Short-Term Commercial Metering Project

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The demand-side management measurement protocols prepared for California's Statewide Collaborative Process indicate that improvements in the estimates of energy savings from utilities' demand-side management programs are to be realized "by relying more on metered or statistical analyses to replace engineering-based estimates." Because end-use metered data are relatively costly to collect, one major California utility developed a pilot program for short-term monitoring to obtain data on energy use at commercial sites where lighting, refrigeration, or motor retrofits had been made in response to the utility's rebates and to use these data to measure the savings resulting from such retrofits. This paper reports on findings from the first year of this short-term commercial metering project and demonstrates that the savings realized from the installation of energy-efficiency measures can be effectively evaluated via short-term metering of end-use loads.

Introduction

The Statewide Collaborative Process in California has encouraged utilities to develop various demand-side management programs to encourage energy efficiency among their customers. As part of its effort in response to the collaborative process, a major California utility has instituted direct and customized rebate programs for its non-residential customers. Measures installed under these programs are expected to produce savings in net avoided capacity, transmission, distribution and energy costs.

For program planning and implementation purposes, the utility had developed initial engineering estimates of the demand reductions and energy savings expected from the various measures eligible for rebates under the programs. However, under the requirements of the collaborative process, the utility was to verify and/or refine these initial estimates of the savings that result from the programs. In particular, the demand-side management measurement protocols prepared for the Statewide Collaborative Process indicate that improvements in the estimates of energy savings are to be realized "by relying more on metered or statistical analyses to replace engineering-based estimates."

Because end-use metered data are relatively costly to collect, the utility developed a pilot program for short-term monitoring to obtain data on energy use at commercial sites where lighting, refrigeration, or motor retrofits had been made in response to the utility's rebates and to use these data to measure the savings resulting from such retrofits. Specific objectives of the work included:

- Identifying "ball-park" estimates of actual savings from the efficiency improvements
- Reconciling actual metered estimates of savings with the initial engineering estimates used in program planning and implementation
- Acting as a pilot test by using end-use metering technology to measure energy and demand savings that result from improved efficiency
- Comparing short-term and long-term metering

The results of the first year's work on this commercial short-term monitoring project are reported in this paper.

Data Collection

Fourteen sites were selected as case studies for the short-term monitoring. Nine of the sites were metered for lighting retrofits, two for refrigeration, and three for motors. (To obtain data on air conditioning energy use from which to estimate kWh savings for measures affecting air conditioning, longer-term monitoring is required because of the higher dependence of air conditioning use on weather conditions.)

In end-use metering, the major cost items are associated with monitoring equipment purchase/leasing, installation labor, and data collection and verification. Cost reductions were realized with the shorter term metering of specific end uses because less costly equipment could be used and the amount of data that needed to be cleaned and verified is less. For example, an 8-channel data recorder was generally adequate when only one end-use is being monitored. (When several end-uses are being monitored at the same time, a 16-channel recorder is required, the cost of which is correspondingly higher.)

For the work on the short-term commercial metering project, an 8-channel data recorder was used at each site to record energy use at half-hour intervals on the circuits where energy efficiency changes had been made. Current transformers were used to measure the current in the panels supplying the end use being metered. This was accomplished by passing the line that carried the electrical current to the metered load through the core of the transformer. Electricity use was initially measured in pulses, which were converted to kWh for reporting and analysis purposes. Real power usage, voltage and amperage were all measured so that the data could be used to calculate the power factor.

The data on energy use were collected and grouped in time series by the data recorder. These data were retrieved from the recorder during a site visit; the data were downloaded into a portable computer during the visit and then transferred to a main computer at the office. Because the recorder used has approximately 26 kilobytes of memory, the frequency of data retrieval from a site depended upon the number of parameters being recorded and the recording interval. In general, the sites were visited every 14 days.

The collected data were inspected to ensure that the time dating was correct. To identify out-of-range values, the recorded data were compared against readings for the site that were taken with an amprobe during the installation of the equipment. Comparisons were also made with utility billing data readings from previous periods. Site characteristics and retrofit data were reviewed with the utility's account representatives to ensure that the data used for the analysis were consistent with the changes made at the sites.

