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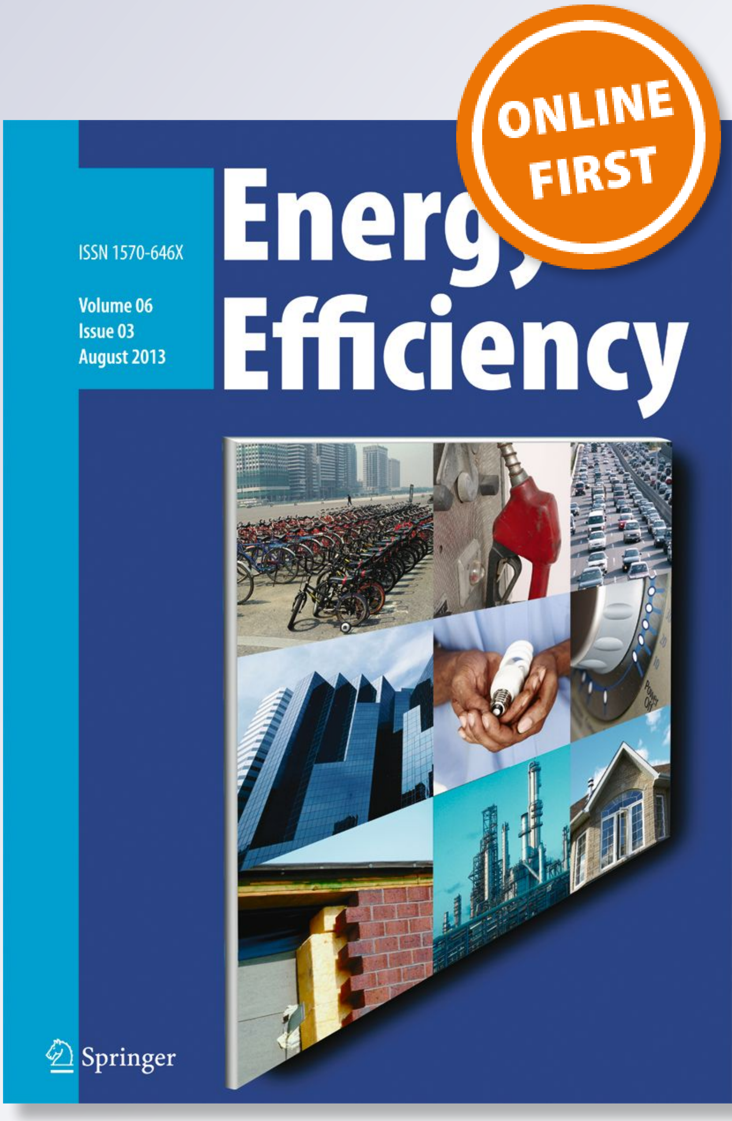

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ORIGINAL ARTICLE

New standby power targets

Alan K. Meier

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Abstract Leaving appliances and other devices in "standby power" mode is a significant source of continual electricity consumption in homes and workplaces. Over the years, a combination of policies and technologies has successfully reduced the amount of power used by devices and appliances when in standby power mode, but these energy savings have been offset by an increase in the number of products drawing standby power and new power requirements for maintaining network connections. Current technologies and policies to reduce energy use during standby have limitations and may not be appropriate for emerging trends in devices such as mobile products, networking, and direct DC power. This work proposes a new strategy to measure and further reduce standby energy consumption, the "Standzero" option, which encourages electrical products to be designed to operate for short periods without relying on grid-supplied electricity. Lower energy consumption is achieved through enhanced efficiency and by harvesting ambient energy. A sensitivity analysis indicates that many electrical devices could be designed to operate for at least an hour without relying on grid power and, in some cases, may be able to operate indefinitely at 0 W until activated.

