Low Power Mode Energy Use in California Homes

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ABSTRACT

Many electrical devices in homes continue to draw power when switched off or not actively performing their primary function. These devices include familiar appliances, such as televisions, microwave ovens, computers, set-top boxes, mobile phone chargers, and video and audio components but also less obvious devices like dishwashers, tankless gas water heaters and smoke detectors. The energy use of these devices while in their low-power modes is now about 980 kWh/year (or 112 W) per home in California, corresponding to about 13% of total residential electricity use in 2006. If treated as a separate end use, low-power mode energy use is the fourth largest residential sector end use. About half of the electricity in the electronics end use is consumed in the low-power modes.

The Increasing Importance of Low Power Mode Energy Use

In the mid 1990s, researchers noticed the rising amount of electricity consumed by appliances that were either switched off or not performing their primary function (Meier 1993; Sandberg 1993). “Standby power” is the best known term used to describe this phenomenon but many other terms were used, including phantom loads, leaking electricity and off-mode power consumption. This electricity consumption was often needed to power internal clocks, infrared receivers (for remote controls), digital displays, or other electronic components. In other cases, the standby power use simply energized power supplies and circuits that were expected to do nothing.

Researchers estimated that standby power use was responsible for as much as 11% of residential electricity use in Australia, 10% in Japan, 5% in the United States, and over 5% in some European countries (IEA 2001). Some of the observed variation was a result of differing definitions and measurement approaches; however, this type of electricity consumption was clearly significant. The Energy Star Program established specifications for sleep modes for computers and displays in 1992 and then announced specifications for standby power use in televisions and VCRs in 1998. European manufacturers also voluntarily agreed to cut standby in those products while Japan established an aggressive program to reduce standby in all products. Considerable progress has been made in reducing the standby power draw in some products, especially in televisions, computers, and external power supplies. Notable power-saving innovations include switch-mode power supplies, auxiliary power supplies (to separately supply low power functions) and improved techniques for power management. However, the number of products with standby power use began to grow rapidly; manufacturers wanted every product to have memory, keep track of the time, display information, or be able to act upon receiving a signal from a handheld remote control, a computer, or from a service provider. The savings achieved in some product types were offset by the increased volume of new products with standby; as a result, the total electricity consumed by products while not being used continued to climb (Meier 2005).

As electrical products became more sophisticated, and performed more services while "off", the problem of standby power use expanded to cover a range of low-power modes that were nevertheless clearly different in function from "active". There now exists a wide range of services performed while the products are not actively switched *on* ranging from *nothing* (beyond contributing waste heat to the space) to maintaining sophisticated communications to ensure security and continuity of communications links. The common feature of all these modes, however, is that they are not in an *active* mode, that is, performing a primary function (the television showing an image, the PC computing, the microwave oven cooking, or the subwoofer pumping out music). These modes beyond standby have many names—sleep, active standby, hibernate, ready, idle, etc.—but no other term effectively describes all the *non-active* modes as does "low-power mode". We use the term "lopomo" to describe all of the non-active modes. Lopomo is a contraction of "Low-power mode".

The goal of this project was to understand the scale of lopomo energy consumption in California homes. By "scale" we mean both the range of products in which lopomo energy is present, and the overall energy consumption of these modes. Along the way to this goal we developed techniques to categorize, measure, and estimate lopomo energy use in a diverse array of products. We also developed tools to assess the sensitivity of our estimates to key variables, which we believe is an important new contribution. Complete results are reported in a larger report (Meier et al. 2008).

Approach

To accurately estimate lopomo energy use, we collected data on over 170 different types of electricity-consuming products. Some products were familiar, such as VCRs, microwave ovens, and computers, but others were not previously carefully investigated, such as tankless gas water heaters, controls for heating systems, toaster ovens, modems, and compact audio systems. Each product had one or more low-power modes and, for each mode, we estimated:

- The functionality associated with the mode
- The average power (in watts, W) of that mode
- The fraction of time the product resided in that mode, as well as the average time which consumers unplugged (or otherwise disconnected) the product

We also estimated the saturation of each product in California homes, taking into account the fact that, for some product types, only some models have low power modes. Some of the preparatory work for this project is reported elsewhere, including testing of measurement protocols (Brown et al. 2006) and establishing a taxonomy of products (Nordman & Sanchez 2006).

The identification of modes and their power use mostly relied on measurements of products in 75 homes, plus intensive measurements in eight homes (Nordman & McMahon 2004). Even though about 2000 products were measured, we still needed to draw on other sources, such as a national study of miscellaneous electrical loads (Roth et al. 2007), a large monitoring study in Australia (Energy Efficient Strategies 2006), independent studies of specific products, earlier work for the California Energy Commission (CEC), and technical literature. Usage patterns were based on a telephone survey of 306 homes, detailed analyses of long-term measurements, and technical literature about specific products. For saturations of products, we

again relied on the telephone survey, utility surveys, and estimates by trade associations. The key sources for data on power, usage, and saturation are shown in Table 1. We considered nearly 200 different types of products and undertook a complete analysis for 170. Our sources were sometimes contradictory, were based on limited data, or used different definitions. We were usually able to reconcile the differences and estimate reasonable values for California.

