HUD Utility Model (HUSM)

Rebenchmarking

Riley & Associates
20130627.Report7r

.HUSMRebenchmarking.Report.doc.

Contents

HUD Utility Schedule Model Rebenchmarking Summary

This report summarizes additional research related to updating the HUD Utility Schedule Model (HUSM), which is used to calculate utility allowances for the Section 8 housing voucher program. The objectives of this study were stated in the Task Order for this work as follows:

- Review the December 2012 HUSM report and update the equation coefficient and adjustment values in the model to produce a revised spreadsheet that would look the same as the existing spreadsheet but with updated parameters, including trending and Energy Star consumption estimates. Use an energy star adjustment factor of 82 percent, which incorporates a combined age and Energy Star adjustment. No Energy Star adjustment for mobile homes is to be provided.
- Simplify the model by:
    - Using fewer structure types (i.e., single-family detached, single-family attached, 2-4 unit apartments, 5+ unit structures, mobile homes).
    - Eliminating age adjustments.
    - Provide a version of the model with parts hidden that users do not need to see.
- Provide estimates of revised model parameters using combined 2005 and 2009 RECS data. Also determine if it appears desirable to base some parameters using only the relatively large 2009 RECS sample. The same methodologies and regression forms used in the December 2012 HUSM report should be used to update model parameter values unless anomalies result.

The revised HUSM Excel model is provided as a separate attachment. Information on how to view the hidden parts of this model is provided separately.

There are three terms used throughout the remainder of this report that merit explanation. Two related to heating and cooling. A **heating degree day** (HDD) is a measurement designed to reflect the demand for energy needed to heat a building related to measurements of outside air temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDDs at that location. A similar measurement, a **cooling degree day** (CDD), reflects the amount of energy used to cool a home or business. Both measures are defined relative to a base temperature—the outside temperature above which a building needs no heating. The standard commonly used by the Department of Energy is 65 degrees Fahrenheit, which is also used in this report. The underlying concept is that temperatures with any significant deviation from an outdoor temperature at this level are likely to result in use of energy for heating or cooling.

The other term most commonly used is **RECS**, which refers to the Department of Energy (DOE) Residential Consumption Survey. This survey has been conducted every four years since 1978. It is the only source of comprehensive survey information on residential energy consumption that includes detailed information on housing characteristics, resident use patterns, and actual energy consumption amounts. Although there are many commonly held beliefs about comparative energy consumption, the RECS data indicate that this is a far more complex matter than most people suspect.

The analysis conducted relied heavily on previous research, especially that of the utility engineering firm of GARD Analytics. Many of the issues found with the first HUSM estimates have been studied and largely resolved by past studies. Some issues remain and more will be raised by future RECS surveys. This study, however, shows that the results of the previous work using 1997-2005 RECS surveys is largely consistent with newer data from the 2009 RECS.

There are three interrelated issues associated with the RECS sample sizes used to derive HUSM estimates:

- The data have to be split into 30 heating-fuel/bedroom size/structure-type categories for HUSM analysis purposes, which results in unusable sample sizes for some categories.
- There are significant differences in the building envelope and heating and cooling efficiencies of different structures.
- Households living in identical units with differing use patterns can have very different energy consumption levels.
- The RECS samples were not designed to help develop HUSM formulas[1], which are constrained to use only variables collected by PHA staff (i.e., number of bedrooms, structure type, and fuel mix).

The regression run for this study used individual case data, and the regression accuracy estimates provided (i.e., the R-squared and related measures) measure how well predictive models developed accurately depict the full range of individual case values. Fortunately, the objective of the HUSM model is to provide estimates of average utility values for different structure types in different locations. This is a far easier objective to attain.

Most of the revised total energy consumption predictions for occupants paying for all utilities are not substantially different from those of the existing HUSM model <u>for unit types which comprise most of the housing inventory</u>. The current HUSM model values appear, on average, to be modestly overstated for some of these categories compared to the revised estimates. This is to be expected given that they are based on somewhat older data. These differences widen when decreasing utility consumption trends are added, again as would be expected. However, compared to the widely varying consumption estimates known to be in use by PHAs with the same heating and cooling loads plus the range of different estimates produced by other methodologies tested in the past, the estimates developed in this study are relatively similar to those of the model currently in use.

Total United States residential energy consumption remained relatively stable from 1978 to 2009 (the latest RECS survey). This is because improved residential energy efficiency has more than offset the increase in the number and average size of housing units. A substantial part of the decrease in average household consumption is related to improvements in equipment efficiency for space heating, air conditioning, and major appliances. In addition, newer homes tend to feature

[1] For instance, a HUSM-oriented sample would probably be longitudinal despite its statistical inefficiency.

better insulation and other energy-saving features, such as thermopane windows. At least in the short term, it is virtually certain that decreases in average per unit energy consumption will continue even without further equipment or building envelope efficiency gains. This is because many equipment efficiency gains have yet to ripple through the existing inventory and some improvements to structural envelopes will continue to be made whether or not equipment efficiency improves.

Part 1. Background

The objective of the HUSM model is to provide a simple and reasonably accurate means for PHAs to establish utility allowance schedules for use in determining rent subsidies for tenants participating in HUD's Section 8 Housing Choice Voucher program (subsequently referred to as the "voucher program"). This program has limits on the rents allowed for assisted units. The sum of the contract rent (i.e., the amount the tenant pays the landlord) plus the estimated tenant-paid utility costs may not normally exceed local program rent limits in calculating tenant assistance subsidies. Tenants may have all or none of their utilities included in contract rents, but most pay for electricity, heating, and cooling. Calculating these utility schedules is the responsibility of local Public Housing Authorities (PHAs). Providing even roughly reasonable estimates is a far more difficult task than most people realize.

Utility costs vary significantly even for housing units of similar size, age, and construction characteristics within the same locality. The only detailed national data on this subject comes from the Department of Energy's Residential Energy Consumption (RECS) surveys, and no equivalent local data source has been identified by any of the researchers working on this effort to date. The RECS data, however, are only useful in deriving consumption estimates for the most common types and sizes of structures and heating fuels. A combination of engineering-based estimates and interpolations is needed for less common structure and heating types. A further complication, even with the RECS data, is that some utility consumption uses need to be imputed because the same energy source is used for multiple purposes.

The objective of the HUSM model is to produce a means of estimating "typical" utility costs for a given construction type with a specified set of utility uses and rates in a designated area. There are strong correlations between a housing unit's average utility consumption and its structure type, number of bedrooms, and heating fuel. There are less clear relationships between energy consumption and structure age, and there are often large consumption variations among structures that appear similar. Possible reasons for such variations include the following:

- Differences in user consumption patterns (e.g., heating and cooling temperature settings).
- Differences in a structure's heating and cooling equipment energy efficiency.
- Differences in building envelope energy efficiency (e.g., due to differences in ceiling and/or wall insulation).
- Differences in construction practices (e.g., due to differences in state and local building codes, code enforcement, and builder practices).
- Extent of energy efficiency improvements to existing structures – new heating and cooling equipment, added ceiling insulation, added exterior wall insulation, and/or new windows or storms can significantly change energy consumption levels in existing homes.

The energy consumption for a given structure type of a given age and size in a given climatic zone normally tends to have a strong central tendency. Variations in individual unit consumption from this central tendency, however, are often as large as 50 percent in both directions.

Energy Conversion Factors

The basic unit of energy consumption used throughout this report is the **BTU**, which is an abbreviation for British Thermal Unit. The BTU is defined as the amount of energy required to increase the temperature of 1 pound of water by 1 degree Fahrenheit at normal atmospheric pressure. Energy consumption is expressed in BTU's or a multiple of BTU's to allow for consumption comparisons among fuels that are measured in different units.

Table 1. 2012 Energy Information Agency Energy Equivalency Factors

Fuel Type	Fuel Unit	Fuel Heat Content Per Unit (Btu)	Approx. Efficiency (%)
Fuel Oil (#2)	Gallon	138,690	78%
Electricity	KiloWatt-hour	3,412	98%
Natural Gas	Therm (kBTU)	100,000	78%
NOTE: RECS gives BTUs in 1,000s (electric values/3.412 = kWh)			
Propane	Gallon	91,333	78%
			65%
Wood*	Cord	22,000,000	55%
Pellets	Ton	16,500,000	68%
Corn (kernels)	Ton	16,500,000	68%
Kerosene	Gallon	135,000	80%
Coal (Anthracite)	Ton	25,000,000	75%
* The heat content value for a cord of wood varies by tree species and is greatly affected by moisture content; the value provided is an approximation.			

Consistent with the RECS practice and that of previous HUSM researchers, unless otherwise noted all energy consumption is expressed in thousands of BTUs, which are referred to as **kBTUs**. The conversion relationships used in this report are the current BTU-equivalent values published by the Department of Energy are found in Table 1.

Weighted versus Unweighted Regressions

The estimates provided in this and previous reports are based on un-weighted regressions. There are advantages and disadvantages to this approach. However, both the analysis done by the Energy Information Agency (EIA) on RECS data and that for the American Housing and American Community Survey by the Department of Housing and Urban Development have almost always used un-weighted regressions. RECS weighted and un-weighted values are similar for most variables of interest because of the sampling methodology used. The sample sizes large enough to be useful for the analysis in this report showed relatively small differences. Partly for comparability and partly because it appeared to make little difference given RECS sample designs, un-weighted regressions were consistently used.

Bibliography

The analysis done for this report made extensive use of related prior research. This research is referenced throughout the report and was of enormous assistance to this research. The research done by GARD Analytics is especially noteworthy. To reduce confusion, the various reports are referenced by using the name in the first column of the following table:

Table 2. Abbreviations Used for Reports Referenced

Reference Used In This Document	RECS Year(s)	Date	File name & Comments	Author
PIH1975	na	1970s	www.**hud**.gov/offices/adm/**hud**clips/**form**s/files/**52667**.pdf PIH's original 3-page instructions for 52667.	HUD
Report1	1997	6/5/2003	Report1.20030605.FinalReportHUD52667.doc: GARD's first full report.	GARD
Report2	2001	5/18/2005	Report2.20060518.2RW_DI.HUD_Report_050930.pdf: "Utility Model Evaluation" report to HUD; and 20060518.new_2001_HUD_Spreadsheet_050920.xls.	2RW
---	2001	Released around 2005	UtilityModel_Web.Omaha.xls: Model on PD&R's web site used in Riley 2009 analysis of 29 cities. Includes some of 2RW's revisions using RECS2001.	Riley Fox
Report3	2001	3/3/2009	Report3.20090303.ReportUtil.doc: Report comparing PIH and GARD/2RW spreadsheet models with Census & AHS data for 29 cities.	Riley Fox
Report4	2001	2/12/2007	GARD, *Final Report on HUD52667 Spreadsheet Update*. File Report4.20070210. FinalReport-HUD52667Update-02.doc. Updates heat pump; HDD vs. consumption equations; comparisons with actual PHA allowances.	GARD
Report5	2005	1/20/2011	Report5.20110120.HUSM_GARDRevisions.20110527.UpdateToHUD522667Model-08-WithCover.docx. January 2011 revisions by GARD, with comments.	GARD
---	2005	2009?	File HUD52667Model-Ver12d.xls. Current utility model; not implemented.	GARD
Report6	1997 2001 2005	12/22/2012	20121222.Report6.HUSMRebenchmarking.Report.doc and 3 appendixes.	Riley Fox GARD

Part 2. Space Heating

Most estimates in this report are based on 2009 RECS data, as opposed to the combined 1997, 2001, and 2005 survey data used in developing 2012 report estimates prior to the release of the 2009 RECS data in early 2013. The 2009 RECs had approximately three times the sample size of previous three surveys, and permitted development of estimates absent the complication of taking into consideration changes in structural and equipment energy efficiencies.

