NEVERMORE?
ANNUAL ON-SITE DATA COLLECTION
FOR COMMERCIAL LIGHTING PROGRAMS

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Abstract

Pacific Gas and Electric Co. (PG&E) has recently completed its second annual evaluation of its Commercial Retrofit Program, including its indoor lighting measures, which like many commercial programs, have contributed the majority of the Program's electric demand and energy savings. The data collection and analysis approach employed in PG&E's lighting evaluations has incorporated three key data sources in a nested sample design: loggers, on-site audits, and telephone surveys. The application of this unique approach to evaluate lighting impacts over two consecutive years has allowed PG&E to assess if relatively expensive on-site data needs to be collected on an ongoing basis for monitoring and evaluation/verification purposes. This paper will examine this important issue and discuss the stability of lighting load shape results in certain analysis segments. The results from the two independent evaluations of PG&E's Commercial Retrofit Lighting End Use over each of the past two years indicates that lighting characteristics among specific technologies and business types remain stable over time. Therefore, it may be unnecessary to collect relatively expensive on-site information surrounding lighting operation on an ongoing basis for certain technologies and business types.

Introduction

The results presented in this paper are extracts from both the 1994 and 1995 evaluations of PG&E's Nonresidential Energy Efficiency Incentives Program for Commercial Sector Lighting Technologies. These technologies are covered by two separate program options, the Retrofit Express Program and the Customized Incentives Program. Although the evaluations carried out by Quantum Consulting (QC) on behalf of PG&E encompassed an integrated evaluation approach, consisting of engineering, statistically adjusted engineering and market-based net-to-gross, the subject matter of this paper is related to the engineering methodology and results alone, and the implications of those results for both future DSM evaluation/verification efforts and other related research.

The paper is organized as follows: (1) an overview of the data collection design used to support each PG&E evaluation; (2) a presentation of the engineering analysis method applied; (3) program impact contributions from several key technology group and business type segments; (4) a comparison between 1994 and 1995 engineering results within those key segments; (5) a comparison between load shapes derived in each evaluation; and finally (6) the implications for future studies.

Data Collection Design

The engineering analysis methods are based upon a nested sample design approach. A core lighting logger sample serves to calibrate a larger audit sample, which in turn, is used to calibrate a less expensive telephone survey sample. The smaller samples provide greater detail surrounding each analysis component, and allow results from these more desirable data sources to be transferred to the larger samples. Lastly, the PG&E MDSS program tracking database is used to generate results for the entire participant population**.** This data collection design, as shown in Figure 1, resulted in the efficient use of available engineering resources.

Lighting Loggers

Lighting loggers, represented by the innermost circle in Figure 1, supply the most accurate source of data used to calibrate the engineering estimates. For a monitored fixture, lighting loggers register the time and date the fixture is turned on or off, for periods up to two months in length. This information allows calibration of self-reported operating schedules, and supplies facility closed-period operating information which cannot be collected during on-site audits.

On-Site Audits

The on-site audit sample, represented by the band around the innermost circle in Figure 1, is designed to support the telephone sample for the largest participation segments. This sample contributes equipment details that are site-specific, and better estimates of operating hours, operating factors, equipment efficiency, lamp burn-out rates, missed opportunities, and other technical factors that are difficult to collect over the telephone. The on-site sample itself is not designed to be statistically representative, but rather to support the estimate of detailed engineering parameters collected within the segments with the highest projected impacts.

Telephone Surveys

A significantly larger telephone survey sample, represented in Figure 1 by the second band from the core circle, is designed to be representative of the participant population by technology and business type. The telephone survey supplies information on participant operating schedules and the parameters needed to estimate changes in the building cooling and heating load (caused by the lighting retrofit).

Participant Tracking System

The participant population, represented by the outermost circle in Figure 1, is based on PG&E's MDSS data that provide the information needed to generalize estimated per-unit impact estimates for the telephone-surveyed sample (to the entire population of program participants). Using the population to leverage impact estimates corrects for potential bias in the sample selection process, especially in terms of the actual distribution of installed measures.

