Utility Allowance Model Final Report

GARD Analytics June 5, 2003

1. Introduction and Objective

The U.S. Department of Housing and Urban Development (HUD) runs the Housing Choice Vouchers program, also called Section 8. The Housing and Community Development Act of 1974 authorized the Section 8 program which has been modified several times including by the Quality Housing and Work Responsibility Act of 1998 which resulted in the current Housing Choice Vouchers program. As part of the Housing Choice Vouchers program, the participant is reimbursed for a share of the total housing cost. The total housing cost does not only include rent but also includes an allowance for providing utilities such as electricity, natural gas and other fuels. The local public housing authorities must routinely update the allowances for utility costs. To make this easier, HUD has provided a standard form called HUD-52667 and guidance in the instructions for that form. The guidance includes the amount of energy consumed by heating, water heating, lighting and refrigeration, cooking, etc. These individual energy consumptions are also called end-uses. The allowances are often portrayed in a tabular format with values in dollars per month for each end use by the number of bedrooms. The tables are then reproduced for each type of housing, such as single family detached, townhouse, or apartment. This is also the format used in the HUD 52667 form.

The history of the guidance provided in the instructions for HUD 52667 dates back to the era of the original Housing and Development Act of 1974. This was soon after the beginning of the energy crisis in the 1970's. Housing from this era had few conservation features that people now take for granted in modern housing, such as sufficient wall and roof insulation, double-paned "thermal" windows, and efficient furnaces and water heaters. The guidance provided for determining the utility allowances has probably not been significantly updated since that time. Yet the common use of more energy conserving building practices, due in part to the energy crisis, has reduced the amount of energy used for heating, cooking and water heating in a typical residence. This may result in the utility allowances being larger than necessary to cover the energy costs for the residents. Of course housing stock has also changed between the 1970's and now, specifically the floor area of newer homes has increased.

The process of updating the utility allowances, often based on form HUD 52667, is performed by local housing authorities across the country. In many cases, the housing authority updates the utility allowances when significant changes occur in the rates charged by local utilities. The process to update the utility allowances varies, as do the assumptions made by the housing authorities and due to this, inconsistencies between utility allowances provided by different, yet near-by, housing authorities call into question the accuracy of the original guidance.

The objective of the work reported here was to revise the method provided in the Housing Choice Vouchers program (Section 8) regarding how housing authorities should update the utility allowances given the dramatic change in energy use in housing over the last 30 years. The revised method is encapsulated in the formulas of a spreadsheet.

2. Approach

The model for estimating the Section 8 utility allowance for housing authorities was revised as part of this project. The approach taken in revising the utility allowance method was simple:

1. Establish a baseline with current housing authority practice
2. Create a model in a spreadsheet based on data from a large residential survey
3. Compare the model with the baseline and refine the model

This approach allowed the model to match the needs of current housing authorities while at the same time incorporating the latest survey results from other sources. Since the large residential survey was performed by the U.S. Department of Energy, the approach takes advantage of that very large effort. The approach also performs initial quality assurance and starts to identify sources of problems and solutions in the model.

2.1 Housing Authority Baseline

As a first step in this process, housing authorities across the country were contacted to better understand the existing methods of updating the utility allowances. HUD identified eleven housing authorities for the review of the Section 8 Utility Allowances. These eleven were not intended to be a statistically valid sample of housing authorities from across the country but rather was an attempt to gather information from a diverse set of housing authorities. It was expected that the selected housing authorities would provide information on a broad range of processes that housing authorities use for updating their Section 8 utility allowances. Given the number of housing authorities included in the study compared to the large number of authorities across the country (thousands), the only conclusions that should be drawn are those regarding the range of approaches used and most common approach used within the sample.

Each housing authority was contacted. The person who was responsible for updating the Section 8 Utility Allowance was sought. Of the eleven housing authorities, ten were reached and interviewed. A formal interview questionnaire was prepared but generally the flow of the conversation was kept informal. Many of the interview questions regarded the derivation of the energy consumptions used by the housing authority but these were often left out of the interview if it was clear that energy consumption numbers were never used (i.e. the housing authority calculated the increase based on the increase in the utility costs quoted by the utility).

In all cases that were well described or documented, the housing authority has adopted a system that minimizes the effort they need to expend to achieve a desired level of accuracy. The level of accuracy does vary by housing authority, as does the actual work that is needed to update the utility allowances. No matter what approach is taken to simplify the utility allowance updating process, it must result in something that is as easy as the current approach and results in something just as accurate as the current approach in order to be used.

Some specific recommendations resulting from the review of eleven different housing authorities and their updating procedures for Section 8 utility allowances include:

- The model being developed should have the ability to do a side-by-side comparison of both the current utility rates and the revised utility rates with a percent change calculated.
- Because of the increasing complexity of utility rates due to a deregulated environment, multiple components may be needed for the consumption charges that individually reflect transmission and distribution charges.
- Background color and cell protection features make spreadsheets easier to use by the housing authority.
- Provide the details and description of all numbers used in the spreadsheet since it may be the only documentation for the assumptions that is kept year-to-year.
- Instructions and background information should be included directly in the spreadsheet since it is often all that is provided to a new housing authority employee when they get the responsibility to update the utility allowances.
- Provide a summary as well as completed HUD-52667 forms. This should try to fit many values on the same page, perhaps sorted by the fuel used for heating, cooking and water heating.
- For cities with deregulated utilities, it is likely that at times prices will change rapidly, so averaging across the last three or six months may be used.
- Spreadsheet programs are widely used; a web site approach is probably not necessary for portability.

Overall, the effort to review a small sample of existing methods for updating Section 8 utility allowances has provided guidance to the tasks in the project.

More details on the results of these interviews are available in an intermediate report prepared under the contract titled “Utility Allowance Reviews.”

2.2 Model Based on Residential Survey

The initial approach was to use tables directly from the RECS report “A Look at Residential Energy Consumption in 1997” published by the U.S. Department of Energy - Energy Information Administration (DOE/EIA) and to create tables that were not directly published by using the same statistical table creation method as used by DOE/EIA using the raw RECS database.

This approach assumed that the consumptions for different end-uses would be directly used in the spreadsheet and that the different tables would be accessed directly. This approach also assumed that only a few of the entries in the tables would either be missing or seem inconsistent. Those missing or inconsistent entries would be replaced with a number based on a linear regression of the remaining numbers.

Missing values occurred because the statistical method used required that a certain number of RECS samples “stand behind” every value and the number of surveyed houses for that combination did not occur in the RECS survey. The inconsistent values were found when a logical pattern did not emerge from the data, e.g., a value that increased for 0, 1, 2, 3 bedrooms and was suddenly lower for 4 bedrooms. This type of problem probably has more to do with the sample representing the 4 bedroom case having other factors which were not as normalized as they were for the 0, 1, 2 and 3 bedroom cases.

To overcome both the missing and inconsistent value issue, linear regression was used on the remaining values to come up with a predicted value for the missing or inconsistent one, thus "filling out" the table assuming linear regression. Many of the derived tables ended up grouping 0 and 1 bedroom together because for certain types of housing both 0 and 1 bedroom cases were unusual. Unfortunately, instead of only a few entries needing replacement in the tables, many entries needed replacement. This meant that regressions were being used for more than just occasionally for filling in the tables and became a substantial number of the values shown. Given this, it appeared more statistically defendable to use a table that was entirely based on a regression formulation than a mixture of regressed values and derived values.

2.3 Baseline Versus Model

Once the model was created and implemented in a spreadsheet, an evaluation was performed to compare the model results to the allowances gathered from the sample housing authorities. The level of agreement that was expected in such an evaluation was low. The housing authorities over years of updating the values of their allowances could have diverged significantly from the original HUD recommendations. During the evolution of the allowances the authority may have changed values based on policy as well as for analytical reasons. Further, the original HUD recommendations that accompany Form 52667 leave room for interpretation on how to compute specific values. In addition, utility tariffs change with time and many utilities offer multiple tariffs that can be chosen, so the costs of energy can be very different.

Given all of these caveats, what was expected was a mixed set of results for the eleven cities. If the comparisons across the eleven cities are consistently higher or lower in the created model, that may indicate a more fundamental change that merits further investigation.

Two of the housing authorities, Philadelphia and Chicago, provided detailed spreadsheets that included a derivation of the allowances they provide. By comparing the model developed for this project to these two spreadsheets not only can differences be observed but also explanations for the differences can be understood.

Given the uncertainties in comparing the allowances from the model and those from the housing authorities, the level of agreement is as good as could be expected. One value of this comparison was finding and correcting a few errors in the spreadsheet model during the comparison analysis. Since the model is calculating heating and cooling energy costs that are lower than those currently being used by authorities, it can be expected that Section 8 Utility Allowances would decrease if the model is put into use. Due to the size of the changes, further validation of the new model is needed before wide adoption by housing authorities should take place.

More details are available in an intermediate report under the same contract titled "Evaluate Actual and Model Allowances."

3. Spreadsheet

The HUD52667.xls spreadsheet contains the model for estimating end use utility allowances. The spreadsheet consists of eight different tabs or sheets:

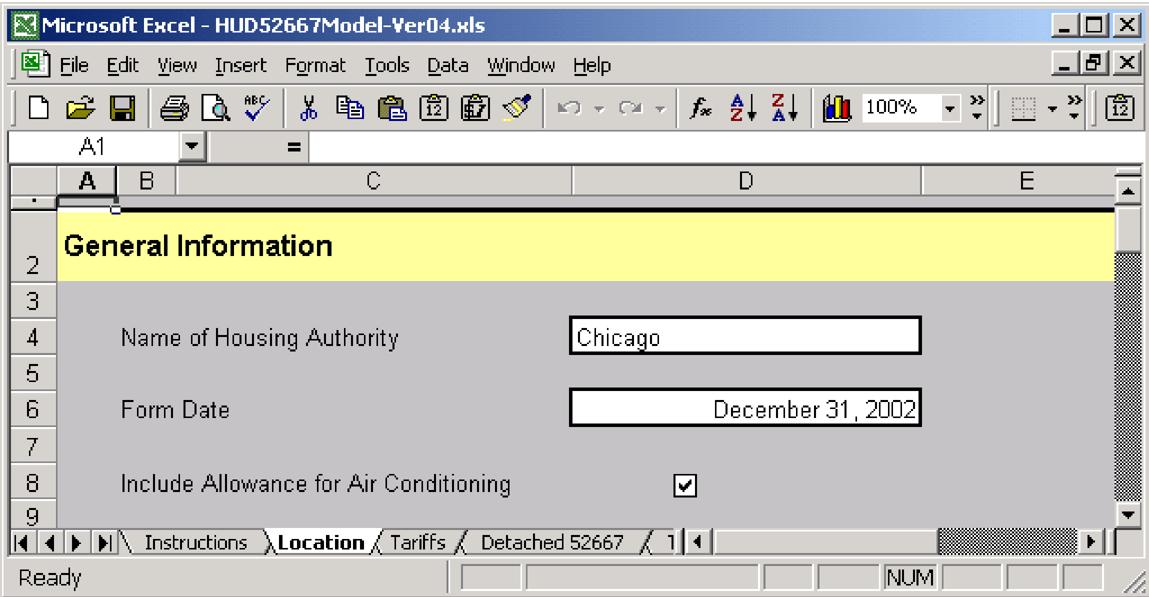
- Instructions
- Location
- Tariffs
- Detached 52667
- Townhouse 52667
- Apartment 52667
- Manufactured 52667
- Summary

The spreadsheet was designed with the housing authorities in mind and inputs were limited to the Location and Tariffs tabs. The Instructions tab contains instructions on how to use the spreadsheet. The four 52667 tabs contain the model. They are identical except for the selection of the type of unit. They contain all the necessary calculations for the allowances so that adding additional unit types and 52667 forms would be as easy as copying that tab. The summary sheet contains the summed allowances for the most common configurations of number of bedrooms and end use energy sources. The model is currently implemented in a Microsoft Excel 2000 spreadsheet. Effort was made to make the spreadsheet portable by not incorporating advanced features unique to Microsoft Excel. It should be possible to open the spreadsheet file using different versions of Excel and perhaps different spreadsheet programs with little lost.

3.1 Location Tab

The Location tab consists of two sections, one for entry of General Information and the other for Climate Data. The housing authority would only need to make changes on this tab once, when they first start using the spreadsheet.

Figure 1 – General Information on Location Tab of Spreadsheet



In addition to the entries displayed above, the Location tab includes entries about the climate consisting of

- Lookup ZIP Code
- State
- Inventory COOPID
- WBANID
- Elements
- Station Name
- Call
- Latitude
- Longitude
- Elevation
- HDD Jan to Dec (12 entries)
- HDD Annual
- CDD Jan to Dec (12 entries
- CDD Annual

These values are available from a climate spreadsheet also developed during the project that is intended for use by the housing authority. The climate spreadsheet includes a database from the National Oceanic and Atmospheric Administration (NOAA) that provides heating and cooling degree-day information. Since the housing authority only needs access to this information once and because the data is so extensive, this data is contained in a separate spreadsheet.

The heating and cooling degree-day database was parsed from the text files that come on the "U.S. Monthly Climate Normals 1971-2000" CD from NOAA. This CD includes about 5500 locations across the country and is the most up-to-date and complete database of its kind.

http://lwf.ncdc.noaa.gov/oa/climate/normals/usnormals.html

The zip code information is based on the "2000 U.S. Gazetteer" ZCTA database available from the U.S. Census Bureau. ZCTA (zip code tabulation areas) are not exactly zip codes but are extremely similar. The differences are that zip codes don't always have precise definitions that meet the requirements of a census (sometimes they are just a single building) but ZCTA's do.

http://www.census.gov/geo/www/gazetteer/places2k.html

http://www.census.gov/geo/ZCTA/zcta.html

These two databases included latitude and longitude and by using the formula for the distance between points a list of the twenty closest stations that have climate data is created every time a zip code is entered. The formula for the distance is based on the "great circle" formula from an Aviation website by Ed Williams.

