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Measured Retrofit Savings from Efficient Lighting and Smart Power Strips

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ABSTRACT

A lighting and smart power strip retrofit evaluation was conducted on 56 all-electric, existing Florida homes to see how lighting and miscellaneous electric loads might be reduced. Retrofits were conducted from March to June 2013. Detailed end-use electricity consumption is being monitored for two years, spanning pre- and post-retrofit. This paper summarizes the end-use energy savings and economic evaluation results from lighting and smart plug measures.

The lighting retrofit included changing incandescent lighting to CFL or LED. Results from pre-retrofit monitoring revealed that the lighting and plug loads constituted 22% of total site electricity consumption (7.7 kWh per day). A short-term analysis of the study homes, for which 56% of bulbs were changed-out, showed a seasonally adjusted reduction to total site power of 1.2 kWh per day.

Home devices such as computers, printers, and gaming centers continue to draw power when unused but left in their low power modes. Advanced Power Strips (APS) can reduce this wasted energy. To study their potential savings, entertainment center energy use was sub-metered in all homes. APSs were intended to be installed in those with low power loads of at least 10 watts, but only nine had both homeowner acceptance and large enough power losses. Often equipment above the energy loss threshold could not be shut down (e.g. remote printers, DVRs) without functionality loss. Average low power mode draw for the final dataset was 15 watts and monitored data showed the APS saved between 0.2 and 0.7 kWh per day over pre-retrofit.

Introduction

In a collaborative effort, the U.S. Department of Energy (DOE) Building America Partnership for Improved Residential Construction (BA-PIRC) and Florida Power & Light (FPL) are pursuing a phased residential energy-efficiency retrofit program. All 56 homes were audited and instrumented during the period August 2012 to March 2013. The homes are located in Central and South Florida, with varied construction characteristics and built between 1942 and 2006. The homes average 1,777 square feet in living area, with an average occupancy of 2.6 persons. End-use data are being collected as well as detailed audit data to evaluate energy reductions and the economics of each retrofit phase.

Shallow retrofit measures conducted as the first phase of this study were chosen based on ease of installation. The retrofit targeted lighting (CFLs and LED bulbs), the home entertainment center (Advanced Power Strips (APS)), domestic hot water (wraps and showerheads), refrigeration (cleaning of coils), and pool pump (reduction of operating hours). Ten homes received deep retrofits, and are the discussion of a separate report currently in draft form.

The lighting retrofit evaluation includes an estimation of the pre- and post-retrofit savings comparing 30 days pre-retrofit to 30 days post-retrofit against the control group change over the same period. The control group consisted of all study sites unaffected by the retrofit given the evaluation period specific to each site. That is, the control group changed depending on when the evaluated site was retrofitted. To bolster estimates, for a subset of the dataset, we provide a year-to-year energy use comparison, selecting one month pre-retrofit and that same calendar month post-retrofit, the following year. Our analysis of smart plugs, with limited subjects, includes detailed descriptions for each retrofit, and one controlled case study.

Past Research

Lighting

Estimates of interior household lighting energy itself in the United States vary from a low of approximately 1,000 kWh per year (EIA 1996) to approximately 1,820 kWh per year based on monitoring individual light fixtures in 161 homes in the Pacific Northwest (Tribwell and Lermann 1996). These homes had a floor area of approximately 1,800 square feet. Another study in 53 homes with a sample of fixtures monitored suggested an annual energy use of lighting of 2,390 kWh per year (Carlson 1994).

In monitoring of 171 homes in Central Florida, the Florida Solar Energy Center (FSEC) estimated lighting energy use and its demand profile in the Progress Energy households (Parker 2002). The lighting fixtures were audited as well with the finding of 29 average lamps in the households and a connected potential lighting load of 1.5 kW. The average fixture power was 60 watts. Estimates ranged from a low of 1,220 kWh to a high of 1,950 kWh per year. Average house size was 1,580 square feet so the median average consumption would be about 0.9 kWh per square foot. A study of 251 homes in England conducted by Intertek provides monitored energy consumption data for lighting per bulb type (Zimmermann et al 2012). The study found 34 lamps per household with lighting consumption of 537 kWh per year, with consumption of 0.9 kWh per square foot, on average. The number of lamps in households has been audited and varies from 26 to 45 lamps per household depending on the utility study (e.g. Jennings et al 1995). It is also worth considering that while the average home has about 35 lighting fixtures, those fixtures are in no way equivalent in terms of energy use. Intertek found incandescent bulbs represented 39% of installed bulbs, but over 75% of the wattage (Zimmermann et al 2012). Another study estimated that 25% of the lighting fixtures use 80% of household lighting (Jennings et. al. 1995). Tribwell concluded that each lamp is on an average of 2.1 to 2.8 hours per day with an average 60 watts per lamp typically installed (Tribwell and Lermann 1996).

