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Aggios-NRDC All-In-One Computer Idle Power Analysis - May 23 2016

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All-In-One Computer Idle Power Analysis

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AiO Idle Power Analysis

Introduction

The aim of this project was to compare the power consumption of typical All-in-One (AiO) computers, in order to assess energy efficiency strategies employed by each manufacturer. We focused on the those states in which the computer is not in use, i.e. idle, sleep, and off.

The idle state is defined as in the Energy Star 6.1 standard where short idle and long idle are being distinguished. In short idle, the computer is inactive with the display active. Long idle is when the computer is inactive, but the display is suspended.

The sleep state is a state in which the operating system (OS) has suspended itself, keeping the memory powered in order to quickly resume when needed. The computer still requires power in this state.

The off state is the state where the OS has shut down. The computer no longer requires power and it is safe to disconnect the power cord, but typically the computer will still offer some wake-up capabilities in this state so the power consumption is not zero.

We also looked at the power consumption for more realistic idle conditions a typical user would experience, based on the real-world-idle definition in the CASE initiative addendum from Aug. 3rd, 2013.¹

¹ http://www.energy.ca.gov/appliances/2014-AAER-01/prerulemaking/documents/comments_12-AAER-2A/

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Devices Tested

The devices chosen were one iMac and one Windows based all-in-one computer with similar specifications:

	Apple iMac	Lenovo B40-30
Model Number	A1418	B40-30
Display	21.5", 1080p IPS Display	21.5" 1080p IPS Display
Processor	Intel i5-4570R at 2.7GHz 65W TDP 4th generation Intel Core i5	Intel i5 4460T at 1.90GHz 35W TDP 4th generation Intel Core i5
RAM	2 DIMMs of 4GB, DDR3 1600MHz	1 DIMM of 4GB, DDR3 1600MHz
Storage	HGST 1 TB SATA HDD, 5400RPM, 2.5" (Model: HTS541010A9E662)	Seagate 1 TB SATA SSHD ² , 7200RPM, 3.5" (Model: ST 1000DX001) 8GB SSD Memory
Optical Drive	N/A	DVD-RW
Ports	4xUSB3.0, 2xThunderbolt, 1xSD-Reader	2xUSB3.0, 3xUSB2.0, 1xHDMI, 1xSD-Reader
Operating System	Apple OSX 10.10.5, (Yosemite)	Microsoft Windows 10
PSU rating	180 W	120 W
Energy Star 6.1 Compliant	Yes	No
Date purchased	Purchased in Aug'2015	Purchased in Oct'2015
List price (before any discounts)	\$1299,-	\$926,-

² Hybrid solid state and hard disk drive.

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Test Setup

The test setup consisted of an AC power meter, a data acquisition device (DAQ) for DC power measurements, as well as a DC electronic load.

Equipment used:

Yokogawa WT310 Digital AC Power Meter

Keysight U2356A Multifunction Data Acquisition (DAQ) device

Steren 602-270 Digital Multimeter

BK Precision 8510 Programmable DC Electronic Load

50 m Ω , 3W Shunt Resistor

Software used:

TECHPOWERUP ThrottleStop 6.00

Primate Labs Geekbench 3

The software used to evaluate the All-in-One computers were TECHPOWERUP ThrottleStop 6.00 and Primate Labs Geekbench 3. ThrottleStop was used to determine the idle state distribution of the processor. The single and multicore performance of the All-in-One computers were determined from Geekbench.

The Yokogawa WT310 Digital AC Power Meter was used to measure the AC power consumption of the computers. The AC power meter was used with the Yokogawa WTViewerFreePlus software to record the AC power consumption of the computers at each time interval, and to adjust the sampling rate of the measurement. Recorded measurements from the software were saved in a CSV file. Sampling rate for the AC power measurements were recorded at 250ms.

The BK Precision 8510 Programmable DC Electronic Load is used to measure the efficiency of the power supply (a.k.a power adapter) of each computer, by generating a DC power load to the output. DC power is adjusted by programming the voltage, current, and power settings in the device. In this

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project, the programmable DC electronic load device was used to generate DC power on the AiO power adapters. DC power was generated by adjusting the “P-Set” settings of the electronic load. In “P-Set” mode, the user may adjust the DC power output to a desired power level. For this project, the programmable DC electronic load device was set to low DC power ranges to determine idle efficiencies. In high load efficiency measurement, the device was adjusted from 25% to the maximum power supported by the power adapter.