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Introduction

Standby power use is the electricity consumed by appliances and devices while waiting to perform their primary functions. This category of consumption occurs in nearly all consumer electronics and in other devices equipped with digital displays, remote controls, and network connections. The electricity consumption per device is small—often less than 1 watt (W)—but billions of devices draw standby power. Thirty years ago, devices with standby power consumption were rare; now, devices *without* standby power use are increasingly rare. For many small appliances, the majority of their total annual energy use is consumed in standby mode. As a result, standby power consumption accounts for 1–2% of global electricity use and at least 10% of residential electricity use in developed countries (IEA 2014). Standby power use is also significant in developing countries such as in China (Meier et al. 2004).

Many countries have established mandatory limits and voluntary targets to address standby power use. These policies have been successful with respect to specific products—notably consumer electronics (Roth et al. 2014)—but it remains unclear if global standby power consumption is rising or falling. The dramatically reduced per-unit consumption in new devices may be offset by the explosive growth in the number of devices

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drawing standby power. Reducing standby power consumption in appliances and devices therefore continues to be a target for government policies.

The goals of this study were to review recent developments in standby power and to propose a new strategy for reducing standby power even further. This paper begins with a brief history of standby power use, which explains how standby power today is rapidly evolving. Options for an updated policy to reduce standby power use are then described, and a different approach, the Standzero option, is presented. The technical feasibility of the Standzero option is investigated and discussed. The paper ends with conclusions and recommendations.

A short history of standby power

In the early 1990s, Olof Molinder, an official at the Swedish Energy Agency, commissioned Eje Sandberg, an engineer, to study the electricity use of TVs and audio equipment while switched *off*. Sandberg's report was the first comprehensive study of appliance electricity use while in the off mode and a version was published in the 1993 European Council for an Energy-Efficient Economy (ECEEE) Proceedings (Sandberg 1993). Sandberg's English was less than perfect, so his translation of "standby power" from the Swedish emerged as "leaking electricity." Soon after this, researchers in Australia, Europe, Japan, Korea, and the USA also began noticing the proliferation of appliances drawing power even when switched off (Meier, Rainer, and Greenberg 1992). The words describing it varied widely, from the Japanese term "waiting electricity" to the more colorful American term "vampire power"[1] but the target of attention was the same. Meier and others published early articles on standby power and, by 1996, estimated the amount of energy being used by standby applications in the typical 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 that the standby power use of all future appliances be reduced to 1 W. The 1-W plan was introduced at the Energy Efficient Domestic Appliances and Lighting conference (EEDAL) and supported by many other researchers. In 1999, Meier and Lebot proposed a "global 1-W plan" (Meier and Lebot 1999). They suggested 2010 as the target year when all new products would achieve that level. Meier and Lebot also estimated that global standby power energy use was responsible for about 1% of global carbon emissions.

In 2001, the International Energy Agency (IEA) adopted the 1-W plan as a recommended energy efficiency policy. Soon afterwards, it worked with the G8 countries to include reducing standby as an element of their energy policies (Jollands et al. 2010). The IEA also established the IEA 4E Standby Power Annex in 2009 to coordinate activities to address standby power. Over time, the governments of Japan, Australia, Korea, the European Union (EU), and the USA adopted policies to reduce standby power, ranging from voluntary guidelines to regulations (Korea Energy Management Corporation 2011). Two notable acts were President Bush's Executive Order to reduce standby power use (Bush 2007) and the European Union Ecodesign regulation 1275/2008, including the amendment in Regulation 801/2013 to cover networked standby power use (European Commission 2008). 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).

In parallel to these activities, groups around the world undertook field measurements of standby power. Researchers measured appliances in typical homes in many countries, including China (Meier et al. 2004), Turkey (Sahin and Aydinalp Koksal 2014), Taiwan (Lu, Yeh, and Chang 2011), and the USA (Ross and Meier 2002) so as to gain a better understanding of the current situation. Other groups in Europe and the Asia-Pacific region performed in-store measurements so as to understand and track the performance of new products (Patrão et al. 2017).

At the same time, the manufacturers of appliances and other electrical devices made remarkable progress in reducing standby power use in nearly all products. The energy-saving innovations can be classified into three major categories:

- Improving the efficiency of the AC-DC power supply (which cuts no-load losses and increases conversion efficiency)

[1] Older power supplies resembled vampires because they had two "teeth" (prongs) and sucked electricity through the night. The source of this expression is not known.

