Energy Savings for Residential Lighting Programs: There's More to It Than Just Counting Lamps

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A detailed energy savings analysis was conducted on Boston Edison Company's Residential Lighting Program using both lamp sales data and customer surveys. The finding indicated that estimated total, lifetime net program energy savings is 12,617 MWh.

Introduction

Residential lighting measures are relatively easy to implement and, for most utilities, are cost-effective under all but the most austere financial assumptions and generous program delivery schemes. Little wonder that electric utilities are beginning to heavily promote discounted or even no-cost energy efficient light lamps to their customers. Technology dissemination has taken every possible form, from add-on items in conventional residential programs to targeted promotions enlisting mail order houses, utility service centers and local charity drives.

Boston Edison Company (BECo) was one of the first utilities in the country to adopt a residential lighting program, offering its customers rebates on a wide variety of lighting measures since 1987 under a program known as "Lite Lights". The eight lamp types available through the Lite Lights program are:

- *All-in-one* - all-in-one compact fluorescent lamps
- *Twin Component* - twin-tube component compact fluorescent lamps
- *Circular* - circular fluorescent lamps
- *Reflectors* - elliptical reflector lamps
- *Halogen Flood* - halogen indoor/outdoor flood lights
- *Quad Component* - quad-tube component compact fluorescent lamps
- *Electronic Ballast* - compact fluorescent lamps with electronic ballasts.

In the past year, a comprehensive impact evaluation of this program has estimated net program energy savings, taking into consideration the proportion of purchased lamps that are actually in service, as well as free ridership, free drivers and snapback.

To develop energy savings estimates, a detailed analysis was conducted of energy efficient lamp purchases via BECo Energy Centers, a mail-order outlet known as EFI, and participating retail stores. Additional purchase and usage data were collected via two customer surveys of participants and non-participants, the first conducted in October 1990 and the second in March 1991. Since customized data collection systems were developed to serve the unique operational requirements of each of these sales outlets, analyses of three distinct databases was required. For the purpose of this evaluation, the databases were restructured into a common format and merged into a unified database system from which all necessary sales data was either immediately available or easily reconstructed. This process resulted in a normalized, internally consistent data-set suitable for statistical analysis.

Volume of Purchases

Sales of energy-efficient lamps through the Lite Lights program have dramatically changed over the past four years, both in total volume of sales and in the volume attributable to each of the three program delivery outlets. Table 1 documents these changes, revealing a doubling of sales from 1987 to 1988, another doubling of sales from 1988 to 1989, and nearly a five-fold increases in sales from 1989 to 1990. In total, approximately 49,668 lamps were sold over the four year period. As shown in Figure 1, EFI accounted for 46 percent, retail stores accounted for 21 percent, and Boston Edison Energy Centers accounted for the remaining 33 percent of the lamps sold.

Table 1. Number of Bulbs Purchased

	Energy Center	EFI	Retail	Totals
1987	--	--	1,544	1,544
1988	--	--	3,666	3,666
1989	838	3,940	3,050	7,828
1990	15,382	19,039	2,209	36,630
Overall	16,220	22,979	10,469	49,668

