UTILITY MODEL EVALUATION

Prepared for:

US HOUSING AND URBAN DEVELOPMENT

P.O. S4C5AAC0062

September, 2005

Prepared by:

2rw+di
100 Tenth Street NE, Suite 202
Charlottesville, Virginia 22902

(434) 977- 0999

NOMENCLATURE

Btu	British thermal unit
CDD	cooling degree days
CFR	US Code of Federal Regulations
COP	coefficient of performance
DHW	domestic hot water
EIA	Energy Information Administration, US Department of Energy
HDD	heating degree days
HSPF	heating season performance factor
HUD	US Housing and Urban Development
kBtu	thousand British thermal units
MMBtu	million British thermal units
PHA	public housing authority
RECS	Residential Energy Consumption Survey by US Department of Energy
SEER	seasonal energy efficiency ratio
SFD	single family dwelling unit

TABLE OF CONTENTS

List of Tables

List of Figures

1. EXECUTIVE SUMMARY

1.1 Background

2rw+di was selected by the US Housing and Urban Development to conduct an evaluation of a spreadsheet tool (referred to in this document as "HUD spreadsheet") and to modify the spreadsheet to improve its usefulness and accuracy. The HUD spreadsheet was developed to predict utility resource consumption and costs, and to use the output data to establish utility allowances for Section 8 housing throughout the US. The purpose of this evaluation was to determine the suitability of the HUD spreadsheet to achieve these objectives with reasonable accuracy.

1.2 Results

2rw+di evaluated the existing HUD spreadsheet and, by comparison to measured residential consumption data, found that the utility allowances generated are reasonably accurate but could be improved. Two recommendations for improvement are indicated:

- Replacing the simple linear correlation presently used to characterize utility use with two linear models, one for warmer climates and a second for cooler climates, would significantly improve the accuracy of consumption predictions as well as the associated utility allowances.
- Currently, the utility allowances generated by the HUD spreadsheet are based upon average resource consumption of US housing stock. A means of encouraging energy conservation could be implemented. This would financially benefit both the tenant and HUD.

Tasks undertaken by 2rw+di, along with the associated deliverables, are summarized in Table 1-1.

Table 1-1. Deliverables for HUD spreadsheet evaluation project.

Task	deliverable
• Incorporate the most recent RECS data.	• First new spreadsheet based on RECS 2001.
• Modify spreadsheet to adjust for building age.	• Second new spreadsheet.
• Develop means of accounting for heat pumps.	• Second new spreadsheet.
• Review model for analytical soundness. • Determine whether regional utility rates could be used. • Provide assessment of model's accuracy.	• Final report.

1.3 Methodology

2rw+di carried out a systematic procedure to evaluate the HUD spreadsheet tool and to implement the modifications requested by HUD. The steps involved were:

1. Evaluate the analytical regression technique used to develop the original HUD spreadsheet models along with the statistical results of the linear regressions, and compile observations and recommendations.
2. Compare the 2001 RECS data to 1997 RECS data upon which the original HUD spreadsheet is based, and develop a new spreadsheet with linear regressions based upon the 2001 RECS data.
3. Determine which variables most significantly affect residential utility resource consumption, and determine how the HUD spreadsheet addresses these variables.
4. Gather measured consumption data from actual residences, compare predictions from the HUD spreadsheet to this metered data, and document the findings.
5. Implement refinements to the HUD spreadsheet to modify predictions to account for building age and the presence of heat pumps.
6. Determine whether regional average utility costs can be used in place of local rate schedules to simplify use of the HUD spreadsheet.
7. Draw conclusions on the utility of the HUD spreadsheet tool, and make recommendations on improvement of the tool.

Details of the evaluation process, conclusions and recommendations are provided in the text of this document.

1.4 Recommendations

<u>Suggested improvements to HUD spreadsheet</u>

- From an analytical standpoint, accuracy of the HUD spreadsheet calculated allowances could be improved by replacing the existing simple linear model with two separate linear models. One would be used for warmer locations (with heating degree-days up to about 4,000 HDD/yr), and a second linear relationship with a shallower slope would be used to represent the colder regions. This would improve the correlation of the model to consumption data.

- The HUD spreadsheet and other consumption-based utility allowance methods establish allowances based upon historical utility resource use, and do not provide encouragement for improved efficiency. Improved resource efficiency benefits tenant and housing authority by lowering utility costs, and benefits all by reducing the emissions resulting from resource use. Incorporating a method to encourage increased resource efficiency would further enhance the HUD spreadsheet tool.

- In its present form, the HUD spreadsheet could easily be altered by an inexperienced user, and results would be compromised. Prior to deployment, a user interface should be developed that guides the user through the process of generating utility allowances, while protecting the workings of the program.

- User training should be developed in three primary areas: utility allowances, utility rate schedules, and use of the HUD spreadsheet tool. More detail is provided in Section 8.2.

Suitability for deployment

- Based upon comparison of the consumption values calculated by the HUD spreadsheet to measured consumption data as shown in Sections 5 and 9 of this document, the HUD spreadsheet in its current form provides reasonable utility allowances. Deploying the HUD spreadsheet would likely provide better results (improved uniformity and accuracy) than the variety of allowance calculation methods currently in use.

2. EVALUATION AND MODIFICATION OF PROPOSED SPREADSHEET MODEL

2.1 Existing HUD Spreadsheet Tool

A spreadsheet based computer program (HUD spreadsheet) was developed in June, 2003 for HUD by contractor Gard Analytics, Inc. (Gard) to predict utility resource consumption and costs, and to use the output data to establish utility allowances for Section 8 housing throughout the US.

The HUD spreadsheet provided by HUD for evaluation is configured with three primary functions: prediction of utility resource consumption for a US residential dwelling unit, adjustment of consumption to account for regional weather characteristics, and application of local utility unit costs to generate utility allowances as outputs. The tool generates these outputs for several different dwelling unit types and a number of fuels as listed in Table 2-1.

Table 2-1. Dwelling unit types and fuels addressed in HUD spreadsheet.

dwelling unit types	fuels
detached houses	electricity
attached housing (duplexes, row houses, town houses)	natural gas
apartments (flats, garden and high rise apartments)	bottled gas
manufactured housing	oil, coal or other

The consumption prediction module in the initial HUD spreadsheet uses the US Department of Energy's Residential Energy Consumption Survey (RECS) for 1997 as its basis. The RECS is a national, statistical survey that collects energy-related data for occupied primary housing units. The RECS was first conducted in 1978; the eleventh and most recent survey was conducted in 2001[1].

The procedure employed by Gard was to apply linear regression fits to the RECS consumption data, and to use the linear regression coefficients to establish linear equations. The HUD spreadsheet uses these equations to predict utility resource use for a typical US residential dwelling unit. Once the typical residential resource consumption has been modeled and the desired geographic location selected, the weather module adjusts the applicable average consumption figures (e.g. space heating resource use) to account for

[1] US Department of Energy, Energy Information Administration, http://www.eia.doe.gov/emeu/recs/contents.html.

regional climate effects. Finally, local resource unit costs are applied to the adjusted resource consumption figures. The result is a list of predicted utility resource costs for various dwelling unit types and fuels. The user can then select the unit type and fuels used, and add all applicable figures to obtain total monthly utility allowances.

The analytical approach Gard used in developing the original HUD spreadsheet was to rely on RECS 1997 as the source of measured resource consumption data for residential dwelling units. Thus, the goal in creating the HUD spreadsheet was to develop a model that predicts the data in the RECS database as closely as possible. The parameters selected for regression analysis of RECS were heating and cooling degree days (HDD and CDD), housing unit type, fuel type, and number of bedrooms. Unit type and fuel type were considered individually, and for each case, coefficients for a linear equation (y=mx+b) were statistically determined to best match the RECS data.

HDD and CDD are surrogates for climactic data; they relate each day's temperatures to the demand for fuel to heat or cool buildings. To calculate heating degree days, each day's average temperature is calculated by adding the day's high and low temperatures and dividing by two. If the average temperature in Fahrenheit is less than 65 degrees, it is subtracted from 65 to reveal the number of heating degree days. If the average temperature is greater than 65, 65 is subtracted from the average temperature to determine the number of cooling degree days.

2.2 Comparison of 2001 and 1997 RECS Data

2rw+di was tasked with implementing the HUD spreadsheet with the newest RECS data, RECS 2001. Several basic checks comparing the 1997 and 2001 RECS databases were first undertaken to understand how they compared statistically.

<u>Database sampling comparison</u>

First, the databases themselves were compared to determine whether the number of samples were similar for the two years. Table 2-2 illustrates that the 2001 database contains fewer data points than 1997 for virtually all categories, but that the differences are not large.

Table 2-2. Number of data points in 1997 vs. 2001 RECS.

Criterion		Occurrences in RECS 1997	2001	% change*
Unit type	Apartment 2 to 4	351	444	3.3
	Apartment 5+	934	692	-1.5
	Mobile home	402	325	-0.1
	Single attached	552	426	-0.5
	Single detached	3661	2935	-1.2
	Total	5900	4822	-18
Heating fuel type	Natural gas	2954	2599	3.8
	Electricity	1663	1264	-2
	Fuel oil	676	478	-1.5
	Bottled gas	306	267	3.5
Heating equipment**	Forced air	3148	2824	5.2
	H2O radiator	879 (steam?)*	688	-0.6
	Heat pump	485	399	0.1
	Built-in electric	458	297	-1.6
Bedrooms	0	68	36	-0.4
	1	714	530	-1.1
	2	1736	1339	-1.7
	3	2352	1996	1.5
	4	823	765	1.9
	5	184	125	-0.5

* Percentage of the total samples. Decreasing numbers can still give an increase in percentage representation, since there are fewer samples in the 2001 database (e.g. if the number of total samples dropped by 10% but the number of samples in the subset dropped by 5%, there was an increase in % representation).

** Categories for heating equipment vary greatly between the two databases.

Weather data comparison

A comparison of the climatological data for 1997 and 2001 is shown in Table 2-3; it illustrates that the weather was milder for 2001.

Table 2-3. Weather and census data.

Region	RECS 1997			RECS 2001			% change in units sampled	%change in HDD
	Units	% of total units	Avg. HDD	Units	% of total units	Avg. HDD		
East North Central	783	13.27%	6618	681	14.12%	5811	0.85%	-12%
East South Central	527	8.93%	3379	409	8.48%	3056	-0.45%	-10%
Middle Atlantic	842	14.27%	5542	691	14.33%	5056	0.06%	-9%
Mountain	466	7.90%	4814	407	8.44%	4620	0.54%	-4%
New England	490	8.31%	6526	396	8.21%	5949	-0.09%	-9%
Pacific	889	15.07%	2958	792	16.42%	3282	1.36%	11%
South Atlantic	871	14.76%	2585	626	12.98%	2539	-1.78%	-2%
West North Central	451	7.64%	6635	366	7.59%	6033	-0.05%	-9%
West South Central	581	9.85%	2501	454	9.42%	2277	-0.43%	-9%

The distribution of unit types in RECS 2001 was similar to that of RECS 1997, but nearly every region showed a marked decrease in heating degree days (HDD). The HDD tables used were specific to 1997 and 2001.

Consumption comparison

Queries were run from the two databases to determine whether or not differences in the data were noticeable. The query isolated data in the same format as was used in the Gard analysis, and included the following fields:

- Bedrooms
- HDD
- Heating consumption
- Fuelheat = "Natural gas"
- Typehuq = "Single detached"

- Equipment type="Warm-air furnace with ducts"

The comparison only addressed standard equipment types where the heat was likely to be central and thermostatically controlled. This eliminated units where the primary heating equipment was a fireplace, room heater, or cooking stove. Steam also was not considered. The results showed the heating consumption data to be stratified by equipment type. To simplify the comparison, the most common configuration was isolated.

Figures 2-1 and 2-2 illustrate a comparison of the most common unit type by far, the three-bedroom (3BR) single family detached (SFD) structure with gas-fired forced air heat. This accounts for 781 of 5900 units in 1997, and 740 of 4822 in the 2001 database; about 13% and 15% respectively.

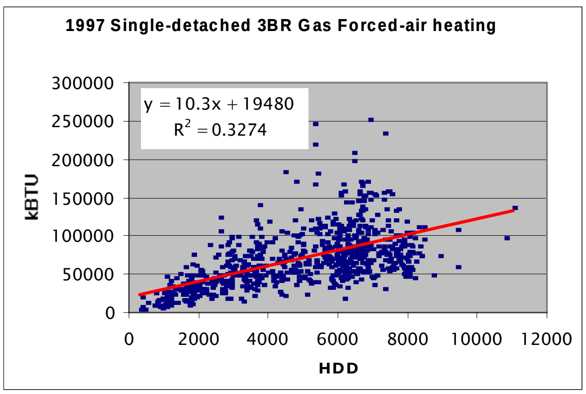


Figure 2-1. 1997 RECS consumption data.

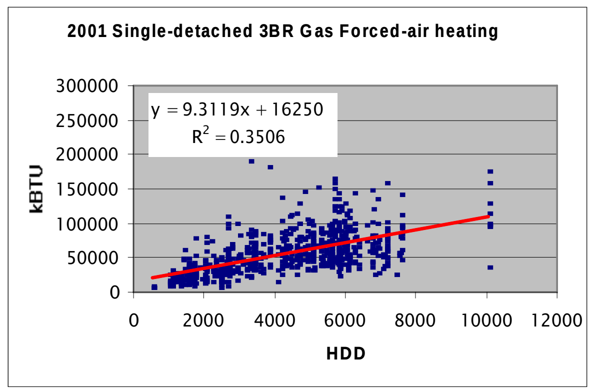


Figure 2-2. 2001 RECS consumption data.

Heating consumption for this configuration is lower in 2001, and the statistical correlation is slightly higher. Since the data is normalized for weather via heating degree days, the lower normalized 2001 consumption (Btu/HDD/yr) indicates that the efficiency of the heating equipment has been improved, insulation added, and/or tenant operating practices have improved.

From a graph of the average energy consumption in thousand Btu (kBtu) per 500 HDD bins for the SFD, 3BR case as in Figure 2-3, it appears that energy consumption bears a linear relationship to heating degree days up to about 4000 HDD. For locations with greater heating needs, the increase in energy use per HDD drops dramatically. This may reasonably illustrate that building insulation values are greater in locations with higher heating requirements, but it also indicates that a linear model may not be the best choice for a nationally-distributed prediction tool.

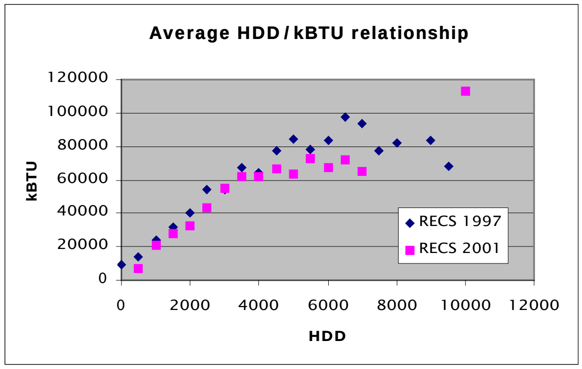


Figure 2-3. Average RECS consumption data.

2.3 Incorporation of 2001 RECS data

<u>Comparison of coefficients: 1997 vs. 2001</u>

The database comparison tests indicated that the method used to obtain model coefficients could be applied to the 2001 RECS data in the same way as was done for the 1997 RECS data. To develop a version of the HUD spreadsheet tool based upon the 2001 RECS database, 2rw+di duplicated as closely as possible the statistical method used by Gard to develop the regression coefficients for the RECS 1997 data. One consumption category, “Other Electric”, could not be modeled with any similarity to the original Gard result; Gard used many simplifications that are specific to the patterns they saw in the 1997 data, and drew from sources other than RECS. Drawing on a 1999 report from US DOE Energy Information Administration[2], 2rw+di applied an annual increase of 3%, compounding to a 12.5% increase over the RECS 1997 data to model the “other electric” category of consumption. Clothes dryer resource consumption from 1997 was left intact, applying to only single-family units with three or more bedrooms. The result is a new HUD spreadsheet containing a new analytical model based upon the RECS 2001 database.

The modeling process yielded new coefficients based upon the 2001 RECS data. Table 2-4 lists the 1997 and 2001 coefficients that apply to the basic equation of the form

$$\text{Energy consumption (kBtu/yr)} = (C_1 * \text{HDD/yr}) + C_2 \text{ (bedrooms * HDD/yr)}$$

[2] A Look At Residential Energy Consumption in 1997, DOE/EIA-0632 (97), 1999.

Table 2-4. Modeling coefficients for 1997 and 2001 RECS.

Utility or Service	Housing	1997 Constant	1997 BR c_x	2001 Constant	2001 BR c_x
Heating with Natural Gas	Mobile	11.44	0.00	8.40	0.45
Heating with Natural Gas	SF Det	8.19	2.31	5.21	2.87
Heating with Natural Gas	SF Att	7.62	2.37	5.40	2.45
Heating with Natural Gas	Apt 2-4	7.86	2.55	5.85	3.16
Heating with Natural Gas	Apt 5+	3.66	1.30	3.72	0.60
Heating with Electricity	Mobile	3.09	0.39	3.87	0.17
Heating with Electricity	SF Det	2.61	0.81	2.20	0.94
Heating with Electricity	SF Att	1.30	0.86	1.60	0.82
Heating with Electricity	Apt 2-4	2.40	0.28	1.62	0.57
Heating with Electricity	Apt 5+	0.75	0.37	1.17	0.68
Heating with Fuel Oil	Mobile	12.59	0.00	8.44	0.00
Heating with Fuel Oil	SF Det	9.01	2.54	5.61	2.50
Heating with Fuel Oil	SF Att	8.38	2.60	3.26	3.38
Heating with Fuel Oil	Apt 2-4	8.64	2.80	5.39	3.86
Heating with Fuel Oil	Apt 5+	4.02	1.43	2.87	1.56
Cooking with Natural Gas	All	4570	1846	4474	1733
Cooking with Electricity	All	2285	923	2237	867
Other Electric	Mobile	6326	3863	7117	4346
Other Electric	SF Det	8016	3727	9018	4193
Other Electric	SF Att	5679	3488	6389	3924
Other Electric	Apt 2-4	5329	3270	5995	3678
Other Electric	Apt 5+	5690	2751	6401	3095
Air Conditioning	Mobile	2.33	1.14	0.14	1.70
Air Conditioning	SF Det	0.23	1.30	0.61	1.55
Air Conditioning	SF Att	0.89	0.79	-0.08	1.68
Air Conditioning	Apt 2-4	1.36	0.78	1.75	0.91
Air Conditioning	Apt 5+	1.15	0.72	0.99	1.08
Water Heating with Nat. Gas	All	14780	3636	7815	4359
Water Heating with Elec.	All	8129	2000	4298	2397
Water Heating with Fuel Oil	All	16258	3999	8597	4794

In general, the new HUD spreadsheet with 2001 coefficients will produce lower consumption values than the 1997 version.

2.4 Conclusions

- The algorithm underlying the HUD spreadsheet is a linear regression. Our review of the relationship between consumption and weather indicates that this relationship is more closely stepwise linear than truly linear. Thus, as developed, the HUD spreadsheet will likely over-predict energy consumption by dwelling units in cold and hot regions, while under-predicting in temperate zones.
- RECS 2001 contains fewer data points than RECS 1997 by a few percent; this difference is considered insignificant.
- As illustrated by heating degree days (HDD), 2001 was a milder weather

year than 1997. This is accounted for by normalizing energy consumption by HDD, removing the effect of that difference between the two databases.

- Lower normalized energy consumption values indicate that the buildings surveyed for RECS 2001 exhibited higher energy efficiency than those of 1997 RECS. Thus, utility allowances calculated using 2001 version of the HUD spreadsheet should be lower than those calculated with the 1997 RECS version. However, in comparing to measured data as described in Section 5, the difference in predicted consumption values of 1997 vs. 2001 HUD spreadsheets was shown to be negligible.

3. DETERMINATION OF SIGNIFICANT VARIABLES

3.1 Introduction

The HUD spreadsheet tool is based upon linear regression models for energy consumption by residential housing units using geographical location, number of bedrooms, building type and fuel type as variables. In development documentation as well as in direct communications, Gard stated that the decision was made to minimize the need for input information by the eventual user, since information about housing units is difficult to obtain.

2rw+di reasoned it would be important to know whether this abbreviated number of variables was sufficient to characterize residential energy use, and to know which variables have the most significant effects on residential energy consumption. 2rw+di decided to run a number of annual energy simulations for a typical residential building, and to use the simulation output data as a check of the analytical basis of the HUD spreadsheet tool.

Residential energy consumption is affected by a number of variables including:

Building related variables

1. Location (causes variations in weather-related energy use)
2. Type of building (mobile home, townhouse, high-rise apartment, etc.)
3. Building construction materials (wood frame, concrete block, precast concrete, etc.)
4. Insulation levels in walls, roof and floors (often thought of as related to building age)
5. Unit size (for public housing, usually number of bedrooms is used as a surrogate)
6. Ratio of roof area to floor area
7. Ratio of exterior wall area to floor area
8. Orientation (south facing long wall, north facing, etc)
9. Window type (single pane, double pane, low emissivity glass)
10. Window and door area
11. Infiltration (unintended air exchange with the outdoors. Typically ranges from 0.2 to 1.0 air changes per hour. Often thought of as related to building age and condition)
12. Location in building (end unit in townhouse, middle unit in high rise, etc.)

Equipment related variables

13. Lighting type (incandescent, fluorescent)

14. Heating system type (gas furnace, oil furnace, electric heat pump, electric resistance, gas hydronic, etc.)
15. Fuel type (this might be accounted for in "Heating system type" above)
16. Equipment efficiencies – especially refrigerators & heating/cooling equip. (often thought of as related to building age)
17. Appliances and other "plug loads" (types and quantities)

Operations related variables

18. Number of occupants (number of bedrooms often used as surrogate)
19. Schedule of occupation

If one tried to run a simulation for every possible combination of these variables, there would be over 50,000 simulations. Thus, 2rw+di chose to use the statistical Design of Experiments method to determine which variables are the most significant using a reduced number of tests. Using this method, not only can the statistical significance of each variable be quantified, but interactions among variables can be determined as well.

