed slightly and are described in further detail below.

[1] EPS Frequently Asked Questions, accessed 1/24/18 at: http://www.energy-performance-score.com/faq

New homes

Cadeo weighted the sample of new homes from the population of efficient new homes built in the state of Oregon between 2015 and 2017 that received incentives from Energy Trust's New Homes program by

- Climate Zone
- Heating Fuel, and
- Physical Size (square feet)

Through the process of matching data across disparate sources and running building simulations, Cadeo received HES and EPS score data for 796 of the 1,000 new homes in the initial sample.

Cadeo weighted each new home in the sample such that the sum of sample weights within each cell, stratified by the characteristics above, is equal to the population of homes in that cell (Table 1).

Table 1. New Home Weighting

Climate Zone	Heating Fuel	Size Group	N	Sample Size	Sample Weight
Medford	Electric	Large (> 3,000 sqft)	4	3	1.33
Medford	Electric	Medium (1,400-2,999 sqft)	39	23	1.70
Medford	Electric	Small (< 1,400 sqft)	55	41	1.34
Medford	Natural Gas	Medium (1,400-2,999 sqft)	47	19	2.47
Portland	Electric	Large (> 3,000 sqft)	63	21	3.00
Portland	Electric	Medium (1,400-2,999 sqft)	655	90	7.28
Portland	Electric	Small (< 1,400 sqft)	124	56	2.21
Portland	Natural Gas	Large (> 3,000 sqft)	1,070	108	9.91
Portland	Natural Gas	Medium (1,400-2,999 sqft)	4,210	172	24.48
Portland	Natural Gas	Small (< 1,400 sqft)	89	43	2.07
Redmond	Electric	Large (> 3,000 sqft)	8	7	1.14
Redmond	Electric	Medium (1,400-2,999 sqft)	33	23	1.43
Redmond	Electric	Small (< 1,400 sqft)	26	17	1.53
Redmond	Natural Gas	Large (> 3,000 sqft)	52	32	1.63
Redmond	Natural Gas	Medium (1,400-2,999 sqft)	460	127	3.62
Redmond	Natural Gas	Small (< 1,400 sqft)	28	14	2.00
Total			*6,963*	*796*	

The scores for each new home represent the HES and EPS simulation outputs for that home under two scenarios

- Code base case: a counterfactual home with similar characteristics constructed at code baseline, and
- Efficient case: as-constructed, above code baseline (i.e., with energy efficiency upgrades)

Existing homes

For the sample of 1,000 existing homes, Earth Advantage used the NREL inputs described above to compute the HES score and associated outputs for each home. Cadeo received data for each existing home that represents the HES simulation inputs and outputs for that home under two scenarios

- Base Case: as-constructed home at existing condition, and
- Efficient Case: similar home after a set of proposed, cost-effective energy efficiency upgrades

For existing homes, Cadeo received EPS score data only for the existing condition, pre-retrofit base case. Energy Trust was unable to provide EPS score data for the proposed, efficient case homes.

Results

This section discusses Cadeo's findings for each of six research questions.

1. What are the distributions and differences of home scores and outputs?
2. How well does one score predict the other in the same home?
3. Do certain home characteristics drive differences and outliers?
4. Does a systematic bias exist in the HES score compared to EPS?
5. What is the impact of retrofits to HES and EPS scores for existing homes?
6. Is there a difference in HES and EPS scores between code base case and efficient case new homes?

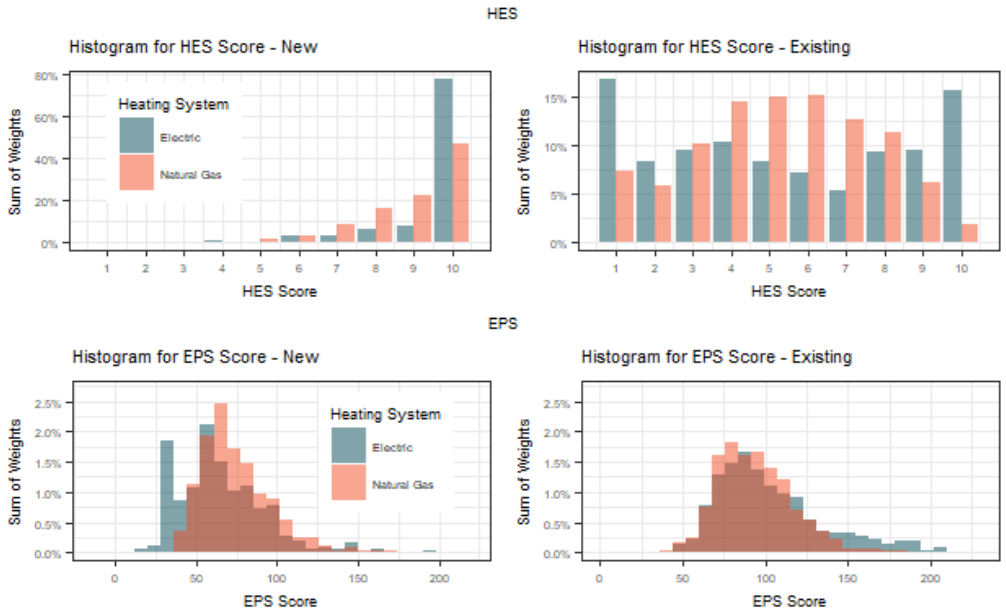
The appendix of this document contains some additional material that Cadeo prepared during the study, including summary tables with HES and EPS scores by home size and vintage.

Research Question 1: What are the distributions and differences of home scores and outputs?

In the sample of new homes, HES scores tend toward the top of the scale (HES score =10), especially in electric-heated homes. In the existing home sample, the HES distribution is more uniform, though the HES scores in electric-heated homes tend toward the tails, while the scores for gas-heated homes tend toward the center of the scale.

Cadeo also found that in the new home sample, the EPS score distribution of electric-heated homes is skewed lower than that of gas-heated homes, while in the existing homes, the EPS score distribution for electric-heated homes is skewed higher than that of gas-heated homes.

Figure 1. Distributions of HES and EPS scores for New and Existing homes



Notes:

- Darker shading in the EPS charts shows the electric distribution behind the natural gas distribution.
- Charts include both baseline and efficient scores for each home.
- Results in new home charts are weighted.

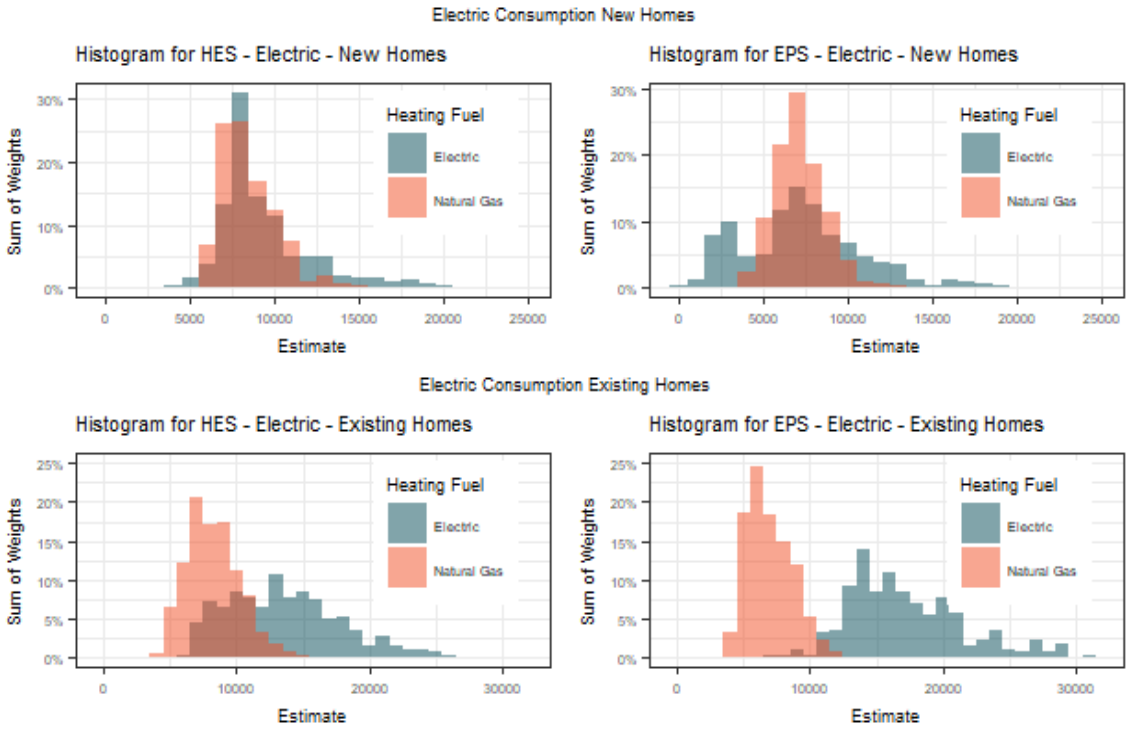
Table 2. Sample Summary Statistics by Vintage: HES and EPS Scores

	New Homes				Existing Homes			
	Electric-Heated		Gas-Heated		Electric-Heated		Gas-Heated	
Statistic	**EPS**	**HES**	**EPS**	**HES**	**EPS**	**HES**	**EPS**	**HES**
N	521	521	996	996	550	550	727	727
Weighted Mean	65	9	75	9	103	5	94	4
Weighted Median	61	10	70	9	93	5	92	4
Weighted St. Dev.	28	1	22	1	33	3	23	2
Weighted CV (%)	44%	13%	30%	15%	32%	59%	25%	50%
Quantile 5%	29	6	47	6	63	1	62	1
Quantile 10%	33	8	51	7	68	1	68	1
Quantile 25%	46	10	59	8	79	2	77	3
Quantile 50%	61	10	70	9	93	5	92	4
Quantile 75%	81	10	88	10	120	9	108	5
Quantile 90%	99	10	104	10	152	10	124	7
Quantile 95%	116	10	117	10	169	10	136	7

- **Note**: Includes all building vintages, efficiency cases, and heating fuels

Figure 2 and Figure 3 show the distributions for HES and EPS energy consumption estimates.

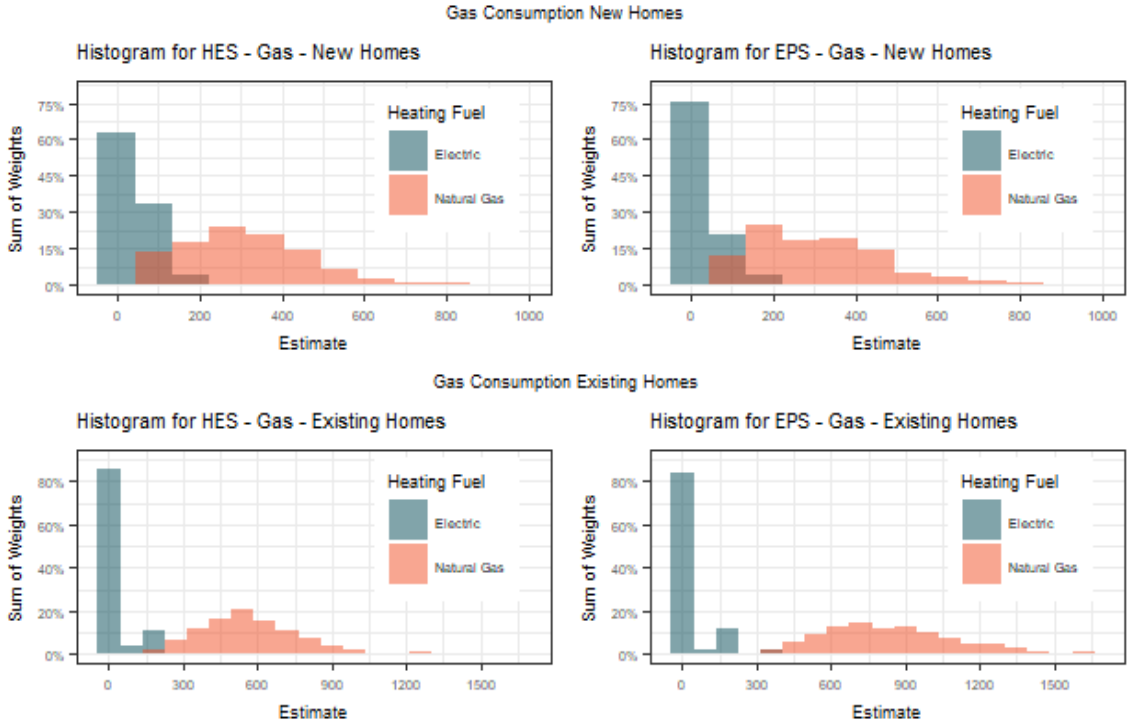
Figure 2. HES and EPS Estimated Electric Consumption Distributions



Notes:

- Darker shading in the EPS charts shows the electric distribution behind the natural gas distribution.
- Charts include both baseline and efficient scores for each home.
- Results in new home charts are weighted.

