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Original research article

Fixing the American energy leak: The effectiveness of a whole-house switch for reducing standby power loss in U.S. residences

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ABSTRACT

Over the past 30 years, the intensity of all major energy use categories has decreased in the residential market, with the exception of the miscellaneous electrical load (MEL). A significant percentage of the MEL is the energy consumed when appliances are in their standby mode. In the United States, standby power accounts for 4–12% of a typical home's total energy consumption. The whole-house switch (WHS) is an energy efficiency measure that reduces standby power by separating appliances from the home's line power through a network of wireless switches and receptacle-level disconnects. This study used a survey of over 12,000 respondents to estimate the energy savings that the WHS would have on a typical US home. The study found that the WHS would save the average household 282 kWh/year, or approximately 1.2–3.7% of their total energy usage. The plug loads of 24 test homes were monitored to validate the effectiveness of the WHS. The study found that the potential savings from the WHS were fairly modest when averaged over a large population; however, they could be substantial for householders away from the home during the day or with a heavy saturation of television peripherals, computers with peripherals, and kitchen equipment.

1. Introduction

Residential energy is commonly categorized into six major end uses: lighting, water heating, space cooling, space heating, major appliances (including white goods and televisions), and the miscellaneous electrical load (MEL). The MEL is comprised primarily of plug loads, such as microwave ovens, but also includes hardwire loads, such as security systems, intercoms, and GFCI receptacles. Over the past 30 years, the intensity (watts per meter) of all major energy use categories has decreased in the residential market, with the exception of the MEL. The MEL is the only category in which energy intensity has steadily increased over time [1–4]. Additionally, according to a report commissioned by the US Department of Energy, the MEL will grow to 36% of the energy used in code-compliant homes by 2020 [5]. Therefore, reduction of the MEL is a key area of research for global energy reduction and for achieving zero-net-energy homes. This study expanded on the work introduced at the Associated Schools of Construction 2013 proceedings and tested the whole-house switch as a means of reducing the MEL by lowering standby power draw [6]. This study uses a nationwide survey and 24 existing homes in the United States (US) as a case study to evaluate the effectiveness of the whole-house switch (WHS) as an energy efficiency measure. The majority of the miscellaneous electrical load (explained in more detail later) comes from plug-load appliances. Plug-load appliances are rarely, if ever, regulated by regional building code and commonly sold internationally. While the data collected for this study is exclusive to the US, because of the international nature of plug-load appliances and the international problem of wasted standby power, the results of the study are globally significant.

1.1. *The miscellaneous electrical load*

Measures for reducing the MEL are generally based on improvements in technology or behavioral changes [7,8]. Many appliances, especially electronics, have become significantly more energy efficient over time. Old style CRT computer monitors, for example, used twice the energy to operate as modern LCD monitors and four times as much as Energy Star-rated units [5]. 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

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manufacturers have encouraged reduced energy use by having low power settings enabled as the factory defaults. Providing energy guide labels that inform consumers of expected energy costs has been very successful with major appliances. Listing smaller appliances' energy consumption could similarly use market pressure to decrease energy use [8].

Changing the behavior of the homeowner is another way of reducing the MEL. Opower is a company that partners with utility providers to analyze households' energy use and provide residents with comparisons of their energy use and their neighbors'. Participation in the Opower program has yielded an average savings of 2.8% of a home's total energy consumption, with some municipalities experiencing more than a 6% decrease in consumption [2]. Home automation, through the use of timers and/or occupancy sensors, is another way of reducing the MEL. Energy dashboards and smart meters 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 by 5–15% [2].

1.2. Standby power

A significant percentage of the MEL comes from appliances in standby mode. While in standby mode, appliances draw a small amount of power despite not performing their primary functions. This load is sometimes called a phantom load, vampire draw, or leaking electricity, and can range from 0.5 to 30 W. Organized efforts to reduce this wasted energy date back to the early 1990s [9]. In 1999, the International Energy Agency introduced their "1-watt plan," which called for international support to reduce standby power to 1 W per device. Although not universally accepted, many countries have introduced regulations and voluntary programs that have significantly reduced the amount of standby power per device. However, while energy efficiency has increased, so has the proliferation of standby power-drawing appliances. The higher market saturation of computers, home entertainment peripherals, portable electronics, and updated models of older appliances that now have standby modes is eroding the energy savings provided by technological improvements. On average, most US homes use 60–110 W of standby power [10–13]. This accounts for 4–12% of a typical household's total energy use and is equivalent to seven CFL 825 lumen light bulbs operating year-round.

