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Desktop Computer Optimization Analysis and Demonstration Project

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FINAL REPORT V1.0

Desktop Computer Optimization Analysis and Demonstration Project

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Executive Summary

The project presented here was conducted in support of the pre-rulemaking proceeding by the California Energy Commission on computers, computer monitors, and signage displays proposed standards. The objective was to analyze currently available commonly used desktop computers and their idle-state power consumption and demonstrate the potential for power optimization through power management software and cost-effective hardware improvements.

The experiments conducted by the researchers have resulted in idle-state power savings on the analyzed desktops of 61% and 54% relative to out of the box configurations through software configuration changes and power supply replacement. The idle-state power consumption of 8.6W of the assembled and 9.7W of the commercial pre-assembled desktop achieves by a wide margin the power levels proposed in the CEC staff document [1].

The report identifies the processor power state configuration, hard disc drive power management and the power supply voltage conversion in idle as the main areas where the power efficiency of the desktops can be further improved.

The report recommends adding the specialized power optimization utility, like the one provided by the motherboard manufacturer MSI, to the standard software package shipped with every desktop computer. The high level cost analysis for the development and distribution of such software estimates the additional costs per computer sold in US at 4 cents for the initial year and 2 cent per year afterwards.

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Introduction

AGGIOS, Inc. is a California corporation devoted to deliver innovative products and services to improve the energy efficiency of mobile, plug load and internet of things (IoT) electronic devices. AGGIOS is engaged in product development, technical standard definition and codes and standards activities. AGGIOS is exclusively owned by its owners and takes pride in its ability to independently serve its most important goal: research and innovation to save energy.

Since 2013 AGGIOS is actively engaged in various energy related activities in California collaborating with the industry, energy efficiency advocates, and regulators. AGGIOS is a regular participant in conferences, workshops, proceedings and requests for comments issued by the California Energy Commission. The project presented here was conducted in support of the pre-rulemaking proceeding by the California Energy Commission on computers, computer monitors, and signage displays proposed standards.

This report presents the results of the analysis of short- and long-idle power consumption of three representative desktop computers currently available on the California market. It is a continuation of the previous analysis and research on set-top boxes [18] and notebooks [16].

Project Goals and Objectives

The goal of this project is the industry-wide reduction of energy consumption by desktop computers in the short- and long-idle states as defined by ENERGY STAR v6.

The global objectives are:

- Analyze the currently available commonly used desktop computers and their idle-state power consumption;
- Demonstrate the potential for power optimization of desktop computers through power management software and cost-effective hardware improvements such as power conversion;
- Collaborate closely with the computer industry, energy efficiency advocates and regulators to analyze and utilize the achieved results to support the ongoing regulatory proceedings;

The specific objectives are:

- Assemble two energy efficient desktop computers to explore the potential for reducing power consumption through changes in the OS power options, BIOS firmware, energy optimization tools and performance tuning utilities;
- Demonstrate that the performed software optimizations of the system have negligible effect on wake up latencies and system performance;
- Use a commercial small business desktop computer to show the possibilities of power management in fully assembled desktop computers available on the market today;
- Demonstrate the impact of using an efficient and right-sized PSU on the system power consumption in idle modes of the desktop computers;

Project Approach

Hardware selection

We have chosen to assemble two desktop computers from standard components available in popular computer stores and online in California. The first selected desktop (DT1a) is based on the motherboard MSI ECO H97M [2] and the second (DT1b) on the motherboard ASUS Z97 PRO [3]¹. The DT1a motherboard was specifically developed for energy tuning in hardware and software by the motherboard manufacturer and comes with energy oriented software utilities and hardware components suitable for that goal. The DT1b board is a high-end board and comes with extensive software tuning capabilities for performance tuning. With this board we expected to leverage the performance tuning capabilities for energy tuning in the short and long idle states.

We have also selected one representative off-the-shelf desktop computer (DT2) based on the ENERGY STAR[™] qualified products list [4] and its availability in computer stores in California. The selected desktop is the HP ProDesk 400 G1 MT [5] belongs to the class of desktops aimed at small-business and home office applications. Some configurations of this desktop are ENERGY STAR-qualified, however this specific configuration is not due to its standard efficiency power supply. It comes fully assembled with a keyboard and mouse, but without utilities aimed at energy or performance tuning. The ENERGY STAR information can be found here [6] .

During the project we identified the need for additional experiments with the AC/DC conversion efficiency and the benefit of a properly size Power Supply Unit (PSU) for short and long-idle operation. We selected the picoPSU-160-XT DC/DC converter [7] and the AC-DC 12V / 16A Switching Power Adapter (model STD-12160) [8] both from the California company Ituner Networks Corporation and their subsidiary Mini-box.com.

