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PG&E Refrigerator Rebate Evaluation
1992 Field Monitoring Report

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PG&E

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Creators of CheckMe!®

I. Summary

PG&E undertook this study to assess the accuracy of the engineering calculations used to estimate the savings form its refrigerator rebate programs. Under contract to PG&E, Proctor Engineering Group, working with PG&E's metering technicians, Barakat and Chamberlin, Inc. and HBRS, Inc., collected and analyzed metered data on the consumption of efficient refrigerators purchased by PG&E customers. A separate study carried out at the same time has assessed PG&E's assumptions about the effects of the rebate programs on the marketing and sales of efficient refrigerators.

OBJECTIVE AND SAMPLE DESIGN

The primary objective of the study was to determine whether the electricity consumption estimates shown on Federally mandated refrigerator labels[1] accurately reflect consumption of refrigerators installed in customers' homes. In particular PG&E wanted to study whether these labels are an accurate basis for estimating the difference in electricity consumption between refrigerators of different efficiencies.

Two groups of refrigerators were selected in a matched sample design. One group contained models between 10% and 15% more efficient than the Federal standard, and the second group contained models 30% to 35% more efficient than the standard. In order to minimize the factors that would contribute to differences in electricity consumption, all models were 17 to 21 cubic feet in size and had top-mounted freezers and automatic defrost, and none had through-the-door features. The two groups were also matched closely for size, presence of an internal automatic ice maker, and climate zone. According to the labels for the metered refrigerators, the 10-15% group should consume 879 kWh per year, and the 30-35% group should consume 692 kWh per year, for an expected difference of 187 kWh per year.

[1]These labels show an estimate of the annual electricity consumption based on a laboratory test procedure established by the Federal Department of Energy as part of its program of minimum energy efficiency standards for refrigerators.

METERING

Customers were recruited in the summer of 1992. A PG&E metering technician visited each home and installed a 120-volt meter on the refrigerator, which was set to collect hourly consumption data. While in the homes, the technicians collected information about the location and operation of the refrigerators and about the household occupants. Meters were installed in August 1992 and read in September 1992. This study is based on an analysis of 15 calendar days of data beginning September 9, 1992, from 119 refrigerators in the 10-15% group, and from 112 refrigerators in the 30-35% group.

ANALYSIS

Multivariate regression analysis was carried out to test the influence of up to 32 different variables on the metered electricity consumption of the 231 refrigerators. Significant influencing factors were found to be the local outdoor temperature, number of household occupants, presence of an automatic ice maker, whether the refrigerator's anti-sweat heater was turned on, and, of course, the labeled efficiency of the refrigerator. Using these regressions, the metered data were used to estimate the relationship between the average outdoor temperature and the expected annual electricity consumption for each of the two groups. Since a full year's data were not available, this relationship was then used, along with the average annual temperature in PG&E's service territory, to estimate average annual electricity consumption for the two groups of refrigerators.

RESULTS

The difference in average annual electricity consumption between the two metered groups was estimated to be 154 kWh per year. At a 95% confidence level, the difference in consumption between the two populations from which the metered samples were chosen was estimated to be from 97 to 212 kWh per year.

CONCLUSIONS AND RECOMMENDATIONS

The estimated difference in annual consumption derived from the Federal labels for the two metered groups is not statistically different from the difference in consumption through this metering study. Metered data should be collected for an additional six months to further test this conclusion.

II. Introduction

The 1992 Field Monitoring was undertaken as a portion of the Pacific Gas and Electric Company's Refrigerator Rebate Evaluation. In 1990, 1991, and 1992 PG&E offered rebates for high efficiency refrigerators purchased for use in its service territory. The program offered rebates that varied by efficiency category (eg. 10-15% more efficient than 1990 Federal Standards, 15-20% better, etc.)

PG&E estimated the savings for each category of rebated refrigerator by multiplying the number of participants in that category by the annual kWh savings expected per refrigerator in that category. The annual kWh savings were based on estimates of annual energy consumption determined by Federally specified laboratory test procedures. (Those test results appear on the yellow label displayed on all new refrigerators offered for sale in the United States.) The savings per refrigerator was estimated as the difference between the labelled annual consumption for a refrigerator of typical size and efficiency in each category and a refrigerator of minimum efficiency.

