

## Appendix C

# End-Use Estimation Methodology

## Introduction

For each household that responded to the 1997 RECS, the annual amount of energy used for five end-use categories--space heating, water heating, air-conditioning, refrigerators, and general appliance usage--was estimated. The end-use estimates were produced for each of the five main energy sources: electricity, natural gas, fuel oil, kerosene, and liquefied petroleum gas (LPG). The end-use amounts were not based on data produced by placing meters on individual appliances; rather, they were obtained by estimating how much of the total annual consumption for each energy source can be attributed to each of the end-use categories for each household by using a regression technique.

For each energy source, the annual consumption attributed to each of the end-use categories can be estimated by use of regression equations. The regression equations are also used to impute energy consumption when the billing data are missing or inadequate. A separate equation was developed for each of the five main energy sources. In each equation, the dependent variable was the annual energy consumption for the 1997 calendar year. The set of independent variables varied according to energy source type. The desire to use a large number of independent variables without using a large number of interaction terms and the desire to adapt the regression procedures to account for heteroscedastic<sup>4</sup> error terms led to the use of a nonlinear regression technique. The use of linear regression would have greatly restricted the ability to adequately model household energy consumption.

This appendix provides an overview of the methodology used for the 1997 RECS end-use estimation. The specific regression equations used are not presented here. (For more detailed information, please contact the person listed as the end-use estimation expert on the "Contacts" page at the beginning of this report.) The procedure used for the 1997 RECS is very similar to that used in the 1990 RECS. Detailed equations for the 1990 RECS were published in Appendix D, "End-Use Estimation Methodology," of *Household Energy Consumption and Expenditures 1990* (Energy Information Administration, February 1993, DOE/EIA-0321[90]).

A comparison between estimates from the regression equations and estimates from end uses submetering studies was presented in Appendix C, "End-Use Estimation Methodology," of *Household Energy Consumption and Expenditures 1993* (Energy Information Administration, October 1995, DOE/EIA-0321[93]).

## General Consumption Equations

### Basic Equation

For electricity, the basic equation is:

$$\begin{aligned} \text{Total Consumption} = & \text{Space-Heating Component} \\ & + \text{Water-Heating Component} \\ & + \text{Air-Conditioning Component} \\ & + \text{Refrigerator Component} \\ & + \text{Appliance Component.} \end{aligned}$$

The basic equation was the same for natural gas, fuel oil, kerosene, and LPG; however, (1) the refrigerator component existed only for electricity and (2) the air-conditioning component existed only for electricity and natural gas. Table

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<sup>4</sup>Error terms are heteroscedastic when the variance of the error terms is not constant but, instead, is a function of the independent variables.

C1 shows which end uses were estimated for each fuel source. Discussions of each component of the general consumption equation will be followed by a discussion of the nonlinear regression technique.

**Table C1. 1997 RECS End-Use Estimation Equations by Fuel Source**

	Space Heat	Water Heat	Air-Conditioners	Refrigerators	Appliances
Natural Gas .....	X	X	X		X
Electricity .....	X	X	X	X	<sup>1</sup> X
Fuel Oil .....	X	X			X
LPG .....	X	X			X
Kerosene .....	X	X			X

X = End use was estimated for this energy source.

<sup>1</sup>Separate estimate for freezer, lighting, cooking, dishwasher, clothes dryer, and appliance subcomponents.

Source: Energy Information Administration, Office of Energy Markets and End Use, the 1997 Residential Energy Consumption Survey.

### **General Space-Heating Component**

For all energy sources, the space-heating component was defined as all energy used to generate heat by space-heating equipment. The equipment could be the main space-heating equipment or secondary space-heating equipment. Hence, for all energy sources, a household could have had a positive amount of energy assigned to the space-heating component even if the energy source was not used as the main space-heating energy source.

For the electricity equation in the 1987 and subsequent RECS, the electricity associated with the operation of fans in any central forced-air heating equipment was assigned to the electricity appliance component and not to the space-heating component.<sup>5</sup>

### **General Water-Heating Component**

The component for water heating was defined as all energy used to heat water for hot running water, as well as water heated at point sources (such as stoves or auxiliary water-heating equipment) for bathing, cleaning, and other noncooking applications of hot water. Energy used at point sources to heat water for cooking and hot drinks was considered part of the general appliance component, as was energy used to heat water for a swimming pool, hot tub, spa, or jacuzzi.

### **General Air-Conditioning Component**

The electricity air-conditioning component was defined as all electricity associated with (1) electric air-conditioning equipment and (2) fans in any central air-conditioning equipment, including natural gas air-conditioning equipment. The regression equations for electricity do not contain specific terms for whole-house fans, window fans, and evaporative (swamp) coolers. Hence, the consumption of electricity to operate these fans and evaporative coolers was not assigned to the air-conditioning component; it was included in the appliance component.<sup>6</sup> There is a term for ceiling fans in the electricity appliance component.

