Any Device, Any Mode:
Measuring All Residential Low-Power Mode Energy Consumption

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ABSTRACT

In recent years there has been increasing interest and attention to "standby power" – the minimum power mode of a device while plugged in. However, an increasing number of products have multiple low-power modes, often defined by electronic components, and many spend little or no time in typical use in the lowest mode. Traditionally, most energy savings efforts have aimed to reduce power levels in particular modes, but savings can also be attained by shifting the operating time so that more time is spent in lower power modes. This shift can be accomplished in similar ways across a wide variety of product types. For these reasons, a focus on all low-power modes for all devices is appropriate. While some studies have assessed standby power for individual devices, homes, or regions, no prior study has comprehensively addressed all low-power consumption. A precondition to such assessment is an adequate measurement protocol for power levels; this paper presents the development and content of one.

While most protocols are for a specific type of device in a controlled laboratory setting, we had the challenge of crafting one for any device that could have a low power mode (including products not yet invented) in real usage settings. The protocol therefore had to encompass a wide range of products and modes, and evolve according to the results of measurements made under the protocol as they accumulate. We review relevant background information, including other test procedures, key principles underlying the protocol, the structure we developed, insights gained from applying it to hundreds of individual products, and results for eight houses.

Introduction

Interest in "standby power" has grown in recent years in many parts of the world. However, an increasing number of products spend a large portion or all of their time in modes higher than their standby level[1]. An example is networked devices that only drop to their standby level when switched off or removed from the network, neither of which occurs in ordinary use. Low power modes are now common in household appliances, safety equipment, and miscellaneous products, in addition to electronics.

Low power mode energy use was previously estimated to be responsible for about 10% of electricity use in California homes — roughly 70 W per home, or 900 MW of connected load (Meier & Payne 2003). It is likely to continue growing rapidly as products with high low power mode energy use proliferate. Other sectors such as commercial buildings and industry also have low power mode energy use. A workshop was held in August, 2002 to review the current state of knowledge about low power mode energy use and to identify research areas for reducing it. Six research topics were identified: estimate *how much energy* is consumed, develop energy *test*

[1] "Standby" is simply the lowest power level that a device can consume while connected to mains power and is not any specific power mode.

procedures, understand human *behavior* and preferences, investigate feasible *technologies* offering energy savings, engage in *short-term research* to address anticipated critical problems, and conduct *long-term research* to increase the efficiency of low power modes.

Our current project (Nordman et al. 2004) works towards the first of these topics — estimating total low power energy consumption for the state of California. Subsequent research will collect survey and field data to support such an estimate. This project set the stage for the estimate by: reviewing existing test procedures, crafting a measurement protocol for individual products, drafting a procedure for whole house low power mode measurement, collecting data on eight houses in northern California, analyzing the results, and revising the procedures. This paper reviews each of these tasks, but for simplicity and clarity, we have incorporated the lessons learned through the field data collection into the description of the procedures.

Test and Measurement Procedures for Low Power Modes

We reviewed both test procedures and measurement protocols related to low power modes. A "test procedure" is usually designed to measure a new device in a laboratory setting, often for safety or regulatory purposes. The test conditions are well-specified, the device's configuration is constant (or as shipped by the manufacturer), and any usage patterns applied during the test are fixed, or dependent on a basic device characteristic (e.g. its size or speed). A "measurement protocol" covers a much larger set of methods, and in general they lack the specificity of test procedures.

We gathered, evaluated, and compared about 20 existing methods to find aspects that were common or worth considering or using directly in our protocols. The existing procedures are varied and include some for standby power only, some for all modes of individual product types, and some for groups of product types. The purposes range across mandatory standards, voluntary standards, energy analysis, and generic purposes. The full list of procedures can be found in Appendix II of (Nordman et al. 2004). The procedures touched on a wide variety of issues which we grouped into topic areas as listed in Table 1.

