MELs: What Have We Found through End-use Metering?

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ABSTRACT

Power Smart's Residential End-Use Metering Program (REUMP) meters all the appliances in 12 volunteer households. The hourly aggregations of data provide insight into a small sample's average use of electricity by end-use and groups of end-uses, as well as the ability to learn from the variations between households. Hourly data shows the impact of the appliance, and the behaviors of timing of use, and the one-minute data shows how the appliances work. For MELs such as televisions, we look at both the usage of individual units, as well as the more complex entertainment systems as a whole.

In this paper we discuss methodology issues of this approach to end-use metering, and discuss our preliminary work with; power factor by end-use, standby loads by end-use. Findings for MELs are highlighted where appropriate. Duration curves of the hourly energy use, for a year, clearly show the active and standby modes for each appliance, and the number of hours in each mode. The 12 household pilot provides some information on the variation in usage that one might expect. Power factor, by household and by end-use were investigated, with a discussion on leading and lagging kvars. Detailed energy use data, by appliance or group of end-uses, and by several households can inform conservation program and regulation/standards planning.

Background

In British Columbia we want to conduct residential end-use research to better understand how electricity is used by key appliances, and which appliances and end-uses are active in peak hours (Nelson and Berrisford, 2010). If the utility were to launch a Time of Use (TOU) rate, in our winter-peaking environment with a significant proportion of electric space heating, we really should know what the customer is using in those peak hours, to predict what appliance use they may be able to change. And when we do residential energy forecasts, we would like to know how much more, or less, new appliances will be using, compared to the existing appliances, but larger samples would be necessary.

This paper begins by referencing some of the larger, earlier residential end-use research work. Then the phases of work and the research methodology for this project are briefly addressed. The preliminary findings section then deals with the variation in the 12 volunteer households' consumption levels by end-use or end-use group, discusses the value of one-minute vs. hourly vs. monthly consumption data, provides some load duration curves and explains what we can learn about standby loads, and finally opens the subject of Reactive Power and kVArs by end-use and the net total, by house. The examples will involve MELs whenever possible, but some concepts are best illustrated with refrigeration. Data is available to requesters. The authors understand that at best, most utilities will see hourly load data at the whole house level, and we attempt to align our findings with that reality. We close with some comments on the materiality of the findings thus far, and the next steps for BC Hydro.

End-use Studies

BC Hydro's research objectives were noted above. Previously utilities had slightly different objectives for end-use research. For example:

1. The Household Energy End-use Project (HEEP) in New Zealand (Isaacs et al., 2006) did end-use 10-minute interval metering to better understand the annual consumption of the appliances, and their standby loads. They studied 400 households for about one year each, over the research period of ten years. Some of their most valuable learnings were in the area of fuel poverty, an unexpected discovery. They only occasionally used their interval data to look at time of day issues.
2. The ELCAP project by Bonneville Power Administration (BPA) (Cahill et al., 1992) did end-use hourly metering to "better understand how" customers used their electricity, in an electric space heating environment. This project, involving over 300 households, many for about six years, ended in 1993, after an investment of approximately $20M (US).
3. Florida Power Corporation (Parker, 2002) studied end-use consumption with a large sample in a cooling environment (over 200 residences), in the late 1990s.
4. A European project called Residential Monitoring to Decrease Energy Use and Carbon Emissions (REMODECE) collected 10-minute interval data, for two weeks in 2007 and 2008, in 1,300 households, for 11,500 appliances. They were trying to better understand appliance and electronics loads, and focused on everything except space heat and water heat.
5. Most recent end-use research in the US has been on air conditioners, and was done to better understand how the TOU and curtailable rates work.
6. The Northwest Energy Efficiency Alliance (NEEA) has 100 homes with most end uses metered, in the largest current study (NEEA, 2012).

REUMP Phases 1-2-3

The project is based on the concept of using a Zigbee wireless network, to collect consumption data from metering recorders at each appliance or outlet in the house. Ideally the utility would want to bring the data back through a smart metering network. We found a British company had developed such a device and we ordered some to try. The first phase of this project was a proof of concept at a single house in September-December 2008, with over 20 end-uses monitored (Berrisford, 2009). In that phase it was learned that the devices could record and transmit energy consumption information, in a Zigbee protocol, for plugged-in appliances. The second phase was a feasibility study which started in September 2009, with 3 homes. In this phase the objective was to ensure that we can actually get valid answers to our research questions, by acquiring, processing and storing interval energy use data from up to 40 devices per house. The third phase, which is drawing to a close involved 12 volunteer homes, and provides the data for this report.

