Residential Electricity Conservation Through Smart Home Energy Management Technology: A Case-study in Milton, ON

Final Report

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Context

The purpose of this report is to present the findings from the investigation into the impact of the Smart Home Energy Management Technology in Milton, ON. This investigation builds upon recent work that the University of Waterloo completed (see thesis by Jeremy Schembri, September 2008). Additionally, an interim report on this project was completed and delivered on 22 December 2008. That latter report, for the sake of completeness of this project, is attached, as Appendix A, at the end of this report.

Purpose

The purpose of this report is two-fold:

1) To explore the 'best' (top) and 'worst' (bottom) performers of those who are using the Home Energy Management Technology, to try to determine whether any characteristics distinguish these groups.
2) To examine the impact of the Home Energy Management Technology upon electricity consumption during particular 'demand response' events among an isolated set of participants.

These two areas are investigated in the subsequent two sections of this report.

'Best' and 'Worst' Performers

As described in our interim report (Appendix A), we examined 123 households that had had the Home Energy Management Technology installed. In this section, we seek to determine whether there were any particular characteristics that distinguished those who were 'good performers' (were 'conservers' – that is, consumed relatively less electricity, year-on-year) and those who were 'bad performers' (were 'consumers' – that is, consumed relatively more electricity year-on-year).

Seven different characteristics were explored: time-of-use start, BCE selected accounts, system installation date, baseline total consumption, baseline peak consumption, winter peak ratio and summer peak ratio. Full details for these groups are provided in Table 1.

To determine if significant relationships existed among conservers (or, alternatively, among consumers) with particular known characteristics, a series of chi-square tests were run, with the Pearson R-value being used to measure the level of significance within the relationship. To complete this, the 123 households had to be divided into conservers and consumers. The next sections describe how this was done.

Table 1 - Descriptions of groups and sub-groups

Group	Definition	Sub-groups
Time-of-use start	Year that participants went on time-of-use pricing.	• 2005 • 2007
BCE selected accounts	BCE provided 19 accounts that they believed were working during the 2008 summer's DR events.	• Group of 19- those accounts selected by BCE. • Remaining accounts- those accounts that were not selected by BCE.
System installation	When the participant had the Home Energy Management Technology installed in their home.	• Innovators- system installed prior to September 2007. • Early Adopters- system installed after September 2007.*
Baseline total consumption	Mean of participant's total consumption for October 2006 to September 2007 (sub-groups were relatively evenly distributed, on 50kWh intervals).	• Low- 250-550 kWh • Mid-low- 551-700 kWh • Mid-high- 701-900 kWh • High- >901 kWh
Baseline peak consumption	Mean of participant's peak consumption for October 2006 to September 2007 (sub-groups were evenly distributed, on 50kWh intervals).	• Low- 75- 150 kWh • Mid-low- 151-200 kWh • Mid-high- 201-250 kWh • High- >251 kWh
Ontario Energy Board (OEB) winter peak ratio	Mean percentage of total consumption occurring during peak hours in OEB winter months. (sub-groups were evenly distributed)	• Low- 9.19%-18.90% • Mid- 18.95%-21.54% • High- 21.55%-30.92%
Ontario Energy Board (OEB) summer peak ratio	Mean percentage of total consumption occurring during peak hours in OEB summer months. (sub-groups were evenly distributed)	• Low- 7.38%-20.62% • Mid- 20.66%-22.60% • High- 22.64%-45.33%

* The terms, 'Innovators' and 'Early Adopters', are taken from Rogers, Everett M. (1962). *Diffusion of Innovations*. Free Press of Glencoe, Macmillan Company.

The participants' year-on-year percentage changes in total electricity consumption were sorted from highest to lowest for up to 15 different time periods: for each month of the study (in which the particular household participated, which will be up to 12), the Ontario Energy Board-defined 'winter' (November to April, inclusive), the Ontario Energy Board-defined 'summer' (May to October, inclusive) and the entire time period (up to 12 months). The participants' year-on-year percentage changes in total peak electricity consumption were also calculated and sorted in the same manner.

With these results – namely, households sorted from 'most consuming' to 'most conserving' – the households were then divided in two different manners. First, the households were divided into thirds. The one-third with the largest percentage reduction was labelled conservers, the one-third with the largest percentage increase was labelled consumers, and the middle third was labelled neutral. (This is subsequently referred to, in this section, as 'method 1'.) And second, all accounts that achieved year-on-year reductions in electricity consumption were labelled conservers; all accounts that did not achieve such reductions were labelled consumers. (This is subsequently referred to as 'method 2'.)

Results from the subsequent chi-square investigations are presented in Tables 2 and 3. In Table 2, those relationships that are significant ($p<0.05$) are presented. Remember that multiple relationships for each of seven variables (Table 1) were investigated. Of the 364 investigations we conducted, the 25 for which there was strong significance are thus presented. In Table 3, we present an additional 11 relationships for which there was some significance ($0.085>p>0.05$).

To clarify the way in which we have presented these results, let us take a closer look at the first row of Table 2 – namely, the row with the data entries of 'Group of 19', 'Conservers', 'OEB total summer 2' and '0.048'. In this case, we are reporting that when we ranked all households on the basis of the change in their total electricity consumption between 'October 2006 plus May 2007 to September 2007' and 'October 2007 plus May 2008 to September 2008'; because there is a '2' at the end of the entry in the 'Period' column, we know that 'method 2', as defined above, was used in this instance. The chi-square test then allows us to query if knowing whether a particular household has been one of the 19 identified by BCE helps us to anticipate whether that household is one of the 'conservers' or 'consumers'. Because this test is reported in this table, the answer is 'yes'; so if a household was identified as one of the 19, then it is more likely to be a 'conserver' – that is, it is more likely to have experienced a year-on-year reduction in its total electricity use during this period.

