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Computers: Technical Report – Supplemental Analysis and Test Results

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1 Executive Summary

This supplemental report provides detailed documentation of testing of efficient desktop computer builds that helped form the basis for the California Investor-Owned Utilities' (CA IOUs) Title 20 computer standards proposal found in the August 2013 Codes and Standards Enhancement (CASE) report (CA IOUs 2013). Additional analysis and test results have also been included which further support the proposal, including a description of the methodology used to calculate the assumed price decline of certain components, an investigation of the impact of alternate power supply configurations and next-generation processor architecture on the energy consumption of desktop systems, and an analysis of the feasibility of enhanced power factor requirements for desktop internal power supplies.

Supplemental testing and analysis concluded that:

- Intel's latest-generation Haswell processor architecture may provide an additional 25% TEC savings for OEMs, based on testing conducted by IOU researchers. For those computers that use Intel processors and chipsets, adopting Haswell will likely be the primary mechanism for complying with the standard. Since Haswell could be a mainstream technology by the time proposed standards are effective, it should represent little or no incremental cost.

- Power electronics manufacturers expect power supply prices to decline by 3-5 % per year as a result of standard cost reduction targets set by computer OEMs for their suppliers. We therefore modified the analysis presented in the CASE report to use a compound annual growth rate (CAGR) of -4% (rather than the original 0%) to approximate power supply prices in 2015, the expected effective year of Title 20 efficiency standards for computers. The impact is reduced incremental costs for power supplies, which are now estimated approximately 9% lower for Tier 1 and 18% lower for Tier 2, resulting in associated cost effectiveness improvements for desktops.

- Mainstream desktop computers (e.g. DT 0, DT I1, DT I2, DT I3) may be able to realize additional power supply-related savings through rightsizing. Our testing demonstrated that power supply rightsizing presented a greater opportunity for these lower power, mainstream performance categories than moving up to 80 PLUS Platinum power supplies, mainly because Platinum supplies are not currently available in sizes appropriate to mainstream desktops.

- Modest power factor requirements down to 10% load conditions are achievable and should be incorporated into any Title 20 computer standard.

2 Introduction

From June through December 2012, Pacific Gas and Electric Company's (PG&E) Emerging Technologies Program funded Ecova to examine the cost effectiveness of incorporating efficient computer components into typical desktop computer builds. This research specifically focused on ENERGY STAR desktop performance categories DT I1, DT I2, and DT D2. Test results indicated that energy savings on the order of 30% could be achieved cost-effectively using desktop components available on the market. Detailed results were published in a report entitled, *Cost-Effective Computer Efficiency* (PG&E 2013). A follow-on research project led by the CA IOUs focused on the remaining three desktop computer categories (DT 0, DT I3 and DT D1) and extended coverage to all desktop computer categories.

On August 6th, 2013, the CA IOUs and NRDC submitted a CASE report to the California Energy Commission (CEC) proposing Title 20 mandatory efficiency standards for computers. The CASE team recommended that California adopt a two-tier – 2015 (Tier 1) and 2017 (Tier 2) – standard based largely on the ENERGY STAR Version 6.0 computer specification framework, performance categories, and test method, with some minor adjustments. These recommendations were supported by PG&E's 2012 cost-effectiveness testing results – provided through the CEC's Invitation to Participate – and the CA IOUs' supplemental testing results provided in this report.

This report serves as a companion to the IOUs' Title 20 proposal submittal and provides the detailed methodology, measured data, and analysis underlying this proposal. This report also presents follow-on testing results and analysis completed after the submittal of the CASE report. This includes:

- An evaluation of the impact of using fourth-generation Intel Haswell CPU architecture and compatible motherboards on desktop computers; and
- The inclusion of PSU price experience curves.
- A demonstration of how rightsizing power supplies can improve savings and cost-effectiveness;
- An analysis of the feasibility of enhanced power factor requirements for desktop internal power supply units (PSU);

3 Research Methodology

The CA IOU technical team employed a three-step process to establish baseline, cost-effective, and most-efficient desktop computer configurations in the DT 0, DT I3, and DT D1 performance categories, to complement the categories covered in the IOU August 2013 proposal. This approach mirrors the process conducted a year earlier and described in detail in the emerging technologies report from 2012 (PG&E). Key steps included:

1. Conducting market analysis to establish baseline system configurations by performance category

2. Modifying baseline system configurations with efficient components to assess energy savings impacts

3. Determining the cost-effective and most efficient system configurations

The sections below describe the basic methodology and any modifications to the procedures made since the original emerging technology report.

3.1 Market Analysis and Baseline Selection Process

The CA IOU technical team first used the web crawler application Mozenda[1] to mine prominent computer retailer web pages for information on the configurations of typical computers being sold at retail.[2] With this "web scrape" information we created an initial database of more than 1,400 different computer models for sale. Duplicate or outdated system configurations[3] were intentionally eliminated. Using product hardware attributes, the team categorized each unique system according to the ENERGY STAR Version 6.0 final computer specification (EPA 2012) and identified the most common builds for each performance categories DT 0, DT I3 and DT D1. Desktop computer models from leading OEMs were then purchased to match these most typical configurations, thus obtaining "baseline" desktop computers most commonly sold in the three performance categories. In addition, the team was able to configure the DT D1 baseline desktop computer to create a "budget" DT I1 system. This unit, although not representative of the most common configuration for DT I1 units, was intended to examine whether inexpensive desktop computers available today could be made more efficient in a cost-effective manner.

