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National Energy Use of Consumer Electronics in 1999

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ABSTRACT

The major consumer electronics in U.S. homes accounted for nearly 7% of U.S. residential electricity consumption in 1999. We attribute more than half of this figure (3.6%) to televisions, videocassette recorders, and DVD players, and nearly one-third (1.8%) to audio products. Set-top boxes currently account for a relatively small fraction of residential electricity use (0.7%), but we expect this end-use to grow quickly with the proliferation of digital set-top boxes, which currently use 40% more energy per unit than the average TV set. In all, these consumer electronics plus telephony products consumed 75 TWh in the U.S. in 1999, half of which was consumed while the products were not in use. This energy use is expected to grow as products with new or advanced functionality hit the market.

Introduction

The U.S. Department of Energy (DOE) keeps records of how the nation uses energy, and draws on this information to forecast energy consumption and develop energy policies. In 1999, the DOE commissioned several studies to determine energy consumption of electrical products that they had not previously studied in detail. In particular, the DOE requested annual energy consumption estimates for common consumer electronic devices, including audio and video equipment, set-top boxes, and telephony products. This paper combines and expands on the findings of these investigations (Rosen & Meier 1999a, 1999b; Rosen, Meier & Zandelin 2000), and includes some newer products not included in previous reports.

Previous U.S. studies have investigated energy use of consumer electronics products. The Annual Energy Outlook 2000 (EIA 1999) included TVs. One of the first comprehensive investigations of the energy use of small domestic appliances in the U.S. was undertaken by a graduate student at the University of California at Berkeley (Sanchez 1997). The results of the Sanchez study were used in several subsequent reports (Sanchez et al. 1998; Wenzel et al. 1997; Zogg & Alberino 1998). Other reports have included power level measurements without regard to total energy use (Huber 1997; Meier & Huber 1998).

This report presents national energy use estimates for several products not addressed in these previous studies, including digital TVs (DTVs), DVD players, digital cable boxes, and component stereo systems. In addition, this report includes power levels and usage of all the commonly used modes, whereas previous studies addressed only one or two modes. The original database on which many of these previous studies were based has been expanded to include a greater variety of models and ages of products. In the case of TVs and VCRs, our database was sufficiently large to allow us to adjust average power levels to reflect actual distributions of age, manufacturer, and screen size in the U.S. stock. Finally, we updated stock estimates to represent the number of products in the U.S. in 1999.

Data and Analysis

The ideal approach to estimating energy use would involve a national metering program under which all products in a statistically representative group of homes would be metered for a year. These measurements could then be extrapolated to the whole country. This approach would take years to complete. Instead, we resorted to a bottom-up approach combining direct measurements and survey data as follows:

1. Determine the products to be included in the study
2. Determine the modes that contribute significantly to energy use for each product type
3. Estimate typical usage patterns, i.e. how much time the product spends in each mode
4. Collect power measurements for the most commonly used modes for each product
5. Estimate the number of units in the U.S. residential sector
6. Estimate annual product energy consumption in the U.S. residential sector

Below we describe this approach in detail, following closely the steps outlined above.

Products

This study includes the energy use of the consumer electronic products shown in Table 1.

Table 1. Consumer Electronic Products Included in this Study

Video Products	Audio Products	Set-top Boxes	Telephony Products
Analog TV	Component stereo system	Analog cable box	TAD
Digital TV	Compact stereo system	Digital cable box	Cordless phone
VCR	Portable stereo	Digital satellite box	Cordless/TAD combo
DVD player	Clock radio	Game console	Cell phone charger

NOTE: TV = television; VCR = videocassette recorder; DVD = digital versatile disc; TAD = telephone answering device (answering machine). TV/VCR combos are included in the analog TV category.

These were the most commonly owned consumer electronic products in the U.S. in 1999. Other products, such computers and other office equipment, will be considered in future studies.

Modes

The term "mode" refers to a device state, and implies that the user has a choice of settings. Most products have many modes, and each usually requires a different power level. An accurate estimate of energy consumption includes the energy use for each mode. This entails identifying common modes, then estimating average power levels and usage for each.