Figure 3. HES and EPS Estimated Gas Consumption Distributions



Notes:

- Darker shading in the EPS charts shows the electric distribution behind the natural gas distribution.
- Charts include both baseline and efficient scores for each home.
- Results in new home charts are weighted.
- Gas consumption in electric heated homes is strongly skewed towards zero because most do not have gas service. However, a small minority of these homes do have some gas base load, which is reflected in the charts.

Table 3 and Table 4 show the summary statistics for distributions for HES and EPS energy consumption estimates. Based on these summaries, Cadeo found that HES and EPS energy consumption estimates are divergent

- In new, electric heated homes there is a large difference in the average EPS-estimated electric consumption (7,277 kWh/year) and the HES-estimated consumption (9,500 kWh/year).
- In existing, electric heated homes, there is a large difference in the average EPS-estimated electric consumption (17,249 kWh/year) and the HES-estimated consumption (13,754 kWh/year).
- In existing, gas heated homes, there is a large difference in the average EPS-estimated gas consumption (840 therms/year) and the HES-estimated consumption (628 therms /year).

These findings are indicative of differences in the underlying simulation engines between HES and EPS, but are inconclusive because there is no indication of how well they represent reality. We use Phase 2 of this study to present a stronger conclusion: how well do the HES and EPS simulations represent weather-normalized annual energy consumption (NAC).

Some of these differences can be explained by the efficiency case (base or efficient), presence of outliers, or building characteristics. Subsequent analyses in this report control for these extraneous factors and drill into the difference between the energy consumption estimates.

Table 3. Sample Summary Statistics: HES and EPS Estimated Energy Consumption, New Homes

	Electric Heated Home, Electric Consumption (kWh)		Gas Heated Home, Electric Consumption (kWh)		Gas Heated Home, Gas Consumption (Therms)	
Statistic	**EPS**	**HES**	**EPS**	**HES**	**EPS**	**HES**
N	521	521	996	996	996	996
Weighted Mean	7,277	9,500	7,142	8,402	313	310
Weighted Median	7,130	8,459	6,994	8,020	296	300
Weighted St. Dev.	3,661	2,794	1,529	1,612	169	150
Weighted CV	50%	29%	21%	19%	54%	48%
Quantile 5%	2,312	6,457	4,906	6,350	95	88
Quantile 10%	2,530	6,795	5,313	6,641	128	118
Quantile 25%	4,806	8,039	6,058	7,163	176	208
Quantile 50%	7,130	8,459	6,994	8,020	296	300
Quantile 75%	9,364	10,493	8,085	9,345	409	402
Quantile 90%	11,998	13,058	9,144	10,629	521	496
Quantile 95%	13,483	15,663	9,706	11,333	620	555

Note: Includes all efficiency cases

Table 4. Sample Summary Statistics: HES and EPS Estimated Energy Consumption, Existing Homes

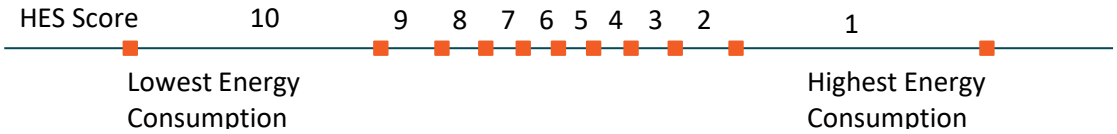
	Electric Heated Home, Electric Consumption (kWh)		Gas Heated Home, Electric Consumption (kWh)		Gas Heated Home, Gas Consumption (Therms)	
Statistic	**EPS**	**HES**	**EPS**	**HES**	**EPS**	**HES**
N	550	550	727	727	727	727
Weighted Mean	17,249	13,754	6,995	8,767	840	648
Weighted Median	16,321	13,347	6,625	8,702	804	632
Weighted St. Dev.	4,470	4,561	1,789	2,221	271	232
Weighted CV	26%	33%	26%	25%	32%	36%
Quantile 5%	11,249	7,473	4,647	5,253	453	307
Quantile 10%	12,603	8,239	5,007	6,028	526	375
Quantile 25%	14,132	10,280	5,626	7,086	639	496
Quantile 50%	16,321	13,347	6,625	8,702	804	632
Quantile 75%	19,945	16,390	8,205	10,247	1,004	766
Quantile 90%	23,666	19,581	9,369	11,628	1,212	913
Quantile 95%	26,688	22,044	9,980	12,529	1,326	1,034

Note: Includes all efficiency cases

Research Question 2: How well does one score predict the other in the same home?

In most cases, Cadeo found overlaps in the EPS score ranges for homes that receive scores in the middle of the HES score distribution. Two factors contribute to this overlap. First, HES scores represent deciles of energy consumption from homes on a national (not regional) basis. Assuming that HES-estimated energy consumption is normally distributed, the middle deciles represent a narrower range of HES energy consumption estimate, as depicted by Figure 4. In addition, EPS is calculated by a different simulation engine and the variability in energy consumption from that different engine is what drives the overlaps in EPS score ranges within HES score.

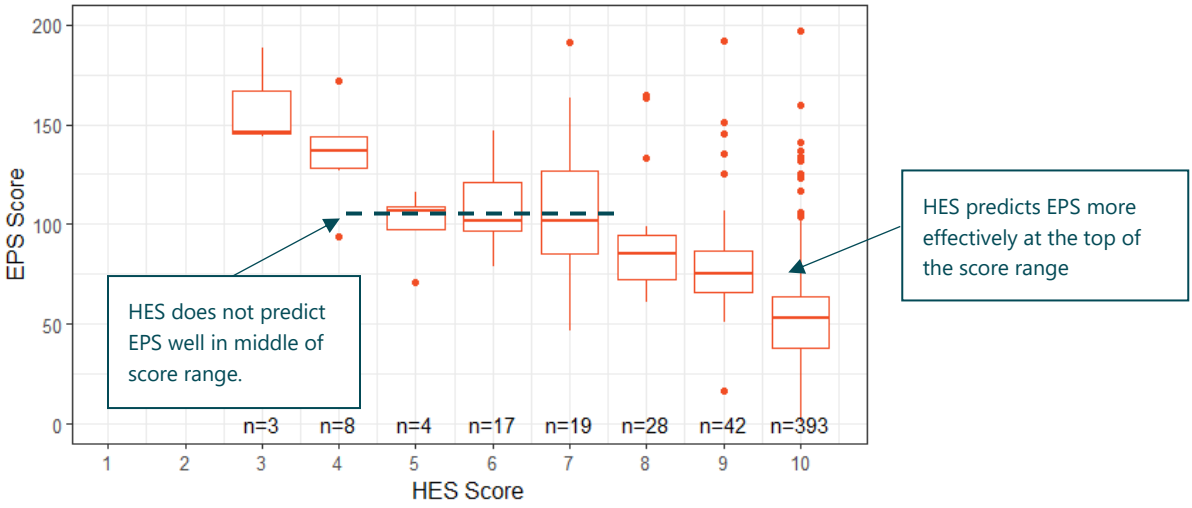
Figure 4. Illustration of HES Consumption to Score Mapping



The box-and-whisker plots shown in Figure 5 and Figure 6 show the range of EPS scores within each HES score for new homes. If HES score predicted EPS score perfectly, the boxes in Figure 5 and Figure 6 would align diagonally from the upper left to the bottom right of the chart, and if there were no correlation between EPS and HES score, the boxes would align horizontally from left to right.

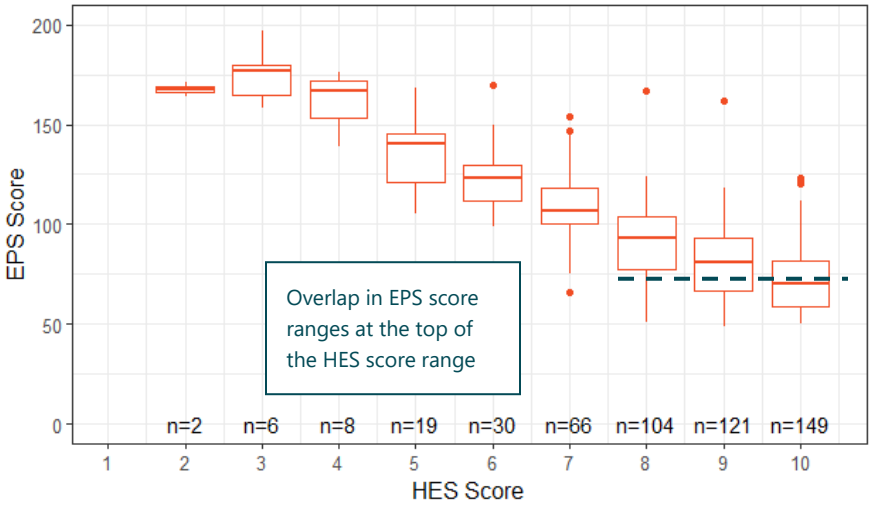
Cadeo found that in electric heated new homes, HES score does not predict EPS score well in the middle of the HES score range (HES scores 5, 6, and 7 in Figure 5), though the sample size is small. The prediction is better at the high end of the HES score range (HES scores 9 and 10).

Figure 5. EPS Score Range within HES Score, electric-heated New Homes



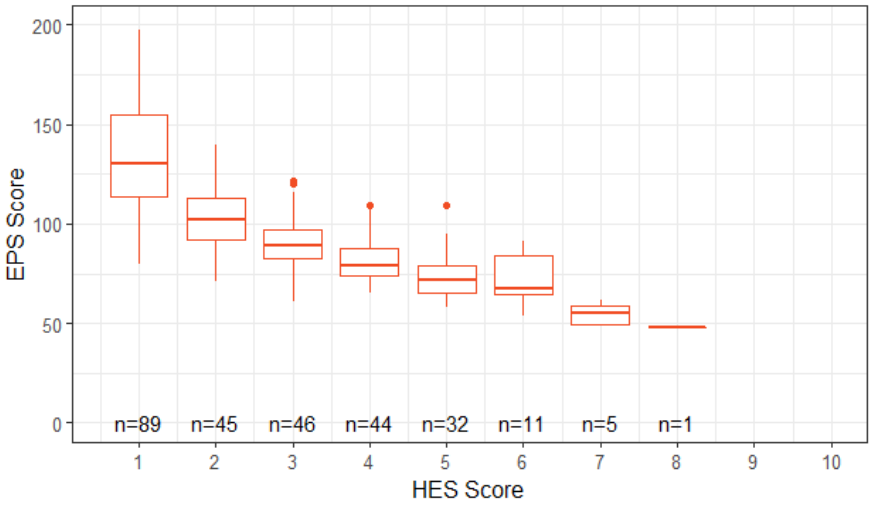
In gas-heated new homes, HES scores generally predict EPS scores well. However, at the top end of the HES range (HES score 9,10), which accounts for most of the homes in the sample, the EPS score ranges overlap (Figure 6). This observation could lead to problems interpreting the HES score for a new, gas heated home that has already received an EPS score.

