

How Much Energy Homes Use, and Why  
Paul Emrath, Ph.D. and Joshua Miller, Ph.D.  
Special Study for Housing Economics  
National Association of Home Builders

Technical Appendix:  
Statistical Model Used to Estimate non-HVAC Electricity Use

The statistical model employed by NAHB to estimate non-HVAC electricity use is based primarily on energy consumption and housing and household characteristics in the single-family detached housing units contained in the Public Use Microdata File from the 2009 Residential Energy Consumption Survey (RECS), produced by the U.S. Energy Information Administration (EIA).

The RECS data records includes household income in ranges and identifies the metropolitan status (Metropolitan Statistical Area, Micropolitan Statistical Area, or neither) and "Reportable Domain" of the area in which the home is located. Reportable Domain is a list of 21 individual states or group of states.

Some information is appended to this data set from the U.S. Census Bureau's 2009 American Community Survey (ACS). From the ACS microdata files, average income is computed for households in each RECS income ranges for each area (where an area is Reportable Domain crossed with metropolitan status, except that the "Micropolitan" and "neither" RECS categories cannot be distinguished and must be combined). These averages are merged with the RECS data and used to generate point estimates of income for each household in the data set.

Information on total households, aggregate household income, number of owner-occupied homes, and aggregate value of the homes is available at a detailed level of geography from the ACS summary files. The aggregates and counts were used to compute an average home value and average income for each Reportable Domain-metropolitan status cross (all three metropolitan status categories for each state are available from the summary files) and the results merged with the RECS data.

Because square footage is often implicitly or explicitly assumed to be largely responsible for residential energy consumption (for example, in the EIA document cited the body of this article) and this can lead to policies such as attempts by local jurisdictions to restrict or penalize the amount of living area in new homes, it is important to model the effect of square footage carefully.

Square footage is, in fact, positively correlated with non-HVAC electricity consumption. NAHB investigated whether this correlation is the result of the exogenous impact of square footage vs. a hypothesis that electricity use

square footage is jointly determined by other factors.

The method used is two-stage least squares (2SLS), using results from a first stage regression of square footage on explanatory variables to estimate electricity consumption in the second stage of the model. The first stage of the 2SLS model is shown in Table A-1.

The table also shows the results of a test for the endogeneity of square footage. The form of the test is a conventional t-test on the coefficient of the predicted value of square footage when added to the full model for non-HVAC energy consumption. The null hypothesis that square footage as an exogenous effect on energy consumption can be rejected at the .1 level, but not quite at the .05 level of significance.

To work well, 2SLS requires valid instrumental variables (IVs) for square footage that do not appear directly in the electricity consumption equation. A standard requirement is that IVs be strongly related to the dependent variable in the first stage equation, in this case total square footage; otherwise, the instruments are said to be "weak." A Wald test for the joint significance of regression coefficients rejects the null hypothesis of weak instruments at a .01 significance level. This result is also shown in Table A-1.

Having established that it is reasonable to treat square footage and non-HVAC energy use as jointly dependent variables, and that we have a reasonable choice of IVs for the first stage of the model, the second stage is estimated and shown in Appendix Table A-2.

Estimating this model with a procedure such as Ordinary Least Squares rather than 2SLS would lead to a biased estimate for the coefficient on square footage in the energy consumption equation. Because square footage is endogenous in the model, the interpretation of the coefficient in A-2 is the change in non-HVAC electricity use that would result if the factors shown in A-1 changed by enough to increase the size of the home by 1,000 square feet.

The SAS software was used to extract and merge the data from RECS and the ACS. The 2SLS estimation was carried out in LIMDEP.

The LIMDEP output was pasted into Excel where it was used to generate the simulations illustrated in Figures 4, 5, 6 and 7. Table A-3 shows the Excel worksheet version of these simulations.