2. Measures for reducing standby power

Standby power is one of the most difficult energy uses to address because the two philosophies that homeowners have for reducing it are mutually exclusive and contradictory to social behavior norms. The first philosophy is to simply unplug the appliance when it is not in use. The simplistic measure is the most effective but least used because it imposes an inconvenience to the user. The "desire to preserve lifestyle" commonly overrides the desire to reduce energy use even when the user understands the impact of energy consumption on global climate change. The second philosophy for reducing standby power is through automation. Smart power strips and timers can be used to reduce the inconvenience of unplugging the appliance but this can be perceived by the user as a loss of control. Control and freedom are social values held deeply by many people who are unwilling to give them up even at the cost of higher utility cost, CO_2 emissions and climate change. This issue of how behavior can be changed without the perception of the loss of control is one of the core questions the journal of Energy Research & Social Science seeks to address [14]. The goal of this study was to introduce a new energy efficiency measure (EEM) that strikes a balance between automation and control and provides homeowners a means of energy reduction without changing their social paradigms.

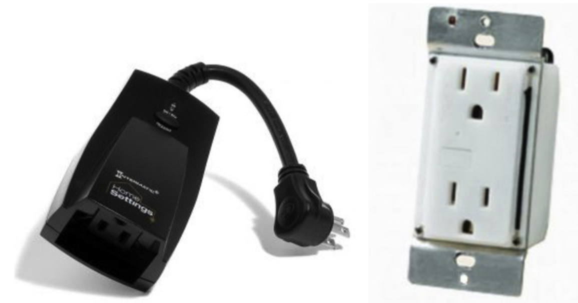
Plug-type Disconnect Hardwired Disconnect

Fig. 1. Z-wave-enabled disconnects.

2.1. The whole-house switch

This paper introduces a new EEM referred to here as the WHS. The WHS uses off-the-self technology originally designed for high-end lighting controls. It uses switches to send wireless signals to receptacle-level disconnects that sever the power to one or more appliances. This EEM is similar to a remote-controlled smart power strip, but is on a larger network that controls all desired appliances. The switches should be conveniently located at home exits and in the master bedroom. Just as homeowners turn off the lights before they leave the house or go to bed, with this EEM they could similarly eliminate all unnecessary standby power with the flip of a switch. This study uses 12,083 households from the US Energy Information Agency's Residential Energy Consumption Survey to estimate the potential savings of the WHS. The estimated savings were verified by simulating the WHS in 24 single-family homes.

2.2. Whole-house switch defined

The premise behind the WHS is that it conveniently reduces standby power loss with minimal interruption of services. In this study, the WHS had two main components. First is the disconnect, which is used to sever power to the appliance (Fig. 1). A plug-type disconnect has the appliance plugged into it, and then it plugs into an electrical wall receptacle. In this way, it is similar to a common power strip. A hardwired disconnect works similarly, but it replaces the traditional electrical wall receptacle and is hardwired into the home's line power. The hardwired disconnect looks identical to a common electrical wall receptacle with all relay switches lying behind the wall plate (Fig. 1). Both the plug-type and hardwired disconnects are controlled wirelessly. This feature makes them ideal for retrofit applications due to the ease of installation. For new construction, homeowners have the option of installing hardwired switches in areas of expected high standby loss, like the primary television, home office, and kitchen outlets.

The second main component of the WHS is the controller that commands the disconnects. A hardwired controller can be installed in a standard electrical junction box just like a common wall switch. The switch could also be a freestanding remote control (Fig. 2). Controllers can command as many disconnects as the householder requires. Controllers commonly use an omni-directional radio frequency transmitter with a radius range of 50–100 feet (15–30 m). Each disconnect also contains a repeater that receives and then rebroadcasts the command. The more disconnects on the network, the larger the web becomes. The technology required for the WHS