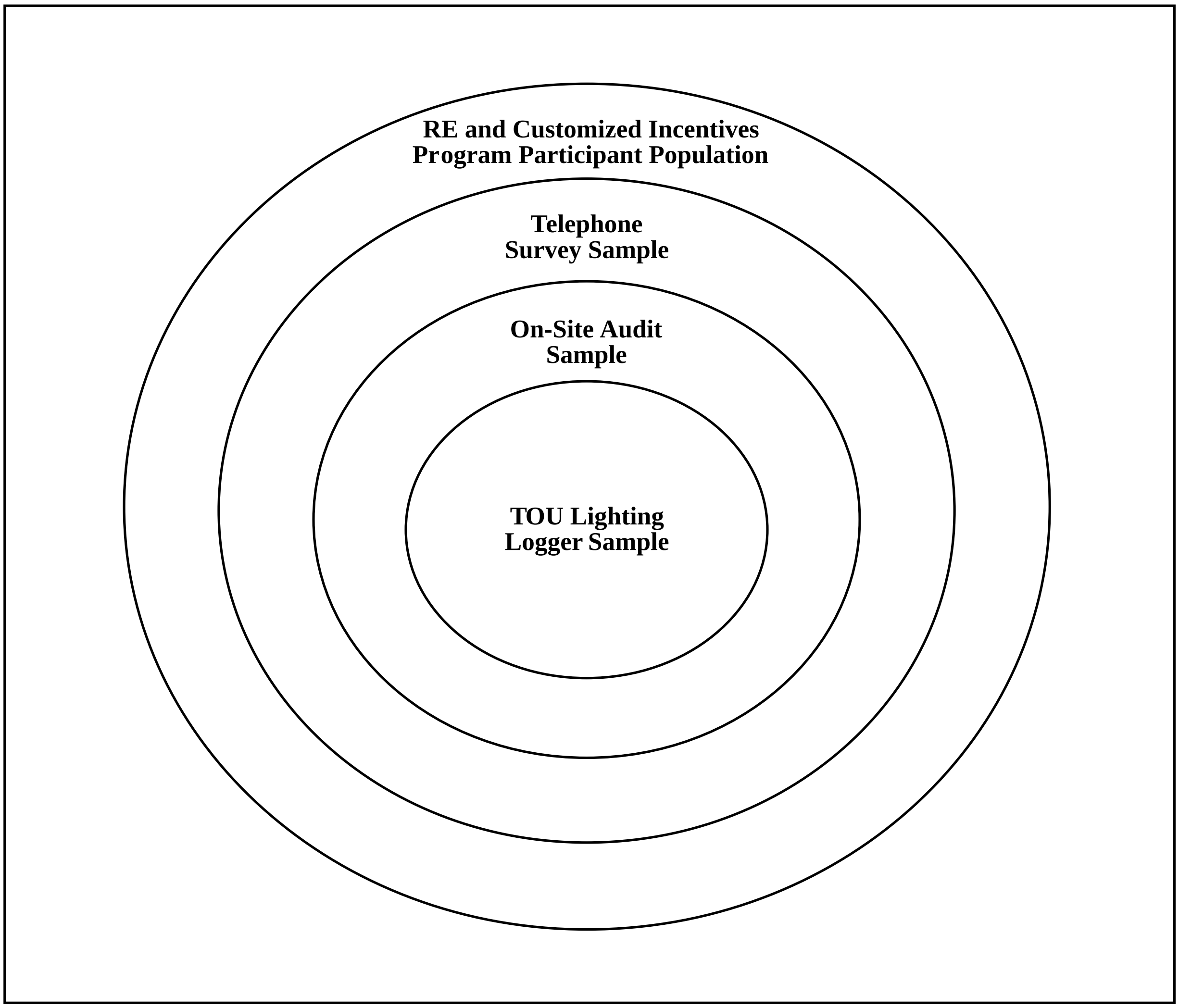

Figure 1. Nested Sample Design

Engineering Method

The engineering analysis performed by QC combines information from the program tracking system with telephone survey data and detailed on-site audit data to develop unadjusted engineering impacts (UEIs). The general lighting model used is founded on the decomposition of lighting impacts into manageable engineering parameters (referred to as the "impact decomposition approach"). This approach is used to develop hourly impacts for each of three daytypes, Weekday, Saturday, and Sunday. The impact decomposition equation used to estimate UEIs is displayed below.

$$UEI_t = [(\Delta UOL \times U \times OF_t) \times T] \times [1+HVAC] \quad (1)$$

Where

- ΔUOL = the technology level change in connected kW associated with a particular measure.
- U = the number of measure units installed for a particular application.
- OF_t = the operating factor which describes the percentage of full load used by a group of fixtures during a prescribed period of time, t.
- T = the time interval for which an impact is estimated; for most measures, the OF term is the engineering parameter that changes significantly over time. Time intervals for lighting estimates were single hours, segmented by hours "on" (open operating factor) and hours "off" (closed operating factor) schedules.[1]
- HVAC = the component of impact associated with both the net savings due to cooling (demand or energy) and the net increase due to heating (energy or therm).

