Large Scale Residential Refrigerator Field Metering

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Refrigerator efficiency is promoted through standards supplemented by utility incentives, with savings estimates based on consumption data as reported on appliance labels. How closely refrigerator energy consumption matches the label value, based on laboratory test data, was evaluated in a year-long study completed in August 1993. In the largest in-situ metering study to date, 256 new refrigerators in two efficiency categories were monitored at three locations within the Pacific Gas and Electric Co. (PG&E) service area. Hourly monitoring permitted the determination not only of energy consumption but also of the load shape, and how both depend on outdoor temperature. The effect of several other relevant parameters—including ice maker use, anti-sweat heater operation, coil location, number of persons in household, and fresh-food compartment thermostat setting—on energy consumption was evaluated using multivariate regression.

Simpler regression models, where only outdoor temperature is considered as a predictor variable, yielded identical estimates on annual refrigerator energy use as the more complex regression model. The regression coefficients obtained in this study can be used to estimate in-situ consumption of similar refrigerators in other areas using local temperature data, thereby extending the usefulness of the results.

In the PG&E service area, actual consumption was found to be 10% to 13% below label values.

Introduction

In the residential sector, energy efficient refrigerators offer one of the most effective opportunities for reducing electricity demand, and putting off or delaying the construction of new power plants and/or transmission and distribution facilities. In 1990, 1991, and 1992, Pacific Gas and Electric Company (PG&E) offered rebates for refrigerators that were more efficient than the (1990) Federal standards, as reported on the label. The amount of the rebate increased with efficiency, grouped as 10-15% better than the Federal standards, 15-20% better, etc. The labeled efficiency of refrigerators is based on a specified laboratory test procedure (ANSI/AHAM HRF-1-1988), also known as the DOE test.

A question has been posed: how closely does the labeled consumption represent energy consumption under actual use? This question becomes fundamental in utility Demand Side Management programs, such as the PG&E refrigerator rebate program, where investments in end use energy efficiency are intended to offset supply-side investments. For an accurate assessment of investment alternatives the costs and energy savings of DSM measures must be known.

The Pacific Gas and Electric Company Refrigerator Rebate Evaluation Monitoring Report (Proctor and Dutt, 1994) was intended to determine how accurately the electricity consumption reported on the refrigerator label reflects actual consumption in customers' homes. Specifically, PG&E wanted to study whether these labels are an accurate basis for estimating the differences in electricity consumption between refrigerators of different efficiencies. This paper summarizes a portion of that report.

Several studies have compared the field performance of refrigerators with laboratory test and/or labeled consumption (Meier and Heinemeier 1988; Bos 1993; Meier et al. 1993; Parker and Stedman 1992; etc.). Alissi, Ramadhyani, and Schoenhals (1988) looked for effects of ambient temperature, ambient humidity, and door openings—some of the most significant differences between the laboratory procedure and actual operating conditions—on energy consumption.

This 1992-1993 PG&E study differs in several ways from the previous studies. It represents the largest sample size of any refrigerator monitoring program, covering 256 units in all, monitored over a year. More relevant to the evaluation of a PG&E DSM program is that the measurements were conducted within the utility service area, representing both local climate and behavioral influences on energy use. Finally, the units tested were energy efficient units of recent vintage.

Methodology

This field monitoring study compared the actual energy consumption of refrigerators qualifying for the PG&E efficiency rebates with corresponding consumption figures reported on the refrigerator labels. For this study two groups were selected:

- Group S (the standard group) - Models that exceeded the efficiency standard by 10 to 15%. These refrigerators were eligible for a rebate in 1991.
- Group E (the efficient group) - Models that exceeded the efficiency standard by 30 to 35%. These were eligible for a rebate in 1992. These models meet the 1993 Federal standard.

Sample Selection

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 location).

The sample was confined to 17 through 21 ft^3 units with top freezer and automatic defrost and reflects the most common refrigerators bought under the rebate program. Three geographical areas were chosen: Coastal (clustered near Hayward), Inland (clustered near Livermore), and Central Valley (clustered near Fresno).