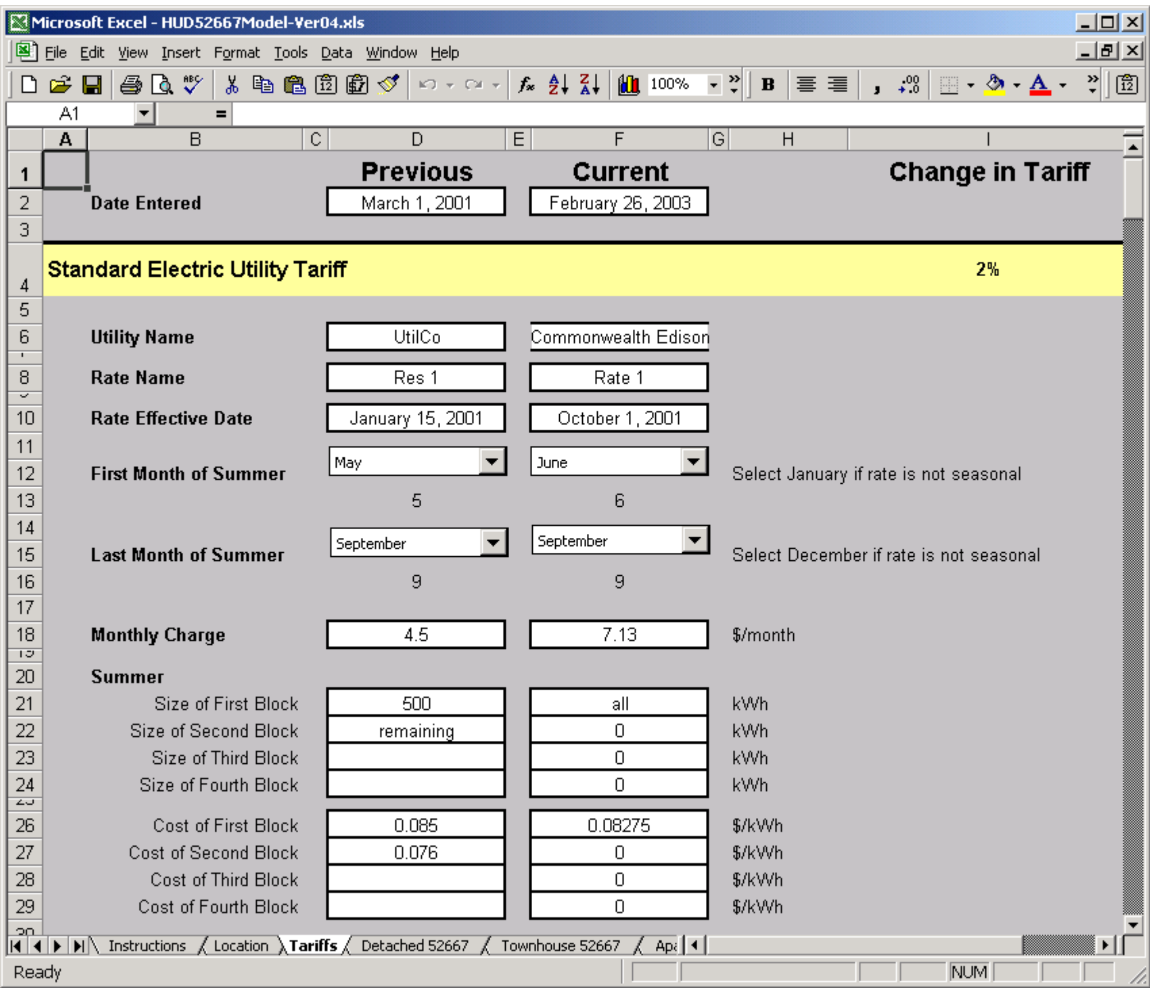
http://williams.best.vwh.net/avform.htm

The NOAA database does not include inlet water temperatures, which was derived using heating degree-day correlations. The derivation is shown in Section 4.3.

3.2 Tariffs Tab

The Tariffs tab is where housing authorities can update their rates as they change or on an annual basis. It is likely that this will be where the majority of their effort will be expended. The top of the tab is shown below:

Figure 2 – Example Tariff Entry on Spreadsheet



The Tariff tab contains sections similar to this for the following:

- Special Electric Heating/All Electric Tariff
- Standard Natural Gas Utility Tariff
- Fuel Oil Delivery Contract
- Liquified Petroleum Gas (LPG) Delivery Contract

- Water Supply Tariff
- Sewer Tariff
- Trash Collection Fees
- Range/Microwave Fees
- Refrigerator Fees
- Other Fees

The Special Electric Heating/All Electric Tariff should be entered when electric utilities have special discounted tariffs for customers that heat with electricity or use only electricity and no other energy source in their homes.

The tab is divided into columns for the Previous and Current entries for each rate. The housing authority is expected to copy the entries from Current to Previous each time they start a new revision cycle. The Change in the Tariff column indicates if the tariff has changed by more than 10%. The 10% threshold is a recommendation for when the housing authority should formally update their utility allowances. The calculation of the 10% is based on a rate calculation method that is the same as the method used for the allowance calculation (see Section 3.5 below) but is for a fixed amount of energy use. The reason to use a fixed amount is that the total energy use can vary considerably for all of the cases computed in the spreadsheet and so a typical number was chosen. The Change in Tariff percentage is calculated for the Standard Electric Utility Tariff and the Standard Natural Gas Utility Tariff only.

The spreadsheet form allows the entry of four block sizes and prices for stepped rates for electric, natural gas, LPG, fuel oil, water and sewer rates. Stepped rates are the most common form of rates used for residential customers in the country. For natural gas and electricity, the rates are also seasonal allowing entry of both summer and winter values. Time of use rates are not supported in the spreadsheet or model because they are quite uncommon for residential customers.

The flexibility and complexity of rate entry was the driving force behind the type of rate calculation process described in Section 3.5 below. If simpler single average rate numbers were all that were allowed to be entered, the rate calculations would have been easier but less accurate. Four block sizes were chosen because most residential rates across the country have four or less blocks.

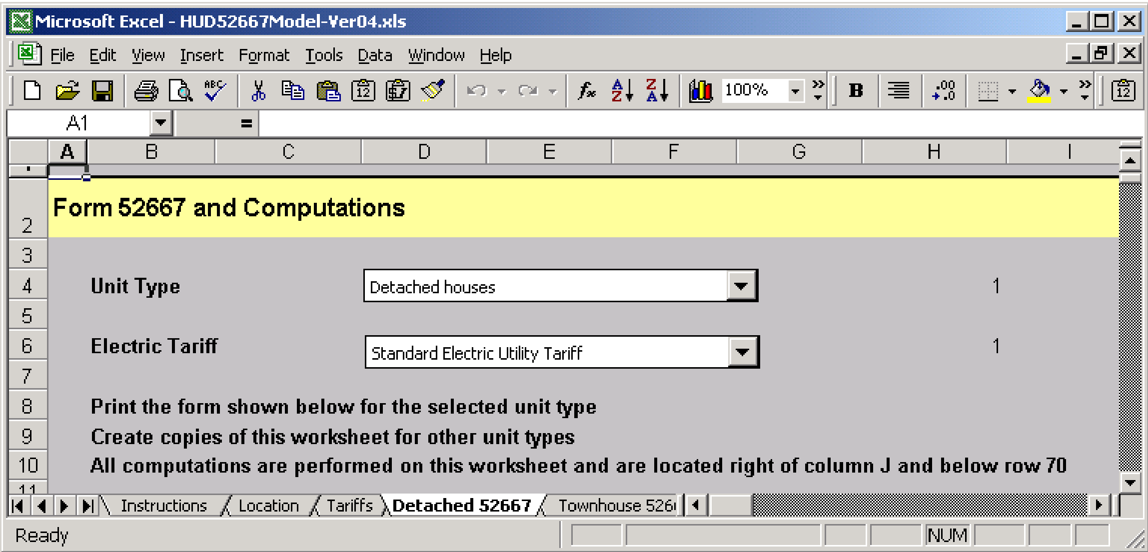
3.3 The 52667 Tabs

The 52667 tabs contain the model and the form that can be printed out. The four tabs in the spreadsheet are identical except for the building type chosen:

- Detached 52667
- Townhouse 52667
- Apartment 52667
- Manufactured 52667

At the very top of the 52667 tabs are a few parameters about that tab:

Figure 3 – Entries on 52667 Tab of Spreadsheet



The unit type pulldown list includes:

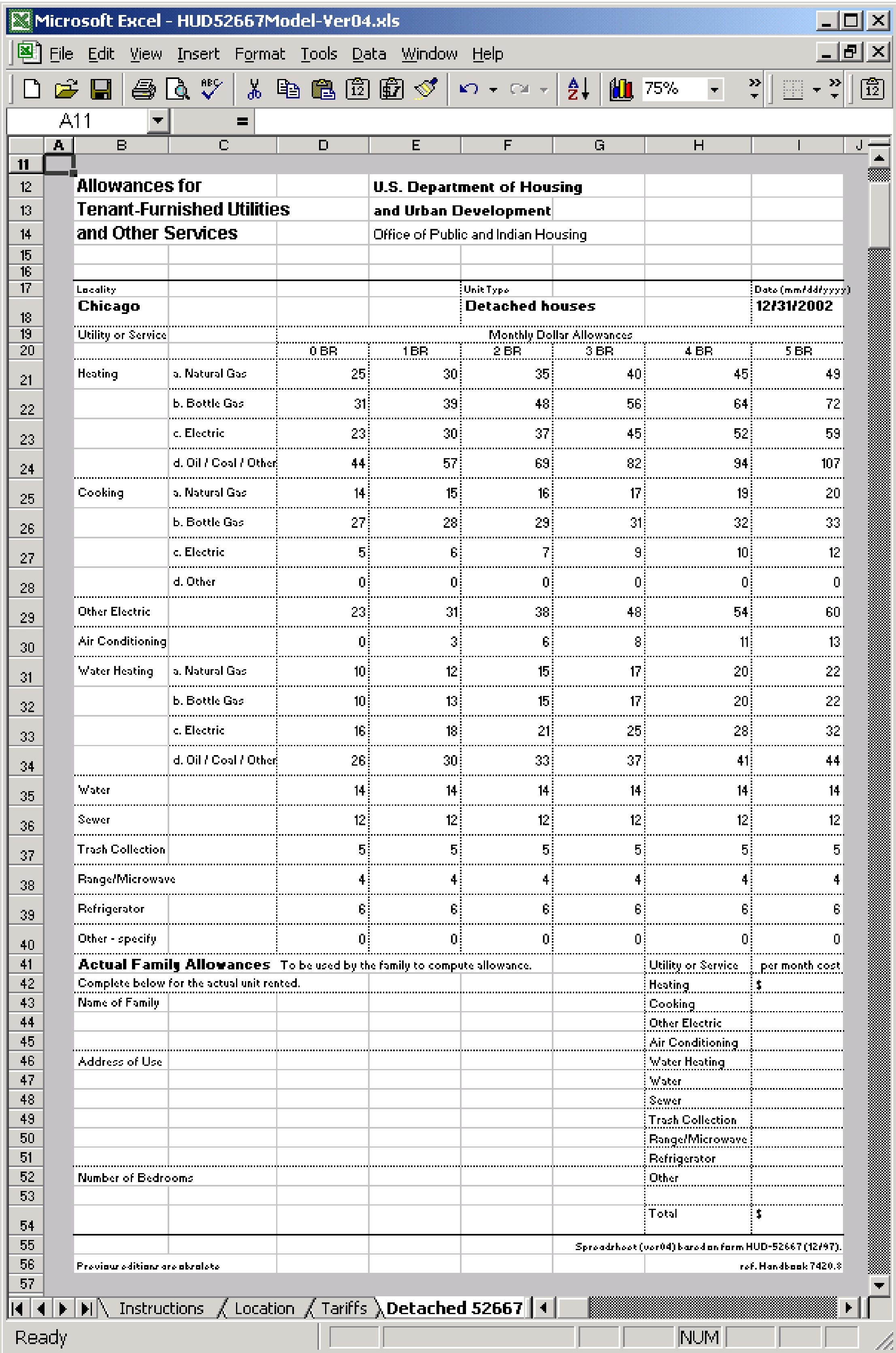
- Detached houses
- Duplexes, row or townhouses
- Garden and high rise apartments
- Manufactured homes
- Duplex
- Triplex
- Fourplex
- Townhouse - within row
- Townhouse - end of row
- Multifamily
- Highrise
- Apartment
- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4

Only the first four unit types have specific energy and water consumption models and the other unit types are based on those four. For example, the Townhouse-within row and Townhouse-end of row options are based on the Duplexes, Row or Townhouses values with some adjustments.

In addition, each tab requires the user to indicate whether the standard electric tariff or the space heating/all electric tariff should be used for the computation.

Directly below these entries is the form while the computational model starts at the lower right hand corner of the form. While the calculations are not concealed, the intention is that most housing authorities may want review them but would not want to change them. The form is shown below in Figure 4 and is essentially the same as the 52667 form except for a change in the categorization of fuel oil.

Figure 4 – Form 52667 from Spreadsheet



Microsoft Excel - HUD52667Model-Ver04.xls

Allowances for Tenant-Furnished Utilities and Other Services

U.S. Department of Housing and Urban Development
Office of Public and Indian Housing

Locality: **Chicago** | Unit Type: **Detached houses** | Date (mm/dd/yyyy): **12/31/2002**

Utility or Service		Monthly Dollar Allowances 0 BR	1 BR	2 BR	3 BR	4 BR	5 BR
Heating	a. Natural Gas	25	30	35	40	45	49
	b. Bottle Gas	31	39	48	56	64	72
	c. Electric	23	30	37	45	52	59
	d. Oil / Coal / Other	44	57	69	82	94	107
Cooking	a. Natural Gas	14	15	16	17	19	20
	b. Bottle Gas	27	28	29	31	32	33
	c. Electric	5	6	7	9	10	12
	d. Other	0	0	0	0	0	0
Other Electric		23	31	38	48	54	60
Air Conditioning		0	3	6	8	11	13
Water Heating	a. Natural Gas	10	12	15	17	20	22
	b. Bottle Gas	10	13	15	17	20	22
	c. Electric	16	18	21	25	28	32
	d. Oil / Coal / Other	26	30	33	37	41	44
Water		14	14	14	14	14	14
Sewer		12	12	12	12	12	12
Trash Collection		5	5	5	5	5	5
Range/Microwave		4	4	4	4	4	4
Refrigerator		6	6	6	6	6	6
Other - specify		0	0	0	0	0	0

Actual Family Allowances To be used by the family to compute allowance.
Complete below for the actual unit rented.

Name of Family

Address of Unit

Number of Bedrooms

Utility or Service	per month cost
Heating	$
Cooking	
Other Electric	
Air Conditioning	
Water Heating	
Water	
Sewer	
Trash Collection	
Range/Microwave	
Refrigerator	
Other	
Total	$

Spreadsheet (ver04) based on form HUD-52667 (12/97).
Previous editions are obsolete | ref. Handbook 7420.8

Instructions | Location | Tariffs | Detached 52667

Ready NUM

The calculations that are contained on this tab are extensive and are described in Section 3.5 below. The calculations are repeated on each 52667 tab so that they are independent of one another. This makes it easy to add or remove tabs depending on the housing unit types needed by the housing authority.