Merging 2005 and 2009 RECS survey data produces larger sample sizes. The downside of using multiple years of data, however, is that energy efficiency improvements occur even over fairly short time spans and estimates based on multiple surveys pose difficulties for use in trending to a more current date. Perhaps more important is that there have been a number of data definition and processing changes applied to the 2009 data that preclude fully compatible merges with previous samples.

2.1 Information on Heating Fuel Use

Fuel: Piped natural gas is the most common primary form of heating. It was used by an average of 50 percent of all units in the three surveys. Electricity was used for heating by 35 percent of all units, oil by 6.3 percent, and LPG/propane by 5 percent.

Table 3. Main Heating Fuels by Structure Type in 2009 (*Weighted estimates*)

Primary Fuel	TYPE HOUSING STRUCTURE					Total
	Mobile Home	Single Family Detached	Single Family Attached	Apartment 2-4 Units	5+ Unit Structures	
Unknown	222,248	1,375,948	196,572	348,610	1,385,928	3,529,306
Natural gas	1,379,004	38,180,577	3,895,359	4,594,702	7,163,422	55,213,064
Bottled gas	821,323	4,363,693	97,016	131,627	104,265	5,517,924
Fuel oil	51,918	4,677,227	397,789	638,861	1,159,882	6,925,677
Kerosene	232,217	205,238	31,468	0	28,553	497,476
Electric resistance	2,974,040	12,977,024	1,410,680	3,040,359	7,985,278	28,387,381
Wood	286,830	2,482,019	36,995	0	17,370	2,823,214
Solar	0	4,357	0	0	0	4,357
District steam	0	0	0	10,039	250,053	260,092
Heat pump	934,405	7,418,391	650,969	248,819	1,005,370	10,257,954
Other	38,976	151,229	0	0	9,577	199,782
Total	6,940,961	71,835,703	6,716,848	9,013,017	19,109,698	113,616,227

Comparisons of Table 3 values with unweighted sample values produce slight differences in percentage values. The two distributions are, however, consistently close because of the sampling methodology used except in the case of very small subsamples. To provide a sense of the underlying soundness of estimates provided, actual sample counts are normally shown.

Ducted natural gas with a central furnace is the most common heating service, and is used by 57 percent of all units. Radiators are used in 15 percent of all residential structures, heat pumps[2] by 8 percent, and various forms of wall units and portable heaters used by about 17 percent.

Table 4. Percentage Changes in Primary Heating Fuels Using 2009 as the Base Compared with the Combined 1997/2001/2005 RECS Samples

Primary Heating Fuel	TYPE HOUSING STRUCTURE (Units with identified heating fuel)					Total
	Mobile Home	Single Family Detached	Single Family Attached	Apartment 2-4 Units	Apartment 5+ Units	
Natural gas	-10.8%	-3.1%	-5.4%	-6.3%	-0.5%	-3.8%
Bottled gas	-4.4%	0.3%	0.5%	1.0%	0.1%	0.1%
Fuel oil	-1.5%	-2.1%	0.2%	-0.8%	-1.7%	-1.7%
Kerosene	-1.4%	-0.4%	0.3%	-0.2%	0.0%	-0.3%
Electric resistance	12.1%	4.5%	4.4%	9.2%	3.0%	5.3%
Wood	1.0%	0.4%	0.2%	-0.5%	0.0%	0.3%
Solar	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
District steam	0.0%	0.0%	0.0%	0.0%	0.5%	0.1%
Heat Pump	4.6%	0.4%	-0.2%	-2.4%	-1.0%	0.1%
Other	0.4%	0.0%	-0.1%	0.0%	-0.4%	0.0%
Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

The RECS surveys indicate some clear trends over time. Data from the 2009 RECS show that electricity was used as the main heating fuel by 26 percent of housing units in 1993 and by 34 percent in 2009. This increase is largely related to the increased use of heat pumps, which have roughly doubled in efficiency in the past twenty years and continue to improve. Use of natural gas fell from approximately 53 percent in 1993 to 49 percent in 2009, and fuel oil use fell from 10.6 percent to slightly under 6 percent.

Structure Type by Bedrooms*:* Table 5 on the following page provides information on sample sizes and percentages for bedrooms by structure type and heating fuel. An examination of this table is helpful in understanding the basis for deciding what bedroom and structure type mixes should be considered for further analysis and which should be dropped or merged because of inadequate sample sizes.

[2] The RECS heat pump variable does not specify if it applies to individual room or whole-house units, but only whole house units would normally meet building code requirements for primary heating or meet the data selection criteria used in this and past HUSM research. All or nearly all of the reported heat pump use had ducted delivery.

Table 5 Unweighted Structure Type and Bedroom Size 2009 RECS Samples for Units with Common Heating Fuels and Limited Secondary Heat (< 10.5%)

Heating Fuel	# Bedrooms	Mobile Home	Single Family Detached	Single Family Attached	2-4 Unit Structures	5+Unit Structures	Total
Natural Gas	Missing	0	0	0	14	49	63
	0	0	0	1	0	1	2
	1	7	37	22	80	238	384
	2	46	490	214	227	290	1,267
	3	46	1,791	206	88	55	2,186
	4	7	1,013	45	16	8	1,089
	5	0	278	6	0	2	286
	6	0	34	3	1	0	38
	7	0	6	0	0	0	6
	8+	0	4	0	0	0	4
	Total	106	3,653	497	426	643	5,325
Propane	Missing	0	0	0	0	1	1
	0	0	0	0	0	0	0
	1	6	7	2	3	4	22
	2	19	52	3	6	4	84
	3	20	138	5	2	0	165
	4	1	64	1	0	0	66
	5	1	25	0	0	0	26
	6	0	2	0	0	0	2
	7	0	1	0	0	0	1
	Total	47	289	11	11	9	367
Fuel Oil	Missing	0	0	0	5	13	18
	0						
	1	0	4	2	13	55	74
	2	6	75	7	29	33	150
	3	0	201	20	13	13	247
	4	0	121	7	5	1	134
	5	0	24	4	0	1	29
	6	0	7	0	0	0	7
	8	0	1				1
	Total	6					660
Electric Resistance Heat	Missing	0	0	0	18	56	74
	0	1	0	0	0	0	1
	1	10	20	22	91	309	452
	2	86	200	98	155	353	892
	3	99	664	48	41	60	912
	4	9	288	14	6	1	318
	5	0	64	0	0	1	65
	6	0	7	0	0	0	7
	7	0	1	0	0	0	1
	Total	205	1,244	182	311	780	2,722
Heat Pump	Missing	0	0	0	0	10	10
	1	1	5	3	2	27	38
	2	15	56	29	19	33	152
	3	31	317	30	2	12	392
	4	9	131	1	0	2	143
	5	1	25	0	0	0	26
	6	0	6	0	0	0	6
	7	0	1	0	0	0	1
	Total	57	541	63	23	84	768

Uncommon bedroom sizes were dropped in regression runs to avoid bias. Separate regressions were run for each structure type for the specified numbers of bedrooms. As found desirable by previous HUSM researchers, bedroom size was made a regression variable when there were sufficient sample sizes to develop estimates. Regression analysis was conducted using standard criteria for initial testing[3] of bedroom size categories with a sufficient number of bedrooms, as follows:

Structure Type	Bedrooms Sizes in Regressions
Mobile homes	1-2 bedrooms
Single-family detached	2-3-4 bedrooms (5 also sometimes could be used)
Single-family attached	1-2-3 bedrooms (weak in 1 bedroom)
Apartment 2-4 units	1-2-3 bedrooms (weak in 3 bedrooms)
Apartment 5+ units	1-2-3 bedrooms (weak in 3 bedrooms)

Filtering out secondary heating fuels: RECS provides energy consumption estimates for all heating sources for all units sampled. The end result is that there is a large sample of single-family detached, an acceptable sample of apartments with 5+ units (per structure), and relatively small samples of mobile homes, single-family attached, and apartments with 2-4 units.

A housing unit can use several different heating fuels. For example, a gas-heated home may use portable electric heaters to heat some rooms. For HUSM purposes, however, it was essential to identify normal heating consumption when a single fuel was used, since it was not feasible to calculate the enormous number of possible fuel consumption mixes possible when multiple heating fuels were used in differing ratios. As was done by GARD and 2rw, sample cases with over 10.5 percent of their heating consumption supplied by a fuel other than the primary fuel were eliminated for this set of calculations.[4]

Heating Fuel*:* After filtering by number of bedrooms and absence of additional heating fuels, gas and electric heat have enough cases to provide statistically acceptable values for all structure types. Only single-family detached units using oil heat or heat pumps provided enough sample cases to be useful. No separate tenant billing for oil heat in apartments was observed by RECS, which is to be expected given that such heat is usually produced in a central location and then distributed to all units. There were not enough LPG/propane heated units in RECS to model.

Table 5 on the previous page shows the results of filtering out the least common heating fuels plus units that use enough secondary heat to distort primary heating fuel estimates. After doing this, a number of fuel/structure type/bedroom size cells are too small for analysis. Alternative approaches therefore had to be used in developing estimates for some heating fuels, as is discussed in the respective heating fuel sections. Fortunately, structure/fuel mixes with insufficient cases for analysis implies that they will only infrequently be covered by the voucher program. PHAs are still required to provide utility schedule values for such units, and providing factually-based, reasonable values poses major challenges that few PHAs have the time and resources to address.

---

[3] A PIN of .05 (the probability of F to enter) and a POUT of .10 (the probability of F to remove) were used, which resulted in requiring up to 300 combined bedroom cases in the size categories considered.

[4] Filtering out secondary heating fuels that accounted for less than 10.5 percent of heating did little or nothing to improve regression results and sometimes had adverse impacts.

2.2 Two Ways of Predicting Heating Consumption

Past HUSM models have estimated most heating consumption using regressions based on RECS micro-data (i.e., individual residence data). The variables used are those available from program and local climatic data sources – types and uses of resident-paid fuels, structure type, number of bedrooms, and heating and cooling degree days. Regressions were run separately for different structure type and fuel combinations. An alternative method was sometimes used that involves calculating mean consumption for each unit size and estimating a linear trend line through the means -- essentially a second-order approximation. The predicted consumption by size using this latter approach is then adjusted by climate.

Past researchers used the second-order approximation approach for water heating and cooking estimates and less common heating types because RECS micro-data produce inconsistent results. This study also tested this approach for heating fuels with limited data and/or questionable results.

2.2.1 Predicting heating consumption using RECS Micro-data

Some of the 2009 regression results and average consumption values by bedroom size are difficult to explain even for fuel subcategories with large sample sizes. The same result occurred when examining previous surveys. These results are undoubtedly partly due to the limited number of variables related to heating consumption that are available in a model for PHA use. For instance, Individual unit building envelope characteristics, heating equipment age and efficiency, and user consumption patterns (e.g., at what temperature thermostats are set) are essential in estimating individual unit consumption estimates. Adding these to a regression significantly increases its predictive accuracy, but this information is not available for use in setting Section 8 utility schedules. Less explainable are anomalous relationships by bedroom size for units with the same structure type, heating fuel, and heating equipment but differing numbers of bedrooms for some heating fuels, as is subsequently discussed.

Despite the statistical advantages of a large, single-year sample of data provided by the 2009 RECS, the results obtained from testing a number of alternative approaches had limited success in improving regression results. This is less troubling than it would be if the objective was to predict individual unit rather than average energy consumption. In general, RECS-based estimates for different years normally show energy conservation improvements, but other factors appear to be in play that are not understood.

Utility consumption research done by the Department of Energy (DOE) has produced models that can predict consumption for individual units across a wide range of structure types and sizes with a high level of precision. These models, however, use a large number (e.g., 100+) of structural, equipment, and resident use pattern data to produce these estimates. The same models are rarely used by the energy industries because of the data collection costs they impose. Unlike the DOE models, the HUSM model seeks to provide reasonable estimates for typical energy consumption for different structure types in different climatic areas. This far less ambitious objective is more compatible with the limited data that PHA staff collect on Section 8 voucher units, and it doubtful that it would be feasible or cost-effective to require the extensive additional information needed to significantly increase estimate reliability.

