Do-it-Yourself Home Energy Audit: Tricks and Techniques

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ABSTRACT

The recent proliferation of electric devices in the home has resulted in increased electric use per household despite the improved efficiency of major end uses, appliances and lighting. This is largely attributable to plug loads, specifically more electronic gadgets and standby ("vampire") loads. This has outstripped application of standards and the energy industry's ability to monitor and influence them. Driven by consumer demand, the sheer number of devices added each year has increased the "miscellaneous" category of electric use to the point where the typical energy profile of homes is becoming even more mysterious.

Recognizing this, the author initiated a do-it-yourself home metering project to reconstruct how energy was used and, most importantly – when! With the expected adoption of smart grid and time-differentiated rates, it is no longer sufficient to simply know how much electric energy is used. Knowing what and when electricity is used could enable cost savings even where overall reduction in energy usage may be minimal.

The results of the study provided significant and unexpected potential sources of energy savings that would not be otherwise noted in typical utility web sites. The most valuable information from the study was the various tricks and techniques developed for metering. Using inexpensive short-term metering, the author was able to identify 100% of the energy end use in the home at a reasonable cost. These techniques could be used by consumers and utilities to provide energy and cost-savings tips for residences, which will prove invaluable right away and once the new smart-grid-enabled rates begin.

Introduction

Background

The purpose of a home energy audit is to catalog energy uses in the house, including all fuels, to identify physical aspects of the house, including building envelope, and to identify measures that could improve the energy efficiency of the house, and reduce energy use and costs via various means. Traditional energy audits of residences have typically focused on reducing overall energy consumption, regardless of when it occurs, because typical residential electric and gas rates have been flat, with only some seasonality (such as higher summer seasonal rates), reflecting utility costs. In researching various energy management sources, the emphasis has generally been on the major end uses and appliances, such as heating, cooling, water heating, refrigeration, cooking and lighting, with other end uses categorized as "Miscellaneous Electric Loads (MELS)." Much of the emphasis of the energy industry has, understandably, been on reducing energy consumption for the major end uses, with appliance standards and labeling initiatives such as ENERGY STAR®, and utility and government incentives, such as rebates, to encourage more efficient end uses.

Scope

This paper focuses on some tricks and techniques developed by the author during over 30 years of evaluation work for the utility and government energy industry, with an emphasis on those “miscellaneous” energy uses (primarily “plug” loads) that have grown and become a more significant factor. As noted by the Department of Energy (DOE) in a 2005 report, “The demand for electricity to power appliances is projected to increase rapidly. Electricity consumption for home electronics, particularly for color TVs and computer equipment, is also forecast to grow significantly over the next two decades. The Energy Information Administration (EIA) projects electricity consumption to grow 3.5 percent annually for color TVs and computer equipment through 2025, to more than double the level of consumption in 2003.”[1] More attention has been paid to these miscellaneous uses recently, particularly as they relate to what has been referred to as “vampire” energy use, representing the small - but mounting – electric use by devices that continue to draw power even when “idle,” such as electronic device chargers, set-top boxes and computers that remain “on” virtually 24 hours a day, 7 days a week.

Methodology

A common expression in the energy industry is “You can’t manage what you can’t measure.” This expression refers to the limitations of assessing energy use without hard data. Typically, the only information on residential energy usage available to the consumer, utility manager or energy program evaluator is monthly energy consumption. The increasing adoption of automated metering infrastructure (AMI) by utilities, a component of the new “Smart Grid” trend, is intended to provide additional information to the utilities and their customers to enable them to assess the load patterns in more detail than what monthly kWh readings can provide. These types of applications provide the means to “measure” detailed energy profiles for the first time on a widespread basis, which had been previously too costly to do on more than a sample of customers for load research purposes. Armed with this information, utilities could then design and develop more innovative rates that more accurately track variable costs for supply and delivery by time of day and day type, possibly even to an hourly basis. Consumers would have more information to inform them on their own energy use patterns. The AMI systems could also serve as two-way real-time connections to end users and their loads for use in managing peak loading on the grid, which previously had been done by separate load control systems – mostly one-way, via switches on major end uses. One-way switch systems have been in use by utilities for many years, going back to Detroit Edison, who built a 200,000 unit water heater radio-controlled load control system back in 1968. With AMI, more of these systems will be possible and certainly more cost-effective.

From a utility perspective, information on appliance saturation, fuels for heating and water heating, thermostat operation, use of high-efficiency products, and operating characteristics of those “miscellaneous” electronic appliances that are growing in importance, is critical in planning for growth and targeting energy programs. From a consumer perspective, residents typically know little about how electric end uses and devices use energy and will need more information to intelligently respond to new rates and energy programs facilitated by utility AMI systems. In anticipation of this, a new industry has already sprouted, referred to as Home Area Networks (HANs) that is intended to provide consumers with monitoring and control capabilities for their electric end uses and devices, many with the cooperation of their local utilities and Smart Grid vendor partners.

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[1] “U.S. Household Electricity Report” DOE 2005

As a first and most basic step, consumers will need to assess their own home energy consumption and use patterns. Utilities have traditionally offered "energy Audit" services to their customers – often for free – as a way of informing them of energy-saving opportunities, with the hope that some (or most) of the recommendations provided will result in energy savings to the customer and associated lower costs for the utility. While helpful, the typical limitation of walk-through audits is that they are often not detailed enough and cannot possibly include even the type of short-term metering (one week or more) to be reliably accurate, especially for the miscellaneous uses that are becoming more of a factor in home energy consumption. If consumers performed their own energy "audits," they would be more invested in the results and more likely to act upon the information. Armed with some basic tools, information and education, the residents can be taught to conduct at least some aspects of an energy evaluation of their own home. From a utility perspective, providing tools and education to consumers can have significant benefits, in terms of public relations and understanding of peak and energy impacts.

