Leveraging Home Energy Scores in a Residential Baseline Study

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ABSTRACT

This paper presents findings from a residential baseline study in Vermont that illustrates how the Department of Energy's Home Energy Score tool can be leveraged to identify and prioritize energy savings opportunities. In addition, this paper explores the accuracy of the HES tool by comparing estimated annual heating energy consumption from the HES models to results of a billing analysis of energy usage data.

The study found that the HES tool allows for a more systematic and comprehensive assessment of energy savings opportunities than was possible in prior Vermont baseline studies. The tool consistently identifies and quantifies the energy savings, allowing for a more comprehensive assessment of the prevalence, level, and distribution of energy savings opportunities. While energy models could have been created using other software tools (such as REM/Rate), the HES tool requires fewer labor hours. These labor savings could yield substantial cost savings while still providing useful results. While the sample sizes for the billing analysis were very small, the results indicate that the annual consumption values estimated by the HES models are generally reasonable.

This paper will be useful to organizations planning baseline studies of the existing homes market, as it illustrates the application of HES models in a residential baseline study.

Introduction

The Department of Energy's (DOE) Home Energy Score (HES) energy modeling software was launched in 2012 and has since scored over 63,000 homes.[1] Compared to other residential energy modeling software, such as REM/Rate, the HES tool provides a simpler energy model that requires fewer data inputs and therefore less labor—making energy audits more feasible for a broader audience. While the HES tool is primarily intended for program implementation, it also offers information that can be useful for residential baseline studies. In this paper, we will leverage the HES models to assess the degree and distribution of energy savings opportunities in the single-family existing homes market in Vermont.

The HES model rates homes on a score from 1 to 10, where 1 represents the least energy efficient homes and 10 represents the most energy efficient homes. The HES tool produces a brief report for each modeled home that provides a list of recommendations to improve the home's energy efficiency, the current Home Energy Score, and the predicted score after all recommended improvements have been completed. The model also calculates the annual energy consumption and costs by fuel type for the home as-is and after improvements.

The HES tool models the efficiency of homes based on features of the building envelope, glazing, mechanical systems, and home area. The model is intended to help homebuyers compare homes. Therefore, it provides an asset rating based solely on the home's features and does not reflect occupant behaviors, such as thermostat set points, appliance usage, or plug loads. Additionally, the model normalizes for local weather conditions so that homes across the United States can be compared.

HES models were incorporated into an ongoing residential baseline study in Vermont, which entailed comprehensive on-site energy audits at 137 single-family existing homes. The on-site data was input into the HES tool to develop energy models for each home. In addition, a multi-fuel billing analysis

[1] https://betterbuildingssolutioncenter.energy.gov/home-energy-score

was completed for 41 of these 137 homes. This billing analysis is used to assess the relative accuracy of the annual energy consumption estimates provided by the HES tool.

Energy Usage Analysis

Based on the HES models, the average annual energy consumed is 130 MMBtus per home. The overall annual electricity usage is estimated to equal 9,597 kWh, or about 800 kWh per month. Annual average consumption of heating fuels (across only those homes using each type of fuel) is estimated to equal 551 gallons of oil, 698 gallons of propane, 648 therms of natural gas, and 3.5 cords of firewood.

Figure 1 displays the annual energy usage (in MMBtus) for the average home as-is and after improvements, assuming all recommendations are completed. After completing all recommended improvements, the average forecasted annual energy consumed is 100 MMBtus per home, an estimated decrease of 23% from current usage. After improvements, the proportional contribution from oil decreases (from 24% to 21%); however, the contribution from electricity increases (from 24% to 29%). This change mostly reflects a shift to heat pump technologies.