While, it is known that changing incandescent bulbs to lower wattage CFL or LED lamps will result in savings in homes, there have been very few studies where this impact has been directly measured. Most of this comes from the difficulty of measuring the separate lighting energy use of the individual lighting fixtures. To our knowledge, this has only been done in two case studies, both by FSEC, where light loggers were used to establish fixture on time and then the changed wattage of lamps installed to that fixture was used to estimate pre and post savings. The first test home in Miami had a very large lighting energy use, particularly for outdoor fixtures (Parker and Schrum, 1996). Pre-retrofit consumption was 11.1 kWh per day versus 4.3 kWh per day after change to CFLs for a 6.8 kWh per day or 61% savings. The second study of a home in Broward County, Florida was much more normal in lighting use. There, we found a measured pre-retrofit lighting energy use of 7.0 kWh per day; post-retrofit consumption was 3.8 kWh per day for a savings of 3.2 kWh per day or 45% (Parker et al. 1997).

Plug Loads

Automating the process of moving unused equipment to no power draw has promising energy savings, given people often do not take the time to unplug appliances when they are not being used (Bensch et al. 2010). A New York study which developed a typical home electronics configuration, estimated average annual savings of an entertainment center APS to be 75 kWh, and for a computer station, 31 kWh (Koser and Uthe 2011). A rigorous study to produce reliable savings estimates for home APS applications is ongoing (BPA 2013). The Northeast Energy Efficiency Partnership (NEEP) has recently begun to formulate an APS test protocol to provide confidence in energy savings potential, and calls for field studies to ultimately understand how energy-efficient APS installations are (NEEP 2013).

Field research on the residential application of APSs is limited. A study of two different smart strip products installed in a home entertainment center measured annual savings of 244 and 264 kWh (ECOS 2009). A third product in this study, applied in a home office retrofit, had reported savings of 82 kWh per year.

Monitoring Approach

Broadband internet connections provided an economical means of collecting large amounts of monitored data. In this study, two web-connected monitoring devices were used to record electric energy details. Whole-house energy was measured by a home energy monitor (eMonitorTM) mounted in the main breaker panel. Along with whole-house power, a number of major end-use circuits were measured with all data sent wirelessly to an internet-connected gateway. Lighting energy was deduced from the remaining, unmonitored energy data.

A second device (Watts up? plug load monitor) used to sub-meter an entertainment center proved to be more difficult to work with. Project budget allowed for only one web-connected plug load monitor (Watts up?) for each of the study homes. The Watts up? monitor required a wired-internet connection that was often unavailable at the chosen monitoring location. An internet power-line adapter was used to connect the Watts Up? to the internet router. This worked reasonably well, except in instances where occupants inadvertently unplugged the adapters from the required 120V outlet. Another problem involved the Watts up? being dependent on an active connection to the internet. The device cannot store data locally resulting in missing data anytime the broadband internet connection was lost.

Measure Description

Lighting Retrofit

All measures of the phased retrofit study were installed at the homeowners' discretion. The lighting retrofit consisted of replacing incandescent and halogen bulbs with energy-efficient CFLs or LEDs of equivalent illumination, but lower wattage. A 15 watt CFL in place of a 60 watt incandescent bulb was a frequent exchange. CFLs were the dominant replacement lamp type with 14-19 watts most typically installed, though wattage ranged from 7 to 32. Base socket extenders were needed for some flood lights to allow the CFL to contact the base. LED replacement bulbs ranged from 4 to 12 watts.

Field staff recorded the number of bulbs and fixtures changed, bulb types, and wattage. Most houses had some energy-efficient lighting at pre-retrofit. Indeed, one home already had

100% LED lighting, whereas six others had mostly CFLs and needed fewer than 20% of bulbs changed. A total of 55 homes were affected by the lighting retrofit. Sixty-four bulbs affecting 29 fixtures were audited per household, on average. On average, 56% of household bulbs (35 bulbs) were replaced with CFLs or LEDs (less frequently), ranging from 5% to 100% of the home's total lighting. Watt reduction ranged from 30 to 3,027, averaging 1,429 watts.