To test this theory, the author conducted an energy audit of his own home, using some of the knowledge gained from over 30 years of energy monitoring experience, without benefit of an engineering background or audit training. To prepare for an energy audit, as per a standard Energy Management course textbook[2], the first phase consists of the following:

- Facility Data: Geographic Location and Facility Layout
- Weather Data
- Analysis of Energy Bills
- Audit Tools (Metering)

The facility information involves the home's layout and size. The author's home consists of a 2,000 square foot colonial style single family wood frame house in a New York City suburb, including the original structure built in 1923 and a second-story addition, added approximately in 1977, consisting of the Den (first level) and master bedroom (second level). The site has eleven (11) rooms, including 4 bedrooms (3 from the original structure), den, study (office), kitchen, living room, dining room and 2 bathrooms, along with unheated areas: a workshop (former 1-car garage), attic, basement, and 2-car detached garage.

Weather data was obtained from the http://www.weatherunderground.com site, using the Laguardia (NY) airport weather station, located approximately 10 miles west. This site is particularly helpful since you can obtain a comma-delimited extract of any time period in the summary monthly format (Table 1) if you are a registered user (free of charge). Heating degree days (HDD) and cooling degree days (CDD) were calculated based on a 65-degree base (mean temperature – 65 for CDD, 65 – mean temperature for HDD) for each time period matching the electric and gas meter readings.

Table 1 – WeatherUnderground.com Daily Summary Weather Data

	Temperature			Dew Point F			Humidity %			Bar. Pressure In.			Visibility (mi.)			Wind Speed (Mph)				Cloud	
Date	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Gust	Precip	Cover	Conditions
2009-8-1	84	76	69	67	61	54	81	63	39	30.09	30.04	29.96	10	10	10	13	7	18	0	3	
2009-8-2	78	75	73	72	69	66	89	82	71	30.02	29.91	29.82	10	7.7	1.5	17	8	23	0.63	7	Rain-Thunderstorm
2009-8-3	84	78	72	68	64	56	87	64	42	29.99	29.95	29.89	10	10	10	12	6		0	3	
2009-8-4	86	78	73	69	63	58	74	57	44	30.01	29.95	29.86	10	10	10	17	5	23	0	1	
2009-8-5	89	82	75	72	67	59	85	64	46	29.92	29.87	29.84	10	9.3	6	21	7	20	0	5	
2009-8-6	79	74	69	59	55	51	61	53	40	29.99	29.95	29.91	10	10	10	10	7		0	6	Rain

[2] Capehart, Turner, Kennedy, *Guide to Energy Management*, Sixth edition, Fairmont Press, 2008

The energy bill analysis included electric and gas bills for at least 12 months, provided below in Tables 2 and 3 below, which also include the average rates per kWh and therm, and HDD and CDD weather for each billing period. Annual consumption from these bills was then disaggregated into gas and electric end uses and appliances in the home. This was done with a combination of regression analysis models for heating, water heating, cooling and other gas end uses, Kill-a-watt™ and Watts-Up Pro™ Logger metering for selected end uses and electronics, and inventories and hours-use estimates for lighting. The following sections detail the analysis for each major end use category, including estimated additional (extra) holiday lighting.

Table 2 – Electric Bills[3] and Weather Summary

Lopes - 49 Cody Ave - LIPA Bills													
Read Date	Meter Read	Actual /Est	Days	kWh	kWh/ Day	CDD	HDD	Delivery/ Supply	Supply & EER	PILOTS & Tax	Total $	Total $/ day	Average Rate
08/19/2009	46982	E											
09/22/2009	48026	A	34	1044	30.7	215	10	$104.54	$107.79	$9.53	$221.86	$6.53	$0.213
10/20/2009	48668	E	28	642	22.9	31	211	$59.38	$66.29	$5.65	$131.32	$4.69	$0.205
11/18/2009	49341	A	29	673	23.2	0	309	$66.93	$78.78	$6.56	$152.27	$5.25	$0.226
12/17/2009	50142	E	29	801	27.6	0	594	$62.84	$73.41	$6.14	$142.39	$4.91	$0.178
01/21/2010	51211	A	35	1069	30.5	0	1145	$92.44	$107.72	$3.07	$203.23	$5.81	$0.190
02/18/2010	51894	E	28	683	24.4	0	915	$60.40	$70.96	$7.65	$139.01	$4.96	$0.204
03/23/2010	52971	A	33	1077	32.6	0	680	$92.60	$111.90	$11.85	$216.35	$6.56	$0.201
04/20/2010	53564	E	28	593	21.2	9	281	$53.31	$61.61	$6.71	$121.63	$4.34	$0.205
05/17/2010	54359	A	27	795	29.4	54	155	$68.97	$82.60	$8.80	$160.37	$5.94	$0.202
06/18/2010	55117	E	32	758	23.7	194	21	$72.41	$76.16	$4.86	$153.43	$4.79	$0.202
07/22/2010	56170	A	34	1053	31.0	575	0	$105.42	$103.00	$6.77	$215.19	$6.33	$0.204
08/18/2010	56939	E	27	769	28.5	409	0	$77.15	$75.23	$4.95	$157.33	$5.83	$0.205
09/22/2010	58146	A	35	1207	34.5	302	1	$120.50	$118.07	$7.75	$246.32	$7.04	$0.204
Totals	11164		399	11,164	28.0	1789	4322	$1,037	$1,134	$90	$2,261	$5.67	$0.202
per year			1.093	10,213							$2,068		
per month				851							$172.34		
Holiday extra				170									