3.2 Energy Savings Potential and Measurements

Each baseline system was measured with the proposed ENERGY STAR Version 6.0 test procedure, which documents power draw in all modes of operation, including off/standby, sleep, short idle, and long idle. The team then used the ENERGY STAR Version 6.0 conventional duty cycle to calculate each computer's typical energy consumption (TEC) in kWh per year.[4]

Table 1. ENERGY STAR Version 6.0 Duty Cycle for Conventional Desktops

Mode	Hours per Day by Mode
Off	10.8
Sleep	1.2
Long Idle	3.6
Short Idle	8.4

Analysts then researched and obtained a variety of energy-efficient desktop computer components, namely hard drives, processors, graphics cards, and power supplies. Components were swapped with each of the baseline systems one by one, and analysts re-measured the systems with the ENERGY STAR Version 6.0 test procedure. The component swap measurements were later used to establish the energy savings achievable through the use of more efficient components.

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[1] More information about this application at www.mozenda.com

[2] The "web scrapes" generated for this work primarily relied on data available from Shopper.com in the April and May 2013 timeframe.

[3] Outdated systems included desktop models introduced before 2012 or models containing individual components introduced prior to 2012.

[4] All testing occurred in Ecova's lab - an EPA-recognized, CEC approved, and ISO/IEC 17205 accredited laboratory and complied with ENERGY STAR's instrumentation measurement accuracy requirements. More detailed information about the equipment used and accuracy requirement is provided in Appendix 8.1.

3.2.1 *Clean install*

To ensure that all measurements were conducted with repeatable system conditions, we performed a clean installation of the appropriate operating system and hardware drivers after each component swap. The operating systems installed (64-bit versions of Windows 7 Home Premium, Windows 7 Professional, Windows 8 Pro) matched the operating system that was originally installed on the computer system by the OEM. After each clean install of Windows, we modified the power plan settings in Windows to match the original, as-shipped power plan settings. Finally, we used Windows Update to ensure that all operating systems were fully updated.

3.2.2 *Real-world adjustment factor*

Anecdotal testing by Natural Resources Defense Council (NRDC), presented in the CEC's Invitation to Participate (ITP), indicates that the ENERGY STAR Version 6.0 duty cycle, test procedure, and TEC equation may under-represent real-world computer energy use, because this procedure ignores the power drawn when common applications are running (e.g. open browser sessions, office applications, video streaming, etc.), and when accessories are connected (e.g. a second display, a docking station or a printer). NRDC estimated that real-world TEC values for notebooks could be 30% higher than ENERGY STAR Version 6.0 TEC numbers. The CASE Report used real-world TEC values for desktops of 15% higher than those reported by ENERGY STAR Version 6.0 when calculating energy use, savings and cost-effectiveness to account for active use and computer accessories. It should be reiterated that proposed standards levels in the CASE Report were established using the ENERGY STAR Version 6.0 method (i.e. without the active mode adjustment). The adjustment factor was solely used to evaluate the cost effectiveness between the baseline and the modified computers and account for savings that might accrue during active operation.

3.3 Maximum Efficiency and Cost-Effective Efficient Build Development

Based on the results from the energy consumption measurements, we determined for each test system what combination of components yielded the greatest energy savings (the maximum efficiency builds). An economic analysis also established for each test system what combination of components yielded the greatest cost-effective energy savings over a 4-year product lifetime (the cost-effective efficient builds). A detailed description of this analysis is provided below. It is important to note that both the Maximum Efficiency and Cost-Effective Efficient builds only represent the optimal builds that could be achieved with the selected components, not the absolute optimums. It is likely that more efficient and more cost-effective builds could be achieved with components not considered here, and with efficiency strategies other than component-swapping, such as system power management optimization.

Analysts then measured the systems with these most-efficient and cost-effective components with the ENERGY STAR Version 6.0 test procedure to determine achievable savings. It is important to note that the savings of the system as a whole can be different than the sum of the savings associated with individual components due to interactions between component-level savings measures, particularly interactions between the power supply and downstream devices.

3.4 Economic Analysis

As noted above, the technical team used a system-level perspective on cost effectiveness rather than an individual component-based approach. This means that, for each test system, the *combination* of components identified yielded the greatest cost-effective savings (in kWh); *individual* components need not be cost-effective so long as the entire system achieves meaningful lifetime net benefits (in present dollars). This enabled us to configure systems for maximum lifetime energy savings with a neutral or slightly positive impact on lifetime costs.

3.4.1 *Component price methodology*

PG&E's CEC 2012 research into achievable, cost-effective efficiency identified incremental cost data for four desktop component opportunities (power supplies, CPUs, GPUs, and hard drives) using retail price points from several online computer parts retailers (e.g. Newegg.com, TigerDirect.com). In the current research, we determined incremental cost data using a similar retail approach, however, a different approach was taken with power supplies.

