Residential End Use Monitoring: How Far Can We Go?

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ABSTRACT

End-use monitoring in residential homes was well described by Bonneville Power Administration's End-Use Load and Consumer Assessment Program (ELCAP), 1986-1992. Since then many things have changed: the measurement equipment is smaller and better, the communications equipment is smaller and better, the data storage and handling is much easier, and overall the costs have plummeted. Residential end-use metering work is still very difficult, but it is now affordable.

Today, with off-the-shelf equipment, one can monitor almost everything in a house, except the lights. One historical weakness in this area was the inability to monitor all of the lighting sources, on an hourly basis, due to the use of mixed circuits carrying hard wired lighting and normal plug loads together. It was possible to economically measure the number of hours specific lights were on, but one did not generally know which hours they were on. Now one can meter all plug loads in the house except the lights, sum these measures by hour, and then subtract these values from the whole house consumption by hour. The residual is the lighting load and the very small wiring losses from inside the home.

This small feasibility study was run to determine the costs, and the implementation issues of "complete" metering. BC Hydro residential rate designers need to know when household loads are on, and which are on at peak, especially since this utility is winter peaking. This paper discusses the initial findings from this study.

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. 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 they may change. And when we do residential energy forecasts, we need to know how much more, or less, new appliances will be using, compared to the existing appliances.

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 discusses methodology learnings, and provides a variety of views on end-use data. And in the conclusions section, some research learnings, and some methodological insights are discussed.

End-Use Studies

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. 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 current end-use research in the US is on air conditioners, and it is done to understand how the TOU and curtailable rates work.

Phases 1-2-3-4

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 is a feasibility study which has expanded to three houses, and has been underway since September 2009. 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. We have three households of staff members in this feasibility study, and plan to expand the project to an additional 20 households (mostly utility staff) in a third (pilot) phase to ensure that we can handle the data flows, and process issues, and to learn more about the participants' reaction to the somewhat intrusive nature of this research, and to better understand the changes they will make, for energy savings. Finally, we want to gain support across the company to fund a 300 household, statistically acceptable sample, the fourth and final phase.

Methodology

In previous residential end-use research, by necessity, lighting and mixed plug loads were often viewed as one load, and metering was done on whole circuits, or not at all. In some studies it is not clear how the lighting loads were measured. With the 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.

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).

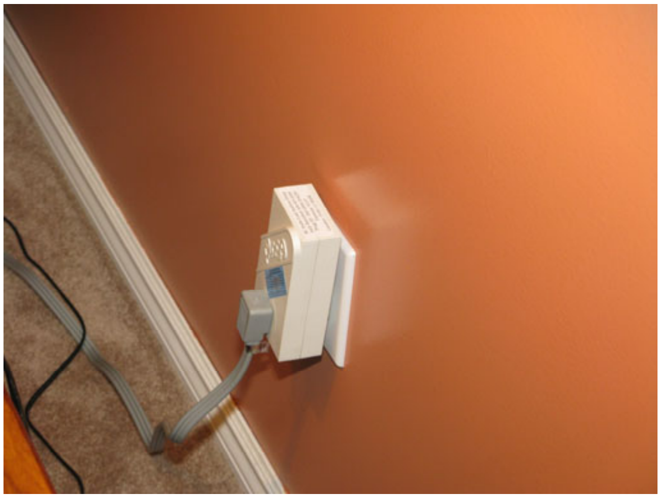
Direct end-use metering is seen as one of several complementary techniques for obtaining end-use loadshapes. We have a long series of residential end-use appliance saturation surveys, run on a biannual schedule. This survey has also been completed by many participants in our residential load research (hourly usage) sample, and experiments are underway with hourly conditional demand analysis (CDA), as well as renewed efforts for annual CDA values. End-use metering and CDA are complimentary tools which should be used together.