**Table A-1. 1st Stage of 2SLS Regression**

**Dependent Variable=Size of Single-family Deattached Home (in 1,000 square feet)**

Variable	Coefficient	Std Err	p-value	Mean of var
Constant	-0.617**	0.1255	.0000	
Owner-occupied	0.698**	0.0465	.0000	0.876
Home built after 1979	0.622**	0.0317	.0000	0.417
Located in an urban area	-0.290**	0.0374	.0000	0.742
Average area <sup>†</sup> income (in \$1,000)	0.055**	0.0025	.0000	68.801
Average area <sup>†</sup> value of owner-occupied homes (in \$1,000)	-0.004**	0.0003	.0000	265.408
Located in New York State	0.458**	0.0741	.0000	0.047
Located in Indiana or Ohio	0.418**	0.0845	.0000	0.036
Located in Wisconsin	0.719**	0.1036	.0000	0.022
Located in Missouri	0.369**	0.0633	.0000	0.067
Located in Arkansas, Louisiana or Oklahoma	-0.588**	0.1106	.0000	0.020
Located in Texas	-0.757**	0.0609	.0000	0.085
adjusted R <sup>2</sup>	0.164			
Number of observations	7,796			
<i>Related statistical tests:</i>				
Test for endogeneity of square footage	-0.839*	0.461	.0686	
X <sup>2</sup> weak instrument test (11 d.f.)	738.530**		.0000	

\* significant at the .1 level; \*\* significant at the .01 level

<sup>†</sup> Area is state (or group of states) crossed with metro status (in a metropolitan statistical area, in a micropolitan statistical area, or neither).

The endogeneity test is a test on the coefficient of the predicted value of square footage when added to the full model for non-HVAC electricity consumption (see 2nd stage results for specification).

The weak instrument test is a Wald test for the joint hypothesis that coefficients on all the instruments shown above a zero in an equation that includes all the exogenous variables in the full, two-equation model.

Source: NAHB analysis of data from the 2009 Residential Energy Consumption Survey (U.S. Energy Information Administration), merged with data on area income and value from the 2009 American Community Survey (U.S. Census Bureau).

**Table A-2. Second Stage of 2SLS Regression**

**Dependent Variable=Non-HVAC Use of Electricity (in Million BTUs) in Single-family Detached Homes**

Variable	Coefficient	Std Err	p-value
Constant	5.26**	1.13	.0000
Price of electricity (per Million BTU)	-0.24**	0.01	.0000
<b>Jointly Dependent Variable</b>			
Size of home (1,000 sq ft)	0.09	0.44	.8455
<b>Household Characteristics:</b>			
Number of persons in household	1.99**	0.14	.0000
Persons age 15 to 19	1.33**	0.35	.0001
Hispanic household head	-2.43**	0.58	.0000
"Other" minority <sup>†</sup> household head	-2.12**	0.70	.0026
Household income relative to area average <sup>††</sup>	1.31**	0.26	.0000
<b>Electricity Using Equipment:</b>			
<b>A. Items usually installed by the builder in an electric home</b>			
Electric water heater	10.05**	0.46	.0000
Electricity used for cooking	2.75**	0.39	.0000
Number of refrigerators	4.13**	0.36	.0000
50+ gallon electric water heater	3.20**	0.56	.0000
Through-door ice on most-used refrigerator	1.22**	0.35	.0004
Number of ceiling fans	0.44**	0.08	.0000
<b>B. Items usually purchased by the home owner without builder</b>			
Clothes dryer	2.79**	0.78	.0003
Number of separate freezers	3.03**	0.36	.0000
Number of freezers over 18 cubic feet	4.98**	1.06	.0000
Number of frost-free freezers	1.84**	0.47	.0001
Dehumidifier	0.98**	0.17	.0000
Number of televisions	1.61**	0.14	.0000
Cable/satellite box connected to a TV	1.19*	0.46	.0102
Home theater system connected to a TV	0.94*	0.38	.0146
Number of desktop computers	1.26**	0.25	.0000
Separate fax machine	2.26**	0.51	.0000
Well water pump	3.99**	0.47	.0000
<b>C. Unusual Items (present in fewer than 10% of homes)</b>			
Electrically heated hot tub	6.07**	0.69	.0000
Large heated aquarium	3.53**	0.79	.0000
Auto engine heater	3.86**	1.39	.0056
Electrically heated swimming pool	22.35**	1.87	.0000
<b>Details of usage:</b>			
Have a home-based business	2.02**	0.54	.0002
Dishwasher used daily	3.56**	0.50	.0000
5 to 9 loads of laundry washed per week	1.95**	0.38	.0000
10+ loads of laundry washed per week	2.88**	0.57	.0000
Number of TVs used 10+ hours on week days <sup>†††</sup>	1.04*	0.55	.0585
Number of TVs used 10+ hours on weekends	1.10*	0.44	.0120
Number of desktop PCs used 6-9 hours a day	0.86**	0.47	.0660
Number of desktop PCs used 10+ hours a day	2.12**	0.32	.0000
Number of lights used less than 12 hours a day	0.25**	0.04	.0000
Number of lights used 12+ hours a day	0.94**	0.13	.0000
Number of outdoor lights left on all night	0.82**	0.18	.0000
Number that are not energy efficient	0.75**	0.24	.0021
Household installed energy efficient bulbs	-1.26**	0.34	.0002
adjusted R <sup>2</sup>	.497		
Number of observations	7,796		