The regression values provided in this report relate to values for individual case determinations rather than an indicator of typical values. More or less by definition, the regression results are a very good measure of the most typical values. A problem can arise, however, when the distribution of values is not statistically normal or the regression used is missing some variables essential to providing good estimates.

Problems with Efficiency, Mobile Home, and Single-Family Attached vs. 2-4 Unit Structures:

Most of the regression results for 0-bedroom (efficiency) units are suspect. These size units are relatively rare and RECS sample sizes are inadequate to provide reliable results even for the largest heating fuel grouping studied. In addition to the sample size problem, efficiency unit characteristics vary more substantially than for other bedroom types. Luxury efficiencies are often larger than average one-bedroom units, while modest efficiencies are usually much smaller.

For mobile homes the coefficients and intercepts were radically different from survey to survey in all surveys examined. Some of the differences in estimates for different bedroom sizes are highly suspect. Specifically, estimates for two and three bedroom units are sometimes lower than for one bedroom units. Age of structure was examined to find if it explained some of the apparent anomalies found, but it did not appear to do so.

Regression estimates for single family attached and 2-4 unit structures also pose questions. Sample sizes for both are limited. Estimates for single family attached are sometimes lower than those for 2-4 unit apartments and rarely much higher. This seems odd, but is largely consistent across the RECS surveys examined. On average, 2-4 unit structures are older and more likely to have older heating and cooling systems, which may explain the results observed. Energy efficiency improvements that have been made to older structures, however, mean that it is unwarranted to make sweeping assumptions about energy consumption and structure age.

2.2.2 Predicting heating consumption using RECS Means

Some energy uses show clear patterns but have extremely low R-squared values. A method for dealing with some of these issues was suggested by GARD Analytics, an experienced engineering firm that specializes in energy modeling and analysis. Their approach was to compute mean consumption by number of bedrooms, run a regression line through the means (*Report 5*, page 11), and then apply an adjustment measure when appropriate. This approach has been used in all past HUSM models for some estimates. It is of special interest when samples are small or normal regression results are suspect because of insufficient analysis variables or other reasons. This approach was used in this and past studies to estimate water heating, cooking, and “Other Electric” with relatively good results. It was therefore examined for this report for space heating, although its use is only considered if micro-data regressions are inadequate or inappropriate. The procedure used was as follows:

1. Compute mean consumption for each bedroom grouping for each structure type, combining data from all three available RECS surveys;
2. Run a linear trend line through the computed means;
3. Predict consumption for all sizes (0 to 5 bedrooms) for each structure type;

4. Compute mean HDDs for each structure type, combining all 3 RECS years;
5. Adjust the prediction for each value of HDDs by the ratio of the local HDD value to the average HDD value in step 4.

The above version of the means method is intended for use when the average values of the primary consumption predictor variables are roughly similar (e.g., heating degree days). In instances where they differ, a somewhat more complex approach would be warranted that involves normalizing bedroom heating consumption at the same HDD level before deriving an equation that adjust for bedroom sizes. One example of how the second order regression method is applied is shown below for 3-bedroom, single family detached homes. In areas with 4,000 HDD, it would be applied as follows:

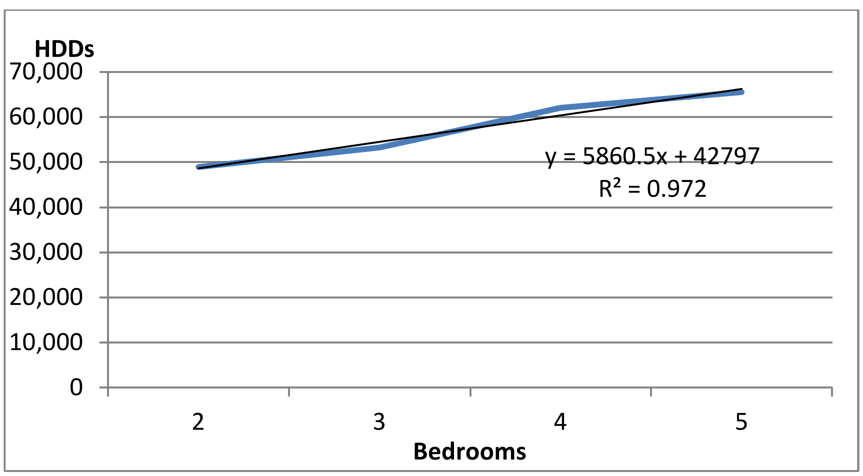
1. The linear trend line equation through the means is: y = 42797 + 5860.5* Bedrooms
2. For 3 bedrooms the prediction is 38467 + 9347.2 * 3 = 60,378.5 kBTU;
3. The mean HDD for single-family detached homes is 4,600;
4. The adjusted prediction for homes at 4,000 HDDs is:

   60378.5 * 4,000/4,467 = 52,503.

5. Thus, for single-family detached homes the complete formula is:

   $y = (38467 + 9347.2 * \text{Bedrooms})*(4000/HDD_{Mean})$

Chart 1. Single Family Regression Using Gas Consumption Means



In this instance, as shown in Chart 1, a linear equation produces a good fit. In some instances other types of line-fitting methods are preferable. As can be seen, this approach forces estimated values to be more symmetrical, as would be expected with large enough samples. The normal regression value for a three-bedroom single family unit with the same heating degree day value is slightly lower, as suggested by the chart. This approach is primarily useful when sample sizes are small and relationships between bedroom sizes more erratic than is believed likely, because it can then be applied over a wider range of HDD values than desirable using limited sample data. The main drawback to the regression-on-means approach is the assumption that energy consumption variations are proportional to the local HDD values to the average national HDD values used in applying a regression-on means approach.

In practice, the normal regression value factors for natural gas heating are reasonable and sample sizes are considered adequate. Use of the regression-on-means approach is therefore not considered desirable.

2.3 Propane/LPG Heating

Propane as a primary heat source is used by less than 5 percent of all residences. Only three-bedroom unit samples had more than 100 cases, and the results of estimates based on three bedroom sample sizes were almost the same as those based on natural gas heating. As was done in past studies, propane heating consumption estimates were provided by assuming that the characteristics and use patterns for propane-heated homes were the same as those for natural gas.

2.4 Electric Resistance Heating

Unlike other types of heating, resistance heating equipment efficiency has not improved noticeably in recent years. There are inefficiencies in producing and transmitting electricity, but the resistance heating equipment used for several years has, of itself, been very efficient. RECS data show there were significant overall decreases in average electric resistance heating consumption from 1997 to 2009. The reasons for this are unclear, but four are suggested for consideration:

- Residents of resistance-heated structures who pay for their own electricity, which includes most renters, have above average financial incentives to be cautious in their use of a relatively expensive fuel.
- Paybacks for building envelope energy efficiency improvements, all other things being equal, have relatively higher paybacks for resistance heated structures because of the electricity's relatively high cost as a heating fuel.
- The least efficient resistance heated homes would have been the most attractive candidates for conversion to other heating fuels, especially if they already had duct work.
- **A large percentage of resistance heated structures have room-zoned heat,** and turning down heating in unused room below temperatures maintained by other, unzoned heating systems is common. (Room-zoned heat is rarely found except with resistance heat, and has enormous potential impacts on energy consumption if heavily utilized.)

Several regression forms were tested to attempt to develop estimates for resistance heated structures. The regressions provide estimates that match large-scale patterns, but the results raise questions. Table 6 and Charts 2 and 3 on the following pages provide information on average values found for resistance heating by structure type and number of bedrooms.

Table 6 indicates that typical resistance heated units for all structure types are located in areas with much lower heating degree day levels than applicable to other major fuels. It also shows that average BTU consumption to heat such units is relatively modest, which is to be expected given average heating degree day values.

Table 6. Mean Resistance Heating Consumption
and Heating Degree Day Values

Structure Type	# Bedrooms	Mean kBTUs	Mean HDDs	Sample Size
Mobile Home	1	4,510	1,363	10
	2	10,668	3,131	86
	3	10,839	2,817	99
	Total	10,439	2,881	195
Single Family Detached	2	9,493	2,812	200
	3	9,252	2,719	664
	4	8,695	2,531	288
	Total	9,155	2,688	1,152
Single Family Attached	1	8,125	2,862	22
	2	8,727	3,076	98
	3	9,533	4,064	48
	Total	8,879	3,330	168
Low-Rise	1	7,982	3,185	91
	2	7,959	3,354	155
	3	9,315	3,607	41
	Total	8,160	3,336	287
5+Floors	1	6,837	3,464	309
	2	7,904	3,380	353
	3	8,721	3,219	60
	Total	7,515	3,403	722

Charts 2 and 3 provide information on the distribution of degree day values and electrical heating fuel consumption for 3 and 4 bedroom single family units. This group has the largest numbers of resistance heat sample units of any structure type, and was selected to better show the nature of the distributions of interest. Two points are especially worth noting:

- Neither distribution can be considered to approximate a normal distribution, since most values have heavily concentrated at relatively low degree day and BTU consumption values but have long tails on the upper ends.
- Given the limited explanatory power of the heating regressions for these values and relatively high estimation error ranges, the estimates are unlikely to be useful for drawing distinctions over a wide range of values.

What this information appears to suggest is that it may be difficult to estimate differentials in energy consumption by bedroom size for this energy consumption category. This does not mean that such differentials don't exist – all other things being equal, units with more bedrooms should have higher heating fuel consumption (and number of bedrooms is consistently highly correlated with unit sizes). Instead, it implies that unit efficiency characteristics and resident use patterns become relatively more important in explaining heating consumption differences when most units are located within a relatively small heating degree day range.

What is more difficult to explain is why past resistance heating regressions produced average bedroom consumption estimates and regression values that appeared reasonable and roughly matched patterns for other major heating fuels. These regressions were re-run with the same results. It was noted, however, that the average heating degree day values applicable to the 1997/2001/2005 merged data used in the last study were noticeably higher and covered a larger range of values in a more symmetrical pattern which, coupled with a moderately larger sample size, should permit better estimates over a wider distribution of degree day values. Relatively more electric resistance heating is found in warmer areas than used to be the case, and fewer such units are in relatively cold areas. What this implies is that providing good estimates for resistance heat in colder areas where it is little used is problematic given data limitations. The approach used to deal with this issue, as noted subsequently, seems conceptually valid but is difficult to test.

