Efficiency Assessment of Modern Home Audio Equipment

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ABSTRACT

The emergence of efficient switch-mode power supplies and efficient Class-D amplifiers has provided a means for additional energy savings in home audio devices. The sale of home audio devices continues to grow. There are more categories of home audio products in today's market than ever before. The variety in home audio products has not taken away from the sale of traditional home-theater-in-a-box systems and audio separate systems, which have remained steady in sales. Adding to this, the cost of home audio devices has decreased over the years because of reductions in the cost of electronics. This has increased sales because home audio devices are now more affordable than ever. The increased sale of portable media devices (smart phones, tables, media players) has led to an increase in home audio devices because of the volume limitations of portable media. This has especially had an impact on the sale of portable speakers and bookshelf speakers. These factors are increasing the number of home audio devices a typical consumer owns. It is important that energy efficiency is assessed because with more sales, the total energy consumed by home audio devices increases. However, there are efficiency improvements that can be included in the design of home audio devices to reduce this impact. Before action is taken, the current state of efficiencies must to be examined to help direct where efforts will be best spent. This project utilizes a newly developed test procedure to provide clarity on the performance of existing products by testing device energy consumption at different sound pressure levels in a controlled environment. In addition, measurements are taken during operation of non-amplification technologies such as networking and during power saving modes. The objective of this study is to identify efficient home audio features including better power supplies, improved amplifiers, and methods of best deploying sleep mode that could improve energy efficiency.

Introduction

The range of home audio products on the market today has expanded from simple powered speakers to advanced pieces of equipment capable of post processing of audio signals, networking with other devices, and running built-in applications. Advanced home audio devices share more traits with computers than the amplifier circuits from which they evolved.

As the complexity of home audio products increases, they start to resemble computers more so than the home audio devices of the previous decade. This added complexity has the potential to increase the energy consumption of these devices because of the addition of circuits to provide features including networking capabilities and online radio applications. However, the actual energy consumed by each of these features is relatively unknown. Market studies provide an idea of the penetration of different types of equipment; but with such a large variety of products available, it is difficult to assess efficiency potential. Energy standards apply to some types of home audio devices including chargers and external power supplies (U.S. Department of Energy 2014)(National Standards n.d.)(Battery Charger Systems and Self-Contained Lighting Controls Rulemaking n.d.)(California Energy Comission 2012), but efficiency guidelines specific to home audio devices are optional. ENERGY STAR® product listings reveal that many home audio manufacturers have not certified their products. (US Environmental Protection Agency and US Department of Energy n.d.)

Recent innovations such as increases in efficiency of power supplies, increased integration of processors within home audio equipment, and improvements in efficient class-D amplifiers has created the opportunity to dramatically reduce the energy use of home audio devices. The goal of this study was to survey devices found on the home audio market today and to determine the current state of efficiency for home audio products.

Background

Depending on the operational mode of the device, home audio equipment has multiple levels of energy consumption. When a device is actively performing its primary purpose (audio amplification for audio devices and optical disk reading for optical disk players), it is in an active state. The power consuming circuits within the home audio device include amplification of audio, detection of signals from remote controls, optical disc motors, signal processing, and displays. However, advanced devices can possess even more power-consuming circuits, including networking with other devices within the home and communicating with cloud servers. Active mode is where the highest power consumption is expected. However, devices do not spend the majority of their operating life in this mode.

The next operating mode, idle mode, is when the device is not performing its primary purpose but is fully powered on. A device is considered in this mode when input signals are removed but the device has not been turned off nor transitioned into a sleep mode. In this mode, the typical power consuming circuits are the same as active mode with the exception of circuits actively involved in the primary purpose of the device. Those exceptions include motors to spin optical disks, amplifiers involved in audio signals, and video processing.

The third and final mode is standby mode. Standby is the mode of a device which has turned off, either manually or automatically after a period of no activity. However, some devices have a distinct difference between off and standby. When a device is off, it consumes zero energy. However, in standby mode, some power consuming circuits are still operating including remote control functionality, power supplies, clocks, and preserving data stored in memory. Standby mode consumes less power than idle mode. When auto power down features are enabled, standby mode is where the device spends the majority of its operating life.

This study will assess each of these three modes for efficiency opportunities.