Methodology

In previous residential end-use research, by necessity, metering was often done on whole circuits, and as a result lighting and mixed plug loads were often viewed as one load. Occasionally it is not clear how the lighting loads were measured. With the BC Hydro focus on measuring the lighting load, in households with wiring circuits that will hold a mix of plug loads and hard wired lighting, it was clear that measuring circuits at the breaker panel could not provide adequate resolution. In addition, the Canadian Standards Association (CSA) now views external current transformers (CTs) as temporary devices, and does not approve their use in permanent installations. In a winter peaking, partial electric heating region, lighting may prove to be a very important load to understand, both in total consumption, and in timing of usage.

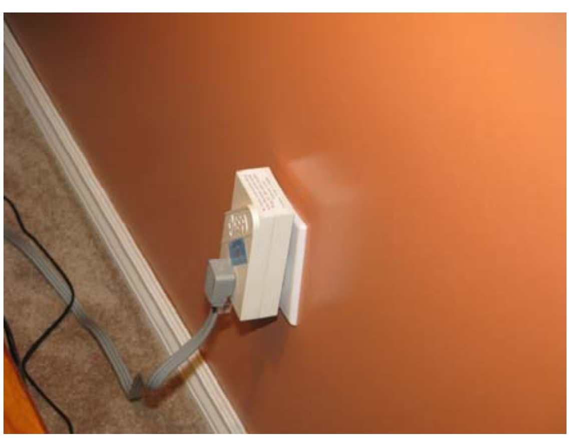
The residential hourly whole house lighting load shape can be derived by summing the interval "plug" loads of all of the non-lighting end-uses, and subtracting that total from the interval load for the total household.

It is simple to outline what is required to accomplish the goal of representative end-use interval data for all significant residential end-uses, but there is an exceptional amount of effort required to ensure that the various pieces of the puzzle come together, with the appropriate quality levels. As part of this phase an evolving protocol was written for residential end-use metering projects, outlining information and data management needs, for expansion and transferability of findings (Nelson, 2009 b).

Direct end-use metering is seen as one of several complementary techniques for obtaining end-use loadshapes. We have a long series of Residential End-use Surveys (REUS), including appliance saturation questions, run on a biannual schedule. This survey has been used with hourly interval smart meter data, for an hourly Conditional Demand Analysis (CDA) model. The next step is to use the more than 10,000 households with current end-use information as the sample for a much improved hourly CDA, as well as integrating learnings from our metering work, improving our ability to understand several end-uses.

The enabling technologies which made this end-use load research possible in 2010 were the cheaper control/metering devices, which plug into a wall outlet, and have the appliances plugged into them. A few firms had equipment which could be used, but our supplier was sold, and most other equipment had concerns.

Energy Optimizers, of the UK, had a plug outlet monitoring and control device (see Figure 1, a) which can also record interval W, Wh, var, and V for intervals between 1 and 60 minutes. This device is accurate within one percent. Currently these recordings are transmitted from the Plogg devices, by Zigbee radio protocol to a computer in the home, which works like a gateway, and then downloaded to BC Hydro, for validation, editing and estimation (VEE), storage and aggregation (see Figure 1, b).



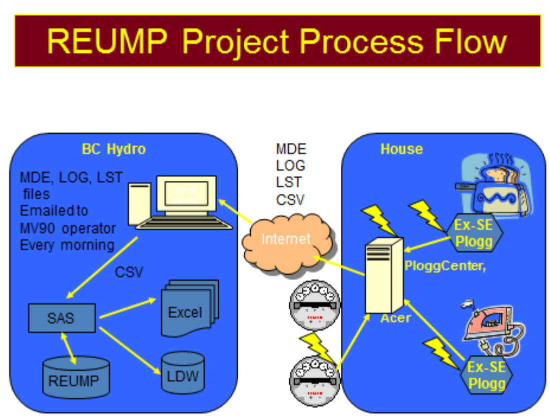


Figure 1. a) Energy Optimizer's Plogg Metering Device. b) Current Network.

Preliminary Findings

Annual Consumption of Residential End-use Categories

The 12 volunteer sites provide a variety of demographic differences (see Table 1):

a. the sample includes eight single family detached (SFD) homes, two town houses (Rows) and one apartment unit,
b. the year of build ranges from 1936 to 2007,
c. square footage ranges from 800 to 2700 sq.ft.,
d. the number of occupants ranges from one to six,
e. home heating fuel has three gas heated, six with electric heat, and three with both fuels.

