Comparing Engineering Estimates to Measured Savings: One Utility's Experience

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Results of a portion of the impact evaluation activities of a major New England electric utility's Demand-Side Management programs are presented. The cumulative effort, believed to be one of the most aggressive set of impact evaluations by an individual utility, includes comparisons between engineering estimates and measured savings for a number of residential and commercial programs. Presented is a summary of the results to date, as well as comparisons between results of different methodologies. Methodologies discussed include end-use metering, billing analysis, and on-site inspections.

Billing analysis results are shown for both a large and a small commercial and industrial retrofit program and a low-income general use program. End-use metering results are presented for lighting retrofits in both the small and large commercial and industrial retrofit programs, and a water heater radio control program. Finally, the results of on-site survey investigations into measure persistence are presented for the small and large commercial and industrial retrofit programs, the low-income general use program and the residential lighting program.

Introduction

In March of 1990, the Massachusetts Department of Public Utilities issued an order allowing the Massachusetts Electric Company (a New England Power Service Company affiliate) to earn financial incentives for aggressively pursuing conservation and load management. The ability to earn these incentives was made contingent upon the Company "measuring" the savings from its programs, i.e., not relying solely on engineering estimated savings. The Company filed a long-term evaluation plan with the Department in June of 1990 (New England Electric, 1991). The first year results of this plan were provided to the Department in the 1990 DSM Performance Measurement Report (MECo, 1991) filed in June of 1991, which documented the savings resulting from programs implemented in Massachusetts Electric Company service territory in 1990. The Company filed second-year results in its 1991 DSM Performance Measurement Report (MECo, 1992) in June of 1992, documenting savings produced in 1991, as well as a "Second Look" at 1990 savings based on application of these 1991 results to 1990 participants. The impact evaluation results presented in this paper represent highlights of the Company's 2-year efforts to implement the long-term evaluation plan. Each of the impact evaluation results described are presented by methodology: billing analysis, end-use metering and on-site surveys.

Program Descriptions

The impact evaluation activities performed for five programs will be discussed. These include: the Residential Lighting, Energy Fitness, Home Energy Management (HEM), Small Commercial and Industrial (Small C/I), and Energy Initiative (EI) Programs. Residential Lighting is a lighting catalogue and rebate program designed to make available compact fluorescent light bulbs at reduced costs. HEM is a load management program where radio switches or time clocks are installed on water heaters, central air conditioners and pool pumps; most activity thus far has been in controlling water heaters. Energy Fitness is a neighborhood blitz type of program targeted at low-income customers, which provides the direct installation of compact fluorescent bulbs, water conservation measures, A/C and refrigerator coil cleaning and some minor space heating measures for those customers that have electric heat. Energy Initiative is a comprehensive commercial and industrial retrofit program offering rebates for lighting, motors/drives, HVAC, building shell, industrial process and custom measures. The Small C/I Program is a direct installation retrofit program intended to address all cost-effective conservation opportunities (primarily lighting) in smaller customers (previously <100 kW, now <50 kW). With the exception of Space Heat and HEM, the primary end-use addressed in the analyses presented here is lighting.

Engineering Estimates

Engineering estimates of savings, tracked for each program on an ongoing basis, are used as the baseline against which to compare evaluation results. Engineering estimated energy savings for all lighting measures were calculated by multiplying the difference in kW demand between the existing and efficient equipment (determined from manufacturers' data) by hours-of-use. For all the programs, except Energy Initiative and Residential Lighting, the hours-of-use are collected on-site. In EI and Residential Lighting, the hours-of-use are determined from surveys of a sample of customers. For all non-lighting measures in Energy Fitness and Space Heat, standard ASHRAE-type engineering algorithms were used for demand and energy savings estimates. For HEM, the engineering estimates were determined from metered results of a pilot version of the program.

Billing Analysis

Most of the billing analyses presented in this paper all follow the same general methodology with variations in the details of control group selection and engineering estimate calculation. In all analyses, the calculation of net savings, or savings attributable to the program, is based on a comparison of what participants actually used in the post-participation period and an estimate of what they would have used in the post-participation period had they not been in the program. The non-program usage estimate is derived from the change in consumption of a nonparticipant comparison group. The participant group's change in kWh consumption is adjusted to reflect non-program changes by multiplying the participant pre-participation period usage by the ratio of non-participant post- to pre-consumption. Participant post-consumption is then subtracted from the adjusted participant pre-period consumption to yield net savings. This calculation can be expressed in the following formula used for calculating all net kWh saving presented in this paper:

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

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

The final step is to calculate the ratio of total net savings of the participant group to the total engineering estimated saving for the participant group. It should be emphasized that the billing analysis presented in this paper is only used for measuring kWh, not kW demand savings.

