

GEOGRAPHIC AND SEASONAL EFFECTS ON RESIDENTIAL END-USE LOADS

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ABSTRACT

Pacific Gas and Electric Company's Appliance Metering Project (AMP) is designed to provide information on residential end-use load patterns. Approximately 850 households in northern and central California have been metered to measure the loads of such end-uses as air conditioning, space heating, water heating, refrigeration, clothes drying, and cooking.

This paper will present the sampling methodology and implementation procedures used in the Appliance Metering Project and discuss the results of an analysis of end-use load shapes. Appliance saturations, household electricity consumption, and end-use load shapes are analyzed by season (summer versus winter) and by geographic zone (California's interior, central valley versus the remaining PGandE service territory).

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INTRODUCTION

In recent years, the field of energy forecasting has turned toward an end-use approach as utilities and state regulators have adopted end-use models to predict future load growth and to plan resource needs. Likewise, the field of load research has increasingly focused on collecting and analyzing end-use load data.

Pacific Gas and Electric Company's (PGandE) load research program includes a large-scale, residential end-use metering study, the Appliance Metering Project (AMP), which is designed to measure the load patterns of residential electric appliances. To date, approximately 850 residential households in northern and central California have been metered to measure the loads of such end-uses as air conditioning, space heating, water heating, refrigeration, clothes drying, and cooking.

End-use load research is gaining popularity as the application of end-use data is becoming more widespread. At PGandE, Appliance Metering Project data are planned for use in the following areas:

- o Peak demand and load forecasting - AMP data will serve as direct inputs to PGandE's peak demand and end-use forecasting models as part of the company's long-term resource planning process.
- o Rate design - AMP data will be used for designing and marketing rate and service options, such as time-of-use rates and baseline quantities, in the residential sector.
- o Conservation and Load Management - AMP data will be used to design residential load management programs, to identify target markets for conservation and load management, and to evaluate the impact of such programs.

This paper will describe the sample design and implementation procedures used in the Appliance Metering Project and present the results of an analysis of end-use load shapes.

* This paper is the product of the authors alone and does not necessarily reflect the views of Pacific Gas and Electric Company or its management.

SAMPLE DESIGN

The AMP sample was chosen from the population of individually-metered, single-family, owner-occupied households in the PGandE service territory.* From this population, the subpopulation of households in the hot climate zones within the service territory, mainly California's central, interior valley, were targeted for intensive sampling. The objective of this strategy was to sample households with air conditioning, as this end-use contributes significantly to PGandE's summer peak load. This strategy was accomplished by drawing two samples: 650 households from the target subpopulation (termed the A sample), and 200 households from the entire population (termed the B sample). Each sample was stratified geographically by PGandE divisions. The sampling and customer recruitment efforts took place over a twelve month period during 1983-1984.

A total of seven different end-uses were metered: air conditioning, clothes drying, space heating, refrigeration, water heating, cooking, and a generic kitchen end-use which included all end-uses in the kitchen except cooking.

For each household, three loads were metered. The total household load was metered at every site. The site-specific end-uses to be metered were randomly selected with two exceptions. First, households in the A sample always had the air conditioning load metered. Second, the kitchen end-use was metered only if there was no other end-use available for metering. In addition, both refrigeration and kitchen loads were never metered at the same site.

The principal goal of the sampling effort was to develop a sample that would provide accurate estimates of the end-use loads. Due to hardware limitations, only appliances (i.e., end-uses) on dedicated circuits were metered. In order to ensure statistical representativeness of the metered end-uses, priorities as to which appliances to be metered at individual sites were determined randomly. If at any site less than two end-uses were available for metering, then that site was judged unacceptable and was rejected from the sample.