For some sites, it was not possible to record energy use data for all of the circuits affected by the energy efficiency changes. For example, complete monitoring of lighting retrofits was difficult at some sites that had multiple electrical panels or where equipment was spread throughout the building. For these sites, a scaling factor was calculated and used to scale the recorded data to the same level as was used in calculating the initial engineering estimates of savings and demand reductions.

Data Analysis Procedures

After the metered data for a site were collected and verified, they were used to develop estimates of actual reductions in peak lighting demand and of actual savings in lighting energy use. The demand reduction and savings estimates developed from the metered data were then compared to the initial engineering estimates used in program planning and implementation.

For each of the metered sites, profiles that depict electricity use for the monitored end use were developed. These profiles are basically descriptive of the patterns of electricity use at the metered sites, both before and after the changes to the lighting system.

The first type of profile graphically represents the measured electricity use for the monitored end for all days for which metered data were collected, both pre-retrofit and post-retrofit. Figure 1 is an example of these profiles, which essentially summarize the collected data in a graphical format. Note that peak demand for the monitored end use can be read directly from this type of profile.

The second type of profile that was prepared depicts electricity use for an average weekday and an average weekend day. Typical working days (i.e., Monday through Friday) were included in the weekday grouping. Non-working days of a week (normally Saturday and Sunday but also holidays) were included in the weekend day grouping. For each type of day and for each site, average electricity use for the monitored end use for each half-hour interval of the day was computed as the mean of the recorded data for that interval. This gave 48 values to describe the profiles for an average weekday and for an average weekend day for each site. Average daily energy use for lighting at a site for a given type of day was found by summing the 48 values for that type of day.

The data generated for the profiles were then used to analyze changes in kW demand and in kWh energy use resulting from the energy efficiency changes. The estimates of demand reductions and energy savings made from the metered data were compared to the initial engineering estimates.

Analysis of Savings from Lighting Retrofits

Nine sites where changes in the lighting systems had been made were monitored. Summary characteristics for the monitored sites are reported in Table 1. The most common lighting retrofits were to delamp four-lamp fixtures down to two lamps, to remove one ballast, and to install optical reflectors. Other changes were to convert incandescent to fluorescent lighting, to install high pressure sodium vapor night lighting, and to install current limiters.