Computer power supplies are seldom purchased at retail, and those products that are available at retail are generally performance models intended for enthusiasts building their own systems. The technical team instead developed a model describing the relationship between power supply cost and efficiency. iSuppli conducted a bill of materials (BOM) analysis on eight power supplies in the 300 to 400 W dc output range. We then measured the efficiency of these same power supplies at 10, 15, 20, 50, and 100% of their rated load per a standardized test procedure (EPRI 2012). We then used BOM and efficiency data to establish a linear relationship between BOM cost and efficiency, showing that BOM costs increased approximately $0.77 for every percentage point increase in average efficiency.[5] Thus, with a baseline and efficient power supply of known efficiency, we could estimate the incremental BOM cost of the more efficient power supply using this model. Finally, we used a BOM-to-retail markup factor of 1.31 to estimate retail incremental costs (DOE 2012).

3.4.2 *Compound annual growth rate approach*

As in the PG&E's 2012 research, we used a compound annual growth rate (CAGR) approach to discount component prices to approximate component prices in 2015 the expected effective year of Title 20 efficiency standards for computers. Price declines reflect the maturing of technology over time (also referred to as an "experience curve" approach) and not the time value of money, which was dealt with separately through discount rates.

We examined price trends in products released between 2006 and the present, tracking prices on a quarterly basis for the first 2 - 2.5 years of their release. From these trends, we were able to establish the average compound annual price decline in each component category (Table 2). The -28% figure for solid state drives (SSD) differs from the -53.2% figure used in the PG&E's 2012 research. The updated figure comes from our analysis of more recent trend information from Royal Pingdom.[6] More specifically, we averaged annual

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[5] We ultimately related BOM costs to the average PSU efficiency at 20, 50 and 100% loads. The correlation we established is only valid for power supplies with average efficiencies in the 78% to 90% range.

[6] See http://royal.pingdom.com/2011/12/19/would-you-pay-7260-for-a-3-tb-drive-charting-hdd-and-ssd-prices-over-time/

price drop for hard drives since 2003, regardless of technology. In lieu of more credible SSD-only figures, we adopted this figure as a good long-term average.

Note that the CASE Report did not reflect any experience curve assumptions for power supplies, as power electronics are relatively mature compared to rapidly evolving processing and storage components. After submission of the CASE Report, however, the CA IOU technical team revisited experience curve assumptions for next-generation, highly efficient power supplies. Power electronics manufacturers reported seeing a required 3-5% cost reduction from OEMs.[7] Based on these findings, we reviewed our experience curve assumptions to assume a 4% price decline for all power supplies, rather than the original 0% average growth. The impact is reduced incremental costs for power supplies, which are now estimated approximately 9% lower for Tier 1 and 18% lower for Tier 2, resulting in associated cost effectiveness improvements.

Table 2. Experience Curve Assumptions

Component	CAGR
CPU	-10%
HDD – Magnetic, 3.5”	-11%
HDD – Magnetic, 2.5”	-20%
HDD – Solid state	-28%
PSU	-4%
GPU	-15%

3.5 Configuration Principles

Our team was focused on adhering to the CEC’s principle of providing enhanced efficiency while maintaining comparable performance and user amenity. Researchers applied three broad principles to ensure comparable performance and amenity in our system modifications:

- **Within-category comparisons**: researchers ensured that all modified systems still fell into the same ENERGY STAR performance categories as the associated baseline systems.

- **Maintain hardware specifications and general performance**: when swapping individual components, we took care to select replacements with comparable hardware specifications. For example, in selecting discrete graphics cards, we identified efficient replacement parts with similar frame buffer width values.

4 Results and Discussion

4.1 Baseline Systems

An evaluation of approximately 1,400 unique system configurations, obtained via a Mozenda web scrape of the Shopper.com computer retail site yielded insights into common configurations of desktop computers.

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[7] Based on communications with Power Integrations during October 2013.

In the DT 0 performance category, we identified 50 unique models. Intel processors dominated, with most processors falling into Intel's "Celeron" line. All systems in this category had integrated graphics, with Intel's HD graphics family being the dominant GPU package. Memory configurations of 2 GB were typical, and a single 320 GB hard drive was most common. Power supplies were generally small, with a median nameplate rating of only 65 W.

In the DT I3 class, we see an expected increase in overall hardware features and performance. From a sample of 241 models, we determined that Intel quad-core Core i5 processors were most common, with median clock speeds in excess of 3 GHz. Intel HD integrated graphics again dominated the GPU configurations. A 4 GB memory configuration with a single 500 GB hard drive was more common in these systems. Power supply ratings were also larger, with median values in the 240 W range.

The DT D1 category proved to be challenging to analyze because of the small number of models in the marketplace that fall into this rather narrow category (a total of only 30 in our search). We generally uncovered hardware configurations that were likely targeting budget price points (e.g. desktops selling at retail for $300 to $350). The most common processor in this category was Intel's dual-core Pentium,[8] with median clock speeds approaching the 3 GHz range. Memory, storage, and power supply components were comparable to the DT I3 category. Table 3 below summarizes the most common attributes for each of the three desktop performance categories we investigated.