Test setup

This section describes the test setup for all three tested units DT1a, DT1b and DT2 including hardware setup, software setup and ENERGY STAR measurement setup [9] for idle state measurements.

Hardware setup

DT1a is an assembled desktop computer which consists of the following components assembled in accordance with the instructions that came with the motherboard [10]:

- Motherboard: MSI ECO H97M
- Processor: Intel i5-4690K
- RAM: 2 DIMMs of 4GB, DDR3 1600MHz (Model: BALLISTIX FH114HN.XR)
- Hard disk drive: Western Digital Blue 1.0 TB (Model: WD10EZEX - 00BN5A0)

¹ The research team was able to complete most of the planned analysis and optimization activities for the assembled DT1a board. Due to budget and time constraints not all the planned activities for the assembled DT1b board could be completed by the time this report was written.

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- Optical DVD drive (Model: HP SH-216DB/HPTHF)
- Power Supply: SeaSonic Platinum Series Fanless 400W (Model: SS-400FL2)
- Generic USB mouse and keyboard

DT1b is also an assembled desktop computer which consists of the following components assembled in accordance with the instructions that came with the product [11]:

- Motherboard: ASUS Z97 PRO
- Processor: Intel i5-4690K
- RAM: 2 DIMMs of 8GB, DDR3 1600MHz (Model: BALLISTIX BG112SH.3L)
- Hard disk drive: Western Digital Blue 1.0 TB (Model: WD10EZEX - 00BN5A0)
- Optical DVD drive (Model: HP SH-216DB/HPTHF)
- Power Supply: SeaSonic Platinum Series Fanless 400W (Model: SS-400FL2)
- Generic USB mouse and keyboard

DT2 unit is the pre-assembled commercial desktop computer HP ProDesk 400 G1 MT.

The following components are part of DT2:

- Processor: Intel i5-4690S
- RAM: 2 DIMMs of 4GB, DDR3 1600MHz (SK Hynix PC3-128000)
- Hard disk drive: Seagate 1TB (Model: ST1000DM003)
- DVD optical drive (Model: HP SH-216DB/HPTHF)
- Power Supply: Max output power 300W @ 25°C, Standard Efficiency (Model: HP D11-300N1A)
- PS/2 mouse and keyboard

Software setup

Definitions: We can distinguish three main states of the device w.r.t. the software configuration:

1. As-shipped state: software is kept as shipped, i.e. not changed by the user nor are any operating system (OS) updates performed on top what is delivered with the device;
2. Post-update state: software is first in the As-shipped state and then gets updated by the OS (from the OS DVD or web site) and all other recommended driver updates (from motherboard manufacturer DVD or web site) are performed; The configuration settings are kept as shipped;
3. Baseline state: software is first in the Post-update state and then the configuration is adjusted by the researchers using the standard OS options to reflect the typical user settings allowed by the OS; The Base-line state mimics as close as possible the power settings of a typical device user;

OS aging is defined as the period of time the device is allowed to:

- Automatically download and install all automatic OS updates;
- Finish all necessary maintenance operations required by the OS (update checking, indexing, etc.);

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OS aging is applicable to the Post-update and Baseline states and partially to the As-shipped state (excludes OS updates). During this project all the tested desktops were aged for 24-36 hours initially and after any major changes to the hardware and the OS. The aging progress was monitored through the computational load, process monitoring and preliminary power measurements.

BIOS: Below are the BIOS versions for each of the desktops:

DT1a: V26.1 (06/30/2014) version

DT1b: 1304 x64 (07/11/2014) version

DT2: L02 v02.36 (11/05/2014) version

OS: Operating system and driver installation

For DT1a and DT1b upon assembly the complete installation of the operating system was performed followed by the installation of the essential and updated drivers from both the Windows and motherboard manufacturer's support sites. This was necessary not only to enable basic functionality, but also to enable proper functioning of the OS power management. We have observed that the newest driver updates are essential for the power management of the desktops. For DT1a and DT1b we installed the following OS and drivers:

- Operating system: Windows Pro 8.1 X64
- Intel Graphics Drivers (version: 10.18.10.3574)
- Intel(R) Network connections (version: 19.1.51.0)

DT2 came with the pre-installed Windows 8.1 and all drivers. Before the measurements only the Windows Update was executed. The DT2 desktop included all HP pre-configured software that came with the product. Application background processes and OS system processes were not modified compared to the As-shipped state.