Figure 6. EPS Score Range within HES Score, gas-heated New Homes



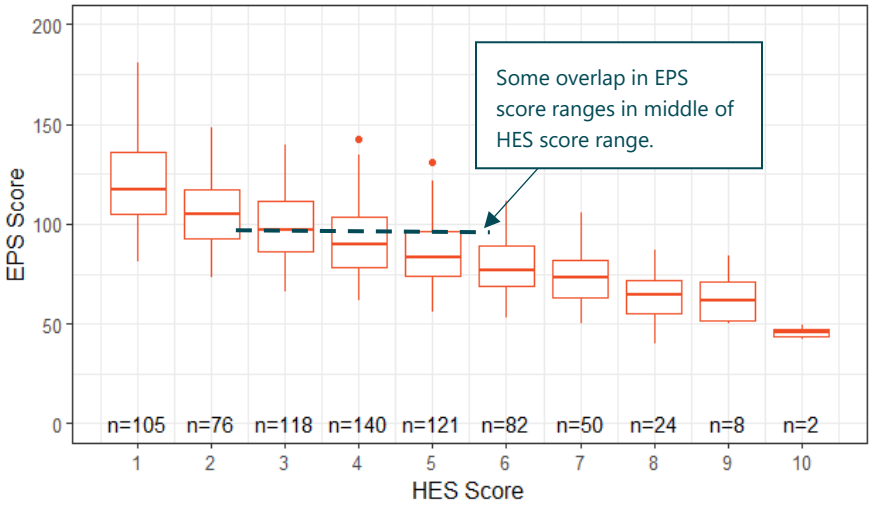
In existing homes, there is a similar trend in EPS scores relative to HES scores, both in electric (Figure 7) and gas (Figure 8) heated homes. In both cases, a higher HES score is associated with a lower EPS score, as would be expected.

Figure 7. EPS Score Range within HES Score, electric-heated Existing Homes



There are overlaps in the EPS scores within HES scores existing gas-heated homes. As an example of the overlap, an existing, gas-heated homes with an EPS score of 100 could get an HES score 3, 4, or 5 (Figure 8).

Figure 8. EPS Score Range within HES Score, gas-heated Existing Homes



Research question 4, addressed later in this document, further quantifies the relationship between HES and EPS scores using Spearman's correlation coefficient.

In contrast to the scores, the relationship between the HES and EPS energy consumption estimates are more linear; Figure 9 and Figure 10 show scatterplots and the associated best fit lines for new homes and existing homes respectively.

Figure 9. Scatterplot of EPS to HES energy estimates by Heating Fuel for New Homes

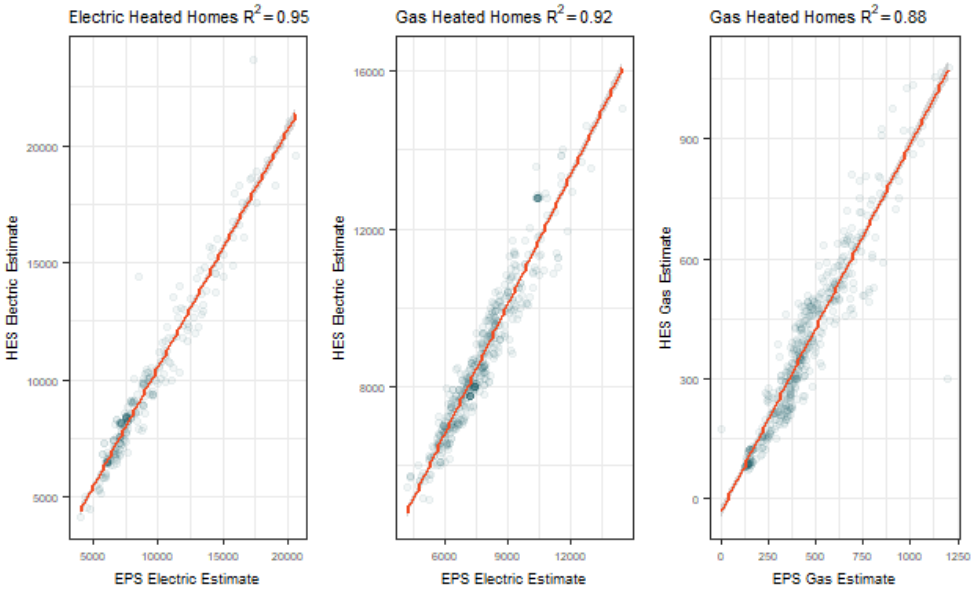
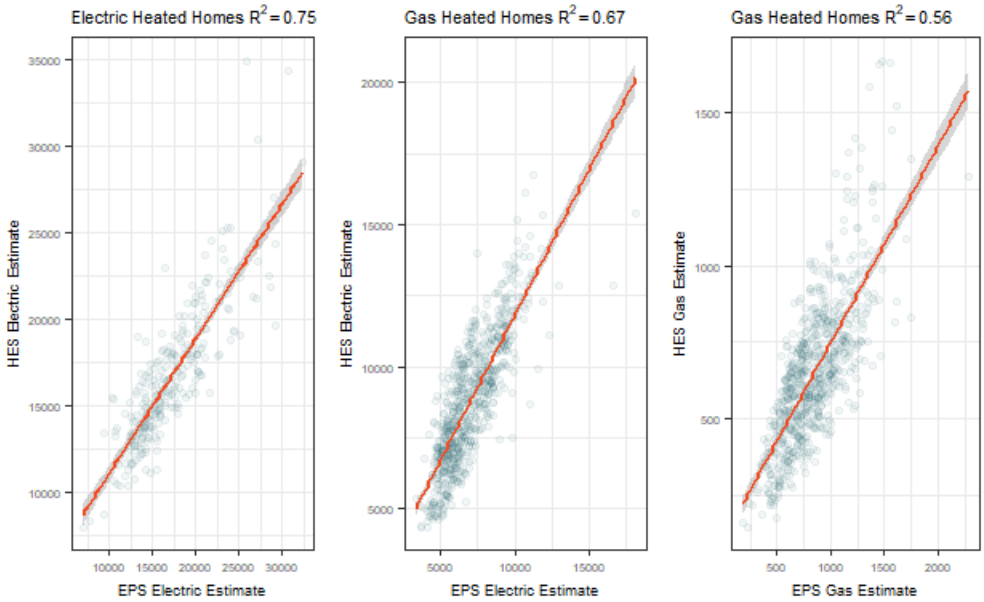


Figure 10. Scatterplot of EPS to HES energy estimates by Heating Fuel for Existing Homes



In new homes, estimates are clustered around the regression line and variability is relatively low. Although the trend between the HES and EPS energy consumption estimates is linear, there is a high degree of variability in their relationship for existing homes. Table 5 shows a summary of the R-squared values, slopes, and intercepts for simple linear regression models that predict HES energy consumption as a function of EPS energy consumption. A perfect relationship between the scores would show an R-squared of 100% and slope of 1.

Table 5. Simple Regression Model Summary – Use EPS to predict HES

Building Vintage	Efficiency Case	Heating Fuel	Energy Consumption	R-squared	Slope
New	Code Baseline	Electric	Electric	95%	1.02
		Gas	Electric	92%	1.10
		Gas	Gas	88%	0.92
	Efficient	Electric	Electric	28%	0.52
		Gas	Electric	58%	0.79
		Gas	Gas	74%	0.99
Existing	Base	Electric	Electric	75%	0.78
		Gas	Electric	67%	1.02
		Gas	Gas	56%	0.64

Note: Data for the existing home, efficient case not available.

After isolating building vintages and efficiency cases, Table 5 suggests that the EPS best predicts the HES (i.e., highest R-squared, slope close to 1) for base case new homes.

- New Homes, Base Case, Electric Heat, Electric Consumption: The EPS electric usage estimates explain 95% of variation in HES electric usage estimates. For each 100 kWh increase in the EPS estimate, there is a corresponding increase of 102 kWh in the HES estimate.

- New Homes, Base Case, Gas Heat, Electric Consumption: The EPS gas usage estimates explain 92% of variation in HES gas usage estimates. For each 100 kWh increase in the EPS estimate, there is a corresponding increase of 110 kWh in the HES estimate.
- New Homes, Base Case, Gas Heat, Gas Consumption: The EPS gas usage estimates explain 88% of variation in HES gas usage estimates. For each 100 therm increase in the EPS estimate, there is a corresponding increase of 92 therms in the HES estimate.
- New Homes, Efficient Case, Electric Heat, Electric Consumption: This model has the lowest R-squared among all models, where EPS electric usage estimates explain only 28% of the variation in HES electric usage. For each 100 kWh increase in the EPS estimate, there is a corresponding increase of 52 kWh in the HES estimate. We explore this case further in Research Question 4.
- New Homes, Efficient Case, Gas Heat, Electric Consumption: The EPS gas usage estimates explain 58% of variation in HES gas usage estimates. For each 100 kWh increase in the EPS estimate, there is a corresponding increase of 79 kWh in the HES estimate.
- New Homes, Efficient Case, Gas Heat, Gas Consumption: EPS electric usage estimates explain 74% of the variation in HES electric usage. For each 100 therm increase in the EPS estimate, there is a corresponding increase of 99 therms in the HES estimate.
- Existing Homes, Base Case, Electric Heat, Electric Consumption: The EPS electric usage estimates explain 75% of variation in HES electric usage estimates. For each 100 kWh increase in the EPS estimate, there is a corresponding increase of 78 kWh in the HES estimate.
- Existing Homes, Base Case, Gas Heat, Electric Consumption: The EPS gas usage estimates explain 67% of variation in HES gas usage estimates. For each 100 kWh increase in the EPS estimate, there is a corresponding increase of 102 kWh in the HES estimate.
- Existing Homes, Base Case, Gas Heat, Gas Consumption: The EPS gas usage estimates explain only 56% of variation in HES gas usage estimates. For each 100 therm increase in the EPS estimate, there is a corresponding increase of 64 therms in the HES estimate. We explore this case further in Research Question 4.

Research Question 3: Do certain home characteristics drive differences and outliers?

In new homes, efficient case HES scores are clustered at the upper end of the scale. Table 6 illustrates the characteristics of the sampled homes with outliers in either HES or EPS score.

- Homes with HES scores of 1-3 (least energy-efficient) are typically larger in size and have gas heating, central air conditioning, and gas water heat.
- Homes with EPS scores of 0-20 (most energy-efficient) are typically smaller in size and have heat pumps and electric water heat. In addition, 92% of these homes in the sample had solar PV installations.
- Homes with EPS scores of greater than 140 (least energy-efficient) are typically larger in size and have gas heating, central air conditioning, and gas water heat; these are the same characteristics as the least energy efficient homes identified by HES.

Table 6. New Homes HES and EPS Score Outlier Analysis

Home Characteristic	HES Score 1-3	EPS Score 0-20	EPS Score 140+	Overall
N	8	12	8	796
Age (Years)				
Avg Size (sqft)	4,188	1,884	3,989	2,176
% Elec Baseboard Heat	0%	0%	0%	0%
% Heat Pump Heat	0%	92%	0%	34%
% Elec Furnace Heat	0%	0%	0%	0%
% Gas Furnace Heat	100%	0%	100%	64%
% No Cooling	12%	0%	12%	43%
% Central Air Conditioning	88%	0%	88%	22%
% Heat Pump Cooling	0%	92%	0%	34%
% Elec Water Heat	0%	75%	0%	39%
% Gas Water Heat	100%	25%	100%	60%
% Solar Installed	0%	92%	0%	3%
% Portland CZ	25%	25%	25%	62%
% Redmond CZ	75%	67%	75%	28%
% Medford CZ	0%	8%	0%	11%

In existing homes, the pre-retrofit HES scores are clustered at the lower end of the scale. Table 7 illustrates the characteristics of existing homes with outliers in either HES or EPS score.

- Homes with HES scores of 9-10 (most energy-efficient) are typically smaller in size and have gas heating, no cooling and gas water heat. Solar PV installations are present in 30% of these homes (30%), which is significantly higher than their presence in the overall sample (2%).
- Homes with EPS scores of 0-50 (most energy-efficient) are typically smaller in size, however, their heating and water heating systems are similar to overall averages.
- Homes with EPS scores greater than 180 (least energy-efficient) are typically larger in size, older, and have electric furnaces and electric water heat.

Table 7. Existing Home HES and EPS Score Outlier Analysis

Home Characteristic	HES Score 9-10	EPS Score 0-50	EPS Score 180+	Overall
N	10	9	12	1,002
Age (Years)	66	68	87	69
Avg Size (sqft)	1,463	1,004	2,853	1,895
% Elec Baseboard Heat	0%	0%	17%	13%
% Heat Pump Heat	0%	33%	8%	10%
% Elec Furnace Heat	0%	0%	50%	4%
% Gas Furnace Heat	100%	67%	25%	73%
% No Cooling	100%	44%	83%	65%
% Split DX Cooling	0%	22%	8%	25%
% Heat Pump Cooling	0%	33%	8%	10%
% Elec Water Heat	20%	44%	83%	48%
% Gas Water Heat	80%	56%	17%	52%
% Solar PV Installed	30%	11%	0%	2%
% Portland CZ	100%	100%	100%	100%
% Redmond CZ	0%	0%	0%	0%
% Medford CZ	0%	0%	0%	0%

Research Question 4: Does a systematic bias exist in the HES score compared to EPS?