Demand estimates are developed for every hour of the year using this equation. Hourly impacts are then aggregated over the entire year, yielding annual energy and therm impacts.

Derivation of Selected Engineering Parameters

This section provides an overview of the methods used to develop selected parameters used in the impact decomposition approach.

For each business type and technology group, operating factors (the OF_t parameter in the impact decomposition equation) were developed for each of the three daytypes. This operating factor variable consists of two parameters; the probability that a given facility is open for that hour (operating schedule), and the percentage of lights operating during a particular period (open-period and closed-period operating factors). The following sections discuss the development of these two parameters.

Engineering Operating Schedules. Calibrated hourly operating schedules (or profiles) for each daytype were developed, by business type, using data gathered from lighting loggers, on-site audits, and participant and non-participant telephone surveys. The method used is described below and depicted in Figure 2.

Operating schedules were first developed for each "schedule group" (a group of similar fixtures that operate together) at a particular site, and then aggregated to the site level. Once operating schedules were developed for each site, business type-specific schedules were developed by taking a weighted average across sites. The business type schedules were calibrated using the nested sample design, according to the following steps:

- First, logger data were used to calibrate customer self-reported operating hours gathered during the on-site audits.
- Then, once calibrated, the on-site self-reported schedules were used to adjust operating schedules derived using telephone survey data.
- Finally, the adjusted telephone survey schedules were used to develop final business type-specific operating schedules. These schedules were used to generate final evaluation impacts for the entire MDSS sample.

By adjusting these operating profiles with two distinct calibration steps, bias adjustment for on-site self-reported schedules, and bias adjustment for telephone survey self-reported schedules; the final operating profiles are grounded in the most accurate information gathered in this research effort: lighting logger data. The final derived schedules represent, at a business type level, the probability that a particular customer will operate their lighting system for a given hour and daytype.

[1] Although there are periods of time when lights are generally considered off, many lights are either accidentally or purposely left on during these periods. The effective hours of lighting operation captured during these off periods were applied using the operating factor term (the probability that lights operate during a particular time interval).