Different types of products have different operational modes. Typical TVs have just two, but an audio system may have a dozen or more. Because this study covers a variety of product types, we define operational modes of the products considered in this report very broadly and limit the number of modes to those that account for a significant portion of product energy use. The definitions we used are summarized in Table 2.

Table 2. Common Consumer Electronic Modes

Mode[a]	Description
Active	The unit is performing a requested service, e.g. record, play, talk, etc.
Charge	The battery charger provides current to the battery
Idle[b]	The unit is on but not Active
Standby	The unit is plugged in and appears off to the user
Disconnected	The unit is unplugged

[a] These definitions were manufactured for the sake of convenience in reporting power levels and energy use for this study. They are not "real" in the sense that they may not be found in the dictionary or product literature. Similar studies may define more or fewer modes, or create different names or descriptions for the same modes.

[b] Idle may occur (1) after the user switches the unit on but before requesting a service, or (2) after the service ends (e.g. end of tape) but before the user switches the unit off. Some consumers never switch units with idle modes off.

In Table 2 and elsewhere, we use the terms "on" and "off" to indicate that the product has a system power switch, and that the user can control changes between these two states by directly or indirectly toggling the physical or electrical position of this switch. Products without a system power switch are always on unless disconnected from the power source.

The product modes considered in this study are as follows. We consider Standby and Active modes for TVs, clock radios, cable and satellite boxes, and TADs. We consider Standby, Idle and Active modes for VCRs, DVD players, and all stereos, but record modes are not included in the Active modes for stereos because they are used so infrequently (CEMA 1996). We consider Standby, Charge and Active modes for cordless phones and cordless/TAD combos, and Standby and Charge modes for cellular phone chargers.

Estimating Usage

Of the three types of data needed for a bottom-up estimate of energy consumption, usage is usually the most difficult to acquire. Unless resources are available for a survey tailored to the needs of the study, the best sources of usage data are existing surveys, often conducted by market researchers. Unfortunately, these surveys tend to deal with household behavior instead of per unit usage. For example a typical survey might publish the time household members listen to radio broadcasts instead of the time household members listen to a clock radio. This becomes a problem when more than one product is capable of the behavior being studied. Existing methods allow the use of such survey data to create upper and lower limits on per product active usage estimates (Rosen & Meier 1999b).

Typical U.S. homes may contain several units of certain product types, and usage values are likely to vary from one unit to the next. For such products, calculations of average household energy use should utilize a distribution of usage values instead of average usage values, thereby avoiding the false appearance that, for example, homes with three VCRs watch movies three times as much as homes with only one VCR.

A more difficult problem involves the time that the product is *not* used. Market researchers survey product usage, but do not inquire about the state of the product while it is inactive. As a result, these surveys are not helpful in estimating usage patterns for the Standby and Idle modes, which are critical for accurate estimates of unit energy use.

Estimating usage patterns for this investigation involved a variety of data sources and assumptions that varied from product to product. In general, Active usage values were based on consumer surveys, while the remaining values were estimated from anecdotal data or best guesses.

Collecting Power Data

Power data may be collected from many places. Retail stores often allow measurements to take place during business hours, provided the customers are not inconvenienced. Where power measurements of older equipment are desired, visits can be made to repair shops and second-hand stores, where available. Data can also be collected at residences, but this can be very time consuming. We adhered to the following steps in collecting power data:

1. Identify the operational modes to measure
2. Plug the power cord of the unit into the power meter
3. Record the Standby power draw before switching the unit on
4. Record the power draw, in watts, of the unit in all other modes studied
5. Switch the unit off, and confirm the Standby mode power consumption

We used a true RMS wattmeter that was custom-built for measuring low power levels (0.1W minimum) with high accuracy (±0.5%+0.1W). This meter displays average power every second. Where readings fluctuated, we visually estimated the average power draw based on the readings. Readings typically fluctuate only one or two tenths of a watt.

Estimating Average Unit Power and Energy Consumption

To calculate the average unit power consumption (UPC) for each product type, we weighted the arithmetic mean of the measured power levels to reflect average usage as follows:

$$UPC = \sum_{i=1}^{M} \overline{P_i} \cdot T_i \tag{1}$$

where M is the number of modes, P_i is the average power draw in watts of the product type in mode i, and T_i is the percentage of time that the unit is in mode i such that $\Sigma T_i = 100\%$.

