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Residential Energy Consumption Survey (RECS)

2015 Consumption and Expenditures Technical Documentation Summary

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The first of three versions of this document was published in May 2018. The second version of the document was published in July 2018 and included additional reference notes for the end-use modeling process. The third version was published in December 2018 and included an additional section on estimating wood consumption.

Introduction

The Residential Energy Consumption Survey (RECS) is a periodic study conducted by the U.S. Energy Information Administration (EIA) that provides detailed information about energy usage in U.S. homes. RECS is conducted in two phases: phase one is a multi-stage sampled Household Survey that collects energy-related characteristics and usage patterns from a nationally representative sample of housing units. Phase two is the Energy Supplier Survey (ESS), which collects billing data for responding households from their utility suppliers to allow EIA to estimate energy consumption and expenditures. Taken together, the housing characteristics data and the billing data are the basis for individual energy end-use consumption and expenditures estimates.

This document provides the methodological descriptions for:

- ***Energy Supplier Survey (ESS)*:** provides details on billing data collection, supplier response rates, and billing data editing and quality
- ***Consumption and Expenditures Annualization and Imputation*:** provides details on the consumption and expenditures estimation for calendar year 2015 using the ESS billing and delivery data
- ***End-use Estimation Modeling and Calibration*:** provides details on the consumption estimation of household end uses and method changes from previous years

The methodology for the RECS Household Survey and household energy-related characteristics, including sampling and weighting, is provided in a separate document called Residential Energy Consumption Survey (RECS) 2015 Household Characteristics Technical Documentation Summary.

Data Products

EIA has released a variety of RECS products across survey cycles, tailored to a wide range of data users. These releases include summary-level tables of energy-related characteristics, detailed tabulations of energy consumption intensities across key variables, and public-use microdata for customized analysis of home energy use.

The 2015 RECS releases include articles highlighting key findings, standard tables, and a microdata file. All current and historical products are available on the RECS website.

RECS data are also used as critical inputs for EIA sector-level forecasts, such as the Annual Energy Outlook and for energy program analysis.

Energy Supplier Survey (ESS)

Overview

The RECS Household Survey asks respondents to report energy characteristics about their homes, energy-consuming equipment, and energy-related behavior, but it does not collect their energy consumption and expenditures. To capture complete and accurate energy usage information, EIA conducts a second data collection called the Energy Supplier Survey (ESS). EIA collects these data directly from energy suppliers under a mandatory authority granted by Congress. The ESS collects household billing data from electricity and natural gas suppliers, and collects delivery data from propane and fuel oil/kerosene suppliers. Usage and cost data for the reference period are collected for most respondents of the RECS Household Survey.

Survey frames

In preparation for the ESS data collection, EIA used responses from the Household Survey combined with staff research to construct the ESS frames. EIA used two types of frames for the ESS: a list of all RECS households for which energy data are requested from energy suppliers and a list of all the unique energy suppliers from the household frame. To populate these frames, the final section of the 2015 RECS household questionnaire asked respondents to provide energy supplier names and customer account numbers. Out of all respondents, 87% of RECS households provided one or more energy supplier name, and 46% of households also provided an energy account number or sample energy bill that displayed their account number. However, more than 1,200 households either did not know the name of all of their energy suppliers or chose not to report them to EIA. When the electricity or natural gas supplier name was missing, EIA determined the likely supplier based on service territory information. In contrast, EIA could not determine which propane or fuel oil/kerosene delivery company services a particular address, because they do not have defined and mutually-exclusive service territories. As a result, when a household respondent did not provide its bulk fuel supplier name, the household was not included in the ESS for that energy source. In addition, EIA does not pursue household billing or delivery data when a RECS household respondent indicated that they did not directly pay their energy costs (for example, when an apartment's electricity costs were included in the monthly rent).

In total, the initial ESS household frame covered 9,037 of the 9,857 (92%) energy sources identified in the 5,686 responding households in the RECS Household Survey.

Data collection, response rates, and coverage rates

ESS data collection occurred between August 2016 and February 2017. A secure ESS data collection website offered energy suppliers two primary reporting options: an interactive data collection web page or an Excel spreadsheet that suppliers could download and submit online. Suppliers could also print or request by mail the hard copy data collection forms to complete by hand, but only 1% of data was submitted this way. EIA provided suppliers with the addresses and account numbers (where available) of the customers for which EIA was requesting data.

The data request covered energy usage and cost information that occurred between September 2014 and April 2016. For electricity and natural gas, the supplier typically submitted 20 billing periods of data

per household. The frequency of bulk fuel deliveries varied, so for propane and fuel oil/kerosene the average was about six deliveries per household during the reference period.

Unlike the RECS Household Survey, which is voluntary, EIA uses its legal authority to conduct the ESS on a mandatory basis to ensure high coverage and data quality for sampled households. Almost all suppliers (93%) responded to the ESS, but some had difficulty finding every requested address in their records. EIA and its data collection contractor worked closely with suppliers in an attempt to locate all requested energy data, which included confirming addresses and account numbers, reviewing sample bills provided by household respondents, and re-assigning household addresses to a different energy supplier if appropriate. Most household-level nonresponse occurred when a supplier could not locate the address in their records, or the energy supplier could not be determined.

While many surveys report one response rate, EIA used three metrics to evaluate the success of the ESS data collection and the overall coverage of household consumption and cost data.

- **Supplier-level response rate:** percent of in-scope energy suppliers that responded to the ESS–*93% (834 out of 900)*
- **Household-level response rate:** percent of households included in the ESS where energy data was received–*94% across all energy sources, shown in Table 1 as "ESS response rate"*
- **Household-level coverage rate:** percent of all RECS households using an energy source where energy data was received–*86% across all energy sources, shown in Table 1 as "ESS coverage rate"*

This table reflects the outcomes of ESS data collection prior to the quality control steps described below. In some cases, energy data were received as part of the ESS but were determined to be unusable for RECS purposes.

Table 1. Household-level ESS outcomes by energy source

Energy source	Uses energy source (a)	Included in ESS (b)	ESS data received (c)	ESS response rate (c/b)	ESS coverage rate (c/a)
Electricity	5,686	5,445	5,203	96%	92%
Natural gas	3,304	2,988	2,777	93%	84%
Propane	573	417	355	85%	62%
Fuel oil/kerosene	294	187	168	90%	57%
Total	**9,857**	**9,037**	**8,503**	**94%**	**86%**

Editing and data quality

Similar to the RECS Household Survey process, EIA employed a multi-phased approach to quality control of supplier billing and delivery data. These processes improve the overall quality and consistency of information within and across phases. When data were submitted through the interactive web page, a limited number of critical edit checks were built into the system to ensure required fields were completed and appropriately formatted by the respondent (for example, characters were not allowed in numeric fields). When data were submitted in Excel or another electronic format, the submission was promptly manually checked against a short list of acceptance criteria to ensure all required variables

were present and formatted to allow for standard data processing. After data from all submission methods were combined, analysts reviewed data inconsistencies, incomplete responses, outliers, and supplier comments. In some cases, suppliers were contacted to resubmit or verify data. During this editing phase a limited number of changes were made to ESS data, including fixing typos or other identified errors and removing a small amount of unusable data.