Customers were recruited for program participation through a marketing campaign. Brochures were mailed to a sample of customers explaining how participation in the program worked. Customers were asked to return a postcard indicating interest in participating. Upon receipt of a response card, a PGandE representative visited the customer's home to determine if the site was suitable from a metering perspective and if the customer had the necessary appliances to warrant eligibility. A large number of sites were

* There are approximately 1.8 million such households within PGandE's total residential population of 3.7 million customers.

rejected because equipment could not physically be installed at the premise. In addition, the mail-out/mail-back marketing strategy initially yielded a very low customer response rate. Nonetheless, enough customers were recruited through several waves of marketing to achieve the current sample of 850 households. Upon installation, each customer was awarded a \$30 installation payment and, as an incentive to remain on the program, given the promise of \$30 per year for a maximum of five years.

DATA ANALYSIS

Methodology

Data Editing. The raw load data for each site consisted of 48 half-hourly loads on a daily basis for the entire household and for the two metered end-uses. The raw load data were checked for non-negative and excessively large values and verified that the sum of the two end-use loads did not exceed the total household load. All data failing either of these two tests were set to missing. Although this is a multi-year study containing data from 1984 through 1986, the data used in this analysis were restricted to 1985. Additionally, for all calendar months, load data for any given total house or appliance were required to have at least 25 non-missing days. This criterion was applied in order to exclude data for those months with at least five days of equipment failure. Load data failing this criterion were excluded from the analysis for that month. The 25-day requirement was also intended to screen-out a household's first month in the study, since most meters were installed after the fifth day of the month.

Sample Biases and Analysis Weights. For all households in the study, sampling analysis weights were developed. These weights compensate for the two major, known biases in the sample -- geography and socio-economic status -- which were discovered during an extensive analysis performed to evaluate the representativeness of the sample.

The discovery of these two biases is not altogether surprising. As described in the sample design section above, the sample was obtained through a combination of volunteer self-selection and a geographic/air conditioning stratification design. Consequently, the geographic bias occurred largely by design. The socio-economic bias also occurred largely by design, due to the sampling requirement of air conditioning for a large part of the sample and to the volunteer nature of program participation.

Load Shape Estimation Procedures. All load data are presented at an aggregate level for two geographic regions: the Central Valley of California and the remaining PGandE service territory (referred to as the Coastal/Mountain area). These aggregate level load data were obtained by using average customer load shapes in conjunction with population frequencies and end-use saturations. There has been no attempt to "correct" for yearly weather variation.

The aggregate load shapes were computed in a four step process. The first step was to derive average load shapes for all four combinations of geographic area and season (summer or winter). The second step involved developing average end-use and average household load shapes. The third step involved estimating the population frequencies of the various end-uses. The final step was to use these end-use frequencies to aggregate the average load shapes to the population level.

For all 48 half hours, average loads and associated standard errors were computed. These statistics were computed separately for the summer and winter seasons. Heat pumps were considered to be used for central air conditioning for the summer season (May through September, inclusive) and for space heating during other months. Cooking configurations used included either stove-ovens or range tops. Refrigeration was measured by the loads of a sample of refrigerators on dedicated circuits. For some households, a kitchen load, including a refrigerator and possibly a microwave, was measured. As expected, the aggregate kitchen load (not shown in the figures below) only slightly exceeded the aggregate refrigeration load, thus verifying that the refrigerator is responsible for the vast majority of non-cooking load in the typical kitchen.

Population frequencies of the households with the end-uses being studied were estimated using saturation and population data from PGandE's 1983 Residential Appliance Saturation Survey (RASS). The end-use frequencies were estimated for all single-family, owner-occupied dwellings in the two geographic areas separately. Geographic-specific frequencies were used because the saturations for certain end-uses, such as central air conditioning, are markedly different between the Central Valley and the Coastal/Mountain areas (see Table I).

Aggregate level load shapes were obtained by multiplying the average end-use and household load shapes by the estimated number of households with that end-use. For each total load, the appropriate total number of households was used. For each end-use load (including refrigeration), the estimated number of households with that end-use, as noted in Table 1, was used.