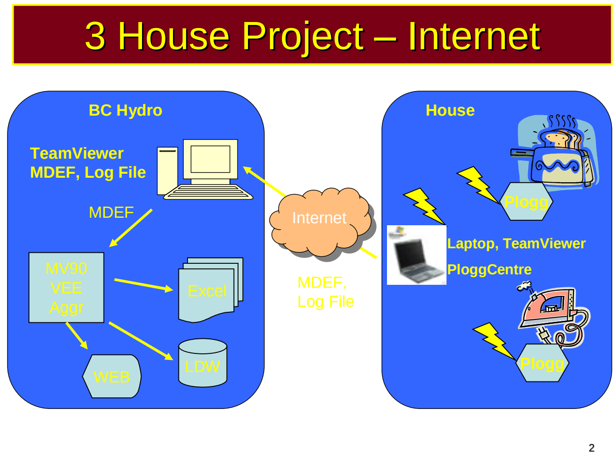
The enabling technologies which make this end-use load research possible in 2010 are the cheaper control/metering devices, which plug into a wall outlet, and have the appliances plugged into them. A few firms have equipment which can be used, or soon will be usable, for these purposes.

Energy Optimizers, of the UK, has a plug outlet monitoring and control device (see Figure 1, a) which can also record interval Watts, Wh, Vars, and Voltage for intervals between 1 and 60 minutes. 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 emailed to an MV-90 system at 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 Household Findings

Intrusion

Electrical extension cords, new plugs and sockets and electrical outlet based metering/recorders are somewhat intrusive. As the Plogg allows the use of only one of the two outlets at a service point, several additional extension cords and power bars are needed. An electric range may end up jutting 2" out into the kitchen, compared to how it fit before, due to the extra space required for the enclosure that we must place the CT versions of the Ploggs in. New outlets and plugs will need to be added for traditionally wired-in units such as gas furnace fans, and dishwashers.

Garburator

A special under-counter outlet for the garbage disposal unit, and a plug on the wiring cord for the unit were needed. We then discovered that with the standard operating switch being located above the kitchen counter, our wiring was on the "cold" side of the circuit. The Plogg device had no power to transmit readings, except for the few seconds that we ran the disposal unit. To correct this problem was going to involve another switch, on the kitchen counter. Then we did the math. The instantaneous load was 176W. The device is used for about 3 seconds, each morning and each evening. [176W x 6 seconds / 3600 x 365 / 1000 = .107 kWh/year] For less than one kWh per year we will not even deem the energy use of a device.

Deeming End-Uses

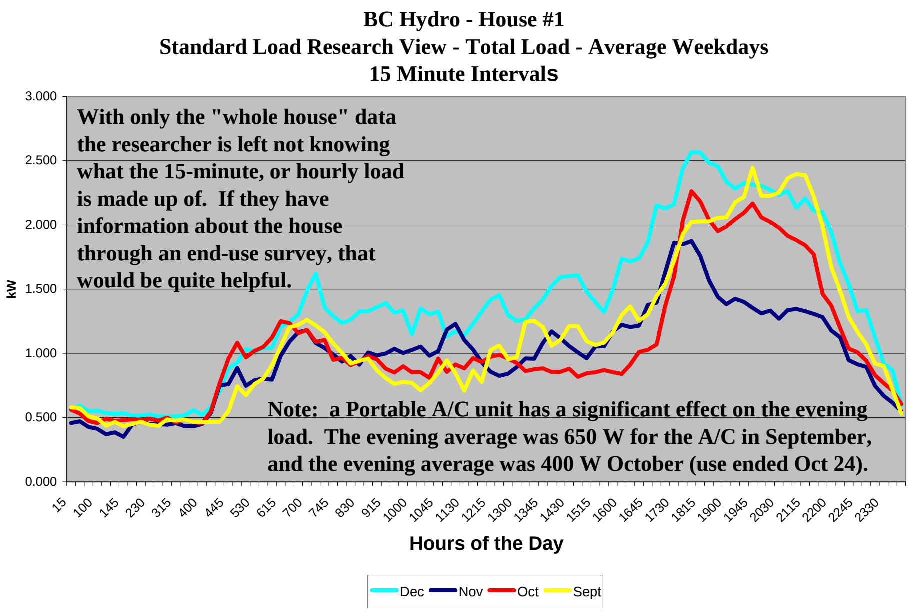
With "BC Hydro – House #1" we started out by trying to meter absolutely everything, knowing that we would not be doing this with very many households. It became obvious that some appliances or end-use loads should be instantaneously metered, and the hourly energy value deemed. Electric clocks and clock radios, at outlets which are only used for this appliance, do not need metering equipment. Small fans, which are switch operated, should be instantaneously metered and have the hours of use estimated by the occupant. The installation of an outlet metering device for fans is possible, but potentially very intrusive, and may leave a metering device in a location where the occupant cannot bypass the device if it fails. We have experienced occasional failures in devices due to the terminals not properly gripping thin male plugs. All recording devices are installed in such a way that the homeowner can easily bypass the device if necessary.