Table 3. The Most Common DT 0, DT D1 and DT I3 Attributes

Attribute	DT 0		DT I3		DT D1	
	Value	% Dataset	Value	% Dataset	Value	% Dataset
CPU Manufacturer	Intel	76%	Intel	76%	Intel	60%
CPU Family	Intel Celeron	38%	Intel Core i5	50%	Pentium	23%
Cores	1	64%	4	95%	2	80%
Processor clock speed (GHz)	1.66	n/a	3.1	n/a	2.8	n/a
Performance Score (GHz*n_{cores})	2.2	n/a	12.4	n/a	5.9	n/a
GPU	Intel HD graphics family	30%	Intel HD graphics family	61%	No clear trend	-
Physical Memory (MB)	2048	26%	4096	67%	4096	46%
Number Hard Drives	1	100%	1	99%	1	100%
Hard Drive Size (GB)	320	22%	500	39%	500	33%
PSU Rating (W)	65	44%	240	14%	302.5	3%

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[8] The Pentium was originally introduced in in the early 1990s, but still exists as a brand in Intel's current processor line. The underlying silicon in Pentium processors has changed significantly since introduction and is based on the same "Core" architecture as Intel's Core i3/i5/i7 processors.

The team purchased baseline desktop systems in the DT 0, DT I3, and DT D1 categories, attempting to find systems from major OEMs (Dell, Hewlett-Packard, Lenovo, etc.) with the same characteristics as the most common builds from the aforementioned market research. Naturally, it is difficult to find an individual computer model that perfectly represents the statistical picture of a "typical" computer; however, priority was placed on identifying systems with comparable processors, memory configurations, and graphics. Other hardware attributes, such as power supply and hard drive sizing, were secondary considerations. In the case of the DT I3 system, the team opted for an AMD-based board with an A-series processor. Although quad-core Intel processors are the more common choice in today's market, a dual-core AMD unit was chosen here to provide more diverse manufacturer representation and to capture the lower end of allowable performance scores in the DT I3 category (quad-core Intel processors tend to cover the higher end of the range). In the case of the DT 0 category, we selected a Dell system with a processor, memory configuration and graphics similar to the most common builds according to our market research. However, this system did have a larger power supply than the median size power supply for this category.

It was also possible to utilize the DT D1 system as a DT I1 system simply by removing its discrete GPU. In this way, we were able to obtain another data point for the DT I1 category, this one more reflective of a "budget" system. It was hypothesized that this budget DT I1 system might provide a more challenging case for cost-effective energy savings opportunities due to its lower purchase price and the potential for fewer efficiency-optimized components. Even in this budget-priced system, however, we were able to identify cost-effective savings opportunities. In fact, the benefit-cost ratio of the system was slightly higher than the average benefit-cost ratio of all systems. Builds of the purchased baseline systems are provided in Table 4.

Table 4. Baseline Configurations of Systems Tested

Component Type	DT 0	DT I1	DT I3	DT D1
CPU	Intel Celeron G465 1.90 GHz	Intel Pentium G640 2.8 GHz	AMD A6-5400B APU 3.8 GHz	Intel Pentium G640 2.8 GHz
Number of Cores	Single	Dual	Dual	Dual
Memory	1x2GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM
Storage	Seagate ST500DM002 500GB	Western Digital WD5000AAKX 500 GB	Western Digital WD5000AAKX 500 GB	Western Digital WD5000AAKX 500 GB
GPU	Intel HD Graphics	Intel Integrated Graphics	AMD Radeon HD 7450D	Sapphire Radeon HD6570 100323L
PSU	Dell H220NS-00	HP PS-5301-02	Huntkey HK340-72FP	HP PS-5301-02
PSU Size (W)	220	300	240	300
Purchase Price	$249	$300	$499	$350[b]

[b] This value represents the purchase price of the DT I1 system plus the retail price of the added discrete graphics card.

4.2 Efficient Component Description

The CA IOU technical team utilized a suite of efficient components to examine efficiency impacts on the baseline systems. We intentionally limited component swaps to CPU, GPU, power supply and storage technologies, as these were identified in the prior emerging technologies report as having the greatest impact on desktop computer power consumption (PG&E 2013).

Alternate processors were limited to parts with comparable performance (determined by ENERGY STAR Version 6.0's performance score, the product of CPU clock speed and number of cores). In most cases, this usually meant that replacement CPUs were models with very comparable technical specifications, but were marketed for small form factor computers or other applications with greater power and thermal constraints.

Graphics investigations were limited to the DT D1 system, as all other systems inherently used integrated graphics. Here, we tested two different discrete graphics cards, both falling into the ENERGY STAR Version 6.0 G2 graphics performance.

As in the prior emerging technologies report, we measured power supply impacts on the systems using a variety of 80 PLUS-labeled power supplies in the 240-300 W output range. Products ranged in efficiency from 80 PLUS Bronze to 80 PLUS Gold levels.