The Keysight U2356A Multifunctional DAQ device is a high-speed 64-channel digital multimeter, and simple scope function. For the purpose of this test, the DAQ device was used with the Keysight Measurement Manager for data logging the DC power consumption of each SATA components in the computer. Since the device is limited to input voltages of 10 V, DC power measurements of the components were determined by attaching a 50mΩ shunt resistor to the ground line of the SATA power cable. The shunt resistor was used to determine the current traveling through the wire. By applying the Ohm’s Law equation, the DC power was calculated by using the measured voltage of the power cable multiplied by the current of the shunt resistor. To record the DC power consumption, a scaling factor was calculated by using the measured voltage of the shunt resistor divided by the DC power produced on the wire. The scaling factor inside the Keysight Measurement Manager were adjusted to the computed result.

$$I_{shunt} = V_{shunt} / R_{shunt} \text{ (Eqn. 1)}$$

$$P = V_{actual} \cdot I_{shunt} \text{ (Eqn. 2)}$$

$$\text{Scaling factor} = V_{shunt} / P \text{ (Eqn. 3)}$$

Voltage measurement of the shunt resistor and computer component, were measured from a digital multimeter.

Measurements

The following aspects were evaluated:

- System performance
- System AC power consumption in idle states
- System AC power consumption in real-world idle
- Component DC power
- Power Adapter efficiency
- Processor C-States

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System Performance

The AiO computers performance was measured in order to ensure that any potential power savings were not achieved by compromising performance. The benchmarking software Geekbench 3 from Primate Labs was used to determine the performance as that software is available on Windows and MacOS, in both cases the “64-bit benchmarks” option was selected. The benchmark results of the computers are shown in the table below.

	Apple iMac	Lenovo B40-30
Single-Core Score	3200	2496
Multi-Core Score	10400	7311

Table 1: GeekBench 3 benchmark results for the Apple iMac and Lenovo B40-30

Idle Power Measurements

Before the test, each computer was powered on for at least a day to ensure that the system completed any initial software updates and maintenance tasks.

In this test the All-in-One computers were left at their default settings, the values were measured without any open applications.

The same Lenovo-default desktop wallpaper was loaded to both computers to ensure a fair comparison. The image used saves 2W of power when compared to the iMac’s default background image. As most users are likely to adjust the background image to their preference, we assumed that the same user would choose the same background image regardless of which computer they purchased.

The AC power consumption of the computers were measured in short idle, long idle, and sleep states. For measuring short idle, the computers were left inactive for three minutes before measurements were recorded. To measure long idle, the display option for the monitor of the computer was adjusted to one minute. Long idle measurements are recorded three minutes after the display is suspended.

The AC power measurement of each computer was recorded at a sampling rate of 250ms. The measurements were repeated at least five times. For each measurement run, the AC power consumption was recorded by averaging the measurements over the test period.

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As we noticed that the antivirus software (McAfee) of the Lenovo PC appeared to be constantly busy, we also repeated the measurements with the antivirus software disabled, resulting in a significant reduction of the power consumption in both short and long idle. For a fair comparison we also measured the Lenovo PC's power with the antivirus software removed. The iMac on the other hand does not come with any antivirus software pre-installed.

In their sleep state, power is still required in order to power the DRAM memory, which is being kept in an energy-efficient self-refresh state. Additionally power is being consumed in order to keep Bluetooth connections active for communication with the keyboard, as the computers can be woken up via keyboard.

Both computers still consume power when turned off but plugged in. This is most likely due to wake capabilities, such as timer-wake, as well as Ethernet wake (Wake-on-LAN), despite such features not being enabled.

	Apple iMac w. original background	Apple iMac w. Lenovo background	Lenovo B40-30 with Antivirus Enabled	Lenovo B40-30 with Antivirus Disabled
Short Idle	24.1 W	22.1 W	46.9 W	37.3 W
Long Idle	9.1 W	9.1 W	27.9 W	16.8 W
Sleep	1.4 W	1.4 W	1.2 W	1.2 W
Off	0.5 W	0.5 W	1.2 W	1.2 W

Table 2: Idle measurements of Apple iMac and Lenovo B40-30

Real-World Idle Measurements

The purpose of the real world idle measurement was to determine the idle power consumption of the computer under representative use. In the Energy Star 6.1 standard, short idle implies that the user does not have any background windows opened or processes active before the computer reaches the idle state. To determine the possible idle conditions of a typical user, the idle consumption of the computers was measured in three real world cases where the average user may have the web browser and standard application windows (Microsoft Word, PDF reader, Windows

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Media Player, and Windows Explorer) opened. The different scenarios are outlined in the table below.