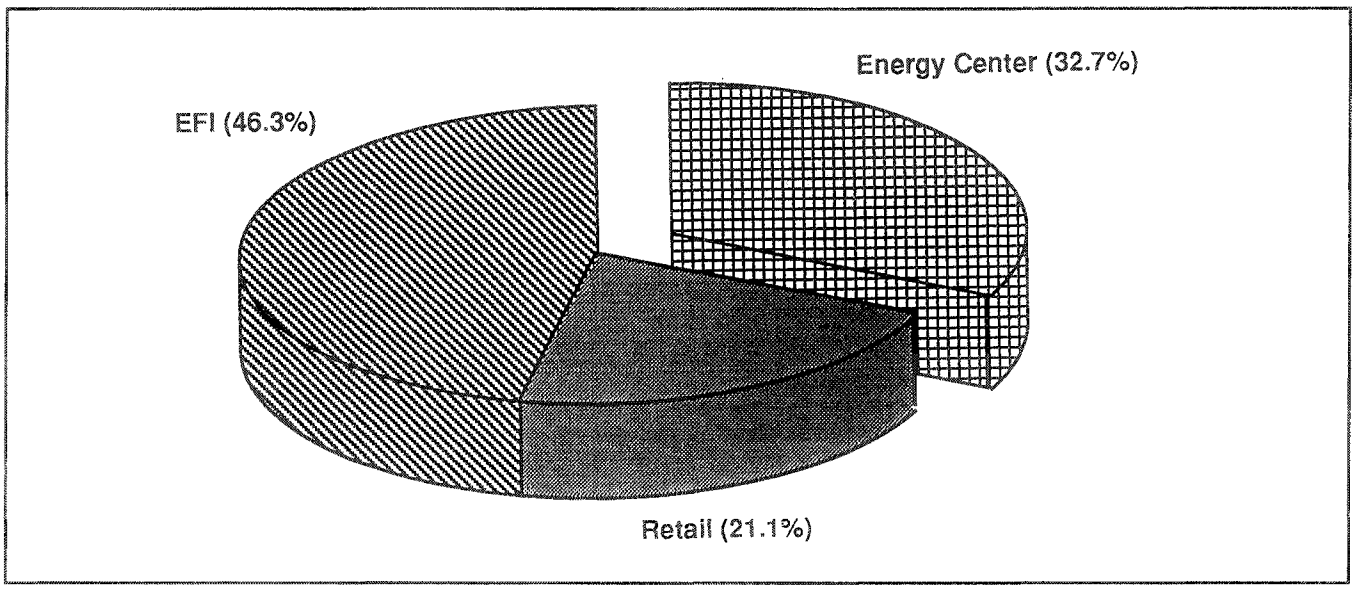

Figure 1. Share of Bulb Sales by Outlet

Figure 2 provides a visual display of the volume of lamp sales from the inception of the program in 1987, when the only sales outlet for the lamps was retail dealers, through 1990, when all three outlets were in operation. The graph illustrates the current decline in sales from retail outlets, concurrent with the dramatic rise in sales from the Energy Centers and EFI.

It is worth noting that the Energy Centers experienced a dramatic surge in lamp sales during the last four months of 1990. Sales data show that for the first eight months of 1990 the Energy Centers sold 6,392 lamps. Assuming an even sales distribution throughout the year, 3,196 lamps could be expected to be sold between September and December of 1990. In fact, the Energy Centers sold 8,990 lamps during this time frame. The "Lite for Sight" Lions Club promotion happened to coincide with this time frame and customer awareness of this promotion is likely to have caused these increases in sales.

Gross Energy Savings

Analysis of the program data indicates that 8,037 households to date have participated in the Lite Lights program. To assure that double counting of households did not occur, households were screened by names to determine if lamps were purchased two or more times via the same outlet, or purchased via two or more outlets. This screening resulted in a count of "unique" households. As suggested in Table 2 by the total number of lamps purchased, these participating households acquired an average of 6.2 energy-efficient lamps through the program. Further, the average retail value of these lamps was $8.93, of which slightly more than half was rebated from Boston Edison to customers. Tables 3, 4 and 5 provide this same data, broken out by program year. For convenience, cost, rebate, and savings estimates within this study are rounded to whole numbers.

