Title

Should the next standby power target be 0-watt?

Permalink

https://escholarship.org/uc/item/566951pn

Authors

Meier, A
Siderius, HP

Publication Date

2023-12-11

Peer reviewed

Title:
Should the next standby power target be 0-watt?

Author:
Meier, A
Siderius, HP

Publication Date:
06-29-2017

Series:
Recent Work

Permalink:
http://escholarship.org/uc/item/566951pn

Local Identifier(s):
UCPMS ID: 2162454

Abstract:

The standby power use of appliances continues to consume large amounts of electricity. Considerable success has been made in reducing each device's use, but these savings have been offset by a huge increase in the number of products using standby power and new power requirements for maintaining network connections. Current strategies to reduce standby have limitations and may not be most appropriate for emerging energy consumption trends. A new strategy for further reductions in standby, the “Standzero” option, encourages electrical products to be designed to operate for short periods without relying on mains-supplied electricity. Energy savings are achieved through enhanced efficiency and by harvesting ambient energy. A sensitivity analysis suggests many appliances could be designed to operate for at least an hour without relying on mains power and, in some cases, may be able to operate indefinitely at zero watts until activated.

https://doi.org/10.7941/S9J040

LBNL- 2001019

Should the next standby power target be 0-watt?

Alan Meier, Lawrence Berkeley National Laboratory
Hans-Paul Siderius, Rijksdienst voor Ondernemend Nederland

Energy Technologies Area
June 2017
Presented at the *Eceee 2017 Summer Study – Consumption, Efficiency & Limits*. Presqu'île de Giens, Hyeres, France: European Council for an Energy-Efficient Economy and to be published in the Proceedings

Disclaimer:

Acknowledgements

Research for this paper was supported by the California Energy Commision’s Electric Program Investment Charge (EPIC) program.

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Should the next standby power target be 0-watt?

Alan Meier
Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720 USA
Email: akmeier@lbl.gov

Hans-Paul Siderius
Rijksdienst voor Ondernemend Nederland
Croeselaan 15
NL-3521 BJ Utrecht
Email: hans-paul.siderius@rvo.nl

Abstract

The standby power use of appliances continues to consume large amounts of electricity. Considerable success has been made in reducing each device's use, but these savings have been offset by a huge increase in the number of products using standby power and new power requirements for maintaining network connections. Current strategies to reduce standby have limitations and may not be most appropriate for emerging energy consumption trends. A new strategy for further reductions in standby, the "Standzero" option, encourages electrical products to be designed to operate for short periods without relying on mains-supplied electricity. Energy savings are achieved through enhanced efficiency and by harvesting ambient energy. A sensitivity analysis suggests many appliances could be designed to operate for at least an hour without relying on mains power and, in some cases, may be able to operate indefinitely at zero watts until activated.

Introduction

The reduction of standby power use in appliances continues to be a goal of many technical improvements and government policies. While the annual standby power energy consumption of an individual device is typically small, the combined impact of billions of devices is large with respect to both energy consumption and carbon emissions. At the same time, the underlying requirements for standby power use and the technologies available to provide those services are constantly evolving. These changes periodically justify a re-examination of the strategies to reduce standby power use. The goal of this paper is to review the key developments and propose a new approach to dealing with standby power. This paper first provides a brief history of standby and indicates why standby now is different from what it was in the past. Then a number of options for updated standby policies are indicated, and a different approach, the Standzero option, is presented. The technical feasibility of this option is investigated and discussed. Finally, the paper provides conclusions and recommendations.

A brief history of standby

Nobody can claim to have discovered the problem of standby power because it entered our awareness gradually and piecemeal. In the early 1990s, Olof Molinder, at the Swedish Energy Agency, commissioned Eje Sandberg to study electricity use of TVs and audio equipment while *off*. This was the first comprehensive study of appliance electricity use while in the off-mode and was published in the 1993 ECEEE Proceedings (Sandberg 1993). Sandberg's English was less than perfect, so the translation of "standby power" from the Swedish emerged as "leaking electricity." Other researchers in Europe, Japan, Australia, and the United States also began noticing the proliferation of appliances drawing power even when switched off (Meier, Rainer, and Greenberg 1992). Meier and others published early articles on standby power and, by 1996, estimated the typical standby power use in an American home (Rainer, Meier, and Greenberg 1996). Even then, however, appliances with standby power use were still the exception; most appliances, when switched off, drew no power.

