# Measured Savings vs. Engineering Estimates: An Analysis of Differences Between Program Assumptions, Engineering Surveys and Field-Monitored Data.

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## 1. SYNOPSIS

This paper presents findings from in-situ impact evaluations of commercial sector DSM savings under both direct rebate and custom rebate approaches. The focus of the paper is a quantitative analysis of differences between DSM program planning assumptions, engineering surveys and field-monitored data.

## 2. ABSTRACT

This paper presents findings from in-situ impact evaluations of commercial sector DSM savings under both direct rebate and custom rebate approaches. The focus of the paper is a quantitative analysis of differences between DSM program planning assumptions, engineering surveys and field-monitored data. This information provides real-world feedback to DSM implementation staff. Impact parameters of interest include gross first-year savings and load shape impacts. The major method discussed in this paper is short-term before-and-after field monitoring of affected end-uses coupled with an analysis of DSM program rebate forms. This paper uses results obtained from short-term energy measurements performed at sites monitored as part of the Commercial, Industrial and Agricultural (CIA) Retrofit Incentives Evaluation Program sponsored by the Pacific Gas & Electric Company, a major U.S. utility in California. A total of 90 sites were field-monitored for this project. The DSM measures include those typically found in these sectors; i.e., lighting, motors and HVAC modifications.

The paper addresses the following topics: determination of DSM savings through short-term measurement techniques; comparison of field-measured savings to prescribed savings for direct rebates and to custom rebate engineering estimates; and an engineering assessment of differences in these estimates. It is these custom rebate sites that are most interesting. Even with detailed on-site engineering surveys supporting the rebate savings estimate, differences in key parameters such as connected lighting load and hours of operation were uncovered. The paper explains these differences and recommends procedures to improve DSM estimates.

## 3. INTRODUCTION

The emphasis of this paper is to describe how short-duration energy impact monitoring techniques are applied to determine energy savings in the following commercial, industrial and agricultural (CIA) DSM technology groups: lighting; agricultural irrigation; space conditioning; refrigeration; and process motors. DSM measures from both the Express Rebate (formerly called the Retrofit Rebate program) and Customized Rebate portions of the program have been selected for evaluation. Across these five major technology groups, the initial Sampling Plan called for 120 Express Rebate and Customized Rebate monitoring sites. Monitoring sites from the commercial, industrial and agricultural sectors are included.

Although 120 field measurement sites were planned for monitoring equipment installation and analysis, only 92 sites were successfully recruited with 90 of those sites finally instrumented. Subsequently, four fully instrumented sites never completed their retrofits before the incentives program deadline expired. The remaining 86 sites completed the planned retrofits. Site recruitment was extremely difficult with various unforeseen obstacles impeding the full measurement sample implementation. The two largest factors contributing to the reduced measurement sample were timing (pre-retrofit period too short) and installation complexity (monitoring system too large for the scope of this project).

Express Rebate sites use the standardized application forms to calculate the demand and energy reductions and rebate funding for the retrofit to be installed in the site. The numbers behind these calculations come from extensive surveys and studies of the utility's customer base and represent the characteristics of average utility customer in various categories. The Customized Rebate sites, however, use the actual equipment to be retrofitted into the site to calculate the savings numbers. Direct comparisons of site measurements to the Customized application numbers are possible on a site-by-site basis, while the Express Rebate sites may or may not be close to the average of a utility category and may indicate results that are considerably uneven. This is because characteristics for a specific site often vary considerably from customer class averages. However, average results should be very close if studied in the aggregate with numerous Express Rebate sites.

## 4. METHODOLOGY

Short-term energy impact monitoring is a method by which actual on-site measurements and observations can be used to determine energy consumption and demand savings due to a building or energy systems retrofit. On a stand-alone basis, this short-duration energy impact study was intended to achieve the following general objectives:

- Verify site-operation parameters, such as operating hours, used by the utility in customized rebate applications.
- Provide site-level, time-differentiated energy and demand savings results using short-term metering/monitoring.
- Produce site-level estimates of the first-year, annual kWh saving and load-shape impacts attributed to selected demand-side management measures.
- Compare metered estimates of energy and demand savings results to the energy and demand savings projections in the utility's rebate applications.
- Explain the differences between the utility's estimates and the monitored results.

