

Reducing Residential Miscellaneous Electrical Loads with a Whole-House Switch

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Over the past 30 years, the intensity of all major energy use categories has decreased in the residential market, with the exception of miscellaneous electrical loads (MELs). A significant percentage of MELs is stand-by power. Stand-by power is the energy used by an appliance when it is in the off mode. In the United States, stand-by power accounts for 2 - 8% of a typical home's total energy consumption. The whole-house switch (WHS) is an energy efficiency measure that reduces stand-by power by separating appliances from their power sources with a network of wireless switches and plug-level disconnectors. This study uses data from the Residential Energy Consumption Survey (sample size 12,083) to estimate the effect the WHS would have on US homes. The study found that using the WHS would save the average household 318kWh/year or approximately 2.7% of their total energy usage. The WHS calculation was then simulated on six sample homes. The study found that the savings that can be enjoyed by the WHS is fairly modest when averaged over a large population; however, they can be substantial for householders away from the home during the day and with heavy saturations of television peripherals, computers with peripherals, and kitchen equipment.

Key Words: whole-house switch (WHS), energy efficiency measure (EEM), miscellaneous electrical load (MEL), residential

Introduction

Over the past 30 years, the intensity of all major energy-use categories has decreased in the residential market, with the exception of miscellaneous electrical loads (MELs). MELs stand alone as the single category in which energy intensity has steadily increased over time (EIA, 2011; Nordman & Sanchez, 2006; Parker et al., 2011; KEMA, 2010). The rapid expansion in the markets of home entertainment, personal electronics, and convenience items are key contributors and are expected to continue to increase (Fanara et al., 2006; Roth et al., 2008a). MELs constitute approximately 15 – 25% of the energy used in a code-compliant home (Porter et al., 2006; US DOE, 2012; Roth et al., 2006; Ecos Consulting, 2004; Sanchez et al., 1998). However, the MEL percentage can be in excess of 50% for high efficiency homes (Steemers & Yun, 2009; Hendron & Eastment, 2006; Nordman & Sanchez, 2006). Additionally, according to a report commissioned by the US Department of Energy, MELs will grow to 36% of the energy used in code-compliant homes by 2020 (Roth et al., 2008a). Therefore, the reduction of MELs is a key area of research for national energy reduction and for achieving zero-net-energy homes.

Current practices for reducing MELs fall into the two general categories of technical or behavioral (Mohanty, 2001). Perhaps the most obvious of the technical improvements is from increased energy efficiency from advances in technology. Old style CRT computer monitors for example use twice the energy to operate than modern LCD monitors and four times as much as Energy Star rated units (Roth et al, 2008a). Equipping units with sleep or low power modes is another improvement that many appliances have adopted. However, having the option of a low power mode is only effective if the owner chooses to use it. Many manufacturers have encouraged reduced energy use by having low power setting enabled as the factory default. Providing energy guide labels that inform consumers of expected energy cost has been very successful with major appliances. Having smaller appliances list their energy consumption would similarly use market pressure to decrease energy use (IEA, 2001). Changing the behavior of the occupant is another way of reducing MELs. Opower is a company that partners with utility providers to analyze households and provide them with comparisons between their energy use and their neighbors. Participation in the Opower program has yielded an average savings of 2.8% of the homes total energy consumption with some municipalities experiences over a 6% decrease (Parker et al., 2011). Home automation through the use of timers and occupancy sensors is another way of reducing MELs. Energy dashboards and smart meters are devices or networks of devices that provide the householder real time feedback on their energy use. Several nationwide studies have shown that when householders are provided this instant feedback total energy consumption is reduced from 5 – 15% (Parker et al., 2011).

Stand-by power is the energy used by an appliance when it is not functioning or is in the off mode. It is sometimes called a phantom load, vampire draw, trickle current or leaking electricity. Existing literature indicates that stand-by power accounts for 2 – 8% of a typical household's total energy use (Fung et al., 2003; Meier & Huber, 1997; Meier, 2001). Several measures are available to reduce stand-by power. Perhaps the most effective is to simply unplug the appliance when it is not used. The inconvenience of this measure especially in areas where the plug is not easily accessible has kept this from being a widely used measure. Another option is to use smart power strips where peripheral equipment is controlled by the primary appliance. Technical improvements to appliances such as more efficient power supplies (low-voltage transformers) is another measure that can reduce stand-by power by 40% (Mohanty, 2001).