Table 1. Topics Addressed by Test and Measurement Procedures

Topic	Comments
Purpose / Scope	Reason for creating the procedure
Basic Power Characteristics	Voltage, frequency
Power Quality	Total harmonic distortion, crest factor
Other Conditions	Air speed, temperature, humidity
Accuracy	Accuracy and resolution of metering equipment
Configuration	Settings, attached hardware, information environment
Usage Patterns	% of time in each operating mode
Mode Definitions	What to name modes, what characteristics they have
Mode Derivation	How to determine what modes a product has
Controls	Controls (e.g. switches, automatic) within the device or attached to it
Procedure Steps / Timing	How long to integrate power use over
Sampling	How many units to measure
Reporting	What to record / report
Whole-house Measurements	Entire house and all devices within it

Our protocol covers all of these topics. We specifically exclude active modes since they can introduce many factors necessary to get consistent and representative results, such as display brightness, volume, etc. However, for many products it is reasonable to record active mode

power levels as indicative (rather than conclusive) of active power requirements when the modes are relatively stable. The measured power levels feed into statewide total low power mode estimates combined with values for the number of units of each product type in the state (the stock) and data for usage patterns. Resolution of 10 mW (and similar accuracy) is quite sufficient. As stocks and especially usage have large uncertainties, greater accuracy than this for power is not warranted.

IEC 62301 (draft) on "Measurement of Standby Power" (IEC 2003) provides a sound foundation for our test procedures (while still a draft it may be final in late 2004). We devised a procedure for individual device measurement, and one for measuring an entire house. A major challenge for this project is to identify what products have what modes and how they are used.

Most of our measurements were made in the field, in actual homes, in which: the conditions are not well-controlled, the provenance of the device is not well-known, it may have been customized for the consumer's use, the configuration changed, or by it being connected to other devices in ways that change its energy consumption patterns, through data or power flows. Usage patterns are those of the customer, and so while they could be measured, they are not fixed or replicable.

Individual Product Procedure

Our measurement procedure is generic for any product and has three parts. First is the procedure itself, with definitions, conditions, measurement specifics, and reporting guidelines. A growing set of "empirical data" accompany the procedure to organize information known about existing products and so guide the approach to any particular one. Most important of these are the relevant modes that are known to exist in particular product types (at the present time since this does change). Finally, a third part of the procedure documents the "rationales" behind the choices made in developing the procedure. Following are highlights and key points of the procedure.

Scope

The purpose of the protocol is to measure power levels consumed in each low-power mode for any individual electrical product found in residential settings connected to ordinary mains power (either from a standard receptacle or by hard-wiring). It can be adapted to commercial, industrial, or other settings. It is intended principally as a field measurement protocol (in homes or stores) though it can also be used in a laboratory.

The primary intended use of the protocol is in developing data about typical consumption of products as actually used. This is distinct from procedures designed for regulatory purposes which require measurements be done in a laboratory with tightly controlled conditions and specific clarification or definition of exact configuration of the product being measured, which is new and unmodified.

Definitions

A "Product" is a piece of equipment that can be powered directly from mains power. When power is supplied at low voltages to other hardware (e.g. through USB ports), then the other hardware is considered part of the product and included in its energy consumption. A

"product model" is a specific brand and model of a product (e.g. Sony KV-27V65). A "product type" is a general category of product within which there is a sufficient amount of common functionality, modes, and behavior. Example product types are: "Television, CRT", "Telephone, cordless", and "Timer".

A product type is "known" when it has been measured enough times to determine what modes it commonly has and what low-power modes are stable and so can be measured with an abbreviated procedure (see below). Known product types are added to the database of empirical information. A type becomes known when five instances (all different models) have been evaluated and measured, though if the product has a well-defined set of modes that are all stable, the criterion is reduced to three.

A "power conditioning device" may alter the power delivered, other than simply turning it on or off. The most common examples are surge protectors (usually found on power strips) and uninterruptible power supplies. Power conditioning devices always consume some power themselves, even in a no-load situation, and are always products themselves. The utility meter could be considered another example.