For storage or hard drive technology, we examined three distinct options apart from the conventional spinning magnetic drives found in the baseline systems. First, we included products like the Western Digital WD5000AZRX, representing spinning hard drive technology with purported efficiency gains (usually due to modified spin speeds). Secondly, we investigated solid state drive (SSD) technologies like the Samsung 840 Series, which use non-volatile flash memory instead of spinning magnetic platters to store information, reducing moving parts and lowering power requirements.[9] Lastly, we included so-called "hybrid" hard drives like the Seagate Momentus XT that buffer a user's most frequently requested information on a solid state drive, while using a magnetic drive for longer term storage. This arrangement can allow the magnetic portion of the drive to spin down frequently, thus generating power savings.

A summary of all components tested is provided in Table 5 below**.**

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[9] It should be noted that the SSD drives used in this research were smaller in overall capacity than comparable spinning magnetic drives (250 GB vs. 500 GB). We use SSDs in this research as an example of best-available technology and acknowledge that it may not be possible at the present to use SSD technology as a replacement for all given magnetic drive configurations, particularly when higher capacities are needed.

Table 5. Alternate Desktop Computer Components Tested

Computer Category	CPU	GPU	Power Supply	Storage
DT 0	Intel Celeron G460 Intel Celeron G440	Intel HD graphics	Seasonic SS-300TGW Active PFC (80 PLUS Gold) Athena Power AP-MFATX32 (80 PLUS) Seasonic SS-300ES Active PFC F3 (80 PLUS Bronze)	Seagate ST500DM002 Western Digital WD5000AZRX Seagate Momentus XT Hybrid HDD/SDD Western Digital WD5000AAKX Samsung 840 Series
DT I1	Intel Core i3-3220T Intel Pentium G640T	Intel integrated	Coolmax CA-300 Seasonic SS-300ES Active PFC F3(80 PLUS Bronze) FSP Group FSP300-60GHS-R (80 PLUS) Seasonic SS-300TGW Active PFC (80 PLUS Gold)	Seagate ST500DM002 Seagate Momentus XT Hybrid HDD/SDD Samsung 840 Series
DT D1	CPU was not upgraded for this system	Sapphire Radeon HD6570 100323L (G2) EVGA 02G-P4-2645-KR	Seasonic SS-300TGW Active PFC (80 PLUS Gold)	Western Digital WD5000AZRX 500 GB Samsung 840 Series
DT I3	AMD A4-5300 3.7 GHz	AMD Radeon HD 7450D	Seasonic SS-300TGW Active PFC (80 PLUS Gold) Athena Power AP-MFATX32 (80 PLUS) Seasonic SS-300ES (80 PLUS Bronze)	Seagate ST500DM002 Seagate Momentus XT Hybrid HDD/SDD Western Digital WD5000AZRX Samsung 840 Series

4.3 Cost-Effective Efficient and Most Efficient Builds

To determine the cost-effective and most efficient computer builds in each category, we employed a four-stage process for each system. First, each efficient component was installed in the system and its energy impacts measured *independently* of other components. Second, we conducted a cost-benefit analysis on each component to determine its contribution toward annual energy savings over the baseline system, the associated incremental cost, and the expected lifetime net benefits to ratepayers. Third, we determined which combination of components would yield: 1) the greatest amount of lifetime energy savings without increasing total cost of ownership (the cost-effective efficient configuration) and 2) the greatest lifetime energy savings regardless of cost (most efficient configuration). Finally, both the cost-effective and most efficient configurations were measured to verify the *combined* energy savings impacts. This final measurement is extremely important, since certain components can have interactive effects when integrated together and can alter the overall savings. For example, the use of different graphics cards and hard drives might change the loading on a computer's power supply. A change in loading will alter the efficiency of the power supply under operation, resulting in slightly different savings than when the power supply was tested in isolation.

Figure 1 provides a summary of individual component measurements and "total build" measurements conducted on the DT I3 system. The bars marked with red arrows signify the components in the cost-effective configuration; the lowest bars in each component category reflect components in the most efficient configuration. The green bars to the right show results for the fully integrated cost-effective (CE EFF) and most efficient (Most EFF) builds.