In 1997, Meier proposed a guideline that the standby power use of all future appliances be reduced to 1 watt (W). In 1999, Meier and Lebot proposed the "global 1-Watt plan" (Meier and Lebot 1999). They also estimated that global standby power energy use was responsible for about 1percent of global carbon emissions. The 1-watt proposal was introduced at the Energy Efficient Domestic Appliances and Lighting conference (EEDAL) and supported by many other researchers. In 2001, the International Energy Agency adopted the 1-Watt plan as a recommended strategy. Over time, Japan, Australia, Korea, the European Union, and the United States adopted policies to reduce standby power, ranging from voluntary guidelines to regulations. Two notable acts were President Bush's Executive Order to reduce standby (Bush 2007) and the European Union (EU) Ecodesign regulation 1275/2008, including the amendment in Regulation 801/2013 to cover networked standby. At the same time, the International Electrotechnical Commission (IEC), with leadership from Australia, developed a test method to measure low power modes specifically tailored for the unique technical challenges of accurately measuring very low power (International Electrotechnical Commission 2011).

Since then there has been remarkable progress in reducing standby power use of nearly all products. The innovations fall into three major categories:

- improve the efficiency of the AC-DC power supply (by cutting no-load losses and increasing conversion efficiency);
- reduce the energy used by circuitry in the device (including switching off circuits not needed while in standby), and
- reduce the power consumed by displays operating all the time.

Manufacturers were able to reduce no-load power use in external power supplies from 3 W to less than 0.2 W. The standby power use of TVs fell from 15 W to 0.5 W.

Standby is Different Now

The current global status of standby energy consumption is difficult to assess and no recent estimates have been undertaken, although some careful estimates have been made for certain regions and appliance groups (Roth et al. 2014). For many simple products, the standby power consumption has fallen sharply. Improved power supplies—greater efficiencies and lower off-mode losses—are probably responsible for most of the savings. At the same time, the number of devices constantly drawing power has increased enormously. The fraction of devices drawing standby has also grown because many were transformed from a simple on/off configuration to one that requires standby (for a display or a remote, for example). Nowadays, nearly every new electrical product draws power continuously (that is, has standby power use) and the exceptions are products that truly draw no power when switched off.[1]

Today we are also in a different technical environment. This new environment is reflected in three transformations. First, a new, always-on function has emerged, the network connection, which allows the device to exchange information with other devices and often includes a connection to the Internet.[2] An example is networked lights (EDNA 2014). The energy cost of maintaining a network connection (and ignoring the upstream router and cloud energy impacts) can be several watts. If the 11 W light-emitting diode (LED) is operated less than two hours per day, then the annual standby energy use exceeds the energy consumed by the LED. Many different technical solutions have been created to provide network connections in electrical products. These solutions employ a wide variety of wired and wireless communications procedures, but they all require additional power. Ultimately, devices with network connections will be nearly as ubiquitous as those with standby power consumption.

The second transformation is the ubiquitous use of mobile devices. A growing number of products carry a battery and can operate without a connection to the mains. The most notable examples are electronics, such as mobile phones, laptops, and tablets; however, vacuum cleaners and lawn mowers, portable oxygen concentrators, and other devices are increasingly providing their primary functions while disconnected from mains power. Mobile devices also have driven a related transformation: ubiquitous power management. This feature is essential in mobile devices to extend operating times, but manufacturers have often transferred these innovations to larger appliances designed to be permanently mains-powered.

A third transformation is the appearance of natively DC-powered products. Many devices already rely on an AC-DC power supply to convert mains power to DC; however, an increasing number of products operate solely on DC via USB or Power over Ethernet (PoE). Recent changes in technical standards (Belkin 2017) enable much

---

[1] We use the term "standby" to represent a collection of low-power modes accessed through power management.

[2] The presence of network connections in today's appliances (from set-top boxes to thermostats, to lights) parallels the situation with "traditional" standby in the early 1990s, when products with standby use were the exception. A high proportion of future electrical products will have some sort of network connection, and the "deaf" device (without a network connection) will be the exception.

higher power transmission (up to 100 W). Some commercial lighting systems now use PoE and scanners, printers, and other small electronic devices rely on USB. In this way, the AC power source may no longer be directly associated with the specific product because the power flows through intermediate products.

The current status of standby energy consumption is therefore difficult to assess because there are more products and modes. For many simple products, the standby power consumption per unit has fallen (De Almeida et al. 2011). This drop in per-unit consumption is offset by a huge increase in the number of products constantly drawing power. The sales of external power supplies, which power a large fraction of these devices, is a good proxy for the rapid growth. Measurements of whole-home power use also suggest increases. A study of new U.S. homes found that standby consumption of products installed by the builder (and often required by updated building health and safety codes) often consumed 650 kilowatt-hours (kWh)/year before the occupants moved in (Meier and Alliot 2016). A California study identified exceptionally high "idle loads" in 70,000 homes (Delforge, Schmidt, and Schmidt 2015). The net impact of these trends has probably resulted in a greater fraction of standby energy use than 20 years ago. In any event, standby—or its variants—continues to represent a significant fraction of electricity use in residential and commercial buildings and perhaps even a greater absolute amount of electricity and emissions.