### 4.1 Short-term Monitoring

The steps involved in the savings estimation process based on short-term energy impact monitoring are as follows:

First, the site is visited prior to the retrofit to install the field data loggers[1] on the end-use device(s) to be retrofitted. The total end use, or a representative portion of the end use, is monitored by the field data logger. Site survey information is obtained to quantify how the site's energy usage profile. In addition, "spot-watts" (i.e., hand held kW measurements) are taken of all appropriate end uses monitored at the site.

Voltage measurements and electrical service information determined which watt-hour transducer was to be installed and used with current transformers. The other equipment groupings are temperature, water and air flow, pressure, miscellaneous equipment (i.e., run-time sensors) and data logging equipment. Ultimately, it was the retrofit itself that defined the measurement, and the site survey information set a guideline for instrument specification.

Second, data are collected from the data loggers (usually over the telephone) to characterize the end use to be retrofitted. As soon as it is confirmed that one week of good pre-retrofit data has been collected, the site representative is told to proceed with the retrofit. Data continued to be collected and analyzed until at least two weeks of good post-retrofit data are collected.

The third step is to return to the site, remove the instrumentation, and re-survey the site to ensure that the retrofits planned for the site were actually installed. "Spot-watts" of the new retrofitted equipment installed by the building owner are taken.

Fourth, the measured energy savings are calculated. Demand profiles of the retrofitted end-use device are plotted for the various day-types (including average Weekday, Saturday, Sunday, and Holiday) from the pre-retrofit and post-

[1] Data loggers are special-purpose electronic devices designed to collect and store time-series data from kilowatt-hour meters and other types of sensors. Periodic readings of energy sensors at 15-minute intervals are stored in the data logger's memory for retrieval via telephone modem. Watt-hour transducers provide a continuous measurement of electricity usage, taking into account service voltage, amperage draw of the end-use equipment, and power factor.

retrofit data. The pre-retrofit daily energy use is calculated for each day-type. The connected load before the retrofit is installed is then calculated based on the "spot-watt" measurements and adjusted for any items such as burnt-out bulbs, non-monitored areas, etc. The non-adjusted measure load (in kW) is then divided into the daily energy use (in kWh) for each day-type and multiplied by the number of the day-types in annual equivalent full-load hours (EFLH, which are discussed later on.) The annual EFLH's are then multiplied by the total adjusted connected load to arrive at the annual energy use figure. This process is then repeated for the post-retrofit measured data. The annual savings are then calculated by subtracting the annual post-retrofit energy use from the pre-retrofit energy use figure.

The short-term energy impact monitoring methodology described above relies on the following two assumptions in order to simplify the monitoring and analysis approach:

- Measured end-use technologies are utilized consistently throughout the monitoring period. If the technology is seasonally utilized (i.e., summer, winter), seasonal performance can be estimated from the short-term measurements and assumptions are made regarding usage patterns. These are "informed" engineering judgements based on on-site inspection data.
- Monitored sample systems are representative of the total affected area. This method is used if monitoring the total affected area or system is cost prohibitive. Care is taken to ensure that the monitored areas are representative of the total affected area. This is true, not only for short-term monitoring, but for any metering project.

The fifth step involves comparing the site measured results to the utility rebate application calculations. The last step is writing the individual site report and documenting the site. Copies of the specific site reports were provided to the customers whose sites were metered.

### 4.2 Analysis of Retrofit Impacts

Data analysis consists of interpreting results obtained from short-term measurements to determine the energy impact resulting from the energy efficiency measure. The difference in the energy consumption from the pre- to the post-retrofit periods is of interest, rather than the absolute values. Empirical engineering adjustments particular to each energy efficiency measure type are made to extrapolate these short duration measurements to annual results.

Energy impact results are developed for: (1) the monitored areas or systems, and (2) the affected areas or systems. The monitored areas or systems may be a subset or a superset of the affected areas or systems depending on the specific application. An on-site electrical/mechanical system assessment, performed at the time of the monitoring system installation, provides a precise relationship between the monitored and affected areas and systems.