Group E refrigerators were randomly selected from a list of rebated customers that met the sample selection criteria. Each Group E refrigerator was matched with a Group S refrigerator of the same volume, identically equipped with (or without) an automatic ice maker, and located in the same area. The list of rebated refrigerators was prepared by the Electric and Gas Industries Association (EGIA), which manages the rebate program for PG&E.

Some sample bias was unavoidable. Group S customers bought refrigerators from the least efficient group of rebated refrigerators in 1991, while the Group E customers purchased refrigerators from the most efficient group of rebated refrigerators in 1992.

Data Acquisition and Analysis

An hourly recording meter (a 120-volt version of PG&E's residential time of use meter) was installed on each refrigerator to measure its energy consumption. At the time of meter installation, a PG&E technician interviewed the occupant(s), and recorded "snap shot" information on factors that might influence refrigerator energy consumption, including temperatures (fresh food compartment, freezer compartment, kitchen), number of people in household, use of an automatic ice maker, anti-sweat heater switch on or off, refrigerator thermostat setting, refrigerator clearances, whether the house had an air conditioner or an evaporative cooler, etc.

Since the refrigerators in Group S were one year older than those in Group E, refrigerator coils were cleaned on all units. Meters were installed beginning August 1992 and data collected until August 1993. After data attrition there were 136 metered refrigerators in Group S and 120 in Group E.

The data analysis consisted of six stages: 1) data checking and merging, 2) model development and diagnostics, 3) climate normalization, 4) analysis based on physical principles, 5) analysis of potential estimation bias, and 6) development of load curves.

All the data collected by the technicians (occupancy, presence of ice maker, etc.) were checked carefully to eliminate errors. Hourly data from each metered refrigerator were summed to daily total kWh, annualized (multiplied by 365) and matched with the average daily temperatures from the closest weather station.

The basic data analysis procedure is multivariate (multiple) regression. The measured annualized consumption is the dependent variable. The predictor variables are chosen to produce the best model (judged by statistical and practical analysis).

- Model 1 - annualized consumption against daily average outside temperature and several static variables (that do not change from day to day). This model has a data point for each day each refrigerator was metered (Group S, N=35239; Group E, N=31063).
- Model 2 - annualized consumption against daily average outside temperature. (Model 1 with only temperature variables)
- Model 3 - an aggregated regression of annualized consumption against daily average outside temperature. This model was limited to days when there were

data for at least 75 refrigerators in the group (N=302 for Group S and 299 for Group E).

These models were initially developed using an Ordinary Least Squares (OLS) analysis. This was followed by a General Method of Moments (GMM) for the preferred model. General Method of Moments provides a more accurate standard error estimate than OLS.

In order to be valid the model's assumptions need to be reasonable. Moreover, the regression coefficients need to be statistically significant and stable, physically meaningful, and internally consistent. [1]

Model 1–Analysis of Consumption of Individual Refrigerators

Model 1 was the precursor of the other models. For this model the electrical consumption of the refrigerator is a linear function of a number of predictor variables:

$$Ann.kWh = A + B \times vl + C \times v2 + ... \quad (1)$$

where: A is the intercept constant, B is the coefficient of predictor variable 1, etc.

The predictor variables include the daily average outside temperature and several static variables.

This model assumes that the effect of each of the predictor variables is independent (which implies that the effect of the static variables is the same over the whole range of the other variables). It also assumes that the effect of outside temperature is linear within a temperature range.

Model 1 was developed in four steps. First, potential predictor variables were identified and examined for interactions. Interactions between variables can cause regression coefficients to take on the effect of another variable, reducing or invalidating the physical meaning of the coefficients. Second, combinations of predictor variables were explored to create a model with good fit and apparently valid coefficients. In the third step, the final combination of predictor variables was selected. Fourth, the validity of the model coefficients was examined.