While the original study design was to primarily install LEDs, they were about ten times more expensive than CFLs even at bulk rates. Also, field staff expended much time working with homeowners to find just the right lighting solutions. An LED lamp's color temperature or direction was often disagreeable to a homeowner. (Above a bathroom vanity was a common objection for an LED retrofit.) In the case of LED lamp installations, the additional field time became onerous.

Owners sometimes objected to lighting retrofits in particular lighting fixtures and those bulbs were not changed. In fixtures where an appropriate LED or CFL could not be found (most notably chandeliers with decorative 40 to 60 watt bulbs), incandescent bulbs were replaced with lower wattage incandescent bulbs, provided owner acceptance. Many sites presented ample opportunity for lighting efficiency improvements. For example, one site's lighting retrofit included an eight-bulb vanity lighting fixture of incandescents totaling 360 watts converted to CFLs totaling 72 watts.

We did experience a quality control problem on a specific brand of CFLs. Fortunately the vendor exchanged the bulbs for others without reluctance.

Power Strip Retrofit

Advanced Power Strips (APS) are a way to reduce energy consumption for devices that stay in low power modes when they are not being used. An APS can provide energy use savings by turning these devices off automatically when they are not being used. The smart strip's master outlet will turn off devices plugged into the slave outlets when the master device is turned off. The APS chosen for the home entertainment center energy use reduction was a load-sensing strip that detects the master device current. When the master device appears unused, the chosen slave components are turned off. We used the Smart Strip SCG3 which has 7 outlets: 4 slaves, 1 master control, and 2 standard. The strip has a 0.35 watt idle current in minimum power mode, and maximum controlled load of 15 amp, and 1,875 watts.

The power strip retrofit involved replacing existing plugs or power strips with the Smart Strip SCG3. The measure targeted entertainment centers and computer stations with low power mode energy loads greater than 10 watts of continuous use. Project staff measured component power draw to determine potential slave devices. Ultimately, the smart plug was only installed in nine homes, at either the entertainment center or computer station (or both). Reaching the 10-watt power draw threshold proved to be a difficult bar for three reasons:

1. Many modern models for some components have little power loss in their low power mode, such as DVDs, CDs, sound systems, and amplifiers. Research conducted by the National Renewable Energy Lab reported similar findings (Earle, 2012).
2. Equipment such as wireless printers, printers with head-parking needs, modems, DVRs, and satellite boxes devices could not be shut down without loss of functionality. Such peripheral devices could not serve as slave devices to the master equipment. This is a strong argument for appliance standards on these devices since they often drew 25 watts or more in our measurement.

3. Music-related devices co-located with the entertainment center were sometimes used independently of the television, and therefore could not be controlled by the television.

The APS was also not installed in several eligible homes because homeowners objected to this measure. Reasons cited included cable boxes (only considered as a slave device when they did not have an imbedded DVR) that took too long to boot up, and in one case the computer screen saver was used for a rolling display of personal photos. Field staff believe a few homeowners rejected the savings measure because they did not fully understand the smart plug proposal. Finally, the installation and access to loads to be controlled proved difficult—often behind furniture adjacent to a wall with poor access or located on power strips with no indication as to which device each of many plugs powered. We believe this may be a real market barrier to use of smart power strips as a retrofit measure.

Only home entertainment centers were isolated for monitoring during the project set-up; therefore we had no pre-retrofit data to evaluate the computer station smart strip retrofits. Additionally, two entertainment center APS retrofits were also removed from analysis. In one case, the pre-retrofit monitoring did not capture the same equipment attached to the smart strip at retrofit. The second site was eliminated because of lost WattsUp? communication followed by homeowner electronic component reconfiguration. Of the 56 home study, threshold shortfalls, homeowner objection, and lack of comparable pre-retrofit data reduced the final smart strip evaluation to just two homes. To supplement the APS evaluation, one carefully controlled smart strip installation has been added as an independent case study to examine the savings potential when the homeowner was motivated to use such devices in spite of the difficulties in application.

Evaluation Results

Lighting Retrofit

The lighting retrofit involved a change-out of 56% of the homes' bulbs. Incandescent bulbs, which comprised 54% of the bulb types pre-retrofit (65% of total lighting wattage), represented 13% post-retrofit (20% of total lighting wattage). LED bulb installations rose from 4% (1% of total lighting wattage) to 15% (6% of total lighting wattage) as a result of the retrofit. The change in composition of bulb type is depicted graphically in Figure 1.

