Leaking Electricity: Individual Field Measurement of Consumer Electronics

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ABSTRACT

Leaking electricity or "parasitic load" is energy wasted by electronic devices when they are not performing any useful function, typically in an "off" or "standby" state. Before this study, little was known about the magnitude or source of this waste. While whole house losses have been estimated to be approximately 50 watts, little data has been available to quantify energy waste from individual loads. This paper summarizes measurements of over 600 consumer electronic devices taken by researchers at both the Florida Solar Energy Center and Lawrence Berkeley National Laboratory. Combined they form the largest data set of consumer electronic loads ever assembled. Measurements were recorded at national electronic stores, a nationwide retailer and in individual's homes. Measured loads include heat pumps, televisions, videocassette recorders, digital video disk players, cable boxes, portable stereos, DSS receivers, telephones, and other miscellaneous residential electronic appliances. Detailed power consumption of each device was measured in the most common modes of operation (on, off and standby) and the features most likely to affect energy consumption were recorded. Loads for each product type and category are summarized in all modes of operation and methods to reduce parasitic loads are proposed.

Introduction

While all consumer electronic devices consume energy while performing a particular task or service, many also consume energy while "off" or in a powered down state. Loads of this nature have been labeled vampire, parasitic or simply leaking electricity because often no obvious function is being performed for the energy consumed. Individual loads of this type are often small (<30W) but collectively add to a substantial load. Estimates range from 37 to 50 TWh consumed annually in the US alone (Thorne & Suozzo 1998) or approximately 5% of an average household electrical load. European stand-by power consumption was estimated to be 10 TWh per annum (Molinder 1997), which confirms the global significance of this problem.

Leaking electricity plagues a variety of consumer electronics. Leaks originate in the design of the product or component(s). More specifically leaks are from (Rainer et al. 1996):

- Use of inefficient linear power supplies that are usually left "on" when the device's switch is turned "off".
- Instant "on" capabilities (remote control).
- Memory retention and internal clocks (i.e. TV channels, user preferences).
- Displays and lighting (LEDs, LCDs).
- Battery charging.
- Compressor crankcase heaters.

The various sources of leaking energy create some confusion about terminology. Some of these functions can be thought of as standby functions. That is, the device is waiting to be turned on and requires power either to be able to respond to a signal (e.g. remote control), to maintain an environment beneficial to the user (memory) or to speed up the device's response to an on signal. Other functions, such as clocks on microwaves and VCRs, offer a legitimate service to the user, although it is not the primary function of the device. Other loads are pure losses and offer no service to the user. We refer to these loads collectively as "standby losses."

While it can be argued that some standby losses perform a useful service, it is often possible to reduce or entirely eliminate the load without reducing the service performed. For the majority of these leaks there are solutions that could be implemented, however, there is little incentive for manufacturers to redesign products to reduce parasitic loss. It is also doubtful if consumers would demand the improvements, especially if conveniences such as remote control are eliminated. This report examines a large variety of consumer electronics to identify the magnitude of individual device standby losses.

Measurement Protocol

Readings were taken using watt meters that measured true root mean square voltage and current. This is critical in measuring these loads since few loads are purely resistive in nature (Stiles & Fuller 1997). Measurement errors caused by phase shift between the voltage and current waveforms as well as waveform distortion must be considered when selecting metering equipment. All of the meters selected for data collection were of this type and ranged in accuracy from (0.25 to 1.5%). Careful attention was also taken to select the appropriate range for each reading. This is especially important when taking watt readings since the accuracy can be diminished if the meter is set to an inappropriate range.

Our primary interest was in measuring standby power. For most devices, standby power was measured with the device plugged in and the power switch (if any) in the off position. For devices without a power switch, standby power was taken to be the lowest sustained power draw. For battery chargers, power draw may drop once the battery is fully charged. Standby measurements, therefore, were taken either with a fully charged battery or no battery at all in the device. Whenever possible, we also measured active power with the device in a common operation mode (e.g. charging a battery, playing a videocassette, etc.). Because active power varies far more widely than standby power (depending, for example, on volume setting and the nature of the signal for audio and video equipment), our data on active power should be used with caution.

