Technical Note on 2015 RECS Energy Data

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July 2018

The energy consumption and expenditures data from the 2015 Residential Energy Consumption Survey (RECS) were released (https://www.eia.gov/consumption/residential/) by the Energy Information Administration (EIA) at the end of May. This technical note covers an initial look at the residential energy use data. EIA has indicated (https://www.eia.gov/consumption/residential/reports/2015/comparison/) that users should be aware of differences between the 2015 data and previous surveys:

> ". . . differences between the 2015 Residential Energy Consumption Survey (RECS) and the 2009 RECS and previous studies [are described here], and [this report also] compares RECS with estimates derived from external sources. Users should be aware of these differences when comparing estimates from one round of RECS to another, and when comparing RECS with other studies."

EPMI has emphasized comparisons of EIA sectoral energy use estimates with data from The State Energy Data System (SEDS). SEDS is the EIA's comprehensive repository of US state-level energy statistics (http://www.eia.gov/state/seds/). SEDS focuses on covering sectoral energy use in total.

One important characteristic of RECS to understand is that it does not cover "total" residential sector energy use. Many housing units are excluded, e.g., military housing and "seasonal" occupancies. In addition, limitations in the survey approach appear to also reduce national energy use totals. A major concern for potential energy research or policy is just how acceptable are the RECS estimates for use in setting policy or agendas.

Some (mostly high-level) comparisons of data from SEDS, 2009 RECS, and the latest 2015 RECS will be used here to illustrate potential concerns. Previously, EPMI has indicated significant concerns with the end-use energy breakouts, and the switch to engineering-based end-use estimation in the 2015 RECS leads us to a new generation of end-use estimates, where the *intentions are good, but now the sorting begins to examine what might be misunderstood.*

Populations

The in-scope number of housing units in the 2015 RECS is 118 million, while the Census Bureau estimate of total housing units as of July 2015 is 135 million, 14% more (implying RECS covers 87% of the full total). The weighted sum of "household members" for the entire country in 2015 is 301.5 million people. The Census estimate for July 2015 is 321.4 million, so the RECS household members weighted sum is almost 94% of the Census estimate. In the 2009 RECS, the RECS weighted sum of household

members was 95% of the Census estimate. For the RECS geographical divisions, the 2015 range is from 90.0% for the Mountain South up to 98.4% for the East North Central division.

Total Sectoral Energy Use

The 2009 RECS estimate of total national energy use was 94% of the SEDS national total, in line with the population total of 95% of the Census total for July 1, 2009. For the 2015 survey, the RECS national estimate is reduced to only 82% of the national total (compared to almost 94% of population), raising even more concerns here about what the survey is accomplishing.

The 2009 RECS did include wood use, while the 2015 survey does not, and the estimated wood energy total from SEDS is 3.9% of the national total, so that would raise the comparison percentage for energy from 82% up to 86% of the national total, which then becomes more in line with the percentage of total housing units that are in-scope for the nation, but the reduced national energy use total is a concern. The next table shows a comparison of SEDS and RECS national fuel consumption totals for 2015.

Comparison of SEDS and RECS Residential Energy, 2015

	SEDS	RECS	RECS vs SEDS/Census
Fuel	**Trillion Btu**		**%**
Electricity	4,791	4,324	90%
Natural Gas	4,791	3,965	83%
Fuel Oil/Kerosene	561	464	83%
LP fuels	421	361	86%
Solar	128		0%
Geothermal	40		0%
Wood	440		0%
SUM	11,171	9,114	82%
	Census	**RECS implied**	----------
US Population (000s)	321,419	301,525	94%
US Housing units (millions)	135	118	87%

More concerning are questions regarding what is the RECS really telling us about US residential sector energy use? If RECS is ignoring almost 15% of the housing stock, what should we know about that part of the housing stock? If RECS is only capturing 82% of the estimated US residential sector energy use from SEDS (or 86% if the absence of a wood estimate is acknowledged), how useful are these totals for setting policy or understanding national energy performance?