Test Method Development

Effective analysis of each state of operation requires a test procedure that is able to capture a number of relevant measurements and compare them to the other products tested. These measurements included active mode power consumption at various loading levels, the power consumed by the device in both idle and standby mode, and finally the amount of time a device waits after input signals are removed before transitioning into standby mode. Only devices that provided audio amplification were evaluated in active mode. Therefore, optical disc players were not evaluated in active mode.

An assessment of current home audio test methods found that there were relatively few test methods available. Many test methods were purpose-built for non-efficiency testing, including functionality testing after installation of audio systems (studios and homes) or fault diagnostic testing to investigate faulty electronics within an audio device. The ENERGY STAR home audio test method appeared promising for efficiency testing as it provided the means for an analysis of home audio products and captured the majority of electrical data points desired for this analysis. In all ENERGY STAR tests, power measurements are taken between the plug and the electrical outlet.

Modification of Active Mode Test Method

The ENERGY STAR test method was designed to serve as a standardized test method for manufacturers to report the power consumption of their products while operating in each of the various operating modes mentioned above. Although the goals of this study were similar (to analyze the power consumption of home audio devices), the study needed to evaluate home audio devices at multiple levels of amplification because it was suspected that active mode efficiency improvements may not provide substantial savings at lower amplification. The ENERGY STAR test method only evaluated active mode energy consumption with a single data point. Therefore, the ENERGY STAR method for active mode would be modified to fit this requirement.

During the study, ENERGY STAR finalized a third revision of their test procedure with the help of a number of prominent audio companies such as Bose, Sony, and Lab Gruppen. This was beneficial to the study because the conversations between ENERGY STAR and the contributors were published and contained a number of excellent suggestions regarding how to conduct home audio testing. (US Environmental Protection Agency and US Department of Energy 2012)

The changes made to the active mode testing portion of the test procedure are discussed within the following section.

Audio Efficacy

To accurately record the power consumed by a device, the study needed to capture the amount of power required to produce the same effect on the end user; i.e., the same audible signal. Electrical measurements inaccurately gauge this because speaker design and the frequency response of the device can influence the user's perception of the audible signal.

The study needed to adopt an *efficacy* measurement in place of an *efficiency* measurement to capture this. *Efficacy* measurements are well known to lighting experts. Lighting measurements are expressed in terms of luminous efficacy, or how well humans perceive the light emitted from a source. In the case of lighting, efficacy is a popular measurement as it compensates for how the human eye perceives variations in wavelengths. Efficiency measurements, lumens per watt, do not capture this behavior.

The human ear perceives sound differently than a spectrum analyzer. This is because the human ear perceives very high and low frequencies as less loud than mid-range frequencies. This important aspect needed to be captured by this study. The overall design of the device including speaker design, speaker efficiency, and post processing of the audio source has an impact on the overall perception of the end user. For example, lower quality speakers and devices with a lot of filtering alter the frequency response of the output. This may cause a user to change the gain of a device to get the same level of perceived loudness. This gain adjustment must be captured to provide a proper comparison among devices.

Testing using an efficacy measurement allows testing of home audio devices without deconstruction. Efficiency measurements require disassembly of the device so measurements are collected between the speaker and the device. In compact devices, identification of this measurement point requires basic knowledge of the circuit design and is not something the investigators possessed.

Efficacy testing is more difficult to conduct than efficiency testing, as there is a potential for error in the frequency response of the test chamber, the impact of slight variations within the room between tests, and the noise level in the room. While these variations may have occurred, this study worked to minimize any changes between tests. The room used in testing had an ambient sound pressure level of about 40 dB. 40 dB is commonly related to a quiet room. (sengpielaudio n.d.)

Amplifier Load

In order to conduct testing to determine the efficacy of each product, the investigators modified the ENERGY STAR test procedure to include speakers. In the ENERGY STAR test method, resistors are the standard load for devices where the manufacturer does not include speakers. However, this would not provide an audible signal required for an efficacy measurement. Therefore, all active mode testing was performed using either the speakers included with the device or a set of reference speakers described in the testing section.