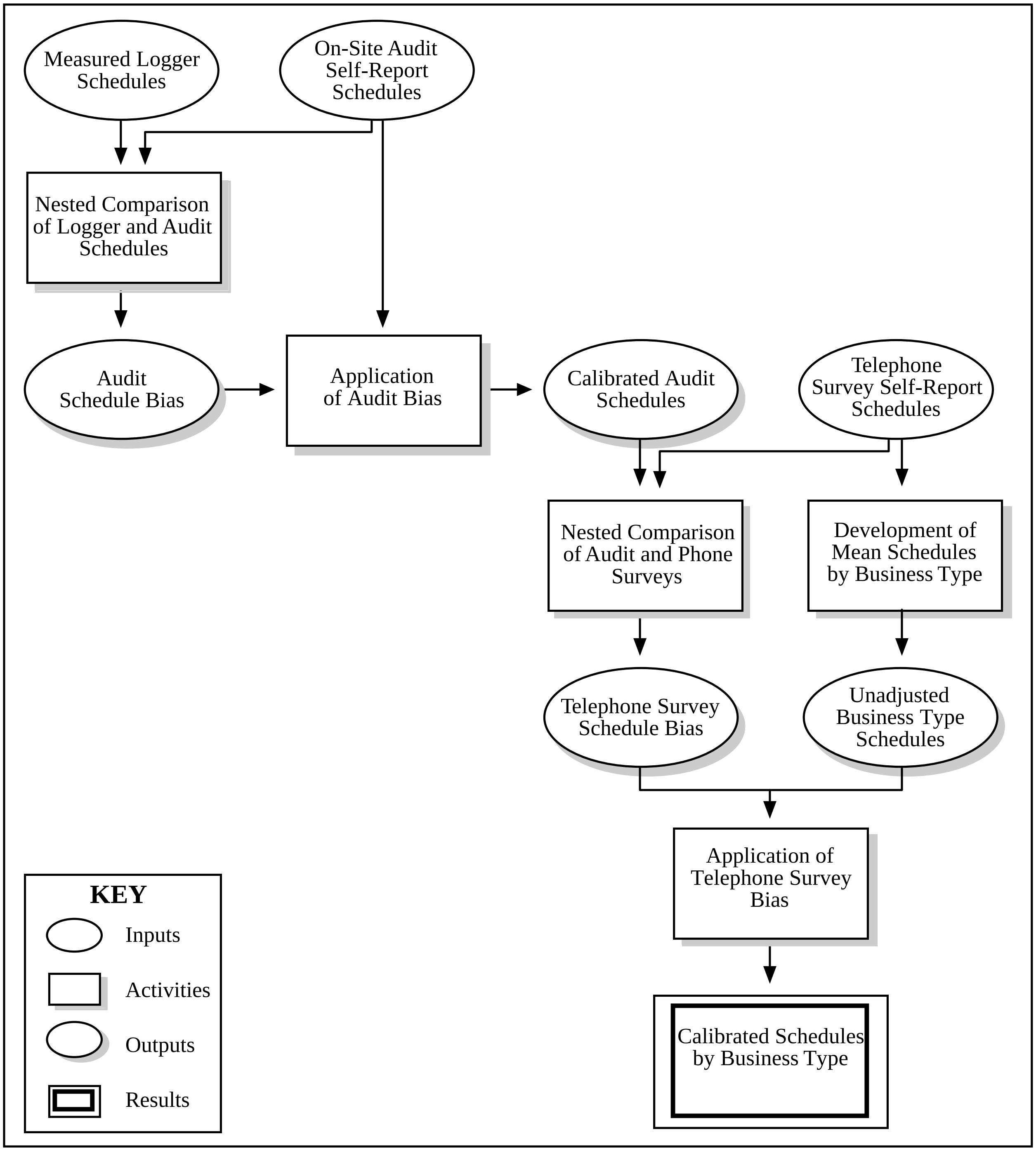

Figure 2. Derivation of Operating Schedules for Use in Engineering Estimates

*Engineering Open-Period and Closed-Period Operating Factors***.** Operating factors, the percentage of lights operating during a specified time interval, were generated by business type, technology group, and daytype for facility open and closed periods. The data sources contributing to these estimates were taken primarily from two sources: lamp counts performed at the time of each audit, and lighting logger data used in conjunction with the calibrated schedule group profiles. The methods used to generate open-period operating factors (OOFs) or closed-period operating factors (COFs), for each daytype varied according to available data.

Development of Hourly Impact Estimates

Using the engineering parameters discussed above, hourly engineering impact estimates are developed. To estimate hourly energy impacts, fixture connected loads are used along with the applicable schedule and operating factors, according to the following equation:

$$UEI_{ijzdh} = \Delta UOL_i \times U_{ij} \times \begin{bmatrix} (PO_{jdh} \times OOF_{izd}) + \\ ((1 - PO_{jdh}) \times COF_{izd}) \end{bmatrix} \times [1 + HVAC_{ij}] \quad (2)$$

Where

UEI_{ijzdh} = the unadjusted engineering impact for measure i, customer j, business type z, daytype d, and hour h.

ΔUOL_i = the change in connected load for technology measure i.

U_{ij} = the number of units of technology type i installed by customer j.

PO_{jdh} = the schedule defined probability that customer j will be open on daytype d during the hour h.

OOF_{izd} = the open-period operating factor which describes the percentage of full load (during normal business hours) used by a group of fixtures of type i, in business type z, during daytype d.

COF_{izd} = the closed-period operating factor which describes the percentage of full load (during non-business hours) used by a group of fixtures of type i, in business type z, during daytype d.

$HVAC_{ij}$ = the contribution of impact caused by both heating and cooling interaction for technology measure i, installed by customer j.

Aggregated Hourly Engineering Impact Estimates

Hourly (demand) estimates provide the host utility or other client with a result that is readily aggregated by year, month, daytype, utility costing period or even hourly, yielding a variety of useful load shapes that support cost-effectiveness tests or other important functions. This is a valuable product that is achieved using Quantum Consulting's unique utility lighting program DSM evaluation approach.