Each site installed about 20 to 60 Ploggs, monitoring all possible plug-in loads, at 1-minute, 15-minute or 60-minute intervals.

Table 1, below, summarizes the end-use annual energy consumption of the 12 households into 11 appliance categories. Very small loads like hard-wired garbage disposals, bathroom fans, security systems, as well as the loads for project measurement were estimated with an average of 1 kWh per day.

We are still separating 'heat from light' in nine households. By that we mean that both the electric space heat and the lighting loads are in the un-metered residuals. Food refrigeration averaged 1,063 kWh/year. Miscellaneous electric loads (MELs) consumed an average of 1,583 kWh/year, with a range, in this small sample of 12 households, from 844 kWh/year to 3,591 kWh/year.

In end-use research, percentage values should be used with caution. From perspective of cross-effects, in heating jurisdictions much of energy losses from MELs off-sets electric space heating loads. In primarily cooling environments, the A/C load is increased by the waste heat from MELs. And more important, in this heating region, the average gas heated single family dwelling uses 10,029 kWh/year of electricity, and the average electrically heated single family dwelling uses 21,547 kWh/year. If a family moved from a gas heated home to an electrically heated home, their MELs energy use, if it were 1,583 kWh/year, from a percentage perspective would drop from 15.8% to 7.3% due to the increased total house load.

Table 1. Annual Energy Consumption By Household (kWhs)

	Characteristics of the Sample	P-001	P-002	P-004	P-005	P-006	P-008	P-009	P-011	P-012	P-013	P-015	P-017	
	Dwelling Type	SFD	SFD	Row	Row	SFD	Apt	Row	SFD	SFD	SFD	SFD	SFD	
	Year of Build	1,983	1936	1977	2008	2000	2007	1988	1948	1965	1977	1951	1981	
	Square Footage	2,192	911	1572	1193	2687	811	1248	2210	2206	1798	1565	2411	
	Number of People	2	1	2	3	6	2	1	3	3	4	3	4	
	Space Heating Type	Gas	Gas	Elec	Elec	Gas & Elec	Elec	Elec	Gas & Elec	Gas & Elec	Elec	Elec	Gas	
	End-use Categories (kWh)													**Average**
1	Space Heating - supplimental and furnace	2,645	239				16		442	313	159		398	602
2	Space Cooling	524	1,003							18				515
3	Water Heating	n/a	n/a	1,992	n/a	n/a	n/a	976	2,308	2,311	n/a	n/a	n/a	1,897
4	Refrigeration	1,931	391	1,202	431	1,143	819	838	1,567	1,026	1,671	1,092	644	1,063
5	Laundry	390	78	249	135	914	107	265	61	746	458	257	277	328
6	Cooking	210	36	255	22	477	175	93	347	89	453	73	65	191
7	Dishwasher	167	n/a	148	10	139	125	18	84	112	262	24	161	114
8	Entertainment	735	551	874	1,158	781	1,292	453	245	862	1,204	666	847	806
9	Computers/Office	502	267	820	11	558	293	456	1,124	389	2,387	1,212	533	713
10	Chargers	30	26	4	12	194	118	38	335	18	0	1	0	65
11	General	174	244	649	88	829	115	62	595	1,002	720	904	613	500
	Deemed Loads (Est.)	131	35	34	32	131	105	18	41	38	34	39	70	59
	Plogg Device Loads (Est.)	350	263	336	263	263	343	329	217	229	183	483	350	301
	Estimated Lighting (Cal.)	3,752	1,076										3,190	
	Residuals (Cal.)	0	0	9,089	2,283	7,779	2,773	7,001	8,176	4,765	11,618	8,989	0	5,874
	Total House Loads	**11,540**	**4,209**	**15,652**	**4,444**	**13,209**	**6,282**	**10,546**	**15,544**	**11,918**	**19,149**	**13,740**	**7,148**	**11,115**
	MELs[1] (sum 8-10)	1,267	844	1,698	1,181	1,533	1,702	947	1,705	1,270	3,591	1,878	1,380	1,583

Note: 1. Miscellaneous Electric Loads include Computers, Printers, Fax Machines, CD Players, DVD Players, Audio Systems, PVRs, Radios, Record Players, TVs, and small electronics for entertainment or home office.
2. Deemed Loads includes hardwired small loads, such as Bathroom Fan, Door Bell, Garburator, Range Hood Fan, and Smoke Detector. We only collected one week sample data from one site and replicated loads for the rest.

Interval Data: When Does Length Matter?