Audio Source

The characteristics of the audio source used in testing were of much discussion between contributors during the refinement of the ENERGY STAR test method. The ENERGY STAR test method uses a commonly used test input for audio equipment, a 1-kilohertz signal. However, some contributors argued that this was not a realistic input signal. Bose commented that typical audio spends the majority of its time near peaks. (US Environmental Protection Agency and US Department of Energy 2012) A 1-kilohertz sine wave does not capture this behavior. In response to a suggestion by another contributor to use pink noise, Sony added that pink noise was not a desirable alternative to the sine wave method as it has high peak levels, a wide frequency response, and constantly varying frequency and peaks. Additionally, Lab Gruppen suggested their own proprietary signal consisting of timed bursts of varying amplitude. The discussions between contributors make it clear that there is not a consensus on this topic.

Lower frequencies require more power to amplify because of the increased energy content of the wave. Therefore, it is unlikely that a 1-kilohertz input signal will capture typical home audio behavior. However, determining a standard audio source is difficult because of differences between the frequency response of different styles of music, television programs, and movies.

We selected this as an area for potential improvement in the modified test procedure. The study used pink noise as it spans the frequency range of 20 Hz to 20-kilohertz and is closer to expected audio behavior than a 1-kilohertz tone. Alternative input sources may be more realistic, but pink noise is easily characterized. We felt it was an acceptable choice for our test.

Loading Setpoints

The ENERGY STAR test method uses a single test point defined as 1/8th of the maximum output that a home audio device could provide without going over a certain distortion level. In order to avoid missing any loading impacts on the efficacy measurements in our study, it was determined that the tests would be performed at a number of different output levels from barely perceptible in the testing environment (45 dB) to loud (100 dB). This method provided the data required to capture any loading related questions such as how each device performs at various volume levels.

Testing

We tested thirty-five home audio devices, including five audio video receivers, three subwoofers, nine power speaker varieties including docks and bookshelf systems, four Blu-ray speakers, four home theater in a box systems, four computer speakers, and six soundbars. The division of home audio products tested is shown in Figure 1. Each device was selected to represent some portion of the home audio market. This was not intended to be a statistical representation of the market, but rather a collection of currently available products. Less than a third of these home audio devices were ENERGY STAR-qualified.

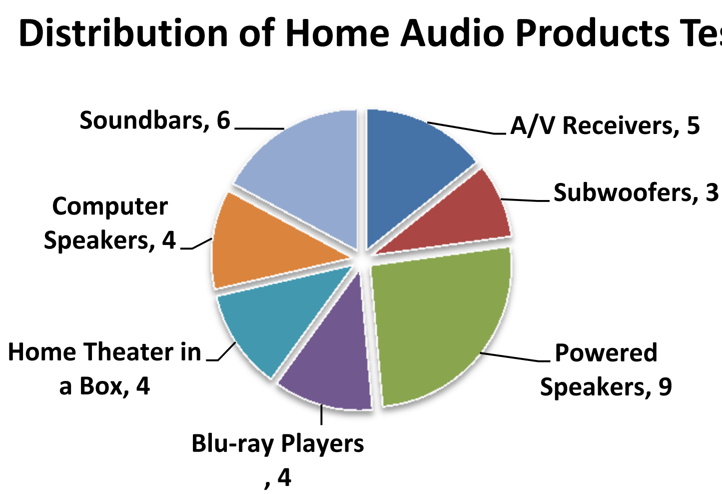

Figure 1. The distribution of home audio devices within each category.

Active Mode Testing

All the devices except for receivers include speakers. Receivers were tested with a set of Polk Audio Monitor 60s on the left and right channels, a Polk Audio CS20 on the center channel, and any remaining speakers, Polk Audio Monitor 30s. Receivers were tested with the number of speakers supported. Stereo receivers were tested with two speakers; surround sound receivers were tested with five to seven speakers.

This study used a sound pressure level (SPL) meter to measure the combination of audio output from the device under test and the ambient noise in the room. SPL meters measure the change in pressure from a sound wave. SPL measurements were selected because they are used as the standard method for OSHA sound level requirement testing.

As previously mentioned, the frequency response of the human ear is not perfectly flat because it perceives very high and low frequencies as less loud than other frequencies. However, SPL meters can apply weightings to the measurements to compensate for this variation. Though not calculated in this study, the dBZ measurement allows for the calculation of sound power. The most common measurement found on SPL meters is the A-weighted measurement denoted by the unit dBA. This measurement weighs each frequency how the human ear perceives it. It is the standard unit for OSHA standards.(U.S. Department of Labor n.d.) dBA will be used as the primary measurement for efficacy in this study.

