Impact Evaluation Using Load Research Data

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This paper discusses how 15 minute load research type demand data on a sample of large commercial and industrial customers can be used as an integral part of the impact evaluation of a C&I rebate program.

The analysis for this paper was performed using software that is able to present three dimensional building "energy prints" that can visually describe the energy use patterns of the participating building. These energy prints were developed for a period of one year prior to the installation of the measure and a period of 3 to 12 months after the measure installation. The analysis compared pre- and post- retrofit time periods for lighting, motor and air conditioning measures. The analysis included 24 buildings who participated in Con Edison's Enlightened Energy Rebate Program. Buildings were selected where significant savings were achieved as compared to the entire building load (over 5% of total kWh usage). Building ranged from 200 to 10,000 kW peak demand.

The visual analysis software calculated the average kW and kWh during the pre- and post- retrofit time periods and the resulting energy and demand reductions from the retrofit.

The goal of the paper is to demonstrate the visual data analysis approach and evaluate its use in analyzing program impacts where whole building demand data is available.

Introduction

This analysis attempts to identify and isolate the effects of a commercial and industrial rebate program on a small sample of program participants. Data visualization and standard engineering analysis were used to develop estimates of savings for program participants where demand reductions could be identified by visual inspection of the data. This paper provides a discussion and illustration of the data visualization used, with detailed data and printouts of the graphs used in the analysis for three participants. Included are sections on problems encountered, quantitative findings, and recommendations for the use of this type of analysis in impact evaluations.

Methodology

Customer Identification and Selection

The analysis for this paper was completed using a sample of Con Edison Commercial/Industrial Enlightened Energy Rebate Program participants in 1992. Customers with 15-minute whole building load research data and total kW demand greater than 300 kW were used. These large participants were identified by cross referencing the program participants with large (over 300 kW) load research sample customers with 15-minute interval records. These customers were then screened for program participation between January and December, 1992. Customers were selected where sufficient pre-retrofit and post-retrofit data were available for the analysis. The selection found 90 customer accounts that met the matching criteria for the analysis.

Following this screening, a sample of 25 customers were drawn from the remaining participants. This additional screening examined the program estimate of kW saving compared to the participants peak kW demand. Participants were selected when the kW savings estimate was greater than 5 percent of the peak kW. The 15-minute interval data on these customers were provided by the utility.

Visual and Engineering Analysis Tools

The data were analyzed using visualization and analysis software running on a UNIX based Mini-computer. Each customer was analyzed using a set of software based routines developed by RLW for DSM impact analysis. Data for each customer were analyzed independently using interactive techniques. A step by step description of the analysis technique is provided below.

Data Preparation

Data were prepared for analysis using software based routines for identifying and flagging missing intervals in large datasets. No editing or substitution of missing data was performed. Two customers did not have sufficient post retrofit data for the analysis. Only customers with sufficiently large retrofits were analyzed, allowing the study to focus on customers where the savings could be identified using visual data analysis techniques. Each retrofit was treated as a separate analysis

Analysis Steps

The analysis was performed using a series of diagnostic routines developed to readily identify and isolate DSM impacts. Each step is described below and example graphics and figures are provided to illustrate each concept. The following example and discussion uses a large commercial office building with about 5000 kW peak demand. Data from 1990 (pre-retrofit) and 1992 (post-retrofit) was used.

Visual Inspection of the Dataset. The 15-minute interval whole building load data for each customer is selected and loaded into the software from a menu of customers. For this analysis, each customer dataset included 2 years of data covering the time period from 1/1/90 to 12/31/90 and 1/1/92 to 12/31/92. Data from each year were analyzed as a single continuous dataset, allowing the analyst to look across the two years and visually isolate impacts from seasonally effects.

The key diagnostic tool used to identify and isolate the DSM impacts is the "EnergyPrint", a 3-dimensional plot of the 15-minute interval data. In the graph, the kW demand for each interval is normalized between minimum and maximum kW by "n''- day chart on the high resolution computer screen. Figure 1 illustrates the Energy Print for a large office building included in the analysis. In this figure, kW-Demand is coded using a gray scale gradient where 0 kW appears black, to high kW which appears white. The "Energy Print" presented in this paper uses gray shades to represent higher and lower kW demand. The software uses color to represent the magnitude of kW which provides a much clearer picture of the buildings energy pattern.