Time-differentiated data (i.e, the time series pre- and post-retrofit data collected from the site), including demand load profiles, are only applicable to the monitored areas or systems. However, the time-differentiated data collected from the monitored areas and systems, combined with information gathered during the site survey may be used to extrapolate energy savings resulting from the retrofit to areas outside the monitored areas. For example, identical office floors with the same lighting equipment and operating schedule can be assumed to follow measured patterns if this can be confirmed through visual inspection and tenant interviews.

The following discussion provides more detail on the key steps necessary to complete the analysis of the data from a retrofitted site and compare it to the utility Rebate Application.

### 4.3 Actual Demand Profile

Pre- and post-retrofit average 24-hour demand profiles are generated for each of three day types from monitored data: Weekday, Saturday, and Sunday/Holiday. These profiles are used to evaluate the actual monitored demand difference and the daily energy use by day type because of the installation of energy-efficient measures. These profiles present the adjusted pre- and post-retrofit system demand. The adjustments are described below.

If only one channel is monitored at the site, then one set of demand profiles is generated for the site. The "measured" area data are then adjusted to account for items such as burnt-out bulbs and non-measured areas to make the profile representative of the total "affected" area. If two or more channels are monitored at the site, then individual sets of demand profiles are generated to quantify each measured area. These are then adjusted to illustrate the total "affected" area demand for the pre- and post-retrofit period. Again, these profiles are adjusted for the areas they represent, burnt-out bulbs, and other factors that convert the measured results into the total "affected" area results.

The demand profiles presented in the site reports represent the total "affected" area of the retrofitted devices. A sample of an actual pre- and post-demand profile is shown below in Figure 1.

### 4.4 Equivalent Full Load Hours

Energy use for a device such as a light fixture can be estimated as the product of its rate of use (in watts) multiplied by its hours of usage. If a 100-watt light bulb operates for one hour, then its energy use in that period will be 100 watt-hours. Traditional engineering estimates employ this basic relationship to approximate energy consumption or changes in energy consumption. For example, if a convenience grocery store is open from 7:00 a.m. to 11:00 p.m., then the lighting system is often assumed to operate for 16 hours. Estimates of daily lighting usage may be made by multiplying the connected lighting load of the lighting fixtures (in kW) by the 16 hours of daily operation. Furthermore, if the store maintains the same business hours year round, the daily consumption estimate can be annualized by multiplying it by the 365 days in the year. However, past field monitoring projects have identified a number of key factors which can introduce significant error into the simple estimating process described above:

- Equipment diversity. Load studies and on-site surveys have shown that not all energy using devices may operate at any given point in time. For example, office workers often shut off lights when they are away or out to lunch. It is rare that the entire installed capacity of lighting systems is actually "on-line" at once. Thus, the simplified approach above may inadvertently make this erroneous assumption concerning equipment operation and duty cycling.

- Part-load operation. Many end-use devices such as air conditioners have variable energy consumption profiles depending on external conditions such as temperature and humidity. These devices only operate at maximum rating conditions during a relatively few hours a year. Most of the time, they are in a part-load operating condition.

  This phenomenon can also show up in lighting systems that are switched or controlled according to California's Title 24 building standards; i.e., three levels of lighting in multi-tube fixtures. Thus, three identical rooms with exact types and quantities of fluorescent light fixtures can be operating at different levels of lighting output and power consumption. Again, not accounting for this effect can introduce error into estimating methods, especially if lighting run time loggers are the only monitoring devices used.

- Actual vs. nameplate energy use. Many estimates of energy use rely on the nominal or nameplate ratings of light fixtures and other devices. However, past field measurement studies have shown that actual watt draw can differ from nominal ratings by as much as 20 percent (Landsberg and Amalfi 1992). This has been attributed to misidentification of ballast type and effects of fixture operating temperature due to mounting and fixture housing details affecting air flow around the light fixture. In-situ field measurements (i.e., "spot-watts") can correct for this effect.

The approach used in this analysis is use of Equivalent Full-Load Hours, or EFLH. Use of EFLH yields a measurement-based estimate of operating hours at full measured loads. Basically, EFLH are computed by dividing kWh usage in a given period by a measured kW load. Thus, the EFLH fully capture diversity and part-load effects. The approach also captures differences between actual and nameplate watt draw due to site-specific effects when "spot-watt" measurements are taken. Measurement studies nationwide have shown this to be an effective approach.