A further round of editing checked for consistency between household responses and ESS data. This editing phase was new for the 2015 RECS and included reviewing potential disagreement between a household's reporting of their fuels and end uses and the observed energy usage. For example, a response of *electricity* for main heating fuel on the Household Survey was revised to *natural gas* where ESS data indicated strong winter seasonal use in utility-reported natural gas bills for that household. Analysts also looked for vacancies or other gaps in energy data, inclusion of non-household energy use, or exclusion of some household energy costs. About two-thirds of the data changes during this round of editing were to RECS household characteristics items, and the remaining one-third were changes to ESS data. The most common ESS data change during this editing phase was to remove data that were determined to be unusable. For example, an apartment respondent reported using natural gas for heating, water heating, and cooking, but the ESS data submitted for that apartment unit appeared abnormally low and non-seasonal. The analyst determined the consumption data covered only cooking, as the apartment building had central natural gas heating and water heating equipment that the tenants paid for through their rent. In this situation, the submitted ESS data was not used, and natural gas consumption and expenditures for this apartment were imputed. This additional editing step improved the consistency between characteristics and household consumption data, which improved the modeled estimates of space heating and other end uses.

Another notable review step during this final editing phase was examining the electricity ESS data submitted for RECS households that reported on-site solar generation. Because RECS reports site household energy consumption, the ESS data and any sample energy bills for these homes were reviewed to ensure that both on-site electricity generation as well as electricity delivered from the grid were included. Unfortunately, for more than half of these homes, the submitted ESS data only included delivered electricity and so it was not usable for RECS purposes. By the time the unusable data were identified, it was too late to re-contact either the household or energy supplier to collect the amount of on-site electricity generation. Consumption and expenditure amounts for these cases were imputed. For future RECS cycles, EIA will consider modifying ESS procedures to improve the collection of energy data for homes with solar generation (non-delivered electricity).

Across all phases of ESS editing, data for about 3% of submitted cases were determined to be unusable and removed; for these households the energy consumption and expenditures were imputed as described in the **Annualization** section below. Quality control was performed at all stages to ensure the editing and processing were done consistently and correctly.

Consumption and Expenditures Annualization and Imputation

Overview

Annualization for the 2015 RECS estimated the expected consumption and expenditure of a housing unit from January 1, 2015, to December 31, 2015, using the energy supplier billing and delivery data. The billing records received from the energy suppliers rarely correspond exactly with calendar year 2015. In most cases, the records were complete, but the first and last billing periods covered a small amount of consumption outside of 2015. In other cases, the suppliers reported consumption and expenditures for only part of the year. In either situation, the reported totals of these partial cases were adjusted to more accurately reflect the household's annual consumption for 2015. In general, consumption reported for a housing unit by an energy supplier is prorated to fill any missing time periods. This proration is based on the expected consumption for the missing period as determined by engineering models. More information about these models is provided in the **End-Use Estimation** section of this report.

Table 2 outlines the distribution of data completeness for each fuel type. A set of billing records was considered complete if it covered all of 2015 calendar year. For electricity and natural gas, a complete case was defined as having a series of monthly bills that covered the 365 total days from January 1 to December 31, 2015. Unlike electricity and natural gas, propane and fuel oil are delivered and billed irregularly. Therefore, it is harder to identify the true billing data completeness of a case that uses these fuels. Here, EIA considered the billing records for a bulk fuel case to be complete if at least one delivery was reported from each of the calendar years 2014, 2015, and 2016.

Table 2. Consumption data completeness for electricity, natural gas, propane, and fuel oil

Energy Source	Complete cases (n/%)	Partial cases (n/%)	No data cases (n/%)
Electricity	4,849 (85%)	217 (4%)	620 (11%)
Natural gas	2,580 (78%)	117 (4%)	607 (18%)
Propane	182 (32%)	107 (19%)	284 (49%)
Fuel oil	117 (40%)	39 (13%)	138 (47%)

Note: Expenditure data completeness was not exactly the same as for consumption but had only minimal differences.

The methodology used to perform annualization varies by fuel type, and more details are provided in the sections below. For households that had no reported consumption, the annual total was imputed using statistically adjusted engineering models. That process is detailed in the **Imputation** section.

In addition, a few examples are provided in **Appendix A** to illustrate the annualization and imputation procedures.

Electricity and natural gas annualization

For households with complete billing data for electricity and natural gas, bills that only cover days within 2015 were added together. Bills that straddled the beginning or end of 2015 were prorated according to how many days fell within calendar year 2015. The annual consumption was simply the sum of the bills that were entirely within 2015 and any prorated bills.

Because electricity and natural gas are billed at regular intervals, if an extended time period had no reported data, EIA assumed that the energy billing data were missing for that period. For housing units with partially reported energy data, the consumption from the reported months was prorated to impute the missing data. The amount prorated depended on the estimated consumption for heating, cooling, and non-HVAC[1] end uses for the missing period. These estimates were based on the engineering end-use models detailed in the **End-use Estimation** section and they depended on heating degree days, cooling degree days, and total calendar days during the missing portion of the year. The process to handle cases with no reported consumption is documented in the **Imputation** section.

If the Household Survey respondent reported a vacancy and the supplier did not provide information for any time period, then the consumption for that missing period was not imputed. EIA assumed that the information was not missing, but rather that no consumption occurred during that time period. This method was a change from the methodology for the 2009 RECS, where any missing periods, whether vacant or not, were imputed.

Methods to annualize expenditures data were similar to the consumption methods. If a case did not include a complete record of expenditures, the missing expenditure of a billing period was imputed by using an average price computed within the case or supplier and multiplying it by the corresponding consumption for that billing period.

Propane and fuel oil annualization

The nature of bulk fuel usage and deliveries prompted different annualization procedures. Unlike monthly electricity and natural gas billing records, bulk fuels are often delivered at irregular intervals. A large gap between deliveries would not necessarily mean that a time period had missing data. In addition, a delivery occurs on a specific date, but the time period during which the fuel is actually consumed is less certain. For the purposes of RECS, EIA assumed that a delivery would refill a storage tank, replacing fuel that had been consumed since the last delivery.

To annualize a housing unit's bulk fuel consumption, EIA chose the subset of deliveries that included as much of 2015 as possible, while coming as close as possible to 365 days. In some cases, this subset included all of 2015, plus some extra days in 2014 or 2016. In other cases, this subset could have excluded some days at the beginning or end of calendar year 2015. In either case, the total consumption was summed for the time period that was included in the chosen deliveries. This sum was prorated to match calendar year 2015. The amount of the proration depended on the estimated consumption for heating and non-HVAC end uses for the chosen time period. These estimates were based on the engineering end-use models detailed in the **End-use Estimation** section, and they depended on heating degree days and total calendar days during the time period covered by the chosen deliveries.

As with electricity and natural gas, consumption for unreported time periods was not imputed if the Household Survey respondent reported a vacancy. Because vacancy could not be inferred from the pattern of deliveries, EIA used the electricity billing records to determine the time periods when a

[1] Short for heating, ventilation, and air conditioning.

household was vacant. The process to handle cases with no reported bulk fuel consumption is documented in the **Imputation** section.

The annualized expenditure for bulk fuels had the same procedure as the annualized consumption for a complete case. If a bulk fuel case did not include a complete record of expenditures, EIA calculated the missing expenditures as the annual total consumption multiplied by an annual average price.

Imputation

When no billing or delivery data were available for a household, the annual consumption was imputed using estimates derived from the end-use engineering models, which are based on housing characteristics and weather data. More specifically, EIA used engineering model estimates as variables in a regression model, and the best fit to the total reported consumption from all housing units was used for imputation. A representative model for electricity is:

$$C_{elec} = \beta_1 \times E_{heat} \times \left(\beta_2 \times X_{cold} + (1 - X_{cold})\right) + \beta_3 \times E_{cool} + \beta_4 \times E_{water} + \cdots + \beta_N \times E_N$$

Where

C_{elec} is annual electricity consumption
E_{heat} is the engineering estimate for space heating
X_{cold} is a variable that equals 1 for housing units in colder climates, and 0 otherwise
E_{cool} is the engineering estimate for space cooling
E_{water} is the engineering estimate for water heating
E_N is the engineering estimate for the Nth end use or group of end uses
$\beta_{1...}$ β_N are the model coefficients

For space heating, including the extra term X_{cold} for location in a cold climate improved the fit of the model. The term is constructed so as to simplify the analyst's interpretation; as written, the β_2 parameter is a factor that applies to housing units in colder climates but not to others.

