Teamwork in the Assessment of the Residential Market: California's Consortium Residential Appliance Saturation And Unit Energy Consumption Study

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ABSTRACT

For the first time in California, the large investor-owned utilities (IOUs) pooled resources and performed a residential appliance saturation and unit energy consumption (UEC) study as a team. The objective of the study is to inventory residential equipment and usage patterns as well as to model overall energy use by appliance. The study was designed to allow comparison of results across utility service territories, climate zones, and other variables of interest (i.e., dwelling type, dwelling age, heating type). The study includes results for 21,918 residential customers plus air conditioning and whole-house load data from 180 sites. This rich set of customer data includes information on all appliances, equipment, and general usage habits. The study also includes a detailed conditional demand analysis that calculates UEC values.

This paper describes the study design and implementation methods and an overview of the results. We draw some overarching conclusions about energy use throughout the state and discuss how different elements of the study aid in the development of these results.

The core study was completed in early 2004, and load shapes will be available in late summer 2004. The results will be useful for parties implementing, planning, and evaluating energy-efficiency programs in California.

Study Sponsorship

In an effort to consolidate planning across California, the California Energy Commission (Energy Commission) sponsored this Residential Appliance Saturation Study (RASS). While the study was overseen by the Energy Commission, there were five utility sponsors including: Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), Southern California Gas Company (SoCalGas), and Los Angeles Department of Water and Power (LADWP).[1] These five sponsoring utilities serve energy to the majority of Californian households. They represent just over 10 million households, which is 88% of the total households in the state when compared to California results from the 2000 census.[2]

Using a statewide survey instrument provided the Energy Commission and other parties with a consistent set of questions and study results to use for statewide planning and cross-utility comparisons. In addition, the sample includes sufficient data to enable utility-specific analyses.

The project required a cooperative effort among the sponsors to create a unified research plan, program materials, and implementation strategy. The sponsors shared project costs and final results. Each utility provided the data necessary to create a unified sampling plan and

[1] Sacramento Municipal Utilities District (SMUD) was also invited to participate, but declined.
[2] Census Data Source: Census 2000 5% PUMS for California

provided specific information for customers who were selected for the sample. To ensure individual customer anonymity, study participants were assigned a generic identification number that includes details about their sampling strata. Respondent ZIP codes are the only other information that is generally available in the final study database as to the customer's location.

Study Methodology

The project used a hybrid data collection strategy. Most of the survey data were collected using a mail survey. Telephone interviewing was used to gather data initially from electrically master-metered accounts (those with a single meter serving multiple dwellings or units) and to collect survey data from a sample of non-respondents to the mail survey. An in-person interview was also used to provide non-response follow-up. Finally, on-site meters were installed to collect hourly electric load data for both the whole house and central cooling system for a small sample of homes. In association with the meter installations, field surveyors gathered detailed heating, cooling, and building shell information about each targeted dwelling.

Sample Design for Individually Metered Accounts

The study used a stratified modified proportional sampling design using the utility population data from all four sponsoring electric utilities.[3] Separate strategies were used for the individual and master-metered sample frames. For individually metered customers, there were 105 strata based on 5 variables: electric utility, age of home, presence of electric heat, home type, dwelling type combined with usage, and Energy Commission forecast climate zone.

By assigning a minimum number of target completes per sampling cell, the sample ensured representation in each of the population segments. Likewise, higher mail-out rates were specified for groups that were likely to have lower response rates based on experience from prior RASS studies. The total individually metered sample was set at 100,999. The individually metered customers' response rate was 18.8% overall, with 2,260 responses coming from the non-response portion, which is described later. While the response was lower than projected, the overall volume of responses still yields results with reasonable confidence bounds. Sampling variability at the 90% confidence for the worst case (proportional estimate of 50%) varies across utility as shown in Table 1.

