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Standby Power Consumption in U.S. Residences

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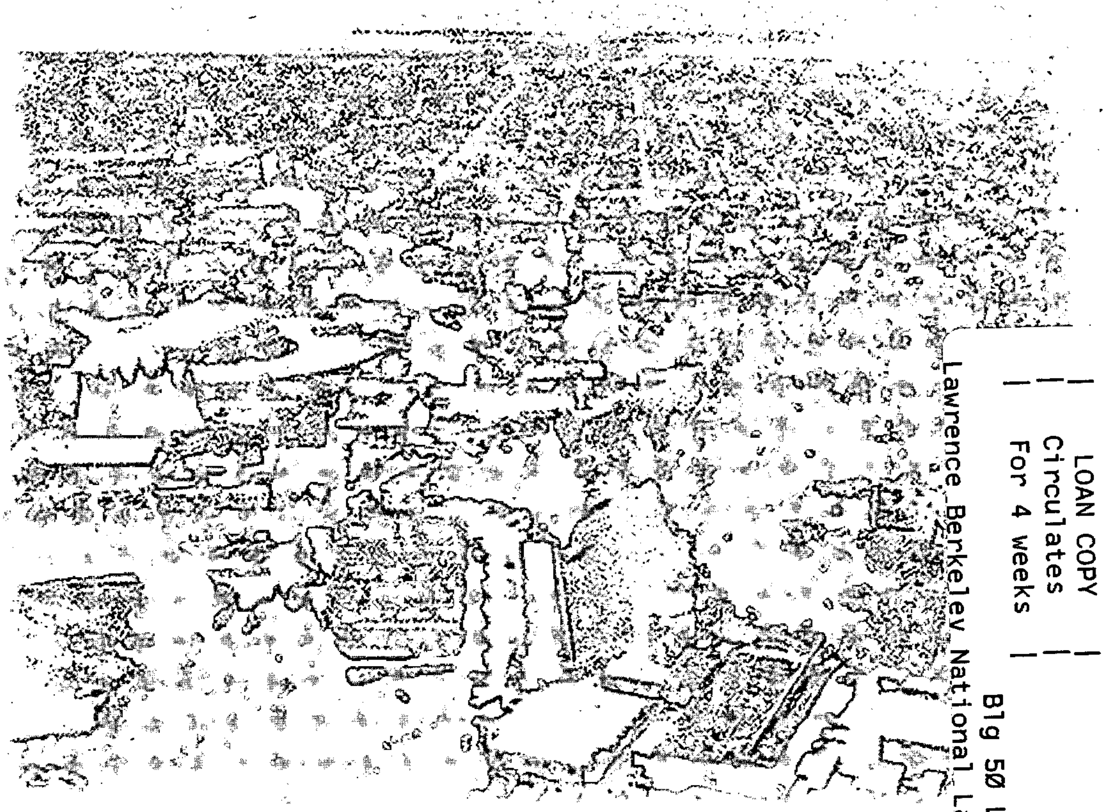
Master's Project
(Diplomarbeit)



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Masters Project
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Submitted in Partial Satisfaction of the Requirements for the Degree
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Abstract

"Leaking electricity" is the electricity consumed by appliances while they are switched "off" or not performing their principal function. Leaking electricity represents approximately 5% of U.S. residential electricity. This is a relatively new phenomenon and is a result of proliferation of electronic equipment in homes.

The standby losses in TVs, VCRs, compact audio systems, and cable boxes account for almost 40% of all leaking electricity. There is a wide range in standby losses in each appliance group. For example, standby losses in compact audio systems range from 2.1 to 28.6 W, even though their features are identical. In some cases, leaking electricity while switched off was only slightly less than energy consumption in the on mode. New features in these appliances may greatly increase leaking electricity, such as electronic program guides in TVs and cable boxes. In the standby mode, these new features require many extra components energized to permit the downloading of information.

Several techniques are available to cut standby losses, most without using any new technologies. Simple redesign of circuits to avoid energizing unused components appears to save the most energy. A separate power supply, precisely designed for the actual power needed, is another solution. A switch mode power supply can substitute for the less efficient linear power supply. Switch mode power supplies cut no-load and standby losses by 60-80%. The combination of these techniques can cut leaking electricity by greater than 75%.

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Acronyms and Abbreviations

ACEEE	American Council for an Energy-Efficient Economy
AHAM	Association of Home Appliance Manufacturer
BEW	Bundesamt für Energiewirtschaft
DPF	Displacement Power Factor
DVD	Digital Video Disc
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPG	Electronic Program Guide
ESPS	Energy Saving Power Supply
FSEC	Florida Solar Energy Center
GDP	Gross Domestic Product
HDTV	High Definition Television
IEC	International Electrotechnical Comission
IEEE	Institute of Electrical and Electronics Engineers
IC	Integrated Circuit
IF	Intermediate Frequency
LBNL	Lawrence Berkeley National Laboratory
LCD	Liquid Crystal Display
LED	Light Emitting Diode
NOVEM	Netherlands Agency for Energy and the Environment
PF	Power Factor
PIP	Picture In Picture
RMS	Root-Mean-Square
SEC	Standby Energy Consumption
SMPS	Switch Mode Power Supply
THD	Total Harmonic Distortion
UEC	Unit Energy Consumption
UL	Underwriters Laboratory
VBI	Vertical Blanking Interval
VCR	Video Cassette Recorder
VFD	Vacuum Fluorescent Display
W	Watt
YR	Year

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1. Introduction

Energy intensity, measured as energy use per dollar of gross domestic product, has generally declined in the U.S. since 1970. The energy use per capita is nearly stable, but the electricity demand is still growing at 1.5% per year (EIA, 1996). This is due to the higher demand for energy services that was not offset by efficiency gains.

Both the scarcity of energy resources and the environmental impacts of the energy use are crucial. Carbon emissions, which are a major contributor to global warming, are still increasing by 1.2% per year. These emissions together with methane, nitrous oxide, and other greenhouse gases might be responsible for a climate change.

Therefore a reduction of the energy use in all sectors must be part of an environmental strategy. Residential energy consumption for example is projected to increase by 17% overall between 1995 and 2015. Most of the growth (81%) in total energy use is related to increased use of electricity (EIA, 1996).

Previous work on residential electricity use shows that miscellaneous electricity use is the second largest end use (Sanchez et al., 1997). For the period 1990-2010 miscellaneous electricity use is expected to account for nearly all net growth in carbon emissions from the residential sector (Koomey, 1995). Much of this energy "leaks" out of the sockets due to appliances which consume energy while they are switched "off" or are not performing their principal function.

These standby losses were considered negligible and generally ignored until 1993. Eje Sandberg (Sandberg, 1993) collected data from TVs, VCRs, and audio equipment in the "off" mode in Swedish electronics stores. He called the standby power consumption "**leaking electricity**." The Swiss Federal Institute of Technology published the first report on this subject in January 1993 (Bundesamt für Energiewirtschaft, 1993). Alan Meier from the Lawrence Berkeley National Laboratory cited Sandberg's work and contributed additional information in *Home Energy* Magazine(Meier, 1993). Rainer et al. (Rainer et al., 1996) were the first to estimate average losses per home and national losses.

Since that time several organizations in the U.S. have monitored leaking electricity including the American Council for an Energy-Efficient Economy (ACEEE), the Florida Solar Energy Center (FSEC), and the U.S. Environmental Protection Agency (EPA). In Europe, the European Union contracted NOVEM (Netherlands Agency for Energy and the Environment) to compose the "Study of Standby Losses and Energy Savings Potential for Television and Video Recorder Sets in Europe" (NOVEM, 1995) and (Omvärden, 1997) to compose the "Study on Miscellaneous Standby Power Consumption of Household Equipment." Another European report (Herring, 1996) and a Japanese study (Nakagami, 1997) have also been written on this subject. All these reports comprehensively describe the status quo of standby power consumption in various countries. However, their results are often difficult to compare due to differences in their definitions of leaking electricity.

Studies from the EPA and FSEC were the first large scale attempts to collect data about leaking electricity in the U.S. beyond the anecdotal data collected by Rainer et al. (Rainer et al., 1996). However, their investigations are limited to TVs and VCRs and did not cover the entire spectrum of appliances in a typical U.S. household. Therefore, the conclusions of their work are limited and need to be expanded. For this reason, this report tries to develop a better estimate of standby energy consumption in the U.S. residential sector.

1.1 Study Objectives

Leaking electricity is the energy consumed by appliances when they are switched “off” or not performing their principal function. This report highlights different aspects of leaking electricity in order to identify methods to reduce the electricity use in the residential sector. Similar problems in the commercial and industrial sector, while important, are not addressed.

The main objectives of this study are:

- to determine the magnitude of leaking electricity on a national level
- to identify and analyze the main leakers
- to demonstrate methods to reduce leaking electricity

Field investigations were conducted to verify published estimates from different groups and to meter appliances for which no data were available. Low-voltage power supplies and their impact on the power quality were tested. Further investigations were made to determine the feasibility of reductions in standby losses in general and, in particular a ceiling of one watt per device.

1.2 Organization of the Report

The introduction in chapter 1 is followed by the definition of leaking electricity in chapter 2. Chapter 3 describes the meter and measurements. These measurements are discussed and analyzed in chapter 4. A comparison of two low voltage power supplies and their impact on power quality is in chapter 5. Chapter 6 shows solutions of the problem and the technical potential. This thesis ends with a summary, conclusion and possible further research in chapter 7.

2. Definition

2.1 Definition of Leaking Electricity

A precise definition of leaking electricity is important for test procedures and standards. This report defines leaking electricity as follows:

"Leaking electricity" is the electricity consumed by appliances while they are switched *"off"* or not performing their principal function.

Standby losses can be described mathematically as follows:

$$\mathbf{E_{sb} = P_{sb} \times t_{sb}} \quad (2.1)$$

E_{sb}: Standby losses, watt-hours per day or year
P_{sb}: Effective output consumed in standby mode, watts
t_{sb}: Time in the standby mode, hours

This report focuses on the measurement of P_{sb}. The measurement has to be sophisticated enough to indicate the "real" power. This subject is discussed in chapter 5. Data from other sources were used to estimate E_{sb} (see Appendix A). However, electricity consumption is a function of the time the appliance spends in each "mode" of operation. The different modes of operation are defined in the next section.

Other definitions, such as the one used by Nakagami, define leaking electricity as the least electricity that an appliance consumes while it is plugged into a power source. This definition has the advantage that it is easy to meter the leaking electricity in a household with a single measurement by switching off all appliances and metering the remaining electricity consumption. With this methodology, appliances which are not considered to be leakers in this report, such as the anti-condensation heating unit in refrigerators, contribute to leaking electricity. The magnitude of leaking electricity thus depends on the definition. The average standby power consumption in the Japanese report is double the calculated value of this report.

2.2 Definition of Modes

A characteristic of all appliances with standby losses is that they operate in at least one "mode." There are differences in the number of different modes an appliance can operate and how to distinguish one mode from another. In fact, the number of modes for complex appliances is growing. Televisions, for example, that had once only an on and off mode have now also a "standby" mode and, if they have an electronic program guide, they may be in yet another mode in which they await program information. The electricity consumption varies from mode to mode. Up to 7 different modes were defined in previous reports.

For simplicity, this report considers only four modes (see Table 2-1). The "off" mode is the mode in which the appliance is connected to the power source but provides no service. Any electricity consumed in this mode is considered leaking electricity.

There are also two different standby modes, “passive” and “active.” In the “passive” standby mode, the appliance awaits information such as transmitted data or an activation signal from a remote control. A television which is waiting to be switched on by a remote control or a fax machine which is waiting for an incoming phone call are examples of appliances in the “passive” standby mode. In the “active” standby mode, the appliance is performing either an additional or a support function. An additional function is, for example, the clock display on a VCR or the temperature display on a freezer. A support function assures that the primary function of the appliance can be performed on request, such as the function of a battery charger for a cordless telephone or a portable vacuum cleaner. In the “active” standby mode, the appliance does not perform its principal function but uses electricity to provide some kind of service.

In the “on” mode, the appliance is performing its principal function. The electricity consumed in this mode is not considered to be leaking electricity.

Table 2-1 Definition of Modes

mode	**function**	**leaking electricity**
off	no function at all	• transformer losses • poor design (“internal” on)
passive standby	not performing principal function	• awaits activation • awaits information
active standby		• additional function • support function
on	principal function	not leaking

3. Metered Losses of Individual Appliances

3.1 Metering Campaign

Two metering campaigns were conducted to determine leakage rates for common appliances. During the first campaign, data were collected in electronic retail stores[1]. Most of the data were from audio and video equipment but also a few kitchen appliances were metered. These data show the energy consumption of new appliances which will be found in many households in the future. Data were collected between April and August 1997.

The second campaign collected data in households. Thirty-five different types of leaking appliances were metered. This campaign began in March and continued through October 1997. The households ranged from a single person apartment to a house with 4 occupants. A total of 15 households were metered. There were also additional measurements of individual appliances.

No new measurements on office equipment in homes were undertaken because a database from previous work (Koomey et al., 1995) was deemed adequate. The only new data in this area are for multifunctional devices (copier, fax, and telephone combined) and modems. There are six major end use categories: audio, video, communication, kitchen, personal care, and miscellaneous.

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[1] The data were collected at "Circuit City" and "The Good Guys," two large consumer electronic chain stores.

The power in the standby mode was metered over short periods of time. Measurements for each model were added and divided by the number of different models to find the average for each appliance. Sales-weighted data were not available.

The two metering campaigns were an attempt to get a representative sample of the existing appliance stock. The combined data from these two campaigns might be representative of the appliance stock in the near future.

Data were collected for a total of 435 appliances. Table 3-1 shows the appliance types, the category, the number of metered appliances per appliance type, and the average standby power[2].

3.2 Metering Equipment

Two different meters were used, the AEMC NUWATT and the FLUKE 41 Power Harmonics Analyzer. At a low power range, the accuracy and measurement bias of the meter is an important issue.The uncertainty in the measurements, however, is dangerously close to the measured values. The AEMC NUWATT is a true RMS Digital Power Meter which is capable of measuring power consumption from 0.1 watt to 2 megawatts. Details of the instrument are in Appendix B. The Fluke 41 allows measurements of currents from 1 to 500 A AC RMS, 5 Hz to 10 kHz without interfering with the circuit. More information about the meter and the accuracy is in Appendix C.

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[2] Names of manufacturers and products are occasionally mentioned in this report to help the reader better understand the issues raised.
Lawrence Berkeley National Laboratory neither endorses or recommends any products mentioned in this report.

Table 3-1 Average Standby Power

End Use Name	Category	Number of Metered Devices	Average Standby Power(W)
Amplifier	AUDIO	6	1.6
Answering Machine	COMMUNICATION	19	3.3
Battery Charger	MISCELLANEOUS	7	2.4
Boom Box	AUDIO	30	2.2
Cable Box	VIDEO	7	11.6
Cassette Deck	AUDIO	5	3.6
CD Player	AUDIO	32	3.2
Clockradio	AUDIO	14	2.0
Color TV	VIDEO	65	4.0
Compact Audio System	AUDIO	36	10.6
Computer	OFFICE EQUIPMENT	0	65.0
Copier	OFFICE EQUIPMENT	0	10.0
Cordless Phone	COMMUNICATION	12	2.8
Doorbell	MISCELLANEOUS	1	2.0
Digital Video Disc Player	VIDEO	9	4.4
Electric Toothbrush	PERSONAL CARE	3	2.3
Fax Machine	COMMUNICATION	0	30.0
Electric Toothbrush	PERSONAL CARE	3	2.3
Halogen Lights	MISCELLANEOUS	5	0.5
Hand-Held Rechargeable	MISCELLANEOUS	8	1.8
Microwave Oven	KITCHEN	13	3.1
Modem	OFFICE EQUIPMENT	5	1.4
Multifunctional Device	OFFICE EQUIPMENT	5	4.7
Oven	KITCHEN	1	2.1
Power Strip	MISCELLANEOUS	2	0.3
Projection Color TV	VIDEO	9	2.2
Printer	OFFICE EQUIPMENT	0	15.0
Rack Audio System	AUDIO	7	5.8
Receiver	AUDIO	12	1.5
Satellite Earth Station	VIDEO	7	14.9
Screwdriver	MISCELLANEOUS	2	1.9
Security System	MISCELLANEOUS	1	12.0
Shaver	PERSONAL CARE	3	1.4
Timer	MISCELLANEOUS	2	2.1
Tuner	AUDIO	4	2.3
Turntable	AUDIO	2	0.7
TV/VCR Combo	VIDEO	10	9.8
Video Cassette Recorder	VIDEO	69	5.6
Video Game System	MISCELLANEOUS	1	2.0
Wall Pack	MISCELLANEOUS	10	1.0

3.3. Discussion of Measurements

Even though many appliances have standby losses, only a few appliances account for most of the residential leaking electricity. Ten leaking appliances represent more than 70% of the total leaking electricity. Standby power measurements for the four largest leaking appliances are reported in this chapter. In addition, two appliances which could become large leakers in the future are analyzed.

The standby power of different brands of the same appliance type are compared. The model and manufacturers are listed, but one should not infer that any particular manufacturer is more efficient than another; a different selection of measurements could have easily reversed the rankings.

3.3.1 Televisions

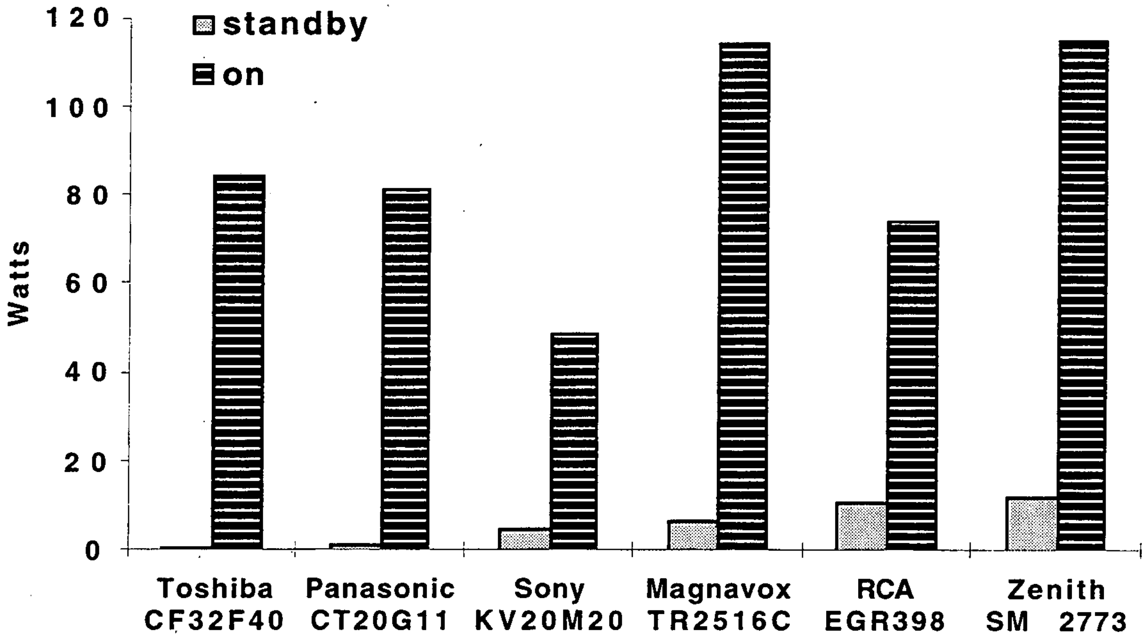
Sixty-five televisions were metered. A list of all metered appliances is in Appendix D. Table 3-2 shows a representative sample of all metered TVs. The model with the lowest and the highest standby power are listed together with four other models. The size of the screen, and power consumption in the standby and in the on modes are listed. Standby power ranged from 0.5 to 12.3 W with the average at 4.0 W. A few older TVs lack a remote control and therefore have a "hard" off switch. These TVs have no standby power consumption. All appliances in Table 3-2 have a remote control. All of these TVs are examples of appliances in a passive standby mode. The only service provided in this mode is to wait for the signal from the remote control to activate the appliance. Other modes exist, such as awaiting a download of program information, but there was no appliance in this sample with a sophisticated technology like an electronic program guide (see 3.3.6 Electronic Program Guides). The power consumption in the standby mode can be assumed to be stable.

Table 3-2 Sample of Metered TVs

Brand	Model Number	Description	Standby (W)	On (W)
Toshiba	CF32F40	32" Stereo	0.5	84
Panasonic	CT20G11	20" Stereo	1.1	81
Sony	KV20M20	20" Stereo	5.0	49
Magnavox	TR2516C	25" Mono	6.5	114
RCA	EGR398WR	17"	10.4	74
Zenith	SM 2773BT	27"	12.3	115

The data shown in Table 3-2 are presented in Figure 3-1 as a bar chart. The different models are shown as well as their energy consumption in W in the standby and in the on mode.

Figure 3-1 Comparison of Power in the Standby and On Mode of TVs



No direct relation between the standby and the on mode power can be seen, nor is the size of the screen an indicator for power consumption in the standby mode. However, TVs with larger screens tend to have a higher power consumption in the on mode. While large projection TVs consume more power while on, their standby power is lower than that of regular TVs. Differences in the quality of the picture and other technical characteristics were not investigated.

Figure 3-2 shows the cumulative distribution of standby power of all 65 metered TVs. Note that this plot can be used in two different ways. The graph shows how many TVs would qualify for a given minimum efficiency standard or award label. For example, approximately 50% of the TVs would qualify under a 4-watt efficiency standard. Also, if 20% of the sample should get an award label, then the maximum standby power should be 1.2 W.

Figure 3-2 Cumulative Distribution of TV Standby Power

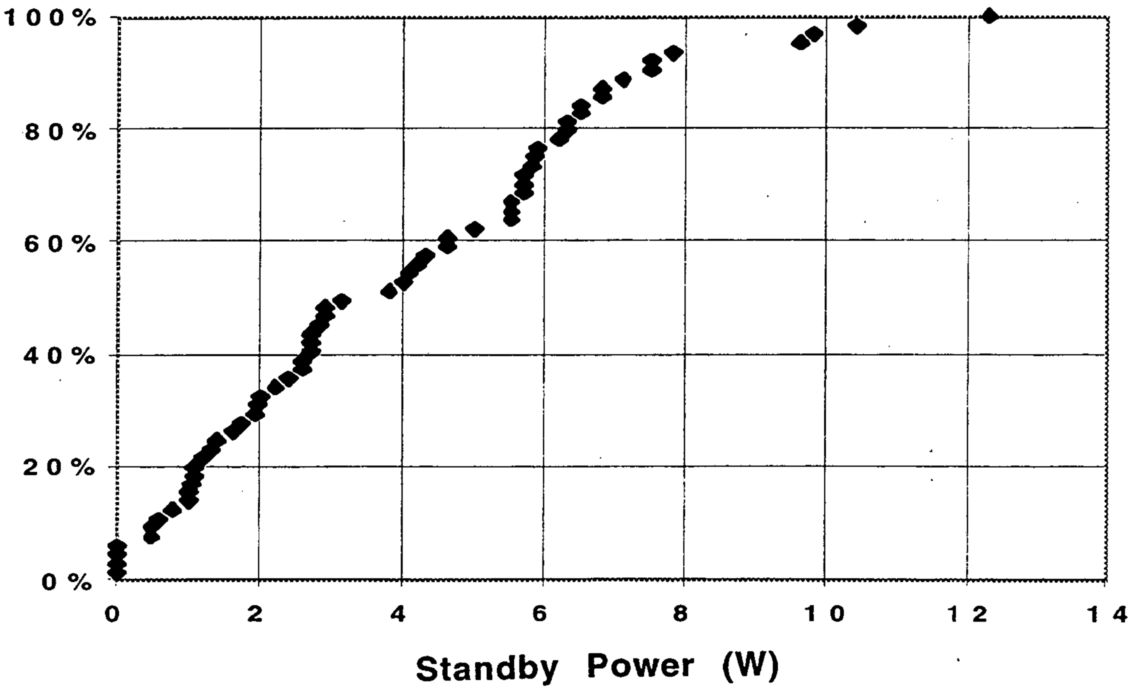


Figure 3-2 shows an almost linear distribution in the range from zero to eight watts. This indicates that there are the same number of appliances at every standby power level. Four TVs in this sample have no standby power. (These are the TVs without a remote control. They have a hard off switch.) There are also four televisions with a high standby power from 9 to 12.3 W.