The 1992 field metering study measured whether the actual energy consumption difference between two groups of rebated refrigerators varied from the difference estimated by the Federal lab tests. To test the actual difference, two groups of refrigerators were metered. They were:

- Group A -- Models that exceeded the efficiency standard by 10 to 15%. These refrigerators were eligible for a rebate in 1991.
- Group B -- Models that exceeded the efficiency standard by 30 to 35%. These refrigerators were eligible for a rebate in 1992.

This present study details the results of metering 231 refrigerators[2].

[2] In 1991 PG&E studied 20 refrigerators as a prelude to this evaluation. The results of that study are detailed in Pacific Gas and Electric Residential Refrigerator Field Metering Project, 1991 Case Studies (Proctor and Dutt, 1992).

III. Methodology

Matched pairs of refrigerators were sampled from Groups A and B. An hourly recording meter was installed on each refrigerator and data was analyzed by a multivariate regression technique. These regression models were used to estimate the average difference in annual energy consumption between the two groups.

SAMPLE SELECTION

One significant goal of the sample design was to make the two test groups as similar as possible. This makes the difference in rated efficiency the primary source of differences in energy consumption between the two groups. Refrigerator energy use may vary by size, freezer style (top-mounted, or side-by-side), presence of energy-consuming features (automatic ice makers, and anti-sweat heaters), temperature settings, kitchen temperatures, number of household occupants, clearances around the unit, and many other factors. The sample design attempted to control four important factors by matching the two groups by size, freezer style, presence of automatic ice maker, and ambient (outdoor) temperature (geographic matching).

Households who had purchased new rebated refrigerators in 1991 and 1992 were potential metering sites. In order to insure that the two groups would be comparable, the sample was confined to 17 through 21 ft^3 units with top freezer and automatic defrost. Three areas were chosen for these tests: Coastal (clustered near Hayward), Inland (clustered near Livermore), and Central Valley (clustered near Fresno).

The pool of potential metering sites was limited by the number of refrigerators in Group B. Group B refrigerators were randomly selected from a list of rebated customers that met the above criteria. Each Group B refrigerator recruited was matched with Group A refrigerators of the same volume and identically equipped with (or without) automatic ice makers. These matched units were recruited for inclusion in Group A. The list of rebated refrigerators was prepared by the Electric and Gas Industries Association (EGIA), which manages the rebate program for PG&E.

All potential participants were contacted by phone and offered an incentive of $100 to participate in the monitoring project.

DATA ACQUISITION

Refrigerator energy consumption was measured using a 120 volt version of PG&E's residential time-of-use meter. This submeter stored the total kWh for hourly time increments. Each location was visited by a PG&E technician who installed a submeter, completed a short interview with the occupant, and recorded one-time measurements of temperatures and other factors that might influence refrigerator consumption. Since the refrigerators in Group A were one year older than Group B, refrigerator coils were cleaned on all refrigerators. Meters were installed in August 1992 and read in September 1992. In order to assure that both groups were consistently represented over the same range of temperatures, the data used in this analysis is limited to days when data was available for most of the refrigerators. Those days cover a 15 day period beginning September 9, 1992. Complete data was available for 119 refrigerators in Group A and 112 refrigerators in Group B.

DATA ANALYSIS

Hourly data from each metered refrigerator was summed to daily total kWh, annualized (multiplied by 365), and matched with the average daily temperatures from the closest weather station. All the on-site data gathered by the technicians (about occupancy, presence of automatic ice maker, etc.) underwent extensive investigation to eliminate data errors. The on-site data set was matched with the metered data for use in a multivariate regression (multiple regression).

Multiple regression describes the linear relationship between one dependent variable (the estimated annual consumption from the metered data) and several predictor variables that influence the annual use (Velleman, 1989). This regression technique produces a refrigerator energy consumption model for each group based on predictor variables such as size, house occupancy, etc. The data available was reduced to 32 possible predictor variables. Regression models were developed for each group by testing combinations of these variables to obtain the best fit. Once a best fit was determined, regression diagnostics were run to determine the validity of the estimate.