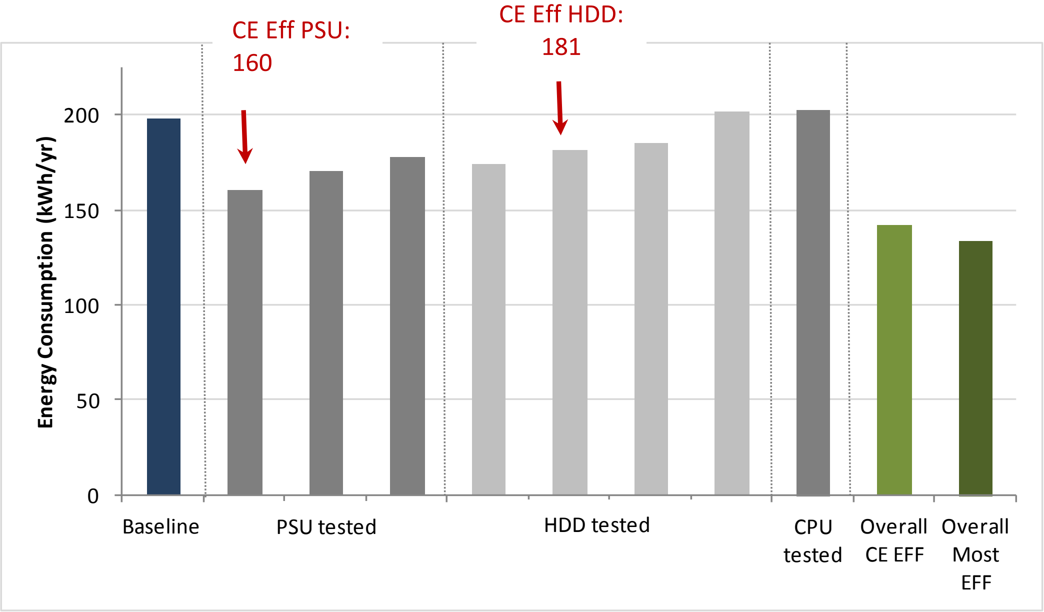


Figure 1. Detailed Test Results for Desktop Computer Category DT I3

Tables 6 through 9 below provide the specific components chosen for each performance category, including the baseline, cost-effective, and most efficient configurations. Detailed specifications on each component and its average retail purchase price are provided in Appendix 8.2. Detailed tables providing the results of economic analysis — including incremental costs, net present value of lifetime savings, and benefit-cost ratios — are provided in Appendix 8.3.

Table 6. DT 0: Baseline, Cost-Effective, and Most-Efficient Configurations

Component Type	Baseline Build	Cost-Effective Build	Most-Efficient Build
CPU	Intel Celeron G465 1.90 GHz	Intel Celeron G465 1.90 GHz	Intel Celeron G465 1.90 GHz
Number of Cores	Single Core	Single Core	Single Core
Memory	1x2GB DDR3-1333MHz SDRAM	1x2GB DDR3-1333MHz SDRAM	1x2GB DDR3-1333MHz SDRAM
Storage	Seagate ST500DM002 500GB	Seagate ST500DM002 500GB	Samsung 840 Series 250GB
GPU	Intel Integrated Graphics	Intel Integrated Graphics	Intel Integrated Graphics
PSU	Dell H220NS-00	Seasonic SS-300TGW Active PFC	Seasonic SS-300TGW Active PFC
PSU Size (W)	220	300	300

Table 7. DT I1 (Budget): Baseline, Cost-Effective, and Most Efficient Configurations

Component Type	Baseline Build	Cost-Effective Build	Most-Efficient Build
CPU	Intel Pentium G640 2.8 GHz	Intel Pentium G640 2.8 GHz	Intel Pentium G640 2.8 GHz
Number of Cores	Dual Core	Dual Core	Dual Core
Memory	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM
Storage	Western Digital WD5000AAKX 500 GB	Western Digital WD5000AZRX 500 GB	Samsung 840 Series 250GB
GPU	Intel Integrated Graphics	Intel Integrated Graphics	Intel Integrated Graphics
PSU	HP PS-5301-02	Seasonic SS-300TGW Active PFC	Seasonic SS-300TGW Active PFC
PSU Size (W)	300	300	300

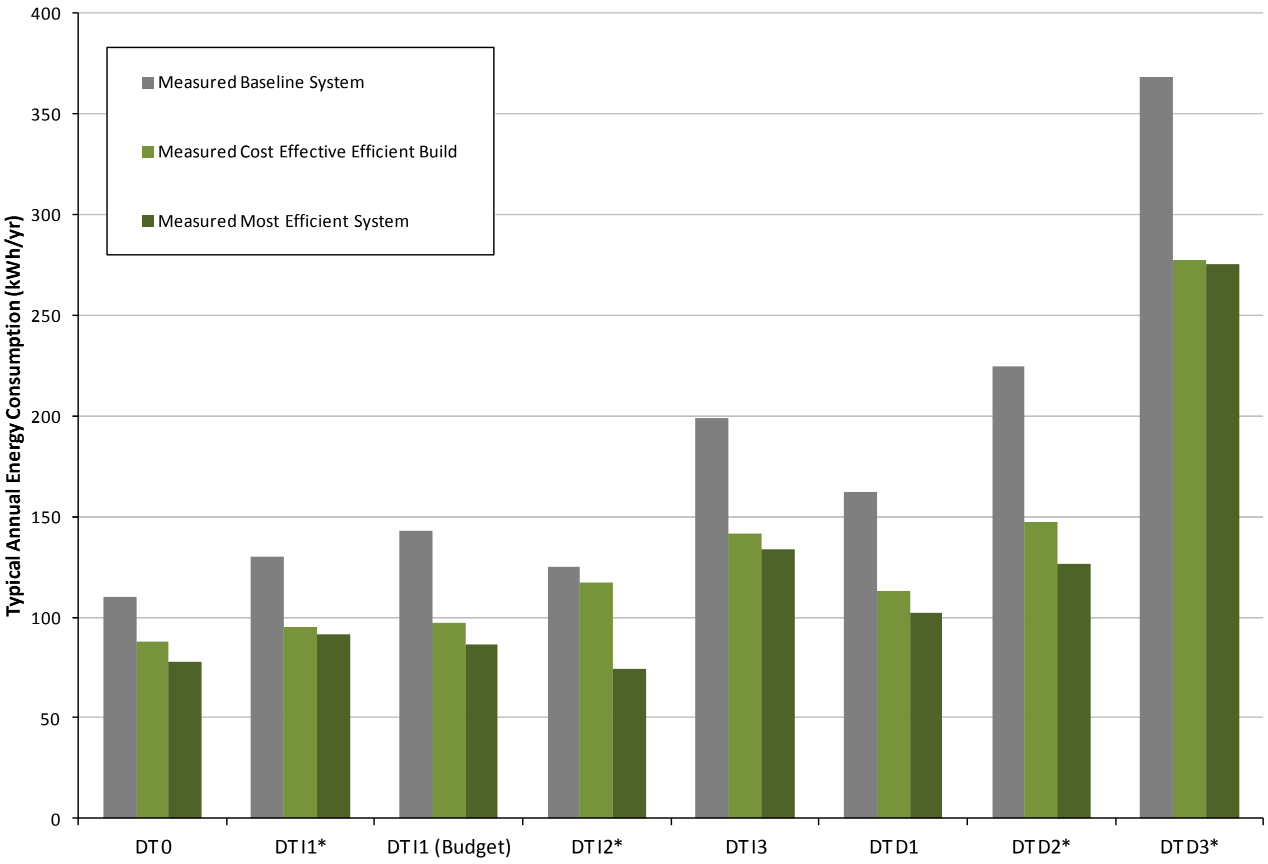
Table 8. DT I3: Baseline, Cost-Effective, and Most Efficient Configurations