3.3.2 Video Cassette Recorders

Data were collected for 69 VCRs. The range of the standby power was from 2.0 to 12.8 W with an average at 5.6 W. A complete list with all metered data is in Appendix E. Table 3-3 shows a representative sample of metered VCRs including the one with the lowest and the one with the highest standby power.

Table 3-3 Sample of Metered VCRs

Brand	Model Nr.	Description	Standby (W)	On (W)
JVC	HR-J200U	1992	1.5	7.9
Hitachi	VTUX615A	5-head, VCR+, 1997	2.3	11.1
RCA	VR 519	4-head, VCR+, 1997	4.8	7.7
Zenith	VR4156	4-head, VCR+, 1997	8.7	8.9
Sanyo	V14R9820	1990	10.0	20.2
Hitachi	VT-F462A	1993	12.8	18.3

Age is not an strong indicator of the standby power. The two appliances with the highest standby power were four and seven years old. The VCR with the lowest standby power level is five years old, and the new VCRs are in the middle. All metered VCRs provide the same services in the active standby mode. They show the time and are ready to be switched on by remote control. The new VCRs have the "VCR Plus+" feature which allows the consumer to record a certain program by typing in its associated code number; the VCR sets the time and the channel of the desired program. Figure 3-3 shows the standby and the on power consumption of the sampled VCRs.

Figure 3-3 Comparison of the Standby and On Power of VCRs

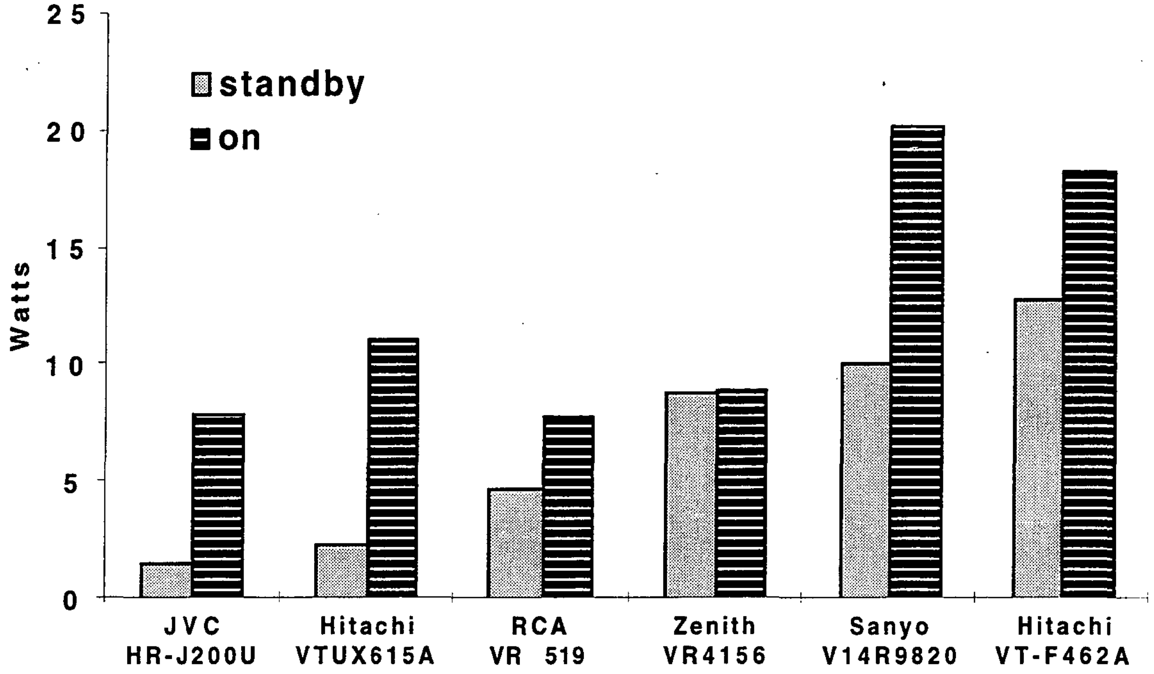
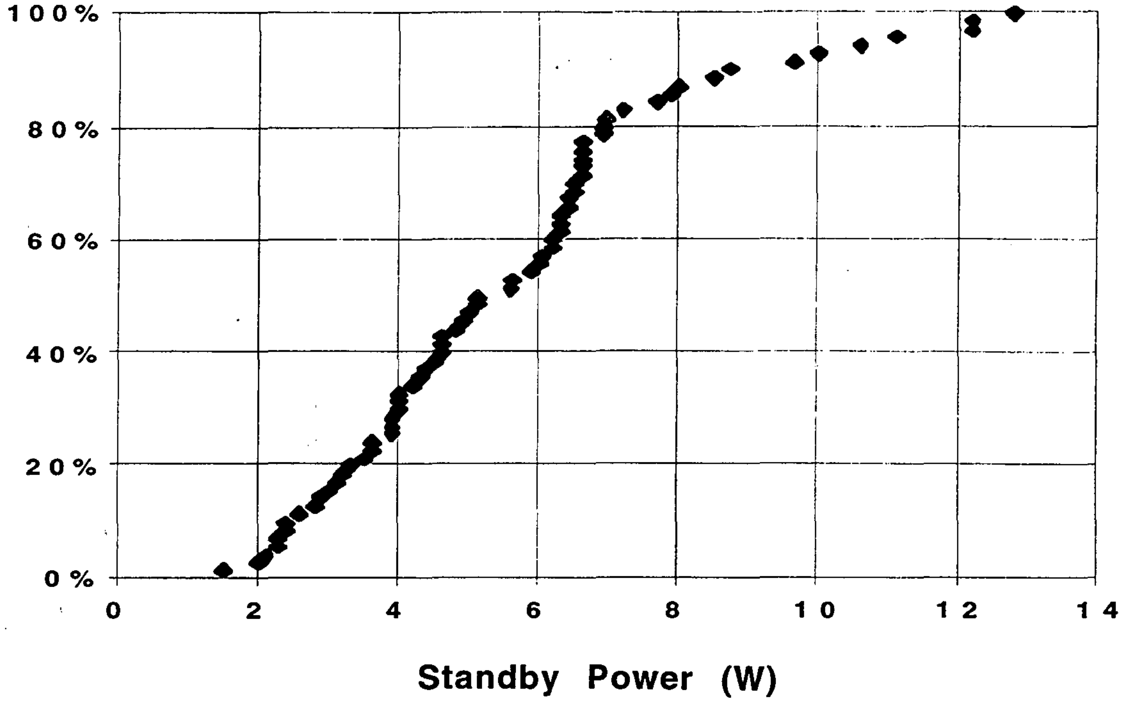


Figure 3-3 shows a wide range for the standby power from 1.5 to 12.8 W. No relation between the energy use in the standby mode and in the on mode can be seen. The newer models have a significantly lower power level in the on mode.

The cumulative distribution of standby power for the 69 metered VCRs is shown in Figure 3-4. Eighty percent of all metered VCRs have an standby power between 2 and 7 W. There is an equal distribution of standby power level for VCRs in this range. Only one VCR had a lower standby level than 2 W. The other 20% of VCRs are approximately evenly distributed in a range from 7 to 13 W.

Figure 3-4 Cumulative Distribution of VCR Standby Power



3.3.3 Compact Audio Systems

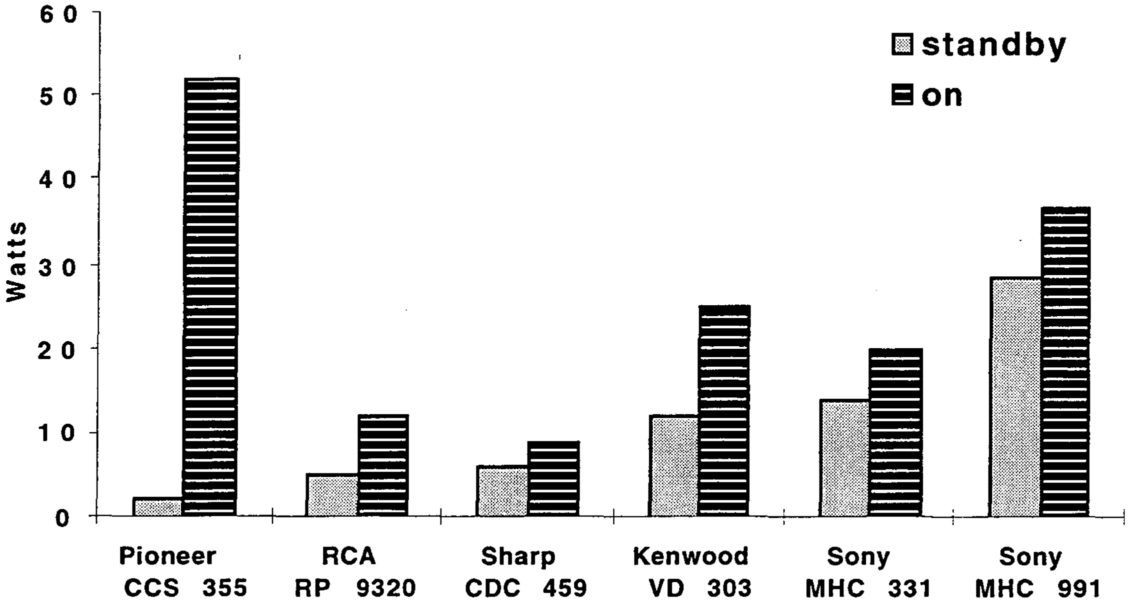
Compact audio systems are audio systems for which one common housing contains all components. A typical unit consists of an amplifier, CD player, cassette deck, radio, and a clock. Thirty-six different compact audio systems were monitored. A complete list with all metered data is in Appendix F. Table 3-4 shows a representative sample of compact audio systems including the most and the least efficient. Their brand and model numbers are given together with the standby and the on power. All the units had an active standby mode in which they showed the time. There are many different on modes, depending on the components in use. In this report, the definition of "on" is playing the radio at lowest volume possible.

Table 3-4 Sample of Metered Compact Audio Systems

Brand	Model	Standby (W)	On (W)
Pioneer	CCS 355	2.1	52.0
RCA	RP 9320	4.9	12.0
Sharp	CDC 459	5.8	8.7
Kenwood	VD 303	12.0	25.0
Sony	MHC 331	14.0	20.0
Sony	MHC 991	28.6	36.8

These data are presented in figure 3-5 as a bar chart showing the standby and the on power of each appliance.

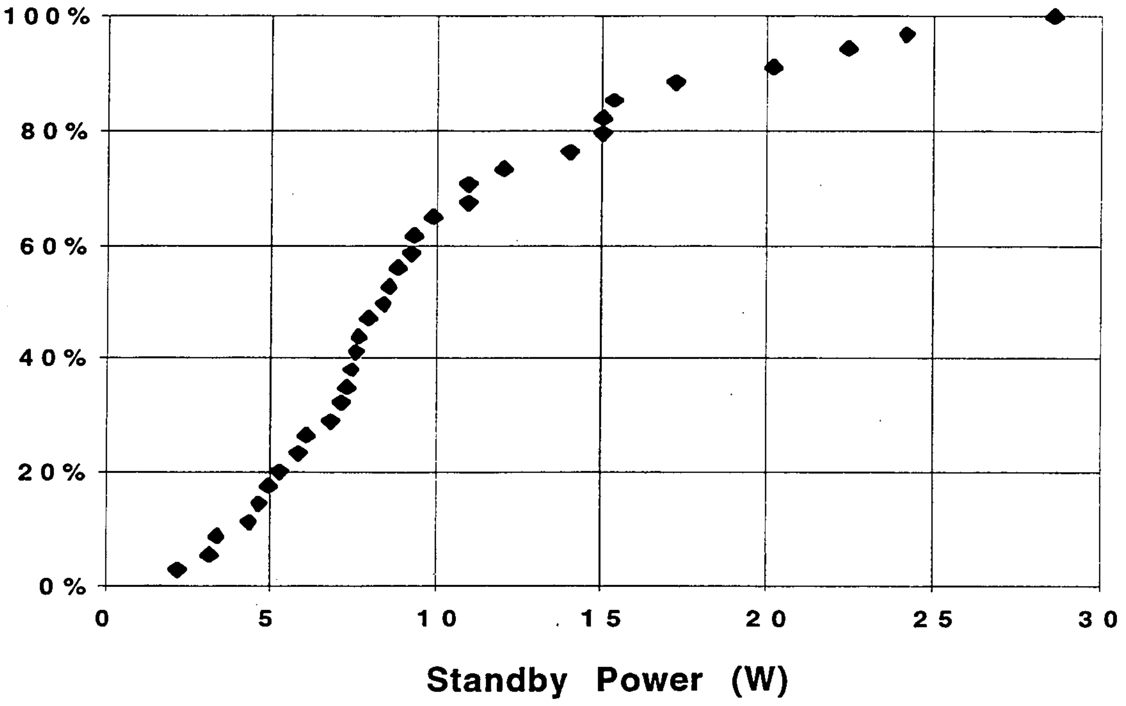
Figure 3-5 Comparison of Standby and On Power of Compact Audio Systems



There is a wide range in the standby power from 2.1 to 28.8 W even though the features were essentially the same. For example, all appliances showed the time constantly. The only exception was the unit with the lowest standby power. This appliance could be set up to show the time on request. This is an example of an appliance with increasing number of power levels in the standby mode. The consumer can choose between the "active" and the "passive" standby mode. On power ranges from 8.7 to 52 W.

Figure 3-6 shows the cumulative distribution of standby power of compact audio systems. The standby power of 65% of the appliances in this sample are evenly distributed in the range from 2 to 10 W. The other 35% are from 10 to 29 W.

Figure 3-6 Cumulative Distribution of Compact Audio Systems Standby Power



3.3.4 Cable Boxes

Cable boxes are devices which interpret programming information from the cable provider and display it on TVs. Some are also used to receive digital music. In the future there will be more cable boxes which provide additional multimedia services, such as access to the internet. Many different cable boxes were metered with standby power ranging from 4.8 to 18.0 W with an average of 11.6 W. These cable boxes represented 7 models. Cable companies provide the boxes to their subscribers. The consumer has no choice of which box to get. The power consumption of the metered cable boxes in the on mode ranged from 5.8 to 19.0 W. Table 3-5 compares the standby and on mode power consumption of cable boxes.

Table 3-5 Sample of Metered Cable Boxes

Brand	Description	Model Nr.	Standby (W)	On (W)
Scientific Atlanta	old model	8529300	4.8	5.8
Nokia	multimedia box	DCR 9500C	5[3]	40[3]
Scientific Atlanta	addressable[4]	8600-SZNN	10.6	11.6
Scientific Atlanta	digital music receiver	DM-2000	12.2	13.7
Zenith	addressable[4]	ST 1622	12.3	13.0
Zenith	1983	ST 1083	18.0	19.0

These data are presented in figure 3-7 as a bar chart, comparing the power level of different cable boxes in the standby and on mode. It is striking that there is almost no difference in the energy consumption between the standby and on mode for the metered appliances. Cable boxes have a passive standby mode. Their only service in the standby mode is to await the activation signal from the remote control. The small difference between the passive standby and on mode indicates that the unit stays "internally" on all the time.

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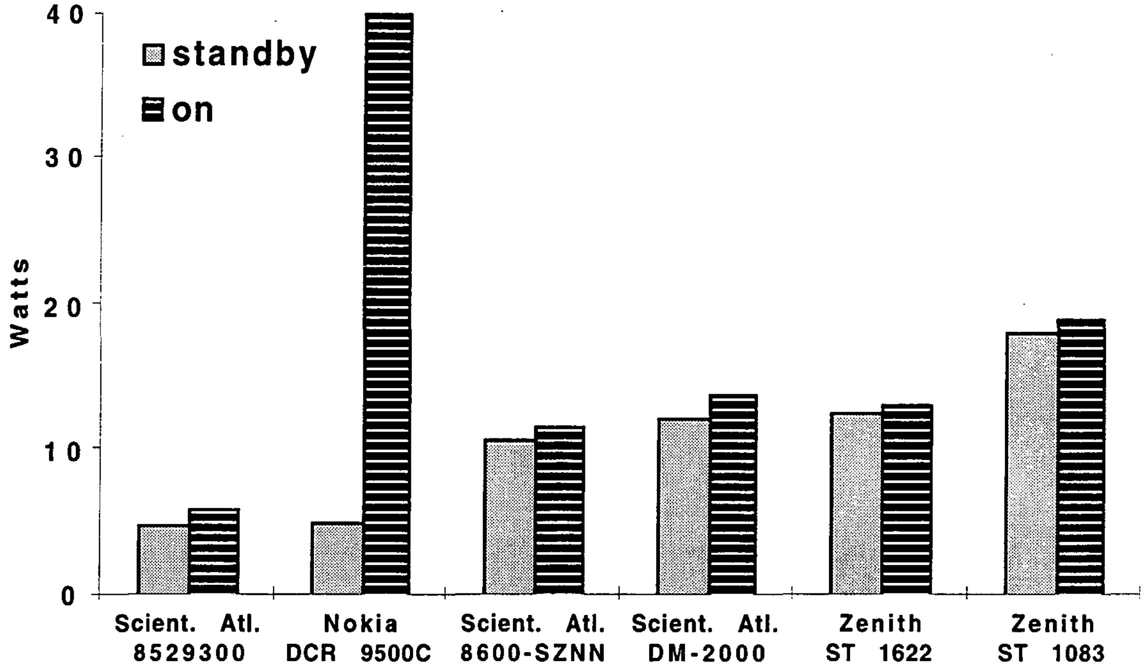
[3] The power data were provided by Nokia

[4] Most new cable boxes are "addressable." Addressable cable boxes accept input from the cable company and canophisticated services to the viewer, such as individual premium channels and pay-per-view.

Figure 3-7 Comparison of Power in the Standby and On Mode of Cable Boxes



(Note: Scientific Atlanta DM-2000 is a cable box for digital music only.)

3.3.5 Satellite Receiver Systems

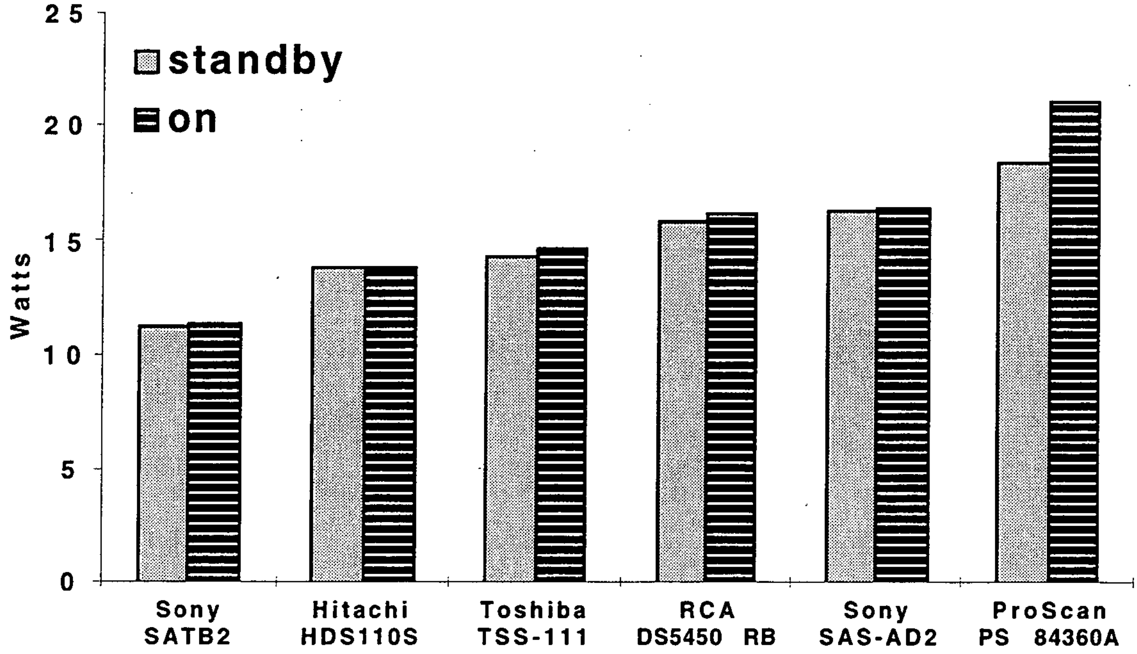
These systems receive and interpret information broadcasted to satellite dishes. While older devices used an analog signal, the new devices transmit their information digitally. With this new technology the speed of transmission is much faster and therefore the range of optional services is greater. The metered satellite receiver systems in table 3-6 show a standby power ranging from 11.3 to 18.4 W and an on power from 11.4 to 21.2 W.

Table 3-6 Sample of Metered Digital Satellite Systems

Brand	Model Nr.	Standby (W)	On (W)
Sony	SATB2	11.3	11.4
Hitachi	HDS110S	13.8	13.9
Toshiba	TSS-111	14.4	14.7
RCA	DS5450 RB	15.9	16.2
Sony	SAS-AD2	16.3	16.4
ProScan	PS 84360A	18.4	21.2

Figure 3-8 shows a comparison of the standby and the on mode. There is almost no difference between the standby and on mode. The off switch does not deactivate any parts of the internal circuit. The only component deactivated is the LED in the front panel. The satellite receiver box stays "internally" on and allows the program provider to download information even in the passive standby mode.

Figure 3-8. Comparison of the Standby and On Mode Power of Satellite Systems



3.3.6 Electronic Program Guides

Electronic program guides (EPGs) are an example of a technology that has created a new mode. EPGs allow a TV watcher to display program listings and episode descriptions on their TV. In addition to program information, these program guides can also allow one-button programming of the VCR. This technology can be integrated into TVs, VCRs, satellite receivers, and cable boxes. Alternatively, a separate set-top unit can be used to receive and decode signals.

Different service providers use different methods to deliver their information via broadcast, cable, or satellite signals. The data transmission rate via broadcast band is very slow, only about 960 bits per second (bps). The typical download with the StarSight system contains 128-512 kilobytes, depending on the number of channels available in an area (each additional channel adds about 1 kilobyte per week of program information). At the slow transmission rate, a download may require three hours. StarSight, for example, broadcasts information continuously on a 3-hour cycle. Gemstar's TV Guide Plus+ service, on the other hand, has four scheduled 2-hour download periods, although each device would typically only download once if successful.

In broadcast signals, information is carried on the vertical blanking interval (VBI), a part of the television signal which is not displayed. The circuitry that interprets the data embedded in the VBI is dedicated to the primary tuner (this circuitry is mandated by the FCC for the interpretation of closed captions, which are also carried on VBI). While some units have two tuners, secondary tuners are not designed to interpret the VBI, so the primary tuner must remain powered.

Future televisions will be high-definition TV (HDTV). HDTV is based on a digital standard. Digital signals transmit at 19 Mbps, much faster than analog. Most of the signal is compressed video, but some of the bandwidth is reserved for EPG signals. About 100 Kbps is available for EPGs, which is about 100 times faster than analog transmissions. Because the signal is faster, program information can be received upon request rather than during a lengthy download cycle. Table 3-7 summarizes the types of technologies which may incorporate EPGs.