\* significant at the .1 level; \*\* significant at the .01 level

<sup>†</sup> Household head not white, African-American or Hispanic

<sup>††</sup> Area income by state (or group of states) and metropolitan status from the 2009 American Community Survey, U.S. Census Bureau.

<sup>†††</sup> Based on first and second most TV only

**Table A-3. Using the Model to Estimate and Simulate Changes in Non-HVAC Use of Electricity (Million BTUs) in Single-family Detached Homes**

Variable	Coefficient	Baseline		Items Usually Installed by the Builder			Items Usually Purchased by the Household			Attributes of the Household and its Behavior		
		value of var	impact on use	value of var	impact on use	difference	value of var	impact on use	difference	value of var	impact on use	difference
Constant	5.26**	1.000	5.258	1.000	5.258	0.000	1.000	5.258	0.000	1.000	5.258	0.000
Price of electricity (per Million BTU)	-0.24**	36.502	-8.832	36.502	-8.832	0.000	36.502	-8.832	0.000	36.502	-8.832	0.000
<b>Jointly Dependent Variable</b>												
Size of home (1,000 sq ft)	0.09	2.728	0.234	5.456	0.468	0.234	2.728	0.234	0.000	2.728	0.234	0.000
<b>Household Characteristics:</b>												
Number of persons in household	1.99**	2.854	5.692	2.854	5.692	0.000	2.854	5.692	0.000	4.000	7.979	2.287
Persons age 15 to 19	1.33**	0.206	0.274	0.206	0.274	0.000	0.206	0.274	0.000	1.000	1.328	1.055
Hispanic household head	-2.43**	0.106	-0.257	0.106	-0.257	0.000	0.106	-0.257	0.000	0.106	-0.257	0.000
"Other" minority <sup>†</sup> household head	-2.12**	0.056	-0.119	0.056	-0.119	0.000	0.056	-0.119	0.000	0.056	-0.119	0.000
Household income relative to area average <sup>††</sup>	1.31**	1.089	1.424	1.089	1.424	0.000	1.089	1.424	0.000	2.178	2.848	1.424
<b>Sum</b>			<b>7.014</b>		<b>7.014</b>	<b>0.000</b>		<b>7.014</b>	<b>0.000</b>		<b>11.779</b>	<b>4.765</b>
<b>Electricity Using Equipment:</b>												
<b>A. Items usually installed by the builder in an electric home</b>												
Electric water heater	10.05**	1.000	10.052	1.000	10.052	0.000	1.000	10.052	0.000	1.000	10.052	0.000
Electricity used for cooking	2.75**	1.000	2.752	1.000	2.752	0.000	1.000	2.752	0.000	1.000	2.752	0.000
Number of refrigerators	4.13**	1.000	4.131	1.000	4.131	0.000	1.000	4.131	0.000	1.000	4.131	0.000
50+ gallon electric water heater	3.20**	0.000	0.000	1.000	3.197	3.197	0.000	0.000	0.000	0.000	0.000	0.000
Through-door ice on most-used refrigerator	1.22**	0.000	0.000	1.000	1.221	1.221	0.000	0.000	0.000	0.000	0.000	0.000
Number of ceiling fans	0.44**	2.000	0.880	4.000	1.760	0.880	2.000	0.880	0.000	2.000	0.880	0.000
<b>Sum</b>			<b>17.814</b>		<b>23.112</b>	<b>5.298</b>		<b>17.814</b>	<b>0.000</b>		<b>17.814</b>	<b>0.000</b>
<b>B. Items Usually Purchased Separately by the Home Owner</b>												