A "power control device" is any external switch that controls the supplied power such as switched outlets, timers, power strips with switches, power-line carrier (PLC) controls, occupancy sensors, daylight sensors, and circuit breakers in main electrical panels or subpanels. Some power control devices consume power themselves; these are also products.

The protocol specifies that the configuration of the product should be recorded, including the power supply (e.g. a power strip upstream), network connectivity, and power management settings. While power control and conditioning are not major factors today, this may change in future and their use is a method to reduce low power mode energy.

Power Consumption

For each mode measured, note when the mode was initiated so that the first ten seconds of data can be discarded to account for any transition period. Then, record the power consumption for at least 5 minutes (or 30 seconds if the type is known and the mode is known to be stable) before switching to the next mode. The result is the average power level over the measurement period.

"Mode stability" is classified as stable (not varying more than a certain amount during the measurement), cyclical, or unstable. Most low power modes are stable, with most of the remainder being charge modes that drop over time. We found relatively few products with cyclical low power modes, though those with cycles greater than five minutes might not be captured by our measurements.

Modes

A power mode is condition or state of a product that broadly characterizes its capabilities, power consumption, power indicator coding, and responsiveness to input. Some modes can be maintained indefinitely, and others only for a finite time. Some modes are short transitions or infrequent (e.g. most alarm modes), and so can be ignored for energy consumption purposes.

There are some modes that are on the edge of what should be considered within low power modes. For a power tool charger that explicitly finishes charging and then enters a different mode (visually and in power consumption), we considered the charging mode an active

mode. For products that have a constant trickle charge for a battery, that power could presumably be modulated via a timer or sensor to reduce consumption — this brings it within the low power purview. While ready modes are in general on modes, they are not active. We used the state "on" only for products without a ready mode (though in some product types there are some individual examples with a ready mode and some without).

It is important to not dwell on whether particular modes are low-power modes or not. It is more critical to identify and measure the modes. Similarly, it is not critical to have a rigid definition of a principal function to help decide what modes are active.

We chose to be expansive in what was included in our definition of low power modes. Single-mode products such as clocks may have efficiency options that are largely the same as those for low power modes in general.

It is common for different models of the same product type to have different sets of modes. This complicates interpreting averages across a group of products of the same type for their power levels, and combining them with usage information.

It is important to distinguish between *operational* modes — such as on, sleep, and off — and *power* levels, such as the definitions of standby recently adopted by the Department of Energy (DOE) and the International Electrotechnical Commission (IEC).[2] The DOE and IEC definitions of standby refer simply to the device's lowest power level while connected to the mains, irrespective of functionality. Members of the committee that drafted IEC 62301 recognized that many products have other low power modes and left it to product committees to define these.

Types of Modes

We attached similar names with similar characteristics and grouped these all into the following general types of modes. In many cases there are qualifiers such as for cordless phones, "Ready, handset present" and "Ready, handset removed".

Disconnected. Disconnected products consume no power. Disconnection can be accomplished by unplugging or using a power control device. A off mode with zero W power consumption that occurs when the device is still connected to the mains is "off" and not disconnected.

External power supply only. This most commonly occurs with portable products such as mobile phones and notebook computers. However, measurement of this does provide the no-load power supply efficiency.

Off. For most products, only a power control will bring a device out of an off mode. Some products have auto-off and regular off modes which can consume different power levels. A few products have two power switches, such as a TV with one on the front equivalent to using the remote control's power button, and a rocker switch on the back to remove all power. Some

[2] A product may consume its standby power level in any of the three basic operating modes: on, sleep, or off. For example, a telephone answering machine is fully on at its standby level; some printers lack a power button so are asleep in their minimum power mode; and many devices consume standby power when off. Thus, "standby" is a power level, not a operational mode. While it is sometimes more convenient to talk about a product's "standby mode", that really refers to the mode at which the device consumes its standby level, since there is no mode consistent across all devices that is *the* standby mode.

projectors have the same dual control (as do some commercial copiers). Not surprisingly, the lower off mode of dual power switch products is usually zero power.