Chart 2. Electric Resistance Heat 3-4 Bedroom SFD Units, HDD Distribution

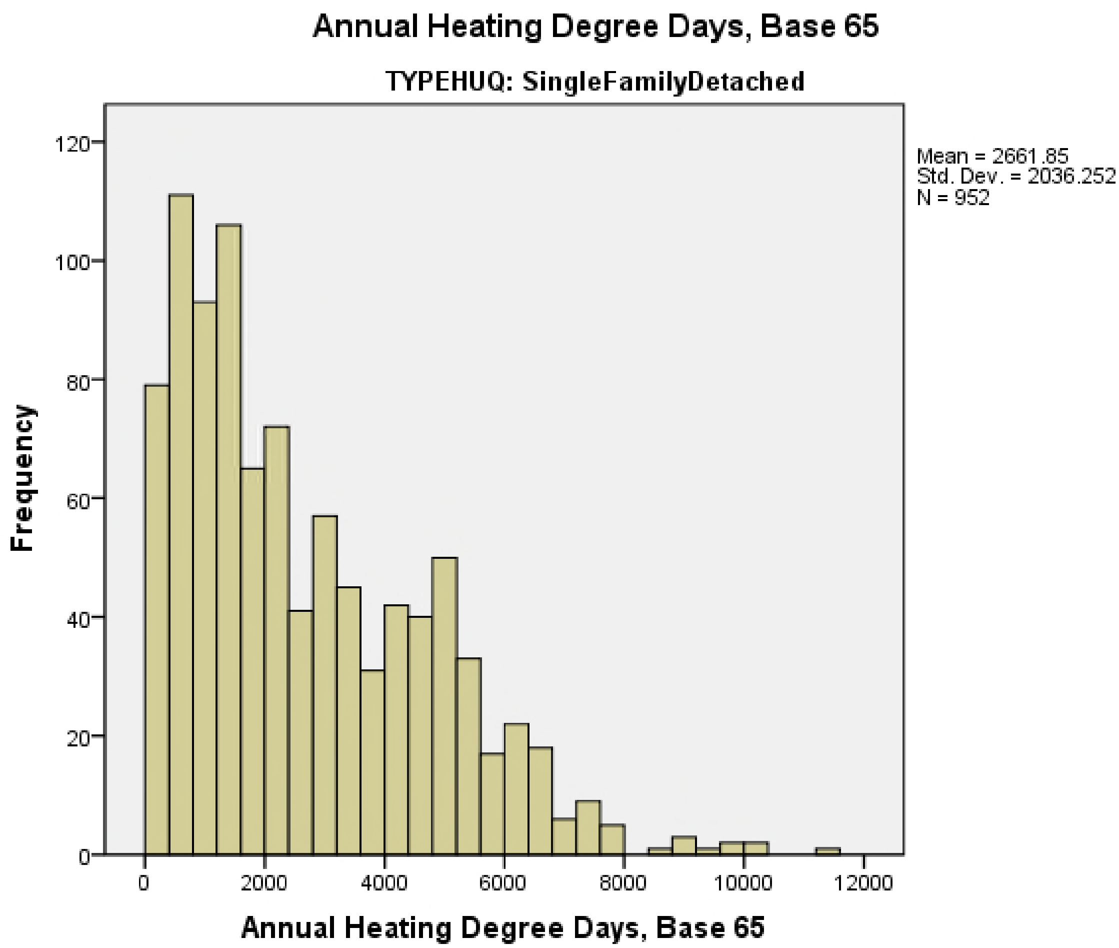
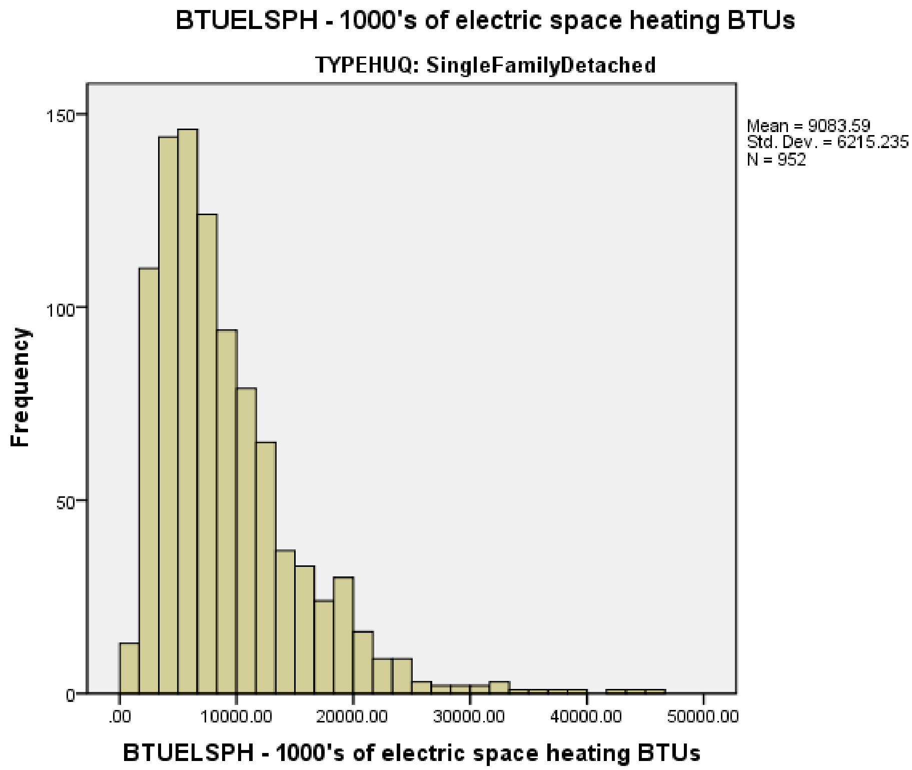


Chart 3. Electric Resistance Heat 3-4 Bedroom SFD Units, BTU Consumption



Approximately 60 percent of all units reporting that they use electrical resistance heating and limited other heating sources also reported that they had and use central air conditioning. This is suspicious. Although such instances certainly exist and at one time were more common, the marginal cost of installing a heat pump when a central air conditioner needs to be replaced is marginal and the heating efficiencies gained significant. This suggests the possibility that some units classified as having resistance heat and separate central air conditioners may actually have heat pumps.

There is an anomaly in differences between resistance heat and hat pump heating consumption estimates provided by RECS. Heat pumps are far more efficient than resistance heating in the climate areas in which they are most used. Attempts to draw restricted comparisons between heat pumps and resistance heating using the 2009 RECS (i.e., comparing 3-bedroom single family units in heating degree ranges where both are commonly used) showed very similar heating values. This outcome is inconsistent with known facts **if** all other things are equal, which by implication cannot be true. Average unit sizes for the two heating types are not significantly different. Individual room heating controls for resistance heat are relatively common, however, and can minimize heating in rooms not in use relatively easily. No other commonly used heating systems have an equivalent ability. Misclassification of heat pumps as resistance heating would further erode the accuracy of an attempt at direct comparisons.

Average RECS resistance heating values as well as regression-based estimates have been declining over time. The 2009 results, if taken at face value, show further declines. The decreases in heat pump consumption are to be expected given increasing equipment efficiencies. Resistance heating efficiency, however, has not changed, so some significant factor or factors associated with resistance heat are not understood. Plausible speculations can be made, but are hardly a substitute for valid data.

Table 7 provides information on resistance heating consumption by type of heat distribution equipment. No obvious differences between units likely to have individual room zoned heat and other equipment types is shown. This and other attempts were made to try to better understand resistance heating values with no success. The limited number of estimates for electric resistance heat found from utility companies from internet research suggest that the revised values in the December 2012 HUSM study are reasonable, in that they fall within what is a fairly wide range of utility company estimates. In the absence of additional data, no change is recommended in either that study's resistance or heat pump methodology.

Table 7. Type Heat Distribution for Single Family Detached Homes with Electric Resistance Heating (2009 RECS)

Type of main space heating equipment	Mean kBTUs	Mean HDDs	Sample Size
Steam/hot water	8,928	5,473	7
Central air furnace	8,456	2,424	978
Built-in Electric	16,028	5,110	121
Floor or wall pipeless furnace	9,564	3,181	3
Fireplace	11,543	1,873	1
Portable electric	7,586	2,236	94
Cooking Sove	7,739	2,269	3
Other	13,560	3,758	9
Total	9,186	2,705	1216

Given the questions surrounding how to interpret the 2009 RECS data resistance heating results, it is recommended that the older estimates continue to be used. These results are within the (admittedly large) range of estimates provided by utility companies. Although the associated kBTU values are low relative to most other fuels, the 2009 data would provide even lower values if utilized. It is worth noting that a significant number of resistance heated units lack the type of room-zoned heat that may explain some of the patterns observed. Rental units with tenant-paid utilities are somewhat less likely than average to be the focus of energy improvements, which further reduces the apparent desirability of assuming lower average renter consumption of resistance heating.

2.5 Electric Heat Pump Heating

Two methods were tested for estimating heat pump consumption. One is a partly engineering-based approach developed by GARD Analytics that has been used in all past HUSM models. It produces an adjustment factor that is applied to estimated regression-on-means electric resistance heating values. A full explanation of heat pumps and this approach is provided in Report 4, Section 1.

Developing energy consumption estimates for heat pumps has some of the same problems associated with resistance and oil heat estimation. Heat pumps are not typically used in areas with cold winters (e.g., New England), so regression calculations are less likely to provide good estimates because of the very limited data for such areas. In addition, the regression-based values for heat pumps are much lower than for gas or oil heat, but not much different than electric resistance heat estimates even though large differences are known to exist in moderate climates.

Largely because of problems found with normal regression methods, an engineering approach has been applied to developing heat pump estimates. It has the advantage of providing a single, consistent means of calculating estimates for all structure types and producing values that are consistent with expert observations. Its continued use is recommended.

The less the difference between the outside air temperature and the desired inside air temperature, the greater the efficiency advantage of heat pumps. When temperatures go below a specific heat pump's efficiency threshold, it effectively converts to resistance heating and has the same consumption requirements. Heat pump efficiencies continue to increase, but generally are of limited value below 32 degrees Fahrenheit. The engineering approach used takes this pattern into consideration. An example of the heat pump estimation method is shown for Detroit using an adjustment factor for heat pump efficiency related to how the degree day ranges for a specific local area.

Table 8. Heat Pump Calculation Example

Heat Pump HSPF (6.6 to 9.1, default 6.7)	7.85
Typical Low Temperature *	14.9
Constant	0.412069
Coefficient for Typical Low Temp	-0.012766
Calculated degradation	0.2218556
Adjusted HSPF with degradation (BTU/W)	6.1084335
Heat pump factor [Factor.HPump]	**0.558572**

Source: HUD HUSM model; assume average HSPF. See text

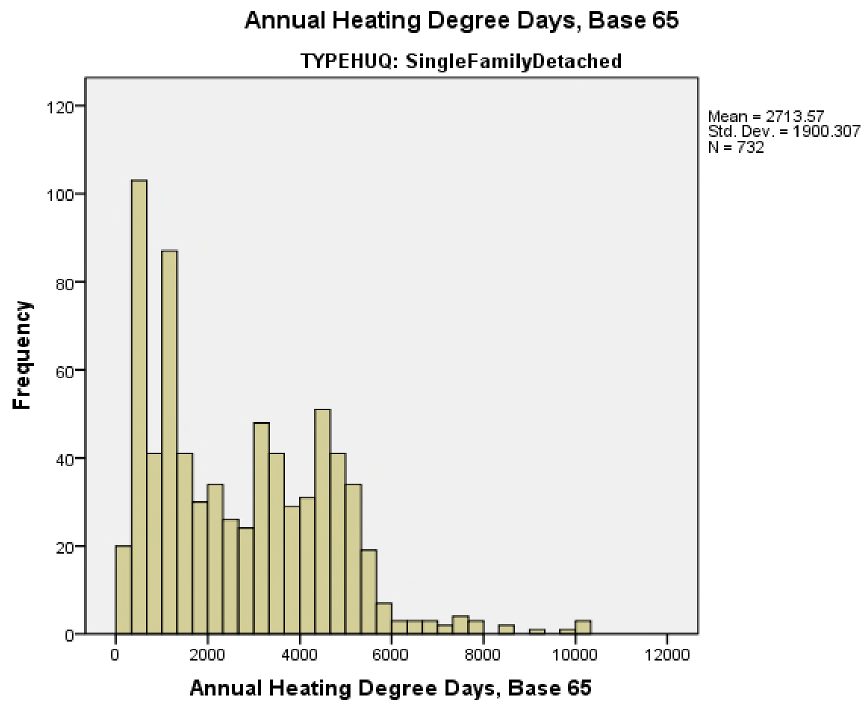
* Climatography of the US, No 81, Michigan, p 24. Average of Detroit Metro and Detroit City Airports

Heat pumps are of special interest because of the large and continuing efficiency increases that have been achieved in the last 30 years. The average efficiency of heat pumps in use is well below the minimum standard for new heat pumps. The current HUSM model assumes an average heat pump efficiency rating of 7.85 for cases whose mid-point was in 2001. The minimum allowed HSPF for new equipment in most areas is now 13 (almost twice as efficient as the assumed current average).