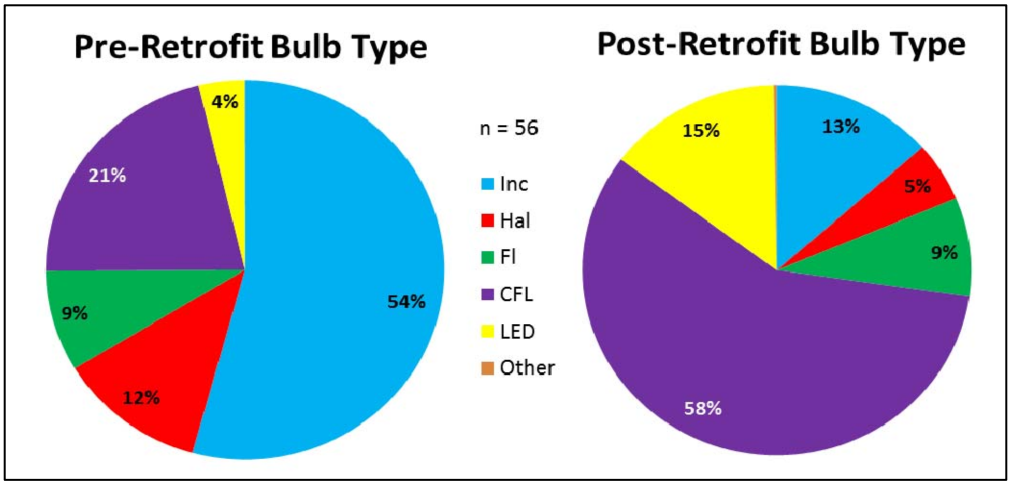

Figure 1. Light source composition, pre-retrofit and post-retrofit.

Shifting to monitored results, ‘lighting and other’ energy was obtained by subtracting all monitored end-uses from measured total power, thereby obtaining mainly lighting, ceiling fans, and plug loads. To provide insight on how individual homes were affected by the shallow retrofit, one subject house is shown in detail below. The shallow retrofit performed on May 22, 2013 at Site 54 included changing out 95% of bulbs from incandescents to CFLs, with a reduction in the connected lighting load from 2,115 watts to 539 watts. Figure 2 shows daily lighting and other plug load energy for one site during a 61-day analysis period, spanning 30 days prior to and 30 days after the retrofit. The vertical, dashed line indicates the retrofit date.

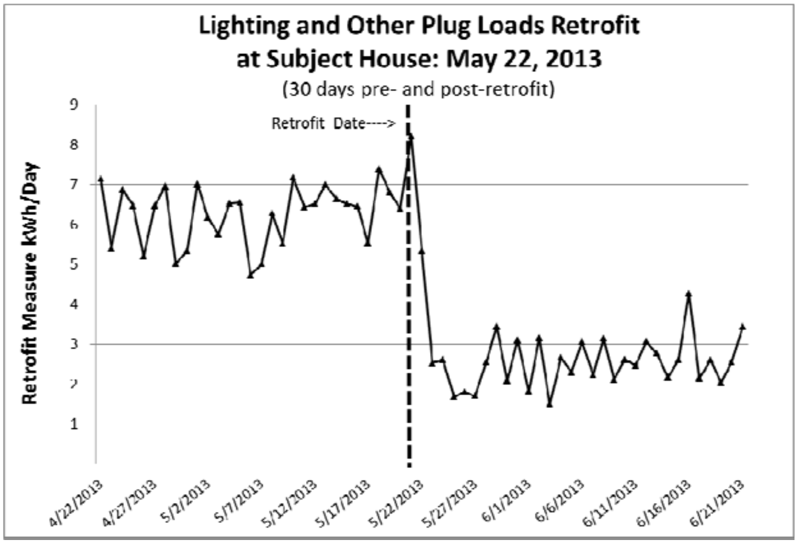

Figure 2. Site 54, showing hourly lighting and other plug loads energy use, pre- and post-lighting retrofit.

The lighting retrofit at site 54 reduced energy use by more than 50% or about 4 kWh per day. However, examination of the monitored change must be normalized given the seasonal changes during the analysis period. We might expect reduced lighting use over the analysis period as daylight length increased. Thus, we normalized savings for seasonal variation. For each site we identified a unique set of control homes comprised of all study homes retrofitted either before or after the site’s 61-day analysis period. The changes in this control group in lighting and plug loads was then used to modify the change seen in the site-specific lighting and plug load energy. This normalization process reduced the monitored lighting savings at this site slightly, from 3.5 kWh per day or 50.4% savings over pre-retrofit, to 3.4 kWh per day or 47.8%.