Table 3 – Natural Gas Bills

Lopes - 49 Cody Ave - National Grid Gas Bills													
Read Date	Meter Read	Actual/ Est	Days	ccf	ccf/ Day	Avg Temp	Therm Factor	Therms Used	Delivery Cost $	Gas Supply Cost $	NYS / Local Surcharges	Total $	Total $/ Therm
09/09/2009	1450	C					1.0180						
11/30/2009	1560	C	82	110	1.34	56	1.0180	112.0	$128.86	$76.51	$3.19	$208.56	$1.86
12/17/2009	1662	E	17	102	6.00	40	1.0230	104.3	$62.59	$96.01	$1.55	$160.15	$1.53
01/21/2010	1920	E	35	258	7.37	31	1.0260	264.7	$145.00	$242.75	$3.61	$391.36	$1.48
02/18/2010	2137	E	28	217	7.75	31	1.0260	222.6	$120.20	$198.96	$2.99	$322.15	$1.45
03/23/2010	2184	A	33	47	1.42	44	1.0230	48.1	$61.10	$41.16	$1.49	$103.75	$2.16
04/20/2010	2262	E	28	78	2.79	55	1.0170	79.3	$74.38	$66.34	$1.84	$142.56	$1.80
05/17/2010	2265	A	27	3	0.11	60	1.0170	3.1	$13.11	$2.26	$0.31	$15.68	$5.14
06/18/2010	2304	E	32	39	1.22	70	1.0180	39.7	$50.59	$26.09		$76.68	$1.93
07/22/2010	2343	E	34	39	1.15	80	1.0190	39.7	$50.26	$28.28		$78.54	$1.98
08/18/2010	2374	E	27	31	1.15	79	1.0180	31.6	$40.29	$21.96		$62.25	$1.97
09/22/2010	2415	E	35	41	1.17	72	1.0160	41.7	$52.52	$24.63		$77.15	$1.85
10/19/2010	2464	E	27	49	1.81	63	1.0140	49.7	$54.75	$27.79		$82.54	$1.66

The frequency of utility readings may vary, although monthly bills are typical. Readings can often be estimated by the utility, especially, as in this case, if the location of the meter is not convenient for monthly meter reading. The gas meter in this case is indoors in the basement, which resulted in most readings being estimated and often inaccurate. The electric meter was read every other month, and was more accurate. As a result, it is recommended that consumers read their own meter and, for more accuracy

[3] LIPA bills separate various components, including Delivery/Supply (distribution), Supply and EER (generation and energy efficiency program/system benefits charges), PILOTS & TAX (payments in lieu of taxes). Surcharges are temporary fuel adjustments collected over several months. Meter reads are noted as either A-Actual, E-Estimated, or C-Customer-supplied

and to enable weather modeling, read it more frequently – even daily – to better understand their consumption patterns. For the period 2005 through 2010, the author logged gas meter readings at least weekly during the winter and mostly daily in the cold weather, which enabled a more accurate regression analysis to be done, as described in the results section on Heating and Water Heating.

In terms of audit/metering tools, the principal tools used were Kill-a-Watt™ meters, a Watts-Up Pro™ Logger and the PowerCost Monitor Wi-fi system. Three Kill-a-Watt™ meters and one Watts-Up Pro™ logger were used and rotated among end uses for short periods up to a week, sufficient to establish the load patterns. Each is appropriate for consumer (non-energy professional) use and is no more difficult to use than programming a VCR, although the Wi-fi option for the PowerCost Monitor will require some moderate computer skills. For lighting, a simple inventory of fixtures, bulbs and wattages was used, together with the author's own estimates of hours per week usage. It should be noted that the meters and systems used for this analysis are typical, but not the only options available.

The Kill-a-Watt™ meter (pictured at right[4]) is a plug-in unit that records instantaneous electric use statistics, specifically volts, amps, watts, volt-amps, frequency, and power factor, as well as cumulative kWh and time elapsed. It does not have recording capability, so repeated readings must be taken, recognizing that typical devices have three states: full-on, standby and off, each with its own profile. The technique used was to record the instant readings during each "state," meaning active "on," standby, and off (if different) and take readings each time the state changes, averaging wattage during each state over a sufficient period of time to get an accurate average level for each state. Most equipment has an active "on" state, like when a light bulb is on. Switching the units "off" often only switches them to a standby state, which may still use electricity for some devices, and so is often referred to as "vampire" usage. This usage is typically overlooked, hard to detect and these devices may draw power all the time even when the unit may appear to be off. A true "off" state may only be possible when the device is unplugged. By utilizing a watt meter, you can detect this standby load and estimate annual consumption based on the number of hours per year that the device is in each state.