Updated policies to address standby

The earliest policies and initiatives to reduce standby focused on limiting power consumption to 1 watt. Later initiatives lowered the target to 0.5 W and 0.3 W for special situations. These policies relied on labelling, regulations, purchasing requirements, and other voluntary measures. Some of these policies treated standby use of a product separately from its active energy use, while others were incorporated in a typical operating pattern.

Standby power consumption has not been eliminated and may even be growing. The initial policy objective of reducing standby power levels to 1 W in most products has been rendered obsolete or made less relevant by improved technologies and the three transformations described above. Nevertheless, further reductions are technically feasible and economic. What should those updated policies look like? In the remainder of this paper, we explore one technical option to support an updated policy to reduce standby power use. However, we first briefly review some of the options under consideration. These include:

- declare victory and focus on reducing a product's active energy use,
- preserve the existing approach and lower standby to much less than 1 W,
- adopt power budgets for specific functions,
- establish typical operating patterns for each device and establish targets for total energy use, and
- adopt a different approach.

These approaches are examined in detail other publications (Harrington and Nordman 2010; Harrington, Siderius, and Ellis 2008) so they are only briefly described below.

Declare victory over standby and focus on reducing a product's active energy use

One option is to not actively promote further reductions in standby power use and instead target energy savings of products in their active modes. The easy savings have already been captured and future reductions will be relatively small, more expensive, and technically difficult to achieve. In contrast, greater savings are possible in active modes (because more energy is consumed in those modes). Manufacturers of mobile products will in any case have an inherent incentive to make them efficient (to conserve batteries or extend operating time). There are also high transactions costs—for both policymakers and manufacturers—in dealing with the small amount of energy savings extracted from each of the billions of affected products. In practice this option might translate into leaving 1 W (or other relevant targets) in place.

Preserve the existing approach and reduce standby to much less than 1 W

This option is, on the surface, the simplest because it involves only making the target levels more stringent. In other words, targets of 1 W today are reduced to 0.5 W (or 0.25 W or 0.2 W, etc.), the 0.5 W targets are similarly cut, and so on. This approach is purely "horizontal" in the sense that it applies to all products or all products within a family. An increasing number of products have this mode but operate little or no time in it.

Adopt power budgets for specific functions

This option involves setting power allowances for major product functions. The limit for each device is then the sum of the functional allowances. ENERGY STAR, the EU, and various codes of conduct employ this approach.

It is flexible and can accommodate a wide range of products. However, a disadvantage is that power allowances tend to "mushroom." A second drawback of this approach is that allowance for each product must be indicated.

Establish typical operating patterns for each device and establish targets for total energy use

A "Typical Energy Consumption (TEC)" is established for each product, based on a defined operating pattern. This is the most rational approach because it allows manufacturers to optimize investments in energy savings, regardless of the mode. Policymakers adopted this approach for refrigerators, clothes washers, TVs, and many other products with relatively high energy use. It has a high administrative cost because each product must be clearly defined and have its own test procedure.

All of these approaches have significant limitations, which were already noted in 2010 (Harrington and Nordman 2010). The emerging transformations in standby energy use described above since then have further limited their applicability. For these reasons, it is worthwhile to consider alternative approaches to limiting standby power.

Adopt a different approach: the Standzero option

Perhaps the most intriguing approach to dealing with standby energy use (and active energy use) is the Zero Energy Appliance (ZEAP) strategy proposed by Ellis et al. (2015). A ZEAP is an appliance that derives sufficient energy from non-grid sources to fully offset its consumption (on a net basis). The authors argue that technologies related to ambient energy harvesting and storage have improved rapidly, while the energy required by appliances to provide the desired services is falling. Costs have fallen for harvesting, storage, and consumption, too. An increasing number of appliances will therefore be technically capable of achieving net-zero behaviour and, not long after that, become economically attractive. Indeed, this is already the case for many devices where grid-supplied electricity is especially expensive to supply (such as remote buoys, sensors, etc.)

We propose here a variant of the ZEAP, the "Standzero" option, which focuses on the length of time a product can operate without mains power. The target is operation with no mains-power for a specified time period. The Standzero option (short for Standby zero) requires a product to be disconnected from the mains and continue operating at a minimal level of functionality for, say, one hour. The Standzero option focuses on standby consumption because the minimum level of functionality will typically be a standby mode. The Standzero option has an unusual metric of performance (in addition to 0 watts), namely, the duration of time a product can operate without mains power. Thus, Standzero might be measured in hours.

The Standzero and ZEAP approaches target different modes of energy consumption. The ZEAP seeks to offset energy use in all modes. In contrast, Standzero targets only the lowest modes. Figure 1 illustrates the distinction. Thus, Standzero is inherently less ambitious than ZEAP with respect to energy savings in a given product. On the other hand, Standzero might be applicable to more products. The remainder of this paper explores the Standzero option.