Sleep. Sleep modes are characterized by needing a "wake event" to transition from sleep to ready or on. They are most common for information technology devices, but we should expect to see them used on more consumer electronics in coming years. Power consumption is below the ready level, the transition time to an on mode may be noticeable, and displays may be dimmed, off, or not backlit.

Ready. A ready mode is one in which the product is immediately ready to be active, based on a functional control, or information from a network connection.

Some low power modes embody some function, but clearly not the primary function of the product. For example, many audio systems and video components always display the time. Other examples are the lights in some kitchen appliances (e.g. microwave ovens, dishwashers, and refrigerators) that come on when the door is opened, and the lights in most garage door openers that are turned on when the opener is activated. In the latter case there is usually a delay time after which the light goes back off.

Sometimes the existence of a ready mode depends on a product's capability. For example, some powered speakers can sense if there is a signal being sent to them and change their power status accordingly, much like a computer display does. Other speakers (and some older displays) do not have this intelligence or the "sleep" mode. Another example of this is network devices (e.g. switches and routers) that could in principle use less energy when not connected to a network at all, or when only some of their network connections are active.

Active. In active modes the product is performing a primary function. Examples include a TV being on, an audio system playing music, a clothes washer washing, etc. In some cases, a product may be on but possibly not needed. An example is a set top box that is not performing any needed function such as providing signals when no TV connected to it is on or being watched.

Usage Patterns

While some field studies include usage measurements, lab measurements either ignore the issue or use a standard usage pattern to extrapolate the measured results to monthly or annual consumption. Some studies note the difficulty of assessing usage patterns. Usage is clearly the weakest link in estimating annual low power mode consumption for many product types.

Usage is a combination of product characteristics, the usage environment, and the user. Some product types, like smoke detectors, have a clear profile of use regardless of the user. For other types, usage varies widely with the particular user(s); for example, computers are commonly left in any of their power modes — on, sleep, off, or disconnected.

For some products, usage is bi-modal. For example, some people leave hair dryers plugged in most of the time so that the circuit breaker function uses energy continuously. Others only plug them in during active use so that there is almost no low power mode energy use.

We have not yet arrived at a standard method for asking about usage — that is left to the discretion of the person collecting the data. However, the first step is to ask about how much of the time the device is plugged in at all, which can be how often (e.g. twice a month), or as a

percent (e.g. half the time). Then, ask about how often the product is actively in use. Finally, if there are multiple low-power modes, ask about how much of the time it is in each, either in hours per day, hours per week, or in percent of time. Ultimately, usage is converted to percent of year in each mode.

Whole House Procedure

There are two primary purposes of the whole house procedure. One is to assess the consumption of unmeasured products (principally hardwired ones) and reveal if any significant loads were missed. The other is to determine if a whole house measurement by itself is a useful way to collect data about low power mode consumption.

There are two parts to the procedure for assessing an entire house. First, apply the individual product procedure to each product in the house that might have a low power mode (noting those that are unmeasurable for some reason). With the user, assess every room of the site, including basements, attics, garages, and any auxiliary rooms such as mechanical closets that may have relevant equipment. Equipment to look for that may be difficult to find include transformers for doorbells, thermostats, or HVAC controls (the latter two may be powered by the furnace), alarms, irrigation timers, garage door openers, structured wiring cabinet equipment, and IT equipment. Inspect the outside of the house and landscape. Assess all circuit breaker boxes, looking for GFCI (ground fault circuit interrupter) circuit breakers, clues to products present at the site, and breakers to turn off products not readily turned off otherwise.

Second, take a whole-house measurement. Record the status (mode) of each device, ensuring that to the degree possible, none are in active modes. Disconnect devices that may turn themselves on unexpectedly such as the refrigerator. Observe the meter for eight minutes, recording the "counts" of the spinning disk, and convert the counts to the power level they represent. Keep track of the counts for each minute to assess the stability of the reading. Finally, sum the appropriate power levels for all the devices measured and compare the two figures. In principle, the sum of measured products should always be less than the utility meter shows due to unmeasured products.