Table 4 – Hi-definition LCD TV Kill-a-Watt Reading Log

Samsung 53" LCD HD TV (EnergyStar)								
				KILL-A-WATT LOG				
Date		Time		kWh	kWh	Hours	kwh/hr	
12-Nov-10	Fri	11:35 PM	installed on					
13-Nov-10	Sat	12:35 AM		0.3	0.3	1.00	0.3000	on
13-Nov-10	Sat	01:35 AM		0.52	0.22	1.00	0.2200	on
13-Nov-10	Sat	03:00 AM		0.84	0.32	1.42	0.2259	on
13-Nov-10	Sat	08:45 AM		0.85	0.01	5.75	0.0017	standby
13-Nov-10	Sat	09:45 AM		1.06	0.21	1.00	0.2100	on
13-Nov-10	Sat	10:15 AM		1.16	0.1	0.50	0.2000	on
13-Nov-10	Sat	11:00 PM		1.17	0.01	12.75	0.0008	standby
14-Nov-10	Sun	01:00 AM		1.56	0.39	2.00	0.1950	on
14-Nov-10	Sun	01:15 AM		1.61	0.05	0.25	0.2000	on
14-Nov-10	Sun	09:00 AM		1.62	0.01	7.75	0.0013	standby
14-Nov-10	Sun	10:05 AM		1.63	0.01	1.08	0.0092	standby
14-Nov-10	Sun	11:00 AM		1.79	0.16	0.92	0.1745	on
14-Nov-10	Sun	03:20 PM		1.8	0.01	4.33	0.0023	standby
14-Nov-10	Sun	05:10 PM		2.18	0.38	1.83	0.2073	on
14-Nov-10	Sun	06:14 PM		2.19	0.01	1.07	0.0094	standby

As an example, Table 4 presents the results of the Kill-a-Watt™ readings for a hi-definition 53" LCD television (ENERGY STAR qualified) over a three-day period, with cumulative kWh, period kWh, recording interval and average interval kW (kWh/hr). Note that several "on" and "standby" states were recorded and averaged to produce the resulting estimates of 0.215 kW (215 watts) "on" and 1.3 watts during standby. Longer-term readings (over approximately one month) resulted in an estimate of 5.72 hours on per day, or 2,088 hours on per year and 6,672 standby hours per year, which calculates to 457 kWh per year.

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[4] The **Kill-a-Watt™** meter is available at computer and electronics stores, including Radio Shack, for under $40. The **Watts-Up Pro™ Logger** is available from the Watts-Up web site or Amazon.com for under $180. Other similar devices are listed in the end notes

The **Watts-Up Pro™ Logger** (pictured at right) is a more sophisticated meter that operates similarly to the Kill-a-Watt™ in that it is designed for use with plug loads. However, it does have recording capability, battery storage for readings and can be set to any recording interval down to 1 second. After initializing the unit and plugging in the device/appliance, the display can show the same set of statistics as the Kill-a-Watt™, as well as max and min watts, volts and amps, and current and cumulative cost, based on input pricing. The version used can hold 2,000 data values, which for the full set of data is about one week of 5-minute data, or one week of 1-minute data for only wattage data. The data can be downloaded via USB port (blue cable). The included software provides tables, which can be easily copied into a spreadsheet, as well as graphs that can be configured and zoomed. This meter is more useful for devices that have more static stages or variable levels, such as air conditioners, refrigerators and freezers, which may cycle often.

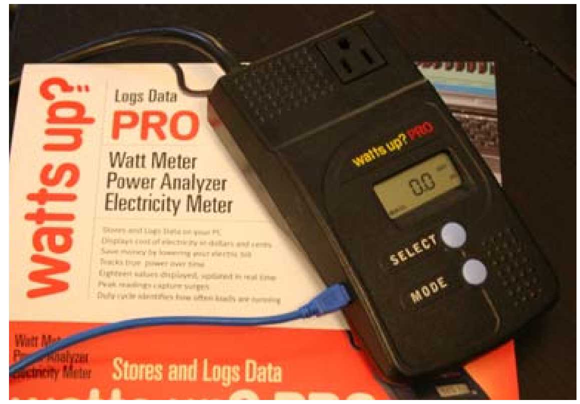


Figure 1 below shows the Watts-Up Pro™ graphic output for a camera battery charger. This device does not have a static stage. Instead, it declines gradually over about 2 hours, until the battery is fully charged, then declines to zero (no vampire use). In other measurements, a cell-phone battery charger was monitored and charged the cell-phone at 6 watts in 90 minutes, but then declined gradually (over 60 minutes) before dropping to zero. However, a battery charger for rechargeable "AA" batteries used a constant 1.8 watts and did not drop to zero after the batteries were charged (a vampire!). These chargers could be consolidated in a separate power strip (charging station).