Step 1–Potential Predictor Variables. A total of 32 potential predictor variables were considered. The most significant are listed in Table 1.

Table 1. Significant Predictor Variables

Variable code	Description
Avg temp	average daily outside temp. °F nearest weather station
Icemaker	if on (=1), if not (=0)
Sweat	anti-sweat heater switch on (=1), off (=0)
Occupants	number of people in household
Frez temp	freezer temperature at technician visits, °F
Ref temp	fresh food temperature at technician visits, °F
Ref set	thermostat setting, between coldest (=100) & warmest (=0)
Lab kWh	label consumption data, kWh/yr
Adjusted vol	1.63 x Frez vol + Fresh vol, cu.ft.
AC	does house have an air conditioner? yes (=1), no (=0)

The mean values and standard deviations of the dependent variable and the 32 potential predictor variables are reported in Proctor and Dutt (1994). Of these, only Avg temp is based on daily data corresponding to the measurement of consumption; all others are based on prior information or on "snap shot" measurements taken at instrumentation and meter readings. Table 2 shows how closely the groups were matched on the more significant variables.

Groups E and S are not identical. When the variables are different and they significantly affect energy consumption, their differences must be accounted for in the final analysis. As long as the coefficients derived by Model 1 are statistically valid and physically meaningful, these differences will be corrected in the analysis.

Not all the predictor variables are independent, and this would affect the regression results. To determine the correlation of these variables, Pearson Product-Moment Correlations between the predictor variables (and the dependent variable) were computed, for each group. The correlation coefficients are listed in Proctor and Dutt (1994) and were used as one factor in selecting and evaluating the predictor variables for the regression (for example only the adjusted volume was used since it combined both fresh food and freezer volumes).

Step 2–Outdoor Temperature, Kitchen Temperature, and Air Conditioning. Refrigerator energy consumption increases with kitchen temperature (Meier et al. 1993). The large sample size of this study made the measurement of kitchen temperatures unnecessary. The ambient temperature variable chosen

Table 2. Summary Statistics for Significant Predictor Variables

	Group S	Group E	Dif.
	Mean [StDev]		
Avg temp	61.3 [12.2]	61.4 [12.1]	-0.1
Icemaker	0.243	0.281	-0.038
Sweat	0.532	0.447	0.085
Occupants	2.96 [1.69]	2.51 [1.29]	0.45
Frez temp(1)	5.3 [6.3]	5.5 [7.2]	-0.2
Ref temp(1)	37.6 [3.8]	39.1 [3.6]	-1.5
Ref set	54.2 [16.9]	63.8 [16.4]	-9.6
Lab kWh	875.4 [63.3]	694.6 [30.9]	180.8
Adjusted vol	22.47 [1.95]	22.39 [1.73]	0.08
AC	0.473	0.509	-0.036

1. "Snapshot" reading, not necessarily a reliable estimate of long term temperatures

was the daily average outside temperature (Avg. temp), easily obtained from a nearby weather station. Using the average temperature makes the data from this study useful in predicting energy consumption in other climates.

The kitchen temperature is only indirectly linked to the outside temperature. A space heating or air conditioning system and an interior thermostat setting temper the relationship between the two sets of temperature.

To explore the outdoor temperature/consumption relationship, the annualized consumption, aggregated by temperature bin, was plotted against average outdoor temperature for two subsets of the data. Group E (higher efficiency) refrigerators in the warmest location (Fresno) were selected and split between houses with and without an air conditioner. The results, smoothed by a lowess fit, are plotted in Figure 1.

In winter, a space heating system keeps most houses near a constant daily average temperature. Under these circumstances, the kitchen temperature would be nearly independent of the outside temperature and refrigerator energy consumption would be nearly constant.

When it is mild outside, the heating system is turned off in most houses, and the interior temperature tends to "float". Under these conditions, refrigerator energy consumption would track outside temperature.