Small Commercial and Industrial Program

The first year analysis used in the 1990 Performance Report for this program was based on 1989 participants in an earlier lamps-only pilot version of the program which ran in the Rhode Island service territory of the Company. The analysis began with a sample of the 256 customers who had received lighting installations between January 1 and July 31, 1989. The pre- and post-periods were defined as the 1988 calendar year and August 1, 1989 through July 31, 1990, respectively. Customers were screened for incomplete pre- or post-period billing data, which was defined as more than one month of missing billing data. In addition, the sample was screened to flag participants whose engineering estimated savings exceeded 100% of pre-period consumption. For some customers with more than one meter per site, this screening indicated that the meter entered into the program database may have actually been for some part of the facility which either did not contain the installed measures or contained only a portion of them. Participants were removed in cases where a known mismatch was discovered between the billing account used in the analysis and the site account(s) where the installations actually occurred. These two steps produced a core sample of 163 participants.

A non-participant universe of over 5,000 small commercial and industrial customers was drawn to create a stratified comparison group randomly drawn from 8 businesses and 10 kWh strata. The final comparison group contained 428 customers.

The mean participant consumption for the 163 participants in the pilot version of the Small C/I Program decreased from 63,358 kWh/year to 61,730 kWh/year, while the mean non-participant consumption increased from 56,826 kWh/year to 57,676 kWh/year. The mean engineering estimated savings was 4,375 kWh/year. The results showed net savings to be 59%[1] of engineering estimated savings with 154% precision at a 90% confidence level. The mean net participant savings was 2,575 kWh/year, or 4% of pre-program usage. Using these results the 1990 program was cost-effective with a benefit/cost ratio[2] of 1.7, and will save 108,632 MWh over its lifetime.

The 1990 participant billing data, used to document savings in the 1991 Performance Report, was processed in a manner similar to that of the 1989, though the data cleaning and multiple account matching process was done by an outside consultant. This second year analysis compared the pre- and post-participation usage data for participants with lighting installations between July 1, 1990 and November 30, 1990. The pre-period was defined as the calendar year 1989 and the post-period was defined as the calendar year 1991.

The analysis began with a sample of 963 customers who had received installations in the defined participation period. In an automated process, billing data from all associated participant accounts were matched by name. Even after this more automated attempt to match up all accounts for a given participant, there were still some participants whose engineering estimated savings exceeded 100% of their pre-period kWh usage, these customers were deleted from the sample. Our final participant sample contained 831 customers.

Two control groups were developed for the second year analysis -- a stratified random control group and a control group made up of either recent participants with installations after the close of our defined post-period or customers signed up and waiting for their installation in the 1992 program. A non-participant universe of over 2,000 small commercial and industrial customers was drawn to create a stratified comparison group. Prior to stratification, these customers were put through the same multiple accounts matching process used for the participant group. This non-participant comparison group was randomly drawn from 7 business and 6 kWh size strata to match the participant sample as closely as possible. After screening for complete billing data, the two comparison groups contained 698 and 782 non-participants, respectively. Since the "pipeline" participant group did not contain sufficient customers to fill in the kWh and business strata, the random control group was thought to be more representative for this analysis.

The mean participant consumption decreased from 67,476 kWh to 61,050 kWh, while the mean non-participant consumption increased from 62,964 kWh to 63,651 kWh for the random control group. The ratio of net savings to engineering estimated savings for the random control group was 77.8% with 47% precision at 90% confidence level. The mean net participant savings was 7,162 kWh/year, or 10.6% of pre-program usage. Using these results, the 1991 program was very was cost-effective with a benefit/cost ratio of 3.1 and saved 240,080 MWh over its lifetime.

Energy Initiative

A billing analysis of early 1990 Energy Initiative participants was done (MECo,1991), but because of the limited time the program had been in full operation, only six months of pre- and post-billing data were available. In addition, because many of these participants had also participated in other Company sponsored C&LM programs, there were only 93 customers left with adequate pre- and post-billing data. Applying the same methodology as was done in the Small C/I program yielded a ratio of net saving to engineering estimated savings of 51% with a precision of 118% at the 90% confidence level. Clearly a billing analysis with more participants and a minimum of one year of pre and post billing data was desirable.

The second billing analysis used to document 1991 Energy Initiative savings was based on an a statistically adjusted engineering (SAE) model which incorporated detailed survey results with engineering estimates of savings and billing data (RCG, 1992). Given the dramatic changes in the New England economy and the number of non-program related factors that could affect energy consumption, an econometric model was thought to be the best way to capture consumption changes related to program activity. By accounting for factors related to changes in electricity consumption, such as changes in square footage of lighted and conditioned space, hours of operation and number of employees, regression models can better predict changes in consumption which may be masked by these other non-program related changes.