Once the analyst understands this shading scheme, the customer's hours of operation, summer and winter seasonal patterns, and end uses such as outdoor lighting become apparent. Any supporting knowledge regarding technologies at the site, such as schedules, and production or occupancy patterns is extremely useful to the analysis at this point. For the example project, the measure implementation date was 6/8/92, where the customer installed Variable Speed Drives (VSD's) on several supply air fans that resulted in a tracking system savings estimate of 189 kW. The change in shading from light gray to a darker gray provides the analyst with the visual tip-off that the implementation occurred there.

Locating the Implementation Date. After using the information from the Energy Print as a guide, a second diagnostic tool, the 2-D Constant Hour chart was used in the assessment of when implementation of the measure actually occurred. The 2-D chart showing kW demand vs. days is shown in Figure 2. On the computer screen, the Constant Hour chart is displayed above the Energy Print

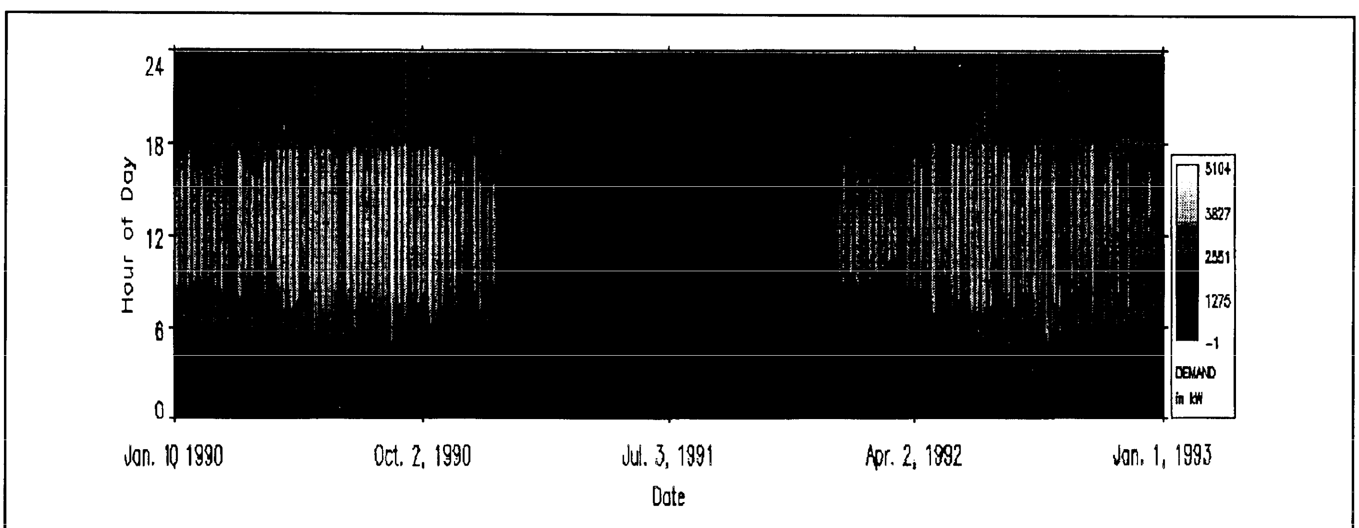

Figure 1. Example of an Energy Print Used to Identify and Isolate DSM Impacts

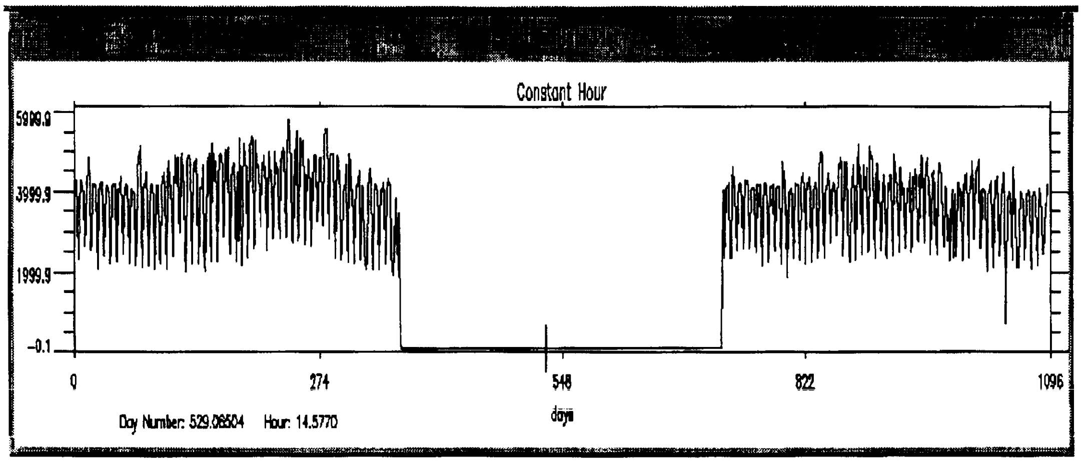

Figure 2. Exarnple or a 2-D Constant Hour Profile

and positioned so that days on both charts are aligned. As the analyst sweeps the cursor up and down and across intervals on the Energy Print, the Constant Hour plot displays the kW demand data for that interval across the years. Using this tool, the analyst can identify the actual kW demand of the building at any time. In this case, there appears to be a decrease in demand around 6/8/92. In most cases, the actual reduction in kW demand and implementation date can be seen. In Figure 2, the constant hour shown is 14:57 or approximately 2:35 p.m. and it appears that the post-retrofit period shows a reduction in demand over the pre-retrofit period.

Selecting the Pre/Post Analysis Period. The third step in the analysis is to select the pre-retrofit and post-retrofit periods for the customer. The analyst selects the weeks for pre and post analysis that appear to be free of confounding effects. The analyst can select weeks on either side of the apparent implementation date, or can compare post-retrofit performance with previous years. For this analysis the comparison was done for the month of August.

