Development of Measured Savings for a Small Commercial/Industrial Lighting Program

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The results of a measured savings investigation are presented for a commercial/industrial lighting program. The program has been operated by a major New England electric utility for more than three years, providing direct installation of energy-efficient lighting measures in small commercial, industrial, and government facilities at no cost to the customer. In fulfillment of its regulatory commitment, and in an effort to improve program quality, the utility has pursued a multi-faceted measured savings evaluation approach. The methodologies employed include: billing analysis, end-use metering, on-site surveys, and process evaluation surveys.

Energy savings were measured in a one-year pre-/post-billing analysis in which a non-participant comparison group was used to model the effects of non-program factors. Demand and energy savings were measured using short term pre- and post-installation metering of retrofitted lighting circuits. This paper considers these data and, in addition looks at an on-site survey investigation of measure persistence and other factors affecting the realization of program savings. The results of process evaluation telephone surveys of participants are also considered with respect to free-ridership impacts. Finally, results from these component investigations are integrated in the calculation of overall program savings.

Introduction

In June of 1992, the Massachusetts Electric Company (one of three retail company affiliates of New England Power Service Company) filed its second DSM Performance Measurement Report (MECo 1992) with the Massachusetts Department of Public Utilities (MDPU). This paper presents the 1991 impact evaluation results from the above report for the Company's Small Commercial/Industrial Program (Small C/I). The information is presented by evaluation methodology and then integrated into an overall assessment of 1991 program achievements.

Program Description

The Small Commercial/Industrial Program was originally developed in collaboration with the Rhode Island Least Cost Planning Committee as part of the Statewide Lighting Program. The Rhode Island pilot began in 1989 providing direct installation of energy-efficient lamps at no charge to participants. The program was expanded System-wide in June 1990 to service customers in all three retail territories with lighting analysis and installation of more permanent energy-efficient lighting measures. Through the end of 1990, services were provided to small commercial and industrial customers with an average monthly demand under 100 kW or annual electricity usage under 300,000 kWh. Beginning on January 1, 1991, the eligibility criteria were reduced to a monthly demand under 50 kW or annual electricity usage under 150,000 kWh, in order to focus program efforts on those customers least likely to participate in the Company's large commercial/industrial program.

The market segment targeted for this program is characterized by significant lighting load, limited access to capital for efficiency improvements, and relatively low interest in conservation. By emphasizing cost-effective direct installations, the program is able to surmount these barriers and provide savings to a class of customers who historically have not participated in Conservation and Load Management programs.

End-Use Technologies. The Small Commercial/Industrial Program was intended to address end-uses that have typically been shown to offer retrofit conservation opportunities in the existing small non-residential market. Lighting technologies offered in 1991 included: energy-efficient fluorescent lamps, ballasts, and fixtures; specular reflectors; hard-wired compact fluorescent systems; screw-in compact fluorescent lamps; interior and exterior high-intensity discharge systems; reduced-wattage incandescent lamps; occupancy sensors; time switches and photocells for outdoor lighting. Non-lighting measures added in 1991 include programmable thermostats and electric water heater tank wraps.

Delivery Mechanism and Marketing. The 1991 program was delivered by vendors organized by service territory districts. Twenty lighting dealers had product vendor contracts to supply program equipment and 5 labor vendors were responsible for lighting analyses, program data entry and measure installations. An estimated 40 electrical contracting crews were required to perform actual installations.

From a market perspective, the ongoing program has proved so successful (the refusal rate is estimated to be less than 5%), that it required virtually no additional marketing beyond what was done by the labor vendors. Each labor vendor was given a list of the eligible customers in their district(s) for telemarketing. It is estimated that more than 40% of participants were initially contacted by a labor vendor; an additional quarter of participants reportedly became aware of the program through word-of-mouth (HBRS 1992).

Measured Savings Evaluation Approach

Engineering estimates of savings are used as the baseline against which to compare evaluation results. Engineering estimates of gross kW (defined here as non-coincident or maximum displaced kW) and gross kWh (unadjusted for free-ridership) savings for this program were tracked on an ongoing basis in the Company's data tracking system. Displaced kW savings were determined on a per-measure installed basis from a rated system wattage list used to standardize lighting system loads. The wattage list was developed from a survey of the major lighting manufacturers, and is updated regularly to include standard connected wattages for each measure implemented through the program, as well as connected wattages for all baseline lighting configurations. Actual hours of operation are provided by the customer during the audit and incorporated into the data tracking system on a fixture-by-fixture basis, and then used in the calculation of gross energy savings.

End-use metering and pre/post billing analysis are techniques which can "measure" actual performance and savings in the field. When such field measurements are compared to engineering estimates, the results reflect the impact of errors in those estimates from factors such as: overreporting of hours-of-use, misassignment of measure wattages, misidentification of baseline equipment type or quantity, installation miscounts, unaccounted for burned out lamps in the baseline, and premature removal or failure of installed measures. On-site surveys can estimate the occurrence of removal and data tracking miscounts, thus potentially giving insight as to how the difference between anticipated and actual savings may break down. These techniques enable the development of factors by which engineering estimates of gross demand and energy savings can be adjusted to reflect field performance. "Measures" of coincident diversity (the percentage of displaced kW savings for a class of measure installations likely to be experienced at the time of the Company's summer and winter peaks) and free-ridership (energy-efficiency installations which the customer would have initiated in the absence of the C&LM program) further define the actual useful impact of program savings to the utility. Each of these evaluation components is described below and then combined in the assessment of 1991 program achievements in the Integration of Results/Impacts section.