All other factors remaining unchanged, refrigerator energy consumption will increase (roughly linearly) as the interior temperature increases. The nature of the interior-exterior temperature relationship explains the shape of the curves in Figure 1. Refrigerator energy consumption is less responsive to outside temperature below some value (reference temperature). Above the reference temperature, refrigerator energy consumption is likely to increase linearly with outdoor temperature.

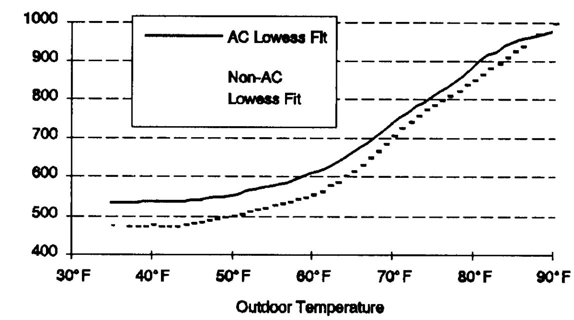

Figure 1. Effect of AC and Temperature on Refrigerator Energy Consumption

The refrigerator consumption in houses with air conditioning is higher over the entire range of outdoor temperatures (except the very highest). Since the air conditioner cannot cause the refrigerator to use more energy in the winter when it is not running, the higher consumption with AC in the winter is the consequence of an unknown indirect relationship.

The two curves converge at the highest temperatures, and the curve for homes with air conditioners is flatter above 83°F. This suggests that, at these temperatures, the air conditioners are likely to be operating and keep house interior at a lower temperature than their non-AC counterparts. Thus consumption does not increase as quickly with temperature as in the houses without air conditioning.

Step 3–"Elbow" Dependence on Average Outdoor Temperature. Based on the analysis of the Fresno data, the general model was developed to include an "elbow" response to outside temperature. This is accomplished by adding the variable Cool temp which is defined as (Reference temp - Avg. temp) below the reference temperature and zero elsewhere. The reference temperature is determined by iteration and corresponds to the value that gives the smallest sum of squares of the residual to the regression. This method of optimizing the break point of an elbow regression is familiar to users of the Princeton Scorekeeping Method (PRISM). The model takes the form of Equation 1 with the variable Cool temp included with the other predictor variables: Icemaker, Sweat, etc. The results for both groups in all locations are shown in Table 3.

Table 3. OLS Elbow Regression—Model 1 Reference Temperature 59° F

	Group S	Group E
Adjusted R squared	.611	.549
Standard Error of Residual	163 kWh	140 kWh
Coefficient Value [Std. Error]		
Constant	- 1174 [13.8]	- 786 [13.9]
Avg. temp	16.3 [.13]	13.9 [.12]
Icemaker	78.2 [2.18]	99.9 [1.93]
Sweat	137 [1.77]	73.3 [1.61]
Occupants	36.0 [.55]	21.9 [0.63]
Ref set	2.43 [.05]	1.62 [.05]
Adjusted vol	27.7 [.49]	13.7 [.51]
Cool temp	12.3 [.27]	10.5 [.25]

Step 4–Validity of Model Coefficients. Model coefficients that are statistically valid and stable, physically meaningful, and internally consistent can be confidently considered valid. [1]

The statistical validity of the coefficient was judged first by its t-ratio and second by the effect of its inclusion on the overall R squared and standard error of the regression (when using OLS). The stability was judged by how much it changed as other explanatory variables were added or deleted. Prior knowledge, including other field and lab studies as well as engineering estimates were used to determine if the coefficient could be physically meaningful. For the anti-sweat heater for example, regression coefficients were compared against lab results.

The coefficients for Average temperature, Occupant effects, and Icemaker represent the response of the refrigerator to equal increases in load. To be internally consistent, coefficients of the two groups must differ no more than the percentage difference in annual consumption as judged by the label consumption (with allowances for standard errors). This is called the Ratio Test. The percentage difference in the label consumption is 20% {(875-695)/895}.

How well Model 1 coefficients meet those criteria is summarized in Table 4 and detailed in Proctor and Dutt (1994).

