HUD Utility Model (HUSM)

Rebenchmarking

Riley & Associates
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HUD Utility Schedule Model Rebenchmarking
Summary

This report summarizes research results 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 to:

- Evaluate the 1997, 2001, and 2005 Department of Energy Residential Energy Consumption Surveys (RECS) to determine what years would be best to use.
- Evaluate the best methods of estimating consumption for end use categories for the most common structure types and bedroom sizes.
- Establish simplified structure type categories that avoid overlapping.
- Group structures by age to reflect efficiency improvements, and establish a category for structures built in the past 10 years.

The Department of Energy (DOE) Residential Consumption Survey (RECS) has been conducted every three 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. Three earlier sets of HUSM equations were developed, each based on a single RECS survey. As part of this study, all of the previously-used equations were replicated. It was found that, if the same derivation methods were applied to different RECS surveys, the results were sometimes significantly different and the formulas derived often very different. RECS staff were consulted, and they indicated that neither data coding nor analytical problems appear to have produced these differences. It was concluded that use of a single year's sample could produce results that differed more than was anticipated or desirable using only the information available within the HUD voucher program. Given this finding and with input from RECS staff, it was decided that the best option was to merge data from the three most recent surveys to obtain larger sample sizes and increase model stability.

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. Sample sizes are inadequate for many of these categories even after combining data from the 1997, 2001, and 2005 surveys.
- Households living in identical units with differing use patterns can have very different energy consumption levels. Although good estimates of "typical" utility consumption can be estimated using an HUSM approach with large enough sample sizes, no predictive model that fails to include data on household use patterns plus more construction and heating and cooling equipment information than collected by PHAs will have high R-squared values (i.e., statistically very reliable estimates) for individual unit predictions.

- 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). Larger RECS sample sizes than might otherwise be needed are therefore required.

This analysis indicates that some significant simplifications to the HUSM model are advisable. Estimates based on combining the three surveys produce more stable and reliable results, but still indicate that some heating consumption estimates would be improved if they were based on relationships with more common heating fuels. In addition, the three surveys show a pattern of decreasing average heating and cooling energy use that continues a trend reflected in all RECS surveys to date. There was also a pattern of increasing “Other Electric” consumption related to use of more appliances, especially clothes driers and electronics, which it is less clear will continue.

It is worth noting that all estimates provided by RECS are developed using total actual energy consumption for a given fuel type. These values are distributed among end-uses when more than one end-use is involved. For instance, if natural gas is used for space heating, water heating, and cooking, RECS provides estimates for each end-use and the sum of these end-use estimates is forced to equal the total consumption figure obtained from a utility company. Although RECS total fuel consumption values should be extremely reliable, fuel end-use consumption estimates provided by RECS are based on derived statistical estimates that will not necessarily relate well to a specific unit. Another implication is that the revised estimates provided in this report may redistribute end-use estimates without changing total fuel consumption estimates when compared with the current HUSM estimates.

The revisions suggested in this report standardize and simplify HUSM calculations. Although past estimates had a statistical basis, that basis was not strong enough to preclude illogical relationships for less common utility/structure-type/bedroom-size estimates because of overlapping confidence intervals.[2] Two approaches were used to address this problem. Larger samples and stricter statistical standards eliminated some anomalies. For some categories, however, there was less data than desirable for analysis even using combined data from three surveys. In instances where statistical relationships were weak or highly suspect, ratio relationships from categories with larger sample sizes were applied.

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.

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

[2] Calculating confidence intervals for these estimates is difficult because the inefficiency of the sampling method used relative to HUSM modeling is unknown, but it appears that the confidence intervals for cells with few cases are large.

One underlying theme inherent in the data patterns examined for this report is worth noting—many energy conservation measures are a "one-way street" in that, once made, they do not measurably deteriorate. Large such investments have and continue to be made in existing home insulation and windows. Improvements in heating, cooling and refrigeration equipment also have been significant, and benefit old as well as new homes.

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 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.

As part of this study, the engineering firm of GARD Analytics developed a method for trending average utility consumption decreases by taking into consideration three factors:

- heating and cooling equipment efficiency improvements tied to industry practices, code changes, and energy efficiency incentives;
- heating and cooling equipment retirement and replacement; and,
- heating and cooling structural load improvements (e.g., due to better insulation and tighter building envelopes).

Some assumptions had to be made in developing trending estimates that are detailed in Appendix 2. There is little reason to believe that any of these assumptions is likely to prove significantly in error over the time interval during which they would be applied (i.e., from the date of the most recent RECS data release used until the "as of" forecast date of the model if estimates are trended). In practice, the estimates may understate efficiency gains for reasons discussed in the body of this report.

The mid-point of the data used to develop the revised estimates is 2001, and some adjustment to these estimates is needed to obtain a more current estimate of average residential energy consumption. GARD estimated that average air conditioning consumption decreased approximately 21 percent from 2001 to 2012, and that average heat pump consumption decreased by 22 percent. For heating, there was a 4 percent reduction for furnaces, 22 percent for heat pumps, and no change for electric resistance heat.[3] The equipment efficiency factors quoted need to be multiplied by the change to the estimated load improvements for residences (i.e., structural efficiency improvements) of 4 percent for cooling and 13 percent for heating to estimate average total energy savings.

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[3] The GARD estimate relates solely to the efficiency of electric resistance heating equipment. No real improvements in resistance heat equipment efficiency have been made, partly because it is already highly efficient in terms of consumption at the point of end-use. RECS data show significant decreases in average residential consumption for resistance heating, but most of this change may be due to building envelope improvements plus conversions of less-than-average efficiency resistance heat homes to heat pumps or other heating sources.

The question of exactly what trending adjustment(s) to make for Section 8 voucher rental units is less clear, since revised model estimates are based on all units rather than only rental units because of sample size requirements. For the two structure type categories where ownership units dominate – single family attached and detached – rental units are older and less efficient but also smaller. Given that subsidy payment standards for voucher units are calculated to provide for modest, standard quality housing, it is doubtful that most program units fall into the very lowest rent categories, but they are still very likely to be in the bottom half of the rent distribution. Even under the most conservative assumptions, heating and cooling equipment need to be periodically replaced and the least expensive replacements that can be purchased are almost certain to be far more efficient. It is still something of a leap of faith to apply average utility consumption estimates to single-family detached and attached program rental units. Landlords with tenant-paid utilities have little incentive to replace heating and cooling systems with anything other than the least expensive alternatives that meet housing code requirements. Nor do they have much incentive to be concerned about improving the building envelopes of their structures.

Energy Star construction was also examined with the goal of developing an adjustment for the improved efficiencies it produces. There were about 1.2 million Energy Star residences in 2010 and more continue to be built. RECS does not provide any information on Energy Star homes. GARD Analytics conducted a literature search on related engineering studies, which showed that it was significantly more efficient than new construction built to typical local building codes. However, it was also noted that at least some Energy Star residents are less conservative in their heating and cooling temperature settings. To further confuse matters, the Energy Star program has been successful in promoting a number of cost-effective building practices that exceed local building code requirements and have become relatively common in the industry. Estimates related to this are provided in the body of the report and Appendix 3. Some adjustment appears warranted. It is recommended that the adjustment applied should include a new construction adjustment plus trending adjustments in addition to whatever Energy Star adjustment HUD decides to add. The most reasonable decrease factor for Energy Star construction, apart from the two other adjustments, appears to be in the 4 to 12 percent range.

In the two tables on the following page, this report's estimates are compared with a slightly updated version of the current HUSM model using the approximate U.S Heating Degree Day (HDD) average of 4,000 HDDs and the Cooling Degree Day (CDD) average of 1,500 CDDs. Any heating efficiency changes shown will be somewhat greater in colder than average areas, and somewhat less in warmer than average areas. The two comparisons are as follows:

- Table 1 shows revised energy consumption values developed in this study expressed as a percentage of current HUSM estimates.
- Table 2 shows 2001-2012 energy improvement-adjusted report values expressed as a percentage of current HUSM estimates.

The underlying values for each utility end-use category plus summary tables with energy consumption values are provide in Appendix 1, Table 18. A comparison table showing energy use reductions due solely to equipment efficiency gains is also provided.

Table 1. Energy Consumption: Revised Estimates Compared to Current Model

Revised Model as % of Current HUSM Model (shaded cells most common)						
Gas Used for Heat and Hot Water	**Bedrooms**					
	0	**1**	2	**3**	**4**	**5**
Mobile Home	95%	101%	107%	110%	112%	111%
Single Family Detached	111%	119%	107%	97%	92%	88%
Single Family Attached	117%	125%	108%	95%	87%	80%
Apartment 2-4 Units	105%	113%	105%	98%	94%	90%
Apartment 5+ Units	101%	108%	110%	109%	109%	106%
All Electric, Resistance Heating						
Mobile Home	78%	84%	92%	92%	91%	90%
Single Family Detached	90%	97%	94%	89%	87%	85%
Single Family Attached	89%	96%	92%	87%	85%	83%
Apartment 2-4 Units	78%	84%	86%	84%	84%	84%
Apartment 5+ Units	80%	86%	86%	86%	85%	83%
All Electric, Heat Pump Heating						
Mobile Home	79%	86%	92%	92%	91%	90%
Single Family Detached	87%	94%	92%	88%	86%	85%
Single Family Attached	88%	96%	92%	86%	84%	82%
Apartment 2-4 Units	75%	81%	85%	83%	83%	83%
Apartment 5+ Units	79%	86%	86%	86%	85%	83%

Table 2. Energy Consumption: Revised Estimates with Estimated 2001-2012 Consumption Reductions Compared to Current HUSM Model

Revised Trended Model as % of Current HUSM Model (Trended from 2001 to 2012; shaded cells most common)						
Gas Used for Heat and Hot Water	**Bedrooms**					
	0	**1**	2	**3**	**4**	**5**
Mobile Home	85%	91%	97%	100%	102%	101%
Single Family Detached	99%	106%	96%	88%	83%	79%
Single Family Attached	104%	111%	97%	86%	79%	73%
Apartment 2-4 Units	94%	100%	95%	88%	85%	82%
Apartment 5+ Units	93%	99%	101%	101%	100%	97%
All Electric, Resistance Heating						
Mobile Home	73%	78%	86%	86%	86%	85%
Single Family Detached	84%	91%	87%	83%	81%	79%
Single Family Attached	83%	89%	86%	81%	80%	78%
Apartment 2-4 Units	73%	78%	81%	79%	79%	79%
Apartment 5+ Units	76%	81%	82%	81%	80%	78%
All Electric, Heat Pump Heating						
Mobile Home	73%	79%	84%	85%	84%	83%
Single Family Detached	79%	85%	84%	80%	79%	77%
Single Family Attached	81%	88%	85%	80%	78%	76%
Apartment 2-4 Units	70%	75%	78%	77%	77%	77%
Apartment 5+ Units	74%	80%	81%	80%	79%	77%

Implementation formulas for all suggested changes are provided in the body of this report. The most significant are as follows:

- **Use combined data** from the 1997/2001/2005 RECS surveys until 2009 consumption data become available and can be analyzed. Such analysis will probably require combining the 2009 RECS data with 2005 and possibly 2001 surveys to obtain adequate sample sizes.
- **Reduce the number of structure types** from twelve to four or five. The structure types in the current model have overlaps, and some categories are too finely distinguished to show meaningful differences. The structure categories recommended for use are:
    - mobile homes,
    - single-family detached,
    - single family attached (i.e., duplexes or town houses)
    - 2-4 unit apartments exclusive of single family attached, and
    - 5+ unit apartments.

  Even the differences between row houses and 2-4 unit structures are statistically in doubt, but it may be advisable to wait until the larger samples from the 2009 RECS can be analyzed prior to deciding whether to merge these categories.
- **Apply single family and 5+ unit apartment bedroom and energy use ratios to other structure types and sizes with insufficient data**.
- **For efficiency units (i.e., 0-bedrooms), set energy consumption values at 85-86 percent of the respective one-bedroom values**. Regression results for efficiency units are often unreliable or inappropriate for reasons noted in this report.
- **Use a simple, standardized regression form for all heating fuels except oil**. More complex forms produce, at best, only slightly better results. The fact that the form with the highest R-squared varies from survey to survey argues for use of a standardized form. For oil, continued use of the current HUSM derivation methodology is recommended.
- **Apply an energy efficiency trending factor to heating and cooling**. The efficiency gains related to equipment appear applicable to voucher program units, but those due to building envelope improvements appear more questionable.

There are three questions that need to be considered by HUD if most or all of the estimates provided in this report are to be implemented. The first relates to whether some or all of the energy efficiency trend estimates developed by GARD Analytics should be implemented. From a technical perspective, at least the equipment efficiency gains should be applied to existing Section 8 voucher units. A technical recommendation for the other two matters is more difficult, since they need to be decided within the context of HUD policy and program administration complexity. Information on these is provided in the body of this report. The two questions that need to be addressed are as follows:

1. Should adjustments for structure age continue to be used?
2. What adjustment should be allowed for Energy Star Construction?

Part 1. Background

The HUSM model calculates utility allowance schedules for utilities paid by 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). Accomplishing this in a competent manner has been a complex and time-consuming task. The HUSM was developed to provide reasonably accurate utility schedules with a modest staff time investment.

Utility costs usually vary widely even for housing units of similar size, age, and construction characteristics within the same locality. The best and effectively only detailed national data on this subject comes from the Department of Energy's Residential Energy Consumption (RECS) surveys. This information, however, is only statistically 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.

It is worth remembering that the objective of this effort is to produce a means of estimating "typical" utility costs for a given construction type with a specified set of utility rates in a designated area. Utility consumption data analysis indicates this is a reasonable goal. 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. There are also often large utility consumption variations among structures that otherwise 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 improvements to existing structures (e.g., added ceiling insulation, added exterior wall insulation, and new thermopane windows or storm windows).
- Differences in construction practices (e.g., due to differences in state and local building codes, code enforcement, builder practices, and application of Energy Star or equivalent standards).
- Extent of energy efficiency improvements to existing structures – 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.

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 or therms. Similarly, the standard American measures of volume are used for water and natural gas. The conversion relationships used in this report are the current BTU-equivalent values published by the Department of Energy, as follows:

Table 3. 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.			