Table 3-7 EPG Device Types

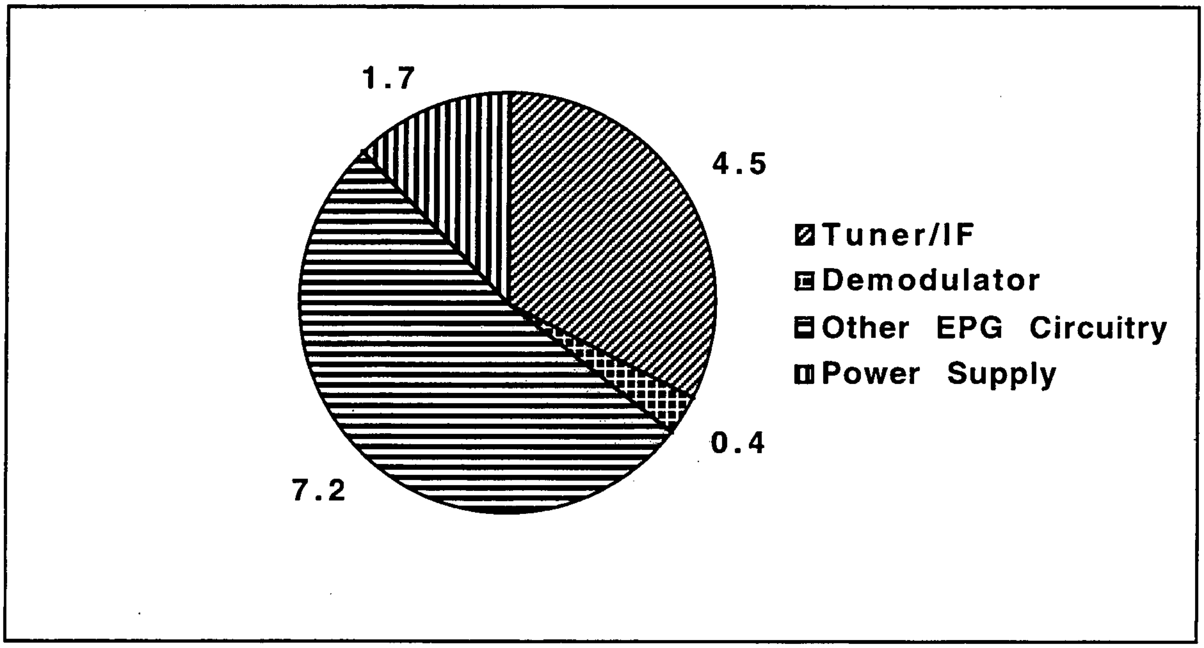
	Analog	**Digital**
TVs	Less than 5% of analog TVs have EPGs.	Penetration of EPGs could increase to 100% as program offerings increase.
VCRs	Make a small percentage of EPG device sales.	Unlikely to represent a large share of EPG device in the future.
Set-top Boxes	Discontinued due to poor sales.	Unlikely to be introduced
Satellite Receivers	Analog systems will likely be replaced by digital systems in the near future.	Most have EPGs.
Cable Boxes	Some have EPGs	All have EPGs.

The information on EPG energy consumption comes from examination of a StarSight set-top box (which included detailed power monitoring of both the box and its components) and from manufacturers.

The power level of added circuitry for the EPG feature is minimal—less than 0.5 W (5V, 60-70 mA for both StarSight and TV Guide Plus+) for the newest generation technology. However, certain standard TV components must be powered for the EPG to work—primarily the tuner, the IF (the "IF" or "intermediate frequency" component generally includes a variable gain amplifier and filter), and audio and video demodulators (the tuner/IF assembly). These components are powered continuously in a StarSight TV. On a TV Guide Plus+ TV, the tuner/IF assembly is powered only when a download is scheduled (a total of 8 hours per day).

The StarSight set-top box consumes about 14 W with almost no variation over the course of a day, even during download periods. The tuner and IF for this unit consumed about 4.5 W, the demodulator consumed 0.4 W, and the power supply consumed 1.7 W, leaving 7.2 W for the other components (see Figure 3-9). However, the metered box contained an earlier generation of the StarSight board, which consumes more energy than their current product.

Figure 3-9 Power Draw of StarSight Set-top Box (W) by Component



First-generation StarSight TVs consumed about 30 W (Milnes, 1997). Newer StarSight designs consume only 11 to 12 W. About 5 W probably goes to powering tuner/IF assembly, while StarSight circuitry accounts for another 0.5 W. The remaining power (6 W) is consistent with standby power for non-EPG TVs.

For digital satellite receivers and eventually with digital TVs and VCRs, the tuner/IF assembly need not be powered constantly. Since programming information is received on demand, the tuner and IF do not need to be powered when the set is off. The program information does not need to be stored in memory, so digital technology would reduce the energy consumption of EPG circuitry as well. This would eliminate most of the leaking electricity associated with EPGs.

4. National Standby Electricity Losses

4.1 Assumptions

The national energy consumption of leaking electricity for each appliance was calculated according to the following equation:

$$\mathbf{E_{sb(US)} = P_{sb} \times t_{sb} \times n} \qquad (4.1)$$

with: $\mathbf{E_{sb(US)}}$ standby energy consumption per end use in the U.S.

$\mathbf{P_{sb}}$ average standby power per appliance type (calculated in chapter 3)

$\mathbf{t_{sb}}$ average time in the standby mode

$\mathbf{n}$ number of appliances in the U.S.

The national estimates of leaking electricity are calculated with the average value of the standby power for each end use from chapter 3. The standby power per end use are multiplied by the time in the standby mode and the number of appliances in the U.S.

Average usage

The average usage was assumed for each end use. The hours per year in the "on" mode (t_{on}) was taken from published sources (Appendix A). The hours per year in the "standby" mode (t_{sb}) for most of the appliances was calculated as follows:

$$\mathbf{t_{sb} = 8760 - t_{on}} \qquad (4.2)$$

Number of appliances (stock)

Stocks represent all products possessed by consumers regardless of usage. Stocks are taken from previous work (Sanchez et al., 1997).

Limitation of the estimates of standby electricity consumption

The aggregate national energy losses are estimated. There are uncertainties both in measurements of individual appliances and in extrapolation to the whole nation. Uncertainties could be attributed to:

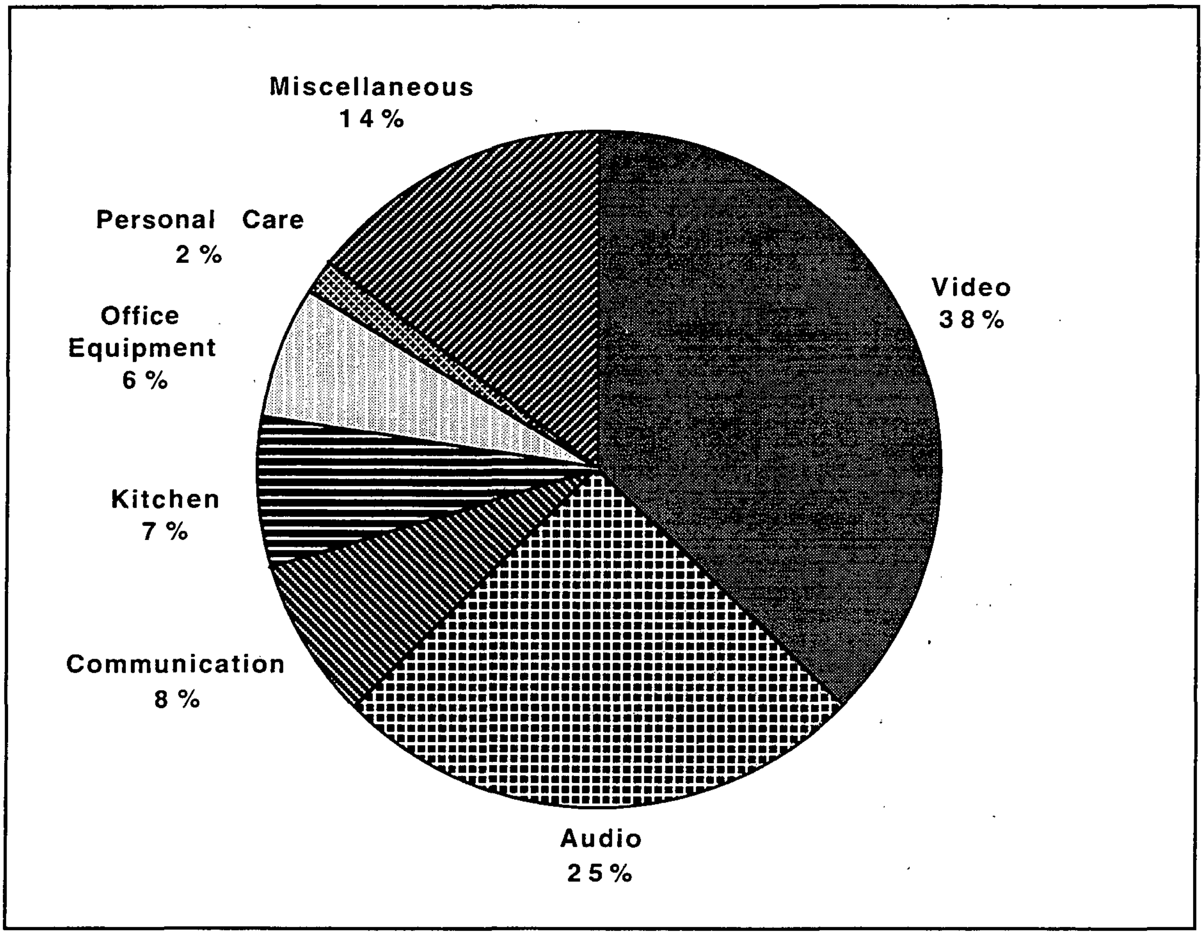
- meter inaccuracy
- choice of the metered appliances
- usage assumptions
- data on stock or saturation of appliances

With the methodology used in this report, estimates of the magnitude of leaking electricity are limited to appliances for which data are available. The estimate of the average standby power consumption per household will increase if more leaking appliances are identified and added to the established database.

4.2 Overview

Leaking electricity can be classified into six different categories. Figure 4-1 shows the percent of leaking electricity per category.

Figure 4-1 Leaking Electricity per Category



A total of 35 different end uses are investigated. Table 4-1 shows an overview of the metered end uses, their category, the average standby energy consumption, and the total standby energy consumption per end use category in the U.S. A detailed list of the assumptions for the usage and the source of the data is in Appendix A.

Table 4-1 Leaking Electricity Overview

End Use Name	Category	Average Standby Pwr (W)	Sb Energy Consumption (TWh/yr)	SEC per Category (TWh/yr)
Color TV	Video	4.0	5.44	16.3
Video Cassette Recorder	Video	5.6	4.85	
Cable Box	Video	11.6	3.69	
Video Game System	Video	2.0	1.07	
Satellite Earth Station	Video	14.9	0.57	
TV/VCR Combo	Video	9.8	0.56	
Projection Color TV	Video	2.2	0.07	
Digital Video Disc	Video	4.4	0.05	
Compact Audio System	Audio	10.6	4.73	11.1
Rack Audio System	Audio	7.0	3.21	
Clockradio	Audio	2.0	1.77	
Boom Box	Audio	2.2	1.34	
Answering Machine	Communication	3.3	1.92	3.4
Cordless Phone	Communication	2.8	1.49	
Microwave	Kitchen	3.1	2.11	3.2
Oven	Kitchen	2.5	1.06	
Computers	Office Equipment	65	1.46	2.8
Laser Printer	Office Equipment	80	0.55	
Printer	Office Equipment	15	0.21	
Modem	Office Equipment	1.4	0.20	
Copiers	Office Equipment	10	0.14	
Multifunctional Device	Office Equipment	4.7	0.12	
Fax Machine	Office Equipment	30	0.09	
Men's Shaver	Personal Care	1.4	0.46	0.8
Electric Toothbrush	Personal Care	2.3	0.23	
Women's Shaver	Personal Care	1.4	0.13	
Battery Charger	Miscellaneous	2.4	2.05	6.3
Doorbell	Miscellaneous	2.0	1.20	
Security System	Miscellaneous	12	0.88	
Garage Door Opener	Miscellaneous	4.0	0.80	
Timer	Miscellaneous	2.1	0.45	
Hand-Held Rechargeable	Miscellaneous	1.8	0.34	
Power Strip	Miscellaneous	0.3	0.26	
Halogen Lights	Miscellaneous	0.5	0.17	
Electric Lawn Mower	Miscellaneous	2.2	0.14	
			total:	44

The standby electricity consumption of 44 TWh per year represents approximately 5% of the total residential electricity use in the U.S. (EIA, 1996).

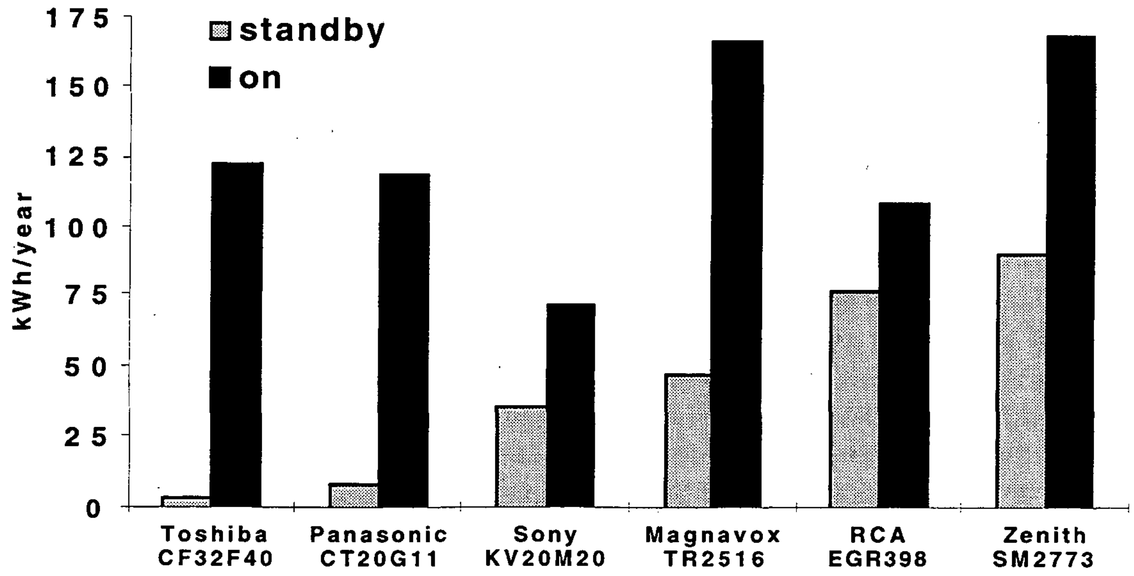
4.3 Analysis of the Metered Data

This section analyzes the national energy consumption and historic shipments of the four largest leaking end uses. In addition, the national impact of the energy consumption of satellite systems and electronic program guides (EPGs) are presented as examples of future technologies and potentially big leakers.

4.3.1 Televisions

Leaking 5.4 TWh per year, TVs are the biggest leaking end use. There are approximately 186 million televisions in the U.S., or 1.9 TVs per household. Figure 4-2 compares the leaking electricity in the standby mode with the electricity consumption in the on mode of the TVs from table 3-2.

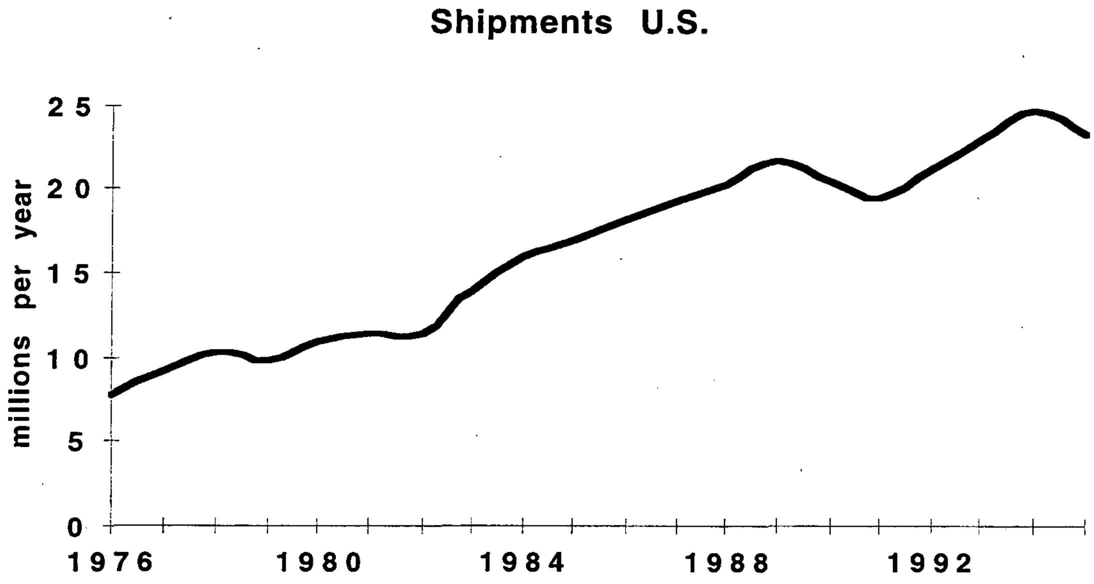
Figure 4-2 TV Energy Consumption in the Standby and On Mode



The average TV operates 4 hours per day in the on mode and 20 hours per day in the standby mode (Webber, 1997). Energy consumption in the standby mode ranges from 3.7 to 90 kWh annually per TV. In the on mode the energy consumption ranges from 71 to 167 kWh per year.

The number of shipments from 1976 to 1995 are in Figure 4-3. Shipments per year increased since 1976 from 8 to 23 million per year in 1995. Eighty percent of the shipped units are used in the residential sector.

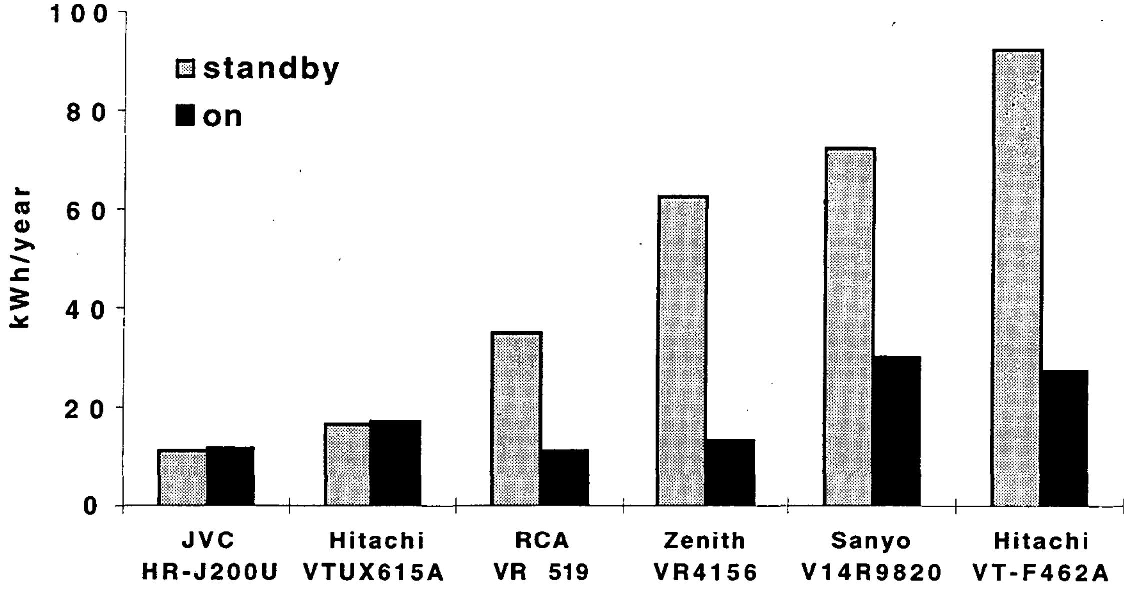
Figure 4-3 TV Shipments from 1976 to 1995



4.3.2 Video Cassette Recorders

The second largest leaking appliances are VCRs with 4.8 TWh per year. There are approximately 120 million VCRs in the U.S. The VCRs operate an average of 4 hours per day in the on mode and 20 hours per day in the standby mode (Webber, 1997). Figure 4-4 shows energy consumption per year of the VCRs in table 3-3.

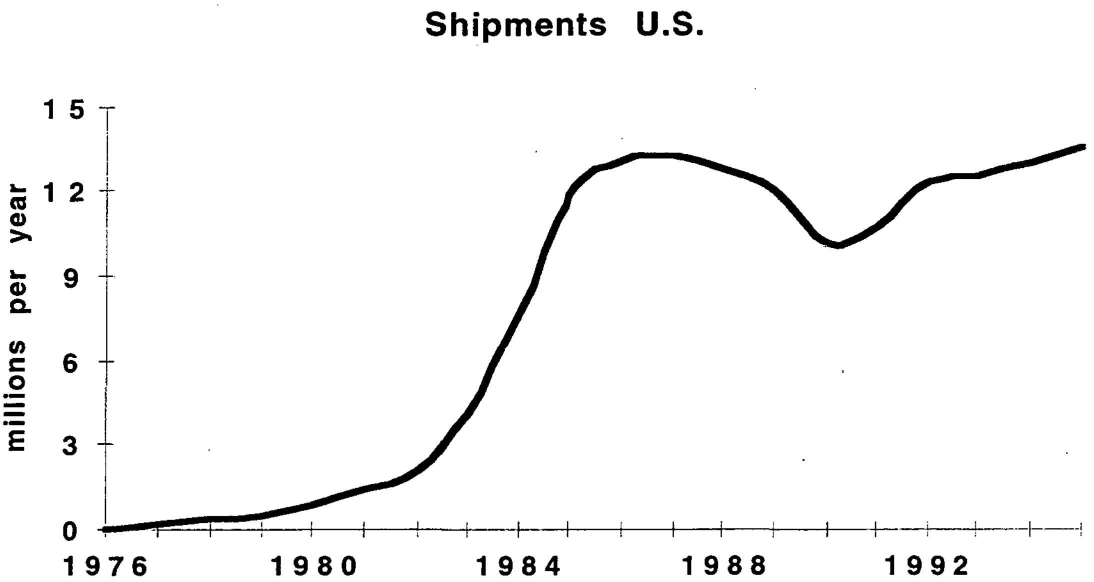
Figure 4-4 VCR Energy Consumption in the Standby and On Mode



Energy consumption can be up to three times higher in the standby mode than in the on mode. Energy consumption ranges from 11 to 93 kWh per year for the standby mode and from 12 to 31 kWh per year in the on mode.

There are an average of 1.2 VCRs per household in the U.S. Figure 4-5 shows the historic shipments of VCRs from 1976 to 1995. About 90% of all shipped units are used in the residential sector.

Figure 4-5 VCR Shipments from 1976 to 1995



In 1976, 43,000 units were shipped. This number remained low until 1981 when 1.4 million units were shipped. Sales increased from 1982 to 1985 from 2 to 12 million per year. Since that time shipments were almost stable and reached 13.6 million units per year in 1995.

4.3.3 Compact Audio Systems

Nationally, compact audio systems leak about 4.7 TWh per year, making them the third biggest leaker in the US. The average time in the on mode is one hour per day. These appliances leak approximately ten times more electricity in the standby mode than than they consume in the on mode. Some appliances leak more than 15 times as much in standby than while in the on mode. Figure 4-6 shows the energy consumption in the standby and on mode for the appliances described in table 3-4.