Software Utilities

The utilities installed are used for monitoring system activity and changing system settings in order to reduce overall power consumption. The software we have installed on all three desktop computers includes:

- Intel Extreme Tuning Utility – software application that provides system information, measuring performances of current setup (benchmarking), monitoring CPU parameters and allows the fine-tune settings of the processor;
- Windows Assessment and Deployment Kit for Windows 8.1 – include Windows Performance Toolkit which records system events by using Event Tracing for Windows and analyzes performance data in a graphical user interface.

DT1a specific software includes:

- MSI ECO Center Pro - is a motherboard configuration utility provided by the motherboard manufacturer MSI that is used to reduce the power consumption as well as tune the system performance.

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Standard test setup

For measuring the power consumption of desktop computers the following components and test conditions defined in [9] were set up.

- The desktop computers were configured in accordance with the instructions provided with the products, unless otherwise stated in the test procedure;
- The pre-assembled desktop included a PS/2 mouse and keyboard, while we used a generic USB mouse and keyboard for the manually assembled desktop computers. No other external peripherals were connected;
- An external 1080p computer display was connected;
- The sleep timer of the desktop computer was disabled to prevent the desktop from entering the sleep state during the idle tests;
- Since desktop computers have Ethernet support, they were connected to an active network switch that supported highest link speed supported by the units themselves;
- Alternative internet connection like Wireless was turned off;
- AC measurements: The HP-100 watt meter was placed between the main power supply and computer's power supply. No power strips or UPS units were connected between the meter and computer. The meter remained in place until all required power mode data had been recorded;

AC test procedure and instrumentation setup

Standard test procedure (ENERGY STAR v6)

The procedure defined in [9] to enter the relevant idle state was followed:

1. Switch on the desktop;
2. Once logged in with the operating system fully loaded and ready, close any open windows and wait for the system to enter idle mode;
3. Reset the power meter if necessary and begin accumulating true power values;
4. Accumulate power values for 5 min and record the average value observed during that 5 min period;

The standard test procedure is insufficient for reliable power measurements aimed to properly represent the actual power consumption of a desktop computer in the idle state over prolonged periods of use. The problem is in the numerous OS processes which randomly start or start as soon as the desktop enters the idle state. In order to reduce the impact of these processes on the power measurements and optimization we have followed these additional steps:

1. OS aging: the computers were connected to the internet for a certain time, usually 24 – 36 hours, before the measurements were conducted. This process allowed all necessary processes and updates to terminate before starting power measurements and optimizations.

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2. Windows update settings were configured not to install new Windows updates in order to keep identical configurations for all measurements.

3. It was observed that frequently after approximately 4 minutes in idle mode the “RanFulMemoryDiagnostic” system process would start automatically. This process typically uses ~25% of processor utilization (or one core) and takes a certain time which is dependent of the size of RAM memory used (about 10 minutes for 8 GB of RAM memory). In order to get correct measurements this process was terminated before the start of the measurements.

DC test procedure and instrumentation setup

DC power measurements

The standard test procedure deals only with the AC measurements of the desktop under test. For more detailed information about the power consumption the researchers needed the ability to determine the individual power consumption of the motherboard components and peripherals. This includes the motherboard, CPU, HDD, DVD and similar. Although all these components have individual power supply connectors or interfaces that are used for connecting to the power supply, on a typical desktop only certain power supply connections are accessible and can be used to conduct the measurements.

One of the common ways to measure the power supplied to the circuits is to measure the voltage and the current flowing through the supply rail. High-precision shunt resistors were used on the high side of each voltage rail and the voltage drop across the shunt resistors was measured. Resistors connected in such a manner will slightly reduce the effective voltage supplied to the circuit being measured. In order to minimize this impact the resistors have to be as small as possible. On the other hand, the voltage drop across the shunt resistors has to be large enough to be properly detected by the voltage meter. By using a high-resolution measurement device the resistors can be kept sufficiently small to limit the impact on the voltage supplied to the circuits.

We have used the following shunts:

- Resistance: 50mOhm
- Precision: 1%
- Maximal power: 2W

Measurement Device Properties:

- Keysight (Agilent) USB Data Acquisition Module U2500A series (DAQ)
- Precision: 16 bit
- Minimal measurement range: +/- 1.25 V
- Minimal detectable voltage change: 0.038 mV

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Desktop computer has the following voltage rails:

- Motherboard is powered by a 24 pin connector including: 3.3V, 5V, 12V, 5Vsb and -12V rails
- CPU is powered by an ATX 4 or ATX 8 connector including 2 or 4 of 12V rails
- Hard disk drive is powered by an ATX 6 connector including 5V and 12V rails
- DVD is powered by an ATX 6 connector including 5V and 12V rails

Figure 1 shows the shunt resistors inserted between the main power supply and components power supply on each of the internal voltage rails.