### 4.5 Energy Impact Estimate

The estimated pre- and post-retrofit annual consumption is calculated for the total affected area. The estimated annual energy savings is calculated by subtracting the estimated post-retrofit annualized energy consumption from the estimated pre-retrofit annualized energy consumption, normalized to full load conditions, which includes utilization of full retrofit count, adjusting for burnt-out lamps or broken fixtures when lighting is the retrofitted measure. These annual energy savings estimates can be used to assess the impact resulting from installation of energy-efficient measures. There are two simple steps to this process.

- Determine the annual energy use. The annual energy use for the total affected area is calculated by multiplying the annual EFLH's times the total adjusted connected load represented by the EFLH's to equal the annual energy use. Note that this process is repeated for the total number of channels measured at the site. Each channel uses the connected load that it represents, with the aggregate equal to the total affected areas connected load.

- Calculate the annual savings. The annual energy savings are calculated by subtracting the estimated post-retrofit annual energy consumption from the estimated pre-retrofit annual energy consumption.

### 4.6 Energy Savings Comparisons to Utility Rebate Application Estimates

Once the energy savings are calculated from the actual site measured results, a complete comparison is made to the impact estimates presented in the utility's Rebate Application. The process is described as follows, according to each of the Rebate Programs.

- Express Incentives Program Comparisons. The Express Incentives Program follows prescribed methods to arrive at the energy and demand savings. These are calculated based on average customer and facility characteristics in various utility customer sectors. These assumptions are detailed in the worksheets for each area in the Express Program. The objective for this comparative analysis is to determine if the assumptions used in the worksheets for projecting the energy savings are valid.

- Customized Rebate Incentives Program Comparisons. The Customized Rebate Incentives Program is different from the Express Program in that it uses estimates prepared by the customer applicant rather than a prescribed method to estimate the savings. The objective of this comparative analysis is to verify the method used by the applicant, determine if an appropriate process was used, and then finally compare these savings to those based on the measured data.

## 5. FINDINGS

Results from the 86 measured sites and 14 pump test sites (analyzed through a separate engineering and billing analysis) are presented in this paper. The results show that for the metering study sample the annualized measured energy savings are approximately 23% lower than expected based on the utility application estimate, or 77% of the estimated savings. The percent differences, per site, range from +917% to -147% (a positive value meaning that the measured savings were greater than the application estimate and a negative value meaning that the measured savings were less than the application estimate). Reasons for these discrepancies are discussed in the next section. Although there may be large differences between the measured energy savings and the utility application for particular sites, the total energy savings for the program are comparable when viewed in the aggregate.

### 5.1 Discrepancies Between Application and Measured Savings Estimates

There are several reasons for the discrepancies between the utility's projected energy savings and those projected using measurement-based estimates. However, imprecise engineering estimations of the two most important variables used when projecting potential energy savings, annual operating hours and equipment connected load (kW), account for the majority of the differences. The estimated savings projections are directly related and proportional to these two variables.

The importance of accurate values for these critical parameters is illustrated in the series of data charts in Figures 2, 3 and 4. These data illustrate the percent differences in estimates between the rebate applications and field-measured values for kilowatt-hour impacts, kilowatt demand impacts and operating hours. These data are shown for all the Custom and Express lighting sites for which all three parameters are available (not all applications had completed entries for these items). Several observations can be made from these data:

- The variance between the two impact estimating methods in Figure 2 is far more pronounced in the Express sites than in the Custom sites. Here, the value of site-specific data is evidence for producing more accurate savings estimates. The custom sites don't exhibit the extreme overestimates in many of the Express sites.

- The variance in estimates of kW in Figure 3 follows the same trend. The kW impact estimates in the Custom sites are grouped much tighter than the Express sites where sector-wide parameters were assumed.

- The same trends are exhibited in Figure 4 where, with the exception of one Custom site, the assumed operating hours are far closer to measured EFLH than in the Express sites.

Although the Customized and Express rebate programs are very different, the projected savings for each program are estimated using similar types of engineering algorithms. The major difference is in the use of site-specific engineering data.