Billing Analysis

Objectives

The Small C/I billing analysis (MECo 1992) pursued three objectives: (1) measure actual participant bill changes before and after program installations (gross kWh savings); (2) calculate what portion of these savings could be attributed to program impacts (net kWh savings) rather than non-program factors, taking free-ridership into account; and (3) develop a statistically-valid ratio adjustment factor of net bill savings to engineering estimated savings which could be applied to engineering estimates for the larger population of program participants.

Methodology

The general approach used was to determine net participant savings based on a comparison of actual post-installation kWh usage with changes in kWh consumption for a non-participant comparison group used to model the "no-program" condition for the participant group.

The participant group change in kWh consumption was adjusted to reflect non-program changes by multiplying the participant pre-installation usage by the ratio of non-participant post- to pre-period consumption. Participant post-installation period consumption was then subtracted from the adjusted participant pre-installation period consumption to yield net savings. This calculation can be expressed in the following formula:

$$((A/B*C) - D) = Net\ Bill\ Savings \qquad (1)$$

Where A = Comparison Group Post-Installation Period Usage
B = Comparison Group Pre-Installation Period Usage
C = Participant Group Pre-Installation Period Usage
D = Participant Group Post-Installation Period Usage

Finally, the ratio of total net participant savings to total engineering estimated savings for the participant group was calculated.

Sample Development

The billing analysis compared one year of pre- and post-installation usage data for participants with lighting installations between July 1, 1990 and November 30, 1990. The pre-installation period was defined as the 1989 calendar year; while the post-installation period was defined as the 1991 calendar year. The analysis began with a sample of the 963 customers who had received installations in the defined participation period.

In order to capture billing savings for sites with multiple meters, an effort was made to combine the billing data of all accounts associated with a particular participant in the analysis. The problem of multiple accounts occurring at a single participant premise was highlighted during the previous impact evaluation of this program performed in early 1991 (MECo 1991). In some cases where participants had multiple meters, the meter listed in the program data base encompassed only a portion of the area where the retrofits were installed. In other cases, the identifying meter was found to serve an unrelated part of the customers facility which did not contain any of the installed measures. Subsequent changes in program data collection procedures should assist in later evaluations but were too late for this evaluation due to the lead time needed to have a full year of post-installation data available. To surmount this problem, the original participant accounts in this analysis were cross-matched with all small commercial/industrial customers by name and street to match billing data with participant accounts. In addition, participants were screened to exclude those with incomplete billing data, changes in tenancy, and participation in other Company-sponsored C&LM programs during the analysis period. Similar screening was repeated for the development of both comparison groups described below.

Finally, the participant sample was screened for matched customers whose engineering estimated savings exceeded their total pre-installation usage for all associated accounts. The majority of these twenty participants turned out to be multiple accounts cases where inconsistent naming prevented proper matching of accounts; others may have been caused by erroneous engineering estimates. These steps yielded a final participant sample of 831 customers. Of these, 162 were identified as having multiple meters, yielding 1,081 participant accounts in total.

Two comparison groups were considered for the analysis: A) a stratified random sample of non-participants; and B) a "pipeline" comparison group comprised of customers who participated in the program after the close of the post-period. A non-participant universe of more than 2,000 small commercial/industrial customers was drawn to create the random stratified non-participant group. Multiple accounts matching was performed for the non-participant universe so that each potential sample point included all associated accounts, and could be treated as a single consolidated entity when compared to the associated accounts consolidated for each participant. The final non-participant sample was then randomly selected from seven business and six kWh size strata to match the participant sample as closely as possible. This resulted in a comparison group of 698 customers and their associated matched accounts.

The "pipeline" comparison group was developed from those customers who were either in the pipeline to participate in the program, or had participated since the end of the defined post-installation period (after January 1, 1992). This approach was considered as a way to compensate for potential differences between participants and non-participants which might prevent non-participants from being representative of participants in the absence of the program.

Due to the limited number participants in the pipeline universe, this group was made up of all 728 pipeline customers who remained after screening, without regard to stratification. Unfortunately, this small comparison group population could not adequately fill the kWh and facility-type strata needed to match the participant group; therefore, it was decided to use the random stratified non-participant comparison group for this analysis. It was also believed that potential differences between participants and non-participants were less significant for this program than they might have been for other programs due to its direct install/no-cost incentive structure, and to the low refusal rate by customers approached to participate in the program. Figure 1 below shows the stratification by facility type for both the participant and non-participant samples.