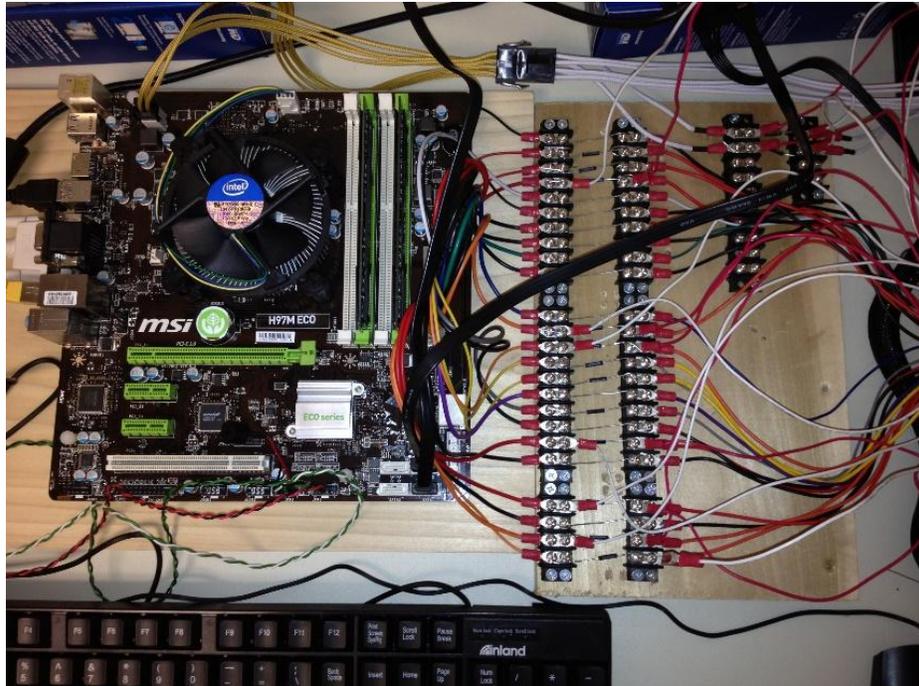


Figure 1. Voltage rails with inserted shunt resistors and measurement wires attached

The measurement wires are fed into the DAQ, which is attached via USB cable to a PC running the measurement and visualization software “Agilent Measurement Manager”. The complete measurement setup is shown on Figure 2.



Figure 2. Complete setup for desktop power measurement

For measuring all the power supply rails used (motherboard, CPU, HDD and DVD) we would need a DAQ device with 18 channels. Since the available DAQ did not have that many channels, we assumed that the multiple power rails of the same voltage levels are used just for decreasing the overall currents, so the measurements were performed in a manner that the same voltage level rails were measured in the same group. This was achieved using all of the available DAQ channels at the sampling frequency of 1 kHz for each channel. The raw voltage measurements for each channel were converted to power data and then written to a file by the measurement software. We ran the acquisition for 5 minutes on each channel and calculated the average power consumption on each rail. The total DC power was calculated as the sum of the average rail power.

The AC power was measured by the AC power meter placed between the power supply connector and the AC power source. The difference between the total AC and DC power gives the power consumption of the PSU.

Baseline state settings

The idea is to first measure the power consumption of the desktop computer in the Baseline state with no project-specific settings changed in hardware or software and then make measurements after the advanced software changes to reduce the power consumption, as well as after exchanging the selected hardware components with their more efficient counterparts. The Baseline state is the state against which the power consumption improvements will be compared. For this project the Baseline state differs from the Post-update state as follows:

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- Sleep option is disabled in Windows power settings;
- Display is set to be turned on;
- Windows updates are disabled;
- OS aging was performed;

Processor C-states

The C-states of a processor are defined in the ACPI specification [13]. The C0 state indicates normal operation where the processor is active and executes instructions. All other C-states (C1 – C7) describe states where different parts of the processor are either powered down or the clocks are gated. Higher C-state means higher power savings level, but also longer wake up latencies.

The desktops we tested support core idle state and package C-states. Package idle states are idle power conservation states for the entire package, meaning all cores and supporting circuitry on the silicon. At some point, cores share resources, e.g. the L2 cache or the clock generators. To drop into certain package C-state all cores of processor have to be in that core C – state, and then common resources can be powered off. More information about package C-states can be found in [14].

In most cases the C-states limits can be set in the BIOS. Many motherboard vendors have chosen to disable the power saving C6/C7 states by default in the BIOS, because of legacy power supplies available on the market that don't support C7 state which can cause a significant customer support burden. The legacy power supplies are built to automatically switch off the complete power supply when the currents on selected voltage rails drop under a certain level, which is the case with the deeper processor sleep states [15].