Analysis Findings

Population Frequencies and Appliance Saturations. Table I contains the population frequencies and appliance saturations of households with various end-uses. The major difference in end-use saturations between the two geographic areas is in central and window/wall air conditioning. A household in the Central Valley is about 4.5 times as likely to have central air conditioning than a household in the Coastal/Mountain area. Similarly, window/wall air conditioning is almost twice as likely in the Central Valley as elsewhere. Otherwise, the extent of agreement in the appliance saturations is quite high. Population size is another major difference between the two geographic regions. The population in the Coastal/Mountain area is nearly double that of the Central Valley.

Decomposition of Electricity Consumption. Table II shows the estimated daily electricity consumption for each end-use. With the major exception of space conditioning, the percentage of consumption by end-use does not differ greatly by season or by geographic area.

The percentage of electricity consumption due to space conditioning follows generally expected patterns. In the Central Valley, central air conditioning in the summer is responsible for about 13.4 percent of total electricity consumption, whereas otherwise it represents less than 5 percent of total consumption. In the Coastal/Mountain area, the percentage of total consumption due to electric space heating is more than ten times greater in the winter than in the summer; for the Central Valley, the factor is about 2.5. Preliminary analysis indicates that in winter central space heating loads are being recorded as central air conditioning because the same space conditioning equipment (most likely a heat pump) is used for both purposes. In general, the percentage of total consumption due to space heating appears to be too small.

By combining the population frequencies and the total, daily consumption amounts, we estimate that the average household in the Central Valley consumes about 9,500 kWh per year. In contrast, the average annual household consumption in the Coastal/Mountain area is approximately 7,600 kWh.

Average Daily Load Shapes. Figures 1 through 3 show the average daily total household and end-use load shapes for selected end-uses and for each combination of season and geographic area. The selected end-uses are central air conditioning, clothes drying, space heating, refrigeration, water heating, and cooking.

The total household load shapes (Figure 1) appear quite similar across the two geographic zones for both summer and winter. However, the summer loads are generally larger than the winter loads in the Central Valley, whereas just the opposite is the case in the Coastal/Mountain area. The summer loads exhibit a peak around 7 p.m., but not a morning peak. In contrast, the winter loads show a morning peak around 8 a.m. and a daily peak around 7 p.m.

The central air conditioning loads (Figures 2 and 3) have three notable features. First, the only substantial percentage of total load due to central air conditioning occurs in the Central Valley during the summer. This air conditioning load is quite substantial from around noon until midnight. From about 3 p.m. until about 8 p.m., the central air conditioning load actually exceeds the refrigeration load in the Central Valley. Second, there are corresponding, though markedly smaller, central air conditioning loads between noon and midnight during the summer in the Coastal/Mountain area. Finally, for both geographic areas, the winter loads exhibit a peak at about 8 a.m. This morning peak is much more noticeable in the Central Valley than in the Coastal/Mountain area. These peaks are consistent with one another as some central space heating load is being attributed to central air conditioning.

The load shapes for clothes drying are generally the same across geographic area and season. There is a build up of load in the early morning with a peak around noon, and then a slow descent until about 5 p.m. At that time, the load stabilizes until about 10 p.m., at which time it drops sharply.

The space heating load shapes are similar between the two geographic areas for each season. As would be expected, neither area exhibits much space heating load during the summer. During the winter, the loads in both geographic areas show small increases in the early morning and in the early evening. Otherwise, the loads are fairly flat. Generally, the winter central air conditioning loads parallel the winter space heating loads. This pattern provides additional evidence that some space heating load is being measured as air conditioning.

The refrigeration load shapes are also the same across geographic area and season. They tend to be relatively flat with a small to moderate increase in load around breakfast time and a moderate to large increase in load at dinner time. Refrigeration loads comprise about 20-25 percent of the total household load in each geographic zone.

The water heating load shapes display geographic differences but not seasonal differences. Generally, there are both morning and evening peaks with the evening peaks being more pronounced in the Coastal/Mountain area. This difference may be attributable to the fact that the Central Valley is largely rural and the Coastal/Mountain area is predominantly urban. Other explanations for this difference include higher saturations of dishwashers and clothes washers in the Coastal/Mountain area.

