Integrated Data Analysis Approach to Understanding Behavior Change in TOU Programs: An Application of Quartile Analysis

Marc Pedersen, BC Hydro and Power Authority, Vancouver, B.C.

ABSTRACT

Statistical analysis of consumption data collected from time-of-use (TOU) pricing programs reveals: (1) the extent of total demand response achieved, (2) change in load shapes, and (3) depending on the program design and information captured in the billing system, insights by customer sub-groups such as rate plan, region and dwelling type. While this tried and true approach to evaluating TOU programs would satisfy most regulators, it falls short of fully leveraging the value of the load data and uncovering insights that would be found useful to program designers and implementers.

BC Hydro recently completed a two-year winter pilot among its residential customers to explore the extent to which they would respond to TOU pricing signals. By integrating consumption data with detailed information collected from baseline and post-pilot surveys, a more insightful view of the TOU program was achieved. Specifically, the construction of quartile partitions among treatment group participants based on their ability to shift electricity use off-peak uncovered the key demand response enablers and behavioral drivers that characterized the most successful households.

Looking forward, it is expected that this diagnostic information will be leveraged to better inform program design, positioning and supporting communications when TOU pricing is eventually rolled-out across the utility's full service territory.

Background

As a part of BC Hydro's Smart Metering Initiative (SMI), the Conservation Research Initiative (CRI) time-of-use rate pilot involving over 2000 residential customers was first launched in the winter of 2006-2007 (November 1, 2006 – February 28, 2007) and followed up in the winter of 2007-2008 (November 1, 2007 – February 29, 2008).

The goal of the pilot was to determine whether customers respond to pricing signals and information on energy use and to determine the magnitude of the responses. More specifically, the time-of-use rate pilot provides BC Hydro with opportunities to: (1) learn about customers' pricing preferences and their responses to pricing signals, (2) assess whether pricing can be used as a tool to delay future supply needs and infrastructure investments, and (3) gain operational experience with advanced metering infrastructure. For residential customers, the residential time-of-use pilot offers: (1) more rate options, (2) more control over electricity costs, and (3) potential savings on electricity bills.

The overall approach for this TOU pilot program was a randomized experimental design with control group households and treatment group households in each of three inter-jurisdictional regions. Treatment cells were comprised of five different rate groups with a common evening[1] peak time of 4:00 pm to 9:00 pm[2] – Monday to Friday – and three levels of communications.

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[1] Treatment households in Campbell River also had a weekday morning peak period.

[2] In year 2 of the pilot, the evening peak period for all Campbell River households was shortened: from 4:00 to 8:00 pm.

Additional treatment groups were constructed in the second year of the pilot to gain insight on the effects of a peak period one hour shorter in duration, the impact of critical peak pricing and the effect of automated load control. This paper focuses on the evening peak period common to all three regions in year 2 of the pilot.

Interval consumption data from the advanced meters was leveraged to create quartile performance groups according to the extent treatment households were able to shift their electricity use from the peak to off-peak periods in year 2 of the pilot. Direct matching of household survey data to their respective quartile partitions allowed for subsequent deconstruction and profiling of successful and unsuccessful shifters. Although this paper does provide an overview of the construction of the quartile groups, its primary focus is on how the groups were leveraged to uncover deeper insights into the enablers and behaviors associated with time-of-use pricing programs.

There is a sizeable amount of material on time-of-use rate pilots and programs, with most emphasising rate design and performance. However, with the exception of qualitative research specifically in regards to BC Hydro's CRI pilot, a literature review failed to turn up any published work germane to the objectives herein. It is hoped that this paper will help fill this gap.

Methodology

Survey Overview and Data Collection

Population and Survey Samples. A comprehensive baseline survey was conducted among all treatment group and control group participants just prior to the inaugural winter's launch, capturing house characteristics, household demographics and compositions, as well as baseline attitudes and peak behaviors regarding in-home electricity use. At the completion of each of the year 1 and year 2 winter pilots, a similar survey was re-administered with the primary objectives of capturing current attitudes and typical appliance use during the peak periods.

A self-administered mixed-mode methodology was utilized such that participants received and completed surveys – as per their preference – either electronically via e-mail or through printed copies via Canada Post. Table 1 and Table 2 detail the populations of interest and related survey sample sizes.

Among the 2,070 baseline surveys sent to all registered pilot participants, a total of 1,720 surveys were tabulated for inclusion in the baseline sample – 585 from control group participants and 1,135 from treatment group participants. Accordingly, the baseline survey yielded a response rate of 83 percent, and with the finite population correction factor, a maximum margin of error of ± 1.0% at the 95 percent level of confidence.