This single case provides a look at potential lighting retrofit energy use savings, though this was by no means typical of the homes in our study. Results from a comprehensive analysis conducted on the 56 site sample follows. Table 1 provides average monitored and normalized post-retrofit energy savings results for all study homes, including one site without a lighting retrofit.

The top four data rows present monitored pre- and post-retrofit energy consumption and savings. Rows five and six introduce the average change among control homes during this same period. Normalized savings, the monitored savings less any change observed in the controls, are provided in the rows seven and eight. The final two rows provide results from a t-test of paired mean savings before and after retrofit, used to establish statistically significant differences.

Table 1. Monitored and normalized lighting and other plug loads energy savings.

n = 56	Lights & other plug loads
1. Avg. Monitored kWh/Day Pre	7.7
2. Avg. Monitored kWh/Day Post	6.6
3. Avg. Monitored kWh/Day Savings	1.1
4. Percent Monitored Savings	15.3%
5. Avg. Control kWh/Day Change	(0.1)
6. Percent Control Change	-1.7%
7. Avg. Normalized kWh/Day Savings	1.2
8. Percent Normalized Savings	16.9%
9. Uncertainty (+/-) kWh/Day*	0.3
10. COVAR	0.17

* Evaluated at a 90% confidence interval.

Significance is indicated by t-test results lower than the average normalized daily kWh savings. The value “uncertainty” indicates the estimated uncertainty at a 90% confidence interval. The final component in this table, “COVAR” (coefficient of variation), provides the variation in savings achieved (standard error divided by mean savings level). Low values of this parameter indicate reliable savings, while values above 0.5 indicate declining reliability.

The lighting retrofit change was a reliable measure (COVAR = 0.17), and was highly significant at the 90% confidence interval. As lighting and other plug load end-use increased slightly among the control homes, the normalization improved savings slightly. Savings from the lighting retrofit averaged 1.2 kWh per day, or 16.9%. Savings rose to 1.3 kWh per day or 17.4% when the one, non-lighting affected home is dropped. Considering only homes where more than 20% of fixtures were replaced, average savings were 1.5 kWh per day (19.9%).

While more time is required before we can do a robust pre- to post-retrofit per site savings evaluation over half a year or more, we gain insight even using a short period of time. We also may gain some idea on how seasonality may actually increase observed savings. Using a sub-sample of 17 homes, we examined the lighting and other circuit for October 2012 versus October 2013. The sample size was limited to homes fully monitored by October 1, 2012 and excludes deep retrofit sites. October has been selected among the few months with many homes monitored by October 1, 2012 and for its typical Florida weather behavior. Weather differences between the months were subtle; therefore weather normalization would impact results little.

Lighting and other plug load energy use was significantly reduced between years, 2.5 kWh per day, or 29% savings over pre-retrofit. This was more than twice the 1.2 kWh daily savings than found in our normalized 30 day pre- and post-retrofit methodology above. One large caution with this presentation concerns the small sample: only 17 homes versus the 56 evaluated in the larger analysis. However, we have reason to believe that some of the greater kWh savings may be due to the greater degree of interior illumination needed in October vs. the late spring used in the 30 day pre/post analysis method.

Despite the highly heterogeneous nature of the lighting and other (ceiling fans and miscellaneous plug loads) loads, there is a clear connection between the degree of lighting retrofit (how many bulbs were changed) and the overall savings. This relationship is displayed in the scatterplot below (Figure 3). Since the lighting, plugs and other estimate is not a pure lighting load, we would expect considerable scatter or even negative savings in some cases where other non-monitored plug loads were used in the post period.

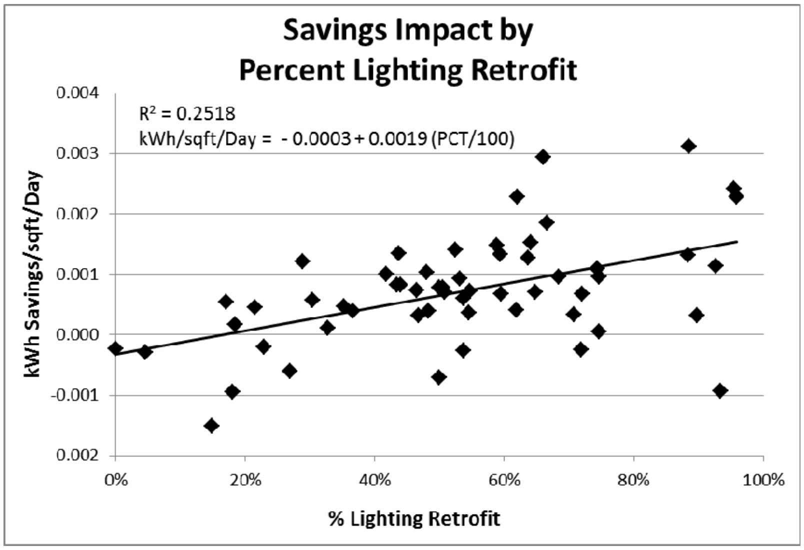

Figure 3. Scatterplot of percentage lighting change-out with predicting savings/sqft/day.