Average annual unit energy consumption (UEC) was then calculated as the product of the average UPC in watts and the number of hours per year (h/yr) as follows:

$$UEC = (UPC) \cdot 8760 \; h/yr \tag{2}$$

where UPC is the average unit power consumption calculated using Equation 1.

**Estimating the Number of Units in the U.S. Residential Sector**

Because taking a national census of products is impractical, an accurate count of the existing residential stock is not directly available. Two methods can be used to estimate the residential stock count of a given product nationwide. One method involves estimating penetration by counting the products in a representative number of homes and extrapolating to all U.S. homes. The other involves combining historical sales/shipment data and average product lifetimes in a stock turnover model.

Estimating stock from penetration statistics. Penetration statistics are often available as a result of market research surveys or service provider subscription records. Penetration values present a serious problem to energy analysts because they represent the shares of homes with *at least* one of the product in question. It is unknown whether that respondent has one unit, two units, or perhaps three or more units.

To correctly estimate stock from penetration data, the number of units per unit-home[1] must be a factor in the equation, as follows:

$$Stock = (Households) \cdot (Penetration) \cdot (Units / UnitHome) \qquad (3)$$

Stock turnover model. It is possible to construct a stock turnover model where number of units sold or shipped and average product lifetimes are available. For this study, we used a simple model – the "4/3 Retirement Function" – which assumes that stock retires according to the function shown in Figure 1 (Koomey, Webber & McMahon 1998).
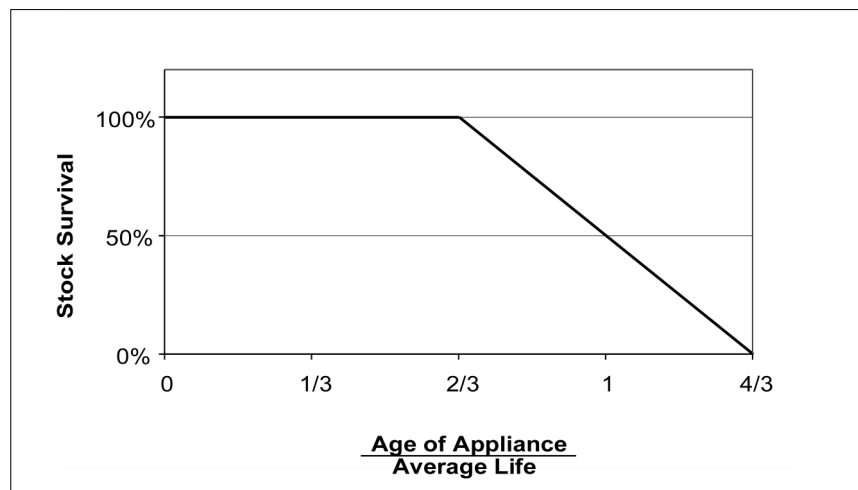
Figure 1. The 4/3 Retirement Function

This method should perhaps only be used where ownership surveys are not available, due to the uncertainties associated with product lifetime estimates. Where possible, it may be desirable to use both methods for comparison purposes.

Estimating National Energy Consumption

National energy consumption values for all product types were calculated as follows:

$$E = (UEC) \cdot (Stock) \qquad (4)$$

where *UEC* is calculated using Equation 2 and *Stock* is calculated using Equation 3.

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[1] A "unit-home" is a home that has at least one unit of a given appliance.

Results and Discussion

Using the methods described in the previous section, we collected a database of over a thousand product measurements. Table 3 shows average measured power levels in watts (W) and estimated usage patterns for the consumer electronic products included in this investigation. Also shown are the average annual UEC values, calculated using Equations 1 and 2.