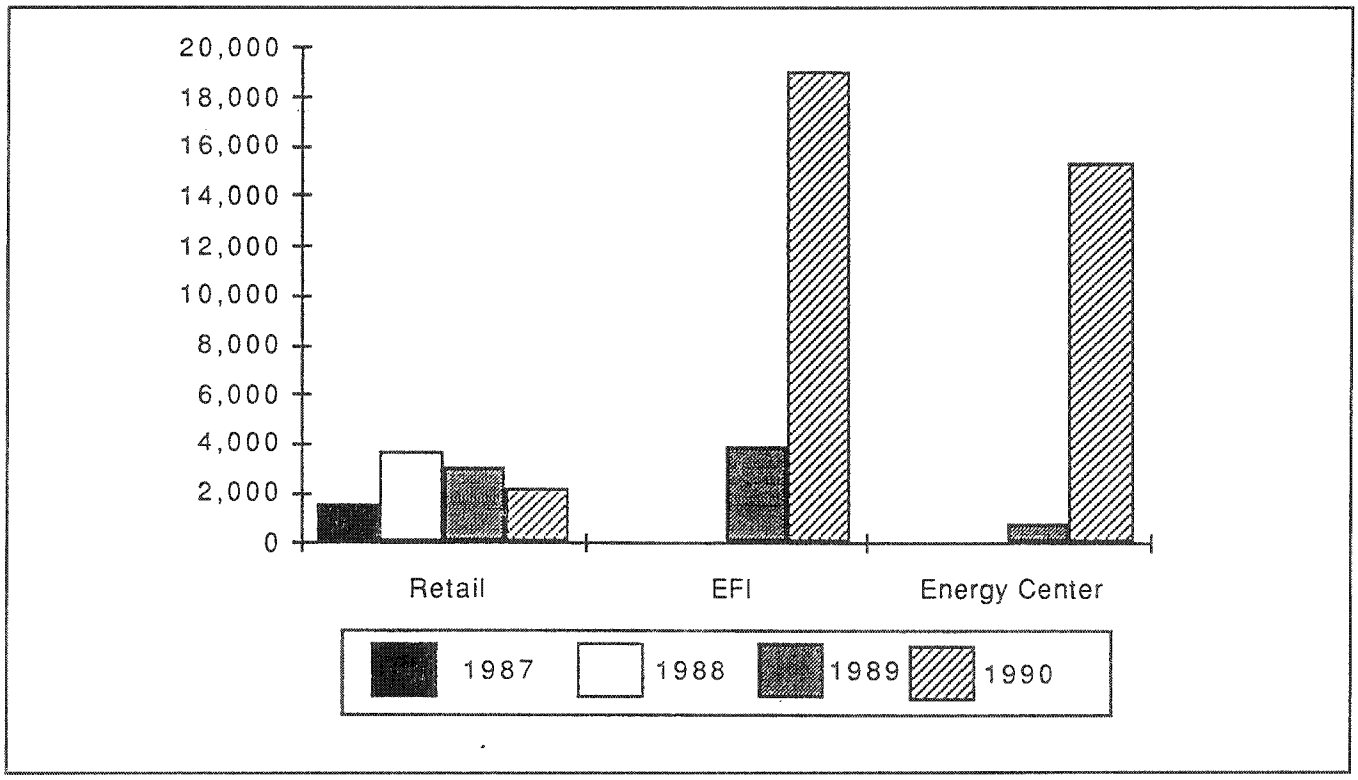

Figure 2. Bulb Sales Trend by Outlet

Table 2. Lite Lights Data, 1987 through 1990

	Energy Center	EFI	Retail	Totals
No. of Bulbs Purchased	16,220	22,979	10,469	49,668
Households	3,103	2,319	2,836	8,037
Cost Before Rebate	$130,089	$215,656	$98,021	$443,766
BECO Rebate	$77,121	$110,989	$45,752	$233,862
Cost to Customer	$52,968	$104,667	$52,269	$209,904
Gross kWh Savings	4,025,460	6,872,400	3,544,812	14,442,672

To estimate the energy savings associated with each energy-efficient lamp, the watts used by each lamp were subtracted from the watts used by a conventional lamp with an equivalent luminescence as claimed by the manufacturer. For example, about the same lighting is produced in a compact fluorescent lamp of 15 watts as in a conventional incandescent lamp of 60 watts - thus the instantaneous energy savings resulting from retrofit is 45 watts. The instantaneous energy savings obtained by replacing a conventional lamp with an energy-efficient lamp is based on published lamp replacement tables for each lamp style. Where an energy-efficient lamp is capable of replacing conventional lamps of varying wattage, the average wattage of the conventional lamps is used.

To calculate energy savings over the life of a lamp, the instantaneous energy savings is multiplied by the manufacturer's estimate of the number of hours a lamp is expected to operate. Dividing this number by 1,000 yields the total kWh savings per lamp. The total energy savings for the Lite Lights program is the sum of the energy

Table 3. Lite Lights Data, 1987 and 1988

	Retail 1987	Retail 1988
No. of Bulbs Purchased	1,544	3,666
Households	643	1,040
Cost Before Rebate	$14,918	$36,011
BECO Rebate	$6,174	$16,339
Cost to Customer	$8,744	$19,672
Gross kWh Savings	563,662	1,343,776

savings for all lamps purchased through the program. Table 6 shows the estimated instantaneous and lifetime energy savings for each lamp available in the program.