	Description
Energy Star	No background process active or windows opened.
Real World A	3 Google Chrome tabs opened (Google homepage, GMail, NY times op-ed), 3 Word windows (3 generic Word templates), 1 PDF document opened from a generic reader, a Windows Explorer tab opened on the C: drive, and an AVG antivirus suite running in the background without scanning.
Real World B	Continuation of Case A, but with three additional web content opened on the browser (LA Times homepage, Amazon.com homepage, and a user login Facebook newsfeed).
Real World C	Resumption from Case B with Pandora in the browser tab to determine.

Table 3: Real-world idle scenario definitions

Our measurements revealed different behaviors between the two computers. The iMac exhibited a 7 Watt increase in short-idle only, while the Lenovo's power consumption increased by only around 3 Watts but in both the short and long idle states.

	Apple iMac		Lenovo B40-30	
	Short Idle	Long Idle	Short Idle	Long Idle
Energy Star	22.1 W	9.1 W	37.3 W	16.8 W
Energy Star with equal brightness³	28.1 W	9.1 W	37.3 W	16.8 W
Real World A	29.0 W	9.3 W	40.5 W	19.2 W
Real World B	29.5 W	9.3 W	40.7 W	19.4 W
Real World C	29.8 W	9.4 W	40.9 W	20.4 W

Table 4: Measurements under real-world idle conditions

³ iMac auto brightness control (ABC) disabled and manually set to same brightness as Lenovo machine

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Component Power Measurements

The power consumption of the SATA drives and the displays of the AiO computers was measured to determine the contribution of those components to the overall power consumption of the computers.

The SATA components measured for the Lenovo B40-30 were the SSHD hybrid drive, and the optical drive. The iMac is equipped with an HDD only.



Figure 1: SATA DC power measurement test setup

To measure the DC power of the SATA components a DAQ device was connected to shunt resistors on the SATA power cable. The measurements were recorded at a sample rate of 10ms and averaged over 1 minute.

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iMac HDD

	Short Idle	Long Idle
5 V	-	-
12 V	1.68 W	0.5 W
Total	1.68 W	0.5 W

Table 5: iMac HDD DC power

Lenovo SSHD

	Short Idle	Long Idle
5 V	0.19 W	0.13 W
12 V	3.18 W	3.25 W
Total	3.37 W	3.38 W

Table 6: Lenovo SSHD DC power

Lenovo Optical Drive

	Short Idle	Long Idle
5 V	0.08 W	0.08 W
Total	0.08 W	0.08 W

Table 7: Optical drive DC power measurement

Display Power

The power consumption of the displays of the AiO computers was determined by measuring the AC power of the AiO computers after disconnecting the built-in display and connecting an external display instead.

The iMac was shipped with auto-brightness control enabled, which adjusts display brightness to ambient lighting conditioned, whereas the Lenovo B40 was shipped with display brightness set to maximum. We first tested the two computers in typical office lighting conditions with display brightness settings as shipped, then disabled auto-brightness control on the iMac and manually set it to equal the brightness of the Lenovo.

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	Apple iMac	Lenovo B40-30
Effective Display Power Consumption (DC)	7.1 W	17.0 W
Effective Display Power Consumption, equal brightness	12.3 W	17.0 W

Table 8: Effective display power consumption of Apple iMac and Lenovo B40-30

For the remaining components, such as CPU, motherboard, memory, we have not been able to measure each of them individually due to the compact design of the motherboards. Nevertheless, we are able to estimate the power consumption of the CPUs based on their C-states reported in the short idle state.

Component Power Breakdown

	Apple iMac	Lenovo B40-30
Display	7.1 W	17.0 W
HDD	1.7 W	3.4 W
PSU	3.8 W	4.8 W
CPU (est.)	4.0 W	3.8 W
Motherboard + Memory (est.)	5.6 W	8.3 W
Total	22.2 W	37.3 W

Table 9: Component power breakdown in Short-Idle

Power Supply Unit (PSU) Efficiency Measurements

The purpose of this task was to determine the efficiency of the power supply (a.k.a power adapters) used in the AiO computers. Efficiency of the adapters were observed in idle and high DC load configurations.