The resulting coefficients $\beta_{1...}$ β_N of that model were applied on a case-by-case basis to the characteristics and engineering estimates of households without reported billing data. The total consumption for a housing unit was equal to the sum of the model terms. This method is a change from the 2009 methodology, which used a purely statistical model to estimate total consumption and end uses without first calculating engineering estimates.

Like fuels with partially reported expenditures, EIA calculated the expenditures as the imputed total consumption multiplied by an average price. In this case, the price used was the average reported for the same geographic location as the housing unit.

Estimating Wood Consumption

For electricity, natural gas, propane, and fuel oil, EIA relies on energy suppliers to provide most of the information used to estimate annual household fuel consumption. For wood consumption, however, EIA relies only on household respondent reports of wood use. For the 2015 RECS, EIA asked for wood

consumption to be reported in cords of wood or 40-pound bags of pellets. For the RECS, a cord of wood is a pile of stacked wood with a volume of 128 cubic feet.

EIA conducted the 2015 RECS using in-person Computer Assisted Personal Interviewing (CAPI), web, and mail modes. EIA asked for cordwood consumption differently depending on the survey mode. CAPI respondents (43% of all respondents) were asked to give a categorical response of up to five cords of wood, and if more than five cords of wood were used, the actual number of cords used was collected. The respondents were also shown a picture of a cord of wood to help guide their responses. Web and mail respondents were allowed to give an open-ended number of cords without the assistance of categories or a visual aid.

EIA staff analysis of respondent-reported data showed that the difference in survey mode possibly caused a difference in the amount of cords reported. Web and mail respondents were more likely to report larger cord amounts than CAPI respondents. The percentage of web and mail respondents who reported using more than five cords of wood was more than double the percentage of CAPI respondents. After collecting the data, EIA analysts reviewed and edited the data where necessary to correct errors. Analysts deleted some impractically high amounts of reported cord use, for example. EIA staff imputed missing wood consumption responses, including those amounts deleted during editing, using the engineering modeling method described below in this document. EIA's editing and imputation processes corrected many of the misreported large cord amounts, and the resulting edited final distributions of wood consumption by survey mode were similar. For reporting, the amount of wood used in cords or pellets were converted from the physical amount of wood used to Btu.[2]

EIA does not include the final wood consumption estimates in total or average household energy consumption estimates. Instead, EIA presents wood consumption estimates as special tabulations in Table CE7.2.

[2] EIA staff used the assumptions that one cord of wood consists of 20,000,000 Btu of energy content, and that one 40-pound bag of pellets consists of 330,000 Btu.

Updates from the 2009 RECS Annualization and Imputation Process

The methodology used in 2009 had a number of differences from the 2015 procedures:

- If a household indicated vacancy for any part of 2015 and the supplier reported no consumption, EIA considered the consumption for that period to be 0. In 2009, no Household Survey vacancy indicators were collected, so consumption for all vacant periods was imputed. Note that for 2015 RECS, as in prior rounds, electricity and natural gas consumption during a vacant period was often just observed as a low bill amount relative to bills during occupancy.
- If the household respondent reported an end use for which they were not directly billed (for example central water heating in an apartment building), the bills for that household were not used, and the annual total was imputed. Augmentation, which was used in prior years to adjust the billing data to account for the excluded end use, was not performed.
- If the household indicated that a large part of their reported energy usage included energy used for non-household purposes, such as on a farm, the reported bills were not used, and the annual total was imputed. EIA did not perform disaggregation, which was used in prior years to extract the non-household energy consumption.
- Disaggregation was also not used to separate energy consumption for individual apartments or mobile homes when billing data for the entire building or mobile home complex were reported. Annual consumption totals were imputed for apartments or mobile homes where reported bills included consumption for more than one household.
- For natural gas consumption reported in therms, a *local pressure factor,* based on altitude, and the state-level heat content factor were applied when converting therms to ccf (hundreds of cubic feet). For the 2009 RECS and prior RECS, the conversion was done using only the national heat content factor. Using this new method, the average (weighted) natural gas conversion factor for all 2015 RECS households using natural gas was 1.003 therms per ccf, compared with the 2015 conversion factor of 1.038 therms per ccf published in EIA's *Monthly Energy Review*.

End-Use Estimation

Overview

For the RECS program, an energy end use is a particular need, appliance, or device in a housing unit that consumes energy. Because direct measures of energy end uses, which often require installing special devices in homes, are rare, national estimates of energy consumption by end use must rely on some amount of modeling. The RECS Household Survey collects characteristics about a household's end uses, and the annualized ESS data dictate how much total energy was used by each fuel present. End-use estimation is done using both Household Survey and ESS data, combined with publicly available weather data.

End-use estimation is done in two main steps:

1. A suite of engineering *end-use models* is used to estimate the expected consumption of each end use present.
2. The known total consumption is used to *calibrate* the engineering model-based end-use estimates.

Each step is applied, in order, to each housing unit in the RECS. The calibration step ensures that the final end-use estimates for each particular fuel sum to the annualized total while preserving the distributional information the engineering models provided. The end-use models and the calibration procedures have been updated for the 2015 RECS. In the end-use modeling step, an engineering-model approach replaced the statistical modeling approach used in previous RECS; in the calibration step, an optimization approach based on uncertainties of and correlations between end uses has replaced the simple normalization approach used in previous RECS.

In RECS cycles before 2015, the end-use models were statistical. All consumption was attributable to an end use, and each end use had its own model, which by construction contained at least one unknown parameter. The models became fully specified once the best (least squares) values for the unknown parameters were found using nonlinear regression. For each fuel, the annualized energy total was regressed on the sum of end-use models under constraints that certain parameters could not be negative (i.e., negative energy consumption is unphysical). The calibration method used was simple normalization, where the difference between the annualized ESS total and the modeled sum for a given housing unit was prorated over all end uses in the housing unit. In practice, every individually modeled end-use value for a given housing unit was multiplied by the same factor—the ratio of the ESS total to the sum of modeled end uses. Additional details on the prior end-use estimation methodology are available in the 2009 RECS End-use models FAQs.

In the 2015 RECS, the end-use models follow an engineering approach, and the calibration is based on the relative uncertainties of and correlations between the end uses being estimated. Also, the 2015 RECS published results include more end-use estimates than in previous RECS cycles. The sections below describe the updated methodology and provide further details on the modeling approaches for each of the published end-use estimates.

Engineering end-use modeling

Engineering models might best be thought of as expert models. Instead of estimating unknown parameters and interpreting their solution values, as is done in statistical modeling, engineering models improve upon statistical models by drawing on existing studies to construct physically principled models using published values for parameters, such as estimates for Unit Energy Consumption (UEC). Unlike the statistical models, engineering models do not rely on the ESS data, which allows EIA to obtain the modeled end-use estimates faster without having to wait for the ESS data to become available. These initial end-use estimates can also be used in the editing process to detect any inconsistences between the household data and the ESS data.

The complexity of the end-use models depends on the end uses and how much information about them is collected in the Household Survey. Some models are simple, such as the expected energy consumption for a coffee maker. Respondents are asked whether a coffee maker is present and used at least once a week, and no other specific usage information is collected. If the response is *yes*, the engineering model estimate is the average UEC value found from published sources, and zero otherwise. Other models are moderately complex, such as the expected energy consumption for a refrigerator. The model assigns an effective UEC value[3] based on the reported configuration, size, and age of the unit, and then it applies adjustments based on the reported defrost mechanism, the presence of a through-the-door ice maker, and its ENERGY STAR® status. Finally, a few models are complex, such as space heating and space cooling. Each of these follows an approach of first estimating an underlying conditioned load based on building characteristics and weather/climate variables and then estimating how much energy is required to meet that load given the efficiency of the equipment and fuel used in the housing unit (e.g., a natural gas furnace that is 10 to 14 years old).