While the regression relationship only explains 25% of the variation in the observed savings, it is noteworthy that the t-statistic for PCT, the percentage of lighting fixtures changed, was 4.26 - indicating an undeniable relationship to the post-retrofit savings observed.

To conduct an economic analysis, we have assumed a rate of $30 per hour for the retrofit labor and energy costs of $0.12 per kWh. Assessing the cost-effectiveness of the lighting retrofit, labor costs are $67 (2.24 hours x $30). Adding this to the average materials costs of $214, the average total cost for the retrofit is $281. Using the 30 day pre- and post- retrofit analysis savings estimation (1.3 kWh per day), simple payback is 5 years; while using the greater savings estimated in the October 2012 versus October 2013 evaluation (2.5kWh per day) simple payback is 2.5 years. We conclude that homeowner economics, or that of a retrofitting service, are extremely good in either case.

Power Strip Retrofit

The following is an evaluation of energy use changes observed at the two successful APS installations in the phased retrofit project. Given the case study nature of our observations, each site will be described individually.

Site 5 was instrumented for monitoring September 24, 2012 and retrofitted May 7, 2013. Daily average power draws for the entertainment center from pre-retrofit instrumentation through January 2014 are plotted in Figure 4.

The plug load retrofit at Site 5 involved a television (master) controlling two devices, a DVD and a home video game console. Power reduction mode losses were measured with a Watts up? plug load monitor. The DVD was measured as a single watt. The game console has two power reduction modes, a minimum power mode drawing 3 watts, and a low power mode drawing 11 watts. It is noteworthy that, although the owner reported they had not used the game console in months, the equipment was found "on" during the site visit, drawing 17 watts continuously. Thus, depending on occupant behavior, greater than expected savings are possible when an APS is used. Entertainment center end-use was analyzed for the entire seven-month pre-retrofit and the nine-month post-retrofit periods available.

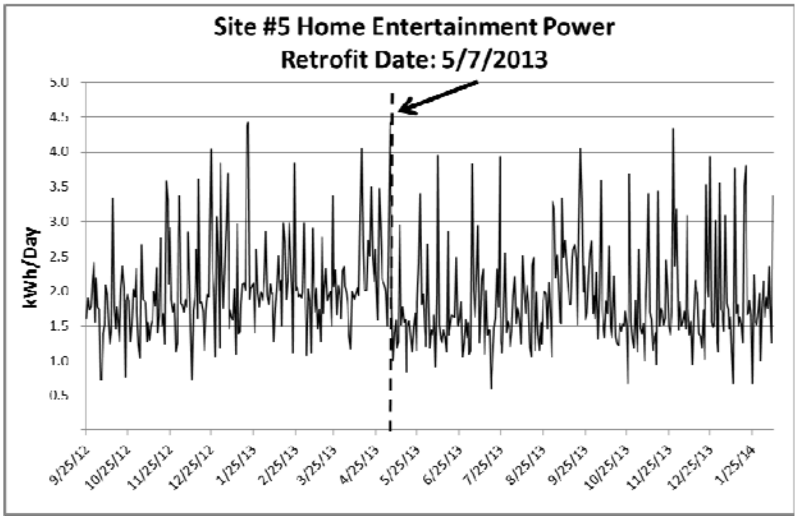

Figure 4. Site 5 home entertainment center energy consumption pre- and post-retrofit.

The smart strip at Site 5 saved an average of 0.2 kWh per day, a 10% energy use reduction from pre-retrofit. Pre- and post-retrofit energy use and savings for both sites plus the controlled case study are summarized in Table 2.

Table 2. Pre- and post-retrofit entertainment center energy use

Site	Low Mode Power Loss (watts)	kWh/Day		Savings			
		Pre-Retrofit	Post-Retrofit	Avg. Daily kWh	Est. Annual kWh	%	Annual @ 0.12/kWh
5	12/4	2.05	1.84	0.21	77	10%	$9.26
10	20	4.82	4.12	0.70	256	15%	$30.72
Case Study	14/6	2.07	1.68	0.39	143	19%	$17.12

With electricity costs at $0.12 per kWh, the APS at Site 5 produced about $9 savings annually. The retail price of the smart strip, including sales tax, was $32. Assuming a homeowner could install the equipment without a labor charge, simple payback would occur at Site 5 in a little over 3 years. Device configuration may likely change during this period, weakening this payback projection.