3.2 Experimental Design

2rw+di enlisted the help of statistician Dr. Gerald J. Shaughnessy of the Department of Mathematics and Statistics at the University of Dayton. Dr Shaughnessy developed the test matrix and analyzed the results.

First, a reduced set of the most significant variables was selected from the list of 19 above. "High" and "low" settings, representing the range of values these variables could take, were determined. Eleven (11) variables were retained, and high and low settings were determined for each, as shown in Table 3-1. Weather related effects were treated as a statistically blocked variable.

Table 3-1. Reduced set of variables affecting residential energy use.

Variable letter name	Variable	parameter	Low setting (-1) [energy intensive bldg]	High setting (1) [low energy bldg]
A	Wall construction materials	walls	8in cmu	2 x 4 brick
B	Insulation values	roofs floors	flat r-19 slab	flat r-38 2 x 10 frame
C	Unit size	area (ft2) volume (ft3)	2000 16000	500 4000
D	Window area.	% floor area	20	10
E	Window type (single pane, double pane low e)		4060 single, alum	4060 double low-e, alum with thermal break
F	Infiltration (unintended air exchange with the outdoors. Ranges from 0.2 to 1.0 air changes per hour.)	ELA ACH	0 1.0	0 0.2
G	Lighting type (incandescent, fluorescent)	W/ft2	0.2	0.05
H	Heating/Cooling system efficiencies.	heating (% eff) cooling (SEER)	75 8	95 12
I	Occupancy (occupants per bedroom)	occ/BR	2	1
J	Temperature setback used?	wkdy sched wkend sched	continuous continuous	residence continuous
K	Location in building (set by selecting East & West wall R-values. Detached = standard. Mid = R1000)	E,W walls	not mid unit. same as wall type, var. A	mid unit R1000

Next, an orthogonal test matrix was developed to establish the settings of each variable for each test run. With 11 variables, 128 test runs were needed to determine individual effects of each variable separately. The first few runs of the test matrix are shown in Table 3-2, where "-1" indicates the "low" setting, and "1" indicates the "high" setting.

Table 3-2. Partial test matrix for designed experiment.

Test Run	VarA A	VarB B	VarC C	VarD D	VarE E	VarF F	VarG G	VarH ABCG	VarI BCDE	VarJ ACDF	Var K ABCDEFG
1	-1	-1	-1	-1	-1	-1	-1	1	1	1	-1
2	1	-1	-1	-1	-1	-1	-1	-1	1	-1	1
3	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1
4	1	1	-1	-1	-1	-1	-1	1	-1	-1	-1
5	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	1

3.3 Energy Simulation

2rw+di selected Energy-10, the whole-building, hourly analysis simulation software developed by the US Department of Energy, for the simulation runs. All variables other than the 11 selected for evaluation were held constant. Output was a single value, annual energy intensity, measured in Btu/ft2.

Simulated energy consumption varied from a low of 30.9 Btu/ft2 to 230.2 Btu/ft2.

Statistical analysis of the output values indicates that seven (7) of the variables have high significance, as well as one interaction among two of those variables. The F value as shown in Table 3-3 indicates that wall construction, Variable A, has the greatest significance, followed by location in building (detached, end or middle unit) and unit size (floor area). These variables are shown in order of decreasing significance.

Table 3-3. Statistical significance of variables.

Variable	DF	Sum of Squares	Mean Square	F Value	Pr > F
A	1	8.45132561	8.45132561	1807.27	<.0001
K	1	3.71029047	3.71029047	793.42	<.0001
C	1	3.67503589	3.67503589	785.88	<.0001
F	1	3.12109768	3.12109768	667.43	<.0001
H	1	1.29027812	1.29027812	275.92	<.0001
E	1	0.96034315	0.96034315	205.36	<.0001
B	1	0.58751127	0.58751127	125.64	<.0001
A*K	1	0.49781759	0.49781759	106.46	<.0001

To determine the meaning of the interaction between Variables A and K, an interaction plot was constructed, shown in Figure 3-1.

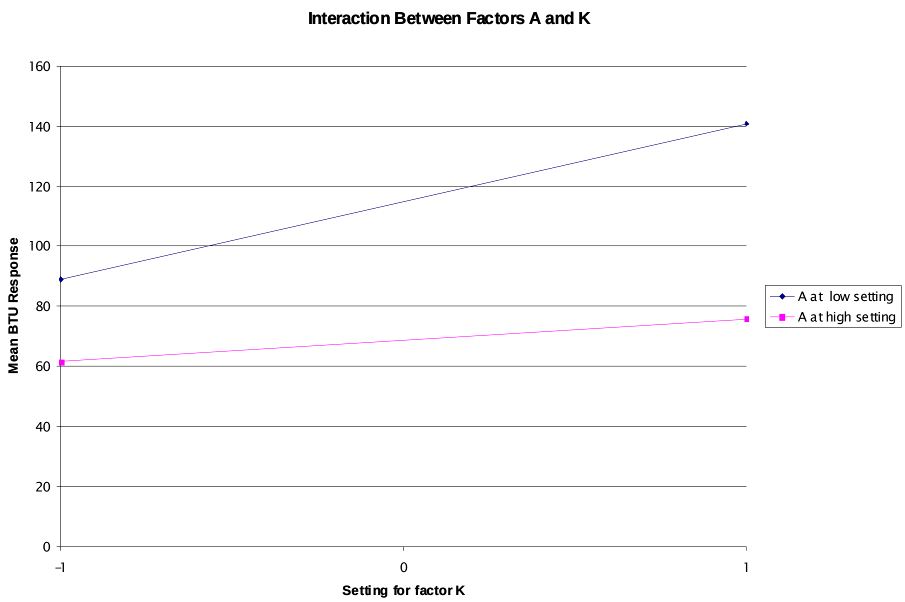


Figure 3-1. Interaction plot for Variables A and K.

The interaction plot indicates that, when Variable A is at its high setting (wall construction with high R value), the effect of Variable K (location in building) is small. However, when Variable A is low (low R value), the effect of Variable K is important. This result is somewhat intuitive, because it means that the higher the R value in walls, the less difference it makes where the unit is located within the building. This is because, in the limit, if R value approached infinity, there would be no heat loss through the wall, regardless of where it was located.

Finally, a predictive model was developed for the output variable, annual Btu/ft2, as a function of the eight most significant variables. From an analysis of residual plots and other technical considerations, the output variable Btu/ft2 was replaced with its logarithm. Under this transformation, the theoretical assumptions underlying the regression analysis are better satisfied. Thus, the predictive model, using the estimated coefficients of Table 3-4, represents log(annual Btu/ft2).

Table 3-4. Regression coefficients for output variable.

parameter	estimate	error	t Value	Pr > |t|
Intercept	4.428035	0.00940754	470.69	<.0001
A	-0.256955213	0.00940754	-27.31	<.0001
B	-0.067749035	0.00940754	-7.20	<.0001
C	0.169443849	0.00940754	18.01	<.0001
E	-0.086618017	0.00940754	-9.21	<.0001
F	-0.156152411	0.00940754	-16.60	<.0001
H	-0.100400686	0.00940754	-10.67	<.0001
K	0.170254645	0.00940754	18.10	<.0001
A*K	-0.062363450	0.00940754	-6.63	<.0001

A comparison of this predictive model with actual output data was accomplished by calculating the residuals, the differences between predicted output values and those from the simulation dataset, and developing a normal plot. If the normal plot is linear, the predictive model matches well with the data. As shown in Figure 3-2, the predictive model agrees well with the data.

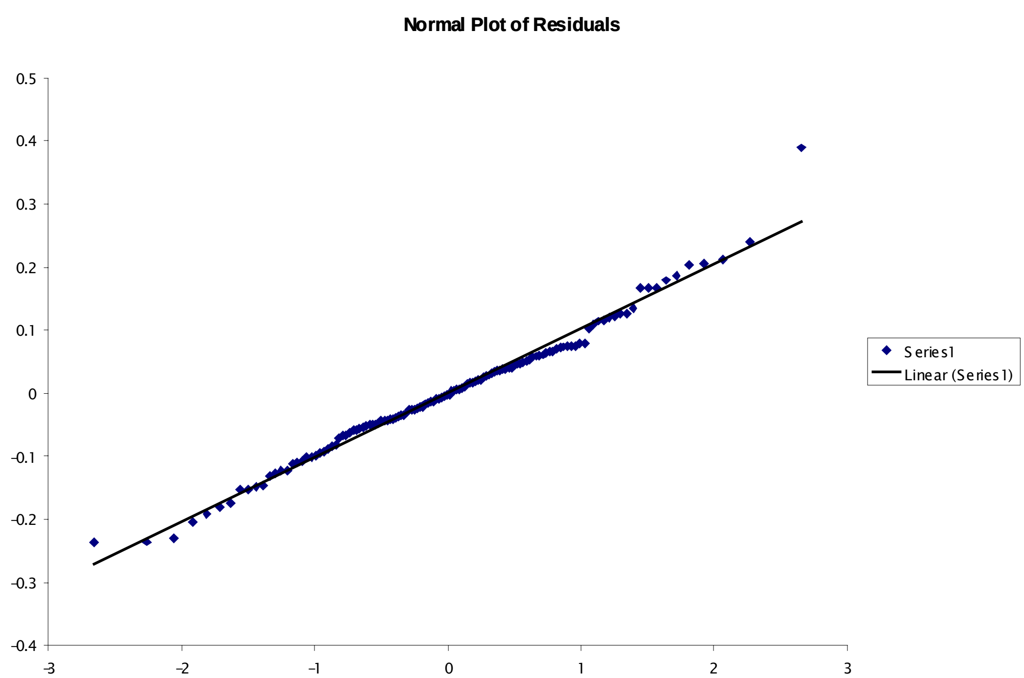


Figure 3-2. Normal plot indicating good agreement of predictive model.

The predictive model is given as follows:

Annual energy intensity (Btu/ft2) =
$10\wedge(4.428 - 0.257A - 0.068B + 0.169C - .087E - 0.156F - .100H + .170K - .062AK)$

3.4 Conclusions

- In order of decreasing significance, the 4 variables that most significantly affect residential energy use are:
  1. Wall insulation value
  2. Area of exterior walls
  3. Unit size
  4. Infiltration
- Variables with the next lower level of significance are:
  5. HVAC system efficiencies
  6. Window insulating value
  7. Roof & floor insulation values
- Attention should thus be applied to building characteristics in this order of priority when buildings are constructed or improved for maximum energy efficiency.
- The HUD spreadsheet model accounts for the No. 2 and 3 variables by modeling for building type and number of bedrooms. However, neither wall insulation value nor infiltration, two of the most significant variables, are considered. This was done because a.) the RECS dataset that forms the analytical basis for the HUD spreadsheet does not include information about these variables, and b.) it was determined that this type of information would not be available for Section 8 dwelling units, and thus could not be used as an input parameter to the spreadsheet tool. HUD has recognized the importance of including these significant parameters, and has asked 2rw+di to modify the HUD spreadsheet model to include an adjustment for age of dwelling units, as a surrogate for these and the remaining significant variables.

4. DEVELOPMENT OF MEASURED CONSUMPTION DATABASE

4.1 Comparison of HUD model output to measured data

The HUD spreadsheet tool for determining Section 8 utility allowances is based upon a statistical approach using nationally available measured energy consumption data from the US DOE Residential Energy Consumption Survey (RECS) database. In order to check the validity of its output, 2rw+di compared the values determined by the HUD spreadsheet to measured data from an alternative source: measured data from public housing authorities (PHA).

4.2 Consumption Data from PHAs

RECS is a national database; that is, the energy consumption and cost information contained therein was obtained from a wide variety of residential housing types using various energy resources throughout the United States. The initial HUD spreadsheet determines utility resource consumption for an average US housing unit, and scales that consumption to account for location (weather) effects and dwelling unit size. A source of alternative data was needed for use in evaluating the output of the spreadsheet.

2rw+di collected metered data from four different geographic locations in order to test the accuracy and legitimacy of the 1997 and 2001 HUD spreadsheets. Since metered utility data is generally not available for Section 8 housing, all data collected were from conventional Public Housing units, providing a considerable quantity of reliable metered data. The four locations and number of units were:

housing authority	location	0 BR	1 BR	2 BR	3 BR	4 BR	5 BR
Atlanta Housing Authority	Atlanta, GA	196	81				
Housing Authority of the City of Wilson	Wilson, NC	24	163	205	188	58	
Cincinnati Metropolitan Housing Authority	Cincinnati, OH		148	337	175	165	26
St. Paul Public Housing Agency	St. Paul, MN		109	445	552	230	86

After collection, the data were separated by four different factors: location, number of bedrooms, dwelling unit type, and fuel types. Histograms were created from these final data groups to characterize the distributions of metered data given different specifications of the factors listed above. 2rw then generated predicted consumptions from both the 1997 and 2001 HUD spreadsheets for all necessary variables. The results are illustrated and characterized in Section 5 of this document.

It is worthy of note that some housing authorities place a particularly strong emphasis on energy efficiency. Of the four PHAs supplying data for this task, Cincinnati is known to be one such authority. By comparison, Section 8 housing is generally privately owned, landlords are subsidized by HUD for rental income, and these units are rented to lower-income tenants. As a result, it is reasonable to expect that PHA properties could have better energy efficiency characteristics than Section 8 housing, and thus, lower utility consumption characteristics. If so, it is also reasonable to expect that consumption predictions by the HUD spreadsheet would be higher than consumption in public housing units.

5. COMPARISON OF MODELS AND DATASETS

5.1 Methodology

Measured consumption data groupings

In order to evaluate the validity of predictions made by the HUD spreadsheet tool, 2rw+di developed a methodology to compare measured data with predicted data. The measured data, described in Section 4, were grouped according to location, dwelling unit type, size (as number of bedrooms), and the existing combination of utility resource-using appliances and systems. The measured data obtained from public housing authorities were categorized by existing equipment, into groups of dwelling with similar characteristics as per Table 5-1.

Table 5-1. Dwelling unit groupings by installed equipment.

group 1	group 2	group 3
gas cooking	elec cooking	elec cooking
gas heating	elec heating	gas heating
gas DHW	elec DHW	gas DHW

Predicted consumption

Using the HUD spreadsheet based upon the entire 2001 RECS dataset, consumption values were calculated to correspond to each measured data grouping. Consumption values from each end use were summed to obtain the annual resource consumption.

Comparison

Measured data from each category were examined using histograms. This revealed the frequency distribution (number of datapoints sorted into bins of similar magnitude) of actual measured consumption in public housing units. Next, the predicted total consumption values from the HUD spreadsheet were plotted on the histograms to graphically show how they compared to measured data. Histograms are provided in Appendix 9.2.

In addition, the mean of measured consumption values in each group was determined, and a ratio of the predicted value to this mean was calculated. A comparison scale was developed to show quantitatively how the predicted and measured values compared. As shown in Figure 6, predicted values within 25% of the mean of measured data were considered “middle” range. Predicted values 25-75% higher than the mean were considered “high”, and above that , “very high”. Predicted values lower than the mean by 25 to 75% were considered “low”, and lower than that, “very low”.

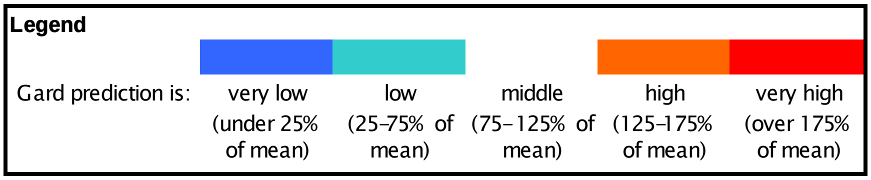


Figure 5-1. Scale of comparison for predicted vs. measured consumption data.

5.2 Results and Conclusions

The ratio of predicted consumption to the mean of measured data for each category, expressed in percentages, were tabulated and the scale of comparison of Figure 6 applied. Table 5-2 illustrates the results for electricity consumption, and Table 5-3 for natural gas consumption.

Table 5-2. Electricity consumption: ratio of HUD 2001 spreadsheet predictions to measured data.

location	# bedrooms	dwelling unit type	gas cooking gas heating gas DHW	elec cooking elec heating elec DHW	elec cooking gas heating gas DHW
Atlanta	0	flat		86.0%	
Atlanta	1	flat		88.6%	
Cincinnati	2	detached house	104.7%		
Cincinnati	3	detached house			97.8%
Cincinnati	3	detached house	89.3%		
Cincinnati	4	detached house	80.5%		
Cincinnati	1	flat	41.7%		
Cincinnati	2	flat	51.1%		
Cincinnati	3	flat			80.6%
Cincinnati	3	flat	57.6%		
Cincinnati	4	flat	80.8%		
Cincinnati	5	flat	69.9%		
St. Paul	3	detached house	123.7%		
St. Paul	4	detached house	142.1%		
St. Paul	5	detached house	143.1%		
St. Paul	1	townhouse	123.4%		
St. Paul	2	townhouse	101.4%		
St. Paul	3	townhouse	106.3%		
St. Paul	4	townhouse	115.7%		
St. Paul	5	townhouse	116.6%		
Wilson	4	detached house	153.4%		
Wilson	1	duplex	107.4%		
Wilson	2	duplex	111.3%		
Wilson	3	duplex	123.2%		
Wilson	0	row	66.3%		
Wilson	1	row	117.5%		
Wilson	2	townhouse		104.1%	
Wilson	3	townhouse	104.5%		
Wilson	3	townhouse		94.8%	

The following conclusions can be drawn for electricity:

1. For all-electric dwelling units (with electric heating), HUD spreadsheet predictions are good: within 20% of metered data. Of three data groups, two predicted lower than metered data, and one predicted 4% higher.
2. For all dwelling units characterized as “flats”, electricity predictions were low. In flats with gas heating, electricity predictions were 20-60% lower than metered data.
3. For detached houses with gas heating, electric consumption predictions were 20-45% high in areas of high heating needs, 50+% high in areas of low heating needs, and 20% low to 5% high in temperate regions. This matches our analysis of RECS data in Section 2.2, Figure 3 that indicates a non-linearity in the energy consumption rate normalized for heating needs.

4. For the remaining unit types and sizes, HUD spreadsheet predictions for electricity use were good: generally higher than metered data, but less than 25% high.

Table 5-3. Natural gas consumption: ratio of HUD 2001 spreadsheet predictions to measured data.

location	# bedrooms	dwelling unit type	gas cooking gas heating gas DHW	elec cooking gas heating gas DHW
Atlanta	0	flat		
Atlanta	1	flat		
Cincinnati	2	detached house	133.3%	
Cincinnati	3	detached house		101.3%
Cincinnati	3	detached house	104.9%	
Cincinnati	4	detached house	95.3%	
Cincinnati	1	flat	97.7%	
Cincinnati	2	flat	98.1%	
Cincinnati	3	flat		82.1%
Cincinnati	3	flat	106.8%	
Cincinnati	4	flat	110.6%	
Cincinnati	5	flat	93.3%	
St. Paul	3	detached house	110.7%	
St. Paul	4	detached house	119.1%	
St. Paul	5	detached house	135.3%	
St. Paul	1	townhouse	265.6%	
St. Paul	2	townhouse	187.5%	
St. Paul	3	townhouse	159.7%	
St. Paul	4	townhouse	160.0%	
St. Paul	5	townhouse	156.7%	
Wilson	4	detached house	100.0%	
Wilson	1	duplex	146.9%	
Wilson	2	duplex	143.9%	
Wilson	3	duplex	121.4%	
Wilson	0	row	148.0%	
Wilson	1	row	162.1%	
Wilson	2	townhouse		
Wilson	3	townhouse	147.8%	
Wilson	3	townhouse		

The following conclusions can be drawn for natural gas:

1. Natural gas predictions were high for all dwelling units in areas of high or low heating needs.
2. In temperate locations, natural gas consumption predictions were good: generally 7% lower to 10% higher than metered data.
3. These results match our analysis of RECS data in 2.2, Figure 3 that indicates non-linearity in the energy consumption rate normalized for heating needs.

6. REFINEMENTS TO HUD SPREADSHEET TOOL

6.1 Adjustment for Dwelling Units with Heat Pumps

HUD has requested that 2rw+di determine a means of estimating energy consumption in dwelling units with heat pumps. Currently, these systems are treated by the HUD spreadsheet as electric heating systems, and are grouped with electric resistance heating systems. For this reason, utility allowances for electricity are higher than necessary for dwelling units utilizing heat pumps.

2rw+di added two new input fields to each 52667 worksheet. First, the user checks a box if heat pumps are used, and leaves the box blank if not. Second, the user enters a value that indicates the nominal efficiency of the heat pump system, in HSPF. If this information is unknown, a default value of 6.7 is used; this value represents the approximate median efficiency of heat pumps shipped throughout the US over the period 1982-1990, as illustrated in Figure 6-1[3]. The new output 52667 forms are annotated to indicate the presence of heat pumps by changing the label for heating category “c. Electric” to “c. Heat Pump”.