Figure 4-6 Compact Audio System Energy Consumption in the Standby and On Mode

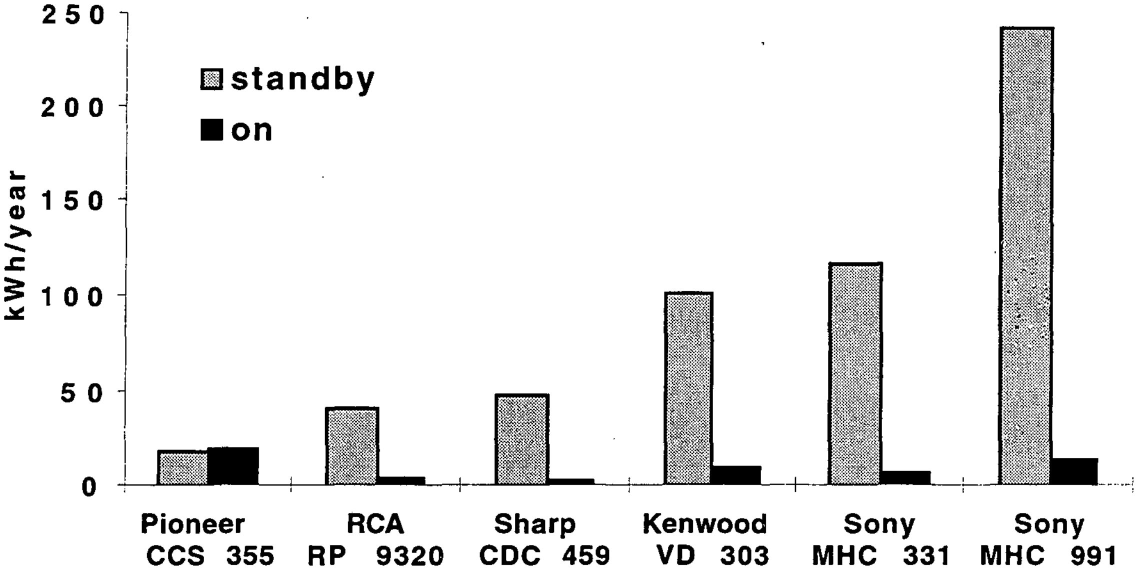
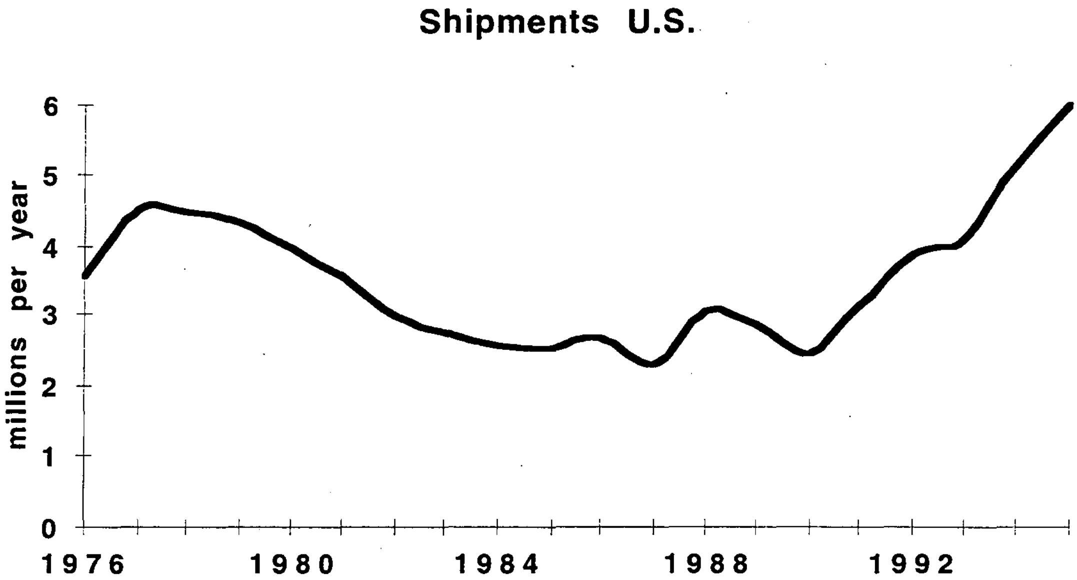


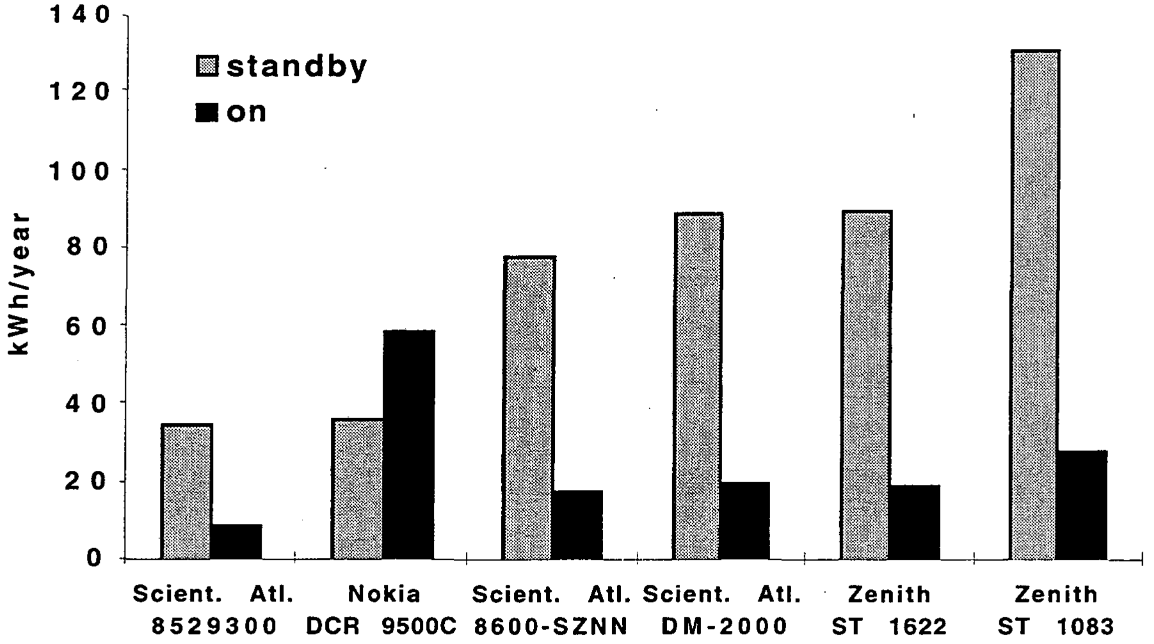
Figure 4-7 Compact Audio System Shipments from 1976 to 1995



4.3.4 Cable Boxes

The fourth largest consumer of standby energy are cable boxes with 3.7 TWh per year. Figure 4-8 compares the electricity consumption in the standby and on mode for the units described in table 3-5. The energy consumption per year for most cable boxes is five times higher in the standby mode than in the on mode assuming an average usage time of 4 hours per day (Webber, 1997). The high electricity consumption in the on mode of the Nokia DCR 9500 C is caused by the fact that this multimedia box can process information transmitted via telephone line, satellite, and cable. To provide this service different receiver units have to be powered.

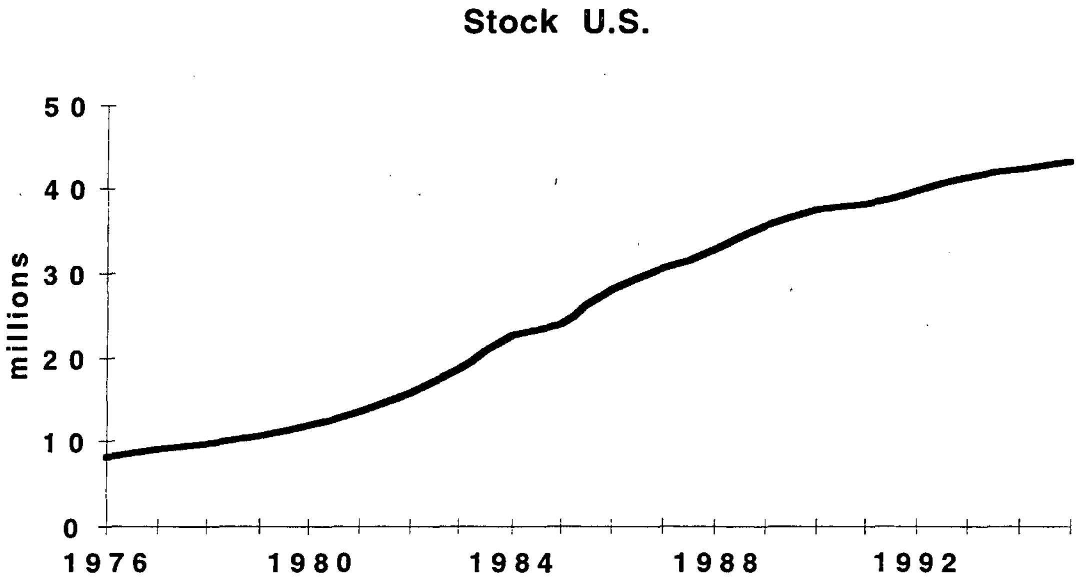
Figure 4-8 Cable Box Energy Consumption in the Standby and On Mode



The stock of cable boxes is approximately 45 million units. Most of them are cable television boxes, but in the future there will be more multimedia boxes and digital music boxes.

Seventy-five percent of all cable television subscribers have a cable box. Even though an increasing fraction of televisions are manufactured "cable ready," the number of cable boxes is unlikely to decline. Cable companies use the boxes to store credits for pay-per-view programs. Access to the internet via cable is a future application of cable boxes. Shipment data are presented in figure 4-9.

Figure 4-9 Stock of Cable Boxes from 1976 to 1995*



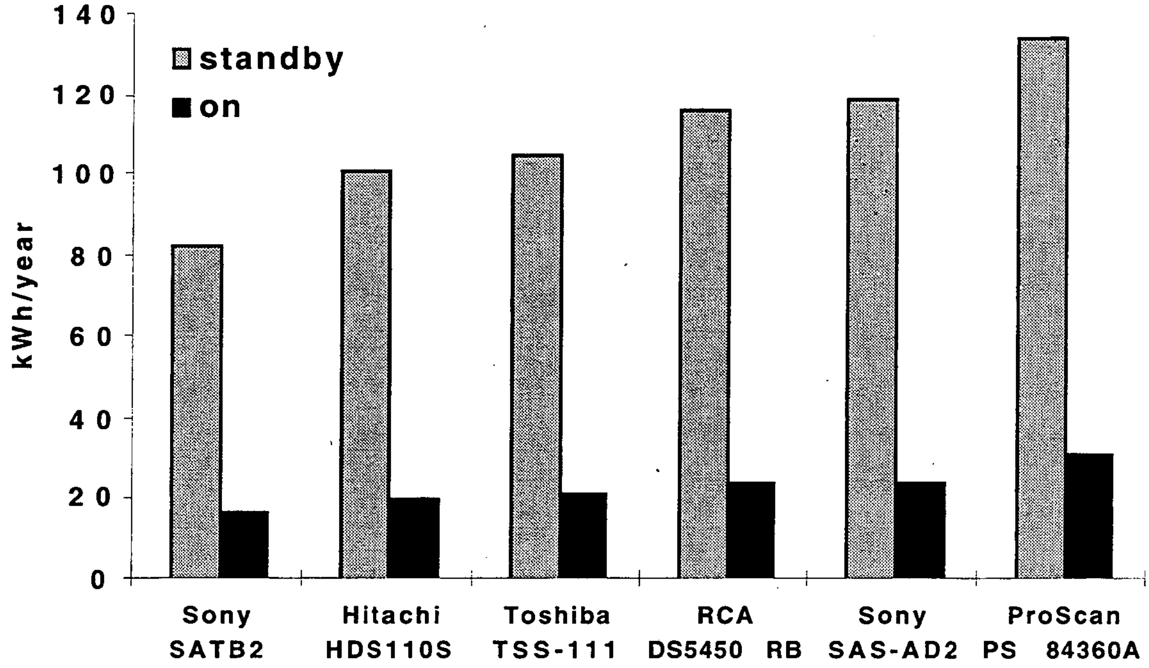
These data were calculated because shipment data for cable boxes were not available.

4.3.5 Satellite Receiver Systems

The rankings of leaking appliances presented in Table 4-1 are rapidly changing as the leakage rates in some appliances are reduced and as new appliances suddenly appear. One leaking appliance with accelerating sales in the U.S are satellite receiver boxes.

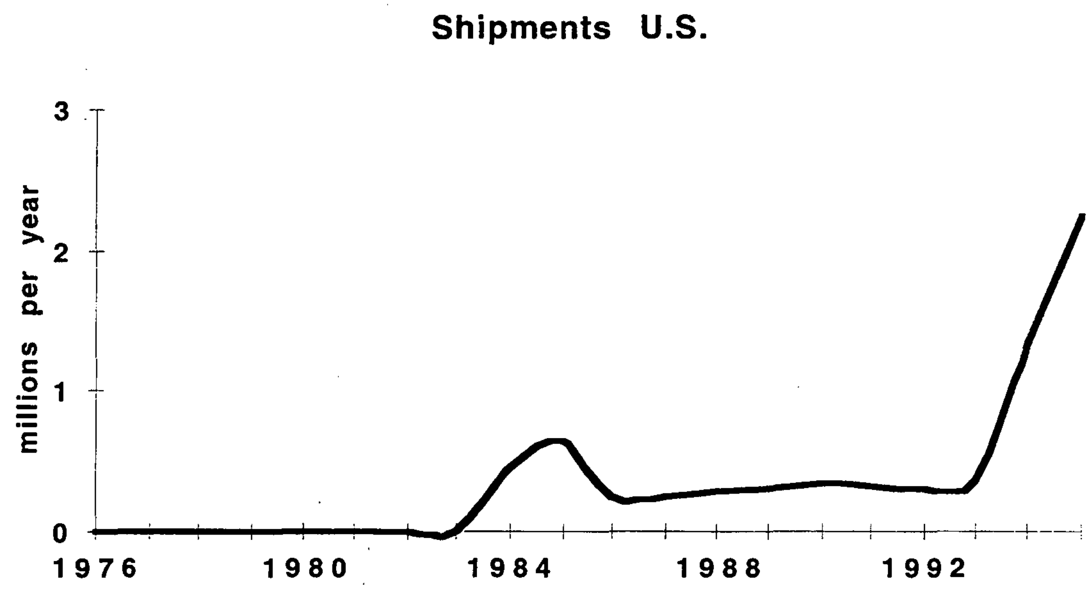
The electricity consumption per year is in this case five times higher in the standby mode than in the on mode, assuming 4 hours per day in the on mode. Figure 4-10 shows the energy consumption in the standby and on mode for digital satellite systems.

Figure 4-10 Satellite System Energy Consumption in the Standby and On Mode



Sales of this appliance type started in 1984 with 450,000 units. After a peak in 1985 with 630,000 units, shipments remained low until 1993. Since 1994 and the rise of digital technology, satellite systems have become one of the fastest growing end uses and may become one of the major leaking appliances in the future. Figure 4-11 shows the shipment data from 1976 to 1995.

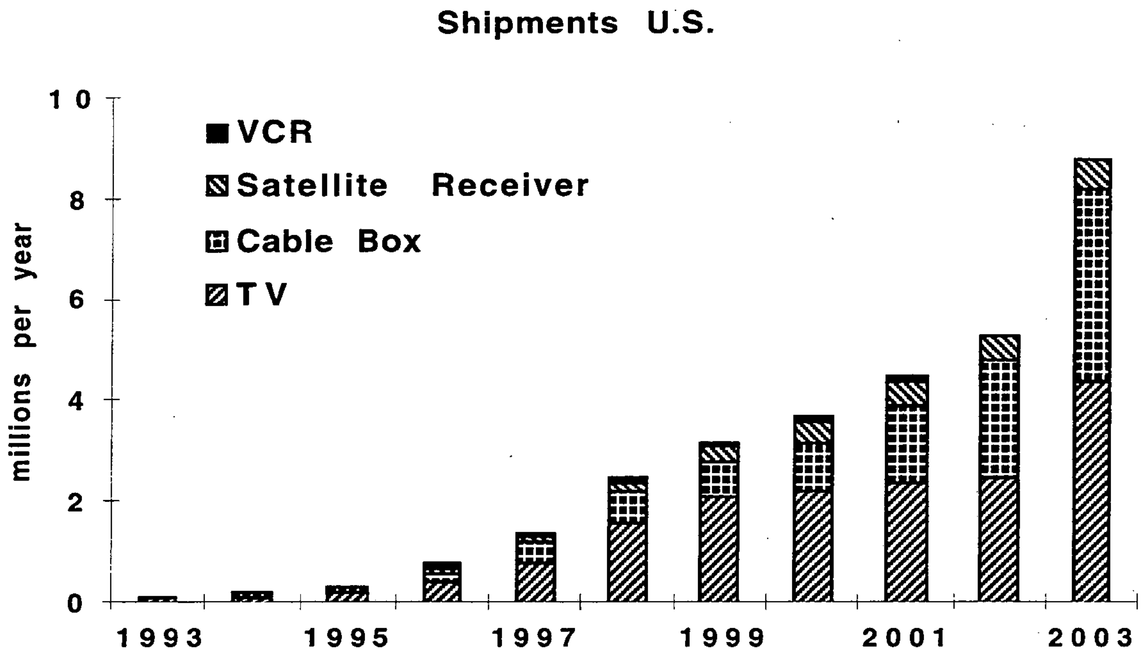
Figure 4-11 Satellite System Shipments from 1976 to 1995



4.3.6 Electronic Program Guides

Electronic program guides (EPGs) will become more common as digital broadcast technology dramatically expands the number of TV channels available. Today, more than 150 channels can be received with a digital satellite system. Figure 4-12 presents historic shipment data and projected future shipments by appliance type. The numbers are from the manufacturer (Milnes, 1997).

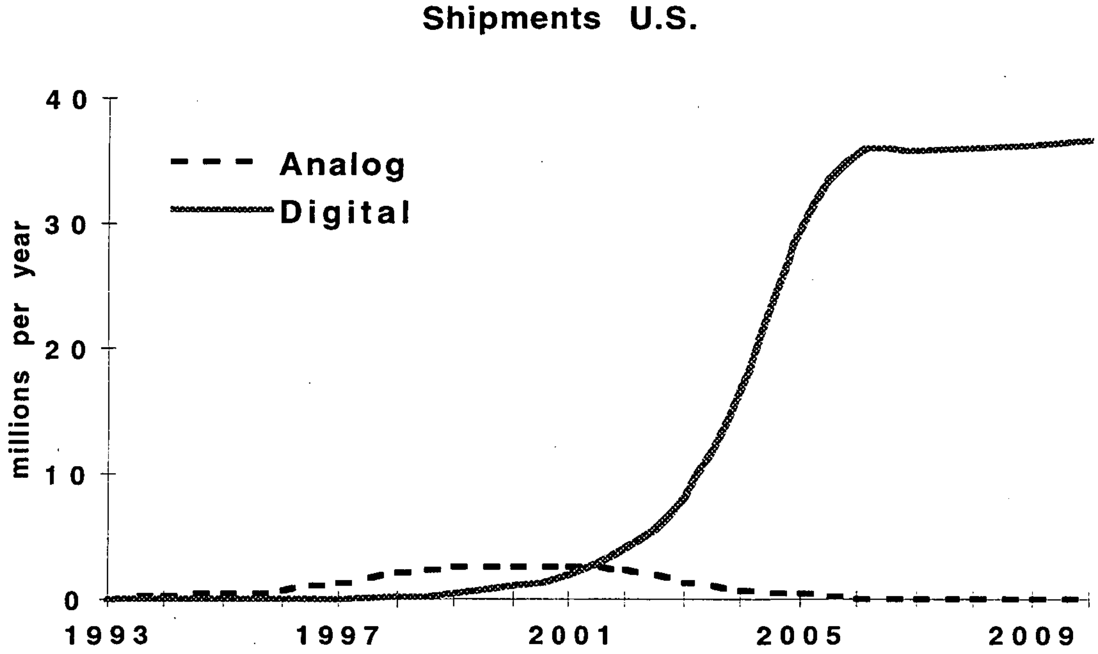
Figure 4-12 EPG Shipments by Device from 1993 to 2003



Source: StarSight, Inc.

According to the manufacturer, the penetration of EPGs will reach 100% in 15 years due to the dominance of digital. As noted in chapter 3, however, digital signals would also facilitate the delivery of program information. EPGs are already almost universal in existing digital systems (some satellite and cable systems). Figure 4-13 illustrates the expected growth of EPGs in the pre- and post-HDTV eras.

Figure 4-13 Total EPG Device Shipments



Source: StarSight, Inc.

Leaking electricity from EPGs may eventually disappear if analog devices are replaced with digital technology. However, the extent of the leaking electricity depends on the current growth of analog EPG devices. It will be at least ten years before analog is completely phased out, and devices sold during that time could remain in use for longer. If analog EPGs achieve a significant market penetration before HDTV become standard, aggregate standby losses could be quite high.

5. Power Consumption and Power Quality of Low Voltage Power Supplies

Different technical options to reduce leaking electricity have been proposed in several reports (Molinder, 1997; Stiles et al., 1997). One option is to improve the efficiency of low-voltage power supplies. Manufacturers of switch mode power supplies (SMPSs) claim that their products have an efficiency of up to 90% (Power Integrations, 1997). While SMPSs appear to be the perfect solution, these power supplies create more harmonic currents. This degradation in "power quality" causes additional losses in high-voltage transformers and in the transmission and distribution systems. The issue of power quality is often neglected due to its complexity. Simple measurements of power consumption are not sufficient to determine how much electricity an appliance "really" consumes. Test procedures should incorporate power quality issues.

In this chapter, a case is investigated in which an SMPS directly replaces a linear power supply. Both power supplies were monitored in the unloaded and in the standby mode. The power consumption and quality can be reasonably compared because the remainder of the appliance was not modified in any other way. Both power supplies were monitored in the unloaded and in the standby mode.

5.1 Background

Power quality first emerged as an important issue in industrial and manufacturing facilities. Voltage sags created by faults on the power system, transient overvoltage caused by the switching of the utility's capacitor banks, and harmonic currents drawn from the power system by non-linear loads are responsible for the malfunction of production facilities. Tiny power disturbances can wreak havoc with increasingly complicated, computerized machinery found along assembly lines. They can cause computer crashes and data scrambles. The costs associated with such work stoppages can cost a company up to $500,000 per hour, and power-related problems may cost U.S. companies $25 billion per year (de Almeida, 1993).

Currently much of the work on harmonic problems is concentrated around high-voltage power systems such as transmission networks, where harmonics cause many problems including overheating, additional losses, and unreliable system performance. However, there are similar problems in low-voltage level circuits, such as building distribution systems (120V, etc.), telephone lines, or other communication circuits. By the year 2005, non-linear electronic loads may account for 1/3 of the U.S. electrical demand, and much of that growth will occur in the residential sector. Household appliances that were once simple electro-mechanical devices—such as furnaces, air conditioners, and heat pumps—are becoming electronic, and even electronic fluorescent ballasts for lighting are becoming more common. At the same time, there are an increasing number of devices sensitive to power distortion, such as video recorders, personal computers, microwave ovens, and digital clocks. In general, more sophisticated equipment tend to be more sensitive to variations in power quality.

A common source of harmonic currents in power systems is electronic equipment that uses a rectifier, high-frequency switching transistor, and transformer supplying a DC-link with storage or ripple-smoothing capacitor. This type of electronic power supply is used in everything from factory adjustable-speed drives to personal computers and home electronics. These SMPSs are increasing in popularity. This technology now competes in price with linear power supplies in almost all power ranges (from 5W up). Due to their smaller size, lighter weight, and higher efficiency they are replacing linear transformers. There are approximately 400 million so-called "wallpacks" (small AC/DC power supplies with transformers that plug directly into the outlet) currently in the U.S. To understand better the concept of power quality a few definitions are introduced.

5.2 Definitions

5.2.1 Power Quality

Power quality is affected from both sides of the meter, by the quality and reliability of the power supply and by the type of customer loads. While a power supply is generally regular and reliable, it can be interrupted by storms and overloads. Conversely, an ideal load—with a power factor of 1 and no harmonic distortion—draws power that matches the sinusoidal voltage and current waveforms as supplied by the utility, while loads that deviate from that waveform increase current and decrease efficiency in the transmission and distribution system. Deviations from the regular sinusoidal wave, both on the utility side and on the customer side, result in poor power quality.

5.2.2 Harmonics

Harmonics are a distortion of the utility-supplied waveform and are caused by non-linear (distorted) loads, which include many motor controls, computers, office equipment, compact fluorescent lamps, light dimmers, televisions, and most electronic loads in general. High harmonics increase line losses and decrease equipment lifetime. There are two different definitions of the Total Harmonic Distortion (THD). The more common definition in the U.S. (IEEE) is THD-F, the amount of harmonic distortion as a percentage of the waveform at the fundamental frequency.

$$THD-F=\frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_F} \tag{5.1}$$

where h is the order of the harmonic (2 = 120 Hz, etc.)

In Europe (IEC), the THD-R defines the amount of harmonic distortion as a percentage of the root-mean-square (RMS) value of waveforms at all frequencies (fundamental and harmonics).

$$THD-R=\frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_{RMS}} \tag{5.2}$$

Because of their different definitions, values for THD-F and THD-R cannot be directly compared. THD-F values greater than 100% are common, while THD-R values greater than 100% are not possible.