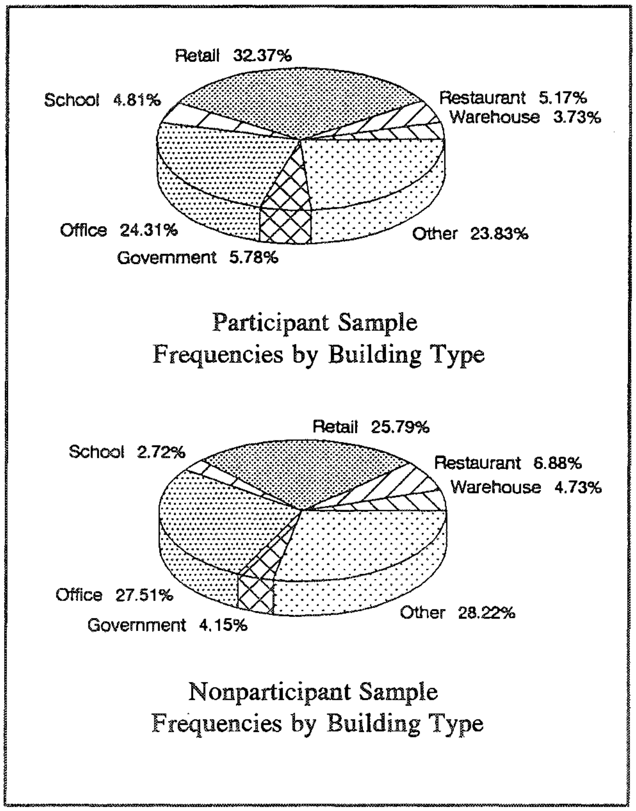

Figure 1. Stratification of Small C/I Billing Analysis Samples

Findings

Results were calculated using the random comparison group based on Equation (1) above. Mean participant consumption was found to decrease from 67,476 annual kWh in the pre-period to 61,050 annual kWh in the post-period (a 9.5% decrease); while the mean comparison group consumption increased from 62,964 annual kWh to 63,651 annual kWh (a 1.1% increase). Mean net savings for participants were calculated to be 7,162 annual kWh, or on average 10.6% of pre-period consumption. When compared to the mean engineering estimate of gross savings for the participant population of 9,203 kWh, this yielded a net savings ratio of 77.8% with 48% precision at a 90% confidence level.

End-Use Metering

Objectives

This study analyzed short-term kW and kWh changes at 21 Small C/I sites based on multi-week pre- and post-retrofit monitoring. The primary goal was to more accurately quantify program savings, kW in particular. In addition to the short-term study, longer-term monitoring is underway at five of the sample sites, and will continue for approximately one year after the installation of energy-efficiency measures. Finally, an additional secondary goal was to test the comparative accuracy of an inexpensive photo-sensitive lighting logger for measuring hours-of-use, and possibly as a alternative to full-scale metering when used in combination with wattage measurements.

Methodology

Development of this project involved three main areas of work: sample design, recruitment and installation, and analysis.

Sample Design. In order to provide unbiased estimates of program impact with measurable precision, a statistical sampling plan based on the MBSS (Model-Based Statistical Sampling) approach (Wright 1989) was used to select potential sites for end-use metering. This plan defined strata based on the historical distribution of projected kW savings of customers who had participated in the program in 1991. Non-lighting measures were not included in the study. This type of plan promoted the efficient use of sample points by ensuring an appropriate distribution of large and small projects.

Recruitment & Installation. A Monitoring Contractor (MC) was hired to oversee the recruitment and installation phase of the project. The MC had responsibility for recruiting customers from the list of randomly selected sites, determining the feasibility of installing monitoring equipment installing equipment, compiling and preparing the data collected for analysis, and final removal of equipment.

During the monitoring equipment installation, an on-site survey was performed which recorded space characteristics such as hours-of-use, type and number of lighting fixtures, and instantaneous measurements of full-load fixture wattages ("spot watts"). A multi-channel data logger was used to meter circuits containing the major fixture types representing the bulk of savings anticipated at each site. (Whole building loads were not metered and the study results do not include lighting interactions with space conditioning.) The data logger collected total usage for each circuit monitored. These data were used to determine hours-of-use and load profiles by area or fixture grouping. For spaces or fixture types with small anticipated savings impact, operating hours reported in the on-site survey were relied on to estimate savings instead. Displaced kW savings estimates were determined from spot watt measurements, except in instances of other than major fixture types, where manufacturers data were used instead.

The integration of on-site lighting surveys, spot metering, and end-use metering was used to measure energy and demand savings for each selected monitoring site. Monitoring periods typically consisted of two weeks before and after retrofits were completed.

Analysis. Savings were estimated in three ways at each sample retrofit site: Engineering Estimated Savings, On-Site Savings Estimates, and Metered Savings. In all three the following formulae were used:

$$kW_1 = kW_2 - kW_3 \qquad (2)$$

$$kWh_1 = (kW_2 - kW_3) \times h_1 \qquad (3)$$

The three methods differ in the manner in which inputs to the formulae were determined or calculated. These are explained below for each of the methods.

Engineering Estimated Savings: Gross demand and energy savings from the program data base, based on the original program audit. Demand savings (kW_1) were equal to calculated displaced wattage (kW_2 for the pre-installation condition, and kW_3 for the post-installation condition) based on manufacturers' specifications. Energy savings (kWh_1) are calculated by multiplying kW_1 by the appropriate fixture- or room-specific operating hours (h_1) reported in the original audit.