Table 4 presents a summary of Tables 2 and 3. This is presented in order to quickly show the reader the extent to which relationships of at least some significance were found, across our various investigations. The finding that those in the BCE's 'Group of 19' came out as 'conservers' is not particularly surprising, given how this group may have been defined (see the discussion in the next section). But the finding that those larger consumers have seen a 'better' impact from the installation of the Home Energy Management Technology is one that is perhaps less predictable. Still other results are less than equivocal.

Table 2 - Relationships of (strong) significance

Group	Relationship	Period	Significance
BCE selected accounts			
Group of 19	Conservers	OEB total summer 2	0.048
Group of 19	Conservers	Annual peak 1	0.050
Group of 19	Conservers	May total 2	0.023
Baseline total consumption			
High baseline total	Conservers	March total 1	0.048
High baseline total	Conservers	September total 1	0.011
High baseline total	Conservers	September peak 1	0.021
Low baseline total	Consumers	October peak 2	0.036
Baseline peak consumption			
High baseline peak	Conservers	November total 1	0.020
High baseline peak	Conservers	September total 2	0.047
OEB winter peak ratio			
High winter peak ratio	Consumers	December total 2	0.050
High winter peak ratio	Consumers	February total 2	0.031
Low winter peak ratio	Consumers	February peak 2	0.006
Low winter peak ratio	Consumers	April peak 2	0.002
OEB summer peak ratio			
High summer peak ratio	Consumers	October total 2	0.008
Mid summer peak ratio	Conservers	OEB summer total 2	0.013
Mid summer peak ratio	Conservers	OEB summer peak 2	0.017
Low summer peak ratio	Consumers	May peak 1	0.002
Low summer peak ratio	Consumers	May peak 2	0.018
Low summer peak ratio	Consumers	June peak 1	0.029
Low summer peak ratio	Consumers	June peak 2	0.007
Low summer peak ratio	Consumers	July peak 1	0.000
Low summer peak ratio	Consumers	July peak 2	0.013
Low summer peak ratio	Consumers	August total 2	0.025
Low summer peak ratio	Consumers	August peak 2	0.015
Low summer peak ratio	Consumers	September peak 1	0.001

Table 3 - Relationships of (some) significance

Group	Relationship	Period	Significance
BCE selected accounts			
Group of 19	Conservers	November peak 1	0.073
Group of 19	Conservers	November peak 2	0.076
Group of 19	Conservers	January peak 2	0.059
Group of 19	Conservers	July peak 2	0.065
System installation			
Innovators	Consumers	May total 2	0.083
Innovators	Conservers	June total 2	0.073
Baseline total consumption			
Low baseline total	Consumers	Annual summer peak 2	0.069
Low baseline total	Consumers	July peak 1	0.065
Low baseline total	Consumers	July peak 2	0.073
Baseline peak consumption			
High baseline peak	Conservers	November total 2	0.065
High baseline peak	Conservers	March total 2	0.056

Table 4 - Summary table of significance

Group	Characteristic	Relationship	Number of incidents of some level of significance
BCE selected accounts	Group of 19	Conservers	7
System installation	Innovators	Conservers / Consumers	1 / 1
Baseline total consumption	High baseline total	Conservers	3
Baseline total consumption	Low baseline total	Consumers	4
Baseline peak consumption	High baseline peak	Conservers	4
OEB winter peak ratio	High winter peak ratio	Consumer	2
OEB winter peak ratio	Low winter peak ratio	Consumer	2
OEB summer peak ratio	High summer peak ratio	Consumer	1
OEB summer peak ratio	Mid summer peak ratio	Conserver	2
OEB summer peak ratio	Low summer peak ratio	Consumer	9

Impact of the Home Energy Management Technology During 'Demand Response' Events

BCE identified 19 households that it believed had functioning Home Energy Management Technologies during a series of 'demand response' (DR) events that took place during the summer of 2008. In this section, we seek to determine the electricity consumption reductions achieved by these households during these events. (The dates and times of these DR events are listed in Table 5. It should be noted that the time of the DR event of 18 August 2008 was not known by BCE. Instead, we used the data from these 19 households to estimate the time. It is this time that is reported in Table 5.)

Table 5 - Study's demand response dates and times

Dates	Times (EDT)
Tuesday, 8 July 2008	14:00-18:00
Friday, 18 July 2008	13:00-17:00
Monday, 18 August 2008	15:00-19:00
Tuesday, 2 September 2008	14:00-18:00
Wednesday, 3 September 2008	14:00-18:00

The basic goal of this investigation was to determine the reduction in electricity consumption during the DR event from what it would otherwise have been (in the absence of the DR event). Without knowing what the consumption would 'otherwise have been', we needed to generate an estimate of the same. The two key determinants of household consumption about which we knew something were the 'day of the week' (with consumption patterns on 'weekdays' hypothesized to be different than those on 'weekends and holidays') and the 'weather' (with consumption driven by air conditioning demand on hotter summer days hypothesized to be higher than that on cooler summer days). Hence, we 'controlled' each of the DR events with another weekday (all of the five DR event days were weekdays) of a similar temperature. Additionally, we included only those dates that occurred on the same week as any of the five DR events. Our reasoning for this was that we did not want to choose a different week, for concern that householders may have, for instance, had different 'holiday patterns' on these different weeks. Table 6 presents temperature data for the five DR event days, as well as the three days that we selected as the 'control days'. Together, these were some of the hottest days during the July-September 2008 period (following data taken from the weather station at the University of Toronto at Mississauga[1]); we further elaborate how we selected the control dates below.

[1] http://www.utm.utoronto.ca/8701.0.html.