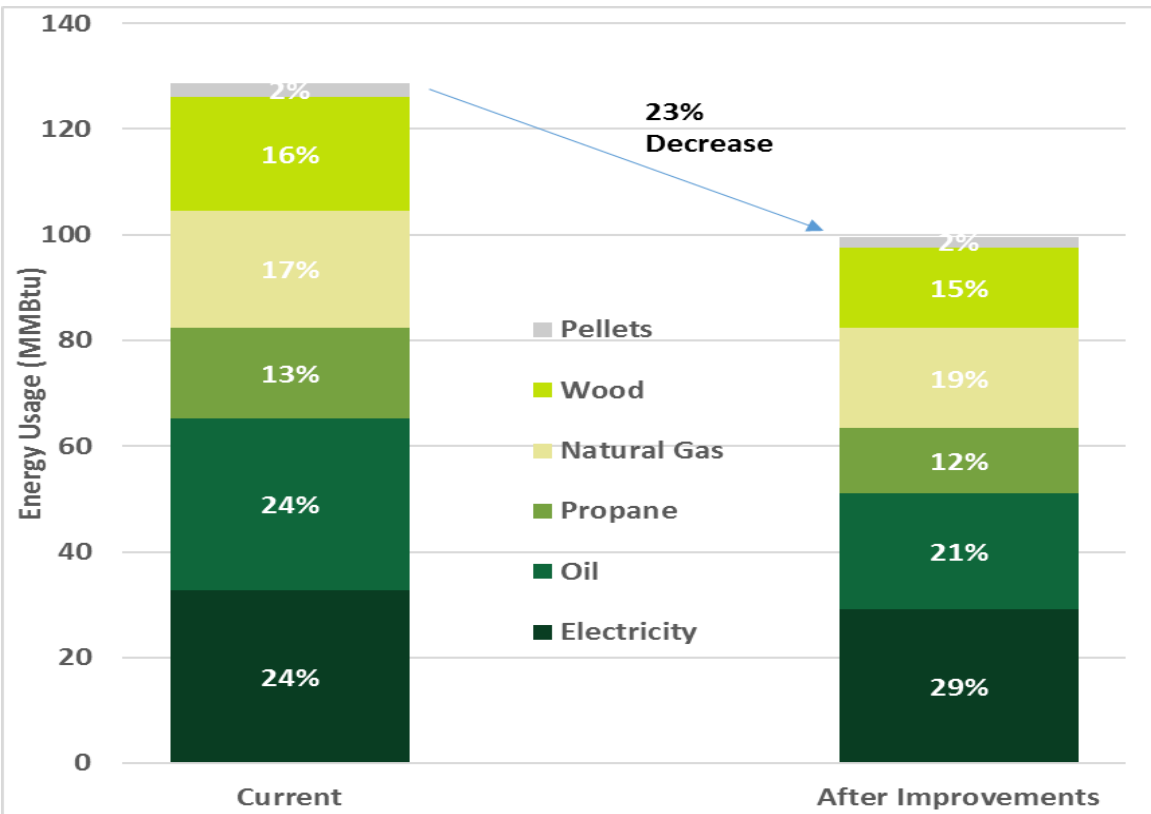

Figure 1: Average annual energy consumption before and after all recommended improvements.

Figure 2 displays the average annual energy consumption per home by fuel type before and after all recommended improvements. Heating fuels exhibit the largest decrease after improvements. Fuel oil demonstrates a particularly large decrease (33%), followed by cord wood (29%) and propane (28%). However, natural gas exhibits a smaller decline (15%), as does electricity (11%). The smaller decrease for natural gas homes is likely due to the limited availability of natural gas in Vermont and the newer vintage of homes in this region. The smaller decrease for electricity can be attributed to the shift to heat pump technologies.