The actual wattage for the purchased energy-efficient lamps was not directly available for any of the delivery outlets. For the Energy Centers and EFI outlet, this information was reconstructed based on lamp style (each lamp style represents a specific wattage lamp.) For the retail outlets only the lamp type was obtainable. In this case, the wattage was calculated as the average wattage of all lamp styles within that lamp type. For example, halogen floods (lamp type) were available in either 45 watt or 90 watt styles; therefore, all halogen floods within the retail outlet were considered as 67.5 watt lamps. Table 7 shows the average estimated instantaneous and lifetime energy savings for each lamp type.

Based on the gross savings analysis, the total estimated lifetime energy savings from the Lite Lights program is 14,443 MWh. As demonstrated in Table 8, the average lifetime of all energy-efficient lamps purchased under this program is 6,919 hours. Assuming an average daily use of about 3.2 hours, all of which replaces an ordinary lamp, the total energy savings from these lamps can be annualized by spreading the savings for each lamp over 6 years. Table 9 displays the gross annual kWh savings resulting from this calculation. As is evident, the savings from lamps purchased in 1987 would be expected to last

Table 4. Lite Lights Data, 1989

	Energy Center	EFI	Retail	Totals
No. of Bulbs Purchased	838	3,940	3,050	7,828
Households	228	545	707	1,369
Cost Before Rebate	$6,569	$32,510	$27,438	$66,516
BECO Rebate	$2,623	$14,264	$12,172	$29,059
Cost to Customer	$3,946	$18,246	$15,266	$37,458
Gross kWh Savings	231,102	1,066,713	999,860	2,297,675

Table 5. Lite Lights Data, 1990

	Energy Center	EFI	Retail	Totals
No. of Bulbs Purchased	15,382	19,039	2,209	36,630
Households	2,885	1,813	554	5,226
Cost Before Rebate	$123,520	$183,146	$19,655	$326,321
BECO Rebate	$74,498	$96,725	$11,068	$182,290
Cost to Customer	$49,022	$86,422	$8,587	$144,031
Gross kWh Savings	3,794,357	5,805,684	637,514	10,237,555

Table 6. Estimated Savings for Specific Bulb

Type	Style	Replacement	Estimated Watt Savings	Estimated Lifetime (in hours)	Energy Savings (in kWh)
All-in-one	15w	60w	45.0	9,000	405.0
Twin Component	7w	25-45w	28.0	10,000	280.0
	9w	40-50w	36.0	10,000	360.0
	13w	60-75w	54.5	10,000	545.0
Circular	27w	60-75w	40.5	10,000	405.0
Reflectors	50w	75w	25.0	2,400	60.0
	75w	100-125w	37.5	2,400	90.0
Halogen Bulb	42w	50-60w	13.0	3,500	45.5
	52w	60-75w	15.5	3,500	54.3
	72w	90-100w	23.0	3,500	80.5
Halogen Flood	45w	75w	30.0	2,000	60.0
	90w	125w	35.0	2,000	70.0
Quad Component	9w	40-50w	36.0	10,000	360.0
	13w	60-75w	54.5	10,000	545.0
	22w	75-85w	58.0	10,000	580.0
Electronic Ballast	11w	40w	29.0	9,000	261.0
	15w	60w	45.0	9,000	405.0
	18w	75w	57.0	9,000	513.0
	20w	75w	55.0	9,000	495.0
	27w	100w	73.0	9,000	657.0

Table 7. Estimated Average Savings by Bulb Type

Type	Average Watts	Replacement Watts	Estimated Savings (in watts)	Estimated Lifetime (in hours)	Energy Savings (in kWh)
All-in-one	15.0	60.0	45.0	9,000	405.0
Twin Component	9.7	49.2	39.5	10,000	395.0
Circular	27.0	67.5	40.5	10,000	405.0
Reflectors	62.5	93.8	31.3	2,400	75.1
Halogen Bulb	55.3	72.5	17.2	3,500	60.2
Halogen Flood	67.5	100.0	32.5	2,000	65.0
Quad Component	14.7	64.2	49.5	10,000	495.0
Electronic Ballast	18.2	70.0	51.8	9,000	466.2

Table 8. Estimated Lifetime by Bulb Type

Type	Bulbs Purchased	Manufacturer's Estimated Lifetime (hours)	Total Estimated Lifetime (hours)
All-in-one	15,984	9,000	143,856,000
Twin Component	3,903	10,000	39,030,000
Circular	2,405	10,000	24,050,000
Reflectors	4,508	2,400	10,819,200
Halogen Bulb	12,480	3,500	43,680,000
Quad Component	3,702	10,000	37,020,000
Electronic Ballast	4,543	9,000	40,887,000
Totals	49,668		343,628,200
Weighted Average Lifetime			6,919

through 1992, and the savings from lamps purchased in 1990 would be expected to last until 1995.