Measurement procedure:

1. Record nameplate info, product model #, and a description including features that may effect power consumption.
2. With the device "off", connect the watt meter in series with device to be measured.
3. If the device was previously unplugged, allow the device sufficient time to reach operating temperature. Select the appropriate watt range for the load. Monitor the reading for several minutes to verify that the reading is stable. If the reading wanders, note the range of swing and record the median of the range. Record this as the "off" mode power.
4. Power "on" the device and select a common mode of operation (i.e. play mode for a VCR).
5. Select the appropriate range for the watt reading. Allow the device to reach a steady state by monitoring the reading for several minutes. If the reading wanders up and down use the minimum and maximum to record the median. Record this as the "on" mode power.

Results

Our data set now consists of 633 devices. Of these, 598 consumed at least some power when ostensibly turned off. The average standby power for the sample was 3.8 while the median was 2.5. Figure 1 shows the distribution of standby power consumption in the sample. The distribution is skewed significantly toward the low end of the range. The cumulative distribution is given in Figure 2, which shows the percent of the sample at or below each standby wattage level.

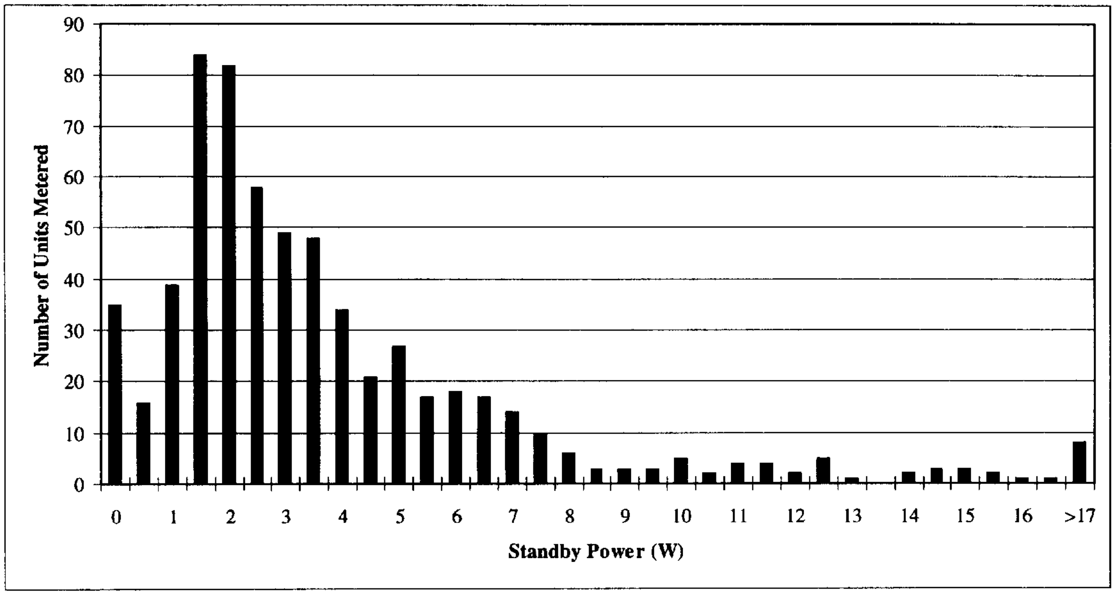

Figure 1

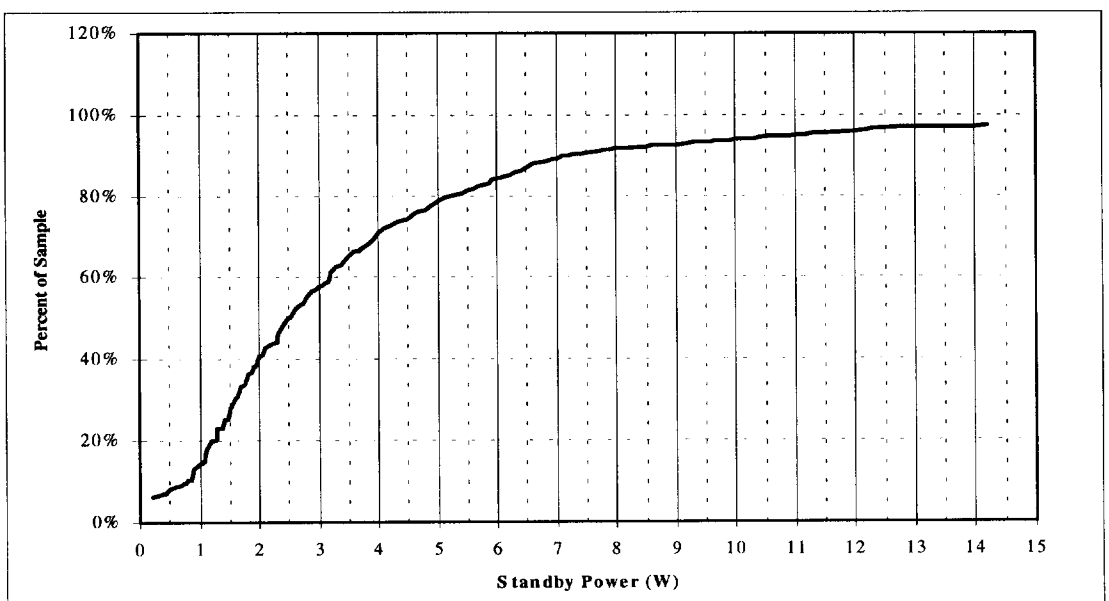

Figure 2

The device with the highest measured load while "off" was a residential heat pump. Source of this load was attributed to the compressor's crankcase heater and was measured at 65 watts (sample average of 30 watts). Crankcase heaters extend the life of the compressor by minimizing oil migration out of the compressor, but some control strategies leave the heater connected when it is not needed. Since the heater does perform a function at times and our sample size is small, care must exercised when interpreting the results. One design only activates the heater when the compressor's discharge line temperature falls bellow 70°F (Stamp 1998). This resulted in the crankcase heater on for only 15% of the time where ambient temperatures varied between 53°F and 93°F (Parker 1998). Another design had the crankcase heater energized continuously.