New heat pump HSPFs of 16 are more typical, and ones with HSPFs of over 20 can be purchased. HSPF values for air-source heat pumps (as opposed to geo-thermal), however, are irrelevant once temperatures fall below the point where heat pumps are effective and resistance heating takes over.

As can be seen in Chart 4, heat pumps are typically found in moderate and warm climatic areas. Northern Virginia, for instance, is a borderline area in terms of heat pumps, since it is cold enough that the resistance heating built into heat pumps sometimes needs to take over. The average heating degree day (HDD) requirement for the country as a whole is about 4,000 HDDs.

Chart 4. Heat Pump Heating Degree Day Distribution For
Single Family Units with Limited Secondary Heat



It should be noted that the 2012 study and this report contain recommendations inconsistent with RECS data, in that the RECS data show relatively similar consumption values in 2009 and smaller than anticipated differences from previous surveys. The engineering approach used to develop heat pump estimates assumes that the resistance heating and heat pump values are for equivalent space heating uses. If there is a problem with the accuracy of the resistance heating value or if a significant number of resistance heated units are making more extensive use of room zoned heating to reduce their electricity consumption, the engineering values will be overstated relative to average actual use. On the other hand, applying average resistance heating values to units without room-zoned heat would be likely to result in serious under-estimates of utility costs.

It is known that heat pumps are more efficient than equivalent resistance heating, especially within the climatic zones where they are most used. It appears most likely that the problem lies with resistance heat and relates to use of room zoned electric heat, but this cannot be conclusively determined. If that is the problem, than the two sets of estimates cannot be considered comparable.

Table 9 shows mean electric heating consumption and heating degree days for homes primarily heated with resistance heat. As is readily apparent, the mean values for heat pump consumption provided by the 2009 RECS do not fit normal expectations that consumption increases with number of bedrooms.

Table 9. Heat Pump Mean Consumption by Number Bedrooms

TYPEHUQ	BEDROOMS	Mean kBTUs	Mean Heated Square Feet	Mean HDDs	N
Mobile Home	2	8,406	1,116	1,951	15
	3	8,831	1,292	2,860	31
	4	7,572	1,942	1,870	9
	Total	8,509	1,355	2,450	55
SingleFamilyDetached	2	6,519	1,434	2,282	56
	3	8,089	1,848	2,785	317
	4	7,929	2,896	2,696	131
	5	7,641	4,133	2,705	25
	Total	7,862	2,162	2,706	529
SingleFamilyAttached	2	7,112	1,266	2,648	29
	3	10,461	1,791	3,969	30
	4	14,973	1,840	4,851	1
	Total	8,918	1,499	3,345	60
Low-Rise	1	8,405	746	4,024	2
	2	6,588	1,074	3,226	19
	3	4,851	732	1,672	2
	Total	6,595	1,016	3,160	23
5+Floors	1	4,864	658	3,240	27
	2	6,971	1,079	3,198	33
	3	4,000	1,170	2,866	12
	4	11,156	1,359	3,887	2
	Total	5,833	905	3,178	74
		Refers to unusable sample sizes			

2.6 Oil Heating

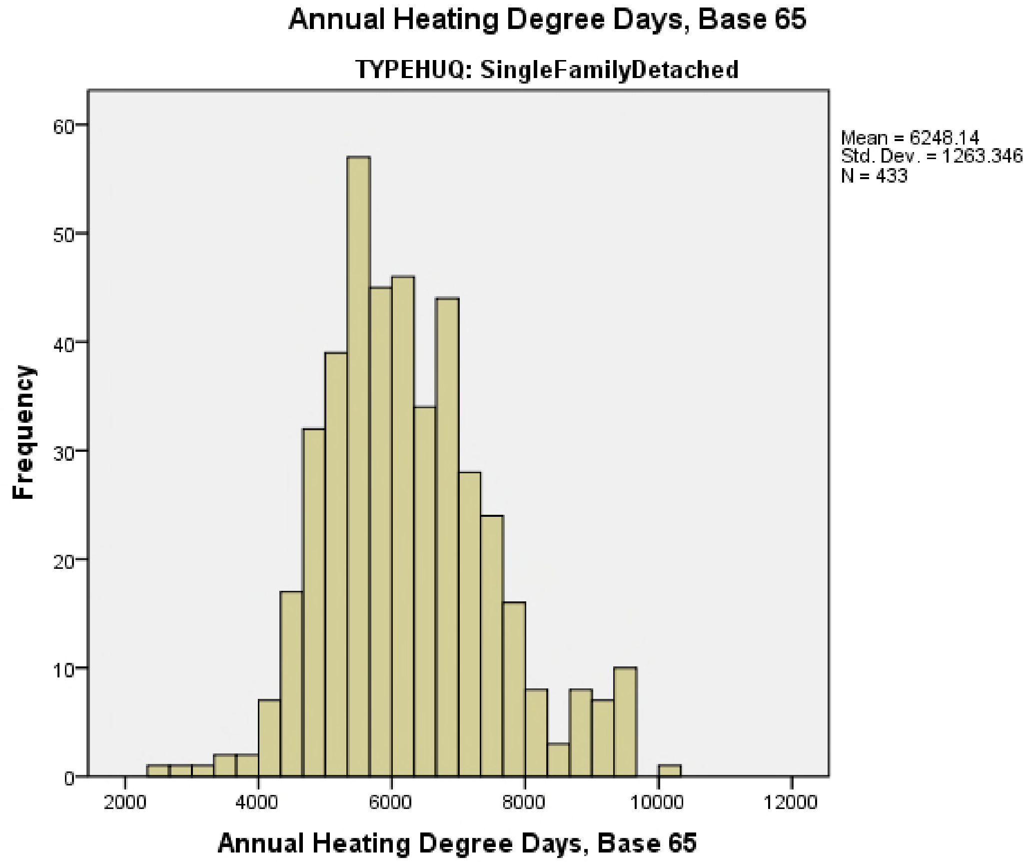
Oil heating is mainly used in cold climates and areas without good access to natural gas lines, or where oil is cheap relative to propane. Resident-paid oil heating is most common in single-family detached residences and, of those, half are hot water or steam systems with radiators rather than forced air systems.

The 2009 RECS shows that oil heat use continues to decline. RECS samples for the aggregated surveys provide 660 total cases with oil heat and limited use of a secondary heating fuel. About two-thirds of these are single family detached units, and only three and four bedroom units have what are considered good samples sizes for analysis. There are two more serious problems:

- Oil is normally delivered in large quantities once or twice a year rather than daily or monthly. Oil purchases for a RECS survey year will reflect actual consumption only by an unusual coincidence, but is the only information available to estimate annual consumption.
- Oil consumption is highly concentrated in the Northeast in areas with relatively high heating degree day values, and do not provide good representation for other climatic conditions. Worse, they are concentrated in a relatively limited heating degree range.

Chart 5 provides information on the distribution of oil-heated, single family detached units by heating degree day values.

Chart 5. Single Family Detached, Oil-Heated Homes
with Limited Heat)



2.6.1 Regressions Using RECS Micro-data

Unlike regressions for natural gas, oil heating regressions have anomalies. For example, the coefficient on HDD alone is very low and in most cases not statistically significant. For units with forced air delivery the HDD coefficient is negative, implying that there should be lower oil consumption the colder the climate. This oddity is somewhat offset by positive (and statistically significant) coefficients on the multiplicative variable HDDxBED, but these results are still troubling and may be related to the relatively narrow climatic range within which oil heat is commonly found.

Table 10 shows the regression values for the standard approach used. A number of other more complex approaches were examined but none had a significant advantage. The following summarizes what are considered to be the major implications of these results:

- The low R-squared values indicate that these results have limited predictive ability.
- The values at 4,000 and 6,000 HDDs are close to values estimated using a different procedure in the December 2012 HUSM study. Since three-bedroom detached units are by far the common and most oil-heated units fall close to or within this temperature range, this should not be assumed to mean that the regressions are reliable for other values.

- Radiator and forced air heat have much different regression values, and quite different regression-based estimates at moderate and low HDD levels.

These regression results are considered unacceptable for use. Only single family units in the three and four bedroom categories had enough units to be useful, and those results are also anomalous.

Table 10. Oil Heating Regression Values

Type of Heating Distribution	Regression Values					Heating Degree Days		
	Constant	HDDs	Bedrms* HDDs	R-Square	Sample Size	2000	4000	6000
All Oil Heat Units	69768.158	-.770	1.042	.025	433	74,479	79,189	83,900
Radiators using Steam or Hot Water	62302.764	2.490	.496	.017	214	70,257	78,212	86,166
Forced Air from Central Furnace	73208.960	-3.222	1.551	.045	195	76,072	78,936	81,799

2.6.2 Regressions Using RECS Means

The regression-on-means approach described in the previous section on gas and electric heating for single family detached units was tested for oil heating. No other structure type makes large-scale use of oil heating, and none had sufficient sample cases to derive estimates. This approach provided results that were more consistent with the patterns for gas and electric heat. As Table 11 shows:

- The effect of climate is much greater than with the regression-on-means method and consistent with patterns for other fuels.
- The bedroom ratios are more plausible.
- The predicted consumption at 6,000 HDDs for the means method (the approximate value at which oil heating is most likely to be found) is moderately higher than the predicted consumption using the micro-data approach at this HDD value.

It was concluded that the regression-on-means approach yields more plausible results for oil heat, and it is recommend that it be considered more reliable than micro-data regressions. The results are somewhat higher than those in December 2013 report, which were based on older data. The reasons for this are unclear. The combined 1987/2001/2005 data used in the 2012 report provided a larger sample of oil heated units, but that sample is not as representative of the 2009 inventory. Also, there appears to be more variability in RECS sample results for the variables studied (e.g., HDDs) than would be expected from something resembling a random sample.

The recommended equation is based on the 2009 survey and is as follows:

$$kBTU_{Oil} = (78{,}210 + 5{,}704 * Bedrooms + 3741 * Bedrooms^2) * (HDD_{Local}/6200) * \text{Structure Type Factor}$$

Table 11. Oil Heating Regression-on-Means by Delivery Method

Regression Factors				Bedrooms				
Constant	Bedrooms	Bedrms. Squared	HDDs	1	2	3	4	5
78,210	5,704	3741.1	2,000	28,276	33,737	41,611	51,898	64,600
78,210	5,704	3741.1	4,000	56,552	67,473	83,221	103,797	129,200
78,210	5,704	3741.1	6,000	84,828	101,210	124,832	155,695	193,800
78,210	5,704	3741.1	8,000	113,104	134,946	166,443	207,594	258,399

2.6.3 Structure Type Factors

Oil heating and heat pumps had too few cases to develop statistically acceptable estimates except for single family detached homes. Since the HUD utility schedule format calls for values for all heating fuels and structure types with tenant-paid utilities, however unusual, structure type consumption relationships based on other heating fuels needed to be developed.

In order to provide structure type heating consumption ratios for unit types that lacked desired sample sizes, both micro-data and regression-on-means regressions were used to examine relationships for gas and electric heated units of different sizes and structure types. Gas heat, however, had by far the largest sample sizes and most stable results. It also was used for heating over a relatively large range of climatic zones. While it can be argued that structure type adjustments could be based on natural gas heat, there is reason to consider using American Housing Survey (AHS) relationships for all fuels and bedroom sizes for the following reasons:

- Mobile home relationships to single family detached, which have much larger samples and more stable values, are based on relatively few cases and results change from year to year. However, they tend to be vary in a range around AHS values, which are based on much larger samples and are fairly stable from survey to survey.
- Single family attached and 2-4 unit structure values have relatively modest samples, and their consumption relationships with single family detached are less stable than desirable. Also, age differentials between these two structure types appear to explain most differences. Again, the AHS values appear to provide good compromise estimates.
- Five-plus unit structure values from the 2009 survey provide erratic estimates, with one-bedroom consumption higher than two-bedroom consumption. The AHS relationships are virtually identical with previous RECS survey results.