In addition to the explicitly modeled end uses in the 2015 RECS, each fuel now has the possibility of an *unknown* source of energy consumption. Historically, the consumption from end uses not asked about in the RECS has been absorbed into the consumption total from the explicitly modeled end uses during calibration. In principle, carrying through the possibility for an unknown end-use component should allow for more accurate estimation of the explicitly modeled end uses. More detail about the unknown end-use model and how this component is treated in the calibration step is provided in the **Unknown consumption** section below.

Also in 2015, reported vacancy was preserved as a characteristic of housing units as described above in the **C&E Annualization and Imputation** section. Modeled engineering totals were prorated to reflect only the consumption from occupied periods. The proration was according to calendar days for all modeled end uses except space heating and space cooling, which instead were prorated according to heating degree days (HDDs) and cooling degree days (CDDs), respectively.

[3] UEC values are calculated based on values reported in the Compliance Certification Management System (CCMS) database (accessed in 2014): https://www.regulations.doe.gov/certification-data/CCMS-4-Refrigerators__Refrigerator-Freezers__and_Freezers.html

Minimum variance estimation calibration procedure

Although end-use modeling provides information about how the end-use consumption is distributed across the end uses in a housing unit, the model outputs for a housing unit rarely equal the home's annualized billing total. EIA used a calibration procedure to preserve the distribution of a fuel across end uses while ensuring the end-use estimates equal the known billing total. The difference between the initial modeled sum of end-use consumption and the known annualized billing total is a Target Value. If the Target Value is positive, then a calibration procedure must increase the sum of the initial modeled estimates. If the Target Value is negative, then a calibration procedure must reduce the sum of the initial modeled estimates. Either way, the calibration procedure corrects the initial modeled estimates.

Under the simple normalization calibration method used in previous RECS, every individually modeled end-use value for a household was multiplied by the same factor. The 2015 RECS calibration method, known as *minimum variance estimation,* uses estimates of the models' likely errors, or uncertainties, to produce unique factors for each end use. Because models vary in complexity and use of RECS data, the various model outputs have varying levels of uncertainty. Further, certain end-use pairs are also likely to be correlated. For example, housing units that use clothes washers more than average are likely to use clothes dryers more than average. The uncertainties associated with the end-use estimates and the correlations between certain end-use pairs were used to make the calibration adjustments information-based and internally consistent.

Mathematically, if the set of initially modeled end uses in a given housing unit is x, a column vector that has the same number of components as the housing unit has end uses, then the calibration procedure corrects each end-use estimate, Δx, so that the final, corrected estimates are $x + \Delta x$. The uncertainties and correlations are used to define a weighting matrix, a variance-covariance matrix, $\boldsymbol{P}$, whose inverse can be used in a cost function, J, which is a quadratic form that assigns a scalar cost to each possible vector of corrections:

$$J(\Delta x) = \frac{1}{2}\Delta x^T \boldsymbol{P}^{-1} \Delta x$$

The optimal—or most likely—set of corrections is found as the vector that minimizes the cost function subject to two types of constraints. First, the final estimates cannot be negative or zero, because negative consumption is unphysical, and zero consumption would effectively erase a reported end use from a housing unit. Hence, $x_i + \Delta x_i > 0$, with the subscript *i* indexing each end use present. Second, to satisfy the calibration goal, all of the corrections must sum to the Target Value, ΔY, which is the difference between the initial modeled sum of end-use consumption and the known annualized billing total: $\sum_i \Delta x_i = \Delta Y$.

Minimizing this cost function under these constraints is a standard problem in quadratic programming, but it is easily solved in many software packages. Defining the uncertainties and correlations to use in the weighting matrix (described below) is challenging.

Estimating uncertainties

The general approach taken to estimate the uncertainty associated with the output from each end-use model is to separate each model into its most basic components, both inputs and assumptions, and try

to ascribe a reasonable uncertainty estimate to each component. The total uncertainty of the model output then comes from classic error propagation.

Model inputs introduce uncertainty based on likely response errors in the Household Survey. Model assumptions introduce uncertainty based on the accuracy of approximations made in the models, including how well an underlying regression is expected to work, how believable a stated effect size is, and how plausible the published estimates are.

Estimating the uncertainty for every end use present in every housing unit in the RECS sample is impractical. An implementable approach assumes that the uncertainty of an end use in any housing unit can be effectively represented by an average value of *relative uncertainty* across all housing units. Relative uncertainty is framed as plus or minus a percentage of the estimate value. For example, if an end use is estimated to have 20% relative uncertainty, then a modeled estimate of 1,000 kWh has resulting absolute uncertainty of ±200 kWh, whereas a modeled estimate of 200 kWh has resulting uncertainty of ±40 kWh. Both have ±20% uncertainty, but their absolute uncertainties are quite different (200 vs. 40). Technically, the uncertainty estimates for some models depend on certain RECS data, such as survey mode or if secondary space heating is present. Working with relative uncertainty makes the prospect of ascribing uncertainty to each engineering model output manageable.

As an example of assessing the uncertainty of a model's output, consider the RECS engineering model for water heating. Functionally, the model can be written as:

$$Output = \frac{Effective\ Load}{Efficiency} \propto \frac{Frac \cdot GPD \cdot DeltaT \cdot Loss\ Fac \cdot Ins\ Fac}{Efficiency}$$

where the model *Output* is the total energy required by particular equipment with a given *Efficiency* to meet an *Effective Load* for water heating demand, both of which are uncertain. The *Effective Load* is a product of known physical constants and five terms, each with potential uncertainty:

1) *Frac*: a fraction that specifies for housing units with more than one water heater how much of the load is satisfied by a particular set of equipment (i.e., main or secondary).
2) *GPD*: an estimate for the gallons of hot water per day based on the number of occupants of a housing unit.
3) *DeltaT*: an estimate of the number of degrees Fahrenheit between the temperature of water coming into the housing unit (assumed to be the local ground water temperature) and an assumed target temperature of 120 °F.
4) *Loss Fac*: a multiplicative adjustment factor accounting principally for energy losses due to standby time for tank units.
5) *Ins Fac*: a multiplicative adjustment factor accounting for conserved energy due to the presence of an insulating blanket around a tank heater.

The uncertainty in the assumed value for equipment *Efficiency* is based on reported specifications about the water heater in use.

When all six sources of potential uncertainty are assumed to be uncorrelated, then classic error propagation dictates that the square of the relative uncertainty of the *Output* is equal to the sum of squares of each term's own relative uncertainty:

$$\left(\frac{\Delta Output}{Output}\right)^2 = \left(\frac{\Delta Frac}{Frac}\right)^2 + \left(\frac{\Delta GPD}{GPD}\right)^2 + \left(\frac{\Delta DeltaT}{DeltaT}\right)^2 + \left(\frac{\Delta Loss\ Fac}{Loss\ Fac}\right)^2 + \left(\frac{\Delta Ins\ Fac}{Ins\ Fac}\right)^2 + \left(\frac{\Delta Effic.}{Effic.}\right)^2$$

Among the six components, the relative uncertainty of *GPD* is the largest, which comes from a regression relating gallons of hot water per day to the reported number of occupants in a housing unit. *Frac* contributes sizeable uncertainty for housing units with more than one water heater but contributes no uncertainty for housing units with only a single water heater. The uncertainty in the *DeltaT* term comes not from uncertainty in the ground water temperature near a housing unit but from the assumption that all housing units heat their hot water to 120°F exactly. The uncertainty in equipment *Efficiency* results from both potential respondent errors in the reported size of a water heater and the values in the lookup tables of efficiencies based on tank vs. tankless, tank size, and fuel used. The uncertainty in the *Loss Fac* term comes from the model's assumed effect size for standby/distribution losses, and similarly, the uncertainty in the *Ins Fac* term comes from the model's assumed effect size for using an insulating blanket around a water heater.