Results

Individual Products Measured

We measured 269 products with low power modes in the eight houses which we placed into 108 product types, and grouped the types into ten categories. The meter reports power levels every 2 seconds to 0.01 W; for further details see (Nordman et al. 2004).

We reached the criterion of five examples of a product type needed for it to be "known" for 16 product types: audio minisystem, audio receiver, CD player, cassette deck, cellular telephone charger, computer, computer speakers, DVD player, night light, microwave oven, power strip (surge), clock radio, cordless telephone, television, timer, and VCR. Relaxing the criterion to three for products with known and simple modes adds 12 additional types: answering machine, aquarium pump (water), battery charger, power tool charger, toothbrush charger, CRT computer display, carbon monoxide detector, garage door opener, hair dryer, DSL modem, inkjet printer, and irrigation timer.

Selected Quantitative Results

The full set of results is lengthy, so we only present here aggregate results and a few results for individual products. The 56 external power supplies that we measured ranged from 0.10 W to 4.95 W unloaded. We found more lights with low power mode consumption than expected. As lighting becomes increasingly electronic, we should expect to see an increasing portion of lights with low power mode consumption. The two GFCI (ground fault circuit interrupter) outlets we measured averaged 0.73 W in their normal position, and when tripped, neither changed consumption. By contrast, the three hair dryers (not hard-wired) averaged only 0.10 W, and one cut all of its own consumption when tripped.

Average Low Power Mode Consumption

The low power mode data collected at our eight houses resulted in average power levels for each low power mode for each product, as well as user-reported usage data for each product. The usage data (including disconnected time) were converted into a "percent of year" value for each mode. The total of all active mode time is the residual from summing the low power mode times and the disconnect time.

Tables 2, 3, and 4 show brief excerpts of the measured data that we gathered for all products. Table 2 lists each individual product; Table 3 has the average for each mode across all examples of the product type; and Table 4 incorporates usage data to arrive at the as-used annual average low power level. Active modes ("Play" in this case) are marked with an asterisk. For some products, the mix of modes present and readily measurable varies among units measured resulting in different "n"s for different low power modes. From Table 4, at least one of the DVD players was on a power strip or otherwise disconnected for most of the off time. The 1.32 W for average as-used low-power power is 11.6 kWh/year. Active energy could be calculated from these figures, but we only use the active power levels to compare to the low power levels for indications, not for robust estimates of active mode energy consumption for these products generally.

Table 2. Individual Product Data

Product Type	Mode 1	Avg.	Mode 2	Avg.	Mode 3	Avg.
DVD Player	Off	6.50	Ready	27.74	*Play	32.47
DVD Player	Off	0.00	Ready	9.91	*Play	13.55
DVD Player	Off	0.73	Ready	7.33	*Play	10.08
DVD Player	Off	0.40	Ready	12.71		
DVD Player	Off	0.39	Ready	6.05	*Play	7.71
DVD Player	Off	1.43	Ready	6.87		

Table 3. Average Low Power Modes by Product Type *(W)* and Count *(n)*

Product Type	Mode	*W*	*n*	Mode	*W*	*n*
DVD Player	Off	1.57	6	Ready	11.77	6
	*Play	15.95	4			

Table 4. Usage-Weighted Average Power Levels by Product Type

Product Type	Average *(W)*	As-used low power mode power for each product *(W)*
Audiovisual		
DVD Player	1.32	0.01, 0.01, 0.4, 0.43, 0.73, 6.37

Multiplying the usage percent and power level for each mode and then summing over all low power modes for a product results in a usage-weighted annual average power level consumed by the device in low power modes. This can be considered to be a constant power consumption, or multiplied by any convenient time period (e.g. a year) to get energy consumption. For example, 1 W is 8.76 kWh/year. Note that while this is an average over all hours of the year (including that time when the product is in an active mode), it does not reflect any of the active mode energy. All further power levels reported in this paper are usage-weighted annual average power levels and *not* the measured power levels for a single mode.