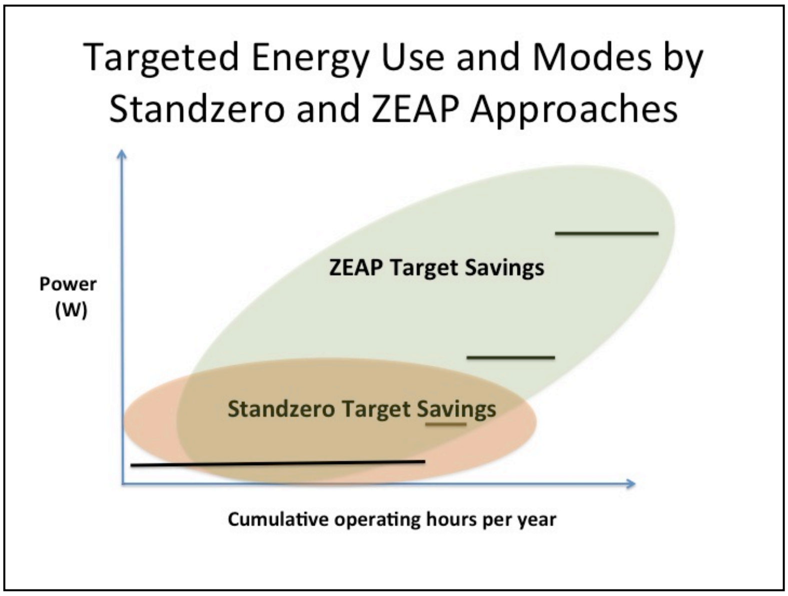

Figure 1. Targeted energy use and modes by the Standzero and ZEAP approaches.

The Standzero metric is the operating time while disconnected from mains power. Manufacturers could comply simply by inserting a small battery (or supercapacitor) in the power supply, which is continuously recharged by mains power. When no mains power is detected, the battery discharges and maintains the product's functionality for a brief period. This scenario saves no energy; it merely shifts mains power use from one period to another (and might even increase total energy use since there are new charging and discharging losses). So how does Standzero reduce standby?

Manufacturers have only one means of creating 0-watt (mains power) operation, that is, by installing an energy storage function (e.g., a battery or super-capacitor). However, they have three means of extending 0-watt operating times:

- increase the battery capacity,
- harvest ambient energy, and
- reduce power consumption during standby (that is, increase efficiency).

A conceptual design of a Standzero solution for an external power supply (EPS) is shown in Figure 2. The EPS must be modified to include energy storage and accommodate DC power input from energy harvesting sensors. The EPS must also include logic to select sources of power feeding the product (from the mains or the battery). In Figure 2, the EPS is shown supplying a Wi-Fi router. Ideally, the router would rely on off-mains sources for all standby activities and switch to mains power for high-speed data transfers.

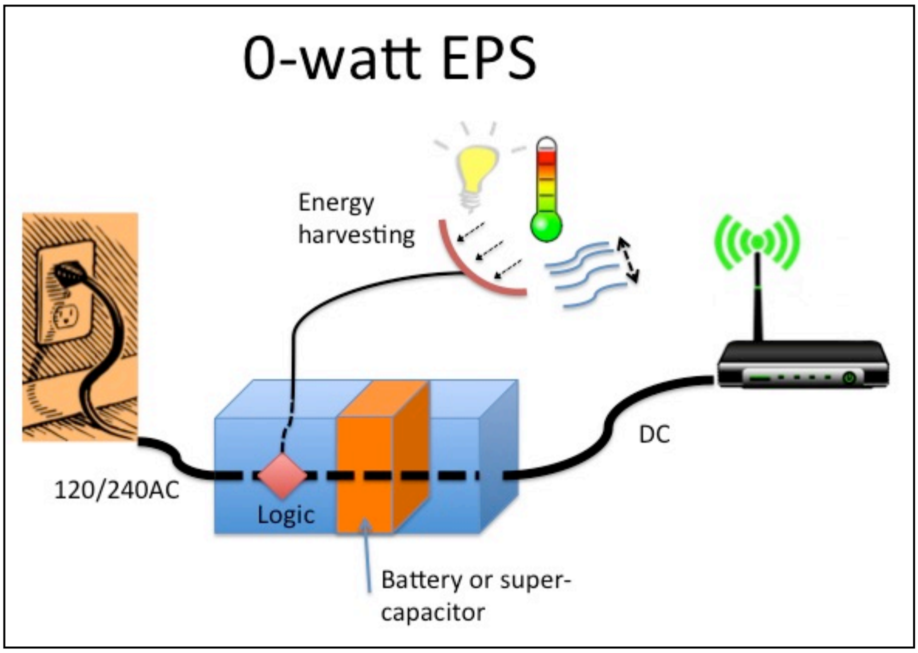

Figure 2. Schematic illustrating how Standzero would be applied to an external power supply (EPS).