**Figure 1**

**Example Pre/Post Demand Profile for a Monitored Site**

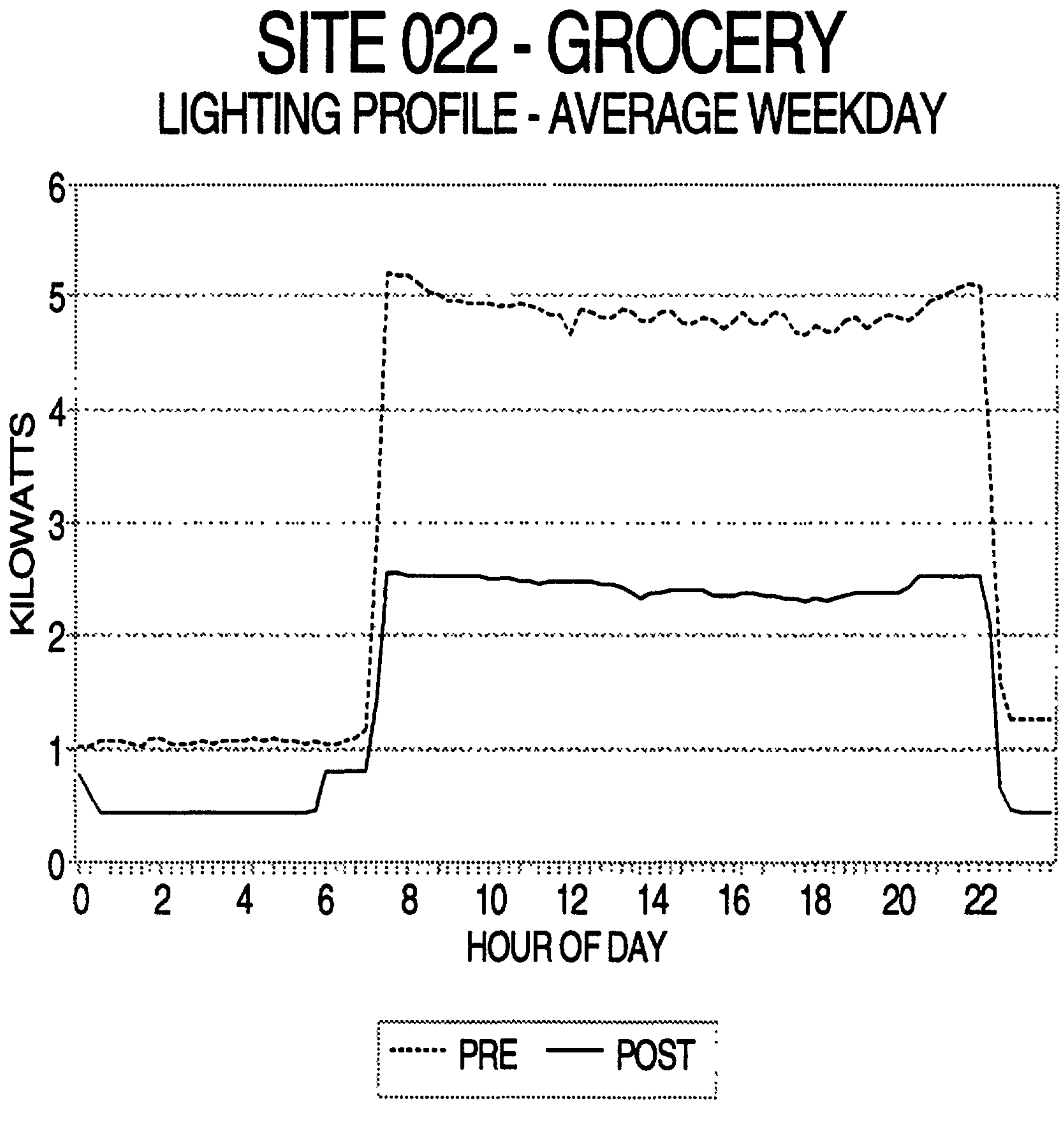
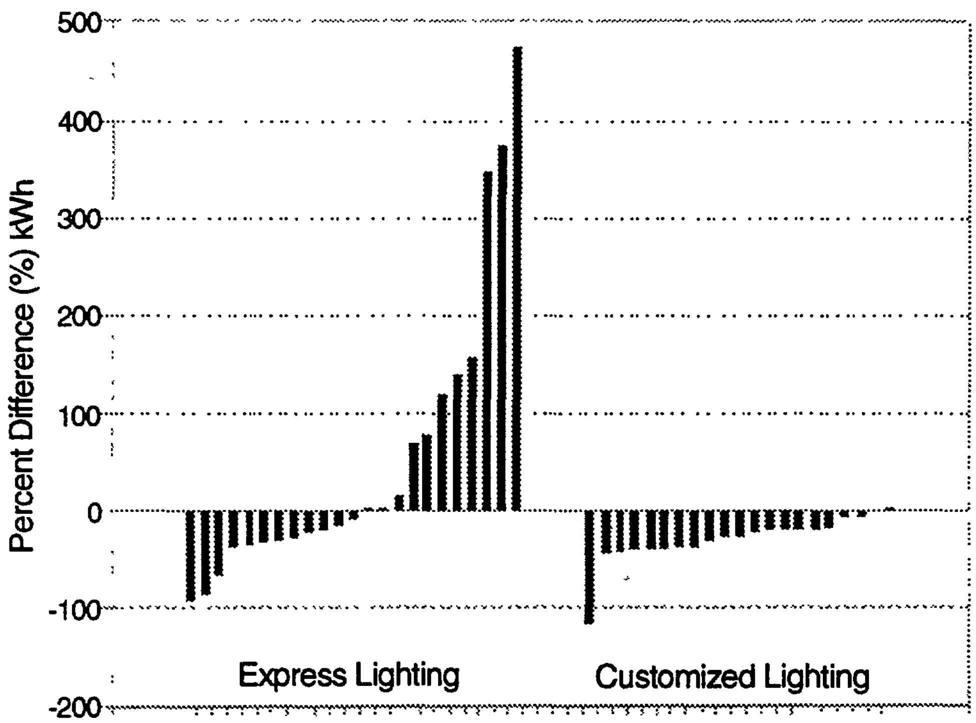