Software techniques used to reduce power consumption in Idle

Techniques that are used to reduce the power consumption in the idle mode include:

- Enabling idle power saving processor states (C – states)
- Switching off any components that are inactive in the idle states
- Disabling the background processes not expected to execute while in idle

For making changes in the system we used the software utilities supplied with the motherboard:

- MSI ECO Center Pro utility;
- BIOS setup utility;

The goal is to measure power consumption with such changes applied and demonstrate the influence of each particular changes on the decrease of power consumption.

Hardware techniques used to reduce power consumption in Idle

Initial measurements indicated that for both DT1 and DT2 the measured AC power was significantly higher than the sum of rail DC power indicating large losses in the AC/DC power supply. In order to further explore these losses we experimented with alternative power supplies. Our goal was not

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to explore in a detailed way the power supply efficiency in idle states, in this report we are only reporting the initial findings of using the better sized picoPSU-XT160 DC/DC power supply [7] and the associated AC/DC power adapter [8].

Project Outcomes

Software used for power management control

In order to reduce the power consumption of the DT1a device in idle we have first made changes using the Eco Center Pro utility. The list of components that can be controlled by this utility is shown in Table 1.

Table 1. Changes in ECO Power tab of the ECO Center Pro utility

Component	Action	Description
HDMI / DVI / D – sub ports	off	Turning off HDMI / DVI / D – sub ports
PCI slot	off	Disabling PCI slot
CPU fan	off	Under certain temperature of 42°C fan stops
LEDs	off	Turning off LEDs
Audio ports	off	Turning off audio port, if audio driver is installed

Changes made in the BIOS setup (or alternatively Power Management tab in the Eco Center Pro utility) that allowed the processor to enter low power idle states are shown in Table 2.

Table 2. Changes made in the BIOS setup of the DT1a's ECO Center Pro submenu

Setting	Action	Description
Intel C – state	Enabled	Detects the idle state of system and reduce CPU power consumption accordingly
C1E Support	Enabled	Enables C1E function to reduce the CPU frequency and voltage for power savings
Package C State limit	C7s	The highest power saving level

For DT1b the following changes shown in Table 3 were made in the BIOS Setup in order to reduce the power consumption in idle:

Table 3. Changes made in the BIOS setup of DT1b

Bios Setup Submenu	Setting	Action
Ai Tweaker	EPU Power Saving Mode	Enabled
Ai Tweaker -> External DIGI+ Power	Active Frequency Mode	Enabled
Ai Tweaker -> Internal CPU Power Management	CPU Integrated VR Efficiency Management	Balanced
Ai Tweaker -> Internal CPU Power Management	Power Decay Mode	Enabled
Advanced -> CPU Configuration -> CPU Power Management Configuration	CPU C-states	Enabled

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Advanced -> CPU Configuration -> CPU Power Management Configuration	Package C state support	C7s
Advanced -> PEH Storage Configuration	Aggressive LPM Support	Enabled
Advanced -> Platform Misc Configuration	PCI-E Native Power Management	Enabled
Advanced -> Platform Misc Configuration -> PCH PCI Express	DMI Link ASPM Control	Enabled
Advanced -> Platform Misc Configuration -> PCH PCI Express	ASPM Support	Auto
Advanced -> Platform Misc Configuration -> SA - PCI Express	DMI Link ASPM Control	L0s
Advanced -> Platform Misc Configuration -> SA - PCI Express	PEG ASPM Support	Auto
Advanced -> Onboard Device Configuration	HD Audio Controller	Disabled
Advanced -> Onboard Device Configuration	Bluetooth Controller	Disabled
Advanced -> Onboard Device Configuration	ASMedia USB 3.0 Controller	Disabled
Advanced -> Onboard Device Configuration -> ASMedia Storage Controller	ASPM Support	Enabled
Advanced -> Onboard Device Configuration	PCI-EX16_3(Black) Slot Bandwidth	X4 mode

Turning off the hard drive in idle state

The desktop OS has an option to turn off the HDD after a certain period of time of inactivity which can be set in the power option menu of the control panel. One would expect that the HDD power consumption would decrease after such a period of time, like in the similar cases of display or sleep timeouts. In the desktops we analyzed such behavior could not be observed and in most cases the HDD would continue spinning and consuming power, independently of the HDD timeout settings.

The analysis has shown that despite user inactivity the HDD continues to receive write/read requests from software processes, both OS services and application background tasks. Each such access request to the HDD resets the inactivity timer and the HDD is never turned off.

