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Development of a U.S. Household Sample for Furnace/Boiler Life-Cycle Cost Analysis

Camilla Dunham Whitehead, Victor Franco, Alex Lekov, Jim Lutz, and Jim McMahon

Energy Analysis Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720

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ABSTRACT

Residential household space heating energy use comprises close to half of all residential energy consumption. Currently, average space heating use by household is 43.9 Mbtu for a year[a]. An average, however, does not reflect regional variation in heating practices, energy costs, or fuel type. Indeed, a national average does not capture regional or consumer group cost impacts from changing efficiency levels of heating equipment.

The US Department of Energy sets energy standards for residential appliances in, what is called, a rulemaking process. The residential furnace and boiler efficiency rulemaking process investigates the costs and benefits of possible updates to the current minimum efficiency regulations. Lawrence Berkeley National Laboratory (LBNL) selected the sample used in the residential furnace and boiler efficiency rulemaking from publically available data representing United States residences. The sample represents 107 million households in the country. The data sample provides the household energy consumption and energy price inputs to the life-cycle cost analysis segment of the furnace and boiler rulemaking. This paper describes the choice of criteria to select the sample of houses used in the rulemaking process. The process of data extraction is detailed in the appendices and is easily duplicated.

The life-cycle cost is calculated in two ways with a household marginal energy price and a national average energy price. The LCC results show that using an national average energy price produces higher LCC savings but does not reflect regional differences in energy price.

[a] http://www.eia.doe.gov/emeu/recs/recs2001_ce/ce2-1c_climate2001.html

1 INTRODUCTION

Residential household space heating energy use comprises close to half of all residential energy consumption. In 2001, the national average space heating energy use by households was 43.9 MBtu and cost, on average, $480 per household. To reduce national energy consumption due to residential space heating, the Department of Energy (DOE) furnace and boiler energy-efficiency standards rulemaking considers the change in life-cycle cost (LCC) due to increased energy efficiency of furnaces and boilers. Energy consumption is the key part of the operating-cost input of the LCC calculation. The energy consumption of a furnace or boiler includes gas or oil and electricity.

A national average, however, does not reflect regional variation in heating practices, energy costs, or fuel type. Indeed, a national average does not capture regional or consumer group cost impacts from changing efficiency levels of heating equipment. For the LCC analysis to represent actual housing units likely to purchase and use furnaces and boilers, Lawrence Berkeley National Laboratory (LBNL) for DOE used a set of housing units from DOE's Energy Information Administration (EIA)'s Residential Energy Consumption Survey of 2001 (RECS01).[1] For each housing unit, RECS reports space-heating energy consumption, which is based on the existing heating equipment.

The goal of our LCC analysis was to calculate the total cost of purchasing equipment in 2015 and operating it for its entire lifetime in houses that are representative of the U.S. population. The LCC analysis used a subset of RECS variables (heating equipment type, heating fuel type, quantity of energy used annually for space heating, etc.), which are readily available from the RECS data set. Other variables (such as marginal energy prices) need to be developed from additional RECS data provided by EIA. We used the marginal energy price data associated with the RECS households to calculate the savings or costs of varying heating energy consumption on a household basis.

In this report, we describe the methodology used to augment the data representing US households using furnace or boilers for their primary space heating needs. To adequately capture equipment changes to improve efficiency, we further separated the data sample by the heating equipment type. We defined six heating equipment product classes (non-weatherized gas furnaces, weatherized gas furnaces, mobile home gas furnaces, oil furnaces, hot-water gas boilers, and hot-water oil boilers). The work described here focused on two operations performed for the LCC Analysis: (1) capturing a set of RECS data to model energy consumption on a household basis for the LCC analysis and (2) calculating the marginal prices for electricity and natural gas used to determine the operating expenses by household.

2 GENERAL APPROACH

We used a nationally representative data sample to analyze energy consumption and cost as inputs into a LCC analysis for residential furnaces and boilers. However, our method can be used to analyze energy consumption patterns and changes for most household energy using appliances.

Regional differences show considerable variation in space heating equipment type, energy consumption and price. Energy use for space heating also changes with other factors such as the age of the household residents, household ownership, and household income.

For our purposes, the LCC calculation drove the data selection. Even though the selected data source did not provide all the inputs needed by the LCC calculation, it enabled us to make a LCC calculation for all households. The data report the different kinds of furnace and boiler heating equipment, energy costs and heating energy consumption by household. This allowed LCC calculations to be done separately for particular consumer groups.

2.1 Life-Cycle Cost Equation

Life-cycle cost consists of two main components: (1) the initial cost of buying and installing a furnace or boiler in 2015 (in 2001$), and (2) the annual operating costs over the lifetime of the equipment, discounted to 2015 and reported in 2001$. The following equation shows the two primary components of the LCC.

$$\text{LCC} = \text{total installed cost} + \sum_{n=1}^{lifetime} \frac{operating\,cost}{(1+discount\,rate)^{n}}$$

The key inputs to the calculation of LCC are total installation cost, operating cost, discount rate, and equipment lifetime. Total installation costs include the equipment purchase price plus the installation cost. Operating costs include energy expenditure associated with operating the equipment and maintenance cost for maintaining equipment operation.

Energy expenditure can be further unbundled into energy consumption and energy price. We used RECS data for the energy consumption and energy price part of the operating cost portion of the LCC equation. For the other LCC equation inputs, see Chapter 8 of the Technical Support Document of the Residential Furnace and Boiler rulemaking [2]. For a complete listing of RECS variable used, see Appendix D.

2.2 Data Source: RECS Description

The 2001 Residential Energy Consumption Survey[b] (RECS01)[1] served as the basis for determining the representative sample. In RECS01, data were collected from 4,822 households in

[b] The RECS is a national statistical survey that collects energy-related data for occupied primary housing units. RECS was first conducted in 1978; the eleventh, and most recent survey, was conducted in 2001. Previous RECS were conducted annually form 1978 to 1982 and triennially since 1984. The RECS consists of three parts:

- Personal interviews with households for information about energy used, how it is used, energy-using appliances, structural features, energy efficiency measures, and demographic characteristics of the household.
- Telephone interviews with rental agents for households with energy use included in their rent. This information augments information collected from those households that may not be knowledgeable about the fuels used for space heating or water heating.
- Mail questionnaires sent to energy suppliers (after obtaining permission from households) to collect the actual billing data on energy consumption.

housing units statistically selected to represent the 107 million housing units in the United States.