Table 1. 90% Confidence Bounds by Utility for Individually Metered Households (Includes Non-Response Follow-up Results)

Electric Utility	Population	Percentage of Total Population	Actual Completes	Percentage of Total Completes	90% Confidence Bounds (+/-)
PG&E	4,047,694	41%	9265	44%	1.9%
SCE	3,857,361	39%	7979	38%	2.0%
SDG&E	1,128,806	11%	2527	12%	3.7%
LADWP	879,001	9%	1382	7%	4.5%
Total	9,912,862	100%	21153	100%	1.2%

[3] SoCalGas' population data was not part of the electrically based sampling plan.

Sample Design for Master-Metered Accounts

Master-metered accounts were surveyed differently, depending on the type of units the account serves. All master-metered accounts were assigned to a stratum based on a proportional sample design that approximates the ratio of target completes to the number of units or dwellings (not accounts). For this study, we stratified master-metered accounts by utility and by type of account: master-metered accounts serving 2 to 4 units, mobile home parks with 5 units or more, multi-family complexes with 5 to 20 units, and multi-family complexes with more than 20 units.

Accounts serving two to four units were surveyed similarly to individually metered accounts. Master-metered accounts serving more than four dwelling units were surveyed using a two-stage method. In the *first* stage, we conducted telephone surveys with a facility manager of the multi-family complex or mobile home park to obtain data on the common area equipment and to obtain mail addresses for the dwelling units served by the account.

The *second stage* involved selecting a sample of units. We collected information on occupants from the facility manager and assigned the number of units per account type based on expected response rates. In all master-meter cases, we randomly selected addresses within the complex, entered information provided by the facility managers, and mailed the surveys. Customers completed the remaining portion of the unit-specific questions. The overall response rate for the master-metered sector was 13.7%.

Table 2 presents the sampling variability at the 90% confidence for the worst case for the master-meter accounts at the utility level.

Table 2. 90% Confidence Bounds by Utility for Master-Metered Homes

Electric Utility	Master Meter Population	Percentage of Total Population	Actual Completes	Percentage of Total Completes	90% Confidence Bounds (+/-)
PG&E	203,394	47%	382	50%	5.7%
SCE	153,954	35%	261	34%	6.0%
SDG&E	61,400	14%	120	16%	12.4%
LADWP	16,198	4%	4	1%	na
Total	434,946	100%	767	100%	4.0%

Direct Mail Survey Implementation

Survey packages were mailed out to all targeted customers. The survey package consisted of a cover letter, business reply envelope, scannable survey, and an outer envelope. There was no incentive. The survey was designed to capture as much information as possible to produce saturation estimates and calculate UECs as well as to collect some market intelligence information to help utilities better understand customers. The Energy Commission and all utilities participated in the design of the survey package.

Survey packages were mailed out third class. The first round of mailings yielded a lower response rate than was expected. A second batch of survey packages was mailed to customers who had not initially responded several weeks after the initial mailing. The second batch of surveys was also sent via third-class mail with the same materials. All surveys were processed with optical scanning equipment to expedite processing and ensure consistency.

Non-Response Follow-Up

To reduce the non-response bias that was likely to occur from the mail survey, a second surveying effort was made on a sample of 5,000 non-respondents to the mail survey. These customers were targeted using a combination of mail, telephone, and/or in-person contacts. The goal was to complete surveys for 2,500 of the non-respondents.

To most cost effectively gather non-respondent data from across the state, the sample was divided into two groups. More densely clustered ZIP codes were sampled with between 10 and 20 households per ZIP code, for a total sample of 4,395 in 229 ZIP codes. Less densely clustered ZIP codes were sampled with between 1 and 10 households per ZIP code for a total sample of 605 in 236 ZIP codes. Clusters were selected with probability proportional to size such that each non-respondent had an equal chance of being selected for the follow-up sample.

Clustered households were targeted using a third questionnaire mailing with a $1 incentive, follow-up phone calls, in-person solicitations, and door hangers with survey information in an escalating process to obtain a target number of responses within each sampled area. Data collection for non-clustered households included a USPS Priority Mail package sent to each household with a $5 incentive and the promise of a $15 incentive upon receipt of the completed questionnaire. The non-clustered households were then targeted with phone call follow-ups but did not receive in-person visits because of their disparate locations.