In this case, the following variables proved to be significant: outdoor temperature, anti-sweat heater on or off, number of persons in the household, presence of an automatic ice maker, and estimated energy consumption from the lab test.

Appendix A contains additional information about the regressions including regression equations, t-statistics, and coefficients of determination.

IV. Results

The analysis of metering results from this sample produced an estimate of the difference in annual consumption of these two groups that is not statistically different from the figure derived using the Federal labels from each group.

CHARACTERISTICS OF THE SAMPLE REFRIGERATORS

The average characteristics of each monitored group are shown in Table 1.

Table 1. Characteristics of Monitored Refrigerators

	Adjusted Volume (1)	Average Outdoor Temp. (2)	Automatic Ice maker (3)	Persons per House	Lab Annual kWh (4)
Group A (10% group)	22.34	73.6°F	27%	2.9	879
Group B (30% group)	22.25	73.8°F	27%	2.5	692

(1) This is the adjusted volume calculated as 1.63 x freezer volume (cu. Ft.) + fresh food volume (cu. Ft.). This is the volume used to rate refrigerators in the Federal standard
(2) This is the weighted average outdoor temperature for each group during the test period. The range of temperatures is 62°F to 82°F.
(3) These are internal automatic ice makers only. None of the metered refrigerators had through the door features.