3.4 Summary Tab

The summary tab displays a simple summary table of the total energy and non-energy portions of the allowance for different combinations of energy sources.

Figure 5 – Summary Tab from Spreadsheet

Microsoft Excel - HUD52667Model-Ver04.xls

F43 = ='Detached 52667'!M898

ENERGY PORTION OF ALLOWANCE ($/month)

Energy Sources			Detached Houses			Duplexes, Row or Townhouses				Garden and Highrise Apartments				Manufactured Homes			
Heat	Hot Water	Cooking	2 BR	3 BR	4 BR	Studio	1 BR	2 BR	3 BR	Studio	1 BR	2 BR	3 BR	Studio	1 BR	2 BR	3 BR
In Rent	In Rent	Natural Gas	60	73	83	34	44	54	66	35	43	51	59	38	50	61	71
In Rent	In Rent	Bottle Gas	73	86	96	47	57	67	79	48	56	64	72	51	63	74	85
In Rent	In Rent	Electric	51	64	75	25	35	46	57	26	34	43	51	29	41	52	63
In Rent	Natural Gas	Natural Gas	75	90	103	44	56	68	83	45	55	66	76	48	62	75	89
In Rent	Natural Gas	Electric	66	81	94	35	48	60	74	35	47	58	68	39	53	67	80
In Rent	Bottle Gas	Bottle Gas	88	104	116	57	70	82	97	58	69	79	90	62	75	89	102
In Rent	Bottle Gas	Electric	66	82	95	35	48	61	75	36	47	58	69	39	54	67	80
In Rent	Electric	Natural Gas	81	98	111	51	63	75	91	52	62	73	84	55	68	82	96
In Rent	Electric	Bottle Gas	95	111	125	64	76	88	104	65	75	86	97	68	81	95	109
In Rent	Electric	Electric	72	89	103	42	55	67	82	43	54	65	76	46	60	74	87
Natural Gas	In Rent	Natural Gas	95	113	128	58	73	88	105	48	59	70	81	72	82	93	103
Natural Gas	In Rent	Electric	86	104	119	49	65	80	96	39	51	62	73	63	74	84	94
Natural Gas	Natural Gas	Natural Gas	110	130	147	68	85	103	122	58	72	85	98	82	95	107	120
Natural Gas	Natural Gas	Electric	101	121	139	59	77	95	113	49	63	77	90	72	86	99	111
Natural Gas	Electric	Natural Gas	117	138	156	75	92	109	130	65	79	92	106	89	101	114	127
Natural Gas	Electric	Electric	108	129	147	66	84	101	121	56	70	84	98	79	93	106	118
Bottle Gas	In Rent	Bottle Gas	121	142	160	76	95	113	134	62	75	88	101	94	106	117	127
Bottle Gas	In Rent	Electric	99	120	139	54	73	92	112	39	53	67	80	72	84	95	105
Bottle Gas	Bottle Gas	Bottle Gas	136	160	180	86	107	128	151	72	87	103	118	104	118	132	145
Bottle Gas	Bottle Gas	Electric	114	138	159	64	85	107	129	49	66	82	97	82	96	110	123
Bottle Gas	Electric	Bottle Gas	142	167	189	93	114	134	159	79	94	109	126	111	124	138	152
Bottle Gas	Electric	Electric	120	145	167	71	92	113	137	56	72	88	104	89	103	116	130
Electric	In Rent	Natural Gas	97	118	135	46	63	80	100	41	53	64	75	66	80	95	109
Electric	In Rent	Bottle Gas	111	131	148	59	76	94	114	54	66	77	89	79	93	108	122
Electric	In Rent	Electric	89	109	126	36	54	72	92	32	44	56	67	56	72	86	100
Electric	Natural Gas	Natural Gas	112	135	154	55	75	95	118	51	65	79	93	75	92	110	126
Electric	Natural Gas	Electric	103	126	146	46	67	87	109	42	56	71	85	66	84	101	117
Electric	Bottle Gas	Bottle Gas	126	148	168	69	89	109	131	65	78	92	106	89	106	123	140
Electric	Bottle Gas	Electric	104	126	146	46	67	87	109	42	57	71	85	66	84	101	118
Electric	Electric	Natural Gas	119	142	163	63	82	102	125	58	72	86	100	82	99	116	134
Electric	Electric	Bottle Gas	132	156	176	76	95	115	138	72	85	99	113	96	112	129	147
Electric	Electric	Electric	110	133	155	53	74	94	116	49	63	78	92	73	90	108	125

NON-ENERGY PORTION OF ALLOWANCE ($/month)

Water/ Sewer	Trash Collection	Range/ Microwave	Refrig- erator	All Dwelling Unit Types Studio	1 BR	2 BR	3 BR
In Rent	In Rent	In Rent	In Rent	0	0	0	0
In Rent	In Rent	In Rent	Occupant	6	6	6	6
In Rent	In Rent	Occupant	In Rent	4	4	4	4
In Rent	In Rent	Occupant	Occupant	10	10	10	10
In Rent	Occupant	In Rent	In Rent	5	5	5	5
In Rent	Occupant	In Rent	Occupant	11	11	11	11
In Rent	Occupant	Occupant	In Rent	9	9	9	9
In Rent	Occupant	Occupant	Occupant	15	15	15	15
Occupant	In Rent	In Rent	In Rent	26	26	26	26
Occupant	In Rent	In Rent	Occupant	32	32	32	32
Occupant	In Rent	Occupant	In Rent	30	30	30	30
Occupant	In Rent	Occupant	Occupant	36	36	36	36
Occupant	Occupant	In Rent	In Rent	31	31	31	31
Occupant	Occupant	In Rent	Occupant	37	37	37	37
Occupant	Occupant	Occupant	In Rent	35	35	35	35
Occupant	Occupant	Occupant	Occupant	41	41	41	41

Notes:
Combinations of Bottle Gas and Natural Gas excluded in this summary.
Combinations of number of bedrooms with certain types of dwelling units excluded from this summary
Air conditioning and other electric uses are included in all numbers in table above.

Location / Tariffs / Detached 52667 / Townhouse 52667 / Apartment 52667 / Manufactu

Please note that if air conditioning is included as a portion of the allowance it is included in all of the allowances shown in the summary.

3.5 Calculation Steps

The calculations part of the 52667 tab are below and to the right of the form and are not intended to be modified. They use values entered on the "Location" tab and the "Tariffs" tab and the entry selections at the top of the 52667 tab and generate all of the values needed for HUD Form 52667. The calculations start with the *Derived Consumption Equations* section and proceed downward in a step-by-step manner.

The following section devotes a paragraph to each section of the calculation sequence in the same order as they appear on the 52667 spreadsheet. Each section of the calculation includes a group of rows and columns that involve similar computations. Generally the spreadsheet takes care of the logistical details of turning the energy regression equations into allowances in dollars.

The *Derived Consumption Equations* are based on an analysis performed primarily using data from DOE/EIA Residential Energy Consumption Survey (RECS). Most of the coefficients of the equations were derived by examining regression equations that best fit the data from individual RECS survey cases. The coefficients were derived for the five basic housing unit types that RECS uses and a table is present to adjust these five housing unit types into the unit types you have selected. The derivation of the equations is described later in Section 4. The following quote appears at the top of this section in the spreadsheet:

> *The coefficients in the following table were mainly derived from DOE/EIA Residential Energy Consumption Survey for 1997 database. The derivation is not part of this spreadsheet but may be found in the ModelDataSummary.xls spreadsheet and is described in the final report. The number of digits shown for the coefficients is based on the numbers provided by Excel's regression function and do not reflect the inherent accuracy of the numbers. For accuracy information see the previous cited sources and see the error terms. All end-uses were checked against a variety of sources and at times the coefficients reflect choices based on professional judgment.*

The *Unit Types and Adjustment Factors* section lists the different unit types and which of the five RECS unit types are the closest match. The five RECS unit types are single family attached, single family detached, apartments in buildings with 2 to 4 units, apartments in buildings with five or more units, or mobile homes. They all map directly to HUD 52667 categories. The HUD 52667 category for garden and high rise apartments uses the RECS category of apartments in buildings with five or more units. Adjustment factors can be applied to the RECS coefficients for heating, cooking, other electric, air conditioning, water heating, and cold water. In most cases the adjustment factors are 1, in other words, no adjustment. For the Townhouse – within row the heating and air conditioning factors are 0.91 and for Townhouse – end of row the heating and air conditioning factors are 1.09.

The *Selected Unit Types* section shows the result of the unit type selected at the top of the 52667 tab. It also pulls together the adjustments from the previous section and the shows the appropriate equations with and without the adjustments applied.

The *Consumption Table (kBtu per year)* section has several parts. The first part shows the annual heating and cooling degree days (base 65) from the Location tab. The next part shows the adjustments to the water heating energy usage based on the inlet water temperature. The derivation of the adjustment is shown later in Section 4. The third part shows the energy and water consumption based on applying the equations from the previous section. The energy estimates are all in kBtu/year and are based on the regression equations derived primarily from the RECS data. The values shown are for zero (studio) to five bedroom housing units. The types of consumption are:

- Heating with Natural Gas
- Heating with Electricity
- Heating with Fuel Oil
- Cooking with Natural Gas
- Cooking with Electricity
- Other Electric
- Air Conditioning
- Water Heating with Natural Gas
- Water Heating with Electricity
- Water Heating with Fuel Oil
- Water
- Sewer

The *Consumption Table (per Month)* converts the annual consumption table from the previous section into monthly consumptions using more common units. For electricity, kWh are used, for natural gas, therms are used, etc. The consumptions are for all of the different end uses based on the number of bedrooms in the housing unit.

These are then combined into groups by utility in the section labeled: *Average Consumption Per Month Component Subtotals and Ordering*. In each group, the services are added individually until all services are included. For electricity, first "Other Electric" is included, then "Other Electric + Cooking" etc., until finally the last group for electricity "Other Electric + Cooking + Water Heating + Heating + Air Conditioning" is shown. The reason for this is that the utility bills are estimated for each group and then the difference between the groups, the incremental cost, for each added service can be independently determined.

Unit conversions are then performed for the energy consumptions that could have different measurement units applied. The next four sections perform the conversion based on the units that were selected when entering the tariff. While electricity is always measured in kWh, fuels often have a variety of measurement units that utilities use. For natural gas for example, the values in the tariffs may be in therms, MMBtu, CCF, or MCF. The next four sections perform the unit conversions and are labeled *Natural Gas Conversion, Liquified Petroleum Gas Units Conversion, Fuel Oil Units Conversion, and Water and Sewer Units Conversion*.

The *Average Consumption Per Month in Units Used by Tariffs* section applies the unit conversions from the previous sections to the table in the *Average Consumption Per Month Component Subtotals and Ordering* section. These are the values that will be applied to the rates. Again they are in a table from zero to five bedrooms and arranged by fuel. Within each fuel group are total energy consumptions for each end-use component added up in order.

The next section labeled *Tariff Summary* has links to the Tariffs tab but is shown in a more compact summary format. The service charges, extra charges, taxes and the start and ending month of summer are shown in the first part of this section. The next part of the section shows the sizes and costs for the four blocks that are for the summer and winter.

Next are the *Electric Tariffs Shown Monthly* and *Natural Gas Tariffs Shown Monthly* sections. These repeat the tariff data on a month-by-month basis depending on the starting and ending month selected for each. The other utilities do not vary by season so they do not need to be represented monthly. The charges are shown for each month of the year based on the starting and ending month for summer indicated on the Tariffs tab.

Climate Monthly Adjustments are made for the heating and air conditioning uses. They are adjusted by the degree days entered on the Location tab and are shown on a monthly basis. The energy consumptions will vary by month due to differences in the heating and cooling requirements. The energy consumptions are needed on a monthly basis because the utility rate calculations are performed monthly and this affects the bill if the tariffs have multiple blocks. The amount of consumption in each block means that the cost per energy unit varies each month.

The *Heating and Cooling Monthly Consumptions* section shows the incremental consumptions are then also expressed on a monthly basis for each heating fuel and for air conditioning with electricity. This is the first of several sections that are shown with annual totals on the left of the table for the housing unit type with different numbers of bedrooms from zero (studio) to five bedrooms. The right part of the table repeats for the six different numbers of bedrooms tables of results from January to December. This makes this a very wide table of over 80 columns but each unit size has values for each month.

The *Annual and Monthly Consumptions* section is also a very wide table with twelve months for each unit from zero to five bedrooms. Consumptions are grouped by fuel and shown with the incremental energy uses shown in Average Consumption Per Month Component Subtotals and Ordering. These are the values of energy consumption for which the monthly utility bills will be calculated.

The *Annual and Monthly Electric Bill Estimates* provide the calculation details of how much energy is used in each block of the tariff, how much each block costs, the service charges, extra charges and taxes. This is repeated for:

- Other Electric
- Other Electric + Cooking
- Other Electric + Cooking + Water Heating
- Other Electric + Cooking + Water Heating + Heating
- Other Electric + Cooking + Water Heating + Heating + Air Conditioning

The incremental costs between each of these groupings are the cost for each of the respective end uses. This method of calculating the incremental costs is more rigorous than specified in other HUD literature on the topic but is more accurate since multiple block rates deserve careful calculation. The utility bill estimates are compiled for each of the consumptions groups and then the incremental difference between the groups are determined to obtain the incremental cost for just that end-use. The number of consumption units and the cost of each consumption unit for each block is separately calculated. The monthly charges and the extra charges are calculated as are the taxes and total bill for each consumption group. This is repeated for each consumption group and for each utility. The monthly and annual costs are then calculated. The formulas for each utility bill estimate are very similar.

The *Annual and Monthly Natural Gas Bill Estimates* section is similar to the previous section but applies to natural gas bills. The costs are again computed for different groups with more and more end-uses included and the incremental costs between the units are shown. The groupings for natural gas are:

- Cooking
- Cooking + Water Heating
- Cooking + Water Heating + Space Heating

The *Annual and Monthly Liquified Petroleum Gas Bill Estimates* repeat the same calculations as the previous section but for LPG. The *Annual and Monthly Fuel Oil Bill Estimates* repeats the calculations for fuel oil except no cooking estimate is included.

The *Annual and Monthly Water Bill Estimates* and *Annual and Monthly Sewer Bill Estimates* section compute the costs of those consumptions but do not need to compute incremental costs since they are concerned with total water consumption only.