Response to the non-response follow-up effort was 47% of the eligible customers in the non-response sample. A total of 2,260 non-response surveys were completed. Almost a third of these responses came from the mail. The non-response first class package yielded 10.6% response. The priority mail package with high incentives yielded an impressive 32.4%. Response to telephone interview efforts was 12%, which was somewhat lower than expected because of difficulties getting customer phone numbers. In-person interviews yielded approximately a 34% response.

On-Site Metering

A subsample of the initial study targets was used for on-site metering. On-site meters were installed on 200 homes in the general population with an over-weighting of homes with air conditioning to capture more detailed information on this important end use. The on-site sample was designed to collect data from 50 homes without air conditioning (AC) and 150 with AC. The sample was drawn in a regionally clustered manner to control field costs while ensuring statewide data collection. The target sites were split into 6 categories and regionally selected such that there were 20 large geographic areas with 10 customers in each area. This strategy captured a ratio of AC to non-AC customers in each area in a way that mirrors the split in that climate zone with an excess of targets attributed to AC customers.

Cooling and total home hourly loads are being monitored with current loggers. Meters were installed throughout the state in the summer of 2003. Data are retrieved from the meters approximately every 4 months by field technicians. Because of turnover, changing participation willingness, or other conflicts, approximately 20 participants have dropped out of the study. We expect to have load-shape data for at least 180 sites at the end of the study. Final data collection will occur after the summer of 2004 and hourly load shapes for the whole-house and AC end uses will be developed after that point.

Survey Processing and Data Cleaning

Once surveys were received, they were processed using an optical scanning machine. The survey data were then cleaned using a customized cleaning process. The survey data were checked for multiple responses, logical non-responses, missing values, logical response inconsistencies, and fuel misreporting.

The billing data preparation involved both a standard data-cleaning task as well as a matching task. SoCalGas is the gas provider for customers who fall in SCE's, SDG&E's and PG&E's service territory. To obtain billing gas data for as many of the customers from the electric sample that are served by SoCalGas as possible, the study included a billing-data matching process that linked customer data between the utilities using the customers' name and address. This allowed for the usage-based gas and electric analyses.

Conditional Demand Analysis

A conditional demand analysis (CDA) was performed on the individually metered response data. The goal of the CDA analysis is to develop UECs using a method that yields the greatest precision. The underlying spirit of the approach is that a household's energy consumption is directly related to the stock of appliances present in the dwelling and the energy consumption levels associated with these appliances. Unit consumption, in turn, is related to specific features of these appliances, dwelling characteristics, and the household's utilization patterns. The analysis is built around a regression model where the customer's energy consumption is the dependent variable and the following items make up a series of independent variables.

Appliance stocks are generally defined for specific appliance types. Binary indicators (0,1) are used to indicate whether or not a particular system (e.g., central AC) is present, whereas cardinal variables (0,1,2…) are used to represent appliances (such as TVs or refrigerators) where multiple units may be present.

Appliance features include general characteristics like sizing, as well as efficiencies and auxiliary equipment. Features are included directly or indirectly by including variables that are expected to be correlated with the features (e.g., dwelling age, dwelling size, etc.).

Dwelling characteristics are most pertinent to space conditioning uses and might include dwelling age, insulation values, window types, and other thermal shell characteristics.

Utilization patterns cover thermostat settings as well as a variety of behavioral patterns relating to the use of other appliances. These utilization patterns are either captured by survey data or indirectly through the inclusion of market, weather, economic, and demographic variables thought to affect them.

As is the case with virtually any survey database, the survey dataset contained a number of missing values because customers left questions blank or provided inconsistent answers. Simply allowing these missing values to disqualify an observation from the regression dataset would create non-response bias in the estimation of model parameters. Replacing these missing values with overall means for the variables in question would also lead to biased estimates insofar as question-specific non-respondents tend to be different from respondents. To minimize non-response bias, we used a multi-step approach:

- First, a set of logit equations, each explaining the likelihood of responding to a specific question, was estimated. Once estimated, these equations were used to calculate an inverse Mills' ratio.
- Second, a regression model was used to calculate the predicted value of the missing variable. The inverse Mills' ratio is used in this regression model, as an independent variable, to control for non-response bias.
- Third, remaining missing responses were replaced with means drawn from the specific housing segment into which the household in question falls.