To decrease stand-by power, one energy efficiency measure (EEM) that households have available is the whole-house switch (WHS). The WHS uses switches to send wireless signals to various disconnectors that sever the power to appliances. The switches are generally conveniently located at home exits and the master bedroom. The idea is that householders can eliminate stand-by power loss when they leave the home or go to sleep. This study uses data from the Residential Energy Consumption Survey (RECS), with a sample size of 12,083, conducted by the US Energy Information Agency (EIA) to estimate the effectiveness of the WHS in reducing home power consumption. The calculated results were then verified by testing the WHS with six typical single-family homes. The cost of a typical retrofit WHS and the expected simple payback period were provided in this paper.

Whole-House Switch Defined

The premise behind the WHS is that it conveniently reduces stand-by power loss with minimal interruption of services to the householder. For this study the WHS has two primary components. First is the disconnector, which is used to sever power to the appliance. A plug-type disconnector has the appliance plug into it, and then it plugs into a wall receptacle; in this way, it is similar to a common surge protector (Figure 1). An integrated disconnector works similarly, but it replaces the traditional electrical receptacle and is hardwired into the home's line power. The integrated disconnector looks identical to a common electrical receptacle with all relay switches lying behind the wall plate. Both the plug-type and integrated-type disconnectors are typically controlled wirelessly. This measure is ideal for retrofit applications due to the ease of installation and because the disconnectors can be moved with appliances as they are relocated. For new construction, homeowners have the option of installing hardwired switches in area of expected high stand-by loss like the primary television, home office and kitchen outlets.

The second primary component of the WHS is the controller that commands the disconnectors. A hardwired controller can be set up as a common house switch, or a free-standing remote control can be used. Controllers can command as many disconnect switches as the householder requires. Controllers commonly use an omni-directional radio-frequency transmitter with a range radius of 50–100 feet. Each disconnect switch also contains a repeater that receives and then rebroadcasts the command. The more disconnectors there are on the network, the larger the web becomes. The technology required for the WHS is available off the shelf. Wireless communication protocols such as Z-Wave and Zigbee are being used by manufacturers such as General Electric, Honeywell, Levitron, and Black and Decker. Using a common communication protocol allows components from different manufacturers to be used together in the same home network. Although this study focuses on the reduction of stand-by power, this technology can also be adopted to reduce other energy demands. Thermostats, lighting, and entire circuits can be controlled with these wireless protocol-enabled devices.

Residential Energy Consumption Survey

Since 1978, the US Energy Information Agency has been conducting the Residential Energy Consumption Survey (RECS). The survey is very detailed and contains over 90 pages of questions. The questions primarily relate to home energy use but also include demographical information such as number of children, residents' ages, income, and characteristics of the home. The survey also asks about appliances in the home such as coffee makers, toasters, computers, printers, and DVD players. More detailed questions, such as duration of use, type, and size, are asked about more energy-intensive appliances, such as televisions, computers, and microwaves. The survey does not rely completely on the responses of the occupant but verifies the information with utility and tax records as well as field measurements, to the extent possible (US EIA, 2011). The RECS is published every four years with the most current survey conducted in 2009. The 2009 RECS is different from previous years as it makes available to the public the individual responses from over 12,000 households interviewed. The current study made use of this large dataset to estimate the potential savings of the WHS.