In research question 2, we qualitatively assert that that the HES score is predictive of the EPS score, indicating that there is no systematic bias in the scoring systems. As part of research question 4, we use a quantitative measure, Spearman's correlation coefficient, to measure agreement in the ranked scores for individual homes (i.e., are high HES scores always associated with low EPS scores).

The magnitude of these correlations indicates a lack of bias in the scoring systems[2]; Table 8 shows that all Spearman correlations between HES and EPS scores for the as-is structures (efficient case new homes and base case existing homes) are strong, with correlations of at least -0.66. The strongest agreement occurs in efficient-case scores for new, gas-heated homes (correlation = -0.86) and base-case scores for existing, electric-heated homes (correlation = -0.82).

[2] We expect that the Spearman correlation will be negative due to the inverse relationship in the scores – EPS score decreases as HES score increases.

Table 8. Spearman Correlation Coefficients, HES versus EPS scores

Building Vintage	Efficiency Case	Heating Fuel	Spearman Correlation
New	Base	Electric	-0.57
		Gas	-0.71
	Efficient	Electric	-0.66
		Gas	-0.86
Existing	Base	Electric	-0.82
		Gas	-0.66

Note: Existing home, efficient case not available. Negative correlation indicated that EPS score decreases when HES score increases.

In addition, Cadeo conducted further analyses for the cases identified in Research Question 2 where the EPS energy consumption did not predict HES energy consumption well. We added water heating fuel and home size variables to the simple linear regression models to better predict the HES energy consumption estimate from the EPS energy consumption estimate. These more robust regression models explain much more of the variation in HES energy consumption estimates than the EPS energy consumption estimate alone. Table 9 and Table 10 show the regression model coefficients for each combination of heating fuel and energy consumption.

Table 9. HES/EPS Regression Model Coefficients, New, Efficient Case Homes

Heating Fuel	Electric	Gas	
Energy Consumption	**Electric**	**Electric**	**Gas**
EPS Energy Consumption	0.08	0.09	0.71
Building Size (per 1,000 sqft)	3,082	1,951	45
Hot Water Fuel = Gas	-1,438	-1,165	112
Full Model R-Squared	91%	94%	83%
Simple Model R-Squared	28%	58%	74%

Table 10. HES/EPS Regression Model Coefficients, Existing, Base Case Homes

Heating Fuel	Electric	Gas	
Energy Consumption	**Electric**	**Electric**	**Gas**
EPS Energy Consumption	0.71	0.38	0.65
Building Size (per 1,000 sqft)	1,043	1,840	-59
Hot Water Fuel = Gas	-282	-1,990	138
Full Model R-Squared	78%	90%	67%
Simple Model R-Squared	75%	67%	56%

In the models that predict electric consumption:

- The building size coefficients indicate that as home size increases, the HES electric use estimates increase more quickly than the EPS estimates, in both new (Table 9) and existing (Table 10) homes.
- The gas hot water coefficient indicates that the HES estimate of electric consumption will be lower than the EPS estimate in homes with gas water heat.

In the models that predict gas consumption:

- In new gas-heated homes, (Table 9) HES gas consumption estimates grow at a faster rate than EPS gas consumption estimates as home size increases.
- In existing homes (Table 10), the trend is reversed: as home size increases, EPS-estimated gas consumption grows at a faster rate than HES.

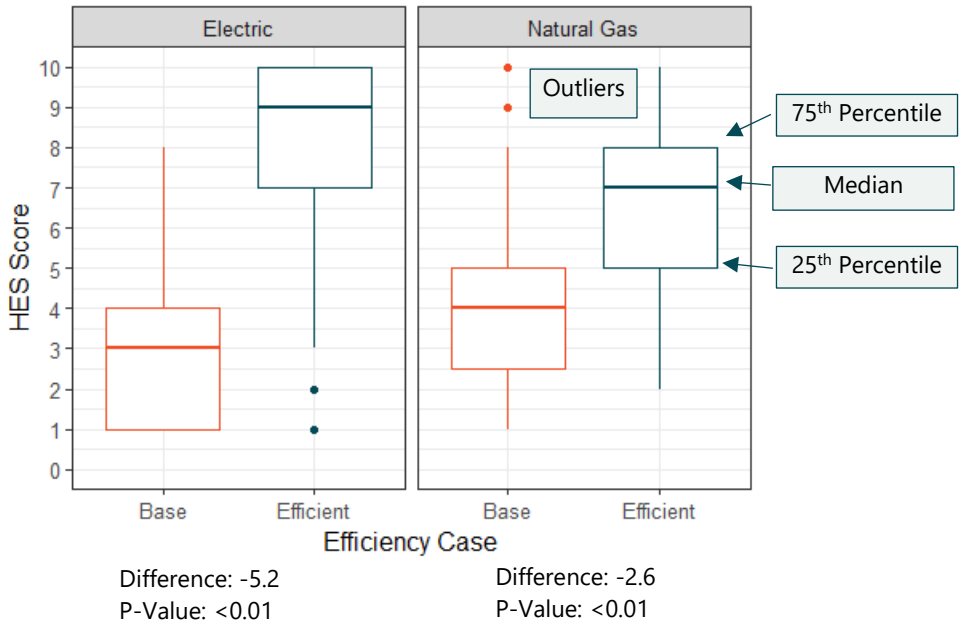
The HES and EPS building simulations are independent, so the differences described above are likely a function of differences in how the HES and EPS building simulations scale heating, water heating, and base load energy with respect to home size.

Research Question 5: What is the impact of retrofits to HES and EPS scores for existing homes?

For existing homes, the efficient case is simulated from an assumed set of cost-effective energy efficiency measures, and not based on empirical data. These simulations were done within the HES scoring tool only; the EPS software does not conduct comparable simulations automatically as a function of the report, so for this analysis, efficient case EPS scores were not available.

In existing homes, HES scores show statistically significant improvements from existing, pre-retrofit condition (base case) to the assumed post-retrofit condition (efficient case). For electric-heated homes, mean HES score increases from 2.8 to 8.0, and for gas-heated homes, the mean HES score increases from 4.0 to 6.6 (Figure 11).

Figure 11. Paired Comparison Base and Efficient Case HES Scores by Heating Fuel, Existing Homes



In both electric and natural gas heated existing homes, the efficient HES score indicates the estimated improvement after the installation of a set of cost-effective energy efficiency measures. Though the HES scores are unit-less, the smaller base-to-efficient case difference in HES score for gas-heated homes could

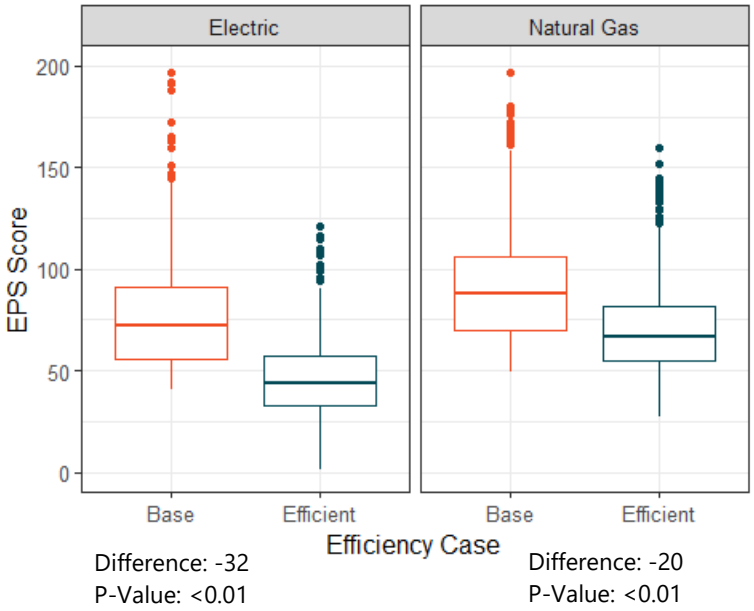
indicate that there are fewer cost-effective energy efficiency measures for those homes relative to electric-heated homes, as determined by the HES scoring tool.

Research Question 6: Is there a difference in HES and EPS scores between code baseline and efficient case new homes?

In new homes, both HES and EPS scores show statistically significant differences between the counterfactual code baseline condition (base case) to as-built condition (efficient case). However, the mean difference in HES is very small and is non-existent for many homes with high baseline scores.

For electric-heated homes, mean EPS score decreases from 80 to 48, and for gas-heated homes, the mean EPS score decreases from 91 to 71. Both differences are statistically significant, with p-values < 0.01. Figure 12 shows the ranges of base and efficient case scores.

Figure 12. Paired Comparison of Base and Efficient Case EPS Scores, New Homes



For electric-heated homes, mean HES score increases from 9.3 to 9.7, and for gas-heated homes, the mean HES score increases from 8.3 to 8.7 (Figure 13). In both cases, the code baseline HES score for the homes in our sample is very close to the top end of the scale, so the absolute differences in HES scores for new homes are minimal when compared to existing homes but are still statistically significant (electric and gas heat p-values < 0.01).

Figure 13. Paired Comparison of Base and Efficient Case HES Scores, New Homes

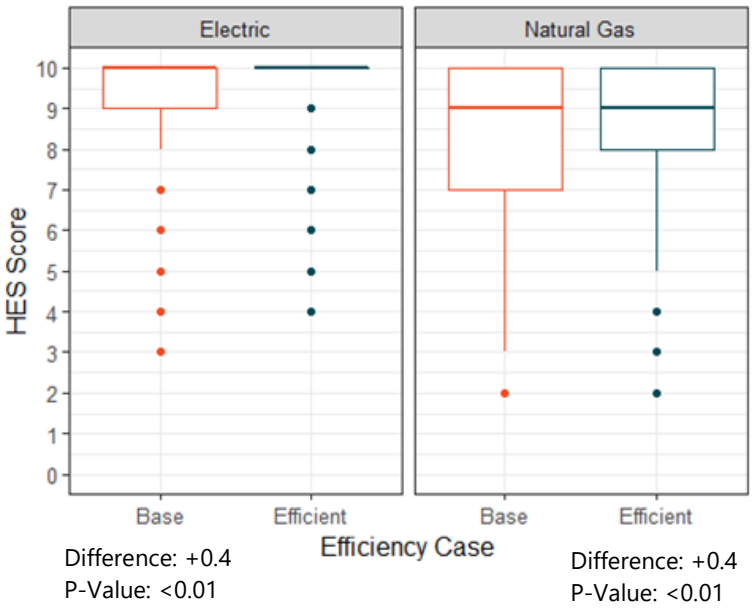


Table 11 shows the proportion of new homes that had no change in HES score from base to efficient case. The efficient case HES score is always higher than or equal to the base case HES score, and the efficient case HES score is more likely to improve in electric heated homes than in gas heated homes. Additionally, we found that the HES score increases by more than 1 point in 13% of electric heated homes and 10% of gas heated homes.

Table 11. Paired Comparison of Base and Efficient Case HES Score, New Homes

	Electric Heated Homes		Gas Heated Homes	
Base Case Score	Number of Homes	Homes with No Change in HES	Number of Homes	Homes with No Change in HES
10	207	100%	148	100%
9	22	55%	119	70%
8 or less	50	25%	233	64%

Phase 2: Validate EPS and HES Energy Usage Estimates with Utility Billing Data

In this phase of our analysis, we compare modeled (HES and EPS) energy consumption with weather-normalized, actual energy consumption for the 791 new homes and 1,006 existing homes described in Phase 1. Our analysis covers three scenarios for new and existing homes:

- Electric consumption in electric-heated homes
- Electric consumption in natural gas-heated homes, and
- Natural gas consumption in natural gas-heated homes.