The DC load was generated using a programmable DC electronic load attached to the output terminal of the power adapters. The AC power was measured at each DC load using the AC power meter. The AC/DC efficiency of the power adapter was determined by dividing the induced DC power by the measured AC power.

For the efficiency measurement of the B40-30 power adapter, an external female module was connected to the output terminal of the power adapter. The positive terminal of the power adapter was connected to the positive channel of the programmable DC electronic load, and negative terminal to the negative portion of the channel. The DC load was adjusted from 2W to 12W to simulate idle conditions. To determine the efficiency of the power adapter in high DC load, the DC power was set at 25% to 100% (i.e. 25%, 50%, 75%, and 100%) of the supported nominal power rating. For example, the B40-30 nominal power rating is 120W, at 25% load, the programmable DC load is set to 30W. AC power consumption of the power adapter was recorded from reading the display of the AC power meter, while the DC power was displayed on the electronic load.

Since the iMac has an integrated power adapter, it had to be disassembled in order to gain access to the power adapter. The positive and negative channels of the power adapters were connected directly to the programmable DC electronic load device. Efficiency of the power adapter was determined by following the same procedures as the B40-30.

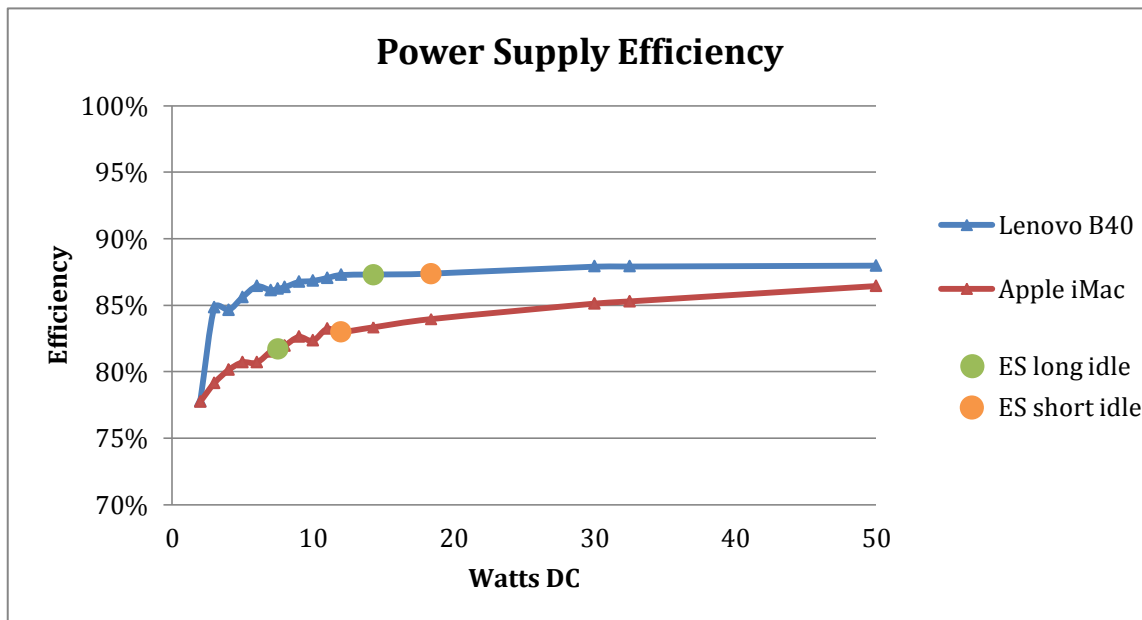


Figure 2: Power adapter efficiency from low load to 25% load

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Lenovo B40-30 with clean OS installation

To determine the power consumption impacts of the preinstalled software for the AiO computers we did a clean install of the OS. This was not possible on the iMac as Apple doesn't enable users to install the OS from scratch. On the Lenovo B40-30 we did a clean installation of Windows 10.