2.3 Data Extraction

The RECS01 database is part of the EIA's public use data and is available at http://www.eia.doe.gov/emeu/recs/public.html. The website gives two options for the format of the data, ASCII file and EXCEL. LBNL imported the data into an ACCESS format which allows for more efficient data extraction. Appendix C contains the names of the variables used in the LCC spreadsheets (and their EIA variable names). Appendix D contains the EIA variable names and their meanings.

3 FURNACE AND BOILER HOUSING UNIT SUBSET

3.1 Household Sample Development

From within the larger RECS data set, LBNL extracted a subset of housing records that were relevant to our analysis. We examined only those houses that used a furnace or boiler as the primary space heating equipment. We restricted our sample to households that used their furnace or boiler to heat only one housing unit because we wanted to correlate demographic information with household heating consumption and cost. Because LBNL examined changes to consumption resulting from possible changes to furnace or boiler efficiency ratings, we studied three fuel types: natural gas, LP gas, and fuel oil.[c] Figure 3.1 illustrates the household selection process for a gas furnace using household.

Of the 4822 households surveyed in the 2001 RECS, 2972 households representing 61% of the housing population have a natural gas, LP gas or oil burning central furnace or boiler. Using households with a central heating equipment of a furnace or boiler, we performed an LCC analysis on a household-by-household basis to estimate the impact on consumers of an increase in the minimum efficiency standard.

For some variables, such as energy price and climate, each calculation used the values associated with the RECS house. For these variables, the RECS houses were sampled according to the weighting assigned to them by the EIA.[d] This weighting was designed to reflect the prevalence of various features in the national population of houses.

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[c] Our assumption was that electric heating equipment has efficiencies of close to 100%; therefore, the changes in efficiencies for electric heating equipment would be small. The resulting savings from improved electric efficiencies would also be small.

[d] See: http://www.eia.doe.gov/emeu/recs/recs2001/append_a.html for more information on EIA's weighting methods.

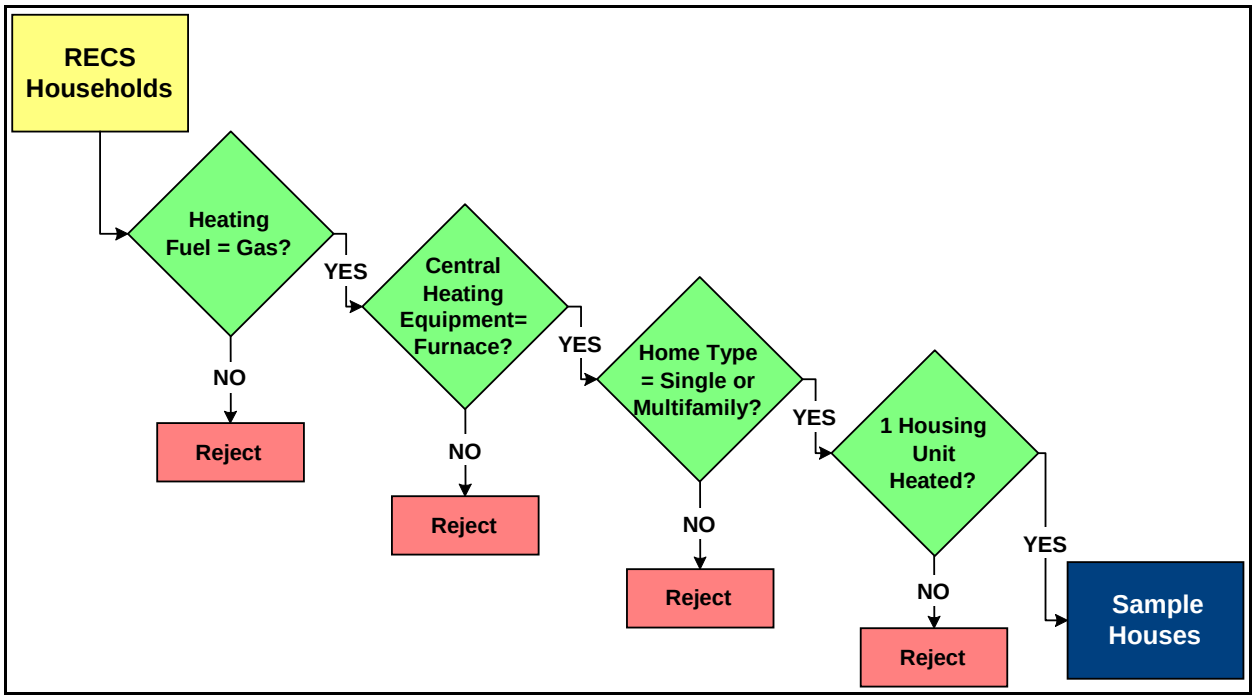

Figure 3.1 Household Selection Chart

3.2 Selection Criteria

To determine the subset used to analyze the LCC of furnaces and boilers, we excluded households without that type of space heating equipment. In this section, we characterize the accepted records, the rejected records, and then we show the characteristics of the records that did make it into the subset.

Records were rejected for one of five reasons. If the household:

1. Did not have or use central heating equipment
2. Used a fuel other than natural gas, LPG, or fuel oil
3. Heated more than one housing unit
4. Had main home heating equipment that is not a boiler or furnace.
5. Had no space heating consumption or expenditure data available.

3.3 Product Class Identification

Furnaces and boilers can be divided into product classes depending on fuel type used, the type of equipment, or housing type for which the equipment was manufactured. We used four furnace product classes and two boiler product classes in our analysis: non-weatherized gas furnace, weatherized gas furnace, oil furnace, manufactured housing furnace, gas hot water boiler, and oil hot water boiler. The resulting data set is summarized in Table 3.1.