Weighted versus Un-weighted 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 values 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. To reduce confusion, the various reports are referenced by using the name in the first column of the following table:

Table 4. 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 ***This report***	1997 2001 2005	12/22/2012	20121222.Report6.HUSMRebenchmarking.Report.doc and 3 appendixes. *This report.*	Riley Fox GARD

Part 2. Space Heating

All estimates provided in this report are based on combined data from the 1997, 2001, and 2005 surveys unless otherwise noted. Combined data are normally shown in all tables because these data formed the basis for the energy consumption estimates provided. Each year's RECS sample was independently selected, so using three years of data roughly triples the independent data points for analysis. Given modest sample sizes relative to the number of structure type, size, and fuel mix categorizations required for HUD utility schedules, combining data from different surveys was needed to provide as many sample cases as possible for analysis. The downside of using multiple years of data is that energy efficiency improvements occur even over fairly short time spans, so data from an eight year range (i.e., 1997-2005) has some disadvantages.

2.1 Information on Combined 1997/2001/2005 RECS Heating Fuel Use

Fuel: Piped natural gas is the most common primary form of heating. It was used by an average of 52 percent of all units in the three surveys. Electricity was used for heating by 28 percent of all units, oil by 10 percent, and LPG/propane by 5 percent.

Table 5. Main Heating Fuels by Structure Type (*Weighted estimates*)

Main Heating Fuel	Mobile Home	Single Family Detached	Single Family Attached	Apartment 2-4 Units	Apartment 5+ Units	Unweighted Sample Count	Weighted Sample Count
Unknown	0.7%	0.3%	0.2%	0.0%	1.0%	0.4%	0.2%
Gas	31.2%	55.0%	64.3%	59.2%	38.0%	52.0%	53.5%
LPG	17.5%	6.4%	1.3%	0.5%	0.4%	5.4%	4.9%
Oil	3.0%	11.5%	7.4%	9.9%	9.6%	10.2%	7.9%
Kerosene	5.3%	0.8%	0.2%	0.5%	0.2%	0.9%	0.8%
Electric	30.3%	13.1%	17.5%	24.5%	41.2%	19.7%	20.3%
Wood	3.4%	3.3%	0.5%	0.5%	0.1%	2.4%	2.2%
Solar	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
District Steam	0.0%	0.0%	0.0%	0.1%	1.0%	0.2%	0.1%
Coal	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
Heat Pump	7.6%	8.8%	8.2%	3.8%	5.9%	7.9%	9.1%
Other	0.2%	0.2%	0.0%	0.0%	0.6%	0.2%	0.2%
No Heating/NA	0.9%	0.5%	0.3%	0.9%	1.9%	0.7%	0.7%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5 shows that the estimated weighted counts for main heating fuel have a modestly different distribution than the un-weighted sample distribution. 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 in subsequent tables.

Heading Equipment: Ducted delivery is the most common, and is used by 57 percent of all units.[4] Radiators are used in 15 percent of all residential structures, heat pumps by 8 percent, and various forms of wall units and portable heaters used by about 17 percent. More details are provided in Table 1 of Appendix 1.

The RECS surveys indicate some clear trends over time. Preliminary 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 directly 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 6 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.

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. Even with combining three surveys, sample sizes are sometimes small even before subgrouping by heating fuel. Regression analysis was conducted using standard criteria for initial testing[5] 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
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: A housing unit can use several different heating fuels. For example, a gas-heated home may use portable electric heaters to heat some rooms. 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, and relatively small samples of mobile homes, single-family attached, and apartments with 2-4 units. 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.[6]

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[4] 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.

[5] 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.

[6] 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.

Table 6. Structure Type and Bedroom Size Samples for Common Heating Fuels

Main Heating Fuel	**Bedrooms**	**Structure Type**					Total
		Mobile Home	Single Family Detached	Single Family Attached	Apartment 2-4 Units	Apartment 5+ Units	
Natural gas	0	0	3	2	6	62	73
	1	21	93	60	170	344	688
	2	175	880	329	309	369	2,062
	3	107	2,617	324	125	57	3,230
	4	3	1,206	95	23	6	1,333
	5	2	223	17	5	1	248
	6	0	37	2	0	0	39
	7	0	5	0	0	0	5
	8	0	1	0	0	0	1
	9	0	1	0	0	0	1
	Total	308	5,066	829	638	839	7,680
Fuel oil	0	0	0	0	2	15	17
	1	1	24	4	30	92	151
	2	16	202	18	49	82	367
	3	10	493	48	22	18	591
	4	1	258	14	3	5	281
	5	0	60	7	1	0	68
	6	0	13	2	1	0	16
	7	0	2	0	0	0	2
	8	0	2	0	0	0	2
	Total	28	1,054	93	108	212	1,495
Electric	0	1	1	4	9	41	56
	1	20	35	27	76	398	556
	2	127	219	112	150	403	1,011
	3	131	642	67	26	77	943
	4	12	189	8	2	6	217
	5	2	37	2	0	1	42
	6	0	2	0	0	0	2
	9	0	1	0	0	0	1
	Total	293	1,126	220	263	926	2,828
Heat Pump	0	0	0	0	1	10	11
	1	2	5	2	6	56	71
	2	19	86	48	31	55	239
	3	48	450	40	4	11	553
	4	5	175	10	0	1	191
	5	1	28	1	0	0	30
	6	0	5	0	0	0	5
	Total	75	749	101	42	133	1,100

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 provided enough sample cases to be useful, which is unsurprising since oil heat is unusual in other structure types where tenants pay separately for heating fuel. 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 7 shows the results of filtering out the least common heating fuels and unit sizes. Even 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. That there were insufficient cases for analysis for some categories implies that few voucher program units are likely to require related utility schedules. 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.

Table 7. Common Bedroom Sizes and Heating Fuel Types for Structures with Less Than 10.5% Secondary Heat Source

Main Heating Fuel	**Bedrooms**	**Structure Type**					**Total**
		Mobile Home	**Single Family Detached**	**Single Family Attached**	**Apartment 2-4 Units**	**Apartment 5+ Units**	
Natural gas	1	21	0	60	170	344	595
	2	175	880	329	309	369	2,062
	3	107	2,617	324	125	57	3,230
	4	0	1,206	0	0	0	1,206
	Total	303	4,703	713	604	770	7,093
Fuel oil	1	1	0	4	30	92	127
	2	16	202	18	49	82	367
	3	10	493	48	22	18	591
	4	0	258	0	0	0	258
	Total	27	953	70	101	192	1,343
Electric	1	20	0	27	76	398	521
	2	127	219	112	150	403	1,011
	3	131	642	67	26	77	943
	4	0	189	0	0	0	189
	Total	278	1,050	206	252	878	2,664
Heat Pump	1	2	0	2	6	56	66
	2	19	86	48	31	55	239
	3	48	450	40	4	11	553
	4	0	175	0	0	0	175
	Total	69	711	90	41	122	1,033
Totals for Selected Fuel and Bedroom Types		399	6,367	873	746	1,084	9,469

2.2 Two Ways of Predicting Heating Consumption

Past HUSM models have predicted most heating consumption using regressions based on RECS microdata (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 because RECS microdata produce inconsistent results. This study also tested this approach for heating fuels with limited data and/or questionable results. It appears that the second method is more stable over time for single-family detached dwellings, but not for large apartments. The second method also works better for mobile homes and for oil heating.

2.2.1 Predicting heating consumption using RECS Microdata

Even for fuel subcategories with large sample sizes, there is significant variation in predicted consumption among the three RECS survey waves for some structure types and heating fuels. This is shown by the regression coefficients and single-year model estimates. These differences cannot be explained by differences in heating degree day patterns for the survey years, which could conceivably produce different regression results if patterns had changed substantially in different surveys. RECS consumption estimates are not normalized for weather because that would involve modeling rather than basing reported figures on actual consumption, but the HDD/CDD differences for the years examined were generally not significant and did not explain the consumption differences observed.

Table 8 on the following page shows the regression values for a typical single-family detached 3-bedroom home with gas heating. All estimates shown in this and most tables related to the approximate U.S. average of 4,000 HDD values because this normally provides a basis for valid generalizations. Using the 2005 RECS and a 4,000 HDD value to develop the admittedly simple regression form possible with available program data results in a predicted consumption of 48,081 kBTUs annually. This is less than 75 percent of the 64,474 kBTUs predicted from the 1997 RECS. Both predictions use precisely the same methodology, functional form, structure type definitions, and filters. Generally, for gas heating of single-family detached houses, the 2005 RECS estimates are the lowest of the three surveys and the 1997 estimates are the highest. Part but not all of the differences can be attributed to energy conservation improvements. Some the other differences observed at the 4,000 HDD level are:

1. For gas-heated two-bedroom apartments, the 2001 RECS estimates are lowest, while 1997 and 2005 estimates are similar.
2. For electrically heated, three-bedroom, single-family detached homes, the 2005 RECS predicts about one-half the consumption of either the 1997 or 2001 regressions.
3. For electrically heated two-bedroom units in 5+ unit apartments, the 2001 RECS predictions are higher than either the 1997 or 2005 regressions.
4. Bedroom consumption relationships changed somewhat due to use of more data. For gas heat, for instance, single family detached one and two bedroom units have higher consumption relative to three-bedroom units than shown by the one year of RECS data used to produce the regression found in the current HUSM model.

Table 8. Regression Values for 3-Bedroom Single Family Homes with Gas Heating
(4,000 HDDs

Type Heat and Number Bedrooms	Regression Coefficients [All Sizes]					Predictions at Selected HDD		
	Intercept	HDD	HDDxBED	#Cases	R^2	2,000	4,000	6,000
All Years 1997-2001-2005	11,353	6.856	1.572	4,703	0.39	34,497	57,641	80,785
RECS 1997	15,210	6.640	1.892	1,809	0.40	39,842	64,474	89,106
RECS 2001	15,290	4.377	2.101	1,515	0.39	36,650	58,010	79,370
RECS 2005	3,649	8.438	0.890	1,373	0.44	25,865	48,081	70,297
Ratio: 2005/1997						65%	75%	79%

Despite testing a number of alternative approaches as part of the research for this report, we were no more successful than past researchers in improving the consistency of regression results using different data years. Even adding a limited number of additional variables that could conceivably be collected for program use to try to improve results was of little help.[7] We also explored with RECS staff the possibility that changes in survey design or data processing might be the cause of the problem, but found nothing to indicate that either was the case. In general, the estimates for different years reflected energy conservation improvements, but there also appeared to be other factors that caused some randomness in this pattern.

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 burden 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 less ambitious objective is more compatible with the limited data that PHA staff are required to collect on Section 8 voucher units, and it doubtful that it would be realistic or cost-effective to require the extensive additional information needed to significantly increase estimate reliability.

No single RECS survey can be said to be “good” or “bad” based on the consistency of its regression outcomes using only the variables available for use with the Section 8 voucher program. Based on our analysis and contacts with RECS staff, samples from the last three RECS surveys with complete end-use consumption data were used to increase effective sample sizes and reduce inconsistencies.[8] The main disadvantages of this approach are that new structures tend to have more efficient heating and cooling systems and that existing structures have also been improving their energy efficiency. Ideally, some method of trending energy efficiency improvements to adjust dated RECS-based estimates is therefore desirable, which is especially true when RECS data releases are delayed (e.g., most current detailed consumption data were from 2005 as of the date of this 2012 report).

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[7] ‘For example, adding heated square footage as an additional explanatory variable did not produce better results.

[8] The 2009 RECS survey has larger sample sizes than in previous years. Although it is probably not large enough for use by itself for most calculations, combining it in un-weighted form with the 2001 and 2005 surveys would update predictive estimates and may well improve them.

The detailed results of regressions based on combining the three most recent RECS surveys are provided in Table 4 of the Appendix 1. Using the combined survey data, regressions were run separately by structure type and fuel. Many functional forms were tested, but the simplest works just about as well and more consistently as the others, and is the easiest to reproduce[9]. This relatively simple form is:

HeatingBTUs = HDD factor * HDD + HDD-Bedroom factor * HDDxBR + equation constant, where:

HeatingBTUs = BTUs of gas (thousands)
HDD = Heating Degree Days for measurement year
BR = Number of bedrooms

The reason why a composite HDDxBR term was tested and used in this and past HUSM regressions is that it provides a multiplicative relationship to reflect the fact that consumption increases by more BTUs per additional bedroom in colder than in warmer climates. Thus, an additional bedroom requires *x* percent more consumption, rather than *x* more BTUs. The regression coefficients are different, although the explanatory power of the models for gas and electrically heated single family detached homes are similar.

Problems with results for 0-bedroom and mobile home units: Most of the regression results for 0-bedroom (efficiency) units were suspect. This was partly due to small sample sizes, but it is suspected other forces were also at play.

For mobile homes the coefficients and intercepts were radically different from survey to survey. In addition, the coefficient for bedrooms is negative, which implies that larger mobile homes use less energy for heating than smaller ones. Given the possibility that smaller (i.e., 1 bedroom) mobile homes might be older and less energy-efficient, a regression was run limited to mobile homes built within 21 years of the respective surveys. The results were essentially the same—a negative coefficient on bedrooms. These latter results are not as conclusive as desired because there were only 64 mobile homes in the "newer" age range that heated with gas (the most common heating fuel for all structure types), which is too few to produce statistically valid results given the significant variability in HDD values and unmeasured factors such as occupant use patterns and construction quality. As with past research using program-available variables, the R-squared values are much lower than can be obtained with a much larger range of RECS variables such as those used in the DOE2 and successor models.

2.2.2 Predicting heating consumption using RECS Means

A method suggested by GARD Analytics, an experienced engineering firm that specializes in energy modeling and analysis, is to compute mean consumption by the number of bedrooms and run a regression line through the means (*Report 5*, page 11). 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 would only be desirable in situations where sample sizes for microdata regressions were

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[9] This is equivalent to model M6 in Report 4.

inadequate or inappropriate. (Detailed results are shown in Table 5 of Appendix 1.) 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;[10]
3. Predict consumption for all sizes (0 to 5 bedrooms) for each structure type;
4. Compute mean HDD for each structure type, combining all 3 RECS years;
5. Adjust the prediction for each value of HDD by the ratio of the HDD value to the average HDD value in step 4.