Lamps Not in Service

Not all newly purchased lamps end up in use. Lamps that are never installed, are broken, or are removed from service for aesthetic or other reasons should be netted out of program-related energy savings estimates. For this analysis these lamps are designated as "withdrawn from service." The normal incidence of lamp burn-out is not included in this adjustment since this type of withdrawal is incorporated in gross energy savings estimates via producer ratings of expected lamp lifetimes.

It is worth noting that survey data indicate participants purchased 7.34 lamps per household and that on average 6.18 lamps are currently installed. Although this indicates that slightly more than 1 lamp is no longer in use, the "uninstalled" lamps include burnouts and spare lamps stored for future use.

For the first group of customers surveyed, 39 participants (5.2%) indicated that one or more qualifying lamps were not in use. In all, approximately 147 lamps were out of service; this number is based on 117 reported lamps as well as the assumption that 5 respondents who claimed that no lamps were currently in use had purchased 6 lamps each. Eight participants reported that at least one

Table 9. Gross Annual kWh Savings

Year	Energy Center	EFI	Retail	Totals
1987	0	0	93,944	93,944
1988	0	0	317,907	317,907
1989	38,517	177,786	484,550	700,853
1990	670,910	1,145,400	590,803	2,407,112
1991	670,910	1,145,400	590,803	2,407,112
1992	670,910	1,145,400	590,803	2,407,112
1993	670,910	1,145,400	496,859	2,313,168
1994	670,910	1,145,400	272,896	2,089,205
1995	632,393	967,614	106,253	1,706,259
Totals	4,025,458	6,872,497	3,544,813	14,442,672

lamp had burned out. Assuming only 8 lamps were removed due to burnout leaves 139 lamps withdrawn from service.

Of the second round of customers surveyed, 54 respondents (21.4%) indicated that one or more qualifying lamps' were not in use. Of these, only 38 knew how many of the lamps were not in service; each of the remaining 16 respondents are conservatively estimated to have purchased 6 lamps, all of which are no longer in use. In all, approximately 204 lamps were out of service; including 108 reported lamps and 96 estimated lamps. Ten participants reported that at least one lamp had burned out. Assuming only 10 lamps were removed due to burnout leaves 194 lamps withdrawn from service.

In total, 93 participants (9.3%) indicated that 333 qualifying lamps were not in use for reasons other than normal burnout. Assuming an average of 6 lamps per each of the 1002 households, approximately 5.5% (333/6012) of the lamps purchased through the program can be designated as withdrawn from service.

The impact of purchased lamps not being used or being removed for causes other than burnout must be factored into the analysis. This can be accomplished by reducing the number of lamps in use and the associated energy savings by 5.5%, which is 2,732 lamps or approximately 1/3 of a lamp per household. As a more conservative estimate, we instead eliminated 1 lamp per household (16.2%). Since the average energy savings per lamp is 290.8 kWh the effect of removing 8,037 lamps, one per household, is a reduction of about 2,337,160 kWh. The net effect of these changes are shown in Table 10. Table 11 shows the annual kWh savings adjusted for lamps not in service.

Adjustments to Gross Savings

Determining the net energy savings that can be attributed to an energy efficiency program like Lite Lights is a complex matter. Because this program targets end uses that are directly under the customer's control, customer behavior can be a major factor in how much energy is ultimately saved.

At present, the only method available for studying customer behavior is self-reported behavior gathered through surveys. In the analysis that follows an attempt is made to incorporate these data into estimates of program-related energy savings. Being experimental, this analysis rests upon a number of assumptions that cannot be verified without more data. Therefore, the results of this analysis should be viewed as a preliminary attempt to develop methods for resolving behavioral issues; the results are suggestive of the magnitude of these effects, rather than definitive estimates of their impacts on energy use.

To transform the gross estimates of energy savings for the Lite Lights program into net or "program-related" savings that do not rely exclusively on volume of sales and technical potential data, at least four major behavioral factors can be identified. Data used to explore these issues were collected as part of the first survey of 750 participants and 750 non-participants and the second survey of 252 participants and 750 non-participants. The first factor (lamps withdrawn from service) was discussed in the previous gross savings section. The remaining factors are examined below.