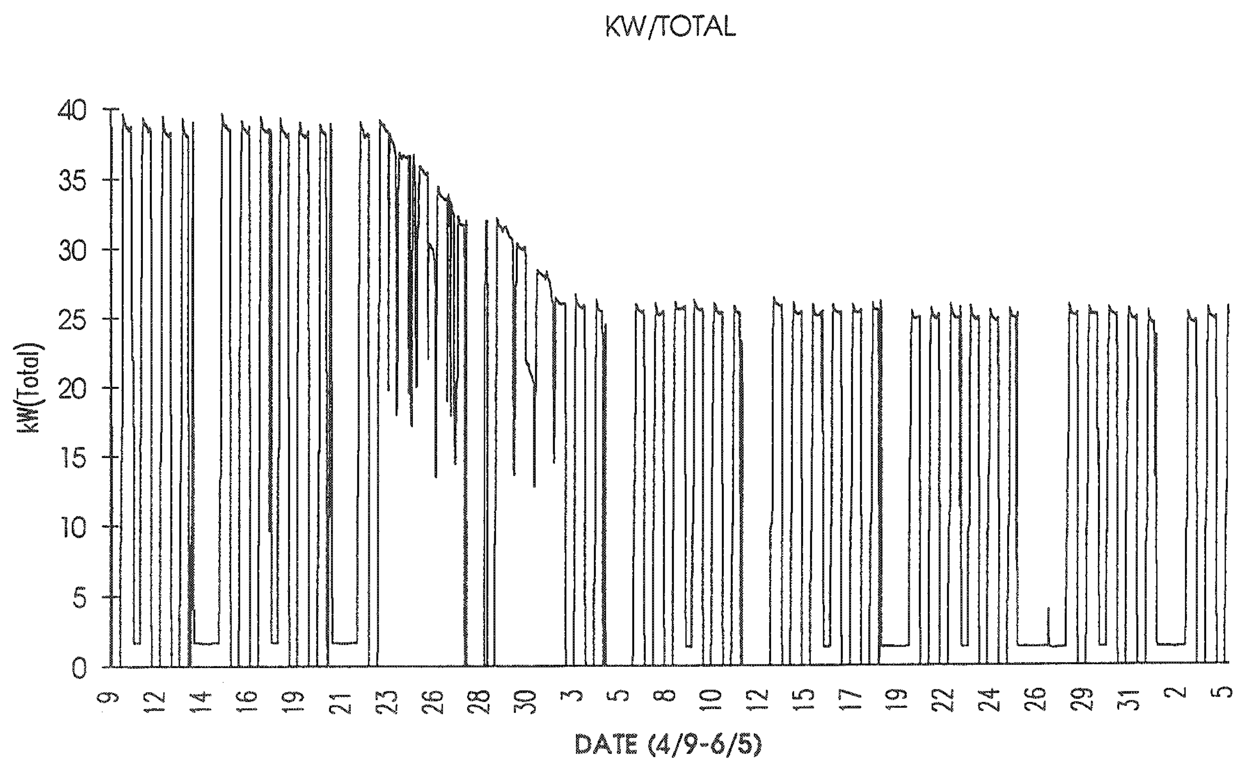

***Figure 1.** Example of Electricity Use Profile over Monitoring Period*

***Table 1.** Characteristics of Sites Monitored for Lighting Retrofits*

			Business Hours		
Site	Square Footage	Business Activity	Monday-Friday	Saturday	Sunday
1	22,000	Retail	10 am-9 pm	10 am-7 pm	11 am-5 pm
2	44,000	Office	9 am-5 pm	n/a	n/a
3	2,700	Retail	10 am-9 pm	11 am-6 pm	11 am-5 pm
4	3,000	Retail	10 am-8 pm	10 am-6 pm	10 am-5 pm
5	4,430	Retail	10 am-6 pm	10 am-6 pm	10 am-6 pm
6	3,300	Office	9 am-5 pm	n/a	n/a
7	12,500				
8	18,000	Retail	9 am-7 pm	11 am-6 pm	11 am-6 pm
9	2,800	Gas/Con-venience	24 hrs	24 hrs	24 hrs

The lighting retrofits were of course expected to reduce the peak demand for lighting at the sites. Accordingly, peak demands for lighting electricity use in pre- and post-retrofit periods were determined for each site. These peak demand data are reported in Table 2 for the nine sites. Also reported there are the comparisons between the initial engineering estimates of reductions in lighting demand and the reductions as estimated from the metered data. As calculated from the metered data, the percentage reductions in lighting kW demand ranged from 30% to 46%, with the average percentage reduction being 36.2%. Moreover, the lighting demand reductions estimated from the metered data are all less than the initial engineering estimates of the expected reductions.

Further analysis of the data indicated that the initial engineering estimates of the demand reductions were higher than the estimates from the metered data because lighting utilization factors were captured in the metered data but had not been incorporated in the initial engineering estimates. That is, the initial engineering estimates of demand reductions calculated at the time of the rebate audit were based on the assumption that all of the connected lighting load is fully utilized at the time of peak demand. However, taking lighting utilization to be the percentage of connected lighting load being used at a given time, Figure 2 shows that lighting utilization in the pre-retrofit period was less than 100% at all sites. The metered data also showed that realized reductions in peak lighting demand were dampened somewhat because of increased utilization in the post-retrofit period. On average, lighting utilization was about 20% higher in the post-retrofit period than in the pre-retrofit period.

Estimates of energy use for lighting (measured in kWh) were also developed from the metered data. Average daily lighting energy use (in kWh/day) was calculated from the metered data for each site. These averages are reported in Table 3 for both weekdays and weekend days and for both pre- and post-retrofit. Average daily energy use for lighting during weekdays dropped at all sites, with reductions ranging from 17.2% to 42.8%. Average daily electricity use on weekend days also dropped for all sites but one; the reductions for weekend usage ranged from -1.7% to 77.5%.