The cooking load shapes are generally the same across geographic area and season. They are relatively flat after 7 a.m. with moderate increases at dinner time. These dinner time increases appear to be larger in the Coastal/Mountain area than in the Central Valley.

In summary, the total load shapes exhibit two major periods of increasing load: an early morning period and a late afternoon/early evening period. The morning increase is largely attributable to the simultaneous use of cooking, water heating, clothes drying, and, in the winter, space heating. The late afternoon/early evening increase is largely due to the nearly simultaneous use of refrigeration and cooking, and, in the summer, central air conditioning.

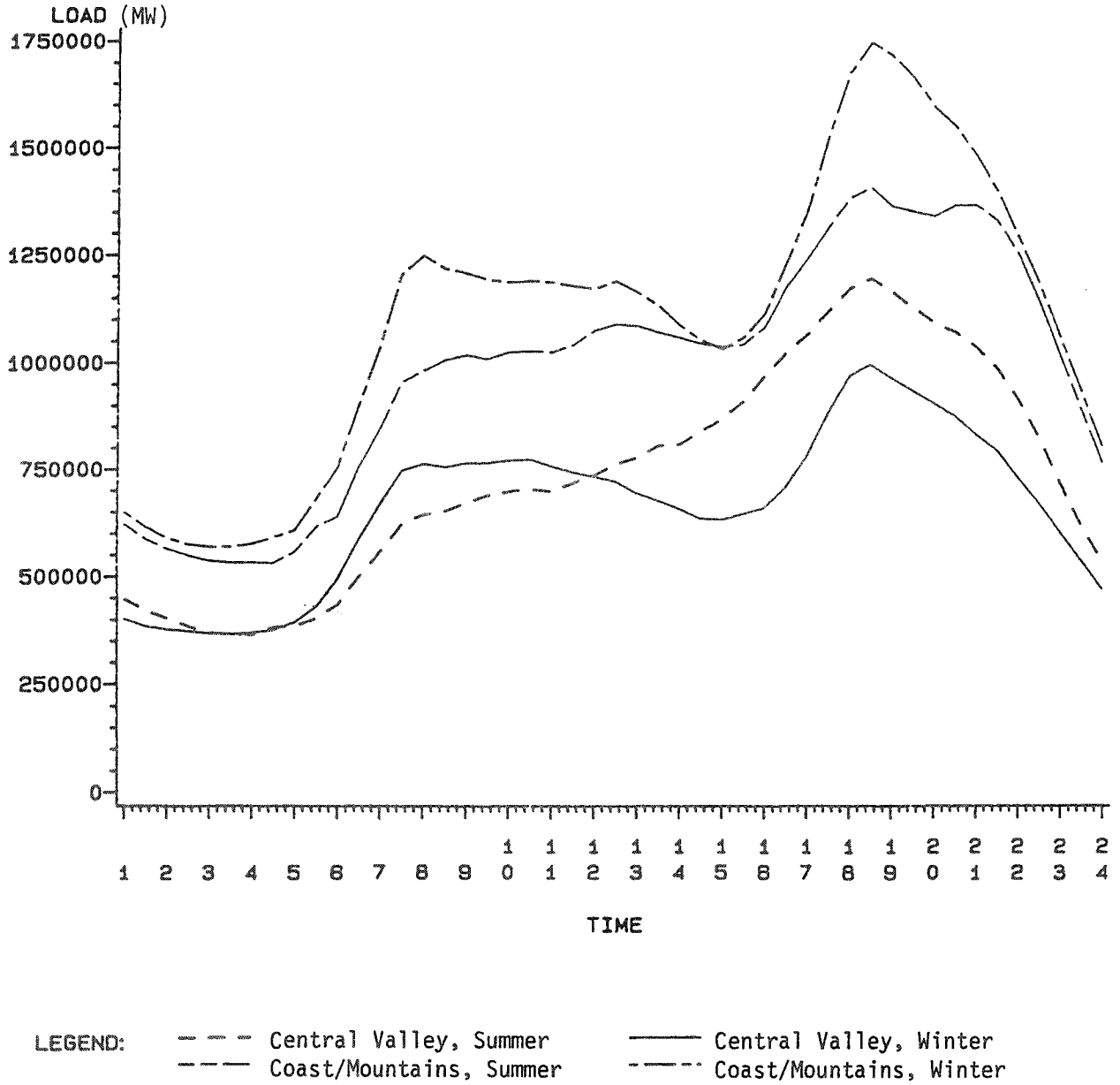


Figure 1. Average daily total load by geographic area and season.

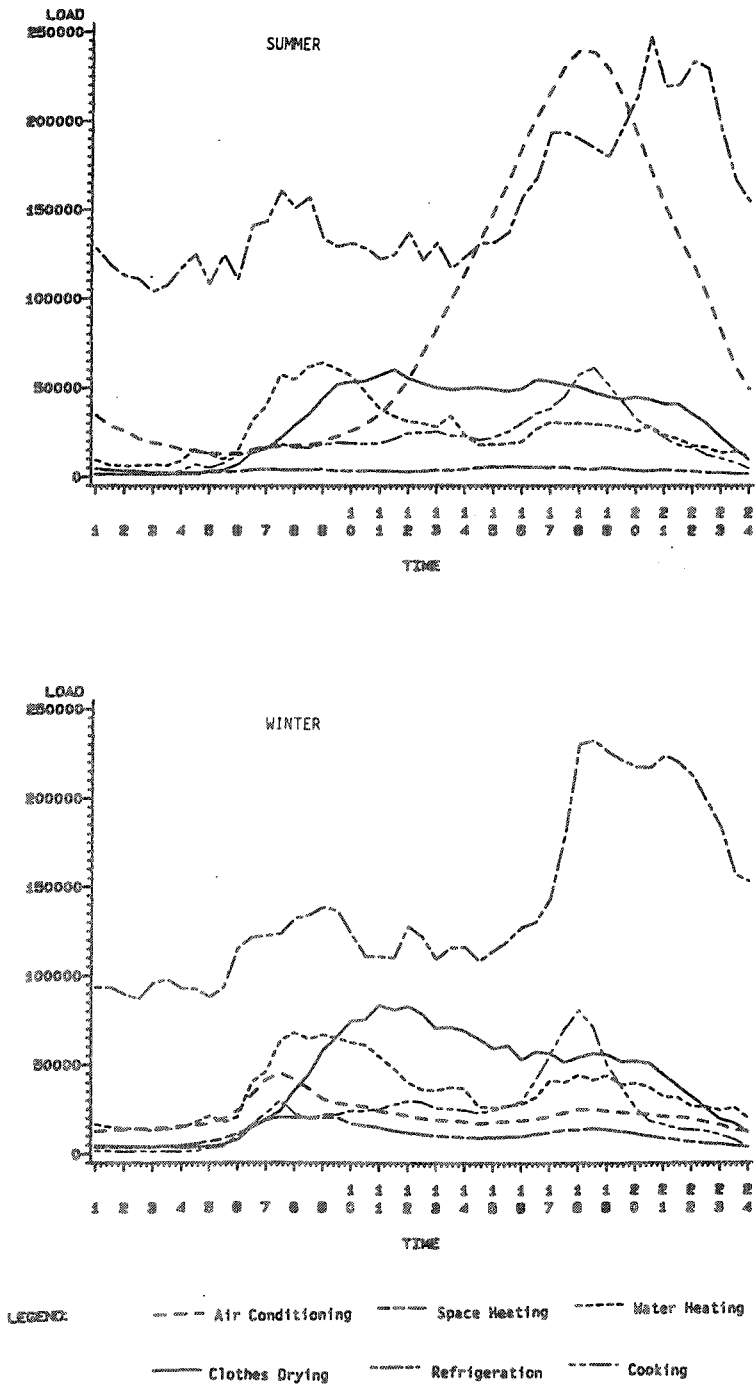


Figure 2. Average daily enduse load shapes - Central Valley.