Estimating correlations

A calibration procedure should recognize when end uses are correlated so that the initial modeled values can be adjusted according to their expected correlations. However, the true correlations between various end uses in housing units are inaccessible and immeasurable by any data sets or measurements currently available. As a result, any correlations, and any assumptions that end uses are uncorrelated, are approximations. After experimentation and research, this general approach for estimating the correlations between various pairs of explicitly modeled end uses was implemented:

- Where available, use the direct correlations between Household Survey data that ask about the frequency of use or behaviors for a given end use, such as weekly usage of clothes washers and dryers, to approximate the correlations between the end uses' energy consumption.
    - EIA determined that the correlations in usage would account for most, if not all, of the true correlation between the covered end-use pairs. In the clothes washer/dryer example, their strong correlation in consumption is most likely due to their correlation in usage rather than something intrinsic about the installed units in the housing units.
- Use the outputs from the engineering models across suitably defined subsets of similar housing units to estimate the correlations between the three largest end uses: space heating, air conditioning, and water heating.
    - Addressing these end uses is necessary because of their large share of total consumption. After experimentation, EIA found that the best strategy for defining similar housing units is based on five different climate zones, derived from the IECC Climate Code designations. This strategy seemed to offer the best trade-off between meaningful division of cases and retaining reasonable sample sizes.
- Combine the first two approaches, when appropriate, to estimate the cross-correlations between end uses with usage variables in the Household Survey and space heating, air conditioning, and water heating.
- Otherwise, assume correlations between end-use pairs are zero.
    - The assumption of zero correlation between all other end uses was supported by the results of finding the correlations between all of the RECS usage variables. Although some of the correlations across these usage variables are notable and non-zero, most of

the correlations are very small. Clothes washer use and clothes dryer use are understandably highly correlated—higher than the 0.9 level—as are the usage of TV1 (the main TV in a housing unit) and TV2 (the second-most used TV in a housing unit)—at about the 0.5 level. However, many pairs, like TV1 usage and oven usage, correlate empirically at less than the 0.1 level, even with a very large sample size. These results provided further confidence in assuming zero correlation between the many end uses for which no usage information is collected.

Unknown consumption

For the 2015 RECS, each household had the opportunity to have an *Unknown* end-use estimate, although the *Unknown* component is modeled differently for electricity than for other fuels. EIA assumed that the Household Survey is likely incomplete in asking about all end uses of electricity, and so all housing units are assumed to have some amount of *Unknown* electricity consumption. Conversely, EIA assumed the Household Survey was complete in asking about all likely end uses of natural gas, propane, and fuel oil, and so all housing units are assumed to begin with zero *Unknown* consumption for these fuels.

For most housing units, the calibration procedure treats the *Unknown* end use as if it were like all other end uses, specified by its initial modeled value and its uncertainty estimate. The *Unknown* component is assumed to have high uncertainty and no correlations with any other end uses. For electricity, each housing unit is initially assigned a small *Unknown* value, which is calibrated up or down similar to the other end uses. For natural gas, propane, and fuel oil, the initial *Unknown* value is zero and, for most cases, remains at zero after calibration.

For some cases, an unexpectedly large differences occurred between the annualized billing data and the sum of initial modeled end-use estimates. Large differences result because household end uses not captured in the Household Survey that consume abnormally high amounts of energy (e.g., a tanning bed or a propane greenhouse heater) or unreported non-household end uses (e.g., a farm). Large mismatches between the household characteristics and billing data could also result from respondent error that was not detected in the data editing process.

When the calibration procedure detects an unexpectedly large difference between the annualized billing data and the sum of initial modeled end uses—specifically, in cases where the billing data are higher—the *Unknown* end use gets special treatment. In such cases, the calibration procedure greatly increases the uncertainty of the *Unknown* end use; consequently, the calibrated values for the *Unknown* end use can sometimes account for most of the unexpectedly large misfit. This procedure, which can be applied to any fuel in any case, prevents the other end-use estimates from being unduly affected by whatever might be causing the unexpected large difference.

Appendix A: Examples of Annualization and Imputation

This appendix provides examples illustrating different scenarios for the consumption annualization and imputation processes of an individual housing unit. As previously mentioned, the procedures for electricity and natural gas were similar; and the procedures for propane and fuel oil were similar.

Table A1: Reported ESS Sample Case for Natural Gas – Complete

Billing End Date	Billing Days	Consumption (CCF)	Notes
12/09/2014	-	126	Not included as part of 2015 consumption
01/07/2015	29	193	Included 7 days of prorated consumption for January 2015
02/05/2015	29	241	Included as part of 2015 consumption
03/06/2015	29	297	Included as part of 2015 consumption
04/07/2015	32	174	Included as part of 2015 consumption
05/06/2015	29	76	Included as part of 2015 consumption
06/05/2015	30	32	Included as part of 2015 consumption
07/07/2015	32	27	Included as part of 2015 consumption
08/05/2015	29	19	Included as part of 2015 consumption
09/04/2015	30	19	Included as part of 2015 consumption
10/05/2015	31	20	Included as part of 2015 consumption
11/03/2015	29	24	Included as part of 2015 consumption
12/04/2015	31	88	Included as part of 2015 consumption
01/06/2016	33	138	Included 27 days of prorated consumption for December 2015

Annualization steps of a complete case for electricity and natural gas

- Step 1: Adjust the consumption amount for the 2015 end months
  - Adjusting January 2015: only 7 days in the 1/7/2015 bill were assigned to 2015. The new consumption was (193/29)*7 = 47
  - Adjusting December 2015: need 27 more days in the 12/04/2015 bill, which can be computed from the 01/04/2016 bill. The new consumption was 88 + (138/33)*27 =201.
- Step 2: Adding the amounts from January 2015 to December 2015, so the new total consumption for this case was 1,177.

However, for natural gas, an extra step is required for unit-conversion. If the consumption of a case was reported in volume (e.g., ccf, hundred cubic feet), then EIA used the equation: *therms = unit in volume * local heat content factor * pressure factor* to convert volume to energy. The values for the heat content factor were the state-level heat-content factors reported on the eia.gov website. In the previous RECS, the conversion was done by multiplying the volume by a constant national heat content factor.

In addition, if a case had a vacancy flag, the calculation procedure for the total consumption was the same as above except the consumption of the unreported billing periods was counted as zero.

Table A2: Reported ESS Sample Case for Propane or Fuel Oil – Complete

Billing End Date	Billing Days	Consumption (kBtu)	Notes
04/24/2014	-	63	Not included as part of 2015 consumption
01/08/2015	259	166	Not included as part of 2015 consumption
02/14/2015	37	134	Included as part of 2015
04/09/2015	54	129	Included as part of 2015
12/15/2015	250	89	Included as part of 2015
02/12/2016	59	136	Included as part of 2015
04/22/2016	70	94	Not included as part of 2015 consumption

Annualization steps of a complete case for propane and fuel oil

- Step 1: Add the deliveries that include as much of 2015 as possible, getting as close as possible to 365 days
    - The February 2015 through February 2016 deliveries provide 400 days of data and include almost all of 2015. The January 2015 delivery mostly represents 2014 consumption, so it is excluded.
    - These deliveries sum to 488.
- Step 2: Adjust the preliminary sum to better match calendar year 2015
    - The engineering estimate for heating in calendar year 2015 is 74,631 thousand Btu (kBtu). Because this household only uses LPG for heating, that value is also the total estimate of consumption.
    - The engineering estimate of heating for the 400-day span covered by the chosen deliveries is 88,534 kBtu.
    - The final annualized estimate is (74,631/88,534) * 488 = 411.