(4) This is the estimated annual consumption based on the Federally established laboratory test. This estimate is based on running a refrigerator at steady state in a 90°F room. The PG&E energy savings estimate is based on these numbers.

The sample design and matching methodology has produced two groups with virtually the same volume (the basis for the standard), that operate under the same average outdoor temperatures, and have the same percentage of automatic ice makers. While occupancy rate is different between the two groups, that difference is accounted for in the regression analysis. On the basis of the Federal lab test results, the expected difference in energy use between the two groups is 879 kWh - 692 kWh = 187 kWh. These two groups are well suited to determining whether the measured consumption difference is significantly different from the anticipated 187 kWh.

DIFFERENCE IN ANNUAL CONSUMPTION

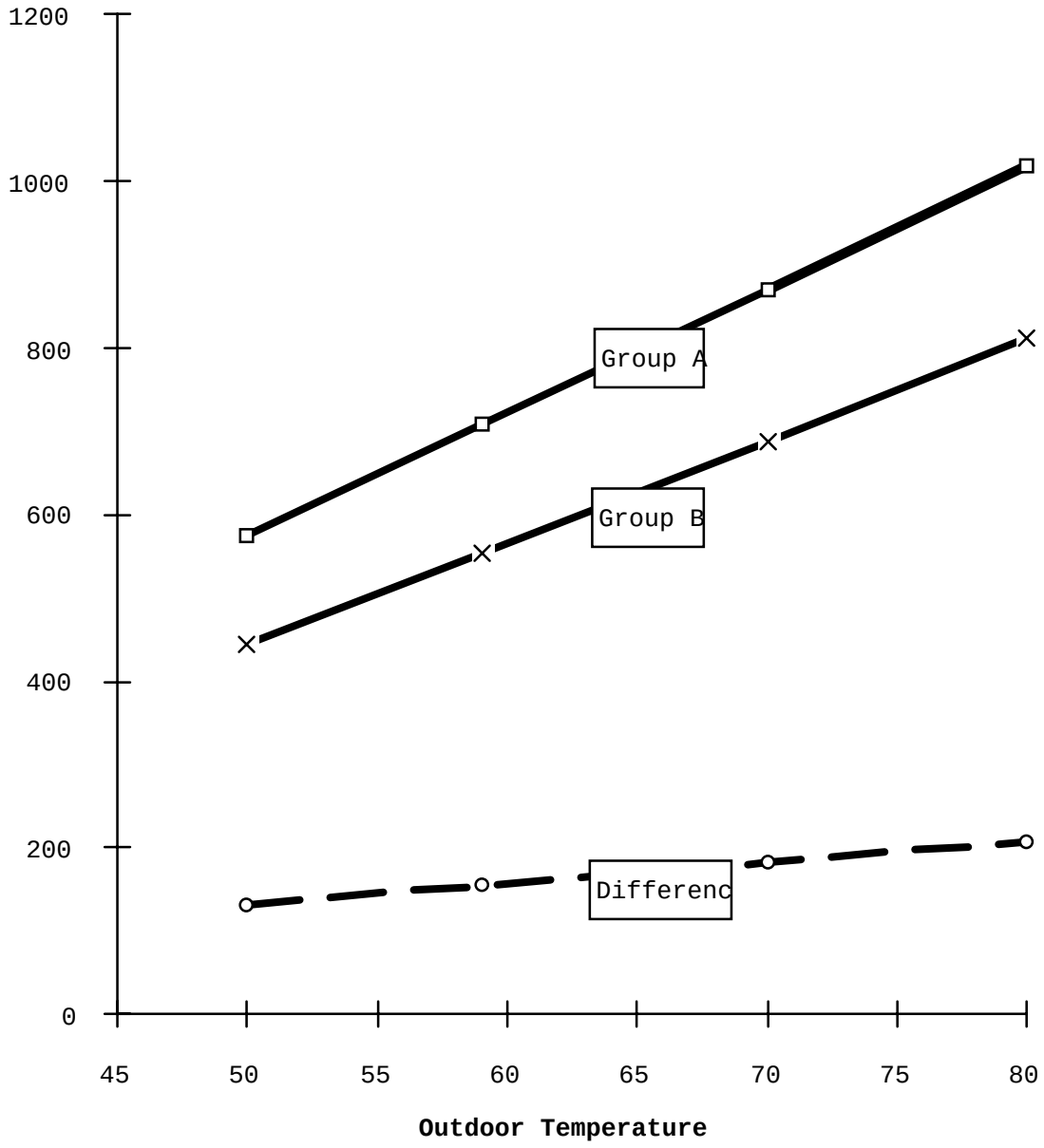
We know intuitively that the energy consumption of a refrigerator will increase as the kitchen temperature rises. Studies prepared for the Federal Energy Administration in 1977 (A. D. Little, Inc.) and by the National Bureau of Standards in 1979 (Chang and Grot) both showed that consumption increased as the difference between freezer temperature and room temperature increased.