Manufacturers will seek the lowest-cost combination of these strategies but also combinations that offer the greatest reliability. Efficiency improvements will generally be the cheapest option, which will result in lower energy use. Energy harvesting, which will generally be the most expensive option, also will result in lower energy use. The Standzero option will probably not save energy until the 0-watt period is long enough to push manufacturers to investigate options other than larger batteries. Thus, an early technical question will be, what is a technically feasible length of 0-watt operation? Since this is a new concept, we explore Standzero feasibility in some detail in the next section

Technical feasibility of Standzero

The length of 0-watt (mains power) operation depends on three characteristics:

- the power consumption of the product while in standby,
- the energy stored in the battery, and
- the energy supplied through ambient energy harvesting.

If no energy is collected through ambient energy harvesting, then the operating time is (roughly) the energy stored (in watt-hours) divided by the load (watts); that is:

$$operating\ time\ (hours) = \frac{Energy\ Stored\ (watt\text{-}hours)}{Operating\ Load\ (watts)}$$

When energy harvesting is present and contributing power, the operating time is extended

$$operating\ time\ (hours) = \frac{Energy\ Stored\ (watt\text{-}hours)}{Operating\ Load\ (watts) - Harvested\ Power\ (watts)}$$

Note that a negative operating time will occur when the harvested power exceeds the operating load. This corresponds to a surplus of energy. With clever design, this surplus energy could be applied to power higher operating modes. This behaviour avoids further mains-supplied electricity consumption.

Is the operating time described above on the order of milliseconds or hours for typical appliances? We surveyed the literature to determine the range of performance of these three characteristics to estimate operating times. We then selected low, mid-range, and high values for each characteristic to understand the likely range in operating times.

Operating load

The operating load varies by the product and depends on the functionality in that mode. Common functions include signal detection (infrared [IR], radio, motion), display, processing, and signal transmission. A huge range in loads are possible, even while in the standby mode. Table 1 lists some representative values found in the recent literature. The state-of-the-art is rapidly improving so we focused on literature less than two years old. Two off-the-shelf products—an LED status light and a ground fault interrupt circuit—were included to illustrate potential Standzero applications.

Table 1. Loads caused by typical components of products in standby

Component	Load (milliwatts)	Representative Citation
Radio	0.004	(Moss et al. 2015)
LCD Display (~6 square centimetres [cm^2])	0.015	http://www.mouser.com/
Digital microcontroller unit (MCU)	0.1	(Moss et al. 2015)
Personal sensors	1	(Niu et al. 2015)
Power consumption sensors	3.75	(Tsunoda et al. 2016)
LED indicator light	130	(Cree Inc. 2016)
PC control (S3 state)	210	(Te Huang, Bai, Ying-Wen, and Hsu 2015)
Ground fault interrupt circuit	500	Lawrence Berkeley National Laboratory measurements

In this simple exploration, we will assume that the range of standby loads in milliwatts (mW) of components in a wide range of applications is represented by: 0.004, 1.0, and 500 (low, mid-range, and high).

Energy harvesting

Energy harvesting depends on both technical characteristics of the harvesting technology and the energy source. Furthermore, the source energy is likely to vary over time. Research results are often reported for specific conditions and are therefore difficult to compare. Table 2 lists representative peak performances for some energy harvesting technologies found in the recent literature. They have been crudely normalized to 1 cm^2 of interception area (although area has a different interpretation for each technology). Furthermore, 1 cm^2 seems roughly appropriate for standby applications (that is, 100 cm^2 seems large).

Table 2. Energy harvesting technologies (normalized to roughly 1 cm^2)

Technology	Peak Performance (mW)	Representative Citation
Ambient radio	0.001	(Ferdous, Reza, and Siddiqui 2016)
Thermoelectric	0.06	(Ferdous, Reza, and Siddiqui 2016)
Ambient indoor light	0.1	(Ferdous, Reza, and Siddiqui 2016)
Ambient airflow	1	(Ferdous, Reza, and Siddiqui 2016)
Biomechanical	1	(Niu et al. 2015)
Vibration	7	(Moss et al. 2015)

In this simple exploration, we assume that energy harvesting can deliver peak power (in mW) in the range of 0.001, 0.06, 1.0 (low, mid-range, high). Next we assume that the average power delivered is 10 percent of the peak, with the exception of radio (which could be continuous). This yields average harvesting powers of 0.001, 0.006, and 0.1 average mW for the low, mid-range, and high values.

Energy storage

Two principal energy storage technologies are available at this small scale: batteries and ultracapacitors. Neither technology is ideal; batteries have high energy density and can store energy for long periods but have short cycle lives, and ultracapacitors (also called *supercapacitors*) have long cycle life but lose energy rapidly through self-discharge. Hybrids are now being developed to capture the best performance characteristics of both. Table 3 lists the energy densities for various storage technologies. The densities have been normalized to milliwatt-hours (mWh) per gram (g) of battery mass because one gram is in the range of the anticipated size. Many of these batteries are designed for larger applications, so they may not scale downwards. A second category of energy storage devices is emerging to serve the anticipated market for wearable electronics; these may ultimately be more appropriate for many Standzero applications.