- Reducing energy used by always-on circuitry in the device (including switching off circuits not needed while in standby)
- Reducing power consumed by displays and status lights operating all the time.

Manufacturers were able to reduce no-load power use in the most common external power supplies from 3 W to less than 0.2 W. The standby power use of TVs—the largest source of standby energy consumption—fell from 15 to 0.5 W.

Thus, in less than 20 years, the problem of standby power use was identified, quantified, and greatly reduced through technical innovations.

Standby has evolved

The status of standby power has changed dramatically in the last decade. This new environment is reflected in three technical transformations. First, a new, always-on function, the network connection, has emerged. Network connectivity enables the device to exchange information with other devices. Wirelessly controlled lights are an example of the network connection (EDNA 2014). The energy cost of continuously maintaining a network connection can exceed 2.5 W (SSL Annex 2016). One survey of wirelessly controlled light-emitting diodes (LEDs) found that, when operated an hour a day, about one third of the lamps consumed more in standby energy than in active mode (SSL Annex 2016). Many different technical solutions have been created to provide network connections in electrical products, employing a variety of wired and wireless communications procedures, but they all require additional power. This is important because, eventually, devices with network connections will be as ubiquitous as those today 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 main power grid. 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 the power grid. Major improvements in efficiency have made disconnected operation feasible. Mobile devices also have driven a related innovation: ubiquitous power management. This feature is essential in mobile devices to extend their operating times, but manufacturers have often transferred these modifications to larger appliances designed to be permanently grid-powered.

The third transformation is the appearance of natively DC-powered products. Many devices already use a power supply to convert grid AC power to DC; however, an increasing number of products operate solely on DC via universal serial bus (USB) or Power over Ethernet (PoE). Recent changes in USB technical standards (Belkin 2017) enable transmission up to 100 W. This power is sufficient to enable many appliances formerly powered with AC. Some commercial lighting systems now use PoE. Scanners, printers, and other small electronic devices rely on USB. This arrangement complicates energy measurements. For example, most test methods assume that a product directly draws AC power and measures the AC energy consumption. However, measuring the AC power cannot be applied to products powered through DC networks because the source of DC power may be remote or also powering other products.

The present status of standby energy consumption is difficult to assess because there are more products and more modes to consider. For simple products, the standby power consumption per unit has almost certainly fallen (De Almeida et al. 2011). This drop in per-unit consumption has been 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. Whole-home power use in unoccupied homes is another proxy. A recent study (Meier and Alliot 2016) examined new U.S. homes prior to occupancy, when the only electrical devices present were those installed by the builder to satisfy health and safety regulations and meet minimum requirements by the future owners (such as heating, ventilation, and air conditioning [HVAC] controls, communications infrastructure, and security systems). The continuous power draw amounted to 650 kilowatt-hours per year (kWh/year). A 2015 study of 70,000 occupied homes in California (Delforge, Schmidt, and Schmidt 2015) used smart meter data to identify the minimum power draw. These homes exhibited a median minimum load of 185 W (about 1600 kWh/year). Most of this load occurs during standby mode. The net impact of these trends—efficiency improvements, increased number of devices, and network requirements—has most likely resulted in a greater fraction of standby energy use than 20 years ago. In any event, standby energy use continues to represent a significant fraction of total electricity consumption in buildings and may even be responsible for a greater absolute amount of electricity and emissions.

Bringing standby policies up to date

The earliest policies and initiatives to reduce standby focused on limiting power consumption to 1 W (or higher for certain products). Examples include the U.S. Executive Order (Bush 2007) and others proposed by the IEA (IEA 2001). Later policies and regulations lowered the target to 0.5 and 0.3 W for special situations. Examples included European ecodesign regulations (European Commission 2009) and U.S. regulations for power supplies (Department of Energy, Office of Energy Efficiency and Renewable Energy 2011). These policies typically relied on labelling, regulations, purchasing requirements, and voluntary measures. Some of these policies treated standby use of a product separately from its active energy use, while others incorporated standby energy in a typical operating pattern.