We calculated the as-used low power mode power levels for each product, as well as the average for each product type. For product types with many examples measured, there is often a wide range in the average power. This can be due to wide variations in power levels of the products, the usage patterns, or both. Products with zero as-used power levels are rarely or never in low power modes because they are always in an active mode, mostly disconnected, or mostly in a zero off mode. 40 products in 33 product types had zero as-used low-power power.

Table 5 presents the usage-weighted average power for each category, by site. Only products that we measured are included in the category totals. The data show that electronic products are the most consistent types with low power mode consumption, with audiovisual, information technology, and telephony the only categories that appear at all eight sites.

Table 5. Usage-weighted Average Power by Category and House *(W)*

House / Category	11	12	13	14	15	16	17	18	Average	Standard Deviation
Audiovisual	15.8	21.5	28.8	55.3	24.8	33.2	25.2	34.3	29.9	11.9
Food / Beverage	6.0	3.6	1.4	6.1	2.3	0.8	—	1.9	2.8	2.2
HVAC	7.8	—	0.0	12.3	—	4.6	—	—	3.1	5.2
Health / Hygiene	2.2	—	1.2	1.9	0.1	2.9	2.1	—	1.3	1.0
Infrastructure	1.4	9.9	0.8	22.9	19.1	4.3	0.8	2.5	7.7	8.8
Information Technology	8.0	41.9	14.0	17.8	12.9	8.0	16.1	24.9	17.9	11.1
Lighting	—	1.3	0.7	2.3	12.0	2.3	0.6	0.2	2.4	4.1
Garden, Workshop	2.5	—	—	3.7	9.6	—	—	2.0	2.2	3.5
Other	0.0	10.7	—	14.2	—	0.7	—	—	3.2	7.1
Telephony	7.5	7.2	5.5	11.6	6.6	3.9	4.4	6.2	6.6	2.4
TOTAL — Measured	51.1	96.2	52.4	148.1	87.3	60.7	49.2	71.9	77.1	33.5
Imputed Products	1.4	4.9	9.5	25.4	23.6	9.1	0.7	8.1	10.3	9.4
TOTAL — Measured and Imputed	52.5	101.1	61.9	173.5	110.8	70.0	49.9	80.0	87.4	41.0

Note: The power levels shown are the as-used annual average power.

We did a limited amount of "imputing" unmeasured products from the power levels observed at other houses or from the literature. This amounted to about 10% of the total low power mode consumption we report. Most of the imputed power is due to infrastructure products (GFCI outlets and breakers, furnaces, and a security system), and the average for infrastructure is over 12 W when these are included.

Analysis by Mode Type

Most products had only one low power mode with reported usage. In total, 299 low power modes were reported to be used. The distribution of power among modes and types of devices is easiest to assess when all eight houses are grouped together for a "composite" house. Table 6 summarizes the average power level by category and mode type for the composite house. Most audiovisual low power mode use is in off modes, but for information technology and telephony, most use is ready modes.

External power supply only modes are included in "off" in Table 6 but are only 0.08 W for audiovisual and 0.06 for telephony, and less than 1% of the total off power. For ready modes, those with no function being performed were over 90% of the total. For products with integral batteries, those modes that have some charging (usually a maintenance charge) are mostly found in ready modes. These totaled 6.49 W, mostly cordless phones.