Assumptions Used to Calculate the WHS Energy Savings

Despite the comprehensive nature of the RECS questions, not all of the information needed to calculate the effectiveness of the WHS was provided. Specifically, reasonable assumptions of the length of time that the householder would implement the WHS were made. The three most significant periods of time when the EEM could be implemented are when the homeowner is asleep, away during the day, and away for overnight trips. According to the US Department of Labor, the average American adult sleeps between 8.2 and 9.0 hours per day (2012). However, of the 12,000 householders who participated in the RECS, only 12% lived by themselves, and there is insufficient data in the literature to determine when all members of a household are asleep. Since that is a period during which the WHS would be activated, an assumed time had to be used for this study: the assumption of 6 hours was made. The RECS asked the respondents whether someone was home throughout the day. For the respondents who indicated that there was someone home throughout the day, it was assumed that the home was vacated for 2 hr/weekday to account for miscellaneous errands. For households that did not have someone at home during the day, US Census data (2009) was used to estimate that they were away 9.25 hr/weekday for work (8 hrs), commute to work (45 min), and miscellaneous errands (30 min). All householders were assumed to be away 4 hr per weekend day. Another important consideration is the number of days the householder was away traveling. The US Department of Labor estimates that the average paid time off for full-time workers ranges from 7–18 days per year (1996). In addition, the average full-time worker has between 7 and 9 paid holidays per year. Although not intended for recreational use, paid sick days, which typically range from 7–11, can often be converted to paid time off. For this study, it was assumed that all householders were away from home for 14 days per year. See Table 1 for a summary of the assumed hours that the WHS was implemented.

Energy Consumption Calculation

The RECS is very comprehensive and asks the survey respondent about appliances that make up, on average, about two-thirds of a home's miscellaneous load. Some of the appliances, such as fax machines and cordless phones, use much of their energy in stand-by mode, but it is unlikely that the householder would want to disconnect the power to these devices when they are asleep or away from home. For some appliances, the only information that the RECS provides is whether it was present in the home or not. For appliances reported to be present, the unit energy consumption (UEC) from the literature review was used to calculate the total load (Roth et al., 2008a; Roth et al., 2008b; Hendron & Engebrecht, 2010). The UEC is the estimated total annual energy used by the average person with a typical model appliance. It averages usage patterns over a range of people and weights the energy consumption of the different appliance models based on their market penetration. Other appliances, such as televisions, television peripherals, computers, monitors, microwaves, rechargeable electronics, and rechargeable tools, have more detailed information collected by the RECS about the appliance type and usage. When present, this information was used to calculate the UEC for each individual survey respondent.

The RECS did not ask the respondents about all their appliances and those not asked about create approximately one-third of the average home's total MEL. This additional MEL was accounted for by employing the method used by RESNET's Home Energy Rating System (HERS) index and the Department of Energy's Building America Program (RESNET, 2006; Hendron & Engebrecht, 2010). A list of the most common appliances not included in the RECS was created. The UEC of each of these appliances as found in a literature review (Sanchez et al., 1998; Roth et al., 2008a; KEMA, 2010) was then multiplied by its market saturation to estimate the typical energy load of the appliance as a national average. Market saturation is defined as the average number of appliance per home (total appliance / all homes). A similar method was used to calculate the WHS energy savings. The wattage for each appliance in its lowest power mode was multiplied by its market saturation and by the weighted average of the number of hours the EEM would be activated.

Effectiveness of WHS

The methods described above were applied to all 12,083 RECS respondents in order to calculate the effectiveness of hypothetically utilizing the WHS in these homes. Results indicate that the average WHS savings over all the respondents would be 318 kWh/year, which is 7.7 – 19.5% of the averaged home's total MEL (Table 2). The range is one standard deviation from the mean and captures approximately two thirds of the homes. Factors like varying efficiencies of appliance models, number of appliances, individual usage patterns and householder preferences cause a high degree of variability in residential MELs. This high variability is reflected in Table 3 with a relatively high standard deviation. Using the RECS to estimate the entire home energy load is beyond the scope of this research; however, past studies indicated the MEL ranged from 15 – 25% of total home energy use (Porter et al., 2006; US DOE, 2012; Roth et al., 2006; Ecos Consulting, 2004; Sanchez et al., 1998). Assuming 20%, this equates to a WHS savings of 1.5 – 3.9% of the average householder's total energy cost. Householders with specific characteristics, such as urban vs. rural, married vs. unmarried, and various income levels, were calculated separately. The results indicate that the overall savings varies little across the different occupant groups, ranging from 1.3 – 4.5%. The most influential factor of the effectiveness of the WHS was whether the householder was away on weekdays (Table 3).