Included in the model were program participants who installed lighting measures only in calendar year 1990, did not participate in Energy Initiative in 1989 or 1991 (or any other DSM program in 1989, 1990, or 1991), had clean billing data (cleaned in the same manner as the 1991 Small C/I analysis as discussed above) and completed the survey on factors affecting energy use during the study period. A non-participant sample of customers, who had not participated in any DSM program during the 1989-1991 study period and had clean billing data for the same time period, was selected to match participants by facility type and consumption level. Non-participants from this sample, who completed the survey on factors affecting energy use during the study period, were included in the model. The final model listed in Table 1 included 369 participants and 611 non-participants.

The resulting coefficient on the engineering estimate of savings variable, which represents the ratio of net savings to engineering estimated savings, is 53%. The t-value on the coefficient of this variable (4.88) indicated that the result was statistically significant. The precision at the 90% confidence level was 30%. The calculated net annual energy savings attributable to lighting measures installed in 1991 by program participants were 1,239,802 lifetime MWh. The overall program which was 87% lighting was

Table 1. Energy Savings Model for Energy Initiative Program

Independent Variables	Dependent Variable: 1991 Annual Consumption of Electricity Coefficient (t-value)
Constant	-28,613 (-3.22)
Engineering estimate	-0.53 (-4.88)
1989 annual consumption of electricity	1.004 (183.12)
Business better in 1991 than in previous years	37,849.1 (2.08)
Increase in air conditioned floor space	107,251.47 (2.32)
Change in employees from 1989 to 1991	-223.84 (-1.43)
Changed lighted floor space in 1990 times % of lighted floor space	1,332.47 (1.46)
Increased exterior lighting fixtures in 1990	8,128.13 (1.64)
Increased hours of operation during 1990	148,748.15 (8.72)
Participated in other utility-sponsored programs	-142,521.59 (-2.70)
Selectivity Correction Term	-1,267.1 (-1.35)
Sample Size	980
R-Squared	0.98

very cost-effective with benefit/cost ratio 4.0. The mean net savings was 19,418 kwh/year or 4.6% of pre-program usage.

Energy Fitness

The billing analysis provided in the 1990 Performance Report (MECo, 1991) was based on data from customers who participated in mid-1989 in the Worcester area. These early participants were part of a pilot version of the program and were served by only one vendor. Over 94% of the kWh savings were projected to come from the installation of compact fluorescents, though the savings from non-lighting measures, such as water heater wraps and refrigerator coil cleaning, were included in the billing analysis.

Participants included in the 1990 Energy Fitness billing analysis were chosen from between June and September of 1989. Billing records of kWh consumption were accumulated for one year of both pre- and post-installation. The pre-period was set for April 1, 1988 through June 1, 1989 and the post-period was set for September 1, 1989 through November 1, 1990. The comparison group which best matched the consumption characteristics of the participant group consisted of "pipeline" participants who received installations after November 1, 1990. When the 1990 evaluation was performed, about 2,000 participant records were available.

Both participant and comparison group billing data were screened to remove customers with a greater than four month gap in their records, with pre- or post-installation annual consumption less than 500 kWh or with electric space heat. In addition, members were excluded from the participant group if they had engineering estimates of zero savings. These steps produced a participant group with 1,001 customers and a comparison group of 1,230 customers.

The mean annual consumption for the participant group decreased from 5,165 kWh to 4,897 kWh while the mean consumption for the comparison group remained almost unchanged from 5,282 kWh to 5,260 kWh. The mean engineering estimated savings for the sample was 529 kwh/year. Net measured savings were 43% of engineering estimates with 48% precision at a 90% confidence level. Using these results, 1990 participant lifetime savings were 8,370 MWh, but the program was found to be not cost effective, with a benefit/cost ratio of 0.72.

The second year billing analysis, used in the 1991 Performance Report (MECo, 1992), included customers who participated in a window from May 1990 to August 1990. This analysis used data from three vendors who served customers in five cities. Again, most of the savings were projected to come from the installation of compact fluorescents. The pre- and post-periods were defined as April 1, 1989 through April 1, 1990 and September 1, 1990 through September 1, 1991, respectively. Both participant and comparison group data were screened by the criteria outlined for 1990 customers. Based on the previous year's experience, a comparison group was again selected from recent program participants. After screening, there were 2,235 customers in the participant group and 1,315 customers in the comparison group.

In this analysis mean participant group consumption decreased from 4,809 kWh/year to 4,596 kWh/year. The mean comparison group consumption decreased from 5,020 kWh/year to 4,951 kWh/year. The mean engineering estimated saving for this sample was 355 kWh/year. The ratio of net measured savings to the engineering estimate of savings was 41%, with 45% precision at a 90% confidence level. Using these results, the 1991 program saved 16,214 lifetime MWh, but again was found not to be cost-effective with a benefit/cost ratio of 0.90.