End-Use Energy

End-use energy estimates are even more a concern. The end-use estimating methods were switched from statistical to engineering-based for the 2015 survey (https://www.eia.gov/consumption/residential/reports/2015/comparison/). EPMI would recommend a combined statistical-population approach (geographical approach?), using triangulation to refine results from both methods. Experience has shown that engineering-based estimates of heating energy are often significantly in error, and space cooling estimates are also often problematic. Statistical estimates for individual homes can also have significant error, so using both top-down sectoral

statistical calculations combined with engineering-based calculations for samples of individual housing units may offer the best potential for reasonable triangulation on final sectoral estimates.

This technical note will not go into extensive detail about potential issues with the end-use estimates, and instead will summarize initial findings and concerns. The effort to increase the level of breakout of the end uses is to be highly commended, and the resulting information is likely to be useful to many. But there is something quirky about the sample weighting — weighting that leads to estimates of 94% of the total US Census population (people) but only 82% (or 86% if SEDS wood use is added) of the total SEDS US total energy. This "quirk" may affect adjustments to end use energy, discussed below.

Overall Electrical Breakout

RECS Tables CE5.1a and b, Detailed household site electricity end-use consumption, parts 1 and 2—totals, 2015, provide an extensive breakout of electricity end-use for the country. However, adding up the wide range of electrical end uses tabulated by EIA (or calculated as weighted sums of the microdata) only amounts to 87% of the total electrical energy. This is a second diminution of total energy, in that the table above shows RECS data sum to only 90% of the SEDS residential sector national total, and now an extensive estimation of electrical end uses only accounts for 87% of the RECS total national electricity use. The RECS sum of electrical end uses is now only 78% of the SEDS total. That is a lot of electricity use to be missing. Where is it all hiding? (The answer is probably NOT in miscellaneous electrical loads.)

EPMI Population-Based End Use Adjustments

Previous work on RECS data has strongly indicated that the major electrical end uses of domestic hot water, refrigeration, air conditioning, and space heating are under-estimated by surprising amounts. Accordingly, a simple population-based calculation approach was used to provide new estimates for these end uses. This alternate approach uses the RECS data directly — no changes are made, but instead of using the weights to calculate weighted sums of the electrical end-use totals, weighted averages of energy use per person (for the specific end-use population) are multiplied by the weighted sum of the number of people identified as having the end use present in their homes to arrive at new (EPMI) end-use estimates.

Revising the estimates for the previously identified problem end uses of DHW, refrigeration, AC, and space heating, and using these new estimates to calculate an end use sum total, leads to a revised sum total that is 98.3% of the RECS total electricity use. In addition, more detailed examination of air handler energy use for heating and cooling (using W-h per degree-day weighted averages) strongly indicates that space heating air handler energy use for heat pumps may be much too low (possibly up to a factor of two). This finding is puzzling in that heat pumps are combined with central air conditioners in the AC calculations, and there did not seem to be an issue with the W-h per DD results for cooling. This possible issue is not large as far as total electrical use for the country, but increasing the heat pump space heating air handler energy use may increase the end-use sum of electricity to 98.5% of the total RECS value.

The table below is an adaptation of the electrical end-use table (CE 5.1) published by EIA to allow all the high-level end uses to be seen more easily (e.g., multiple "TV"-related end uses are combined, and multiple refrigerator and freezer uses are combined). The tabulated RECS results (or sums of the RECS results for combined categories) are shown in the first two columns: end-use category, and trillion Btu of electrical energy used (site energy). The EIA tables cover two printed pages, so subtotal rows are

introduced to show totals for each table. At the bottom, a TOTAL row is introduced to add the subtotals, and the total electricity use tabulated in EIA Table CE2.1 is also added.

Table CE5.1a Detailed household site electricity end-use consumption, part 1—totals, 2015

RECS End Use Categories		Total site electricity consumption (trillion Btu))		
		RECS	EPMI, using RECS data	
Space heating	637.9	Heating	822	Heating
Air handlers for heating	71.3	709.2	71.3	893
Air conditioning (AC)	730.8	AC	899	AC
Air handlers for cooling	33.8	764.6	33.8	933
Evaporative coolers	11.5			
Ceiling fans	78.4			
Dehumidiifiers	52.7			
Humidifiers	25.8			
Water heating	590.4		627	DHW
Clothes washers	19.5			
Clothes dryers	195.9			
Lighting	445.6			
Sub-total	2893.6	66.9%		

Table CE5.1b Detailed household site electricity end-use consumption, part 2—totals, 2015