Table 3.1 Selection of RECS01 Households by Product Class

Product Class	Algorithm	# of Records	# of US Households Represented (million)
Non-Weatherized Gas Furnace	Central heating equipment = furnace Heating fuel = gas Home type = single or multi-family Number of Housing Units Heated = 1	1880	40.6
Weatherized* Gas Furnace	Central heating equipment = furnace Heating fuel = gas Central air conditioning = yes (assume packaged unit) Home type = single or multi-family Number of Housing Units Heated = 1 Census Division = West or East South Central Large State = California, Florida or Texas	373	7.9
Manufactured-Home Gas Furnace	Central heating equipment = furnace Heating fuel = gas Home type = manufactured home Number of Housing Units Heated = 1 House Vintage = after 1979**	72	1.4
Oil-Fired Furnace	Central heating equipment = furnace Heating fuel = oil Home type = single or multi-family Number of Housing Units Heated = 1 Fuel Oil Consumption >0	169	2.7
Gas Hot-Water Boiler†	Central heating equipment = boiler Heating fuel = gas Home type = single or multi-family Number of Housing Units Heated = 1	266	5.0
Oil Hot-Water Boiler	Central heating equipment = boiler Heating fuel = oil Home type = single or multi-family Number of Housing Units Heated = 1 Fuel Oil Consumption >0	208	3.1

* LBNL used some of the same housing records for analyzing both weatherized and non-weatherized furnace product classes. Equipment placement within the building is not given in RECS01. For weatherized furnaces, we looked at the subset of housing records that had gas furnaces and central air conditioners, and were located in the West South Central, East South Central Census divisions or in the states of California, Florida, or Texas.

** Federal regulation for manufactured housing construction changed the structural quality for units manufactured after this year. We assumed that these housing unit would last at least as long as the furnace.

† Because RECS does not distinguish between steam and hot-water boilers, for the purposes of this analysis we assumed that all boilers in RECS are hot-water boilers. Hot-water boilers comprise 84% of gas boiler shipments and 88% of oil-fired boiler shipments.

3.4 Identification of Regional and Consumer Groups

For non-weatherized gas furnaces, we added the following variables to help identify household types and enhance the LCC analysis:

* Census regions – Northeast, Midwest, South, and West (representing the continental US)
* Senior-only – all residents within the housing unit are at least 65 years old.
* Low-income – households with an overall income at, or below, the poverty line
* Renter – households occupied by a people other than the owner of the housing unit.

For analysis purposes, groups must have at least ten housing records to be statistically representative. In Table 3.2, we show that each consumer group has sufficient housing records to analyze their space heating LCC costs.

Table 3.2 Summary of RECS01 Household Data by Region and Consumer Group

Region or Consumer Group	Algorithm	Total of # Records in Sample (% of US Households)	Consumer Group # of Records and (% of US Households)		
			Senior-Only	Low-Income	Renter
Northeast	Census Region = 1	724 (12.3)	83 (1.5)	60 (1.1)	139 (2.6)
Midwest	Census Region = 2	825 (18.3)	76 (1.7)	67 (1.6)	158 (3.6)
South	Census Region = 3	586 (13.7)	57 (1.3)	67 (1.3)	101 (2.2)
West	Census Region = 4	548 (9.9)	40 (0.7)	51 (0.9)	104 (1.9)

4 ENERGY PRICE DETERMINATION

Energy cost is the major component of the operating expenses of a furnace or boiler and an input into the LCC calculation. Energy consumption and energy price determine annual household energy cost. RECS provides space heating consumption values and EIA provided billing data that had been gathered from a subset of RECS housing records. For each household with billing data, the following are provided for each billing cycle: the start and end date, the electricity consumption in kWh, the electricity cost in dollars, the natural gas bill in dollars, and the gas consumption in hundreds of cubic feet.

4.1 Billing Data Overview

The LCC analysis required the price of natural gas, LPG, or heating oil during the winter, as well as the price of electricity used by electrical components of the furnace and boiler. For all product classes of gas equipment, LBNL used the average price of gas for each house to calculate the energy costs of base case equipment. Marginal energy prices are the prices consumers pay for the last unit of energy used. We used the marginal energy prices for each house for the cost of saved energy associated with the use of higher-efficiency equipment. Since marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for

determining energy cost savings associated with possible change to efficiency standards.

For oil-fired furnaces and boilers, LBNL used the average oil prices for each house for both base case equipment and higher-efficiency equipment, as the data necessary for estimating marginal prices were not available. We used the same method for LPG-fired equipment.

A furnace fan operates during both the heating season and the cooling season. We used annual marginal prices.