On-Site Savings Estimates: A revised engineering estimate of the gross demand and annual energy savings based on the survey data collected at the monitoring sites. In this case, demand savings (kW_1) were calculated in a similar manner as the Engineering Estimate, but the energy savings (kWh_1) of each retrofitted fixture were calculated as the change in Watts (kW_2 - kW_3) of the fixture, based on manufacturers' specifications, times the operating hours (h_1) determined during the on-site surveys.

Metered Savings: Demand and annual energy savings calculated from the short-duration end-use metering, spot-metering, and on-site characteristics' data. Three types of metered demand savings were developed: non-coincident, summer peak coincident, and winter peak coincident. In this case the non-coincident, or connected, demand saving (kW_1) was calculated by taking the difference between initial fixture spot watts (kW_2) and the retrofitted fixture spot watts (kW_3).

The metered savings for summer and winter coincident peak (kW_1) were calculated from the change in metered consumption during each season's peak demand hour (2pm for summer peak and 6pm for winter peak), by taking the difference between the pre-retrofit peak hour average demand (kW_2) and the post-retrofit peak hour average demand (kW_3). The energy saving (kWh_1) of each retrofitted fixture was calculated as the change in watts of the fixture based on spot watt metering (kW_2 - kW_3) times the full-load-equivalent operating hours (h_1) measured by end-use metering.

All lamps and fixtures were assumed to be operational both before and after the retrofit for the calculation of metered savings. (In cases where lamps were burned out prior to the retrofit, the spot wattage measured for a comparable lamp was added into the pre-retrofit kW tally.) Full-load-equivalent operating hours (h_1) were calculated for this definition in the following manner:

$$h_1 = \frac{\left(\frac{kWh_{avg} \times d}{kW_{max}}\right)_{pre} + \left(\frac{kWh_{avg} \times d}{kW_{max}}\right)_{post}}{d_{pre} + d_{post}} \qquad (4)$$

Where kWh_{avg} = average daily kWh metered for the period indicated.
kW_{max} = maximum kW metered in the period indicated
d = the number of days in the period indicated.

The critical relationship in this study was the association between measured and engineering estimated demand and energy savings. This relationship was quantified in part by ratios between average metered and engineering estimated savings where each average was based on case weights (number of population sites per stratum/number of sample sites per stratum) assigned to the sites.

Findings

The end-use metering study concentrated on the four measured savings results: non-coincident kW savings, summer peak coincident kW savings, winter peak coincident kW savings, and annual energy savings. The results indicate that the reduction in savings expressed as a percent of metered to engineering estimated savings are 93.9% for non-coincident kW savings, 84.3% for summer peak coincident kW savings, 77.1% for winter peak coincident kW savings and 96.1% for annual energy savings. At the 90% confidence level, the ratio of observed to current tracking savings has been measured with a relative precision of 9.7%, 16.4%, 19.9%, and

16.7% respectively for these quantities. We can therefore conclude that the direct savings from measure implementation are in the range of 84.8% to 103.0% for non-coincident kW savings, 70.5% to 98.1% for summer peak coincident kW savings, 61.8% to 92.4% for winter peak coincident kW savings and 80.1% to 112.1% for annual energy savings with respect to the engineering estimates currently calculated from the data tracking system. Figures 2, 3, 4, and 5 demonstrate the strong correlation between metered and engineering estimated savings for the 21 metered sites. They also show the amount of bias in the engineering estimates in the distance between the actual results line and the ideal results line.

Additional insight into differences between field performance and engineering estimates can be gained by looking at some of the ratio components. The observed ratios for non-coincident kW savings and annual energy savings reflect several factors: number of installed measures, hours-of-use (kWh only), and reduction in Watts per measure. The surveyed number of measures installed was, on average, 103% of the number reported in the data tracking system. Measured hours-of-use of the lighting were, on average, about 102% of the hours reported by the customer in the data tracking system. However, the observed reduction in wattage per measure was about 92% of the reduction calculated from the tracking system; therefore, savings were proportionately smaller than anticipated.

The relationship between on-site and engineering estimated savings was also considered as an indicator of the overall relative accuracy of current program audit procedures. The results showed on-site savings estimates of gross kW and kWh to be 97.3% and 98.8%, respectively, of engineering estimated savings from the program data base. At the 90% confidence level, these ratios were calculated for kW and kWh with a relative precision of 10.6% and 17.6%, respectively.

Finally, the end-use metered results for annual energy savings can also be seen as supporting evidence for the kWh billing analysis discussed above. When the annual energy savings ratio of 96.1% is adjusted further by a kWh-weighted free-ridership for the program (7% based on the figures listed in Table 1 below), the overall result is a ratio of 89% as compared to 77.8% from the billing analysis. Given the precision associated with these studies, this end-use metered result can be considered generally supportive of the billing analysis finding, which is based on a significantly larger sample and longer period of measurement.

On-Site Surveys of Measure Persistence

Objective

An on-site survey investigation of installations completed in the first 6 months of the System-wide Small C/I program was conducted to consider direct-install lighting measure persistence in the short term (HEC 1992). The study was limited by the relatively short implementation history of the program, but even within the limited time frame, was able to provide some preliminary indication of short-term degradation of savings.