Fig. 1 – Camera Battery Charger Watts-Up Pro™ graphic output

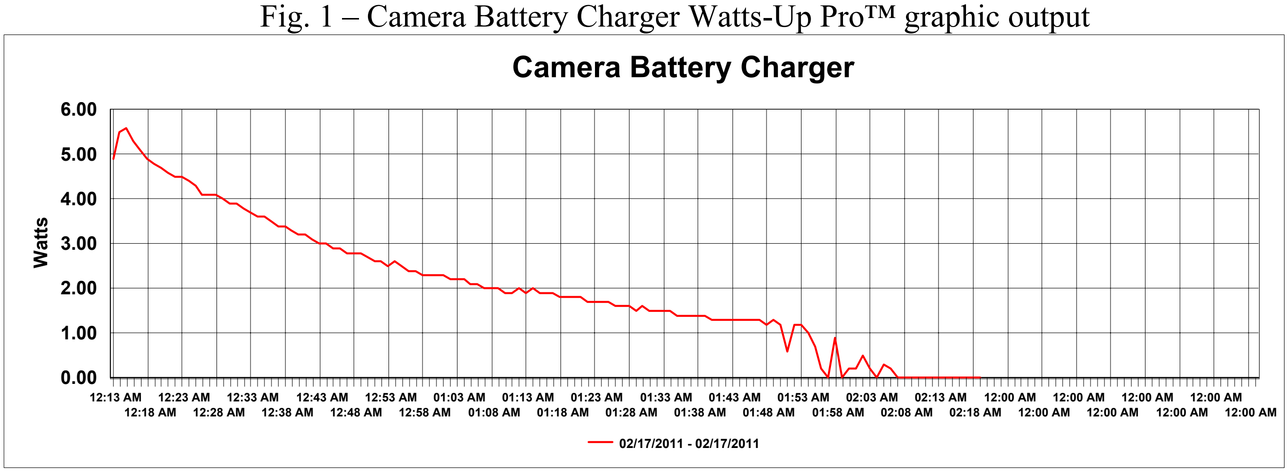
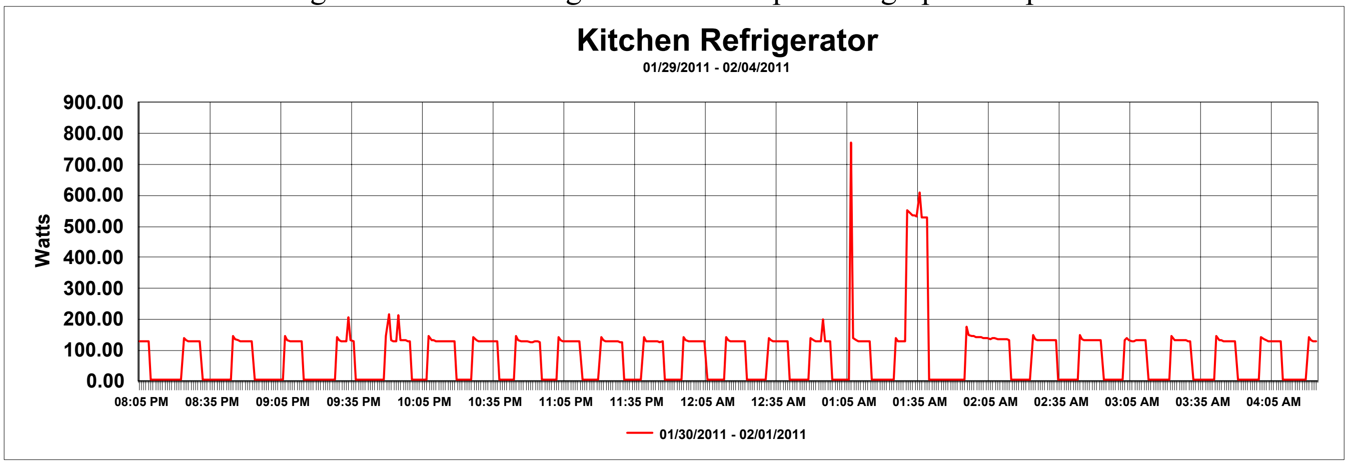


Figure 2 below shows a standard 10 year old 18 cu. ft. ENERGY STAR refrigerator load pattern using 1-minute interval data. Two higher levels are shown where the refrigerator and freezer each went through a defrost cycle of 600 – 800 watts of 2-5 minutes. On average, the unit cycles on for about 9 minutes, then off 10 minutes. The on-cycle averaged 138 watts, the off-cycle 4 watts. This pattern projects to an annual kWh consumption of 508 kWh, consistent with the Energy Guide label estimate of 450 kWh.

Fig. 2 – Kitchen Refrigerator Watts-Up Pro™ graphic output



The third metering tool used was the **PowerCost Monitor**[5] **Wi-fi system**,[6] which consists of a Blue Line Innovations (BLI) meter collar, a sensor that detects the utility meter dial spins, and a wi-fi collector unit. The system multiplies the dial spins by the meter multiplier and converts to kWh, and then communicates results in real time via radio with both an in-home display and the home wi-fi network. The data is then transmitted to a subscription service with Microsoft's Hohm site, which stores and reports on electric meter data.

Fig. 3 – PowerCost Monitor System, Wi-fi unit and in-home display

Microsoft Hohm is currently a beta test web site (http://www.microsoft-hohm.com) that recently developed links to the PowerCost Monitor.[7] The Microsoft Hohm site enables the user to input various characteristics of their residence and displays various graphics of the energy consumption interval data for monthly, daily and hourly bar graphs and line charts for detail down to one-minute intervals. The figures below show two of the displays. Fig. 4 shows hourly bar charts, which display the numeric values if you cursor over the hour's bar. These can be input to a spreadsheet for additional analysis. Fig. 5 shows a detailed chart showing spikes at 10:11 am (toaster) and 10:18 am (single-cup coffee-maker)

[5] http://www.powercostmonitor.com/

[6] The system is available from both the Blue Line innovations web site and is also sold in home improvement stores under the Black & Decker brand for under $150.

[7] Other interfaces are available, as noted in the end notes, including Google Meter.