Nevertheless, standby power consumption has not been eliminated, and it may even be growing. The original policy target of reducing standby power levels to 1 W is mostly obsolete (or certainly less relevant) through improved technologies and the three transformations described above. There is still a significant potential for further reductions in standby power use. But what should those updated policies look like?

The remainder of this paper explores one technical option to support an updated policy to reduce standby power use. As an introduction, some of the existing options under consideration are first reviewed. These include the following:

- Ignore standby power and focus on reducing a product's active energy use
- Continue lowering the standby limit to much less than 1 W
- Adopt power budgets for specific functions
- Create a typical operating pattern for each device and then select a target for its total energy use
- Adopt a different approach

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

Ignore standby and focus on reducing a product's active energy use

The first option is to no longer aggressively promote reductions in standby power use and instead target energy savings of products in their active modes. The justification for this strategy is that the easy savings have already been captured and future reductions will be negligible, expensive, and technically difficult to achieve. Manufacturers of mobile products will in any case have an inherent incentive to make their products more efficient (to conserve batteries or extend operating time). Finally, dealing with the small amount of energy savings extracted from each of the billions of affected products has high transactions costs—for both policymakers and manufacturers. One should focus instead on products where active-mode energy consumption dominates. Adopting this policy might translate into leaving the standby 1-W target (or other relevant targets) in place.

Continue lowering the standby limit to much less than 1 W

This policy corresponds to reducing the current 1-W target to 0.5 W (or 0.25 W or 0.2 W, etc.), cutting the 0.5-W targets similarly, and so on. This is the simplest approach because it involves only making the target levels more stringent. This approach is "horizontal" because it applies to all products or all products within a family. Note that an increasing number of networked products may have a compliant mode but will operate little or no time in it. Thus, the limit may have little impact on actual energy consumption.

Adopt power budgets for specific functions

This approach involves setting maximum power allowances (or limits) for each major product function (network, displays, etc.). 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. The approach is flexible and can accommodate a wide range of products. However, a disadvantage is that function-specific power allowances tend to multiply. A second drawback of this approach is that an allowance for each product must be created and adopted by the relevant authorities.

Create a typical operating pattern for each device and select a target for its total energy use

In this approach, a typical energy consumption would be established for each product, based on a defined operating pattern. This is the most economically rational approach because it allows manufacturers to optimize investments in energy savings across all modes. Policymakers have adopted this approach for products with relatively high-energy consumption, such as refrigerators, clothes washers, and TVs. The administrative costs are high, though, because each product must be clearly defined and have its own test procedure.

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

A different approach: the Standzero option

An 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 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 are improving, while the amount of energy required by appliances to provide the desired services is falling. The costs of these technologies have also fallen. As a consequence, an increasing number of appliances will be technically capable of achieving net-zero behavior and, not long after that, become economically attractive. Indeed, ZEAP devices are already economically viable where grid-supplied electricity is especially expensive to supply (such as remote buoys and sensors)

A variant of the ZEAP—the Standzero option—is proposed below. The Standzero option (short for Standby zero) focuses on the length of time a product can operate without mains power. The Standzero target is operation of the product for a specified time period with no grid power. In practice, the Standzero option translates into a product being disconnected from the grid and continuing to operate at a low level of functionality for, say, 1 h. The Standzero option targets standby consumption because the minimum level of functionality will typically be a standby mode. The Standzero option has a new metric of performance (in addition to 0 W), namely, the *duration* of time a product can operate without grid power. Thus, Standzero might be measured in hours. In fact, the public is already intimately familiar with the Standzero concept as it applies to their smartphones (where it is about 12 h).

The ZEAP and Standzero approaches target different modes of a device's energy consumption. The ZEAP seeks to offset energy use in all modes—an ambitious goal. In contrast, Standzero targets only the lowest power modes. Figure 1 illustrates the differences in these approaches. Standzero is less ambitious than ZEAP with respect to targeted energy savings in a given product. On the other hand, Standzero might apply to more products. The remainder of this paper explores key aspects of the Standzero option.