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:

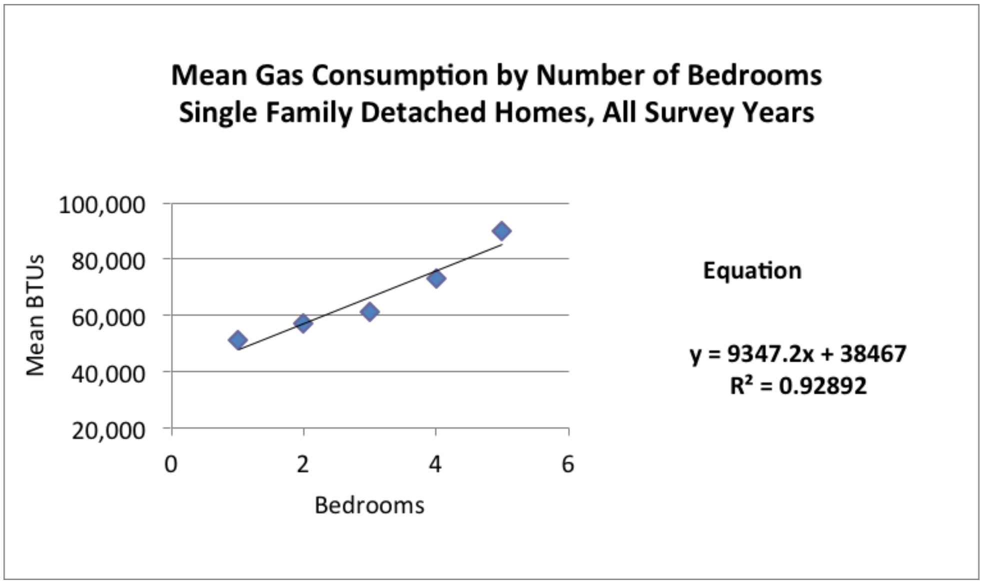
1. The linear trend line equation through the means is: y = 38467 + 9347.2 x Bedrooms
2. For 3 bedrooms the prediction is 38467 + 9347.2 * 3 = 66,509 kBTU;
3. The mean HDD for single-family detached homes is 4,467;
4. The adjusted prediction for homes at 4,000 HDDs is:

   66,509 * 4,000/4,467 = 59,555.
5. Thus, for single-family detached homes the complete formula is:

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

The data and trend line are shown in the following table:

Table 9. Regression Using Gas Consumption Means



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[10] Using only sizes where there were at least about 60 sample cases.

These calculations were repeated for electric heating with similar results. It should be noted that electric heating is most common in milder climates. Consumption estimates for electric as well as other types of heating are least reliable in climatic areas where few units use a given heating method. The mean HDD value for units heated with electricity was about 3,300 HDDs, while that for units heated with natural gas was about 4,600 HDDs.

2.2.3 Sensitivity over RECS Survey Years

The two structure categories with the most units and therefore the most reliable statistical results are single-family detached and 5+unit apartment multi-family structures. The regression on means approach yields modestly more consistent results over time for single-family detached homes, but it is less consistent for apartments with 5+ units. This outcome was not expected. All related calculations and data files, however, were closely examined and verified. Repeating the same calculations with case weighting to produce sampling universe estimates produced similar results.

It was concluded that there is little to be gained by using the second order method for most gas and electric heating predictions, and continued use of microdata regressions is normally recommended. The regression-on-means method, however, provides more plausible results for mobile homes and oil heating, as is subsequently discussed.

2.3 Propane/LPG Heating

Propane as a primary heat source is used by less than 5 percent of all residences. There were too few propane cases to produce statistically acceptable results even after combining data from three RECS surveys. As was done in past studies, propane heating consumption estimates were calculated by assuming that the characteristics and use patterns for propane-heated homes were the same as those for natural gas. In practice, this means converting kBTU consumption for natural gas into into gallons of propane. The generally accepted, current EIA equivalency standard is that 100 kBTUs of natural gas has the same energy content as 1.09489 gallons of LPG/propane. (This is a slightly higher conversion factor than the older measure used in the current HUSM model.)

2.4 Electric Resistance Heating

Predicted consumption for electric resistance heating is shown in Appendix 1, Tables 4 and 5. Until recently, HUSM estimates for electric resistance and heat pump heating were lumped into one category when deriving consumption estimates. The increasing use and relative efficiency of heat pump heating has provided sample sizes large enough to measure differences in the two heating methods.

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 decreases in average electric resistance heating consumption from 1997 to 2005. The reasons for this are unclear, but two are suggested for consideration. One is that owners of resistance-heated structures had above average financial incentives to make energy efficiency improvements. The other is that 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. In other words, the likely explanation for the decrease in average consumption is because of changes in the inventory rather than improvements in equipment efficiency.

The resistance heat estimation process selected for use, with one exception, is based on microdata regressions. The exception is 2-4 unit apartments, which had a relatively modest sample size. The regression values fell below the standards applied and the equation results were clearly inconsistent with other observed patterns. This anomaly also occurred with regression on means values, which were otherwise similar to the microdata regression values, and is likely due to a sampling or data problem. Since single family attached and 2-4 unit apartment heating consumption estimates were very similar for other heating types, these values were substituted for the 2-4 unit regression values.

The kBTU consumption for resistance and heat pump heat estimates provided by RECS and used to develop the models in this and past reports show remarkably lower consumption than for oil or natural gas heat. There are several possible reasons why this occurs:

- Assuming that a gas furnace is 70%-80% efficient (estimated average values, although efficiencies of higher than 90 percent are possible with new furnaces) and oil furnaces somewhat worse, gas kBTU consumption estimates are going to be 20%-30% higher than the electric resistance numbers.
- Many localities have stricter energy efficiency construction standards for electric resistance heating.
- The cost of heating with electricity tends to be higher, since a BTU of electricity costs two to four times as a BTU of natural gas in most areas. This provides a strong incentive for occupants paying for their own electricity to be more frugal and consider adding insulation or weather stripping where they would be of value.
- Electric resistance heating is often zonal with electric heating units controlled in each room with a local thermostat. This permits residents to turn down or off heat in rooms not being used for part or all of a day, which would use much less energy than if a whole house is being heating.
- The estimates provided by RECS start with the monthly total electricity and natural gas consumption and disaggregate how much is used for heating, cooling, water heating, etc.. This estimation process is based on a number of assumptions, and consistency between gas heating and electric heating has not been one of them. It is difficult to assess how much this might bias heating estimates, although it is doubtful it could be by a large amount.

2.5 Electric Heat Pump Heating

Combining survey data provided enough cases to estimate heat pump consumption for single family detached homes. Two estimation methods were tested. 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 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, so regression calculations cannot be used to provide good estimates over a wide range

HDD values. In addition, the regression values for heat pumps are much lower than for gas or oil heat, but not much lower than for electric resistance heat even though large differences are known to exist in moderate climates. The reasons for the limited differences with electric resistance heat are unclear, but may again relate to the range of climatic areas where heat pumps are found as opposed to the distribution of areas where resistance heat is used.

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.

An example of the heat pump estimation method is shown for Detroit using the current HUSM model with an adjustment factor of 0.56 (i.e., that heat pumps are estimated to use 56 percent as much electricity as electric resistance heating in this climate zone):

Electric Heat Pump 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 6.7. The revised estimates in this report assume an average HSPF of 7.85. 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 common, and ones with HSPFs of over 20 can be purchased. What are referred to as ground effect heat pumps (i.e., with buried heat exchangers) are far more efficient than the air source heat pumps commonly in use, but it is unclear if they will win widespread market acceptance.

It should be noted that there appears to be an inconsistency between the calculation methods for resistance and heat pump heat and RECS values. The resistance heat estimates are based on RECS. The heat pump values shown by RECS are lower than the resistance heat values, but not nearly as much lower than the engineering approach recommended for continued use. Heat pumps are clearly far more efficient currently than resistance heating. A possible explanation is that resistance heat, which is typically zoned, is often turned down in rooms not in use. Heat pumps as well as other major heating sources do not lend themselves to this degree of control. Further study on this is desirable once 2009 RECS data become available.

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.

RECS samples for the aggregated surveys provide 1,082 single-family detached homes with oil heat and limited samples for other structure types. The single family detached sample size is further reduced by filters that eliminate unusual unit sizes and high levels of secondary heating. There are two more serious problems. One is that oil is typically 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 coincidence, but is the only information available for that purpose. The other issue is that oil consumption is highly concentrated in relatively higher heating degree day areas in the Northeast. Oil heating samples therefore do not provide good representation for all climate conditions. Worse, they are concentrated in a relatively limited heating degree range. For all these reasons, oil heating estimates based on RECS data need to be treated with caution.

2.6.1 Regressions Using RECS Microdata

Unlike regressions for gas and electric heating, the 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. Oil Heating Regressions

	Regression Coefficients								**Predictions at Selected HDDs and Number of Bedrooms**			
					BEDx HDD				**Bed-Rooms**	**BTUs/year (thousands)**		
	Constant	**Sig**	**HDD**	**Sig**		**Sig**	**n**	**R^2**		**2,000**	**4,000**	**6,000**
Delivery Method												
All Units	43,054	0.00	0.091	0.93	2.61	0.00	1,436	0.19	3	58,896	74,738	90,580
Radiator Hot Water	26,784	0.00	2.760	0.06	2.91	0.00	847	0.25	3	49,758	72,732	95,706
Warm Air Ducts	54,315	0.00	-1.149	0.37	2.10	0.00	588	0.13	3	64,623	74,931	85,239
					Note: this is swamped by BEDxHDD coefficient							
1997	44,517	0.00	-0.988	0.53	3.24	0.00	627	0.25	3	61,969	79,421	96,873
2001	43,004	0.00	-2.940	0.08	2.95	0.00	445	0.19	3	54,836	66,668	78,500
2005	63,922	0.00	0.358	0.84	1.63	0.00	362	0.11	3	74,436	84,950	95,464

The plausibility of the regression estimates shown in Table 10 becomes more suspect when the results are examined in detail:

1. There is relatively little difference by climate—the estimated consumption at 6,000 HDD is only about 54 percent higher than at 2,000 HDD while it would be about three times as high if based on typical relationships for other heating fuels.
2. Results based on the 2001 RECS are far lower than those based on either 1997 or 2005 RECS.[11]
3. The bedroom ratios are all around 1.012, indicating that an additional bedroom is associated with only about a 1 percent increase in consumption.

These regression results were unacceptable for use. The single family regression, which is the only one which had reasonably large sample sizes, produces similar values to the partly engineering based calculation used in the past in the 6,000 HDD range where oil heat use is concentrated.

2.6.2 Regressions Using RECS Means

Analysis of oil heating data was repeated using the regression-on-means approach described in the previous section on gas and electric heating. This approach provided results that were much more consistent with the patterns for gas and electric heat. As Table 11 shows:

- The effect of climate is much greater than with the first method and consistent with patterns for other fuels.
- The bedroom ratios are more plausible -- 1.25 between 1 and 2 bedroom units, and 1.20 between 2 and 3 bedroom units.
- As before, there are large differences among the three RECS surveys, with the results of the 2001 survey far lower than the other two.
- 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 about the same as the predicted consumption using the microdata 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 continue to be used in place of microdata regressions. Although the regression estimates differ somewhat because different data are used, the method and end results resemble those in the current HUSM model. The preferred equation is:

$$BTU_{Oil} = (44762 + 15238*Bedrooms) * (HDD_{Local}/5911) * Structure\ Type\ Factor$$

The above equation applies to single family detached homes. Its results are plausible in terms of degree day patterns and BTU consumption adjusted for fuel efficiency. There were too few cases to develop meaningful estimates for other structure types, for which oil heat is rarely paid for separately by renters. As was necessary in some other instances, estimates for other structure types had to be developed using average fuel consumption relationships for heating fuels with much larger samples. Estimates for oil heat used in radiators and warm air ducts were developed but what is shown in the recommended tables is based on a combination of these two methods of heat distribution. Ducted heat appears to be more efficient. A related adjustment could easily be added to the HUSM model, but HUD would need to decide if the additional data burden this would impose on PHAs was warranted.

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[11] This was also observed in *Report 5*.

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

	Regression Coefficients					Predictions at Selected HDD and Number of Bedrooms			
							kBTUs/year		
Delivery Method	**Constant**	**Bed-rooms**	**Mean HDD**	**n**	**R^2**	**Bed-Rooms**	**2,000**	**4,000**	**6,000**
All Units	44,762	15,238	5,911	1,437	0.99	3	30,613	61,226	91,838
Radiator Hot Water	43,043	17,738	5,757	848	0.95	3	33,440	66,880	100,320
Warm Air Ducts	42,297	13,847	6,132	589	0.96	3	27,344	54,689	82,033
Single Family Detache	**51,152**	**14,903**	**6,107**	**1,006**	**0.89**	**3**	**31,394**	**62,788**	**94,181**
Radiator Hot Water	70,706	11,894	6,004	529	0.75	3	35,439	70,878	106,317
Warm Air Ducts	53,627	11,707	6,223	477	0.98	3	28,523	57,045	85,568
Apartment 5+ Units	37,075	5,657	4,969	208	0.98	3	21,753	43,505	65,258
Radiator Hot Water	40,260	3,537	4,926	184	0.73	3	20,654	41,308	61,962
Warm Air Ducts	[Too few cases]								

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 consumption estimates for unit types that lacked enough RECS data to do so, both microdata and regression-on-means regressions were used to examine relationships for gas and electric heated units of different sizes and structure types. These fuels were used because they had by far the largest and most statistically useful sample sizes. Structure ratios were developed separately for 2-bedroom and 3-bedroom units. A summary is shown in Table 12 that follows, and in more detail in Appendix 1, Table 8.