When multiple items need to be imputed for a single respondent, the joint distribution of these items becomes important. The project team used a range of imputation methods to insure that missing data were plugged in a way most appropriate for the respondent. Imputed values were then used in the CDA modeling process.

The final CDA model incorporated a subset of the customer survey data, site-specific energy usage, and local weather data. The UEC estimates are based essentially on the tendency for household consumption to vary as appliance holdings vary. If homes with electric water heating tend to consume more energy than homes without this appliance, all other things equal, this tendency will be captured by the estimate of the coefficient on the water-heating appliance variable. Each coefficient is interpreted as the increment in consumption due to the presence of the appliance in question, given the holdings of other appliances. The model is then used to create UEC values for a series of pre-determined end uses.[4]

Study Results

The CDA model produced UECs for both electricity and gas. There were several results that varied from previous studies. The most notable are electric space heating and AC, which are both lower than previous studies.[5] This is likely a result of the statewide electricity price increases and statewide 20/20 Program in effect during 2001 and 2002.[6] These two simultaneous effects combined to provide customers with a strong incentive to reduce their consumption. In the peak summer months, energy use dropped significantly, with roughly 30% of customers in PG&E's territory participating in the program.[7] While 2002 consumption was higher than that achieved in 2001, almost 50% of the conservation observed in 2001 persisted in 2002.[8] The CDA used 2002 billing data in the modeling process and thus was impacted by these effects. Figure 1 provides electric UECs.

[4] For a more thorough description of the CDA process, refer to: "The Total and Appliance-Specific Conditional Demand for Electricity in the Household Sector" The Rand Journal of Economics, Spring 1980.

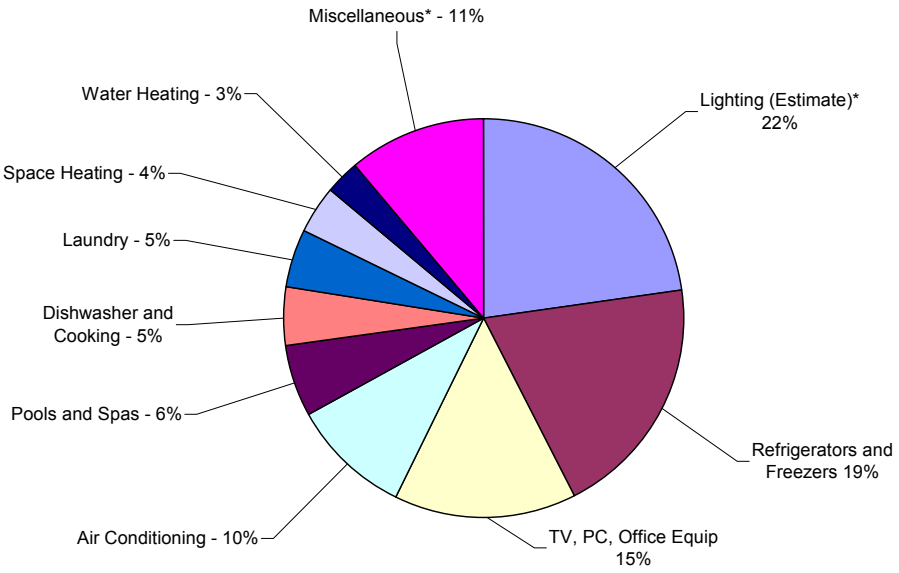
[5] Previous RASS studies were performed by SCE in 1995, PG&E in 1995, and SDG&E in 1993.

[6] Details on the 20/20 program can be found at the Energy Commission web site: http://www.energy.ca.gov

[7] PG&E press release dated 8/31/2002 which discusses 20/20 program savings in the residential market (http://www.pge.com/news/archived_news_releases/006a_news_rel/020831.shtml).