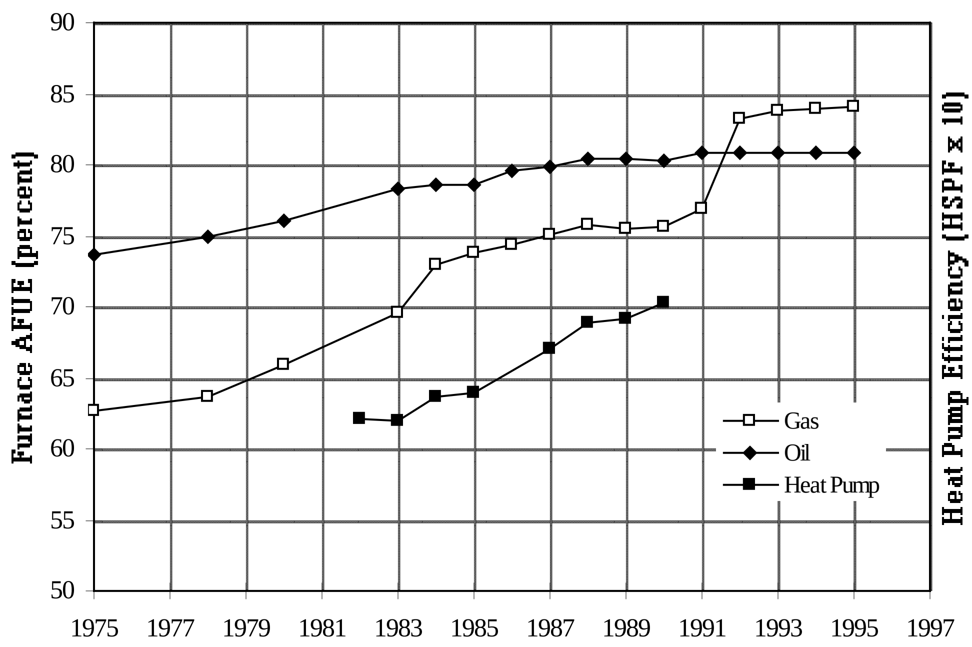


Figure 6-1. Shipment-Weighted Efficiencies for Residential Furnaces and Heat Pumps, 1975-1995

[3] Source: US DOE 1982b; LBNL calculations from ACHR News 1996 for Furnaces; ARI 1991

HSPF, or Heating Season Performance Factor, is a ratio of the estimated seasonal heating output divided by the seasonal power consumption for an average U.S. climate, and is expressed in units of kBtu/kWh:

HSPF = 3.412 (kBtu/kWh) x COP [heating energy output / electrical energy input]

where COP = Coefficient Of Performance. The current national efficiency standard[4] for new heat pumps requires a minimum SEER 13 and HSPF of 7.7 (or average annual heating COP of 2.25, making such heat pumps more than twice as efficient as electric resistance heating). Currently available high-performance heat pumps are available with HSPF ratings over 10.0.

The adjustment is carried out within the calculations on each 52667 form by dividing the linear coefficient for electric heating by the heat pump COP. If a heat pump with HSPF of 6.8 were in use, the COP would be about 2. Thus, electricity consumption for heating would be half that of an electric resistance heating system. If a heat pump is not used, the consumption value is calculated using a COP of 1, corresponding to an electric resistance heating system.

6.2 Adjustment for Age of Dwelling Units

HUD has requested that 2rw+di implement a means of adjusting energy consumption for dwelling units of different ages to more closely match utility allowances. Currently, all dwelling units are treated as if they correspond to the average of the RECS data.

The effect of building age on energy consumption is determined by a number of more specific effects. As discussed in Section 3 of this document, 2rw+di undertook a statistical simulation study to determine which particular variables have the most significant effects on energy use in dwelling units. The most significant, in order of decreasing effect, were: exterior wall insulation value, exterior wall area, dwelling unit size, and infiltration rate. The next most significant, at about half the level of effect, were: HVAC system efficiency

[4] Federal Register Vol. 69, No. 158, August 17, 2004, "Rules and Regulations", "…January 22, 2001 final rule: 13 SEER for split system and single package air conditioners, and 13 SEER, 7.7 HSPF for split system and single package heat pumps.", per the National Appliance Energy Conservation Act of 1987 (NAECA), as amended January 22, 2001 and reaffirmed April 2, 2004, 10 CFR 430.32(c)(2).

and window insulating value.

To make adjustments for age, therefore, 2rw+di determined that at least the most important variables should be accounted for in the HUD spreadsheet. It is important to note that the effect of age is not constant, however, because some building elements have shorter service lives than others. The 2rw+di statistical study revealed that the four most significant variables are ones that will likely remain constant throughout the life of the building since they would be difficult to change. For example, increasing the level of wall insulation would be a major effort and expense, and thus is rarely undertaken. On the other hand, windows and HVAC systems are replaced as they reach the end of their service lives, and thus the "effective age" of the building is reduced. The institution of minimum energy codes is another variable that has tended to improve the efficiency of new buildings over time. For all these reasons, it is reasonable to expect that by grouping residential units by age, buildings with similar construction features and system replacements would be grouped together.

RECS 2001 provides 13 age groupings beginning with units constructed prior to 1940. Attempting to adjust for each age group would be very difficult given the sparseness of data in each case, but the task becomes more manageable with only a few groups. Recognizing that the adoption of energy codes established minimum energy efficiency standards and improved the energy efficiency of housing stock, 2rw+di decided to consider three cases of construction. Prior to the institution of energy codes, construction post energy codes, and new construction were selected as significant groupings to which energy consumption adjustments can be applied. ASHRAE Standard 90, developed during the energy crisis of 1974, became the basis for the Model Energy Code and many energy conservation codes for new building construction. Standard 90.1 is now referenced in the United States Energy Policy Act as the reference standard for state energy codes. Many states enacted state energy codes in the late 1970s and early 1980s. When matched with the RECS groups, the following three generalized groupings were established: pre-1980, 1981 to 1995, and 1996 and newer. All unit types below 2,500 square feet were considered and the heating consumption was normalized for square footage, HDD, and typical heating system efficiency by fuel and heating equipment type.

The resulting heat loads were averaged within each age group, and the middle group (1981-1995) was set to equal the existing HDDxBR coefficients from the HUD spreadsheet as developed by Gard Analytics. The older and newer categories were assigned factors corresponding to the ratio of their heat loads to those of the center group. These new scaling factors can be seen in the revised HUD tool on the 52667 spreadsheets directly above the table of coefficients. Age multipliers corresponding to each group are respectively, 1.43, 1, 0.78. The adjustments to utility resource consumption are carried out within the calculations on each 52667 tab by multiplying the linear coefficient for each weather-dependent end use by the appropriate age multiplier.

2rw+di added a new selection box to each 52667 worksheet in the HUD spreadsheet tool. When filling out the 52667 form, the user selects the age group from the drop-down box at the top. This changes the factor that is applied to the heating and cooling "HDDxBR Coefficients" and the updated values are used throughout the consumption calculations. The output 52667 forms are annotated at the top to indicate for which building age group the calculations were done.

7. APPLICATION OF BILLING RATE SCHEDULES

HUD has requested that 2rw+di investigate whether regional or average statewide utility rates can be used in place of local rate structures to convert resource consumption to monthly utility allowances. Presumably, the advantage of this approach would be to simplify the data input process for housing authorities.

As currently implemented in the HUD spreadsheet tool, the user must gather utility rate structure information from utility resource providers and enter the components of these rate structures into the “Tariffs” sheet. These are the values used to generate monthly utility dollar allowances.

7.1 Natural gas

2rw+di identified the US Department of Energy’s Energy Information Administration (EIA) as the primary source of information about residential natural gas pricing[5]. In general, whether “tariff” rates from utility companies or “transportation” purchasing agreements from wholesalers are in place, the commodity component of the end user’s cost is indexed to the current market rate for natural gas. This is usually the most volatile component of price. Transmission rates generally do not vary as much, and are a smaller portion of the total price. Local distribution fees, however, vary significantly from location to location, and can be as high as the commodity portion.

The following figures and information from EIA[6] illustrate the variance in gas pricing over time, the difference between tariff vs. transportation purchasing, and the variation in end user prices among locations.

[5] EIA, http://www.eia.doe.gov/oil_gas/natural_gas/analysis_publications/natbro/gasprices.htm

[6] Source: Energy Information Administration, Natural Gas Monthly, August 2004

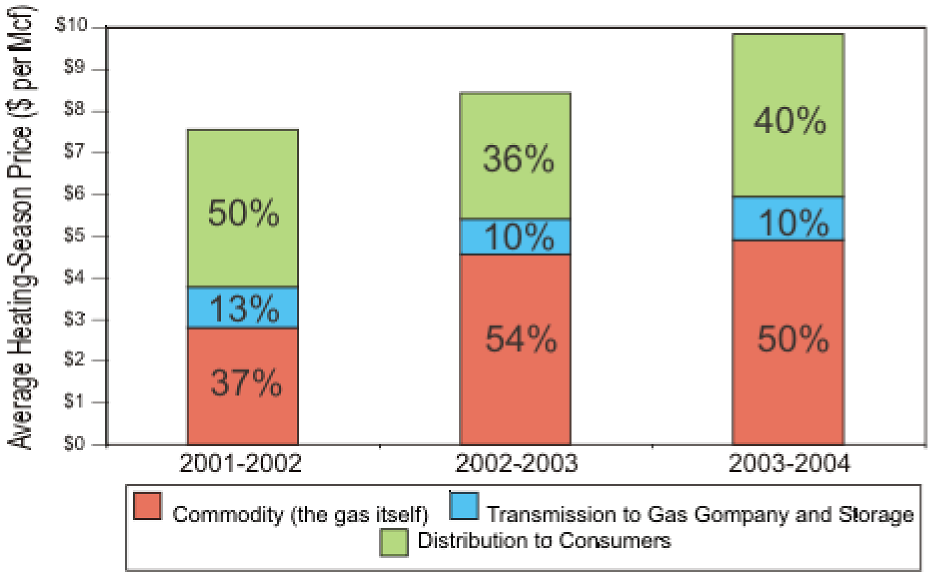


Figure 7-1. Components of natural gas prices.

According to EIA's document Evaluation of the EIA-910 Survey Residential and Commercial Natural Gas Prices[7], the difference in price between residential and commercial gas sold on tariff rate schedules (EIA-857) varies 28% in GA, 22% in MD, 21% in NY, 10% in OH, 15% in PA. This information is based on a 5-state study of on-system purchasing (buying gas on the tariff rates) versus off-system gas purchasing (buying gas wholesale, and paying local system for transportation and distribution services); see Table 7-1.

Table 7-1. Regional differences in natural gas prices[7].

Dollars per MCF for Annual Data from 2002

	Average EIA-910 Price		Average EIA-857 Price		Difference in Average Prices	
States	Residential	Commercial	Residential	Commercial	Residential	Commercial
Georgia	$11.99	$9.36	$9.59	$6.88	$2.40	$2.47
Maryland	$9.31	$6.28	$11.26	$8.73	$1.95	$2.44
New York	$8.85	$6.03	$10.83	$8.57	$1.98	$2.54
Ohio	$8.16	$6.26	$8.17	$7.32	$0.01	$1.06
Pennsylvania	$10.54	$6.36	$10.53	$8.98	$0.01	$2.62

Based on the above table, citing the reported prices from the EIA-857 and the EIA-910, the difference in price for the commercial sector in the state of Georgia is $2.47. Combined with the knowledge that 80% of the respondents in Georgia are off system, we can conclude from the Bias Table that EIA would over estimate the actual price by close to $1.80.

The Bias Table is a tool that can be used to answer the following question: Should EIA expand the EIA-910 to other states? One could create a "rule of thumb" based on this table, deciding to add states to the EIA-910 if the expected bias exceeds $0.50, for example, which is the portion of the table highlighted in yellow.

Although this kind of information from other areas of the country is not

[7] Thursday October 15, 3:15 pm Breakout session #5, www.eia.doe.gov/smg/asa_meeting_2003/fall/files/natgaseval.pdf

available, Energy User News publishes a monthly ranking by state of natural gas prices. This data shows significant fluctuation with time and variation by location. For example, in Cincinnati, Ohio, the average price over 2004 was $7.784 per million Btu (MMBtu), but rose steadily from $7.809 in the first quarter to $8.411 in the second quarter. Nationwide over the second quarter of 2005, prices varied from $6.684 per MMBtu in San Diego, CA to $10.453 in Pittsburgh, PA. As of this writing, the commodity price of natural gas on the New York Mercantile Exchange is over $14.00.

In 2004, 2rw+di examined natural gas pricing on a regional basis and found significant variation in pricing within the same state. In central Virginia, the local distribution component of pricing varies over 350% as shown in Figure 7-2. Currently, the distribution component for the central Virginia region represents from 5% to 25% of the end user price. Thus, use of a regional average could overstate costs from 10-50% for some localities, and understate costs by up to 45% in other localities.

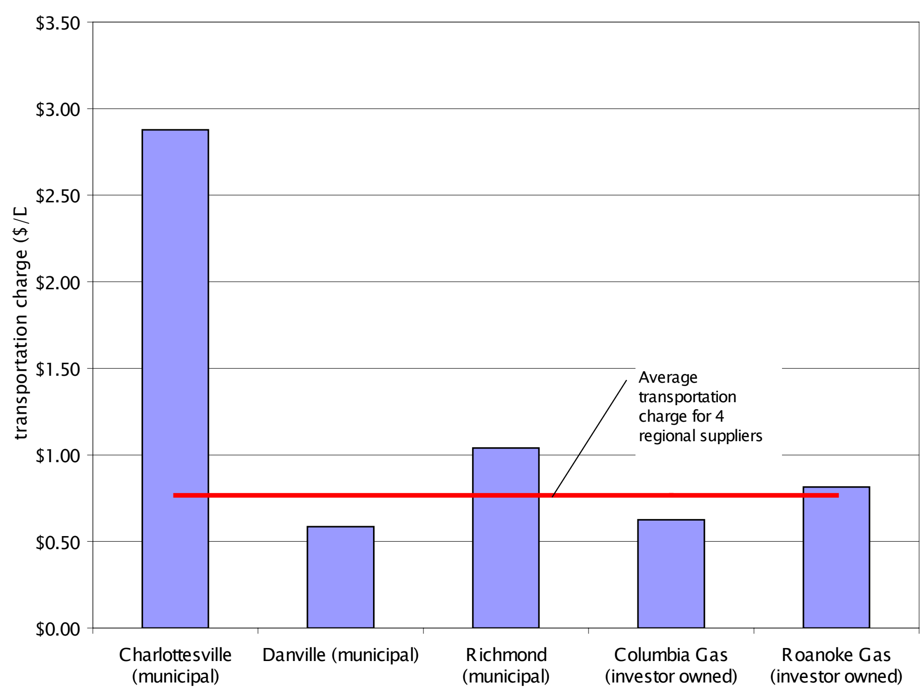


Figure 7-2. Variation in local distribution fees for natural gas, central Virginia.

<u>Conclusion for natural gas</u>

Based upon analysis of natural gas pricing, 2rw+di does not recommend the use of regional or state-wide prices for natural gas. Entry of local price structures into the HUD spreadsheet as currently established is recommended for best results.

7.2 Bottled fuels and fuel oil

In 2rw+di experience, many public entities such as housing authorities negotiate annual contracts for bottled gas and fuel oil prices with local suppliers. The result is that the authority would have a constant fuel price for an entire season. Negotiated rates are generally applicable across the entire housing authority, but we are not aware of larger areas of applicability (e.g. several housing authorities within a region negotiating a common contract). Those that do not negotiate contracts simply purchase fuel from local suppliers on an as-needed basis at the then prevailing price. Thus, pricing for bottled fuels and fuel oil are specific to the location, and use of regional average prices would likely result in incorrect allowances for any individual location.

Conclusion for bottled fuels and fuel oil

Pricing for bottled fuels and fuel oil are highly localized; 2rw+di does not recommend the use of regional or state-wide prices. Entry of local price structures into the HUD spreadsheet as currently established is recommended for best results.

7.3 Water

2rw routinely conducts utility analyses for public housing entities and has examined local water and sewer rates. More than any other utility, water and sewer rates vary widely even within local geographic areas. For example, a recent analysis of utilities in a small housing authority in northeast Ohio revealed that four different water/sewer districts provide services to 244 dwelling units as shown in Table 7-2. The water+sewer combined prices vary from $2.43 to $6.94 per thousand gallons. In general, these significant price variations are due to large differences in sewer rates among localities. Thus, use of a regional average would incorrectly estimate costs in nearly all localities. In this local area alone, use of the local average price would result in understating the cost by 4% to 30% in three of four locations, and overstating by nearly 60% in the remaining location.

Table 7-2. Current incremental water & sewer costs, Wayne County, OH.

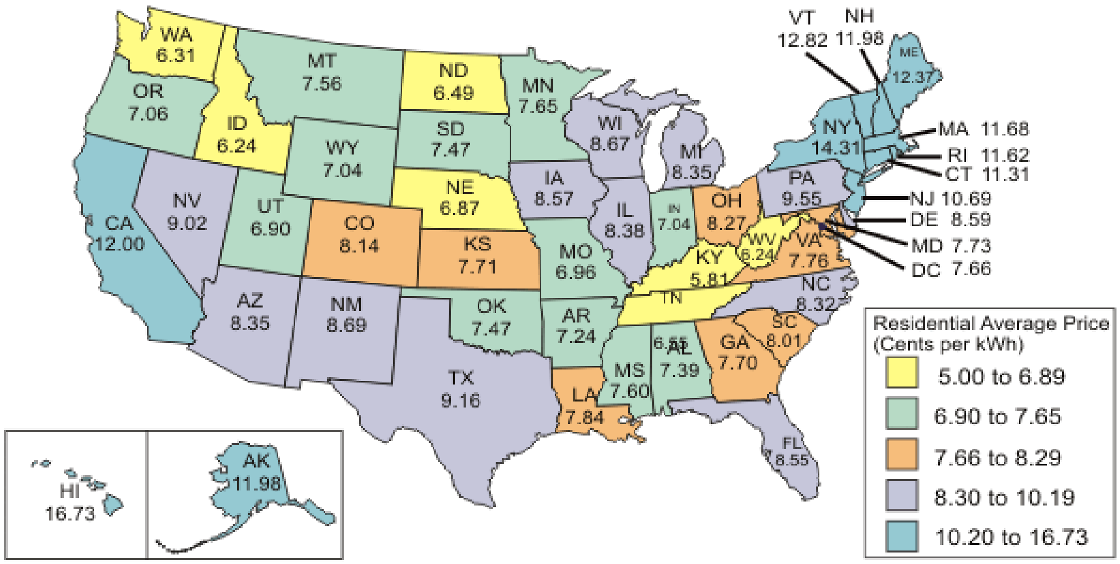
	Quantity	Wooster	Orrville	Rittman	Shreve
water	2000-8000 gal	21.78	20.48	18.70	6.63
sewer	0-5000 gal	9.85	17.65	17.55	6.62
water + sewer	($/kgal)	$ 5.60	$ 6.94	$ 6.63	$ 2.43

<u>Conclusion for water</u>

Because of the large number of local water and sewer utilities and the wide variation in price among them, 2rw+di does not recommend the use of regional or state-wide prices for water or sewer services. Entry of local price structures into the HUD spreadsheet as currently established is recommended for best results.

7.4 Electricity

Electricity rates seem to change less over time than other utility resources, though this may change considerably if and when deregulation occurs. US DOE has published a map of average electricity prices by state (see Figure 7-3)[8], which indicates that regional trends exist to some degree.



Source: Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report."

Figure 7-3. Average residential utility prices, 2003.

2rw+di investigated further by gathering residential electric rate information from both investor owned and public utility companies around the US, with all the major geographic regions represented. As shown in Table 7-3, the prices for 500 kWh using the average DOE data were compared to actual utility rate structures.

[8] US DOE, Energy Information Administration, http://www.eia.doe.gov/neic/brochure/electricity/electricity.html

Table 7-3. Comparison: average residential electric prices vs. actual utility prices.

state	2003 average price (cents /kwh)	2003 average price for 500 kWh	number of utility companies	maximum difference	minimum difference
Alaska	11.98	$ 59.90	3	0.5%	-14.6%
Hawaii	16.73	$ 83.65	1	-6.2%	-6.2%
Washington	6.31	$ 31.55	4	24.5%	-10.5%
California	12	$ 60.00	4	6.4%	-34.6%
Arizona	8.35	$ 41.75	2	36.1%	8.5%
Montana	7.56	$ 37.80	2	31.5%	19.7%
Kansas	7.71	$ 38.55	2	3.9%	3.1%
Texas	9.16	$ 45.80	3	-2.5%	-12.9%
Minnesota	7.65	$ 38.25	3	22.1%	-6.8%
Ohio	8.27	$ 41.35	2	7.5%	-13.9%
Kentucky	5.81	$ 29.05	3	37.4%	18.8%
Georgia	7.7	$ 38.50	1	7.1%	7.1%
Florida	8.55	$ 42.75	2	24.5%	7.5%
Maine	12.37	$ 61.85	3	26.1%	6.1%
New York	14.31	$ 71.55	2	-5.5%	-33.2%
Virginia	7.76	$ 38.80	2	-0.7%	-4.4%

In Table 7-3, a negative difference indicates that the average rate is higher than the actual rate from a rate structure; use of average costs would overstate the electricity cost and result in a higher-than-necessary electric utility allowance. A positive rate indicates that use of average costs would understate the actual cost, and tenants would be forced to pay more than necessary for their electric utilities.

From Table 7-3, a number of cases appear in which use of average utility data would result in tenants paying 20% to 40% more for electricity than if actual rate schedules were used to calculate allowances. Conversely, in many cases, the subsidy by HUD would be 5% to 35% too high.

Conclusion for electricity

To achieve the most accurate utility resource pricing, local rate structures should be used. On a national scale, it may be that using average electric price data would result in a neutral utility subsidy for HUD - e.g. overstated allowances might roughly equal understated ones. Without investigating each and every rate schedule nationwide, this cannot be known. However, using local rate schedules would appear to be the most fair for tenants.

7.5 Conclusions

Entry of local price structures into the HUD spreadsheet as currently established is recommended for best results. The “Tariffs” spreadsheet as developed by Gard is straightforward to use and good instructions are provided. Rates data would be entered once, and reviewed once per year or whenever a significant change in rates occurred (10% or greater change, per 24 CFR IX, Subpart E, Section 965.507 a & b).

8. SUMMARY AND RECOMMENDATIONS

8.1 Summary

The analytical approach within the HUD spreadsheet tool for determining utility allowances has been shown to be generally valid. A comparison of utility consumption predictions from the HUD spreadsheet to actual measured data from public housing units has shown that predictions are in the general range of measured consumption.

Buildings are upgraded over time. Windows are replaced, insulation is added to attics, and air leaks are plugged, improving the energy efficiency of the building's envelope. Heating and cooling systems and refrigerators reach the end of their useful lives and are replaced, improving the efficiency of appliances and central space conditioning systems. Electrical appliances are added, increasing use of electricity. The efficiency of new appliances tend to improve over time as programs such as EPA Energy Star and efficiency regulations take effect. As a result of these changes, the "effective age" of a building is usually lower than its original construction age, and the efficiency of buildings changes over time.