Methodology

A statistically-representative sample of 120 customers was drawn from the more than 2,200 customers who participated in the 1990 System-wide Small C/I Program, based on stratification by engineering estimated kWh savings. More than 80% of the sample drawn was located and agreed to participate, resulting in a study population of 99 Small C/I sites whose installations were at least one year old. Of the 21 who were not recruited, 7 had gone out of business, 4 declined to participate, 8 could not be reached, and 2 failed to make appointments. The sample was thus biased by the necessary omission of these customers. The Company plans to investigate the potential for non-response bias in a follow-up study of these "drop outs".

Electricians experienced in lighting retrofit installations were assigned to perform the field surveys. Their primary tasks were to: (1) determine by physical inspection how many of the scheduled retrofits remained in place and operating; (2) identify via customer inquiry reasons why equipment was missing and what equipment was found in its place; and (3) identify instances of and reasons for customer dissatisfaction with retrofits. Finally, survey results were analyzed and converted into updated estimates of displaced kW to indicate what percentage of engineering estimated kW savings were represented by missing retrofits. No attempt was made to verify pre-retrofit conditions, confirm retrofit wattages, or to evaluate program retrofit decisions. Results were tracked by major measure category so that any technology-specific problems could be identified in the results.

Findings

The findings indicated instances of actual retrofits resulting in both more and less savings than expected for the originally specified retrofit (positive and negative