**Figure 2**

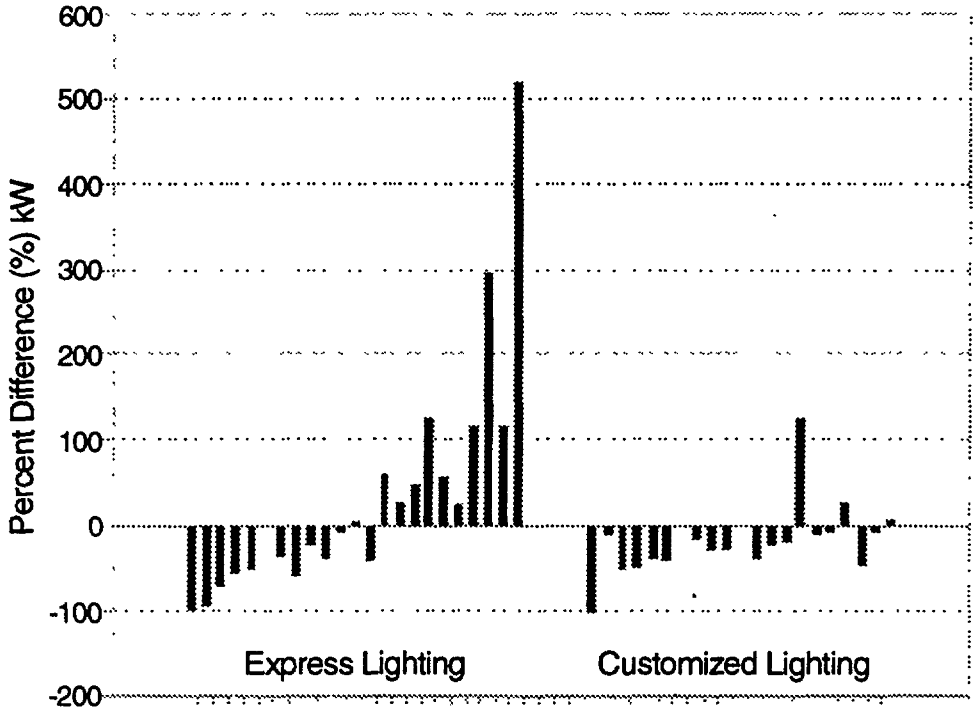
**Application Estimates vs. Measurement-Based Estimates: Percentage Differences in Estimates of Kilowatt-Hour Impacts**