[8] Energy Commission Forecast Demand Office, April 2003, settlement-quality metered load data from the California Independent System Operator (CAISO) and revised employment data from the California Employment Development Department. Further detail is also available in the Public Interest Energy Strategy Report (Energy Commission Publication #100-03-012F).

Figure 1. Statewide Electricity Use per Household—5,914 kWh per Household



*Note: An estimate of 1,200 kWh per household (20% of the total use) has been designated as interior lighting and was shifted from Miscellaneous to Lighting where it is combined with exterior lighting usage. This number comes from other lighting studies[9] that are better able to pinpoint this estimate than a conditional demand model as was used for the RASS.

The UECs presented in Table 3 are a subset of the full CDA results and are displayed by dwelling type. The CDA results include individually metered customers by dwelling type; single-family dwellings make up 61%, multi-family dwellings 37%, and mobile homes 2%.

While air conditioning is a driver of peak use, it makes up only 10% of the overall household use. However, the saturation of central AC units is 41% for homes that were built before 1997 and 78% for homes built more recently so usage is likely to increase in the future. Interestingly, while the presence of central AC is rising and more programmable thermostats are being installed, the majority of homes with a programmable thermostat do not set back their thermostats, and homes with programmable thermostats do not differ from those without in terms of how they use the thermostats.

Lighting and refrigeration continue to have the highest UECs. Computer use is increasing, and the combination of TVs, PCs, and home office equipment now make up 15% of the total. This is a result of the fact that 69% of all homes have a computer and 23% of homes report using their home as a home office.

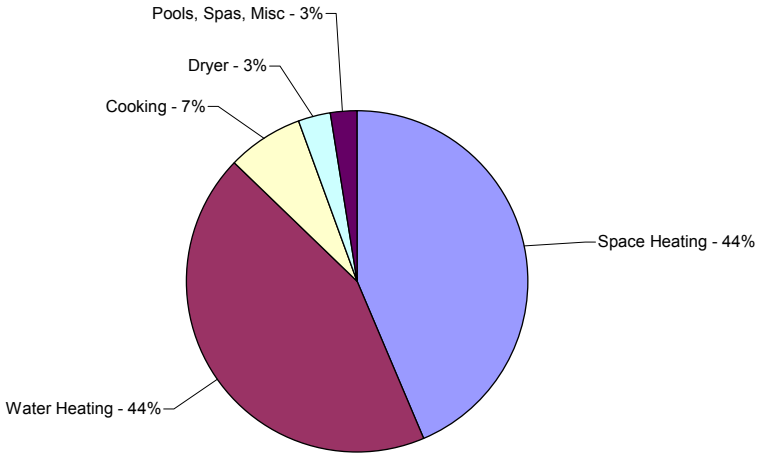
[9] Lighting numbers triangulated from Baseline Energy Use Characteristics, Technology Energy Savings, Volume I, California Energy Commission, May 1994, publication p300-94-006 as well as various KEMA-XENERGY RECAP Program results.

Table 3. Electric Unit Energy Consumption Summaries

	All		Single Family		Multi Family		Mobile Home	
	UEC	Saturation	UEC	Saturation	UEC	Saturation	UEC	Saturation
All Household	5,914		7,105		3,953		5,662	
Primary Space Heating	823	11%	1,409	5%	597	21%	1,124	13%
Central Air	1,236	41%	1,423	46%	803	32%	1,143	39%
Water Heating	2,366	7%	3,033	5%	1,591	9%	3,258	17%
Dryer	663	29%	713	34%	535	20%	549	42%
Clothes Washer	108	74%	127	95%	45	39%	11	86%
Dish Washer	77	61%	84	70%	62	48%	47	55%
First Refrigerator	789	100%	824	100%	731	100%	809	100%
Add'l Refrigerator	1,178	18%	1,245	25%	673	6%	1,143	13%
Freezer	935	18%	937	24%	917	6%	951	30%
Outdoor Lighting	264	54%	284	67%	201	33%	232	56%
Range and Oven	263	42%	301	41%	209	46%	208	27%
Televisions	490	95%	519	96%	442	94%	457	93%
Computers	565	69%	578	75%	542	59%	458	45%
Indoor Lights & Miscellaneous	1,819	100%	2,134	100%	1,319	100%	1,434	100%

Average annual natural gas use is 431 therms per household with a gas account.[10] Overall, 82% of the customers from the electrically based population have gas accounts. Figure 2 provides the gas breakdown by end use.