In the HEEP studies, conducted by BRANTZ in New Zealand, the researchers determined that 10-minute intervals were needed to see the cycling of refrigerators. In the REUMP study we have collected (or summed) a variety of interval lengths for many reasons. In the figures below, we use refrigerator data to look at the information provided by 15-minute, 1-minute and monthly intervals. The value of detailed information varies by end-use, and client.

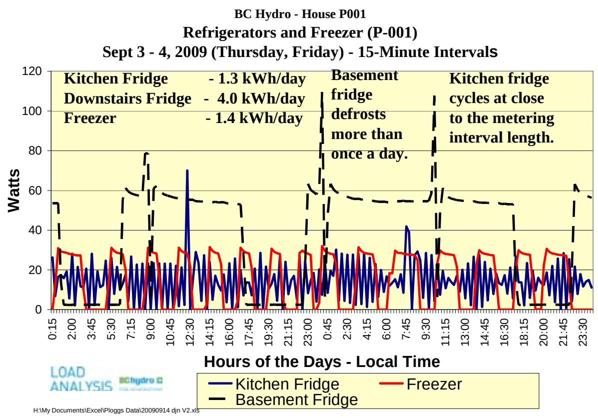


Figure 2. Traditional 15-Minute Intervals

Notes: With 15-minute intervals and a day's data, we can see how the three cooling devices operate quite differently. The older, second fridge (dashed line) has a larger compressor, and cycles less frequently. It defrosts more than twice a day. The newer fridge cycles frequently (blue line), and the manual defrost freezer, with a larger compressor, cycles routinely.

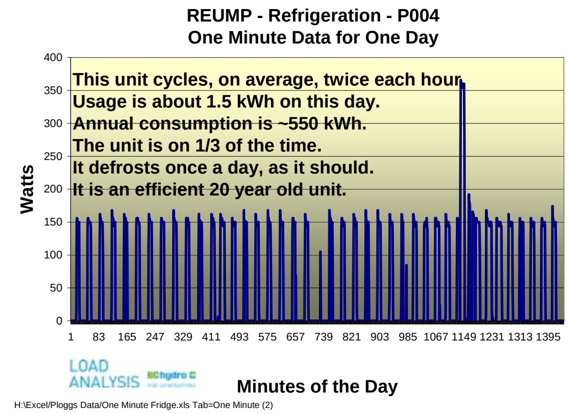


Figure 3. 1-Minute Data – A Technical View of the End-use

Notes: 1-Minute intervals better inform the researcher as to how the machine works. One can see that this 20-year old efficient fridge defrosts once a day, and cycles twice an hour at the current ambient temperature, with no warm food being added. Hourly data would show a rather flat line for the day.

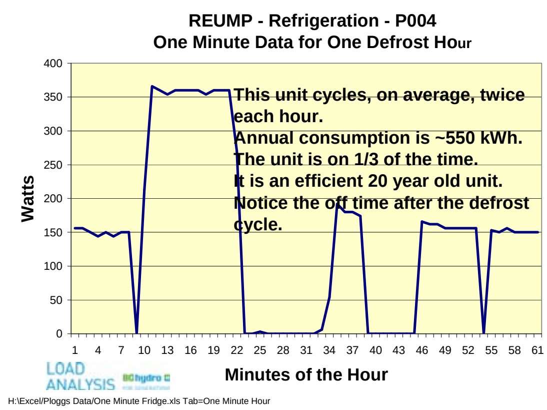


Figure 4. A Close-up Look

Notes: Besides interval length, scale determines a lot about the information gained. When we look at one hour's 1-minute data, we can see that the defrost cycle lasts about 12 minutes, the element uses an average of 350 Watts per minute, and the fridge is prevented from cooling after the defrost cycle for about 10 minutes to allow the melted frost to completely drain down the black hose into the high-tech evaporator pan at the rear.

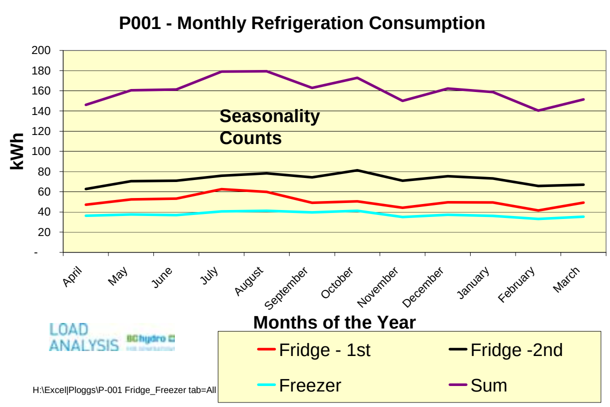


Figure 5. The Material View

Notes: If the analyst averages one fridge's hourly consumption for 30 days, only if the defrost timer was perfect would one see anything but a flat line. Average 30 separate fridges for one day, and you would also see a flat line, due to diversity. What counts is ambient temperature and warm food inputs, so monthly data is best. In this graph we show kWh/month as billed, but average hourly kWh would work as well.