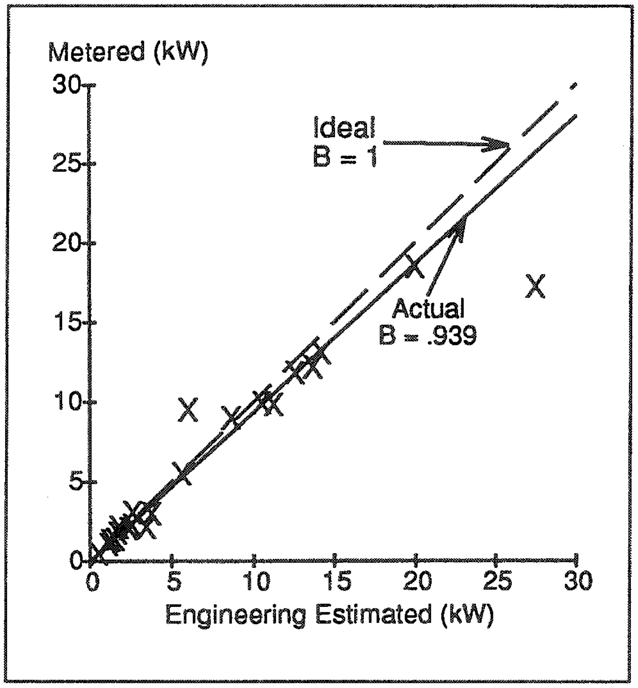

Figure 2. Non-Coincident kW Savings

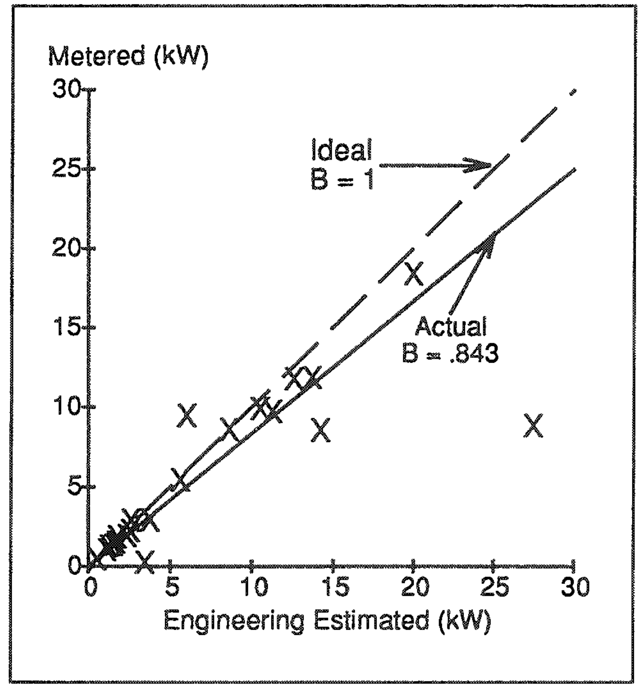

Figure 3. Summer Peak kW Savings

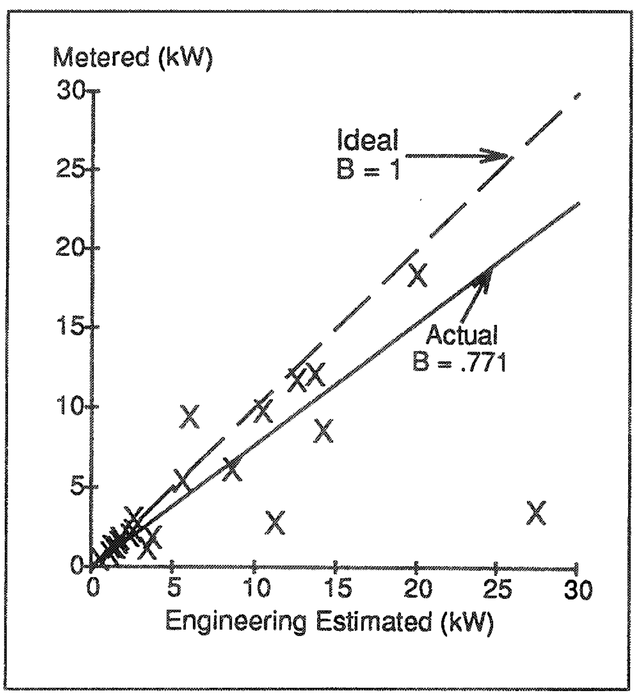

Figure 4. Winter Peak kW Savings

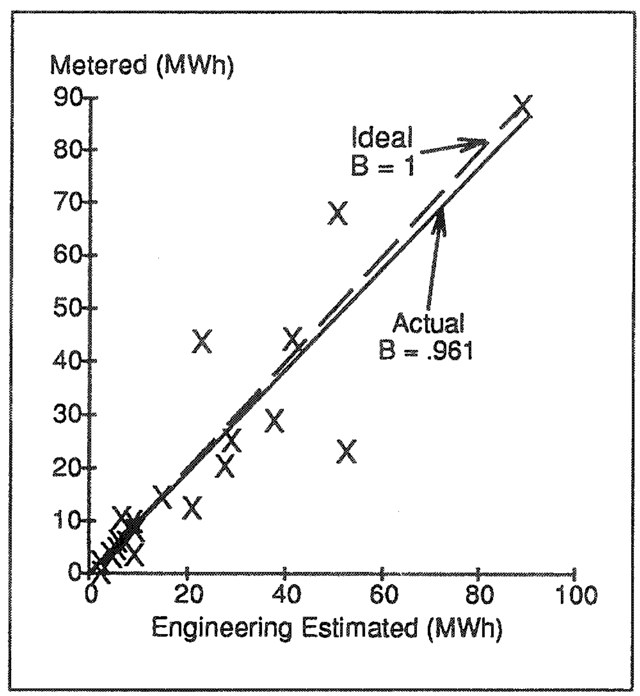

Figure 5. Annual MWh Savings

variances). The most surprising finding overall was that positive variances in savings surpassed negative variances, resulting in a small net gain in kW savings over what was anticipated from engineering estimates recorded in the program data base. A total of 678.4 non-coincident kW had been predicted for the 99 sites at the time of the retrofits; the electricians counted a total of 695.1 non-coincident kW savings in place and working, a gain of 2.5%. The variance was spread out across a large percentage of the facilities surveyed; only 34% of facilities had no variance at all.

Positive variances were attributed exclusively to initial data collection errors such as miscounts and miscoding of fixture types. There were some additional positive variances (27.4 kW) associated with post-retrofit delamping, i.e., the disconnection of lamps or fixtures unrelated to program measure installations. Since these variances could not be attributed directly to program effects, they were not included in the results given.

If the positive variances are ignored, the actual savings found in operation is 612.1 kW, as compared to 624.7 kW predicted, a 98% persistence rate. While 27 of 99 customers surveyed expressed some form of dissatisfaction, only 21% of negative variances could be correlated with expressions of dissatisfaction. In addition, no consistent pattern of missing measures was identified for any particular facility type, measure category, or specific type of equipment.

Negative variances tended to show up in three ways: (1) the original equipment was still in place instead of the proposed retrofit (62% of negative variances); (2) a less efficient measure than proposed was in place (9%); and (3) the quantity of installed measures exceeded the proposed quantity (29%).

Overall, the data collected suggest that Small C/I program savings should not be discounted for measure removal in the short-term. However, further investigation is clearly warranted, both to quantify the impact of non-response bias, and to consider longer-term persistence as the program matures.

Free-Ridership

Purpose and Methodology

Free-ridership in the Small C/I Program was investigated as part of the 1991 program process evaluation (HBRS 1992) which surveyed 427 program participants via telephone. The purpose of this investigation was to assess the percentage of Small C/I participants who would have installed energy-efficient lighting measures, in each of twelve major measure categories, without program incentives. The findings allowed measure category-specific program savings estimates to be adjusted for the installations that presumably would have taken place anyway.

To estimate free-ridership in each measure category, participants were asked if they had planned to install the same measure themselves, and if so, whether they would have (1) installed the same amount of equipment, (2) installed it at approximately the same time or waited one or two years, and (3) purchased equipment with efficiency comparable to what was installed through the program. Pure free-riders, for a given measure category, were defined as those who reported that they would have installed the same energy-efficient measures, at approximately the same time, in the absence of the program. The other extreme were participants who reported that they would have taken no action without the program. Between these two extremes were the participants exhibiting some degree of program influence, causing them to either install more efficient equipment, install more equipment, or to install equipment sooner.

Findings

The percentage of participants reporting that they were not influenced by the program at all (pure free-riders) ranged from 1.9% for specular reflectors to 18.8% for occupancy sensors. Incremental free-ridership, associated with participants who exhibited some degree of free-ridership, ranged from 0% for occupancy sensors to 6.8% for fluorescent systems with electronic ballasts. In all of the major lighting categories, more than 80% of participants reported that they would have taken no action in the absence of the program. Estimates of pure free-ridership were used to discount measured program savings. (See Table 1 in the Integration of Results/Impacts section.)