A Western Digital Green 1TB HDD was used for the OS installed. That drive consumes 1 Watt less in short idle, and about 2.5W less in long idle, when compared to the Seagate SSHD drive built into the Lenovo AiO computer. The results below have been normalized to eliminate the difference in HDD consumption from this comparison.

After the standard OS installation procedure, the background of the computer was modified to the background image included by Lenovo. The AC and DC power measurements were conducted using the same equipment and procedures as the previous idle and component test.

	AC Power Fresh Windows 10 install	AC Power Pre- Installed OS	AC Power Pre- Installed OS with anti-virus
Short Idle	35.80 W	37.30 W	46.94 W
Long Idle	16.95 W	16.77 W	27.93 W

Table 10: Windows 8 idle measurements for the Lenovo B40-30

From the measured results, the power measured for the Lenovo B40-30 with the clean OS installed demonstrated a lower power consumption than the pre-installed operating system in the short idle state, while there was no significant difference in long idle. The additional 1.5 Watts observed in the short-idle state can most likely be attributed to the pre-installed software included with the Lenovo AiO computer.

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C-State Analysis

In this step we analyzed the idle power states reached by the processors, also known as the C-States according to the ACPI standard. The C-States apply to both the core as well as the package. Core C-states specify the C-states of the CPU only (without caches, GPU, on-chip peripherals, etc) whereas the Package C-State involves the complete processor. The higher the C-state levels (C6, C7) the lower power they draw.

To identify the C-States reached, the software ThrottleStop was used on Windows. The enabled C-States were determined by reading out the reported C-state breakdown in ThrottleStop after allowing the computer to remain idle for five minutes, . For the iMac, the powermetrics command was used in the terminal to display C-State statistics.

The 4th generation Core-i5 CPUs used in these AiO computers both support the C7 and package-C7 state as the lowest possible power state. However, neither of the AiO computers was able to reach these states. According to the data reported by the software used, the iMac only reached a Core-C6 and Package-C3 state, while the Lenovo reached Core-C7 and Package C2, which basically indicates that either the rest of the system configuration does not satisfy the preconditions for entering those states, or they were not enabled on the software side.

Lowest C-States Observed

	Apple iMac	Lenovo B40-30
Lowest Core C-State	C6	C7
Lowest Package C-State	C3	C2

Table 11: C-State analysis for the Apple iMac and Lenovo B40-30

The motherboards used in the AiO computers do not have a separate 12V input for the CPU hence it is not possible to take dedicated power measurements for the CPU only. However, based on previous measurements with Intel Haswell processors used in desktop computers we have seen power savings of 2-3 Watts between the C3 and C7 package C-states.

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Apple iMac with Windows 8

In order to determine how much impact the MacOS operating system has on the power savings achieved by the iMac, we installed Windows 8 on the iMac. Similar to the Windows idle and C-state measurements, the same procedure and equipment was used for the measurement.

Installation of Windows 8 was performed on the iMac through the “Boot Camp Assistant” application included in MacOS. Hence the same hard drive is used for either OS on the iMac.

In short idle the iMac running Windows 8 showed an even lower power consumption than with MacOS, while MacOS was slightly more efficient than Windows in the long idle state.

	OSX 10.10.5 ⁴	Windows 8
Short Idle	22.15 W	19.44 W
Long Idle	9.14 W	10.72 W
Sleep	1.40 W	1.48 W

Table 12: Idle measurement for Apple iMac with OSX and Windows

Lowest C-States Observed

	OSX 10.10.5	Windows 8
Lowest Core C-State	C6	C6
Lowest Package C-State	C3	C6

Table 13: C-State analysis for the Apple iMac and Lenovo B40-30

The C-State analysis shows that Windows 8 is able to get the CPU into a lower idle state than MacOS, which most likely contributes to a significant portion of the power savings in the short idle state, as we typically see a 1 watt difference between the C3 and C6 package C-states.

⁴ The default Windows 8 setting for the iMac had been set to full brightness. Returning to OSX and measuring the computer with the same brightness setting, the short idle power consumption is 35.24W.

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Wake-up Latencies

On stationary computers that don't use a battery, users are typically less motivated to keep power management features enabled. One critical factor here are the latencies observed when waking up out of sleep mode. The quicker the wakeup latencies are, the less likely it is that power management (such as automatic display switch off and automatic transition to sleep mode) will annoy the user, and the user will disable this energy savings feature.