A pre-retrofit day is selected by clicking the mouse at the point of interest. Next, the analyst selects the post-retrofit period by once again clicking the mouse over the point of interest. In the office customer's case, the analyst selected 7/3 1/90 as the beginning of the pre-retrofit month, and 8/4/92 as the beginning of the post-retrofit month. This selection then triggers the creation of 3 screens that provide load profiles in the pre and post periods.

The Impact Analysis. After the pre-retrofit and post-retrofit analysis time periods are selected, 3 standard plots are immediately generated that show average weekly and daily pre/post 15-minute kW demand profiles. An algorithm matches the day of the week in the post-period with the pre-period. For example, pre-retrofit Mondays are always compared to post-retrofit Mondays, and weekends are always compared to weekends. Figure 3 shows a typical 24-hour load profile for the first day in the analysis period which is displayed in the first chart. The second chart shows an average week in the pre and post period. The third chart shows the difference between the pre and post period for the average week period. Changes in the load profile and hours of operation are clearly seen between the pre and post period.

The charts in Figure 3 are used to determine the estimate of kW demand savings. The analyst determines the typical kW demand reduction from the graphs. Because there can be a large number of confounding effects in the data, occupancy changes, weather changes, and other anomalies, the analyst typically iterates through this process 4 to 5 times, selecting a pre/post period and inspecting the graphs for estimates of savings. In this case, the estimate was 204 kW. Hours of operation are determined judgmental, based on the analyst's understanding of the facility's function and the wealth of data gained from studying the Energy Print.

Once the analyst selects a set of pre/post periods as representative of the sites typical performance, the analyst can read off operation hours from the Energy Print shown in Figure 1 and from the three charts shown in Figure 3. This office site clearly has ventilation operation from 6 a.m. to 6 p.m., 5 days a week. This equates to about 3130 hours per year. Energy savings can then be determined by multiplying the typical 204 kW reduction seen in Figure 3 by 3130 operating hours. The resulting kWh savings were estimated at 639,260 kWh. To maintain an accurate record of the analysis, a copy of the analysis screens is made and saved as a computer file.