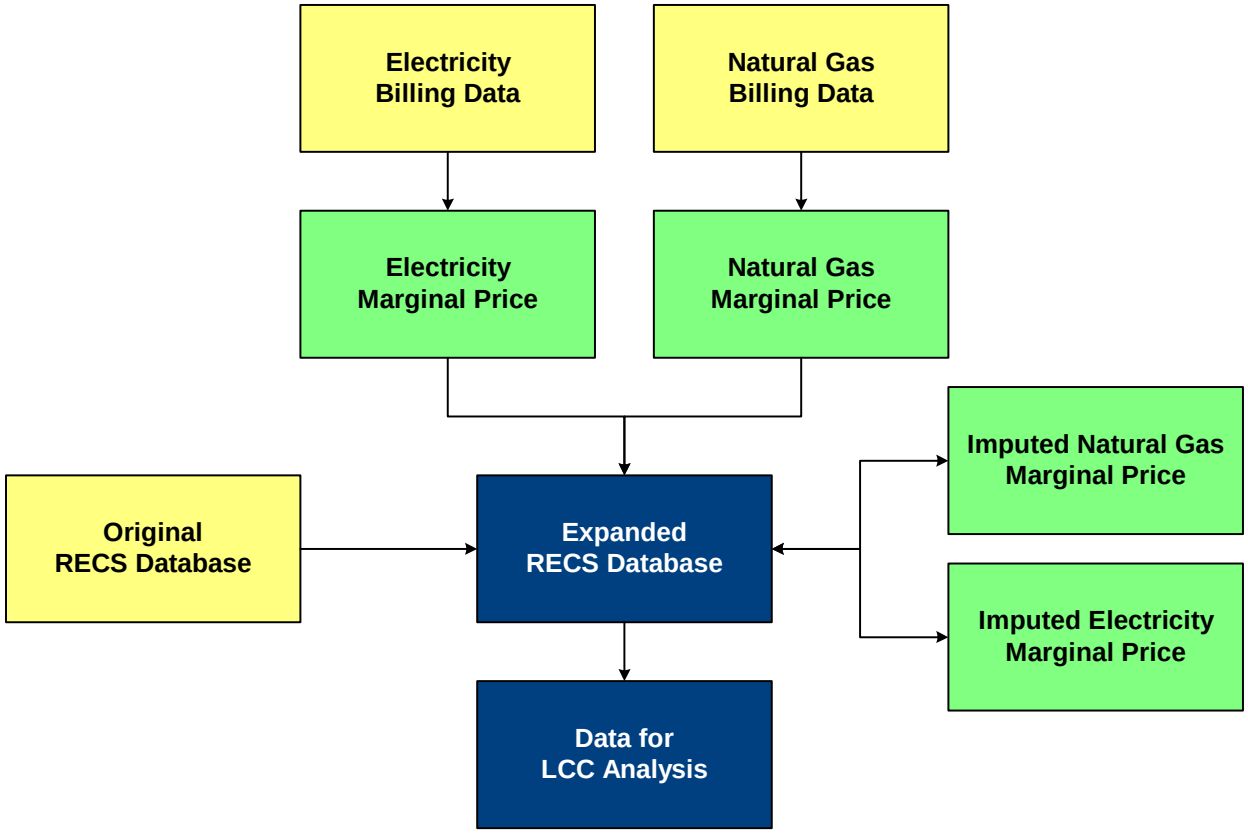

Figure 4.1 Energy Price Determination Using RECS Data and EIA Billing Data

4.2 Marginal Price Calculation for Electricity and Natural Gas

LBNL determined how to calculate average and marginal energy prices for each sample house. For RECS 2001, the EIA processed the billing data to calculate household average and marginal energy prices.

To derive marginal energy prices by calculating energy bills based on even a detailed knowledge of a consumer's utility tariff would be hampered by the lack of information on items that affect marginal energy prices but are not normally on utility tariffs. Taxes, special fees, and one-time surcharges or rebates included in the energy bill are examples of this type of item. Use of RECS billing data avoids having to estimate the effect of non-tariff items on consumer marginal energy

prices.

LBNL developed two spreadsheets for estimating marginal electricity and natural gas prices from the RECS monthly billing data. Marginal energy prices were calculated with a linear regression of monthly customer bills to monthly customer energy consumption for each household with billing data available. Household identifying features such as state, utility service area or zip code were not reported in the data preventing a localized aggregation.

We interpreted the slope of the regression line for each household as the marginal energy price for that household. The spreadsheets were used by EIA to preserve household confidentiality. We kept the marginal energy prices only for sample housing records with regression values greater or equal to 85%. We decided on the 85% limit to get a close correlation in the cost and consumption data. A limit any higher excluded most of the housing records from the analysis; a limit any lower and we lost the linearity of the relationship between the seasonal costs and consumption. Figures 4.2 and 4.3 show an example household's monthly energy bill costs and consumption and the associated seasonal regression lines. The slopes of these regression lines are our estimate of the seasonal marginal prices for that household.

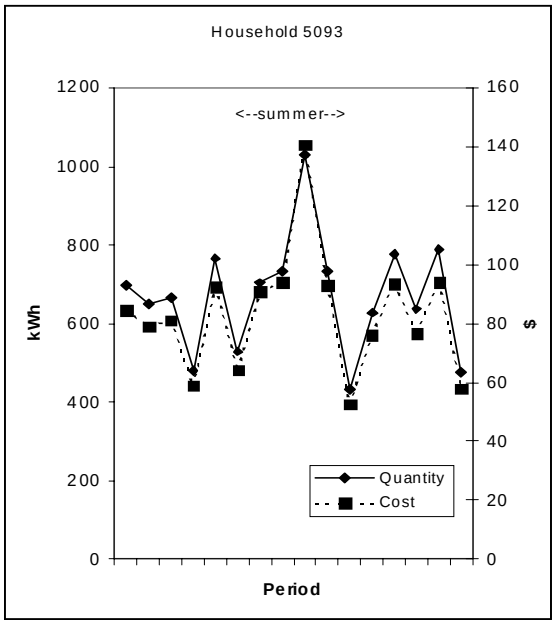

Figure 4.2 Example RECS97 Household: Billing Data

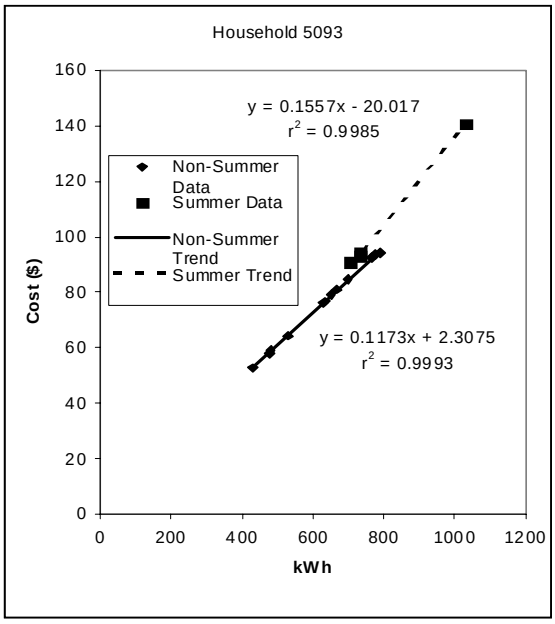

Figure 4.3 Example RECS97 Household: Regression Lines, Slopes

LBNL calculated annual average LPG prices with data from RECS2001 houses with LPG-fired equipment using the cost of LPG in dollars divided by gallons of LPG used . Monthly data necessary to calculate marginal prices were not available for households using LPG for heating. The same method was used for houses with oil-fired equipment. We used cost of oil in dollars divided by gallons of oil used. Households with oil-fired equipment and a reported oil consumption of zero were

not included as a part of the LCC sample. Lack of information about heating fuel consumption prevented any meaningful calculations of heating energy.

LBNL's RECS regression method uses actual billing data that incorporates factors such as taxes in energy bills that can otherwise slip through in the determination of consumer marginal energy prices. The method is not sensitive to energy tariff rate changes that occur within a monthly billing period. For example, if a consumer has a time-of-use rate, the method is not refined enough to recognize it since it relies on a regression of monthly billing data.

4.3 Imputation of Missing Marginal Prices

While the values showing "goodness of fit" to a regression line and the percentage of variation in the dependent variable that is explained by the independent variable for the regressions of RECS electricity bills were generally very high, we rejected marginal energy prices where the linear regression had an R^2 value less than 0.85. Based on this criteria, we rejected 16 percent of the households for electricity billing data. Resulting in 3368 households of the 3999 households with electricity billing data that had an acceptable R^2 value. Similarly based on this criteria, we rejected 29 percent of the households with natural gas billing data. Of the 2246 households with natural gas billing data, 1587 households had regressions with acceptable R^2 values.