A summary of natural gas heating fuel consumption ratios for different structure types is provided in Table 12 that includes the average of micro-data and means regressions for 2- and 3-bedroom ratios by average heating degree day values. Although in theory this set of ratios should be at least roughly applicable to other heating fuels if all other things are equal, it should be noted that the values shown have significant variances.

Table 12. Gas Heating Relationships for Structure Types

Heating Regressions by Structure Type	2-Bedrooms Ratio To Single Family Detached Heating Degree Days			3-Bedrooms Ratio To Single Family Detached Heating Degree Days			Combined Ratios Average for 2000-6000 HDDs		
	2000	4000	6000	2000	4000	6000	2 Bedrms.	3 Bedrms.	Avg. 2 & 3
Using Microdata, Gas Heating									
Mobile Home	Unstable Results			Unstable Results			0.81	0.72	0.77
Single Family Detached	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Single Family Attached	0.90	0.85	0.83	0.92	0.89	0.87	0.97	0.88	0.93
Apartment 2-4 Units	0.94	1.05	1.10	0.91	1.00	1.04	0.97	0.95	0.96
Apartment 5+ Units	Unstable Results			Unstable Results			0.48	0.49	0.49
Using Means, Gas Heating									
Mobile Home	0.78	**0.78**	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Single Family Detached	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Single Family Attached	0.89	**0.89**	0.89	0.94	0.94	0.94	0.89	0.94	0.92
Apartment 2-4 Units	0.97	**0.97**	0.97	0.95	0.95	0.95	0.97	0.95	0.96
Apartment 5+ Units	Unstable Results			Unstable Results			Unstable Results		

A set of ratios was developed for the 2012 HUSM study based on American Housing Survey results for all fuels and bedroom sizes. The significant advantage offered by using these ratios is that they are based on mostly the same units from year to year, which means that variations in the sample selection do not pose a huge risk in comparing estimates from different surveys. These relationships have been quite stable in recent years, and are as follows:

Table 13. American Housing Survey Fuel Consumption Ratios

Single family detached	1.00
Mobile homes	0.86
Single family attached	0.89
Apartment with 2-4 units	0.90
Apartment with 5+ units	0.51

If building codes were uniformly enforced and builders always built to minimum energy efficiency standards, separate energy efficiency multipliers would likely be needed for end row houses and possibly for duplexes. Also, something other than the statistically weak differential of .01 between single family attached and 2-4 unit apartments might be expected. No such patterns are found in either the RECS surveys or the American Housing Surveys, and no “conceptually based” adjustments to refine the estimates developed are recommended. Such adjustments are found in some PHA utility schedules. While adjustments may be valid in some circumstances, especially in areas with unusually large amounts of one or the other type of recent construction, they do not generally appear warranted.

2.6.4 Bedroom Adjustment Ratios for Calculating Efficiency Unit Values

Efficiency units presented the same problem they did in past analyses. Some are luxury units in prime locations that cost more than typical one-bedroom units within the metro area (e.g., in Manhattan, which disrupts normal bedroom interval calculations for FMRs). Others are very small, basic units. Still others are almost comparable to one-bedroom apartments, but somewhat smaller and less expensive. The relatively small number of such units plus their variability makes producing a normal statistical relationship with other bedroom sizes problematic. The intent within the Section 8 voucher program is to have efficiency FMRs reflect a more modest sized version of a typical one-bedroom unit in the same metropolitan or nonmetropolitan area. For this reason, a conversion factor of 85 percent in reference to a one-bedroom value, which has been typically used by HUD in the past and has a defensible basis, is used in this report.

Part 3. Air Conditioning

Air conditioning in this country has become increasingly common. As shown in Table 14, only about one-fourth of all residences surveyed have no air conditioning at all. Central air conditioning units are the most common, even for apartments. Air conditioning has become increasingly common even in areas with modest CDD values, as shown in Table 14.

Table 14. Air Conditioning Utilization by CDDs and Structure Type (Unweighted)

		CDD RANGE					
Structure Type	Air Conditioning	0-999	1000- 1999	2000- 2999	3000- 2999	4000+	Total
Mobile Home	Not Used	29%	9%	11%	4%	7%	17%
	Used	71%	91%	89%	96%	93%	83%
	Total	100%	100%	100%	100%	100%	100%
Single Family Detached	Not Used	24%	9%	5%	5%	5%	15%
	Used	76%	91%	95%	95%	95%	85%
	Total	100%	100%	100%	100%	100%	100%
Single Family Attached	Not Used	24%	16%	5%	0%	11%	18%
	Used	76%	84%	95%	100%	89%	82%
	Total	100%	100%	100%	100%	100%	100%
2-4 Unit Apartments	Not Used	41%	25%	8%	14%	11%	31%
	Used	59%	75%	92%	86%	89%	69%
	Total	100%	100%	100%	100%	100%	100%
5+ Unit Structures	Not Used	33%	13%	5%	2%	9%	21%
	Used	67%	87%	95%	98%	91%	79%
	Total	100%	100%	100%	100%	100%	100%
Total	Not Used	27%	12%	6%	4%	7%	18%
	Used	73%	88%	94%	96%	93%	82%
	Total	100%	100%	100%	100%	100%	100%

In case the reader is wondering about the fact that air conditioning use in Table 14 appears to decline slightly in the 3,000-3,999 CDD to 4,000+ CDD ranges. This outcome was carefully rechecked and is unlikely to be due to sample sizes. Some consistently warm areas near the coast in Hawaii and Southern California have some high quality units that do not have air conditioning, but without geographic information not provided by RECS, the reason for this outcome must remain speculatory.

Regressions using RECS micro-data were tested with the same types of variables used for estimating heating, except that cooling degree days (CDDs) were substituted for heating degree days. The 2009 RECS data produced better first order regression results than in the past. Given these results, there was no reason to consider using second order regressions. Results for areas with national average cooling degree values are shown in Table 15.

Table 15. Regression Values and Related Estimates for Areas with 1500 CDDs

TYPEHUQ	Regression Values			Bedrooms				
	Constant	CDD65	BEDxCDD	1	2	3	4	5
Mobile Home	-71.632	.495	1.300	2,621	4,571	6,521	8,471	10,421
SFD	162.910	-.593	1.967	2,223	5,173	8,124	11,074	14,024
SFA	-101.221	.446	1.378	2,634	4,701	6,768	8,835	10,902
2-4 Unit Apartments	-724.323	1.289	.861	2,501	3,793	5,085	6,377	7,669
5+ Unit Structures	-278.491	1.177	.747	2,608	3,729	4,850	5,971	7,091

The Table 15 values are modestly higher in most categories than the results in the 2012 report, which was based on older data. Air conditioning equipment efficiency has increased, but air conditioning use has increased even faster. Also, in the past units with any air conditioning were included. RECS shows, however, that the large majority of units with air conditioning cool most of the living space rather than just a bedroom or two, as was more common in the past. Only units that cool most of the living quarters, as is true of most units using air conditioning, were used in the estimates provided above. Including units with one or two window units biases the results downward for most units with air conditioning, which is inconsistent with the objectives of Section 8 utility schedules.

Air conditioning equipment efficiency and its associated electrical consumption are highly correlated with the age of the equipment – far more so than even with heating equipment. The ability to use a single survey for estimates, as was made possible with the large 2009 RECS sample, probably had a large role in improving regression results. Inclusion of air conditioning equipment age would greatly increase predictive accuracy, but is probably not a realistic option for the voucher program.

Chart 4. Water Heating

Analysis of water heating in past HUSM studies using the results of regressions based only on program-available unit characteristics produced unacceptable results. This also occurs using other RECS surveys. R-squared values were less than 10 percent for all structure types for all regressions tested. There are several reasons why this probably occurs, but two are likely the most important. One is that water heating consumption is largely dependent on the amount of heating required, and water inlet temperatures are not available in RECS. The other is that consumption is highly dependent on individual user patterns.

An alternative approach that is partly based on RECS data and partly on an engineering-based adjustment has been used since the HUSM model was developed. It was evaluated by two engineering firms and the authors of this report in previous studies, and its continued use is recommended. It is conceptually sound, produces plausible estimates consistent with observed values, and makes good use of all data normally available to PHAs. This approach involves developing separate regression equations by structure type and heating fuel with consumption as the dependent variable and bedrooms as independent variables. An engineering-based adjustment based on local HDD values is then made for the impact local temperature patterns have on cold water inlet temperatures. This method is described in some detail in Report 1 and subsequently in this report. The RECS-based regression results used in the first half of this process were re-estimated with 2009 RECS data, but no change was made to the water inlet temperature adjustment calculation.

4.1 Gas Water Heating

As can be seen in Chart 6, the regression-on-means approach results in a very linear relationship with mean bedroom consumption and an R-squared value of .997. Other types of fit offer no improvement. Combing this result with the engineering adjustment used for water inlet temperature produces the following equation"

kBTU gas water heating = (6366.5 + 5096.6*Bedrooms) * Multiplier, ***where***

Multiplier = (60 – IWT)/100+1 ***and***

IWT (Inlet Water Temperature) = 74.3 - .003161*HDD

In the past, HUSM studies have merged all structure types for purposes of calculating hot water heating. Analysis of the 2009 RECS survey suggests that doing so introduces no obvious bias except possibly with respect to 5+-unit structures, which have lower consumption. Chart 6 shows the mean bedroom and heating degree day relationships from a regression on means approach. It is apparent there is a very strong pattern not reflected by first-order regression results. The addition of a factor adjustment for water inlet temperatures produces results that are reasonably consistent with actual average values at different HDD levels.

Chart 6. Natural Gas Water Heating Regression-on-Means

All except 5+-unit structure types showed similar average water consumption by bedroom size. Five-plus unit structure gas hot water consumption was in the range of 20-40 percent less. Water inlet temperatures for 5+-unit structures should, on average, be at least slightly less since more pipes run through heated space. This would reduce consumption, but the size of the decrease and the fact that it is not apparent with electric hot water heat suggests other factors may be involved. Without better understanding the reason for this differential (e.g., occupancy differences), it is not recommended that a separate adjustment for 5+-unit structures be made.

4.2 Electric Water Heating

As with natural gas, there is a strong and simple relationship between consumption and number of bedrooms. As can be seen in Chart 7, the regression-on-means approach results in a very linear relationship with mean bedroom consumption and an R-squared value of .995. Other types of fit offer no improvement. Combing this result with the engineering adjustment used for water inlet temperature produces the following equation"

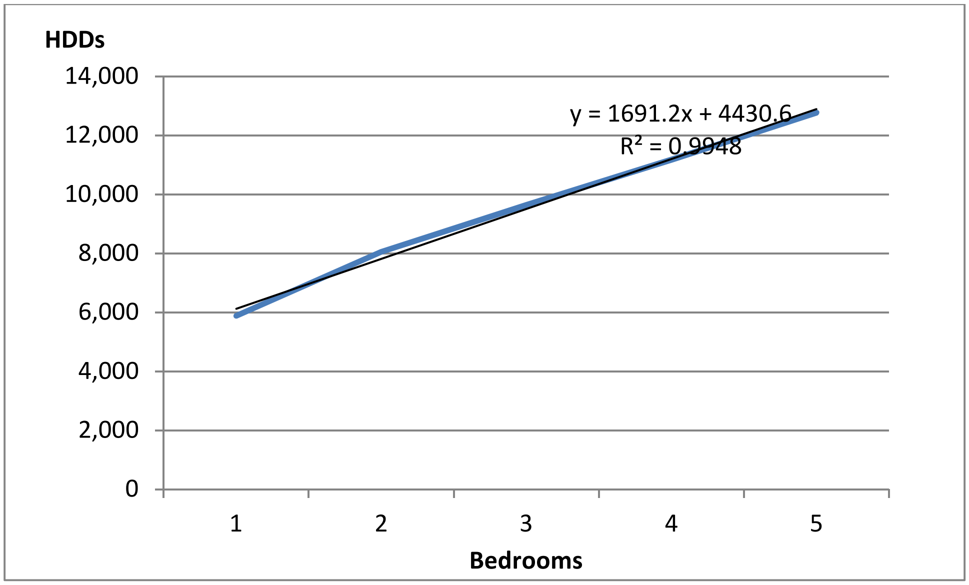
kBTU gas water heating = (4430.6 + 1691.2*Bedrooms) * Multiplier, ***where***

Multiplier = (60 – IWT)/100+1 ***and***

IWT (Inlet Water Temperature) = 74.3 - .003161*HDD

Analysis of the 2009 RECS survey indicates that all structure types with electric hot water heating had similar fuel consumption. Chart 7 shows mean bedroom and heating degree day relationships and the resulting regression-on-means values. The addition of a factor adjustment for water inlet temperatures produces results that appear consistent with RECS values at different HDD values to the extent comparison can be made.