One concern regarding the use of self-reported free-ridership for a program like Small C/I was that participants may not know enough about program costs and equipment standards to provide an accurate assessment of whether they would have installed the measures on their own. With this in mind, two additional measures of program influence were considered. First, participants were asked whether they had already planned to purchase any lighting equipment, irrespective of type and efficiency, at the time they enrolled in the program. More than 80% reported having had no intentions of buying any lighting equipment at that time. Of the 16% who had intended to purchase some lighting equipment at that time, 80% of these indicated they planned to purchase energy-efficient equipment. This second measure of program influence corroborates the previous result that more than 80% of participants, in each of the major measure categories, exhibited no free-ridership.

For the last measure of free-ridership, each participant was informed of the dollar value of the program investment made at their site in labor and materials, and asked whether or not they would have been willing to pay project costs in the absence of the program. Twenty percent of respondents indicated that they would have been willing to pay all costs. Note that this is somewhat different from pure free-ridership since the respondents have the benefit of program experience, whereas pure free-ridership indicates whether the customer would have done the work without any experience with the program. Nevertheless, this measure of free-ridership provides a result which is similar to levels indicated by the previous two methods.

Integration of Results/Impacts

Tables 1 and 2 below illustrate the application of the results outlined above to the calculation of revised kW and kWh savings for the 1991 MECo Small C/I Program. In order to arrive at the summer and winter peak savings shown, engineering estimates of gross kW savings were first pro-rated to reflect short-term end-use metering results in two ways. Gross kW savings associated with interior lighting systems and interior lamps were adjusted based on peak coincident savings measured for the end-use metering sample (84.3% summer, 77.1% winter). While exterior lighting and lighting control measures were also represented in the end-use metering sample, the overall sample-wide diversities did not make sense for these measures individually since their pattern of use was so dramatically different from interior lighting measures which accounted for 95% of gross savings for the 1991 program. Therefore, the non-coincident kW savings adjustment ratio (93.9%) developed from the end-use metering sample was applied to gross savings in these categories to yield adjusted non-coincident kW savings. The adjusted non-coincident savings were then further discounted, to reflect diversity of on-peak use, with more conservative summer and winter diversity factors based on two sets of recent surveys of commercial/industrial operating schedules (HBRS 1991, HBRS 1992). Peak savings in each of the lighting measure categories were then finally discounted to exclude free-ridership (2% to 19%) based on the process evaluation results. Gross savings associated with non-lighting measures (water heater wraps and programmable thermostats) were adjusted directly for diversity (100% and 0%, respectively) and free-ridership (5%), based on staff estimates, since they were not represented in the evaluation studies. These calculations yielded summer and winter peak savings for the 1991 Massachusetts program of 5,110 kW and 4,940 kW, respectively, or, on average, 2.9 summer kW and 2.8 winter kW for each of the 1,766 participants.

Energy savings for lighting measures were determined by pro-rating engineering estimates of gross kWh savings from the program data base to reflect the billing analysis results (77.82%), taking into account free-ridership. It was decided to use the billing results rather than end-use metering results for the adjustment of kWh savings because the billing analysis was based on a much longer period of measurement for a much larger sample of participants. In addition, the billing analysis results included interactive effects between lighting and space conditioning. Gross kWh savings for non-lighting measures were again adjusted directly for free-ridership (5%) based on staff estimates. These calculations yielded annual energy savings of 15,701 MWh for the 1991 program in Massachusetts, or 8.9 MWh, on average, per participant.

Lifetime kWh and kW savings were calculated by multiplying annual kWh or maximum annual peak kW savings in each specific measure category in Tables 1 and 2, by an assigned measure life filed previously with the MDPU. Measure lives ranged from 1 to 6 years for lamps only installations, up to 20 years for hybrid and electronic ballast installations. Lifetimes were based on manufacturers' data and historic hours-of-use data. Overall lifetime savings were calculated to be 82,656 lifetime kW and 240,080 lifetime kWh. Program expenses for 1991 were $7.26 million, yielding a benefit/cost ratio of 3.10 with externality benefits.[1]

Conclusions

This paper illustrated how the results of a number of evaluation studies were synthesized to produce credible estimates of measured demand and energy savings for a small commercial/industrial lighting program. While separate studies were relied upon for the calculation of kW and kWh savings, results between studies were generally supportive. Most specifically, energy savings measured with billing analysis were within the range of precision for kWh savings measured with end-use metering, after adjustments for free-ridership.

Both the billing analysis and end-use metering study showed engineering estimates of lighting savings, based on manufacturer-specified wattage and customer-reported hours-of-use, to overstate actual savings experienced in the field for this program. The gap between engineering

Table 1. Adjusted Demand Savings Achievements for the 1991 MECo Small C/I Program