Data contained in the Residential Energy Consumption Survey (RECS) is a sampling of measured consumption for all housing types throughout the United States. It contains housing units that were built prior to the 1940s through the present. Based upon the common improvements made to buildings over time and on trends in utility resource use, some utility consumption end uses will increase over as the building ages (e.g. electrical plug loads increase as tenants purchase more appliances), and some will decrease (e.g. heating and cooling loads decrease as building envelope improvements are made and more efficient central HVAC systems are installed). We expect that with each update, the RECS database will change along with the consumption trends, and some end uses will increase, while others will decrease.

The original HUD spreadsheet made no adjustments for the age of dwelling unit. HUD requested that 2rw+di make modifications to the HUD spreadsheet tool to account for building age. This is a refinement on the original HUD spreadsheet, and generally results in lower consumption predictions for newer buildings. Another refinement that achieves the same result is a modification that accounts for use of electric heat pumps for space heating. The original HUD spreadsheet and utility allowance methods to date treat heat pumps as electrical resistance heating. This overstates the electricity consumption for space heating. The modified version of the HUD spreadsheet adjusts consumption for the presence of heat pumps.

8.2 Recommendations

- Address the non-linearity issue in heating-related end uses, discussed in Section 2.2. One possible solution is to apply a piecewise-linear model in place of the simple linear fit to the RECS consumption data. A linear relationship would represent the consumption data for warmer locations (with heating degree-days up to about 4,000 HDD/yr); and a second linear relationship with a shallower slope would be used to represent the colder regions.
- The HUD spreadsheet and other consumption-based utility allowance methods establish allowances based upon historical utility resource use, and do not provide encouragement for improved efficiency. Improved resource efficiency benefits tenant and housing authority by lowering utility costs, and benefits all by reducing the emissions resulting from energy use. Incorporating a method to encourage increased resource efficiency would further enhance the HUD spreadsheet tool.
- User training should be developed in three primary areas: utility allowances, utility rate schedules, and use of the HUD spreadsheet tool. These training modules would include, respectively:
  - General information about the reason for allowances, requirements for instituting allowances (e.g. individual metering, phantom billing period, etc.), how allowances are determined, and how they are paid for by HUD through the PHA;
  - Purchasing variations for utility resources (tariff vs. wholesale), explanation of utility resources and units of measure, descriptions and examples of various rate schedules, determination of unit costs;
  - Selecting the appropriate weather location; gathering and entering utility rate structure information, making selections for building age and heat pump use, interpreting the output 52667 forms.

9. APPENDICES

9.1 Detailed Analysis of HUD Spreadsheet Algorithm

Methodology of calculation

The display values for individual components (heating, cooking, etc.) are derived by subtracting values as necessary in a matrix of values such as:
A Other Electric
A Other Electric + Cooking
A Other Electric + Cooking + Water Heating
A Other Electric + Cooking + Water Heating + Heating
A Other Electric + Cooking + Water Heating + Heating + Air Conditioning

The methodology is complex but seems to work properly; I doubt that any deficiencies in the model lie in the calculations. As verification, I traced the value for "Space heating with electricity" back to the base values and, except for taxes and surcharges, found it to be

Heating cost = HDDjan ´ (2.605 + 0.814 ´ bedrooms) / 3.413

Example: January electric heating costs for 1-br detached

Display value E23 for heating is N818 = N542/12
= SUM(AF542:AQ542)/12 monthly average

Taking only January…

AF541-AF517 (TC of OCWH minus TC of OCW).

(AF538+AF539-AF514+AF515)/12

((AF526´M365) + (AF527´M366) + (AF528´M367) + (AF529´M368)+ AF536+AF537 +AF538 ´ M358/100 -
(AF502´M365)+(AF503´M366)+(AF504´M367)+(AF505´M368)+AF512+AF513+AF514´M358/100 All divided by 12, which is dropped from here on.. (added back later)

M numbers are monthly rates of first through fourth blocks.
AF numbers are typically amount of use in each block and then we have service charges.

(Min(AF427,M360) ´ M365) + [remaining blocks] + M356+AF524 ´ M357 + tax -
(Min(AF426,M360) ´ M365) + [remaining blocks] + M356+AF500 ´ M357 + tax

This takes the actual usage and calculates the cost of usage in each block.
AF427 and 426 are electric use in kWh, OCWH-OCW
M360 and M365 are the size and rate for the first block.
AF524 and AF500 are estimates, OCWH-OCW, used for service charges

M356 and M357 are service charges

So the key is finding out what AF426 and AF427 are. Actually this next section isn't used but it does show the typical calculations made.

AF426:
= N211 (Other adder) + N210 (cooking adder) + N214 (water heating adder)
= N195/(3.413´12) + N194/(3.413´12) + N198/(3.413´12)

These come from the Annual consumption table

N195 = O163 + N163 ´ N189 = O146 ´ Q137 + N146 ´ Q137 ´ [1 bedroom]
N194 = O162 + N162 ´ N189 = O145 ´ P137 + N145 ´ P137 ´ [1]
N198 = O166 + N166 ´ N189 = O149 ´ S137 + N149 ´ S137 ´ [1]

= constant + bedroom coefficient ´ bedrooms + a 3-br factor for a dryer
Q137, P137, and S137 are 1.
These values are in the "Adjusted Table for selected unit type" and draw from the "Unadjusted table for selected unit type" in the following lines.

So AF426 = (O146+N146) + (O145+N145) + (O149+N149)
These three parts reflect the bedroom coefficient plus a constant for 'Other electric,' 'Cooking with electricity,' and 'Water heating with electricity.'

Likewise, AF427 = AF426+AF414 so the preceding part is actually canceled out and all we're left with is AF414, which is indeed the monthly cost of heating with electricity.

AF414 = N281 ´ N403 = N207 ´ (N400´12)

N400 is a monthly factor for January's portion of the annual heating use. 1 is the average.
N207 is monthly electric heating cost. So the result is the annual heating cost if every month were like January.

= N191/(3.413 ´ 12) ´ (N397/M397) ´ 12
= ((M175 ´ R159 + M175 ´ S159 ´ N189)/3.413) ´ N397/M397

= (HDDyr ´ (xDD elec heat cx + xDD br elec heat cx ´ bedrooms) /3.413) ´ HDDjan/HDDyr
= HDDjan ´ (xDD elec heat cx + xDD br elec heat cx ´ bedrooms)/3.413

Still the annual cost if every month were like January, but if we add back the 12 that we ignored earlier we are left with the actual January cost:

AF414 = HDDjan ´ (R159 + S159 ´ bedrooms) / 3.413

Adjusted table drawing from unadjusted table, again, with O137 being 1:

R159 = R142 ´ O137
S159 = S142 ´ O137

AF414 = HDDjan ´ (2.605 + .814 ´ bedrooms) / 3.413

Adding in a few service charges and taxes, this is the January cost for electric heating, and matches the model given on page 18 of the report. 3.413 is a BTU to Watt conversion used for all electric services; the other energy types have their own factors here.

These two numbers are hard-coded into the "Derived Consumption Equations" data table.

Derived Consumption Equations

The modeling coefficients were mainly derived from DOE/EIA Residential Energy Consumption Survey for 1997 database. The derivation is not part of the main 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 previously 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.

One logical place to start analyzing the methodology is to see if the values in this table make sense relative to each other.

Example 1: Predicted energy usage for a duplex heated with electricity rises by 66% per bedroom, but if heated with gas or oil it only rises 31% per bedroom. However, an apartment in a small building heated with electricity only gets a 12% increase per bedroom, while gas and oil bring a 32% increase.

Example 2: For Single Family Attached units, the electricity C1 is 15% of the oil C1, but for SFD and small apartment buildings this relationship is around 28%.

Unless there is a proven mechanism by which these relationships turn upside down for different combinations of housing types and fuel type, they cannot be relied on. Although the data may indicate this relationship, there should be a proven causal relationship before it is used to justify different housing allowances.

A major limitation in their analysis is their decision to only use housing unit type and number of bedrooms in all energy models, due to the unreliability of information on square footage, number of occupants, etc. It's not surprising that some of the correlation is so low. For example, baseboard vs. forced-air heat vs. heat pumps is never addressed. The correlation for air conditioning (all electric, all forced air) is much better than it is for heating.

Other energy uses

The previous pages relate almost entirely to the heating costs. Cooling is calculated using CDD65 similarly to heating, but without the array of fuel types. The correlation is much better. There are also calculations for water consumption, water heating, cooking, household electricity usage, trash collection, and others.

Allowances for water/cooking/other

Again, a linear equation was used to relate cooking and water heating energy to the number of bedrooms, with very high correlation.

kBTU/yr = X + Y ´ bedrooms

In fact, the correlation was so good that housing unit type was ignored. An inlet water temperature correction, derived from the HDD/yr, is applied to the water heating.

"Other electric" showed a very irregular correlation with number of bedrooms and housing type and was used in some cases and not in others. However, this is a fairly high number and needs all of the accuracy it can get. It should have a good correlation with number of bedrooms, but this wasn't always done: use of a clothes dryer is 450 kWh/yr across the board, and only on single-family 3+ bedrooms.

Summation and Conclusion

GARD's goal in creating this model was to predict the data in the RECS database using HDD/CDD, housing unit type, fuel type, and number of bedrooms. Unit type and fuel type were considered individually, and for each case variables for a linear equation (Y=mX+b) were statistically determined to best match the RECS data. In the cases of heating and cooling, the entire equation was scaled by the HDD or CDD.

The actual statistical correlation (R2) with the actual data appears to be less than 0.1 for heating, due to a manipulation GARD used with the calculation. Cooling would be better but wasn't calculated. Water consumption and water heating may be good enough to use. Whether or not any of this is a problem depends on the interpretation of the goal; determining a fair utility allowance may or may not depend on matching actual data.

There are many ignored variables with this approach, specifically with heating costs, that may further refine the usage prediction. At the same time, unjustified differences between unit types and fuel types may have been created in an effort to track the actual data more closely.

9.2 Measured Data Histograms with Predicted Data

2rw+di obtained metered utility resource consumption data from four public housing authorities. Data values were categorized by dwelling unit type, dwelling unit size and the fuel type used for space heating, cooking and water heating. Histograms were developed to illustrate the distribution of data within each group.

Next, 2rw+di produced consumption predictions using the HUD spreadsheet based on the 2001 RECS database. Predicted consumption values were then plotted on the histograms to show how predicted values compared to measured consumption values.

The following charts were generated to illustrate the comparison of predicted consumption to actual measured consumption in public housing dwelling units.

9.2.1 Zero Bedroom (efficiency) Dwelling Units

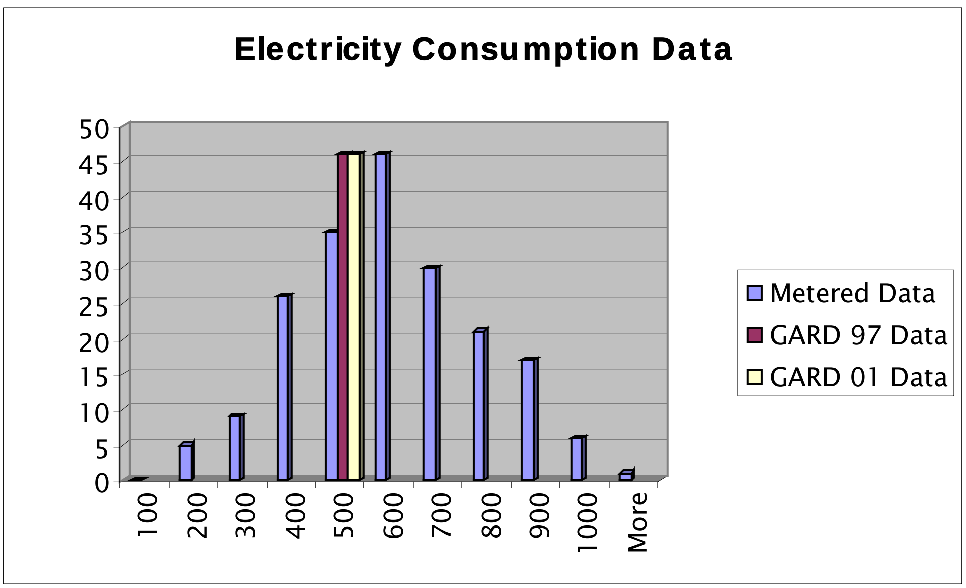


Figure A.1. Atlanta, GA, 0 bedroom, all-electric units.

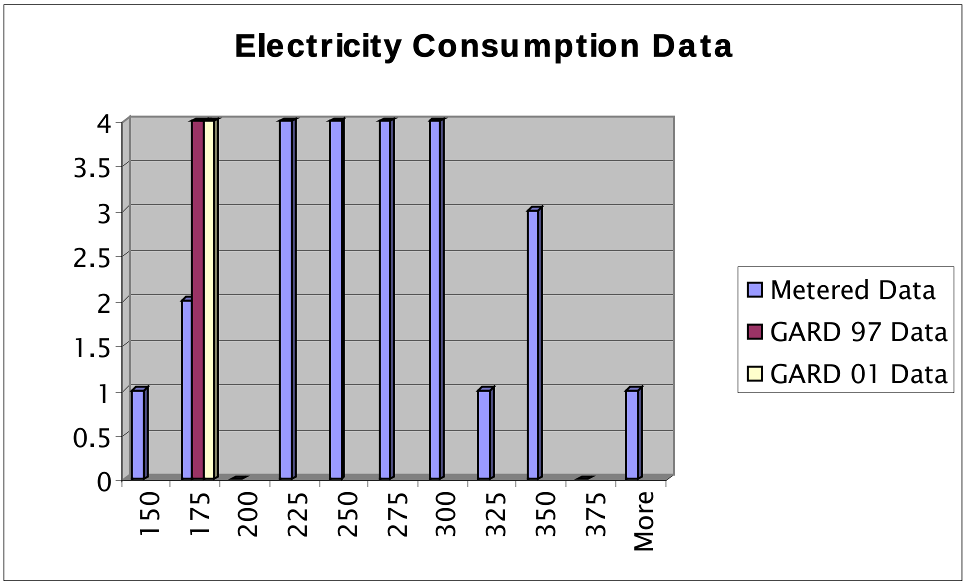


Figure A.2. Wilson, NC, 0 bedroom, gas heating, cooking & DHW.

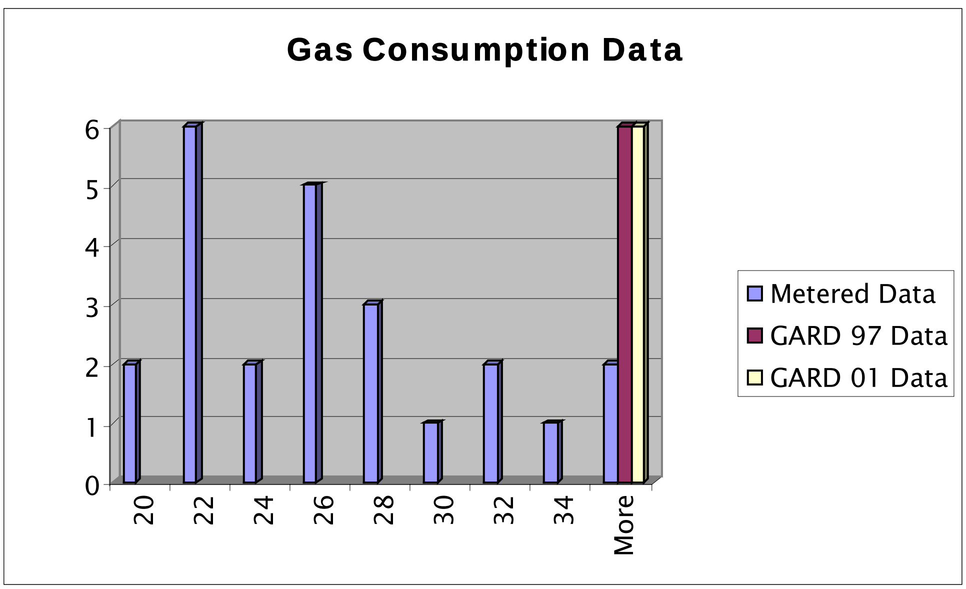


Figure A.3. Wilson, NC, 0 bedroom, gas heating, cooking & DHW.

9.2.2 One Bedroom Dwelling Units

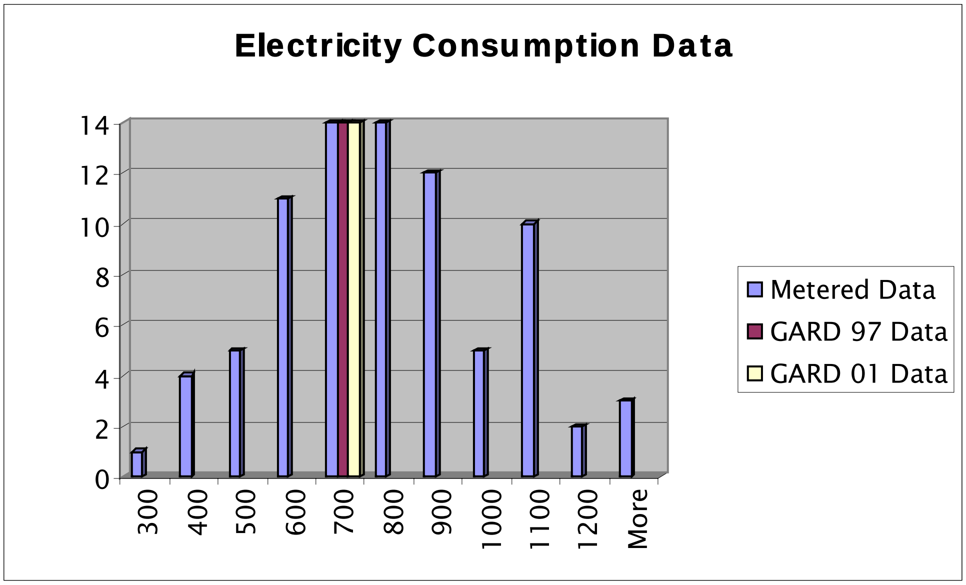


Figure A.4. Atlanta, GA, 1 bedroom, all-electric units.

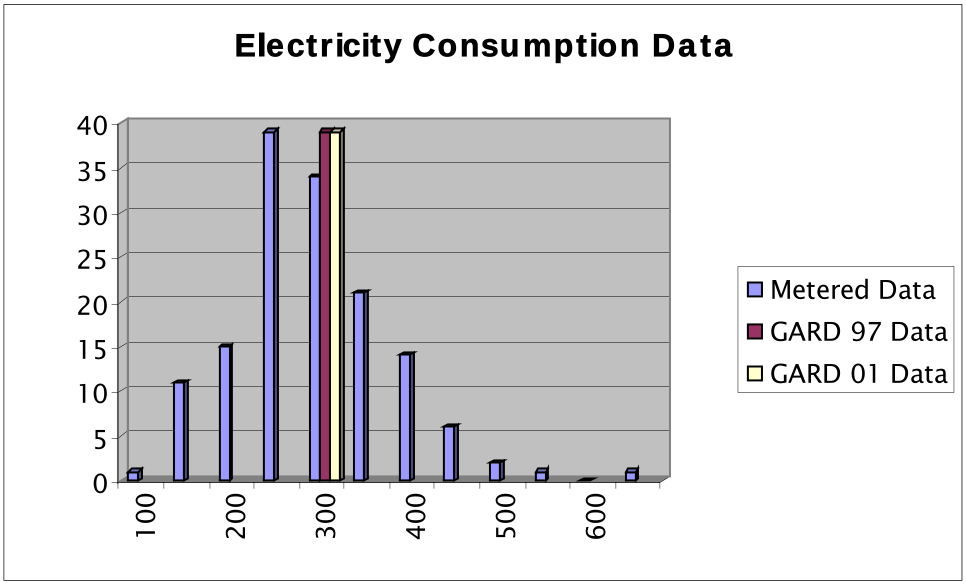


Figure A.5. Wilson, NC, 1 bedroom duplex, gas heating, cooking & DHW.

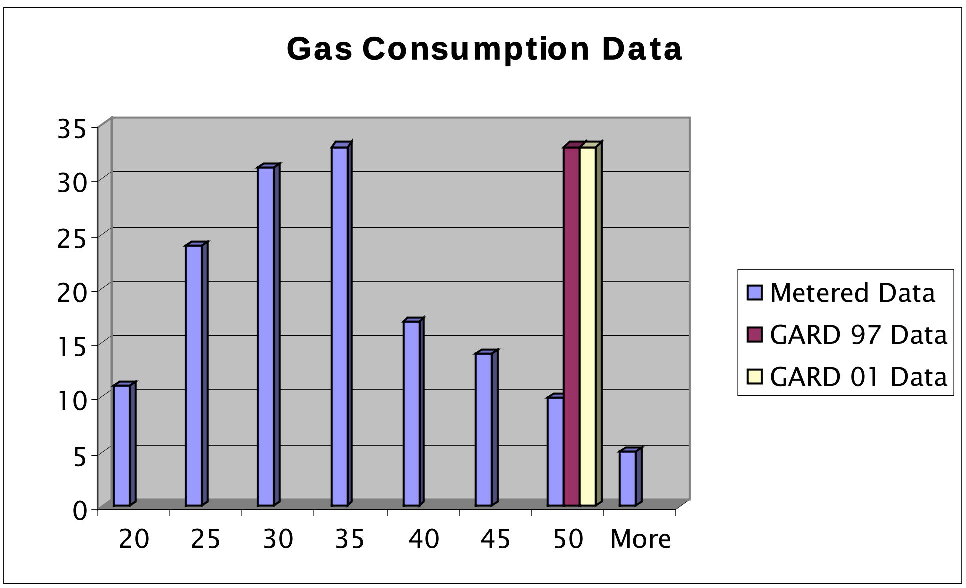


Figure A.6. Wilson, NC, 1 bedroom duplex, gas heating, cooking & DHW.