The 1991 engineering estimate of savings was calculated in a similar, but not identical manner to the 1990 estimate. In 1991, participant estimates of hours of use were reduced to account for 37% discrepancy found between participant estimates and the results of lighting surveys collected through the process evaluation, as discussed in the On-Site Verification section. Between 1990 and 1991 the measured savings per customer dropped from about 246 kWh/customer to about 147 kWh/customer. Because the calculations used in the 1991 engineering estimates differed from those used in 1990 it is not possible to directly compare the ratios between the two years. For a discussion of potential explanations for the drop in measured savings see the On-Site Verification and Conclusions and Comparison of Study Results sections.

Due to the results of the 1990 evaluation, Energy Fitness was merged with a residential audit program to reduce costs. The results of the 1991 evaluation indicate that this was a prudent decision.

On-Site Verification

In an effort to better understand the results of our billing analysis and gain additional insight into measure persistence and customer satisfaction with measures, a series of on-site surveys were performed. The first four programs surveyed were Energy Initiative, Small C/I, Energy Fitness and Residential Lighting.

Energy Initiative and Small Commercial/Industrial Program

In order to measure persistence of savings in the Energy Initiative and Small C/I programs, a contractor was hired to visit a group of participants to determine if measures were still in place, and if not, the reasons for their removal. The 248 site visits included a sample of 99 Small C/I participants whose measures were in place for approximately 1 year, and 101 and 48 EI participants whose measures were in place for approximately 1 and 2 years, respectively. For the two 1990 programs, the samples were randomly drawn within savings strata. Since 1989 was the beginning of the EI Program, and fewer participants had EI installations, the sample was selected from all participants who agreed to have on-site surveys. It should be noted that the results do not include a number of customers from the originally selected samples, who had moved, changed ownership or tenancy, refused to participate, or were unable to be scheduled. The rate of such "dropouts" varied significantly by program: 34% for the 1989 EI sample, 25% for the 1990 EI sample, and 14% for the Small C/I sample. Their absence from the study may have biased the sample towards installations which have higher rates of persistence. The Company plans to investigate this potential for non-response bias in a follow-up study of these sites specifically.

The on-site visits were performed by licensed electricians and included physical inspection and counting of all retrofits listed on the application. While on-site, any variances from the applications were categorized. Once new fixture counts were determined, demand savings were recalculated and compared to the original estimates.

The findings indicated instances of actual retrofits resulting in greater than anticipated savings (positive variances), as well as instances of actual retrofits resulting in less savings than the originally specified retrofit (negative vacancies). The positive variances resulted from more efficient fixtures being installed or the number of new fixtures installed being less than listed. (Positive variances associated with post-retrofit delamping, i.e., the disconnection of lamps or fixtures unrelated to program measure installations, are excluded from results since they cannot be attributed to program effects.) Negative variances resulted from the original equipment still being in place, less efficient fixtures having been installed, or the number of new fixtures being greater than specified.

The net result was very similar across the three program samples. Energy Initiative was found to have 99.7% and 99.3% of kW savings in place for the 1989 and 1990 samples, respectively. The net savings retention rate for Small C/I was 102.5%, indicating a net positive variance. The overall result for the 248 site visits was that 98.6% of the kW savings were still present in the short term. Clearly, these results indicate, for the most part, that the customers visited were not removing measures after 1 or 2 years.

Energy Fitness

Preliminary billing analysis of the Energy Fitness Program indicated savings levels were far lower than expected. It was hypothesized that premature measure removal may have caused the lower savings. In order to assess the persistence of compact fluorescent light bulbs installed, two separate on-site studies were done (MECo, 1991, SRC, 1991). Principal objectives of these studies were to: (1) estimate the percentage of gross installed kW reduction still in place; (2) collect data regarding hours of use to compare reported hours of use at the time of installation with that reported during the site visits; and (3) identify patterns of lamp removal. Both studies involved on-site inspections performed by contractors, as well as administering short surveys on customer perceptions about the program, hours-of-use, and reasons for bulb removal.

The first study done in 1990 (MECo, 1991) involved audits of 95 randomly selected customers who participated in the summer of 1989. All measures were installed by one vendor. The study was done by two contractors, and their results were combined. The results indicated that 55% of the customers no longer had in place at least one bulb (out of an average of 5.8 installed per household), and overall, that 25% of the total number of bulbs installed through the program had been removed. This represented 20% of the displaced wattage reduction of this group of customers. Forty-one percent of those surveyed admitted removing at least one functioning light bulb. The rest claimed the missing bulbs had burned out, been broken, stolen from hallways, or never installed as reported on the data forms. By far, the most common reason for removing functioning light bulbs was that they did not provide enough light for tasks such as reading, doing homework and shaving. Other reasons for removal included flickering, taking too long to turn on, general appearance, discoloring of objects, making humming noises, and being too heavy.