The budget of this project did not allow for monitoring of kitchen temperatures. However, the 1991 PG&E refrigerator metering case studies showed that the daily average outdoor temperature was an excellent predictor of refrigerator energy use, since room temperature is affected by outside temperature. For three seasons of outdoor temperatures, over 90% of the variations in refrigerator group average energy use were predicted by variations in the ambient temperature ($R^2 > .9$).

In addition to refrigerator energy use changing with seasons, consumption will be higher in warm climates where kitchens remain warmer and lower in climates where the kitchens remain cooler. The regression analysis described above can be used to estimate the relationship between annual electricity consumption of each group of refrigerators and average outdoor temperature. Average annual consumption for these refrigerators can then be estimated as the point on the regression line representing the population-weighted average annual temperature for PG&E's service territory (59 degrees F). For this sample set this calculation involves extrapolation outside the temperature range of the 15 days of data. This extrapolation results in a substantially wider confidence interval than would be achieved with a larger sample of refrigerators metered over a longer period of time.

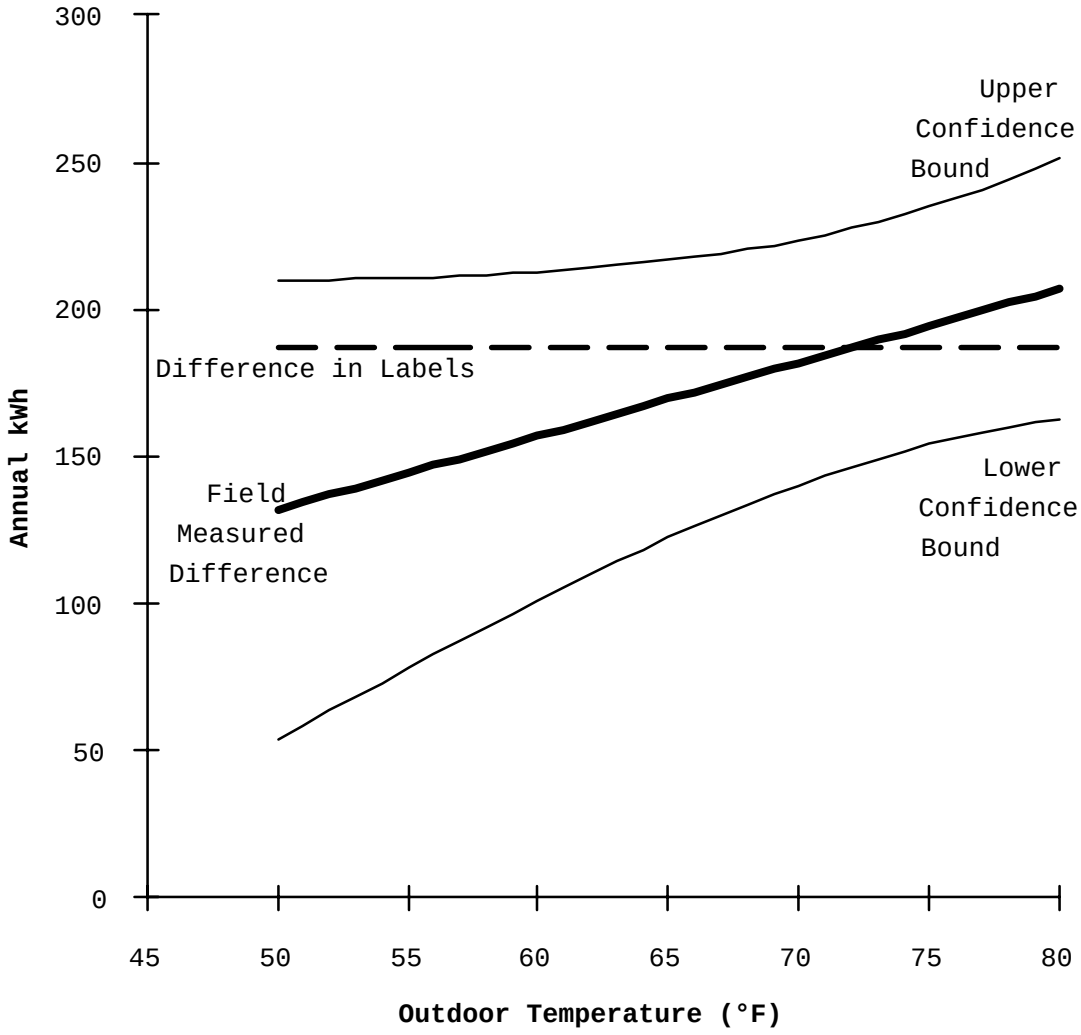
Using the regression techniques listed in the methodology section, the annual consumption as a function of average outdoor temperature is modeled. Figure 1 displays the results.

Figure 1. Annual Consumption vs. Outside Temperature



Clearly the energy consumption of these refrigerators is dependent on outdoor temperature. In addition, the difference in consumption (savings) decreases as the outside temperature drops. Figure 2 shows the projected annual savings at an average outdoor temperature of 59°F (the weighted average temperature for PG&E's residential customers). Also shown is the 95% confidence interval for the metered difference.

Figure 2. Field Measured Difference vs. Label Difference



The confidence interval is smallest at the mean of the sampled data. As the sample grows to include data in cooler weather, the precision of the estimate will be improved and the confidence band narrowed.

V Conclusions

For refrigerators represented by this sample, we conclude with 95% confidence the actual annualized consumption difference between the two groups is between 152 kWh and 231 kWh for an average annual outside temperature at 73.7°F (the mean of the sampled data). The actual annual difference in consumption at an average annual outside temperature of 59°F (the mean for PG&E's residential customers) will be less. With 95% confidence this difference will be between 97 kWh and 212 kWh. The expected value of 187 kWh, as predicted by the Federal label, falls within this range.

VI. Recommendations

We recommend that the planned sample extension to 300 meters be pursued and that 6 months of additional data be gathered. This will narrow the confidence band on the actual annual difference in energy consumption between these two groups of refrigerators.

On the basis of that additional data, the peak reduction due to differences in these refrigerators can be projected.