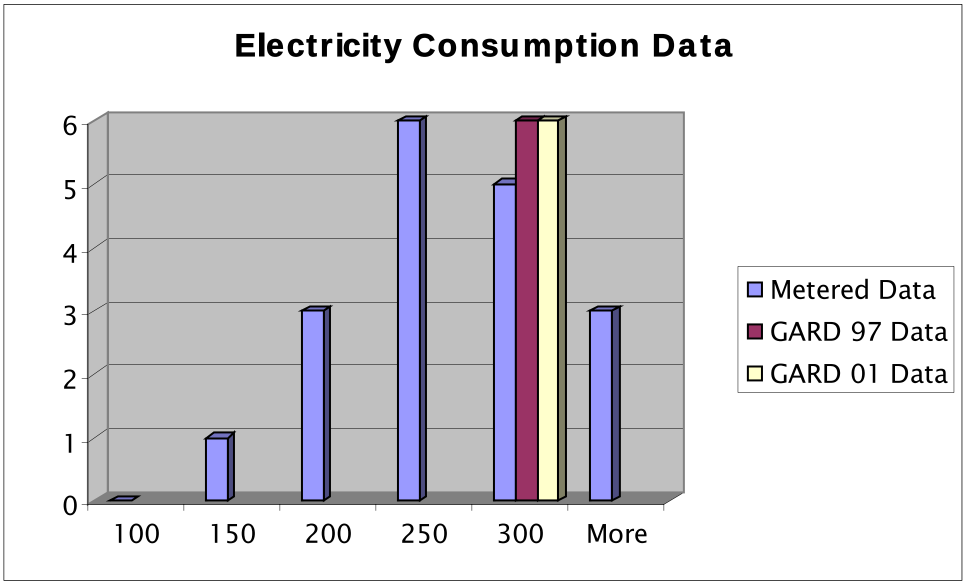


Figure A.7. Wilson, NC, 1 bedroom row, gas heating, cooking & DHW.

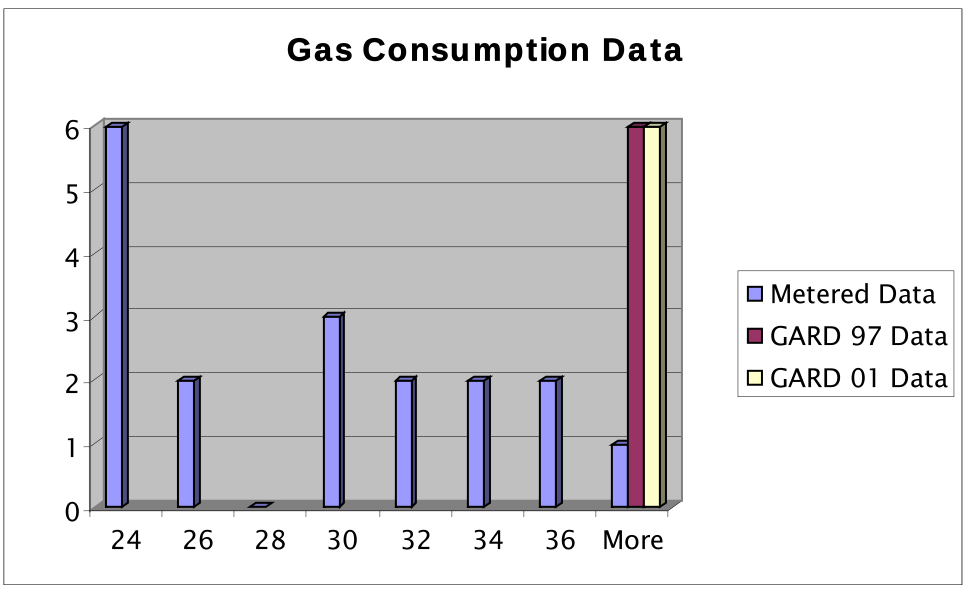


Figure A.8. Wilson, NC, 1 bedroom row, gas heating, cooking & DHW.

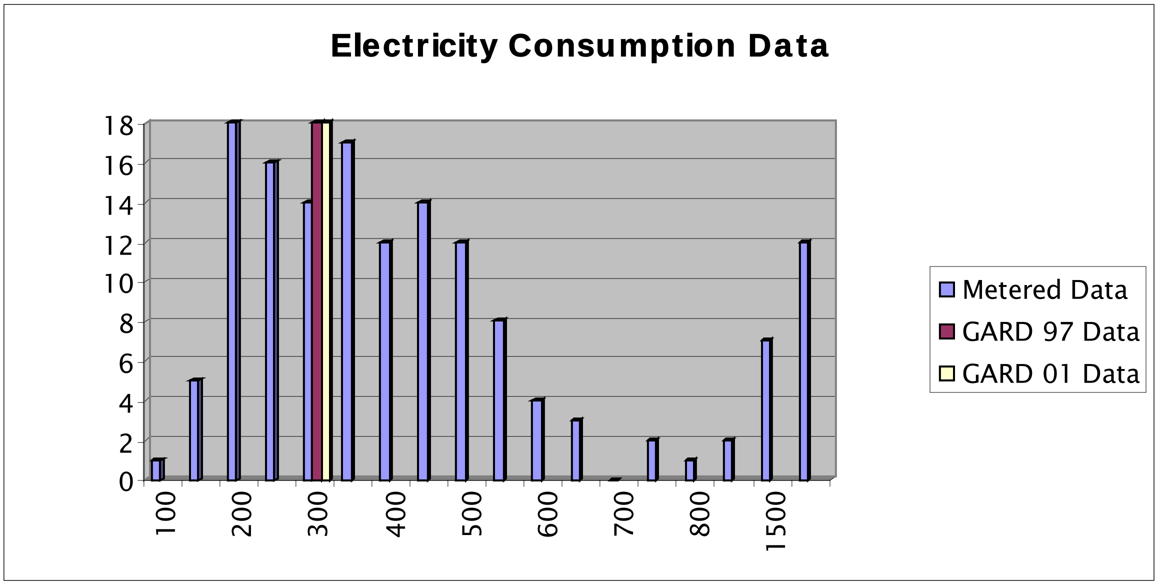


Figure A.9. Cincinnati, OH, 1 bedroom flat, gas heating, cooking & DHW.

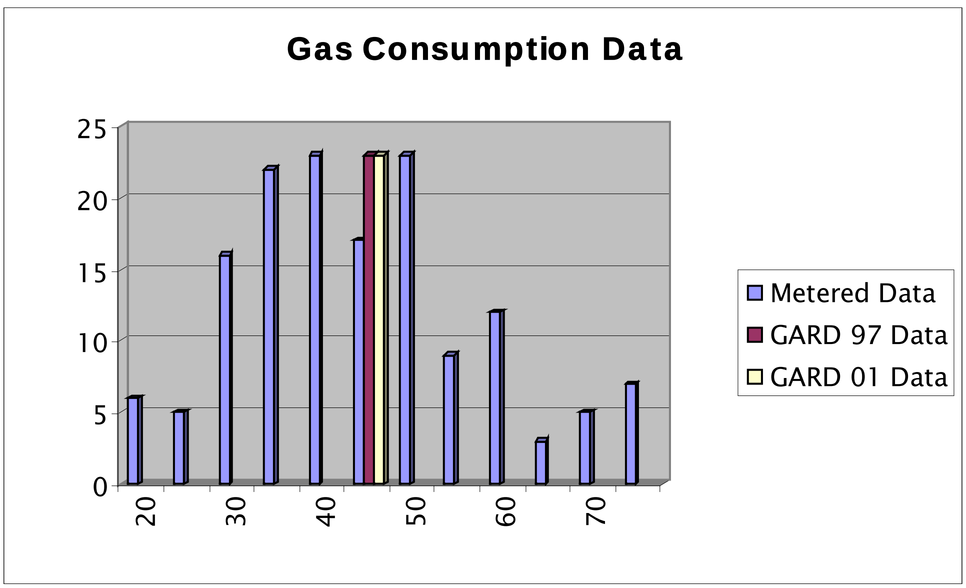


Figure A.10. Cincinnati, OH, 1 bedroom flat, gas heating, cooking & DHW.

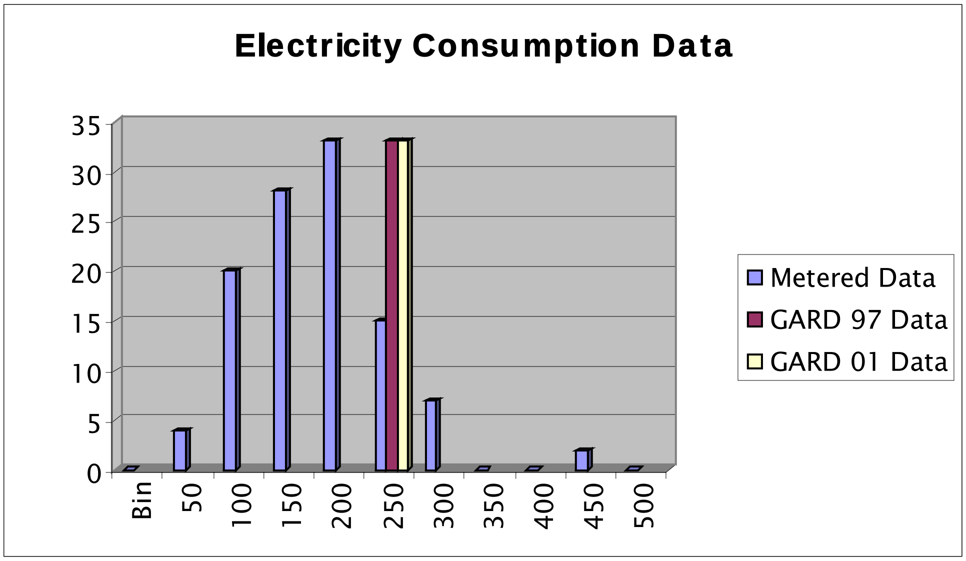


Figure A.11. St. Paul, MN, 1 bedroom townhouse, gas heating, cooking & DHW.

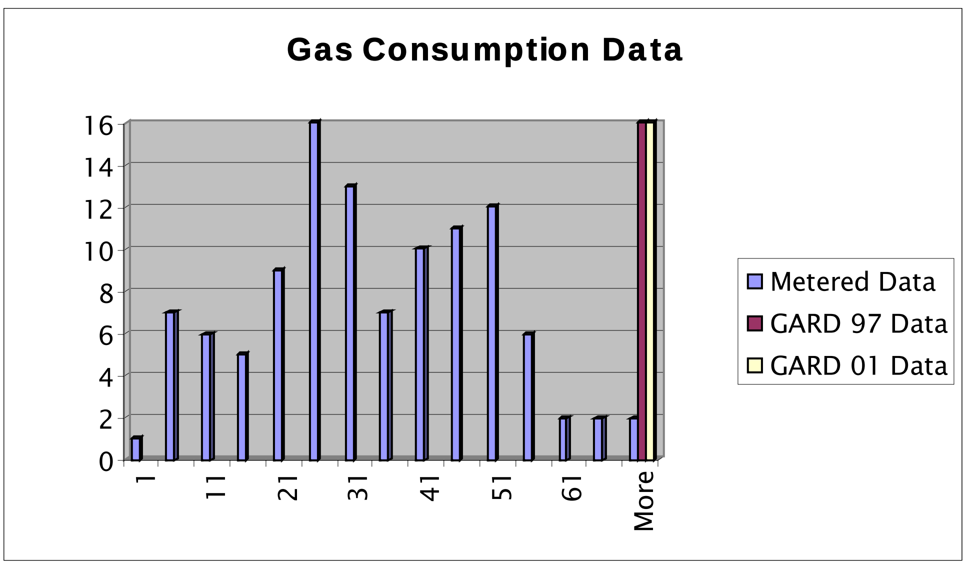


Figure A.12. St. Paul, MN, 1 bedroom townhouse, gas heating, cooking & DHW.

9.2.3 Two Bedroom Dwelling Units

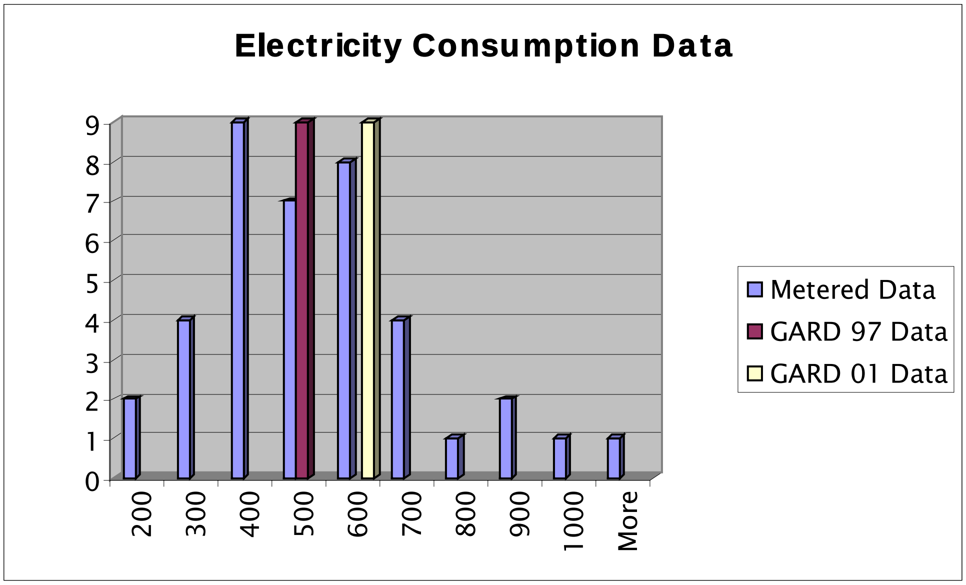


Figure A.13. Cincinnati, OH, 2 bedroom townhouse, gas heating, cooking & DHW.

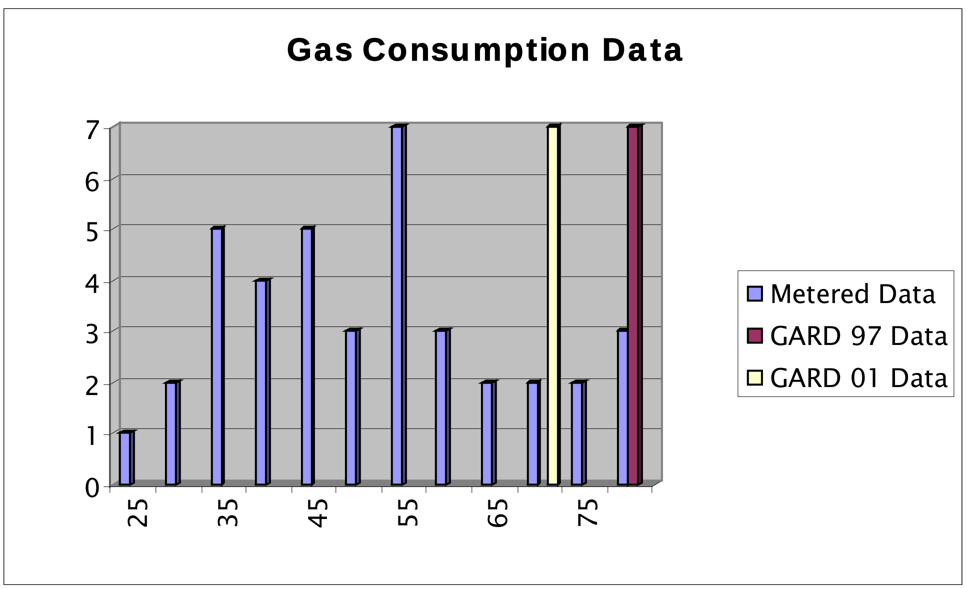


Figure A.14. Cincinnati, OH, 2 bedroom townhouse, gas heating, cooking & DHW.

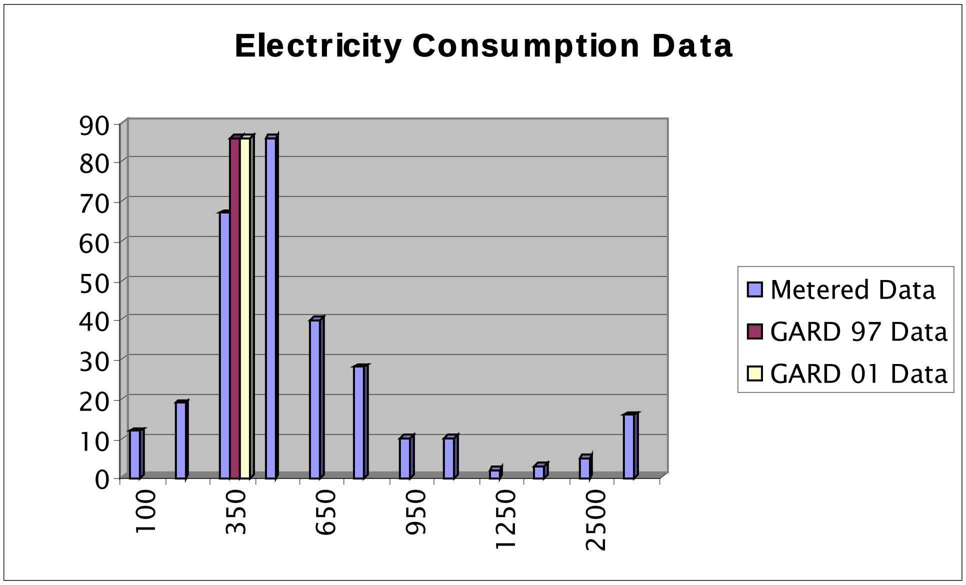


Figure A.15. Cincinnati, OH, 2 bedroom flat, gas heating, cooking & DHW.

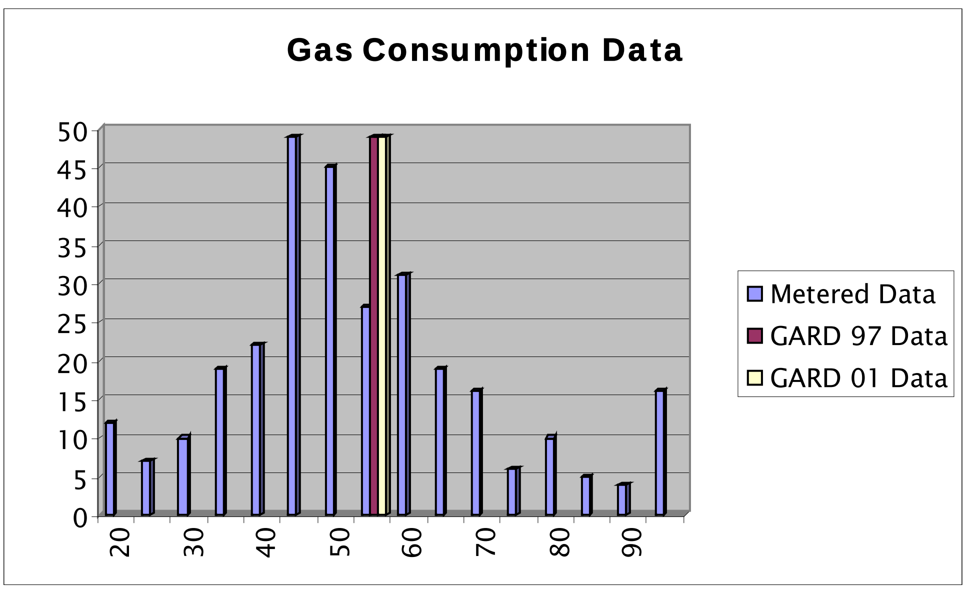


Figure A.16. Cincinnati, OH, 2 bedroom flat, gas heating, cooking & DHW.

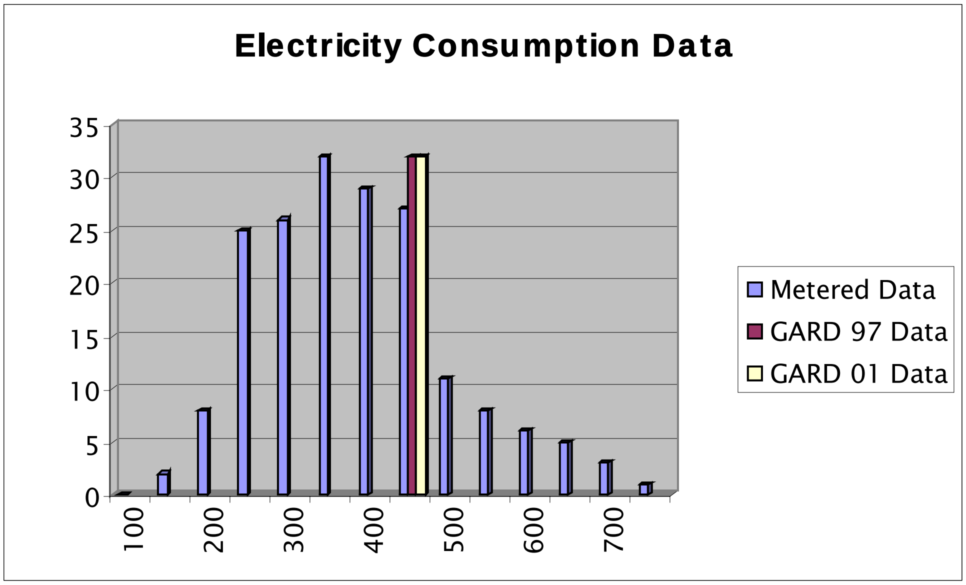


Figure A.17. Wilson, NC, 2 bedroom duplex, gas heating, cooking & DHW.