The *Average Cost Per Month* shows the incremental costs for each end use by fuel. This is the first section that is not showing the January to December monthly details for zero (studio) to five bedroom units. The average costs are used because it is assumed that residents are on budget plans provided by the utilities so that they will pay the same amount all year. This is the section where the values from the form are explicitly shown. The form at the top of the 52667 tab directly links to values in this section

The *Check Totals (Should be Zero)* section simply checks if the calculations were performed and totaled correctly.

The *Non-Energy Related Expenses* section shows in a compact format similar to the utility tariff summary section all of the non-energy related expenses:

- Water/Sewer
- Trash Collection
- Range/Microwave
- Refrigerator
- Other-specify

The *Energy Related Expenses Summary* is a summary of total utility allowances for energy and is shown for a variety of combinations of heating, hot water and cooking fuels. The expenses include air conditioning and other electric use. This summary is copied and "paste linked" to the Summary tab. Not all combinations of fuels are shown. Less likely combinations are not shown such as LPG heating and natural gas water heating. It is also possible that the tenant does not directly pay for heating and water heating end uses. These end uses are often provided centrally in large apartment buildings and the costs for these are included in the rent. No allowance for those end uses would be included in those cases.

Non-Energy Related Expense Summary is also a summary of expenses but for non-energy expenses. These are shown for a variety of combinations if they are included in the rent or not for:

- Water/Sewer
- Trash
- Range
- Refrigerator

4. Energy Model

The U.S. Department of Energy's Energy Information Administration (EIA) has performed extensive residential surveys for many years. The database for the 1997 survey was used in this project to determine the energy uses by end-use for U.S. residences. Some detail on the survey itself can be found in "A Look at Residential Energy Consumption in 1997" published by EIA in November 1999. A description of the survey methodology included the following summary:

> *The Residential Energy Consumption Survey (RECS) was designed by the Energy Information Administration (EIA) to provide information about energy consumption within the residential sector. The RECS is conducted in two major parts: the Household Survey and the Energy Suppliers Survey. The Household Survey collects information about the housing unit via personal interviews with a representative national sample of households. The Rental-Agent Survey is an adjunct to the Household Survey and is used to verify information provided by renters in the Household Survey. In the Energy Suppliers Survey, data concerning actual energy consumption are obtained from household billing records maintained by the energy suppliers. The data are collected by questionnaires mailed to all the suppliers for the households in the Household Survey. This report is based on the results of the Household Survey, the Rental-Agent Survey, and the Energy Suppliers Survey. A subcontractor to EIA collected and processed the 1997 RECS.*

The end use energy consumptions were not metered for the over five thousand housing units surveyed, but instead a regression technique was used by EIA to determine the end-uses based on total energy consumption and many different energy related characteristics. This is described in the same reference above as:

> *For each household that responded to the 1997 RECS, the annual amount of energy used for five end-use categories--space heating, water heating, air-conditioning, refrigerators, and general appliance usage--was estimated. The end-use estimates were produced for each of the five main energy sources: electricity, natural gas, fuel oil, kerosene, and liquefied petroleum gas (LPG). The end-use amounts were not based on data produced by placing meters on individual appliances; rather, they were obtained by estimating how much of the total annual consumption for each energy source can be attributed to each of the end-use categories for each household by using a regression technique. For each energy source, the annual consumption attributed to each of the end-use categories can be estimated by use of regression equations. The regression equations are also used to impute energy consumption when the billing data are missing or inadequate. A separate equation was developed for each of the five main energy sources. In each equation, the dependent variable was the annual energy consumption for the 1997 calendar year. The set of independent variables varied according to energy source type. The desire to use a large number of independent variables without using a large number of interaction terms and the desire to adapt the regression procedures to account for heteroscedastic error terms led to the use of a nonlinear regression technique. The*

use of linear regression would have greatly restricted the ability to adequately model household energy consumption.

In each of the following sections the details of the consumption model will be discussed for each major end-use appearing on the 52667 form.

4.1 Heating

A variety of methods were considered when attempting to characterize heating energy use. The RECS database has a very rich set of parameters that could be related to heating energy use but the housing authority, when determining the allowance for a specific unit, only has limited information that it can trust. The information is usually the number of bedrooms and the type of housing unit. Other parameters such as the number of occupants, the area of the housing unit, and the age of the unit, could be estimated but with less certainty. Due to this the focus of the analysis was simply to relate heating energy use with the number of bedrooms and the type of housing unit.

The types of housing units in the RECS database are:

- Mobile Home
- Single-Family detached
- Single-Family Attached
- Apartment in Building containing 2-4 units
- Apartment in Building Containing 5 or more units

These correspond closely with the main categories for housing units that HUD uses:

- Detached houses
- Duplexes, row or townhouses
- Garden and high rise apartments
- Manufactured homes

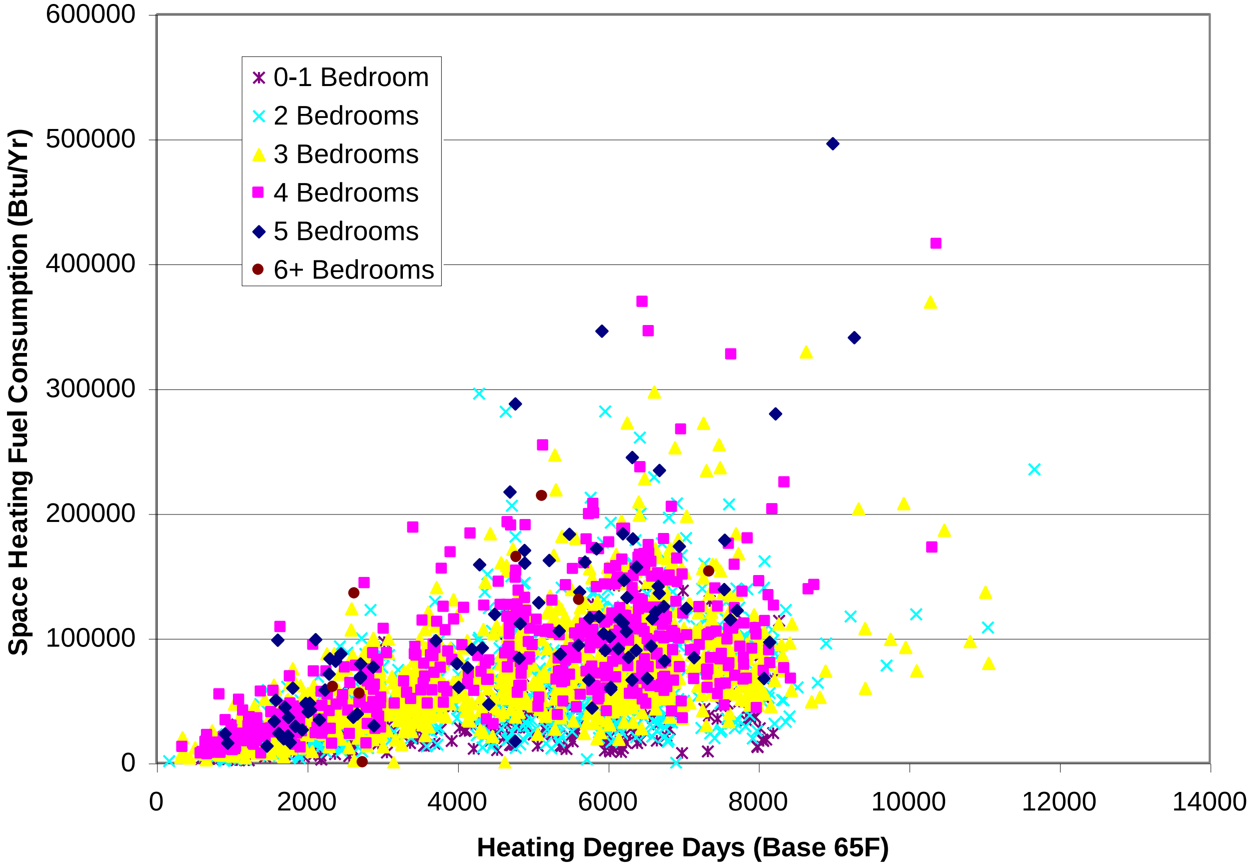
In addition, the RECS database has several parameters related to the location and climate including:

- Census Region
- Census Division
- Cooling Degree-Days to base 65
- Heating Degree-Days to base 65

Ultimately, the parameter most sensitive to the amount of heating, naturally, was the Heating Degree Days (HDD), which was used in the analysis.

An example of the variation can be seen in the following two graphs. Figure 6 shows the variation in space heating energy consumption by number of bedroom for all units versus the HDD. The variation is quite large but it is clear that heating degree days does directly affect the heating consumption.

Figure 6 – Space Heating with Natural Gas by Climate



If a linear regression is performed for each dataset, as shown in Figure 7, and the HDD coefficient for each different "bedroom" regression are themselves compared, a very strong dependency on number of bedrooms emerges.

Figure 7 – Regression of Natural Gas Space Heating Annual Energy Use by Number of Bedrooms

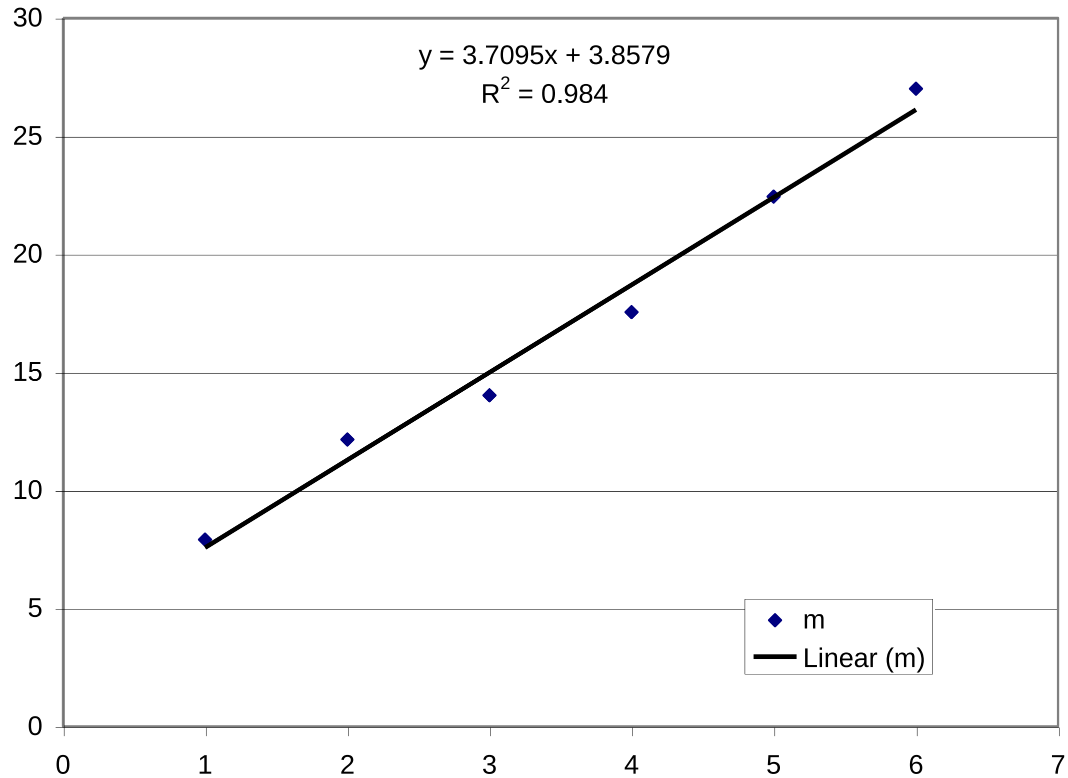
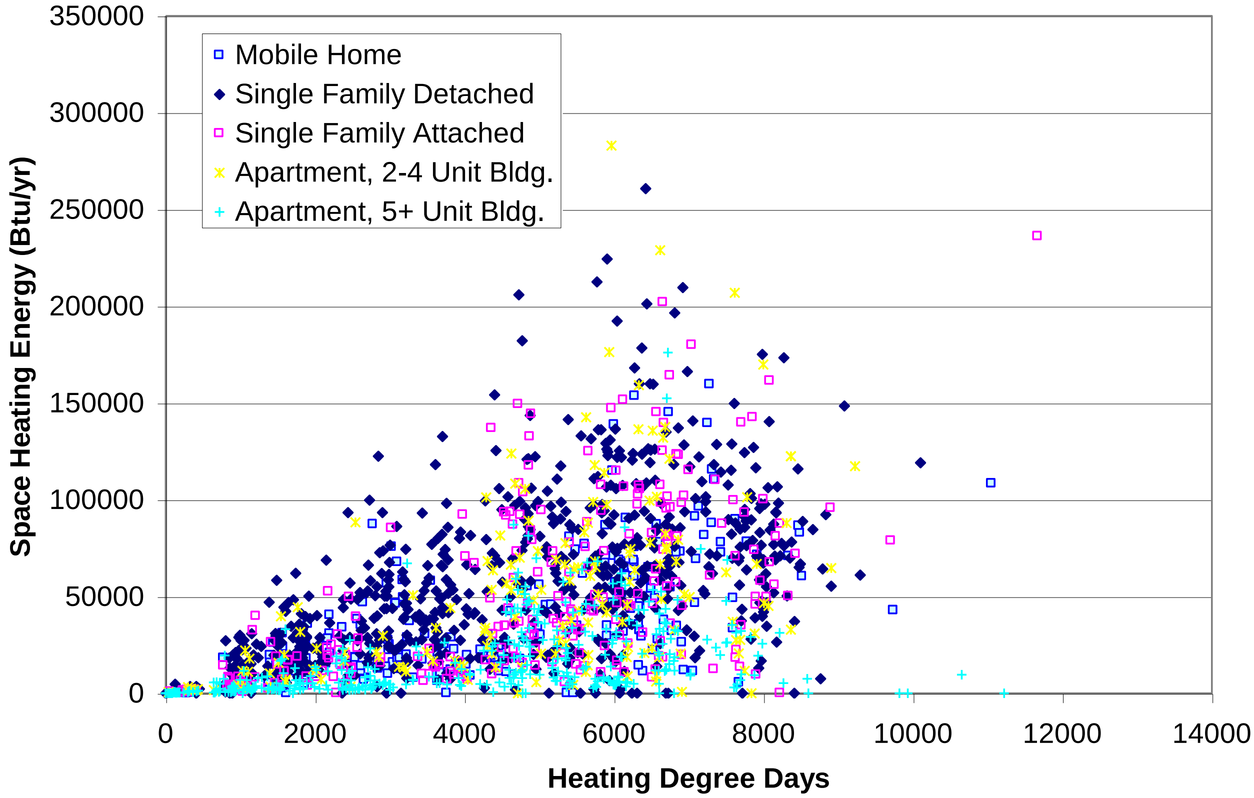


Figure 8 shows the difference in natural gas space heating by unit type for the specific case of two bedroom units. Again the variation is considerable. Most of the housing unit types overlap considerably but the apartment in buildings with five or more units is consistently lower. These units are in large buildings, typically are smaller units, and very often have only one exterior wall and are less likely to be adjacent to the roof. Having a single exterior wall and not being adjacent to the roof would affect the heat transfer characteristics of the home considerably.