Interval Length Issues

Data has been collected in 15-minute intervals, the same approach this utility has used for its whole house load research for decades. While 15-minute intervals may be valuable to the distribution equipment side of the operation, to understand household appliances one might choose to use one minute data intervals for short periods. To communicate with stakeholders, hourly data provides a much clearer perspective, as with hour data there is no confusion between demand and energy values.

The traditional Load Research view of a household is 15-minute data at the whole house level. In Figure 2 it is clear that the evening usage is high in the September – October timeframe. With end-use monitoring we can learn why it is high.

Figure 2. Whole House View



Views of the Interval Data

There are several ways to look at interval data. The furnace data below provides two approaches. To understand how an appliance operates throughout the year, it may be valuable to look at average hourly or 15-minute interval use for all the weekdays, for each month (see Figure 3). With the furnace data we can see the change in the overnight load, and how long it takes to warm the house up in the morning, after the overnight set-back.

To better understand the impact of appliance loads on the system peak day, we can superimpose the peak day profile on the average weekday profile. In Figure 4 we show the actual 15-minute interval usage of the furnace fan on the system peak day, and the monthly average for December. The larger challenge with continuous-fan operation of new furnaces is to determine what the incremental load is for the system. To provide answers to this type of question will require recruiting households with both new and old furnaces into the sample, and using end-use survey data to better understand the changing mix.