The further analysis has shown that among the OS processes which reset the HDD timer two basic types can be distinguished: (a) OS processes which are essential for proper device operation in the idle state and fast transition to the active state after wakeup (“essential OS processes”), and (b) OS processes which in most cases can be postponed until the device enters the active state (“non-essential OS processes”). The examples for the latter type of processes are processes aimed at information gathering, standard maintenance and troubleshooting, file system maintenance and similar.

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Most background processes of user installed applications are non-essential processes and can be postponed until the device exits the idle state. One such user application is the anti-virus program which frequently accesses the HDD and thereby resets the inactivity timer.

In order to determine the impact of improved process handling on the HDD power consumption, the researchers have conducted the following three steps.

1. Configure timeout in the OS power management

The time out for HDD was decreased. The minimum idle time that can be set in the OS to turn off the HDD is 1 minute, so in the OS Power Options are set to:

Hard disk -> Turn off hard disk after -> Setting: 1 minute

2. Configure minimal timeout in the OS registry

For the above change to be effective, additional changes were needed in the OS registry as the OS Power Option setting shorter than 5 minutes is overridden by the value in the registry. To set the minimum IDLE HDD time to 1 minute the following actions are needed:

- Run regedit.exe
- Navigate to:
HKEY_LOCAL_MACHINE/SYSTEM/CurrentControlSet/Enum/SCSI/
<DeviceID>/<Instance>/Device Parameters/Storport/
- Add the following DWORD value:
 - Name: MinimumIdleTimeoutInMS
 - Type: REG_DWORD
 - Specify a value 60000 (min: 60,000). Value is in ms.

Device needs to reboot in order to apply these changes.

3. Disable selected processes

In order to reduce hard disk drive activity we disabled the following services in the OS Task Manager:

- SysMain - Superfetch
- DPS - Diagnostic Policy Service
- wuauserv - Windows Update
- WSearch - Windows Search

In order to track the HDD activity pattern the researchers have used the xperf command line program from the Windows Assessment and Deployment Kit of Windows 8.1. Also, the Windows Performance Analyzer was used to see which processes trigger HDD activities and how frequently.

The HDD timeout interval of less than 1 minute would be inappropriate for this class of devices because such short intervals could cause frequent energy spikes while the HDD restarts the spinning. This can lead to increased average power consumption and cause the HDD to crash. For other storage devices like the SSDs it is likely that the timeout interval can be further shortened

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without negative impacts on average power and reliability. The limited time and labor resources planned for this project have not allowed us to further explore the tradeoffs.

The HDD experiment described above was conducted on all three devices under test, i.e. DT1a, DT1b and DT2.

Idle-efficient power supplies

For DT1a and DT1b we have first conducted the measurements with the SeaSonic Platinum-400 Fanless power supply. This power supply is 80 Plus® Platinum certified which guarantees greater than 90% efficiency at 20% of load (80W). For smaller loads like in idle this efficiency is around 80%. Once we optimized the devices the efficiency went further down to 60% and below. Once the total power consumption was decreased by software optimizations below 40% of the initial idle power, the power consumption of the power supply stayed fixed at around level of 5W independently of the load.

In order to experiment with the better dimensioned power supplies we connected the picoPSU DC/DC power supply and the AC/DC adapter to achieve around 2W in lowest idle and still cover the full dynamic range of the currents needed for the proper operation of the device under all loads. In summary the picoPSU power supply was able to still deliver 80% efficiency at all idle loads.

The commercial desktop DT2 came integrated with a 300W standard efficiency power supply (Model: HP D11-300N1A). Our measurements have shown that the power consumption of this PSU in the Base-line state was 43% of the total power consumption of the device. Once software optimized, this percentage went further up and reached more than 50% of the total power consumption of the device.

Influence of the DVD optical drive

Power consumption of the DVD drive in idle seems to be lower than 0.5W. With software optimizations it can be further lowered to the level of 0.1W. Although these levels are insignificant compared to the whole device, proper power management of the DVD drive is important as it can increase the overall power consumption by preventing other components from entering low power states.

Influence of size and number of occupied slots of RAM memory on power consumption and performances

In Table 4 we are showing the influence of the RAM memory size and the slots occupied on the total power consumption and performance of the device DT1a. The performance benchmark score was obtained using the Intel Extreme Tuning Utility. As we can see the total power depends on the memory slots filled rather than the size of the RAM memory inserted.