The Standzero metric is the operating time while disconnected from grid power (effectively drawing 0 W). Manufacturers could comply simply by inserting a small battery (or supercapacitor) in conjunction with the power supply, which is then continuously recharged by mains power. When no power from the mains is detected, the battery discharges and maintains the product's

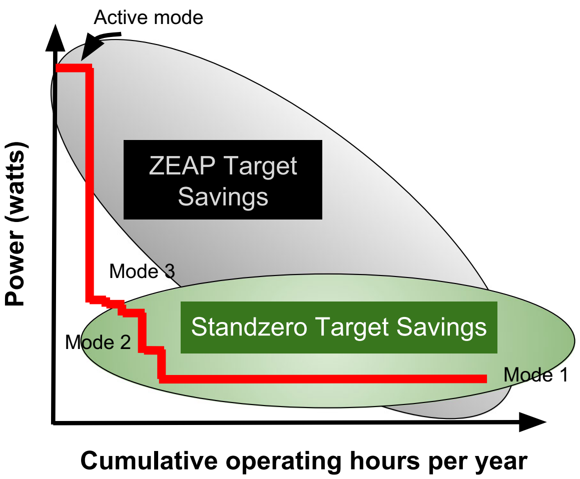

Fig. 1 Targeted energy use and modes by the Standzero and ZEAP approaches. Each step corresponds to a power mode

functionality for a brief period. This design saves no energy because it merely shifts grid power use from one period to another. It might even increase total energy use since there are new charging and discharging losses.

Manufacturers have only one means of creating 0-W operation (e.g., inserting a battery or supercapacitor), but they have three means of *extending* 0-W operating times. These means are as follows:

- Increase the capacity of the battery
- Harvest ambient energy
- Reduce the product's power consumption during standby

Energy harvesting is the means by which energy is derived from ambient sources, as ambient light, small thermal differences, and movement. Energy harvesting is increasingly used to power small electronics, such as wireless autonomous devices.

A Standzero solution for an external power supply (EPS) incorporating these features is shown conceptually in Fig. 2. The EPS must be modified to incorporate energy storage and accommodate DC power input from energy harvesting components. The EPS must also include logic to manage the two power sources; that is, from the grid or the battery. In Fig. 2, the EPS is shown supplying power to a Wi-Fi router. Ideally, the router would rely on off-grid sources for all standby activities, possibly for periods of low data transfer activity, and switch to grid power only for higher-speed data transfers. This behavior implies a greater degree of power scaling inside the router than is common today; however, this feature is already commercially available.

The Standzero option will not save energy until the minimum 0-W period is long enough to push manufacturers to investigate options other than larger batteries, such as efficiency and energy harvesting. Thus, an early technical challenge will be to determine the technically feasible length of 0-W operation. Since this is a new concept, Standzero feasibility is explored in some detail in the next section.

Technical feasibility of Standzero solutions

The duration of 0-W (grid power) operation depends on three characteristics:

- The power consumption of the product while in standby
- The storage capacity of the battery
- The energy captured and supplied through ambient energy harvesting

If no energy is collected from ambient energy harvesting, then the operating time is (roughly) the energy stored (in W-hours) divided by the load (W); that is as follows:

$$\text{Operating time (h)} = \frac{\text{Energy stored (W-hours)}}{\text{Operating load (W)}}$$