Table 6 - Temperature (°C) for the hours (EDT) of the demand response events and control dates

Date	Kind of date	13:00	14:00	15:00	16:00	17:00	18:00	19.00
Tuesday, 8 July	DR event		30.89	29.41	28.45	27.95	27.74	
Wednesday, 9 July	DR control	28.53	28.99	28.28	27.89	26.87	26.21	24.74
Thursday, 17 July	DR control	27.40	28.62	28.77	30.37	30.01	29.75	28.66
Friday, 18 July	DR event	26.63	26.88	27.83	27.98	28.25		
Monday, 18 August	DR event			28.27	23.94	22.46	24.22	24.11
Friday, 22 August	DR control	25.45	26.28	25.50	26.19	25.30	24.56	24.03
Tuesday, 2 September	DR event		26.62	27.04	27.00	23.15	21.23	
Wednesday, 3 September	DR event		29.47	30.12	29.48	29.01	26.49	

Two comparisons were thus able to be conducted. For each of the five DR event days, comparison was made with an average of the three control days (the same time of the day). This we will call the 'average method'. Additionally, for two of the DR event days, we were able to compare to a contiguous date, which was, notably, also part of the 'control days' identified above. More specifically, Tuesday, 8 July 2008 was also compared with Wednesday, 9 July 2008, and Friday, 18 July 2008 was compared with Thursday, 17 July 2008. The day following Monday, 18 August 2008 was a cold day, with a maximum temperature of 20.57°C at 3pm (EDT). By that Friday, however, hot weather had returned (see Table 7), so that is the contiguous date we chose in this instance. Meanwhile, for the two September dates, a control date on the same week was not able to be used, for the Monday was a public holiday (Labour Day), and Thursday and Friday were relatively cooler days (temperatures did not surpass 25°C during the DR event times on either day). So we were not able to pursue this second method – which we will call the 'day method' – for these last two DR event days.

The impact of the Home Energy Management Technology during the DR event days was calculated by two methods. First, the reduction in total electricity consumption – across the four hours of the DR event – was calculated. And second, the reduction in peak electricity consumption was also calculated. This was done by taking the peak hourly consumption figure during the DR event for the comparison day (either, as appropriate, the average day or the contiguous day) and then subtracting the peak hourly consumption figure during the DR event. It is important to recognise that while both values occurred during the hours of the DR event, they did not necessarily occur at exactly the same time (though they were both 'peak values' within their respective DR periods).

To give further substance to this, we pull out the results from one of the 19 households investigated. In Figure 1, we have plotted consumption values for Tuesday, 8 July (the blue line). We have also plotted the two sets of values against which we are comparing these DR event day values. First, the green line represents the average hourly consumption across the three control days identified above. And second, the red line represents the average hourly consumption from the contiguous day – namely, the following day, Wednesday, 9 July. Changes in total electricity consumption are represented by the sum of the differences at 3pm, 4pm, 5pm and 6pm. This is represented, in Figure

1, by A1 (for the change with the contiguous day) and by A1 plus A2 (for the change with the average day). Changes in peak electricity consumption are represented by the arrows labelled 'B1' and 'B2'. Table 7 presents the numerical data associated with this one comparison.

Figure 1 - Investigating the impact of the Home Energy Management Technology on one home on 8 July 2008 (kW consumption)

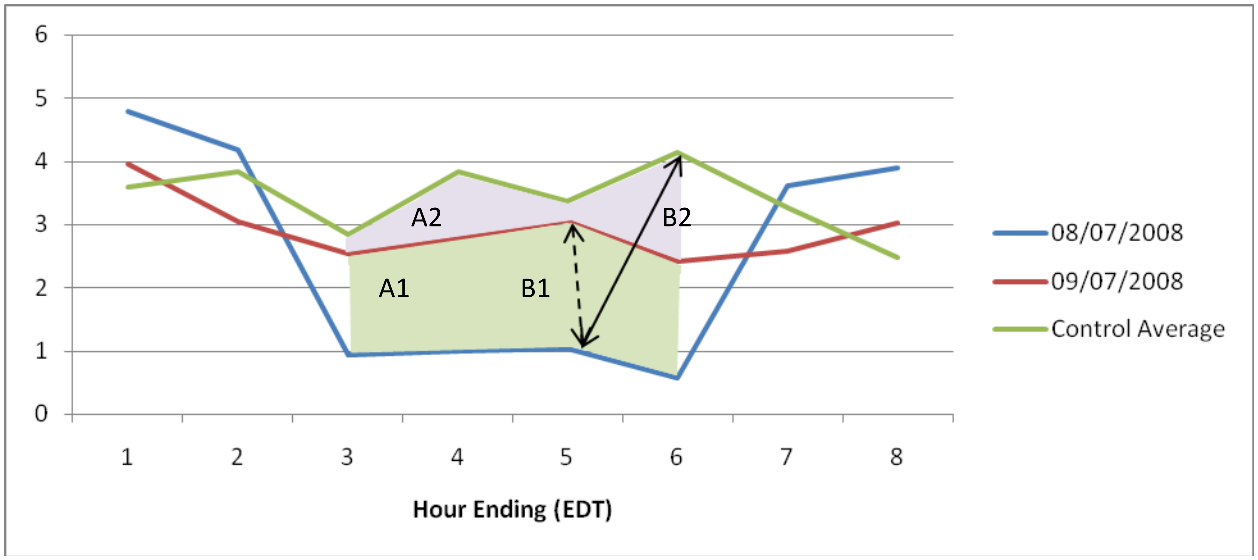


Table 7 - Investigating the impact of the Home Energy Management Technology on one home on 8 July 2008 (kW consumption)

Hour ending (EDT)	Tuesday, 8 July (DR event date)	Wednesday, 9 July (contiguous date)	Average (three control dates)
1:00pm	4.78	3.95	3.59
2:00pm	4.17	3.04	3.83
3:00pm	0.95	2.54	2.84
4:00pm	1.01	2.78	3.83
5:00pm	1.05	3.06	3.37
6:00pm	0.58	2.41	4.13
7:00pm	3.61	2.57	3.27
8:00pm	3.89	3.02	2.48

This procedure was repeated across all five DR events, across all 19 households. Tables 8, 9 and 10 provide results from this investigation. Table 8, more specifically, provides information about the change in each of the 19 household's electricity consumption (total consumption and peak consumption) across each of the five DR events – in each of the five, we compared with the average DR control. More specifically, the percentage change for 'total change' was found by dividing the average total change across the five DR event dates (reported in the third column of Table 8) by the average consumption across the three control dates. Similarly, the percentage change for 'peak change' was found by dividing the average peak change across the five DR event dates (reported in fifth column of Table 8) by the average peak hourly consumption across the three control dates. From this, we see that 18 of the 19 houses experienced reductions in both their total consumption and their peak consumption. One house (household H) had dramatic reductions – over 75 per cent. For the group as a whole, reductions in total electricity consumption during the four hour events were, on average, almost 44 per cent, while reductions in peak electricity consumption were, on average, more than 26 per cent.