This analysis does not cover a fourth case, natural gas consumption in electric-heated homes, in detail. For this scenario, we assume that natural gas consumption is small and not weather sensitive.[3]

Data Preparation Process

For this energy usage validation, we use a consistent data preparation and cleansing process across each of the scenarios:

- **Calculate average daily consumption for each billing period.** Divide the total billing period consumption by the number of days in the billing period.
- **Calendarize the billing data.** We construct calendar month-based consumption by aggregating billed, daily consumption to have same usage period for all customers.
- **Screen the billing data.** In this step, we eliminate customer records from analysis if they meet any of seven criteria. This ensures the analysis is using the appropriate billing data.
    - **Not matched to billing data**: sampled home does not have billing data.
    - **Missing modeled consumption**: sampled home does not have an HES or EPS consumption estimate.
    - **Primary Heating Fuel**: sampled home's primary heating system is different than the one specified by the scenario being analyzed.
    - **Insufficient billing data**: sampled home does not have 12 months of billing data between August 1, 2016 to July 31, 2017. For new homes, this step excludes homes with less than 12 months of occupancy. For existing homes, this step excludes homes where the billing account number changed within the last 12 months, which indicates a change in occupant.
    - **Energy consumption outlier**: sampled home is in the top or bottom 1% of energy consumption for all homes that pass the screening steps above.
    - **Program Participation:** sampled home has a major retrofit during the billing analysis period. This criterion is applicable to existing homes only; for new homes that

[3] In our sample, 68% of electric-heated new homes had gas bills that average 19 therms per month. 25% of electric-heated existing homes had gas bills that average 27 therms per month.

participated in ETO's new homes program, we compare actual consumption to the efficient case EPS/HES consumption estimate.

- **Solar PV System:** sampled home has solar PV system installed.

We present the results of this screening process for each scenario below.

- **Add weather to the billing data.** For each home, Cadeo supplemented energy bills with actual and NREL typical meteorological year, version 3 (TMY3)[4] dry bulb temperature. For each home, Cadeo used the same weather station that NREL identified in the building simulation inputs (Table 12).

Table 12. Weather Stations by Climate Zone

Weather Station
Portland International Airport
Redmond Roberts Field
Medford-Rogue Valley International Airport

- **Calculate Normalized, Annual Consumption (NAC).** Our process for calculating NAC for each home has three steps.
  - **Fit regression models to estimate average daily consumption (ADC) for each home.** For each home, we calculated degree days and fit the regression model shown in Equation 1 for a range of setpoints between 50 and 80 degrees.

Equation 1. ADC regression model

$$ADC_{ij} = b_{0ij} + b_{1ij}HDD_{ij} + b_{2ij}CDD_{ij} + e_{ij}$$

Note: homes represented by subscript i, setpoint temperature represented by subscript j

  - **Select best ADC model for each home.** Our criteria for determining best fit for each home is the setpoint that has the regression model with the highest R-squared value and a clear heating signature (HDD coefficient > 0).
  - **Calculate NAC with TMY3 weather.** We use normal weather (average HDD per day at each home's optimal setpoint, denoted by TMYHDD in Equation 2) and the coefficients from the best fit ADC model for each home to calculate NAC.

Equation 2. NAC estimation model

$$NAC_i = 365 * (b_{0*} + b_{1i}TMYHDD_i + b_{2i}TMYCDD_i)$$

Note: homes represented by subscript i

For homes with poor ADC model fit, (highest r-square < 0.5 or HDD coefficient < 0), we assume that NAC is equal to that home's actual, unnormalized, consumption.

[4] National Solar Radiation Data Base accessed on August 19, 2017 at: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

Results

Table 13 shows summary metrics for the differences between EPS and HES modeled energy consumption and NAC. The remainder of this section discusses detailed findings from Cadeo's energy usage validation.

Table 13: Modeled Consumption and NAC: Summary of Results

Home Vintage	Heating Fuel	Energy Consumption	Scoring Tools	Mean Percent Difference (Model vs NAC)	Homes within 25% Difference (Model vs NAC)	Direction of Bias
New Homes	Electric	Electric	EPS	-24%	52%	Underpredicts
			HES	-18%	53%	Underpredicts
	Gas	Electric	EPS	0%	39%	Not sig. difference
			HES	11%	37%	Overpredicts
		Gas	EPS	-24%	51%	Underpredicts
			HES	-41%	28%	Underpredicts
Existing Homes	Electric	Electric	EPS	38%	32%	Overpredicts
			HES	34%	34%	Overpredicts
	Gas	Electric	EPS	-10%	43%	Underpredicts
			HES	13%	43%	Overpredicts
		Gas	EPS	38%	37%	Overpredicts
			HES	5%	54%	Overpredicts

New Homes: Electric Consumption in electric-heated Homes

Using a sample of 119 new, electric-heated homes, Cadeo found that both the HES and EPS underestimate annual electric consumption relative to the NAC, though the difference between HES-estimated consumption and NAC is not statistically significant (Table 15).

Table 14. Attrition Summary for Electric Consumption in electric-heated, New Homes

Attrition Step	N Removed	Percent Removed	N Remaining
All homes	0	0%	791
Not matched to billing data	106	13%	685
Missing modeled consumption	25	4%	660
Primary Heating Fuel	439	67%	221
Insufficient Billing Data	89	40%	132
Energy Consumption Outlier	3	2%	129
Solar PV System	10	8%	**119**

Table 15. Modeled Electric Consumption versus NAC, electric-heated New Homes

Scoring System	Billing Fuel	Avg Modeled Consumption (kWh)	Avg NAC (kWh)	Difference (kWh)	90% CI LB (kWh)	90% CI UB (kWh)	p-value
EPS	Electric	10,117	13,226	-3,109	-5,460	-759	0.04
HES	Electric	10,780	13,226	-2,446	-4,729	-164	0.08

The average HES and EPS consumption estimates are both well below the average NAC. In addition, 25% of the homes have differences of more than 50% between modeled electric consumption and NAC, for

both scores (Table 16). Thus, the electric consumption estimates are extremely inaccurate for a substantial portion of homes.

Table 16. Relative Difference between Modeled Electric Consumption and NAC, electric-heated New Homes

Scoring System	Homes within 10% Difference (Modeled v NAC)	Homes within 25% Difference (Modeled v NAC)	Homes within 50% Difference (Modeled v NAC)
EPS	24%	52%	77%
HES	24%	53%	79%

In our sample, HES and EPS-estimated electric consumption were less than, but not significantly different than NAC for all but the largest home sizes (Table 17).

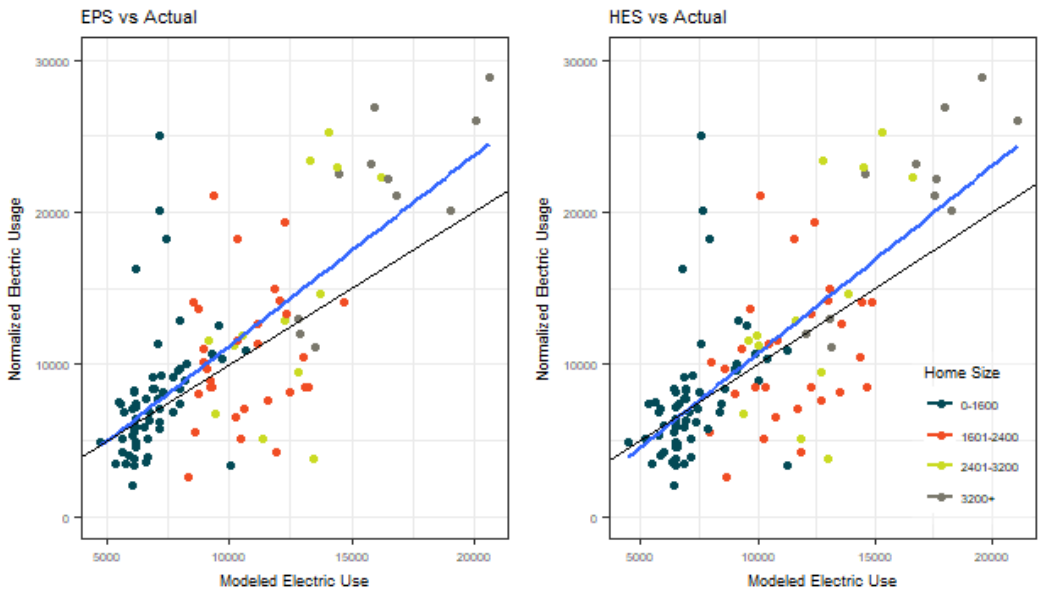
Table 17. Percentage Difference Between Modeled Electric Consumption and NAC by Size, electric-heated New Homes

Home Size (Sqft)	N	EPS	HES
< 1600	63	-16%	-11%
1601-2400	0	N/A	N/A
2401-3200	13	-11%	-11%
> 3200	13	-30%	-29%

Note: shaded cells indicate differences that are statistically significant.

Figure 14 illustrates the findings that both EPS and HES underestimate electric consumption, as the best fit lines for both scores are above and to the left of the reference line.

Figure 14. Scatterplot of EPS and HES versus NAC, electric-heated New Homes



Note: Blue line represents best fit modeled consumption vs NAC, black line is a reference line where modeled consumption = NAC

New Homes: Electric Consumption in gas-heated Homes

Using a sample of 197 new, gas-heated homes, Cadeo found that HES overestimates average annual electric consumption relative to the NAC (8,839 kWh HES-estimated versus 7,960 kWh NAC, Table 19). In contrast, the EPS estimate is not significantly different than the NAC (7,960 kWh EPS-estimated versus 7,970 kWh NAC, Table 19). This suggests that estimated annual electric consumption for new, gas-heated homes that are rescored under HES, will increase and be less accurate, on average.

Table 18. Attrition Summary for Electric Consumption in gas-heated, New Homes

Attrition Step	N Removed	Percent Removed	N Remaining
All homes	0	0%	791
Not matched to billing data	106	13%	685
Missing modeled consumption	18	3%	667
Primary Heating Fuel	337	51%	330
Insufficient Billing Data	127	38%	203
Energy Consumption Outlier	5	2%	198
Solar PV System	1	1%	**197**

Table 19. Modeled Electric Consumption versus NAC, gas-heated New Homes

Scoring System	Billing Fuel	Avg Modeled Consumption (kWh)	Avg NAC (kWh)	Difference (kWh)	90% CI LB (kWh)	90% CI UB (kWh)	p-value
EPS	Electric	7,960	7,970	-10	-482	462	0.97
HES	Electric	8,839	7,970	869	392	1,347	<0.01

Table 20, shows that fewer than 40% of the homes in our sample have an HES- or EPS-estimated electric consumption within 25% of NAC. Comparison of Table 19 and Table 20 shows that although the average HES and EPS electricity estimates are within 10% of the NAC, on average, both tools are relatively inaccurate for individual homes. Both HES- and EPS-estimated electric consumption is within 25% of NAC for less than 40% of homes.

Table 20. Relative Difference between Modeled Electric Consumption and NAC, Gas-Heated New Homes

Scoring System	Homes within 10% Difference (Modeled v NAC)	Homes within 25% Difference (Modeled v NAC)	Homes within 50% Difference (Modeled v NAC)
EPS	18%	39%	69%
HES	15%	37%	61%

EPS-estimated electric consumption is not significantly different than NAC across the range of home sizes. HES significantly overestimates electric consumption in all but the largest homes (Table 21).

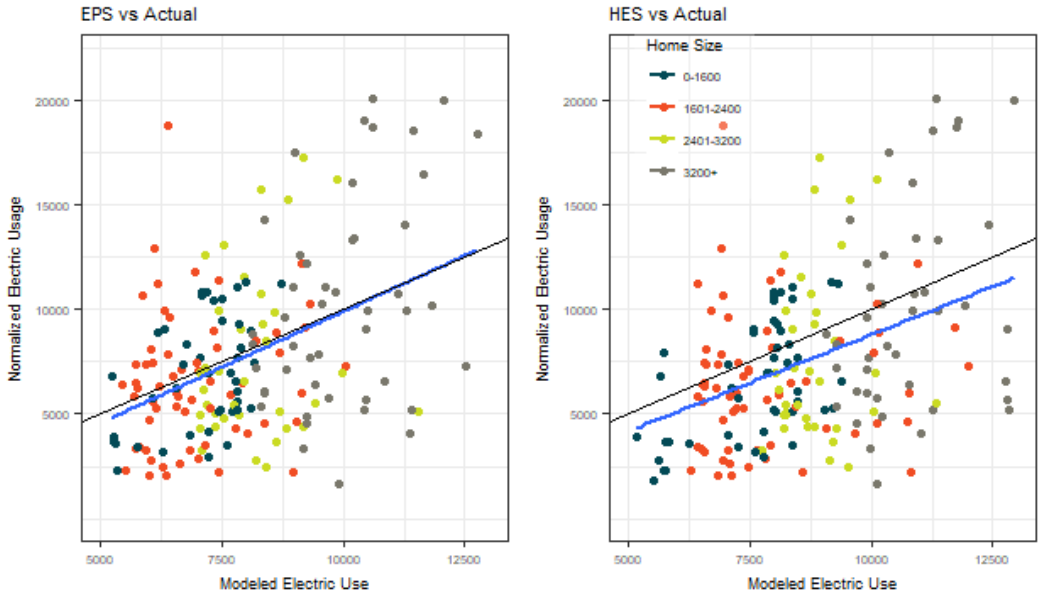
Table 21. Percentage Difference Between Modeled Electric Consumption and NAC by Size, Gas-Heated New Homes

Home Size (Sqft)	N	EPS	HES
< 1600	47	4%	15%
1601-2400	63	7%	21%
2401-3200	36	7%	17%
> 3200	51	-11%	-2%

Note: shaded cells indicate differences that are statistically significant.