Table 1. Baseline Population and Survey Samples

	Total	Metro Vancouver	Campbell River	Fort St. John
Control Households	n=585	n=440	n=88	n=57
	N=699	N=530	N=97	N=72
Treatment Households	n=1,135	n=830	n=175	n=130
	N=1,371	N=1011	N=194	N=166
Total Households	n=1,720	n=1,270	n=263	n=187
	N=2,070	N=1,541	N=291	N=238
Overall response rate	83.1%	82.4%	90.4%	78.6%
Maximum margin of error	± 1.0%	± 1.2%	± 1.9%	± 3.3%

The population of year 2 participants – on which this paper is focused – fell to 1,717 due to attrition in the way of metering problems and voluntary opt-out. A total of 1,167 surveys were tabulated for inclusion in the post-pilot sample – 265 from control group participants and 902 from treatment group participants. The completions yielded a response rate of 68 percent, and with the finite population correction factor, a maximum margin of error of ± 1.6% at the 95 percent level of confidence.

Table 2. Year 2 Population and Post-Pilot Survey Samples

	Total	Metro Vancouver	Campbell River	Fort St. John
Control Households	n=265	n=175	n=57	n=33
	N=411	N=284	N=79	N=48
Treatment Households	n=902	n=603	n=227	n=72
	N=1,306	N=898	N=297	N=111
Total Households	n=1,167	n=778	n=284	n=105
	N=1,717	N=1,182	N=376	N=159
Overall response rate	68.0%	65.8%	75.5%	66.0%
Maximum margin of error	± 1.6%	± 2.1%	± 2.9%	± 5.6%

Due in part to the high response rates, the two samples of interest proved to be representative of their pilot populations by region, rate group and communications type. As such, it was not necessary to mathematically weight the data at the sample processing stage.

Behavioral Metrics. Behavioral metrics in the surveys were based on participants' self-reported peak use of electricity for various end-uses related to space heating, water heating, lighting, kitchen appliances, laundry appliances, televisions, computers and other home entertainment and office systems. Four-point labeled scales were utilized as they provided the best balance of factors related to respondent-friendliness, reliability, representativeness, low ambiguity and data analysis requirements[3].

Quartile Construction

The consumption data recorded by the advanced meters allowed the creation of quartile performance groups according to the degree treatment group participants were likely able to shift consumption from the evening peak to off-peak periods in year 2 of the pilot. It is important to note that the statistical approach as outlined below is constrained by the fact that the advanced meters were not in place prior to launch of the pilot to capture baseline hourly data and to discriminate households' natural peak load from their daily load.

Analysis was based on daily consumption records from all rate groups and adjustments were made to standardize the performance of households on the shortened evening peak with households on the regular evening peak. For participants on the Peak Power Saver Automatic program[4], records from critical peak price days were excluded so as to discount any peak reduction due to the automated load control.

[3] Scale: Always, Usually, Occasionally, Never.

[4] In year 2 of the winter pilot, BC Hydro recruited 44 new participants in Campbell River to test automated load control devices on home heating equipment. These devices utilized paging technology to remotely cycle heating systems and/or to shut-off hot water tanks during critical peak price days.

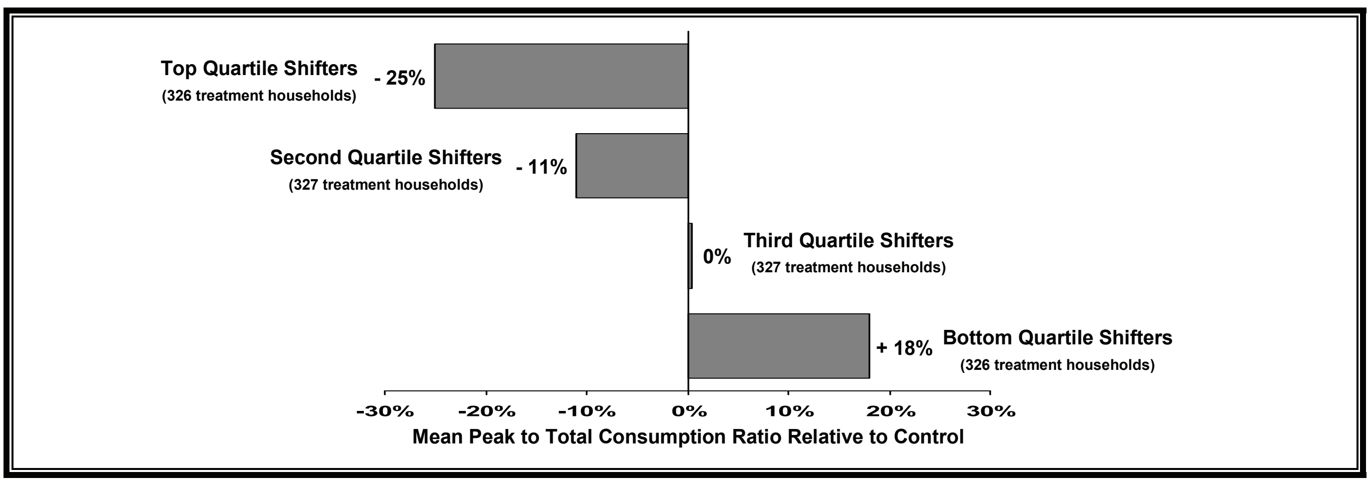
A ratio statistic [$R_{i\ (T)}$] was first constructed for each treatment household based on its average daily proportion of evening peak to total consumption. This ratio statistic was then compared to the mean ratio for its regional control group [$R_{region\ (C)}$] by subtracting the control mean from all treatment proportions and deriving a probability distribution for the differences. This distribution formed the basis for demarcating each performance group. All values were based on daily customer usage recorded during year 2 of the pilot and consisted of both regional and pooled results.