Table 3. Usage, Power, and Unit Energy Consumption of Consumer Electronics

Product	Standby		Idle		Charge		Active		UEC
	W	Time	W	Time	W	Time	W	Time	kWh/yr
Analog TV	4.6	84%					75	16%	140[a]
Digital TV	8.8	84%					177	16%	320
VCR	5.9	77%	13	24%			17	4%	74
DVD	4.1	72%	15	24%			17	4%	64
Component Stereo	3.0	65%	43	16%			44	19%	150
Compact Stereo	9.8	72%	20	18%			22	10%	110
Portable Stereo[b]	1.8	51%	4.9	13%			6.1	6%	17
Clock Radio	1.7	99%					2.0	2%	15
Analog Cable Box	11	78%					12	22%	95
Digital Cable Box	23	78%					23	22%	200
Satellite Receiver	16	78%					17	22%	150
Game Console	1.1	78%					7.9	22%	23
TAD	3.2	99%					3.6	1%	28
Cordless Phone	2.6	35%			3.6	60%	3.1	5%	28
Cordless/TAD	3.1	35%			4.5	60%	4.2	5%	35
Cellular Phone[b]	1.0	75%			5.0	5%			9

a. UEC values shown here assume that all units are used equally. When the propensity of consumers to watch larger TV sets is taken into account, UEC increases to 150 kWh/yr (Rosen & Meier 1999a).
b. Time does not sum to unity because this product is disconnected part of the time.

We estimated the number of units in U.S. stock using both ownership surveys and stock turnover models. In most cases, the two methods resulted in similar stock estimates. Where results differed significantly, we chose the estimate that seemed more probable. Our final stock estimates and national energy consumption estimates, by mode and total, are given in Table 4.

Table 4. Number of Units and National Energy Consumption

Product	Units in 1999	Standby Energy	Idle Energy	Charge Energy	Active Energy	Total Product Energy Use	Share of U.S. Residential Electricity Use in 1999[a]
	M	TWh/yr	TWh/yr	TWh/yr	TWh/yr	TWh/yr	%
Analog TV	220	7.3			23.5	30.8	2.7%
Digital TV	1	0.1			0.3	0.3	0.0%
VCR	130	5.2	3.7		0.7	9.6	0.9%
DVD	3	0.1	0.1		0.0	0.2	0.0%
Component Stereo	75	1.3	4.6		5.5	11.4	1.0%
Compact Stereo	50	3.1	1.6		0.9	5.6	0.5%
Portable Stereo	70	0.6	0.4		0.2	1.2	0.1%
Clock Radio	130	1.9			0.0	1.9	0.2%
Analog Cable Box	40	2.9			0.9	3.8	0.3%
Digital Cable Box	3	0.5			0.1	0.6	0.1%
Satellite Box	13	1.5			0.4	2.0	0.2%
Game Console	54	0.4	0.0		0.8	1.2	0.1%
TAD	77	2.1			0.0	2.1	0.2%
Cordless Phone	87	0.7		1.6	0.1	2.5	0.2%
Cordless/TAD	35	0.3		0.8	0.1	1.2	0.1%
Cell Phone	70	0.5		0.2	0.0	0.6	0.1%
Total		**28**	**10**	**2.6**	**34**	**75**	**6.7%**

[a] Based on the 1999 U.S. residential electricity consumption of 1122 TWh/yr (EIA 2000).

According to Table 4, 37% of consumer electronic energy consumption (28 of 75 TWh) occurs during the Standby mode alone, and more than 50% (38 of 75 TWh) occurs when the products are not in use.

Video Products

In the video product category, TVs clearly require the most energy per unit. According to Table 4, the digital TVs we measured use more than twice as much energy as the analog sets. This difference exists because the average digital TV is about twice the size of the average analog TV.[2] When compared to sets of similar size, digital TVs do not require significantly more Active power. The higher average Standby power is also somewhat misleading, because the variance was very high. Excluding outliers, the average Standby power of the measured DTVs was nearly two watts lower than that of analog sets measured.

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[2] The median screen size in our sample of DTVs was 50 inches, while the median analog TV screen size was only 25 inches.

While the Active energy use of TVs will continue to increase if the preference for larger screen sizes continues, Standby energy use is likely to decrease as a result of national and international energy efficiency programs targeting this mode. Implications for overall TV energy use are uncertain, but in the long-term, advances in low-power display technology may cut TV energy use to a fraction of its current total.