Figure 3. Average Furnace Usage by Month

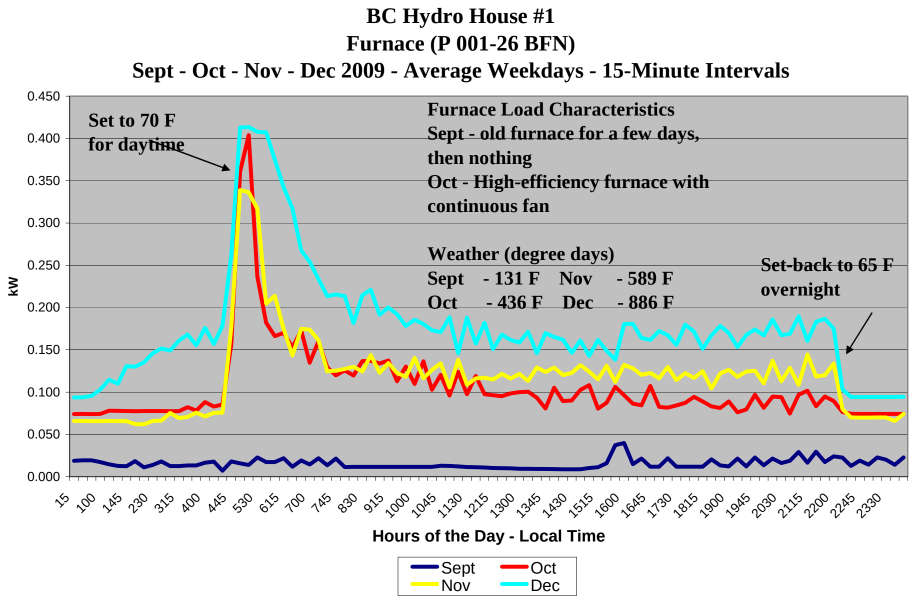
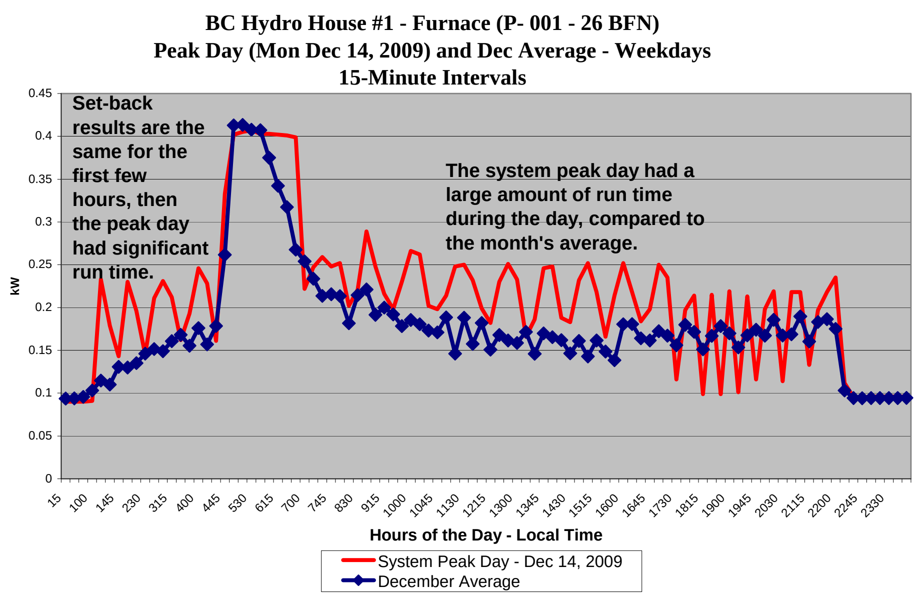