Standby Load, Baseload, and Smart Meter Data

Standby loads can be defined in many ways, but our objective in this paper is to present granular information so readers can assemble the end use numbers the way they wish. Standby power is generally considered to be the energy used by some products when they are turned off but still plugged into a power/wall outlet. In this paper we acknowledge load used by appliances in an "off-cycle" to be standby as well.

Table 2, below presents a snapshot of each household's lowest consumption hour in June. This eliminates constant heating or cooling loads from influencing the findings. This lowest monthly hour's consumption is what can be seen with smart meter data, and in this paper we use that as a comparison to the end-use consumption information BC Hydro has. The lowest consumption hour has been termed "baseload" (Nelson, 2008) and is what the customer sees, in BC Hydro' case, through the Customer Portal's displays of hourly consumption. Baseload varies by month, but for consistency we selected the month of June for this example. It is valuable to the utility to understand how appliance standby load which can be measured only with end-use metering, relates to baseload, which is the lowest hour the customer sees.

Table 2. Standby Loads and Baseloads (Watts)

	Characteristics of the Sample	P-001	P-002	P-004	P-005	P-006	P-008	P-009	P-011	P-012	P-013	P-015	P-017	
	Dwelling Type	SFD	SFD	Row	Row	SFD	Apt	Row	SFD	SFD	SFD	SFD	SFD	
	Space Heating Type	Gas	Gas	Elec	Elec	Gas & Elec	Elec	Elec	Gas & Elec	Gas & Elec	Elec	Elec	Gas	
	End-Use Major Categories (Watt)													Average
1	Space Heating - supplimental and furnace	87	6				10		6	42			4	26
2	Space Cooling	0	0			0	0		0	0				0
3	Water Heating	n/a	n/a	58	n/a	n/a	n/a	40	13	91	n/a	n/a	n/a	51
4	Refrigeration	69	32	114	48	75	0	1	133	78	39	115	31	61
5	Laundry	3	2	4	0	2	0	0	2	0	2	4	3	2
6	Cooking	3	2	4	2	7	3	5	3	4	4	5	3	4
7	Dishwasher	0	n/a	2	1	21	0	0	0	17	2	0	1	4
8	Entertainment	56	13	53	86	98	112	52	21	73	104	67	73	67
9	Computers/Office	47	29	66	0	66	32	49	51	45	217	33	53	57
10	Chargers	3	3	2	2	1	17	5	3	1		0	0	3
11	General	8	3	29	6	50	6	2	21	13	62	65	42	26
	Baseload (sum 1-11)	**320**	**130**	**335**	**150**	**330**	**203**	**190**	**360**	**370**	**461**	**350**	**270**	**289**
	Standby Load (sum 5-11)	120	53	159	98	245	170	113	100	154	391	173	176	163
	Standby vs. Baseload (%)	38%	41%	48%	65%	74%	84%	59%	28%	42%	85%	49%	65%	56%
	MELs Standby Load (sum 8-10)	106	45	121	88	165	161	105	75	120	321	100	126	128
	MELs Standby vs. Baseload (%)	33%	34%	36%	59%	50%	79%	55%	21%	32%	70%	29%	47%	44%

Standby loads look to be about 50% of the customer's selected monthly baseload value (lowest hour in June). The MELs are the source of most of the standby load, as we show in the sub-totals in Table 2. The load duration curves present a different type of information, as they show the Watts the end-use uses in standby, so refrigeration, which we exclude in Table 2's calculations, has a few watts of standby load. Combining both sets of data would produce some minor changes.

Figures 6 and 7 present load duration curves (sorting the consumption per hour in the period, from highest on the left to lowest on the right), which enable the researcher to better understand the levels of "off" loads, and numbers of active hours, and standby hours by end-use. For appliances such as modern refrigerators, which cycle twice an hour, better understanding of the active and inactive period require 1-minute data, as hourly data will suggest the appliance is always active.