5.2.3 Power Factor

Power factor (PF) is a measure of how the current is being used to transmit power. Power factor is a number between zero and 1, with 1 indicating perfect power factor. For example, electric resistance heaters and incandescent bulbs have a perfect power factor of 1, while newer electronic equipment, like electronically ballasted compact fluorescent lamps, have lower power factors. When a load draws current that is not "in phase" with the voltage waveform, or draws a current that differs from the sinusoidal waveform provided by the utility, the power factor is less than 1. Poor power factor causes inefficiency in the delivery of electricity to the end-user, requiring more energy to compensate for losses on the line. For example, a load with a power factor of 0.5 will require twice as much current as a load with a power factor of 1 for the same amount of usable power. The definition of the power factor is the ratio of active (or "real") power to apparent power (including all harmonics).

$$PF = \frac{P_{active}}{P_{apparent}} \tag{5.3}$$

Another related definition is the Displacement Power Factor (DPF). DPF is the ratio of active power to the apparent power at the fundamental frequency, which is equivalent to cos (φ), where φ is the displacement angle between the two waveforms at that frequency.

5.2.4 Crest Factor

The crest factor is the ratio of the waveform's peak value to its RMS value. A high crest factor indicates a highly distorted waveform rich in harmonic currents.

5.3 Results

5.3.1 Metered Appliances

Iomega Corporation replaced the linear power supply in its Zip drives with an SMPS because the SMPS can function with voltage levels used in most countries. There was no price difference and lower weight, smaller size, and higher efficiency were secondary reasons. The meter and the test setup are described in Appendix C. Table 5-1 shows a comparison of the two power supplies.

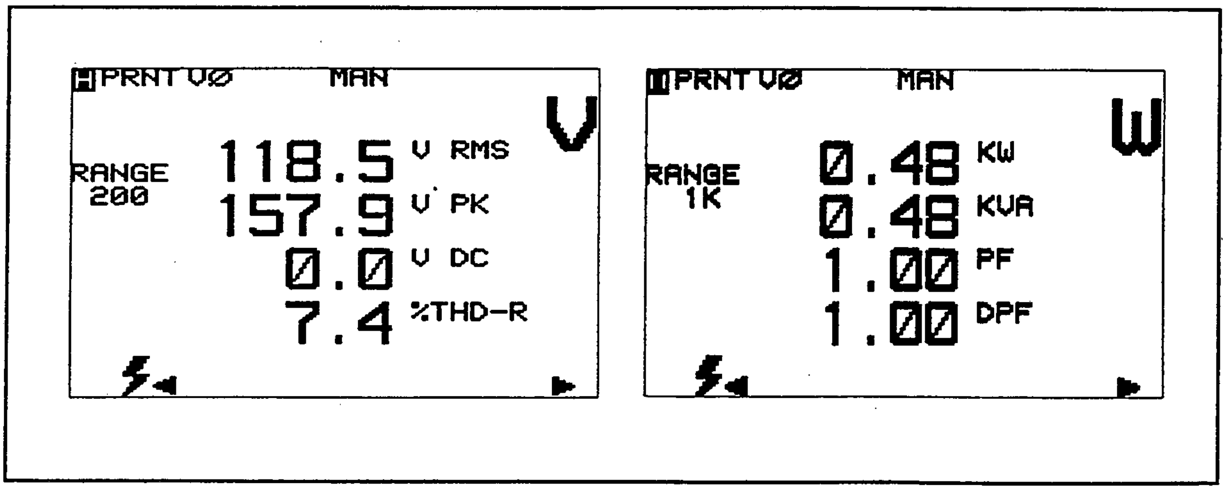
Table 5-1 Tested Power Supplies

Rated Data	**Linear Transformer**	**Switch Mode Power Supply**
Model	ITE Power Supply NO: 02477800	AP05Z-US
Input	120 V AC 60 Hz 13 W	100-240 V AC 50/60 Hz 8 W
Output	5 V 1 A DC	5.0 V 1.0 A DC

5.3.2 Power Source

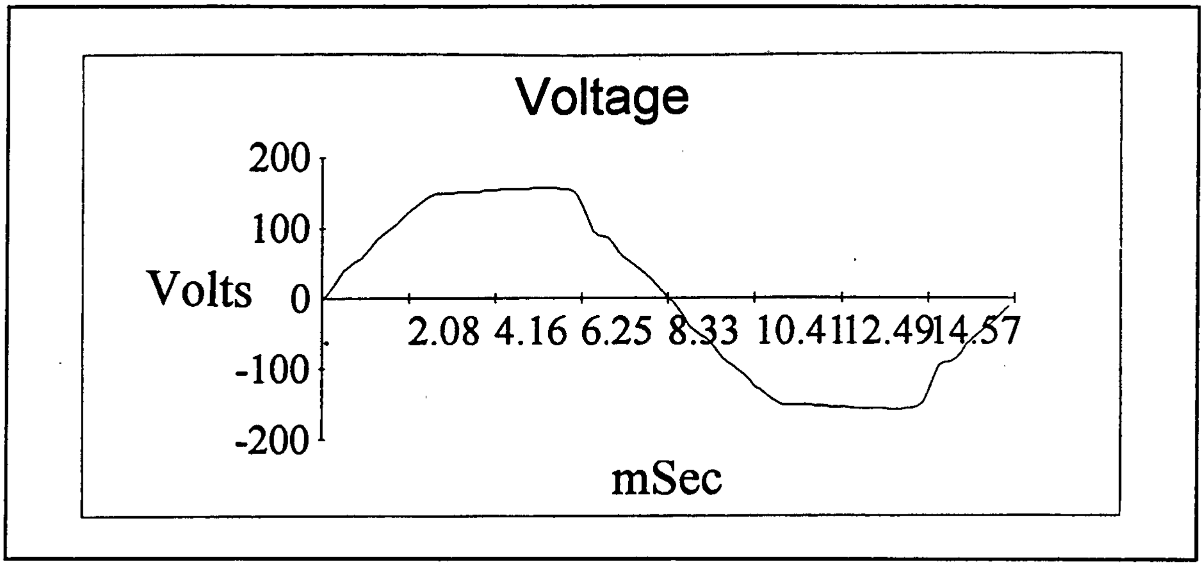
To test the harmonic distortion of the voltage waveform, a linear load (incandescent light bulb) was connected to the power source. Figure 5-1 shows the meter's display for the voltage and power measurements.

Figure 5-1 Voltage and Power Consumption for a Resistive Linear Load



The power factor and the displacement power factor are 1. This indicates a purely resistive linear load. The indicated data for the power and KVA should be divided by ten because of the modified measurement setup (Appendix C). The load was a light bulb consuming 48 watts. Figure 5-2 shows the distorted waveform as supplied by the utility.

Figure 5-2 Voltage Waveform



5.3.3 Linear Power Supply without Load

Figure 5-3 Linear Power Supply without Load

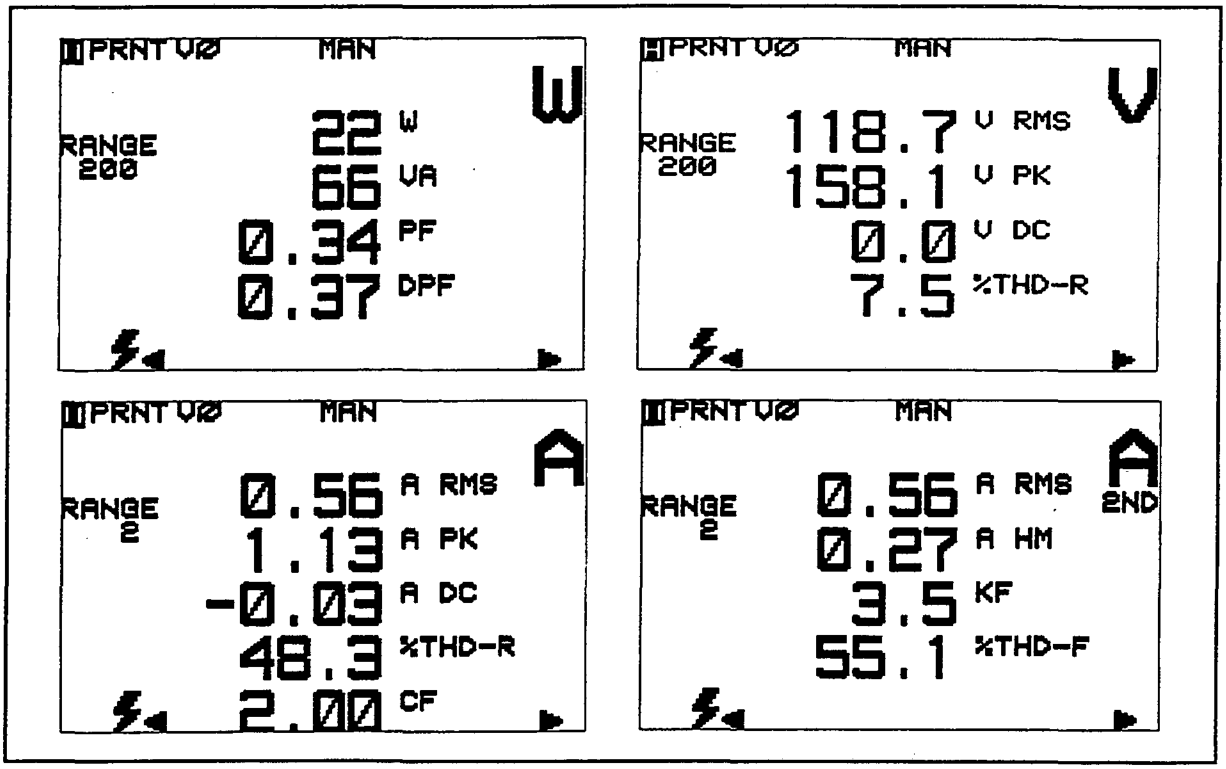
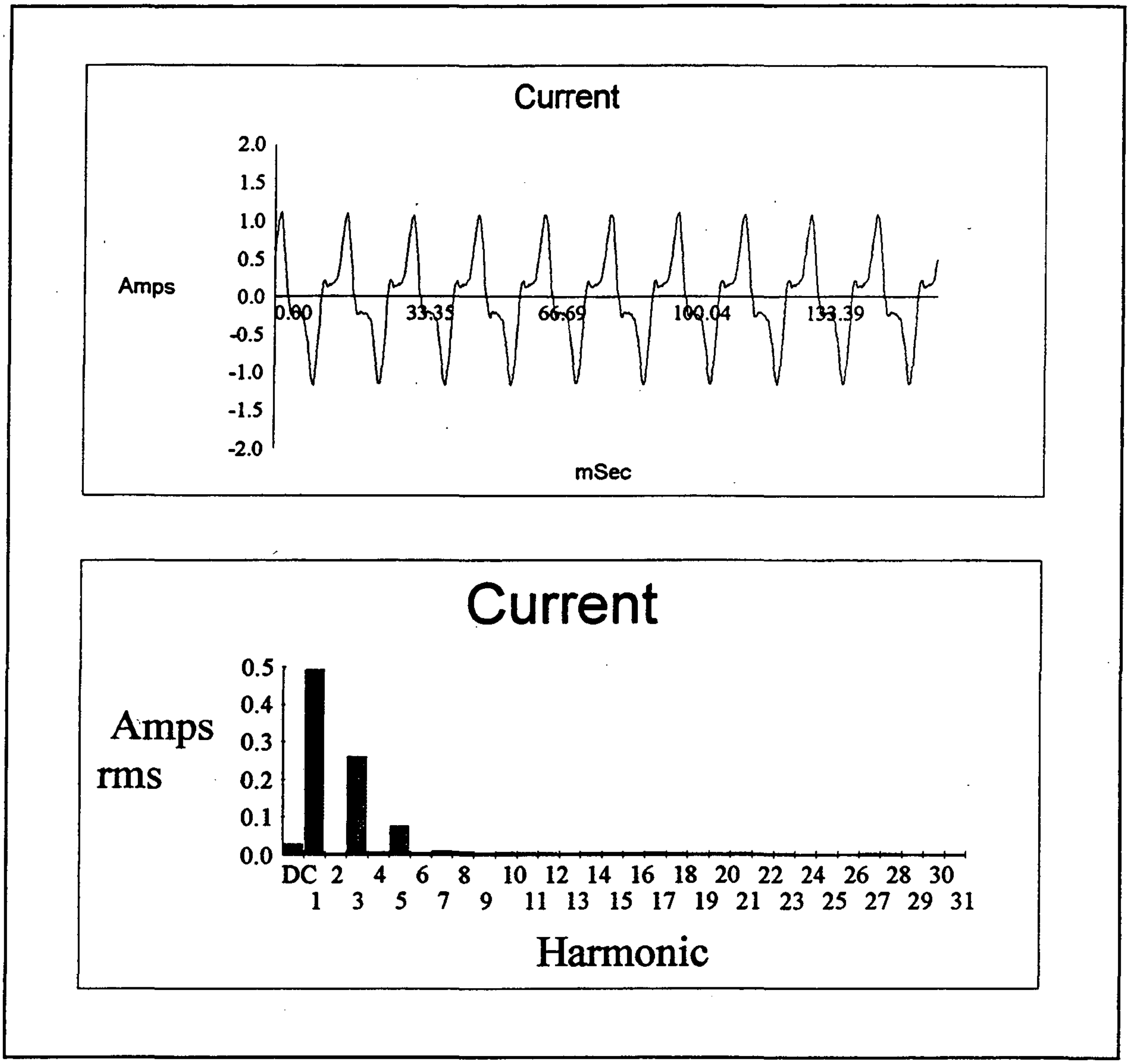


Figure 5-3 shows the metered data of the voltage, current, and power consumption of the linear power supply without load. The linear power supply uses 2.2 watts even when it is not connected to the appliance. The power factor, the ratio of real power to apparent power, is 0.34. The current waveform and the current harmonics are shown in figure 5-4. The current waveform is distorted and the 3rd and 5th harmonic have significant amplitudes. The THD-R is 48.3% and the crest factor is 2.0.

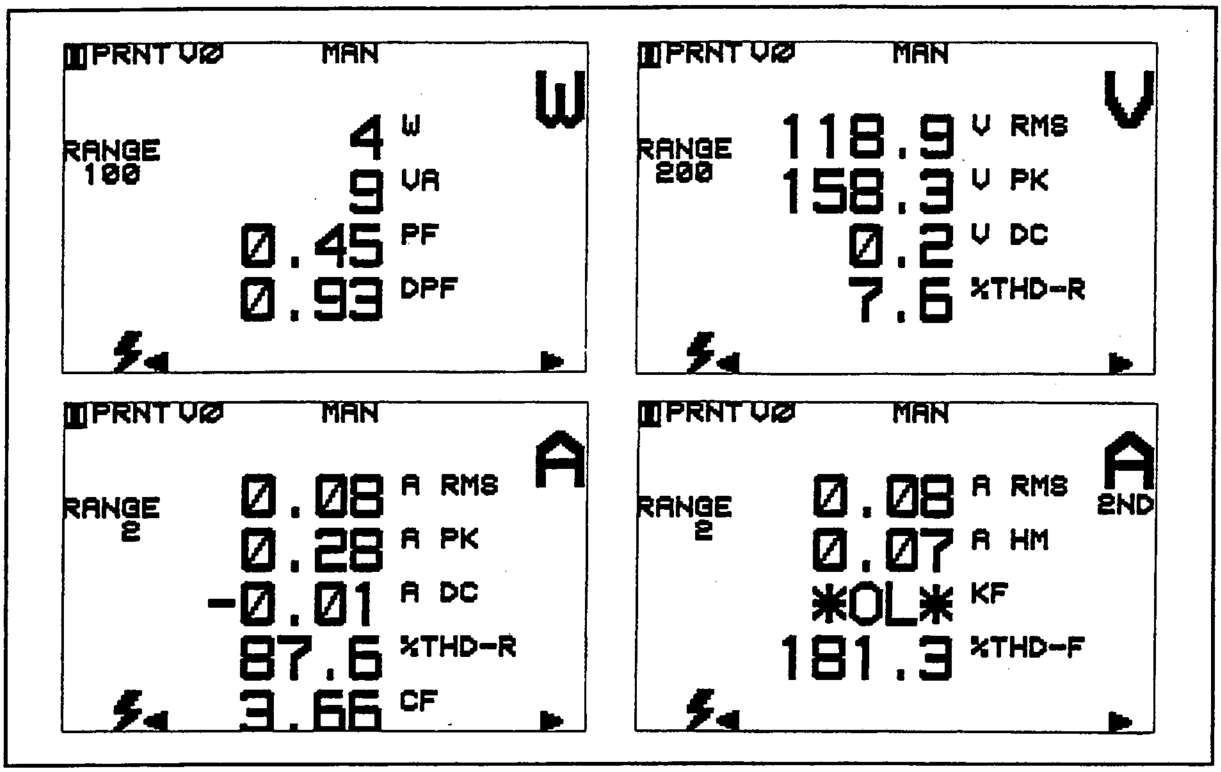
Figure 5-4 Current Waveform and Harmonics of Linear Power Supply without Load



5.3.4 Switch Mode Power Supply without Load

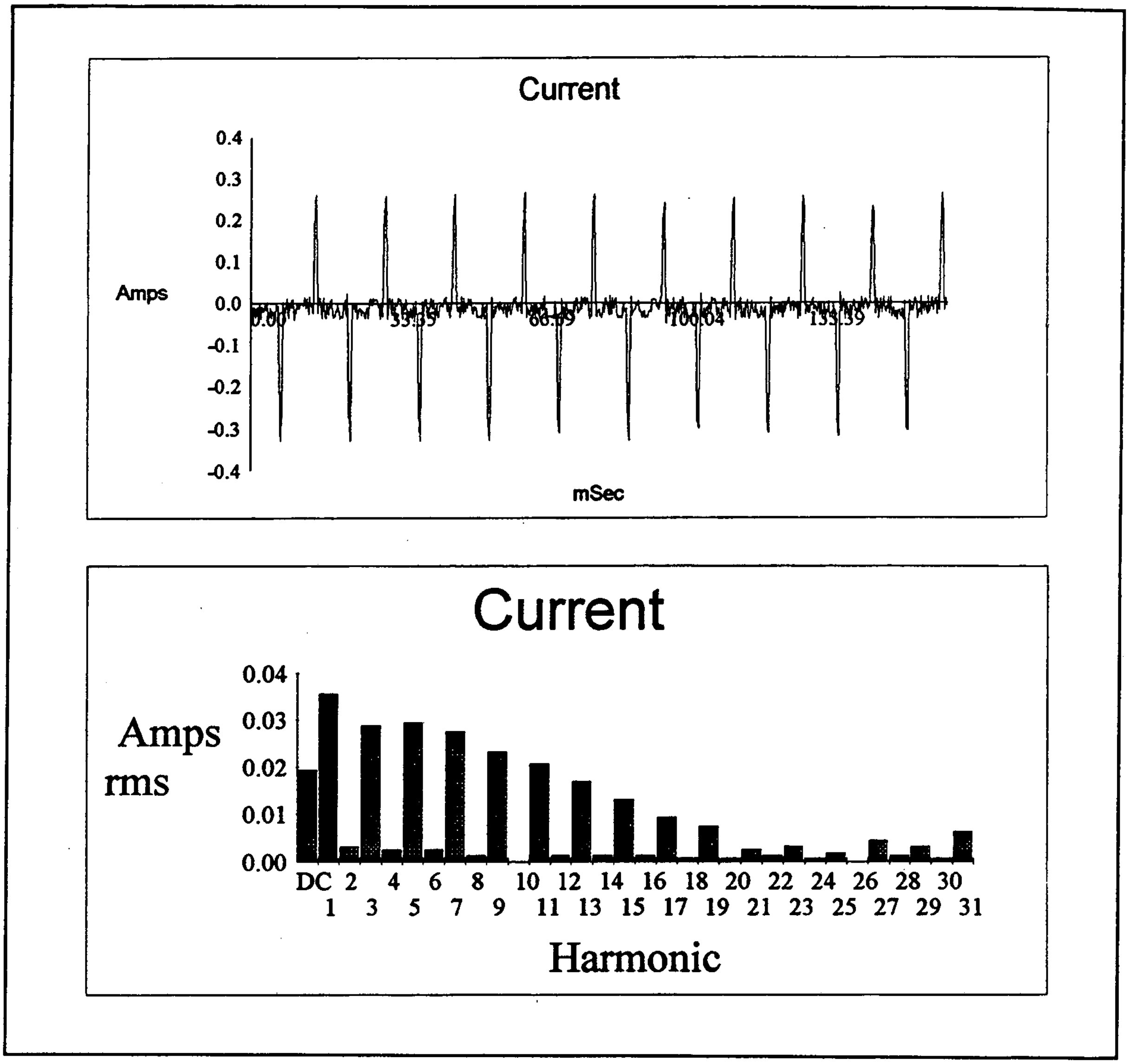
The linear power supply was replaced by a SMPS. Figure 5-5 shows the metered data of the voltage, current, and wattage of the SMPS in the unloaded case (not connected to the appliance).

Figure 5-5 SMPS without Load



The SMPS uses 0.4 watts, which is less than 1/5 of the power consumed by the transformer-based unit in the no-load case. The power factor at 0.45 is only slightly higher than that of the linear power supply. The THD-R at 87.6% is much higher for the SMPS than that of the linear transformer. The high THD and a high crest factor of 3.66 indicates that there are additional losses in the distribution system due to harmonic currents. Figure 5-6 shows the current waveform and harmonics. The odd numbers of harmonics up to the 31st have significant amplitudes.