The initial engineering estimates of savings in energy use were on an annual basis. Accordingly, to compare the savings in lighting energy use derived from the metered data to the initial engineering estimates of the expected savings, it was necessary to develop estimates of annual energy use implied by the metered data. These estimates were developed according to the following formula:

$$Annual\ Energy\ Use = \sum_{i=1}^{2} AVEKWH_i * N_i$$

where AVEKWHi is average daily energy use for lighting for type of day i (either weekday or weekend day) and Ni

Table 2. Comparison of Lighting Demand Reductions: Metered Estimates vs. Initial Engineering Estimates

	Initial Engineering Estimates		Estimates from Metered Data			
Site	kW Reduction	Percentage Reduction	Pre-retrofit kW	Post-retrofit kW	kW Reduction	Percentage Reduction
1	26.3	50.0	39.7	26.7	13.0	32.7
2	24.1	41.8	34.9	24.0	10.9	31.2
3	3.1	50.0	4.9	3.2	1.7	35.3
4	2.6	48.5	4.3	2.6	1.7	40.3
5	2.1	34.4	5.5	3.8	1.7	31.2
6	3.3	50.0	5.1	3.1	2.0	38.8
7	86.7	47.2	133.7	80.1	53.6	40.1
8	20.0	53.9	24.4	17.0	7.4	30.3
9	2.9	50.0	5.3	2.9	2.5	46.1

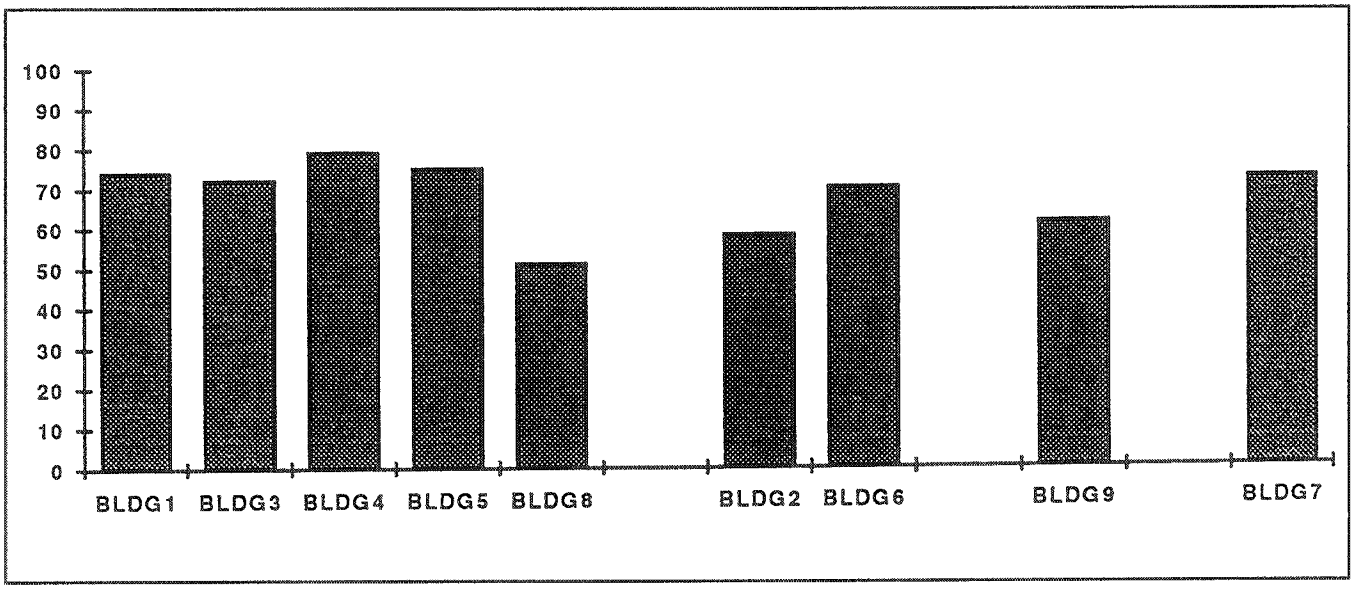

Figure 2. Percentage of Connected Load Utilized at Monitored Sites During Pre-Retrofit Period

is the number of days of a given type of day. Two estimates of annual energy use for lighting were developed from the metered data, one using average daily kWh from the pre-retrofit period and the other using data for the post-retrofit period. The same assumptions about numbers of days by type of day were used for each calculation.