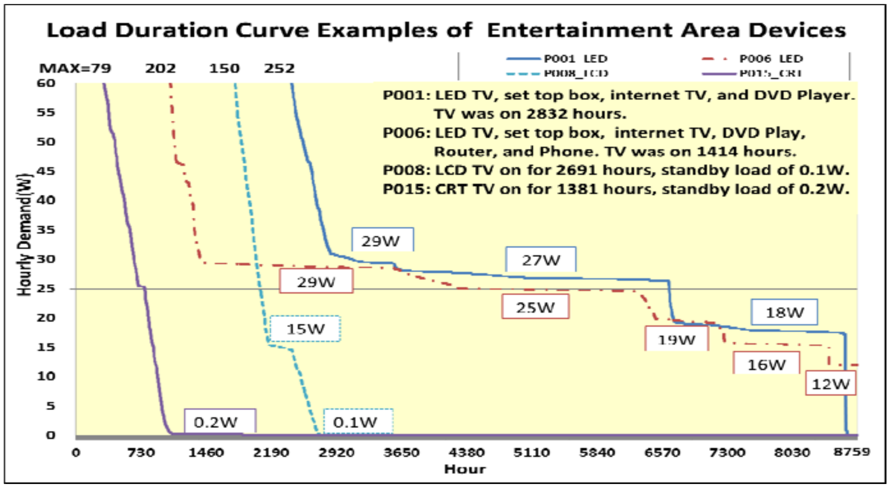


Figure 6. Television Load Duration Curve Examples.

This study metered TVs in two ways. Some TVs were metered independently, and in other locations we metered the power bar for the whole entertainment area. In some situations, metering by end-use would result in a lot of hardware in small space. Figure 7 shows two TVs metered separately, their standby loads are clear, and partial hours of operation create the slopes for the curves. The two examples where we metered the entertainment systems show the mix effects of the various devices. During the installation process we used a KilloWatt meter to measure the instantaneous loads of most devices. For P-001 from the right of the graph we can see the 18W constant load of the PVR set-top unit, the 9 W step up reflects time periods where the DVD player was left on, and the next 2 W step likely reflects the time when the PVR had the front lights on (i.e. not turned “off”).

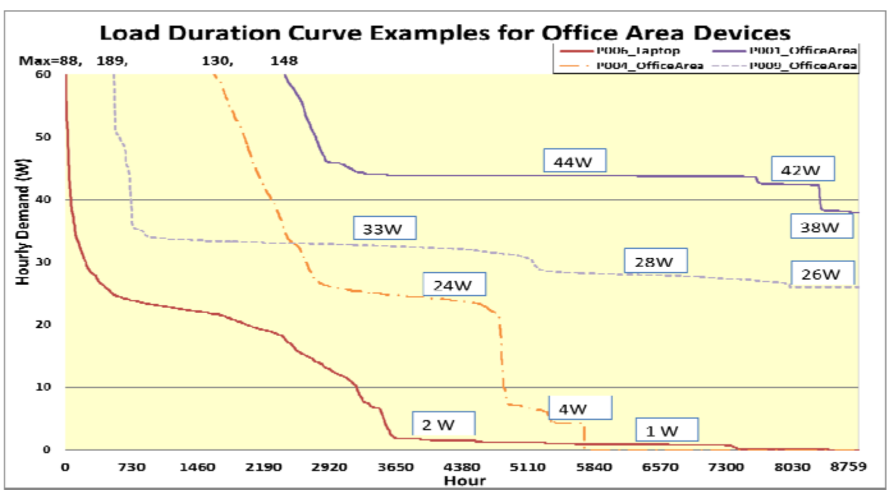


Figure 7. Office Area Device Load Duration Curve Examples.

Office areas, as seen in Figure 7, were handled similar to entertainment, with some devices metered separately and where necessary, the power bars were metered. The usage periods for devices such as computers, printers modems, and routers are summed for examples P001, P004 and P009.

Figure 8 below provides the load duration curve for one specific whole house, for June, and clearly shows the loads which contribute to the lowest 500 hours.