Table 1. Major Sources Of Data

Power	Usage	Saturation
Spot measurements in 75 homes with analyses from RLW and Ecos	RLW telephone survey of 306 homes	RLW telephone survey of 306 homes
LBNL preliminary measurements of lopomo energy use in eight houses (from an earlier part of this project)	Ecos and RLW analyses of time series measurements in 50 homes	RLW/Ecos in-home survey of 75 homes
LBNL measurements of builder-installed miscellaneous energy	Surveys (e.g., Nielsen)	California Residential Appliance Saturation Survey (RASS)
Other LBNL measurements	Earlier phases of this project	California Lighting and Appliance Saturation (CLASS)
Australia (*in situ* and in-store measurements)	Magazine articles	Trade journals
Product technical specifications	Australian case studies	Trade associations
Measurements from other countries (principally Denmark, UK, Germany, New Zealand)	Journal articles, typically dealing with specific product types	Australian case studies
Journal articles	Other technical reports, notably reports by TIAX	U.S. DOE Residential Energy Consumption Survey (RECS)
Personal communications		Earlier phases of this project

Results

We describe below the results of three intermediate studies used to help us estimate lopomo energy use.

The Telephone Survey

A telephone survey is valuable because ownership and usage data on many products can be collected quickly and inexpensively. The principal drawback is that consumer responses to these kinds of questions are notoriously unreliable because the respondent may not be the principal user of the product and, even if he or she is, cannot accurately estimate operating hours. Our survey (conducted in 2006 by RLW Analytics) covered 306 homes and captured ownership information on over 8000 products, consisting of 60 product types, and usage information about a smaller set of product types. Every effort was made to make these homes representative of California's housing stock but, in the end, the homes were skewed towards single-family and an above-average number of occupants. About 77% of the homes were owner-occupied and about 52% were single-family houses. There were about 2.7 occupants per home. Some results are summarized below.

Desktop computers. The survey was intended to help us more accurately estimate the number of computers and the hours computers were switched on. The total saturation of all types of computers was 140%. About 75% of the respondents reported having desktop computers. About

16% of the computers were on all the time. The average desktop computer was on 6.7 hours per day. Among the computers not operated continuously, the average on-time was about 3 hours per day. At the other end of spectrum, almost one quarter of the units (23%) were switched on for one hour or less per day.

Televisions. There were approximately 1.33 standard televisions, 0.16 large-screen CRT televisions, 0.13 LCD or Plasma televisions, and 0.22 televisions with built-in VCRs per household. Together, this equals 1.84 televisions per household. Note that this is significantly lower than the 2006 national value found by Nielsen of about 2.3 televisions per household (Nielsen Media Research 2006). These data are surely obsolete now (2years later) because sales of flat screens have increased rapidly.

Uninterruptible power supplies (UPS). About 3% of the homes had uninterruptible power supplies that were operating continuously. One more person switched it on only while operating the computer (2 hours/day).

Mobile telephones. Nearly 90% of the homes reported having one or more mobile telephones. This is much higher than national estimates (Roth et al. 2007). Unfortunately, these responses address charging habits rather than the status of the charger itself. For example, the responses cannot tell us if the persons charging their phones daily remove the chargers from the outlets when finished or (more likely) leave them in the outlets.

In-Home Survey of Product Saturations

Our contractors (RLW Analytics and Ecos Consulting) undertook an inventory of all electricity-using devices in 75 homes selected for power measurements (see below). A total of 123 different product types were catalogued. Since 123 is still much less than the 170+ product types evaluated in this project, we also drew upon other sources for saturations. The survey gave qualitative clues to uncertainties in product ownership. The occupants often reported having products but were not found by the auditors (and vice-versa). The 75 homes did not closely match the mix of California homes overall so the results should be taken as indicative rather than conclusive.

In-Home Power Measurements

The largest and most important source of power data were in-home measurements of instantaneous (or spot) power use. The in-home measurements provided power consumption data for 62 product types. A total of 1925 products were measured by trained auditors using calibrated watt-meters. The number of each product type metered ranged from one to over forty. Over six thousand independent measurements were made since each product had up to five power modes measured. For each mode of each product type, the mean, minimum and maximum values were calculated. Note that even this intensive metering exercise was unable to capture measurements for over 100 product types with lopomo energy use that were included in the overall statewide estimate. We relied on other sources for power data when no in-home measurements were available or the number of products was so small as to be not representative.