The next highest standby power consumption, 29 watts, belonged to a mini-system. Mini-systems are compact audio systems small enough to fit on a shelf. They combine a receiver, CD player and/or cassette player in a single unit but have separate speakers and are typically less portable and more powerful than a boom box. Unlike other high active power devices, losses for mini-systems are highly correlated with rated power. This suggests that a single power supply is used in both active and standby modes. Because the power supply is sized for active power, it is significantly oversized for standby loads, thus increasing standby losses. The unit with the highest rated power of 275 W had losses of almost 29 W, while the device with the lowest rated power, 20 W, leaked only 3.3 W.

The highest leakers were concentrated in a surprisingly narrow number of products. Forty-one products leaked 10 watts or more. These represented only 10 product types, primarily audio and video. Set-top boxes were among the worst offenders: five of the seven cable boxes we metered and all eight of the digital satellite systems used more than 10 watts in standby. Forty percent of TV/VCR combination units, 36% of mini-systems and 33% of powered speakers used more than 10W. Two of the three security systems we metered also consumed more than 10 watts in standby, as did two of the three heat pumps metered. Some TVs, VCRs and receivers were also among the highest leakers; however, these units represented only a small share of the total sample for those products.

There were 58 products with standby losses of one watt or less (excluding zero losses). Well represented were receivers (24% of our total sample), power supplies, battery chargers and rechargeable products. Power strips with surge protection were the lowest consumers at 0.2 W. Four TVs, three clocks/clock radios, two cassette players, a CD player, three boom boxes, a turntable, a baby monitor, a timer, a ground fault circuit interrupter (GFCI) receptacle, a heat pump and a modem rounded out the lowest leakers. The devices were categorized first by product type (e.g. TVs) and then by product category (e.g. video equipment). While many groupings of the products were possible, it was decided to classify them by industry, which would facilitate policy-making. Divisions included:

- Audio equipment.
- Hardwired devices (e.g. security systems).
- Heating and cooling.
- Kitchen products.
- Office equipment.
- Personal care products.
- Portable tools.
- Power equipment.
- Telephony.
- Video equipment.
- Miscellaneous.