Latency measurements from sleep and long idle to active state were performed to determine the responsiveness of the two computers.

The latency from long idle to active state was determined by opening an image file when the system is in long idle. A previously unopened image was transferred to the computer to avoid system cache files. Once the system entered long idle, a timer was used to record the time it would take for the computer to reach active state from opening the image file. The sleep to active state was determined by recording the amount of time it takes for the computer to transition from sleep state to active display.

The iMac displayed a faster wake up latency than the B40-30. Judging by the power consumption display on the Yokogawa WT310 AC power measurement, the B40-30 reaches the active state in less than one second. Most of the latency for the B40-30 is from the display activation time. The display of the B40-30 appeared to introduce a significant additional delay for the system to turn back on.

	Apple iMac	Lenovo B40-30	Windows8 on iMac
Sleep to Active	1.74 s	5.37 s	4.08 s
Long Idle to Active	1.35 s	4.22 s	2.5 s

Table 14: Latency measurement for Apple iMac and Lenovo B40-30

In order to assess the impact of the hardware on the wakeup latencies, we also repeated the same measurements using Windows 8 installed on the iMac. The results confirm that the display does appear to play a significant role. Nevertheless, MacOS still wakes up roughly twice as fast from Sleep as well as from Long Idle when compared to Windows when hardware differences are eliminated.

When strictly looking at the idle power consumption, Windows appears to have a slight edge over MacOS provided the same underlying hardware. However, even when factoring out the impacts of the faster display, MacOS wakes up from long idle about twice as fast as Windows, and 2.5 times faster from its sleep state.

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Given the significantly lower wake-up latencies of the iMac, users are much less likely to weaken or disable the default power management settings. Furthermore the default settings on the iMac were more aggressive than on the Lenovo, so that the iMac would go to sleep much faster than the Windows PC. Due to the low wakeup latency however the user does not notice the sleep state in the iMac. This in turn leads to the most significant effective power reduction when the user goes inactive.

Assuming that higher wake-up latencies will motivate more users to disable sleep, the effective energy used by the average Lenovo B40 will increase from 156kWh to 188kWh, while the effective energy used by the average iMac remains close to the original 105kWh, as illustrated in the chart below.