Figure 8 – Unit Type Variation of Heating Energy



When regression equations are applied to the data in Figure 8 for each unit type the measurement of how well they fit statistically, the R^2 values, are low: 0.2 to 0.4. R^2 are on a 0 to 1 scale and the curve fit is better when the R^2 is closer to 1.

A multiple linear regression technique was used so that both number of bedrooms and heating degree-days could be related in a single equation. The form of the equation used was:

heating consumption= c1 * hdd + c2 * bedrooms * hdd

The second term may not seem intuitive, why include HDD and bedrooms together? One reason is related to cases with low HDD. If HDD is zero, then the total heating consumption should also be near zero and without the HDD in the second term of the equation it would remain positive for low HDD. In addition, the number of bedrooms acts as a proxy for the total size of the housing unit, and it is not consistent from an engineering perspective that the heating consumption would vary by the number of bedrooms by the same amount in all climates. For these reasons, the second term needs to include both bedrooms and HDD.

Table 1 – Statistics on Natural Gas Heating Regressions

	Mobile Home	*Single-Family detached*	*Single-Family Attached*	*Apartment in Building containing 2-4 units*	*Apartment in Building Containing 5 or more units*
Multiple R	0.729221103	0.628023602	0.588244723	0.583354368	0.568810803
R Square	0.531763417	0.394413644	0.346031854	0.340302319	0.323545729
Adjusted R Square	0.519728691	0.393604785	0.340942721	0.332473557	0.317957548
Standard Error	24306.06088	37496.38804	40258.66512	39025.98095	16894.74489
Observations	124	1987	327	214	302
Intercept	0	0	0	0	0
HDD65	12.79886203	8.191226147	7.617462573	7.857387232	3.655671728
HDDxBedrm	-0.558165052	2.306887364	2.366455483	2.546019654	1.296438153

The table above shows the coefficients and the statistics from five different multiple regressions for natural gas. The R^2 values are still in the 0.3 to 0.5 range. Note that for mobile homes, the HDD times Bedrooms coefficient is negative. Since a negative coefficient does not match the engineering model of how these factors are related, that variable was later eliminated from the analysis with little affect on the R^2.

A similar regression was also performed for electric heating but for fuel oil, the natural gas numbers were simply modified to increase usage by 10%.

Like apartment buildings, single-family attached housing units often come in two different configurations. Duplexes are essentially two single-family homes sharing a common wall while townhouses are typically thought of as row of homes sharing common walls between them. From a heat transfer perspective, the duplexes have three walls exposed to the outside while most townhouses have only two exterior walls, the front and back. Unfortunately, the 1997 RECS database that was used for the analysis does not have a parameter that indicates if the single-family attached unit is attached to only one other unit or two other units. Instead, a previous version of the RECS database from 1987 that did contain this parameter was used to determine a factor for this adjustment.

An approximate 17% difference was found between the heating energy consumption for single-family attached homes with one attached wall versus two attached walls. An adjustment factor was then used from this of 9% higher or lower if such a housing unit is explicitly selected. The default categories do make use of this adjustment since they place duplexes, row houses and townhouses in the same category.

The equation coefficients of the final model for heating energy usage for the four main types of housing units is:

Table 2 – Summary of Heating Model Coefficients

Utility or Service	*Housing*	*Units*	*Adjustment from Natural Gas*	*Coeff for HDD*	*Coeff for HDD*Bedrooms*
Heating with Natural Gas	Mobile	kBtu/yr	na	11.44095	0
Heating with Natural Gas	SF Det	kBtu/yr	na	8.191226	2.306887
Heating with Natural Gas	SF Att	kBtu/yr	na	7.617463	2.366455
Heating with Natural Gas	Apt 2-4	kBtu/yr	na	7.857387	2.54602
Heating with Natural Gas	Apt 5+	kBtu/yr	na	3.655672	1.296438
Heating with Electricity	Mobile	kBtu/yr	na	3.089799	0.391122
Heating with Electricity	SF Det	kBtu/yr	na	2.605749	0.814271
Heating with Electricity	SF Att	kBtu/yr	na	1.299717	0.85996
Heating with Electricity	Apt 2-4	kBtu/yr	na	2.401615	0.27894
Heating with Electricity	Apt 5+	kBtu/yr	na	0.747741	0.366913
Heating with Fuel Oil	Mobile	kBtu/yr	1.1	12.58504	0
Heating with Fuel Oil	SF Det	kBtu/yr	1.1	9.010349	2.537576
Heating with Fuel Oil	SF Att	kBtu/yr	1.1	8.379209	2.603101
Heating with Fuel Oil	Apt 2-4	kBtu/yr	1.1	8.643126	2.800622
Heating with Fuel Oil	Apt 5+	kBtu/yr	1.1	4.021239	1.426082

Table 3 is used to compare the heating model to existing the HUD-52667 form instruction estimate. The HUD 52667 instructions assume 2.5 bedrooms and 4000 HDD. The number of households is used to weight the different unit types.

Table 3 – Weighting of Natural Gas Heating Results for HUD Typical Case

	therms/month	*Weight (millions of households)*
Mobile	38.1	6.3
Detached	46.6	63.8
Attached	45.1	9.9
Apt2-4	47.4	5.6
Apt5+	23.0	15.8
Total	42.2	101.5

Assumes 2.5 bedrooms and 4000 HDD

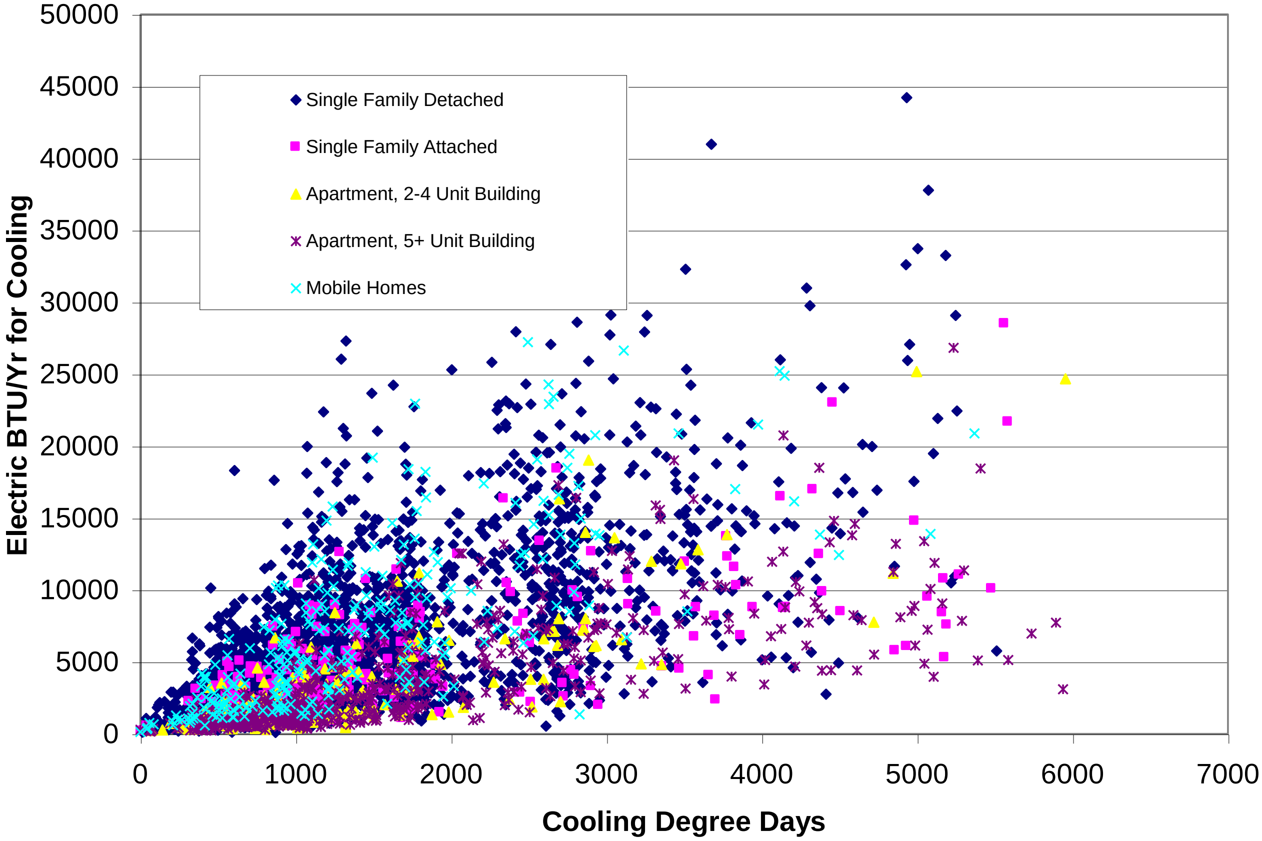
The value from the HUD 52667 instructions is 48 therms/month. The 42.2 therms/month value from the model is 12% lower than the 48 therms/month. This is a smaller change than the 30% change expected from overall RECS data. For electric heating the HUD 52667 instructions indicate 680 kWh/month for the same conditions. The weighted regression results in 385 kWh/month. This is a 43% difference, significantly larger than expected.

In an attempt to confirm the results of the regression model, the values from several different studies were compared. Eight different studies (see the references) contained numbers that could be compared with the results of the heating regression analysis. Results were mixed with wide variation depending on the source. Further efforts to compare the results are warranted but were beyond the scope of the analysis.

4.2 Air Conditioning

The air conditioning analysis using the RECS database was performed in a manner similar to the heating analysis. Cooling degree days (CDD) base 65 and number of bedrooms were the two independent variables in the multiple linear regression.

Figure 9 – Air Conditioning Impact on Climate for Different Unit Types



Again, the variation in electric use for air conditioning is considerable but displays an increasing relationship with cooling degree-days. For similar reasons as described in the heating section, the form of the regression equation was chosen to be:

cooling consumption= c1 * cdd + c2 * bedrooms * cdd

Applying a multiple linear regression technique with this form of equation to the RECS database results in Table 4:

Table 4 - Statistics on Air Conditioning Regressions

	Mobile Home	*Single-Family detached*	*Single-Family Attached*	*Apartment in Building containing 2-4 units*	*Apartment in Building Containing 5 or more units*
Multiple R	0.757052	0.725063	0.757003	0.824412	0.779504
R Square	0.573128	0.525716	0.573054	0.679655	0.607627
Adjusted R Square	0.567843	0.525149	0.568807	0.67302	0.605314
Standard Error	4180.907	3934.944	2574.004	2203.925	2323.864
Observations	272	2602	338	201	604
Intercept	0	0	0	0	0
CDD65	2.333228	0.232669	0.885153	1.358756	1.150998
CDDxBedrm	1.139855	1.302551	0.793576	0.77805	0.716829

The R^2 values are higher than for heating, ranging from 0.5 to 0.7. That means that the model accounts for more variation in air conditioning energy use than the heating model.

Table 5 is used to compare the air conditioning model to the HUD-52667 form instruction estimate. The HUD 52667 instructions assume 2.5 bedrooms and 2000 HDD. The number of households is used to weight the different unit types.

Table 5 - Weighting of Air Conditioning Results for HUD Typical Case

	KWh//month	*Weight (millions of households)*
Mobile	126.6	6.3
Detached	85.2	63.8
Attached	70.1	9.9
Apt2-4	80.7	5.6
Apt5+	71.9	15.8
Total	84.0	101.5

Assumes 2.5 bedrooms and 1000 CDD

The air conditioning electric use value from the HUD 52667 instructions is 180 kWh/month. The 84 kWh/month obtained with the model is 53% lower than the 180 kWh/month.

To confirm the results of the air conditioning energy use regression model, the values from several different studies were compared. Five different studies (see the references) contained numbers that could be compared with the results of the cooling regression analysis. Again, results were mixed with wide variation depending on the source.

The model values are much smaller than the values from the housing authorities. The spreadsheet used by the Chicago authority uses the HUD 52667 assumption of 180 kWh/month and then adjusts the value by the cooling degree-days. The Philadelphia numbers are consistently 26% higher than the Chicago values leading one to believe that the difference in usage is due to the assumption for the cooling degree-days for Philadelphia, which is not shown in their spreadsheet.

The model values range from 20% to 65% lower than the authorities' values with three bedroom detached houses (one of the most common configurations) being 43% less. Some equipment efficiency improvements should have been expected. We can assume that the original HUD value that the authorities are using is based on values from the early 1980's (or perhaps earlier). According to the LBL Energy Data Sourcebook for the U.S. Residential Sector (LBL-40297) the unit energy consumption should have decreased about 20% from the early 1980's to the mid 1990's. From the same source, the average shipment weighted efficiency for central cooling equipment went from about 7.5 SEER (seasonal energy efficiency ratio) to 10.5 SEER during the same time, an improvement of 40%. Efficiencies of air conditioners based on shipments is not a good measure of the average efficiency of air conditioners operating during those years.

To confirm if the model contained an error or if the original basis of the model, the DOE Residential Energy Consumption Survey (RECS) from 1997, also shows this low air conditioning energy consumption, the RECS data was reexamined. From the RECS 97 report DOE/EIA-0632(97), Table CE3-4c shows the electric air conditioning energy use is 1677 kWh/year per household. From the same table, the corresponding 1997 cooling degree-days for households with electric air conditioning was 1435. The HUD 52667 instructions use 1000 cooling degree-days. Using a ratio of cooling degree-days, the value that would correspond to the HUD instructions would be 1169 kWh/year or 97 kWh/month. That is 46% reduction. Repeating these calculations for single family detached houses results in a reduction of 41%. The RECS data is based on a statistical disaggregation technique so it is not as reliable as a large study of end-uses based on sub-metering, but unfortunately, no recent national statistically valid study of metered end-uses exists.

The Air-Conditioning and Refrigeration Institute (ARI) statistical profile is another source of efficiency data for air conditioning units. For complete air conditioning systems, the following table shows the shipment-weighted efficiency for each year.