**Note:** **Each bar represents the results from an individual monitored Express or Customized lighting site.**

**Figure 3**

**Application Estimates vs. Measurement-Based Estimates:**
**Percentage Differences in Estimates of Kilowatt-Demand Impacts**




**Note:** **Each bar represents the results of an individual monitored Express or Customized lighting site.**

### 5.2 Custom Rebate Program

In general, the Customized Rebate program engineering estimates were representative of actual site conditions. However, estimated hours of operation were used for the savings calculations as opposed to Equivalent Full Load Hours (EFLH). This will tend to over estimate the projected savings as it does not take into account equipment part-load operation. For lighting systems, part-load conditions are represented by individual areas within the facility not operating all light fixtures continuously. For HVAC systems, part-load conditions are represented by the equipment not operating at design conditions continuously. At a few large sites, large over-estimations of projected energy savings were caused by equipment control problems. For example; motion sensors were installed and not adjusted; control sequencing equipment for an air compressor system was installed but not activated. Unfortunately, correction of these control problem are only detected by post-retrofit monitoring and retrofit measure commissioning. Simple post-retrofit site audits will not detect these type of engineering assumption errors. The various difficulties that caused Customized program projected energy savings to be either over-estimated or under-estimated are discussed in detail below:

- Retrofit Completed Improperly. In 2 of the 59 monitored Customized sites, there were failures to delamp targeted fixtures. This consequently affected the site's projected demand reduction which proportionally affected the utility-projected energy savings.

- System not operating as anticipated. This problem was found in 10 of the 59 monitored Custom sites. In general, systems, such as occupancy sensors and variable speed drives, were anticipated to reduce operating hours by a specific amount. In many other cases, such as 9 out of the 10 Custom space conditioning retrofits, the anticipated operating hour reductions did not materialize. This was due to changes to building set-point temperatures and other HVAC control problems which resulted in the retrofitted system operating much the same as during the pre-retrofit period. This same effect was also observed at the two Custom process sites. Within the Customized lighting program, the anticipated EFLH savings did not materialize at 4 sites, 3 of which were occupancy sensor control retrofits. These problems were due to setting the occupancy sensor's sensitivity too high.

- Equipment hours of operation estimated high/low. Estimating the equipment hours of operation either high or low was discovered to be the main reason for the discrepancies in projected energy savings estimates in 25 of the 59 monitored Customized sites. Most of these discrepancies were found in the Customized lighting program. In general, the utility-estimated operating hours were derived using the site's business hours. This does not take into account equipment part-load operating conditions and usage diversity. Consequently, the EFLH were overestimated for the majority of the customized sites. Figure 2-3 illustrated these effects at the customized lighting sites.

- Equipment demand reduction estimated high/low. This effect was found to affect 16 of the 59 Custom sites. The estimated demand reduction on custom applications was found to generally be over stated, mostly due to incorrect fixture counts and overly high estimations of retrofit fixture wattage savings.

### 5.3 Express Rebate Program

In contrast, the Express Rebate program engineering estimates were not very representative of the actual sites. This was to be expected as the energy savings calculations were predetermined and averaged by technology type and customer type. However, the overall program results were good with overall measurement-based estimates within 5% of the overall savings estimated on the rebate applications. This can be explained by the fact that although the engineering assumptions for connected load reduction or operating hours were not reflective of the actual site, the errors were often times offsetting. For example, the predetermined operating hours for a particular site were greater than the measured operating hours, but the measured connected load reduction was also greater than the predetermined value for the retrofit. Also, many of the retrofits performed under the Express program did not exactly match a line item on the rebate application. This caused 'creative interpretation' of the actual retrofit measure. This interpretation increased the error in any engineering assumptions used to calculate the projected energy savings for the Express rebate program. Adding additional line items to the rebate application or performing such retrofits under the Customized program could decrease the error. The various difficulties that caused Express program projected energy savings to be either over-estimated or under-estimated are noted below:

- Equipment hours of operation estimated high/low. Estimating the equipment hours of operation either high or low was found to be the main cause of the discrepancies between the two energy savings projections in 14 of the 41 monitored Express sites. These results were expected and can be contributed to the utility workpaper's predetermined hours of operation for particular business types. It was also found that EFLH's in office buildings had the largest discrepancies in overestimation.