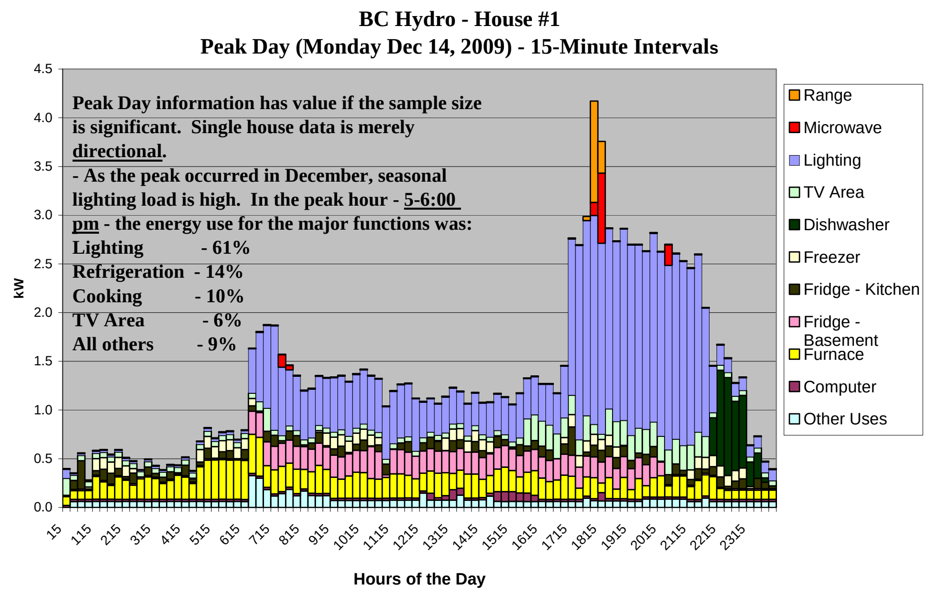
Figure 4. Peak Day Furnace Usage



Peak Day Analysis

From a system planning, or TOU rates perspective the energy use on the peak day, and especially in the peak hour is very important. The information in Figure 5 is only for a single house, so it cannot be interpreted as representing the residential sector. But in the "dinner hour" when the peak occurred, lighting, refrigeration, cooking and the TV accounted for 90% of the household consumption. The lighting load was especially high due to the use of seasonal lighting (Christmas) which almost tripled the expected lighting load. BC Hydro is a winter peaking utility, with about 45% of the system peaks occurring in December, so seasonal lighting load is a factor.

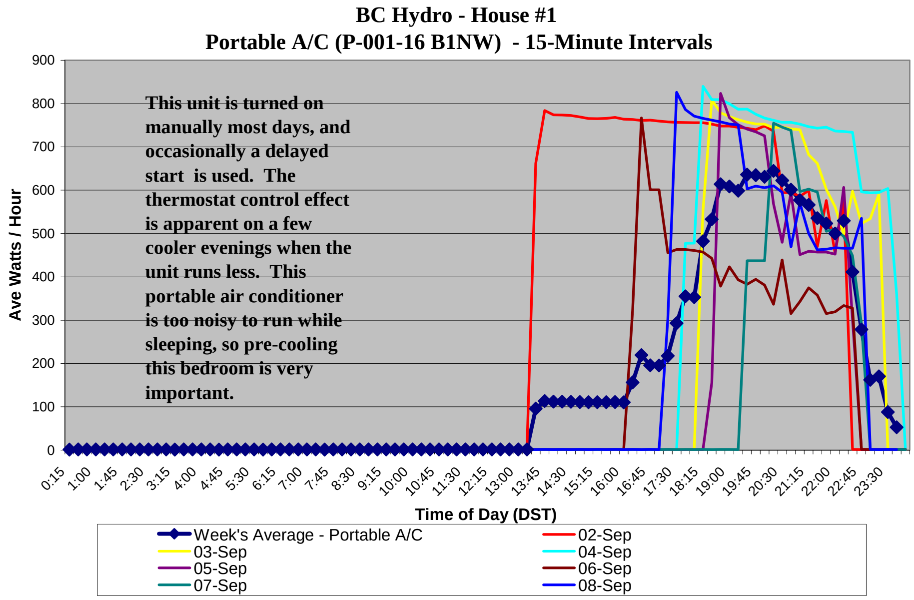
Figure 5. Peak Day Consumption by End-use



Effects of Averaging Load Shapes

Averages are made up of many different days for the individual household, and when available, for different households. In Figure 6 one week's average 15-minute use for the portable air conditioner is shown. To illustrate the variations in the daily loads, and show how the equipment is actually used, the 15-minute usage, for each of the seven days is also shown. This view is particularly important for equipment which is used sparingly, but has high instantaneous load.