Calculation of Lopomo Energy Use

The lopomo energy use of a single product is the sum of the product's energy use in each low-power mode. This can be written as:

$$\text{Annual lopomo energy use (in kWh/year)} = 8.76 \cdot \sum_{\text{all low power modes, i}} P_i \cdot U_i$$

where P_i is the Power (in watts) and U_i is the Usage (in terms of a fraction of time), both for mode i. The term 8.76 converts the watts into kWh/year. If the *active* mode is included, then the formula predicts a product's total energy use.

One product type's California-wide lopomo energy consumption is calculated by multiplying the single unit's energy consumption by the number of homes in California and the product type's saturation:

$$\text{Lopomo energy use in California} = N \cdot S \cdot 8.76 \cdot \sum_{\text{all low power modes, i}} P_i \cdot U_i$$

where N is the number of homes in California and S is the saturation of that product type. The saturation typically ranges from zero to one though can exceed one for products like televisions, ceiling fans, and mobile phones. Some designs of the product may have three modes while others may have only two modes. In a perfect world, these would be defined as different product types but, in practice, they are not differentiated in stock data and so we combined them with appropriate modes, power levels and usage times. As a result, the power and usage data represent an aggregate of the products with diverse modes. This calculation is repeated for each product type studied.

The saturation must also take into account the fact that some designs within a product type may not have any low-power modes while others do. For example, some washing machines rely on electromechanical controls (and have no lopomo use) while many modern machines rely on electronic controls (which do have low power mode use).

Lopomo Energy Use in California Homes

Based on the data collected and considered in this project, California's lopomo energy use is 112 W per home (or 982 kWh/year). This corresponds to roughly 13% of 2005 residential electricity use. This estimate includes contributions from 170 product types, although many others were considered and some were consolidated where appropriate. The key results are summarized in Table 2.

Table 2. Estimated Lopomo Energy and Power Use in 2006

Feature	Per Home		California	
	Power	**Energy/year**	**Power**	**Energy/year**
Lopomo energy	112 W	982 kWh	1.29 GW	11,300 GWh
Standby energy (mode 1)	54 W	470 kWh	0.617 GW	5,410 GWh
Total residential electricity use	840 W	7,350 kWh	9.6 GW	84,500 GWh
Number of lopomo products	44		506 million	

A common definition of standby power is the lowest power use of a device while still connected to the mains (IEC 2005). In our measurements, this power mode generally corresponded to "mode 1". In California homes, mode 1 power consumption equals about 54 W per home. The other low-power modes typically have greater functionality (but are still less than fully active) and account for 58 W.

The ten product types responsible for the largest lopomo energy use are listed in Table 3. Note that the values listed include homes not having those products. Together, these product types account for roughly 40% of total lopomo energy use. Two forms of set-top boxes dominate the list. Other product types within the video category, televisions and DVRs, also rank among the highest users of lopomo energy.

Table 3. Top Ten Lopomo Product Types

Product Type	Average Lopomo Electricity Use Per Home (kWh/year)	Average Lopomo Electricity Use Per Home (W)	Fraction of Total Lopomo Energy Use
Set-top box, satellite	58	7	6%
Set-top box, digital cable	50	6	5%
Television, CRT	47	5	5%
Video, DVR	38	4	4%
Audio minisystem	38	4	4%
Computer, desktop	37	4	4%
Receiver (audio)	33	4	3%
Phone, cordless	33	4	3%
Air conditioning, central	27	3	3%
Oven, microwave	26	3	3%
Total of top 10	**387**	**44**	**40%**

This ranking should be interpreted with caution because some product types might have ranked higher if similar product types had been combined. For this reason it is sometimes more useful to examine the fractions from the different categories.

Many of these products fall into a new category of devices whose primary function is related to information display, processing, storage, and transmission. About half of the electricity in this electronics end use is consumed in the low-power modes.

Number of Lopomo Products per Home

The average California home contains about 44 products with lopomo energy use. This estimate includes the visible products like televisions, VCRs, and computers and often overlooked devices such as doorbell transformers, GFCI outlets, and smoke detectors. The saturation of these less-visible devices is certainly expanding as a result of code requirements for new homes and through remodeling of existing homes. As a result, the average number of products with lopomo energy use per household will climb.

Sensitivity of Results to Errors in Key Assumptions

The presentation of confidence intervals and other conventional measures of uncertainty is not appropriate for this kind of project. Instead we explored different kinds of errors and their impact on the estimated lopomo energy use. A summary of those explorations is presented below in Table 4.

In the process of estimating California lopomo energy use, this project required estimates for as many as thirteen values for each product type. These values included:

- 2 kinds of saturations (overall and fraction with low-power modes);
- 5 power levels; and
- 6 usage values.