Since so many bulbs were removed for providing inadequate light, it is reasonable to expect higher removal rates for lower wattage bulbs. The resurvey data bear out this hypothesis, although the small sample size does not allow for significant conclusions. In addition, hours-of-use were found to be 20% less than originally reported at time of installation. These results were only accurately tabulated for one contractor representing about half the sample.

The second study (SRC, 1991) was based on a random sample of 200 participants who had measures installed by three vendors. This investigation was able to look at participation from three years of program activity, showing differences in bulb removal rates by year of installation. Participants in the study was also asked to complete a lamp usage diary which, over the course of one week, would be used to record the time of day and hours-of-use for each bulb still in place. Approximately 60 of the 200 participants returned the diaries. Given the small sample for the three years, participants were combined across years.

The results of the second study indicated approximately 58% of the customers removed at least one bulb and 24% of the total number of bulbs were removed after 1 year. After 2 years, 71% of the customers removed at least one bulb, and 38% of the total number of bulbs installed were removed. After three years, 83% of the customers removed at least one bulb, and 54% of the total bulbs were removed. Of the total displaced wattage installed in 1989, 1990 and 1991, 54%, 62% and 75% were still in place respectively. Reasons for removal were similar to those cited in the first study. Hours-of-use collected on-site and in lamp diaries were 35 and 21% below those originally reported by the participants.

Both on-site studies pointed to several recommendations for enhancing the Energy Fitness Program's cost-effectiveness: (1) The installers should ensure, to the greatest extent possible, that the customer is satisfied with the light output of the fluorescents. This is especially important for the fixtures used for task lighting where it may be advisable to try out the activity with the new light; (2) Stricter enforcement of replacement wattage guidelines should be considered; and (3) The installers should make sure that the original cover or lamp shade fits over the fluorescent.

Residential Lighting

To determine the persistence of savings for compact fluorescents purchased through the Residential Lighting Program, 150 on-site surveys were performed (Xenergy, 1992). Since this was not a direct install program, a different approach was needed to account for bulb removals and bulbs not installed. The not-in-service bulbs fall into three general categories: bulbs installed and removed, bulbs currently in place where the participants indicate that they plan to remove the bulbs, and bulbs never installed and not likely to be installed in the near future. For the mail-order component of the program, 5.9% of the bulbs had been installed and then were removed, or the customer planned to remove them; 9.9% of the bulbs purchased through mail order were not currently installed nor likely to be installed in the near future. This results in an overall in-use rate for the mail order portion of the program is 84.2%. For the retail component of the program, customers removed or planned to remove 3.5% of the bulbs, and had not installed, and were not likely to install in the near future, 4.0% of the bulbs, resulting in a net in-use rate of 92.5 percent. Reasons for bulbs being removed or never installed included poor fit, premature failure, low light levels, or customers simply "didn't get around to it."

Two observations can be drawn from this data. The first observation is that customers who purchased the bulbs from retailers rather than through mail order were more likely to retain their lamps. This could be attributed to their being able to see them before purchase, thus having a better idea about aesthetics and fit prior to purchase. The second observation relates to the fact that customers who purchased lamps of their own volition through the Residential Lighting Program were more likely to retain them than in Energy Fitness where the bulbs were directly installed for customers at no-charge.

End-Use Metering

In order to better measure demand savings a number of end-use metering studies were undertaken. The studies described below involved the small and large commercial and industrial retrofit as well as the HEM programs.

Home Energy Management

The impact evaluation used to determine savings for 1990 participants relied on the metering of a sample of radio controlled electric water heaters. The sample included both of the program options, 6 and 16 hour control of lower tank elements. A sample of 39 participants was selected from a group of 67 volunteers solicited through a mailing to 183 participants.

To minimize variation in water consumption between households, it was decided to use the participant group as their own comparison group. This was accomplished by controlling them on Tuesday and Thursday and leaving them uncontrolled for the other weekdays. The data was stored on-site and downloaded over the existing phone line at regular intervals. Once collected, the data was run through a screening program where a number of tests were performed to check for data validity before being analyzed further.

After analysis of the initial data, it became apparent that the participants fell into three groups defined by the reliability of reception of the radio control signal: those inside the radio reception area, those outside it, and those on the fringe. Those outside the reception area were identified in that category because they exhibited no control. Of the 39 original sites, 20 were included in the analysis as sites inside reception area. Eight sites were classified in the fringe area, and 8 sites were outside the reception area. Two sites were excluded due to mechanical problems that resulted in their not producing acceptable data until the very end of the winter monitoring period and one site was not installed in time to collect data during the winter season. The final sample contained 36 sites.

Weekly group averages for control and non-controls were used to produce a monthly figure. Monthly values were in turn averaged to create two separate (morning and evening) seasonal values for average hourly demand reductions. Peak demand reductions were calculated for morning and afternoon; but since the Companies' System peak was in the afternoon, only those values were used to calculate System peak reductions. Analysis of the data found the 6 hour and 16 hour control participants inside the reception area group had average demand reductions of 0.64 kW and 0.33 kW, respectively. The fringe area participants' average demand reductions were 0.40 kW and 0.23 kW for the 6 hour and 16 hour control participants. The lower savings for the 16 hour control are thought to be the result of late afternoon depletion of hot water causing the upper element to come on.