For the sample of 2683 household records used in the LCC analysis 874 did not have marginal prices for electricity. To estimate marginal energy prices for these households, we imputed marginal energy prices from the closest households that did have marginal prices. Households (874) without electricity marginal prices were imputed from a set of 3085 households with electricity marginal prices. The 1463 households without natural gas marginal prices were imputed from a set of 1444 households with natural gas marginal prices.

We calculated "distance" between households based on climate (heating and cooling degree days (HDD and CDD)) and average energy price. To calculate the closest household, we started with households with acceptable marginal prices in the same census divisions or large state[e]. For each household sampled from the RECS database, we calculated the average electricity and natural gas price, using RECS variables of estimated cost of electricity divided by kilowatt hours of electricity used and estimated cost of gas in dollars divided by hundred cubic feet of gas. The HDD and CDD of the nearest airport are reported for each RECS record.

The equation calculating the square root of the difference in the sum of squares determines the "distance" between the household without marginal price and the households with marginal prices. All data are taken from RECS 2001.

$$"Distance" = \sqrt{(HDD_2 - HDD_1)^2 + (CDD_2 - CDD_1)^2 + (ElectPrice_2 - ElectPrice_1)^2}$$

[e] In addition to other geographical designations (census regions and census divisions), EIA identifies four states: New York, California, Texas, and Florida.

where,

HDD2	=	heating degree days for a household without marginal price,
HDD1	=	heating degree days for a household with marginal price,
CDD2	=	cooling degree days for a household without marginal price,
CDD1	=	cooling degree days for household with marginal price,
ElectPrice2	=	average electricity price (DOLLAREL/KWH) for household without marginal price, and
ElectPrice1	=	average electricity price (DOLLAREL/KWH) for a household with marginal price.

5 RESULTS

The marginal energy prices are then bundled back into the energy expenditure part of the operating cost section of the LCC equation. We make two comparisons between LCC savings using household marginal prices and one national average price in the LCC calculation: we show LCC national and regional savings results for non-weatherized gas furnaces. The national average prices were calculated to be $0.097/kWh for electricity and $1.091/therm for national gas using the RECS01 quantities.

The average total LCC cost for equipment complaint with the existing standard (baseline equipment) differs when you apply marginal or average energy prices. The average total LCC cost of the baseline equipment with marginal prices is $10,463 and with average prices is $11,216. Table 5.1 shows the LCC savings for both cases. As Table 5.1 shows, the LCC savings using marginal prices tend to be lower than the LCC savings using national average price, since marginal prices tend to be lower than average prices.

Table 5.1 Average LCC Savings and Average Total LCC Cost Using Marginal Energy versus National Average Energy Prices

Design Options	LCC Savings with Marginal Prices	LCC Savings with National Average Prices
Baseline Average LCC Total Cost	$10,463	$11,216
80% AFUE - Single-Stage	$0	$0
80% AFUE - Two-Stage*	-$1	$2
81% AFUE - Single-Stage	-$6	$10
81% AFUE - Two-Stage	-$10	$9
82% AFUE - Single-Stage	-$303	-$272
90% AFUE - Single-Stage	-$185	-$45
90% AFUE - Two-Stage	-$221	-$75
92% AFUE - Single-Stage	-$206	-$36
92% AFUE - Two-Stage	-$255	-$74
96% AFUE - Step Modulation	-$1,032	-$773

* Two-Stage design options include an ECM (Electronically Commutated Motors) blower motor, which is generally more efficient than the standard PSC (Permanent Split Capacitor) blower motor.

Table 5.2 shows the variation in household weighted average regional energy prices and marginal regional energy prices as reported in RECS01 for the four census regions. Comparing the regional prices with the national average price and marginal average prices, one notices that marginal prices tend to be lower than average prices, with the exception of the electricity prices in the west region. National average marginal electricity prices were estimated to be 7% less than average electricity prices. For natural gas, marginal prices were 16% less than average annual prices.

Table 5.2 Average Regional Energy Prices from RECS01

	Northeast	Midwest	South	West	National Average
Electric Price Average ($/kWh)	$ 0.129	$ 0.088	$ 0.084	$ 0.100	$ 0.097
Electric Marginal Price Average ($/kWh)	$ 0.110	$ 0.080	$ 0.080	$ 0.105	$ 0.090
Percentage Price Difference	15%	10%	4%	-5%	7%
Natural Gas Price Average ($/therm)	$ 1.470	$ 0.880	$ 1.134	$ 1.001	$ 1.091
Natural Gas Marginal Price Avg. ($/therm)	$ 1.064	$ 0.827	$ 0.959	$ 0.843	$ 0.916
Percentage Price Difference	28%	6%	15%	16%	16%

However, the national average energy price fails to capture the regional variation and does not address the idea behind improvements to equipment to reduce energy consumption. Table 5.3 shows the variation in LCC savings for the four census regions.

Table 5.3 Average LCC Savings and Average Total LCC Cost Using Marginal Energy Prices and National Average Energy Price by Census Region

	Marginal Energy Price				National Energy Price			
	NE	MW	South	West	NE	MW	South	West
Baseline Average Total LCC Cost	$13,334	$11,745	$9,664	$7,735	$12,800	$13,619	$9,625	$8,498
80% AFUE - Single-Stage	$0	$0	$0	-$1	$0	$1	$0	-$1
80% AFUE - Two-Stage	$17	$12	$15	-$57	-$12	$35	$37	-$90
81% AFUE - Single-Stage	$9	$8	-$14	-$25	$16	$33	$0	-$13
81% AFUE - Two-Stage	$22	$16	-$3	-$85	$0	$64	$32	-$107
82% AFUE - Single-Stage	-$216	-$216	-$380	-$399	-$203	-$166	-$355	-$374
90% AFUE - Single-Stage	-$13	-$59	-$260	-$384	$44	$165	-$160	-$275
90% AFUE - Two-Stage	-$34	-$59	-$283	-$473	$3	$166	-$161	-$390
92% AFUE - Single-Stage	-$6	-$58	-$296	-$439	$63	$216	-$177	-$307
92% AFUE - Two-Stage	-$40	-$104	-$325	-$536	$20	$202	-$182	-$428
96% AFUE - Step Modulation	-$732	-$836	-$1,140	-$1,388	-$608	-$410	-$951	-$1,221

6 CONCLUSIONS

We have described a methodology to augment national space heating data to include marginal energy price. The expanded data set now combines household level energy price and consumption information with household furnace and boiler use, housing unit and householder characteristics, and location. Associating national household information with marginal energy prices permits policy makers to analyze impacts of changes to space heating efficiencies and consumer costs. The data allow examination by heating equipment product classes and different consumer groups.