Site 10 was instrumented for monitoring September 27, 2012 and retrofitted April 24, 2013. The APS set up at Site 10 was an amplifier (master) controlling subwoofer with 20 watts of minimum power mode energy. Pre-retrofit entertainment center end-use was high at this site, approximately 5 kWh per day. The smart plug retrofit savings were also large, averaging 0.7 kWh per day (15%). With annual savings estimated to be $31 per year, the smart strip pays for itself in 1 year. Daily average power draws for the entertainment center from pre-retrofit instrumentation through January 2014 are plotted in Figure 5.

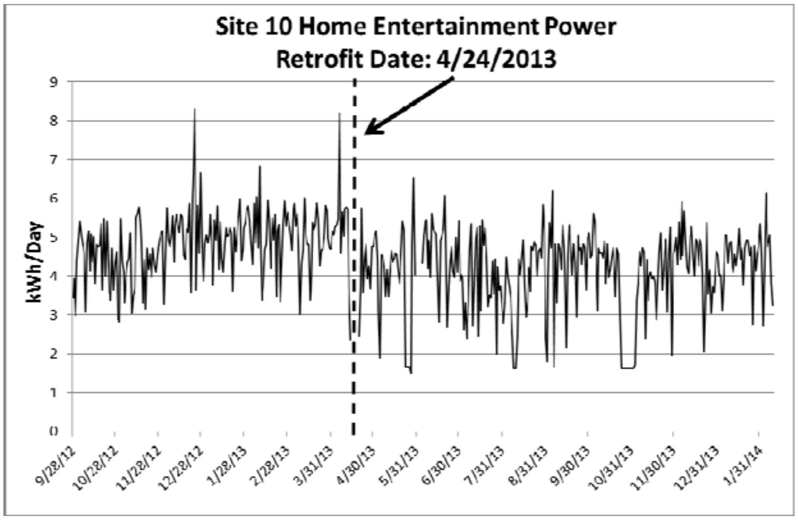

Figure 5. Site 10 home entertainment center energy consumption pre- and post-retrofit.

Given the limited number of qualifying sites with homeowner acceptance to the smart power strips that we experienced in the phased retrofit project, we conducted a supplemental experiment at an occupied home, external to the project. The home entertainment center at an FSEC staff's home is being monitored with the same equipment collecting project site data. A standard power strip with surge protection was replaced with the Smart Strip SCG3 on February 7th, 2014. This configuration was altered between the APS and the original condition every few weeks for several months. The evaluation compares 49 days pre-retrofit to 49 days post-retrofit. The devices being controlled by the television (master) include a home video game console with two power reduction modes; a minimum power mode drawing 1.9 watts and a low power mode drawing 10.0 watts; a DVD with surround sound with minimum power mode losses of 0.3 watts; and a universal wireless internet adaptor with 2.5 in minimum power mode losses. The original power strip used 1.3 watts, compared to the SCG3 draw of 0.4 watts, for an additional 1 watt of continuous savings.

The game console's selected power reduction mode depends on how the equipment is shut down. When the device is powered down with its remote control while plugged into a typical power strip, the higher energy-drawing mode is used (10.0 watts). This mode allows the device to send message alerts to the user; arguably a feature the owner may have no interest in, especially considering what the owner can save using the more conservative mode. When the APS is used and the master device is on, the unused game console draws only 1.9 watts. Because of this, the smart strip reduces energy use not only when the master device is turned off.

Energy use for a 28-day snapshot of the evaluation period is graphically displayed in Figure 6, where the post-retrofit troughs and peaks (because of the multiple power reduction modes) are both generally lower than those during the pre-retrofit period.

End-use energy consumption for this home entertainment center dropped from 2.1 to 1.7 kWh, saving about 0.4 kWh per day, a savings of 19% (See Table 2). Payback for the APS at this site is under 2 years. With the added savings related to the game console's minimum power mode, and continuous savings from the more energy-efficient power strip, savings were very good. Thus, this research shows that when installed with an aim to reduce standby loads, APS devices can be very cost-effective. We did, however, experience some degree of consumer resistance to installing such devices.