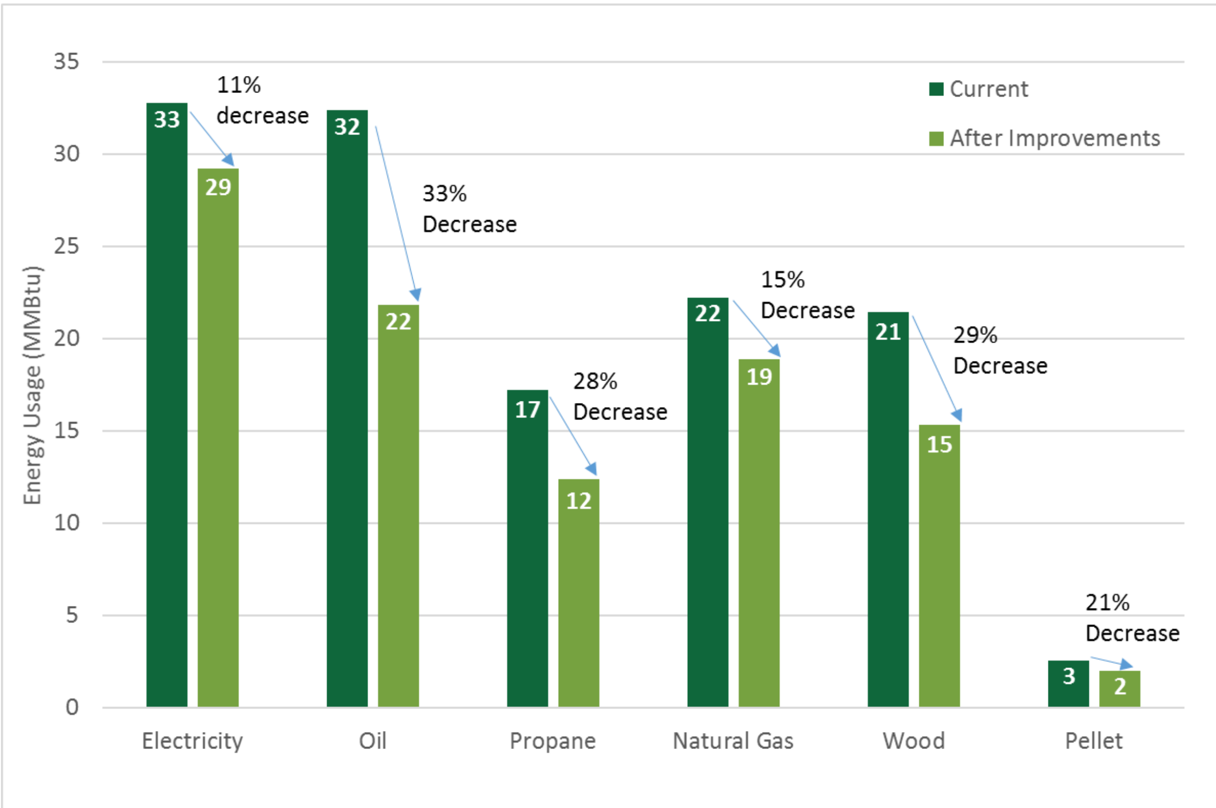

Figure 2: Average annual energy consumption before and after all recommended improvements by fuel type.

Figure 3 shows the annual energy consumption before and after all recommended improvements for each of the 137 homes, sorted by the homes' current energy usage. The median and mean current energy usage is 125 MMBtu and 130 MMBTu, respectively, and after improvements is 100 to 102 MMBtu. The chart illustrates the fact that larger energy savings opportunities exist at homes with higher energy usage.