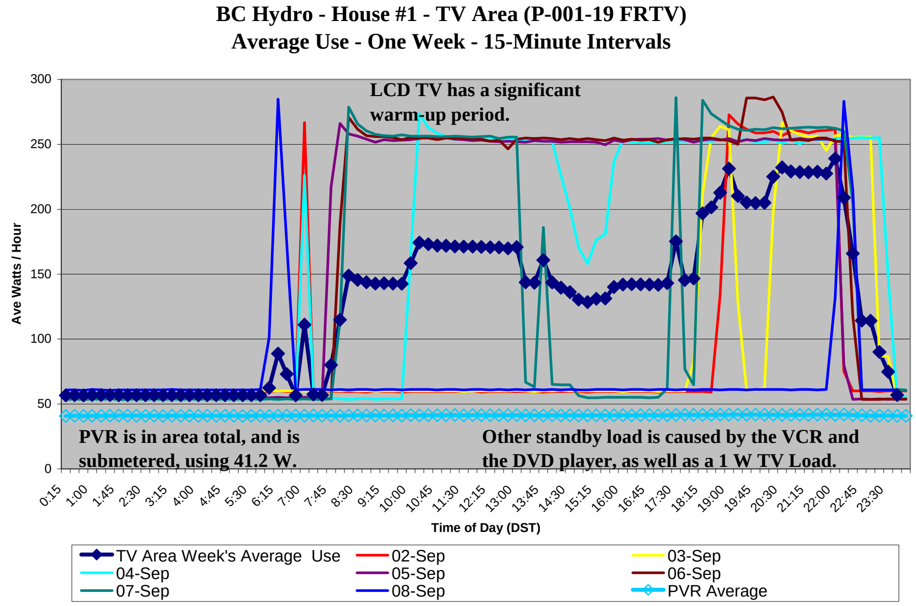
Figure 6. Daily Usage vs. Weekly Average – Portable A/C



Home Electronics

One of the most concerning end-use residential loads is the “new” TVs and the high-definition set-top boxes that many customers now use. A few years ago House #1 replaced an 80W 27” TV with a 200W 40” LCD TV. And it is likely that viewing time has increased. In this project BC Hydro is obviously looking for older TVs to monitor, as well as new units, as the load forecast group will want to estimate the effects on household consumption of that part of their customer base which is increasing their TV load. The Personal Video Recorder (PVR) which operates like a little computer and stores schedules and programs (like a TIVO), draws 40 W and is on all the time. Using the “off key” will only turn off the 1 W indicator light. Unplugging the unit will cause the TV to not operate properly for a few moments upon plugging the PVR back in, and it takes about 2 hours for the program schedules to be reloaded. The 40” LCD TV is estimated to use 300 kWh/yr. (1,500 hours) and the PVR is estimated to use 360 kWh/yr., compared to the previous 27” TV which used about 120 kWh/yr. From a household electricity consumption perspective, an impact equivalent to a “very large refrigerator” has been added to this home.

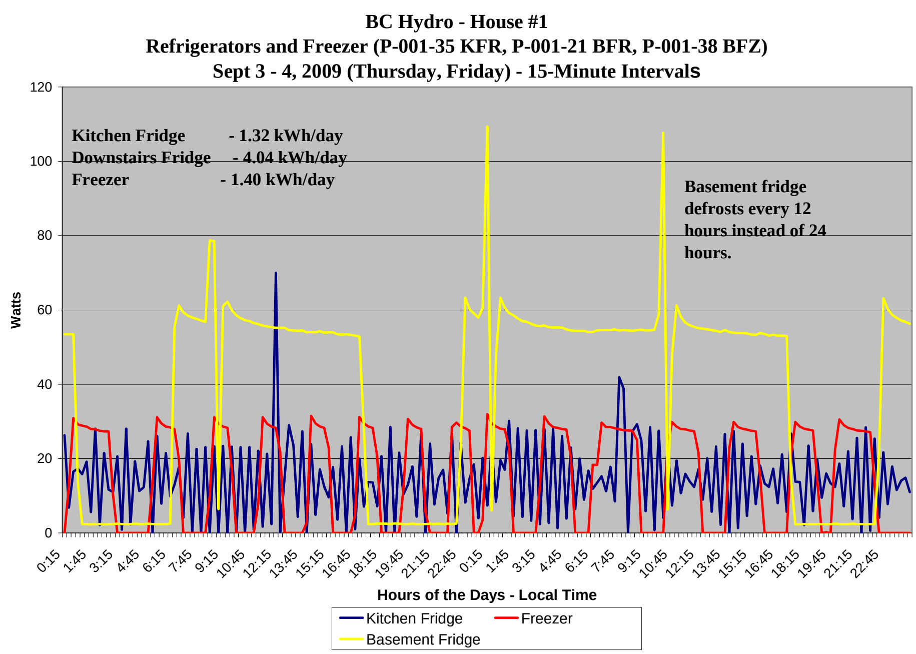
Figure 7. Daily Use vs. Weekly Average – TV Area



Refrigerators

Refrigerators do not all work the same. From a data quality and a mechanical interest perspective, looking at different refrigeration products' operating patterns, as we do in Figure 8, can be very interesting. However, the important load research information will be the average use per hour for the average day, and the seasonal response to temperature changes.