There are differences in the results shown in Table 12, but the more interesting point is how similar most are. A "summary of summaries" set of heating fuel consumption ratios for different structure types was also estimated that is the average of the microdata and means regressions for 2- and 3-bedroom ratios by average heating degree day values. This set of ratios is very similar to those developed using American Housing Survey data for all fuels and bedroom sizes, and is as follows:

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

Table 12. Heating Relationships for Different Structure Types

Heating Regressions by Structure Type	2-Bedrooms			3-Bedrooms			Combined Ratios		
	Ratio To Single Family Detached			Ratio To Single Family Detached					
	Heating Degree Days			Heating Degree Days			Average for all Climates		
	2000	4000	6000	2000	4000	6000	2 Bedrms.	3 Bedrms.	Avg. 2 & 3
Using Microdata, Gas Heating									
Mobile Home	0.77	0.82	0.85	0.69	0.72	0.73	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	0.96	0.98	0.99	0.88	0.88	0.88	0.97	0.88	0.93
Apartment 2-4 Units	0.87	0.99	1.04	0.87	0.97	1.01	0.97	0.95	0.96
Apartment 5+ Units	0.42	0.50	0.53	0.43	0.51	0.54	0.48	0.49	0.49
Using Microdata, Electric Heating									
Mobile Home	1.03	0.96	0.94	0.93	0.87	0.84	0.98	0.88	0.93
Single Family Detached	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Single Family Attached	0.82	0.75	0.72	0.86	0.81	0.79	0.76	0.82	0.79
Apartment 2-4 Units	0.76	0.69	0.67	0.70	0.64	0.62	0.71	0.66	0.68
Apartment 5+ Units	0.55	0.51	0.50	0.58	0.55	0.54	0.52	0.56	0.54
Using Microdata, Gas or Electric Heating									
Mobile Home	0.91	0.90	0.90	0.82	0.80	0.79	0.90	0.90	0.90
Single Family Detached	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Single Family Attached	0.91	0.91	0.91	0.87	0.86	0.85	0.91	0.91	0.91
Apartment 2-4 Units	0.84	0.89	0.92	0.81	0.86	0.89	0.88	0.91	0.92
Apartment 5+ Units	0.49	0.51	0.51	0.52	0.53	0.54	0.50	0.51	0.51
Using Means, Gas Heating									
Mobile Home	0.70	0.70	0.70	0.79	0.79	0.79	0.70	0.79	0.74
Single Family Detached	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Single Family Attached	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Apartment 2-4 Units	0.98	0.98	0.98	1.00	1.00	1.00	0.98	1.00	0.99
Apartment 5+ Units	0.48	0.48	0.48	0.44	0.44	0.44	0.48	0.44	0.46
Using Means, Electric Heating									
Mobile Home	0.86	0.86	0.86	0.90	0.90	0.90	0.86	0.90	0.88
Single Family Detached	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Single Family Attached	0.71	0.71	0.71	0.77	0.77	0.77	0.71	0.77	0.74
Apartment 2-4 Units	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Apartment 5+ Units	0.52	0.52	0.52	0.57	0.57	0.57	0.52	0.57	0.54
Using Means, Gas or Electric Heating									
Mobile Home	0.78	0.78	0.78	0.85	0.85	0.85	0.78	0.85	0.82
Single Family Detached	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Single Family Attached	0.86	0.86	0.86	0.88	0.88	0.88	0.86	0.88	0.87
Apartment 2-4 Units	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Apartment 5+ Units	0.50	0.50	0.50	0.51	0.51	0.51	0.50	0.51	0.51

Use of the set of averaged structure type factors on the previous page is recommended for deriving results for most heating and cooling structure subcategories where there are inadequate sample sizes for reliable analysis. For instance, the oil heating equation shown in Section 2.6.2 must be multiplied by the structure type factor for structures other than single family detached. Most of the differences in Table 12 are probably due to sample sizes, although some of the degree day relationships pose questions.

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 larger than the statistically weak differential of .01 between single family attached and 2-4 unit apartments might be expected. Such differences are not apparent in the RECS data to date, although it is possible that larger samples from the 2009 and future surveys may produce different results. Since the RECS survey data provide the only available detailed information on a broad sample of structure types in different climatic conditions and show the same fairly consistent patterns from survey to survey, no “conceptually based” adjustments to refine the estimates developed are recommended. Exceptions undoubtedly exist, but the only statistically representative data on this matter come from RECS and have repeatedly shown minimal differences between some categories where many people may believe differences should exist. The one structure type differentiation that may be worth exploring once 2009 RECS data are available is that of 5+ unit low-rise versus high-rise structures. The 2009 RECS will have about twice as big samples as past surveys, which offers the potential for more analysis of a single year’s worth of data than possible to date.

2.6.4 Bedroom Adjustment Ratios for Calculating Efficiency Unit Values

Efficiency units presented the same problem they did with other analyses. This may be due to the fact they vary so much in nature. 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 more 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 or 86 percent in reference to a one-bedroom value, depending on the application, is used in this report based on linear trend relationships with other unit sizes.

Part 3. Air Conditioning

Air conditioning in this country has become increasingly common. As shown in Table 13, 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. Only at less than approximately 1,000 CDDs does a majority of units have no air conditioning. In contrast, RECS surveys show that above 2,500 CDDs air conditioning is almost universal.[12]

Regressions using RECS microdata were tested with the same types of variables used for estimating heating, except that Cooling Degree Days (CDDs) were substituted for Heating Degree Days. Some anomalies quickly become apparent:

- For mobile homes the regression coefficients display a negative regression value for CDDs, suggesting consumption decreases in hotter climates.
- There is little stability in the estimates among the three RECS years.

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[12] HUD guidance specifies that if a majority of rental housing units have air conditioning, an allowance for air conditioning must be provided.

- The best regression forms for the three RECS surveys have very different regression coefficients.

Table 13. Air Conditioning Utilization by Equipment and Structure Type

	Structure Type					
Type and Number of Air Conditioners	Mobile Home	Single Family Detached	Single Family Attached	Apartment 2-4 Units	Apartment 5+ Units	Total
Central Only	45%	52%	43%	28%	38%	47%
Wall 1 Unit	18%	11%	12%	23%	24%	15%
Wall 2 Units	8%	8%	9%	11%	7%	8%
Wall 3+ Units	2%	4%	5%	3%	2%	4%
Both	1%	1%	1%	1%	1%	1%
No AC or Not Answered	26%	24%	31%	35%	28%	26%
Totals	100%	100%	100%	100%	100%	100%

Regressions using RECS microdata were tested with the same types of variables used for estimating heating, except that Cooling Degree Days (CDDs) were substituted for Heating Degree Days. Some anomalies quickly become apparent:

- For mobile homes the regression coefficients display a negative regression value for CDDs, suggesting consumption decreases in hotter climates.
- There is little stability in the estimates among the three RECS years.
- The best regression forms for the three RECS surveys have very different regression coefficients.

Details of these results are provided in Appendix 1, Table 9. To summarize, they do not provide a basis for having much confidence in this approach. Given past research, this outcome was not unexpected. Such results can occur if a key driver of air conditioning consumption has been omitted.

Nearly all air conditioning consumption occurs within a much smaller range of CDD values than HDD values. It also occurs over a much smaller range of absolute temperature values. This means that air conditioning consumption will be highly sensitive to equipment temperature setings and what those settings translate into in terms of differentials with outside temperatures. While some people set their air conditioners at 80 degrees, others set them at 72 degrees, which is a huge difference in terms of air conditioning requirements. Another issue is that air conditioning consumption is highly sensitive to the age of the equipment, which may be the single most important explanatory variable within structure types in areas where air conditioning is most used. Unfortunately, air conditioner equipment age is not normally available to voucher program managers and cannot be considered in setting associated allowances for the voucher program.

In addition to normal case-level regressions, regressions were run on mean electric consumption for air conditioning by number of bedrooms for each structure type using combined data from the three RECS surveys. The same methodology described in section 2.2.2 was used. A summary of the results follows in Table 14.

Table 14. Microdata and Regression-on-Means Results for Air Conditioning

Air Conditioning	Microdata Regression			Regression on Means		
	Constant	CDD	CDDxBED	Constant	CDD	CDDxBED
Mobile Home	890.0	-0.315	1.850	-38.5	0.595	1.284
Single Family Detached	-8.9	0.459	1.577	-45.0	0.695	1.500
Single Family Attached	456.2	0.679	1.076	-40.1	0.619	1.336
Apartment 2-4 Units	-1,084.1	1.801	1.119	-40.5	0.626	1.351
Apartment 5+ Units	-684.4	1.393	1.123	-23.0	0.355	0.765

More detailed information on the regression results is provided in Appendix 1, Table 9, but the preceding table provides a good summary. Negative constants are not necessarily anomalous, since air conditioning is rare in areas with less than 1,000 cooling degree days. The following conclusions were drawn based on this information:

- **Mobile Homes:** The regression-on-means approach needs to be used because the other results are implausible.
- **Single Family Detached:** The two methods yield virtually the same results; we recommend using the regression-on-microdata approach as the default choice when this occurs because it is more straightforward.
- **Single Family Attached:** The two methods yield similar results, but the regression-on-means approach is recommended because of concerns that the relatively small sample sizes make microdata regression results suspect.
- **Apartment 2-4 Units:** The two methods yield different results, partly because the regression-on-means approach does not produce a linear relationship between mean electricity use and number of bedrooms. For this reason we recommend using the microdata regression approach, which shows plausible relationships.
- **Apartment 5+ Units:** The two methods yield different results. Even though the microdata regression method has a low R-squared, the results are closer to patterns for structure types with stronger statistical relationships and are recommended for use.

Three of the regression forms tested for this and previous studies produce the best results. Because the R^2s are so similar (differing mostly by less than 1 percent), there is little advantage to using anything but the simplest model. The fact that it produces more stable values compared to the other methods also argues in its favor. The microdata regression method used is the same as Report 5's method M1.

Part 4. Water Heating

Analysis of water heating using combined data from the 1997/2001/2005 RECS surveys showed that the results do not provide an acceptable direct means of estimating water heating utility consumption. The statistical significance of the regression is weak and the results not credible. They show water heating consumption roughly proportional to HDDs, which is inconsistent with the fact that ground temperatures even one foot below surface levels vary far less than air temperatures. This type of suspect result can occur if the regression is mis-specified by leaving out a key variable, which in this case is the water inlet temperature. This same problem occurred in single-year analyses of the 1997, 2001, and 2005 RECS data. Although regressions that were intended to test results for water heating are provided in Appendix 1, they are not recommended for use in their normal form.

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 has been 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.

The alternative 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. The RECS-based regression results used in the first half of this process were re-estimated with additional data, but no change was made to the water inlet temperature adjustment calculation.

4.1 Gas Water Heating

The chart in Appendix 1, Table 10, shows that the regression on means approach results in a very linear relationship with mean bedroom consumption and an R-squared value of .978. A polynomial relationship, shown on the right side of the table and used in the past, produces a slightly better fit (R^2=.994), and is included in the recommended set of implementation calculations.

Combing this result with the engineering adjustment used for water inlet temperature produces the following equation”

kBTU gas water heating = (10953 + 4345..8*Bedrooms) * Multiplier, ***where***

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

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

4.2 Electric Water Heating

As with gas, the relationship between consumption and number of bedrooms is slightly non-linear (linear R^2=.979 linear, polynomial R^2=.999). We again recommend using the polynomial relationship.

Table 15 shows mean electric consumption and its relation to mean gas consumption by bedrooms. Except for efficiency units, which are consistently an issue because of sample sizes and other problems, the ratio is a highly stable 0.42-0.44. This means that it takes about 42-44 percent as many electric BTUs as natural gas BTUs to provide the same amount of water heating. The electric-to-gas ratio is about 0.43 if based on the one-to-five bedroom sizes, which are the only ones with enough data for meaningful estimates. In the current and previous HUSM models, a ratio of .55 was used to convert gas to electric consumption.[13] This estimate was based on typical engineering-base values when it was developed rather than on the one RECS survey evaluated at that time. Based on a review of three RECS surveys and the consistency of values from survey to survey, the recommendation of this report is to use the RECS-based electric water heating estimate of 0.43.

Table 15. Electric-to-Gas Water Heating Ratios

Bedrooms	Mean kBTUs			
	Gas	Electric	Ratio: Elec/Gas	
0	11,948	7,481	0.63	<---- 0-bdrm value not statistically reliable
1	14,086	5,908	0.42	
2	19,759	8,423	0.43	
3	23,988	10,637	0.44	<---- note consistency of 1-5 bedroom ratios
4	29,249	12,292	0.42	
5	31,070	13,448	0.43	
1-5 Bdrm. Avg.	23,631	10,142	0.43	
0-9 Bdrm. Avg.	22,991	9,673	0.42	

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. 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

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[13] Because electricity has multiple uses, it is difficult to directly measure electric water heating consumption using RECS data as opposed to natural gas water heating, for which data are available. In HUSM models, an assumption about the relative efficiency of electric versus natural gas water heating is therefore needed.

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.

4.4 Consumption and Cost by Fuel and Climate

This section summarizes the results of water heater calculations in three climate zones -- 2,000, 4,000 and 6,000 HDDs -- for 2, 3 and 4 bedroom units. Separate regression equations are shown for gas and electric heating. Table 16 indicates that the national average cost of running a water heater is about 25 percent higher for electricity than for gas using recent cost relationships, although the local ratio can be significantly different in areas with unusually low electricity costs.

Table 16. Gas and Electric Water Heating Consumption Examples

				Estimated kBTUs			**Estimated Therms/kWh**			**Estimated Cost**		
		Coefficients		**Heating Degree Days**			**Heating Degree Days**			**Heating Degree Days**		
Bed- rooms	**Con- stant**	**Bdrms**	**Bdrms- squared**	**2,000**	**4,000**	**6,000**	**2,000**	**4,000**	**6,000**	**2,000**	**4,000**	**6,000**
				Gas Water Heating						[At $1.20/therm]		
				----kBTUs----			---Therms---					
2	7,258	7,204.7	-476.5	18,185	19,434	20,683	182	194	207	$218	$233	$248
3				22,622	23,922	25,731	226	239	257	$271	$287	$309
4				26,183	27,982	29,780	262	280	298	$314	$336	$357
				Electric Water Heating						[At $0.12/kWh]		
				----kBTUs----			---kWh---					
2	2,820	3,298.5	-234.0	7,804	8,340	8,877	2,287	2,444	2,601	$274	$293	$312
3				9,763	10,434	11,105	2,861	3,057	3,254	$343	$367	$390
4				11,291	12,067	12,843	3,308	3,536	3,763	$397	$424	$452

4.5 Water Heating Using Fuel Oil

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 actual fuel delivery timing. 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 the three surveys. In place of applying a 1.1 factor to natural gas water heating BTUs to estimate fuel oil consumption, a higher factor of 1.2 times natural gas water heating BTUs is recommended for use.