A treatment household's final test statistic (Π_i) was defined as: $\Pi_i = (R_{i\ (T)} - R_{region\ (C)})/R_{region\ (C)}$

The test statistic (Π) classified treatment households according to the degree they were able to shift consumption from evening peak to off-peak periods. As the test statistic decreased, the proportion of peak usage was assumed to diminish, indicating that a customer had shifted electricity use from peak to off-peak. Performance groups were established by dividing the distribution of the test statistic (Π) into quartiles (4 equal sets) for all 1,306 active treatment households in year 2 of the pilot[5].

Because this statistic only considered the percentage of peak to total consumption and the fact that each of the three regions were comprised of a treatment and control group, differences in total consumption among households due to economic, cultural or weather effects were controlled for in the analysis. Figure 1 details the average test statistic (Π) for treatment households in each of the four quartiles. The top quartile shifter group had a mean evening peak period consumption to total consumption ratio that was 25 percent less than that for the control group.

Figure 1. Treatment Households Peak to Total Consumption Relative to Control Households



The methodology undertaken had to serve as a proxy for classifying treatment households into quartiles due to the absence of baseline peak consumption readings. It is therefore possible, though not likely with any confounding frequency, that a household was inadvertently categorized as, for example, a top quartile shifter because it always had a relatively shallow load shape for the evening peak period. The profiling of the quartile groups on a pooled basis further mitigated the implications of individual misclassification.

The last step to facilitate profiling of the performance groups was to insert the new derived variable back into the survey dataset so as to indicate each household's quartile membership.

[5] Performance groups were based on the billing data of all 1,306 treatment group participants in year 2 of the pilot. Post-pilot surveys, not needed for quartile construction, were collected among 902 of them.

Findings

Demand Response Enablers

Space Heating Profile of Quartile Shifter Groups. The profile of the four groups, especially the top quartile shifters and the bottom quartile shifters, differed on an array of parameters. Due to the experimental design of the pilot, however, many of these parameters were interwoven such that careful analysis and interpretation was needed to isolate causal effects. With this in mind, space heating fuel was found to be a key discriminator and set the top quartile group apart from the others. In turn, this causal effect also explained many of the other differences among the groups.

On the space heating front, use of electricity as the space heating fuel was a key catalyst for shifting. As detailed in Table 3, electrically heated homes comprised 16 percent of all treatment group households, but their share measured 36 percent among the top quartile performance group and just 7 percent among the bottom quartile group. In the top quartile group, electrically heated homes were also more likely to have a secondary heating fuel which would have accommodated fuel and system switching during peak periods. Other electrically heated homes utilised electric baseboards exclusively which would have accommodated targeted room heating. Such peak use of electric baseboards is corroborated later in this paper.

Table 3. Heating Profile of Quartile Shifter Groups

	Top Quartile Shifters	Second Quartile Shifters	Third Quartile Shifters	Bottom Quartile Shifters	Total Treatment Households
Main Space Heating Fuel	%	%	%	%	%
Electricity (including for portable heaters)	36	13	6	7	16
Natural gas	55	79	89	88	78
Wood	6	2	3	2	3
Oil	3	3	2	2	3
Main and Secondary Space Heating Fuels	%	%	%	%	%
Electricity (main) with no secondary	15	7	2	2	6
Electricity (main) with any other fuel	22	7	5	5	10
Natural gas (main) with no secondary	24	34	48	52	40
Natural gas (main) with any other fuel	33	48	42	38	40
All other (main) with no secondary	2	2	3	2	2
All other (main) with any other fuel	4	2	1	2	2

Water Heating Profile of Quartile Shifter Groups. The top quartile shifters were also over-represented by households with electric hot water heating, but this variable was intertwined with space heating and region. Among all treatment households with electric space heating, two-thirds were in Campbell River, which had a 60 percent share of the electric water heating. Furthermore, 78 percent of treatment households which had both electric space heating and electric water heating were in Campbell River. As such, Campbell River comprised only 23 percent of treatment households but had a 41 percent share of the top quartile shifters.

After limiting the analysis to non-electric space heated households – which helped control for the influence of electric space heating fuel – electric water heating continued to be significantly over-represented in the top quartile group. This confirmed electric hot water tanks as a key enabler of peak shifting.