Table 4. Validity of Model 1 Coefficients

Coefficient	Statistical Tests	Physical Meaning	Ratio Test
Avg temp	Yes	Yes	Yes (15%)
Icemaker	Yes	Yes	No (-28%)
Sweat	Yes	No	N. A.
Occupants	Yes	Yes	No (39%)
Ref set	Yes	Unkn.	N. A.
Adjusted vol	Yes	No	No (51%)
(Avg temp - Cool temp)[1]	Yes	Yes	Yes (15%)

1. This coefficient measures the increased consumption with increased temperature at temperatures below 59°F.

Step 5–Estimating Annual Consumption: Normalization. Since refrigerator energy use is highly dependent on temperature, it is necessary to normalize the metered results based on the climates of PG&E's residential customers. This normalization consisted of a bin analysis based on the weather conditions across PG&E's service territory. Based on the weather in each of the PG&E divisions residential meter weighted temperature bins were established. These bins represent the percentage of time the outdoor ambient temperature will be in that bin based on typical meteorological data. These bins are given in Proctor and Dutt (1994). Regression coefficients for Avg. temp and Cool temp were combined with bin temperature data to estimate annual consumption in a Typical Meteorological Year (TMY).

The weather normalization procedure can be used to estimate the energy consumption of similar refrigerators in other parts of the country if the appropriate temperature bin data corresponding to the geographical location are used.

Model 1 attempts to normalize for variables other than temperature. The non-weather related regression coefficients are multiplied by the average value of the appropriate parameter in Equation (1), e.g., multiplying the coefficient of "Occupants" by the number of occupants. If the regression coefficients are valid, Model 1 coefficients could be used to adjust to local demographics.

Model 2–Analysis of Consumption Based on Temperature Only

Model 2 is Model 1 with predictor variables limited to the daily average outside temperature. This model assumes that all other variables are extraneous variables that occur randomly in the selection process. The model takes the form of Equation (1) with the variable Cool temp included. The results for Models 2 and 3 are shown in Table 5.

Table 5. Elbow Regression — Models 2 and 3 Reference Temperature 59°F

	Group S	Group E
Coefficient Value [Std. Error]		
Model 2		
Constant	- 293 [62.8]	- 309 [46.1]
Avg. temp	17.4 [1.0]	14.6 [.75]
Cool temp	14.2 [1.4]	12.2 [1.0]
Model 3		
Constant	- 234 [20.8]	- 271 [20.1]
Avg. temp	16.6 [.31]	14.1 [.31]
Cool temp	12.3 [.56]	10.9 [.53]

The weather normalization procedure is the same as Model 1, and the normalized results are presented in Table 7.

Model 3–Analysis of Averaged Consumption Data

With Model 3 the varying effect of temperature from house to house, as well as the effects of other randomly distributed variables, is reduced by averaging the data. The averaged data closely corresponds to the diversified effect of these refrigerators viewed from PG&E's perspective. For each day the consumption for all the refrigerators in each group is averaged and this consumption is the dependent variable in the regression. The model takes the form:

$$Ann.kWh = a + b \times Avg\ temp + c \times Cool\ temp \quad (2)$$

where: a is the intercept coefficient, b is the coefficient of the 24 hour average temperature that day for the nearest weather station, and c is the coefficient of Cool temp (defined in the same manner as with Model 1)

This model has a number of assumptions. First, the effect of temperature is linear in both the cool and warm temperature regions. Second, aside from efficiency range, size, and the presence of an icemaker, all other variables that influence refrigerator energy consumption are randomly distributed among all the study refrigerators and between the two groups.

The model coefficients are shown in Table 5 and the temperature response is plotted in Figure 2.