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<sup>5</sup>In previous RECS (prior to 1987), the electricity used to run fans for central forced-air heating systems was assigned to the space-heating components. This was changed in the 1987 and subsequent RECS so that the households that did not use electricity as a space-heating energy source (either main or secondary), by definition, did not have positive amounts of electricity assigned to the space-heating component.

<sup>6</sup>Previous RECS (prior to 1987) included a term for evaporative coolers, whole-house fans, ceiling fans, and window fans in the air-conditioning component of the electricity equation. Therefore, the consumption of electricity to operate these types of coolers and fans was assigned to the air-conditioning component. Consequently, some households that did not have air-conditioning equipment had positive consumption assigned to their air-conditioning component.

In the 1997 RECS, the households that reported that they had air-conditioning equipment but did not use the equipment were assigned a value of zero for their electricity air-conditioning component. In RECS prior to 1987, these households were assigned small but positive values for their electricity air-conditioning component.

The natural gas air-conditioning component was defined as all natural gas used to operate natural gas air-conditioning equipment. There was no air-conditioning component for fuel oil, kerosene, or LPG.

### **General Refrigerator Component**

The refrigerator component for electricity consisted of all electricity used to operate refrigerators. The electricity used to operate freezers that are not part of a refrigerator was assigned to a separate component under General Appliance. There was no refrigerator component for natural gas, LPG, fuel oil, and kerosene.

### **General Appliance Component**

The general appliance component consisted of all energy not used specifically for any of the other end uses. For natural gas, fuel oil, kerosene, and LPG, the general appliance component consisted of all end uses other than space heating, water heating, and (for natural gas), air-conditioning. For these fuels, there is the single general appliance component.

For electricity, the general appliance component was split into six subcomponents: (1) Appliance Subcomponent, (2) Lighting Subcomponent, (3) Cooking Subcomponent, (4) Dishwasher Subcomponent, (5) Clothes Dryer Subcomponent, and (6) Freezer Subcomponent. Electricity was the only energy source where the nonlinear regression technique was used to estimate the consumption for subcomponents of the general appliance component.

Energy used in appliances during the winter will frequently help heat the housing unit. This secondary effect of the appliance consumption was not included in the estimation of the space-heating component. In addition, during the summer, energy used in general appliances may add to the load on the air-conditioning system. This was not included in the air-conditioning component.

### **Appliance Subcomponent.**

Natural Gas. For natural gas, the appliance subcomponent included outdoor gas lights, pool heaters, clothes dryers, hot tub heaters, natural gas outdoor grills, and other natural gas appliances.

LPG. For LPG, the appliance subcomponent included pool heaters, clothes dryers, and hot tub heaters. The consumption of LPG in outdoor grills was not covered in any LPG component. Households that use LPG only in outdoor gas grills were coded as not using LPG, and their LPG consumption and expenditures were treated as if they were zero.

Fuel Oil. The appliance subcomponent for fuel oil was zero except for 4 households that used fuel oil for heating a hot tub.

Kerosene. The appliance component for kerosene was zero for all households.

Electricity. The appliance subcomponent consisted of all electricity not used for any of the other five subcomponents or the other four main components. This included electricity used to heat water beds, hot tubs, and pools, and electricity used to operate fans (including fans for forced-air, space-heating systems), water pumps, small kitchen appliances (such as toasters, mixers, and can openers), home entertainment equipment (such as radios, televisions, stereos, video cassette recorders, electronic games, and computers), and numerous other appliances and uses not covered elsewhere.

**Lighting Subcomponent.** This subcomponent was estimated only for electricity; it consists of all electricity used for indoor and outdoor lighting. Natural gas lights are included in the appliance component for natural gas.

**Cooking Subcomponent.** This subcomponent was estimated only for electricity. The cooking subcomponent was positive if one or both of the following conditions were met. The first condition is if the household reported that electricity was the main cooking fuel and the household cooked hot meals once a week or more. The second condition is if the household reported that it used an electric oven once a day or more (even if the main cooking fuel was not electricity). If neither condition was met, the subcomponent was zero. Other than the frequent use of an electric oven, the definition of the subcomponent did not involve the type of cooking equipment that was used. Consequently, households with some electric cooking equipment (including microwave ovens) could have been assigned a zero value for the electricity cooking subcomponent if the household did not list electricity as a cooking fuel. The electricity used to operate the electric cooking equipment in households that did not list electricity as a cooking fuel was included in the appliance subcomponent. Similarly, electricity used to operate common kitchen appliances, such as toasters and mixers, was included in the appliance subcomponent. For the 1993 RECS, the definition of the cooking subcomponent did not involve the number of meals cooked or the frequency with which the oven was used.