1995 Program Impacts

Lighting end use 1995 program impacts are presented in Table 1, both for selected technology group and business type segments and for the program overall. The selected five (5) business type/technology group segments (out of 60 for the entire program), which contributed over 55% of the total program gross energy and demand impacts, had a large share of the data resources allocated both in 1994 and 1995. The lighting equipment impacts within these particular segments are stable across evaluation years, and those results have been statistically validated as shown in the following presentation of results.

Table 1. 1995 Lighting End-Use Impacts In Selected Technology Groups and Business Types

Technology Group	Business Type	Ex-Post Gross Energy Impacts (kWh)	Ex-Post Gross Energy Impacts Percentage of Total	Ex-Post Gross Demand Impacts (kW)	Ex-Post Gross Demand Impacts Percentage of Total
Standard Fluorescent	Office	49,840,931	36%	11,391	35%
	Retail	11,988,580	9%	3,478	11%
	School	8,545,166	6%	2,202	7%
Compact Fluorescent	Office	1,977,153	1%	454	1%
High Intensity Discharge	Retail	3,543,663	3%	558	2%
All Other Segments		62,111,003	45%	14,184	44%
Program Total		138,006,496	100%	32,267	100%

Table 2. 1994 and 1995 Lighting End-Use CDF Results In Selected Technology Groups and Business Types

		Coincident Diversity Factor†						
Technology Group	Business Type	1994 Mean Estimate	1994 90% Lower CB	1994 90% Upper CB	1995 Mean Estimate	1995 90% Lower CB	1995 90% Upper CB	Accept or Reject that 1994 and 1995 are not different?
Standard Fluorescent	Office	0.78	0.66	0.90	0.85	0.78	0.92	Accept
	Retail	0.94	0.85	1.03	0.86	0.77	0.95	Accept
	School	0.46	0.25	0.67	0.38	0.22	0.54	Accept
Compact Fluorescent	Office	0.70	0.53	0.87	0.83	0.73	0.93	Accept
High Intensity Discharge	Retail	0.85	0.64	1.06	0.87	0.70	1.04	Accept

† The coincident diversity factor represents the probability that a particular lamp will operate during the summer system peak hour (weekdays during the hour 3:00 PM - 4:00 PM, May 1 - October 31.

Results Comparison

Two critical engineering results used by PG&E to forecast lighting impacts are Coincident Diversity Factors (CDFs), representing the probability that a particular fixture will operate during the summer system peak hour, and annual fixture operating hours (the total number of hours per year that a fixture operates, estimated by dividing the annual energy impact by the change in connected load, ΔUOL x U). Quantum Consulting's engineering methods were designed specifically to provide PG&E with improved forecasting parameters for the lighting end use, including CDFs and annual fixture operating hours. Table 2 provides the 1994 and 1995 CDF evaluation results and Table 3 presents the annual fixture operating hour results, to highlight the consistency between parameters derived from these independent studies.

To validate that the 1994 and 1995 results are not statistically significantly different at the 90 percent confidence level, hypothesis tests were performed to compare the two annual estimates, both for CDF and annual fixture operating hours. Tables 2 and 3 both provide the results of those tests, yielding a conclusion that the means are not significantly different.

Load Shape Comparison

To further illustrate the consistency between the 1994 and 1995 evaluation results, hourly impact profiles for the Office business type are presented in Figure 3. This load shape suggests that all weekday hourly impact estimates are consistently distributed in each of these two independent evaluations. That is, the hourly impacts that contribute to the annual fixture operating hour estimates (validated above) are also well behaved year-to-year.

Table 3
1994 and 1995 Lighting End Use Annual Fixture Operating Hour Results
In Selected Technology Groups and Business Types

		Annual Fixture Operating Hours						
Technology Group	Business Type	1994 Mean Estimate	1994 90% Lower CB	1994 90% Upper CB	1995 Mean Estimate	1995 90% Lower CB	1995 90% Upper CB	Accept or Reject that 1994 and 1995 are not different?
Standard Fluorescent	Office	3,900	3,177	4,623	4,100	3,640	4,560	Accept
	Retail	4,300	3,694	4,906	4,700	4,075	5,325	Accept
	School	2,000	842	3,158	2,300	1,172	3,428	Accept
Compact Fluorescent	Office	3,600	2,512	4,688	4,000	3,380	4,620	Accept
High Intensity Discharge	Retail	4,000	2,603	5,397	4,700	3,379	6,021	Accept