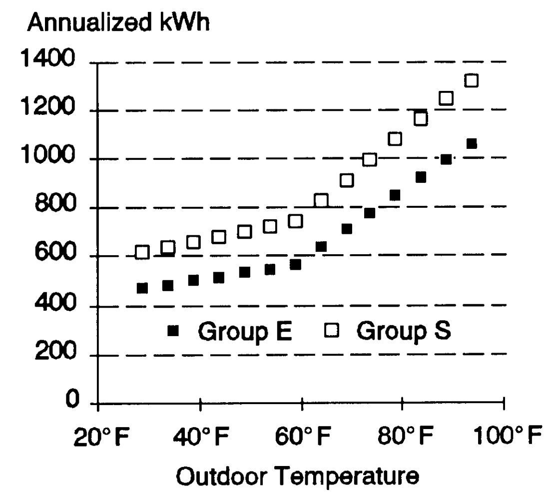

Figure 2. Model 3—Consumption vs. Outdoor Temperature

The weather normalization procedure is the same as Model 1, and the normalized results are presented in Table 7.

Differences in the values of significant explanatory variables between different populations will produce a biased estimate of annual consumption, which can be compensated for, as shown below, for the comparison of the two Groups in this study.

Correcting Annual Consumption for Estimation Bias

The sampled refrigerators were randomly selected from refrigerators that met the stratification criteria. In spite of this random selection, the two samples differed from each other on a number of significant parameters (see Table 2). Both the number of occupants and the percentage of anti-sweat heaters on were lower for Group E than they were for Group S. This would lower the metered consumption for Group E, and increase the difference between the two groups. This potential bias may be counteracted by colder refrigerator temperature dial settings for Group E, if those settings are representative of lower refrigerator and freezer temperatures.

The difference in anti-sweat heater operation may be a result of the refrigerator design, or it may be truly random. The difference in refrigerator temperature dial setting is likely just an artifact of the design. The numbers on the dial only show relative "colder" temperatures so 63% cold on one refrigerator may represent the same temperature as 54% on another (see Table 2). In fact the "snapshot" temperatures measured by the technicians (not considered a reliable measurement) showed Group E fresh food compartments 1°F warmer than those in Group S.

It is likely that the differences in occupancy came from the source of the two groups of customers. Group S customers purchased refrigerators from the least efficient group of rebated refrigerators in 1991, while the Group E customers purchased refrigerators from the most efficient group of rebated refrigerators in 1992.

The difference in consumption, estimated using Models 2 and 3, between the two groups of refrigerators is potentially biased because of differences in the number of occupants and the proportion of units with the anti-sweat heater on. The magnitude of this bias may be estimated in two parts as detailed in Proctor and Dutt (1994). The occupancy effect may be estimated from load shape data obtained in this study, while the effect of the anti-sweat heater operation may be obtained from reported laboratory test data (AHAM, 1991).

Estimation of Consumption Difference Based on Physical Principles

The difference in annual consumption between the two groups of refrigerators can be estimated based on physical principles, the labels, and metered results. The measured differences in the lab test (labels) establish a relationship between the two groups of refrigerators under identical conditions. The consumption differences are only due to differences in cabinet efficiency and/or Coefficient of Performance (COP). When these refrigerators are moved into identical homes and identical food and door opening loads occur, the difference in consumption can be estimated as shown in Table 6.

Development of Load Curves

Load curves were developed from the data in a process analogous to Model 3 using an ordinary least squares method. Data for each hour of the day are used for a total of 24 regressions. For each hour the diversified hourly load is modeled as:

$$\textit{Watts} = a + B \times \textit{Avg temp} + y \times \textit{Cool temp} \qquad (3)$$

Figure 3 shows the response for Group E for two different time periods, 5 to 6 AM (the usual minimum) and 4 to

Table 6. Estimated Difference in Annual consumption (Normalized to Group S Label)

	Refrig. S	Refrig. E	Refrig E˙
Laboratory Test (Labels)			
Cabinet load at 90°F	100%	79%	100%
COP	1	1	1.26
Label	100%	79%	79%
kWh use	(100/1)	(79/1)	(100/1.26)
In Identical Homes			
Cabinet load at kitchen T	75% (100 x .75)	60% (79 x .75)	75% (100 x .75)
Food & Door Load 15%			
Total load	90% (75 + 15)	75% (60 + 15)	90% (75 + 15)
In-situ kWh use	90% (90 / 1)	75% (75 / 1)	71% (90 / 1.26)
Difference		15% (90 - 75)	19% (90 - 71)