Table 6 – ARI Shipment Weighted Efficiency (EER or SEER)

Year	*Unitary Air Conditioners*
1976	7.03
1977	7.13
1978	7.34
1979	7.47
1980	7.55
1981	7.78
1982	8.31
1983	8.43
1984	8.66
1985	8.82
1986	8.87
1987	8.97
1988	9.11
1989	9.25
1990	9.31
1991	9.49
1992	10.46
1993	10.56
1994	10.61
1995	10.68
1996	10.68
1997	10.66
1998	10.92
1999	10.96
2000	10.95
2001	11.07

Note that for 1980 and earlier the numbers are EER and for 1981 and later the numbers are in SEER.

The improvement shown from 1980 to 2001 is an increase of 42% but that does not reflect that most of the air conditioners operating at any time are older and are not from the current year. In an analysis performed by DOE to justify the increase in air conditioning efficiency titled "Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps" from May 2002, a similar analysis was performed for the year 1997. In that year DOE determined, based on a sophisticated retirement and replacement analysis, the in-place efficiency for residential air-conditioning units was 9.13 SEER. The 9.13 value is close to the 1988 value from ARI, nine years before. Using the nine-year difference as a proxy for the average installed efficiency versus sold equipment efficiency, we can project back nine years from 1980. Assuming that efficiency changes linearly, the estimated average in-stock SEER in 1971, nine years before 1980, would be 6.6 SEER. The improvement from that value to the 1997 estimate of in-stock efficiency is 38%.

Overall, while the difference in the air conditioning energy use is large between the authority spreadsheets and the model, the differences can be mostly explained by an increase in efficiency from the era that the original estimate is based on, presumably the early 1980's, and now.

4.3 Water Heating

The RECS database also contains data on the energy consumption for water heating. Using the database and aggregating values using a similar technique as EIA does resulted in the following table of water heating natural gas consumption for different housing unit types by the number of bedrooms:

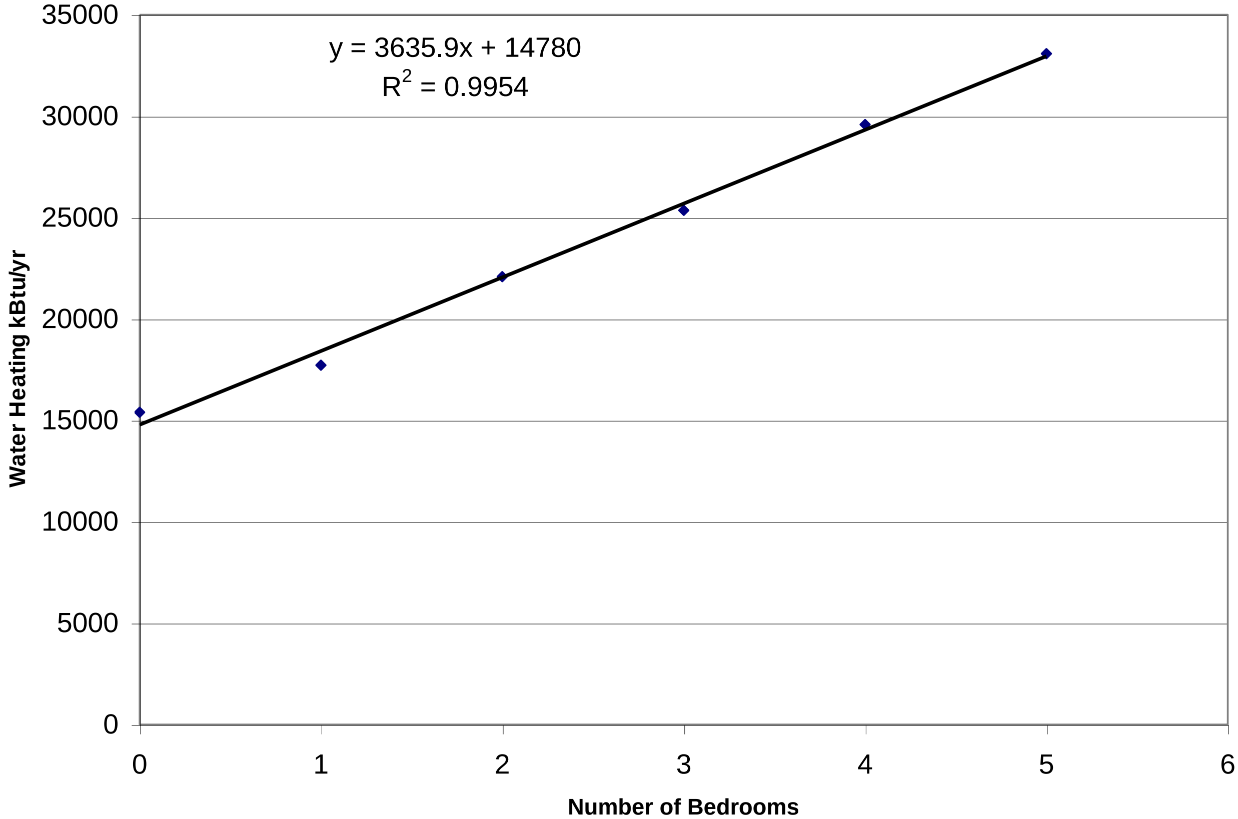
Table 7 - Natural Gas Water Heating (kBtu/yr)

Bedrooms	*Total*	*Mobile*	*SF Det*	*SF Att*	*Apt 2-4*	*Apt 5+*
Total	24542.788	21501.51	25902.97	23252.89	22286.6	20546.429
0	15395.89	Q	Q	Q	Q	15951.94
1	17721.377	Q	18955.88	18935.201	15855.374	17847.375
2	22087.577	21332.399	20872.91	21956.357	23924.27	23890.968
3	25348.993	21791.978	25200.18	25658.668	30595.038	27936.038
4	29585.055	Q	29723.15	28600.716	27607.149	Q
5+	33076.653	Q	33286.33	Q	Q	Q

Q indicates a combination without enough survey responses to be shown.

When the total natural gas consumption per year is compared to the number of bedrooms the following is shown:

Figure 10 – Water Heating by Natural Gas Regression



The R^2 is very high indicating that almost all the variation in water heater usage can be accounted for by the change in number of bedrooms. Keep in mind that the numbers included in the regression are already averages from the RECS database. When this correlation is applied to each individual housing unit type, the amount of error is shown below:

Table 8 – Regression Errors Water Heating with Natural Gas

Bedrooms	*Mobile*	*SF Det*	*SF Att*	*Apt 2-4*	*Apt 5+*
0					7%
1		3%	3%	-16%	-3%
2	-3%	-6%	0%	8%	8%
3	-18%	-2%	0%	16%	8%
4		1%	-3%	-6%	
5+		1%			

The poorest fit is the housing unit in apartment buildings with 2 to 4 units but the individual numbers for that type of housing unit decrease for the four bedroom case. This is highly unlikely and probably results from a relatively small number of surveyed units for that combination. Overall, the variation by unit type seems small enough that it can be ignored. Variation by region and census division was also investigated but the variation seemed small enough and did not warrant their being included. Later, the affect of cold water inlet temperature on water heating energy consumption will be discussed.

Other energy sources for water heating were also examined. Using the RECS database the energy use by number of bedrooms was aggregated for each fuel.

Table 9 – Water Heating Energy Usage by Energy Source (kBtu/yr)

Bedrooms	Electric	Nat Gas	LP	Fuel Oil
0	5995	15395	Q	21659
1	6218	17721	16134	26827
2	8546	22087	19790	30614
3	10893	25348	25694	31544
4	12293	29585	25668	30515
5+	13197	33076	40986	39552

Q indicates a combination without enough survey responses to be shown.

The LP and natural gas energy consumption for water heating track closely. Fuel oil consumption seems consistently higher than natural gas consumption while electric consumption seems consistently much lower. Looking at the ratios versus natural gas reveals a pattern:

Table 10 – Ratios of Energy Source to Natural Gas for Water Heating

Bedrooms	electric/natural gas	oil/natural gas	LP/natural gas
0	0.39	1.41	na
1	0.35	1.51	0.91
2	0.39	1.39	0.90
3	0.43	1.24	1.01
4	0.42	1.03	0.87
5+	0.40	1.20	1.24
Average	0.40	1.24	0.97

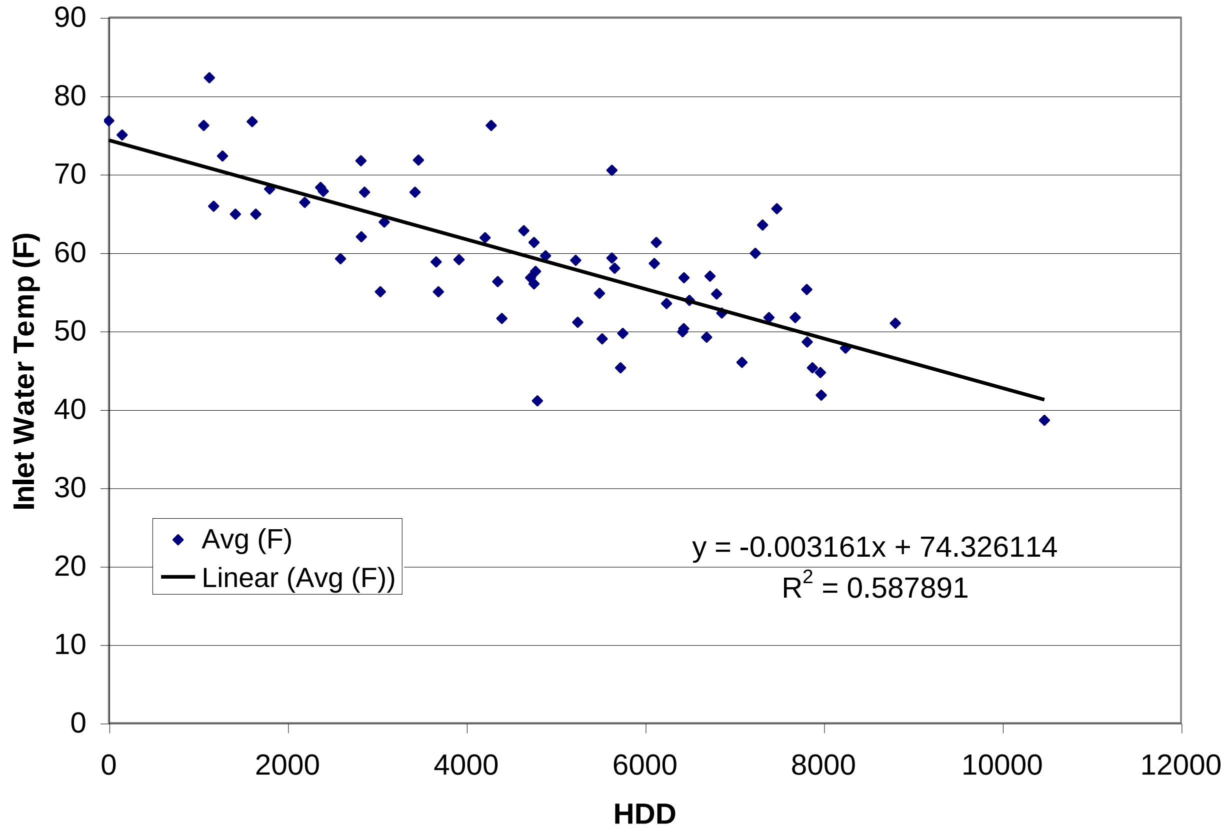
The small difference between LP and natural gas is probably not meaningful given how close the actual water heaters are in performance. A slight increase for oil water heaters is expected although 24% higher is much more than expected. From an engineering perspective a 10% increase is more likely. The difference may be due to the demographics of areas that use oil water heaters rather than a representation of how natural gas and fuel oil water heaters differ in efficiency.

The average consumption for electric water heaters is only 40% the consumption of a natural gas water heater. This seems unrealistically low and was investigated further from other sources. The instructions for the HUD 52667 form uses a 55% fraction. Other sources (see References) were checked and range from 50% to 60% fractions when comparing electric use to gas use for water heating. The method that RECS uses to disaggregate energy use is based on statistics and it is possible that energy actually used for water heating at the sites in their survey could have also had other electric uses that have a similar occurrence with other parameters. For example, electric water heating and electric heating often occur together or not at all. This may have caused an underestimate for the water heating energy used by electric water heaters. Due to these issues, the RECS data for electric water heaters was ignored and instead the same fraction as previously used in HUD 52667 instructions was used which is 55%.

In order to estimate the affect of different inlet water temperatures in different climates two issues needed to be resolved. First, inlet water temperature estimates were related to heating degree-days. Second, the impact of inlet water temperature on the water heater needed to be examined.

Inlet water temperature to the water heater is related to many factors. The most significant factor is the ground temperature at the depth that the pipes are located prior to reaching the housing unit. Ground temperature data is available from NOAA and other sources but they are either for above the frost line, such as three feet, or are for well below the depth that pipes are located, such as 50 feet. Other factors that affect the inlet water temperature are the ultimate source (well, lake, spring, or reservoir), the distance the water travels in the ground, the distance the water travels in the home prior to reaching the water heater, pipe diameters. Luckily a source was found that provided inlet water temperatures for a variety of cities, EPRI TR-100212, December 1992, "Commercial Water Heating Applications Handbook" by D.W. Abrams & Assoc. This source included 74 locations. For each location the other weather parameters that were in the degree-day database from NOAA were also found. Then graphs were made and least squares linear regression was used to try to find the weather parameter that could be used in a predictive model.

Figure 11 – Inlet Water Temperature Variation with Climate



The R^2 of 0.59 was considered good enough given the number of factors involved. This correlation provides a method of relating heating degree-days, which is known for over 5000 locations in the United States, to approximate the inlet water temperature.

Since the inlet water heater temperature can be estimated for any location, the impact of different inlet water temperatures was estimated. A report (REF06) by Abrams and Shedd looked at the seasonal impacts of inlet water temperature and contained tables of measured inlet water temperatures and the measured quantity of hot water gallons consumed for 16 different residential sites. About half the sites showed a direct relationship between temperature and consumption and when least squares regression was performed for these sites the overall conclusion was that the amount of hot water needed decreases about 1% for each 1F increase in inlet water temperature.

This estimate was confirmed using an engineering approach also. The engineering approach started with finding references (REF07 and REF09) to determine what fraction of hot water energy use was controlled by people, 78%.