Table 1 shows metering results for each product type, grouped by category. Included are the largest standby loss, the smallest standby loss, the smallest non-zero standby loss, and the average active power. Because the number of products metered for active and standby power differs, sample sizes were reported separately. Why was it necessary to look at products with non-zero standby losses separately? For some products it may be easier to eliminate standby losses than to reduce them. This is because most of the products in our sample have power supplies. If the device is using any power at all, that power must pass through the power supply. Since power supplies typically lose 0.5 - 1 watt even when not supplying a load, very few (less than 2%) of the products in our sample consume under 0.5 watts. Some products do not require power for functions during standby; these can be reduced to zero standby by placing the power switch on the primary side of the transformer (some products could do this but do not) (Meier & Huber 1997). The minimum non-zero standby power consumption provides a better measure of the technical potential for units which provide some sort of service in standby (e.g. remote control or memory) than the overall minimum.

One quandary that arose in categorizing our product list was what to do with the array of rechargeable products. These ranged from an electric lawn mower to a rechargeable shaver. In spite of their obvious differences, these products are very similar in terms of their standby mode operation. Therefore, rechargeable products and battery chargers were broken out in a separate group. The results are presented in Table 2. For these products the active power shown is power when the charger is actively charging. All of these products had standby losses.

Parasitic Load Reduction

Energy is a function of both power (watts) and time. Strategies to reduce parasitic power consumption should therefore strive to reduce the devices energy use or simply reduce the time it is consuming electricity. Each strategy is useful, however the function of a particular device will ultimately determine which strategy is most appropriate. For example, increasing the efficiency of the power supply (watt reduction) would be the most appropriate strategy to reduce leaking electricity in a security system since the electronics must be powered all the time to monitor sensors. Rack audio system components although would benefit more from total disconnection (reduced operating time) since they are used infrequently.

Increasing Efficiency

Recently, substantial effort has been concentrated on reducing the energy waste from transformers or power supplies (Thorne & Suozzo 1998). As a plug in power pack or integrated into the device, power supplies comprise a significant portion of leaking electricity. There are basically two types of power supplies, Linear Power Supplies (LPS) and Switch Mode Power Supplies (SMPS). LPS are inherently inefficient in nature (50-60%) but appeal to manufacturers due to their low cost. SMPS are more efficient (85%) and can be controlled to match loads (Frizzell). SMPS, can however, effect power quality similar to electronic ballasts and may not be appropriate where line noise is a concern (audio equipment). Power supplies also waste electricity because they are often switched on the low voltage side (output) rather than the high voltage side (input). This is most likely due to the added expense of manufacturing a transformer with switching on input side and instant on features required by devices that are controlled remotely.

Table 1. Metering Results by Product Category

	"Off" Mode Power						"On" Mode Power	
	All Devices				Only those Devices that have Off-Mode Losses		All Devices	
	Maximum (W)	Average (W)	Min. (W)	Sample Size	Minimum (W)	Sample Size	Average (W)	Sample Size
Audio								
Amplifier	5.5	1.4	0.0	10	1.2	7	31	10
Boom Box	7.7	2.2	0.7	37	0.7	37	4.8	37
Cassette Deck	6.6	2.7	0.0	23	0.6	19	2.0	32
CD Player	8.0	3.1	0.0	38	0.2	32	16	11
Clock Radio	3.2	1.7	0.9	32	0.9	32	8.3	3
DVD Player	7.1	4.5	1.6	12	1.6	12	20	24
Equalizer	5.9	3.1	0.0	3	3.5	2	52	10
Mini-System	29	9.4	1.3	25	1.3	25	34	28
Power Speaker	11	4.6	0.0	6	1.5	5	5.8	8
Preamp/Tuner	3.2	2.4	1.4	3	1.4	3	18	3
Rack	15	3.2	1.1	10	1.1	10	6.2	22
Receiver	5.9	1.8	0.0	29	0.8	28	6.7	38
Tuner	4.0	2.0	0.0	8	1.5	5	6.2	3
Total Audio	29	3.2	0.0	236	0.2	217	14	229
Hardwired								
Garage Door Opener	5.4	4.0	3.2	4	3.2	4	55	1
Security System	22	14	5.4	3	5.4	3	15	1
Total Hardwired	22	8.3	3.2	7	3.2	7	35	2
Heating and Cooling								
Heat Pump	65	29.8	0.1	3	0.1	3	1875	3
Room Air Conditioner	0	0.0	0.0	3	NA	NA	NA	0
Total Heating and Cooling	65	14.9	0.0	6	0.1	0.1	1875	3
Kitchen (1)								
Microwave Oven	6.0	3.0	1.5	25	1.5	25	NA	0
Range	4.1	2.7	0.9	13	0.9	13	NA	0
Refrigerator	8.2	6.1	2.8	3	2.8	3	NA	0
Small Kitchen Appliance	2.9	1.8	0.9	5	0.9	5	NA	0
Total Kitchen	8.2	3.0	0.9	46	0.9	46	NA	0
Miscellaneous								
Alarm clock	2.0	1.3	0.7	2	0.7	2	0.7	1
Baby Monitor	1.6	1.2	0.7	3	0.7	3	2.0	3
Controls	3.5	1.9	0.6	3	0.6	3	5.6	2
Total Miscellaneous	3.5	1.5	0.6	8	0.6	8	3.0	6
Office Equipment								
Computer (2)	3.5	2.0	0.0	11	1.3	10	NA	0
Modem (external)	1.8	1.4	1.0	5	1.0	5	5.4	5
Phone/Fax/Copier Combo	6.5	4.7	3.3	5	3.3	5	22	1
Total Office Equipment	6.5	2.5	0.0	21	1.0	20	8.2	6