It is unusual for any structure type except single family detached to have residents that 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 is a declining number of units with fuel oil water heating because of its relatively higher costs and maintenance requirements. It is used in some apartment buildings with central water heating, which does not lend itself to individual billing.

Part 5. Cooking

No separate estimates for cooking consumption have been provided since the 1997 RECS, and only electric cooking estimates were given for that survey.. The manner in which gas appliance estimates are provided, however, permits calculating separate heating and water heating estimates, and can also be used to derive natural gas consumption for cooking.

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 primarily due to increased use of microwave cooking.

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."[14]

The previous approaches to estimating natural gas cooking were reproduced and applied to the three RECS surveys as well as the combined data, keeping only cases that cooked with gas and didn't have gas clothes dryers. It was concluded that, as with water heating, microdata regressions are inappropriate because of the unreliability of the resulting regression coefficients and low R-squared values (in the range 0.02 to 0.06). Regressions were then developed using mean consumption values for natural gas by bedroom, as has been done in the past.

The average BTUs for cooking differed for the three RECS surveys. There was a notable downward trend in cooking fuel consumption. This might be due to better-insulated, self-cleaning ovens and the electronic ignition on most new gas stoves. It is suspected, however, that the large increase in the number of microwave ovens and their associated use is primarily responsible. 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 is a significant trend, as shown in Table 17.

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[14] Report 5, Page 14.

Table 17. Gas Cooking Consumption for
2- and 3-Bedroom Units

Survey Year	Average kBTU Consumption	Annual to Avg. Consumption
Average	7,058	100.0%
1997	7,484	106.0%
2001	7,041	99.8%
2005	6,509	92.2%

Use of the three-survey average to measure cooking fuel consumption is recommended, partly because of sample size considerations and partly for consistency with other calculations. This results in the following equation for natural gas:

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

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. These cover space heating, cooling, refrigerators, washers, dryers, and freezers. All other electrical consumption is a single derived estimate, although detailed information on the types and number of such other uses is recorded. 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."*[15]

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

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

Any error in estimating electric cooking will affect the accuracy of the "Other Electric" consumption estimates, since "Other Eectric" is calculated as the remainder of total electric consumption less specified appliance use amounts less estimated electric cooking used by stoves and stovetops. Fortunately, electric cooking consumption is relatively small, and no related estimation errors are likely to significantly bias "Other Electric" estimates.

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

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, 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 for HUD's "Other Electric" utility expense category. 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, freezers, dishwashers, and dryers. As previously discussed, gas stove consumption can also be estimated. Except for major appliance and estimated electric stove consumption, only a single number can be calculated for electrical uses for which no separate estimates are provided. A list of RECS variable names and items for which individual consumption estimates are provided follows:

BTULP	LPG Annual Use In Thousands Of BTU
BTUELSPH	Electric Space Heat Use (Estimated)
BTUNGSPH	Natural Gas Space Heat Use (Estimated)
BTUFOSPH	Fuel Oil Space Heat Use (Estimated)
BTULPSPH	LPG Space Heat Use (Estimated)
BTUKRSPH	Kerosene Space Heat Use (Estimated)
BTUELWTH	Electric Water Heat Use (Estimated)
BTUNGWTH	Natural Gas Water Heat Use (Estimated)
BTUFOWTH	Fuel Oil Water Heat Use (Estimated)
BTULPWTH	LPG Water Heat Use (Estimated)
BTUKRWTH	Kerosene Water Heat Use (Estimated)
BTUELAPL	Electric Appliance Use (Estimated)
BTUNGAPL	Natural Gas Appliance Use (Estimated)
BTUFOAPL	Fuel Oil Appliance Use (Estimated)
BTULPAPL	LPG Appliance Use (Estimated)
BTUKRAPL	Kerosene Appliance Use (Estimated)
BTUELCOL	Electric AC Use (Estimated)
BTUELRFG	Electric Refrigerator Use (Estimated)
BTUELFZ	Electric Freezer Use (Estimated)
BTUELDWH	Electric Dishwasher Use (Estimated)
BTUELCDR	Electric Dryer Use (Estimated)

Two of these terms merit further clarification:

BTUEL = T**otal electrical consumption**
= BTUELSPH (electric space heat)
+ BTUELWTH (electric water heat)
+ BTUELCOL (air conditioning)
+ BTUELRFG (refrigerator)
+ BTUELAPL (electric appliance uses)

BTUELAPL = All electrical appliances not otherwise listed as parts of BTUEL
= **BTUELFRZ** (electric freezer)
+ **BTUELDWH** (electric dishwasher)
+ **BTUELCDR** (electric clothes dryer)
+ **All electrical uses without estimated energy consumption amounts** (includes lighting, microwaves, and all electronics)

In the past, the HUSM approach to calculating "Other Electric" was as follows[16]:

1. Exclude households with luxury features (i.e., swimming pools, saunas, hot tubs, water beds, and fish tanks larger than 20 gallons) from the "Other Electric" analysis.
2. Calculate "Other Electric" as follows:

= **BTUELAPL**
- **BTUELFRZ** (est. freezer consumption)
- **BTUELCOOK** (est. electric cooking consumption
- **BTUELCDR** (est. electric clothes dryer consumption except for 3+ bedroom single family units);
+ **BTUELCDR** (electric clothes dryer for 3+ bedroom single family units)
+ **BTUELRFG** (refrigerator)

Per guidance from the Office of Public and Indian Housing, this study includes estimates for clothes dryers in calculating estimates for "Other Electric" for all structure types and bedroom sizes to the extent that, on average, they exist in the inventory. This decision is partly based on the fact that they are found in most units and already included to the extent they occur when all utilities are included in rent. This calculation change, however, means that the estimates in this report include more appliance use than if they were calculated in the same way as previous HUSM estimates for "Other Electric".

6.1 Washer, Dryer, Freezer, & Dishwasher

(a) Dishwashers and Clothes Washers and Dryers

As shown in Table 18, dishwashers are becoming increasingly common -- 46 percent of all RECS homes had them in 1997, 52 percent had them in 2001 and 57 percent in 2005. Having a clothes washer or electric dryer has become more common, especially in detached and attached single family dwellings. By 2005, 80 percent of all dwellings (96 percent of single family, 32 percent of

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[16] HUD Handbook 7420.10g, Chapter 18.

apartments) had clothes washers, and 78 percent of all dwellings (93 percent of single family, 27 percent of apartments) had electric dryers. RECS surveys show an increasing trend in these items over time. Clothes washers require relatively little electricity. Dryers, however, can consume a significant amount of electricity or natural gas.

Table 18. Frequency of Selected Appliances in Recent RECS Surveys

		Structure Type					
RECS Survey Year	**Appliance**	**Total**	**Single Family Detached**	**Single Family Attached**	**Apartment 2-4 Units**	**Apartment 5+ Units**	**Mobile Homes**
1997	Clothes Washer	76%	94%	76%	41%	19%	80%
2001		79%	96%	89%	47%	21%	86%
2005		82%	96%	87%	55%	32%	85%
2009		82%	97%	88%	52%	36%	90%
1997	Clothes Dryer	71%	86%		29%	18%	72%
2001		74%	90%		43%	18%	76%
2005		79%	93%	82%	49%	29%	80%
2009		79%	95%	84%	48%	34%	81%
1997	Separate Freezer	34%	46%	20%	11%	4%	28%
2001		35%	46%	28%	11%	5%	31%
2005		32%	42%	25%	10%	5%	33%
2009		30%	41%	19%	10%	4%	33%
1997	Dishwasher	46%	54%	46%	17%	33%	27%
2001		52%	59%	59%	27%	40%	37%
2005		57%	65%	50%	33%	44%	38%
2009		59%	68%	60%	33%	49%	33%

Appliance growth for the four items identified above appears to be slowing, since all but freezers are fairly common in all but old structures. The decreases in freezers may be related to the increase in larger refrigerators, which now often provide 20 or more cubic feet of space.

(b) Freezers

Separate freezers have become relatively common, and were found in over 30 percent of all dwellings. They were most common in single family detached homes, and are more likely to be found in owner-occupied than renter-occupied structures. HUD's position has been that separate freezers constitute a "luxury" item that should be excluded from Section 8 utility allowances.[17] They are not included in the analysis done for this or previous studies.

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[17] Note that consumption for separate freezers is eliminated from total appliance consumption, though the records themselves are retained in the analysis. This is different from the treatment of other "luxury" items, where the presence of even one such item causes the entire record to be dropped because no related consumption estimates are provided by RECS.

6.2 Presence of "Luxury" Features

The following tables show percentages and numbers of residential records that were excluded from "Other Electric" consumption analyses because they had one or more of the specified "luxury" items and lacked the separate RECS energy consumption estimates that would have allowed them to have such consumption deducted from total residence energy consumption of the respective fuel:

Table 19.a. Percent Units Excluded Because of Luxury Items

	Structure Type					
RECS Survey Year	**Mobile Home**	**Single Family Detached**	**Single Family Attached**	**Apartment 2-4 Units**	**Apartment 5+ Units**	**Total**
1997	11%	22%	10%	10%	6%	17%
2001	12%	21%	13%	9%	4%	16%
2005	7%	21%	6%	3%	3%	15%
Combined Data	**10%**	**21%**	**10%**	**7%**	**5%**	**16%**

Table 19.b. Average Energy Consumption of Excluded Luxury Items

Appliance	**Cases in all 3 Surveys**	**Estimated Kilowatts Used/Year**
Swimming Pool	893	1,500
Water Bed	826	900
Hot Tub	638	2,300
Aquarium (20+gal.)	581	548

The presence of any of these luxury items is greatest in single family detached households (21 percent) and least in apartments (5 percent). As seen in Table 19.b, waterbeds and most aquariums normally involve relatively low energy consumption, but there are a large number of sample units left after these are excluded, and therefore little reason to be concerned about their omission.

6.3 Other Electric Computations

As previously noted, the current and previous HUSM models excluded clothes washers and dryers in estimating "Other Electric" allowances except for 3+ bedroom single family structures, where both were allowed. The calculations in this report includes the average consumption value for both across all units and structure types, including units that lack one or both of these appliances.

6.3.1 "Other Electric" Regression Values for Combined RECS Survey Data

The derivation of "Other Electric" consumption was done separately by structure type. If there were enough sample cases (generally 100 or more) 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 are shown in Table 20 and the estimated consumption amounts resulting from these values shown in Table 21. Regressions were based on 1-4 bedroom values. Other bedroom sizes had inadequate sample sizes for inclusion, and the estimates shown for such units are based on trend line patterns for their respective structure types.

Table 20. Regression Values for Other Electric

Other Electric	**Constant**	**Bedroom Factor**
Mobile Home	6,487.4	4,909.0
Single Family Detached	8,849.8	3,947.9
Single Family Attached	6,456.2	3,831.0
Apartment 2-4 Units	5,154.1	3,880.8
Apartment 5+ Units	6,117.9	2,823.1

Table 21. Estimated kWh Values for Other Electric

	Bedrooms								
Structure Type	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mobile Home	6,487.4	11,396.4	16,305.4	21,214.4	26,123.4	31,032.4	35,941.4	40,850.4	45,759.4
Single Family Detached	8,849.8	12,797.7	16,745.6	20,693.5	24,641.4	28,589.3	32,537.2	36,485.1	40,433.0
Single Family Attached	6,456.2	10,287.2	14,118.2	17,949.2	21,780.2	25,611.2	29,442.2	33,273.2	37,104.2
Apartments 1-4 Units	5,154.1	9,034.1	12,914.1	16,794.1	20,674.1	24,554.1	28,434.1	32,314.1	36,194.1
Apartments 5+ Units	6,117.9	8,941.0	11,764.1	14,587.2	17,410.3	20,233.4	23,056.5	25,879.6	28,702.7
All Structure Types	6,205.8	10,610.9	15,016.0	19,421.1	23,826.2	28,231.3	32,636.4	37,041.5	41,446.6

The values in the previous two tables are based on the same methodology used in previous years with the exception of the change in the treatment of clothes washers and dryers. The following observations are worth noting:

- Including electric dryers for all units raises “Other Electric” consumption by around 2,000 BTUs per year. The impact of adding clothes washers could not be determined, but would have been much smaller.

- Structure type clearly affects “Other Electric” consumption. Apartments with 5+ units use about 30 percent fewer BTUs than single family detached units. This is at odds with HUD-PIH instructions for form HUD-52667, which call for identical electric consumption regardless of structure type.

- Mobile homes and single family detached homes with the same number of bedrooms had about the same amount of “Other Electric” consumption.

- The structure type factors for “Other Electric” differ from those calculated for heating.

- The relationship between mean consumption and number of bedrooms is linear with the exception of efficiency units, for which a polynomial relationship fits better than a linear relationship because studio apartments seem to use a disproportionately large amount of electricity compared to one bedroom units. For reasons noted previously, however, use of the 85 percent of the one-bedroom value is again used for efficiencies.
- Bedroom values were tabulated by structure type and expressed in relationship to single family detached values. Because the trends are linear, the percentage differences are much larger at the low end than at the high end. It follows that bedroom differentials should be stated as "add or subtract *x* BTUs for each bedroom greater or less than 2", as is done with current HUSM calculations.

6.3.2 Trends Over Time

"Other Electric" use has generally been growing even when the change in definitions to include washers and dryers is ignored. For 3-bedroom units there was an increase of about 10 percent during the 8-year period from 1997 to 2005. For one-bedroom units there was a slight decrease that may have been due to sample sizes, while for the larger units there was an above-average increase. These apparent patterns should be treated with some caution, as they are artifacts of the estimation process. The main conclusion one can make is that, *in general*, there has been somewhat of an increase in "Other Electric" use. This is consistent with results showing increases in dishwashers and electronic appliances such as computers, phone chargers, and gaming equipment.