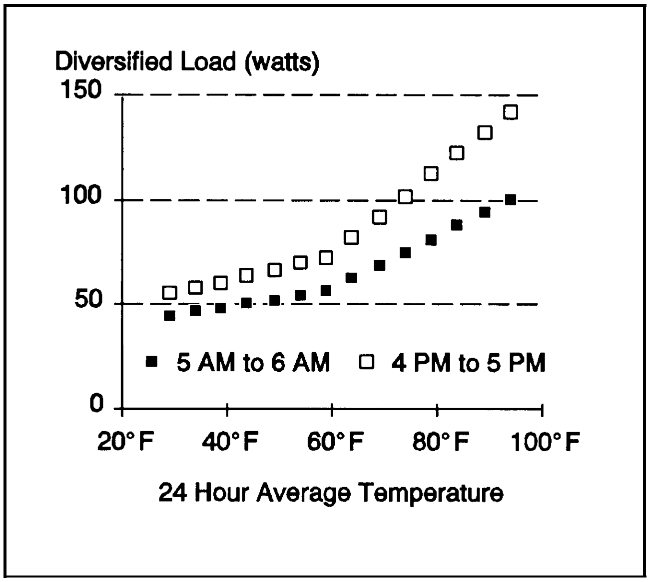

Figure 3. Group E—Diversified Load vs. 24 Hour Average Temperature

5 PM (near the time of system peak). The coefficients for each group are contained in Proctor and Dutt (1994).

The diversified load at any hour of the day is responsive to outside temperature. Based on the 24 regressions for each group a full day load curve can be plotted for any average outside temperature. Figure 4 shows the load curves for both groups at a daily average temperature of 87°F. This is the weighted 24 hour average outside temperature corresponding to the two hottest TMY days in PG&E's service territory.

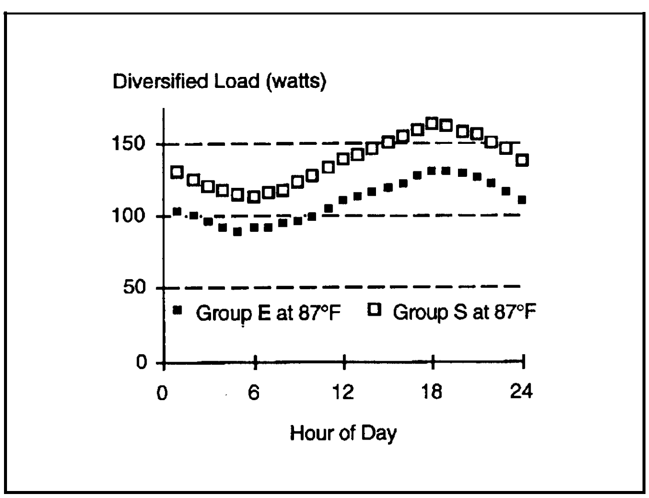

Figure 4. Diversified Load at High Temperature

After 6 AM, as breakfast is being prepared, the load curve begins to rise. As the effect of breakfast preparation begins to disappear, lunch, and then dinner preparation have their effect on refrigerator electric consumption. After 7 PM (hour 19) the consumption begins to fall back to its lowest point, which occurs near 6 AM.

Estimation of Occupancy Effect

An upper limit of the occupancy effect can be calculated assuming that the consumption above the 6 AM minimum is due to occupancy effects. In reality, daytime interior temperature (and refrigerator consumption) rises both from night setback (winter) and from temperature float (mild periods and summer without air conditioning). At any average temperature T (and cool temp C), the upper limit of the occupancy effect in hour i (OEi) is given by:

$$OEi = (\alpha i - \alpha 6) + (\beta i - \beta 6) \times T + (\gamma i - \gamma 6) \times C \quad (4)$$

For the year, the upper limit of the occupancy effect is:

$$OEyear = \sum_{j=1}^{14} \sum_{i=1}^{24} OEi \quad (5)$$

where there are 14 temperature bins for T and C (see Proctor and Dutt, 1994).