LBNL developed a method to calculate marginal residential energy prices using a regression analysis based on a nationally representative sample of actual consumer energy bills. Based on the RECS01, national average marginal electricity prices were estimated to be 7% less than average electricity prices. For natural gas, marginal prices were 16% less than average annual prices.

The method we have described can be helpful in estimating marginal energy prices. An important advantage of LBNL's RECS regression method is that its use of actual billing data means that it incorporates factors such as taxes in energy bills that can otherwise slip through in the determination of consumer marginal energy prices.

However, the method is not sensitive to energy tariff rate changes that occur within a monthly billing period. For instance, if a consumer has a time-of-use rate, the method is not refined enough to "see" it since it relies on a regression of monthly billing data. If time-of-use

rates or real-time rates become more prevalent, even in the residential sector, a marginal price estimation method that can better account for these types of rate structures would be needed. An offsetting factor would be the potential move toward higher fixed charges and lower variable charges.

APPENDIX A: RECS2001 Monthly Billing Data Variables

LBNL calculated the average and marginal energy prices for each sample household in 2001 using RECS 2001 billing data.[3] Along with household data, EIA collects billing data (for up to 16 billing cycles) for a subset of households in the total RECS sample. For each household with billing data, the RECS data set includes, for each billing cycle: the start and end date, the electricity cost in dollars, the electricity consumption in kilowatt-hours (kWh), the natural gas bill in dollars, and the gas consumption in hundreds of cubic feet. Variables used to calculate marginal prices included: DOEID, BDATE, EDATE, MDATE1 through MDATE16, and PERIODS, QUANT1 through QUANT16, and COST1 through COST16. For confidentiality reasons, the spreadsheets developed by the Department were given to EIA, which then provided the marginal price results together with the "r^2" value for the households with billing data.

Table A.1 RECS 2001 Billing Data Variables

Variable	Start Column	Length	Description
DOEID	1	4	ID number on the DOE version of the RECS Household File
BDATE	5	6	The meter reading date of the bill prior to the earliest bill in the record.
EDATE	11	6	The meter reading date of the most recent bill in the record
COMPANY	17	6	Company ID number
PERIODS	23	2	Number of billing periods (leading 0)
REASON	25	1	Reason fewer than 12 months: 1=Not at address for 12 months, 2=Not in company records, 5=0ther, 8=Unknown, 9=Not applicable
SOLDEL	26	1	B=Listed company marketed and delivered fuel, D=Listed company delivered fuel (marketer costs not included), S=Listed company is marketer (delivery charges not included)
UNITS[f]	27	1	Units reported by company: 1=Therms, 2=CF, 3=CCF, 4=MCF
MDATE1 to MDATE16	28	6	Meter reading date for billing period (MMDDYY)
QUANT1 to QUANT16	124	5	Quantity for Electricity in kilowatt hours (xxxxx) and for Natural Gas in CCFs (xxxx.x)
RDTYPE1 to RDTYPE16	204	1	Source of Information: A=Actual, E=Estimated, R=Customer read S=Split bill, 6=DK, 8=NA
COST1 to COST16	220	5	Bill amount ($$$.cc)

[f] This column is blank for electricity data.

APPENDIX B: Determining Missing Marginal Prices

1. Import into Excel RECS housing records with the values: DOEID, Census Division and Large State, Heating Degree Days, and Cooling Degree Days.
2. Name three worksheets "HousingwithElecMP," "HousingwithoutElecMP," and "ImputationResults.".
3. From the RECS2001 data separate the housing records into two group: those with marginal energy prices and those without.
4. In the "HousingwithElecMP,"create six rows (See Figure B.1):
    a. On the first row, create a header that identifies the area where households without electricity marginal prices will be assigned a marginal price.
    b. Also in the first row, create an index cell that will refer to an index cell on the worksheet "HousingwithoutElecMP"
    c. On the second row create headers for the information that is going to be imported from worksheet "HousingwithoutElecMP": DOEID, Census Division, HDD, CDD, and Average Electricity Price
    d. The third row will include the imported data and the calculation of the closest household.
    e. The fifth row, create a header that identifies the area where the data for households with electricity marginal prices will be placed.
    f. In the sixth row, create columns that place the housing identification number in the first column, the census division and large state in the second column, heating degree days in the third column, cooling degree days in the fourth column, average electricity price in the fifth column, and the distance formula calculation (from section 4.3 of this report) in the sixth column.
    g. Copy the records with marginal prices onto the "HousingwithElectMP" and sort the housing records by census division and large state.

Household without Electricty Prices			Index =	1				
ID	Division + 4	HDD	CDD	ElecPrice	**Closest ID_1**		MAX HDD	MAX CDD	MAX ElecPrice
1077	1	5312	777	0.12896	3285		10045	5161	0.401559454
Households with Electricty Prices									
DOEID	Division + 4	HDD65	CDD65	ElectPrice	Calculation				
1004	1	5978	671	0.08480686	0.130				
1046	1	5053	903	0.100936411	0.078				
1047	1	5053	903	0.103050936	0.074				
1058	1	5791	781	0.105167274	0.076				
1078	1	5053	903	0.108335252	0.062				
1094	1	5247	820	0.103478011	0.064				

Figure B.1 Screen Shot of HousingwithElectMP Worksheet

5. In the "HousingwithoutElecMP,"create four rows: (See Figure B.2)
    a. On the first row, create a header that identifies the area is where the data for households without electricity marginal prices lies.
    b. Also in the first row, create an index cell.
    c. On the second row, create columns that place the Index in the first column,

imputed household DOEID in the second column, and data from the household without electricity prices: housing identification number of the household in the third column, the census division and large state in the fourth column, heating degree days in the fifth column, cooling degree days in the sixth column, and the average electricity price in the fifth column.

d. The third row will be a copy of the fourth row without an index number. This row serves as the "sample calculation row" for excel to repeat the same calculation to all households.

e. To complete the calculations on all households without electricity prices, we will use the Data Table function in Excel. Select cell A3:B? (where ? represents the last row of data of households without electricity prices). Then from the menus choose "Data", "Table". When the Table dialog asks you to identify the cell reference for the input cell, then type in F1 (index number cell) in the "Column input cell" box.