All refrigerators	302.8	Refrigeration		
Separate freezers	69.8	372.6	472	Refrigeration
Cooking	61.7			
Microwaves	47.1			
Dishwashers	24.5			
All TVs and related	298.0			
Pool pumps	41.3			
Hot tub pumps	6.1			
Hot tub heaters	16.8			
Sub-total	868.1	20.1%		
TOTAL	3761.7	87.0%	4250.2	98.3%

Table CE2.1 Annual household site fuel consumption in the U.S.—totals and averages, 2015

Total Electricity	4,324

The 2015 RECS space heating and air handler (heating) values are summed to have an overall heating total (709.2 TBtu). Similarly, an overall cooling total is 764.6 TBtu. End uses in RECS Table CE5.1a account for 67% of the RECS total electricity use in Table CE2.1, and Table 5.1b accounts for 20% of the electricity total. Overall, Table 5.1 end uses account for 87% of the electricity total. This result is troublesome, and from a policy or research agenda perspective is highly problematic if the estimates may be flawed. How can all these end uses only sum to 87% of the overall electricity use total?

An initial check on the refrigeration energy indicated about a 40% drop from 2009. That drop was disconcerting, so the simple re-calculation of the previously identified problem uses was done.

The recalculated EPMI values for the problem end uses are shown in the last two columns. Air handler (/pump) energy was not recalculated for heating or cooling, and sums of heating and air handler/pump energy for space heating and cooling are in the middle RECS column for the RECS data and the last column for the EPMI recalculations. For the TOTAL row at the bottom, the recalculated total for the end uses based on the EPMI values is shown, and it is 98.3% of the RECS overall electricity use total.

RECS microdata calculate a weighted average of 5633.5 kBtu per capita for electric space heat energy and 145.9 million people live in homes using electric space heat energy. Multiplying the two leads to 822 TBtu of electric space heat energy. A similar calculation for space cooling leads to 3425 kBtu per capita and 262.5 million people in the pertinent population, for 899 TBtu of cooling energy.

The population using refrigeration energy calculates as 300.1 million people, at 461 kWh/capita, for 472 TBtu of site energy. Water heating microdata showed 138.2 million people with electric water heating, at 1330 kWh/capita, for 627 TBtu total.

The weighted average of individual household per-capita energy, combined with total energy-using populations implied by weighted sums of the parameter NHSLDMEM, is providing much different energy totals than weighted sums of household estimates of end-use energy. Using the household averages is a type of normalization that may be factoring out certain issues in the weights, affecting the weighted national sums of electrical energy.

This author feels more comfortable saying the wide range of end uses estimated by RECS accounts for 98% of total electrical use. Trying to defend that all these end uses amount to only 87% of total electrical use would appear to be a contortionist act. The use of normalizing parameters to calculate totals does have issues though, and the real end use totals may be lower than the adjusted values here, due to the effects of outliers in the data. The use of engineering-based end-use estimates in the 2015 RECS should have ameliorated the outlier effect in a significant way, but some outlier impacts likely remain.

Outliers, Weights, and Limitations

In a previous study of energy use in the commercial sector, the problem of using the product of average normalized parameter (EUI, kBtu per square foot of floor area) times total floor area in the Commercial Building Energy Consumption Survey (CBECS) data to calculate total energy use was discussed.[1] The total energy calculated is too high with this method. The presence of extreme outliers in buildings data is something that cannot be avoided with real world data, but better estimates of the central trends of the normalized parameters were obtained by trimming the tails of the CBECS data.

Similarly with the RECS data for 2015, attempting to calculate the total fuel use for any fuel based on multiplying the average fuel use per capita, calculated using RECS weights and all RECS data, by total population using the fuel will lead to results that are higher than the SEDS total (as explained more fully in the commercial report for the commercial sector). Using an approach similar to that explained in the commercial sector report for the RECS data (trimming the data to include only data in the range of the mean +/- one standard deviation, based on Ln of energy use per person, unweighted) to calculate the

[1] *Understanding Commercial and Service Sector Energy Use*, 2016, pp 43–44 (pp 55-56 of the PDF). EPMI. http://epminst.us/commercial/commercial.htm

average fuel use per person leads to reasonable results for the RECS data, but also suggests that the RECS total fuel use values are too low (as the comparison on p 2 of this technical note also indicates).