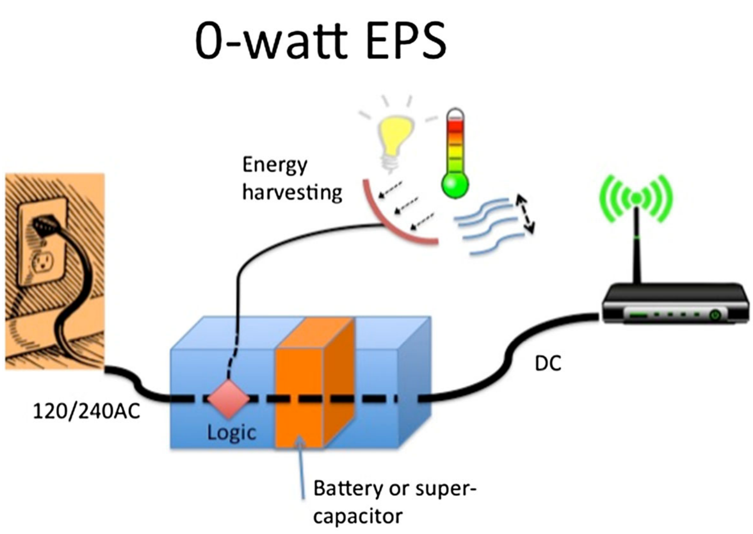

Fig. 2 Schematic illustrating how Standzero would be applied to an external power supply

Table 1 Loads caused by typical components of products in standby

Component	Load (milliwatts)	Representative source
Radio	0.004	(Moss et al. 2015)
Liquid-crystal display (LCD) (~6 cm^2)	0.015	Mouser Electronics website (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)
AC-DC power supply (no load)	15	(Taranovich 2017)
LED indicator light	130	(Cree Inc. 2016)
Personal computer control (S3 state)	210	(Te Huang, Bai, Ying-Wen, and Hsu 2015)
Ground fault interrupt circuit	500	Lawrence Berkeley National Laboratory measurements

When energy harvesting is present and contributing power, the operating time is extended because it behaves like a negative load.

$$\text{Operating time (h)} = \frac{\text{Energy stored (W-hours)}}{\text{Operating load (W)} - \text{harvested power (W)}}$$

Note that a negative operating time can occur when the harvested power exceeds the operating load, which corresponds to a surplus of energy. With clever design, this surplus energy could be accumulated for longer periods when no ambient energy is available. Alternatively (or in addition), this surplus can be applied to offset energy consumption during higher-power operating modes. This alternative reduces overall grid-supplied electricity consumption.

In order to estimate likely operating times, the literature was surveyed to determine the range of performance of loads, storage, and harvesting. Low, mid-range, and high values for each characteristic were then selected to understand the likely range in operating times. A sensitivity test was performed to determine which characteristics have the greatest influence on operating hours.

Operating load

The operating load is determined by the product. The load varies by the product and depends on the functionality in the standby mode(s). Common functions in that mode include signal detection (infrared [IR], radio frequency [RF], motion), display, processing, and signal transmission. A wide range in loads is possible; Table 1 lists some representative values found in the recent literature. The state-of-the-art is rapidly improving, so literature reported after 2014 was used. Two off-the-shelf products—an LED status light and a ground fault interrupt circuit—are included to illustrate potential Standzero applications.

In the sensitivity tests, the following range of component standby loads in milliwatts (mW) was assumed: 0.004, 1.0, and 500 (low, mid-range, and high).

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

Technology	Peak performance (mW/cm^2)	Representative source
Ambient RF	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)

Table 3 Energy storage (normalized to 1 g)

Technology	Energy Stored (mWh/g)	Representative source
Hybrid battery ultracapacitor with graphene	39	(El-Kady, Shao, and Kaner 2016)
Ultracapacitor (0.5 kg)	57	Skeleton Technologies website (http://www.skeletontech.com/)
1 g of a lithium-ion (Li-ion) battery @ 120 Wh/kg	120	(Bruce et al. 2012)
Li-ion battery (commercial)	200	(Manthiram 2017)
Future Li-ion battery	600	(Bruce et al. 2012) (Lee et al. 2016)

Energy harvesting

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

In the sensitivity test, energy harvesting is assumed to deliver peak power (in mW) in the range of 0.001, 0.06, and 1.0 (low, mid-range, high). To account for variability in supply, the average power delivered is assumed to be 10% of the peak, with the exception of RF (which could be continuous). This yields average harvesting powers of 0.001, 0.006, and 0.1 mW for the low, mid-range, and high values.