Households without Electricty Prices				Index =	1	
Index	ID_Imputation	DOEID	Division + 4	HDD65	CDD65	ElecPrice
	3285	1077	1	5312	777	0.12896
1	3285	1077	1	5312	777	0.12896
2	5458	1109	1	5939	708	0.119986
3	4635	1124	1	5312	777	0.115197
4	1564	1178	1	5312	777	0.13052
5	4208	1230	1	5312	777	0.133607

Figure B.2 Screen Shot of HousingwithoutElectMP Worksheet

6. Extract DOEID's of households without electricity and their imputation ID's to the ImputationResultsElect worksheet. (See Figure B.3)

DOEID	ID_Imputation				
1077	3285				
1109	5458				
1124	4635				
1178	1564				
1230	4208				

Figure B.3 Screen Shot of ImputationResultsElect Worksheet

APPENDIX C: RECS 2001 Variables Used in LCC Analysis

Using Microsoft ACCESS, the Department created a database containing a subset of the records and variables from DOE's Energy Information Administration (EIA)'s RECS 2001.[1] The Department used this RECS subset in the life-cycle cost (LCC) analysis of the Residential Furnace and Boiler Rulemaking. This appendix explains the variable name abbreviations and provides definitions of the variable values. For the entire RECS 2001 dataset, refer to http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html.

The Department divided the RECS sample by product classes, using different classification algorithms based on fuel type, home type, (the presence of) central air conditioning, etc. (Table C.1). The variables can be categorized into five classifications: location, house characteristics, equipments characteristics, householder characteristics, and energy use.

Table C.1 RECS 2001 Variables Used in Life-Cycle Cost Analysis

Location	House Characteristics	Equipment Characteristics	Householder Characteristics	Energy Use
Census Region	Housing Type	Heating Equipment Type	YearX for Senior-Only Determination	Annual Heating Energy
Census Division	Year Made	Heating Equipment Age	Low Income	Annual Cooling Energy
Large State (NY, CA, TX, FL)	Square Foot	Heating Fuel	Renter	Gas Rate
Heating Degree Day 65	Weighting	Central Air Presence	Number of People in Household	Electricity Rate
Cooling Degree Day65		Central Air Age		Gallon of Fuel Oil
				Gallons of LPG
				Dollars of FO
				Dollars of LPG

APPENDIX D: Variables and Their Values From EIA's RECS01

This appendix explains the RECS variable name abbreviations and provides definitions of the variable values.

In the glossary below, the variable names are listed alphabetically. A brief explanation of the variable name as it appears in the database file follows the name. Definitions of the variable's values are listed below the name.

AGECENAC AGE OF CENTRAL A/C EQUIP
LESS THAN 2 YEARS OLD = 1
2 TO 4 YEARS OLD = 2
5 TO 9 YEARS OLD = 3
10 TO 19 YEARS OLD = 4
20 YEARS OR OLDER = 5
AS OLD AS THE HOME (IF VOLUNTEERED) = 6
DON'T KNOW = 96
NOT APPLICABLE = 99

BTUELCOL ELEC AIR COND USE EST IN THOUSANDS OF BTU
9999999 = NOT APPLICABLE

BTUFOSPH FO SPACE HEAT USE EST THOUSANDS OF BTU 9999999 = NOT APPLICABLE

BTULPSPH LPG SPACE HEAT USE EST IN KS OF BTU 9999999 = NOT APPLICABLE

BTUNGSPH NAT GAS SPACE HEAT USE EST THOUSANDS OF BTU
9999999 = NOT APPLICABLE

CDD65 COOLING DD TO BASE 65 1-97 TO 12-97
COOLING DEGREE DAYS ARE THE NUMBER OF DEGREES THE AVERAGE DAILY TEMPERATURE IS ABOVE THE BASE TEMPERATURE.
TO CALCULATE DEGREE DAYS:
AVERAGE DAILY TEMPERATURE (ADT) =
HIGH TEMPERATURE FOR DAY PLUS THE LOW DIVIDED BY 2.
COOLING DEGREE DAY (CDD) = ADT - BASE TEMPERATURE. IF HDD OR CDD = OR < 0, DEGREE DAY (DD) = 0.
CUMULATED DEGREE DAYS ARE IN WHOLE DAYS.

COOLTYPE TYPE OF AC EQUIP
CENTRAL SYSTEM = 1
INDIVIDUAL UNITS = 2
BOTH CENTRAL AND UNITS = 3
DON'T KNOW = 6
REFUSED = 7
NO ANSWER = 8
NOT APPLICABLE = 9

DIVISION CENSUS DIVISION
NEW ENGLAND = 1
MIDDLE ATLANTIC = 2
EAST NORTH CENTRAL = 3
WEST NORTH CENTRAL = 4
SOUTH ATLANTIC = 5
EAST SOUTH CENTRAL = 6
WEST SOUTH CENTRAL = 7
MOUNTAIN = 8
PACIFIC = 9

DOEID DOE 4-DIGIT IDENTIFICATION NUMBER

DOLLARFO ESTIMATED COST OF FO IN DOLLARS 99999 = NOT APPLICABLE

DOLLARLP ESTIMATED COST OF LPG IN DOLLARS 99999 = NOT APPLICABLE

ELECRATE LOCAL ELECTRIC RATE FOR 1000KWH AVERAGE RESIDENTIAL RATE, IN CENTS PER KILOWATT, OF ELECTRICITY COMPUTED FROM 1997 TYPICAL ELECTRIC BILL DATA. WHERE DATA WERE NOT AVAILABLE, A RATE WAS IMPUTED FROM KNOWN RATES IN AREAS NEAR THE HOUSEHOLD WITH MISSING INFORMATION. DATA INCLUDES AN ERROR TERM.
FIELD CONTAINS ONE IMPLIED DECIMAL PLACE.
999 = NOT APPLICABLE

EQUIPAGE AGE OF MAIN HEATING EQUIP
LESS THAN 2 YEARS OLD = 1
2 TO 4 YEARS OLD = 2
5 TO 9 YEARS OLD = 3
10 TO 19 YEARS OLD = 4
20 YEARS OR OLDER = 5
AS OLD AS THE HOME (IF VOLUNTEERED) = 6
DON'T KNOW = 96
NOT APPLICABLE = 99