Unlike the annualization procedure for electricity and natural gas, the big gap between April 2015 and December 2015 was not treated as a missing period.

Table A3: ESS Sample Case– No data reported

End Use	Engineering Model Estimates	Coefficients of Imputation Model	(Engineering Model Estimates) × (Coefficients)
Hot water	1,890	0.607	1,148
Refrigeration	664	0.298	198
Lighting	34	0.676	23
Others	839	1.791	1,503

Annualization steps of a no-data case for all fuels

- Step 1: Compute the end-use coefficients from the imputation model

Step 2: Compute each end-use estimate by multiplying the corresponding engineering model estimates by the coefficients, and add all the end-use estimates to obtain the total consumption. The annualized total was 1,148+198+23+1,503=2,872

Appendix B: Detailed Model Descriptions for Published End Uses

Below is a description of the engineering models for each end-use estimate of energy consumption published on www.eia.gov in data tables or the public-use microdata file. Users should consult the microdata file Variable and Response Codebook, which contains an indicator for each Household Survey variable used in these models. Note that some published end-use estimates, for example TVs and Related, are actually the sum of separately modeled end uses.

Initial specifications for the engineering models used in the 2015 RECS were in 2014 and 2015. The below set of references represents the information used to construct the models as implemented. Additional references were consulted to assess and establish the validity of the cited sources shown here. Web links are provided where available, although some of the references used at that time may have since become unavailable.

- **Space heating**: Total energy consumption for a housing unit's space heating is modeled as the energy required by the reported space heating equipment to meet a modeled *space heating load*. The space heating load is modeled as a housing unit's total heat loss from three separately modeled mechanisms: conduction through its building envelope, conduction through its foundation, and infiltration exchange with outside air.

  Conduction follows a *U-A* approach, multiplying insulation properties (U-factors) by the areas (A) over which conduction occurs. Infiltration follows a *normalized leakage* approach. Heating degree days (HDDs) are used to approximate the temperature gradients driving conduction and infiltration, and housing units use base temperatures for their HDDs according to the state where they are located. These base temperatures were estimated in an off-line calculation (most are less than 65°F). Main and secondary space heating equipment are modeled separately, but they work together to meet a housing unit's total space heating load.

- **Air handlers–heating**: Total consumption for air handlers in heating equipment is the sum of the energy used by two components: furnace fans in forced-air furnaces and heat pumps and circulation pumps in boilers with radiators. Both of these circulate heat throughout a housing unit, and both always consume electricity. The model for each component is based on the computed total space heating load from the space heating model and a housing unit's total heated square footage and parameters, which depend on the housing type and climate zone. This end-use estimate is a separate component from space heating because it consumes electricity even for non-electric space heating (e.g., a natural gas furnace).

- **Air conditioning**: Total consumption for air conditioning (AC) is modeled as the energy used by the reported AC equipment to meet a modeled *space cooling load*. The cooling load is based on heat gain from three separately modeled mechanisms: conduction through the building envelope, infiltration exchange of sensible heat (i.e., temperature), and infiltration exchange of latent heat (i.e., moisture). Cooling degree days (CDDs) are used to estimate the temperature gradients driving conduction and sensible heat exchange, and a degree day-like quantity based on dew point temperature is used to approximate the gradients driving latent heat exchange. All CDDs are calculated with respect to 65°F.

- **Air handlers–cooling**: This element is the energy consumption used by the air handler/ventilation component of central AC units and heat pumps run as central AC units in the cooling season. The model is based on the computed cooling load from the space cooling model and a housing unit's total cooled square footage and parameters, which depend on the housing type and climate zone. Similar to air handlers for space heating, this end-use estimate is a separate component from air conditioning end use.

  References for Space heating, Air conditioning, and Air handlers

  - **Air Infiltration**

    ASHRAE. 2012. *Addendum n to ANSI/ASHRAE Standard 62.2-2010: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers. https://www.ashrae.org/File%20Library/Technical%20Resources/Standards%20and%20Guidelines/Standards%20Addenda/62_1_2010_o_Final_09132013.pdf

    ASHRAE. 2013. *2013 ASRHAE Handbook: Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

    Chan, W., J. Joh, and M. Sherman. 2012. *Analysis of Air Leakage Measurements from Residential Diagnostics Database.* LBNL-5967E. https://buildings.lbl.gov/sites/default/files/lbnl-5967e.pdf

  - **U-Factors**

    Huang, J, J. Hanford, and F. Yang. 1999. *Residential Heating and Cooling Loads Component Analysis*. Lawrence Berkeley National Laboratory. LBNL-44636. https://simulationresearch.lbl.gov/dirpubs/44636.pdf

    IECC. 1998, 2006, 2009, and 2012. International Energy Conservation Code. https://energycode.pnl.gov/EnergyCodeReqs/

  - **Equipment Efficiencies**

    AHAM. 2010. *Room Air Conditioners Energy Efficiency and Consumption Trends*. Association of Home Appliance Manufacturers. http://aham.org/

    De Kleine, R. 2009. *Life Cycle Optimization of Residential Air Conditioner Replacement*. Center for Sustainable Systems, University of Michigan. Report No. CSS09-12. http://css.umich.edu/sites/default/files/css_doc/CSS09-12.pdf

    DOE, EERE. 2007. *Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers*. 72 FR 65135. E7-22216. https://www.gpo.gov/fdsys/pkg/FR-2007-11-19/pdf/E7-22216.pdf

    DOE, EERE. 2011. *Energy Conservation Program: Energy Conservation Standards for Residential Furnaces and Residential Central Air Conditioners and Heat Pumps*. 10 CFR 430. 2011-14557. https://www.gpo.gov/fdsys/pkg/FR-2011-06-27/pdf/2011-14557.pdf

    Fairey, P., D. Parker, B. Wilcox, and M. Lombardi. 2004. *Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps*. Florida Solar Energy Center. FSEC-PF-413-04. http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-413-04/

    Wenzel, T., J. Koomey, G. Rosenquist, M. Sanchez, and J. Hanford. 1997. *Energy Data Sourcebook for the U.S. Residential Sector*. LBNL-40297. http://enduse.lbl.gov/Info/LBNL-40297.pdf

  - **Furnace Fans**

DOE, EERE. 2014. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnace Fans*. https://www.regulations.gov/contentStreamer?documentId=EERE-2010-BT-STD-0011-0111&contentType=pdf

- **Circulation Pumps**

  Lutz, J., C. Dunham-Whitehead, A. Lekov, and J. McMahon. 2004. *Modeling Energy Consumption of Residential Furnaces and Boilers in U.S. Homes*. LBNL-53924. http://eaei.lbl.gov/sites/all/files/modeling_energy_consumption_of_residential_furnaces_and_boilers_in_us_homes_lbnl-53924.pdf

- **Thermostat Setpoints**

  DOE, Energy Saver. https://www.energy.gov/energysaver/thermostats. Accessed in 2014.

- **Evaporative coolers**: Total consumption for evaporative coolers is modeled as a given wattage for the unit multiplied by the estimated number of days for which cooling is necessary. If a given day has non-zero CDDs, which means the temperature exceeds 65°F, then the unit is assumed to run all day. The number of days a year for which cooling is necessary is modeled based on the CDD total for each housing unit.

  References for Evaporative coolers

  Representative wattage value drawn from the mode of various sources citing unit wattage, including, for example, this list of representative home costs composed by Duke Energy: http://www.amhomeservices.net/upload/Appliance_OpCost_List_Duke_v8.06.pdf

- **Ceiling fans**: Total consumption for each fan is modeled as an average Unit Energy Consumption (UEC) value, adjusted based on how reported usage compares with the survey weighted-average usage. Housing units with multiple ceiling fans are assumed to use each additional fan only 80% as much as the previously modeled fan.