Table 8 - Group of 19's group and individual demand response event consumption

Household	Comparison	Total change (kWh)	Percentage change	Peak change (kW)	Percentage change
A	Average	-7.16	-68.76%	-2.02	-59.83%
B	Average	-4.82	-40.23%	-1.49	-33.90%
C	Average	-0.18	-2.15%	0.42	18.89%
D	Average	-3.95	-34.46%	-0.56	-18.82%
E	Average	0.91	8.28%	0.48	16.01%
F	Average	-3.52	-26.42%	-0.19	-5.20%
G	Average	-4.83	-53.93%	-1.26	-42.48%
H	Average	-11.46	-80.67%	-3.13	-76.71%
I	Average	-4.95	-46.84%	-0.88	-30.12%
J	Average	-5.01	-44.11%	-1.38	-37.95%
K	Average	-7.31	-57.28%	-0.77	-22.55%
L	Average	-8.41	-55.73%	-1.96	-48.34%
M	Average	-6.59	-53.14%	-0.96	-28.80%
N	Average	-5.13	-49.92%	-1.30	-38.41%
O	Average	-3.21	-31.53%	-0.36	-11.62%
P	Average	-3.73	-53.31%	-0.12	-6.50%
Q	Average	-6.59	-58.93%	-0.77	-25.85%
R	Average	-5.42	-49.88%	-0.90	-26.14%
S	Average	-5.09	-33.22%	-0.84	-19.86%
All households	**Average**	**-5.08**	**-43.80%**	**-0.95**	**-26.22%**

Table 9 adds to the investigation by also comparing three of the DR events with their 'contiguous day' (the 'day method' described above). It is important to reiterate, of course, that this 'contiguous day' is one of the three days used in the 'average method'. In any case, it provides us with a 'check' on the kinds of reductions that were achieved. Additionally, it disaggregates the average method, showing if particular DR event dates achieved particularly high or low results. Indeed, from Table 9, it appears that the 18 August event was a particularly successful one, while the 3 September event was a relatively poorer one (particularly for reductions in peak consumption).

Finally, Table 10 gives a sense of the range in the averages reported in Table 9 (and already hinted at, across all five DR event dates, in Table 8). The maximum and minimum values for each DR event (as compared with the average method and, when available, the contiguous day method) are presented. Here we see that there were dramatic examples of decreases – achievements of 80 per cent reductions, in both total consumption and peak consumption, were achieved virtually every time.

Table 9 - DR events average results

DR events	Comparison	Total change (kWh)	Percentage change	Peak change (kW)	Percentage change
8 July	Following day	-4.07	-32.00%	-1.07	-24.40%
	Average	-4.10	-35.41%	-0.92	-24.37%
18 July	Prior day	-6.16	-51.00%	-1.34	-38.72%
	Average	-4.88	-45.10%	-0.99	-31.23%
18 August	Contiguous day	-5.15	-31.87%	-1.18	-19.36%
	Average	-6.92	-54.40%	-1.41	-37.21%
2 September	Average	-5.38	-43.94%	-0.87	-22.16%
3 September	Average	-3.88	-34.48%	-0.36	-10.41%

To conclude this report, we highlight issues for potential further investigation as BCE and its partners reflect upon the future of the Home Energy Management Technology.

1) We did not have extensive information about how the 19 households investigated in the second part of this report were selected. There were suggestions that they were pre-determined 'best performers' during the DR events. If that is the case, then their 'good performance' should not come as a particular surprise. It is, however, still notable that substantial reductions were achieved, and it would be worthwhile to investigate further how these householders used their systems (their settings, their comfort during the DR events, etc.).
2) Notwithstanding point (1) above, it is noticeable that one household (among the 19 identified by BCE) did not achieve reductions during the DR events. The inclusion of this household encourages further reflection upon the methodology employed to select all 19.

Table 10 - Maximum and minimum individual reductions among the group of 19

DR events	Comparison	Max/Min reductions	Total change (kWh)	Percentage change	Peak change (kW)	Percentage change
8 July	Following day	Max	-10.18	-81.73%	-3.81	-81.02%
		Min	**2.15**	**76.51%**	**1.03**	**137.33%**
	Average	Max	-10.58	-80.53%	-3.08	-83.30%
		Min	2.75	36.95%	1.10	59.78%
18 July	Prior day	Max	**-13.77**	**-86.66%**	**-3.85**	**-78.64%**
		Min	**0.30**	**2.10%**	**1.07**	**28.53%**
	Average	Max	-10.56	-81.50%	-2.83	-81.30%
		Min	**2.93**	**32.66%**	**2.28**	**76.97%**
18 August	Contiguous day	Max	**-15.61**	**-87.40%**	**-5.37**	**-86.75%**
		Min	3.74	132.16%	2.37	145.06%
	Average	Max	-12.35	-84.59%	-3.33	-81.88%
		Min	**-0.23**	**-2.12%**	**1.49**	**50.51%**
2 September	Average	Max	**-12.11**	**-85.47%**	**-3.39**	**-82.10%**
		Min	**3.93**	**36.20%**	**1.31**	**50.51%**
3 September	Average	Max	**-11.69**	**-82.50%**	**-3.19**	**-77.26%**
		Min	2.19	20.18%	2.76	68.97%

NOTE: When figures are bolded that means that the changes in total consumption and peak consumption for that particular row came from the same household; when not bolded, the two results came from different households.