The sound pressure meter used in this study is the SoundPRO-DL-2-1/3-10 Class/Type 2. During testing, the sound pressure meter was positioned two meters from each speaker.

Audio Source

The audio source used in this study is a 20-hertz to 20-kilohertz pink noise signal. An optical disc player transmitted this to the device under test. The same optical disc player was used for each test. The study makes no differentiation between HD and SD audio sources. The default input for this study is the highest definition input accepted by the device under test. There may be differences in power measurements between the various HD and SD audio sources however; the difference would depend on the electrical design of the audio device.

Testing Environment

Testing was conducted in a carpeted room with heavy cloth curtains surrounding the test area. All unnecessary items were removed from the room to reduce sound reflection; however, complete reduction of reflection is not possible without a specially designed room. Remaining items in the room were the same for all tests. SPL measurements in the room indicated that ambient noise was around 40dB. Sources of ambient noise included the power supply (located outside of the curtained test area) and noise from surrounding areas.

Idle and Standby Mode Testing

The sample set of home audio devices for idle and standby mode testing were the same devices tested in active mode. Devices were first powered on and left for fifteen minutes until power consumption remained steady. This ensured that the device had concluded initializing. All input signals were turned off, placing the device into idle mode. The power consumed by the device was recorded over two minutes and the average was taken as the idle mode power consumption. The device remained in idle mode until it automatically powered down. Two measurements were taken for standby mode, power and the total time elapsed between ceasing of all primary functions (removal of input signal) and when the device automatically powered down. The power consumed by the device was recorded over two minutes and the average was taken as the standby mode power consumption.

Results

Active Mode Testing – Class-D Amplifiers

Home audio devices are known to not dramatically increase in power consumption until higher volumes (Assessment of Emerging Technologies June 2009). A common assumption is that energy consumed by a home audio device gradually increases as volume is increased. Amplifier theory states that to double the gain, the input power must increase ten-fold. A two-times increase in gain is associated with an increase of 10 dB. Therefore, an increase of 10 dB requires ten times the power. It makes sense that to increase the volume from 50 dB to around 100 dB the amplifier power will increase approximately 10^5. Therefore, there should be significant energy savings opportunities in active mode. However, testing performed by Ecova found this to be false. They found that the power consumption of the circuits involved in amplification of audio signals is negligible at lower listening volumes. (Assessment of Emerging Technologies June 2009) It is not until higher listening volumes that the increase in power at larger gains is visible. However, power consumed by the device is a combination of the amplifier and other power consuming circuits. Therefore, it is unlikely that efficiency improvements at lower listening volumes will have substantial impacts in the overall energy consumption of home audio devices.

The receivers selected for testing contained both class-D and class-AB amplifiers. Class-D amplifiers provide an opportunity for energy savings over class-AB amplifiers by using fast switching techniques (completely on or completely off) to limit the device's losses when reproducing sound. Figure 2 shows the data from this portion of the study. The results confirm that class-D amplifiers are able to provide significant energy savings, but the savings are not likely to occur until around 80 dB. This is because below 80-db, the energy consumption of the amplifier is negligible compared to the other energy consuming circuits. Given that the EPA has identified 70 dB as the maximum listening volume to protect against hearing loss, it is likely that the majority of end users will operate home audio devices well below the 80 dB point and will not realize the benefits of a more efficient amplifier. (United States Enviromental Protection Agency n.d.) Additionally, in Bose's comments to ENERGY STAR they say that their data supported that 1/8 MUP was much louder than a typical end users would use on home audio devices. 1/8 MUP is typically on the higher end of the SPL measurements. However, because distortion has been accounted for in MUP by ENERGY STAR's test procedure, the sound pressure at 1/8 MUP will vary depending on the quality of the amplifier and speakers.