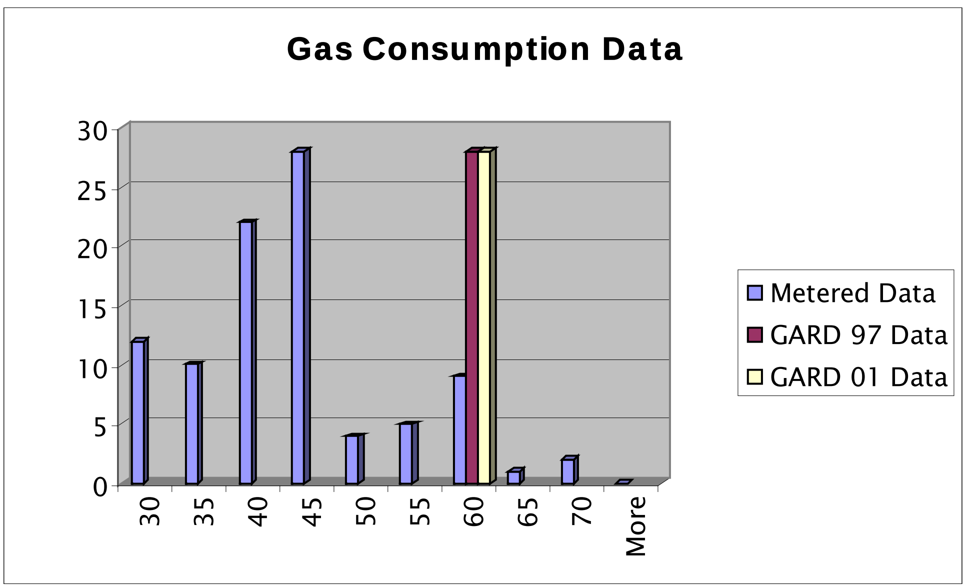


Figure A.18. Wilson, NC, 2 bedroom duplex, gas heating, cooking & DHW.

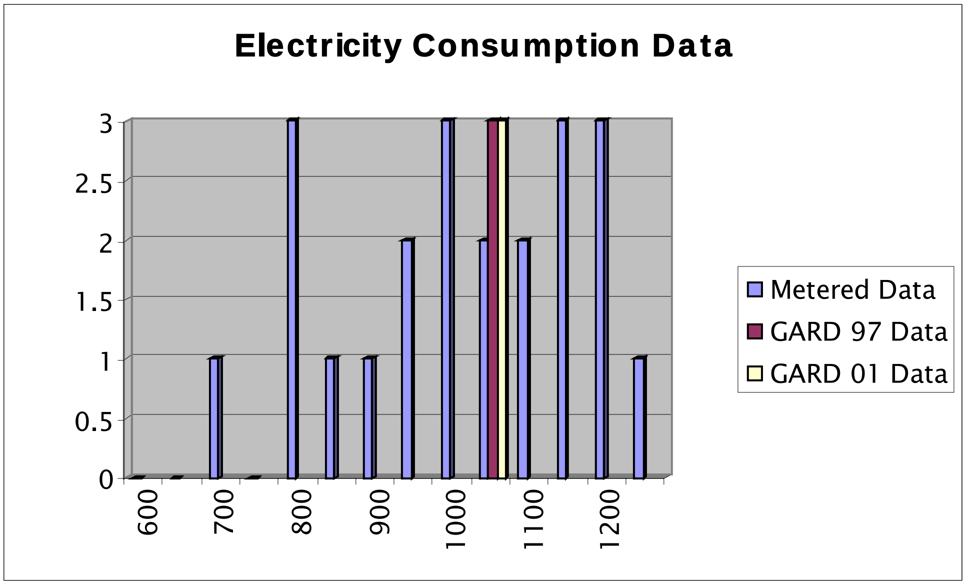


Figure A.19. Wilson, NC, 2 bedroom townhouse, all-electric units.

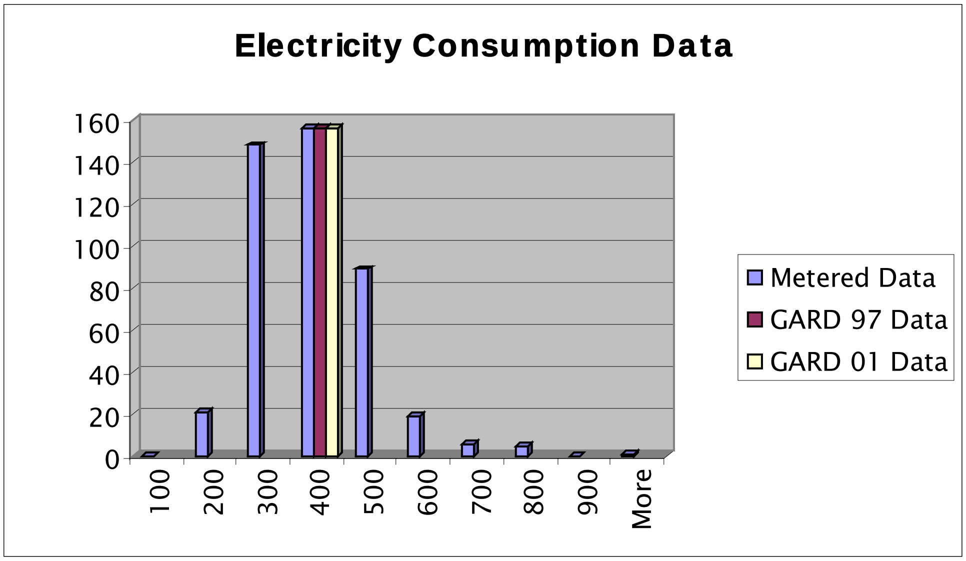


Figure A.20. St. Paul, MN, 2 bedroom townhouse, gas heating, cooking & DHW.

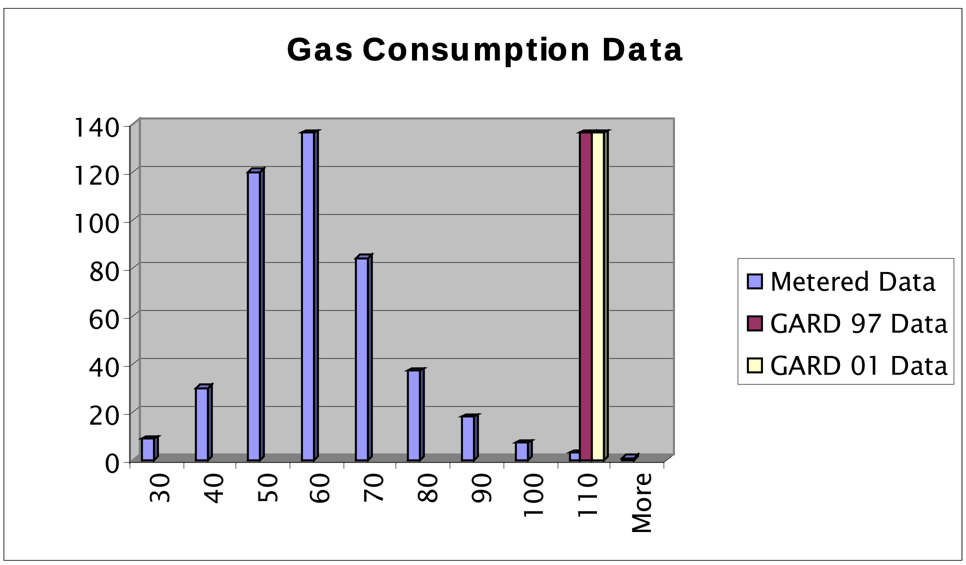


Figure A.21. St. Paul, MN, 2 bedroom townhouse, gas heating, cooking & DHW.

9.2.4 Three Bedroom Dwelling Units

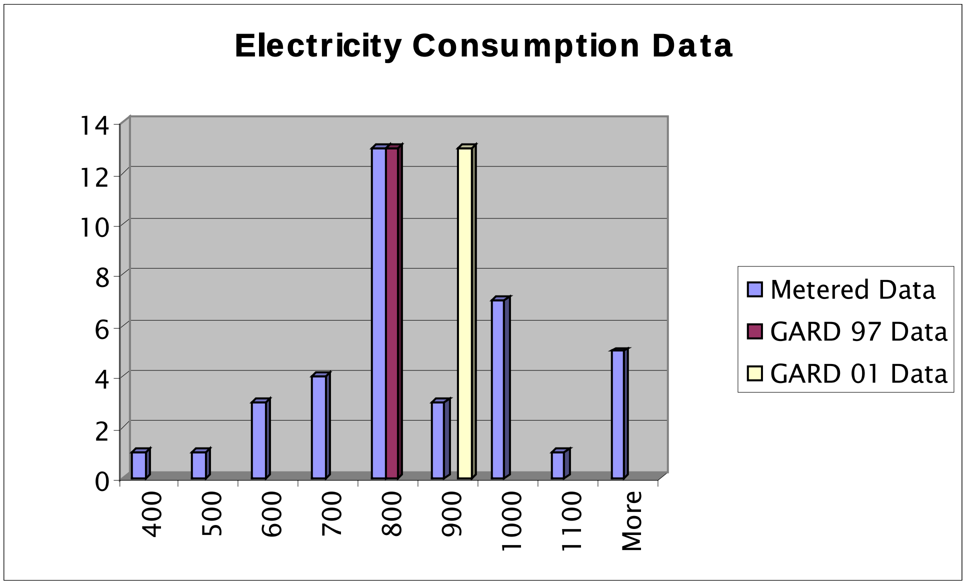


Figure A.22. Cincinnati, OH, 3 bedroom detached, gas heating, electric cooking, gas DHW.

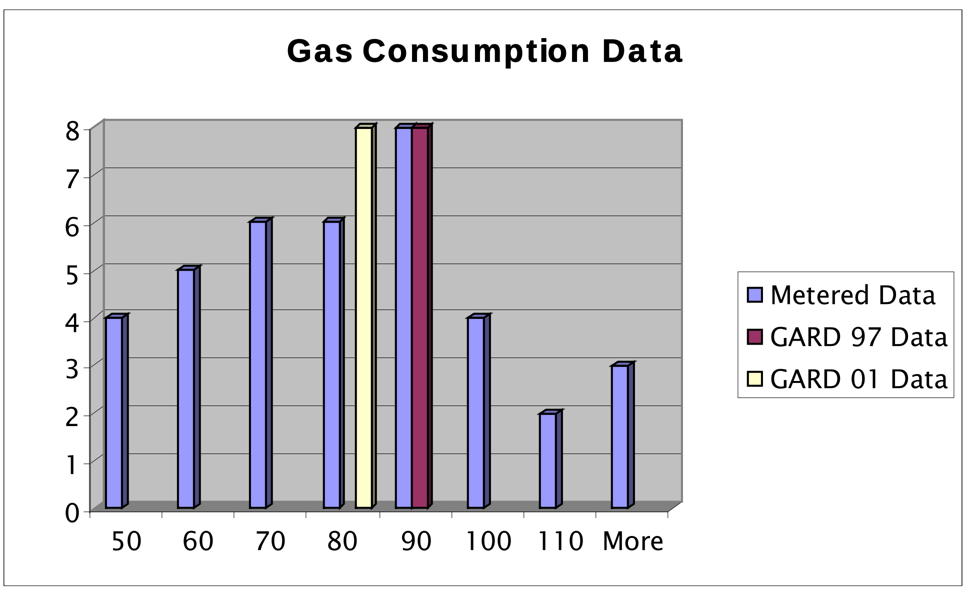


Figure A.23. Cincinnati, OH, 3 bedroom detached, gas heating, electric cooking, gas DHW.

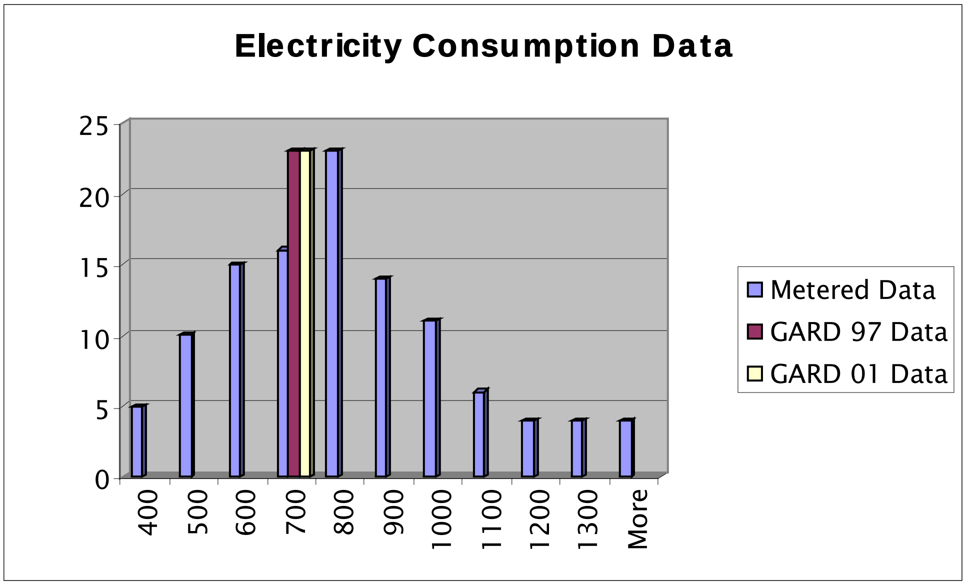


Figure A.24. Cincinnati, OH, 3 bedroom detached, gas heating, cooking & DHW.

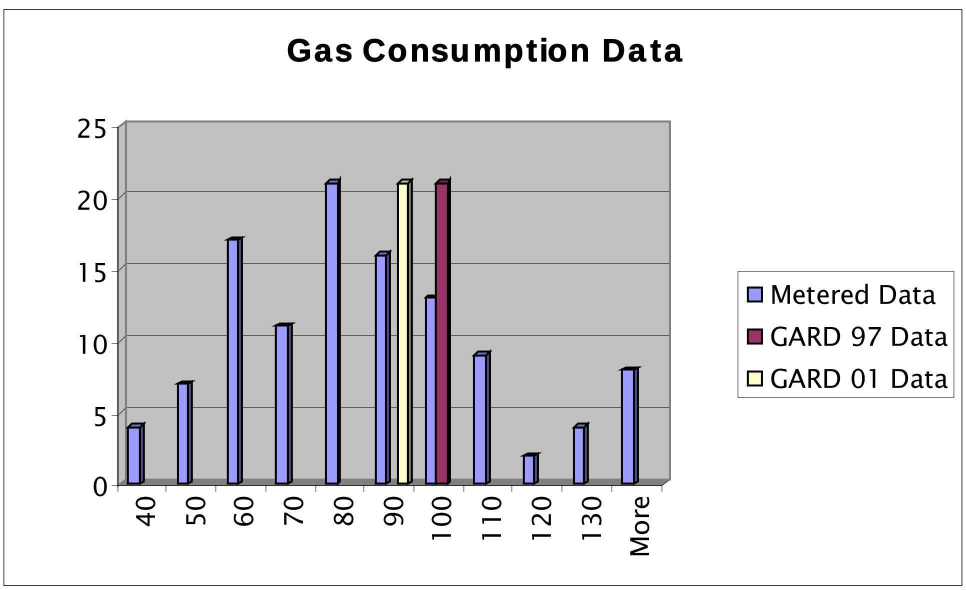


Figure A.25. Cincinnati, OH, 3 bedroom detached, gas heating, cooking & DHW.

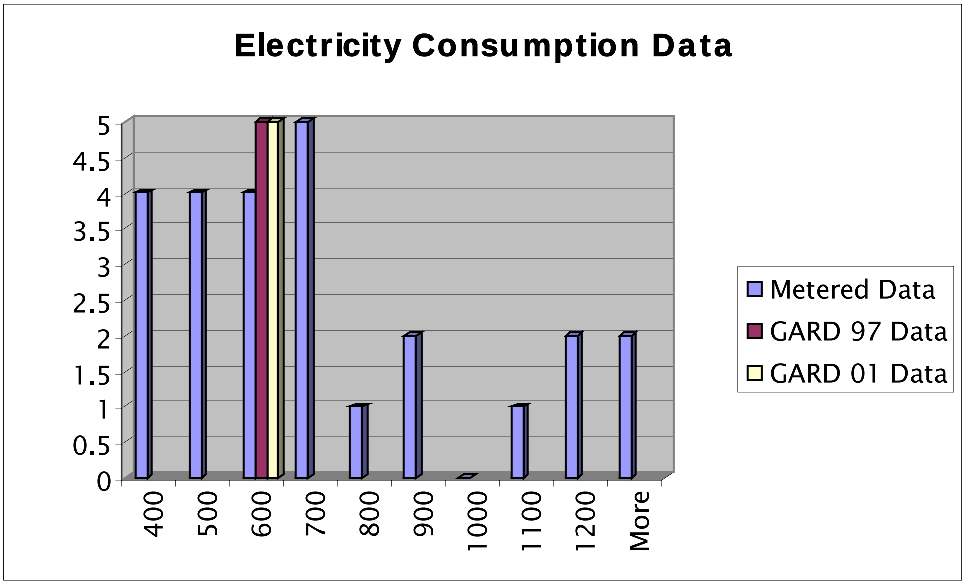


Figure A.26. Cincinnati, OH, 3 bedroom flat, gas heating, electric cooking, gas DHW.

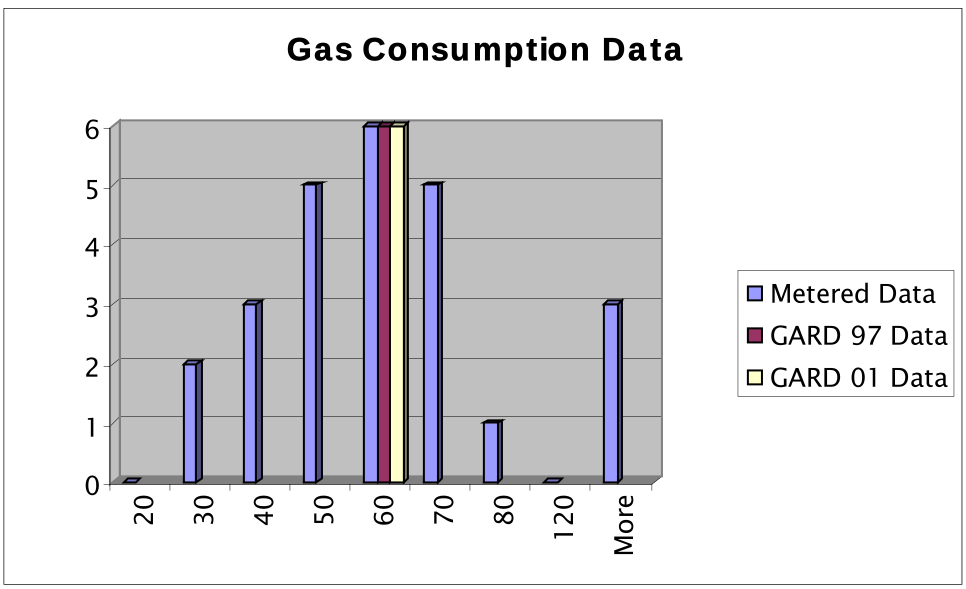


Figure A.27. Cincinnati, OH, 3 bedroom flat, gas heating, electric cooking, gas DHW.

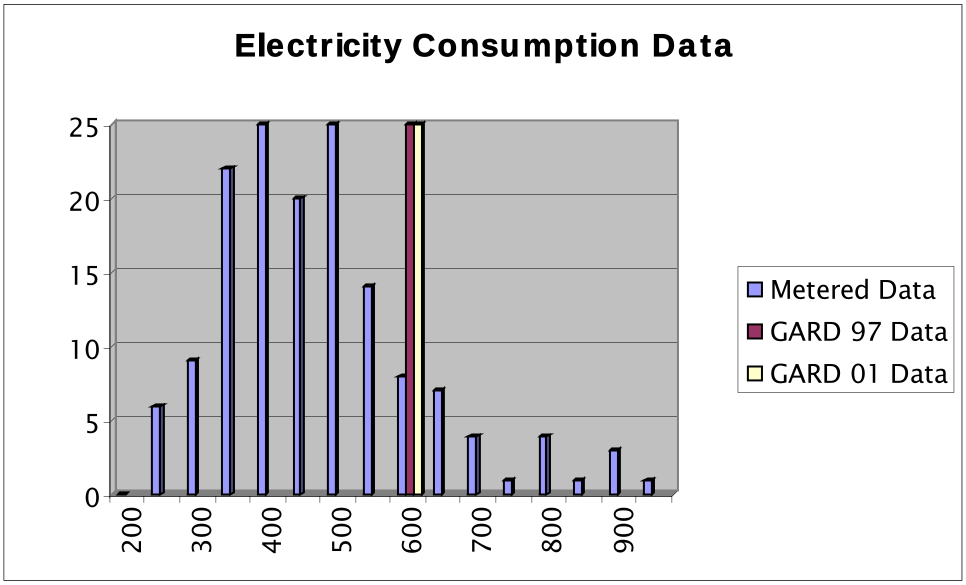


Figure A.28. Wilson, NC, 3 bedroom duplex, gas heating, cooking & DHW.

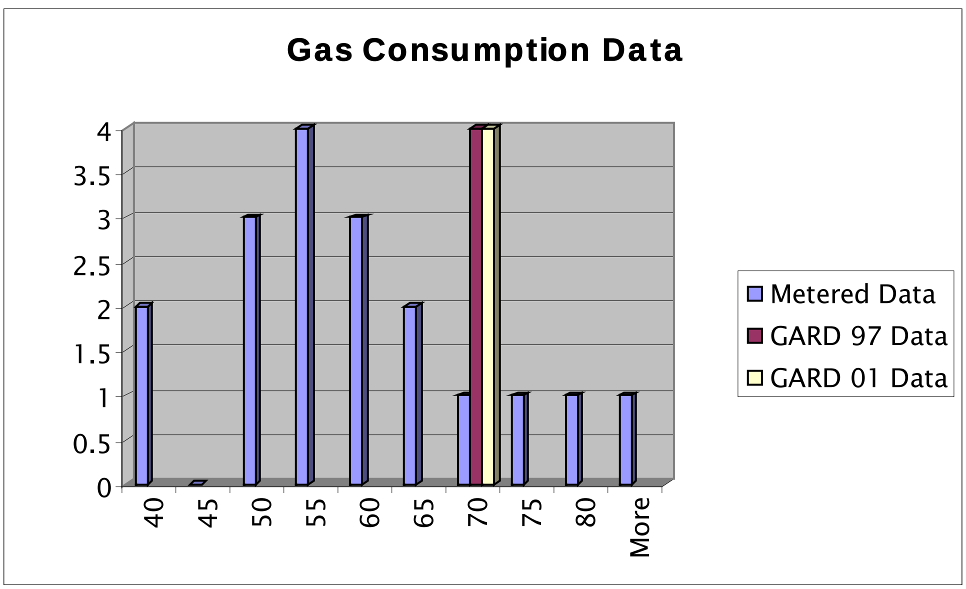


Figure A.29. Wilson, NC, 3 bedroom duplex, gas heating, cooking & DHW.