Principal Results

This study was designed to determine whether the differences in electricity consumption reported on the refrigerator label are an accurate basis for estimating the actual differences in electricity consumption between refrigerators. In addition we were able to determine:

- How accurately the electricity consumption reported on the label reflects actual consumption in customers' homes.
- What the relationship is between the label and the hourly load at different temperatures.

The estimated annual electricity consumption for each group and the consumption difference is reported in Table 7. While Ordinary Least Squares (OLS) techniques were used for exploratory data analysis, General Method of Moments (GMM) were used to improve error estimates for reasons described in Appendix D of Proctor and Dutt (1994).

The laboratory test procedure overpredicts the actual consumption of these refrigerators in the PG&E service territory and is likely to overpredict the difference between refrigerators by at least the same percentage (approximately 10%, based on Group S with 2.5 occupants per household).

Table 7. Metered Annual Consumption vs. Laboratory Estimate

	Group S [std.err.]	Group E [std.err.]	Difference ± 95% conf.
Model 1	784 kWh(1)	600 kWh(3)	184 kWh
Model 2	782 kWh(1) [14.5]	598 kWh(3) [11.4]	183 ±36 kWh
Model 3	787 kWh(1) [1.9]	602 kWh(3) [1.7]	184 ±4.9 kWh
Label	875 kWh(2)	695 kWh(2)	181 kWh(2)
Best Estimate			158 ±26 kWh(4)
Estimate from principles(5)			
Identical cabinets			≈162 kWh
Identical COP			≈131 kWh

1. Anti-sweat heater on 53.1%, occupancy 2.98 persons
2. Anti-sweat heater on 50%
3. Anti-sweat heater on 44.7%, occupancy 2.5 persons
4. Includes an estimated bias of 26 kWh [s.e. = 13.1 kWh] due to occupancy and anti-sweat heater use differences between groups.
5. Based on food load and other occupancy effects equaling 15% of standard unit label

Conclusions and Recommendations

The results of the present study lead to conclusions and recommendations in a number of areas.

Metered versus Labeled Consumption

- The laboratory test procedure overpredicts the actual consumption of these new refrigerators in the PG&E service territory by 10% to 14%. Labeled consumption should be reduced by about 10% for projecting differences in annual consumption or diversified load.

- The estimated difference in annual consumption derived from the Federal labels for the two metered groups (181 kWh) lies within the confidence bounds of the consumption estimated through this metering study. It should be noted that a potential sampling bias exists in the groups and that by physical principles, the in-situ difference would be at least 10% less than the labeled difference (for PG&E's service territory).

- Regression coefficients for average temperature and "cool temperature" from this study may be used to estimate energy consumption of similar refrigerators in other areas, if appropriate temperature data are substituted.

Diversified Load

- The electric load on new refrigerators can be described by 24 equations derived from the data in this study. The load curves from this study are representative of new top freezer frost free refrigerators and may be used for peak reduction projections with new refrigerators.

Effect of Controllable Refrigerator Features

- Refrigerator consumption is increased 100 to 125 kWh by the anti-sweat heater (according to the DOE test) and 75 to 105 kWh by an automatic ice maker. The anti-sweat heater and automatic ice maker can be the target of consumer education.

- The DOE test and label should be revised to show the effect of an automatic ice maker.

Endnote

1. While it can be argued that the regression coefficients do not have to be physically meaningful (because they are controlling for another factor omitted from the analysis), use of these variables as predictors is only

valid if their relationship to omitted variables is the same in the population as it is in the sample. After extensive work with this data, such an assumption does not appear valid.

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