Applying these values to the number of installations in these groups for both 6 hour and 16 hour control periods resulted in a total program savings for the 2,044 controllers of 941 kW. This was 89% of pre-program engineering estimated savings. The benefit/cost ratio of this program was 0.8. It should be noted that the engineering estimates for this program were based on an earlier research project on water heater load control which may account for the relatively high ratio of engineering estimates to measured savings. The low cost-benefit ratio was due to first year start-up costs.

To remedy the problem of poor radio reception, the Company has signed on additional radio stations to fill in the fringe area. With the addition of the new radio stations done in time for the second-year metering analysis, it was decided to calculate a single demand reduction based on an average of all of the monitoring sites which could then be multiplied by the number of installations to get total program savings. This method is preferred over determining a separate reduction for each group (inside, fringe, outside), since the decision of which group each town belongs in is often subjective.

The second year sample consisted of 26 of the original 39 sites. Thirteen were eliminated for the following reasons: equipment not available to the general population had been installed[3] loss of the proper control program (i.e., units were being controlled every weekday, as in the general population) and malfunctioning monitoring equipment. Consequentially, the second year's analysis gave an indication of how much the previously defined fringe and outside reception areas improved. The data analysis methodology used for the second year was the same as the first year with the exception of the elimination of the fringe and outside groups.

Analysis of the data found 0.52 kW and 0.35 kW for the 6-hour and 16-hour control. The total savings were 2,279 annual kW and 34,175 lifetime kW. The precision at the 90% confidence level was 39% and 47%, for the 6 and 16-hour control respectively. This figures takes into account the small removal rate of 0.82% plus 482 6 hour and 243 16 hour transitional inoperative units. Transitional units are sites where radio receivers were temporarily installed in place of timers due to unavailability of timers. Program administrators estimate that 50% of these units are working; therefore, transition inoperative units represent those transitional units which currently are not working. The benefit/cost ratio of the program was 1.8 indicating a cost-effective program. These estimates were 77% of the original estimates but about 60% of the 23% shortfall is due to the transitional inoperative units of which most will be operable by the end of 1992 bringing the value up to about 91%.

Small C/I and Energy Initiative End-Use Metering

In order to directly measure the demand and energy savings associated with the installation of energy efficient lighting technologies in the Small C/I and Energy Initiative Programs, the Company initiated two end-use metering projects. (RLW,1992 a,b) Since the end-uses implemented most frequently in these two programs were lighting, and the measures were similar, it was decided that studies could both share the same general methodology and be implemented by the same contractors. One contractor was responsible for the sample design and statistical analysis of the data, and the other was responsible for the recruitment of participants, development of a metering plan, installation and removal of the equipment, and site-specific savings calculations.

A statistical sampling plan was used to select projects to be metered in order to provide unbiased estimates of program impact with measurable precision. Sample strata were developed, based on historical distribution of program savings and random selection of upcoming retrofit projects, within each stratum. The sampling methodology and statistical analysis of results was based on the theory of Model-Based Statistical Sampling (MBSS) (Wright, 1989). This type of sampling plan promotes the efficient use of sample points by ensuring an appropriate distribution of large and small projects.

Before installation of the metering equipment, a detailed on-site survey was performed which recorded number and type of fixtures in each space, hours-of-use by space and wattage measurements (spot watts). A four channel data logger was then installed to collect total pre- and post-retrofit usage for a sample of circuits representing the predominant fixture types as well as the majority of the savings. This data was used to determine load profiles and hours-of-use. For spaces or fixtures with small savings, operating hours were determined from the on-site surveys, while load profiles were taken from weighted averages from the metered circuits. Wattages were determined from either the spot watt measurements or manufacturer supplied data. Monitoring periods typically consisted of several weeks of pre- and post-retrofit.

Energy savings were developed using measured wattage differences and hours-of-use. On-peak demand reductions were developed using measured wattages differences and measured load profiles. The engineering estimates for demand savings for both the Small C/I and the Energy Initiatives Programs were based on the difference in manufacturers' wattage data between the efficient and the existing fixtures. Engineering estimates of energy savings for the Small C/I Program are based on the demand savings and fixture specific hours-of-use data collected during the lighting audit. Engineering estimates of energy savings for the Energy Initiative Program are based on the demand saving and measure specific hours-of-use from surveys of a sample of participants. Total facility energy and demand were not collected.