Table 3. Energy storage (normalized to 1 g)

Technology	Energy Stored (mWh)	Representative Citation
Hybrid battery ultracapacitor with graphene	39	(El-Kady, Shao, and Kaner 2016)
Ultracapacitor (0.5 kilograms [kg])	57	http://www.skeletontech.com/
1 g of a lithium-ion (Li-ion) battery @ 120 Wh/kg	120	(Bruce et al. 2012)
Li-ion battery	200	(Lee et al. 2016)
Advanced Li-ion battery	600	(Bruce et al. 2012)

Note that 200 mWh of stored energy represents many thousands of hours of energy harvesting. The battery would never get fully charged. For that reason, one gram of energy storage is probably far too large. In this exploration we assume that the range of likely energy storage values, in mWh, are 0.01, 0.5, 2.0 (low, mid-range, high).

Results

We performed a sensitivity analysis of operating time without grid-supplied power based on ranges of loads, energy harvesting, and storage. These ranges are summarized in Table 4. There were 27 possible combinations (three variables, three levels). The results are shown as a histogram in Figure 3.

Table 4. Load, harvesting, and storage values used in sensitivity analysis

	Low	Mid-Range	High
Load (mW)	0.004	1.0	500
Harvesting (average mW)	0.001	0.006	0.1
Storage (mWh)	0.01	0.5	2.0

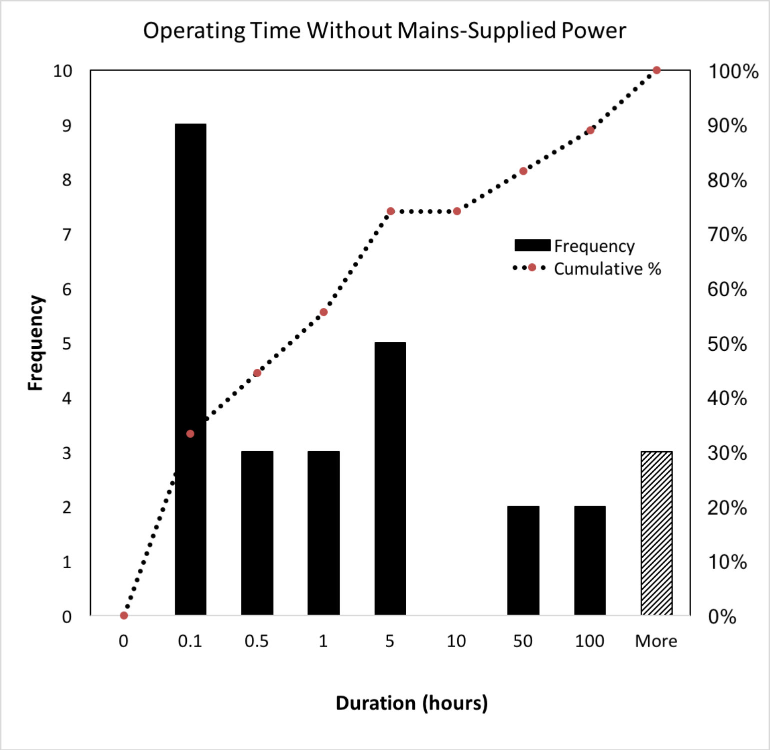

Figure 3. Histogram of operating time without mains-supplied power for 27 different combinations of loads, energy harvesting, and storage

The operating times ranged from 0.0002 to 58 hours. In three cases (shown with shading above "More"), the operating time was infinite because the harvesting power exceeded the load and therefore could contribute power for operation during higher modes. One-third of the combinations resulted in operating times less than 0.1 hour, while one-third had operating times longer than one hour. All of the shortest off-mains operating times occur when the load is 500 mW—indeed, most of them were near zero hours—which demonstrates the importance in reducing standby loads if Standzero is to be achieved. Nevertheless, the overall results demonstrate that, in a wide range of situations, the Standzero option is technically feasible.

Discussion

Earlier we asked if Standzero could deliver mains-free power for seconds or hours. The answer is, in some cases, yes: Standzero enables the device to operate for many hours without drawing on mains power. Standzero was least successful—not surprisingly—for high-load situations, such as 500 mW. However, these are precisely the situations where efficiency improvements are often possible. Manufacturers might prefer to invest in efficiency rather than installing more sophisticated harvesting and storage technologies. Manufacturers of mobile devices adopted this strategy to extend the time their products can operate without plugging in. In any event, a Standzero target above one hour appears feasible for many products.