The actual number of values depended upon the complexity of the product type but never fell below six. Thus, for the 170 different product types examined, over two thousand values needed estimation (or at least consideration). Each of these values has an uncertainty that will be reflected in the overall estimate of lopomo energy use. It is also possible that some product types with lopomo energy use were overlooked and not captured in the calculations, further adding to the overall uncertainty.

Table 4. Impact on Lopomo Energy Use from Different Kinds of Potential Errors

Type of Error	Impact
Overlooked product type	Missing product type's lopomo energy use must exceed 5.6 W with a saturation of 20% in order to change overall value 1%
Underestimated saturations	A 20% increase in saturations leads to 20% increase in lopomo energy use
Underestimated power values	A 20% increase in all power modes leads to 20% increase in lopomo energy use
Underestimated power values (by 1 W in every mode)	A 32% increase in lopomo energy use
Incorrect estimates of the amounts of time that products remain in different modes	If products reside in lowest mode all the time, then lopomo energy use falls to about 100 W If products reside in the mode with the highest power draw all the time, then lopomo energy use rises to about 300 W

It is possible to devise scenarios where lopomo energy use is much higher than our estimate but our explorations demonstrate that such scenarios are unlikely.

Comparisons With Other Studies

Measurements of standby power and other low-power modes have been undertaken around the world. The major studies are summarized in Table 5. Few studies are directly comparable to this one because they either focused on a particular mode (such as minimum power) or group of products (such as electronics). Nevertheless, they help place this study within a global (and historical) context.

Table 5. Recent Estimates of Lopomo Energy Use Or Closely Related Results

Location, Reference, & Number of Homes	What Was Reported?	Results (per home)*
This report, California, 2007, all California homes	Combination of spot and long-term measurements, and estimates	44 lopomo products; 112 W lopomo; 54 W mode 1 power
Australia, (Energy Efficient Strategies 2006), 120 homes	Spot measurements of appliances in mode found by auditors	27 lopomo products (further 16 present but not normally plugged in); 83 W
New Zealand, (Isaacs et al. 2006), 400 homes	Energy use of appliances for several weeks	50 W (after subtracting refrigerator but still including some baseload items like heated towel racks)
Denmark, (Gudbjerg 2005)	Spot measurements of mostly electronic products in various low-power modes	67 W lopomo
Portugal, Greece, Italy, Denmark, (Sidler 2002), 297 homes	Spot and long-term measurements	46 – 60 W lopomo (but appears to include ~16 W for refrigerators and excluded very small products)
California, (Brown et al. 2006), 14 homes	Spot measurements of builder-installed products in new, unoccupied homes	112 W lopomo (after subtracting refrigerator)
California, (Ross & Meier 2002), 10 California homes	Spot measurements of all accessible devices in various power modes	19 lopomo products; 67 W
Japan, (Ohkuni 2006), unknown number of homes	Spot measurements and survey data	35 W
TIAX, (Roth & McKenney 2007), all United States homes	Measurements and estimates for consumer electronics only, usage survey of 2,000 demographically representative households, all modes, excludes digital TVs	47 W for sleep and off modes (based on their conclusion that 32% of 147 TWh of total is consumed while in off and sleep modes) – does not cover many major standby end uses
TIAX, (Roth et al. 2007), all United States homes	Measurements and estimates for miscellaneous electric appliances	60W for idle, sleep, and off modes for 30 key loads; 38 W mode 1 power

* We adjusted reported results to make them as comparable as possible including conversion of energy to average power and regional consumption to per home.

Overall, our estimate of lopomo energy use appears to be higher than that either reported or implied in other studies. Some of the studies are older or are restricted to fewer categories of products, so growth or broader scope may be partly responsible. Our estimate of mode 1 power use is similar to reported estimates for standby power. On the other hand, our estimates of lopomo energy use appear to be higher than other studies. The most likely explanation for the differences are assumptions regarding the definitions of other low-power modes and the time the products reside in them.

Conclusions

For 2006, the average low-power mode use in California was estimated to be 112 W per home (or about 980 kWh/year). This is roughly 13 percent of residential electricity use. The average California home has about 44 products with one or more low-power modes. Four categories are responsible for about half of the total energy: set-top, audio, video, and display. The electronics end use—products whose principal function is processing information—accounts for about 85 percent of low-power mode consumption. If low-power mode energy use were treated as a unique end use, it would rank fourth above air conditioning, miscellaneous, and pools and spas in California.

The ten largest contributors to low-power mode energy use are responsible for 40 percent of total low-power mode energy use, while the remaining 160 product types examined are responsible for 60 percent.

A common definition of standby power is the lowest power use of a device while still connected to the mains. In California homes, the lowest possible mode equals about 54 W. The other low-power modes typically have somewhat greater functionality (but still less than fully active) and account for 58 W. Thus, at present, low-power mode energy consumption is evenly split between the lowest and the higher modes.

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