6.4 Estimation Differences from Previous Studies

Although analytically similar to past HUSM estimates, there are points of difference that affect the "Other Electric" estimates provided in this report:

1. All past HUSM "Other Electric" estimates are based on data from a single RECS survey, and most are based on information from the 1997 RECS or trended 1997 RECS factors. The calculation factors provided are based on combined data from the 1997/2001/2005 surveys.
2. This report's estimates rarely use fewer than 100 data points because of the statistical thresholds applied, and only attempt to provide category-based estimates for bedroom/fuel-type/bedroom-size categories considered to have an adequate number of sample cases. As a result, a number of estimates for infrequently used utility/structure type categories are determined somewhat differently than in the past.
3. Previous HUSM estimates excluded clothes washers and dryers except for 3+ bedroom single family homes in their analyses of "Other Electric" and natural gas consumption. Both are now relatively common, and the Office of Public and Indian Housing directed that the average values for all units should be included in these calculations.

Part 7: Structure Age and Utility Consumption

The current HUSM model permits different utility schedules to be calculated for structures in different age ranges. Three age categories are provided: before 1980, 1980 to 1996, and 1996 or newer. Updated estimates for structure age differentials were calculated for this study. For reasons noted subsequently, however, reconsideration of the desirability of separate age-adjusted utility schedules other than for Energy Star construction appears worth reconsidering.

It is generally assumed that newer residential structures are more efficient than older ones. Two reasons are often offered to support this assumption. One is that building codes have stricter energy conservation standards as the result of changes largely made in the 1970’s and early 1980’s in response to fuel shortages. The other is that the efficiency of heating and cooling equipment has increased.[18] RECS data show that, on average, newer structures are more efficient. They also show, however, that a significant and increasing number of older structures are almost as efficient, as efficient, or more efficient than typical new construction. This result should not be considered surprising, since a number of surveys show that energy efficiency improvements are typically a priority in home renovation investments. Typical building code standards for new construction building envelopes are not difficult for most existing structures to equal or exceed when doing significant renovations. Existing structures also benefit from the same improvements in heating and cooling equipment efficiency realized by new construction as replacements occur.

Although there continue to be heating and cooling consumption differences related to age of structure, some major caveats should be noted. The 1997 and previous RECS surveys showed significant but decreasing differences in the energy efficiency of residences built prior to 1970 and after 1979, and mixed values for structures built in the 1970s. The 1997 survey, which was the oldest examined in detail for this study, also showed that the most recently built structures were the most energy efficient – although in retrospect it appears that the fact that the newer structures had the newest heating and cooling equipment played a significant role. Average energy efficiency levels were also found to be lowest for recently built structures in RECS surveys after 1997, but the differential between pre-1970 and post-1980 housing units continued to narrow. A combination of improvements, such as added attic insulation, new thermopane windows, Styrofoam under-siding on the exterior of structures, new heating and cooling equipment, and use of fluorescent or LED lighting can dramatically reduce energy consumption.

7.1 Definition of Age

7.1.1 Introduction

Year built is presented as a categorical variable in all three RECS surveys, but is coded inconsistently. Revised, standardized definitions are needed if data from multiple surveys are to be compared or combined in any analysis that deals with age-of-structure. Two additional definitions were developed for use in this report, AGE1 and AGE2.

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[18] The first significant Federal legislation setting energy efficiency standards for major household appliances was the National Appliance Energy Conservation Act of 1987, followed by the related Acts of 1992, 1995, 1997, and 2005. These have had significant impacts on appliance efficiency from 1998 to the present.

The current HUSM model categorizes structure age three ways: pre-1980, 1980-1996, and 1996 and later. One problem with this categorization is there are very few cases in the "newest" category even in the most recent RECS survey, and considerably fewer than that when the estimates in the currently used model were developed. The basis for the 1996 and later category is unknown, but was probably based on trends. There was a total of about 5 percent of the cases that were in the 1996 and later category using combined data from three RECS surveys, and this was too few for very reliable analysis when further sub-grouped by heating fuel and structure type.

7.1.2 Definitions Using Time from Construction Year

One way to obtain large enough samples to analyze energy consumption by structure age is to use groups of 0-10 years, 11-20 years, and 20+ years from each survey. This would result in having 12-15 percent of all units in the 0-10 year "newest" category, which is adequate for statistical analysis. This approach defines structure age in relationship to the date of the survey, so the meaning of the values differs depending on which survey the data came from. This approach was used to create a variable referred to as "Age 1," in which 13 percent of units from the combined survey data fall into the newest (0-10 years) category (n=1,937), 16 percent are in the middle category (n=2,409), and 71 percent are in the oldest category (n=10,758).

At the PHA staff level this categorization has some advantages, as "under 10 years" and "over 20 years" are easy to understand. The biggest disadvantages are that "over 20 years" is not very old as residential structures go and the meanings of these groupings is somewhat inconsistent due to changing building practices.

7.1.3 Expressed as Year Built

An alternate measure is year built, standardized across surveys. This approach groups structures by fixed time intervals. The time periods that can be used are limited because structure ages were categorized differently in each of the three surveys studied. All three surveys provide categories of per-1940, 1940-1949, 1950-1959, and 1960-1969, but intervals after 1969 are varied.

The disadvantage of this approach is that combining data from three RECS surveys means that there are differences in the age mix of structures for the "newest" age category in the different surveys. The time divisions selected for use with this "Age2" variable are as follows:

- Pre-1950
- 1950-1969
- 1970-1979 (a transition period associated with a number of energy code changes)
- 1980-on (i.e., to date of each survey)

The 1980-on categorization was needed to provide a large enough sample of relatively recent construction for analysis, but when applied to a combination of three surveys it has different meanings. The intervals included in the respective surveys are as follows:

RECS Survey	Interval Covered by Definition of "1980-on"
1997 RECS	1980-1997 (built within 17 years of survey)
2001 RECS:	1980-2001 (built within 21 years of survey)
2005 RECS	1980-2005 (built within 25 years of survey)

It matters how recently a structure was built, primarily because the newest structures have the newest heating and cooling equipment, which is usually more efficient than that of not too many years before. New equipment rather than the year a structure was built explains some and (especially for air conditioning) perhaps much of why the newest construction is, on average, the most efficient. The "Age 2" variable fails to capture many truly recently built units, since it covers up to a 25 year span and there are few units built within the past few years of the last survey. This issue, however, is inherent to RECS given its sample sizes. RECS would either need to over-sample new construction at the expense of other structure ages or it would need to be several times as large as it currently is to have enough newly built structures to analyze using the limited number of variables available for HUD program use.

The main advantage of the "Age 2" is categorization is that it divides the total (3-survey) sample into approximately equal size bins and separates out the very oldest units (built before 1950). A related advantage is that many of the most significant changes in building codes were made in the 1970's and early 1980's in response to the energy crises of that period. Many building codes have changed little since then with respect to energy efficiency requirements, although appliance and heating and cooling equipment efficiencies have significantly improved due to Federal regulations and market forces.

7.2 Heating by Age of Structure

For gas and electric heating, both microdata regressions and regressions-on-means yielded similar structure and age relationships for most energy consumption values. The major difference between the two was in the "11-20 years old" category, where electric heat had a closer relationship with the "all ages" consumption average than gas, which showed relatively more improvement in energy consumption. Direct gas and electric comparisons are somewhat misleading however, because gas is more concentrated in colder areas where more efficient equipment would have a bigger impact.

Both of the age variables developed are less than ideal for reasons previously noted. They are, however, good enough to show that the current HUSM model assumes much lower absolute and relative efficiency levels for the oldest structures than shown by more current RECS data. The exact basis for the current HUSM age adjustments is not known, but they are far more consistent with old RECS data than more current data. Perhaps the most significant change in energy consumption patterns since the first RECS survey in 1978 is how much the average efficiency of the oldest housing has improved. The differences between the assumptions in the current HUSM model and the combined data used in this analysis are shown in Table 22.

Table 22. HUSM vs. Combined RECS Energy
Consumption Structure Age Adjustments

Currrent HUSM		Combined Data, Mid-Point 2001		
		Current Study	Gas	Electric
All Ages	100%	All Ages	100%	100%
Pre-1980	140%	21+years	106%	109%
1980-1996	100%	11-20 Years	84%	94%
1996 or Newer	78%	0-10 Years	81%	85%

Sample sizes do not lend themselves to calculating RECS-based age-related heating fuel differentials by structure age except for gas and electricity. This means that either a single factor for all heating fuels needed to be developed, or separate factors developed for each fuel. For electricity, a further challenge is that separating resistance heat from heat pumps results in fewer cases than desirable for analysis in the two most recent age categories. Any age adjustment is therefore going to have to be a rough approximation. Alternatively, it may be worth considering dropping these adjustments because of the declining and relatively modest average consumption differentials that apply to all but very recent construction.

Detailed information on the regressions is available in Appendix 1, Table 16.

7.3 Air Conditioning by Age of Structure

No adjustment for structure age is recommended for air conditioning. Structure age has little relationship to air conditioning consumption. Neither microdata regressions nor regression-on-means support an age-based adjustment. In fact, both types of regressions suggest that the several year grouping used for “relatively new construction” had no energy efficiency advantage over older structures.

Age of equipment rather than age of structure seems to drive air condition consumption differentials. The oldest structures (i.e., 21-plus years old) had newer air conditioners than those in the middle range (10-20 years old). This was found to be an artifact of the age groupings used and patterns of equipment replacement. Fifty-six (56) percent of structures over 20 years old had air conditioners less than 10 years old, as opposed to only 36 percent of structures aged 11-20 years old. This is plausible since air conditioners don’t usually last more than 12-15 years. Another possible reason for the pattern may have been due to the inclusion of everything from structures with a single window air conditioner to those with whole-house central air conditioning in analyses of air conditioning, a matter which was briefly explored without any success in improving estimates, but which may warrant further study. Ideally, what should be considered in setting air conditioning allowance is the age of the equipment and how much of a residence is cooled as well as structure type and age. Operationally, this is unlikely to be feasible, which implies that use of typical average figures by structure type, number of bedrooms, and CDD range continue to be needed.

The results of the related regressions are provided in Appendix 1, Table 17.

Part 8: Summary of Revised Estimation Equations

The utility consumption recommendations in this report are grouped by fuel end-use and type in Appendix 1, Table 18. These equations show the predicted consumption in thousands of BTUs for homes in an average climate zone. The last section of Table 18 provides the miscellaneous adjustment and conversion factors associated with these estimates, including bedroom adjustment factors.

Gas Heating: All but one set of calculations is based on the microdata regression equations in Appendix 1, Table 4. The exception was mobile homes, which had small samples and statistically weak results. For this category, the .86 mobile-home/single-family-detached ratio was applied to single family detached heating values to develop estimates. As with other calculations, efficiency values were calculated as a fixed percentage of one-bedroom values.

LPG/Propane Heating: These estimates are set equal to the gas heating values adjusted when necessary by multiplying the gas values by the LPG-to-gas factor (1.0949 gallons of LPG has the heat equivalent of 1 therm of gas).

Electric Heating: As with gas heating, single family detached homes were by far the most numerous and had the best statistical estimation properties. Single family attached electric heating values were based on microdata regressions. Mobile home estimates were based on the .86 ratio applied to single family values. Two-to-four unit structures were assigned single family attached values because of weak regressions and their known structure type consumption relationship. Five+ unit structures were also calculated using structure type consumption relationships.

Heat Pump Heating: These values are calculated by applying the relevant heat pump adjustment equation factor (discussed in Section 2.5) to electric heating values. The percentage factor applied is a function of degree day ranges and operational efficiency estimates. The engineering research assumptions used produce estimates that appear consistent with the limited comparisons that could be made with RECS data for cells with adequate sample sizes. Normal regression methods produce weak statistical results.

Oil Heating: Because oil heating is hard to estimate directly with available data for reasons explained in section 2.6 of the text, the parameters provided are based on regressions on means rather than microdata. Again, only single family detached parameters were considered credible because of sample sizes. Structure type consumption ratios for more common fuels were then applied to develop estimates for other structure types.

Air Conditioning: As with heating, single family detached homes had by far the largest sample sizes. Analysis of alternatives for estimating air conditioning consumption gives significantly varied results. Regressions-on-means produced the best results and were used except for mobile homes and 5+ unit structures. For mobile homes, the .86 ratio to single family detached values was again applied. The 5+ unit structure category posed issues. The regressions yielded higher values than for most single family attached estimates and all 2-4 unit estimates. This is implausible but the results were fairly consistent, although the estimates had questionable statistical properties. As what is admittedly a compromise, the 2-4 unit values were used, which is much closer to what structure type factors would provide than if regression values were used.

Water Heating: As explained in Part 4 of this report, gas and electric water heating were best estimated using a regression-on-means approach with a polynomial term to account for the non-linear relationship between number of bedrooms and consumption. As with all regression-on-means equations used in HUSM estimates to date, the results are adjusted by taking into account the estimated local cold water inlet temperature.

Cooking: Gas cooking consumption is estimated using the regression-on-means approach, as explained in the text. Electric cooking consumption is assumed to be one-half that of gas cooking, in accordance with a previous study. LPG cooking is assumed to use the same energy as gas cooking.

"Other Electric": This category includes all appliances for which separate estimates are not provided. It includes refrigerators, electric clothes dryers, lighting, and electronic appliances. It excludes certain "luxury" items such as swimming pools. The parameters provided are based on a regression-on-means for each structure type.

Part 9: Comparisons with Existing PD&R HUSM Model

Comparisons were made between the recommendations of this report and the HUSM model provided by HUD. The HUD comparison model corrected some technical inconsistencies within the published model and updated a few factors, but most revisions related to unit categories that are infrequently applicable to the program and for which little RECS data exist, so it can be assumed the comparison results are largely applicable to the published model in terms of overall impacts.