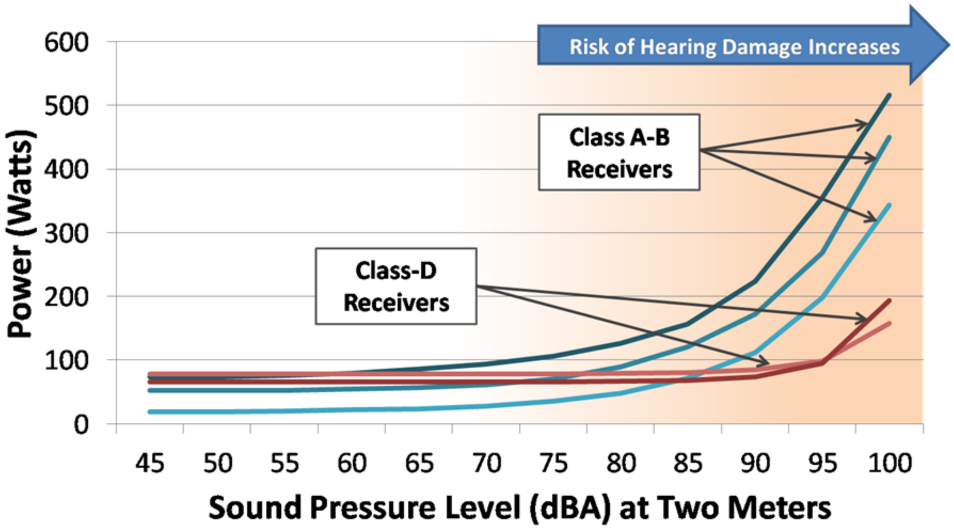

Figure 2. Power consumed by A/V receivers at each of the twelve test points.

Nevertheless, the use of class-D amplifiers demonstrated savings upwards of 70% in four surround-sound receivers that were evaluated in this study. This calculation does not take into account the single stereo receiver as its power rating was less significantly than the other four.

Impact of Non-Amplification Features – Active, Idle, and Sleep Mode

During the study, the investigators approached manufacturers to determine the type of amplifier used. However, none of them would release this information. While selecting products to test, it was noticed that manufacturers only advertise the use of class-D amplifiers when they are included in their premium products. However, it is commonly known that many inexpensive home audio devices likely use class-D amplifiers because of the amplifier's low cost and compact design.

Interestingly, the two receivers known to contain class-D amplifiers contained a number of other non-amplifying features such as networking capabilities, additional downloadable features (Pandora, online-radio), and other advanced features. In Figure 2, the two class-D devices have higher idle power consumption than the other units and this is likely because of these advanced features. The receiver with the lowest energy consumption was the only stereo receiver (two speakers). The rest of the A/V receivers were five to seven speaker systems. The stereo receiver was part of a family of budget receivers that contained no additional features in addition to audio amplification. Therefore, the home audio devices advertised as having efficient amplifiers actually consumed more energy at lower listening volumes.

Therefore, it may be easier to reduce the energy consumption and/or add power management to shut down unused circuits. It is likely that class-D technology will continue to be adopted in applications where device design is limited by available power (battery-powered devices) or size. However, it may not be apparent without opening the device to identify the type of amplifier used.

During the soundbar testing, one particular device (soundbar-one) stood out in terms of standby power. This is shown in Figure 3. This particular soundbar used over five times the power of other soundbars tested. Interestingly, this device was the most advanced out of all of the soundbars and included networking features. This increase is significant to the average household's energy consumption. To put it in perspective, the average American watches approximately thirty-four hours of television per week. (Hinckley 2012) Assuming that soundbar-one spent the remaining time in standby mode, it would consume an additional thirty to thirty-five kilowatt-hours compared to the other devices over a given year. If soundbar one's design was modified to reduce its standby power to that of the other five tested, it would see a 75-90% reduction in standby energy consumption.