3) The differences between the first three DR events (which occurred during the unofficial 'summer holiday' period) and the last two DR events (which occurred once the school year had begun again) might be worth investigating further.
4) Investigation of the extent to which households 'pre-cool' (or 'post-cool') in light of known upcoming (or anticipated) DR events would be of interest. In the absence of such consideration, the impact of the Home Energy Management Technology during DR events may be overstated.
5) Refinement of the largest dataset (the, that is, 123 households) so as to include only those who were actually using the Home Energy Management Technology would allow the same tests (as we complete in section 1 of this report) to be completed with greater confidence.
6) Information about the extent to which households interacted with their Home Energy Management Technology would allow potentially-fruitful investigations into the relationships between use and impact. Additionally, it would allow for investigation into how 'learning' with the Technology occurred.

Appendix A: Study of the Effectiveness of the Home Energy Management System

Interim Report

Submitted by Jeremy Schembri and Ian H. Rowlands (University of Waterloo)

22 December 2008

Purpose

The purpose of this brief report is to provide some interim results regarding the study of the effectiveness of the Home Energy Management System (HEMS) being deployed in Milton, ON. More specifically, this report provides details regarding the calculations of changes in residential electricity consumption arising in those homes with a HEMS installed. The next section lays out the methods used to arrive at the results (which are presented in the subsequent section). A discussion, launching explanation of these results, then follows. Finally, next steps (leading to our final report) are presented.

Methods

In this section, the steps taken to identify the appropriate 'sample households' and 'control households' are laid out.

Information provided by BCE identified 206 study participants in Milton, ON. Of these, it was determined that 124 had used their HEMS at least once after 30 September 2008. This group initially formed the basis for the analysis.

The hourly consumption data for these 124 homes were received from Milton Hydro for the period October 2006 to October 2008. Analysis of these data revealed that one account (114835) had data dating only from May 2008. It was removed from the sample. Two further accounts (119829 and 120462) had data missing for six to ten days during the study period; these 'missing periods' were replaced with contiguous data from the same account. More specifically, for the former, data from 8-13 September 2007 were copied onto the missing period of 1-6 September 2007, and, for the latter, data from 15-24 October 2006 were copied onto the missing period of 1-10 October 2006.

These 123 households formed the basis of one sample subsequently investigated. It should be noted that 43 of these households were placed on to time-of-use rates in 2005, while the other 80 were placed on to time-of-use rates in 2007. For all of these households, their results – that is, the extent to which they were influenced by the presence of the HEMS – were considered for all months following the month in which the HEMS was installed. With the last installation occurring in April 2008, that means for five months (May 2008 to September 2008, inclusive), the full complement of 123 households in the sample could be analysed. For the previous seven months (October 2007 to April 2008), a subset – ranging from 57 to 122 households – were part of the investigation.

A second sample identified consists of those 19 households that were identified by BCE as being households believed to have functioning HEMSs. Of these 19, seven went on to time-of-use rates in 2005, and 12 in 2007. Because of the dates of installation for these homes, there are seven months in which the full complement can be analysed (March 2008 to September 2008, inclusive); for the remaining five months (October 2007 to February 2008), the number of households studied ranges from eight to 16. (It should be noted that these 19 households are also elements of the collection of 123 households described above.)

As with our previous studies, 'control households' (deployed to minimize the impacts of 'interventions' and factors not associated with the HEMS) were identified for each of the 123 sample households. From 600 candidate accounts (households, that is, that had not had the HEMS installed) provided by Milton Hydro, the selection of control group members was based on a combination of the sample participant's total and peak electricity consumption for January, April, and July of 2007. (Please note that attempts were made to include October 2006 among these months, but the consumption variability within the month did not make it possible.) These three months were selected for a representation of each season's electricity consumption. Also note that in the resultant 'coupling' (that is, a sample participant with a control participant), the years upon which the two households went on to time-of-use rates were identical. Finally, recognise that the first accounts to be matched with their respective control pairs were the 19 accounts identified in the 'second sample' above; the remaining 104 accounts were then matched with a control pair.

While the above follows investigations we have completed in the past, we did perform one new variation. More specifically, when investigating the sample of 19 households, we constructed a 'second control group', which consisted of an average of 'three candidate control households' for each sample household. We did this to try to get some insight as to the extent to which the selection of control households affected our results. (These 38 additional control households were selected from the 104 control accounts that were not matched, initially, with the 19 sample households.) We subsequently call this the 'hybrid' control, while our usual method is referred to as the 'conventional' control.

The ways in which the results were calculated, given these households, are laid out in the Appendix to this report.

Results

Results – that is, the calculated impact of the HEMS by comparing the overall consumption and peak consumption of those sample households that had the HEMS installed with those control households that did not – are presented in this section. Tables 1 and 2, along with Figure 1, examine the larger sample – that is, the group of 123 households. Table 1 presents consumption levels (both overall and peak), while Table 2 and Figure 1 report upon the influence of the HEMS. The ways in which figures for these latter two will be briefly explained here.

Table 1 - Monthly Consumption, Group of 123

Months	**Overall consumption**		**Peak consumption**	
	Sample (kWh)	**Control (kWh)**	**Sample (kWh)**	**Control (kWh)**
October 2006 (n=57)	37,332	36,656	6,157	6,558
November 2006 (n=84)	53,970	52,275	12,835	12,706
December 2006 (n=100)	79,223	73,512	15,621	14,897
January 2007 (n=105)	77,462	73,742	17,784	17,230
February 2007 (n=107)	69,232	68,486	16,312	15,670
March 2007 (n=112)	77,117	71,525	17,180	15,978
April 2007 (n=122)	74,932	71,157	14,705	14,115
May 2007 (n=123)	76,144	74,644	14,676	15,295
June 2007 (n=123)	111,539	114,442	23,440	25,630
July 2007 (n=123)	113,952	114,060	23,917	25,261
August 2007 (n=123)	123,859	119,471	27,419	27,964
September 2007 (n=123)	93,715	89,873	17,096	16,896
October 2007 (n=57)	38,727	37,159	6,643	7,084
November 2007(n=84)	57,574	53,408	13,531	12,962
December 2007 (n=100)	80,683	75,253	15,740	14,882
January 2008 (n=105)	78,651	74,568	17,696	17,192
February 2008 (n=107)	74,528	70,094	17,249	16,401
March 2008 (n=112)	79,528	74,219	14,772	14,073
April 2008 (n=122)	74,801	68,544	16,882	15,819
May 2008 (n=123)	75,261	69,432	13,258	11,748
June 2008 (n=123)	109,007	100,359	20,425	19,559
July 2008 (n=123)	130,421	121,968	29,076	28,243
August 2008 (n=123)	111,774	104,621	20,247	19,957
September 2008 (n=123)	92,358	84,588	17,698	17,474