In practice, efficiency, harvesting, and storage cannot be easily separated as done in these calculations. For example, an important standby function in many products is their ability to receive, and respond to, a signal from an infrared remote control. Yamawaki and Serikawa (2015) proposed an intriguing solution that fully eliminates standby power in this situation. They modified a conventional power supply to include energy harvesting on a control circuit. The energy harvesting sensor was optimized to detect and harvest IR radiation from the remote control. The IR power harvested by the sensor was sufficient to switch on the power supply. This category of solutions—that is, those relying on harvesting energy from the signal itself—appears to be a fruitful path towards accomplishing Standzero, and even permanently zero standby loads. This approach also illustrates how entirely new solutions become feasible when standby loads are greatly reduced. Other researchers are integrating energy harvesting and storage so as to increase efficiency and lower costs (Lee et al. 2016).

The economics of Standzero were not explored in this paper. It will be difficult—but not impossible—to justify investing much to save, say, 0.5 W when the annual cost reduction is worth about 1 Euro/year. There may be non-economic reasons to adopt Standzero, such as energy security and resilience. Standzero would be especially useful in regions where power outages are common. There is some evidence that increased weather variability—

presumably caused by climate change—is causing more power outages. In the United States, which has many more power outages than Europe, the frequency of outages has been increasing at about 10 percent per year (Eto 2016). Standzero could extend the off-grid operating time for a home's smoke detectors, security systems, and communications infrastructure.

The environmental impacts of Standzero were also not considered in this paper. Since most solutions require a battery, there will be both new materials and disposal impacts.

Some classes of products may be better suited to Standzero than others. Further investigation is needed to determine if an external or internal power supply can more easily incorporate the Standzero technologies. Some products, such as ground fault interrupt circuits, have more potential surface area for energy harvesting.

Conclusion and recommendations

The principal goal of this paper is to introduce the Standzero option and to explore its technical feasibility. The Standzero approach would mark an important shift in emphasis from current policies because the metric changes from a power level to a period of time. Standzero encourages reduced electricity conservation through higher efficiency and the use of renewable energy sources. Standzero also captures a trend that is already underway among products that have extreme requirements.

We found that, in a wide range of conditions, products could operate without mains power for up to 60 hours. In a few cases—with low load and high energy harvesting—the harvesting power exceeded the load and ambient energy could contribute power for operation during higher modes. One-third of the combinations resulted in positive operating times less than 0.1 hour, while one-third had operating times longer than one hour. The operating time is very brief when the load is 500 mW, which demonstrates the continued importance of reducing standby loads. Nevertheless, the overall results demonstrate that a Standzero target of one hour will be technically feasible in many products.

References

Belkin. 2017. "Learn about USB-C (USB Type-C)." *Belkin*. Accessed January 2. http://www.belkin.com/us/Resource-Center/USB-C/What-Is-USB-C/.

Bruce, Peter G., Stefan A. Freunberger, Laurence J. Hardwick, and Jean-Marie Tarascon. 2012. "Li-O2 and Li-S Batteries with High Energy Storage." *Nat Mater* 11 (1): 19–29. doi:10.1038/nmat3191.

Bush, George W. 2007. "Presidential Executive Order: Further Amendment to Executive Order 12866 on Regulatory Planning and Review." The White House: United States Government. www.archives.gov/federal-register/ executive-orders/pdf/12866.pdf.

Cree Inc. 2016. "Cree 5-Mm Red and Amber Round LED Data Sheet - CLD-CT1079.006." www.cree.com/hb.

De Almeida, Anibal T., Carlos Patrao, Philippe Riviere, David Da Silva, Barbara Schlomann, Michaela Gigli, and Bob Harrison. 2011. "Standby and off-Mode Power Demand of New Appliances in the Market." In *6th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'11), Copenhague: Danemark (2011)*, 12 p.

Delforge, Pierre, Lisa Schmidt, and Steve Schmidt. 2015. "Home Idle Load: Devices Wasting Huge Amounts of Electricity When Not in Active Use." NRDC Issue Paper IP:15-03-A. San Francisco: Natural Resources Defense Council.

EDNA. 2014. "Smart Lamp Testing—Initial Results." Electronic Devices and Networking Annex - IEA.

El-Kady, Maher F., Yuanlong Shao, and Richard B. Kaner. 2016. "Graphene for Batteries, Supercapacitors and beyond." *Nature Reviews Materials* 1 (May): 16033. doi:10.1038/natrevmats.2016.33.

Ellis, Mark, Hans-Paul Siderius, and Kevin Lane. 2015. "Closing the Gap towards Net Zero Energy Appliances." In *ECEEE 2015 Summer Study Proceedings*. Vol. 1-038-15. Hyères, France: European Council for an Energy-Efficient Economy. http://proceedings.eceee.org/visabstrakt.php?event=5&doc=1-038-15.

Eto, Joseph H. 2016. "CERTS Microgrid Project: Status Report." Presented at the LBNL Reliability Research: Overview and OE/AGRD Projects, Lawrence Berkeley National Laboratory, December 6.