**Dishwasher Subcomponent.** This subcomponent was estimated only for electricity. This subcomponent consisted of all electricity used to operate dishwashers.

**Clothes Dryer Subcomponent.** This subcomponent was estimated only for electricity; it consists of all electricity used to operate clothes dryers. Clothes dryers using natural gas or LPG are included in the appliance component for those fuels.

**Freezer Subcomponent.** This subcomponent was estimated only for electricity; there was no freezer component for natural gas, LPG, fuel oil, and kerosene. The freezer subcomponent for electricity consisted of all electricity used to operate freezers that were not part of a refrigerator.

## Nonlinear Regression Technique

The nonlinear regression technique was used to produce end-use estimates for each household and each energy source. The end-use estimates were normalized so that the sum of the end-use estimates was equal to the actual or imputed yearly consumption for each energy source used by the household. The individual household end-use estimates were used to estimate averages and totals for end-use consumption over selected household categories. The results are presented in the text and in the tables in the "Detailed Tables" section of this report. Following is an overview of the basic nonlinear equations. (To obtain the detailed equations and individual coefficients, please see the Contacts page at the beginning of this report for the end use estimation contact person.<sup>7</sup>)

The general regression equation for each fuel splits estimated consumption into its end-use components. The result is:

$$YCOM = SPHTCOM + WTHTCOM + AIRCCOM + RFRGCOM + APPLCOM,$$

where:

YCOM is the estimated annual consumption,  
SPHTCOM is the estimated space-heating component,  
WTHTCOM is the estimated water-heating component,  
AIRCCOM is the estimated air-conditioning component,  
RFRGCOM is the estimated refrigerator component, and  
APPLCOM is the estimated appliance component.

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<sup>7</sup>For a detailed discussion of the end-use estimation procedures and the correlation of variables, see the *National Interim Energy Consumption Survey: Exploring the Variability in Energy Consumption*, DOE/EIA-072 (Washington, DC, July 1981); the *National Interim Energy Consumption Survey: Exploring the Variability in Energy Consumption - A Supplement*, DOE/EIA-0272/S (Washington, DC, October 1981); and *Residential Energy Consumption Survey: Regression Analysis of Energy Consumption by End Use*, DOE/EIA-0431 (Washington, DC, October 1983).

The regression equation for electricity splits estimated consumption for the appliance component into 6 additional subcomponents:

$$YCOM = SPHTCOM + WTHTCOM + AIRCCOM + RFRGCOM + FZZRCOM + DISHCOM + COOKCOM + LITECOM + DRYRCOM + APPSCOM,$$

where:

FZZRCOM is the estimated freezer subcomponent,  
DISHCOM is the estimated dishwasher subcomponent,  
COOKCOM is the estimated cooking subcomponent,  
LITECOM is the estimated lighting subcomponent,  
DRYRCOM is the estimated clothes dryer subcomponent, and  
APPSCOM is the estimated other appliances subcomponent.

The actual annual consumption is called Y. The unit of measure for Y and YCOM is thousands of Btu. This unit of measure is used for all energy sources.

The typical regression error term is as follows:

$$e_1 = Y - YCOM .$$

Unfortunately, the variance of  $e_1$  tends to increase as YCOM increases. Furthermore, the distribution of  $e_1$  is skewed in the positive direction. These two facts violate the assumptions associated with linear least-squares regression. On the other hand, the distribution of

$$e_2 = (Y)^{1/4} - (YCOM)^{1/4}$$

is closer to being normally distributed with a constant variance. Hence, a nonlinear least-squares regression procedure that minimizes the sum of squares of  $e_2$  was used.

For each energy source, the dependent variable was the household's consumption as reported on the RECS Suppliers Survey in thousands of Btu. The specific set of independent variables was not the same for all energy sources. Most of the independent variables are derived from information reported by the individual households on the Household Survey. The end-use components consisted of sums or products of terms that themselves may have been sums or products of the independent variables. The overall methodology may seem complex at first glance, but there was a common structure. In general, the components consisted of an overall term multiplied by various adjustments. This format allowed the components to be adjusted by many factors. The relative size of the adjustments was easy to determine.

The disadvantage of the format was that it yields a basic equation that is intrinsically nonlinear. As a result, standard multivariate linear regression techniques could not be used to estimate the parameters. A nonlinear technique was used. The parameters were estimated by using the nonlinear regression procedure (PROC NLIN) contained in the statistical computer package, SAS.<sup>8</sup>

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<sup>8</sup>Statistical Analysis System (SAS) Institute (Cary, North Carolina).