(1) Most refrigerators, ranges, and small kitchen appliances (toasters, rice cookers and a blender were included in our sample) do not have standby losses. A few high-end devices, however, incorporate electronic controls. Because electronic controls are often an indicator of standby losses, we focused our metering effort on that segment of the market. The average standby losses for these products should not be taken as representative of the entire product category. This caveat does not apply to microwaves, since almost all modern microwaves have electronic controls and clock displays, and therefore have standby losses.

(2) Computers metered included ATX PCs, Power PCs and Macintoshes. These devices were chosen because they have standby losses and do not represent the entire market. However, because the computer industry is moving toward "instant on" and technology, we expect more to have standby losses in the future.

Table 1 (Continued). Metering Results by Product Category

	"Off" Mode Power						"On" Mode Power	
	All Devices				Only those Devices that have Off-Mode Losses		All Devices	
	Max. (W)	Average (W)	Min. (W)	Sample Size	Minimum (W)	Sample Size	Average (W)	Sample Size
Personal Care								
Handheld rechargeable (3)	3.6	1.5	0.4	7	0.4	7	NA	0
Massager	4.2	3.3	1.8	3	1.8	3	NA	0
Total Personal Care	4.2	2.1	0.4	10	0.4	10	NA	0
Portable Tools								
Cordless power tools (4)	4.6	2.3	0.6	8	0.6	8	32	4
Vacuum Cleaner	2.6	2.1	1.7	4	1.7	4	NA	0
Total Portable Tools	4.6	2.2	0.6	12	0.6	12	32	4
Power Equipment								
Battery Charger	2.2	1.2	0.2	6	0.2	6	7.4	4
GFCI	0.8	0.8	0.8	1	0.8	1	NA	0
Linear Power Supply	3.2	1.3	0.3	40	0.3	40	NA	0
Power Strip	0.1	0.0	0.0	3	0.1	2	NA	0
Surge Suppressor	0.4	0.3	0.2	3	0.2	3	NA	0
Switching Power Supply	0.5	0.5	0.5	3	0.5	3	NA	0
Transformer	7.1	5.9	4.6	3	4.6	3	NA	0
Total Power Equipment	7.1	1.3	0.0	59	0.1	58	7.4	4
Telephony								
Answering Machine	5.2	3.0	1.8	29	1.8	29	3.6	14
Cordless Phone	5.0	2.7	1.1	23	1.1	23	3.0	13
Cordless Phone w/ans. mach.	4.9	3.2	2.5	5	2.5	5	2.8	2
Total Telephony	5.2	2.9	1.1	57	1.1	57	3.3	29
Video Equipment								
Cable Box	18	12	4.8	7	4.8	7	13	7
DSS	18	15	11	8	11	8	15	8
Television (5)	12	4.3	0.0	44	0.5	42	76	35
TV/VCR Combo (5)	20	9.8	2.5	10	2.5	10	54	10
VCR	13	5.6	1.5	69	1.5	69	12	66
Video Game	2.0	1.1	0.0	3	1.3	2	9.8	1
Total Video	20	6.2	0.0	141	0.5	138	33	127
Total Sample	65	3.8	0.0	605	0.1	578	32.7	411

(3) Handheld re-chargeables metered include a hair trimmer, two shavers, three toothbrushes and a massager.