Most of the differences between the estimates in this report and the current HUSM model for common structure types and bedroom sizes were less than 15 percent despite the differences in data and some methodological differences. These differences were modest compared to many of the variations seen in local PHA utility schedules for areas with similar climatic conditions. Some of the differences are due to the fact that the report estimates are based on what are, on average, more current data than used in the comparison model. What is interesting (and encouraging) is how similar most of the estimates are relative to the structure type/utility mixes commonly found in the voucher program. The bigger differences for less common structure types are largely due to different calculation methods selected because of stricter statistical standards that favored more frequent use of relational data from other fuel/structure type mixes when sample sizes were inadequate to provide good estimates. This approach eliminated some inconsistencies found in the current HUD model, but it should be remembered that most of these estimates involved so few units as to be of limited importance. Table 23 shows how the revised estimates compare with current HUSM estimates.

Significant residential energy efficiency improvements have been made in the past three decades and continue to be made. The changes are largely of a "one-way street" nature. Once better insulation or windows are added in an existing structure, those improvements do not measurably deteriorate except over a very long time span. Replaced heating and cooling equipment becomes marginally less efficient over time, but is typically far more efficient than that which preceded it.

The detailed consumption data from the 2009 RECS had yet to be released as of the date of this report. In effect, even the average for the data used in this report (2001) is 11 years old. To address this problem, the utility engineering firm of GARD Analytics was asked to develop a means of updating heating and cooling fuel consumption estimates based primarily on equipment purchases and replacements. These adjustments are discussed in the next section.

Table 23. Report Total Energy Consumption Estimates as Percentage of Current HUSM (Shaded cells most common)

Revised Model as % of Current HUSM Model (shaded cells most common)						
Gas Used for Heat and Hot Waters	**Bedrooms**					
	0	**1**	2	**3**	**4**	**5**
Mobile Home	96.4%	103.0%	108.3%	111.9%	115.5%	117.4%
Single Family Detached	110.7%	118.5%	106.6%	97.4%	92.4%	87.6%
Single Family Attached	117.2%	125.3%	107.8%	94.6%	87.0%	80.1%
Apartment 2-4 Units	105.4%	112.5%	105.3%	98.2%	94.4%	90.3%
Apartment 5+ Units	104.0%	111.3%	112.6%	112.7%	113.7%	113.1%
All Electric, Resistance Heating						
Mobile Home	88.1%	94.8%	94.6%	95.5%	97.1%	99.1%
Single Family Detached	90.1%	97.2%	93.9%	89.2%	87.3%	85.4%
Single Family Attached	88.8%	95.8%	92.1%	86.9%	84.9%	82.9%
Apartment 2-4 Units	77.7%	83.5%	85.9%	84.3%	84.4%	84.0%
Apartment 5+ Units	84.0%	90.5%	89.9%	90.3%	91.4%	92.7%
All Electric, Heat Pump Heating						
Mobile Home	87.1%	94.0%	94.2%	95.5%	97.4%	99.6%
Single Family Detached	86.6%	93.7%	91.9%	87.7%	86.3%	84.7%
Single Family Attached	88.4%	95.6%	91.7%	86.1%	83.9%	81.9%
Apartment 2-4 Units	75.5%	81.4%	84.6%	83.1%	83.4%	83.0%
Apartment 5+ Units	84.0%	90.7%	90.3%	91.0%	92.3%	93.8%

Part 10. Energy Consumption Trending

As part of this study, the engineering firm of GARD Analytics developed a method for trending average utility consumption decreases by taking into consideration three factors:

- heating and cooling equipment efficiency improvements tied to industry practices, code changes, and energy efficiency incentives;
- heating and cooling equipment retirement and replacements; and,
- housing heating and cooling load improvements such as insulation and tightness based on code changes and other factors

Some assumptions had to be made in developing the trending estimates. These are detailed in Appendix 2, but there is little reason to believe that any of these assumptions is likely to prove significantly in error over the 5-7 year period to which they would be applied if revised estimates are prepared within a year of each RECS data release. It is, however, possible that these trending estimates will understate total conservation gains.

GARD provided estimates of the following weighted average equipment efficiency changes between 2001 (the midpoint of the 3 RECS surveys used for this report) and 2012, as follows:

- Air conditioning improvements:
  - 21 percent decrease for normal air conditioning; and,
  - 22 percent decrease for heat pump air conditioning.
- Heating improvements:
  - 4 percent reduction for gas furnaces;
  - 22 percent reduction for heat pumps; and,
  - no change for electric resistance heat.[19]

The equipment efficiency factors need to be multiplied by the change to the estimated load improvements for residences (i.e., structural efficiency improvements) of 4 percent for cooling and 13 percent for heating. Table 24 summarizes the adjustment factors.

Table 24. 2001-2012 Energy Consumption Decreases[20]

Energy Use	Equipment-related Energy Decreases	Structural Energy Decreases	Total Decreases	2001-2012 Adjustment		Total Decrease Factor	Equipment Decrease Factor
Air Conditioning							
Electric	21.0%	4.0%	24.2%	75.8%		75.8%	79.0%
Heat Pump	22.0%	4.0%	25.1%	74.9%		74.9%	78.0%
Heating							
Gas	4.0%	13.0%	16.5%	83.5%		83.5%	96.0%
Electric Resistance	0.0%	13.0%	13.0%	87.0%		87.0%	100.0%
Heat Pump*	22.0%	13.0%	29.0%	71.0%		71.0%	78.0%

Application of some adjustment to the revised HUSM estimates is clearly warranted. The question of exactly what adjustment to make is somewhat less clear, since revised model estimates are necessarily based on all units rather than only rental units because of sample size requirements. For two structure type categories where ownership units dominate and are of concern – single family attached and detached – rental units are older and less efficient but also much smaller. Given how Housing Choice Voucher Fair Market Rent payment standards are calculated, it is likely that most program units are below average with respect to size and energy efficiency improvements fall into the smallest and category. It is something of a leap of faith to apply average utility consumption estimates to single-family detached and attached program units. Even under the most conservative assumptions, it remains true that heating and cooling equipment needs to be periodically replaced and that the least expensive replacements that can be purchased are almost certain to be far more efficient. The question that arises is therefore whether the forecast of structural envelope efficiency adjustments should be applied in calculating revised program utility schedules

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[19] RECS data show decreases in average resistance heating consumption. This is probably due to conversions of electric resistance heating to other methods or to above average improvements to the building envelopes of such units..

[20] The combined efficiency increase for heat pumps is partly offset by a timing adjustment. The heat pump estimation method used to date, which it is recommended continue to be used, is based on an engineering model. The engineering model was developed in 2007 using 2004 data and gives slightly lower estimates than RECS values based on data with a midpoint of 2001. For consistency, this report's adjustment calculation is tied to the combined RECS data estimate.

Table 25 provides comparisons with the revised trended estimates and current HUSM model estimates using the average U.S Heating Degree Day value of 4,000 HDDs and the average cooling value of 1,500 CDDs. The energy efficiency changes shown will be somewhat greater in colder than average areas and somewhat less in warmer than average areas, but are good rough proxies for overall national estimation impacts

Table 25. Revised Trended Model as % of Current HUSM Model
(Trended from 2001 to 2012; shaded cells most common)

Gas Used for Heat and Hot Waters	**Bedrooms**					
	0	**1**	2	**3**	**4**	**5**
Mobile Home	85%	91%	97%	100%	102%	101%
Single Family Detached	99%	106%	96%	88%	83%	79%
Single Family Attached	104%	111%	97%	86%	79%	73%
Apartment 2-4 Units	94%	100%	95%	88%	85%	82%
Apartment 5+ Units	93%	99%	101%	101%	100%	97%
All Electric, Resistance Heating						
Mobile Home	79%	85%	86%	86%	86%	85%
Single Family Detached	79%	85%	83%	79%	77%	76%
Single Family Attached	61%	66%	65%	62%	60%	59%
Apartment 2-4 Units	52%	56%	59%	59%	60%	59%
Apartment 5+ Units	73%	79%	79%	79%	77%	76%
All Electric, Heat Pump Heating						
Mobile Home	76%	82%	84%	85%	84%	83%
Single Family Detached	79%	85%	84%	80%	79%	77%
Single Family Attached	81%	88%	85%	80%	78%	76%
Apartment 2-4 Units	70%	75%	78%	77%	77%	77%
Apartment 5+ Units	74%	80%	81%	80%	79%	77%

No adjustments have been made for changes in the efficiency of lighting, refrigerators, and electronics. All three are likely to have has some reductions in average energy consumption. The net result is that actual average energy consumption is more likely to somewhat less than predicted even with the trending adjustments.

Part 11. Adjusting for Energy Star Construction

The Department of Energy's Energy Star program provides standards to identify energy efficient appliances and construction techniques. Tax and other incentives are provided to implement a number of these standards. In the case of residential construction, there are building envelope and system requirements that must be met. To achieve this construction rating, a building is examined during and upon completion of construction. Energy Star standards for new residential construction generally have limited relevance to the Section 8 voucher program, because few rentals of newly constructed units commonly occur. They are, however, often applicable to multifamily residential

Housing Tax Credit program units that may receive voucher assistance.[21] Energy Star or related state program standards also continue to be used in developing single family detached units, especially those built for owners.

There are two approaches to evaluating the impacts of Energy Star construction. One is an engineering approach using the Department of Energy's DOE2 model or its successors. The DOE2 model can provide very accurate measurements. The major weakness of this approach for widespread application is that there is no sound basis for specifying what "normal" new construction standards are in use. The other approach is to use what very limited comparative information is available to draw conclusions about the impact Energy Star standards have in reducing energy consumption in residences. The firm of GARD Analytics, which has had extensive experience with Energy Star standards, was asked to develop a means of quantifying the extent to which HUSM estimates for recently built units should be adjusted in instances when structures have earned Energy Star certification.

As of 2010, about 1.2 million homes had been built to Energy Star new construction standards. These standards include criteria for the following items:

- Insulation – Insulation must be properly installed and inspected in floors, walls, and attics to ensure consistent temperatures with more comfort and less energy use.
- Windows – High performance, energy-efficient windows are required that use advanced technologies to keep heat in during the winter and out during the summer.
- Tight Construction -- Advanced techniques are required for sealing holes and cracks in a home's "envelope" and in heating and cooling ducts, which improve comfort and indoor air quality while lowering utility and maintenance costs.
- Heating and Cooling Equipment -- In addition to using less energy to operate, energy-efficient heating and cooling systems can run quieter, reduce indoor humidity, and improve overall home comfort.
- Appliances and lighting – Energy Star certification requires that both appliances and lighting be more efficient and use less energy than is typical.

As discussed in Appendix 3, good comparative data on consumption reduction associated with Energy Star are limited and inconclusive. Engineering-based estimates using the best models may produce accurate results, but deciding on what specifications should be used to compare Energy Star against poses a major challenge. A large part of the problem appears to be that the Energy Star program has been successful in encouraging widespread use of some of the cost-effective techniques pioneered in the program, such as foam insulation siding, thermopane windows, and fluorescent and LED lighting. However, very little of the decline in average per unit residential energy consumption in the past 30 years can be attributed to more efficient building envelopes due to stricter building codes. New materials have made it easier and less expensive to better insulate and seal building envelopes, and the use of these materials probably explains much of the

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[21] Current IRS directives specify the use of HUD Section 8 utility allowances for all Tax Credit properties, Energy Star or otherwise.

improvement in new and existing structures. Federal and state standards for heating and cooling equipment have had positive impacts, but even with these it is notable how often minimum required standards are often exceeded because of their low marginal cost and more energy-conscious home buyers.

Table 26, which is taken from Appendix 3, provides comparative information on the Energy Star and other common building standards using estimates from predictive engineering models. The impacts are different for different climate zones. Zone 1 has the mildest combined heating and cooling requirements, and Zone 7 has the highest total residential energy requirements.

Table 26. Comparative Residential Energy Efficiency Standards

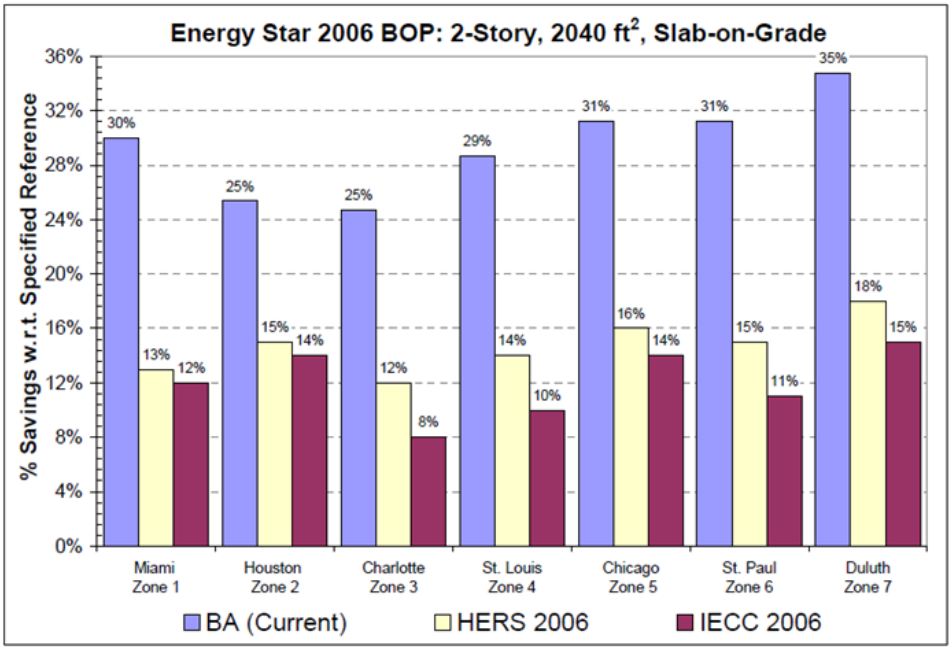

Figure 3.6 Bar chart of % savings for the 2006 ENERGY STAR prescriptive specification under 3 different Reference Home specifications showing that the current BA specification predicts significant savings (=>25%) for ENERGY STAR homes in all climates.

Table 26 is based on comparative calculations for a two-story, slab-on-grade single family detached residence with an Energy Star 2006 Version 2 reference standard. Other values relate to the extent to which additional energy use is estimated to be required. It should be interpreted as follows:

- The Building America (BA) standard, which is intended to represent standard construction practices in the mid-1990s, requires 25 to 35 percent more energy than the comparison Energy Star qualified home.
- The middle bar in each group is the Home Energy Rating System (HERS) estimate of standard American construction in 2006, which requires 12 to 18 percent more energy than the comparison Energy Star home.
- The generally lowest differences with the Energy Star standard (the dark red third bar in each group) are related to use of the 2006 International Energy Conservation Code (IECC) standard, which shows 8 to 15 percent higher energy requirements than Energy Star.