The estimates of annual lighting energy use thus developed are reported in Table 4 and compared to the initial engineering estimates of savings. The estimates of kWh savings based on the metered data imply an average reduction in annual lighting energy use of about 34% for the metered sites, with reductions ranging from 12.5% to 44.7%. Moreover, the estimates from the metered data

Table 3. Average Daily kWh Usage for Lighting Estimated from Metered Data

	Week Days			Weekend Days		
Site	Pre-Retrofit kWh	Post-Retrofit kWh	% Savings	Pre-Retrofit kWh	Post-Retrofit kWh	% Savings
1	489.9	319.3	35	239.7	133.6	44
2	414.8	281.8	32	63.9	35.4	44
3	55.0	35.0	36	31.8	23.2	77
4	61.3	40.9	33	55.7	29.7	47
5	47.3	34.3	27	39.6	27.0	32
6	47.0	27.4	42	9.3	2.1	77
7						
8	245.8	157.8	36	192.7	115.8	39
9	79.7	65.9	17	64.8	65.9	+2

Table 4. Comparison of Lighting kWh Savings: Metered Estimates vs. Initial Engineering Estimates

	Initial Engineering Estimates		Estimates from Metered Data			
Site	kWh Reduction	Percentage Reduction	Pre-Retrofit kWh	Post-Retrofit kWh	kWh Reduction	Percentage Reduction
1	101,248	50.0	151,799	96,497	55,303	36.4
2	136,683	42.0	111,752	75,030	36,723	32.9
3	11,924	50.0	17,585	11,498	6,088	34.6
4	24,134	64.5	21,774	13,731	8,043	36.9
5	13,191	32.0	16,423	11,727	4,696	28.6
6	10,878	50.0	12,899	7,131	5,768	44.7
7		47.5				
8	96,463	54.4	83,987	53,057	30,930	36.8
9	12,449	50.0	27,512	24,060	3,452	12.5

are all lower than the initial engineering estimates of the kWh savings. Further analysis identified degree of utilization (i.e., the percentage of connected load being used at a given time) and hours of operation as the most important factors causing differences between the metered estimates and the initial engineering estimates.

As noted above, lighting utilization factors were captured in the metered data but had not been incorporated in the initial engineering estimates. While 100% utilization of lighting was generally assumed in the initial engineering estimates, the metered data showed that utilization was generally lower. Moreover, the number of operating hours assumed for the initial engineering estimates appeared to be higher than the hours of equivalent full load operation implied by the metered data. Because the implicit utilization factor used in the initial engineering estimates was 100%, the number of operating hours used for those energy savings calculations was effectively full-load hours. For comparison purposes, equivalent full load hours of operation were calculated from the metered data by dividing the estimated annual energy use by the post-retrofit peak lighting load. This comparison showed that the hours assumed for the initial engineering estimates were higher than the inferred hours for six of the nine sites, in some cases significantly higher. (Of course, equivalent full load hours do not necessarily correspond to hours open. That is, the percentage of the lighting that is used during some hours that a site is open may be significantly less than full load. Consequently, hours open are usually higher than hours of equivalent full load operation.)

The representativeness of the sites monitored for lighting changes is of interest in evaluating the extent to which the savings estimated from the metered data for these sites can be generalized to the wider population of commercial customers served by the utility. Accordingly, the representativeness of the monitored sites was evaluated by examining each of the factors that contributes to determining lighting energy use in a building: lighting capacity, the percentage of the capacity that is utilized, and hours of use. The examination of these various factors suggested that, by and large, the sites at which the short term monitoring of lighting retrofits was conducted were fairly representative of the broader population of commercial buildings with respect to lighting capacity and hours of use. Whether the metered savings determined for the monitored sites were higher or lower than would be found in a larger, more representative population therefore appears to depend on the degree to which the utilization of lighting capacity at these sites is representative of lighting utilization in the general population. At this point, data for determining lighting utilization factors for the general population are limited.