The scatterplot in Figure 15 plots EPS and HES electric consumption against NAC. The best-fit line for the EPS estimate lies on top of the reference line, which illustrates the finding that the average EPS electric consumption estimate is not significantly different than the NAC. The best-fit line for the HES estimated electric consumption is below and to the right of the reference line, which illustrates the finding that the HES estimate are higher, on average, than the NAC.

Figure 15. Scatterplot of EPS and HES Electric Consumption versus NAC, Gas-Heated New Homes



Note: Blue line represents best fit modeled consumption vs NA, black line is a reference line where modeled consumption = NAC

New Homes: Gas Consumption in gas-heated Homes

Using a sample of 126 new, gas-heated homes, Cadeo found that both EPS and HES underestimated average, annual gas consumption relative to the NAC (Table 23). These differences are statistically

significant and suggest that there could be some erroneous assumptions in the building simulations, such as the heating setpoints or other occupancy characteristics.

Table 22. Attrition Summary for Gas Consumption in Gas-Heated, New Homes

Attrition Step	N Removed	Percent Removed	N Remaining
All homes	0	0%	791
Not matched to billing data	106	13%	685
Missing modeled consumption	169	25%	516
Primary Heating Fuel	87	17%	429
Insufficient Billing Data	300	70%	129
Energy Consumption Outlier	3	2%	126
Solar PV System	0	0%	**126**

Table 23. Modeled Gas Consumption versus NAC, Gas-Heated New Homes

Scoring System	Billing Fuel	Avg Modeled Consumption (Therms)	Avg NAC (Therms)	Difference (Therms)	90% CI LB (Therms)	90% CI UB (Therms)	p-value
EPS	Gas	423	560	-136	-163	-110	<0.01
HES	Gas	332	560	-228	-258	-197	<0.01

Although there are significant differences in the modeled average gas consumption and NAC, the EPS-estimated gas consumption is less than 25% different than NAC in over half of the homes in the sample—meaning that the estimate is relatively accurate for many homes. However, the accuracy of the HES-estimates is considerably worse: HES-estimated gas consumption is less than 25% different than the NAC in only 28% of the homes in the sample.

Table 24. Relative Difference between Modeled Gas Consumption and NAC, Gas-Heated New Homes

Scoring System	Homes within 10% Difference (Modeled v NAC)	Homes within 25% Difference (Modeled v NAC)	Homes within 50% Difference (Modeled v NAC)
EPS	25%	51%	92%
HES	10%	28%	75%

EPS-estimated gas consumption is not significantly different than NAC in small homes, but consistently underestimates NAC as homes sizes increase. HES consistently underestimates electric NAC across the full range of home sizes (Table 25).

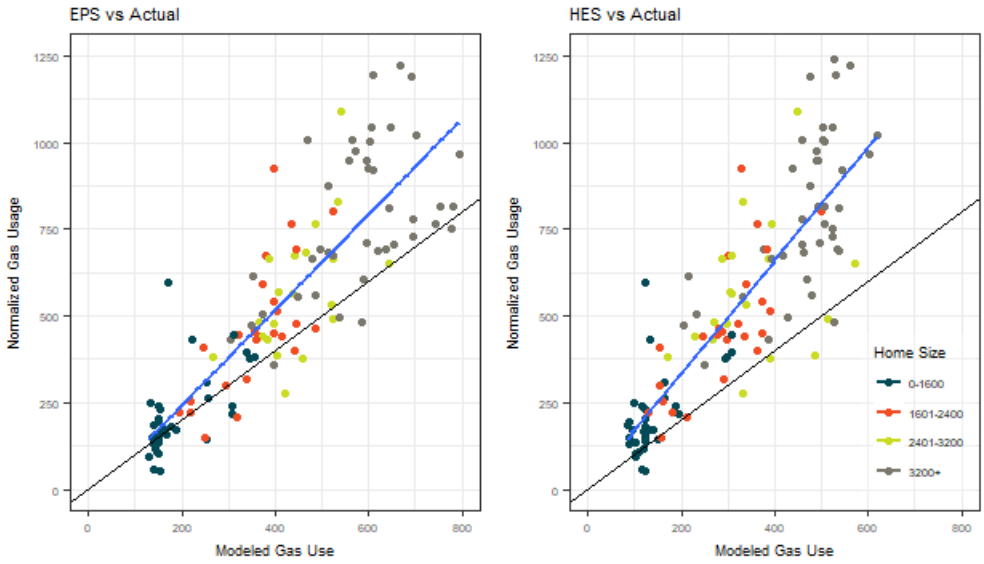
Table 25. Percentage Difference Between Modeled Gas Consumption and NAC by Size, Gas-Heated New Homes

Home Size (Sqft)	N	EPS	HES
< 1600	34	-11%	-34%
1601-2400	25	-22%	-38%
2401-3200	20	-22%	-38%
> 3200	47	-28%	-43%

Note: shaded cells indicate that difference is statistically significant.

The scatterplot in Figure 16 illustrates the consistent inaccuracy in both the EPS and HES gas consumption estimates. In both cases, the blue best fit line is above and to the left of the reference line. Figure 16 also shows that the maximum HES gas consumption estimate is approximately 600 therms, while many homes have NAC in excess of 1,000 therms, which could be another indication that the building simulation assumptions are erroneous in homes that have the largest amount of gas consumption.

Figure 16. Scatterplot of EPS and HES versus NAC, Gas Consumption in Gas-Heated New Homes



Note: Blue line represents best fit modeled consumption vs NA, black line is a reference line where modeled consumption = NAC

Existing Homes: Electric Consumption in electric-heated Homes

On average, the HES and EPS electric consumption estimates in existing, electric-heated homes are similar to each other. However, in contrast to new homes, both HES and EPS electric consumption estimates exceed NAC by over 30%, which could be indicative of erroneous assumptions in the building simulation.

Table 26. Attrition Summary for Electric Consumption in Electric-Heated, Existing Homes

Attrition Step	N Removed	Percent Removed	N Remaining
All homes	0	0%	983
Not matched to billing data	61	6%	922
Missing modeled consumption	0	0%	922
Primary Heating Fuel	679	74%	243
Insufficient Billing Data	0	0%	243
Energy Consumption Outlier	5	2%	238
Program Participation	23	10%	215
Solar PV System	2	1%	**213**

Table 27. Modeled Electric Consumption versus NAC, Electric-Heated, Existing Homes

Scoring System	Billing Fuel	Avg Modeled Consumption (kWh)	Avg NAC (kWh)	Difference (kWh)	90% CI LB (kWh)	90% CI UB (kWh)	p-value
EPS	Electric	17,064	12,387	4,677	4,064	5,291	<0.01
HES	Electric	16,596	12,387	4,209	3,629	4,789	<0.01

Table 28 shows that both EPS and HES electric energy consumption estimates have poor accuracy; EPS-estimated electricity is less than 25% different than NAC in only 32% of homes and HES energy is less than 25% different than NAC in 34% of homes. A large portion of homes have differences greater than 50% from the NAC for both scores.

Table 28. Relative Difference between Modeled Electric Consumption and NAC, Electric-Heated, Existing Homes

Scoring System	Homes within 10% Difference	Homes within 25% Difference	Homes within 50% Difference
EPS	12%	32%	58%
HES	14%	34%	62%

Our analysis of differences of building simulation outputs suggests that the large differences between HES and EPS estimates and NAC are consistent across home sizes (Table 29). Although the differences are not statistically significant for homes larger than 3,200 square feet, the sample size is very small (N=5).

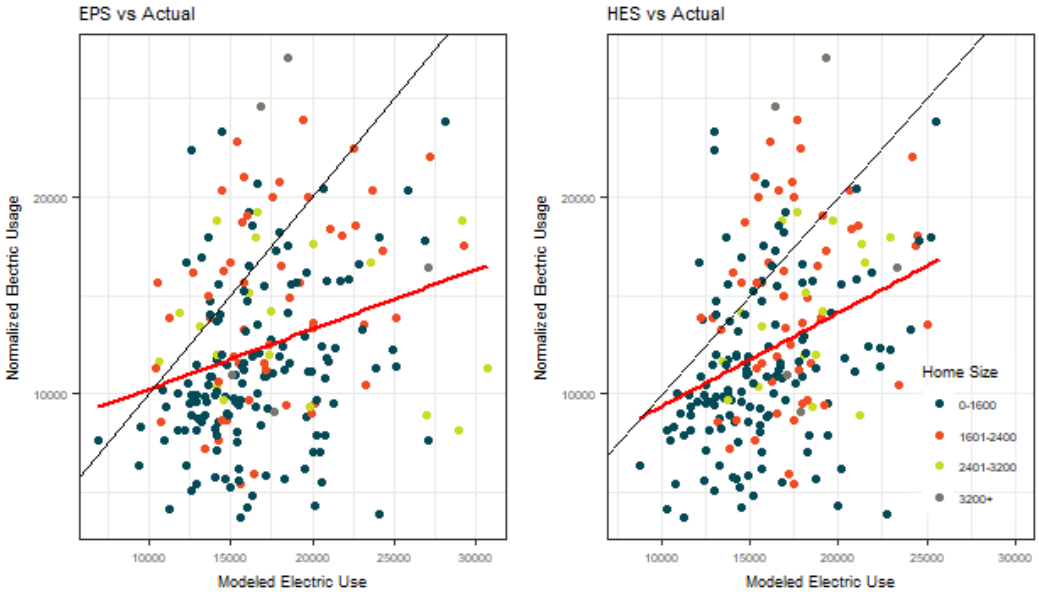
Table 29. Percentage Difference between Modeled Electric Consumption and NAC by Size, Electric-Heated Existing Homes

Home Size (Sqft)	N	EPS	HES
< 1600	137	48%	41%
1601-2400	52	21%	20%
2401-3200	19	37%	41%
> 3200	5	8%	7%

Note: shaded cells indicate that difference is statistically significant.

As indicated by the preceding tables, both the HES and EPS average electric consumption estimates exceed the NAC. Figure 17 illustrates this finding; the individual data points are consistently located below and to the right of the black reference line.

Figure 17. Scatterplot of EPS and HES versus NAC, Electric Consumption in Electric-Heated Existing Homes



Note: Blue line represents best fit modeled consumption vs NA, black line is a reference line where modeled consumption = NAC

Existing Homes: Electric Consumption in Gas-Heated Homes

Using a sample of 573 existing, gas-heated homes, Cadeo found that HES overestimates average annual electric consumption relative to the NAC by about 13%, while the EPS estimate underestimates NAC by about 10%. In both cases, the differences are statistically significant.

Table 30. Attrition Summary for Electric Consumption in Gas-Heated, Existing Homes

Attrition Step	N Removed	Percent Removed	N Remaining
All homes	0	0%	983
Not matched to billing data	61	6%	922
Missing modeled consumption	0	0%	922
Primary Heating Fuel	248	27%	674
Insufficient Billing Data	9	1%	665
Energy Consumption Outlier	13	2%	652
Program Participation	66	10%	586
Solar PV System	13	2%	**573**

Table 31 shows that though the average HES- and EPS-estimated electric consumption in existing, gas-heated homes are within 15% of the average NAC, there is a large difference between the HES- and EPS-estimated electric consumption. This difference between the HES and EPS scoring systems could be problematic for homes that have already been EPS-scored and now, as a result of Portland City Code Chapter 17.108, must be rescored with HES.

Table 31. Modeled Electric Consumption versus NAC, Gas-Heated Existing Homes

Scoring System	Billing Fuel	Avg Modeled Consumption (kWh)	Avg NAC (kWh)	Difference (kWh)	90% CI LB (kWh)	90% CI UB (kWh)	p-value
EPS	Electric	6,964	7,727	-763	-989	-537	<0.01
HES	Electric	8,753	7,727	1,026	799	1,253	<0.01

Table 20 shows the accuracy of the models – 43% of the homes in our sample have an HES or EPS estimate within 25% of NAC.