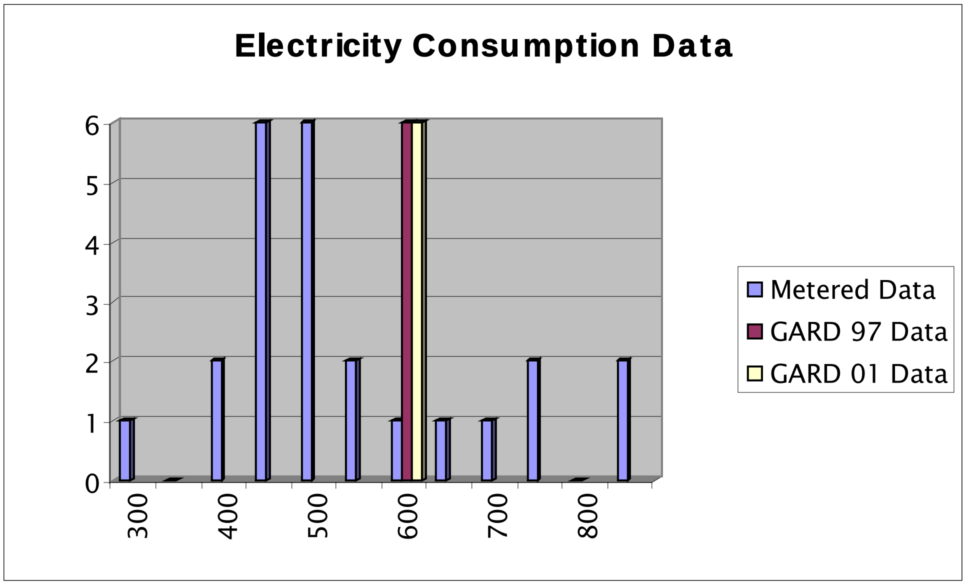


Figure A.30. Wilson, NC, 3 bedroom townhouse, gas heating, cooking & DHW.

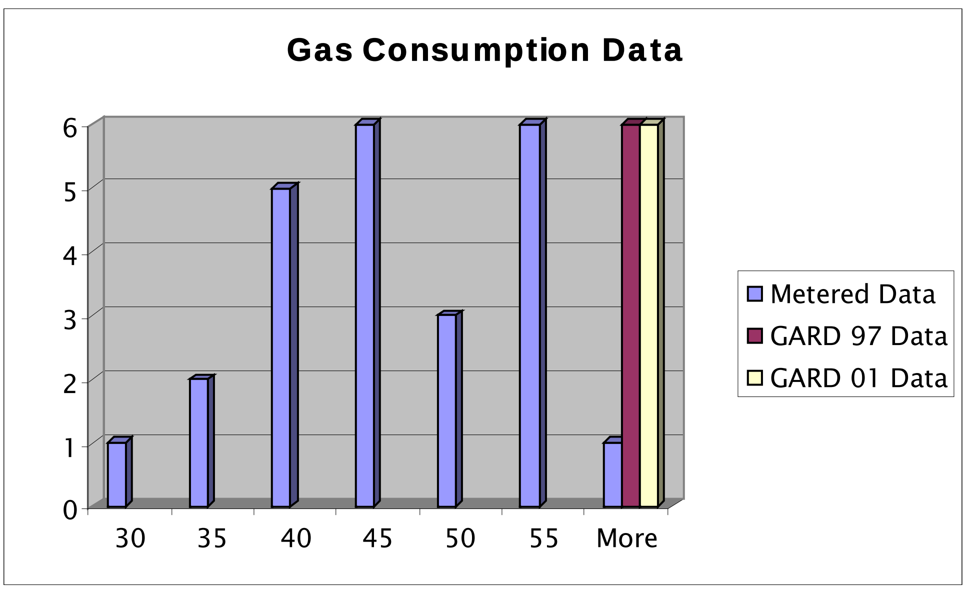


Figure A.31. Wilson, NC, 3 bedroom townhouse, gas heating, cooking & DHW.

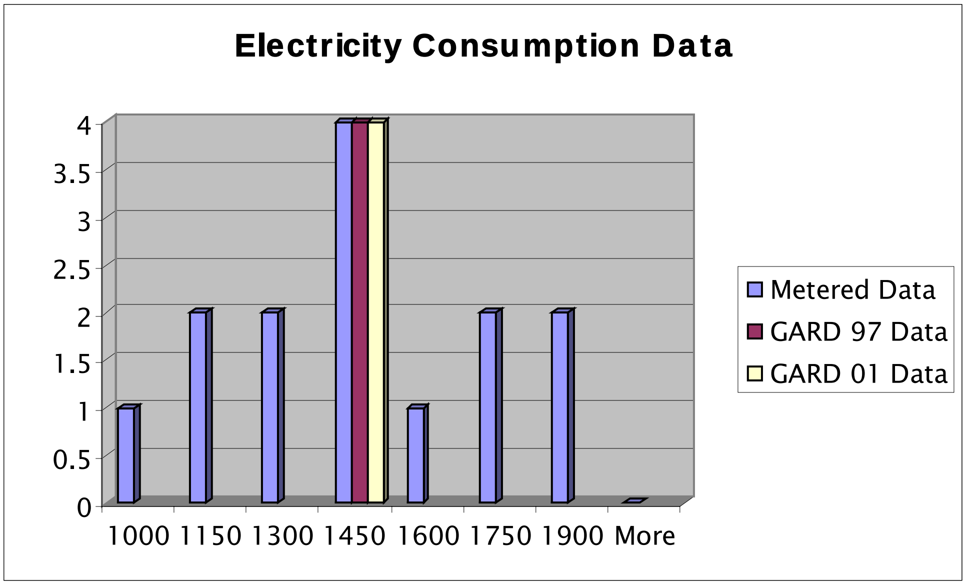


Figure A.31. Wilson, NC, 3 bedroom townhouse, all-electric units.

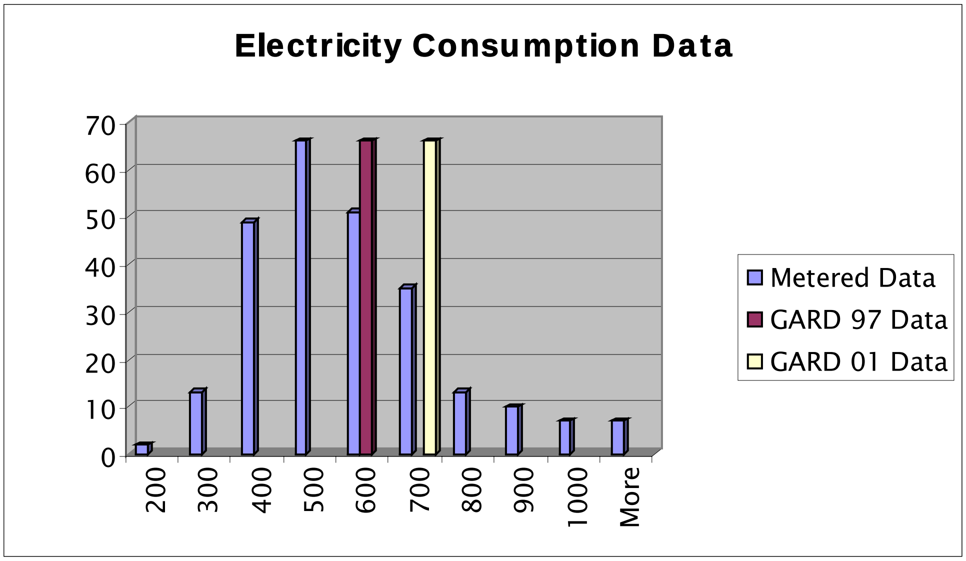


Figure A.32. St. Paul, MN, 3 bedroom detached, gas heating, cooking & DHW.

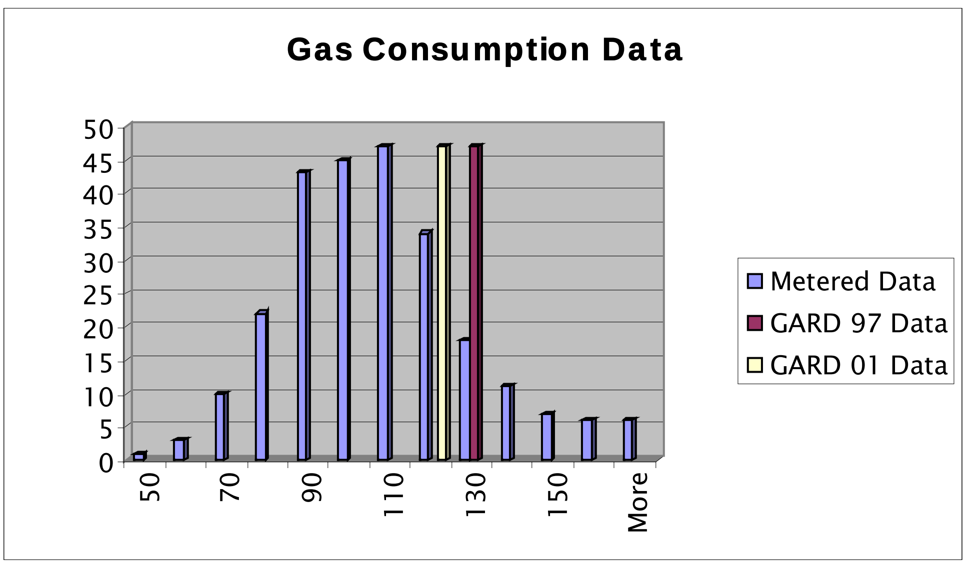


Figure A.33. St. Paul, MN, 3 bedroom detached, gas heating, cooking & DHW.

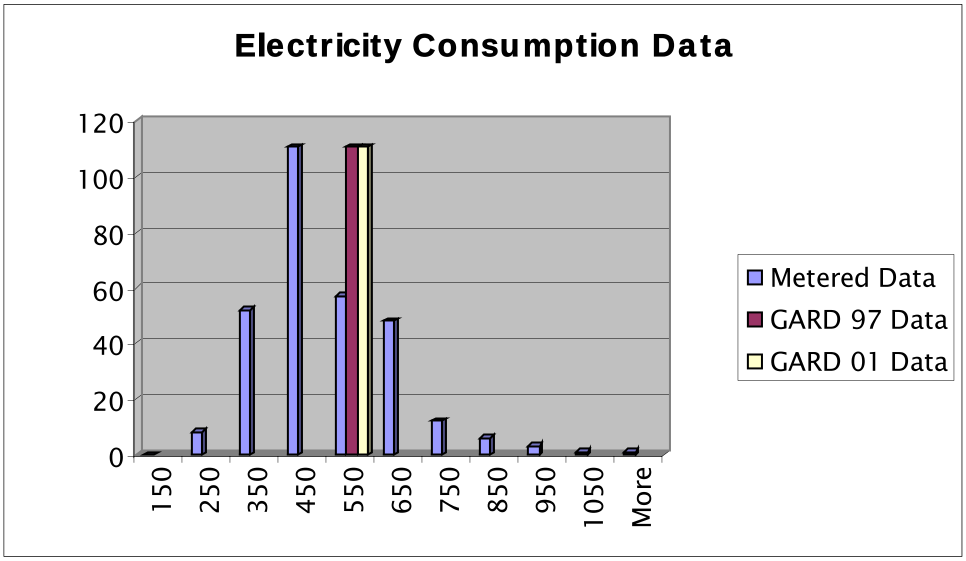


Figure A.34. St. Paul, MN, 3 bedroom townhouse, gas heating, cooking & DHW.

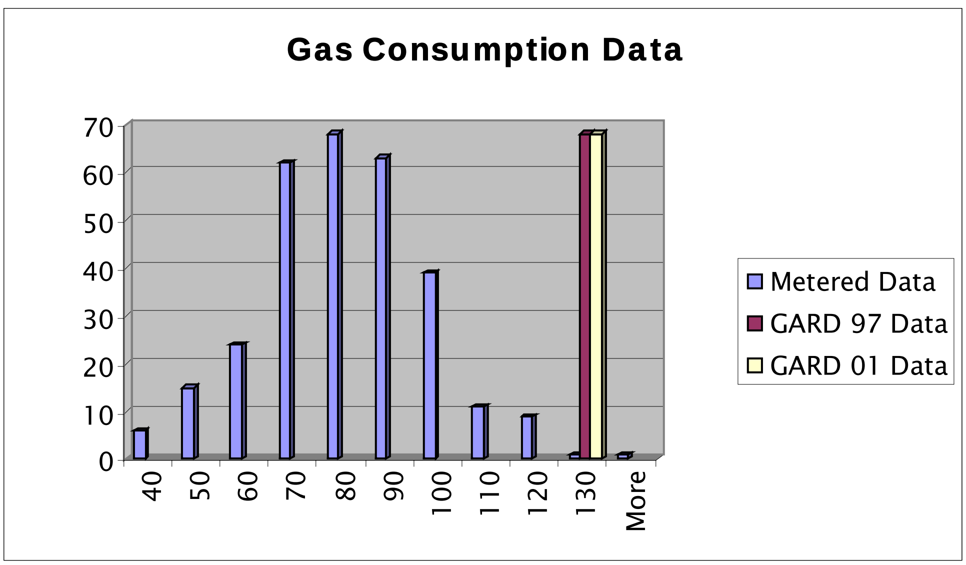


Figure A.35. St. Paul, MN, 3 bedroom townhouse, gas heating, cooking & DHW.

9.2.5 Four Bedroom Dwelling Units

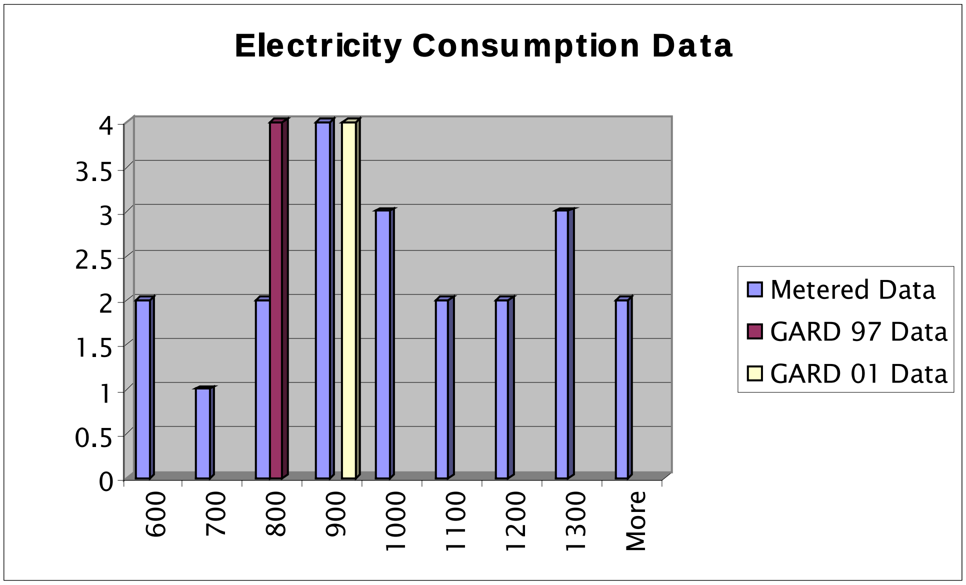


Figure A.36. Cincinnati, OH, 4 bedroom detached, gas heating, cooking & DHW.

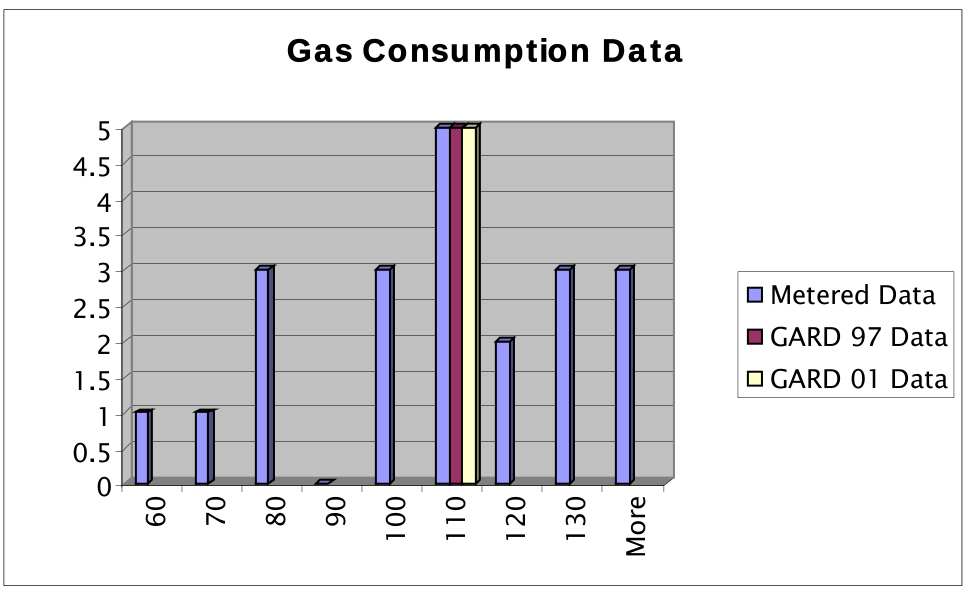


Figure A.37. Cincinnati, OH, 4 bedroom detached, gas heating, cooking & DHW.

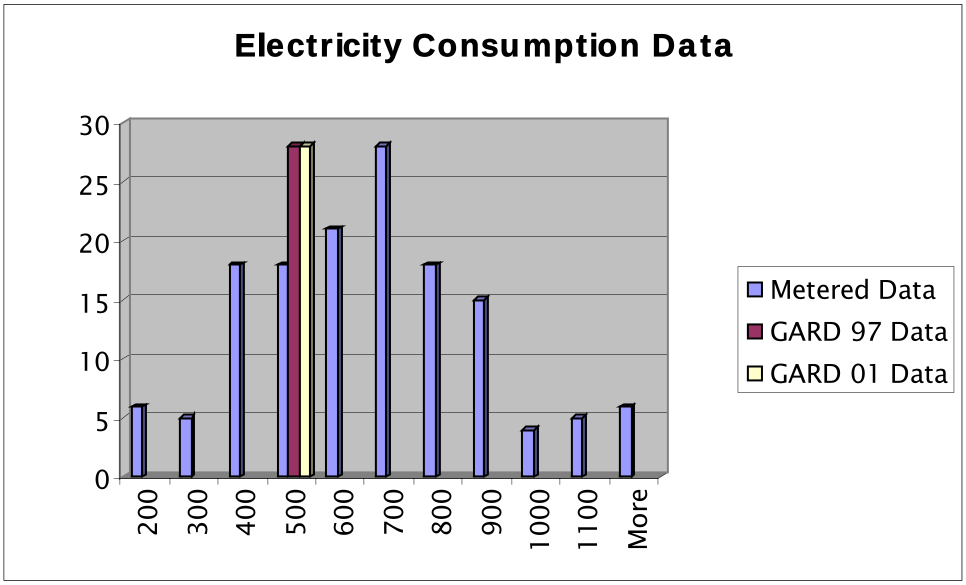


Figure A.38. Cincinnati, OH, 4 bedroom flat, gas heating, cooking & DHW.

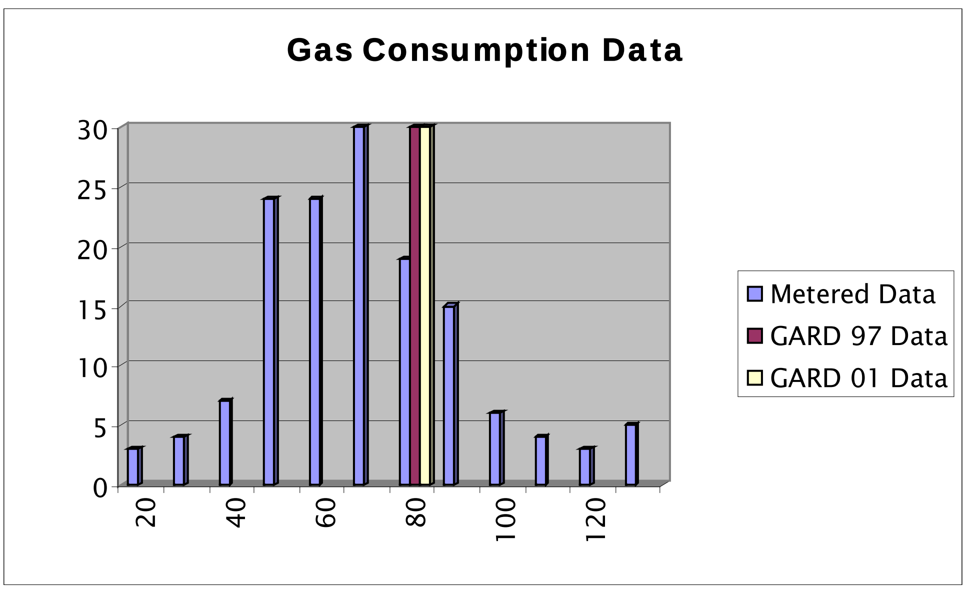


Figure A.39. Cincinnati, OH, 4 bedroom flat, gas heating, cooking & DHW.