Table 4. Water Heating Profile of Quartile Shifter Groups

	Top Quartile Shifters	Second Quartile Shifters	Third Quartile Shifters	Bottom Quartile Shifters	Total Treatment Households
Hot Water Fuel	**%**	**%**	**%**	**%**	**%**
Electricity	40	18	11	11	20
Natural gas	59	79	85	87	78
Oil	1	2	0	1	1
Other	0	0	1	0	0
⇒ electric water heating among non-electric heated homes	24	13	9	9	13

Region and Consumption Profile of Quartile Shifter Groups. With its many electrically space and water heated homes, Campbell River had the largest share of high consumption households, and as such, those homes were more likely than others to be top quartile shifters.

Table 5. Region and Consumption Profile of Quartile Shifter Groups

	Top Quartile Shifters	Second Quartile Shifters	Third Quartile Shifters	Bottom Quartile Shifters	Total Treatment Households
Region	**%**	**%**	**%**	**%**	**%**
Campbell River	41	21	13	17	23
Fort St. John	8	13	9	5	9
Metro Vancouver	51	67	78	79	69
Consumption in 2005/2006 base year	**%**	**%**	**%**	**%**	**%**
Annual consumption: less than 7,200 kWh	23	24	35	45	32
Annual consumption: 7,200 - 11,399 kWh	24	34	36	33	32
Annual consumption: 11,400 kWh +	53	42	29	22	37

Demographic Profile of Quartile Shifter Groups. Table 6 details the demographic profile of the quartile shifter groups. Like the overall group of participants, the majority of household contacts in the top quartile group were at least 55 years old. However, while this age group comprised 48 percent of all treatment contacts, it climbed to 60 percent among the top quartile performance group. Because many of these older participants would have been empty-nesters, they were generally more likely than others to be in smaller occupancy houses and without children – all of which was explicitly reflected in the quartile profiles. These findings might have suggested that these particular demographics more easily facilitated shifting electricity use to the off-peak periods, which may indeed have been the case. However, careful interpretation was needed to delineate the strongest of causal effects underlying these performance levels.

If older participants, those without children, and those in smaller sized households were equally dispersed by region and thus independent of region, then the differences in their shifting performance could be certified as real rather than an artifact of other effects. However, these particular demographics were much more frequently found in Campbell River households than in the Fort St. John and Metro Vancouver households, and in turn, were getting some lift from electric space and water heating's impact and prevalence in Campbell River.

Table 6. Demographic Profile of Quartile Shifter Groups

	Top Quartile Shifters	Second Quartile Shifters	Third Quartile Shifters	Bottom Quartile Shifters	Total Treatment Households
Age	%	%	%	%	%
18 to 24	1	<1	<1	0	1
25 to 34	4	4	6	4	5
35 to 44	14	21	19	27	20
45 to 54	20	26	26	35	27
55 to 64	29	21	23	17	23
65 or older	31	27	26	17	25
⇒ 55 + among non-electric space heated homes	55	49	50	32	46
Household Size	%	%	%	%	%
1 person	18	6	6	7	9
2 people	43	41	39	26	37
3 people +	17	17	16	21	18
4 + people	23	36	39	47	36
⇒ =< 2 people among non-electric heated homes	58	48	45	31	44
Household Make-Up	%	%	%	%	%
Children less than 12 in household: Yes	16	23	24	33	24
Children less than 12 in household: No	84	77	76	68	76
⇒ No, among non-electric heated homes	83	76	74	62	73
Young adults 13 - 24 in household: Yes	23	31	26	38	30
Young adults 13 - 24 in household: No	77	69	74	62	70
⇒ No, among non-electric heated homes	76	70	74	63	70

Looking at the findings through a lens strictly focused on non-electric space heated households sharpened the picture and understanding the role demographics play in shifting electricity usage. Among these homes, the prevalence of main program contacts at least 55 years old was highest at 55 percent in the top quartile group and stepped down evenly to a low of just 32 percent among the bottom quartile group. Furthermore, 58 percent of households in this non-electric top quartile group had no more than two occupants whereas this proportion stepped down evenly to just 31 percent among households in the bottom quartile group. Top quartile shifters were less likely than others to have children in the home. This isolated view of the quartile groups – without space heating interaction – confirmed that age, family size and life stage affected load shifting behaviors.

Experimental Design Characteristics of Quartile Shifter Groups. Many of the newly added participants in year 2 were in Campbell River – recruited to fill added treatment cells in the region. Further, virtually all year 2 households on the shortened evening peak were in Campbell River. These ties to Campbell River explained a large portion of the variance among these design parameters.

Specifically, the top quartile group was over-represented by first year participants – not because they brought a fresh and eager perspective to the task of shifting their peak use of electricity, but because most of them were added in Campbell River where the prevalence of electric fuel was highest and where the enabling demographics were most robust.