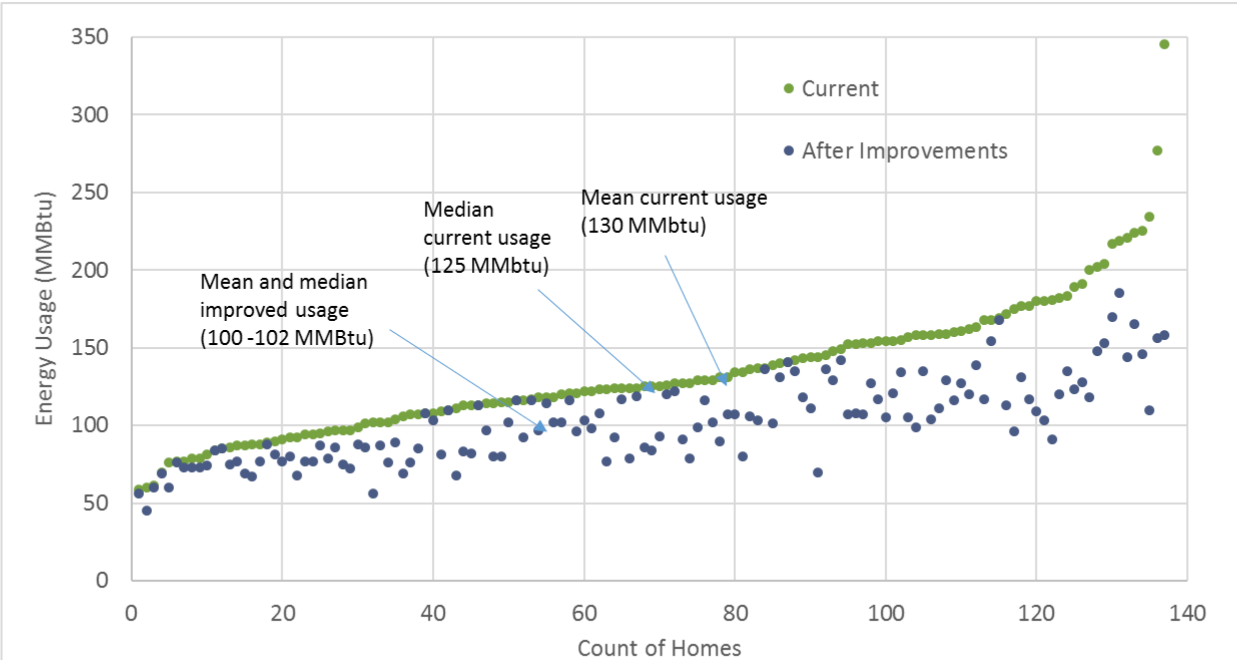

Figure 3: Average energy consumption before and after all recommended improvements.

Table 1 provides various data by quartile of annual energy consumption. The top quartile represents the 25% of homes with the lowest annual energy consumption; in contrast, the bottom quartile represents the 25% of homes with the highest annual energy consumption. On average, the annual energy usage of the bottom quartile declines by over twice that of the top quartile after improvements (32% vs 14%). In addition, while the bottom quartile reflects only 25% of all homes, it consumes 36% of all current energy and represents 50% of the total energy savings.

Table 1: Energy consumption and savings by energy usage quartile

Quartile	Average Annual Energy Usage per Home			Percent of Total Energy Usage		Percent of Total Energy Savings	Number of Homes
	Current (MMBtu)	After Improvements (MMBtu)	Percent Difference	Current	After Improvements		
Top	87	75	14%	16%	18%	10%	34
Second	116	96	17%	22%	23%	16%	34
Third	140	111	20%	26%	27%	23%	34
Bottom	190	130	32%	36%	32%	50%	35

Figure 4 displays the average annual energy consumption per home before and after all recommended improvements, by year of construction. Homes built before 1939 exhibit the largest percent decrease in energy consumption after improvements (31%). In contrast, homes built in 2000 or later show the lowest percent decrease (12%). Overall, older homes offer larger opportunities for energy savings than newer homes, as might be expected.