Figure 2. Statewide Gas Energy Use



One of the highlights is the difference between new (built after 1996) and old dwellings. New dwellings are 42% larger than the average existing stock and have a higher average income. They also have central AC installed at almost double the rate of existing dwellings. The overall usage increase from older to newer dwellings is lower than might be expected using these facts

[10] Because the sample was electrically based, the resulting gas UEC for the population is 356 therms per household across the electric sample. However, this result is not fully representative of statewide use because of overlapping gas and electric service territories.

alone. Statewide, new dwellings use 20% more electricity and essentially the same amount of gas. In addition to the energy savings achieved on account of improved building standards, conservation equipment is going into newer dwellings at higher rates, which is helping to control the rate of energy consumption growth. Table 4 provides a comparison of the new and old dwelling results.

Table 4. Comparison of Newer and Older Dwellings

	Newer Dwellings (Built after 1996)	Older Dwellings	Percent Difference
Dwelling Size	2,061	1,448	42%
Number of Residents	3.15	2.95	7%
Income	87,402	58,978	48%
Percent Single Family	74%	58%	28%
Owners	83%	62%	35%
Annual Electric Household Consumption	7,035	5,846	20%
Annual Gas Household Consumption	434	430	1%
Saturation of Central AC	78%	41%	93%
Cooling Degree Days	962	900	7%
Cooling Degree Days (those with CAC)	1,207	1,250	-3%
Programmable Cooling Thermostat	85%	47%	83%
Pool Saturation	13%	8%	59%
Average Number of Computers per Home	1.21	0.93	30%
Gas Primary Heating	86%	83%	5%
Heating Degree Days	2,050	2,023	1%
Exterior Wall Insulation	91%	51%	77%
Attic Insulation	91%	66%	38%
Double Pane Windows Throughout	79%	31%	157%
Low Flow Showerheads	83%	65%	27%
Average Number of CFLs per Home	2.29	1.74	32%
Horizontal Access Washers	13%	9%	43%

Effect of Combining the Main Sample and Non-response Follow-Up Sample

To combine the results from the main sample and the follow-up efforts, the study combined the weights from both components to create a set of individual weights that represents the number of households that each participant represents. Instead of fully weighting the non-respondent results to represent all non-respondents, the follow-up sample weights were reduced in a systematic approach. This assumed that the follow-up sample represents only those customers who would respond to the follow-up survey but not to the main survey, rather than assuming the follow-up respondents represent all non-respondents to the main survey. This approach improved overall precision and reduced the likelihood of individual outlier cases in the non-respondent sample from skewing overall results. The non-response follow-up proved to be a

successful way to capture a segment of the population underserved by the direct-mail campaign. Table 5 shows several key results for customers by dwelling type and survey method.

Table 5. Comparison of Results by Surveying Method and Dwelling Type

	Single Family		Multi-Family (2-4 Units)		Multi-Family (5+ Units)		Mobile Homes	
	Initial Mail	Non-Response	Initial Mail	Non-Response	Initial Mail	Non-Response	Initial Mail	Non-Response
Completed Surveys	12,599	1,225	2,979	409	2,866	512	526	37
Weighted to Population	2,363,823	3,693,704	524,317	1,155,001	513,069	1,463,655	95,691	103,602
Average Electric Consumption	7,248	7,160	4,429	4,201	3,689	3,969	6,271	6,531
Average Gas Consumption	547	538	341	338	215	216	491	478
Average Dwelling Size	1,837	1,755	1,156	1,061	925	914	1,258	1,083
Average Dwelling Age	14.5	18.9	24.0	24.8	28.4	34.6	19.4	27.9
Average Number of People	2.88	3.42	2.53	2.74	2.10	2.68	2.30	2.22
Average Number of Seniors	0.53	0.30	0.38	0.13	0.37	0.15	0.74	0.42
Average Income	73,389	68,714	54,246	47,346	45,388	41,702	30,971	28,807
Owners	91%	81%	50%	26%	26%	13%	87%	89%
Central Cooling	50%	47%	40%	33%	41%	31%	60%	38%
Gas Space Heating	85%	89%	77%	75%	46%	54%	57%	56%
All Exterior Walls Insulated	56%	61%	45%	48%	43%	44%	65%	59%
CFL Penetration	63%	50%	55%	42%	51%	37%	57%	51%
Primary Language English	92%	80%	85%	67%	87%	69%	95%	81%
Head of Household Hispanic	12%	26%	17%	36%	13%	33%	9%	20%
College Grad or Higher	53%	44%	47%	39%	50%	36%	23%	18%