Table 6. Average Power by Product Type Category and Mode Type *(W)*

House Category	Off	Ready	Ready some function	Single mode	Power products	Sleep	Single mode, active	Total
Audiovisual	23.5	3.6	2.7	—	—	—	—	29.8
Food / Beverage	1.0	1.8	0.0	—	—	—	—	2.8
HVAC	—	2.5	—	0.6	—	—	—	3.1
Health / Hygiene	0.6	0.8	—	0.2	—	—	—	1.6
Infrastructure	0.4	3.2	0.1	3.3	0.8	—	—	7.7
Information Technology	4.6	11.7	—	—	—	1.6	—	17.9
Lighting	0.2	0.7	0.3	1.1	—	—	—	2.1
Garden, Workshop	0.1	2.1	—	—	—	—	—	2.2
Other	—	—	—	0.1	—	—	3.1	3.2
Telephony	0.1	6.5	—	—	—	—	—	6.6
TOTAL	30.4	32.8	3.1	5.3	0.8	1.6	3.1	77.1

Note: The power levels shown are the as-used annual average power. "Ready some function" means that some function is being performed, such as the clock part of a clock radio and night lights. "Single mode, active" includes aquarium pumps and an indoor fountain.

Whole House Reconciliation

The attempt to reconcile measurements of individual products with the power shown by the utility meter was not successful. While we would have expected to find modestly more power on the utility meter at all houses, in three cases the sum of products was greater than the utility meter showed, by 20-29% (this including some imputed products; even without those these were from 11-21% in the "wrong" direction). The utility meter reading at one house was just 5 W (6%) above the sum of the products, which is about what we expected. At another house it was 78% over the sum of products which seems likely to indicate a large missed product. At the remaining three, the discrepancy was in the "right" direction, but varied from 18-35%, larger than seems accountable by small unmeasured loads. With these results and the lack of explanatory power over discrepancies, the whole house low power measurment seems to be of little use in understanding low power mode energy consumption.

Next Steps

The state-wide low power mode estimate is based on equipment stocks, power levels, and usage patterns[3]. Our next step is to gather what data exist on each of these from the literature, industry, and other research. Then, for parameters that are significant to the statewide total and not well known (or known at all) from these sources, we will conduct a combination of phone surveying, site visits, and product energy measurements to fill in the gaps. In this process, the taxonomy of product types (and categories) used should be compared with other systems for this to make sure that it best suits the needs of this work.

From this study and previous work, a variety of other topics related to low power modes clearly need attention, beginning with those product types and categories that use the most low power mode energy at present. One topic is the combination of hard-wired, code-required, and builder-installed products, which present a different regulatory and practical set of concerns from most low power mode devices. Another topic is set top boxes and other networked devices, as the number of these is growing rapidly and on-times can be high and possibly changeable. Low power consumption also exists in the commercial sector and should be assessed in a similar manner to residences and with this test procedure. Usage patterns for some products are not well known and deserve special attention and monitoring. Electronic displays (computer and video) are likely to become more common and need effort to assure that they manage power use well in practice. In addition, products with low power modes may have a role to play in demand response, and demand response systems themselves may add to power consumption in ways that need to be understood.

Conclusions

Measurements of low power modes to date have typically been limited to just standby power, or focused on just one product type or group of types. As a result, they are difficult to compare and aggregate. No existing test or measurement procedure provides a sufficient basis for low power mode measurement. The individual product test procedure provides a sound, unified, and organized way to apply a single method to all residential products with low power modes. We have grouped low power modes from dozens of disparate product types into a small number of categories of modes, making summaries and comparisons more tractable. The quantitative results of applying the procedure to hundreds of products in eight houses shows that electronic products (audiovisual, information technology, and telephony) dominate low power mode consumption, with infrastructure the next largest category. Viewed by modes, most low power consumption is in "off" (most of which is from audiovisual products), or "ready" (with information technology the largest category). We also developed a procedure to measure whole house low power mode consumption from the utility meter and reconcile that with the sum of measurements of individual products, but the comparison does not seem to be reliable or particularly useful. The average as-used low power mode power level from the small sample of eight houses we measured was nearly 90 W, above the 70 W figure estimated in previous work (Meier & Payne 2003) as typical of California residences, suggesting that the topic is even more important than we had previously believed.

[3] An initial estimate reported in (Nordman et al. 2004) suggests that the typical California household consumes an annual average of 112 W of power consumption, nearly one sixth of the average household consumption in the state.

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