Savings and Simple Payback Period for Common WHS Network

The vast majority of stand-by energy loss is from televisions, television peripherals, computers, computer peripherals, and kitchen appliances (Table 2). These appliances are usually clustered, thus multiple appliances could be controlled by a single disconnect switch. Every home is configured differently, but if the typical home were to have a WHS system with six disconnectors that controlled a primary TV with peripherals (1 disconnector), secondary TV with peripherals (1), primary computer with peripherals (2), modem and wireless router (1), and microwave (1), an average savings of 266 kWh/year would be achieved. This is approximately $31 per year ($0.118 /kWh) in energy savings, and it is 84% of the WHS's maximum potential (EIA, 2012). A five-disconnector system with two controllers would cost approximately $200.00 retail (www.Zwaveproducts.com) and would pay for itself in 6.5 years.

Testing of WHS Calculations

The WHS savings calculations using the RECS were tested by simulating the WHS on six actual homes. Six homes are not sufficient to statistically validate the model; however, the test results can provide a general sense of its accuracy. The test home's plug-loads were measured using "Watts Up? Pro ES" (www.wattsupmeters.com) data loggers over a two-week period. Limitations of the study did not allow for an actual WHS to be installed in each of the test homes; however, the information collected from the data loggers was used to "simulate" the potential savings "if" a system was installed. Hardwired loads, seasonal loads, and appliances only used periodically were accounted for using the UEC obtained from a literature review (Roth et al., 2008a; Roth et al., 2008b; Hendron & Engebrecht, 2010; Sanchez et al., 1998; KEMA, 2010). The lowest wattage for each appliance, as recorded by the data loggers, was used to calculate the stand-by loss savings if a WHS was installed. Table 4 provides a summary of the findings. The test homes were evenly divided between households home and away during a normal weekday. The "RECS Calculated WHS Potential" represents the expected savings, calculated based on the RECS data, if all available appliances are on a WHS network. Appliances like refrigerators and security systems that are not applicable to this type of EEM were omitted. The "Simulated WHS on Test Homes Potential" is the maximum savings potential if a WHS was installed in the test houses. This is based on the actual appliances observed and recorded with data loggers. Each of the six householders were questioned about how often they are asleep and away from the home to estimate the likely duration the WHS would be implemented. The simulated savings in all six homes were within one standard deviation from what was expected and affirms the RECS based model.

Not all appliances have the same stand-by power savings potential. In real-world situations, homeowners would purchase enough disconnecting devices to control the most energy-consuming appliances and to control appliances that are clustered. For each of the six test homes, reasonable retrofit packages were selected. Each home was assumed to have a stationary switch at the primary exit and one remote control in the master bedroom. The number of disconnectors varied by the type and clustering of appliances observed in each test home. The retrofit packages and savings are provided in Table 4. Households with someone home during the day experienced an average savings of 173 kWh/year ($20.43), so the system would take 7.3 years to pay for itself. As expected, householders away during the day would enjoy a much higher return, with an average savings of 371 kWh/year ($43.73), corresponding to a simple payback period of 3.9 years. One of the tested households was projected to experience savings of 440 kWh ($51.88) with a payback of 2.7 years. This information supports the assumption that this EEM is much more financially attractive to households that are away during the day.

Conclusions

The energy intensity of miscellaneous electrical loads (MELs) fueled by expansion in the home entertainment, personal electronics, and convenience items markets, has steadily outpaced other energy end uses. The whole-house switch (WHS) is an energy efficiency measure that reduces MELs by eliminating much of the stand-by power loss. Using data from the Residential Energy Consumption Survey, (n=12,083) the effect of the WHS on energy costs was calculated. It was found that the WHS has the potential to save the average household 318 kWh/year or 13.6% of the home's total MEL. This corresponds to an approximate savings of 2 – 3.4% of the home's total electrical consumption. The calculations were tested by simulating the WHS on six actual single-family homes. The results from the six sample homes were within one standard deviation from what was predicted using the RECS. Sample retrofit WHS packages were simulated and showed that the effectiveness of the WHS was greatly influenced by whether the householder was home during the day. A principle finding of the study is that the savings that can be enjoyed by the WHS is fairly modest when averaged over a large population; however, they can be substantial for certain householders. Specifically, householders away from the home during the day and with heavy saturations of televisions, television peripherals, computers and office equipment would have high energy savings and a short payback period.