- Equipment demand reduction estimated high/low. The kW demand reduction was estimated either high or low in 9 of the 41 express sites. These results were also attributable to utility workpaper's assumptions. However, fixture counts on applications were estimated high or low. In some cases, delamping fixtures were not accounted for by the application, or double savings were erroneously documented for a single retrofit.

## 6. CONCLUSIONS AND RECOMMENDATIONS

The short-term metering was very effective from an engineering, research design and cost standpoint. This study is one of the first DSM program evaluations to successfully combine high resolution, limited scope metering samples with broad-based, less detailed on-site survey/engineering modeling samples in a statistically valid manner.

The detailed engineering data developed as part of the field monitoring process provides insights into why program forecasts may differ from measurement results. Among the detailed program parameter data developed from the calibrated engineering model are: end-use measure peak demand estimates; end-use measure load shapes, including time of day; hours of operation and full load hours by measure type; and baseline efficiency levels. These data are valuable for refining the utility's forecasts of DSM impacts and improving the DSM program tracking system.

Short-term metering is becoming an important and effective tool for DSM evaluation, especially when combined with other methods. This project, one of the largest and most ambitious short-term metering projects to date, offers a number of lessons as to how other may perform similar projects in a cost-effective and timely fashion. The key conclusion is the need for integrated program design and evaluation plans. As evaluation becomes more important and as the tools for program evaluation become more varied, the importance of integrating program design and evaluation plans is becoming increasingly apparent.

The above recommendations do not imply that short-term metering projects cannot be successful if DSM programs have not been designed with evaluation metering in mind. It is to say, however, that short-term metering projects that have been integrated with DSM program design will be more cost-effective, and the resulting data will more accurately reflect what is happening in the field.

## 7. ACKNOWLEDGEMENTS

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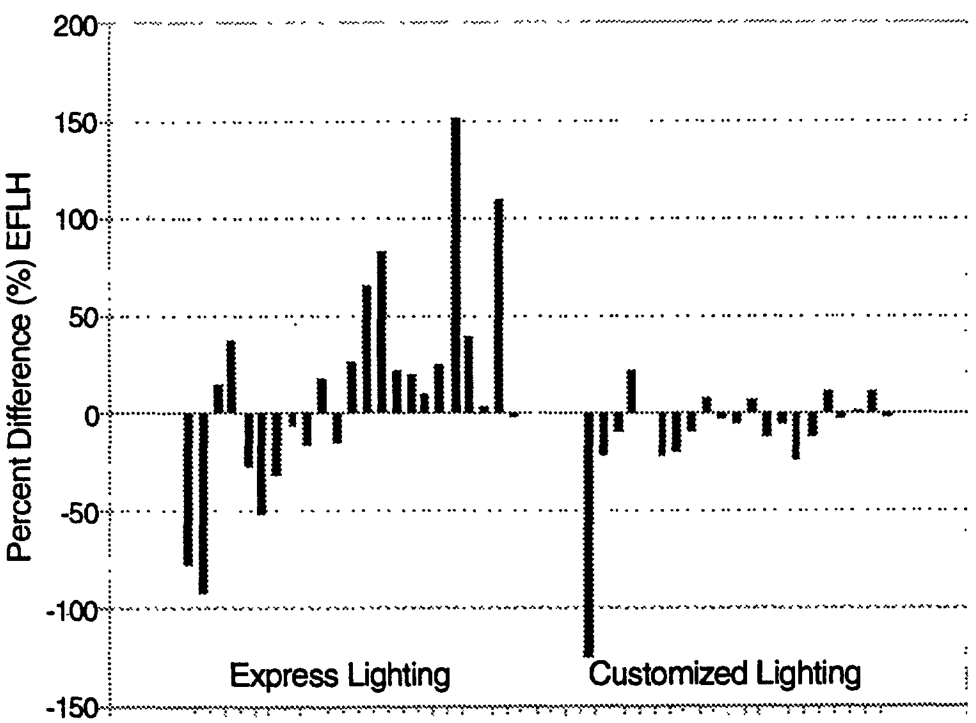
**Figure 4**

**Application Estimates vs. Measurement-Based Estimates: Percentage Differences in Estimates of Operating Hours**




**Note: Each bar represents the results of an individual monitored Express or Customized lighting site.**