Free Riders

If lamps that were purchased through the program might have been purchased anyway, including them as program-related savings would be a form of overcounting. It is impossible to know a customer's true intentions or motivations; however, certain types of survey questions are able to provide indications of prior interest and behavior vis-a-vis program products. To operationalize the concept of free ridership, one key piece of information was sought: was the customer's first purchase of qualifying lamps through the program or prior to the inception of Lite Lights in 1987?

Table 10. Adjustments for Bulbs Not in Service

	Gross Effect	Adjustments	Net Effect
Households	8,037	0	8,037
Bulbs in Use	49,668	-8,037	41,631
kWh Savings	14,442,672	-2,337,160	12,105,512

Table 11. Annual kWh Savings Adjusted for Bulbs Not in Service

Year	Energy Center	EFI	Retail	Totals
1987	0	0	78,742	78,742
1988	0	0	266,462	266,462
1989	32,284	149,016	406,139	587,439
1990	562,341	960,047	495,197	2,017,585
1991	562,341	960,047	495,197	2,017,585
1992	562,341	960,047	495,197	2,017,585
1993	562,341	960,047	416,456	1,938,844
1994	562,341	960,047	228,735	1,751,123
1995	530,057	811,032	89,058	1,430,147
Totals	3,374,046	5,760,283	2,971,183	12,105,512

Participants. In response to the first survey, 200 program participants stated that they had purchased some type of energy-efficient light lamps prior to the inception of the program. Further inquiry revealed that 84 program participants (11.2%) had aided purchased at least one qualifying lamp prior to learning about the program - these households are designated as free riders. The second survey revealed that 23 program participants (9.1%) had purchased qualifying lamps prior to learning about the program. In all, 107 of 1002 surveyed participants (10.7%) can be classified as free riders.

A cautionary note is in order - the designation of free rider assumes that the households would have continued to purchase lamps in the absence of the program. Further, it is not known whether these households would have purchased as many lamps without the rebate as they did with the rebate. Since the survey instrument does not allow us to probe more deeply into purchaser motivations and possible actions the free rider estimate may include households that were truly motivated to purchase additional energy-efficient lamps by the existence of the Lite Lights program.

Non-participants. Free ridership is not applicable to the non-participant group. Although certain households are potentially free riders, by definition only those households that are currently participating in the program are eligible to be designated free riders.

Free Drivers

The publicity surrounding a program often results in an increased customer awareness of energy efficiency and related products. To the extent that this awareness indirectly stimulates purchases of products at full market prices, the program may be credited with encouraging added energy savings and bringing about a market transformation. Free drivers are defined as those households that knew of the existence of the program but purchased qualifying light lamps on their own, without benefit of rebate. A combination of questions was necessary to operationalize the concept of free drivers.

Participants. In the first participant survey, 61 respondents (8.1%) were designated free drivers because they claimed that a) they had not purchased qualifying lamps prior to the Lite Lights program, and b) they had purchased qualifying lamps without a rebate during the course of the program. These respondents reported purchasing 81 qualifying lamps without rebates. In the Phase 2 participant survey, 7 respondents (2.8%) were designated free drivers and indicated purchasing 44 qualifying lamps. In all, 68 participants (6.8%) were classified as free drivers. These participants reported purchasing 125 qualifying lamps without rebates for an average of 1.8 lamps per respondent.

Non-participants. Among the first surveyed non-participants, 59 respondents (8.1%) were designated free drivers in that a) they heard of the Lite Lights program, and b) they had purchased qualifying lamps without participating in the program. This group purchased a total of 120 lamps, or an average of 2 per respondent. Among second non-participants, 26 respondents (3.5%) were designated free drivers. In addition to the above criteria, all 26 of the respondents indicated that the Lite Lights program influenced their decision to purchase qualifying energy-efficient lamps. This further supports classifying them as free drivers. This group purchased a total of 116

lamps, or an average of 4.5 per respondent. In total, 85 respondents (5.7%) purchased 236 lamps without the program for an average of 2.8 lamps per respondent.

Among non-participants, 106 of the first surveyed respondents (14.1%) and 155 of the second surveyed respondents (20.7%) claimed to have never heard of the Lite Lights program, yet had purchased 215 and 814 qualifying lamps respectively, for a total of 1029 qualifying lamps, or an average of 3.9 per household. This group may be deemed "market driven" in that their behavior was apparently unrelated to utility activities. In total, 261 respondents (17.4%) can be classified as market driven.