Clothes dryer	2.79**	1.000	2.793	1.000	2.793	0.000	1.000	2.793	0.000	1.000	2.793	0.000
Number of separate freezers	3.03**	0.000	0.000	0.000	0.000	0.000	1.000	3.027	3.027	0.000	0.000	0.000
Number of freezers over 18 cubic feet	4.98**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Number of frost-free freezers	1.84**	0.000	0.000	0.000	0.000	0.000	1.000	1.840	1.840	0.000	0.000	0.000
Dehumidifier	0.98**	0.000	0.000	0.000	0.000	0.000	1.000	0.977	0.977	0.000	0.000	0.000
Number of televisions	1.61**	2.000	3.227	2.000	3.227	0.000	3.000	4.841	1.614	2.000	3.227	0.000
Cable/satellite box connected to a TV	1.19*	1.000	1.190	1.000	1.190	0.000	1.000	1.190	0.000	1.000	1.190	0.000
Home theater system connected to a TV	0.94*	0.000	0.000	0.000	0.000	0.000	1.000	0.937	0.937	0.000	0.000	0.000
Number of desktop computers	1.26**	0.000	0.000	0.000	0.000	0.000	1.000	1.264	1.264	0.000	0.000	0.000
Separate fax machine	2.26**	0.000	0.000	0.000	0.000	0.000	1.000	2.262	2.262	0.000	0.000	0.000
<b>Sum</b>			<b>7.211</b>		<b>7.211</b>	<b>0.000</b>		<b>19.132</b>	<b>11.921</b>		<b>7.211</b>	<b>0.000</b>
<b>Device Usage</b>												
Have a home-based business	2.02**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	2.021	2.021
Dishwasher used daily	3.56**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.565	3.565
5 to 9 loads of laundry washed per week	1.95**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10+ loads of laundry washed per week	2.88**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	2.877	2.877
Number of TVs used 10+ hours on week days <sup>†††</sup>	1.04**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.039	1.039
Number of TVs used 10+ hours on weekends	1.10*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.098	1.098
Number of desktop PCs used 6-9 hours a day	0.86**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Number of desktop PCs used 10+ hours a day	2.12**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	2.118	2.118
Number of lights used less than 12 hours a day	0.25**	3.000	0.756	3.000	0.756	0.000	3.000	0.756	0.000	5.000	1.260	0.504
Number of lights used 12+ hours a day	0.94**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.935	0.935
Number of outdoor lights left on all night	0.82**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.824	0.824
Number that are not energy efficient	0.75**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.753	0.753
Household installed energy efficient bulbs	-1.26**	1.000	-1.261	1.000	-1.261	0.000	1.000	-1.261	0.000	0.000	0.000	1.261
<b>Sum</b>			<b>-0.505</b>		<b>-0.505</b>	<b>0.000</b>		<b>-0.505</b>	<b>0.000</b>		<b>16.489</b>	<b>16.995</b>
<b>Total for All</b>			<b>28.193</b>		<b>33.726</b>	<b>5.532</b>		<b>40.115</b>	<b>11.921</b>		<b>49.953</b>	<b>21.760</b>