  Reference for Ceiling fans

  Kanter C., S. Young, S. Donovan, and K. Garbesi. 2013. *Ceiling Fan and Ceiling Fan Light Kit use in the U. S.---Results of a Survey on Amazon Mechanical Turk*. LBNL. https://pubarchive.lbl.gov/islandora/object/ir%3A158958/datastream/PDF/view

- **Dehumidifiers**: Total consumption is the sum of the consumption from portable units and whole-home units, which are modeled separately. Each is modeled as a representative UEC, adjusted based on how reported usage compares with an assumed value of base usage, in months.

  References for Dehumidifiers

  DOE, EERE. 2013. *Pre Analysis Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dehumidifiers*. https://www.regulations.gov/document?D=EERE-2012-BT-STD-0027-0015

  Willem, H., T. Burke, C. Whitehead, B. Beraki, J. Lutz, M. Melody, M. Nagaraju, C. Ni, S. Pratt, S. Price, and V. Tavares. 2013. *Using Field-Metered Data to Quantify Annual Energy Use*

of Residential Portable Unit Dehumidifiers. LBNL. https://pubarchive.lbl.gov/islandora/object/ir%3A159064/datastream/PDF/download/citation.pdf

Willem, H., C. Whitehead, C. Ni, V. Tavares, T. Burke, M. Melody, and S. Price. 2013. *Field-Monitoring of Whole-Home Dehumidifiers: Initial Results of a Pilot Study*. LBNL. https://pubarchive.lbl.gov/islandora/object/ir%3A159067/datastream/PDF/download/citation.pdf

- **Humidifiers**: Total consumption is the sum of the consumption from portable units and whole-home units, which are modeled separately. Each is modeled as a representative UEC, adjusted based on how reported usage compares with an assumed value of base usage, in months. Housing units with portable units are further assumed to have one unit in the housing unit for every two bedrooms.

  Reference for Humidifiers

  ENERGY STAR. 2012. *Market & Industry Scoping Report Residential Humidifiers*. https://www.energystar.gov/sites/default/files/asset/document/ENERGY_STAR_Scoping_Report_Residential_Humidifiers.pdf

- **Water heating**: Total consumption for water heating is modeled as the energy required by the reported water heating equipment to meet a modeled *water heating load*. The water heating load is based primarily on the number of household members in the housing unit and the ground water temperature. Further corrections are based on whether the household uses an insulating blanket around its water heater and whether a heater is tankless or not. For housing units with more than one water heater, the water heating load is split by an assumed fraction to determine the load that must be met by the reported main and secondary water heating equipment. For more detail, see the example discussed in the **Estimating Uncertainty** section above.

  References for Water Heating

  Hendron R. and J. Burch. 2007. *Development of Standardized Domestic Hot Water Event Schedules for Residential Buildings*. NREL/CP-550-40874. https://www.nrel.gov/docs/fy08osti/40874.pdf

  Lutz, J., Renaldi, A. Lekov, Y. Qin, and M. Melody. 2011. *Hot Water Draw Patterns in Single-Family Houses: Findings from Field Studies*. LBNL-4830E. https://eta.lbl.gov/sites/all/files/publications/hot_water_draw_patterns_in_single-family_houses_findings_from_field_studies_lbnl-4830e.pdf

- **Clothes washers**: Consumption is modeled as an assumed energy use-per-wash load, which is based on whether the unit is top or front loading and adjusted based on the unit's reported ENERGY STAR status. The energy use-per-load is multiplied by the reported average number of loads per week and multiplied by 52 weeks per year. Estimates are only for washer operation and do not include any energy needed to heat water.

  References for Clothes Washers

  AHAM. 2010. *Clothes Washers Energy Efficiency and Consumption Trends*. Association of Home Appliance Manufacturers. http://aham.org/

DOE, EERE. 2012. *Direct Final Rule Technical Support Document*. https://www.regulations.gov/document?D=EERE-2008-BT-STD-0019-0047

DOE, EERE. 2012. *Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers*. https://www1.eere.energy.gov/buildings/appliance_standards/pdfs/rcw_direct_final_rule_5_14_2012.pdf

- **Clothes dryers**: Consumption is modeled as active-use energy consumption, which is derived from responses to a usage question. Active-use consumption is the product of the annual number of loads, an assumed value of one hour per dryer load, and the energy use per dryer load, which varies based on the dryer fuel. The model also calculates standby energy use (always electric) based on the inactive hours of use through the year and an assumed standby use power draw. For the electric clothes dryers end use, the standby-use consumption is combined with the active-use consumption, but for natural gas and propane dryers, the standby use is included in the *Not Elsewhere Classified* total.

  References for Clothes Dryers

  DOE, EERE. 2011. Clothes Dryer Direct Final Rule Technical Support Document. https://www.regulations.gov/document?D=EERE-2007-BT-STD-0010-0053

  KEMA. 2010. 2009 California Residential *Appliance Saturation Study*. Prepared for the California Energy Commission. http://www.energy.ca.gov/appliances/rass/

  Northwest Energy Efficiency Alliance and Northwest Power and Conservation Council. 2010. Comment submitted in Federal Register. EERE-2011-BT-TP-0054. https://www.regulations.gov/contentStreamer?documentId=EERE-2011-BT-TP-0054-0021&attachmentNumber=1&contentType=pdf

- **Lighting**: Indoor and outdoor lighting are modeled separately, and within each category—incandescent, CFL, and LED—lighting is modeled separately, and total consumption is the sum of these six possible components. For indoor lighting, the model first estimates the total number of bulbs/lamps in a housing unit, regardless of bulb/lamp type, and then models how this total count is distributed over four usage categories: 0–1 hr/day, 1–4 hr/day, 4–12 hr/day, and 12–24 hr/day. The model then estimates the fractional share of bulbs/lamps that are incandescent, CFL, and LED, based on survey responses. Finally, using assumed values for representative bulb wattages, the model multiplies these values by the daily usage of each bulb/lamp type in the housing unit and sums the consumption over a year. The outdoor lighting model is similar, but the usage is only divided into two categories: lights left on all night and lights that are not left on all night. Note that housing units with reported natural gas outdoor lighting are simply modeled by an assumed UEC value, and included in the *Not elsewhere classified* end use for natural gas.

  Reference for Lighting

  DOE, EERE. 2012. *2010 U.S. Lighting Market Characterization*. Prepared by Navigant Consulting, Inc. https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

- **Refrigerators**: Refrigerators 1, 2, and 3 are modeled separately, while any additional refrigerators beyond the third are modeled as a group. Total consumption for a given refrigerator is modeled as an adjusted UEC value. A base UEC value is assigned based on the reported configuration, size, and age of a unit. Adjustments are then applied according to the

unit's reported defrost mechanism (manual vs. automatic), the presence of a through-the-door ice maker, and its ENERGY STAR status. Refrigerators 2 and 3 also include adjustments for the reported number of months of usage and whether they are used in unheated and uncooled spaces.

- **Freezers**: Freezers 1 and 2 are modeled separately, while any additional freezers beyond the second are modeled as a group. Total consumption for a given freezer is modeled as an adjusted UEC value. A base UEC value is assigned based on the reported configuration, size, and age, and an adjustment is then made based on the freezer's defrost mechanism.