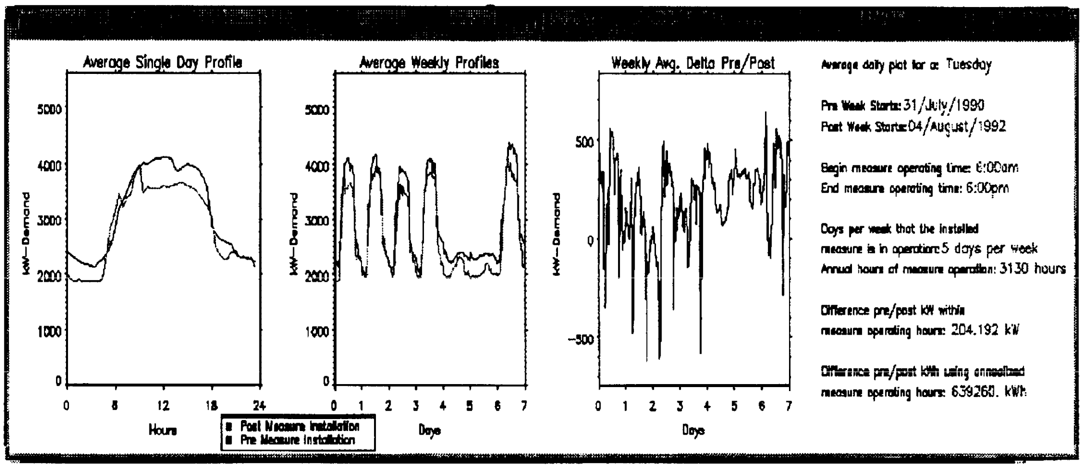

Figure 3. Pre/Post Retrofit Load Profiles

Using the methodology described above, kW and kWh impacts were found for 19 out of the 25 customers in the sample. The 6 customers where impacts were not seen, either had no change or an increase in usage in the post retrofit period.

Results

Results of the Load Research analysis approach are provided below.

Table 1 shows each customer in the analysis and includes hours of operation, kW demand, kWh energy savings estimates from the tracking system, and estimates determined from the load research analysis. Where hours of operation were not available in the tracking system, they were calculated by dividing kWh savings by kW demand reductions.

Software screens were generated for this analysis. Each of the screens includes the fundamental images and plots needed to identify and determine kW and kWh savings. Specific figures provided for each customer include the Figure 1 Energy Print, Figure 2 Constant Hour Profile, and Figure 3, the actual pre/post retrofit profiles for a single day and the analysis week and the pre and post difference graph.

Problems Encountered

Using the preceding methodology, estimates of impact were developed for 19 of the 25 large customers that were examined. The six customers where savings was not determined were known to have implemented the DSM project but it was not possible to identify the impact of these projects in the available total-load data. A variety of factors seemed to be at work, including the following:

- Large Participants: All of the participants in the analysis were very large buildings averaging over 4.4 MW demand with only one building under 1.0 MW.
- Uncertain Date of Implementation: A single implementation date for each project was used in the analysis. For large retrofit projects the actual implementation may take several weeks or months. In some cases the tracking system date was not easily verified in the total load data so that suitable before/after profiles could not be selected.
- Multiple Applications: Some of the customers participated in the program several times during the analysis period and it was difficult to sort out the effects of the individual applications.
- Confounding Factors: If the retrofit occurred during the summer, its impact could have been obscured by air conditioning loads. The impact could also have been distorted if the retrofit occurred in conjunction with a facility renovation or change in occupancy.
- Multiple Account Numbers: In some cases, the load research account may not have been actually affected by the retrofit work due to multiple accounts at the site.
- Lack of Other Supporting Information: In several cases, additional information about the nature of the retrofit and the other end uses affecting the total load might have facilitated the identification of the impact.

This analysis highlighted issues which should be addressed when using this type of analysis for future evaluations.

Table 1. Customer Specific Savings Estimates

Site#	Tracking kW	Data Analysis kW	% of Tracking	Hours	Tracking kWh	Data Analysis kWh	% of Tracking
1	665	-185	-28%	8,760	5,825,400	-1,620,600	-28%
2	259	-122	-47%	3,852	997,668	-469,944	-47%
3	216	-51	-24%	3,130	676,080	-159,630	-24%
4	108	0	0%	8,760	946,080	0	0%
5	181	4	2%	2,808	508,248	11,232	2%
6	268	6	2%	8,400	2,251,200	50,400	2%
7	112	33	29%	3,130	350,560	103,290	29%
8	76	37	49%	3,130	237,880	115,810	49%
9	156	58	37%	4,748	740,688	275,384	37%
10	165	86	52%	2,608	430,320	224,288	52%
11	171	87	51%	3,130	535,230	272,310	51%
12	98	148	151%	3,391	332,318	501,868	151%
13	1,012	158	16%	2,889	2,923,668	456,462	16%
14	102	159	156%	3,130	319,260	497,670	156%
15	234	191	82%	2,808	657,072	536,328	82%
16	287	193	67%	4,174	1,197,938	805,582	67%
17	178	204	115%	3,130	557,140	638,520	115%
18	189	204	108%	3,130	591,570	638,520	108%
19	197	373	189%	6,281	1,237,357	2,342,813	189%
20	185	373	202%	8,760	1,620,600	3,267,480	202%
21	711	414	58%	4,896	3,481,056	2,026,944	58%
22	170	433	255%	3,130	532,100	1,355,290	255%
23	815	531	65%	3,130	2,550,950	1,662,030	65%
24	441	1,081	245%	3,652	1,610,532	3,947,812	245%
25	624	1,318	211%	8,760	5,466,240	11,545,680	211%
Total	7,620	5,733	75%		36,577,155	29,025,539	79%

Recommendations for future applications are presented at the end of this paper.