A previous exploration of 2015 EIA residential sector energy use data also exposed the issue that RECS data cannot cover all fuel-using populations (definitely missing some propane users and likely missing some fuel oil/kerosene users).[2] Missing parts of specific populations does lead to limitations in attempting to use sample weights to cover the missed segments of users, as there are many factors the weights are attempting to cover. These population-missing limitations tend to lead to lower than actual national totals (e.g., of fuel use).

An entire report could be written on all the peculiarities introduced by survey limitations and effects of outliers typically found in real-world building data, but one example from the 2015 RECS will be used to suggest how important outlier impacts may be.

One record in the 2015 RECS data is indicated to be a single-family detached home of almost 8,000 square feet in the South region. One elderly person lives in this home. Almost 5,000 square feet of the "home" are conditioned, and about 3,000 square feet are unconditioned. The "home" is reported to be 10 stories tall. Total annual energy use in this all-electric "home" is reported to be about 43,000 kWh/yr (43,000 kWh/yr per person is a high number). The engineering model breakout of electric use has about 17,000 kWh for heating, about 7,000 kWh for cooling, and about 11,400 kWh not allocated to any specific end use.

Extensive experience has indicated that 10-story buildings tend to have major airflow issues that can significantly increase heating and cooling energy use (and engineering –based models are generally not well-suited to model these issues), while 11,000+ kWh not allocated to any end use is a troubling result. One can begin to understand the challenges in trying to model such a building as part of an effort that includes modeling over 5,000 buildings (or housing units) to develop end-use estimates for all 5,000+ entities. More importantly, this "home" must be one-in-a-million (or maybe ten million, since one person in a 10-story building is highly unusual), meaning a sampling weight of 100-200 would be appropriate. The actual RECS weight is 21,631.45, so the challenges in trying to characterize the residential building sector by having to assume there are over 20,000 such "homes" in the country begin to be evident. Having 20,000+ homes with 11,000+ kWh/yr of unallocated electric use does not lead to confidence in end-use totals, and the impact of having to assign 43,000+ kWh/yr per person to 20,000+ homes also makes calculation of "averages" a biased proposition.

The impacts of such outliers on weighted or unweighted averages is significant, and tail-trimming can be important for trying to better understand reasonable national averages of normalized parameters.

The results obtained in extensive calculations (not reported here) indicate that the fuel use totals reported for the 2015 RECS for the reported in-scope population are likely a few percentage points too low (relative to SEDS totals), and also likely some additional percentage points too low due to inadequate representation of the fuel-using populations (five to ten points overall?). Also as presented previously here, some end-use totals may be 5–20% too low.

[2] Exploration of 2015 US Residential Sector Energy Using EIA Data, 2015. EPMI. http://epminst.us/residential/Exploration_of_2015_Residential_Sector_Energy_Using_EIA_Data.htm

EPMI continues to explore methods to better understand commercial and residential sector energy use, and this technical note is meant to urge caution in accepting the 2015 RECS fuel and end-use totals without question.

Conclusion

The 2015 RECS data are reviewed and initial concerns are presented. If RECS only accounts for 82% of total US residential sector energy, what are the implications for development of energy policy or research agendas? The fuel use totals are a concern, and methodological improvements appear needed for estimating these totals. Inadequate representation of the fuel-using populations may require additional adjustments to methods in order to address impacts of under-representation.

The estimation of electrical end uses continues to raise significant concerns, and there may be end-use issues for other fuels as well. The switch to engineering-based end-use energy estimates may be important overall, but new quality assurance issues may have been introduced. The electricity end use totals for space heating, space cooling, refrigeration, and water heating were recalculated using RECS data directly but a different calculation than a straightforward weighted sum of end-use energy. The differences are dramatic and a cause for concern.

There appears to be a need for some type of national-scale end-use monitoring program, probably segregated by end uses (meaning focused efforts on specific end uses), in order to develop reliable per-capita end use values to help guide better understanding and modeling of sectoral energy end uses.

A more focused effort on exploring and explaining differences between SEDS data and RECS data may also be needed.

Overall, the potential for misunderstanding energy use in the US residential sector based on 2015 RECS results appears high, and users should be wary of the potential for misguided efforts or decisions if based on an uncritical consideration of the RECS data.