Fig. 4 – Microsoft Hohm Graphic Electric Display

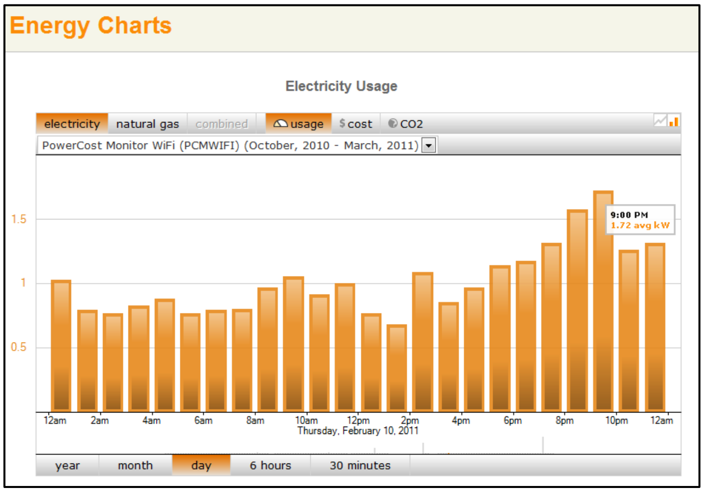
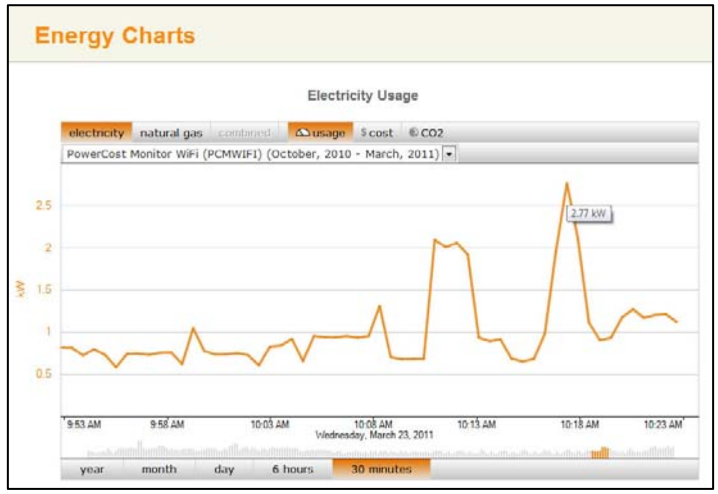


Fig. 5 – MS Hohm 1-minute Electric Profile



The system enables recording and display of interval electric meter data, which was used to calibrate hourly use estimates. For example, hourly load estimates for all electric end uses were calibrated by comparing the estimates for 9 pm and 4 am to the total house meter values from Microsoft Hohm. The 4 am loads were considered a good indicator of standby/"vampire" usage since all devices and lighting were generally turned off at that time, while 9 pm was typically the household peak hour.

For **lighting**, energy evaluators and auditors typically install light loggers to measure hours of use, or estimate based on survey or user self-reported data. One technique used by the author during evaluations is a check-box survey question, used by utilities, which specifically addresses the rebated lighting product as part of a participant or non-participant survey. The survey form typically looks like the following:

Please indicate below in the check boxes the hours on WEEKDAYS when you typically use the CFL you received as part of [UTILITY] rebate program

M	1	2	3	4	5	6	7	8	9	10	11	N	1	2	3	4	5	6	7	8	9	10	11	M

Please indicate below in the check boxes the hours on WEEKEND DAYS when you typically use the CFL you received as part of [UTILITY] rebate program

M	1	2	3	4	5	6	7	8	9	10	11	N	1	2	3	4	5	6	7	8	9	10	11	M

Ideally, these survey questions would be administered to a significant sample during at least summer and winter seasons to capture the seasonal differences, or even each of four seasons, if possible. Based on the results, the average hourly percentage of lighting on, seasonal and annual hours of use, and coincidence factors for utility peaks would be calculated. This technique was used in a lighting program evaluation conducted in 1991 for LILCO and results verified as reasonably accurate with light loggers. For this study, the author (and spouse) conducted a full inventory and made estimates of hours-use per day, including holiday lighting, and whether the lights were on at the key hours of 5 pm (utility system peak), 9 pm (house peak) and 4 am (for overnight base load estimate).

Results

Heating, Cooling and Water Heating - The principal heating system is a 139,000 BTUh high-efficiency condensing boiler, with rated efficiency (AFUE) = 93%, which produces hot water for circulation in a hydronic pipe system throughout the house via three zones, one upstairs (bedrooms) with a programmable heating thermostat and two downstairs (manual thermostats). This is considered a top-of-the-line efficient unit, and was installed during the conversion from oil to natural gas in 2007. The unit is integrated with a 36-gallon natural gas water heating unit, also a top-of-the-line efficient unit. With the gas meter covering all end uses, specifically heating, water heating, gas dryer and gas stove, there is no feasible direct way to meter any individual gas usage, so a regression analysis was performed to isolate the weather-sensitive gas usage for heating from the other gas end uses (dryer, range and water heat). The regression analysis uses an Excel function, which is available to any MS Office licensee. Using gas readings and heating degree days (HDD) for the winter of 2009-2010 taken mostly daily, especially during cold spells, but sometimes up to 5 days apart (44 total readings over the 120 day period), the regression analysis is calculated by the formula:

Table 5 – Gas Consumption Regression Analysis Results

Weather Regression		ccf = HDD x A + Days x B + K; K forced to 0			
		Regression Output:			
	Constant			0	
	Std Err of Y Est			3.233086	
	R Squared			96.7%	
	No. of Observations			44	
	Degrees of Freedom			42	
			HDD	Days	
	X Coefficient(s)		0.178034	0.3097554	
	Std Err of Coef.		0.0039031	0.0239134	
		t-stat	45.6	13.0	
	Normal Annual HDD		4777		
		Annual ccf	850	113	964

Natural Gas usage (ccf) = HDD x A + Days x B + K

with A = weather-sensitive coefficient

B = daily non-weather sensitive Natural Gas usage (ccf)

K = constant term, which was forced to zero

The result was a weather-sensitive coefficient of 0.178 ccf/HDD and consumption of 0.310 ccf/day. The correlation coefficient (R^2) was 96.7% and the t-stats for each variable (A and B) indicated each was a highly significant (meaningful) variable. Applying the normal annual HDD for this area (4,777 HDD vs. actual 2009-2010 HDD of 4,134) yielded a normal annual usage for heating of 850 ccf and non-weather sensitive usage of 113 ccf. This means that the total gas usage for water heating, dryer and stove usage is 113 ccf.