  References for Refrigerators and Freezers

  DOE, EERE. 2014. "Compliance Certification Management System (CCMS) Database." https://www.regulations.doe.gov/certification-data/CCMS-4-Refrigerators__Refrigerator-Freezers__and_Freezers.html

  CEC (California Energy Commission). 2014. *2014 Appliance Efficiency Regulations*. California Energy Commission's Consumer Energy Center. http://www.energy.ca.gov/2014publications/CEC-400-2014-009/CEC-400-2014-009-CMF.pdf

- **Cooking**: Combined cooktop/oven units (stoves), separate ovens, and separate cooktops are all modeled separately. Total consumption for a given component is modeled as an adjusted UEC value. A base UEC value is specified based on housing unit type and then adjusted based on how reported usage compares with the survey weighted-average usage. Housing units with more than one of a given component (e.g., two separate ovens) are assumed to use their additional units half as much as their primary units.

  Reference for Cooking

  KEMA. 2010. 2009 California Residential *Appliance Saturation Study*. Prepared for the California Energy Commission. http://www.energy.ca.gov/appliances/rass/

- **Microwaves**: Total consumption is modeled as an adjusted UEC value, where a base UEC value is assigned based on housing type and then adjusted based on how reported usage compares to the survey weighted-average usage.

  References for Microwaves

  KEMA. 2010. 2009 California Residential *Appliance Saturation Study*. Prepared for the California Energy Commission. http://www.energy.ca.gov/appliances/rass/

  Kwatra, S., J. Amann, and H. Sachs. 2013. *Miscellaneous Energy Loads in Buildings*. Report Number A133. American Council for Energy-Efficient Economy. http://aceee.org/sites/default/files/publications/researchreports/a133.pdf

- **Dishwashers**: Total consumption is the sum of active-use energy consumption and standby use energy consumption, although only relatively new units are assumed to have standby energy use. Active-use consumption is calculated for a year based on multiplying an assumed power draw and length of cycle by the reported average number of uses per week. If applicable, the standby use is calculated for a year based on multiplying the inactive hours per year by an

assumed standby energy draw. Estimates are only for dishwasher operation, and do not include the energy needed to heat water.

References for Dishwashers

DOE, EERE. 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers*. https://www.regulations.gov/document?D=EERE-2011-BT-STD-0060-0007

DOE, EERE. *Appendix C1 to Subpart B of Part 430—Uniform Test Method for Measuring the Energy Consumption of Dishwashers*. Electronic Code of Federal Regulations. Accessed 2014. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=4a5672892c5841035496abcd0db182d8&ty=HTML&h=L&mc=true&n=pt10.3.430&r=PART#ap10.3.430_127.c1

- **TVs and related**: This category is the sum of all TVs, video game consoles, set-top boxes, DVD players, VCRs, and Internet streaming devices.

- **TVs**: TVs 1, 2, and 3 are modeled separately, and any additional TVs beyond the third are modeled as a group. Total consumption for a given TV is the sum of active-use consumption and standby use consumption. An assumed value for active-mode power draw is based on the reported type and size of the TV. Standby power draw is assumed to be a constant wattage for all TV models. The active consumption is calculated by multiplying the active power draw by the total active hours in a year, which is based on separately reported usage for weekends and weekdays. The standby-use consumption multiplies the standby power draw by the total number of inactive hours in a year, the complement of the active hours in a year.

- **Video game consoles**: Consumption is modeled based on an assumed UEC and adjusted by reported usage compared with the survey weighted-average usage.

- **Set-top boxes**: Cable/satellite boxes, separate DVRs, and combination DVRs are modeled separately. Each type of set top box has its own representative UEC value, and households can have multiple reported units of each type.

- **DVD players and VCRs**: Each of these has its own representative UEC value, and housing units can have multiple reported units of each type. “DVD players” also includes Blu-ray players.

- **Internet streaming devices**: Total consumption is modeled based on an assumed UEC, and households can have multiple reported units. Examples include Apple TV, Google Chromecast, Slingbox, or Roku.

Reference for TVs and related

Urban, B., V. Shmakova, B. Lim, and K. Roth. 2015 (rev). *Energy Consumption of Consumer Electronics in U.S. Homes in 2013*. Fraunhofer USA. https://www.cta.tech/cta/media/News/Energy-Consumption-of-CE-in-U-S-Homes-in-2013-%28Fraunhofer,-commissioned-by-CEA,-Revised-March-2015%29.pdf

- **Pool pumps**: Total consumption is modeled as an annual UEC (representative of 12 months of usage), prorated over the reported number of months of usage.

- **Pool heaters (natural gas)**: Total consumption is modeled as an annual UEC (representative of 12 months of usage), prorated over the reported number of months of usage**.**

- **Hot tub pumps**: Total consumption is modeled as an annual UEC (representative of 12 months of usage), prorated over the reported number of months of usage.

- **Hot tub heaters (electric and natural gas):** Total consumption is modeled as an annual UEC (representative of 12 months of usage), prorated over the reported number of months of usage

  References for Pools and Hot tubs

  KEMA. 2010. 2009 California Residential *Appliance Saturation Study*. Prepared for the California Energy Commission. http://www.energy.ca.gov/appliances/rass/

  Kwatra, S., J. Amann, and H. Sachs. 2013. *Miscellaneous Energy Loads in Buildings*. Report Number A133. American Council for Energy-Efficient Economy. http://aceee.org/sites/default/files/publications/researchreports/a133.pdf

- **Not elsewhere classified**: Each fuel has an end-use category called *Not Elsewhere Classified*, which represents the energy consumption from end uses within a housing unit that are not explicitly classified in the other published end uses. Below is a list of the end uses covered in the *Not Elsewhere Classified* category for each fuel.

  ### *Electricity*

  - Desktop computers, laptop computers, monitors, network equipment, and peripherals such as printers, fax machines, and copiers
  - Tablets and smartphones
  - Floor fans, attic fans, and whole-house fans
  - Coffee makers, toasters, toaster ovens, slow cookers, food processors, rice cookers, blenders, waffle makers, bread makers, and declared *other* small kitchen appliances
  - The standby electric consumption from natural gas and propane dryers, but only for dryers with some reported usage
  - Pool heaters, electric vehicles, well pumps, large aquariums, and auto engine block heaters
  - Vacuum cleaners, electric razors, drills, security systems, and medical devices
  - Unknown

  ### *Natural Gas*

  - Lighting
  - Outdoor grills
  - Unknown

  ### *Propane*

  - Pool heaters
  - Hot tub heaters
  - Unknown

Fuel Oil

- Pool heaters
- Unknown

References for Not elsewhere classified

American Gas Lamp Works. Accessed in 2014. https://americangaslamp.com/product-support/btus-gas-facts/.

DOE, EERE. 2011. Clothes Dryer Direct Final Rule Technical Support Document. https://www.regulations.gov/document?D=EERE-2007-BT-STD-0010-0053

DOE, EERE. 2017. https://www.energy.gov/eere/vehicles/articles/fact-994-september-11-2017-electric-vehicle-charging-consumes-less-energy

Duke Energy. 2013. http://www.amhomeservices.net/upload/Appliance_OpCost_List_Duke_v8.06.pdf

KEMA. 2010. 2009 California Residential *Appliance Saturation Study*. Prepared for the California Energy Commission. http://www.energy.ca.gov/appliances/rass/

Kwatra, S., J. Amann, and H. Sachs. 2013. *Miscellaneous Energy Loads in Buildings*. Report Number A133. American Council for Energy-Efficient Economy. http://aceee.org/sites/default/files/publications/researchreports/a133.pdf

Urban, B., V. Shmakova, B. Lim, and K. Roth. 2015 (rev). Energy Consumption of Consumer Electronics in U.S. Homes in 2013. Fraunhofer USA. https://www.cta.tech/cta/media/News/Energy-Consumption-of-CE-in-U-S-Homes-in-2013-%28Fraunhofer,-commissioned-by-CEA,-Revised-March-2015%29.pdf

West, Tristam. 2003. Oak Ridge National Laboratory. https://www.ornl.gov/news/fourth-july-no-picnic-nations-environment