As a reminder, Table 2 presents – in its 'right-hand columns' for both overall consumption and peak consumption – the impact of the HEMS by comparing changes in the sample households with changes in the control households. To further clarify, let us explain the entries in this table for 'October'.

During October 2007, 57 households had already had the HEMS installed (i.e., they had it installed no later than 30 September 2007). As such, these households' consumption data could be compared with October 2006 in order to assess the influence of the HEMS. Calculations reveal that the overall consumption of the sample households increased from 37,332 kWh to 38,727 kWh between October 2006 and October 2007 – an increase of 3.74%. For the control households, overall consumption increased from 36,656 kWh to 37,159 kWh – an increase of 1.37%. Hence, the 'relative change' – comparing the sample households with the control households – was 2.37%. In other words, the presence of the HEMS served, in the absence of other factors, to increase overall electricity consumption by 2.37% from what it would otherwise have been. Positive figures in Tables 2 (and 4 and 5) and Figures 1 (and 2) are 'counterintuitive' results – that is, the presence of the HEMS appeared to increase electricity consumption; negative figures are 'intuitive (expected)' results – that is, the presence of the HEMS appeared to reduce electricity consumption. Similar results for the smaller sample (of 19) are provided in Tables 3, 4 and 5, along with Figure 2.

Table 2 – Impact of HEMS, Group of 123

Month-to-month	Overall consumption			Peak consumption		
	Relative change – 'group' calculation	Relative change – 'individual' calculation	Relative change – avg. of two calculations	Relative change – 'group' calculation	Relative change – 'individual' calculation	Relative change – avg. of two calculations
October (n=57)	2.37%	9.16%	5.77%	-0.11%	6.31%	3.10%
November (n=84)	4.51%	5.97%	5.24%	3.41%	3.88%	3.65%
December (n=100)	-0.53%	1.23%	0.35%	0.86%	1.48%	1.17%
January (n=105)	0.41%	0.75%	0.58%	-0.26%	-1.59%	-0.93%
February (n=107)	5.30%	9.42%	7.36%	1.08%	-0.97%	0.06%
March (n=112)	-0.64%	1.39%	0.38%	-2.09%	-1.78%	-1.94%
April (n=122)	3.49%	5.96%	4.73%	2.73%	3.50%	3.12%
May (n=123)	5.82%	5.11%	5.47%	13.53%	13.93%	13.73%
June (n=123)	10.04%	9.29%	9.67%	10.83%	13.21%	12.02%
July (n=123)	7.52%	6.51%	7.02%	9.77%	10.72%	10.25%
August (n=123)	2.67%	1.15%	1.91%	2.47%	1.34%	1.91%
September (n=123)	4.43%	3.32%	3.88%	0.10%	-2.38%	-1.14%