In general, non-respondents had similar energy usage and major equipment holdings as direct-mail participants but differed significantly in that they were less likely to be property owners, less likely to be using energy-efficient lighting, more likely to be non-English speaking, more likely to be ethnically diverse, and less educated overall. It follows from this that the direct-mail campaign was most successful with individuals who were more aware of energy efficiency, were more motivated because of their ownership, more educated, and more capable of handling an English survey. The non-response follow-up was able to get to more Spanish-speaking customers. While the non-response follow-up adds significant cost to a project of this magnitude, the fact that customers differ in these ways indicates that it is a wise step to take to minimize non-response bias found in a single-method survey approach.

Comparison to Census Data

To understand how the results correspond to the population of California, we compared 2000 census data to the RASS results. Overall, the comparison of the RASS demographic information to the 2000 Census data is reasonable, and the sampling plan yielded a set of customer respondents that closely mirrors the population at large. The most notable area where the study appears to fall short is in the single-occupant rental market. The shortfalls occur predominantly in the young-adult age groups. Because the results aligned with census data, the study group decided to keep the initial sample weights and not post-stratify the results.

A few of the Census-to-RASS comparison values (most notably ethnicity and language) were asked in a different format from the Census so comparisons are not directly relevant. Despite language results that differ in form enough that a comparison is not meaningful, the fact that our Hispanic ethnicity numbers come out very close to the Census helps to confirm that we were able to capture results from that population segment. As noted above, this is in large part because of the non-response follow-up efforts. A series of comparison tables is included below as Figure 3.

Data Presentation

The data provided in this report as well as copies of the report write-ups are available on the Energy Commission's web site at http://www.energy.ca.gov/reports/index.html. The saturation data are presented in banner tables that display survey responses by several categories, including utility service territory, climate zone, heating and water heating fuels, and demographics such as income. The UEC tables are also provided in a number of formats to show how the values vary across reporting categories. The project also included an interactive web site designed to allow more flexible data review and reporting. The web site includes a process for filtering data as well as producing cross tabulations for individual sections of survey questions or specific survey responses. The web site is still under development at the time of this writing but will be in place in the summer of 2004.

Methodology Conclusions

The RASS study's primary objective is to create a broad database that can be used for a wide variety of follow-on activities and research. This study met that objective. While the response rate was significantly lower than anticipated, the sheer volume of responses is sufficient to create an acceptable basis for reviewing energy use throughout California. Future studies will need to adjust materials, incentive considerations, and delivery mechanisms accordingly to most cost effectively gather responses.

The non-response effort provided a valuable adjustment to the results, as it was able to capture data from a different market segment than the customers who responded to the initial direct-mail package.

Energy Usage Conclusions

Energy use in California is 5,914 kWh per household for electricity and 431 therms per household with gas. These numbers provide the baseline for the UEC results presented. The

CDA results provide opportunities to review the energy usage data from a number of different perspectives. Some of the areas of most interest are the growth of discretionary appliances such as home office equipment and computers, the huge increase in the saturation of central AC in new homes, and the fact that while new homes are increasing in size and adding more equipment, these increases are tempered by the energy-efficiency improvements and equipment found in the newer dwellings.

Figure 3. Comparison of RASS Results to 2000 Census Results