VCRs and DVD players are nearly identical with respect to energy use. Both spend the vast majority of time in Standby and Idle modes, where 90% of the average UEC occurs. We do not expect VCR energy use to change dramatically because the VCR market is mature and because VCRs will eventually be replaced by digital recording technologies. If DVD players replace VCRs, there will be no significant change in energy use. On the other hand, if DVD players supplement VCRs, as is expected for the near future, household energy use will increase.

Audio Products

Among audio products, component stereos are the most power-hungry, with compact stereos taking a close second. Portable stereos and clock radios are among the lowest energy consumers in our study. Both have average annual UEC values under 20 kWh/yr.

National audio energy use may increase significantly as a result of the growing popularity of home theater systems. While some homes have always used stereo systems for television sound, advanced home theater setups involve multiple sets of speakers, requiring more amplifier power. In addition, a proper home theater system also includes a subwoofer, which has its own amplifier.

Set-top Boxes

The power needs of cable and satellite boxes in Standby and Active modes are considerable – and nearly identical. Because this significant power use (11-23 watts) is continuous, cable and satellite boxes often use more energy than the TVs they supplement. Digital cable boxes have particularly high UEC values. At 200 kWh/yr, these units use more than twice the energy of an analog box and 40% more energy than the average TV set.

The number of cable and satellite subscriptions has been climbing steadily throughout the nineties and is expected to grow even more quickly with the introduction of new broadband and interactive TV services. There are currently no digital-cable-ready TVs in the U.S. stock, so each TV set, analog or digital, must have a set-top box to receive cable programming. This implies that, even without cable subscriber growth, the switch from analog to digital cable boxes will increase annual cable household energy consumption by over 100 kWh *per TV set*. What is more, only half of existing cable subscribers have a cable box, so the switch to digital cable has the potential to increase cable box energy use by a factor of eight – i.e. twice as many existing subscribers (all of them, not just half) need twice as many boxes (one for each TV) that use twice as much energy. On the bright side, however, we believe that digital cable boxes will become more energy efficient as the market matures.

If all goes as the Federal Communications Commission plans, by 2006 every TV in the U.S. will be replaced by a digital TV or supplemented by a digital set-top box, or both. While the switch from an analog TV set to a DTV set of the same size will not increase energy use, the addition of the accompanying set-top needed for high definition TV will.

More importantly, market research surveys show that a majority of people plan to purchase or rent digital-to-analog converter boxes instead of replacing their analog TVs (De Sonne 1998). This means that nearly every home will have at least one digital set-top by 2006, whether a digital satellite box, a digital cable box, a digital-to-analog broadcast converter box, or a combination unit. The implication for residential energy use is staggering. Assuming only one set-top box per home, U.S. set-top energy will more than triple by 2006 to about 20 TWh/yr.[3]

To date, game consoles have very low or no Standby power needs. Active power needs of units sold before 1999 were also relatively low, resulting in an overall UEC of only 20 kWh/yr. If future game consoles require permanent cable, satellite or wireless network connections, they are likely to use as much energy as digital set-top boxes.

Some of the newer set-top boxes not included in this study are remarkably power-hungry. For example, one of the new personal video recorders has no power switch and consumes 60 watts at all times. At this rate, such a device would cost its owner about $50 in electricity bills every year. Another new product, a combination HDTV/satellite receiver box, used over 30 watts in all modes. The proliferation of such devices could have a noticeable effect on U.S. residential electricity use over the next decade.

Telephony Products

Electronic telephony products use very little power – typically less than 5 watts regardless of the tasks they are performing. But because of the sheer number of them – over 250 million in the U.S. – total energy consumption adds up to 6 TWh/yr.

Opportunities for Future Energy Savings

The three factors that contribute to the national energy use of consumer electronics are power, usage, and number of units. A reduction in any one of these factors will result in a reduction in national energy use.

Power levels can be reduced through better product designs and the use of more efficient components. Products that do not have Standby functionality can be designed to draw zero watts by properly implementing a hard-switch. The use of efficient power supplies is one of the simplest and most effective ways to improve the energy efficiency of consumer electronics, while other power savings can accrue through power-saving chips and displays.