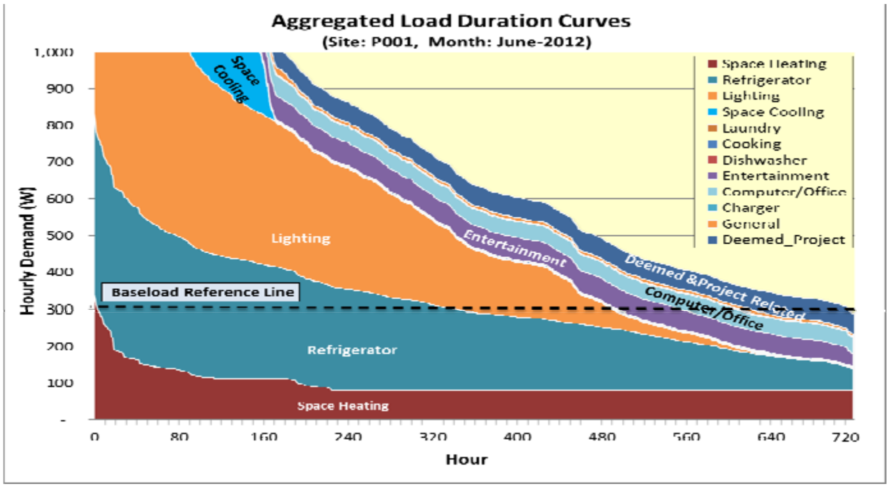


Figure 8. Aggregated Duration Curves of Site P001.

Reactive Power Characteristics of MELs in Homes

Traditionally residential loads have been assumed to have a unity or slightly inductive (lagging) power factor. This is due to the predominance of resistive (e.g. heating, incandescent lighting) or inductive (e.g. fridge motor, fan) loads. Figure 10 shows the annual kWh and kvarh inductive (lagging) for eight of the REUMP homes for 2012 and 2013. The shaded polygon represents an annual average power factor between 0.9 inductive and unity (along the X axis), which is the range of acceptable residential power factor expected by BC Hydro.

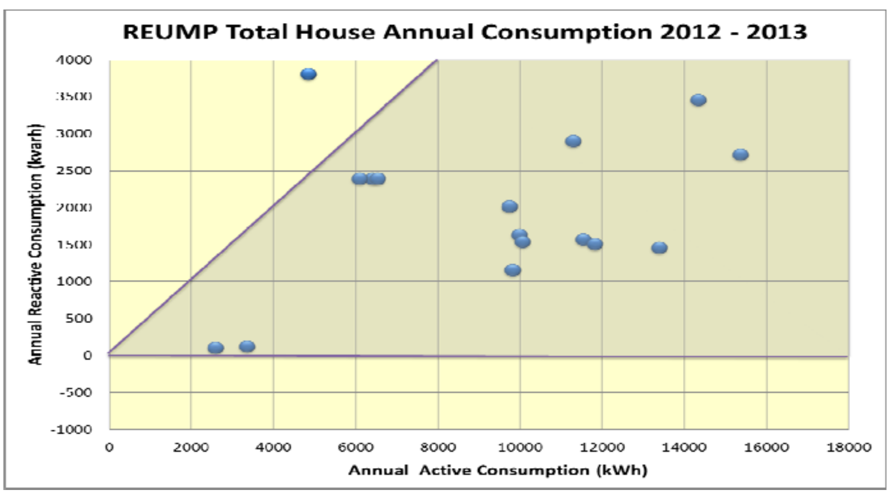


Figure 9. REUMP Total House Annual Consumption 2012-2013.

In recent decades electronic loads and electronic controls for non-electronic loads have increased significantly in homes. Many of these new electronic loads have capacitive rather than resistive or inductive characteristics. Eight of the REUMP homes were fitted with four quadrant meters that can measure the inductive and capacitive components of reactive load separately.

Figure 10 shows the annual kWh consumption of each home for each year along with the total kVArh consumption, blue for inductive and red for capacitive.

Note that almost every home has at times had a capacitive (leading) power factor, and the home with the lowest kWh consumption has consumed more capacitive kVArh than inductive kVArh, for both years. We suspect that these are not isolated cases, but that generally residential loads are becoming less inductive and more capacitive, and that at some point this could become an issue for distribution power factor and voltage management, which assumes that residential loads are always inductive.

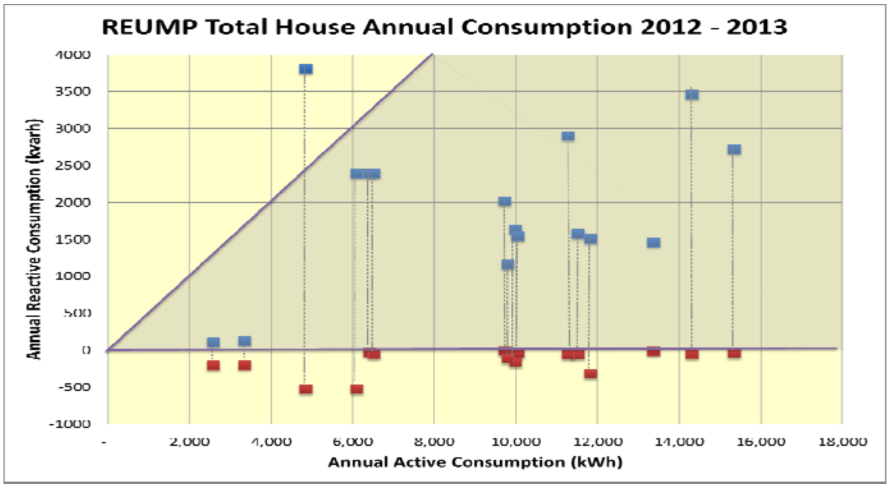


Figure 10. REUMP Total House Annual Consumption 2012-2013.