Analysis of Savings from State-of-the-Art Refrigeration Equipment

To examine the electricity savings that result from the use of higher efficiency refrigeration equipment, short term metering was conducted at two wholesale stores owned and operated by the same company. These two stores were chosen for monitoring because they had nearly identical refrigeration loads but different refrigeration systems. Table 5 provides summary information about those characteristics of the two stores that have the greatest effect on refrigeration energy use. As can be seen, the two stores are similar in building construction, operation and refrigeration load. However, the refrigeration equipment

Table 5. Characteristics of Sites Monitored for Refrigeration Systems

	Store with Conventional System	Store with State-of-the-Art System
Business Activity:	Wholesale Discount	Wholesale Discount
Monday-Friday	10:00 am - 8:30 pm	10:00 am - 8:30 pm
Saturday	9:30 am - 6:00 pm	9:30 am - 6:00 pm
Sunday	10:00 am - 5:00 pm	10:00 am - 5:00 pm
Holidays:	7 days	7 days
Number of Employees:	210*	150
Year Built:	1986	1990
Square Footage:	124,000 sf	117,000 sf
Cooling Equipment:	Direct Expansion Packaged Units	Direct Expansion Packaged Units
Heating Equipment:	Gas Fired Package Units	Gas Fired Package Units
Building Construction:	Wood frame Concrete block walls Built-up roof	Wood frame Concrete block walls Built-up roof
Refrigeration Display Cases:		
Number	10	10
Total Linear Footage	112 Linear Feet	120 Linear Feet
Reach-in Cooler/Freezer:		
Number	2	2
Total Square Footage	2,508 Square Feet	2,508 Square Feet
Walk-in-Coolers/Freezers:		
Number	6	6
Total Square Footage	3,271 Square Feet	3,191 Square Feet
Compressors:		
Number	12	8
Total Nominal Horse Power	182.5 HP	123.5 HP
Total kW Capacity	133.9 kW	90.6 kW

* Includes a significant number of part-time employees.

that is used is very different. One store has a conventional refrigeration system that uses individual compressor systems for different loads (suction temperatures). The other store has a state-of-the-art, custom-designed central refrigeration system that includes a parallel compressor design with two satellite compressors, floating head pressure control, mechanical liquid subcooling, hot gas defrost, heat recovery, and ambient subcooling.[1] Consequently, collecting metered data on electricity use for refrigeration at the two stores allowed comparison of electricity use between a low-efficiency conventional system and a higher efficiency state-of-the-art system and estimation of the energy savings that result from the use of state-of-the-art refrigeration technology.

The metered data collected at the two stores were used to characterize the patterns of refrigeration energy use for the conventional and the state-of-the-art refrigeration systems. Figure 3 shows the average across weekdays refrigeration profiles for the two stores. These profiles show that peak refrigeration demand is substantially lower with the state-of-the-art system. Moreover, while there is a single marked peak for the conventional system, the state-of-the-art system has several smaller peaks. This can be attributed to the greater ability of the state-of-the-art system to match needed refrigeration load and to other savings features that contribute to peak reduction. Moreover, energy use with the state-of-the-art system is uniformly less throughout the day, reflecting the higher overall efficiency of the state-of-the-art system.

Estimates of the changes in electricity use resulting from use of the energy efficient refrigeration system were calculated in terms both of the reduction in highest usage rate at any hour (kW) and of the amount of energy saved annually (kWh). These calculations were made using data for refrigeration energy usage (kWh) and energy demand (kW) derived from the average weekday and average weekend day profiles. For this analysis, summer months were defined to include June through September and winter months to include October through May. Moreover, because the sites were located in somewhat different climatic areas, savings were estimated first using the metered data unadjusted for regional weather differences and then with the data adjusted for the weather differences; that is, savings calculations were based on the difference between the average temperatures of two locations, to which the manufacturer's data (performance curve) was applied.