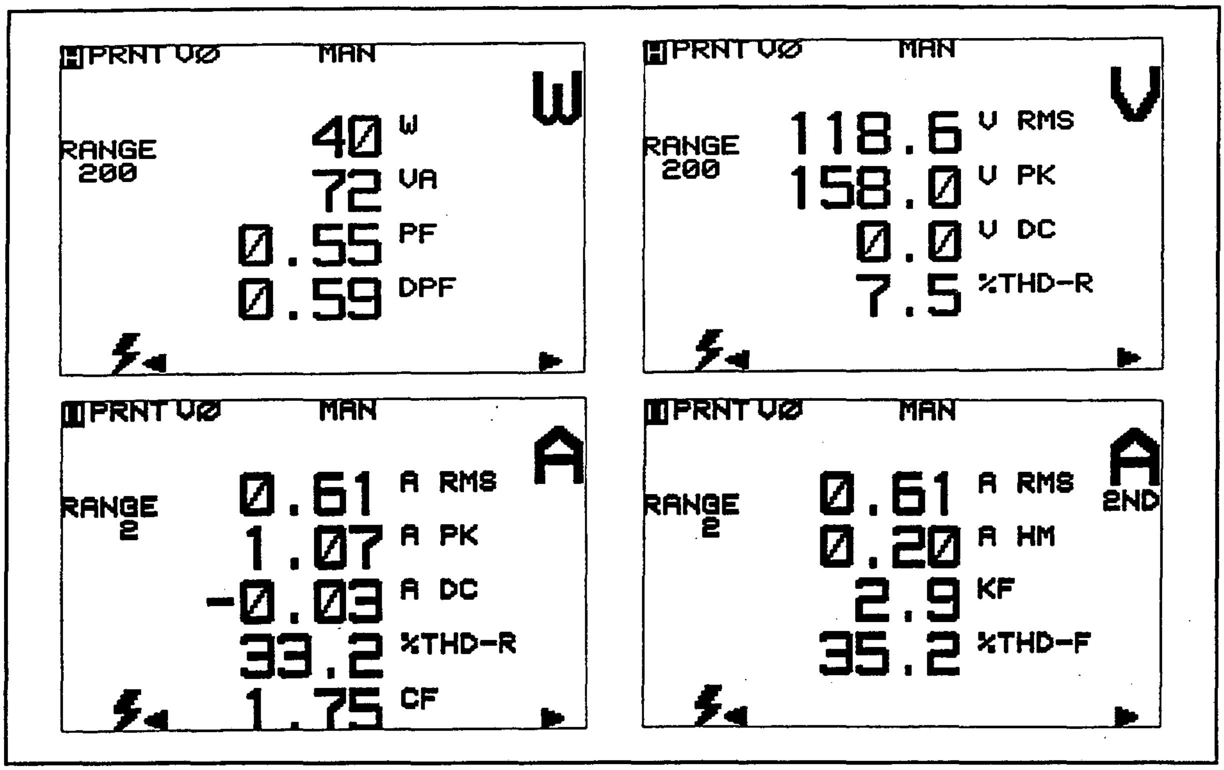
Figure 5-6 Current Waveform and Harmonics of SMPS without Load



5.3.5 Linear Power Supply with Iomega Zip Drive

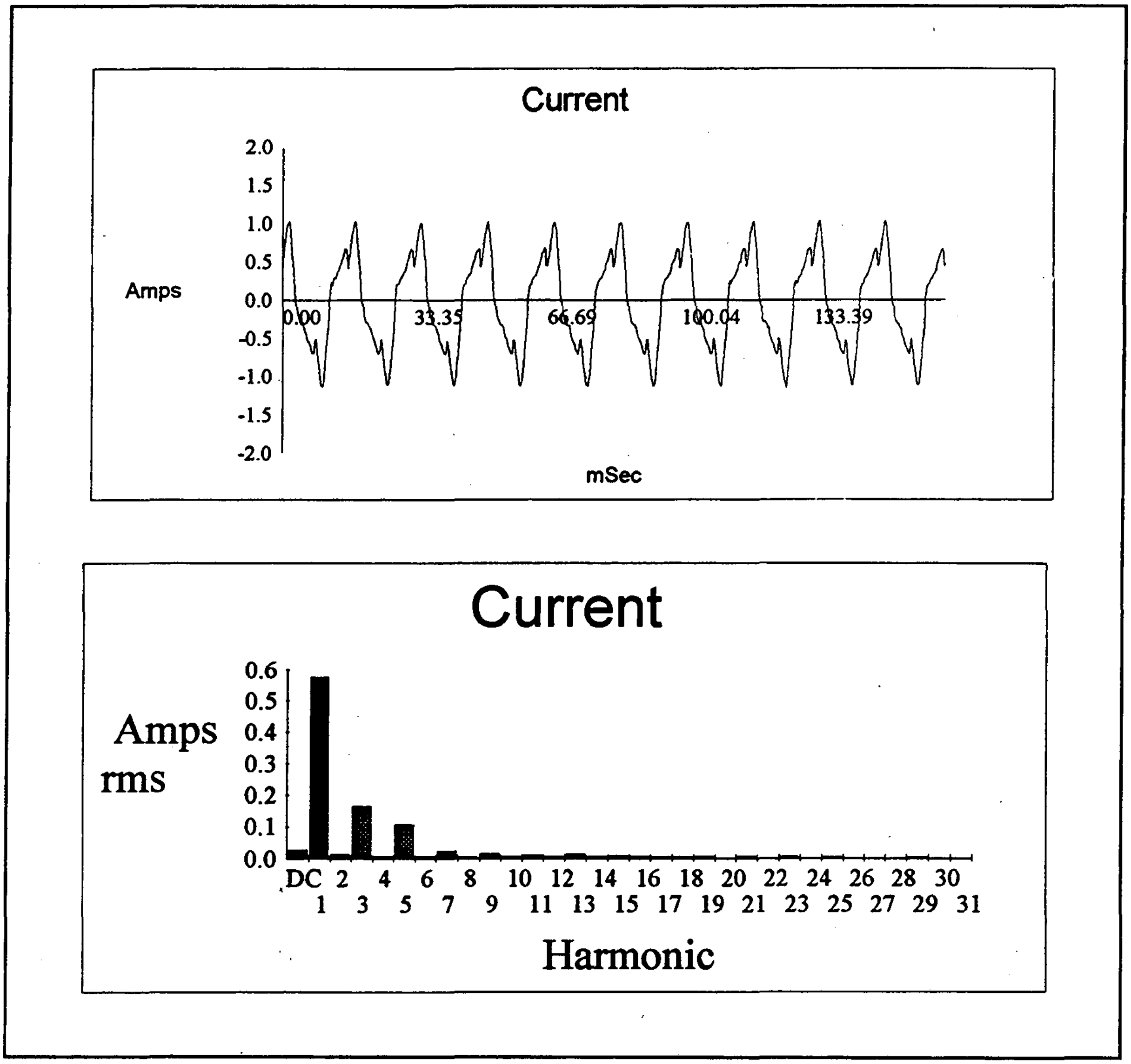
In this case, the linear power supply is connected to the Iomega Zip drive. The Zip drive, having no off switch, is always in the standby mode when not in use. Figure 5-7 shows the metered voltage, current, and power of the linear power supply with the Zip drive in the standby mode.

Figure 5-7 Linear Power Supply with Zip Drive in the Standby Mode



With the linear transformer as its power supply, the Zip drive uses 4.0 watts in the standby mode. The power factor is 0.55 and the crest factor 1.75. Figure 5-8 shows the current waveform and harmonics. The THD-R is 33.2%. The 3rd and the 5th harmonic have significant amplitudes.

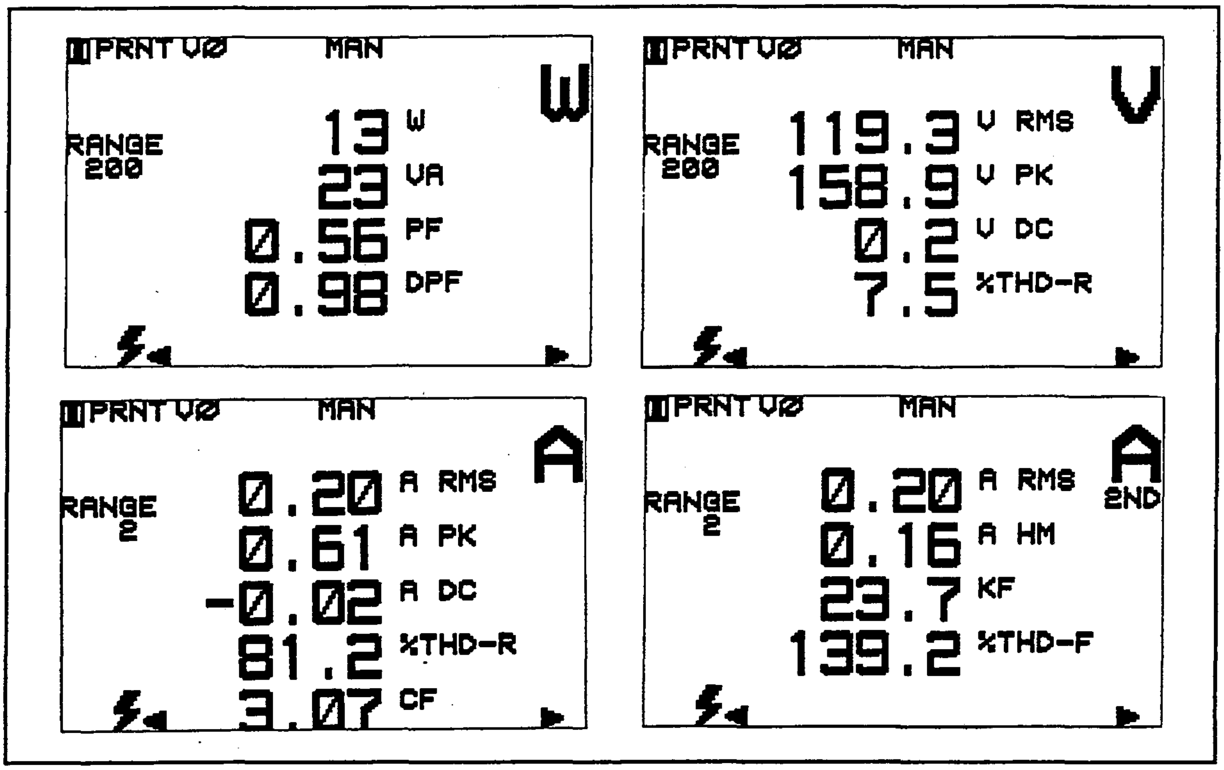
Figure 5-8 Current Waveform and Harmonics of Loaded Linear Power Supply



5.3.6 Switch Mode Power Supply with Iomega Zip Drive

Figure 5-9 shows the metered voltage, current, and power for the Iomega Zip drive in the standby mode with the SMPS.

Figure 5-9 SMPS with Zip Drive in the Standby Mode



```
PRNT V0        MAN
                      W
RANGE      13 W
200        23 VA
         0.56 PF
         0.98 DPF
```

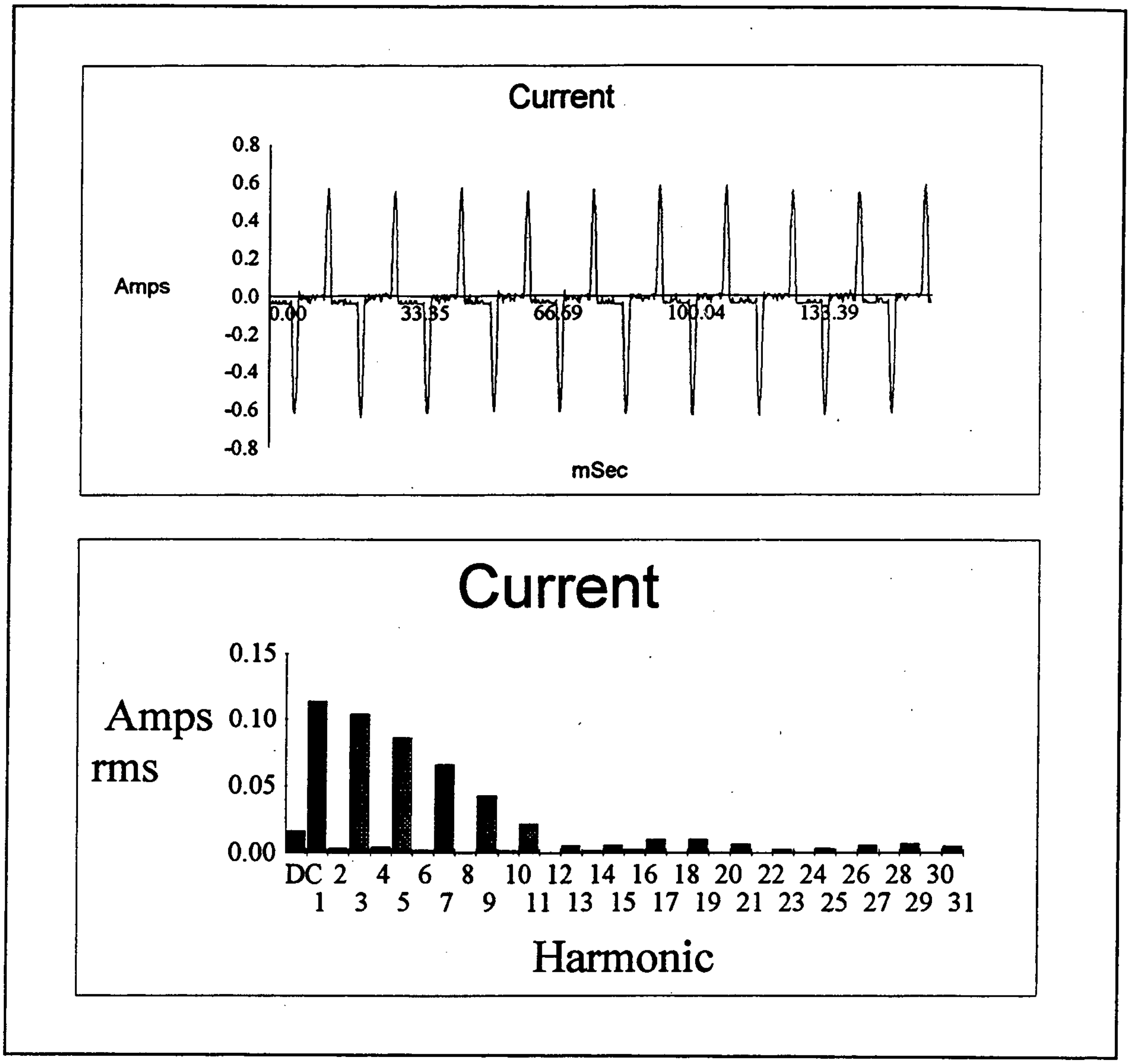
```
PRNT V0        MAN
                      V
RANGE   119.3 V RMS
200     158.9 V PK
          0.2 V DC
          7.5 %THD-R
```

```
PRNT V0        MAN
                      A
RANGE    0.20 A RMS
2        0.61 A PK
        -0.02 A DC
         81.2 %THD-R
         3.07 CF
```

```
PRNT V0        MAN
                      A
RANGE    0.20 A RMS  2ND
2        0.16 A HM
         23.7 KF
        139.2 %THD-F
```

In this case the Zip drive uses 1.3 watts in the standby mode. This is less than 1/3 of the energy consumed with a linear power supply. The power factor, at 0.56, is only slightly higher than the value for the linear transformer. A THD-R of 81.2% and a crest factor of 3.07 imply additional losses in the transmission and distribution system. Figure 5-10 shows the current waveform and harmonics of the Zip drive with the SMPS. There are significant amplitudes for the odd harmonics up to the 11th.

Figure 5-10 Current Waveform and Harmonics of SMPS



5.4 Discussion

The metered data show that the SMPS uses less electricity than the linear power supply in both the unloaded and the loaded cases. The power consumption in the unloaded case dropped from 2.2 to 0.4 watts and in the loaded case from 4.0 to 1.3 watts. The power factor is in the same range in both cases. The displacement power factor is actually much higher for the SMPS because almost all of the power is drawn at the peak of the voltage sine wave.

While the power range of the metered appliances is low, there are an estimated 400 million linear power supplies or "wallpacks" in the U.S. residential sector. These wallpacks are used in a variety of appliances, most of which may someday be upgraded to SMPSs. This chapter demonstrates that SMPSs leak 60 to 80% less electricity in the standby mode with no additional costs. However, SMPSs draw more power than indicated on simple wattmeters because SMPSs cause additional losses in the transformer and in the power grid.

Several solutions have been proposed to eliminate harmonic currents caused by SMPSs (Lai et al., 1991). Unfortunately, these solutions require additional components which increase cost and lower reliability. Future strict power quality regulation may make such modifications necessary. Furthermore, a recent paper (Key et al., 1996) concluded that these modifications would be cost-effective for appliances in office buildings based on energy losses alone. There are also other benefits, such as increased system reliability, fewer cases of overheated wiring, and the release of additional capacity of the power system to serve other loads.

For the residential sector, in which SMPSs are not yet concentrated, the gains in efficiency greatly exceed the costs of lower power quality. However, the increasing penetration into households of electronic devices with SMPSs may create a situation similar to that of office buildings.

6. Conservation Potential

The conservation potential for leaking electricity is large. Savings of 75% are realistic with today's technology. To achieve the maximum savings, policies must be created to provide incentives for further research, development, and implementation of efficient technology. The comparison of appliances in chapter 4 shows saving potentials presently achievable. In this chapter the technical potential is analyzed and possible design options and ideas are presented. Policy actions to overcome market barriers are proposed but not discussed because this exceeds the scope of this work.

6.1 Technical Potential

The technical potential to reduce leaking electricity can be divided into currently available applied technology and proposed design ideas. The main market barriers are the transaction costs to find more efficient solutions and the lack of incentives for manufacturers to invest in the design of more efficient appliances.

There are few functions that appliances perform in the standby mode. In the passive standby mode, usually only a sensor requires power. In the active standby mode, usually only a display, such as a clock or thermometer, is powered.These functions consume very little power. Table 6-1 shows estimates of the power required by different sensors and displays (Werthimer, 1997). This table summarizes different technologies and the power consumption on the low-voltage side. Low-voltage transformers cause additional losses.

Table 6-1 Power Consumption of Standby Functions

Function	**Technology**	**Application**	**Power Consumption (W)**
Display	LCD (liquid crystal display)	Clock display	0.01
	VFD (vacuum fluorescent display)	Green display (time, frequency, temperature)	0.15
	LED (light emitting diode)	10 mA @ 2V per segment (clock with four digits)	0.35
Sensors	Light sensor	To adjust brightness of an LED display, to switch on lights	0.01
	Information sensor	incoming fax, print message, EPG	0.1
	Radio frequency sensor	Garage door opener	0.2
	Infrared sensor	Remote control	0.05
	Motion sensor	Passive (infrared)	0.1
		Active (emitting and receiving beam)	0.25
Others	Internal clock	Clock setting, alarm	0.01

Based on (Werthimer, 1997)

Table 6-1 shows that all these functions can be achieved using only a fraction of one watt. The remaining leaking electricity for these applications comes from low-voltage transformers and from battery recharging.

Displays are common leakers. The power consumption of displays is small, but often parts of the circuit unrelated to the display leak. Also, the losses in the transformer that powers the display account for a much of the power dissipation. The efficiency of low-voltage transformers in a power range below 20% of their nominative power is less than 0.4 (Lechner, 1995). Another common function in the standby mode are sensors. Sensors are used in all appliances that can be activated with a remote control or must be ready to receive information. The sensor itself consumes only a fraction of one watt but the power supply and the design of the appliance are responsible for most of the leakage.

To accomplish low standby power, the following design options are proposed:

- a separate standby power supply
- low power consumption for the components that remain active
- increased number of components switched off in standby mode
- a sleep mode for micro-processor
- disabling ICs
- three-volt IC technology
- an automatic off function
- moving the power switch to the high-voltage side

As the savings possible from increased energy efficiency are limited, so is the money that can be invested in more efficient components and redesigning circuits. Investment should not exceed $5 per saved watt[5] in order to be cost-effective overall.

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[5] assuming 10 cents per kWh and 6 years estimated average lifetime:
1 W x 6 yrs x 8760 h/yr x $0.1/kWh = $5.256

6.1.1 Televisions

The range of power consumption in the standby mode in this sample is from 0.5 to 12.3 watts. Other reports (Novem, 1995) show that it is possible to activate TVs remotely with a standby power of only 0.1W with a redesigned circuit.

The best improvements can be achieved when the efficiency of the power supply in the standby mode is increased. One method of achieving this is by using a separate standby power supply. This supply must be precisely designed for the actual power that is needed. Components that must remain powered constantly should be especially energy-efficient. Further improvement can be achieved by decreasing the number of components that remain on in the standby mode. Further reduction of the standby power could be obtained with a microprocessor that includes a sleep mode in which most of its activities are stopped. During about ten percent or less of the normal operating time the microprocessor carries out the functions determined by software. Some other digital ICs, such as memory chips, can be designed to be easily enabled or disabled via a digital signal sent by the microprocessor. Disabling the IC will account for a large reduction in its consumption. Using a lower voltage of 3 V instead of 5 V—the current trend in modern technology—could also lower the standby power. An automatic off switch after a certain period in the standby mode could also be an optional feature in future designs.

The above discussion shows that the technical potential for TVs with low standby power already exists. The challenge is to implement future technology like electronic program guides or the new digital technology with no increase in the power in the standby mode. Another concern is that the quality of service should not decrease due to lower standby power such as the time required to display the picture on the TV. To shorten the required time, the filament in the picture tube must be kept warm, increasing the standby power.

6.1.2 Videocassette Recorders

Standby power consumption ranges from 1.5 to 12.8 watts in the sampled VCRs. The standby power consumption depends on the functions in this mode, such as a clock and access via a remote control. The design options to reduce the leaking electricity for VCRs are similar to those of TVs.

The greatest reduction of the standby mode power consumption can be achieved with a highly efficient power supply in the standby mode. Another significant improvement can be achieved with highly efficient technologies for the components that are powered constantly, such as the display. Table 6-1 indicates the different options for displays and their required power. One option would be to use an LCD display with a back-light which would be deactivated in the standby mode. An optional off switch for the display would be another option, but consumers may not accept this because it decreases user convenience. By using a microprocessor that is connected to the IR-circuit, it is imperative that these circuits remain active in the standby mode to be able to receive an activation signal. A possible design improvement would be an IR circuit which is connected to a simple microprocessor that receives its power from a separate supply. With fewer components "on" in the standby mode, less power is dissipated. The trend towards a 3 V supply instead of a 5 V supply will of course also reduce the power.

6.1.3 Audio Equipment

The wide range in the standby power consumption for audio equipment is especially surprising. Compact audio systems, for example, have a standby power between 2.1 and 28.6 watts. The only service in the standby mode is displaying the time and awaiting commands from a remote control. One contributor to the high standby power consumption is the use of linear power supplies in audio equipment. Switch mode power supplies are rarely found in high-quality analog audio equipment because of the difficulty of limiting switching noise interference in high-gain, low-noise circuitry. The power in the standby mode is typically drawn from the main power supply. Another improvement can be achieved by switching off more components of the circuitry that are not used in the standby mode. Any reduction of power in the standby mode is mainly attributable to deactivating front panel displays (Molinder, 1997). The options to reduce power consumption in the standby mode are similar to those presented for TVs and VCRs.

6.1.4 Cable and Satellite Receiver Set-top Boxes

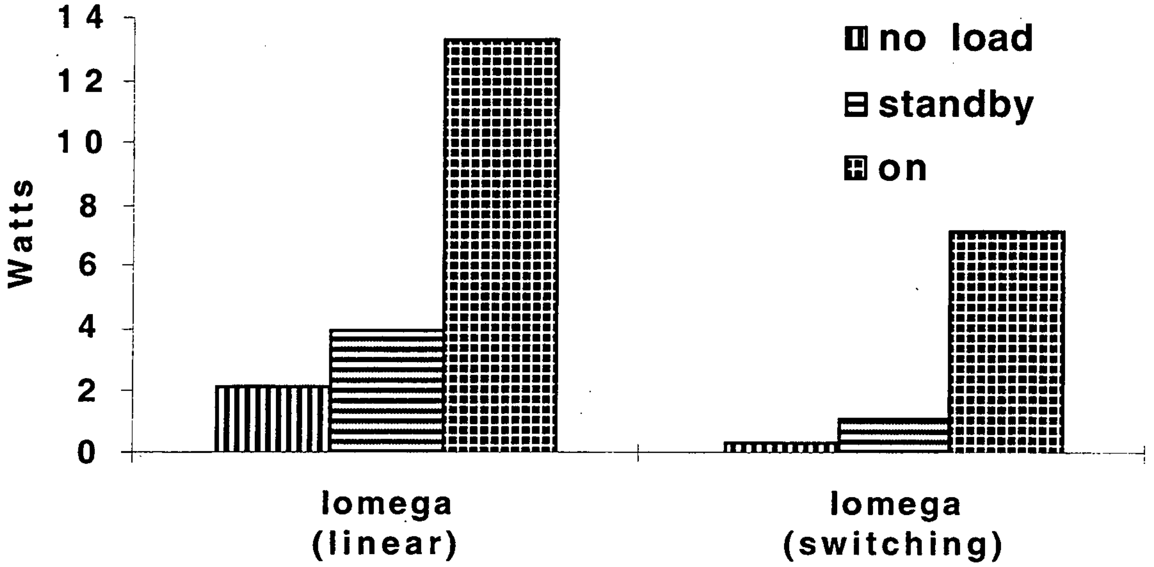
The small difference between the power consumption in the standby and in the on mode is the most surprising fact in this appliance group. The difference was less than one watt for most of the metered appliances and was as low as 0.1 watt for a few appliances. This implies that the off switch merely deactivates the LED in the front panel or changes its color from green to red.

Many different services are provided through these boxes. While most of them only wait to be activated by the remote control, others are downloading information such as electronic program guides, the weather forecast, sports scores, or news. The savings potential for these appliances is very high depending on the services provided in the standby mode. It is technically feasible and overall cost-effective if the box is designed to enter a lower-power mode from which it can "wake up" if it receives a signal.

6.1.5 Power supplies

In chapter 5, a case of replacing a linear power supply with a switch mode power supply was analyzed. High efficiency of the power supply is important for the overall efficiency of an appliance. To achieve a high efficiency, the power supply must be precisely designed for the actual power that is required. A second power supply, designed solely for the standby consumption, could decrease leaking electricity significantly. Figure 6-1 shows the savings from replacing the linear power supply of the Iomega Zip drive with an SMPS.