(4) Re-chargeable power tools metered included cordless drills and screwdrivers, as well as battery chargers for inter-changeable power packs for cordless tools.

(5) Some devices such as TVs were impossible to measure due to the randomness of the reading. In order to stabilize the reading, it was necessary to set all TVs to a channel displaying "snow" or no signal, so that comparative readings could be taken.

Reduction of leaking electricity in other areas will be harder to achieve. Manufacturers will be hesitant to remove conveniences such as instant on and remote control capabilities due to feared market rejection. LED/LCD displays and memory retention consume relatively little energy and improvements would be costly. Displays can be made to activate only with operator interaction, however, often displays present information that is useful even when the device is off such as a clock on a VCR. Memory retention could be retained either through the use of "flash memory" or backed up with a battery as in a PC's bios.

Devices that charge batteries offer some opportunities for improvement since often the chargers continue to draw energy after the battery has reached full charge. Smart chargers that vary the current supplied to the battery as it charges as well as the incorporation of SMPT would improve efficiency.

Table 2. Battery Chargers and Re-chargeables

	Maximum (W)	Average (W)	Minimum (W)	Sample Size
Cell Phone Charger	8.6	8.6	8.6	1
Cordless Phone	5.0	2.8	1.1	26
Rechargeable Personal Care Product	3.6	1.5	0.4	7
Cordless Power Tool	4.6	2.3	0.63	8
Rechargeable Lawn Care	4.3	3.6	2.8	2
Handheld Vacuum Cleaner	2.6	2.1	1.7	4
Multi-Purpose Battery Charger	1.5	1.0	0.2	5
Rechargeable Toy	2.2	2.2	2.2	1
Total Battery Charger	8.6	2.5	0.2	54

Reducing Operating Time

Reducing the operating time of a device can be as simple as using a manual switch to disconnect the load or more elaborately through clocks or sensors. Unfortunately some consumer electronics rely on some power to maintain memory (clocks) or for instant-on convenience (remote control). This could easily be overcome if the devices incorporated backup batteries or capacitors to supply current when the device is disconnected or through the use of non-volatile memory. In fact, some devices already incorporate this technology (e.g. computers).

There is a myriad of ways to reduce the operating time of loads and often this strategy will go above and beyond simply reducing the parasitic portion of the load. For example an occupancy sensor could be connected to disconnect selective loads, as the space becomes vacant. In new home construction a portion of the homes circuits could be designated for occupancy-based control. Another simple idea is to connect all audio components to the switched outlets normally provided by the amplifier. When the amplifier is switched off the components are as well. Other control strategies include proximity sensors, timers, and activity monitors that monitor (internally) if the device is in use.

Conclusions

This report examined, in detail, a variety of consumer electronics that contribute to leaking electricity. Average standby power for the sample of over 600 products was found to be 4 watts. The majority of the products were found to consume less than 10 watts in standby mode. Only 38 products were found to leak more and these were primarily audio and video products. Set-top boxes such as cable boxes and digital satellite systems almost all consumed more than 10 watts. Products that leaked little power included some receivers, power supplies, battery chargers, and rechargeable products.

Data for this paper was gathered in two distinct regions of the US at multiple different locations. Given this diversity and the number of items measured, the averages should give an indication of where improvements can be made. It is now possible to examine in more detail the product types that contribute greatest to this waste. In the Parasitic Load Reduction section, several general strategies were presented that could be applied to most of the devices measured. However, policies or standards designed to reduce parasitic load loss would have to be formulated for each product type (or possibly a group of product types) and would require a more in depth investigation of manufacturers designs and associated loads.

While many methods exist to minimize or eliminate parasitic loads, product redesigns will not happen automatically. Manufacturers have little incentive to redesign products to reduce parasitic loads since consumers do not demand the change. Also it is doubtful if manufacturers or consumers would be willing to sacrifice convenience or reliability to save a few watts. Some reductions may happen automatically, however, as manufacturers switch to more efficient SMPS primarily to reduce weight and size. Many options do exist to reduce parasitic loads and not affect performance or convenience but will probably only materialize through government intervention.

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