The analysis presented here is based on metered data from 21 and 23 Small C/I and Energy Initiative lighting installations, respectively. The results indicate that the Small C/I and Energy Initiative Programs reduced energy consumption by 96 and 68% of engineering estimated savings for the respective programs. At the 90% confidence level, the ratios have a relative precision of 17% and 15% respectively. The mean savings produced were 20,779 kWh/year for Energy Initiative and 11,951 kWh/year for Small C/I.

The on-peak demand savings (around 3 p.m. in the summer) are 84% and 77% of engineering estimates for the Small C/I and Energy Initiative Programs, respectively. These ratios can be thought of as a combination of coincident diversity factors and non-coincident ratios of measured to estimated demand savings. At the 90% confidence level, the ratios have a relative precision of 16% and 9%. The mean on-peak demand savings were 6.41 and 3.45 kW for the Energy Initiative and Small C/I programs, respectively. Figures 1-4 demonstrate the strong correlation between metered and engineering estimated savings for the two programs.

Specific reasons identified for the resulting savings coming in at less than 100% include over-reporting of hours-of-use, incorrect counts of numbers and wattages of existing fixtures, and discrepancies between manufacturer reported wattages and actual field performance of energy efficient measures.

Conclusions and Comparison of Study Results

The results of the Energy Fitness on-site verification studies clearly support the billing analysis results. High levels of bulb removal and lower hours-of-use than reported at time of installation were significant factors in the lower than expected savings. Even after using a portion of these results to update the engineering estimates, the savings estimated in the second billing analysis were still lower than expected. Thus bulb removal and overestimated hours-of-use do not fully explain the lower than expected savings. The residential lighting on-site verification studies also found significant removal rates, pointing to some customer dissatisfaction with compact fluorescent characteristics even when the installation is self initiated.

The findings of the commercial lighting retrofit on-site verification studies did not support the results of the billing analysis or end-use metering studies which showed savings to be less than engineering estimates. In both the Energy Initiative and the Small C/I programs, on-site surveys indicated very small percentages of removed kW savings. In Small C/I, the net percentage of removed kW savings actually slightly increased over what was recorded in the tracking system. This result is a clear contrast to the residential programs where the lighting measures are much more easily removed by the customer if at all dissatisfied with the performance.

The most interesting comparison is between the kWh ratios produced by the end-use metering and by the billing analysis. In order to do direct comparisons, the end-use metering ratios must be adjusted to include the effects of free-ridership. Once the billing analysis ratios of 96% and 68% for Energy Initiative and Small C/I, respectively, are adjusted for kWh weighted free-ridership, determined from process evaluation surveys (MECo, 1992) to be about 7% for both programs, the billing and adjusted end-use meter results are within about 10-20 percent of each other. Given the precision associated with the billing analysis and end-use metering studies, these results can be considered generally supportive of each other.

The evaluation studies presented in this paper represent the Company's initial efforts to measure the actual performance of its C&LM programs. The experience provided key insights into the design of future evaluation efforts as well as program improvements.

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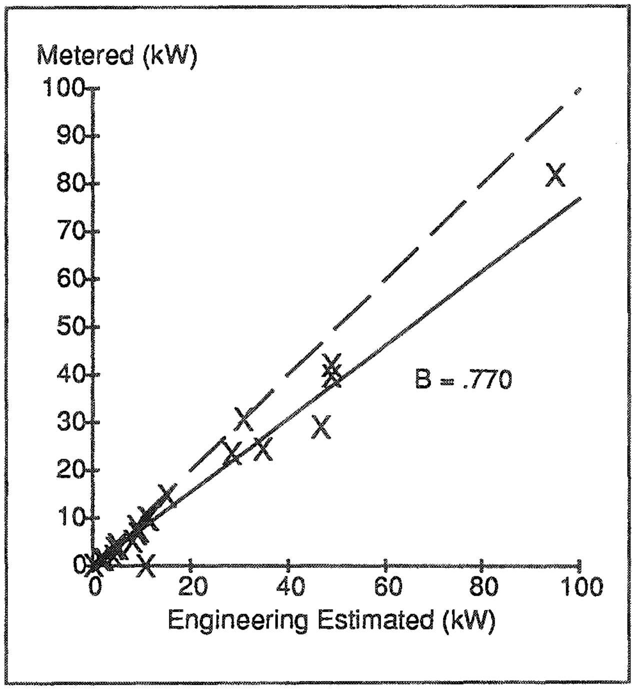