Figure 1 – Impact of HEMS, Group of 123

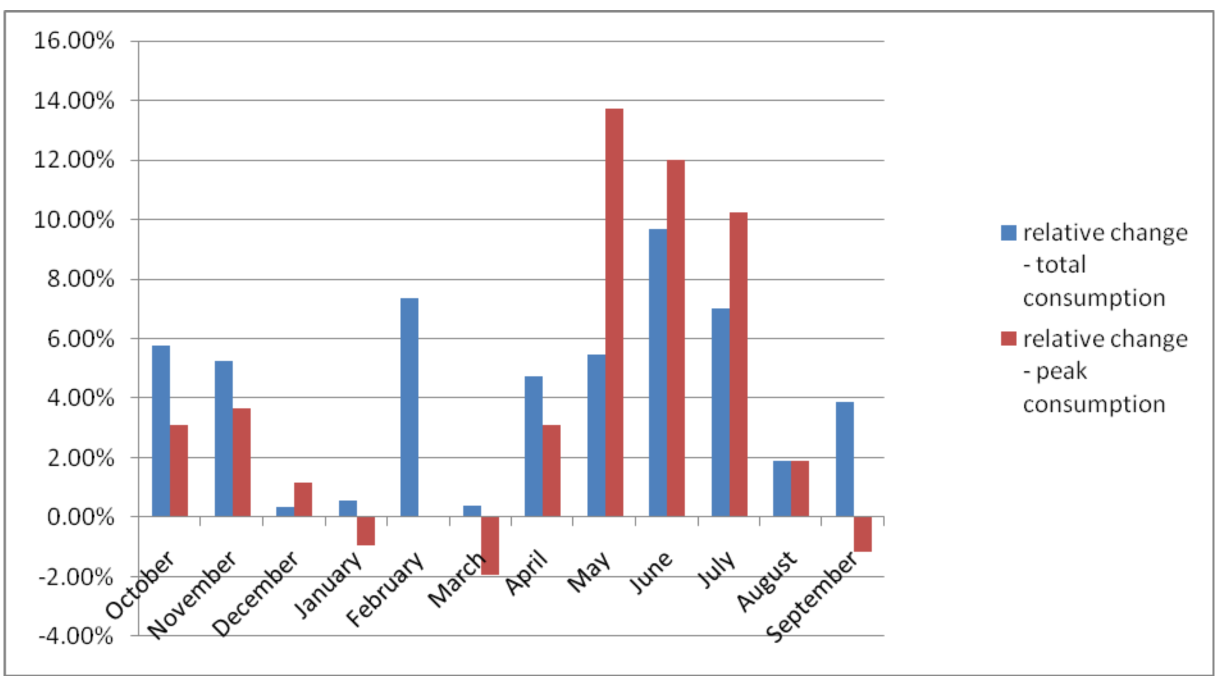


Table 3- Monthly Consumption, Group of 19

Months	Overall consumption (kWh)			Peak consumption (kWh)		
	Sample	'Conventional' Control	'Hybrid' Control	Sample	'Conventional' Control	'Hybrid' Control
October 2006 (n=8)	5,773	5,499	5,347	986	1,204	978
November 2006 (n=11)	7,150	6,829	7,155	1,764	1,932	1,750
December 2006 (n=14)	12,207	10,720	10,848	2,487	2,213	2,186
January 2007 (n=15)	11,955	11,019	11,015	2,859	2,616	2,603
February 2007 (n=16)	10,735	9,999	10,074	2,548	2,446	2,382
March 2007 (n=19)	11,553	10,262	10,625	2,560	2,386	2,415
April 2007 (n=19)	12,002	11,357	11,343	2,387	2,227	2,239
May 2007 (n=19)	18,349	13,157	12,484	2,618	2,786	2,597
June 2007 (n=19)	19,057	20,805	19,185	4,142	4,769	4,220
July 2007 (n=19)	19,292	19,866	18,340	4,153	4,455	3,889
August 2007 (n=19)	20,069	20,549	19,243	4,550	5,140	4,552
September 2007 (n=19)	14,708	15,660	14,642	2,947	3,103	2,802
October 2007 (n=8)	5,906	5,470	5,213	1,051	1,207	997
November 2007(n=11)	6,561	6,927	6,837	1,567	1,876	1,746
December 2007 (n=14)	11,037	10,506	10,566	2,236	2,239	2,189
January 2008 (n=15)	10,868	10,911	10,945	2,466	2,738	2,644
February 2008 (n=16)	10,360	10,217	10,183	2,445	2,633	2,499
March 2008 (n=19)	10,907	11,103	11,005	2,035	2,212	2,100
April 2008 (n=19)	11,041	11,478	11,141	2,444	2,746	2,643
May 2008 (n=19)	16,262	11,722	11,196	2,068	2,024	1,991
June 2008 (n=19)	17,041	17,532	16,455	3,516	3,501	3,226
July 2008 (n=19)	20,915	21,411	20,088	5,063	4,954	4,605
August 2008 (n=19)	17,674	18,764	17,760	3,415	3,777	3,520
September 2008 (n=19)	14,345	14,349	13,855	2,926	2,993	3,000

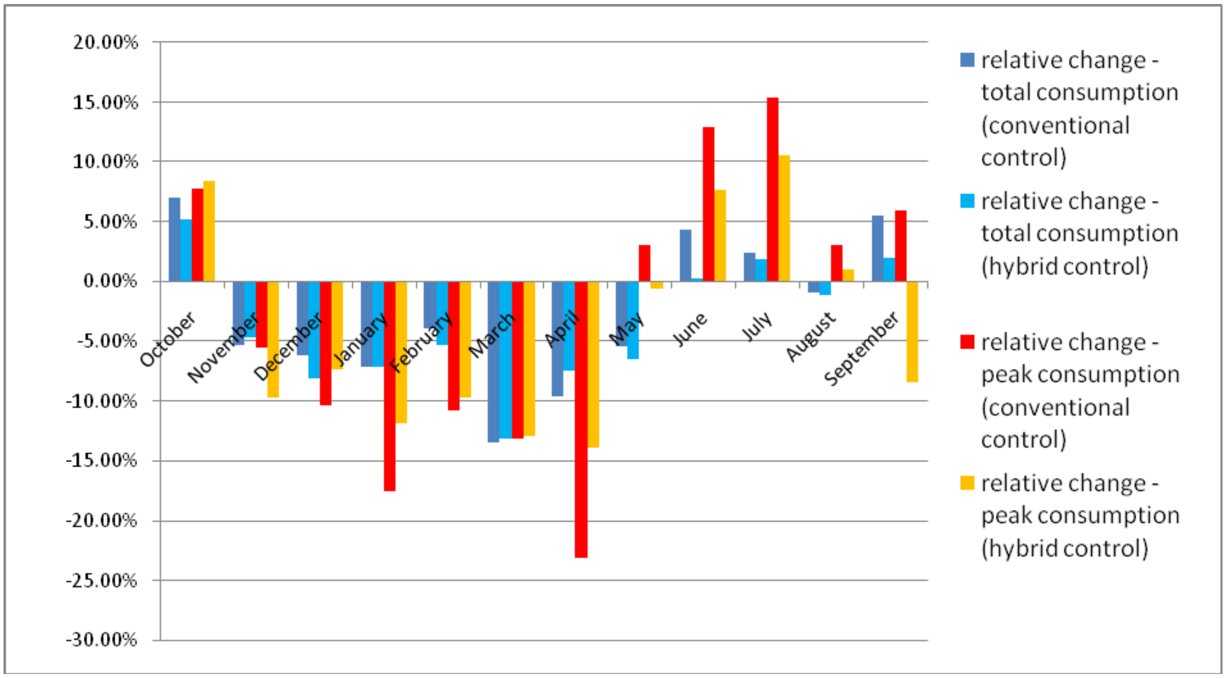
Table 4 – Impact of HEMS on Overall Consumption, Group of 19