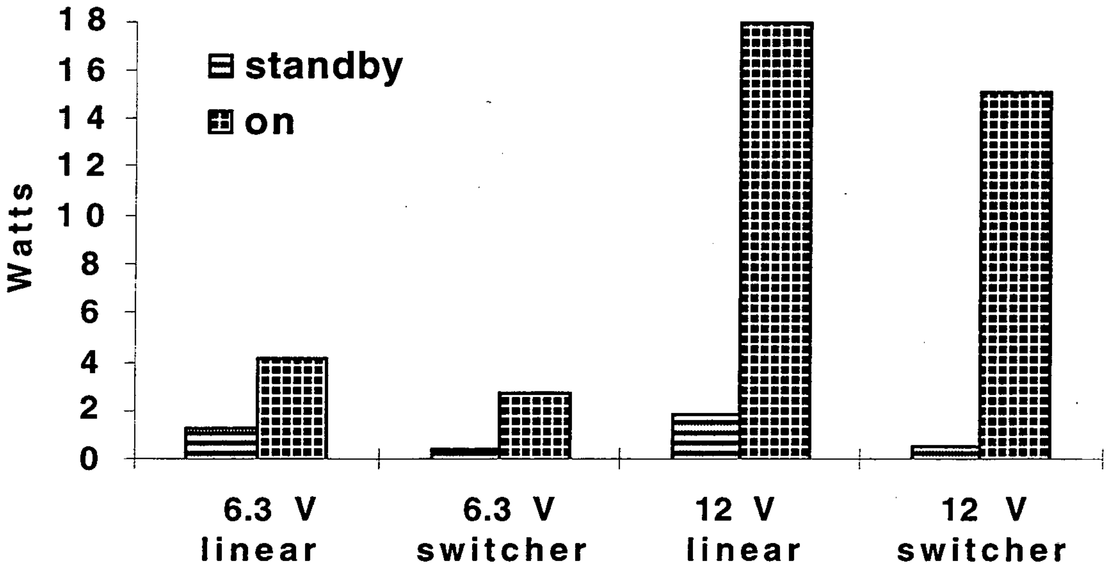
Figure 6-1 Savings from Replacing Power Supplies



Power consumption in the no-load mode dropped from 2.2 to 0.4, in the standby mode from 4.0 to 1.2, and in the on mode from 13.3 to 7.1 watts. There was no increase in cost for the more-efficient power supply.

Figure 6-2 shows two examples of the energy savings from switching power supplies. The reduction for the 6.3V power supply are from 1.3 to 0.4 watts in the standby mode and from 4.2 to 2.8 watt in the on mode. For the 12V power supply power consumption was reduced from 1.9 to 0.5 in the standby and from 18 to 15.1 watts in the on mode.

Figure 6-2 Comparison of Power Supplies



Source: Power Integrations, Inc.

6.1.6 Aspro Technology Concept Description

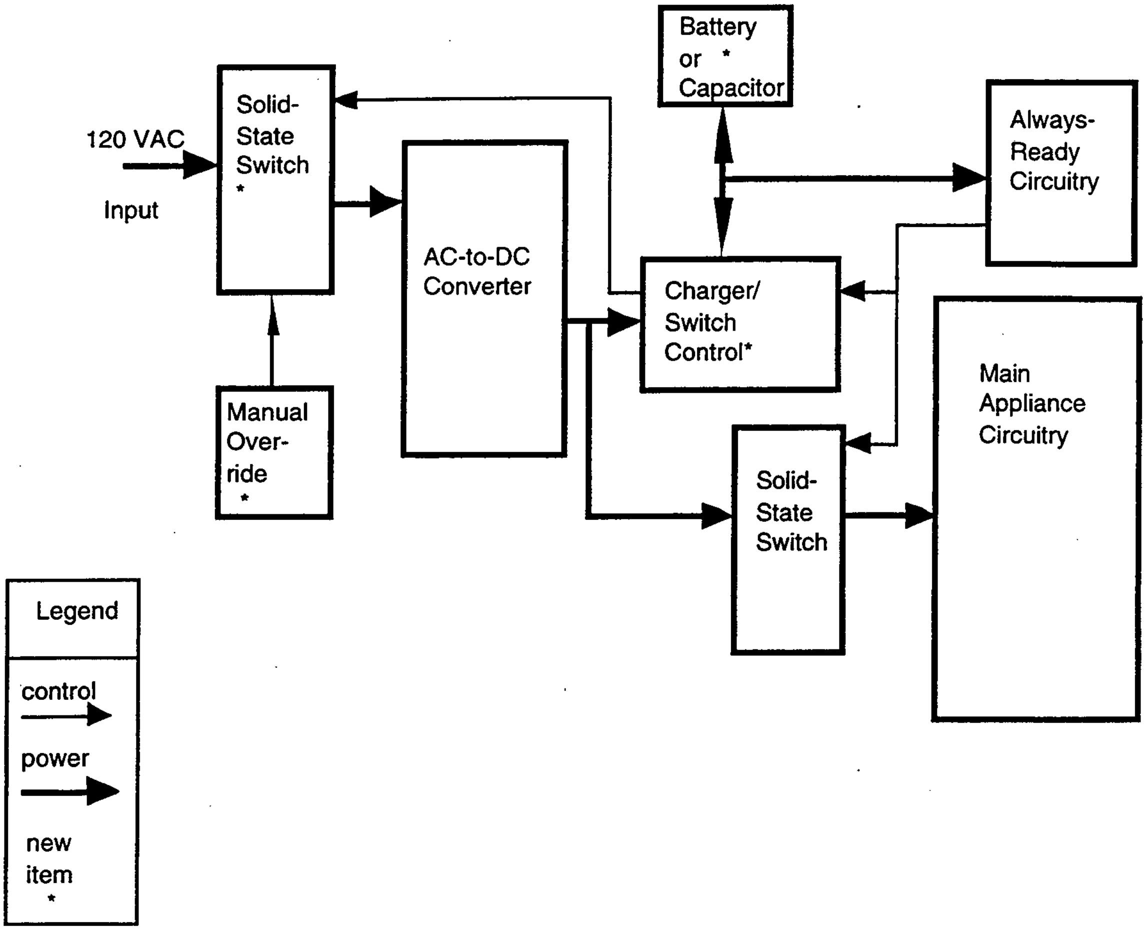
This technology was presented in an earlier report (Molinder, 1997). The Energy Saving Power Supply (ESPS) is an electrical power supply unit for all kinds of applications. For appliances which work only some of the time, such as refrigerators and battery chargers, the ESPS saves up to 90% the electrical energy required by an ordinary power supply unit.

The ESPS identifies work (load) periods and idle (no load) periods automatically. After deactivating the appliance, the ESPS disables the transformer and the no-load current is almost zero. After activating the appliance, the ESPS enables the transformer and supplies electrical power as long the appliance is in use. During the idle period of the appliance, the transformer is disabled and the ESPS periodically checks the status of the appliance. The checking cycle is selected from 1 second to 30 minutes. The transformer may be enabled by an external wake-up signal at any time. The ESPS requires only 0.1 second to check if there is a working period. Energy savings depend on the selected checking cycle and the primary current at no load. According to Aspro Technology, the additional cost range from $5 to $20 per power supply depending of the number of units.

6.1.7 Energy Saving Circuit Design

The power saving circuit proposed by (Rainer et al., 1996) eliminates standby losses for most of the time. Every appliance that leaks electricity in the standby mode could be modified with this circuit. The items to be added to a typical appliance are labeled with an asterisk (*) on figure 6-3. The input solid-state switch is a simple triac device; the manual override is a push-button switch manually triggering the triac in case of battery failure. The battery or "supercapacitor" maintains the always-ready circuit; when its charge drops below a threshold level, the charger/switch control activates the appliance using an internal switch as well as trigerring the input switch. In quantity, the added components should add no more than a few dollars to the price of the appliance.

Figure 6-3 Energy Saving Circuit Design



6.2 One Watt Action Plan

This report demonstrates that there are opportunities to reduce the standby power for almost all appliances to less than one watt. Table 6-1 shows that sensors and displays, representing most of the services in the standby mode, consume only a fraction of one watt. Powered by a highly efficient low-voltage transformer, the total electricity consumption should not exceed one watt. There are still problems such as the heating of the filament of a TV tube or radio interference by switching power supplies, but none appear insurmountable.

One of the standard setting organizations, Underwriters Laboratory (UL), is currently considering ways to protect the integrity of the "off" switch for future appliance approvals. Approved appliances that are "off" will not be allowed to consume more than one watt. If this proposal is approved it would have a large impact on manufacturers because all appliances sold in the U.S. require the UL approval.

6.3 User Behavior

User behavior is an important factorin the amount electricity is used in the standby mode, from the decision at the time of purchase to the actual usage. In this study no survey of actual user behavior and its possible impacts on the electricity consumption was conducted.

6.4 Saving Potential

Potential savings with a reduction of the standby power to one watt have been calculated with the residential electricity forecast model (Sanchez et al., 1997). Approximately75 % of all leaking electricity could be eliminated if the one-watt ceiling is achieved by all appliances. Additional savings could be achieved if leaking electricity is eliminated in appliances which provide no service at all in the standby mode and still consume up to one watt. One solution is to move the switch to high-voltage side of the transformer. Other services could be also provided with significantly less than one watt. Table 6-2 shows the calculated saving potential for the one-watt ceiling. Office equipment is excluded in this table because the one-watt ceiling may be to difficult to achieve with existing technology.

Table 6-2 Potential Savings with the One-Watt Ceiling

End Use Name	**1995 Consumption (TWh/yr)**	**1-Watt Consumption (TWh/yr)**	**Potential Savings (TWh/yr)**
Color TV	5.44	1.36	4.08
Video Cassette Recorder	4.85	0.87	3.98
Compact Audio	4.73	0.45	4.29
Cable Boxes	3.69	0.32	3.37
Rack Audio System	3.21	0.46	2.75
Microwave	2.11	0.68	1.43
Battery Charger	2.05	0.85	1.20
Answering Machine	1.92	0.58	1.34
Home Radio, small/Clock	1.77	0.88	0.88
Cordless Phone	1.49	0.53	0.96
Boom Box	1.34	0.61	0.73
Doorbell	1.20	0.60	0.60
Video Game System	1.07	0.54	0.54
Security System	0.88	0.07	0.81
Garage Door Opener	0.80	0.20	0.60
Satellite Earth Station	0.57	0.04	0.53
TV/VCR Combo	0.56	0.06	0.51
Men's Shaver	0.46	0.33	0.13
Timer	0.45	0.21	0.23
Hand-Held Rechargeable	0.34	0.19	0.15
Power Strip	0.26	0.26	0.00
Electric Toothbrush	0.23	0.10	0.13
Modem	0.20	0.15	0.06
Halogen Lights	0.17	0.17	0.00
Women's Shaver	0.13	0.09	0.04
Projection Color TV	0.07	0.03	0.04
total:	**39.99**	**10.62**	**29.37**

6.5 Policy Actions

A large market barrier for more energy-efficient technology is that the manufacturers bear the costs for more efficient technologies but the benefits flow to consumers and society as a whole. To create incentives for the manufacturer to research and develop more efficient technologies and to implement more efficient components, a variety of policy actions could be used. Previous work (Novem, 1996; Lane et al., 1997) have presented possible policy actions. Table 6-3 provides an overview.

Table 6-3 Overview of Possible Policy Actions

• Label	Award Label
	Comparative Label
	Any Label
• Efficiency Standards	Voluntary Agreements
	Mandatory Standards
• Other Incentives	Procurement
	Rebates and Tax Incentives
	Research and Development Efforts
	Information

All of these programs rely on standard definitions and test procedures. This report contributes to the development of those definitions and test procedures. It also shows which end uses deserve the greatest programmatic attention.

7. Summary and Conclusion

This study analyzes the standby power consumption of appliances in the U.S. residential sector. It is the first attempt to calculate the electricity consumption per appliance category and household on a national level. Data were collected for 35 appliance types in 15 households and in two electronic retail stores.

Leaking electricity accounts for approximately 5% of the residential electricity use. The annual consumption of approximately 44 TWh can be divided into 7 categories. Video equipment is the biggest share with almost 40% of all standby losses. The second largest part is audio equipment with 25% followed by communication with 8%. The remaining categories such as kitchen appliances, office equipment, and personal care account for almost 30%.

The four largest leaking appliance types were investigated. Different models of appliances which provide the same service, but differ in the electricity consumption, were compared. In addition two appliance types, which could become large leakers in the future were analyzed.

The technical options to reduce leaking electricity were analyzed and show a saving potential of 75%. Most of these savings could be achieved simply by redesigning appliance circuits or by using more efficient components. Low-voltage power supplies are a common source of leaking electricity. The power consumption and the impact on power quality was investigated in a case where a linear power supply was replaced by a switch mode power supply. Potential savings of leaking electricity from 60 to 80%, with no additional costs, could be shown in this case, depending on the mode of the connected appliance.

The main market barrier for more efficient technology is the lack of incentives for the manufacturer to improve the efficiency of their products. Another obstacle is that consumers are often unaware of the energy consumption of their appliances, especially in the standby mode. Additional features are more important than high energy efficiency in the decision-making process of buying an appliance.

A reduction of 75% of the leaking electricity could save approximately 30 TWh per year in the U.S. residential sector alone. Leaking electricity is only 5% of the U.S. residential electricity use and represents 12 MTons of CO_2 emissions, but it is unusual because a majority of it can be easily avoided and the CO_2 emission reductions are surprisingly large. Globally, even more can be saved with modest costs. In addition, leaking electricity appears to be rapidly growing, so by devoting attention to reducing it now, future growth can be avoided.

To continue this work, more appliances with standby energy consumption could be identified and added to the established database. The average energy consumption could be determined more precisely by metering a greater sample of appliances or by using the sales-weighted data from manufacturers. Further research could also address the technical feasibility of new or modified energy saving circuit designs.

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Data source and usage assumptions

End Use Name	Estimated Lifetime (yrs)	Usage estimate (hrs/yr)	Power On (W)	Standby Losses (W)	Usage Notes	Power Consumption Notes
Answering Machine	4	0	3.3	3.3	On year-round. Doesn't include listening to messages or rewinding.	Measured data 1997 LBNL.
Battery Charger	11	0	n/a	2.4	Assumed that people leave their battery charger plugged in year-round. Therefore, UEC only includes standby losses as opposed to the actual charging.	Standby mode is from metered data collected by Wolfgang Huber, 1997. It is an average of overcharging as well as plugged in with no battery.
Boom Box	4	365	7	2.2	Assume 1 hour/day=365 hours/day. Estimated by Sanchez (LBNL), 1996.	Active power is metered data collected by Sanchez and Huber (LBNL), 1997. Active power is an average with a typical product range of 5-15 W. Standby power from Huber, 1997: metered data.
Cable Box	n/a	1456	20	11.6	Cable Boxes are on the same amount of time as TV sets are on (estimate by Webber, 1997). Standby losses for the remainder of the year.	Metered data collected by Huber, 1997.
Color TV	11	1456	77	4.0	From Carrie Webber, 1997. Based on 1456 viewing hours/year at 77 W on and 4 W standby loss.	Metered data collected by Huber, 1997.
Compact Audio System	15	365	15	10.6	Assume one hour/day, 365 days/yr. Estimated by Sanchez (LBNL), 1997.	Metered data collected by Huber, 1997.
Computer	n/a	1337	65	65.0	Assumes 1/5 operated like a home office. Numbers taken from Koomey 1996 (active 9% of time, standby 26%). All others active 2 hours/day, standby 15 min/day. Computers off completely when not in use. Sanchez and Huber, 1997.	Assumes pre-Energy Star (no special suspend feature) From Koomey et al., 1996 office equipment report.
Copier	n/a	3600	n/a	10.0	Usage based on assumption that a small copier is plugged in all the time. Sanchez and Huber, 1997.	From Bruce Nordman 1/97. Based on a small cannon copier of ≤16 cpm. LBNL report on office equipment, Koomey et al., 1995.

End Use Name	Estimated Lifetime (yrs)	Usage estimate (hrs/yr)	Power On (Watts)	Standby Losses (W)	Usage Notes	Power Consumption Notes
Cordless Phone	3	0	3	2.8	Usage based on assumption that the telephone is in the base station all year round. This number does not reflect recharging or amount of time out of the base station.	Metered data collected by Huber, 1997.
Doorbell	n/a	0	0	2.0	Doorbells are in the standby mode all of the time.	Davis Energy Group, 1996. From Alan Meier, *Home Energy* 11/12-1993. Huber, 1997.
Electric Lawn Mower	n/a	20	1500	2.2	1 hr/week for 5 months out of the year plus active time for recharging: 100 hrs/year. Sanchez and Huber, 1997.	Davis Energy Group, 1996. From Pacific Gas and Electric Internal Sources. Collected data by Huber, 1997.
Electric Toothbrush	5	n/a	n/a	2.3	For simplicity, UEC is calculated from the standby mode consumption only. This is reasonable since over 95% of the product annual consumption is due to standby losses.	Metered data collected by Huber, 1997.
Fax Machine	n/a	438	175	30.0	Taken from Koomey et al., 1996. Assume that it is in operation for 1 hr/workday. Standby or suspended mode is on for the remainder of the time. People do not turn off their fax machine.	Davis Energy Group, 1996, From ACEEE Fax Machine Power Consumption Rating Data, 1994.
Garage Door Opener	n/a	n/a	n/a	4.0	Assume 0.4 Wh/use. Standby losses of 4 W. From Davis Energy Group	Davis Energy Group, 1996. Monitored Data. Collected data by Huber, 1997.
Halogen Lights	n/a	n/a	n/a	0.5	Only includes standby losses.	Metered data collected by Huber, 1997.
Hand-Held Rechargeable Tools	6	24	n/a	1.8	For simplicity, assumed this is simply plugged in year-round. Reasonable since these are only used 24 hours/yr (Sanchez, 1997).	Metered data collected by Huber, 1997.
Home radio, small/clock	5	365	3	2.0	1 hour/day average. Estimated by Sanchez 11/1996.	Metered data from a visit to Circuit City (10/9/1996) by Sanchez and Huber.

End Use Name	Estimated Lifetime (yrs)	Usage estimate (hrs/yr)	Power On (W)	Standby Losses (W)	Usage Notes	Power Consumption Notes
Laser Printer	n/a	45	250	80.0	Assumes 1/4 of printers operated like a home office. Numbers taken from Koomey 1996 (active 1% of year, 28% susp. 4% standby). 3/4 of stock have printer on while computer is on (2 hrs/day), 5 min. printing: 1 hr 55 min. standby. Sanchez and Huber, 1997.	Assumes pre-Energy Star (no special suspend feature) From Koomey et al., 1995 office equipment report.
Men's Shaver	5	30	15	1.4	365 uses/yr, 5 min/use. AHAM	AHAM and Huber, 1997.
Microwave	n/a	78	1500	3.1	Assumed 15 minutes/day, 6 days/week on. Standby losses the remainder of the time. Sanchez, 1996.	Active power from Davis Energy Group. Standby losses from collected metered data by Huber, 1997.
Modem	n/a	1337	n/a	1.4	Assumed on like a home office. Rest in standby. Huber, 1997.	Metered data by Huber, 1997.
Multifunct. Device	n/a	n/a	n/a	4.7	Only included standby power consumption. Huber, 1997.	Metered data by Huber, 1997.
Power Strip	n/a	n/a	n/a	0.3	Only includes standby losses. 8760 hrs/yr	Metered Data by Huber, 1997.
Printer	n/a	876	45	15.0	Assumes 1/4 of printers operated like a home office. Numbers taken from Koomey 1996 (active 1% of year, 28% susp. 4% standby). 3/4 of stock have printer on while computer is on (2 hrs/day), 5 min. printing: 1 hr 55 min. standby. Sanchez and Huber, 1997.	Assumes pre-Energy Star (no special suspend feature) From Koomey et al., 1996 office equipment report.
Projection Color TV	11	1456	150	2.2	From Carrie Webber (LBNL), 2/97.	Metered data by Huber, 1997.
Rack Audio System	n/a	365	60	7.0	Assumed one hour/day, 365 days/yr. Estimated by Sanchez (LBNL), 1996.	Metered data collected by Huber, 1997.
Satellite Earth Station	7	1456	15	14.9	Standby losses of whenever TV isn't on (television estimate by Webber (LBNL) 1997).	Metered data collected by Huber, 1997.

End Use Name	Estimated Lifetime (yrs)	Usage estimate (hrs/yr)	Power On (W)	Standby Losses (W)	Usage Notes	Power Consumption Notes
Security System	n/a	4992	30	12.0	Assumed that it is on 8 hours/day 5 days per week while at work and an additional 8 hours/day 7 days/week while sleeping. Sanchez estimate, 1997.	Metered data by Huber, 1997.
Timer	n/a	0	n/a	2.1	Only calculated standby consumption. Simply assumed standby losses all year.	Metered data collected by Huber, 1997.
TV/VCR Combo	11	1456	55	9.8	Carrie Webber (LBNL) 1997.	Metered data collected by Huber, 1997.
Video Cassette Recorder	11	1515	12	5.6	From Carrie Webber. Based on 1255 hours on, 78 hours recording, 182 hours playing and 7246 hours off.	From Carrie Webber. Based on 10.7 Watts on, 15.7 W, recording, 15.7 W, playing and 5.4 Watts leaking. Standby power by Webber and Huber, 1997.
Video Game System	4	365	20	2.0	30 hrs/month *Ohio Edison*.	Active power based on 20 W on (Davis Energy Group, 1996 from internal PG&E source. Standby power from Huber, 1997.
Women's Shaver	5	13	15	1.4	three times/week, 5 min/use. AHAM	AHAM

If lifetime is n/a, saturations were used to estimate annual stocks.

If usage estimate is n/a, data are not available or energy use is calculated with number of uses.

If power on is n/a, data are not available.

AEMC NUWATT Wattmeter

Description

The AEMC NUWATT is a true RMS Digital Power Meter which allows a wide range of power measurement. Utilized with both single and three-phase circuits, the meter is capable of measuring power consumption from 0.1 watt to 2 megawatts. Two binding post terminals provide connections for direct measurement on currents up to 5 amperes RMS and 10 amperes sinusoidal. The meter features an expansion scale which increases resolution by a factor of ten for accurate single-phase readings on equipment with low power consumption.

The NUWATT meter was modified for these measurement campaigns for ease of use. A plug and a socket were added. The plug is connected to the wall and the appliance to be metered is plugged into the socket on the meter. With this setup the range of the power metering was restricted to direct measurements and therefore from 0.1 to 199.9 W. To test the accuracy of this meter, its measurements were compared to measurement from a high-quality power analyzer: the Xitron 2503 3-Channel Power Analyzer. Loads ranging from 0 to 160 watts were metered with both meters. The differences in the power readings were in the order of 1% for a wide range of the measurements. Below 2 watts, differences were greater due to the limited digits on the NUWATT's display.