If all 5.7% of the non-participant respondents are actually designated as free drivers, a simple extrapolation of program impacts to Boston Edison's entire residential customer base of 550,000 households would suggest that 31,350 households had purchased 87,809 qualifying light lamps due to the increased awareness brought only by the Lite Lights program. However, it must be stressed that the present survey is limited in its ability to finely distinguish purchasing motivations. Of the 5.7% of the customer base that knew of Lite Lights and purchased lamps without benefit of rebates, perhaps only a fraction were truly influenced by the program advertising. Like the 17.4% of households that were market driven and purchased lamps without any knowledge of the program, some fraction of the free drivers may have been more motivated by increased electric rates or rising disposable income than by the program advertising.

For these reasons it seems prudent to accept 5.7% as the highest possible estimate of non-participant free drivers and to use some fraction of this estimate as a better approximation of program impacts. In the absence of additional data, a conservative estimate may be that 1% of Boston Edison's total residential customer base may be free drivers. This computes to 5,500 households and 15,400 qualifying lamps. The remaining 4.7% of households would be designated as "market-driven", bringing the total estimate of this type of household to 22.1% of the total residential customer base.

Snapback

Changes in end use equipment that tend to lower operating costs per unit of service can also lead to changes in the hours of use, or the intensity of use, of the equipment -- this effect is known as snapback. The magnitude of snapback is contingent on two factors: the energy savings offered by the product and the change in hours of use. For example, suppose a customer replaces a 100 watt light lamp that is normally used for 9 hours a day with a 90 watt lamp and then uses the lamp 1 hour (11.1%) more each day. Since both lamps use 900 Wh per day the net effect is no energy savings. On the other hand, suppose a customer replaces a 100 watt light lamp that is normally used for 9 hours a day with a 25 watt lamp and then uses the lamp 18 hours a day (a 100% increase.) Since the conventional lamp used 900 Wh per day and the energy-efficient lamp uses only 450 Wh per day there is still a 450 Wh savings.

To estimate snapback, the first surveyed participants were asked to reveal how many hours more, or less, they use the energy-efficient lamps that replaced their conventional lamps. In all, 500 participants indicated that hours of use were unchanged; 167 participants claimed an average increase in use of 6 hours per day; 71 participants claimed an average decrease in use of 5 hours day; and 19 participants were uncertain as to if, or how, use had changed. In the second survey, 187 participants indicated no change in use; 52 participants claimed an average increase in use of 3.76 hours per day; and 13 participants claimed an average decrease in use of 2.33 hours day compared to the conventional lamps.

In total, 687 participants indicated no change in use; 219 participants claimed an average increase in use of 5.5 hours per day; and 84 participants claimed an average decrease in use of 4.6 hours day compared to the conventional lamps. Assuming 6 lamps per household, the net effect can be calculated as:

*(219 households * 5.5 hours * 6 lamps - (84 households * 4.6 hours * 6 lamps))*

This is an overall increase of 4909 hours per day of use, or an average of 4.9 hours per day for each of the surveyed participants, or about .82 extra hours per day per purchased lamp.

As discussed above, to calculate snapback the hours of extra use must be combined with the base use of the conventional lamp that was replaced. To obtain this information, the second survey participants were asked how many hours a day had they used the lights that the energy-efficient lamps replaced.

For 212 (84.1%) participants who know the previous base usage, the average usage for the original lamps was 6.8 hours per day. Therefore, the total use for energy-efficient lamps reported by the surveyed participants is 7.62 hours per day. Of this, 6.8 hours per day is base usage and 0.82 hours is extra usage. The extra usage represents a 12.1% increase over base usage.

Having estimated the general effect of snapback as a 12.1% increase in usage over conventional lamps, the analysis must incorporate this factor into the estimated daily base use for program participants. At this point it seems prudent to assume a base use of 3.2 hours per day for each qualifying lamp (as was done for the analysis of gross annual savings in Table 9). This figure is lower than self-reported data, but is consistent with BECO's planning research and non-utility party consensus. A 12.1% (.39 hours) increase over 3.2 hours in usage due to snapback would mean the average qualifying lamp is used 3.59 hours per day.