To calculate total summer weather-sensitive kWh for all air conditioning and fans and for heating-related electric consumption for pumps and fans, a regression analysis was performed for HDD and CDD (cooling degree days), with the following result:

Table 6 Electric Consumption Seasonal Regression Analysis

Annual Regression				
	Regression Output:			
Constant			0	
Std Err of Y Est			129.80658	
R Squared			65.9%	
No. of Observations			13	
Degrees of Freedom			10	
		CDD	HDD	Days
X Coefficient(s)		0.4218	0.1135	25.0783
Std Err of Coef.		0.2813	0.1357	2.8018
	t-stat	1.4991	0.8366	8.9507
2009-2010	Annual kWh	664	490	9,154

The regression indicates weather-sensitivity of 0.4218 kWh/CDD for cooling and 0.1135 kWh/HDD for heating, plus a base load of 25 kWh/day. Using actual 2009-2010 weather, that results in 489 kWh for heating (rounded to 490 above) and 664 kWh for all cooling, which includes three room air conditioners (master BR, Den and partial season use in Study) and attic fan. Several ceiling fans (Den, Master BR) are used year-round so are not included in summer weather-sensitive totals. The author anticipates collecting air conditioner logger data and performing daily regression analyses during the summer of 2011.

Cooking and Food Storage - Cooking consists of a gas stove (gas estimate provided earlier), microwave, coffee-maker, toaster and several miscellaneous cookers. Kill-a-Watt™ readings were taken for each of the latter major end uses to estimate demand, and user estimates of number of cycles were used for projecting annual kWh. For food storage, a main kitchen refrigerator, small portable refrigerator and large freezer were all monitored by a Kill-a-Watt™ to produce on and off and cycling frequency estimates over several weeks.

Laundry - Laundry consists of a gas dryer (estimated previously), a front-load washer, and a dishwasher. The washer usage was monitored with a Kill-a-Watt™, with number of loads per week estimated, while the dishwasher consumption was estimated based on the minimum federal standard (unit is not ENERGY STAR qualified), assuming an energy factor (EF) of 0.46[8].

Lighting - Lighting usage estimates were based on a complete inventory of all lighting fixtures in the home, combined with estimates of hours use per fixture, as described previously in the methodology section. Since this is a residence, occupant estimates were considered reasonably accurate.

Electronics - Electronics were the most difficult to inventory and estimate, because of the variability and number of devices. Kill-a-Watt™ devices were used in nearly all cases to estimate the "on" and standby states, with user estimates to calculate hours per year. In some cases, several days to a week of continuous monitoring were used to assist in the estimate of hours use. In the case of the computers, the power management options were engaged and Kill-a-Watt™ units confirmed their performance. For example, typical power management options turned off the monitor after one hour idling and the hard drive was set to standby after 2 hours. Of particular note in the electronics category were the four digital cable boxes (one with recording capability), two mini set-top boxes, four PC's, seven LCD TVs, 2 printers and various stereo components, including two subwoofer speakers.

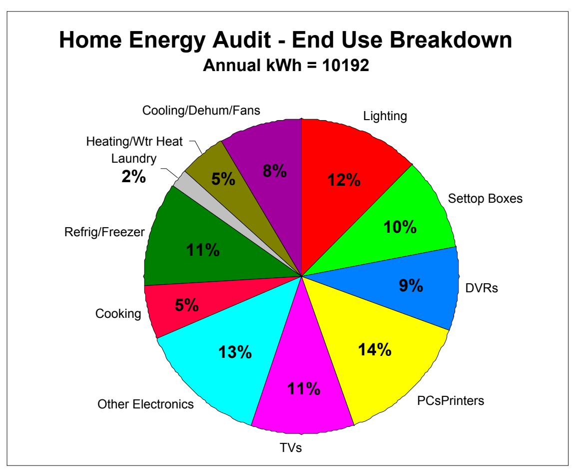
Summary

Altogether, a total of 10,200 kWh was accounted for, virtually 100% of all electric usage. The following table and graph detail each segment, with annual kWh and both 9 pm and 4 am demand estimates. The 4 am estimates were made primarily to identify standby loads:

Table 7 – Electric End Breakdown: Annual kWh, 9 pm and 4 am Peak Contributions

	Electric End Uses					
			Annual kWh	Pct Total	9pm kW	4am kW
1	Lighting		1304	12.8%	0.302	0.000
2	Settop Boxes		972	9.5%	0.097	0.097
3	DVRs		858	8.4%	0.121	0.121
4	PCsPrts		1288	12.6%	0.137	0.137
5	TVs		1081	10.6%	0.253	0.000
6	Other Electronics		1458	14.3%	0.101	0.101
7	Cooking		561	5.5%	0.137	0.000
8	Refrig/Frzr		1119	11.0%	0.124	0.123
9	Laundry		199	1.9%	0.140	0.000
10	Heating/Wtr Heat		489	4.8%	0.100	0.200
11	Cooling/Dehum/Fans		863	8.5%	0.000	0.000
		Totals	10192		1.511	0.779

Fig. 6 – Electric End Use Breakdown



8 Corresponds to Federal efficiency standard, cited at http://www.energystar.gov/index.cfm?c=dishwash.pr_crit_dishwashers

Most notable in these totals is the kWh for the four full set-top boxes. Because these are connected to a Cable TV network, they behave like computers, including one with a hard drive, and require constant connection to operate properly. If they are shut off (unplugged), they can require up to 10 minutes to restart and may not always do so properly. Counting set-top boxes, TVs, computers and DVRs, 56% of total annual electric consumption is for electronics – hardly "miscellaneous." More importantly, because of the standby loads associated with the electronics, 59% of the 4 am load contribution is attributable to electronics.