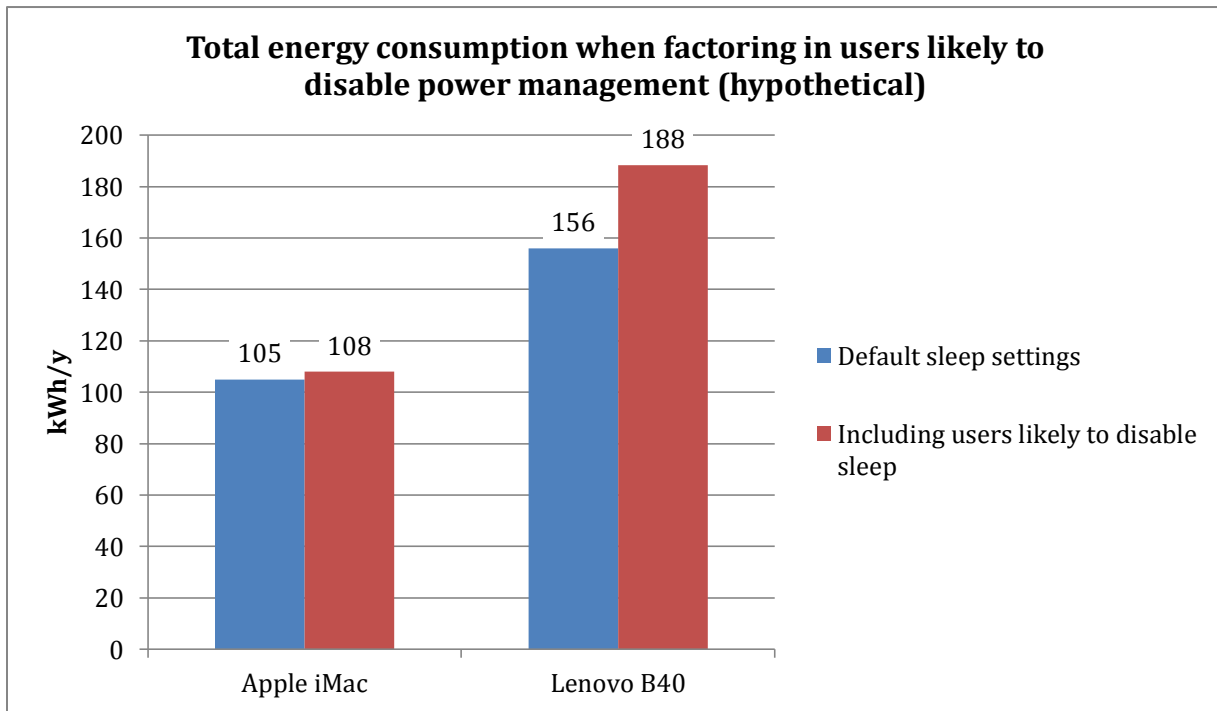


Figure 3: Effective energy consumption factoring in users likely to disable power management

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Summary

The analysis of the AiO computers in this project showed significantly lower idle power levels in the iMac compared to the Lenovo AiO PC. The reason for this difference however appears to stem less from the operating systems but primarily from the more energy efficient components and design used in the iMac.

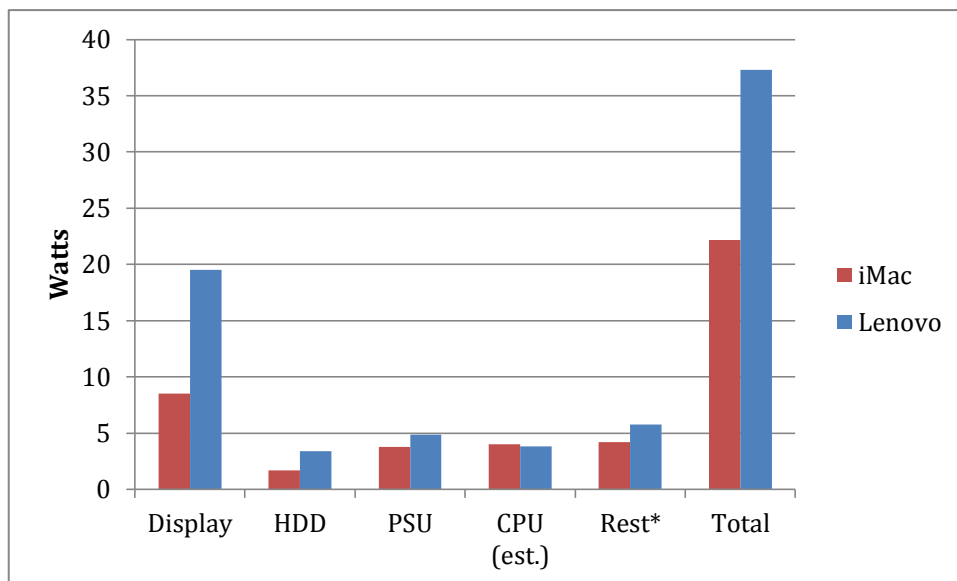


Figure 4 - Breakdown of component power consumption in Short Idle

Running the two different operating systems on the exact same hardware allows to eliminate hardware differences from the equation, however directly comparing the two operating systems regarding energy efficiency is still not straightforward, as the power in idle is not the only metric that impacts overall energy efficiency. Especially the faster wake-up from long-idle and sleep will impact users' inclination to disable or delay sleep or long-idle states, resulting in an even higher effective power consumption for the average Lenovo B40 PC.

Despite its better efficiency in idle, the iMac still leaves some room for improvement. It appears that the iMac we tested could be using less power by enabling the higher C-states in the CPU. The table below outlines a few of the opportunities for improving energy efficiency.

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Apple iMac A1418	Lenovo B40-30
Full utilization of Intel C-states, including package C7	Full utilization of Intel C-states, including package C7
More efficient power supply	Better display efficiency
	Ship display with auto-brightness control, instead of max brightness
	More efficient hard drive
	Reduce sleep wake latency and more aggressive power management settings (shorter time before auto-sleep)

Table 15: Opportunities for improving energy efficiency in the tested AiO computers

The higher performance and lower latency of the iMac show that higher efficiency does not necessarily impact performance, on the contrary in this case.

The iMac is significantly more expensive than the Lenovo, and this may explain part of the efficiency difference in some components, such as the display, however most of the efficiency improvement opportunities could be implemented at little or no cost, and are therefore not constrained by price.

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