Quantitative Findings

As discussed in the preceding sections, pre- and post-retrofit load data was examined for 25 projects. This information was used to estimate the kW demand savings, the operating hours and the MWh energy savings due to the retrofit. The observed savings were compared to the values for gross demand and energy savings reported in the tracking system for each project.

Table 2 summarizes the results of the analysis. Inmost of these projects, the reported demand savings closely tracked the savings estimated from the this analysis on average. The average demand savings estimated from the load research data was 229 kW per project whereas the average of the demand savings reported in the tracking system was 305 kW per project for the 25 projects analyzed. The ratio between these results was 75%. When the participants who either had no change in usage, or increased usage in the post period are excluded, the numbers change significantly.

Table 2. Summary of Results from the Load Research Analysis

Statistic	All 25 Projects		19 Projects were Reduction is Observed	
	Mean	Ratio	Mean	Ratio
*Observed kW	229		320	
Tracking kW	305	75%	312	103%
Observed MWh	1,161		1,643	
Tracking MWh	1,493	79%	1.335	123%

Scatterplots can be used to look at the data underlying these results. Figure 4 shows a scatterplot of the observed demand savings (on the vertical axis) compared to the tracking estimate of the demand savings. The nineteen plotted points shows the results for the nineteen sample projects where a demand reduction was observed. The solid line is a 45-degree reference line. If the observed savings is equal to the engineering estimate, the sample point will lie on the solid line.

The dashed line indicates the average bias in the engineering estimates. The slope of the dashed line is equal to the ratio between the average observed demand savings and the average reported demand savings, i.e., equal to 103%. The dashed line will be less than the solid line to the extent that the average observed savings is less than the average of the engineering estimates. In this case, there is close agreement between the solid and dashed line, indieating that there was little bias in the engineering estimates in this sample for the nineteen projects that had observable demand reductions.

It must be emphasized again that the load research results reflect a very small sample of only 25 projects. In fact, close inspection of Figure 4 reveals that the results are strongly influenced by one or two of the projects. These results have been presented only to illustrate the factors that can effect actual savings and to demonstrate the type of information that might be developed in a study using load research data as part of an impact evaluation.

It should also be emphasized that these results reflect gross savings and are not adjusted for free ridership or other net to gross factors.

Recommendations

Based on this analysis, it appears that existing load research can play an important role in impact evaluation studies. Many of the issues discussed in this paper can be resolved by implementing the following recommendations:

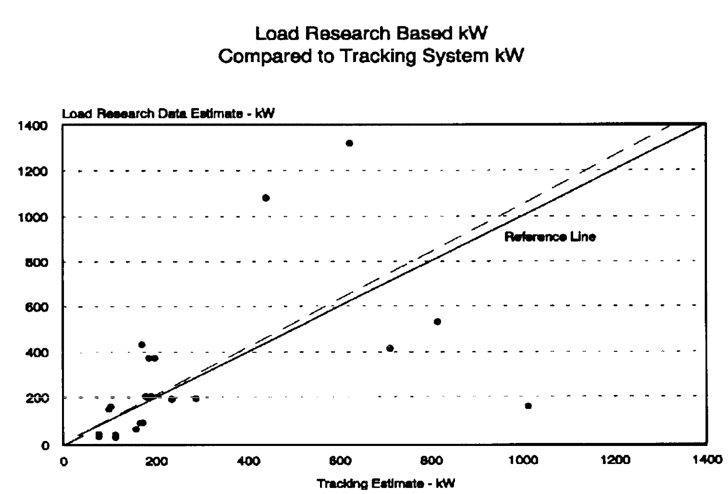

Figure 4. Scatterplot of kW Reduction Estimates

- Exclude Small Projects: Studies should be restricted to retrofit projects for which the demand savings are expected to be at least 5% of the customer's demand. Projects with savings that are smaller than this can not be expected to show up in the total load.

- Avoid Confounding with A/C: Projects that are implemented in the summer should be excluded.

- Multiple Applications: By excluding small projects and summer projects and working with better implementation dates, it should be easier to sort out the effects of multiple projects.

- Use On-site Visits to Validate Account Numbers and Collect Other Supporting Information: Site visits should be planned to give the analyst familiarity with the site and the retrofit project and to confirm that the load research account was actually affected by the retrofit.c