Component Type	Baseline Build	Cost-Effective Build	Most-Efficient Build
CPU	AMD A6-5400B APU 3.8 GHz	AMD A6-5400B APU 3.8 GHz	AMD A6-5400B APU 3.8 GHz
Number of Cores	Dual Core	Dual Core	Dual Core
Memory	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM
Storage	Western Digital WD5000AAKX 500 GB	Seagate Momentus XT Hybrid HDD/SDD 500GB	Samsung 840 Series 250GB
GPU	AMD Radeon HD 7450D	AMD Radeon HD 7450D	AMD Radeon HD 7450D
PSU	Huntkey HK340-72FP	Seasonic SS-300TGW Active PFC	Seasonic SS-300TGW Active PFC
PSU Size (W)	240	300	300

Table 9. DT D1: Baseline, Cost-Effective, and Most-Efficient Configurations

Component Type	Baseline Build	Cost-Effective Build	Most-Efficient Build
CPU	Intel Pentium G640 2.8 GHz	Intel Pentium G640 2.8 GHz	Intel Pentium G640 2.8 GHz
Number of Cores	Dual Core	Dual Core	Dual Core
Memory	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM	1x4GB DDR3-1333MHz SDRAM
Storage	Western Digital WD5000AAKX 500 GB	Western Digital WD5000AZRX 500 GB	Samsung 840 Series 250GB
GPU	Sapphire Radeon HD6570 100323L	Sapphire Radeon HD6570 100323L	Sapphire Radeon HD6570 100323L
PSU	HP PS-5301-02	Seasonic SS-300TGW Active PFC	Seasonic SS-300TGW Active PFC
PSU Size (W)	300	300	300

Figure 2 below presents a summary of desktop computer measurements (including adders). The height of the bars represents the calculated total energy consumption (TEC) levels for the baseline, cost-effective efficient and most efficient builds.



*Indicates results obtained in 2012 under PG&E emerging technology funding (PG&E, 2012).

Figure 2: Summary of Desktop Computer Measurements (Including Adders)

5 Supplemental Testing Results

5.1 Impacts of Next-Generation Computer Architectures

The CASE report forecasts continued improvement to desktop CPU idle power based on recently introduced CPU technologies. Specifically, we cited third party and industry claims of 25% idle power reductions using fourth-generation Intel "Haswell" CPU architecture, but were unable to verify those claims at the time of CASE report submittal. Since Haswell desktops are not yet broadly available from mainstream OEMs, we developed a custom DT I3 Haswell build using off-the-shelf components and conducted a controlled test that examined the impact of enabling and disabling Haswell low-power CPU states.[10] These low-power CPU states are where we anticipate the majority of savings to originate in Haswell, so our testing effectively represents the additional idle power savings that systems may experience as OEMs begin to implement Haswell CPUs across their product lines.

For this build, we purchased and integrated an Intel Core-i5 4750 processor (4 cores, 3.2 GHz per core) on a compatible Haswell motherboard from MSI (MSI Intel Z87-G41 board, using the Intel Z87 chipset). To complete the system, we used the same suite of components found in the DT I3 cost-effective build: hard drive, optical drive, power supply, and physical memory. The switch to the Haswell motherboard and CPU initially shed an additional 14% from the cost-effective build's TEC; however, these numbers do not include the effect of enabling Haswell low-power states. Once low-power states were enabled on the motherboard's BIOS settings, measured TEC dropped an additional 25%, as shown in Figure 3 below (measured idle power values dropped about 32% and 35% for short and long idle, respectively). OEMs should be able to realize the 25% idle power savings claimed in the CASE report given our test results.