Similarly, the top quartile group was over-represented by households on the shortened evening peak because all treatment households in Campbell River were on this tariff in year 2. However, adjustments were made to standardize the performance of households on the shortened peak with households on the regular peak during quartile construction to address the differences in peak duration. This adjustment was to reflect change in peak behavior rather than the experimental design.

Table 7. Experimental Design Characteristics of Quartile Shifter Groups

	Top Quartile Shifters	Second Quartile Shifters	Third Quartile Shifters	Bottom Quartile Shifters	Total Treatment Households
Experience	%	%	%	%	%
Second Year Treatment	76	89	94	90	88
First Year Treatment	24	11	6	10	12
Peak	%	%	%	%	%
Regular Peak	55	73	80	75	71
Shortened Peak	45	27	20	25	30
Communications	%	%	%	%	%
Enhanced Communications	78	71	69	70	72
Standard Communications	22	29	31	30	28
In-home display monitor	%	%	%	%	%
Yes	13	16	18	22	18
No	87	84	82	78	82

Treatment households which received enhanced communications[6] through the pilot were over-represented in the top quartile group – again, mainly because all Campbell River households received this level of communications throughout the pilot[7]. On the other hand, the in-home display monitors were under-represented in the top quartile group mainly because no Campbell River households received them[8].

[6] Communications levels were: i) standard communications, consisting of welcome and launch materials, and access to on-line consumption graphs through the pilot; ii) enhanced communications, consisting of standard communications materials, as well as on-going communications during the pilot; and iii) enhanced communications + in-home display monitors.

[7] A separate analysis, however, showed that households which received enhanced communications had statistically significant lower peak to total consumption ratios than households which received only standard communications.

[8] Further analysis showed that only one of three treatment groups in the Lower Mainland with in-home display monitors had statistically significant lower peak to total consumption ratios than their related control groups.

Evening Peak Behavioral Drivers

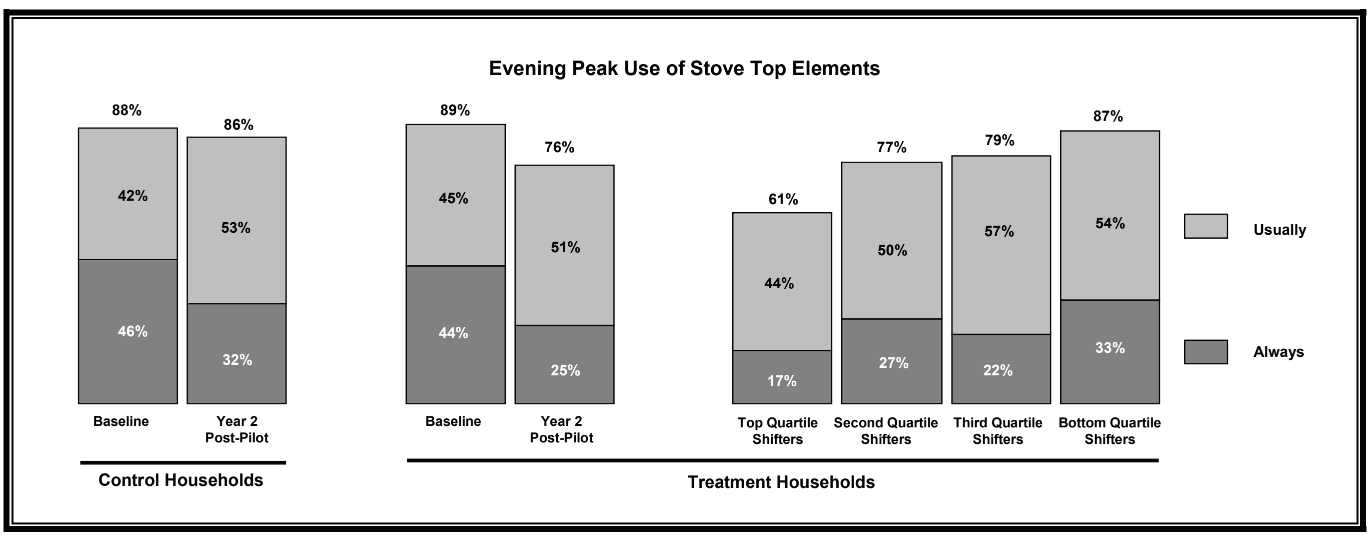
The figures in this section document some of the self-reported peak behaviors during the baseline winter period – essentially, what household behaviors were at the time of the first pre-pilot survey – and behaviors at completion of the year 2 winter pilot. Frequency scores were based on 4-point labelled scales and focused on the change in the top-two box scores (always + usually) as it was a reported decrease in this paired response category during peak hours that could impact peak energy shedding. Analysis of survey data was based on pooled responses rather than matched-record or paired responses[9].