From REF01 the equation for hot water use is:

GasConsump = (Use * TempRise * 8.2928 * 365) / (EF /100)

Use is made up of controlledUse and UncontrolledUse:

GasConsump = (controlledUse * TempRise * 8.2928 * 365) / (EF /100) + (uncontrolledUse * TempRise * 8.2928 * 365) / (EF /100)

Change in energy consumption due to change in TempRise (deltaTempRise) as a ratio can be expressed using deltaGasConsump, note uncontrolled use does not change temperature:

GasConsump + deltaGasConsump = (controlledUse * (TempRise +deltaTemp) * 8.2928 * 365) / (EF /100) + (uncontrolledUse * TempRise * 8.2928 * 365) / (EF /100)

Divide by GasConsumpt to get ratio and eliminate all constants:

(GasConsump + deltaGasConsump) / Gas Consump =((controlledUse * (TempRise +deltaTemp)) + (uncontrolledUse * TempRise)) / ((controlledUse * TempRise) + (uncontrolledUse * TempRise)

Combine:

(GasConsump + deltaGasConsump) / Gas Consump = ((controlledUse * (TempRise +deltaTemp)) + (uncontrolledUse * TempRise))/ ((controlledUse * TempRise) + (uncontrolledUse * TempRise))

say that deltaTemp is 1F to simplify:

(GasConsump + deltaGasConsump) / Gas Consump =((controlledUse * (TempRise+1)) + (uncontrolledUse * TempRise))/ ((controlledUse + uncontrolledUse)* TempRise)

Assuming controlled use is 0.78 and uncontrolled is 0.22 of total use and temperature rise is 75:

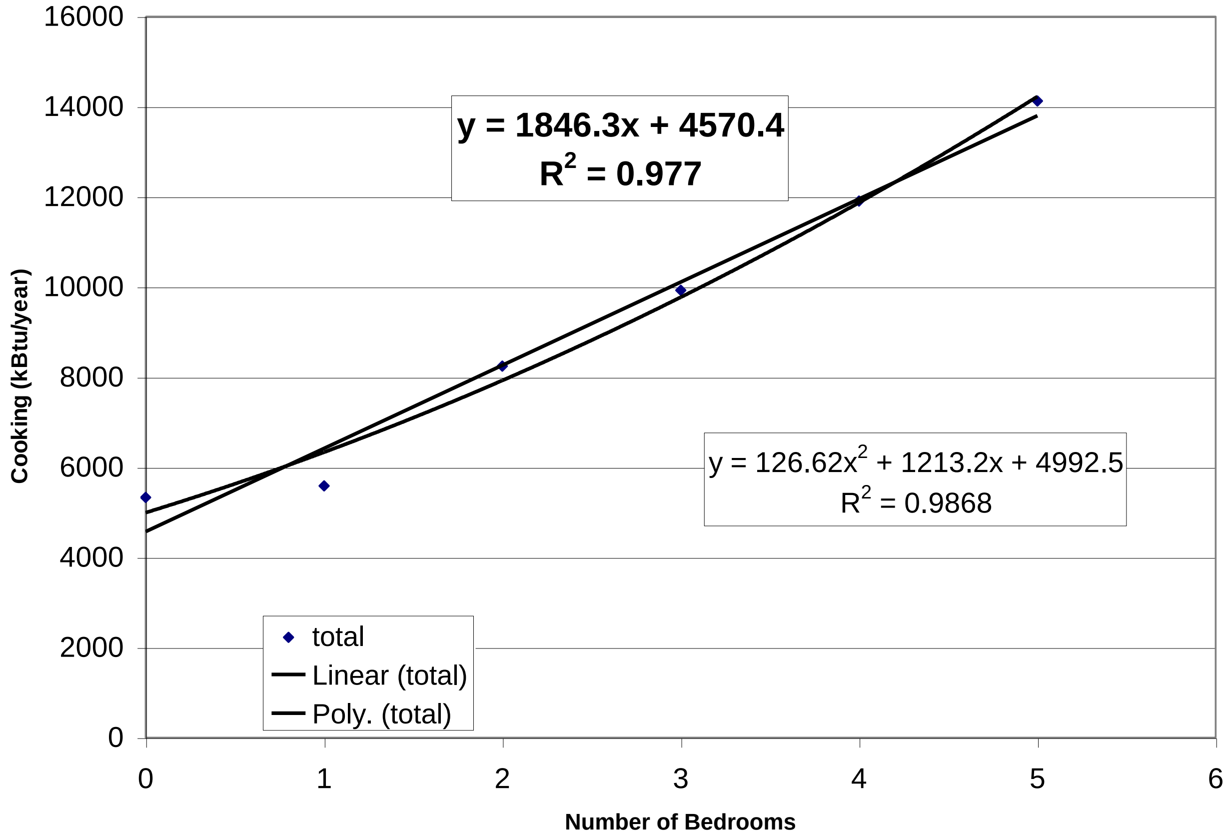
(GasConsump + deltaGasConsump) / Gas Consump = ((.78 * 76) + (.22 * 75))/ 75 = 1.0104

The 1.0104 is very close to the 1% impact (1.01) shown in measurement studies.

4.4 Cooking

The end use energy consumption model for cooking was estimated based on the RECS database and other sources for adjustments. The RECS database was aggregated by the number of bedrooms for natural gas energy consumption for cooking:

Figure 12 – Natural Gas Cooking Energy



A linear and polynomial fit were examined and the linear fit was chosen for the model given the small difference in the R^2 versus the added complexity of a polynomial model. When the model is compared to the existing rule from the HUD 52667 Instructions, which uses 8 therms for a 2.5 bedroom unit, it matches closely. The new model is about 4% lower at the 2.5 bedroom size.

When a similar model is created for electric cooking and compared to the HUD 52667 instructions of 110 kWh, the result of the model is 68% lower. This level of difference prompted further analysis of the RECS data, the source of the model, and comparisons with other literature. The weakness of the RECS database for electric cooking is clear. The electric use for cooking was not separately metered but was derived statistically. Other electric end-uses have a strong likelihood in housing units that have electric cooking including water heating and space heating. It is possible that an underestimate for cooking could be offset by an overestimate in a different end-use. Examining other sources (REF01, REF10, REF23) 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.

Census regions and divisions were examined to see if cooking energy varied by location but no correlation was found.

4.5 Other Electric

Homes consume electricity using a wide variety of methods. Some of the largest end-uses of electricity have been already modeled: space heating, air conditioning, water heating and cooking. This still leaves many "other" end uses such as lighting, refrigerators, freezers, dishwashers, clothes dryers, washing machines, TV's, VCR's, stereos, coffee makers, power tools, pool heaters, furnace fans, home computers, and many more uses. Some of these uses could be considered normal and reasonable for housing units to receive a utility allowance for, others may be considered luxuries. In this analysis the following were included in Other Electric:

- Lighting
- Washer and dryer for single family with 3 or more bedrooms
- Dishwashers
- Small appliances like shavers, hair dryers, cordless phones, vacuum cleaners, coffee machines, toasters, and other cooking appliances, including microwaves.
- TV
- VCR

And excluded:

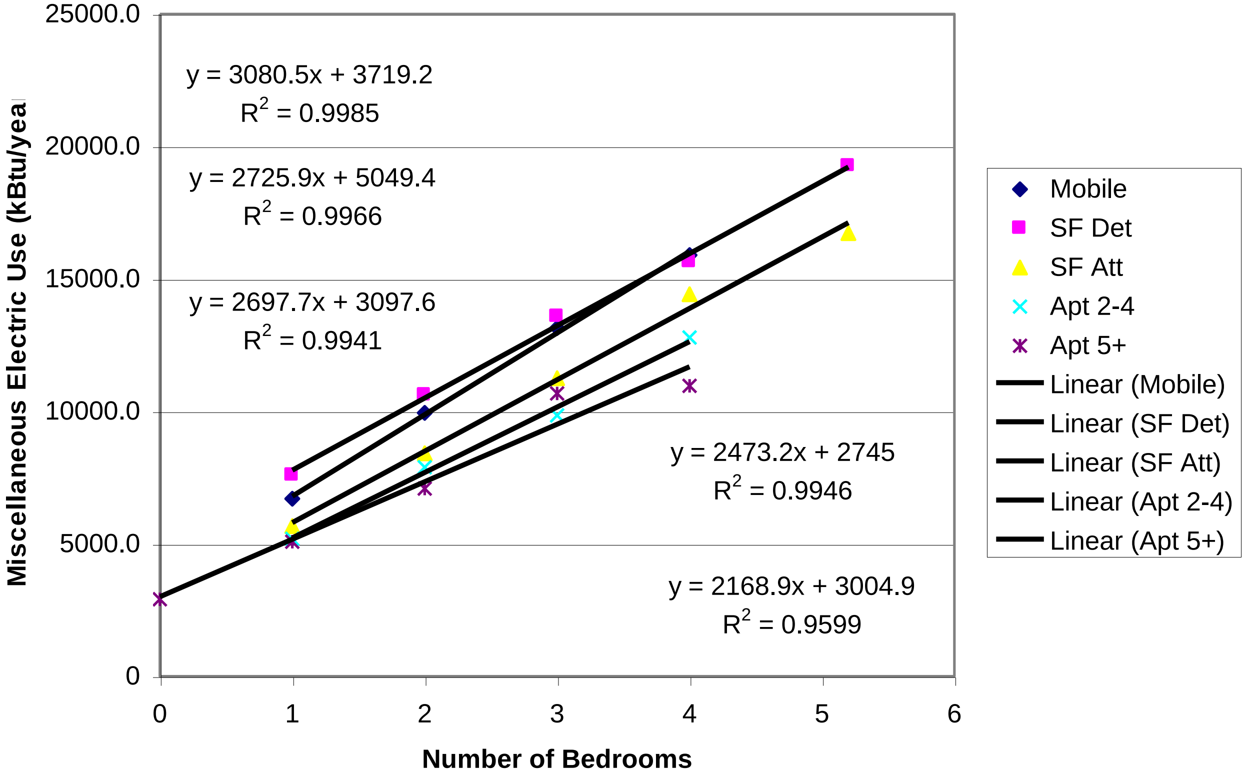
- Freezers
- Computer
- Waterbed heater
- Pool/hot tub/spa heater
- Swimming pool pump
- Laser printer
- Large heated aquarium
- Fax machine
- Copier

While the RECS database has identifiers for most of these end-uses, they did not define a single variable that would account for each of these. Instead many different variables from the RECS database were used to derive these four:

- Miscellaneous non-luxury
- Dishwasher
- Refrigerator
- Clothes dryer

The first variable, miscellaneous non-luxury included lighting and specifically eliminated the other components that were considered luxury items. It was examined by number of bedrooms and unit type.

Figure 13 – Miscellaneous Electricity Usage and Regressions

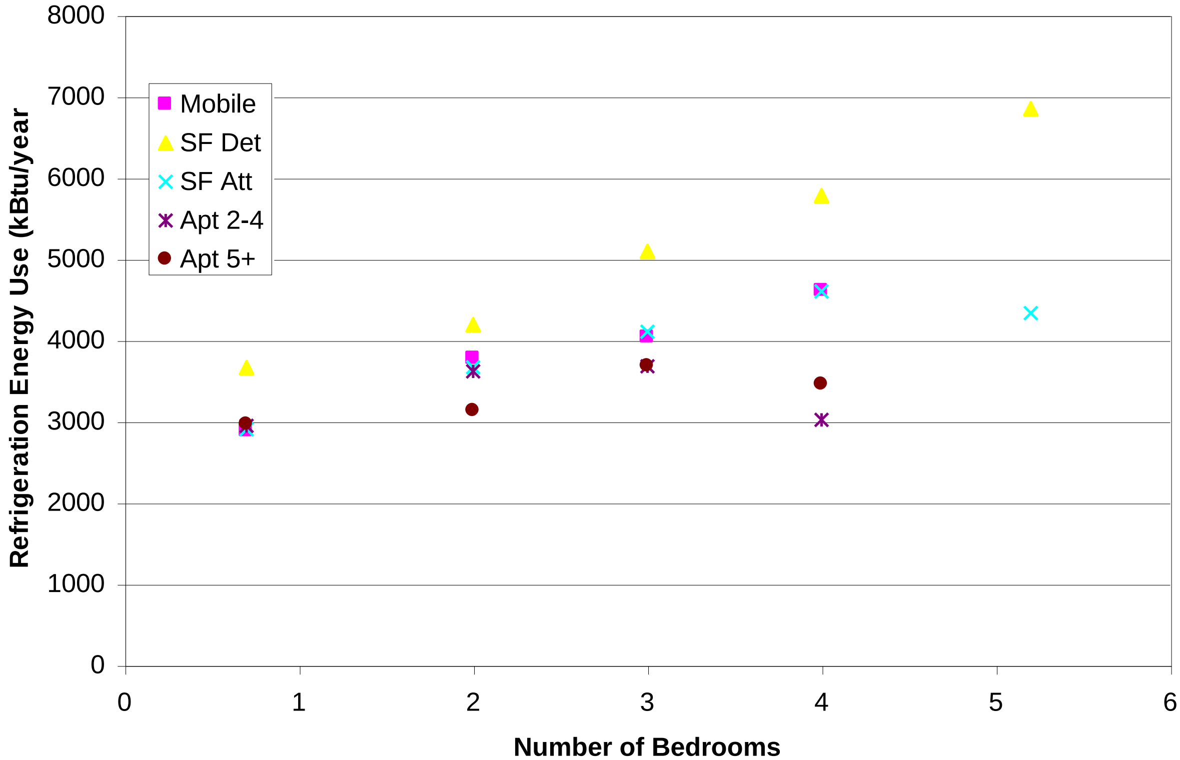


The R^2, or goodness of fit, of the simple linear regression models were all very good indicating a strong dependence on the number of bedrooms for each type of housing unit.

Dishwasher use was first examined by housing unit type and number of bedrooms like the miscellaneous energy but the regressions were poor and the numbers seemed unrelated to the number of bedrooms. Instead, the overall energy consumption across all types of units was used and the regression for that showed good R^2 values.

Similar issues were found when examining refrigeration energy use. In this case, refrigeration energy use had a strong relationship with number of bedrooms for some of the unit types but not others.

Figure 14 – Refrigeration Energy Usage by Type and Number of Bedrooms



Energy consumption for refrigeration in single family detached, and mobile have strong relationships with number of bedrooms but apartments and single-family attached have some points that are not consistent. When those inconsistent points are removed linear regressions were possible for all unit types.