Time in higher power modes can be diverted to lower power modes using existing power management techniques. For example, the battery chargers commonly used for cellular phones supply current to the battery only when the battery charge is low. In other cases, entire systems could be powered down during periods of non-use. Where this involves separate devices (e.g. a set-top box that switches off whenever the TV is off), protocols must allow for power management across a network.

Reducing the number of consumer electronic products in the U.S. would certainly reduce the national energy consumption of consumer electronics; however, this method is unlikely to be popular with manufacturers or most consumers. A similar effect could be realized by reducing the number of appliances that are connected to the grid by using

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[3] Based on preliminary average power levels for digital-to-analog boxes (5.5W Standby, 40W Active) and HDTV converters (8.5W Standby, 48W Active).

switched outlets (e.g. those on receivers or power strips) or by unplugging units that are rarely or never used.

Although existing technologies allow product designers to make significant energy efficiency improvements in consumer electronics products, market forces alone usually do not motivate them to do so. Regulations and government-sponsored voluntary programs have the potential to realize significant energy savings in the near future. For example, the U.S. Environmental Protection Agency's Energy Star Home Electronics program, which sets voluntary Standby[4] power limits for TVs, VCRs, audio equipment and set-top boxes, has the potential to reduce the energy use for this group of products by 15 to 20 percent.[5] In Japan, regulations targeting both Standby and Active modes of TVs may reduce TV energy use worldwide.

Unfortunately, other trends may outweigh these savings. For example, energy-intensive set-top boxes, only present in about half of U.S. homes in 1999, are likely to become ubiquitous within the next five to six years. Other trends, such as the increasing popularity of home theater systems, not only replace existing equipment with more powerful units, but may also encourage consumers to use their equipment more often.

We believe that now is the time to address energy efficiency in consumer electronics. While this study shows that the energy use of existing consumer electronics is significant, we believe that this is only the tip of the iceberg. The explosion of devices designed to take advantage of the deregulated communications market is underway, and measurements of some of these early products show alarming power consumption levels. We should therefore act quickly to encourage manufacturers to consider efficiency in this group of products that has not heretofore been properly addressed.

Limitations

With the exception of TVs and VCRs, no effort was made to ensure that the data samples were representative of U.S. stock. This may have affected average power estimates, for example, as result of regional model or manufacturer bias. In addition, many products measured for this investigation were new. This may underestimate total energy use by neglecting energy efficiency improvements; i.e., older units that are less efficient were not counted. On the other hand, older units sometimes have less functionality, and are therefore less energy-intensive. Excluding such products from our study may overestimate energy use.

Conclusions

Consumer electronics have become a significant power drain in U.S. homes. Combined, televisions, VCRs, DVD players, audio products, set-top boxes, and telephony products account for 75 TWh/yr (6.7%) of residential electricity consumption. The largest energy consumers are TVs at 31 TWh/yr, followed by component stereo systems at 11 TWh/yr. Figure 2 shows the energy use of each of the products considered in this study.

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[4] The Energy Star Home Electronics program does not address Active power levels and does not require automatic shutdown of units accidentally left on.