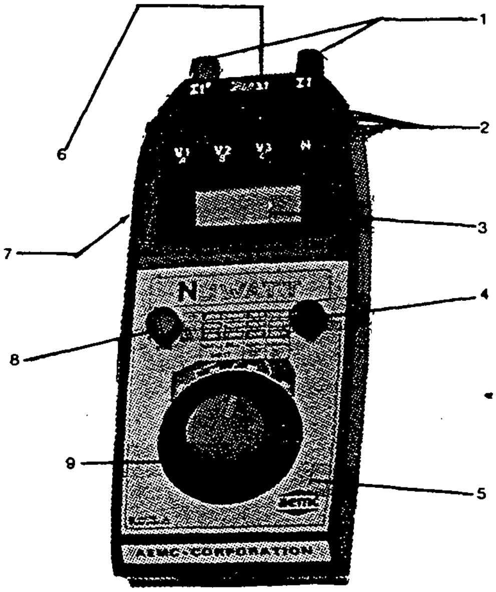
Specifications

ELECTRICAL SPECIFICATIONS

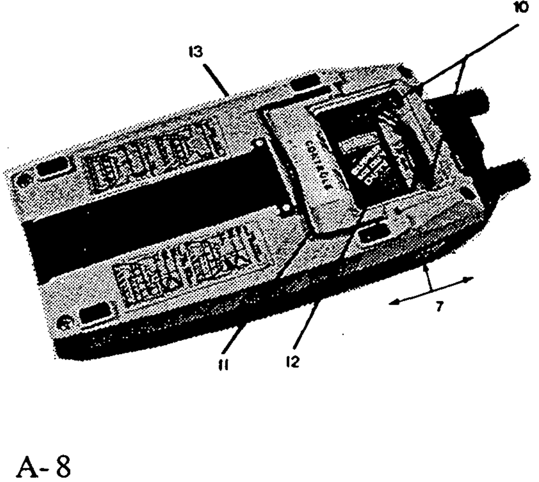
			Direct Measurement		Clamp-On C.T. Ratio			
			0 5 A	5 A	100 1	1000 1	1500 1 5	3000 3
Current	Sine Wave		1 A	10 A	75 A	1000 A	1500 A	3000 A
	Non Sine Wave	RMS Value	0.5 A	5 A	50 A	500 A	700 A	1400 A
		Peak Value	1 41 A	14 1 A	110 A	1414 A	2100 A	4200 A
		Crest Factor	Less than 3 for RMS Value. Maximum crest factor = 6 (see definition)					
Voltage	Sine Wave	1 φ	10 to 440 V	10 to 440 V	10 to 440 V	10 to 440 V	10 to 440 V	10 to 440 V
		3 φ	20 to 700 V	20 to 700 V	20 to 700 V	20 to 700 V	20 to 700 V	20 to 700 V
	Non Sine Wave Peak	1 φ	622 V	622 V	622 V	622 V	622 V	622 V
		3 φ	1000 V	1000 V	1000 V	1000 V	1000 V	1000 V
		Crest Factor	Less than 3 for RMS Value. Maximum crest factor = 6 (see definition)					
Power Range			199.9 W	1999 W	19 99 kW	199 9 kW	1060 kW	1999 kW
	Resolution		0.1 W	1 W	10 W	100 W	1kW	1kW
	Accuracy 1 φ	48-65Hz	0.3% full scale	0.3% full scale	1.5% full scale	0.6% full scale	0.6% full scale	0.6% full scale
		65-400Hz	0.6% full scale	0.6% full scale	1.8% full scale	0.7% full scale	0.7% full scale	0 7% full scale
	Accuracy 3 φ	48-65Hz	0.6% full scale	0.6% full scale	1.8% full scale	0.9% full scale	0.9% full scale	0 9% full scale
		65-400Hz	0.9% full scale	0.9% full scale	1.8% full scale	1% full scale	0 9% full scale	0.9% full scale
Expanded Low Power Range			19.99 W	199 9 W	1,999 W	19 99 kW	199.9 kW	199 9 kW
	Resolution		0.01 W	0.1 W	1 W	10 W	100 W	100 W
	Accuracy 1 φ	48-65Hz	3% full scale	3% full scale	15% full scale	6% full scale	6% full scale	6% full scale
		65-400Hz	6% full scale	6% full scale	15% full scale	7% full scale	6% full scale	6% full scale

Definition of Crest Factor = $\frac{\text{Peak Value}}{\text{RMS Value}}$

CONTROLS AND CONNECTOR IDENTIFICATION



1. Input for direct measurement on current
2. Input voltage terminals
3. 3½ digit LCD with low battery indicator
4. Function selector
   -selects 1Ø, 3Ø, or '1Ø Low Range'
5. Dust and fire resistant ABS case
6. C.T. input jack. To be used with the clamp-on C.T.'s.
7. ON/OFF switch
8. Zero adjustment knob. (Display should read zero when instrument is not connected)



9. Current range selector for direct measurement or measurement with C.T.
10. Analog output
    SEE WARNING ON PAGE 22
11. Tilt stand for bench work
12. Battery compartment
13. Wide range zero adjustment (see page 12)

FLUKE 41 Power Harmonics Analyzer

Description

The Fluke 41 was used to meter the power consumption of appliances and to examine power quality at the time of the measurement. It is a clamp-on AC current probe that is designed to reproduce current waveforms found in the power distribution system. The probe's performance is optimized for accurate reproduction of currents at line frequency and up to the 50th harmonic. This meter allows measurements of currents from 1 to 500 A AC RMS, 5 Hz to 10 kHz without interfering with the circuit. A passive filter eliminates noise and ring on rapidly rising waveforms, ensuring accurate reproduction on oscilloscope displays.

Specifications

FREQUENCY RANGE, FUNDAMENTAL

5-65 Hz and dc

MINIMUM INPUT LEVELS

5V rms or 1A rms

VOLTS MEASUREMENTS (TRUE RMS)

Input Range: 5.0V to 600V rms (ac + dc)
5.0V to +/-933V peak

Basic Accuracy*:

rms (ac + dc):	+/-(0.5% + 2 digits)
peak, dc:	+/-(2% + 3 digits)

** < 15V RMS, add 2 digits*

Input Impedance: 1 MΩ, balanced

Crest Factor: > 3.0 below 300V, 1.56 @ 600V

AMPS MEASUREMENTS (TRUE RMS)

(1 mV/A) Isolated Input

Input Range: 1.00 mV (A) to 1000 mV rms (A) (ac + dc)
1.0 mV (A) to +/- 2000 mV (A) peak

Basic Accuracy:
rms (ac + dc): +/-(0.5% + 3 digits) + probe specs.
peak, dc: +/-(2% + 4 digits) + probe specs.

Input Impedance: 1 MΩ II 47 pF

Crest Factor: > 3.0 below 600 mV, 2.0 @ 1000 mV

WATTS MEASUREMENTS (VOLT-AMPS)

(1 mV/A) Isolated Input

Range: 0 W (VA) to 600 kW (kVA) average
0 W (VA) to 2000 kW (kVA) peak

Accuracy (ac + dc):
Active W (VA): +/-(1% + 4 digits) + probe specs

HARMONICS MEASUREMENT ACCURACY (CURSOR DATA) (Harmonic Level > 5% Using Smooth ∿-20)

Volts:

Fundamental to 13th Harmonic: +/- (2% + 2 digits)
13th to 31st Harmonic: 13th (+/- (2% + 2 digits)) -----
----- 31st (+/- (8% + 2 digits))

Amps* or Watts:

Fundamental to 13th Harmonic: +/- (3% + 3 digits) + probe specs
13th to 31st Harmonic: 13th (+/- (3% + 3 digits) + probe specs) -----
----- 31st (+/- (8% + 3 digits)+ probe specs)

** < 20A, add 3 digits*

Phase:

Fundamental: (±2 degrees) + probe specs
2nd to 31st Harmonic: 2nd (±5 degrees) —— 31st (±20 degrees) + probe specs

FREQUENCY MEASUREMENT ACCURACY (Fundamental, 5.0 Hz - 99.9 Hz)

5.0 Hz - 99.9 Hz: +/- 0.3 Hz

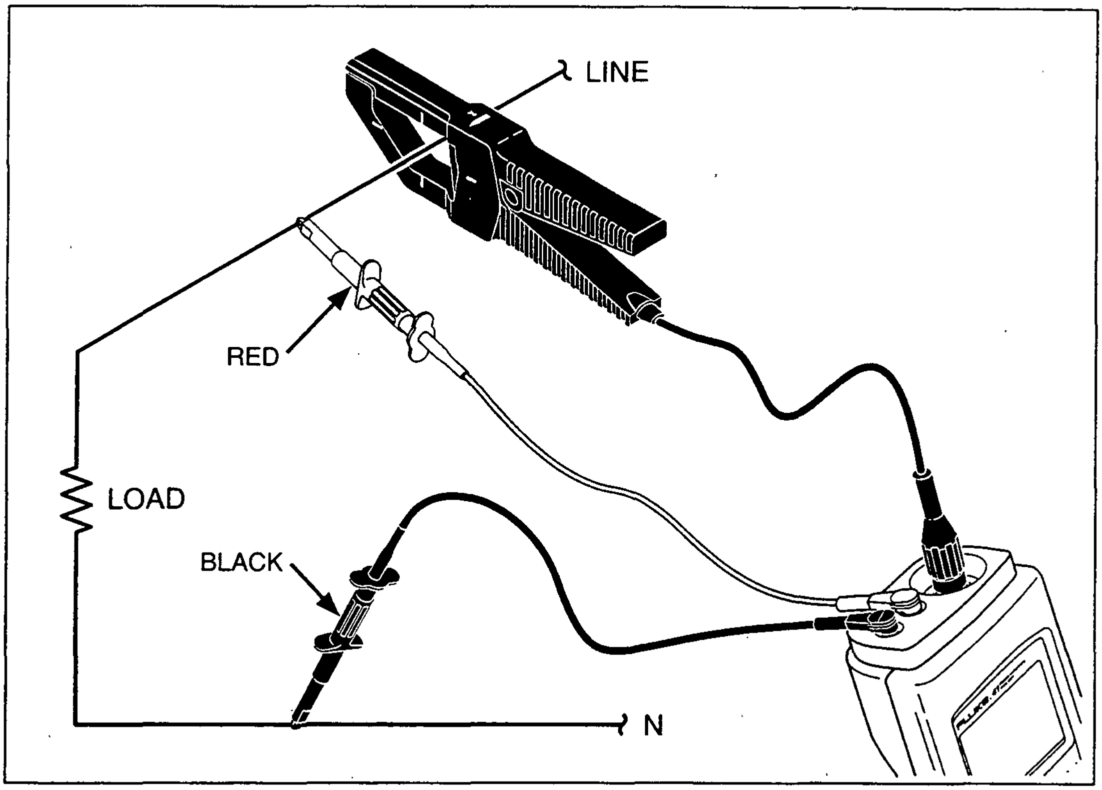
OTHER MEASUREMENT SPECIFICATIONS

Input Bandwidth: (-0.5 dB) DC, 5 Hz to 2.1 kHz
Crest Factor (CF) Range: 1.00 to 5.00
Power Factor (PF): 0.00 to 1.00
Displacement Power Factor (DPF): 0.00 to 1.00
Phase Measurement Range: -179 to 180 degrees
K-Factor (KF) Range (Model 41): 1.0 to 30.0
Total Harmonic Distortion:
%THD-F: 0.0 to 799.9
%THD-R: 0.0 to 100.0

Test Setup

A Fluke 41 Power Harmonics Analyzer was used to meter the power consumption and to analyze the power quality. Figure C-1 is a schematic of the testing setup.

Figure C-1 Test Setup



The test setup was modified to increase the range of the meter. The AC power line was coiled 10 times, increasing power consumption measurements by a factor of ten (see Figure C-2). The value of the measured currents and consumed watts is thus one-tenth of that indicated on the displays illustrated in chapter 5.

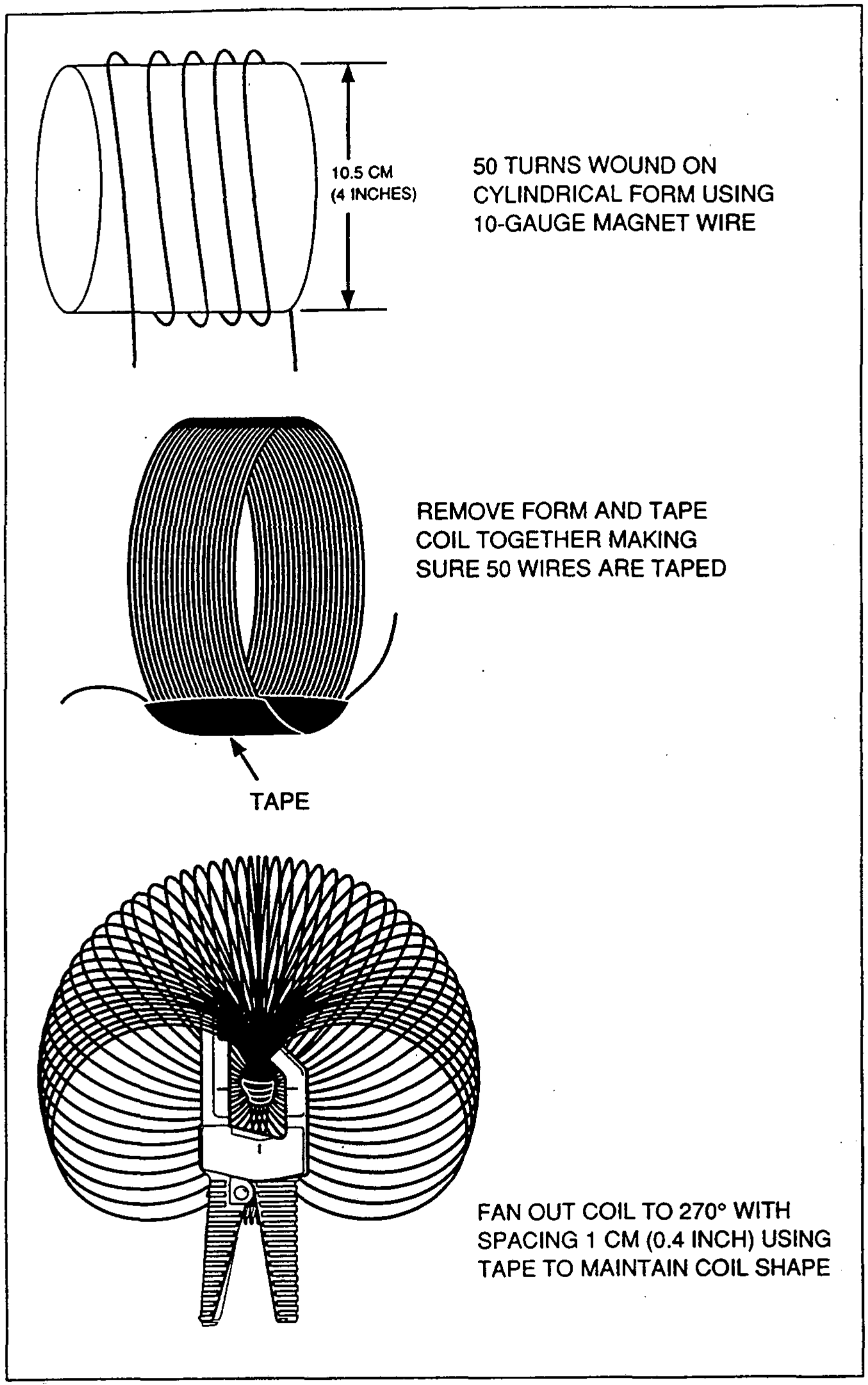


Figure C-2 Modified Test Setup

In this case the coil consists of 10 turns, and 14-gauge wire is used.

Metered Televisions

Brand	Model Number	Description	Standby (W)	On (W)
RCA	AXR120W	12"	0.0	29
Sanyo	K-1321	13"	0.0	38
Hitachi	CT1342	13"	0.0	39
Hitachi	CT1942	19"	0.0	42
Toshiba	CF32F40	32" Stereo	0.5	84
Toshiba	CF35F50	35" Stereo PIP	0.5	75
Toshiba	CF27F30	27" Stereo	0.6	61
Hitachi	20SA3B	20"	0.8	50
Sony	KV27XBR15	27"	1.0	131
Hitachi	20SA3B	20"	1.0	80
Quasar	TP1321DW	13"	1.0	57
Panasonic	CT20G11	20" Stereo	1.1	81
Toshiba	CF27F50	27" Stereo PIP	1.1	n/a
Panasonic	CT27G11	27" Stereo	1.2	102
Panasonic	CTM-1942R	19"	1.3	70
Panasonic	CT27G21	27" Stereo PIP	1.4	n/a
Panasonic	CT27SF12	27" Stereo	1.6	n/a
Panasonic	CTN-1942R	19-20"	1.7	70
JVC	C13710	13" Mono	1.9	35
Panasonic	CT-20510R	19-20"	2.0	78
Proton	VT-290	n/a	2.0	93
RCA	E13334WH	13" Mono	2.2	30
RCA	X20101GS	19"	2.4	71
GE	13GP 210B	13"	2.6	30
RCA	F20539DG	20"	2.6	48
Zenith	SR1324S	13" Mono	2.7	55
Toshiba	CF1927B	19"	2.7	78
RCA	XL 100	9"	2.7	50
Magnavox	PRO91OX	9" AC/DC	2.8	38
Daewoo	DTQ14N2FC	13" Mono	2.9	49
Toshiba	CF917	19"	2.9	58
Hitachi	32CX12B	32" 2T PIP 3D Stereo	3.1	132

Brand	Model Number	Description	Standby (W)	On (W)
Zenith	SM2789BT8	27" Stereo	3.8	104
Sony	KV32XBR45	32" Stereo 2T PIP	4.1	109
Proscan	PS27113	27" Stereo	4.2	149
Sony	KV-19TS20	20"	4.3	60
Zenith	SA1961W	19"	4.6	95
Sharp	195MP	19"	4.6	79
Sony	KV20M20	20" Stereo	5.0	49
Zenith	SY1951Y	19" Stereo	5.5	46
Zenith	SY2549S	25" Mono	5.5	59
Hitachi	27CX7B	27" Stereo PIP	5.5	n/a
Magnavox	PS1963C	19" Stereo	5.7	64
GE	27GT616	27" Stereo	5.7	80
Fisher	PC4525	27"	5.7	108
GE	27GT616	27" Stereo	5.8	n/a
Hitachi	27CX5B	27"	5.9	84
Sony	KV 1972R	n/a	5.9	n/a
Emerson	TC1375	13"	6.2	58
Magnavox	PR1356 B121	13" Mono	6.3	52
Sony	KV-1326R	13"	6.3	63
Magnavox	TR2516C	25" Mono	6.5	114
Magnavox	RS2560	25"	6.5	59
Magnavox	TS2753C 103	27" Stereo	6.8	85
RCA	F27675BC	27" Stereo PIP	7.1	109
Zenith	Z25X31D	25" Stereo	7.5	57
Magnavox	27R502-00BB	27"	7.5	76
Sony	KV27V20	27" Stereo SRS Sound	7.8	n/a
RCA	F32632SB	32" Stereo SLEEP	9.6	93
RCA	F35670MB	35" Stereo PIP	9.8	114
RCA	EGR398WR	17"	10.4	74
Zenith	SM 2773BT	27"	12.3	115

n/a indicates that data were not avalaible

Metered Video Casette Recorders

Brand	Model Nr.	Description	Standby (W)	On (W)	Rated (W)
JVC	HR-J200U	1992	1.5	7.9	19
JVC	HR-J210	n/a	2.0	7.7	n/a
JVC	HRVP436U	4H VCR+	2.1	6.4	19
Hitachi	VTUX615A	5H Stereo VCR+ CBC	2.3	11.1	24
GE	V64235	4 H, HiFi	2.3	10.9	n/a
Zenith	VR4206HF	4H Stereo	2.4	9.2	18
Hitachi	VTFX610A	5H Stereo	2.4	9.1	20
JVC	HRV636U	4H Stereo VCR+	2.6	8.5	21
Zenith	VR2106	2H	2.8	7.9	16
JVC	HR-S5200U	4H VCR+ SVHS	2.9	12.0	26
Panasonic	VDPT657	2H AC/DC	3.0	7.5	19
Toshiba	M461	4H	3.1	8.6	17
JVC	HRVP830U	4H Stereo VCR+ CBC	3.2	10.6	21
Panasonic	PV-4401	1995	3.3	6.1	18
Sony	SLV390	4H VCR+ 3HR Backup	3.5	10.6	24
Goldstar	GVRF468	4H VCR+ Stereo	3.6	10.3	19
GE	VG4251	4H Stereo	3.6	10.6	19
Sony	EVA60	8MM Stereo VCR+ CS	3.9	11.2	26
Sony	SLV-960HF	4H Stereo VCR+ CS CBC I	3.9	12.2	27
Sony	SLV-595HF	early 90's	3.9	13.7	25
GE	VG2056	2H DT	4.0	9.5	17
GE	VG4056	4H	4.0	9.3	17
Proscan	PSVR57	4H Stereo VCR+ CBC	4.0	12.5	22
GO VIDEO	GV4200	Dual Deck 4H Stereo/2H	4.2	13.1	26
Magnavox	VRU222AT	2H	4.3	7.3	17

Brand	Model Nr.	Description	Standby (W)	On (W)	Rated (W)
Sharp	VC-A503U	1992	4.4	9.9	22
Goldstar	VCP-105M	no remote, no clock, no record	4.5	n/a	10
Sanyo	VHR-5420	1990-91	4.6	9.3	18
Fisher	FVH-4508	1992?	4.6	11.2	18
Toshiba	M-222	2 H	4.6	13.2	27
RCA	VR 519	4 H, VCR+	4.8	7.7	18
Criterion	CRV2	2H DT	4.9	6.8	18
Criterion	CRV4	4H DT	5.0	7.4	18
Panasonic	PV2601	2H	5.1	7.4	18
Mitsubishi	HSU 790	Hi-fi, Fly-erase	5.1	14.4	22
Magnavox	VRU-242AT	1996	5.6	8.8	17
Sony	SLV-640HF	1996	5.9	14.7	27
Panasonic	PV 7452	4 H stereo, VCR+	6.0	9.0	23
Mitsubishi	HS-339UR	1986	6.1	12.9	26
Panasonic	PV-4651	4H stereo	6.2	9.1	23
Symphonic	SV211E	1995	6.2	9.0	17
Panasonic	PV-4151	1995	6.3	10.2	23
Sony	SLV-585HF	1993-4	6.3	18.3	30
Magnavox	VR9670AT	n/a	6.3	n/a	27
Panasonic	PV-4114	1995	6.4	10.8	19
Toshiba	M750	VHS HQ, VCR+	6.4	14.8	22
Panasonic	PV-4451	1994	6.5	9.7	23
Toshiba	M750	1995	6.5	14.0	22
Hitachi	VTMX411C	4H	6.6	8.7	17
Toshiba	M 728	6 H Hi-fi,VCR+	6.6	15.0	23
Mitsubishi	HSU 770	VCR+, stereo	6.6	20.2	35
Panasonic	PV-1330	1990	6.6	11.5	20
Funai	FE 436G	1997	6.6	10.3	n/a
Panasonic	PV-4661	4H Stereo VCR+ 3DS	6.9	9.9	23
Panasonic	PV-4651	1996	6.9	10.0	n/a
Quasar	VHQ580	1995	7.0	9.9	23

Brand	**Model Nr.**	**Description**	**Standby (W)**	**On (W)**	**Rated (W)**
Hitachi	VTFX600C	4H stereo	7.2	9.3	20
Sony	SLV-R5UC	n/a	7.7	32.5	n/a
Montgomery Ward	JSJ10625	n/a	7.9	13.6	24
Panasonic	PVS4670	SVHS stereo 3D VCR+ CBC	8.0	11.8	28
Mitsubishi	HS-U770	1995-1996	8.5	n/a	35
Zenith	VR4156	4H VCR+	8.7	8.9	19
Hitachi	VT-1310A	1984	9.7	19.9	32
Sanyo	V14R9820	1990	10.0	20.2	26
Zenith	VR4256HF	4H stereo VCR+	10.6	10.7	19
RCA	VKT-550	1991	11.1	25.5	36
JVC	HRS5300U	SVHS stereo VCR+ CBC	12.2	12.3	26
GO Video	GV 6060	2 deck VCR	12.2	15.5	29
Hitachi	VT-F462A	1993	12.8	18.3	28

n/a indicates that data were not available

Metered Compact Audio Systems

Brand	Model Nr.	Standby (W)	On (W)
Pioneer	CCS 355	2.1	52.0
Panasonic	RX309	3.1	6.7
RCA	RP-9300A	3.3	4.0
Yamaha	GX50	4.3	24.1
JVC	UXC30	4.6	9.8
RCA	RP 9320	4.9	12.0
Pioneer	CCS 106	5.2	20.9
Sharp	CDC 459	5.8	8.7
Sony	MHCG 101	6.0	19.6
Sony	MHCG100	6.8	18.3
Denon	DC1	7.1	14.1
RCA	RP 9325	7.2	13.0
Sharp	CDC2610	7.4	8.4
Denon	D1250	7.5	39.4
Magnavox	FW 355 C37	7.6	17.1
Sony	MHC C50	7.9	18.0
Sharp	CDC 2600	8.4	8.8
Aiwa	NSX-3500	8.5	17.5
Panasonic	SL-CH90	8.8	36.0
Magnavox	FW275P27	9.2	24.6
Aiwa	CXNA30	9.3	14.6
JVC	EXTD5	9.9	25.0
Denon	DC30	10.9	16.0
Kenwood	RXD-F4	10.9	36.6
Kenwood	VD 303	12.0	25.0
Sony	MHC 331	14.0	20.0
Sony	MHCRX 30	15.0	19.6
Pioneer	XC-P410M	15.0	23.0
Aiwa	NSX-V8000	15.3	25.6
Aiwa	NSXA 72	17.2	27.0
Sony	MHCR 100 AV	20.1	32.0
Onkyo	RY505	22.4	25.8
Onkyo	PTS 505	24.1	28.0
Sony	MHC 991	28.6	36.8

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