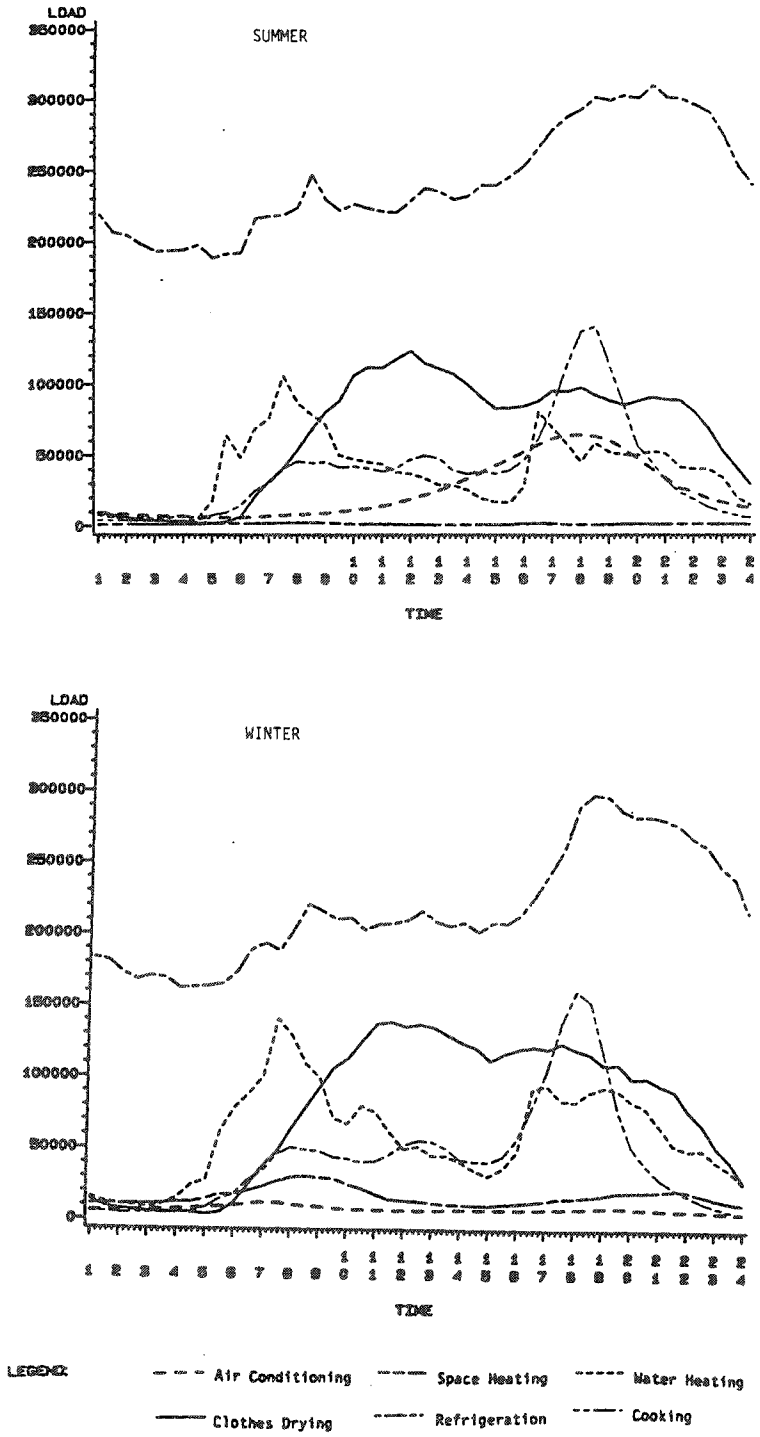


Figure 3. Average daily enduse load shapes - Coast/Mountains.