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Table 1

Assumed hours home is vacated and WHS implemented

	All Household Members Asleep	Away from Home on Weekday	Away from Home on Weekend	Traveling	Total
At Home During Day (43%)	6hrs/day (2,100hrs/yr)	2hrs/day (500hrs/yr)	4hrs/day (400hrs/yr)	14 days/yr (336hrs/yr)	3,336hrs/yr
Not At Home During Day (57%)	6hrs/day (2,100hrs/yr)	9.25hrs/day (2,313hrs/year)	4hrs/day (400hrs/yr)	14 days/yr (336hrs/yr)	5,149hrs/yr
Weighted Average	6hrs/day (2,100hrs/year)	6.13hrs/day (1,532hrs/year)	4hrs/day (400hrs/yr)	14 days/yr (336hrs/yr)	4,368hrs/yr

Table 2

Average MEL and WHS savings potential from RECS data

Appliances	Total MEL (kWh/year)	WHS Savings (kWh/year)	WHS Savings (%)
Television	534	41	7.7%
Television Peripherals	453	164	36.2%
Rechargeable Electronics	57	25	43.9%
Computer and Office Equipment	323	52	16.1%
Small Kitchen Appliances	149	13	8.7%
Well Pump	20	0	0%
Spa	117	0	0%
Other MELs	686	23	3.4%
Total	2,339	318	13.6%

Table 3

Effectiveness of WHS by occupant group

Occupant Group	Sample Size	Standard Deviation	WHS Savings (kWh/yr)	Total MEL	% of MELs	Estimated % of Total Utility*
All Households	12,083	137	318	2,339	7.7 - 19.5%	1.5 - 3.9%
Households Home During Weekdays	6,881	117	281	2,389	6.9 - 16.7%	1.4 - 3.3%
Households Away During Weekdays	5,202	149	367	2,272	9.6 - 22.7%	1.9 - 4.5%
Retired	3,567	128	289	2,281	7.1 - 18.3%	1.4 - 3.7%
Not Retired	8,516	139	330	2,363	8.1 - 19.8%	1.6 - 4.0%
Income Less than 40K/year	3,755	111	238	1,933	6.6 - 18.1%	1.3 - 3.6%
Income Less than 80K/year	5,229	126	321	2,328	8.4 - 19.2%	1.7 - 3.8%
Income Less than 120K/year	1,710	133	398	2,721	9.7 - 19.5%	1.9 - 3.9%
Income More than 120K/year	1,389	136	426	3,004	9.7 - 18.7%	1.9 - 3.7%

* Based on a home with 20% of total energy used for MELs.

Table 4
WHS findings from test houses

	RECS Calculated WHS Potential (kWh/yr)	Simulated WHS Potential on Test Homes (kWh/yr)	Retrofit Package Savings (kWh/yr)	Retrofit Package Savings ($/yr)*	No. of Disconnects and Cost**	Simple Payback of Retro Package
House A	281	317	160	$18.90	4 Disconnects $170	9.0 yrs
House B	281	182	61	$7.16	2 Disconnects $110	15.4 yrs
House C	281	377	299	$35.22	4 Disconnects $170	4.8 yrs
Average	281	173	$20.43	$150	$150	7.3 yrs
House D	367	398	307	$36.17	5 Disconnects $200	5.5 yrs
House E	367	516	440	$51.88	3 Disconnects $140	2.7 yrs
House F	367	404	366	$43.15	4 Disconnects $170	3.9 yrs
Average	367	444	371	$43.73	$170	3.9 yrs

* Nationwide retail price of $.118 /kWh (EIA, 2012)
** All retrofit packages have 2 controllers

Figure 1: Retrofit WHS Disconnector and Remote Control

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