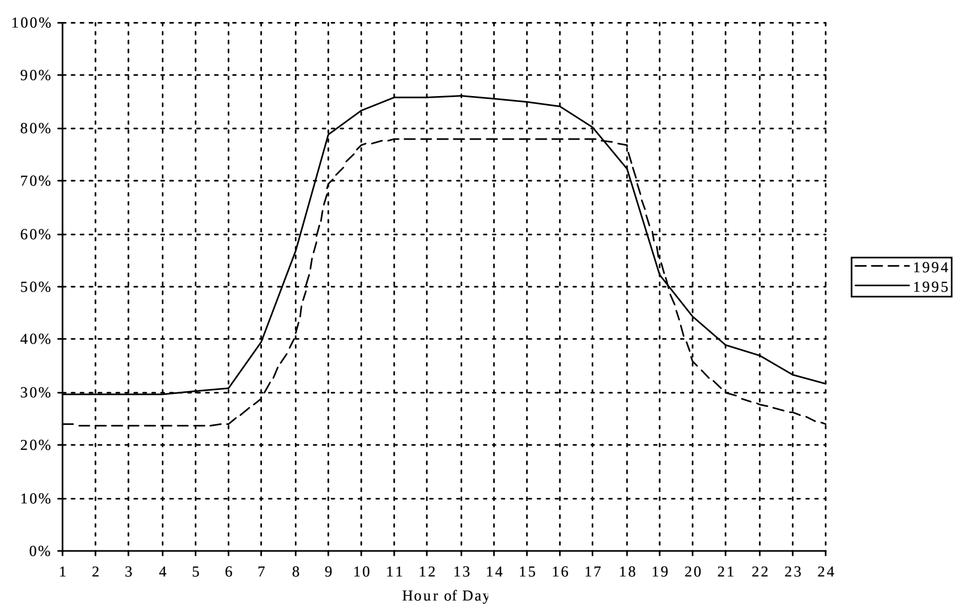

Figure 3
1994 and 1995 Lighting End Use Impact Profiles
In the Office Business Type

Implications for M&E and M&V

Under direction from the California Public Utilities Commission's (CPUCs) Monitoring and Evaluation Protocols, PG&E is obligated to evaluate its commercial sector retrofit programs on an annual basis ending with the 1997 program evaluations in 1998. However, the CPUC guidelines do not require engineering data collection on an annual basis, rather the implementation of a load impact regression model (LIRM) will satisfy the CPUC requirements. If PG&E were to use previous CDF and annual fixture operating hour results in conjunction with current telephone survey data to facilitate the LIRM, then significant savings could be realized in implementing future lighting evaluations (due to the large investments required to gather on-site data and monitored data each year).

The results presented in Tables 2 and 3 suggest that further engineering data collection within the office business type and other key segments will not significantly improve upon the engineering parameters already derived for those participant segments. In the future, evaluation resources should be re-directed to segments that have benefited from fewer resources (such as on-site audits) in past evaluations, to ensure improved measurement accuracy within those particular segments. However, the value of improved accuracy (within those segments with limited participation) should be included in the decision to allocate such resources. For example, it may not be cost-effective for PG&E to collect additional on-site audit data for the 1996 evaluation, given the marginal improvement that can be expected to the engineering parameters derived in 1994 and 1995.

We believe the most cost effective approach for lighting evaluations is to allocate data collection resources based upon program participation (by segment), and to use both current and previous years' data for current-year engineering calculations. This will build upon forecasting methods from previous work in establishing on an annual basis until additional engineering data collection is deemed unnecessary. Once measured segment results are stable, then no additional engineering resources are required and future data collection can be simplified (i.e., cost-effective telephone surveys).

It is also important to note that PG&E has invested significant resources in support of detailed and accurate evaluation results. Great care has been taken to update forecasting methods on an annual basis, using current and improved results. These results should not be neglected in the future as DSM bidding becomes a more prominent industry approach amongst traditional utility implementation. That is, M&V for DSM bidding programs should be based upon these solid forecasting methods rather than alternate strategies designed to verify retrofit savings. In fact, lighting end-use results in particular, may be transferable across utility boundaries.

It appears that a bright future is developing in which M&E and M&V results are valued more aggressively, not only for their use in traditional utility DSM cost recovery mechanisms, but also in providing important customer load profile information. Perhaps too, utilities will seek to use these resources widely and actively in the changing energy and DSM market.

Acknowledgments

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