Table 32. Relative Difference between Modeled Electric Consumption and NAC, Gas-Heated Existing Homes

Scoring System	Homes with 10% Difference	Homes with 25% Difference	Homes with 50% Difference
EPS	17%	43%	78%
HES	18%	43%	68%

HES-estimated electric consumption consistently overestimates NAC across home sizes. In our sample, EPS-estimated electric consumption was not significantly different than NAC in smaller homes, but trended toward underestimating NAC in larger homes (Table 33).

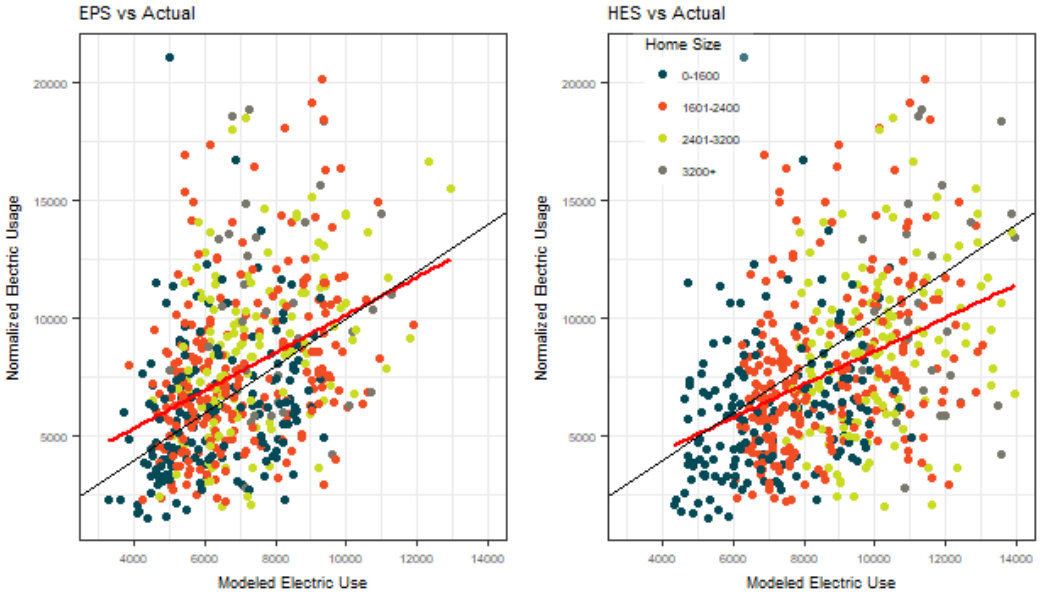
Table 33. Percentage Difference Between Modeled Electric Consumption and NAC by Size, Gas-Heated Existing Homes

Home Size (Sqft)	N	EPS	HES
< 1600	168	2%	15%
1601-2400	242	-11%	10%
2401-3200	129	-15%	16%
> 3200	34	-22%	16%

Note: shaded cells indicate that difference is statistically significant.

In Figure 18, the scatterplots illustrate the direction of the HES and EPS differences noted in Table 31. The best-fit EPS to NAC line is generally above and to the left of the reference line, indicating that EPS-estimated consumption is less than NAC. In contrast, the best fit HES to NAC line is below and to the right of the reference line, indicating that HES-estimated consumption is greater than NAC.

Figure 18. Scatterplot of EPS and HES versus NAC, Electric Consumption in Gas-Heated Existing Homes



Note: Red line represents best fit modeled consumption vs NA, black line is a reference line where modeled consumption = NAC. Cadeo filtered outliers from these plots for display purposes.

Existing Homes: Gas Consumption in Gas-Heated Homes

Cadeo found that HES-estimated gas consumption is approximately 5% higher than NAC (Table 35) for existing gas-heated homes. While a difference of 32 therms may not be practically significant, it is statistically significant due to the large sample size (N=428, Table 34). EPS overestimates average annual gas consumption relative to NAC by 38%, on average, much more than the HES-estimated gas consumption (Table 35). This could be problematic for homes that have already been EPS-scored and now must be rescored with HES, although the gas consumption estimates will likely be more accurate.

Table 34. Attrition Summary for Gas Consumption in Gas-Heated, Existing Homes

Attrition Step	N Removed	Percent Removed	N Remaining
All homes	0	0%	983
Not matched to billing data	61	6%	922
Missing modeled consumption	384	42%	538
Primary Heating Fuel	33	6%	505
Insufficient Billing Data	6	1%	499
Energy Consumption Outlier	10	2%	489
Program Participation	51	10%	438
Solar PV System	10	2%	**428**

Table 35. Modeled Gas Consumption versus NAC in Gas-Heated Existing Homes

Scoring System	Billing Fuel	Avg Modeled Consumption (Therms)	Avg NAC (Therms)	Difference (Therms)	90% CI LB (Therms)	90% CI UB (Therms)	p-value
EPS	Gas	865	629	237	215	258	<0.01
HES	Gas	661	629	32	13	52	<0.01

HES gas consumption estimates are reasonably accurate, as they are within 25% of NAC in over half of the homes in the sample (Table 36). On the other hand, the EPS gas consumption estimates are substantially less accurate, with only 37% of estimates within 25% of the NAC.

Table 36. Relative Difference between Modeled Gas Consumption and NAC in Gas-Heated Existing Homes

Scoring System	Homes within 10% Difference	Homes within 25% Difference	Homes within 50% Difference
EPS	15%	37%	57%
HES	22%	54%	83%

EPS modeled gas consumption consistently overestimates NAC is across all home sizes. HES overestimates NAC in smaller homes, but underestimates NAC in larger homes (Table 37).

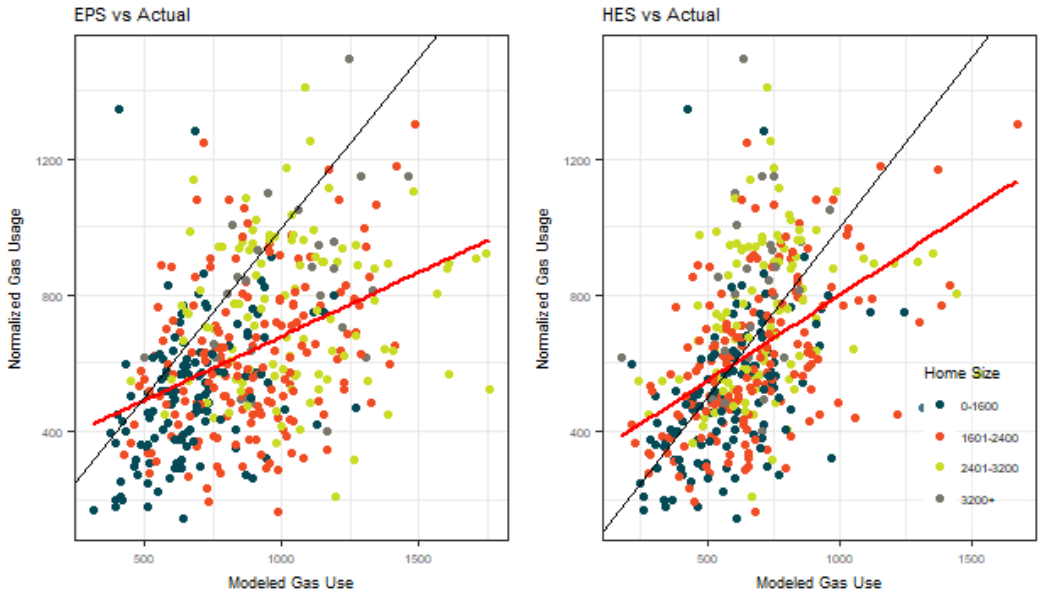
Table 37. Percentage Difference Between Modeled Gas Consumption and NAC by Size, Gas-Heated Existing Homes

Home Size (Sqft)	N	EPS	HES
< 1600	126	32%	16%
1601-2400	172	44%	10%
2401-3200	104	38%	-3%
> 3200	26	24%	-19%

Note: shaded cells indicate that difference is statistically significant.

The scatterplot in Figure 19, where a majority of the data points are below and to the right of the reference line, illustrates the difference in EPS-estimated gas consumption and NAC. Although the overall averages are similar, the HES best-fit line in Figure 19 is influenced by some outliers where HES-estimated consumption exceeds 1,000 therms.

Figure 19. Scatterplot of EPS and HES versus NAC, Gas Consumption in Gas-Heated Existing Homes



Note: Red line represents best fit modeled consumption vs NA, black line is a reference line where modeled consumption = NAC

Conclusions

In Phase 1 of this study Cadeo found that HES scores are highly correlated with EPS scores in some segments of the market – existing homes with electric heat and new homes with gas heat (See Table 8). The correlation is lower in other market segments, but due to the different scales for each scoring system (0-10 for HES, 200 to 0 for EPS), it seems unlikely that a homebuyer would discern systemic differences in scores themselves.

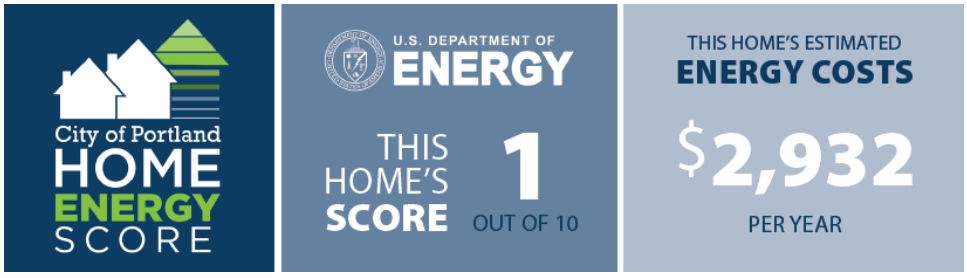
In Phase 2 of this study, Cadeo found that the HES and EPS energy estimates are divergent from each other in some segments of homes. Table 38 shows that the differences in HES and EPS energy consumption are largest in gas-heated homes, where the HES electric consumption estimates exceed those produced by EPS and EPS gas consumption estimates exceed those produced by HES.

Table 38. Differences Between Estimated Energy Consumption and NAC

Building Vintage	Heating Fuel	Billing Fuel	Average Difference (%): HES vs NAC	Average Difference (%): EPS vs NAC
New	Electric	Electric	-18%	-24%
	Gas	Electric	11%	0%
		Gas	-41%	-24%
Existing	Electric	Electric	34%	38%
	Gas	Electric	13%	-10%
		Gas	5%	38%

From a practical standpoint these differences are relevant to consumers because HES and EPS reporting uses energy estimates to calculate annual energy cost (Figure 20)[5].

Figure 20. Sample Home Energy Score Report



In the gas-heated homes that Cadeo studied for this report, HES-estimated electric consumption is higher that the EPS estimate, and HES-estimated gas consumption is lower than the EPS estimate. However,

[5] The City of Portland Home Energy Score. Accessed 1/25/18 at: https://www.portlandoregon.gov/bps/71421

when viewing the results of this study from a total energy cost perspective, the differences in HES and EPS energy estimates offset one another (Table 39).

Table 39. Comparison of HES and EPS Estimated Energy Costs to Actual costs for gas heated homes

Building Vintage	Scoring System	Estimated Electric Consumption (kWh)	Estimated Gas Consumption (Therms)	Estimated Annual Cost ($)	Actual Annual Cost ($)
Existing	EPS	6,964	865	$1,709	$1,536
	HES	8,753	661	$1,683	$1,536
New	EPS	7,960	423	$1,337	$1,487
	HES	8,839	332	$1,334	$1,487

Note: Estimated annual cost uses HES/EPS simulation, actual cost uses normalized annual consumption and assumes a rate of $0.11/kWh, $1.09/Therm.

Though Table 39 shows agreement in EPS and HES estimated costs, in this study, Cadeo found some biases in HES-estimated energy consumption where, on average, HES appears to

- overpredict actual electric consumption by 34% in existing, electric-heated homes,
- underpredict actual electric consumption by 18% in new, electric heated homes, and
- overpredict gas consumption by 41% in new, gas-heated homes.

Should these study observations hold true in reality, the energy cost estimates shown on the HES report could be hundreds of dollars different than what the average homebuyer is actually paying.