It follows that statistical testing for a desired demand response effect for the evening peak was conducted by examining the difference between the desired decrease – from pre-pilot to post-pilot – in the treatment group's top-two box behavior score and any change in the control group's top-two box behavior score[10]. Deeper insights were then gleaned by examining peak behaviors by the quartile partitions.

Cooking Behaviors. For treatment group participants, the evening peak usage score for stove top elements stepped down from 89 percent in the baseline to 76 percent in the 2008 post-pilot study – a total of 13 points. As this score decreased only 2 points among the control group, the difference in the groups' change in evening peak behavior was statistically significant at the 95 percent level of confidence and indicative of a demand response effect.

The use of stove top elements was a good discriminator of how well treatment participants were able to shift their use of electricity off of the evening peak period. In other words, this behavior emerged as being one of several likely ways the most successful households were able to shift their usage. The evidence was in the inclining top-two box behavior score, having measured 61 percent among the top quartile shifters and stepping up to 87 percent among the bottom quartile shifters.

Figure 2. Evening Peak Cooking Behaviors



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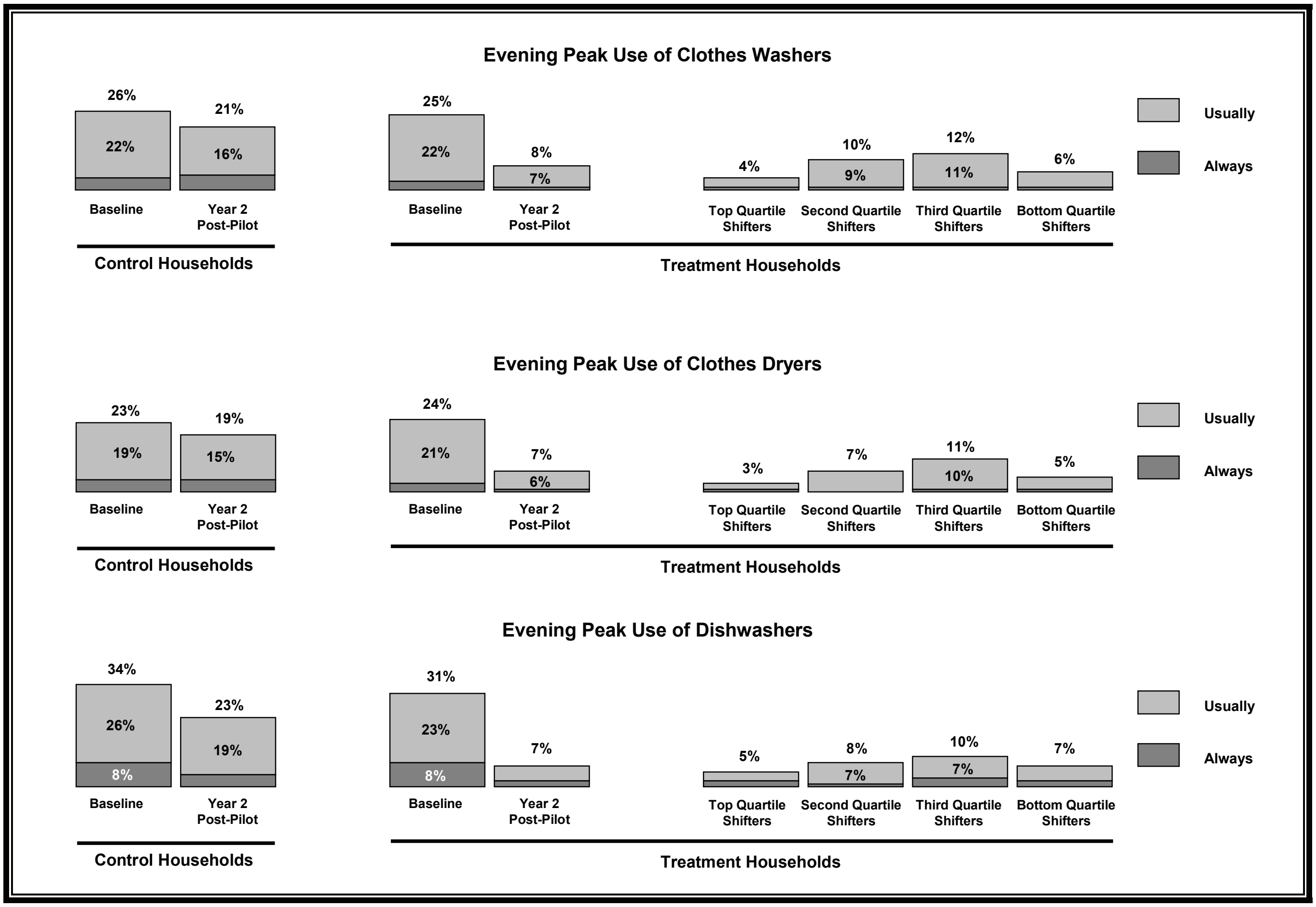
9 Not applicable and don't know responses were been excluded from the calculation of scores.