Table 6 summarizes the unadjusted and weather-adjusted estimates of demand reductions and energy use savings

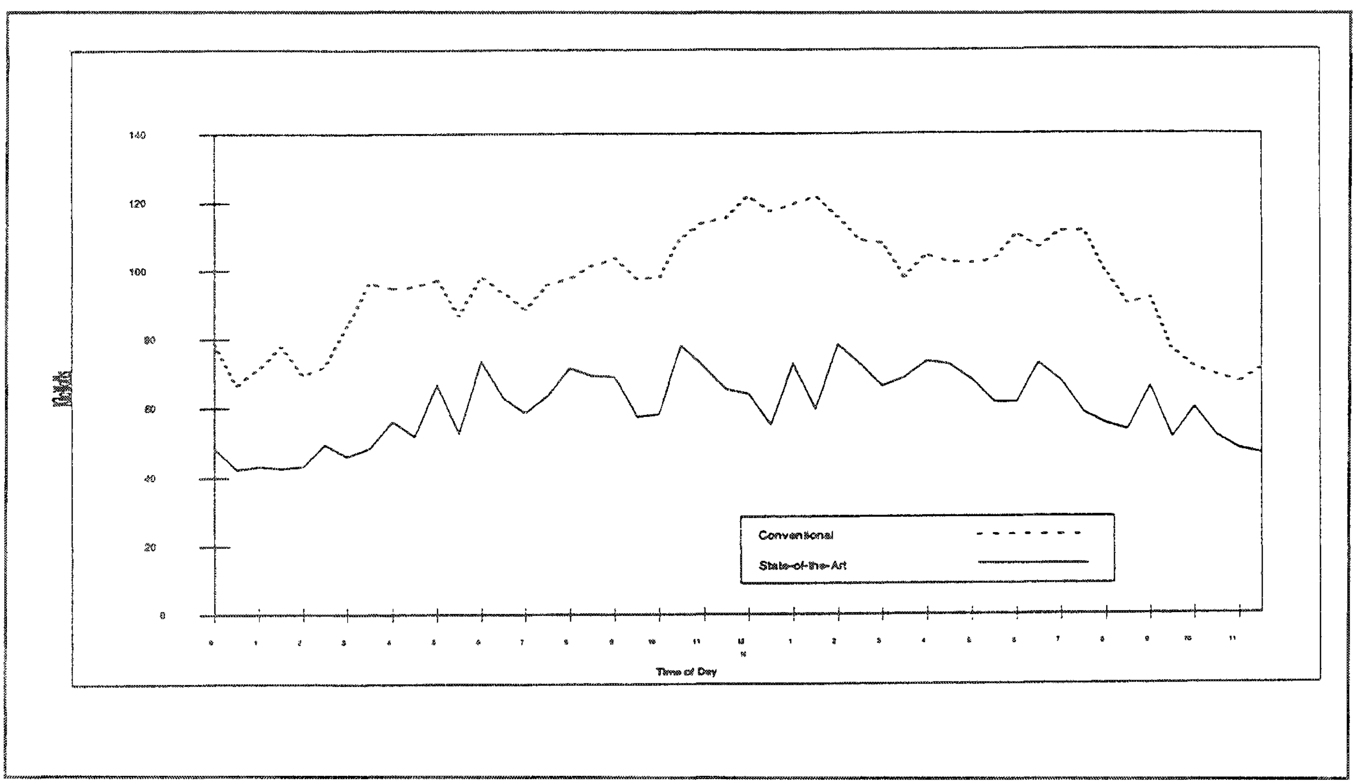

Figure 3. Electricity Use Profiles for Refrigeration Systems on Average Weekday

Table 6. Estimated Savings from Higher Efficiency Refrigeration System

	Expected Percentage Savings per Manufacturer's Specifications	Savings Estimated from Metered Data: Not Adjusted for Weather		Savings Estimated from Metered Data: Adjusted for Weather	
		Absolute	Percentage	Absolute	Percentage
Energy Use (kWh)	28%	255,888 kWh	34.3	278,404 kWh	37.3
Energy Demand (kW)	n/a	46.57 kW	31.4	n/a	n/a

calculated from the metered data. For comparison purposes, the expected percentage savings as calculated from manufacturer's data is also reported.