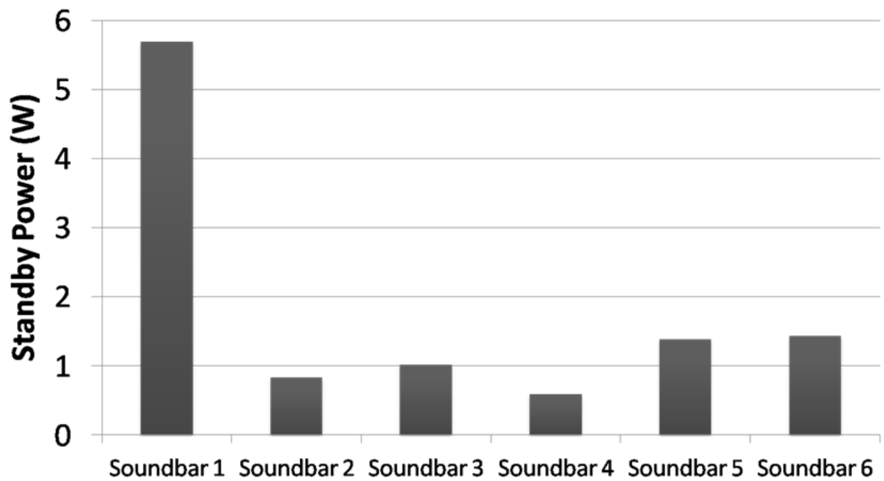

Figure 3. Standby power measurements for each of the six soundbars tested.

Importance of Standby Mode

As previously mentioned, the amount of television watched by Americans accounts for about 20% of their year. (Hinckley 2012) Many categories of home audio devices are connected to televisions including soundbars, receivers, and home theater in a box systems. Therefore, if it is assumed that Americans also spend about the same amount of time using their home audio device, then the typical home audio product spends the vast majority of its operational life inactive. It is important for electronics to have an auto power down feature because they spend such a large portion of their operating life inactive. This concept is captured in policies such as George Bush's Executive Order to mandate standby consumption for products purchased by federal agencies (Executive Order 13221 of July 31, 2001 2001), California's 2005 appliance standards that limit external power supply standby power (American Council for an Energy-Efficient Economy 2007), The Energy Independence and Security Act (EISA) of 2007 which among other things established maximum standby power consumption for external power supplies (Appliance Standards Awareness Project n.d.), and the recently updated European Commission mandate that limits standby power for household and office equipment (National Measurement Office n.d.).

Out of the thirty-five products tested, nine did not have a sleep mode timer as a default setting. One of the nine devices had an auto power down feature; however, it had to be activated by the user and was not default. We suspect cost was a driver for excluding auto power down functionality, but there was not a strong correlation between cost of home audio devices and the availability of auto power down. The highest-end device tested, a $2,500 state-of-the-art receiver, did not have auto power down timers. None of the computer speakers tested had an auto power down feature. All of the sound bars, home theater in a box systems, and Blu-ray players that were tested had auto power down timers. Twenty-five of the devices tested had a standby power of less than one watt. Following the assumption that home audio devices spend 80% of their time in a non-active state, incorporating some form of auto power down timer and reducing standby to one watt can provide energy savings as a high as 90%. However, the energy saved is highly dependent on whether the device already incorporates an auto power down timer and the power consumption of the device in idle mode.

Conclusion

The results shows that though sleep mode timers, idle mode power reduction, and active mode efficiency improvements are all feasible energy savings methods, it is likely that the idle mode and sleep mode improvements will have the largest impact due to the amount of time these devices spend in each state.

This study identifies sleep mode timers as low hanging fruit for efficiency improvements. Home audio devices spend the majority of their operating life in a non-active state. Though idle mode improvements have the potential to decrease energy consumption, off mode timers can reduce the time a device spends in idle mode. Thus, further research is needed on sleep mode timers and reducing sleep mode power consumption with particular attention to obstacles related to sleep mode (reduced response rate to external stimulus including remote controls and reduced functionality of the device such as networking capabilities).

Idle mode improvements are expected to have the second highest impact for home audio devices. This is because power-consuming circuits operating in idle mode are also operational in active mode. Therefore, any reduction or efficiency improvement to these circuits will also decrease active mode power consumption. Further research is needed on the power consumption of various non-amplifying elements within home audio devices and whether there are best practices for implementing efficient alternatives without sacrificing functionality.

Finally, the study showed that class-D amplifiers provide significant energy savings. However, the majority of consumers may not see any of the impacts because they likely operate their devices at lower gain levels. This study focused on residential applications however, there may be potential for class-D amplifiers in high power amplifiers found in commercial applications such as those used for continuous audio playback at high gain. These types of units are found in auditoriums, department stores, and even in outdoor applications such as stadiums where significant noise pollution has to be overcome. In these applications, class-D amplifiers are likely to provide significant energy savings because audio amplification has the potential to become the dominant consumer of electricity compared to those circuits found in idle.

Home audio has the potential to become a much more efficient portion of miscellaneous electric loads. Measuring audio efficacy is an important addition to data collection when informing energy policy for audio devices.

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