10 Statistical testing for a demand response effect considered the pre-pilot to post-pilot change in the top-two box behaviour score for the treatment group [B $_{(T)}$] as compared to the pre-pilot to post-pilot change in the top-two box behaviour score for the control group [B $_{(C)}$]. The null hypothesis was: H_o: $B_{post\ (T)} - B_{pre\ (T)} = B_{post\ (C)} - B_{pre\ (C)}$

Laundry and Dishwashing Behaviors. Treatment group participants appeared to have made significant inroads in shifting their peak use of clothes washers, clothes dryers and dishwashers. As detailed in Figure 3, each of their top-two box behavior scores fell 17 to 24 points through the course of the pilot. For unknown reasons, the scores also fell by 4 to 11 points among the control group, but the difference in the paired sets of scores – the difference of the differences – was statistically significant and indicative of strong demand response effects.

Figure 3. Evening Peak Laundry and Dishwashing Behaviors

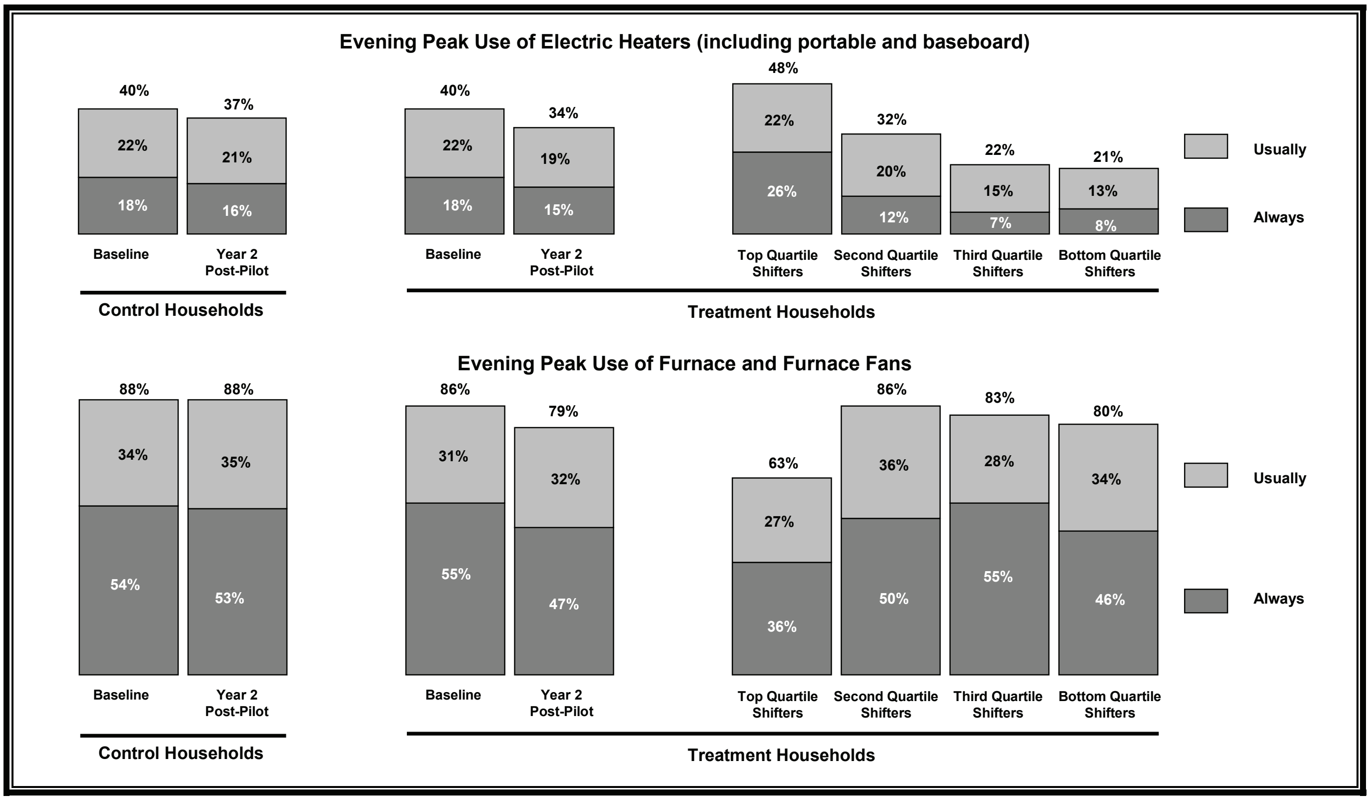


The finding that only 7 to 8 percent of treatment households typically used their clothes washers, clothes dryers and dishwashers during the peak period highlighted the fact that it was fairly easy for many household to displace the use of these appliances to the off-peak hours. The fact that the top-two box usage scores were low and fairly even among all quartile groups further underscored this observation.