Chart 7. Electric Water Heating Regression-on-means



4.3 Cold Water Inlet Temperature Adjustment

The temperature of cold water fed into a water heater significantly affects the amount of fuel needed to raise the temperature to a given standard. Inlet water temperatures are related to local climate, as measured by heating degree days, although not directly. This is explained at length in the first analysis funded by HUD [*Report 1*, pp. 25], and is not repeated here. This approach has been reviewed in two other studies and left unchanged. In addition, it provides results consistent with what limited direct comparisons can be made and its values fall neat the middle of the limited number of estimates of uncertain origin provided by utility companies. The formula for the computing cold water inlet temperature is:

Estimated Inlet Water Temperature [IWT] = 74.3 - 0.003161 * HDD

The water heater temperatures are normally supposed to be set at 120 degrees. If the inlet water temperature is 60 degrees, water would need to be heated 60 degrees to reach 120 degrees. The multiplier that reflects local climate is:

Multiplier = (60 - IWT)/100 + 1

This formula implies that for every degree that the inlet water temperature (IWT) is less than 60 degrees, there is a 1 percent increase in water heater consumption.

Table 16a shows the assumptions used in the examples related to derivation of water heating estimates. In practice, local HDD values would be provided by the current HUD model. Tables 16b and 16c show what estimates result from these assumptions when applied to this study’s regression results. Table 156 provides a comparison between electric and natural gas hot water heating at different values that cover the majority of the nation’s climatic areas.

Table 16a. Water Heating Adjustment Example Assumptions

Water Inlet Adjustement Assumptions	**Heating Degree Days**		
	2,000	**4,000**	**6,000**
Inlet Water Temperature	68.0	61.7	55.3
Multiplier	**0.920**	**0.983**	**1.047**

Table 16b. Electric Hot Water Consumption Estimates

Bedrooms	Constant	Bedrooms	2000 HDDs	4000 HDDs	6000 HDDs
2	4,431	1,691.2	7,190	7,684	8,178
3			8,746	9,347	9,948
4			10,302	11,010	11,718

Table 16c. Natural Gas Hot Water Consumption Estimates

Bedrooms	Constant	Bedrooms	2000 HDDs	4000 HDDs	6000 HDDs
2	6,367	5,097.6	15,240	16,287	17,334
3			19,931	21,301	22,670
4			24,622	26,314	28,005

Table 16d. Ratios of Electric to Natural Gas Water Heating Consumption

Bedrooms	2000 HDDs	4000 HDDs	6000 HDDs
2	47%	47%	47%
3	44%	44%	44%
4	42%	42%	42%

The heating consumption relationship between electric and natural gas hot water heating are fairly stable across common bedroom sizes, as can be seen in Table 16d. They imply that it takes 42-27 percent as many electric BTUs as natural gas BTUs to provide the same amount of water heating. The electric-to-gas ratio averages 0.44 if based on the one-to-five bedroom sizes, which are the only ones with enough data for meaningful estimates. Based on a review of the 1997, 2001, and 2005

RECS surveys, the current HUD model is using an electric-to-gas water heating ratio. The 2009 RECS data estimate provides a result that cannot be said to be statistically different.

4.5 Fuel Oil Water Heating

Water heating estimation for fuel oil is even more problematic than other water heating estimates. The relationship between BTUs from a gallon of fuel oil as compared to any given measure of natural gas is known. As with oil heating, however, the RECS measurement period for purchases can be very different than that for fuel deliveries. In addition, the regression results for fuel oil consumption are illogical – showing an inverse relationship between HDDs and consumption for smaller units. Past HUSM approaches, which are described in the reports noted in the bibliography, dealt with this problem by using partly engineering-based algorithms that provide somewhat higher BTU consumption for fuel oil than natural gas. This outcome is expected given the average relative ages and efficiency of equipment used for water heating. The differential that has been used, however, appears smaller than suggested by actual water heating data from RECS surveys. In place of applying a 1.1 factor to natural gas water heating BTUs to estimate fuel oil consumption, the same higher factor of 1.2 times natural gas water heating BTUs suggested in the 2012 report is recommended for use.

It is unusual for any structure type except single family detached to have residents who pay for their own fuel oil water heating. Except for single family detached renters, there were no renters included in any of the RECS surveys responsible for paying directly for fuel oil heating. There are a declining number of units with fuel oil water heating because of its relatively high cost and maintenance requirements. It is used in some apartment buildings with central water heating, which does not lend itself to individual billing. Structure type factors from gas space heating were used to provide oil heating estimates for other structure types. In practice, hot water heating with oil is increasingly rare and the estimates provided are at least good approximations of reality.

Cooking

No separate estimates for cooking consumption have been provided since the 1997 RECS, and only electric cooking estimates were given for that survey. As shown in Table 17, gas and electricity are by far the most common cooking fuels.

The manner in which gas appliance estimates are provided permits estimation of natural gas consumption for cooking for a limited number of cases. The method used in past HUSM models is to calculate cooking gas consumption with RECS data and apply a conversion factor to estimate electric cooking consumption. This makes conceptual sense and, in any case, there are no obvious alternatives. Use of more current data produces somewhat lower values, possibly partly due to increased use of microwave cooking.

Table 17. Primary Cooking Fuels Used in 2009

Structure Type	Primary Cooking Fuel				Total
	Natural Gas	Propane	Electricity	Other	
Mobile Home	114	112	301	1	541
SingleFamilyDetached	2,634	345	4,756	9	7,803
SingleFamilyAttached	343	4	533	1	890
Low-Rise	400	9	501	0	926
5+Floors	618	4	1,253	2	1,923
Total	4,109	474	7,344	13	12,083

5.1 Gas Cooking

Gas cooking consumption data can be extracted from RECS data as follows:

… *"natural gas cooking consumption was derived based on other variables. The total natural gas use in a household is primarily comprised of natural gas used for space heating, water heating, clothes dryers, and cooking. The RECS database includes variables for space heating, water heating, and appliance use. While this appliance use is not specifically attributed to clothes dryers and cooking, since those are the only remaining uses for natural gas in a household, that variable is assumed to represent the combined natural gas use for both cooking and clothes drying. By excluding records that contain [gas] clothes dryers, the cooking fuel consumption for natural gas was derived."*[5]

The previous approaches to estimating natural gas cooking were reproduced, keeping only cases that cooked with gas and didn't have gas clothes dryers. It was concluded that, as with water heating, micro-data regressions are inappropriate because of the unreliability of the resulting regression coefficients and low R-squared values. The 2009 survey differed from past surveys in that the variable name and estimation method for gas heating consumption exclusive of gas space and water heating had changed. The previous variable was "BTUNGAPL" and the 2009 variable is "BTUNGOTH." Both variables are indirectly estimated, since natural gas bills include a mix of uses. The imputation method used in 2009 results in somewhat higher gas cooking estimates than derived using the older method and do not appear directly comparable. The 2009 survey results are shown in Table 18.

[5] Report 5, Page 14.

Table 18. Natural Gas Use Other Than Space or Water Heating for Units Without Gas Dryer or Luxury Items

BEDROOMS	Mean KBTUs	Sample Size
Missing Value	7,315	60
0	3,582	3
1	5,369	342
2	8,557	704
3	11,059	825
4	16,094	299
5	24,214	71
6	14,519	9
7	16,281	3
8	18,964	1
Total	10,429	2317

The average BTUs for gas cooking for the 1997, 2001, and 2005 RECS surveys showed a notable downward trend in fuel consumption. This might be due to better-insulated ovens and the electronic ignition on most new gas stoves. It is suspected, however, that the large increase in microwave ovens and their associated use also had a significant impact. Microwave consumption falls into the "Other Electric" category, and is not included in the "cooking" component of Section 8 voucher program utility allowances. In any event, the decrease in cooking fuel consumption for stovetops and ovens was a significant trend in pre-2009 surveys, as shown in Table 19.

Table 19. Gas Cooking Consumption for 2- and 3-Bedroom Units

Survey Year	Average kBTU Consumption	Consumption as % of 1997 Average Consumption
Average	7,058	100.0%
1997	7,484	106.0%
2001	7,041	99.8%
2005	6,509	92.2%
2009	9,907	140.4%

The 2009 result is inconsistent with past estimates. Web-based estimates provided by the few utility company estimates found showed huge variability, largely because of differences in assumptions, and were not helpful in examining stove consumption. In the absence of more information, continued use of the 2012 report estimate based on the 1997-2005 RECS studies is recommended. This recommendation is based in part on the fact that a derived estimate for electric cooking using 2009 data matches the 2012 report gas cooking estimate if an adjustment is made for relative efficiencies based on heating fuel use ratios.

The recommended equation for natural gas cooking found in the 2012 report was:

$$\mathbf{BTUNG_{Cook} = 1296.5 * Bedrooms + 3999.6}$$

5.2. Electric Cooking

No method of separating electric cooking consumption in RECS data sets from other household uses of electricity is available. RECS provides separate electric consumption estimates for major appliances that use significant amounts of electricity. Comparing mixes of these can be used to indirectly measure electric cooking consumption, but is subject to error from the imputations used to develop the estimates compared. Past HUD research relied on engineering and statistical information in the professional literature to estimate electric cooking consumption and concluded that:

> *"These reports showed a range for the ratio of electric to gas cooking energy consumption being 0.4 to 0.6. Given the level of accuracy of these other sources, a factor of 0.5 was chosen and applied to the natural gas cooking energy consumption in order to estimate the electric cooking energy consumption."*[6]

Continuing to use this approach with combined data from the 1997-2001-2005 reports to develop an electric cooking estimation method results in the following equation:

$$\begin{aligned}\mathbf{BTU\underline{EL}_{Cook}} &= \mathbf{0.5 * (1296.5*Bedrooms + 3999.6)} \\ &= \mathbf{648.25 * Bedrooms + 1999.8}\end{aligned}$$

The 2009 RECS uses a different imputation procedures than in previous studies. It produces essentially identical results for two and three bedrooms, which are the only unit sizes to provide adequate sample sizes, as results based on earlier RECS studies. For instance, the three-bedroom 1997-2005 RECS estimate for annual electric cooking is 3,945 kBTUs for cooking and the 2009 RECS result is 3,992 kBTUs. In any event, electric cooking consumption is so relatively small that it is of limited concern.

5.2. LPG/Propane Cooking

Propane is used relatively infrequently for cooking. Obtaining consumption data that covers a one-year interval is plagued by the same problems as occur with fuel oil. That is, deliveries and purchases often do not match RECS survey periods or any other routine schedule. As in the past,

---

[6] Report1, page 28; Report5, page 16.

propane cooking consumption is assumed to require the same amount of energy as used for natural gas. DOE energy equivalency standards are used when appropriate.

Part 6. Other Electric

There is no RECS variable that matches HUD's definition of "Other Electric" utility expenses. RECS does, however, provide detailed figures on the number and type of virtually all electrical appliances normally found in a home. Total energy consumption for each fuel source as well as estimates for major appliances are also provided. The HUD utility schedule uses a similar but somewhat simpler approach.