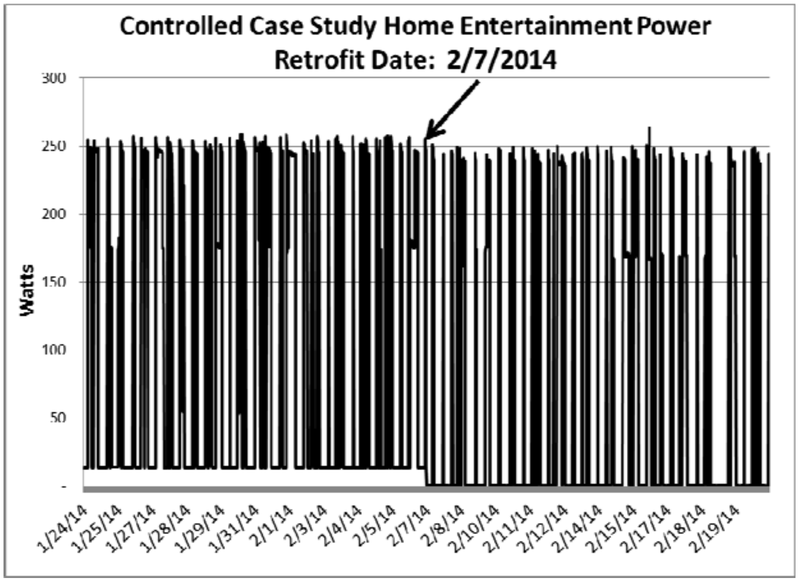

Figure 6. Researcher-controlled home entertainment center end use: 14 days pre- and post-smart strip retrofit.

Conclusions

The lighting retrofit savings evaluation was calculated in two ways.

1. A weather-adjusted 30-day, pre- and post-retrofit end-use comparison for all 56 sites: Results from pre-retrofit monitoring revealed that the lighting and plug loads constituted 22% of total site electricity consumption (7.7 kWh per day). A short-term analysis of the study homes, for which 56% of bulbs were changed-out, showed a large seasonally adjusted reduction to total site power of 1.2 kWh per day, or a 17% reduction over the pre-retrofit condition. This analysis is robust in that it includes the whole dataset; however it only represents a brief period in time before and after the retrofit. Average installation costs were $67 labor and $214 hard costs. Simple payback using this savings estimation technique is projected to be 5 years.
2. A 30-day, same calendar month, pre- and post-retrofit end-use comparison for 17 sites: While this evaluation is equally short and with only a sub-set of the dataset, it provides a glimpse into savings persistence. Average daily savings estimated with this method was 2.5 kWh per day, or a 29% energy use reduction from pre-retrofit. A simple payback of 2.5 years is projected using this savings estimation methodology.

The lighting retrofit persistently produced significant and economically attractive savings regardless of evaluation method. A larger sample studied over a greater period of time will clarify long-term savings levels in 2014.

The study sample for the power strip retrofit was much smaller than expected. Many sites were ruled out because the low power mode loads did not meet the project 10 watt minimum threshold. Often equipment above the loss threshold could not be shut down (e.g. remote printers, HDVRs) without loss of functionality. We also experienced some pushback from homeowners who do not want home entertainment loads altered. The final sample-size limitation was that the sub-metering failed to capture the desired pre-retrofit data in several cases. One solution would be to determine appropriate and acceptable smart plug location(s) at the time of monitoring instrumentation, although home internet configuration may limit this choice.

The power strip retrofit did offer evidence of economically attractive savings. The evaluation period was robust with seven months of pre-retrofit and nine months of post-retrofit data, however we were only able to evaluate two phased retrofit project homes and one controlled home. The project threshold of 10 watts continuous draw appears well vetted. Average daily saving at the study homes were 0.2 and 0.4 kWh, and 0.7 kWh at the controlled home. With a $32 smart strip, simple payback for this measure ranged from 1 to 3 years. The most important findings are:

- Occupants need to consider device functionality to determine acceptable applications. Occupant motivation to save energy may be a factor in acceptance of smart power strips in that they are difficult and time consuming to install in many instances.
- Many modern components have very little loss in their lower power modes, such as DVDs, CDs, sound systems, and amplifiers. Also, many of the devices with higher non-performing power modes (such as DVRs and satellite boxes) could not be controlled without loss of functionality. This strongly argues for appliance standards for such devices since they often drew 25 watts or more in our measurement.
- Continuous non-performing power mode losses for slave devices should be determined prior to installing the APS. Considering we found gaming consoles with multiple power reduction modes, this will be undoubtedly difficult for the average occupant to determine.
- Expected APS savings improves when occupants sometimes leave unused peripheral equipment on rather than in reduced power modes.

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