VII. References

Y-M. L. Chang and R.A. Grot, “Field performance of residential refrigerators and combination refrigerator-freezers”, NBSIR 79-1781, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., July 1979

Arthur D. Little, Inc., Study of energy-saving options for refrigerators and water heaters. Prepared for the Office of Transportation and Appliance Programs, Federal Energy Administration, Cambridge, MA, May, 1977

J. P. Proctor and G. S. Dutt, Ph.D., “Pacific Gas and Electric Residential Refrigerator Field Metering Project, 1991 Case Studies”, Proctor Engineering Group, Larkspur, CA, May, 1992

P. F. Velleman, Ph.D., Data Desk Statistics Guide, Volume II, Odesta Corporation, Northbrook Illinois, 1989

Appendix A

This appendix contains the results of the multivariate regression. The regression equations, the statistics, and how the equations were used are presented.

REGRESSION EQUATIONS

Equation 1.

GrA.AnnCons = -1730 + 14.8 X OutTmp + 150 X AsOn + 48 X #Pers + 111 X AuIce + 1.52 X LabCons

Equation 2.

GrB.AnnCons = -846 + 12.3 X OutTmp + 87 X AsOn + 46 X #Pers + 90 X AuIce + .70 X LabCons

Where:

GrA.AnnCons is	Estimated Annual Energy Consumption for Group A (kWh) (based on metered data)
GrB.AnnCons is	Estimated Annual Energy Consumption for Group B (kWh) (based on metered data)
OutTmp is	Daily Average Outside Temperature (°F)
AsOn is	Anti-sweat Heater On (0 or 1)
#Pers is	Number of Persons Reported in Household
AuIce is	Presence of an Automatic Ice Maker (0 or 1)
LabCons is	Reported Annual Consumption Based on Federal Lab Test (kWh)

REGRESSION STATISTICS

Table 2 presents the statistics for the multivariate regression on Group A data.

Table 2 **Annual Refrigerator Energy Consumption for Group A**

R^2 = 53.7% R^2 (adjusted) = 53.6%
s = 173.6

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	60457364	5	1e+7	401
Residual	52133930	1729	30152.6	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**
Constant	-1730.29	92.36	-18.7
Average temperature	14.7955	0.7493	19.7
Anti-sweat heater on	150.309	8.462	17.8
Number of persons in household	48.0000	2.610	18.4
Automatic Ice Maker	111.077	9.773	11.4
Laboratory Test Estimate	1.52316	0.0875	17.4

Table 3 presents the statistics for the multivariate regression on Group B data.

Table 3 **Annual Refrigerator Energy Consumption for Group B**

R^2 = 47.3% R^2(adjusted) = 47.2%
s = 131.5

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	25250818	5	5e+6	292
Residual	28105985	1625	17296.0	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**
Constant	-846.394	94.37	-8.97
Average temperature	12.2868	0.5847	21.0
Anti-sweat heater on	87.3016	6.680	13.1
Number of persons in household	46.0720	2.606	17.7
Automatic Ice Maker	90.2202	8.468	10.7
Laboratory Test Estimate	0.703966	0.1212	5.81

ESTIMATING THE DIFFERENCE IN ANNUAL CONSUMPTION

The purpose of this study is to estimate the difference between these Group A and Group B refrigerators (different only in lab test estimated energy consumption), as if they were operating in identical (average) houses over an entire year.

To estimate the annual consumption of Group A refrigerators under average conditions, the following values were substituted into Equation 1:

OutTmp	Average Annual Outside Temperature (59°F)
AsOn	Percent of Anti-sweat Heaters On for 231 Refrigerator Sample (45%)
#Pers	Average Number of Persons in 231 Sample Households (2.7)
AuIce	Percent of Refrigerators with Automatic Ice Makers in 231 Refrigerator Sample (27%)
LabCons	Group A Average Federal Lab Test Consumption Estimate (879 kWh)

Group B annual consumption was estimated substituting the above values for average households into Equation 2. The lab test estimate of Group B consumption was used as follows:

LabCons	Group B Average Federal Lab Test Consumption Estimate (692 kWh)

The annual difference in energy consumption between Group A and Group B was estimated by the subtraction shown in Equation 3.

Equation 3.

Difference in Annual Consumption = GrA.AnnCons - GrB.AnnCons