Space Heating Behaviors. Of all peak behaviors investigated, those that related to home heating – including electric heaters and furnaces – proved most interesting when looked at in the context of the quartile performance groups. With a top-two box usage score of 48 percent, the top quartile shifters were the heaviest users of electric heaters during the evening peak periods. To compare, this score plummeted to just 32 percent among the second quartile shifters, 22 percent among the third quartile shifters and further to just 21 percent among the fourth quartile shifters. With these significant differences, the use of electric heaters – presumably, in a limited number of select rooms – was clearly instrumental in many participants' shifting success.

It is important to note that all of this analysis and interpretation was among households reporting to have the related appliances/systems in the home. In this case, the space heating pattern that emerged was truly behavioral in nature as the percentages already discounted those without baseboard or portable electric heaters.

Figure 4. Evening Peak Space Heating Behaviors

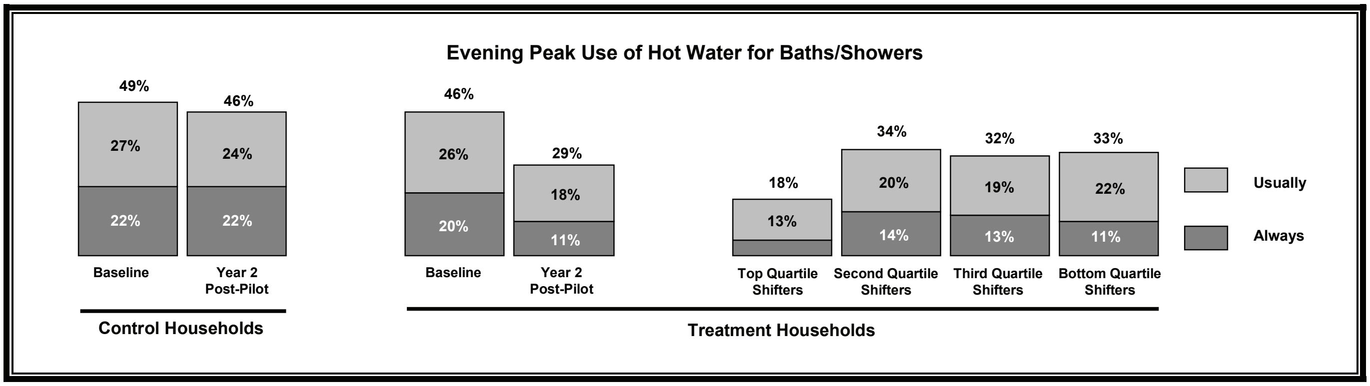


Treatment group households outperformed control group households in terms of shifting their peak use of furnace and furnace fans. Analysis of the quartile performance groups further illuminated what drove successful shifting of electricity use to the off-peak period. For this end-use, top quartile shifters were by far the lightest users of furnace and furnace fans during the peak hours.

All of this suggested that many households in the top quartile group appeared to have used baseboard and portable electric heaters exclusively through their homes in highly selective ways so as to minimize unnecessary heating. In the same way, other households in this best performing group likely dialled-back their main furnaces during the evening peak in favour of secondary fuels such as wood, oil or propane, or secondary systems such as electric baseboards and portable heaters. These scenarios were especially prevalent in Campbell River where the penetration of such electric fuels and systems was the highest.

Hot Water Behaviors. Figure 5 details the very favourable demand response effect in regards to hot water use for baths/showers. By virtue of their lower top-box and top-two box usage scores, households in the top quartile group reported much lighter use of hot water for baths/showers during the evening peak than households in the other three quartiles. This suggested that efforts to shift this hot water use had a strong impact on overall success.

Figure 5. Evening Peak Hot Water Behaviors



Conclusion

Analysis of treatment group households disaggregated by their actual performance revealed the most potent enablers of peak shifting. After partitioning the households into quartile performance groups and exploring their profiles, two main groups of enablers which emerged were space and water heating fuels/systems and demographics relating to age and household composition. This information would be valuable to BC Hydro should it roll-out out TOU rates to residential customers on either a voluntary or mandatory basis and would help inform which areas of its service territory might be best positioned to reduce peak demand. The information would also assist in estimating the expected savings.

This fully integrated approach to data analysis also revealed which change in peak behaviors likely contributed most to actual peak reduction and which behaviors differentiated the best performing households from the poorest. The most substantial peak shedding behaviors related to the displacement of washing machine, dryer and dishwasher use. However, as these behaviors were widely reported by most households, they did not adequately explain the differences between good performers and poor performers. Quartile analysis revealed that the most successful shifters also displaced their peak use of ovens, stove tops, hot water for baths and showers, and lighting. On the space heating front, what appeared to have happened is that many in the top quartile group used baseboard and portable electric heaters exclusively through their homes in highly selective ways so as to minimize unnecessary heating. With this information, programs and communications could be focused on a core set of behaviors and end-uses, and/or those that require the most reinforcement. All of this information would assist the estimation of expected savings.

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