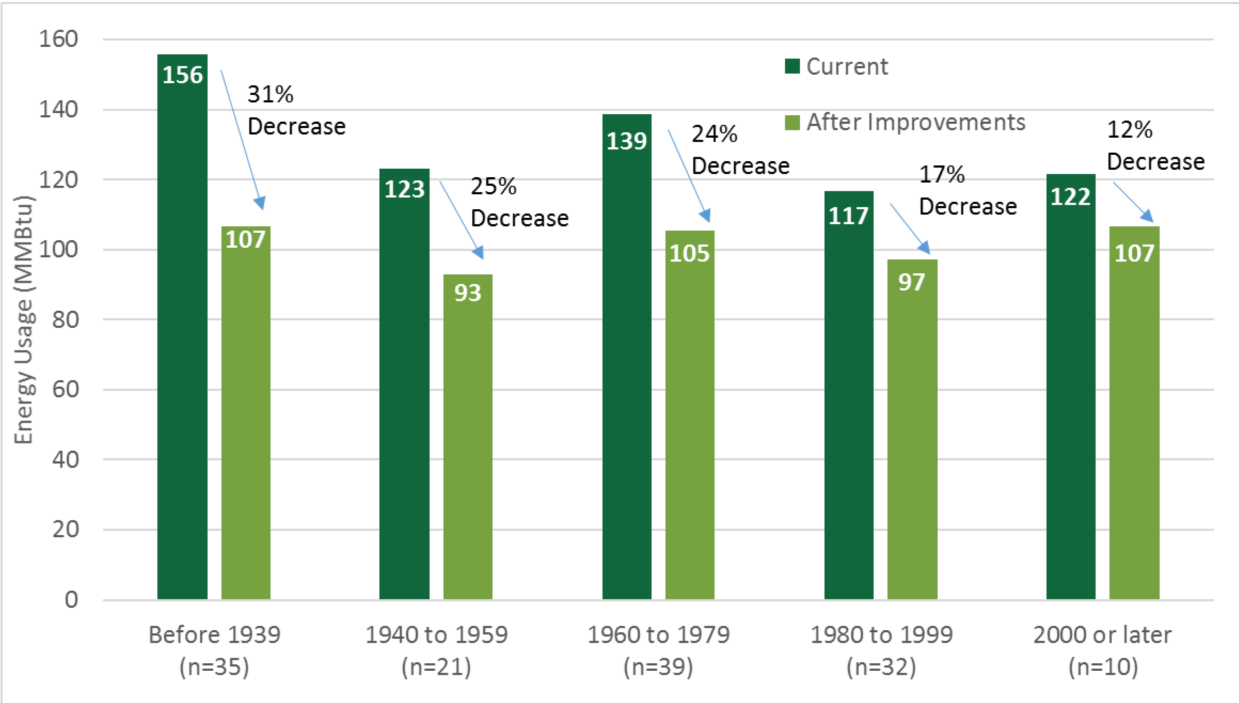

Figure 4: Average annual energy consumption before and after all recommended improvements by home vintage.

Recommendations

The HES report provides specific recommendations to improve the energy efficiency of homes. These recommendations are assigned into *Repair Now* and *Replace Later* categories. The *Repair Now* section of the HES report is described as follows: "These improvements will save you money, conserve energy, and improve your comfort now." While each recommendation listed in the HES report includes the estimated annual energy cost savings, it does not include the energy savings.

Table 2 lists the frequency and cost savings of the primary[2] *Repair Now* recommendations from each HES report. Basement/crawlspace insulation is the largest opportunity, identified in 50% of homes and representing 57% of cost savings. Air sealing was identified as an opportunity in 17% of homes, but represents only 12% of cost savings. Attic insulation was the third most common opportunity (11%), yet represents 21% of cost savings. Exterior wall insulation was identified as an opportunity less often (5% of homes), but still reflects a larger share of cost savings (9%). Overall, 15% of homes had no *Repair Now* opportunities.

Table 2 only includes the recommendation for each home that yields the largest energy cost savings; it does not include common recommendations that yield smaller savings. In addition, because the HES tool is an asset-based model, recommendations influenced by occupant behavior such as lighting, appliances, and thermostats are not included.

Table 2: Primary *Repair Now* recommendations by category

Primary Repair Now Opportunities	Percent of Homes	Percent of Annual Cost Savings across all homes	Count of Homes
Basement/Crawlspace insulation	50%	57%	64
Air sealing	17%	12%	23
Attic insulation	11%	21%	19
Exterior Wall insulation	5%	9%	6
Duct sealing/insulation	2%	1%	5
None	15%	n/a	20
Number of Homes	137	100%	137

[2] The primary recommendation is the recommendation from each home associated with the largest annual energy cost savings.