Ferdous, Raquib Md., Ahmed Wasif Reza, and Muhammad Faisal Siddiqui. 2016. "Renewable Energy Harvesting for Wireless Sensors Using Passive RFID Tag Technology: A Review." *Renewable and Sustainable Energy Reviews* 58 (May): 1114–28. doi:10.1016/j.rser.2015.12.332.

Harrington, Lloyd, and Bruce Nordman. 2010. “Standby Power and Low Energy Networks—issues and Directions.” Report for Asia Pacific Partnership and the International Energy Agency 4E Standby Annex. Warrgul, Vic. Australia: Energy Efficient Strategies. http://standby. iea-4e. org/files/otherfiles/0000/0023/Network-Standby-2010-09-final. pdf.

Harrington, Lloyd, Hans-Paul Siderius, and Mark Ellis. 2008. “Standby Power: Building a Coherent International Policy Framework.” In *ACEEE Summer Study on Energy Efficiency in Buildings*.

International Electrotechnical Commission. 2011. “IEC 62301 Household Electrical Appliances Measurement of Standby Power.” *Edition* 2: 94720–136.

Lee, Joo Hyeong, Chong S. Yoon, Jang-Yeon Hwang, Sung-Jin Kim, Filippo Maglia, Peter Lamp, Seung-Taek Myung, and Yang-Kook Sun. 2016. “High-Energy-Density Lithium-Ion Battery Using a Carbon-nanotube–Si Composite Anode and a Compositionally Graded Li[Ni0.85Co0.05Mn0.10]O2 Cathode.” *Energy Environmental Science* 9 (6): 2152–58. doi:10.1039/C6EE01134A.

Meier, Alan, and Quentin Alliot. 2016. “Permanent Electrical Loads in New Homes.” In *ACEEE 2016 Summer Study on Energy Efficiency in Buildings*. Pacific Grove, Calif.: American Council for An Energy Efficient Economy (Washington, D.C.).

Meier, Alan, and Benoit Lebot. 1999. “One Watt Initiative: A Global Effort to Reduce Leaking Electricity.” In *The ECEEE Summer Study on Energy Efficiency*, 1:II.03.1-II.03.7. Mandelieu, France: European Council for an Energy Efficient Economy.

Meier, Alan, Leo Rainer, and Steve Greenberg. 1992. “The Miscellaneous Electrical Energy Use in Homes.” *Energy - The International Journal* 17 (5): 509–18.

Moss, Scott D., Owen R. Payne, Genevieve A. Hart, and Chandarin Ung. 2015. “Scaling and Power Density Metrics of Electromagnetic Vibration Energy Harvesting Devices.” *Smart Materials and Structures* 24 (2): 023001. doi:10.1088/0964-1726/24/2/023001.

Niu, Simiao, Xiaofeng Wang, Fang Yi, Yu Sheng Zhou, and Zhong Lin Wang. 2015. “A Universal Self-Charging System Driven by Random Biomechanical Energy for Sustainable Operation of Mobile Electronics.” *Nature Communications* 6 (December): 8975. doi:10.1038/ncomms9975.

Rainer, Leo, Alan Meier, and Steve Greenberg. 1996. “You Won’t Find These Leaks with a Blower Door: The Latest in ‘Leaking Electricity’ in Homes.” In *ACEEE Summer Study on Energy Efficiency in Buildings*. Asilomar, Calif: American Council for an Energy-Efficient Economy.

Roth, Kurt, Bryan Urban, Victoria Shmakova, and Brian Lim. 2014. “Residential Consumer Electronics Energy Consumption in 2013.” In *ACEEE Summer Study on Energy Efficiency in Buildings*. Pacific Grove, Calif.: American Council for An Energy Efficient Economy (Washington, D.C.).

Sandberg, Eje. 1993. “Electronic Home Equipment - Leaking Electricity.” In *ECEEE 1993 Summer Study*. European Council for an Energy Efficient Economy.

Te Huang, Bai, Ying-Wen, and Po-Yang Hsu. 2015. “Reducing the Standby Power Consumption of the S3 State for PCs.” *IEICE TRANSACTIONS on Electronics* Vol.E98-C (10): 952–62.

Tsunoda, Y., C. Tsuchiya, Y. Segawa, H. Sawaya, M. Hasegawa, S. Ishigaki, and K. Ishibashi. 2016. “A Small-Size Energy-Harvesting Electric Power Sensor for Implementing Existing Electrical Appliances Into HEMS.” *IEEE Sensors Journal* 16 (2): 457–63. doi:10.1109/JSEN.2015.2472475.

Yamawaki, Akira, and Seiichi Serikawa. 2015. “Power Supply Circuit with Zero Standby Power Consumption on Infrared Remote Controlled Product by Using Energy Harvesting.” In *Proc. of the International MultiConference of Engineers and Computer Scientists 2015*.

Acknowledgments

Research for this paper was supported by the California Energy Commission’s Electric Program Investment Charge (EPIC) program.