Figure 1. Energy Initiative Summer Peak kW Savings

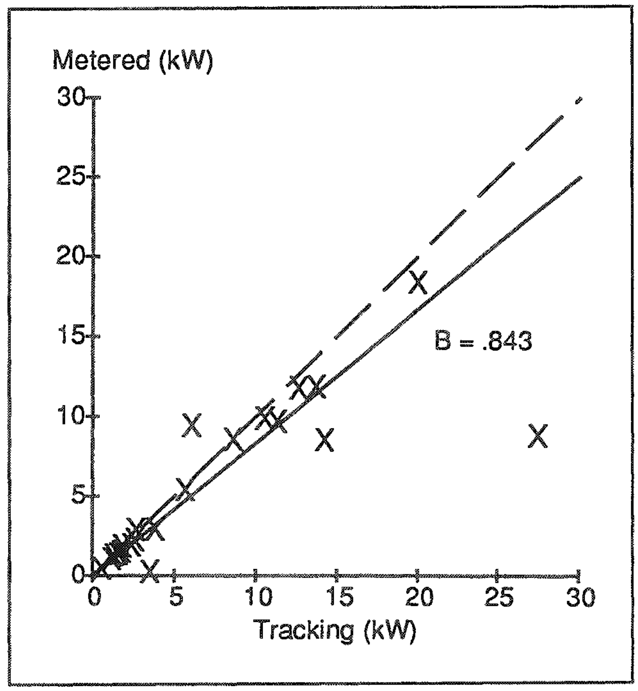

Figure 2. Small C & I Summer Peak kW Savings

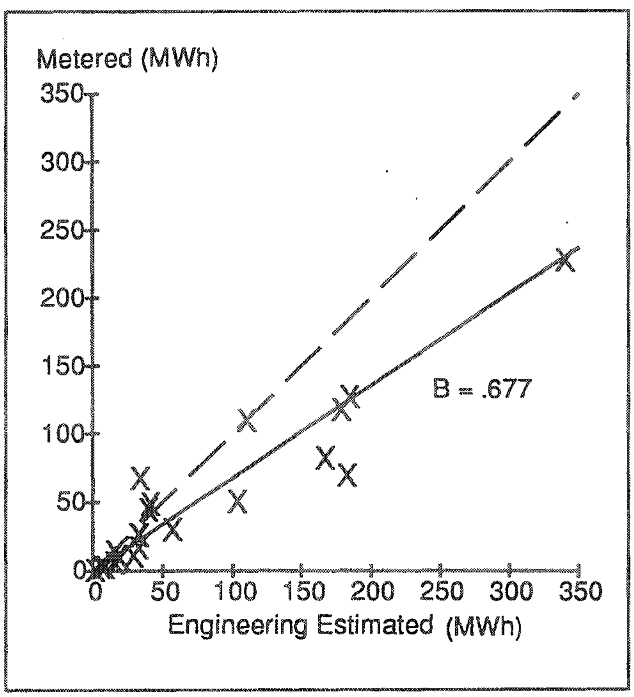

Figure 3. Energy Initiative Annual MWh Savings

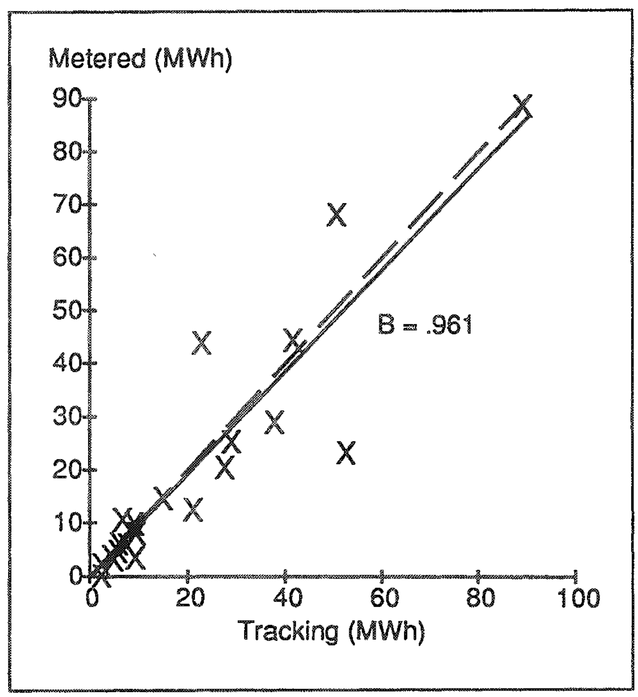

Figure 4. Small C & I Annual MWh Savings

RCG/Hagler, Bailly, Inc., Rob Bordner of SRC, and Mitchell Rosenberg of Xenergy for producing much of the analysis discussed in this paper.

Endnotes

1. Note that the net savings to engineering estimate ratios include the effects of free-ridership which are not included in the engineering estimates.

2. All benefit-cost ratios include environmental externalities values as specified by Massachusetts Department of Public Utilities (MADPU 89-239) and do not include evaluation and planning costs. The benefits produced are based on the tail block rates that New England Power charges it's retail affiliates (W-11 and W-12).

3. The special equipment consisted of radio receivers modified by the manufacturer and NEPSCo personnel which were better able to pick up a weak radio signal than the radio receivers installed for the general population. They also were addressed on-site rather than via the radio transmitters.

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