Energy storage—batteries and ultracapacitors

Two principal energy storage technologies are available at this small scale and application: batteries and ultracapacitors. Neither technology is ideal. Batteries have high energy densities and can store energy for long periods, but they have short cycle lives. 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. Many of these batteries are designed for larger applications, so they may not scale downwards. The densities were normalized to milliwatt-hours (mWh) per gram (g) of battery mass because a few grams is in the range of the anticipated size.

Recently, a new category of energy storage devices is emerging to serve the anticipated market for wearable electronics; these solutions may ultimately be more appropriate for many Standzero applications.

Note that 200 mWh of stored energy represents many thousands of hours of energy harvesting (with a 1-cm^2 interception area). The battery would never get fully charged. For that reason, 1 g of energy storage is probably far too large. In this exploration, the range of likely energy storage values is assumed to be (in mWh): 0.01, 0.5, and 2.0 (low, mid-range, high).

Results

A sensitivity analysis of operating time without grid-supplied power was performed, 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 Fig. 3.

The operating times ranged from 0.0002 to 58 h. In three other cases (shown in Fig. 3 as "Longer"), the operating time was infinite because the harvesting power exceeded the load and therefore could contribute

Table 4 Load, harvesting, and storage values used in the 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

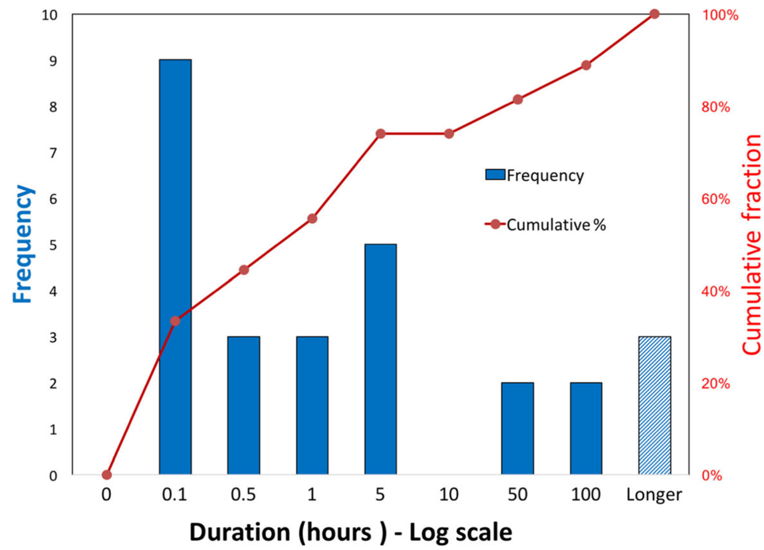

Fig. 3 Histogram of operating time without grid-supplied power for 27 different combinations of loads, energy harvesting, and storage (note log scale for duration)

power for operation during higher modes. One third of the combinations resulted in operating times less than 0.1 h, while one third had operating times longer than 1 h. All of the shortest off-grid operating times occurred when the load was 500 mW—indeed, most of them were near 0 h—which demonstrates the importance of reducing the product's load if Standzero is to be achieved.

Discussion

The sensitivity tests indicate that, in a wide range of situations, the Standzero option in the range of hours is technically feasible. 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 have already adopted this strategy to extend the time their products can operate without plugging in. In any event, a Standzero target greater than 1 h appears feasible for many products.

In practice, efficiency, harvesting, and storage cannot be easily separated as done in these calculations. For example, Lee et al. (2016) describe many ways in which hybrids and other physical combinations of harvesters and storage will yield improved performance.

Products with infinite Standzero times appear increasingly feasible. For example, an important standby function in many products is their ability to receive, and respond to, a signal from an infrared remote control. This includes many TVs, ceiling fans, and lights. 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 the control circuit. The energy harvesting sensor was optimized to detect and harvest IR radiation from the remote control. The IR energy harvested by the sensor—and accumulated in a capacitor—was sufficient to switch on the power supply.