If we could be confident that the engineering-based estimates in Table 26 reflected reality, it would be reasonable to assume that Energy Star single family homes consumed 12 to 18 percent less energy than other typical new construction. What limited comparative data are available from the literature search conducted do not support estimates that high, but are hard to evaluate. A Wisconsin study referenced in Appendix 3 showed natural gas savings of about 9.4 percent with a range of values from 3.7 to 15.1 percent. The improvement for electric resistance heat averaged 5.7 percent with a range of from -1.9 percent of 13.3 percent. Other studies are cited, and there is limited support for savings as high as 12 to 18 percent. This apparent discrepancy appears due to a findings that suggest two other factors are at play – that many “normal” homes are built to higher than code standards and that at least some Energy Star residents are less inclined to conserve energy than their counterparts in less efficient homes.

GARD’s recommendation was to allow a 4 percent saving for Energy Star construction. This assumed, in part, that Energy Star residents were less conservative in their temperature settings than other residents. As a policy matter, however, it is unclear this is a desirable assumption. On the other hand, the 12 to 18 percent savings range appears high. The less than expert opinion of one of the authors, who is fascinated with energy conservation and inspected many Energy Star and other single family homes and a limited number of new multifamily homes, is that builders believe there are significant potential savings but that the extent of those savings is largely driven by resident use patterns.

Given the uncertainty associated with Energy Star estimates, no firm basis for a technical recommendation is made in this report. Some adjustment appears warranted but there is no solid technical basis for selecting among the range of values within which the true value is believed likely to fall. If no allowance is made for the fact that some Energy Star homeowners appear to be less conservative in their energy use, it would appear that a reduction in the range of 10 percent or more in recently built construction estimates may be justified. Also, please note that the reference values provided for Energy Star improvements use other new construction as a comparison base. In the event HUD decides not to apply age-based adjustments to Section 8 voucher utility schedule estimates, it would still need to add those adjustments to any of the Energy Star adjustment values selected based on Appendix 3 and age factors provided in Table 22.

Part 12. Summary of Revised Estimation Calculations

Table 27 summarizes all of the proposed estimation equations and adjustment factors, including factors for energy consumption trending (Part 10) and for Energy Star factors (Part 11.) [22] With the exception of the heat pump calculation, which is covered in the text, it provides the basis for suggested calculations.

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[22] Note that it does not include the 13% energy efficiency improvement calculated in Part 10 because it is uncertain whether low-end rental units will have had such improvements.

Table 27. Summary of Regression Parameters and Computational Elements

	Regression or Other Factors Selected Based on Multi-Year Data	Utility	Estimated Consumption in kBTUs per Year at 4,000 HDD, 1,500 CDD and Cold Water Temperature of 61.7					
1.1 Gas Heating (therms)		**1.1 Gas Heating**	**Bedrooms**					
			0	**1**	**2**	**3**	**4**	**5**
Mobile Home	Applied structure factor (0.86) to Single Family Detached	Mobile Home	32,942	38,755	44,163	49,570	54,978	60,385
Single Family Detached	Regression on microdata	Single Family Detached	38,305	45,064	51,352	57,640	63,928	70,215
Single Family Attached	Regression on microdata	Single Family Attached	42,211	49,661	50,153	50,645	51,137	51,630
Apartment 2-4 Units	Regression on microdata	Apartment 2-4 Units	39,049	45,940	50,934	55,928	60,921	65,915
Apartment 5+ Units	Regression on microdata	Apartment 5+ Units	18,715	22,018	25,595	29,173	32,750	36,328
1.2 LPG Heat (therms)		**1.2 LPG Heat**						
Mobile Home	Both sets of calculations use gas heating BTUs plus an LPG/Natural Gas conversion factor. The revised estimates use a DOE factor which is 4% higher than the old factor, plus standard structure ratio factors.	Mobile Home	32,942	38,755	44,163	49,570	54,978	60,385
Single Family Detached		Single Family Detached	38,305	45,064	51,352	57,640	63,928	70,215
Single Family Attached		Single Family Attached	42,211	49,661	50,153	50,645	51,137	51,630
Apartment 2-4 Units		Apartment 2-4 Units	39,049	45,940	50,934	55,928	60,921	65,915
Apartment 5+ Units		Apartment 5+ Units	18,715	22,018	25,595	29,173	32,750	36,328
1.3 Electric Heat (therms)		**1.3 Electric Heat**						
Mobile Home	Applied structure factor (0.86) to Single Family Detached	Mobile Home*	9,586	11,308	14,978	15,406	15,834	16,262
Single Family Detached	Regression on microdata	Single Family Detached	11,654	13,711	15,895	18,079	20,263	22,447
Single Family Attached	Regression on microdata	Single Family Attached	7,572	8,908	11,296	13,684	16,072	18,460
Apartment 2-4 Units	Single family attached values used	Apartment 2-4 Units	7,572	8,908	11,296	13,684	16,072	18,460
Apartment 5+ Units	Applied Regression structure factor (0.51) to SFD	Apartment 5+ Units	5,201	6,119	8,060	10,002	11,943	13,885
1.4 Heat Pump Heat (therms)		**1.4 Heat Pump Heat**						
Mobile Home	Used engineering relationships with electric resistance heat (single family regression values had only valid factors and gave similar values)	Mobile Home*	4,505	5,315	7,039	7,241	7,442	7,643
Single Family Detached		Single Family Detached	5,477	6,444	7,470	8,497	9,523	10,550
Single Family Attached		Single Family Attached	3,559	4,187	5,309	6,432	7,554	8,676
Apartment 2-4 Units		Apartment 2-4 Units	3,559	4,187	5,309	6,432	7,554	8,676
Apartment 5+ Units		Apartment 5+ Units	2,444	2,876	3,788	4,701	5,613	6,526
1.5 Oil Heating (therms)		**1.5 Oil Heating**						
Mobile Home	Applied structure factor (0.86) to Single Family Detached	Mobile Home	29,680	34,918	43,786	52,654	61,522	70,390
Single Family Detached	Regression on means	Single Family Detached	34,512	40,602	50,914	61,226	71,537	81,849
Single Family Attached	Applied Regression structure factor (0.89) to SFD	Single Family Attached	30,716	36,136	45,313	54,491	63,668	72,845
Apartment 2-4 Units	Applied Regression structure factor (0.90) to SFD	Apartment 2-4 Units	31,061	36,542	45,823	55,103	64,383	73,664
Apartment 5+ Units	Applied Regression structure factor (0.51) to SFD	Apartment 5+ Units	17,601	20,707	25,966	31,225	36,484	41,743

Table 27. Summary of Regression Parameters and Computational Elements (cont'd)

2: Air Conditioning	For all non-heating fuel estimates, 0-bedroom values are set at 85% of 1-bedroom values
Mobile Home	Applied structure factor (0.86) to Single Family Detached
Single Family Detached	Regression on means
Single Family Attached	Regression on means
Apartment 2-4 Units	Regression on means
Apartment 5+ Units	Suspect regressions; used 2-4 unit apt. values
3: Water Heating	
Gas (therms)	Regression on means (Table 9), x cold water temperature factor
Electric (therms)	Regression on means (Table 9), x cold water temperature factor
LPG (therms)	Applied Factor.LPG to gas water heating
Fuel Oil (therms)	Set at 110% of natural gas consumption
4: Cooking	
Gas	Regression on means
Electric	Multiplied gas cooking by 0.5; see section 5.2 of text
LPG (therms)	Applied Factor.LPG to gas cooking
5: Other Electric	
Mobile Home	Regression on means; see table 12
Single Family Detached	Regression on means; see table 12
Single Family Attached	Regression on means; see table 12
Apartment 2-4 Units	Regression on means; see table 12
Apartment 5+ Units	Regression on means; see table 12

2: Air Conditioning						
Mobile Home	2,531	2,977	4,712	6,447	8,181	9,916
Single Family Detached	2,943	3,462	5,479	7,496	9,513	11,530
Single Family Attached	3,248	3,821	5,002	6,183	7,364	8,544
Apartment 2-4 Units	2,033	2,391	3,785	5,178	6,571	7,965
Apartment 5+ Units	2,033	2,391	3,785	5,178	6,571	7,965
3: Water Heating						
Gas (therms)	11,888	13,986	19,761	24,171	28,453	30,525
Electric (therms)	4,867	5,726	8,253	10,324	11,940	13,100
LPG (therms)	11,888	13,986	19,761	24,171	28,453	30,525
Fuel Oil (therms)	14,266	16,783	23,714	29,005	34,143	36,630
4: Cooking						
Gas	4,502	5,296	6,593	7,889	9,186	10,482
Electric	2,251	2,648	3,296	3,945	4,593	5,241
LPG (therms)	4,502	5,296	6,593	7,889	9,186	10,482
5: Other Electric						
Mobile Home	9,687	11,396	16,305	21,214	26,123	31,032
Single Family Detached	10,878	12,798	16,746	20,694	24,641	28,589
Single Family Attached	8,744	10,287	14,118	17,949	21,780	25,611
Apartment 2-4 Units	7,680	9,035	12,916	16,797	20,677	24,558
Apartment 5+ Units	7,600	8,941	11,764	14,587	17,410	20,233

🟨 Shading indicates this utility use is significant for a given category.

Table 27. Summary of Regression Parameters and Computational Elements (cont’d)

6: Miscellaneous Adjustment Factors				**Variable Names**
6.0 Climate				
Heating degree days	4000		Assumed (approximately average)	HDDTot
Typical Low Temperature	14.9		Assumed (example is for Detroit)	LowTemp
Cooling Degree Days	1500		Assumed (approximately average)	CDDTot
6.1 LPG/Propane Factor	1.0949		Engineering relationship; source EIA/DOE	Factor.LPG
6.2 Cold water inlet temp.	61.656		Engineering relationship: = 74.3 - 0.003161*HDDTot	
Cold Water Temp Factor	0.9731413		Factor applied to water heating estimate	Factor.CWater
6.3 Heat Pump Factor				
Heat Pump HSPF	7.85		Heat pump efficiency ; range 6.6 to 9.1; used average	HSPF
Heat pump factor	0.558529231		Calculated from HSPF and Low Temperature	Factor.HHeat
6.4 Structure Type				
Mobile home	0.86		From Table 7, average structure type factors, gas or electric heating, regression on microdata or on means	Factor.MH
Single family detached	1.00			Factor.SFD
Single family attached	0.89			Factor.SFA
Apartment with 2-4 units	0.90			Factor.AP2
Apartment with 5 or more units	0.51			Factor.AP5
6.5 Age of Unit				
All ages	1.00		Average of gas & electric heating age factors; Report 6, Table 15, part 2.2. Applied to air conditioning as well as heating	
21+ years old	1.07			Factor.Age21
11-20 years old	0.89			Factor.Age11
1 to 10 years old	0.83			Factor.Age10
6.6 Trending: Equipment				
	2012/2001	Factor		
Heating, gas or oil	1.04	0.962	Efficiency improvement of equipment from middle of RECS years (1997-2001-2005) to 2012; "Factor" is multiplier applied to 1997-2001-2005 equations	Factor.Trend.GHeat
Heating, Electric	1.00	1.000		Factor.Trend.EHeat
Heating, Heat Pump	1.22	0.820		Factor.Trend.HHeat
Air Conditioning	1.21	0.826		Factor.Trend.AC
6.7 Energy Star	1.04	0.960	Calculated Energy Star factor	Factor.EnergyStar
6.8 Bedroom Adjustments				
All efficiency values based on 85-86 percent of 1-bedroom values				
Electric and heat pump heating for 0- and 1-bedroom mobile homes based on 5+ unit apartment bedroom relationships because this category had most units of this type and mobile home samples were too small or non-existent (0-bedroom units set at 64% or 3-bedroom value and 1-bedrooms set at 75.5 percent).				

Part 13. Additional HUSM Research Items

Although a number of questions that arose in the course of the research for this report were explored, others were not. Sample sizes for individual surveys prior to the yet-to-be released detailed 2009 survey were a major constraint on examining most of these questions. Trying to use combined data from more than two or three adjacent surveys was seriously compromised by the fairly significant improvements in equipment efficiency and building envelope improvements that have been made.

It is unlikely, with the possible exception of resistance and heat pump heating, that any of the topics of interest will significantly change the revised HUSM values. The 2009 data will, however, permit an assessment of the trending methodology proposed for use. The suggested matters that could be addressed with the 2009 data are as follows:

- Determine if comparatively very low resistance heating values and decreases in those values over time are due to lower temperature settings and/or extensive heat reduction settings in zoned rooms not in use. (The 2009 RECS's larger samples will facilitate this type of analysis when the data become available.)

- Separate forced air and coil electric heat using combined data (another matter that would be best examined with the assistance of 2009 RECS data).

- Research best "typical low temperature" value to be used in heat pump calculations (an engineering research question).

- Determine why regression results are sensitive to Age1 vs. Age2 analyses.

- Explore alternative definitions used to categorize air conditioning. (e.g., eliminate units with only or two window air conditioners and include test for whether either are much used. (Inclusion of units with very partial air conditioning may be affecting the regression significance levels that led to rejecting use of normal regression values. The fact that newer units don't appear to be more efficient is also suspicious, although it may be due to the possible reason offered in the report.

- Do more extensive comparisons of weighted vs. unweighted results for regressions results to determine if any significant differences arise.

- Examine relationship between high-rise and low-rise 5+ unit apartment buildings, and whether they deserve separate estimation categories.

- Determine source of decrease in luxury energy consumption items and if some can be disregarded and included in analysis of Other Electric

- Explore combining single family attached and 2-4 unit apartments for both heating and cooling mergers.

- Research renter vs. total vs. owner consumption using PHA-available variables with the assistance of 2009 RECS data.

- Test statistical power of HUSM water heating method.
- Determine if it is possible to measure the statistical reliability of HUSM estimates at the local level with the assistance of the larger samples in the 2009 RECS.