Month-to-month	Overall consumption – conventional control			Overall consumption – hybrid control		
	Relative change – 'group' calculation	Relative change – 'individual' calculation	Relative change – avg. of two calculations	Relative change – 'group' calculation	Relative change – 'individual' calculation	Relative change – avg. of two calculations
October (n=8)	2.84%	11.30%	7.07%	6.46%	3.99%	5.22%
November (n=11)	-9.68%	-0.89%	-5.29%	-6.67%	-2.76%	-4.71%
December (n=14)	-7.59%	-4.73%	-6.16%	-9.34%	-6.84%	-8.09%
January (n=15)	-8.11%	-6.09%	-7.10%	-8.20%	-6.19%	-7.20%
February (n=16)	-5.67%	-2.29%	-3.98%	-6.29%	-4.25%	-5.27%
March (n=19)	-13.78%	-13.13%	-13.46%	-12.95%	-13.38%	-13.17%
April (n=19)	-9.07%	-10.12%	-9.60%	-8.13%	-6.75%	-7.44%
May (n=19)	-1.92%	-8.91%	-5.42%	-5.42%	-7.64%	-6.53%
June (n=19)	5.15%	3.61%	4.38%	0.59%	-0.09%	0.25%
July (n=19)	0.64%	4.09%	2.37%	0.61%	3.06%	1.83%
August (n=19)	-3.24%	1.34%	-0.95%	-2.71%	0.42%	-1.15%
September (n=19)	5.90%	5.16%	5.53%	2.30%	1.64%	1.97%

Table 5 – Impact of HEMS on Peak Consumption, Group of 19

Month-to-month	Peak consumption – conventional control			Peak consumption – hybrid control		
	Relative change – 'group' calculation	Relative change – 'individual' calculation	Relative change – avg. of two calculations	Relative change – 'group' calculation	Relative change – 'individual' calculation	Relative change – avg. of two calculations
October (n=8)	6.28%	9.24%	7.76%	6.59%	10.13%	8.36%
November (n=11)	-8.30%	-2.69%	-5.50%	-11.28%	-8.19%	-9.74%
December (n=14)	-11.24%	-9.58%	-10.41%	-8.07%	-6.75%	-7.41%
January (n=15)	-18.41%	-16.63%	-17.52%	-11.99%	-11.79%	-11.89%
February (n=16)	-11.70%	-9.81%	-10.76%	-9.52%	-9.85%	-9.69%
March (n=19)	-13.23%	-13.00%	-13.12%	-11.44%	-14.35%	-12.90%
April (n=19)	-20.92%	-25.30%	-23.11%	-13.71%	-14.19%	-13.95%
May (n=19)	6.33%	-0.21%	3.06%	0.92%	-2.17%	-0.62%
June (n=19)	11.49%	14.30%	12.90%	7.03%	8.37%	7.70%
July (n=19)	10.71%	20.14%	15.43%	8.34%	12.78%	10.56%
August (n=19)	1.56%	4.64%	3.10%	0.81%	1.16%	0.99%
September (n=19)	2.84%	8.98%	5.91%	-5.82%	-11.10%	-8.46%

Figure 2 – Impact of HEMS, Group of 19



Discussion

Results for the group of 123 are not particularly encouraging: many of the values in Table 2 are positive and many of the bars in Figure 1 are above the x-axis, both of which suggest that the presence of the HEMS has served to increase both overall and peak electricity consumption (though there are some exceptions). Results for the group of 19 are better: many of the same values (this time in Tables 4 and 5 and Figure 2) are in the 'right' direction, namely 'negative' (in Tables 4 and 5) and 'below the line' (in Figure 2). Particularly for the November to April period, the presence of the HEMS in these homes appeared to have a beneficial impact – reducing overall electricity consumption by the order of 4 per cent to 14 per cent, and peak electricity consumption by even more, by 5 per cent to 23 per cent. Results for the June to September period, however, are not as positive.

When reviewing these results, three key points should be kept in mind.

1) There are a small number of households in the samples (particularly, of course, in the group of 19). Accordingly, 'special cases' ('strange' electricity events like new purchases, or new occupants) are less likely to 'even out' and are less likely to be 'lost in the noise'. Instead, they have impact.
2) Reported here are 'means'. There are substantial variances in the figures, and our 'next steps' – particularly when we examine the 'best' performers – will explore this to a greater extent.
3) We do not know – even for the group of 19 – who is using the HEMS (and how often). As such, our samples may not truly reflect users of the technology.

Next steps

To complete the final report, we have two additional tasks.

3) To explore, among both samples, the 'best' (top) and 'worst' (bottom) performers, to try to determine whether any characteristics distinguish these groups.
4) To examine the 'demand response' events in the manner described in our 'Research Outline – Proposal' dated 14 November 2008.

Appendix

When the sample and control groups' total baseline and study months' consumption is found, calculations are completed to find the percentage change in total and peak electricity consumption. The calculation for percentage change in consumption is completed using the average result of the following two equations. The first equation involves finding the group's total consumption for a paired baseline and study month, for instance October 2006 and October 2007. The delta is then found by subtracting the baseline month's consumption from the study month's consumption. To find the percentage change in consumption, the delta is divided by the applicable baseline month's consumption. This process is repeated to find the similar results for each month's peak consumption. The result is referred to as the 'group' calculation.

Equation 1 - Group Percentage Change Equation

Group's study month X consumption – Group's baseline month X consumption
= X group delta
X group delta / Group's baseline month X consumption
= X group percentage change

The second equation involves finding the consumption delta for each participant. Using the consumption delta, the percentage change in consumption is found by dividing the individual's delta by the individual's baseline month's consumption. All the individual percentage changes are summed, the mean is found, and referred to as the individual percentage change. This will be done for the total and peak consumption of each month. The result is referred to as the 'individual' calculation.

Equation 2 - Individual Percentage Change Equation

Individual's study month X consumption - Individual's baseline month X consumption
= X individual delta
X individual delta / Individual's baseline month X consumption
= X percentage change
Sum of X percentage change / Number of participants
= X individual percentage change

Each of these equations is necessary to address the variation in the results the other equation produces. The calculation of the group percentage change gives greater value to the results of the participants that were high consumers in the baseline months. Alternatively, the individual percentage group equation gives greater value to the lower baseline consumers. To address this skewness in the data, the means for both these approaches are averaged to produce a result referred to as the average percentage change (see equation below).

Equation 3 - Average Percentage Change Equation

X month group percentage change + X month individual percentage change / 2
= X average percentage change