Net Energy Savings

As useful as the gross savings adjustment data are for gaining a fuller understanding of customer purchase and use patterns, there is no direct way to use the data to make even the simplest of adjustments to energy savings estimates. A number of assumptions are still required, the broadest of which is that the distribution of lamp types and wattages reported purchased without rebates matched those that were purchased via the Lite Lights program. However, an estimate of net energy savings can be obtained by applying each of the effects described previously in a logical sequence based on how these impacts may realistically occur.

Free Riders

The impacts of free riders are further subtracted from program achievements. Accordingly, it is noted that 10.7% of the participants have been designated free riders. Therefore, 860 households (10.7% of 8,037) must be withdrawn from the program. This implies removing 4,455 lamps and decreasing energy savings by about 1,295,514 kWH.

Free Drivers

The effect of both participant and non-participant free drivers must be factored into the net energy savings estimate. For non-participant free drivers the estimate of households is upgraded by 5,500 and lamps purchased by 15,400. The kWh savings for the additional lamps is 4,478,320 kWh (15,400 lamps 290.8 kWh per lamp.)

For participant free drivers the number of households is not increased since these households have already been counted. Thus, the net energy savings is simply adjusted to account for the additional lamps purchased without a rebate. According to the participant survey, (6.8%) of the participants were also free drivers and purchased an average of 1.8 additional lamps. Given 8,037 program participants, 547 (6.8%) households can be expected to purchase 985 qualifying lamps without a rebate. The kWh savings for the additional lamps is 286,438 kWh (985 lamps * 290.8 kWh per lamp.)

Note that the original number of households (8,037) is used in the above calculation since free riders can also be free drivers. Although the lamps purchased by free riders using the program are eliminated from program achievements, lamps purchased without the program that resulted from participation in the program or knowledge gained from the program can be counted.

In total, the free driver effect can be estimated by increasing households by 5,500; lamp sales by 16,385; and energy savings by 4,764,758 kWh.

Snapback

Each purchased lamp is assumed to be in use for 3.59 hours per day of which 3.2 hours (89.1%) is base use and .39 hours (10.9%) is extra use. Based on the program database, the average lamp purchased in the program uses 31.2 watts and has an expected lifetime of 6,919 hours. Of the 6,919 hours in service, 6,165 hours (89.1%) will meet the original base use needs of the customer and 754 (10.9%) hours will be dedicated to extra usage. The adjustment for snapback must include two factors. First, only 89.1% of the gross savings is actually valid since the other 10.9% of usage is actually an additional source of energy consumption. Reducing the current estimated

Table 12. Adjustments for Free Riders

	Gross Effect	Adjustments	Net Effect
Households	8,037	-860	7,177
Bulbs in Use	41,631	-4,455	37,176
kWh Savings	12,105,512	-1,295,514	10,809,998

Table 13. Adjustments for Free Drivers

	Gross Effect	Adjustments	Net Effect
Households	7,177	5,500	12,677
Bulbs in Use	37,176	16,385	53,561
kWh Savings	10,809,998	4,764,758	15,574,756

energy savings (15,574,756 kWh) by 10.9% requires dropping 1,697,648 kWh. Then, the cost of the additional use must be calculated and also removed from the savings estimate. The energy used to light 53,561 lamps for 754 hours at 31.2 watts per lamp is 1,260,012 kWh. In total, 2,957,660 kWh savings must be eliminated to account for snapback. Since snapback affects only the energy savings, the number of households and lamps in use are not adjusted.

Summary

To experiment with methods for incorporating the impacts of customer behavior into program-related energy savings, self-reported behavior was analyzed. Taking into account lamps that were withdrawn from service for reasons other than burnout, free riders, free drivers, and additional hours of use, total estimated net lifetime energy savings for the program is 12,617 MWh, or 87 percent of expected gross savings. These analyses and adjustments are sensitive to a number of assumptions that can change as more data regarding customer behavior patterns become available. In the meantime, Boston Edison has used these results in various cost-effectiveness tests, adjusting program savings for lamps no longer installed and free riders. As more research is done on the effects of snapback and free drivers, Boston Edison will consider ways of incorporating these adjustments into future savings and cost-effectiveness calculations.

Table 14. Adjustments for Snapback

	Gross Effect	Adjustments	Net Effect
Households	12,677	0	12,677
Bulbs in Use	53,561	0	53,561
kWh Savings	15,574,756	-2,957,660	12,617,096