The *Replace Later* section is another component of the HES report that provides recommendations where "improvements will help you save energy when it's time to replace or upgrade." Table 3 shows the frequency and cost savings of the primary *Replace Later* categories from the HES reports. Statewide, water heaters were the most common upgrade opportunity in homes (25%), representing 29% of cost savings. Boiler upgrades were identified in 16% of homes and reflect 21% of cost savings. Window replacements were identified in 11% of homes with 14% of cost savings. Roof upgrades were also identified at 11% of homes, but represent 9% of cost savings. No upgrade opportunities were found in 20% of homes.

Table 3: Primary *Replace Later* recommendations by category

Primary Replace Later Recommendation	Percent of Homes	Percent of Annual Cost Savings across all homes	Count of Homes
ENERGY STAR Water heater	25%	29%	34
ENERGY STAR Boiler	16%	21%	18
ENERGY STAR Windows	11%	14%	15
Improve roof insulation/efficiency	11%	9%	15
ENERGY STAR Room air conditioner	8%	2%	15
Efficient Wood stove	4%	9%	5
ENERGY STAR Heat Pump	3%	8%	3
ENERGY STAR Furnace	3%	6%	4
ENERGY STAR Central Air Conditioner	1%	1%	2
None	20%	n/a	26
Number of Homes	137	100%	137

Billing Analysis

This section compares the annual heating fuel consumption estimates from the HES models to those from the billing analysis. Heating oil, propane, and natural gas usage data were obtained, cleaned, and analyzed for 41 of the 137 homes with HES models. The core of the analysis is a seasonal degree-day adjustment method approach, where fuel use for each home is compared to measured heating degree-days for each billing period in order to estimate the relationship between incremental heating load and fuel consumption. This analysis allows for the calculation of estimated "typical" fuel consumption based on historical average heating load weather conditions. However, this analysis does not control for supplemental heating, such as electric heat space heaters or wood stoves, which are relatively common in Vermont homes.

Table 4 provides the average annual consumption figures per home for each of the three primary fuel types included in this analysis, in units native to each fuel source. Natural gas, which is the fuel type represented by the most homes (24), also exhibits the closest agreement (3% difference) between the billing analysis and HES model usage. The fuel oil consumption estimates are 11% apart and are represented by 12 homes. Propane is represented by just five homes and yields a discrepancy of 21%. Due to the small sample sizes, we recommend caution in generalizing the results.

Table 4: Average annual consumption of primary heating fuel

	Natural Gas (CCF)	Fuel Oil (Gallons)	Propane (Gallons)
Billing Analysis	924	767	979
HES Model	950	680	770
Percent Difference from Billing Analysis	3%	11%	21%
Number of Homes	24	12	5

Figure 5 displays the annual consumption estimates from the billing analysis and the HES model for each of the 41 homes. The x-axis of the chart is sorted first by heating fuel type then by the billing analysis consumption amount. The HES modeled usage is within ±25% of the billing analysis usage for 15 of the 24 natural gas homes, three of the 12 oil homes, and three of the five propane homes.