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Table 4. Influence of RAM memory used on total power consumption and performances

Memory size	Slots filled	Total power	Benchmark score
4 GB	1	21.4W	515
8 GB	1	21.4W	511
8 GB	2	21.9W	840
16 GB	2	21.9W	833
16 GB	4	22.1W	791

Power optimization and measurements

Table 5 shows the power consumption achieved by conducting individual power state changes on DT1a, measuring the AC power after each change and the resulting power savings:

Table 5. DT1a - Power consumption after power state changes

State ID	Item	Action	Power	Savings
0	Base-line	-	22W	-
1	HDMI/DVI/D-sub port	Off	20.9W	1.1W
2	PCI	Off	20.2W	0.7W
3	C - state, C1E, C7s	Enabled	15.8W	4.4W
4	CPU fan	Off under 42°C	15.4W	0.4W
5	LEDs	Off	15.3W	0.1W
6	HDD, DVD	Off	12.4W	2.9W
7	PSU	picoPSU	8.6W	3.8W

Table 6 shows the power consumption of individual components and the total power consumption for some of the most relevant power saving states, measured on each of the internal voltage rails in the system and on the AC power input of the DT1a.

Table 6. Power consumption of individual components and total power consumption

State ID	Motherboard	CPU	HDD	DVD	PSU	Total
0	7.3W	5.4W	4.1W	0.4W	4.8W	22W
3	4.6W	2.2W	3.7W	0.3W	5.0W	15.8W
6	4.3W	2.1W	0.5W	0.1W	5.4W	12.4W

Table 7 shows power consumption and savings achieved on the DT1b after BIOS setup and HDD optimizations.

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Table 7. DT1b – Power consumptions and savings after power state changes

State	Power	Savings
Base	26.1W	-
Bios setup – optimized	20.3W	5.8W
HDD – off	16.9W	3.4W

Table 8 shows the power consumption and savings achieved on the DT2 device after HDD optimizations and after replacing the original PSU with the picoPSU.

Table 8. DT2 – Power consumption and optimization savings

Item	Action	Power	Savings
Base	-	22 W	-
Display	Off	21 W	1W
HDD	Off	17.5 W	3.5 W
PSU	Replaced with Pico PSU	9.7 W	7.8 W

Transition latencies and benchmark impact

The experiments performed on the DT1a device have shown no loss in functionality or change in latencies after transition from the optimized idle state to the active state when compared to the same transition from the non-optimized Base-line idle state. Performance measurements were conducted using the Benchmark Test from the Intel Extreme Tuning Utility.

The transition latencies were measured through two time parameters. First is the wake up latency which is defined as the time for the system to wake up from long-idle after the mouse was moved. The second is the activity latency which is defined as the time between the first mouse move and the start of the prepared video application. For this test an MP4 file was saved on the desktop and the icon was double clicked as soon as the mouse icon reappeared. The wake up latency was measured around 4s, the activity latency around 6s and the benchmark score was 840. It was observed that these latencies are dominated by the wakeup latency of the computer display/monitor, not the power state transition of the desktop itself. In the case of short idle when the display/monitor is not turned off the researchers have not observed any measurable difference between the wake up latencies from the optimized and non-optimized idle.

Conclusions

The experiments conducted by the researchers have resulted in idle-state power savings of 61% and 54% relative to out of the box configurations through software configuration changes and power supply replacement. The idle-state power consumption of 8.6W of the assembled and 9.7W of the commercial pre-assembled desktop achieves by a wide margin the power levels proposed in the CEC staff document [1]. Due to budget and time constraints the work on the assembled DT1b desktop could not be completed by the time this report was written. The researchers plan to finalize the work on DT1b or a similar desktop device and report the findings in the next version of the report.

The report identifies the processor power state configuration, hard disc drive power management and the power supply voltage conversion in idle as the main areas where the power efficiency of the desktops can be further improved. The researchers have concluded that the processor core and package C-state configurations should be enabled by default in the BIOS for all motherboards and that the “package” principle should extend to the power management of the peripherals, including the hard disc drive. The voltage conversion in idle is a topic of active interest and a strong pace of innovation in the power supply community at the moment. We hope to further explore this topic as part of our ongoing activities and report the findings in the next versions of this report.

Recommendations

The recommendations presented here are meant to serve as the base for further technical analysis and discussions about the technical implementations and cost-benefit tradeoffs for power optimized desktop computers.

The researchers recommend leveraging the MSI H97M Eco Pro motherboard (“MSI Board”) as the reference for further analysis and discussions on the subject of desktop efficiency in the short and long idle states. In particular, the above motherboard was launched as a commercial product on the market, not just as a technical study or prototype. This allows us to conduct detailed cost-time-benefit analysis for the development of the dedicated software and hardware enabling such power efficient motherboards and desktop computers. In this section we are providing the preliminary cost-benefits analysis for the design, implementation and distribution of devices with improved power characteristics based on the MSI Board.