We replicated Yamawaki and Serikawa's design and found that the IR signal was not reliably transmitted beyond 1 m. At longer distances, the IR beam lacked sufficient power density because the beam became too diffuse. An alternative configuration proposed by Kang et al. (2011) claims a range of 2 m. We are exploring alternative beams and configurations that maintain higher power densities and operate at longer distances. This category of solutions (those relying on harvesting energy from the signal itself) appears to be a fruitful path towards accomplishing infinite Standzero times and eliminating standby loads (Ulukus et al. 2015).

Harvesting the signal introduces another performance characteristic: latency. The harvesting circuit must first accumulate enough energy to open the primary power circuit. The delay—a few seconds—needs shortening before it will be acceptable to most users.

Other researchers have reported success harvesting an RF signal to accomplish the same task (Liu et al. 2016). These approaches illustrate how entirely new solutions become feasible when standby loads are greatly reduced and energy harvesting is permitted. Other researchers have proposed integrating energy harvesting and storage so as to increase efficiency and lower costs (Lee et al. 2016).

The costs of implementing 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 value of electricity savings is only 1 USD/year. But there may be non-economic reasons to adopt Standzero, such as increased portability, energy security, and resilience. Standzero capability would be especially useful in regions where power outages are common, since this would avoid rebooting and possibly maintain network connectivity. There is some evidence that increased weather variability—presumably caused by climate change—is causing more power outages. In the USA, which has many more power outages than Europe, the frequency of outages has been increasing at about 10% 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. Most solutions require a battery or capacitor, so there will be both new materials and disposal impacts. These deserve further exploration.

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 capabilities. Some products, such as remote-controlled ceiling fans, curtains, and shades, have more potential surface area for energy harvesting. Ultimately, Standzero is a means for describing the behavior of an emerging category of products rather than a technology requiring evaluation.

Earlier, this paper described the technical transformations now taking place in products drawing standby power. These transformations included portability, use of direct DC, and continuous network connectivity. Since standby targets were first developed 20 years ago, standby has shifted from a feature present in a minority of products to the norm. A consequence of these transformations is that the underlying test procedures, such as IEC 62301, will be less able to capture the behavior and energy efficiency of these products. Mobile products with batteries are also difficult to test because they can draw essentially no power for long periods, exceeding the measurement period. In summary, standby is becoming more multi-dimensional.

A target based on the Standzero concept may address some of these gaps. A Standzero target will not substitute for targets based on maximum power draw, but it may complement them for specific categories of products. Standzero captures performance aspects not revealed in a simple measurement of power. Standzero also captures product behavior that consumers already find useful—that is, the number of hours before it must be reconnected to the grid. It does not assure lower energy use (though reducing the load will typically be the cheapest way to extend Standzero times). Further, once quantified, manufacturers may find that long Standzero times are feature worth promoting. So a policy that includes Standzero might encourage energy savings in ways that would not have occurred otherwise.

Conclusion and future work

This paper introduced the Standzero concept and explored its technical feasibility. Through a sensitivity analysis, it was found that a wide range of products could potentially operate without grid power for up to 60 h. 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 h, while one third had operating times longer than 1 h. 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 1 h will be technically feasible in many products.

Our investigation shows that reductions in standby energy use are technically feasible. Further research and development are still needed to make the Standzero approach more robust. First, power supplies need to be designed to accommodate energy harvesting and storage. Second, other approaches to harvesting the activation signal's energy should be investigated. We described two implementations—using IR and RF—but other solutions may be superior, especially for particular applications. Third, a more sophisticated Standzero model is needed to test varying performance of its components. We created a simple spreadsheet model, with limited input data, to test Standzero sensitivity, but other factors need to be taken into account. One such factor is latency in situations where the energy from the activation signal is being harvested. The performance characteristics of the components must also be updated and expanded. Finally, technical standards committees will need to more carefully define Standzero and translate the definition into a test procedure.

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. It captures the increasing multi-dimensional aspects of standby power use and indirectly encourages reduced electricity conservation through higher efficiency and the use of renewable energy sources. Standzero also reflects the trend among appliances to operate for periods disconnected from the grid.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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