RECS provides separate consumption estimates for air conditioning, refrigerators, water heaters, and space heating. It also has a 2009 variable that represents consumption for all other electrical uses. A list of RECS variable names and items for which individual electric consumption estimates are provided follows:

BTUEL	Total electric usage in 1,000s of BTUs
BTUELCOL	Electric consumption for cooling
BTUELOTH	Electric use for all but space or water heating, cooling and refrigerators
BTUELRFG	Electric use for refrigerators
BTUELSPH	Electric use for space heating
BTUELWTH	Electric use for water heating

Until 2009, RECS surveys provided separate, imputed electric consumption estimates for electric clothes dryers, dishwashers, and freezers. Their absence in the 2009 survey meant that the only way of estimating other electric consistent with HUD definitions was to subtract out estimated electric cooking consumption plus filter out any units with freezers or luxury features. This means that the estimates in this report are not consistent with those in the 2012 report.

Per guidance from the Office of Public and Indian Housing, the 2012 study included estimates for clothes dryers in calculating estimates for "Other Electric" for all structure types and bedroom sizes to the extent that, on average, they existed in the inventory. This is fortunate, since there is no longer a good basis for estimating their consumption.

6.1 Other Electric Computations

The derivation of "Other Electric" consumption was done separately by structure type as well as for the combination of all structure types. If there were enough sample cases for a given bedroom/ structure-type cell, scatter charts were created and regression lines run through the mean data points. There were consistent, simple linear relationships between bedrooms for values with sufficient cases to have confidence in the results. The regression values and regression-on-means values were very similar, but normal regression values were considered preferable in this instance.

Regressions were based on 1-5 bedroom values for single family detached and for whatever bedroom categories had sufficient sample sizes in the other categories.

The suggested regression values for Other Electric are provided in Table 20.

Table 20. Regression Values for Other Electric for Common Unit Sizes

Structure Type	Regression Factors		KBTU Estimates by Number of Bedrooms				
	Constant	Bedroom Factor	1	2	3	4	5
Mobile Home	7,359	3958	11,317	15,275	19,233	23,191	27,149
Single Family Detached	11,732	3801	15,533	19,335	23,136	26,938	30,739
Single Family Attached	7,505	3087	10,592	13,679	16,766	19,852	22,939
Apartment 2-4 Units	3,849	3726	7,575	11,301	15,026	18,752	22,478
Apartment 5+ Units	2691.6	3497.4	6,189	9,686	13,184	16,681	20,179

Table 21 shows the distribution of “Other Electric” mean values by number of bedrooms. The values in Table 20 and 21 are based on the same methodology used in previous years except for calculation changes resulting from definitional changes introduced in the 2009 RECS. The following observations are worth noting:

- The regression values shown are sometimes modestly higher than the 2012 study results. This may be due to different RECS imputation methods and changes in definitions.
- Other Electric values appear in part to be related to structure type. 5+-unit structure apartments have the lowest use.
- Mobile homes and single family detached homes with the same number of bedrooms generally had similar “Other Electric” consumption. The lower values for one-bedroom mobile homes are probably related to their generally quite small sizes.

Table 21. Other Electric Consumption by Bedrooms and Structure Type

Structure Types	Bedrooms	Mean kBTUs	Sample Size
All Structure Types	1	7,030	1043
	2	12,469	2359
	3	18,794	2624
	4	23,064	981
	5	26,622	180
Mobile Homes	1	11,526	27
	2	14,858	160
	3	19,442	143
	4	29,829	14
Single Family Detached	1	9,850	64
	2	15,307	686
	3	19,537	1976
	4	23,411	883
	5	26,687	172
	6	33,143	20
Single Family Attached	1	10,765	55
	2	12,988	331
	3	17,629	237
	4	19,507	50
Low-Rise	1	7,442	201
	2	11,564	414
	3	14,892	128
	4	18,117	22
High-Rise	1	6,182	696
	2	9,700	768
	3	13,177	140
	4	13,504	12

6.3.2 Trends Over Time

Previous RECS studies have shown that “Other Electric” use has been growing since the inception of the survey. Some 2009 estimates are lower, although on the whole results are very similar to those found in the 2012 report. What differences can be noted need to be treated with caution given 2009 definitional differences and normal statistical variance.

Part 7: Summary of Revised Estimation Equations

Table 22. Revised HUSM Equations

Utility	RECS Regression Parameters			# Bedrooms					
	Constant	HDD	HDDxBdrms	0	1	2	3	4	5
1.1 Gas Heating									
Mobile Home	Insufficient cases; assume single family detached consumption			32,721	38,495	43,765	49,036	54,307	59,577
Single Family Detached	13702.744	4.880	1.318	32,721	38,495	43,765	49,036	54,307	59,577
Single Family Attached	14311.694	2.478	1.618	26,089	30,693	37,164	43,635	50,106	56,577
Apartment 2-4 Units	8020.748	7.970	.755	36,483	42,922	45,941	48,960	51,979	54,998
Apartment 5+ Units	Insufficent sample for regression, use bedroom & structure type ratios			16,687	19,632	22,320	25,008	27,696	30,384
1.2 LPG Heating									
Mobile Home	Insufficient cases for analysis -- actual energy use for propane and natural gas assumed to be the same. The DOE conversion factor is 1 therm = 1.0949 gallons of propane.,			32,721	38,495	43,765	49,036	54,307	59,577
Single Family Detached				32,721	38,495	43,765	49,036	54,307	59,577
Single Family Attached				26,089	30,693	37,164	43,635	50,106	56,577
Apartment 2-4 Units				36,483	42,922	45,941	48,960	51,979	54,998
Apartment 5+ Units				16,687	19,632	22,320	25,008	27,696	30,384
1.3 Electric Resistance Heating									
Mobile Home	3,105.5	2.754	0.107	12,367	14,550	14,978	15,406	15,834	16,262
Single Family Detached	2,486.6	2.260	.546	11,654	13,711	15,895	18,079	20,263	22,447
Single Family Attached	2,888.3	0.908	0.597	7,572	8,908	11,296	13,684	16,072	18,460
Apartment 2-4 Units*	2,888.3	0.908	0.597	7,572	8,908	11,296	13,684	16,072	18,460
Apartment 5+ Units	1,874.1	.576	.485	5,944	6,992	8,106	9,220	10,334	11,448
* Single family attached used for 2-4 unit apartments.									
1.4 Heat Pump Heating									
Mobile Home	Apply engineering relationships to resistance heat values			5,813	6,838	7,039	7,241	7,442	7,643
Single Family Detached*				5,477	6,444	7,470	8,497	9,523	10,550
Single Family Attached				3,559	4,187	5,309	6,432	7,554	8,676
Apartment 2-4 Units				3,559	4,187	5,309	6,432	7,554	8,676
Apartment 5+ Units				2,793	3,286	3,810	4,333	4,857	5,380
1.5 Fuel Oil Heating									
Mobile Home	Use Natural Gas Factors			32,721	38,495	43,765	49,036	54,307	59,577
Single Family Detached				32,721	38,495	43,765	49,036	54,307	59,577
Single Family Attached				26,089	30,693	37,164	43,635	50,106	56,577
Apartment 2-4 Units				36,483	42,922	45,941	48,960	51,979	54,998
Apartment 5+ Units				16,687	19,632	22,320	25,008	27,696	30,384

Table 22. Revised HUSM Equations (cont'd)

2: Air Conditioning (Most rooms w/ AC)	Constant	CDD65	BEDxCDD	0-Bdrm.	1-Bdrm.	2-Bdrm.	3-Bdrm.	4-Bdrm.	5-Bdrm.
Mobile Home	-71.632	.495	1.300	2,227	2,621	4,571	6,521	8,471	10,421
Single Family Detached	162.910	-.593	1.967	1,890	2,223	5,173	8,124	11,074	14,024
Single Family Attached	-101.221	.446	1.378	2,239	2,634	4,701	6,768	8,835	10,902
Apartment 2-4 Units	-724.323	1.289	.861	2,126	2,501	3,793	5,085	6,377	7,669
Apartment 5+ Units	-278.491	1.177	.747	2,217	2,608	3,729	4,850	5,971	7,091

AC kBTUs = (constant + #bedrms *Beds + #bedrms * Beds*Beds) *Local CDD/Mean CDD; much higher r-quares with new equipment and excluding unusual values

2: Air Conditioning (Units with any AC)	(Constant)	CDD65	BEDxCDD	0-Bdrm.	1-Bdrm.	2-Bdrm.	3-Bdrm.	4-Bdrm.	5-Bdrm.
Mobile Home	-190.006	.532	1.281	2,150	2,530	4,452	6,374	8,296	10,218
Single Family Detached	42.077	-.371	1.854	1,927	2,267	5,048	7,830	10,611	13,392
Single Family Attached	-273.650	.548	1.347	2,184	2,569	4,590	6,610	8,631	10,652
Apartment 2-4 Units	-709.088	1.263	.849	2,090	2,459	3,732	5,004	6,277	7,550
Apartment 5+ Units	-313.671	1.177	.741	2,178	2,562	3,674	4,785	5,896	7,007

3: Water Heating	Constant	BED	0-Bdrm.	1-Bdrm.	2-Bdrm.	3-Bdrm.	4-Bdrm.	5-Bdrm.
Gas	6,366.5	5,097.6	9,583	11,274	16,287	21,301	26,314	31,327
Electric	4,430.6	1,691.2	5,117	6,020	7,684	9,347	11,010	12,673
LPG (derived from NG)	Use natural gas value		9,583	11,274	16,287	21,301	26,314	31,327
Fuel Oil*	Use natural gas value		9,583	11,274	16,287	21,301	26,314	31,327

* Apply temperature formula to results and use .9 of values for hi-rise

4: Cooking	**Constant**	**BED**	0-Bdrm.	1-Bdrm.	2-Bdrm.	3-Bdrm.	4-Bdrm.	5-Bdrm.
Gas	3,999.6	1,296.50	4,502	5,296	6,593	7,889	9,186	10,482
Electric	1,999.8	648.25	2,251	2,648	3,296	3,945	4,593	5,241
LPG (Use Nat. Gas value)	Use natural gas value		4,502	5,296	6,593	7,889	9,186	10,482

* Natural gas value

5: Other Electric	**Constant**	**Bedroom Factor**	0-Bdrm.	1-Bdrm.	**2-Bdrm.**	**3-Bdrm.**	**4-Bdrm.**	**5-Bdrm.**
Mobile Home	7,359	3958	9,620	11,317	15,275	19,233	23,191	27,149
Single Family Detached	11,732	3801	13,203	15,533	19,335	23,136	26,938	30,739
Single Family Attached	7,505	3087	9,003	10,592	13,679	16,766	19,852	22,939
Apartment 2-4 Units	3,849	3726	6,439	7,575	11,301	15,026	18,752	22,478
Apartment 5+ Units	2691.6	3497.4	5,261	6,189	9,686	13,184	16,681	20,179

Part 8. Additional HUSM Research Items

Although a number of questions that arose in the course of the research for this report were explored, others resulted from this research. Anomalies were found with some of the 2009 RECS-based estimates, especially as relate to electric resistance and heat pump heat. In general, however, the results provided in the December 2012 report appear sound. What effectively results in fairly minor changes are recommended based on the 2009 data.

The suggested matters for which further research would be desirable are:

- Collection of whatever data are available from a limited number of major utility companies on electric heat and heat pump consumption for existing structures. Utility companies often lack the detailed end-use data to be helpful, and are usually reluctant to release such data in any event. Seeking to obtain such information, perhaps with the assistance of an industry organization, is worth attempting.

- Engineering-based research on single-family heat pump and resistance heat consumption. Other structure type consumption could be based on RECS structure type consumption relationships.

- Test statistical accuracy of derived consumption methods by either using climate region groupings or by obtained state and county codes from RECS on micro-data.