Measure	Engineering Estimated Gross kW	kW Eval. Adjustment Factor	Free-Riders	Summer Diversity Factor	Winter Diversity Factor	Summer Peak kW Savings	Winter Peak kW Savings
Interior systems							
EEMAG[1] ballast	1,160.4	1.000	6.9%	84.3%	77.1%	910.7	832.9
EEMAG/reflector	22.1	1.000	1.9%	84.3%	77.1%	18.3	16.7
ELIG[2] ballast	2,262.4	1.000	7.9%	84.3%	77.1%	1,756.5	1,606.5
ELIG/reflector	1,871.9	1.000	1.9%	84.3%	77.1%	1,548.0	1,415.8
STD[3] ballast	29.4	1.000	14.7%	84.3%	77.1%	21.1	19.3
STD/reflector	14.3	1.000	1.9%	84.3%	77.1%	11.8	10.8
CFL[4] Hard-wired	462.4	1.000	14.2%	84.3%	77.1%	334.4	305.9
HID[5]	124.6	1.000	8.3%	84.3%	77.1%	96.3	88.1
Lamps Only							
CFL Screw-in	176.3	1.000	11.9%	84.3%	77.1%	130.9	119.8
3 & 4 foot	95.6	1.000	10.5%	84.3%	77.1%	72.1	66.0
8 foot	86.9	1.000	11.1%	84.3%	77.1%	65.1	59.6
Low Wattage Incandescents	191.9	1.000	12.3%	84.3%	77.1%	141.9	129.8
Exterior							
HID	337.6	0.939	11.2%	0.0%	95.0%	0.0	267.4
Controls[6]							
Occ Sensors	20.9	0.939	18.8%	11.0%	8.0%	1.8	1.3
Ext Controls	1.6	0.939	5.0%	0.0%	0.0%	0.0	0.0
Non-Lighting							
WH Wraps	0.7	1.000	5.0%	100.0%	100.0%	0.7	0.7
Thermostats	0.0	1.000	5.0%	0.0%	0.0%	0.0	0.0
Total	6,836.4					5,110.0	4,940.0

Notes: 1. EEMAG indicates fluorescent system with energy-efficient magnetic ballast.
2. ELIG indicates fluorescent system with electronic or hybrid ballast.
3. STD indicates fluorescent system with standard efficiency ballast.
4. CFL indicates compact fluorescent.
5. HID indicates high-intensity discharge system.
6. For lighting controls, gross kW equals connected kW and is not included in Total Gross kW.

Table 2. Adjusted Energy Savings Achievements for the 1991 MECo Small C/I Program

Measure	Engineering Estimated Gross kWh	kWh Evaluation Adjustment Factor	Free-Ridership[6]	Annual kWh Savings
Interior Systems				
EEMAG[1] ballast	3,450,031	0.778	n/a	2,684,642
EEMAG w/reflector	76,888	0.778	n/a	59,831
ELIG[2] ballast	6,302,792	0.778	n/a	4,904,518
ELIG w/reflector	5,684,362	0.778	n/a	4,423,287
STD[3] ballast	82,480	0.778	n/a	64,181
STD/Reflector	48,760	0.778	n/a	37,943
CFL[4] Hard-wired	1,775,004	0.778	n/a	1,381,220
HID[5]	283,416	0.778	n/a	220,540
Lamps Only				
CFL Screw-in	289,283	0.778	n/a	225,106
3 & 4 foot	214,912	0.778	n/a	167,234
8 foot	247,031	0.778	n/a	192,227
Low Wattage Incandescents	437,685	0.778	n/a	340,585
Exterior				
HID	1,234,928	0.778	n/a	960,959
Controls				
Occ Sensors	26,522	0.778	n/a	20,638
Ext Controls	6,564	0.778	n/a	5,108
Non-Lighting				
WH Wraps	6,856	1.000	5.0%	6,513
Thermostats	6,706	1.000	5.0%	6,371
Total	20,174,221			15,700,901

Notes: 1. EEMAG indicates fluorescent system with energy-efficient magnetic ballast.
2. ELIG indicates fluorescent system with electronic or hybrid ballast.
3. STD indicates fluorescent system with standard efficiency ballast.
4. CFL indicates compact fluorescent.
5. HID indicates high-intensity discharge system.
6. Free-ridership for lighting measures is implicit in the kWh adjustment factor.

estimates and actual savings could be due to a number of factors including: overreporting of hours-of-use, unaccounted for burned out lamps, premature removal or failure of installed measures, actual equipment wattage differing from manufacturers' specifications, or data collection errors. Results of the end-use metering study were analyzed to provide preliminary insight into the potential contribution from some of these factors.

The on-site surveys of measure persistence were not able to explain differences between measured and estimated savings, since no significant pattern of measure removal or failure was found in the short-term. However, this study needs to be expanded upon to include an investigation of non-response bias, as well as longer-term followup on measure installations as the program matures. In addition, sample size should be increased in future persistence studies.

Future billing analysis studies can also provide more information on measure persistence by looking at billing data for participants with installations completed two or more years ago. Such an analysis could be combined with on-site surveys for a portion of the same customers to enable more in-depth consideration of the factors which contribute to less than expected savings in the field. Future short-term metering studies should be expanded to include larger study samples, possibly relying on less expensive monitoring equipment such as photo-sensitive lighting loggers to curtail project costs.

In spite of the difference between engineering estimates and measured savings, the Small C/I Program continues to be a very cost-effective C&LM program for the Company, with benefits valued at more than three times program implementation costs in 1991. In addition, the program is able to provide extensive lighting conservation services to a customer segment not likely to be reached by conventional rebate programs.

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Endnote

1. This benefit/cost ratio includes environmental externalities values specified by the Massachusetts Department of Public Utilities (MADPU 89-239), and does not include evaluation and planning costs. The benefits produced by program savings are based on the tail block rates that New England Power charges its retail affiliates (W-11 and W-12).

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