Almost all electronic devices exhibit capacitive loads, including computers, TVs and other home entertainment devices, and high-efficiency lighting (CFLs and LEDs). Figure 11 shows a similar graph for the TV sets monitored in the REUMP homes. Clearly most of them have capacitive loads, including some older CRT TV sets. Some of the larger loads represented include other devices, such as Set-top Boxes and CD or DVD players.

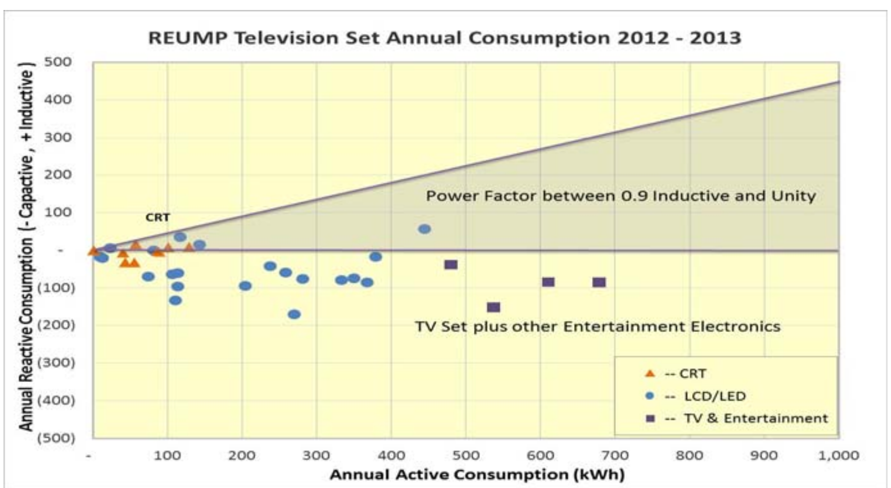


Figure 11. REUMP Television Set Annual Consumption 2012-2013.

Modern fridges, clothes washers, and other appliances that use electronically controlled motors also have capacitive rather than inductive characteristics. We will be monitoring this trend closely, as North American appliance Standards, unlike European Standards, do not address power quality parameters.

Conclusions: What We Have Found through End-use Metering

This paper presents only a few aspects of the REUMP project, and the analysis of the mountain of data (about 550 million records) has only just begun. Nevertheless, we may make the following conclusions now, with more to come as the data are evaluated.

1. Planning and implementing this project was an immense task, expensive and time-consuming. End-use metering is not to be undertaken lightly. Hardware, software from several vendors, communications with equipment and home-owners, data quality, and data security need to be managed together. Failure in any area affects all areas.
2. Some end-uses cannot be metered, for safety, practical, aesthetic, or legal reasons. For this project, these loads were estimated using deemed values.
3. Different sampling intervals provide differing insights into end-use operation and consumption patterns. Data recorded at the highest useful rate (1-minute) can be aggregated to longer intervals (eg 60-minutes) to provide alternative views.
4. The small set of 12 homes in the REUMP Phase III project are by no means a representative sample, but they do provide a glimpse into the diverse range of end-use consumption patterns in the community. It is clear that 'annual averages' have wide ranges from home to home, even for such ubiquitous loads like refrigeration.
5. The concepts of 'base load' and 'standby load' are more complex than they sound, and commonly used definitions do not cater for the subtleties of modern electronics.
6. MELs reactive loads are becoming as important as active loads, as is evident from the reactive load data from the REUMP project, as the reactive characteristics of MELs affects the reactive characteristics of the total house load.
7. Separating electric space heating from lighting, both in the residual unmetered load, has proven more complex than originally anticipated.

Next Steps for BC Hydro

1. Work with other utilities and research groups to improve the understanding of what the customers and the utilities can learn from smart metered hour load data. Continue our work on non-intrusive metering, and working with others in the industry to further this area. Currently we have equipment based on revenue meters which can record loads at 2 second intervals.
2. Expand our work with reactive power and harmonics, at the household level, as MELs may be increasing the utility risks and costs.

References and Related Papers/Presentations

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