Analysis of Savings from Motor Retrofits

Data with which to analyze the savings that are realized from retrofitting with energy-efficient motors were collected at three agricultural processing sites that had received rebates for installing energy-efficient motors. One of the sites processes tomatoes, one processes prunes and cranberries, and one dehydrates vegetables. At the tomato-processing facility, a 7.5 horsepower motor used to run an evaporator feed pump was being replaced with motor of a higher efficiency and the same horsepower. At the prune-processing plant, a 7.5 horsepower motor that runs an agitator in the prune juice holding tank was being replaced with an energy-efficient motor of the same size. At the vegetable dehydrating facility, two motors (one 15 horsepower and one 20 horsepower) that run circulating fans in the vegetable dehydrators were being replaced with energy-efficient motors of the same size. At each of the sites, monitoring equipment was installed before the motor retrofits were made so that both pre-retrofit and post-retrofit metered data could be collected with which to measure the demand reductions and energy savings resulting from installation of the energy-efficient motors.

The demand reductions and energy savings (in percentage terms) that were estimated from each site are reported in Table 7 and compared to the initial engineering estimates of the savings. Based on the estimates made with the metered data, peak demand for the motors was reduced by an average of 0.3% at the sites, while the annual energy use for the motors was reduced by an average of 1.0%. Reductions in peak demand and in energy use were dampened because the load increased during the post-retrofit period as compared to the pre-retrofit period.

Arriving at accurate measurement of savings for these sites was difficult because the random fluctuations in the motor loads were greater than the expected savings to be measured. The analysis of the data from these sites suggested that for short term monitoring to be a valid tool for measuring energy saving, random fluctuations in the load have to be less than 20% of the energy savings. (Note, however, that fluctuations in the load greater than 20% can be accounted for if they are cyclic in nature).

Conclusions

The results of the short-term commercial monitoring project demonstrated that short-term metering of end-use loads is an effective tool for evaluating the savings being realized from the installation of energy-efficiency measures, particularly for lighting and refrigeration. Results of the metering could be developed early enough in a program to allow adjustments to the procedures used to develop initial engineering estimates of the savings to be realized with energy-efficient measures, and to assist account representatives in working with customers to develop their applications for rebates for such measures.

Acknowledgments

The short-term metering of commercial facilities reported on here was conducted for Pacific Gas and Electric Company. However, the opinions, findings and conclusions presented here are solely those of the authors and do not represent the views of PG&E.

Table 7. Comparison of Demand Reduction and kWh Savings for Motor Retrofits: Metered Estimates vs. Initial Engineering Estimates

	Percentage Reduction in kW Demand		Percentage Savings in kWh Energy Use	
Site	Initial Estimate	Estimated from Metered Data	Initial Estimate	Estimated from Metered Data
1	6%	-6%	6%	-11%
2	7%	2%	7%	11%
3 (15 hp)	5%	2%	5%	-2%
3 (20 hp)	3%	3%	3%	6%

Endnotes

1. **A Parallel Compressor System** is comprised of two racks with three compressors each; one rack is for low-temperature applications, and the other is for medium-temperature applications. This parallel arrangement provides a selection of three compressors in any combination to meet the load. The microprocessor-based control system senses the refrigeration load (using load temperature and suction pressure criteria) and selects a combination of compressors to meet the load with highest system efficiency.

   Floating Head Pressure Control allows the compressor discharge pressure to drop when the ambient air temperature drops below system design conditions, resulting in increased system efficiency.

   Mechanical Liquid Subcooling is achieved by passing some of the liquid refrigerant leaving the receiver through an expansion valve and heat exchanger. The remaining liquid flows directly through the heat exchanger and is subcooled well below its saturation temperature. This will result in lower head pressure and improved compressor efficiency.

   Hot Gas Defrost uses saturated vapor from the receiver to defrost the evaporator coils instead of electric resistance used in conventional system. The hot gas defrost is much faster than electric defrost , so case temperature recovery is also faster.

   Heat Recovery from a discharge line is used to heat domestic hot water. This feature has no effect to refrigeration savings.

   An Ambient Subcooling System has automatic flow control for subcooling the liquid leaving the receiver by passing it to the condenser on its way to expansion valve, giving up additional heat to the ambient air.