[5] Assumes 100% replacement of stock at current Energy Star levels.
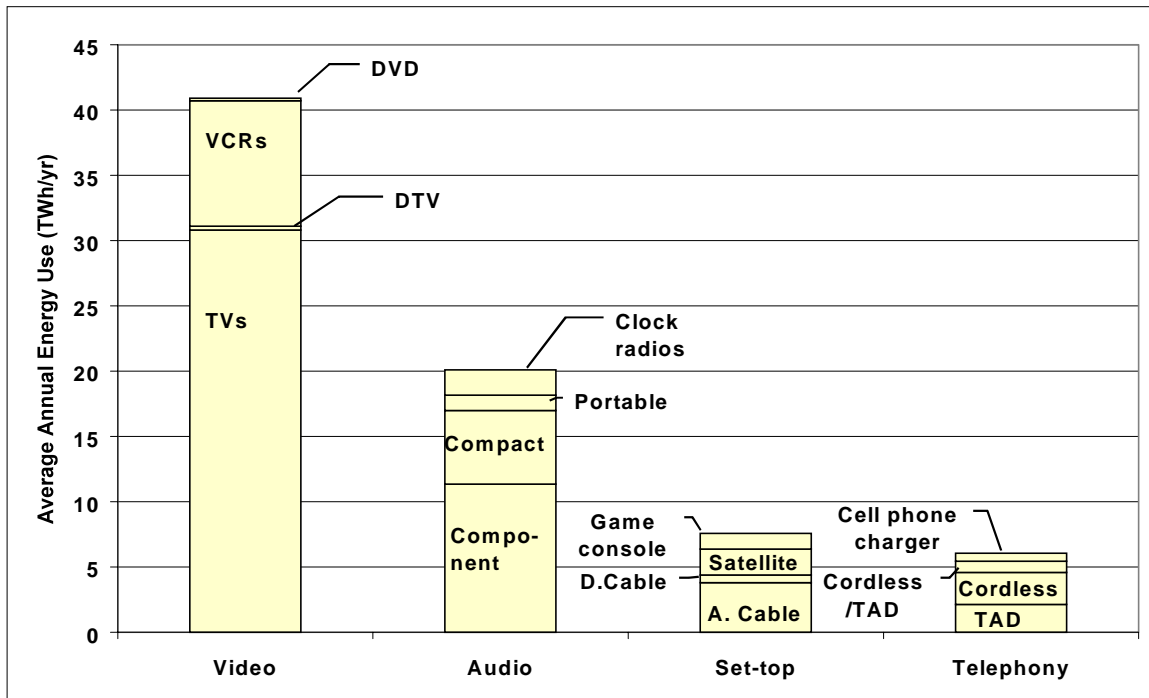
Figure 2. National Annual Energy Consumption of Consumer Electronics

By taking power measurements of the most commonly used modes and estimating typical usage patterns, we calculated the contribution of each mode to total appliance energy use. Figure 3 shows the average contribution of the Standby, Idle, Charge and Active modes to total consumer electronics energy use.
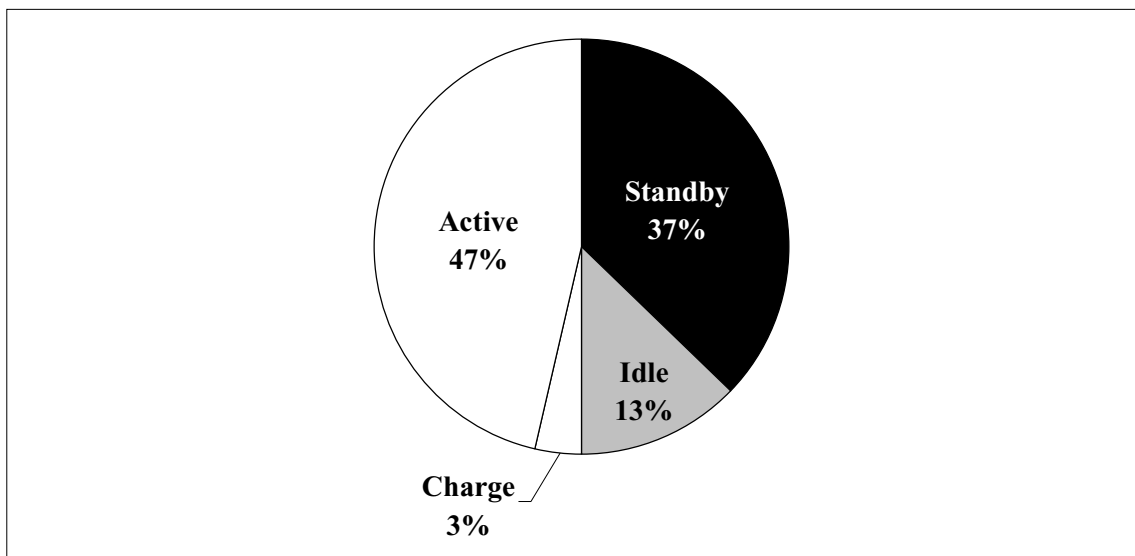
Figure 3. Contribution of Modes to Energy Consumption of Consumer Electronics

More than half of the electricity used by consumer electronics is consumed when the products are not being used, namely, in the Standby and Idle modes. Simple design modifications have the potential to cut this energy use significantly.

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