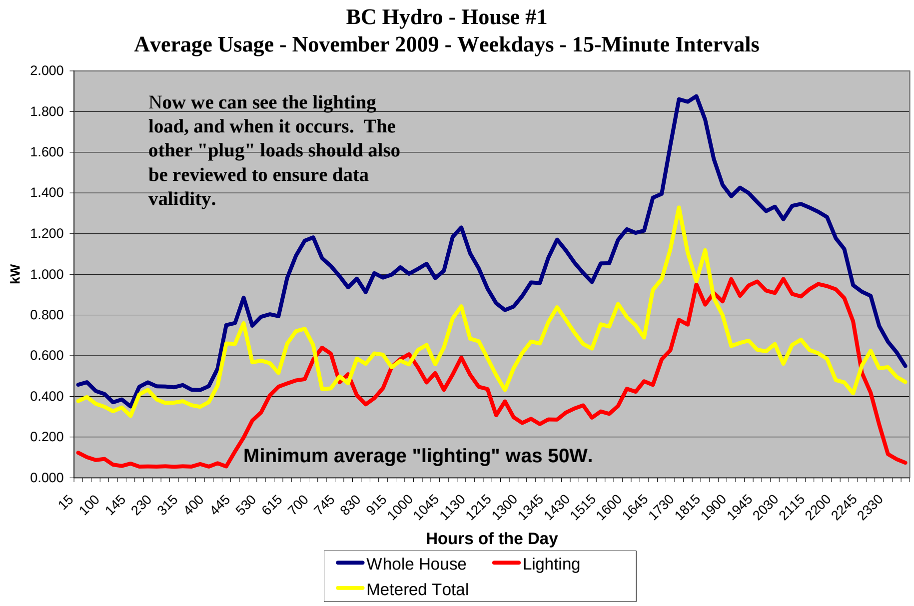
Figure 8. Usage Patterns of Three Refrigeration Appliances



Total Household Lighting

But a primary objective of this research was to understand total household lighting, and that consumption information can be calculated after the data cleaning for all of the other end-uses, as shown in Figure 9.