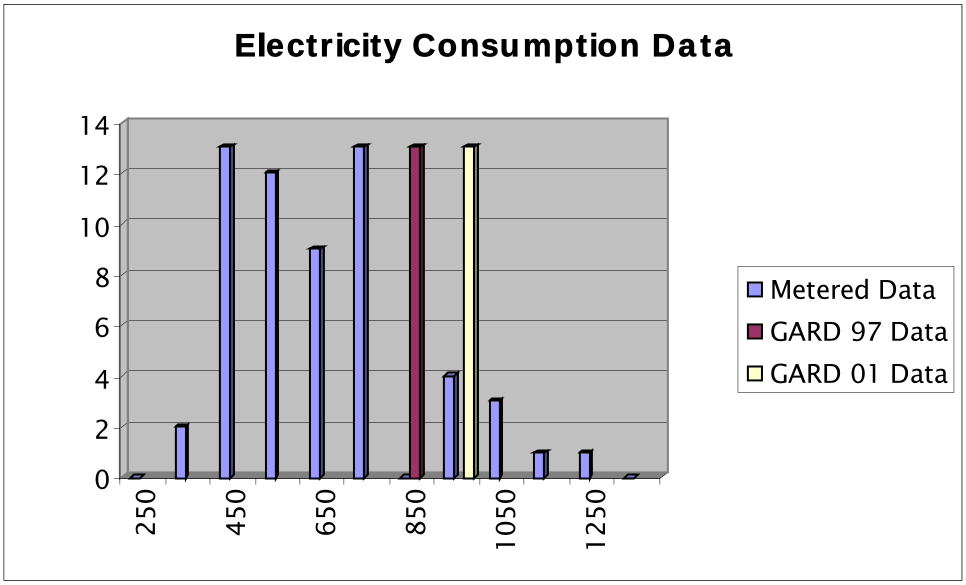


Figure A.40. Wilson, NC, 4 bedroom detached, gas heating, cooking & DHW.

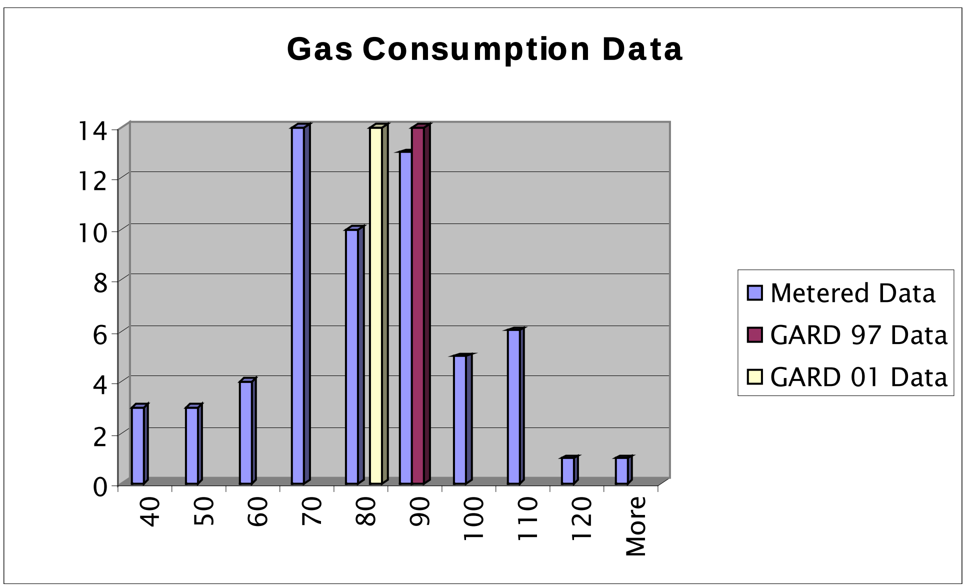


Figure A.41. Wilson, NC, 4 bedroom detached, gas heating, cooking & DHW.

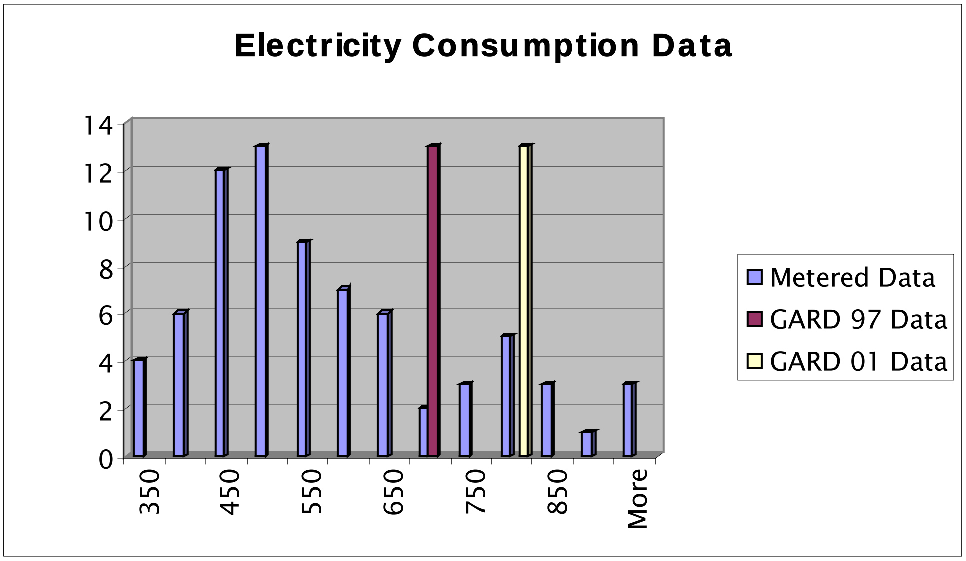


Figure A.42. St. Paul, MN, 4 bedroom detached, gas heating, cooking & DHW.

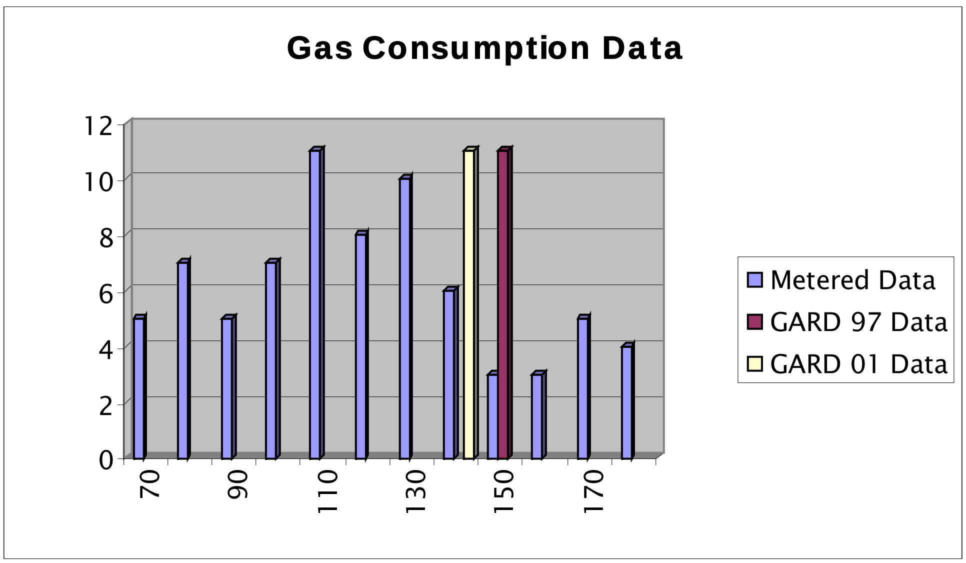


Figure A.43. St. Paul, MN, 4 bedroom detached, gas heating, cooking & DHW.

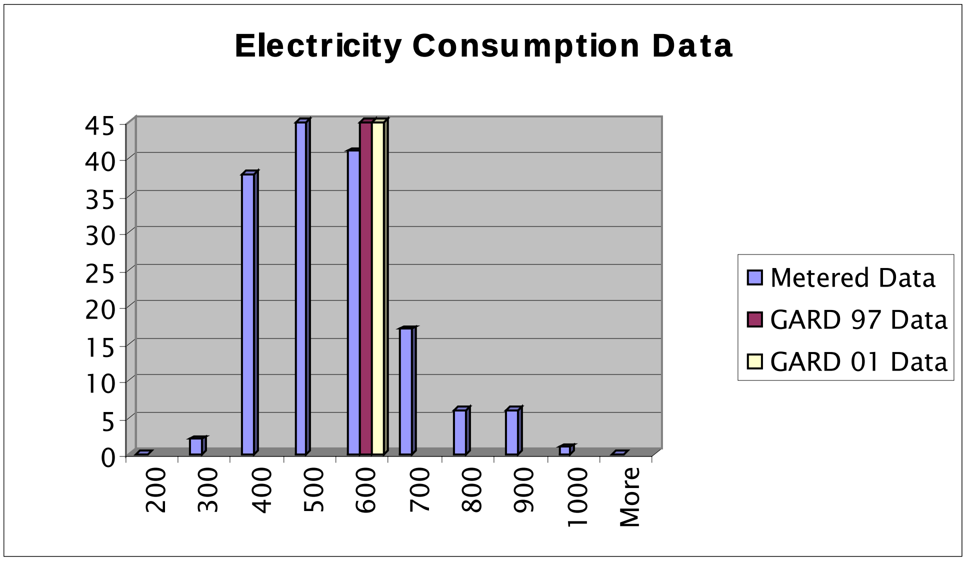


Figure A.44. St. Paul, MN, 4 bedroom townhouse, gas heating, cooking & DHW.

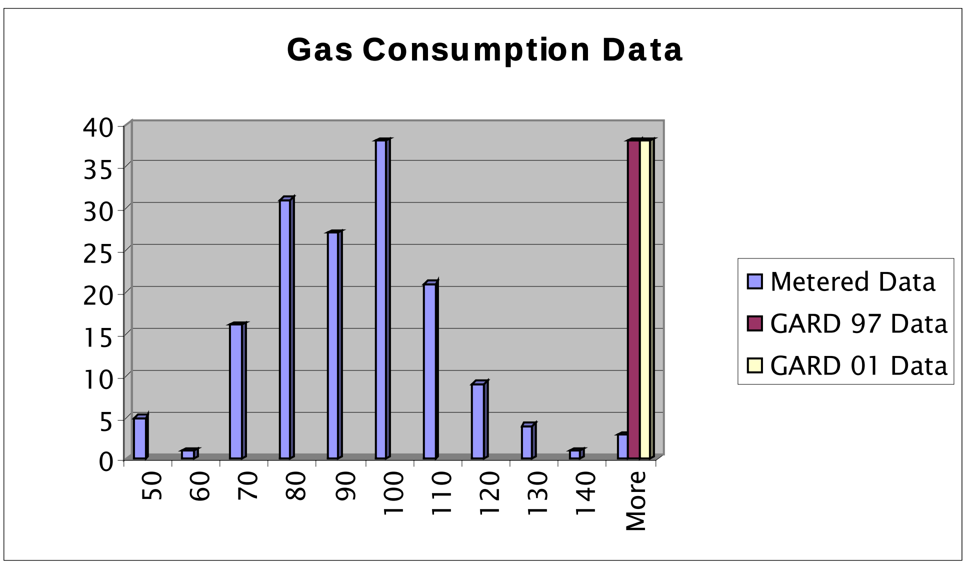


Figure A.45. St. Paul, MN, 4 bedroom townhouse, gas heating, cooking & DHW.

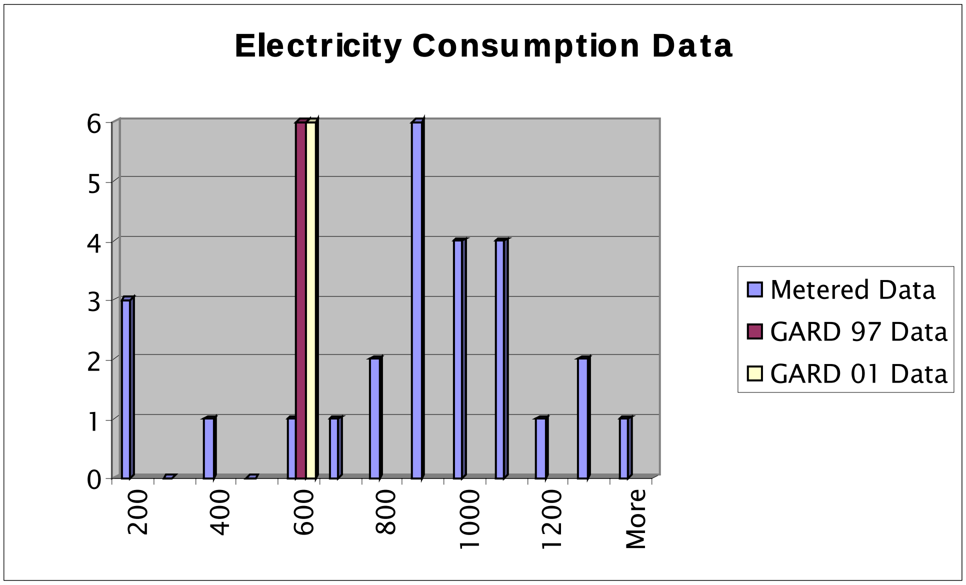


Figure A.46. Cincinnati, MN, 5 bedroom flat, gas heating, cooking & DHW.

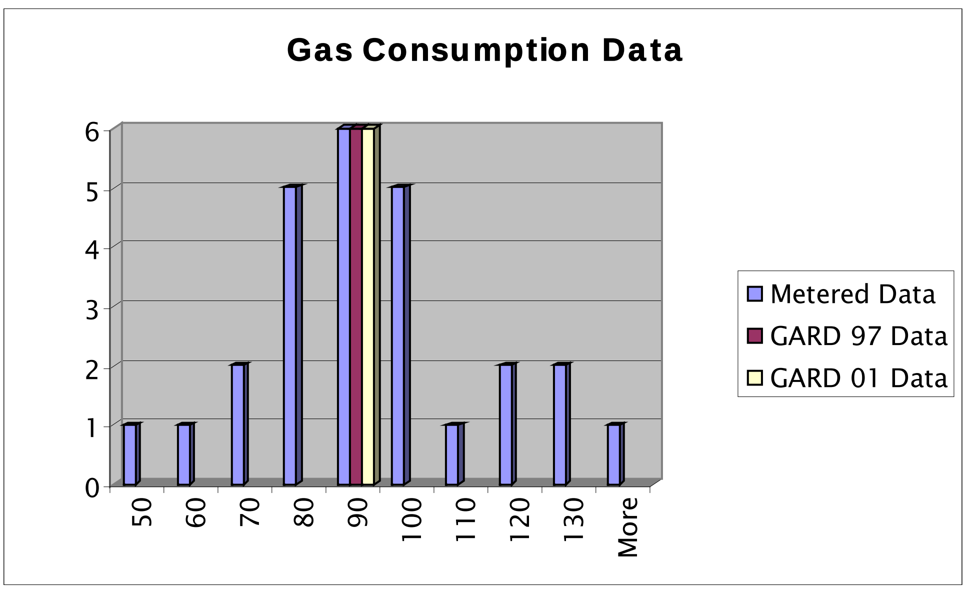


Figure A.47. Cincinnati, MN, 5 bedroom flat, gas heating, cooking & DHW.

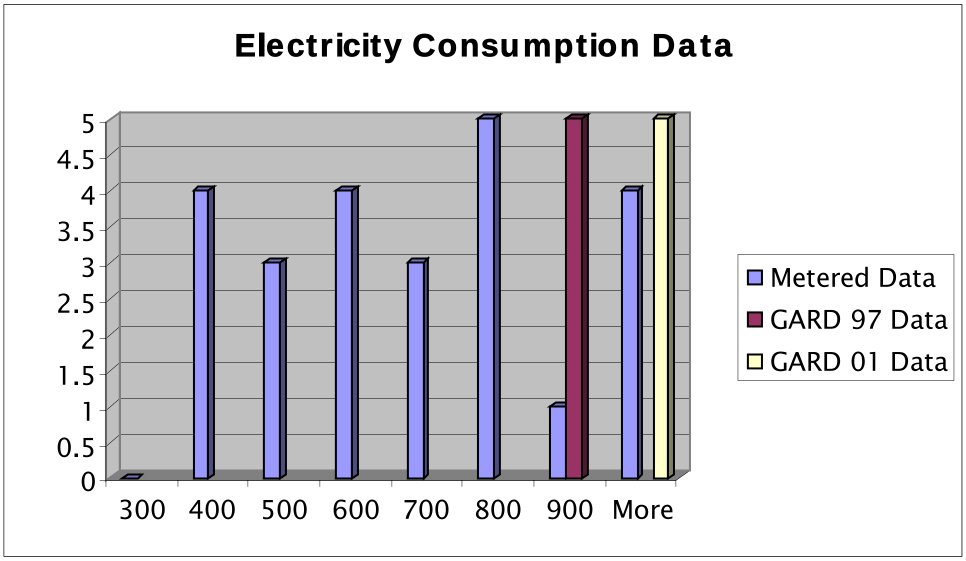


Figure A.48. St. Paul, MN, 5 bedroom detached, gas heating, cooking & DHW.

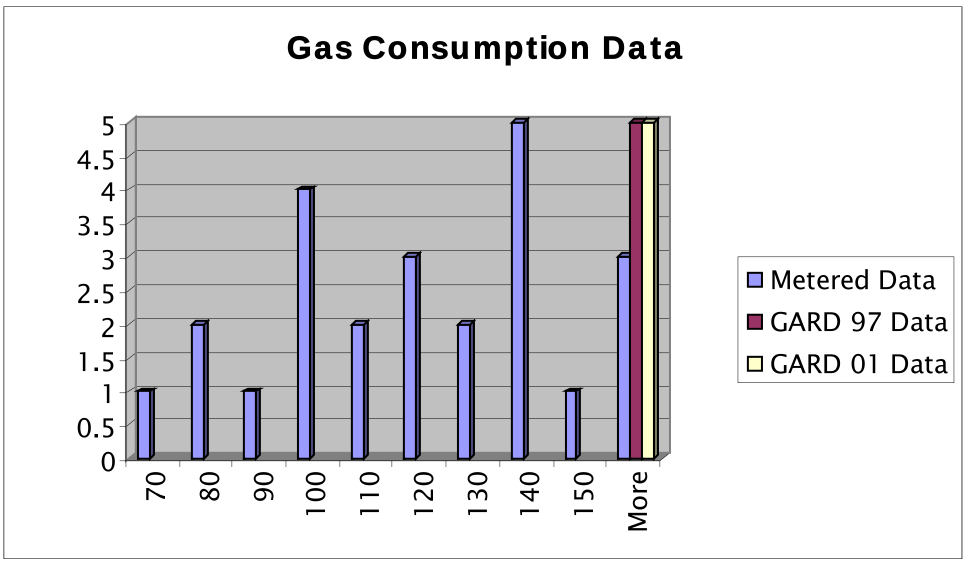


Figure A.49. St. Paul, MN, 5 bedroom detached, gas heating, cooking & DHW.

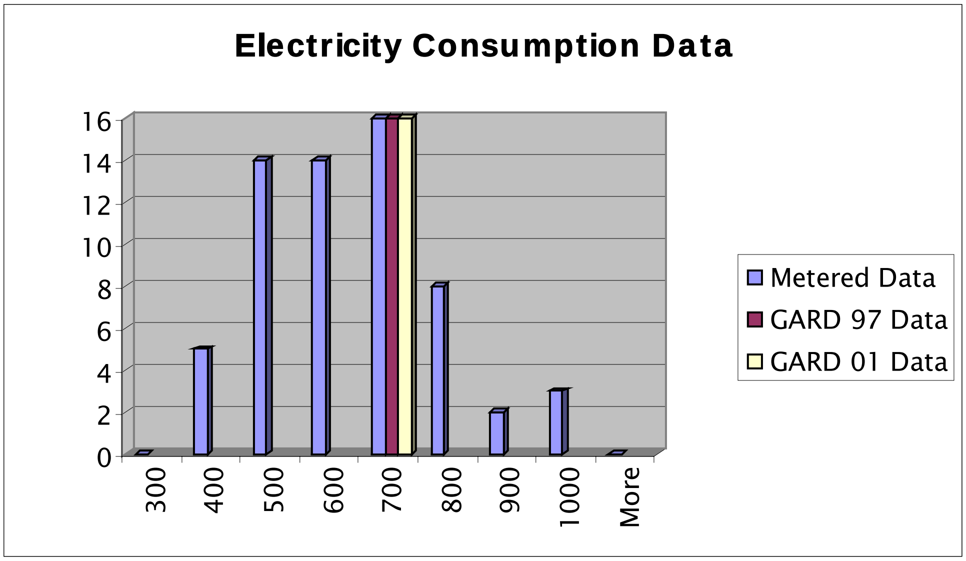


Figure A.50. St. Paul, MN, 5 bedroom townhouse, gas heating, cooking & DHW.

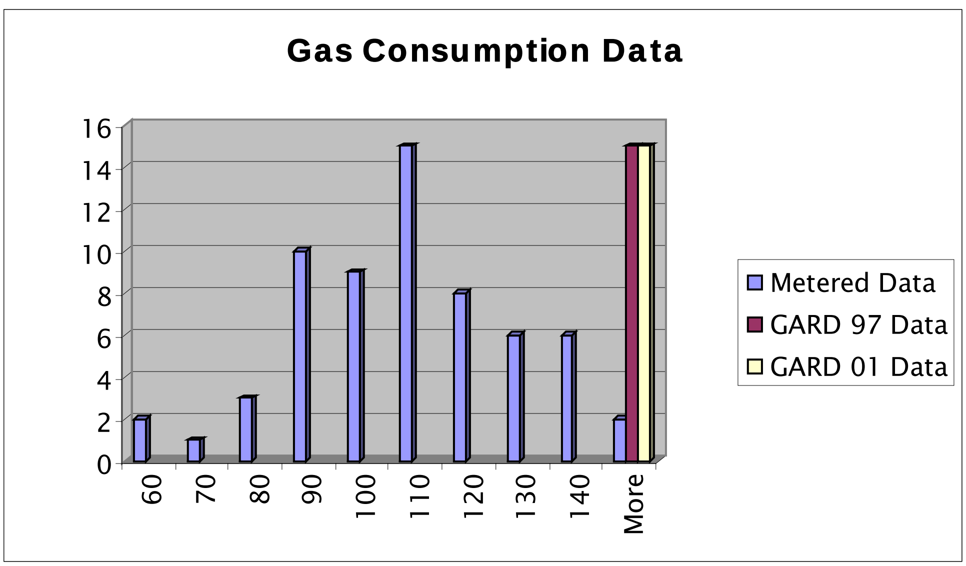


Figure A.51. St. Paul, MN, 5 bedroom townhouse, gas heating, cooking & DHW.