EQUIPM MAIN HOME HEATING EQUIPMENT
STEAM = 2
CENTRAL WARM-AIR FURNACE WITH DUCTS = 3
HEAT PUMP = 4
BUILT-IN ELECTRIC UNITS IN THE WALLS, Etc. = 5
BUILT-IN FLOOR = 6
ROOM HEATER BURNING GAS, OIL, OR KEROSENE = 7
HEATING STOVE = 8
FIREPLACE = 9
PORTABLE ELECTRIC HEATERS = 10
PORTABLE KEROSENE HEATERS = 11
COOKING STOVE (USED TO HEAT HOME) = 12
EQUIPMENT NOT LISTED = 21
NOT APPLICABLE = 99

FUELHEAT MAIN HOME HEATING FUEL CON 3
NATURAL GAS FROM UNDERGROUND PIPES = 1
BOTTLED GAS (LPG OR PROPANE) = 2
FUEL OIL = 3
KEROSENE = 4
ELECTRICITY = 5
WOOD = 7
SOLAR = 8
DISTRICT STEAM = 9
SOME OTHER FUEL = 21

DON'T HEAT HOME = 00

GALLONFO EST GALLONS OF FUEL OIL BOUGHT 999999 = NOT APPLICABLE

GALLONLP EST GALLONS OF LPG BOUGHT OBS 6
999999 = NOT APPLICABLE

HDD65 HEATING DD TO BASE 65 1-97 TO 12-97
HEATING DEGREE DAYS ARE THE NUMBER OF DEGREES THE AVERAGE DAILY TEMPERATURE IS BELOW THE BASE TEMPERATURE.
TO CALCULATE DEGREE DAYS:
AVERAGE DAILY TEMPERATURE (ADT) = HIGH TEMPERATURE FOR DAY PLUS THE LOW DIVIDED BY 2.
HEATING DEGREE DAY (HDD) = BASE TEMPERATURE (E.G. 65 DEGREES) - ADT
IF HDD = OR < 0, DEGREE DAY (DD) = 0.
CUMULATED DEGREE DAYS ARE IN WHOLE DAYS.

LRG+DIV LARGE STATE AND CENSUS DIVISION DESIGNATIONS
NEW ENGLAND = 1
MIDDLE ATLANTIC LESS NY = 2
EAST NORTH CENTRAL = 3
WEST NORTH CENTRAL = 4
SOUTH ATLANTIC LESS FL = 5
EAST SOUTH CENTRAL = 6
WEST SOUTH CENTRAL LESS TX = 7
MOUNTAIN = 8
PACIFIC LESS CA = 9
NEW YORK STATE = 10
CALIFORNIA = 11
TEXAS = 12
FLORIDA = 13

LRGSTATE LARGE STATE DESIGNATION
NEW YORK STATE = 1
CALIFORNIA = 2
TEXAS = 3
FLORIDA = 4

NHSLDMEM NUMBER OF HOUSEHOLD MEMBERS
DON'T KNOW = 96
REFUSED = 97
NO ANSWER = 98
NOT APPLICABLE = 99

NWEIGHT THE FINAL WEIGHT
THE FINAL WEIGHT (REFLECTING THE PRODUCT OF THE PRE-SECOND STAGE WEIGHT AND THREE ADJUSTMENTS)

POOR100 BELOW 100 PERCENT OF POVERTY
POVERTY DEFINED AS 100 PERCENT OF POVERTY LINE. POVERTY LINE VARIES WITH HOUSEHOLD SIZE (1-9), AGE AND HOUSEHOLD INCOME. FOR HOUSEHOLD SIZE OF :
1 - AGE 65 AND OVER, LESS THAN $ 7,525
1 - AGE 64 AND UNDER, LESS THAN $ 8,163
2 - AGE 65 AND OVER, LESS THAN $ 9,491
2 - AGE 64 AND UNDER, LESS THAN $ 10,507
3 - LESS THAN $ 12,516
4 - LESS THAN $16,036
5 - LESS THAN $18,952
6 - LESS THAN $21,389
7 - LESS THAN $24,268
8 - LESS THAN $27,091
9 OR MORE - LESS THAN $31,971
POOR 100% = 1
NONPOOR = 0
NO ANSWER = 8

REGIONC CENSUS REGION
NORTHEAST = 1
MIDWEST = 2
SOUTH = 3
WEST = 4

SQFTREG MODEL-BASED EST. OF HEATED SQ FT
99999 = NOT APPLICABLE

TYPEHUQ RESP REPORTED TYPE OF HOME
MOBILE HOME = 1
SINGLE-FAMILY DETACHED = 2
SINGLE-FAMILY ATTACHED = 3
APARTMENT BUILDING WITH 2-4 UNITS = 4
APARTMENT BUILDING WITH 5 OR MORE UNITS = 5

UGASRATE LOCAL NATURAL GAS RATE FOR MCF AVERAGE RESIDENTIAL RATE FOR MCF OF NATURAL GAS COMPUTED FROM 1997 TYPICAL NATURAL GAS BILL DATA. WHERE DATA WERE NOT AVAILABLE, A RATE WAS IMPUTED FROM KNOWN RATES IN AREAS NEAR THE HOUSEHOLD WITH MISSING INFORMATION. DATA INCLUDES AN ERROR TERM. HOUSEHOLDS THAT DO NOT USE NATURAL GAS ARE CODED 9999 FOR NOT APPLICABLE.
FIELD CONTAINS TWO IMPLIED DECIMAL PLACES.

YEARMADE YEAR HOME BUILT
BEFORE 1940 = 1
1940-49 = 2
1950-59 = 3
1960-69 = 4
1970-76 = 5
1977-79 = 6
1980-86 = 7
1987-89 = 8
1990 = 9
1991 = 10
1992 = 11
1993 = 12
1994 = 13
1995 = 14
1996 = 15
1997 = 16
NOT APPLICABLE = 99

YEARS1 INFANTS IN HH UNDER 1
NOT APPLICABLE = 99

YEARS2 CHILDREN IN HH 1-12
NOT APPLICABLE = 99

YEARS3 ADULTS IN HH OVER 65
DON'T KNOW = 96
REFUSED = 97
NO ANSWER = 98
NOT APPLICABLE = 99

REFERENCE

1. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 2001,* 2001. (Last accessed May 18, 2005.) <http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html>

2. U.S. Department of Energy-Office of Building Technologies, *Technical Support Document: Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers - ANOPR Version,* 2003. U.S. Department of Energy. Washington, DC. Report No. LBNL-53984.

3. U.S. Department of Energy - Energy Information Administration, *RECS 2001 Billing Data,* 2001. (Last accessed March, 2005.) Data provided electronically to LBNL.