The following table summarizes wattages while "on," "standby" and "other" stages for selected electronics and cooking devices/end uses, along with estimated hours use (while on) and annual kWh, in descending order of annual usage.

Table 8 – Selected Appliances/End Use Wattage, Hours and Annual kWh

		ON					STANDBY				OTHER MODES						
Item	Location(s)	volts	watts	amps	volt-amps	PF	watts	amps	volt-amps	PF	description	watts	amps	volt-amps	PF	Annual Hours Use	Annual kWh
Refrigerator	Kitchen	122	138	1.26	154	0.90	4.04	0.033	4.026	0.98	Defrost	506	4.28	506	1.00	3763	507
Samsung 53" LCD TV	Den	122	214.8				1.3									2088	457
Dell PC	Study	122	73	0.91	111	0.64										6705	400
Freezer	Basement	122	112	1.66	201	0.55	155	0.06	115	0.41	Defrost	426	1.65	707	0.60	2723	319
SONY DVDR	BR2 Guest	122	34	0.43	53	0.63										8760	298
Digital DVR Settop Box	Den	122	34	0.45	55	0.62	34									8760	298
Subwoofer	Den	122	22				22									8760	193
Digital settop box (3)	Study, BR1,2	122.5	19.8	0.272	33.4	0.59	18.8	0.25	31.2	0.60	on-demand	20.1	0.263	33.1	0.6	4727	168
Bookshelf Stereo (2)	BR3/Craft	122	29.6				29.6									46	162
Dell 21" LCD Monitor	Study	122	21	0.29	35.6	0.59	1									5789	134
HP 7750 InkJet Printer	Study	122	10	0.14	17	0.59	3	0.05	6	0.50						8760	88
Dynex 21" TV	Study	122	38.5	0.52	64.5	0.60	1									1825	77
Tube TV 32"	BR2	122	77	0.9	112	0.69	0.7	0.03	4	0.20						730	72
LG20L370 TV	Kitchen	122	47	0.55	81	0.70										1095	68
Motorola Mini settop box (2)	Kitchen, BR3	12	6	0.75	9	0.67										1095	61
Phone base	Kitchen	6.5		0.5												8760	28
Bose Radio	Study	122	6.2	0.06	7.9	0.78	2.4	0.02	2.9	0.82						365	22

Most notable on the above list are the computer (one of three), which has higher than typical use (400 kWh) because it is used for a home business during the day, set-top boxes (left on 24/7) and DVRs (digital video recorders) which record often.

Relevant to anticipated recommendations for energy-saving measures, the bookshelf stereo (298 kWh), subwoofer (193 kWh), and HP InkJet Printer (99 kWh) are all ideal candidates for shut-off via remote plug switches (now being used) that would almost eliminate their annual consumption since they have high standby use and/or low actual hours use. Electronics charging stations would also be good candidates for plug-switches. While it may be tempting to shut off the set-top boxes, the prospect of requiring lengthy restarts makes that a problematic option. Other energy-saving measures (all no-cost or low-cost) implemented included LED lighting to replace the twin 90-watt Halogen security lights, unplugging the basement mini-refrigerator except when used, and changing the power saving settings on all the PCs to 2 hours from 6 hours (or off, in one case). Altogether, the do-it-yourself audit identified about 20% savings in electric consumption in a home that was already considered "efficient" and with "energy-aware" occupants!

Conclusions

The use of consumer-oriented metering and control tools is a viable option for consumers to assess and manage their own energy usage. While assessment of major end uses (heating, cooling, water heating) and building envelope measures would still benefit from professional help to identify them, the increasing percentage of energy usage from "miscellaneous" appliances provides a substantial opportunity for energy savings from controlling them, once consumers are aware of just how much they use and how they use energy. With the increasing attention to "smart grid" applications and their anticipated impact on consumer energy choices, including time-differentiated rates and utility-sponsored load control options, home-area network (HAN) applications that enable consumers to monitor and control their own energy consumption - including from their own smart phones – will mean more consumer products like those discussed in this paper. Rather than just depend on their utilities, consumers can be expected to be more proactive and invest in devices that they can use to take control of their own energy costs once their rate structures provide the incentive to do so.

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Other Home Energy Monitoring Systems

Google Meter – Google PowerMeter is a free energy monitoring tool that helps consumers save energy and money. Using energy information provided by utility smart meters and energy monitoring devices, Google PowerMeter enables anyone to view their home's energy consumption from anywhere online. It can be accessed through utility partners (e.g. Sempra/San Diego Gas & Electric) or device partners (e.g. Blue Line Innovations/Black & Decker, Watts-Up) and The Energy Detective. http://www.google.com/powermeter/about/

TED (The Energy Detective) is a simple, accurate, home energy monitor that allows you to see electricity usage in real-time. TED will accurately tell you what your bill is going to be long before the electric bill arrives. Meanwhile, you will learn more about conserving energy, saving money, and helping save the environment. http://www.theenergydetective.com/store/

Other Energy Meter Logger Vendors

Dent Instruments – DENT Instruments designs and manufactures data loggers and energy recorders for today's energy professionals. http://www.dentinstruments.com/

Onset Corp. (HOBO meters) - Onset is the world's leading supplier of data loggers. HOBO® data loggers and weather station products are used around the world in a broad range of monitoring applications, from verifying the performance of green buildings and renewable energy systems to agricultural and coastal research. http://www.onsetcomp.com/