Static Power Management

The MSI Board is shipped with the power configuration and monitoring utility ECO Center Pro. In the project this utility was used to conduct most of the experiments leading to better idle power. The researchers see such utilities as essential for tuning the power beyond the power option utilities integrated in the OS and therefore have conducted an analysis of the necessary engineering manpower for the design, implementation and distribution of such specialized utilities by the motherboard manufacturers.



Figure 3 ECO power screen of ECO Center Pro

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Figure 1 shows the graphical user interface (GUI) of the ECO Center Pro utility and ECO Power tab with checkboxes for changing settings (on/off switches), including visualization for where the component to be turned off sits on the motherboard. It also contains 3 presets (ECO, Lounge, Server) that set the checkboxes to a predefined state. We estimate the engineering for the underlying control functionality to be 2-4 man-weeks for a power software engineer if all required documentation is available (i.e. how to control each of these devices) or 8-16 man weeks if this is done using the UEFI/Windows manuals and trial and error. The effort estimate for the GUI functionality is 1-2 man-weeks for a QT-style² GUI (or 1 day for simplistic QT GUI with equal functionality, without motherboard visualization). The effort estimate for the GUI graphics is 1-3 man-weeks for a graphics designer depending on how advanced the look is expected to be.

Figure 4 shows the Power Management tab of the ECO Center Pro utility. We estimate the engineering effort to develop the underlying functionality to 8 man-weeks of a power software engineer if all required functionality is covered in provided documentation and 8-16 man-weeks if the information has to be extracted from distributed sources. The estimated effort for the GUI functionality is 1 week (for standard QT-style GUI) and 1-3 weeks for graphic design.



Figure 4 Power Management tab

The Hardware Monitor tab (Figure 5) shows the voltage, temperature and fan speed status of the motherboard and allows the control of the fan speed. For the underlying functionality of reading the status and controlling the fan we estimate 4 man-weeks weeks of a power software engineer

² QT - cross-platform application & UI development framework: <http://www.qt.io/>

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provided all features are documented and 8-12 man-weeks otherwise. For the GUI development we estimate 3-4 man-weeks (for standard QT-style GUI) and 2-3 man-weeks for the GUI graphic design.



Figure 5 Hardware Monitor tab

In summary our high level estimate of the total combined engineering effort for the development of the static power management similar to Eco Center Pro is around one man-year for the initial development of the software. As with other similar motherboard utilities the software architecture can be kept fairly scalable to cover a wide variety of motherboards, which means that the additional effort to cover other motherboards of the same manufacturer should be reduced to additional software testing. We estimate that such costs cannot more than to double the necessary software development investment for the initial motherboard. We estimate that the costs for the deployment and customer support of such software with each motherboard shall be not more than 20% of the development costs. In summary we estimate the total costs for providing the additional board-specific power tuning utility to the desktop end users at around 2.4 man-years for the first year and 1.2 man-years per year for the second year and after.

At standard combined engineering rates for this type of work (in countries where most of today's desktop hardware and software are developed), the dollar costs per motherboard manufacturer in the first year are estimated at \$240,000 and \$120,000 for the second and following years. For the 10 leading motherboard manufacturers carrying most of the desktop and notebook volume in the US the total combined costs would amount to \$2.4M and \$1.2M for the first and the subsequent years respectively. For the 59 million new computers (desktops and notebooks) shipped annually in the US we estimate the per device costs of such utility at around 4 cents for the first year and around 2 cents afterwards.

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Dynamic Power Management and Specialized Hardware Support

In the previous report [16] the researchers focused on the power characteristics of notebook computers and have provided a high-level cost-benefit analysis for the design of hardware and software necessary to reach higher power savings in the short and long idle states. Our main recommendations in this report were focused on the improvements of the power management software and the addition of dedicated microcontrollers to improve the idle and sleep states of the motherboard and the whole device. After the analysis of the features of the two selected motherboards, the MSI H97M Eco Pro and the ASUS Z97 Pro motherboards, the researchers see these boards and their software and hardware structure as clear confirmation of our previous recommendations. The efficiency oriented MSI Board comes with specialized power management utilities we discussed in this project report and the advanced ASUS board with a dedicated on-board microcontroller (EPU) for improved power management [17]. These two technology features now available for desktop devices indicate that the industry started innovating its power management solutions and rethinking about the operating system as the dominating power management software and the main processor as the only controller of the power related activities in hardware.

The research team is currently working to further advance the cost-benefit analysis as applied to full-featured desktops computers and make related recommendations. These findings shall be presented in the next versions of this report.

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