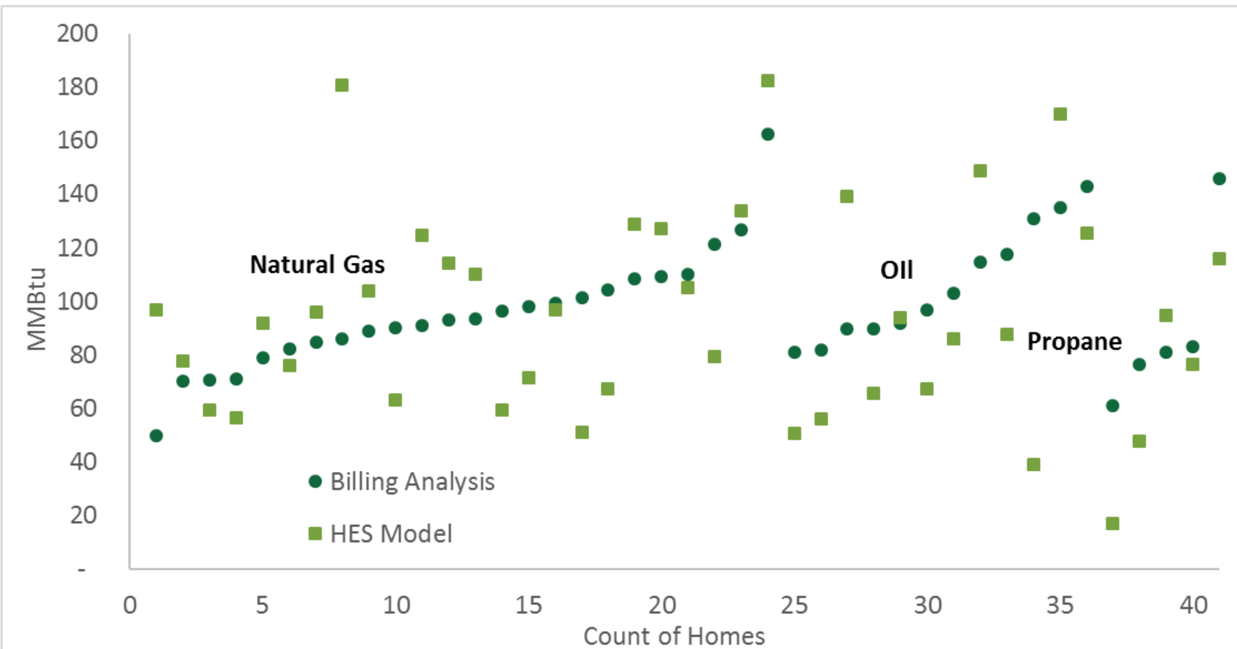

Figure 5: Annual energy consumption from billing analysis and HES models by fuel type.

Conclusions

This paper yielded several key findings about the use of the HES tool in residential baseline studies:

- The HES tool allows for a more systematic and comprehensive assessment of energy savings opportunities than was possible in prior Vermont baseline studies (NMR Group 2013).
  - We were able to comprehensively assess the prevalence and distribution of energy savings opportunities because the tool consistently identifies and quantifies the energy cost savings. Prior baseline studies in Vermont relied on individual energy auditors to identify energy savings opportunities; however, achieving consistency across multiple auditors can be challenging.
  - The HES tool allows for analyses of the level and distribution of savings associated with identified opportunities. While energy models could have been created using other software tools (such as REM/Rate), the HES tool requires fewer labor hours for data collection and model development. Based on our prior experience (NMR Group 2014; NMR Group 2015), we estimate about five hours of labor for a typical HES model versus about 10 hours for a typical REM/Rate model. Depending on the scope of the baseline study, this labor savings could yield substantial cost savings while still providing useful results.
  - The HES tool provides for additional analysis of energy usage and savings that may allow baseline studies that otherwise would not include energy modeling to better inform subsequent potential studies and program planning.
- While the sample sizes were very small, the billing analysis comparison indicates that the annual consumption estimated by the HES models is generally reasonable. In addition, because the relative accuracy improved for the fuels with larger sample sizes, the discrepancies may be primarily due to small sample sizes.
- Future research to assess the accuracy of the HES tool could include a billing analysis study that relies on larger sample sizes and also includes electricity. An alternative approach could involve the construction of energy models for the same homes using more established modeling programs, such as REM/Rate and BEopt, to assess the accuracy of the HES tool.
- Although the HES tool provides valuable data, one shortcoming to incorporating it into baseline studies is its asset-based approach to energy modeling, which excludes key end uses, such as lighting, appliances, and thermostats. In addition, there are a few minor tweaks that would facilitate easier incorporation into baseline studies. First, provide energy savings in addition to energy cost savings for each of the recommendations. Second, allow for the export of the recommendation data; it had to be manually entered into a database, which limited our analysis to just the primary opportunity for each home.

References

NMR Group, Dorothy Conant, Energy Futures Group, and KEMA. 2013. Vermont Single-Family Existing Homes Overall Report.

NMR Group. 2014. Connecticut Single-Family Weatherization Baseline Assessment.

NMR Group. 2015. Maine Single-Family Residential Baseline Study.