Table 40: HES-Modeled Consumption and NAC

Home Vintage	Heating Fuel	Energy Consumption	Mean Percent Difference (Model vs NAC)	Homes within 25% Difference (Model vs NAC)	Direction of Bias
New Homes	Electric	Electric	-18%	53%	Underpredicts
	Gas	Electric	11%	37%	Overpredicts
		Gas	-41%	28%	Underpredicts
Existing Homes	Electric	Electric	34%	34%	Overpredicts
	Gas	Electric	13%	43%	Overpredicts
		Gas	5%	54%	Overpredicts

However, as part of this study, Cadeo cannot determine how much of the energy consumption discrepancies noted above are attributable to the study's methodology and how much are attributable to the HES tool itself. For the sample of homes that Cadeo used in this study, NREL translated each home's characteristics from REM/Rate software inputs and retroactively derived HES scores and energy consumption estimates. That process, while necessary for the study, produces an inherently different result than natively scoring each home with the HES tool; Cadeo could not quantify the magnitude of this difference.

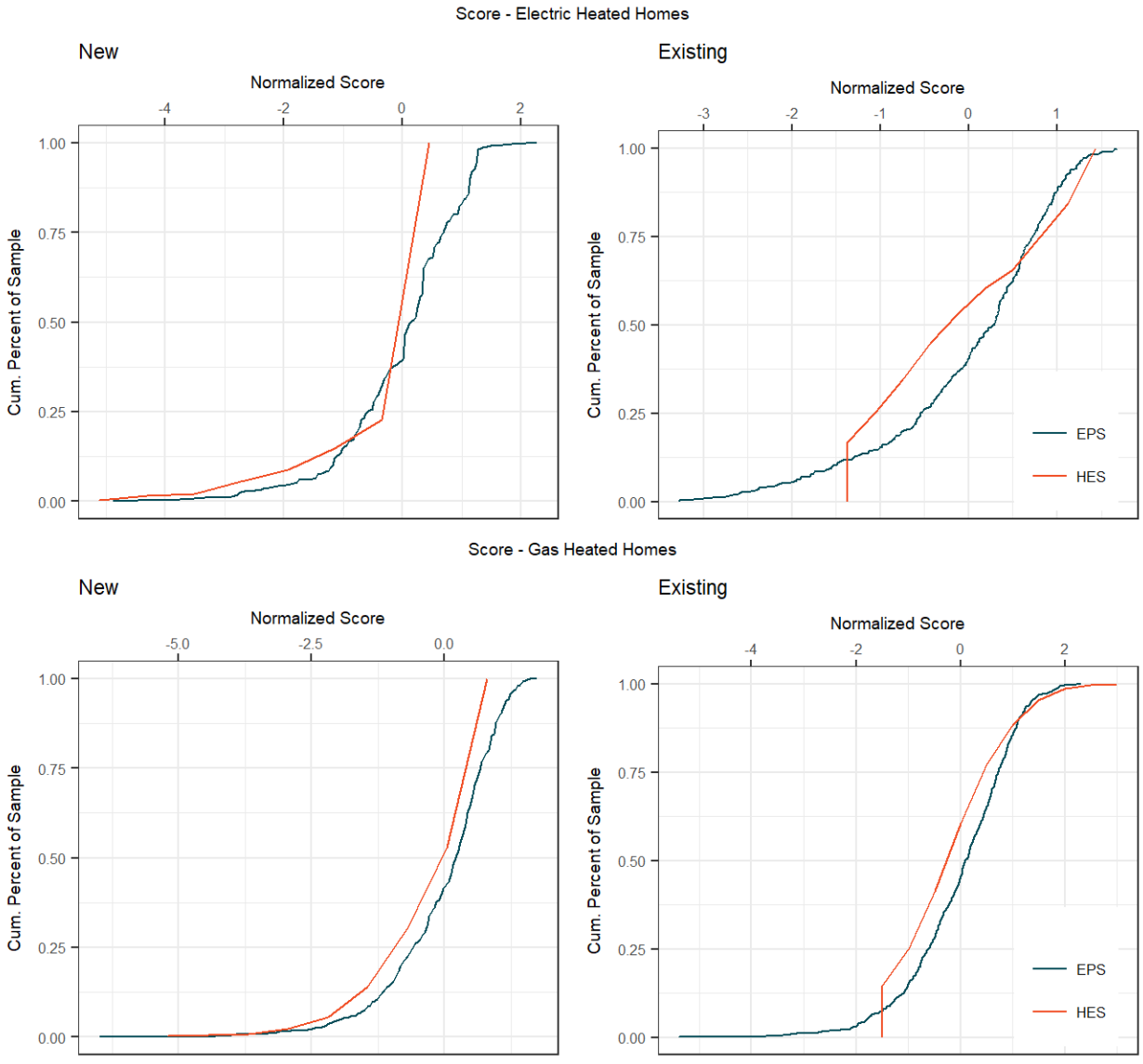
Any remaining differences between actual energy consumption and the estimated values from the HES tool are outside of the purview of Energy Trust. Cadeo has learned through stakeholder feedback that the ongoing improvements to the calibration of HES energy consumption estimates to actual consumption are part of NREL's product roadmap for the HES tool.

Appendix

Phase 1. Compare EPS and HES Home Score Data

Research Question 1: What are the distributions and differences of home scores and outputs?

Figure 21. Comparison of HES and EPS Score Distributions



Notes:

- Interpretation: the more similar the HES (orange) and EPS (blue) curves are, the more similar the score distributions are.
- To control for the different scales, Cadeo normalized the HES and EPS scores with mean 0, standard deviation of 1.

- For EPS, Cadeo transformed the scores such that a higher normalized score is more efficient.

Table 41. Distribution of HES Scores by home size (New Homes, Efficient Case)

HES Score	0-1600	1601-2400	2401-3200	3200+
1				
2				1%
3				2%
4				2%
5			2%	4%
6		1%	2%	15%
7		1%	10%	20%
8	1%	8%	16%	26%
9	3%	21%	32%	19%
10	96%	70%	38%	12%

Table 42. Average EPS score by HES Scores and home size (New Homes, Efficient Case)

HES Score	0-1600	1601-2400	2401-3200	3200+
1				
2				142
3				144
4				126
5			110	118
6		96	103	103
7		86	91	97
8	66	77	79	84
9	61	68	69	76
10	39	54	59	68

Table 43. Distribution of HES Scores by home vintage (Existing Homes, Base Case)

HES Score	2000-Current	1980-1999	1950-1979	1920-1949	Before 1920
1	5%	13%	21%	20%	22%
2	0%	15%	13%	11%	12%
3	16%	13%	20%	15%	16%
4	21%	24%	17%	15%	21%
5	26%	18%	14%	16%	14%
6	11%	9%	9%	11%	8%
7	11%	6%	3%	7%	6%
8	5%	2%	2%	3%	1%
9	5%	1%	1%	1%	0%
10	0%	0%	0%	1%	0%

Table 44. Average EPS Score by HES Scores and home vintage (Existing Homes, Base Case)

HES Score	2000-Current	1980-1999	1950-1979	1920-1949	Before 1920
1	160	115	120	134	136
2		100	97	114	109
3	90	96	89	100	107
4	77	83	85	95	98
5	76	77	76	90	91
6	68	72	74	81	83
7	72	64	67	75	75
8	66	56	62	64	68
9	69	55	60	59	84
10				46	

Phase 2. Validate EPS and HES Energy Usage Estimates with Utility Billing Data

Table 45 through Table 50 show the results of the billing analysis, segmented by size.

Table 45. Modeled Electric Consumption versus NAC by Size, Electric-Heated, New Homes

Home Size (Sqft)	Scoring System	N	Avg Modeled Consumption	Avg NAC	Difference	90% CI LB	90% CI UB	p-value
0-1600	EPS	63	6,853	8,152	-1,299	-2,343	-255	<0.05
	HES	63	7,217	8,152	-935	-1,978	107	0.14
1601-2400	EPS	0						
	HES	0						
2401-3200	EPS	13	12,380	13,945	-1,565	-4,640	1,511	0.38
	HES	13	12,389	13,945	-1,556	-4,554	1,442	0.37
3200+	EPS	13	16,296	23,430	-7,134	-11,357	-2,912	<0.01
	HES	13	16,709	23,430	-6,721	-10,681	-2,762	<0.01

Table 46. Modeled Electric Consumption versus NAC by Size, Gas-Heated, New Homes

Home Size (Sqft)	Scoring System	N	Avg Modeled Consumption	Avg NAC	Difference	90% CI LB	90% CI UB	p-value
0-1600	EPS	47	6,836	6,577	259	-334	852	0.47
	HES	47	7,591	6,577	1,014	424	1,605	<0.01
1601-2400	EPS	63	6,948	6,483	465	-217	1,148	0.26
	HES	63	7,864	6,483	1,381	664	2,098	<0.01
2401-3200	EPS	36	8,159	7,659	499	-627	1,626	0.46
	HES	36	8,986	7,659	1,326	154	2,498	0.06
3200+	EPS	51	10,106	11,311	-1,205	-2,520	110	0.13
	HES	51	11,091	11,311	-219	-1,524	1,085	0.78

Table 47. Modeled Gas Consumption versus NAC by Size, Gas-Heated, New Homes

Home Size (Sqft)	Scoring System	N	Avg Modeled Consumption	Avg NAC	Difference	90% CI LB	90% CI UB	p-value
0-1600	EPS	34	194	217	-23	-52	5	0.18
	HES	34	143	217	-74	-102	-45	<0.01
1601-2400	EPS	25	361	464	-103	-154	-53	<0.01
	HES	25	287	464	-176	-224	-128	<0.01
2401-3200	EPS	20	449	572	-123	-184	-62	<0.01
	HES	20	355	572	-217	-288	-146	<0.01
3200+	EPS	47	612	854	-242	-290	-194	<0.01
	HES	47	484	854	-370	-420	-320	<0.01

Table 48. Modeled Electric Consumption versus NAC by Size, Electric-Heated, Existing Homes

Home Size (Sqft)	Scoring System	N	Avg Modeled Consumption	Avg NAC	Difference	90% CI LB	90% CI UB	p-value
0-1600	EPS	137	16,547	11,178	5,369	4,680	6,058	<0.01
	HES	137	15,816	11,178	4,638	3,965	5,311	<0.01
1601-2400	EPS	52	17,624	14,606	3,019	1,812	4,225	<0.01
	HES	52	17,457	14,606	2,852	1,683	4,020	<0.01
2401-3200	EPS	19	18,736	13,651	5,086	2,070	8,101	<0.01
	HES	19	19,278	13,651	5,627	3,139	8,115	<0.01
3200+	EPS	5	19,041	17,629	1,412	-7,255	10,079	0.75
	HES	5	18,810	17,629	1,180	-6,836	9,197	0.77

Table 49. Modeled Electric Consumption versus NAC by Size, Gas-Heated, Existing Homes

Home Size (Sqft)	Scoring System	N	Avg Modeled Consumption	Avg NAC	Difference	90% CI LB	90% CI UB	p-value
0-1600	EPS	168	6,325	6,216	109	-260	478	0.63
	HES	168	7,122	6,216	906	533	1,279	<0.01
1601-2400	EPS	242	6,998	7,884	-886	-1,236	-536	<0.01
	HES	242	8,707	7,884	823	469	1,177	<0.01
2401-3200	EPS	129	7,437	8,722	-1,285	-1,744	-826	<0.01
	HES	129	10,132	8,722	1,410	922	1,898	<0.01
3200+	EPS	34	8,085	10,302	-2,217	-3,511	-922	<0.01
	HES	34	11,909	10,302	1,607	320	2,895	0.04

Table 50. Modeled Gas Consumption versus NAC by Size, Gas-Heated, Existing Homes

Home Size (Sqft)	Scoring System	N	Avg Modeled Consumption	Avg NAC	Difference	90% CI LB	90% CI UB	p-value
0-1600	EPS	126	671	510	162	129	194	<0.01
	HES	126	591	510	81	51	112	<0.01
1601-2400	EPS	172	882	614	268	235	302	<0.01
	HES	172	674	614	60	32	89	<0.01
2401-3200	EPS	104	1,033	748	284	230	338	<0.01
	HES	104	722	748	-26	-69	16	0.31
3200+	EPS	26	1,021	823	198	110	286	<0.01
	HES	26	669	823	-153	-238	-68	<0.01