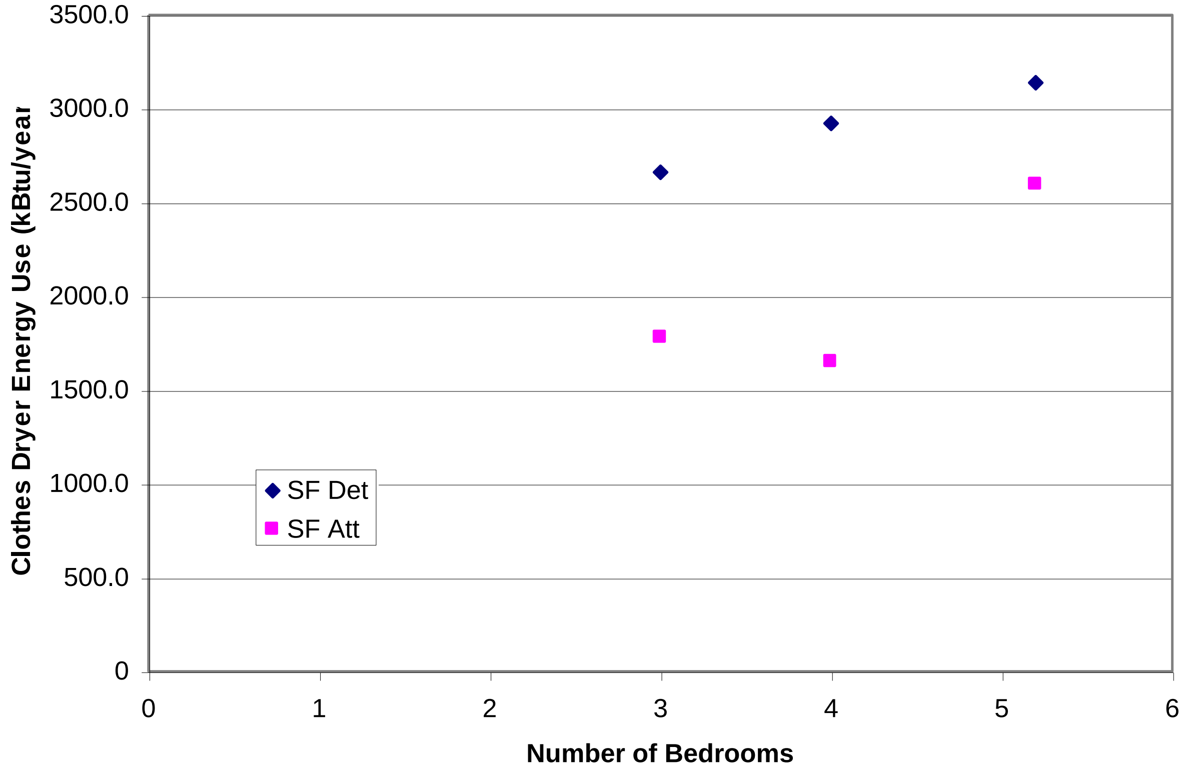
Table 11 - Error of Model Compared to RECS Results for Refrigeration

Bedrooms	*Total*	*Mobile*	*SF Det*	*SF Att*	*Apt 2-4*	*Apt 5+*
0-1	5%	-3%	5%	-1%	0%	2%
2	-6%	4%	-5%	2%	0%	-5%
3	1%	-2%	-1%	0%	-12%	2%
4	0%	0%	-1%	0%	-54%	-13%
5+	1%	NA	2%	-21%	NA	NA
Slope	840.94	502.32	720.73	510.42	516.41	302.19
y-intercept	2308.5	2606.7	2966.2	2581.1	2584.3	2685.0

Only four of the points have large errors (over 10%). Three of those four points may be cases with poor representation in the RECS database, four bedroom units in apartments and five bedroom single-family attached. Given this, the model seems accurate.

Clothes dryers were included in the model but only for single-family homes (attached and detached) with three or more bedrooms. See Figure 15 for a plot of these cases from the RECS database.

Figure 15 - Clothes Dryers for Single Family



Of the six points, all but the four bedroom case for single-family attached look reasonable but due to the small number of data points, and the limited variation across the points, it was decided to simplify the model and have a single "adder" whenever a clothes dryer is to be included. The adder used in the model is 450 kWh/year.

Combining all of the variables discussed for the total "other electric" is shown below:

Table 12 - Other Electric

Bedrooms	*Mobile*	*SF Det*	*SF Att*	*Apt 2-4*	*Apt 5+*
0	154	196	139	130	139
1	249	**287**	224	210	206
2	**343**	**378**	**309**	**290**	**273**
3	437	506	432	**370**	**340**
4	532	597	517	449	408
5	626	688	602	529	475
6	720	779	687	609	542

kWh/month

The bold values are between the 250 to 400 kWh/month range that appear in the HUD 52667 instructions for a 2.5 bedroom unit. Overall, the new model predicts higher energy use for "Other Electric" than the HUD 52667 Instructions. Higher energy use makes sense when you consider the growing number of electrical appliances in the home including more televisions, computer equipment, and a greater number of small appliances. In addition, the only significant energy conservation measure in the "Other Electric" category that did not exist in the 1970s and 1980s is the compact fluorescent light bulb replacing the incandescent light bulb. Unfortunately, it appears that the use of compact fluorescent light bulbs is so small as to not make a significant impact on the RECS data.

4.6 Cold Water

The RECS database only covers energy use in homes so cold water use needed to be derived from other sources. References were examined (REF09, REF20, REF21) as well as the WaterWiser.org web site and it appeared that 50 gallons per day of use per person seemed reasonable. Making a simple assumption about the number of people per unit the conclusion was to use 1600 gal/month for all units and 1600 gal/month for each bedroom.

5. Conclusion

5.1 Model Limitations

The energy and utility bill calculation models developed and described were based on the best information and methodologies available but still have several limitations that should be remembered when implementing and using the models.

- Developed using US data from the RECS database,
- Does not capture regional differences in cooking, water heating, outside water, etc.,
- Based on statistical sampling and disaggregation and not sub-meters,
- Results compared to other studies but not an exhaustive literature review,
- Significant modeling assumptions were made regarding the ratio of electric to gas usage,
- Four rate blocks in the utility tariffs,
- Electric and natural gas rates have two seasons,
- Apartment unit type based on buildings with five or more apartments,
- Actual inlet cold water temperatures should be used if known
- Energy estimates based on degree days not considered as rigorous as building energy simulations
- Energy conservative households represented by average household in RECS database

Even given these limitations, the model should be able to be used with confidence but further confirmation of the model against other sources or by performing further analysis would increase the confidence level.

5.2 Validation

The validation for the model performed to date compares the model with 24 different reports from a literature search. The comparisons included:

Table 13 – Comparisons with References

Ref	Heat	Cook	OthElec	AC	SWH	Water
1	x	x	x	x	x	
2	x	x			x	
3	x	x	x	x	x	
4			x			
5	x	x	x	x	x	
6					x	
7					x	
8	x	x	x	x	x	
9					x	x
10		x	x		X	
11			x			
12			x			
13	x					
14			x			
15					x	
16	x	x		x	x	
17	x			x		
18	x			x		
19	x			x		
20						x
21						x
22	x		x	x	x	
23	x	x	x	x	x	
24			x			

In not all cases were the comparisons with the references made. At times, the references included data that was related to the end-use but not in terms that were convertible to the monthly energy use needed in the energy model. The specific sections describing the energy model contain more specifics about the validation performed.

Additional validation is one of the recommendations of this report.

5.3 Summary of Changes

To create the model for end-use energy consumption in different types and sizes of residences, an analysis of U.S. Department of Energy Residential Energy Consumption Survey (RECS) data was performed. Compared to the original guidance on the HUD 52667 form, most allowance numbers decreased but some did increase. The increase in allowances was unexpected since the wide spread use of more energy efficient equipment should have decreased energy consumptions. Perhaps, the increasing size of homes is responsible for part of that affect.

Overall impressions of the changes in usage due to the new model when compared to the original guidance from HUD 52667 are:

- Cooking – Natural gas number went down very slightly and the electric number from RECS decreased so much that it was not believed and an adjustment factor from the natural gas model was used instead.
- Other Electric - Went up but that may not be surprising given the increased use of small electrical loads and new types of appliances in homes.
- Water Heating - Natural gas stayed about the same. The electric numbers from RECS decreased so much that it was not believed and an adjustment factor from the natural gas model was used instead.
- Heating - Natural gas stayed about the same. The electric heating numbers from RECS decreased significantly and reasonably so the electric regression heating model was used.
- Air Conditioning - The results decreased significantly but was confirmed.
- Water and sewer - Slight decrease.

Overall, the changes were reasonable. The model is currently implemented in an Excel spreadsheet and was constructed to be used by housing authority personnel.

5.4 Recommendations for Utility Allowance Updating

The HUD managed Housing Choice Voucher program currently instructs the public housing authorities across the country to update their utility allowances on an annual basis or when utility rates change by more than 10%. This approach seems reasonable since utility rates usually do not change more frequently than every few years. The exception to this is cost adjustment charges for natural gas. These often change on a monthly basis and can, at times, be a significant portion of the utility bills for residential customers. During times that the natural gas distribution system in a region of the country or a locality is stressed by an unusually high demand or tight supply, the cost adjustments can vary widely. These should not be used directly since they are an indicator of rapidly changing market conditions and not of total annual utility cost. The recommendation for that situation is to wait at least three months between adjustments to the utility allowances and average together the three months cost adjustments for the next period.

Some specific recommendations concerning the HUD 52667 form.

- Add category for apartments in buildings with five or more units.
- Use end of row or middle of row to categorize single family attached.
- Add to form separate items for utility service charges.

These recommendations should be considered the next time the HUD 52667 form or instructions are updated.

Given the wide variety of formats provided by housing authorities, it would be easier for HUD to review them and understand the allowances compared to neighboring housing authorities if they all used a consistent format. HUD should consider making the 52667 format, or something similar, the required format for updating the allowances provided to HUD rather than a recommended format.

5.5 Recommendations

The results of the project described in this report include a spreadsheet form of the HUD 52667 with a new energy model and rate calculations. It was designed to be able to be used by housing authorities and enough validation work has been performed to make this an improvement in the ad hoc approach used by many housing authorities. To gain more confidence in the energy model developed more validation of the energy model is recommended. This may be a good opportunity for future enhancements that would build upon the foundation of this project.

The specific recommendations for additional enhancements resulting from this project are:

- Test with Housing Authorities – The spreadsheet has never been used by the people who regularly update their Section 8 utility allowances. Additional insight can be gained by “beta” testing the spreadsheet with some housing authorities and allowing them to express their concerns and suggest improvements. This could be done by contacting the original eleven housing authorities contacted earlier in the project or perhaps a different set of authorities. Training materials could be developed and training provided to help housing authorities with the spreadsheet. If a wide beta test is desired it could be combined with the effort to find PHA Studies (see next bullet).

- PHA Study Comparison – Several of the housing authorities contacted during the first task of the project (Atlanta Housing Authority, Denver Housing Authority, and Housing Authority of Kansas City, MO) all had performed some type of statistical study of actual housing unit energy consumption. The methodologies varied but all were used to either create or confirm the energy consumption characteristics of the housing units. HUD should use such studies to validate the energy model developed. First, an effort to identify other housing authorities that have performed such studies should be made, then those housing authorities should be contacted looking for any related reports, spreadsheets or raw data that was collected. Finally, an analysis comparing the results to the energy model would be performed.

- Assess Use of Average Energy Price Data – The most difficult aspect of revising utility allowances for housing authorities is updating the utility rates. An assessment to examine the importance of updating using the actual rates should be performed. It is possible that utility or state level average prices for delivering residential service by utilities would provide a sufficient level of accuracy. Examine the data available from DOE, FERC, EEI, AGA, and others for methods of more quickly and easily providing energy cost numbers. If successful, possibly incorporate these average energy prices into a future version of the spreadsheet or web application as an alternative to entering the rate data.
- Occupant Density – The HUD occupancy standards indicate significantly more people living in housing units than the EIA/RECS data indicates. Explore how the density of people affect the heating, cooling, water usage, and other loads in a housing unit. Examine other studies and the RECS data for information. This is a good example of an analysis that might benefit from using building energy simulation (see below).
- Age of Structure – The age of structures used by Section 8 housing varies but often they are older structures that were constructed prior to the energy conservation efforts in the 1980s. Due to this the energy efficiency may be limited due to the difficulty in retrofitting added insulation into the building. Such a structure may warrant an additional credit on the utility bills since the tenant, and to some extent the landlord, is unable to implement measures to lower utility costs. A study of such limitations and the affect of age on utility consumption would illuminate this issue.
- Building Energy Simulations – The energy prediction methodology used in the current energy model assumes a linear relationship of energy use with degree-days. Many experts in the energy analysis field would prefer to see an energy model that was more technically justified such as those implemented in Building Energy Simulation programs such as DOE-2.1e or EnergyPlus. These programs could be used to either validate the current energy model or by their actual use to provide energy estimates. One advantage of building energy simulation models is the ability to understand the impact of so many assumptions such as occupant density, wall insulation, and the age of the structure. In many cases building energy simulation is the only way to predict the impact of changes to assumptions.
- Submetering Studies – Other studies of submetered end-use energy consumption in residential housing units may exist that were not utilized. A more formal literature search could be conducted and studies found that would help confirm the end use estimates used in the model. Likely sources of these studies are states with significant energy related research activities including California, Washington, Oregon, Texas and New York.
- Internet Implementation – The current implementation of the model uses a Microsoft Excel spreadsheet which served as a good test bed for the model and also provides flexibility to the housing authority. One tradeoff made using a spreadsheet is less consistency of submissions and the amount of compliance with providing submissions. To overcome this, the model could be implemented as a web applications that would allow the housing authority with an internet connection to use their web browser to update their utility allowances. This would provide a direct link to HUD of all revisions made to the utility allowances. It would also centralize the maintenance of the energy model. The implementation would be a system that allowed each housing authority to register, then the housing authority would provide a zip code and the would have the option of providing utility rates (assuming that average energy price data is acceptable – see previous point). The utility allowance forms for each housing type would then be provided for printing. This simplicity may increase compliance with the requirement to submit revised utility allowances. A reminder service could also be included to inform the housing authorities when a year has passed.

- Update Form and Spreadsheet – Many of the other recommendations may result in revisions to the model, to the HUD 52667 form, or to related materials. The updates would require some confirmation and testing to be performed and perhaps revised documentation.

The pursuit of any of these recommendations would result in an even better product that would serve the needs of the housing authorities and HUD even better.

Recognition and appreciation should be given to the eleven housing authorities that participated in the initial utility allowance reviews:

- Boston Housing Authority
- New York City Housing Authority
- Philadelphia Housing Authority
- Atlanta Housing Authority
- Chicago Housing Authority
- Fort Worth Housing Authority
- Housing Authority of Kansas City, MO
- Denver Housing Authority
- San Francisco Housing Authority
- Seattle Housing Authority
- District of Columbia Housing Authority

In addition, the project would not have been possible without the thoughtful insight and guidance from Joe Riley and Marie Lihn.

6. Verification References

Many different sources were used to attempt to confirm values derived in the model. The following lists the references used.

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