Figure 9. Average Lighting Load by Month

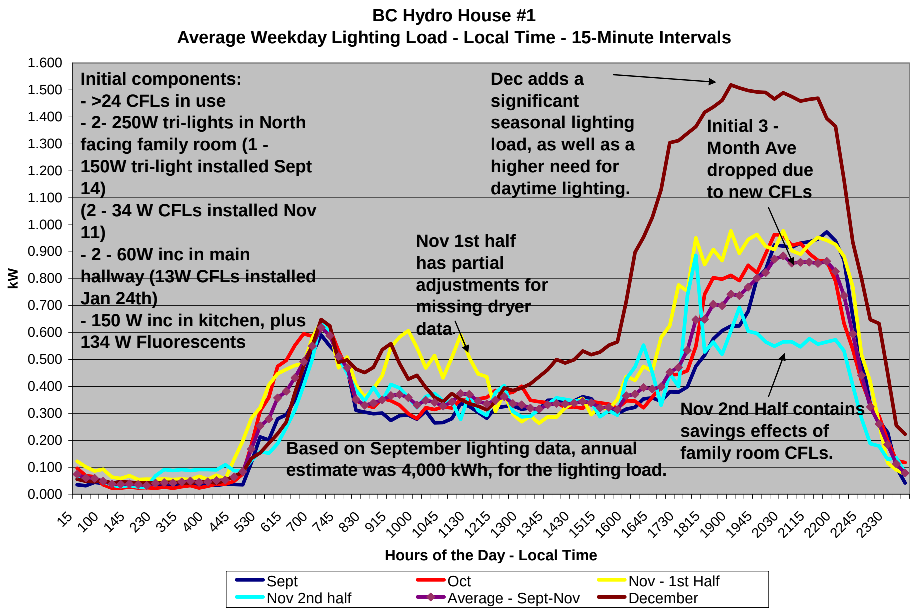


Lighting presents many challenges, and the interpretation of the findings is also complicated by the need for strict data cleaning processes for all metered end-uses. With this approach to lighting, all of the data errors, and timing issues between equipment, affect the data integrity for the lighting load. One unexpected issue related to the timing differences between the whole house recorder, and the Plogg metering devices inside the home. If the whole house recorder is one minute ahead of the in-home outlet recorders, then when a clothes dryer comes on its 3000W load has one minute allocated to the lighting load, which shows up as a 200W jump in the 15-minute interval. If the whole house recorder is one minute behind the in-house outlet recorders, then the lighting load gets a 15-minute interval -200W value. These values get reversed at the end of the clothes dryer duty cycle.

Any missing data for plug loads falls into the lighting load. We have found that irregularities in the lighting load can highlight the larger device metering errors. The data validation or VEE work is fairly simple for appliances that have constant loads. For devices without standby loads, and which are only used occasionally, like a clothes dryer, the missing data was discovered by lighting data issues. BC Hydro has now developed its own data retrieval system to improve the quality and flow of data, and to provide better error flags.

Lighting loads change over the year. At the 49^{th} parallel the daylight varies from 8 hours at the winter solstice to 16 hours at the summer solstice, so each month will have a slightly different average load shape.

Figure 10. Lighting Use by Month



Behaviour and the Effect of Information

Behaviours also change, as does equipment when research participants gain information on their household consumption patterns. Figure 10 shows the average weekday consumption for the months of September, October and December. November is split into two parts due to the significant effect caused by replacing two incandescent tri-lights (50-100-150 W, and 50-200-250 W), with two 34W CFLs. While the study house had over 24 CFLs in it for some time, the two largest incandescent bulbs had not been replaced, as appropriate CFLs were not available. More diligent searching found two CFL bulbs with appropriate colour, and of 34 Ws. The seasonal lighting load at Christmas is very significant, and it is possible to see the advancement of the hours of use in the later months.

Conclusions

1. Research Learnings

a. The whole house lighting load can be measured, and can be quite significant during the peak hours in a winter-peaking utility.
b. The high-efficiency gas furnace electric fan consumption can be very significant, and the information will be important to load forecast staff.
c. Refrigeration electricity usage patterns can be quite different and new refrigerators cycle very frequently.
d. Participants will change their electricity use behaviour, simply because of the end-use metering, and this needs to be considered when contemplating how "expansion" to the population can be handled.

2. Methodology Learnings

a. With all metering equipment errors falling into the "lighting load", minimization of equipment failure or loss of data is extremely important.

b. Timing of the whole house metering equipment, and the end-use metering equipment needs to be synchronized, or data quality issues result.
c. Data validation, evaluation and estimation (VEE) processes are simple for some small, constant load devices, but for most sporadic, large residential loads, VEE is possible on a daily or weekly basis, but while hourly VEE can be done, the impact on the accuracy/relevance on the lighting load is significant.
d. We could not find protocols for end-use research, and so we have written our own protocols, to increase the useful life of the collected data, and to improve the transferability to other jurisdictions, and other analytic uses. These protocols are a work in process, but the current version is available to whoever wants a copy. Residential end-use surveys are a supporting effort, and will facilitate expansion back to the population, and conditional demand analysis is potentially a complementary tool.

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