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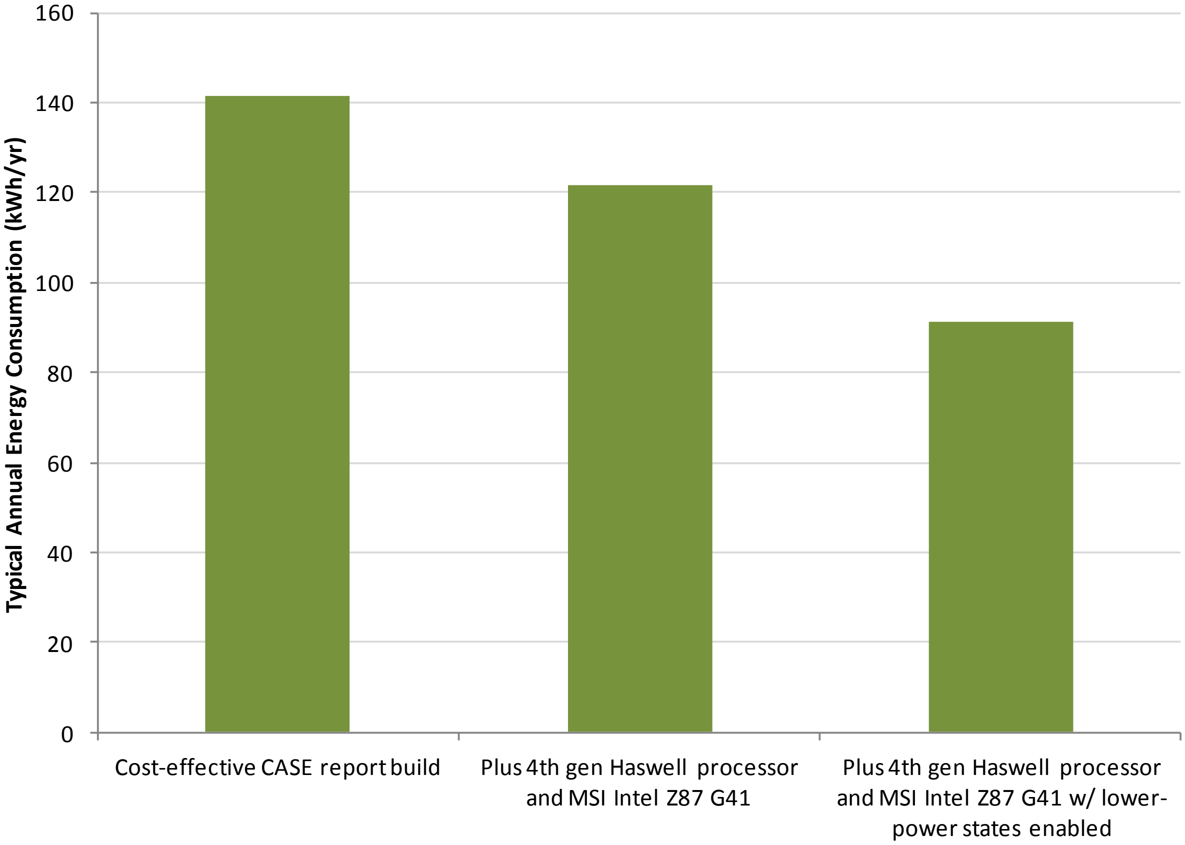
[10] Computer processors are able to enter a number of device-level power states. For the processor, these are known as C states. A state of "C0" represents an idle processor with no power-saving features engaged. As the C state number increases, the processor powers down various subsystems and decreases power consumption. Haswell processors support the new C6 and C7 states, whereas previous generations only support up through the C5 state.

Figure 3: Impacts of Next Generation Computer Architectures on DT I3 Cost-Effective Build



Since Intel's processor line has just undergone a significant upgrade, the latest Haswell technology is not yet available at all price points. However, by the time California Title 20 computer standards might go into effect (assumed January 2015), Haswell technology could dominate all Intel market channels from cost-conscious systems up through high-performance. It represents an evolution in Intel's technology roadmap and another mechanism by which desktop, notebook, and all-in-one computers will be able to comply with the standard.

5.2 Power supply rightsizing

In our previous testing, we found that 80 PLUS Gold power supplies, which are approximately 10% of the market (Ecova 2014), were both the cost-effective and most-efficient option for certain builds. We did not, however, fully explore the impact of more efficient 80 PLUS Platinum power supplies which are generally required to be on average 2.6% more efficient than Gold models. In order to determine whether more cost-effective savings could be obtained, we tested a 400-watt Platinum power supply (Seasonic SS-400 FL Active PFC) in the cost-effective and most-efficient builds of the DT I3 system. Surprisingly, we found that the cost-effective build with the Platinum supply used slightly less energy than the same build with the 300-watt Gold supply, and the most-efficient build used more energy with the Platinum supply than the same build with the 300-watt Gold supply. We saw similarly counterintuitive results when examining efficient power supply configurations on the DT0 system. Adding more efficient components downstream of an efficient supply actually resulted in *higher* energy consumption than before.

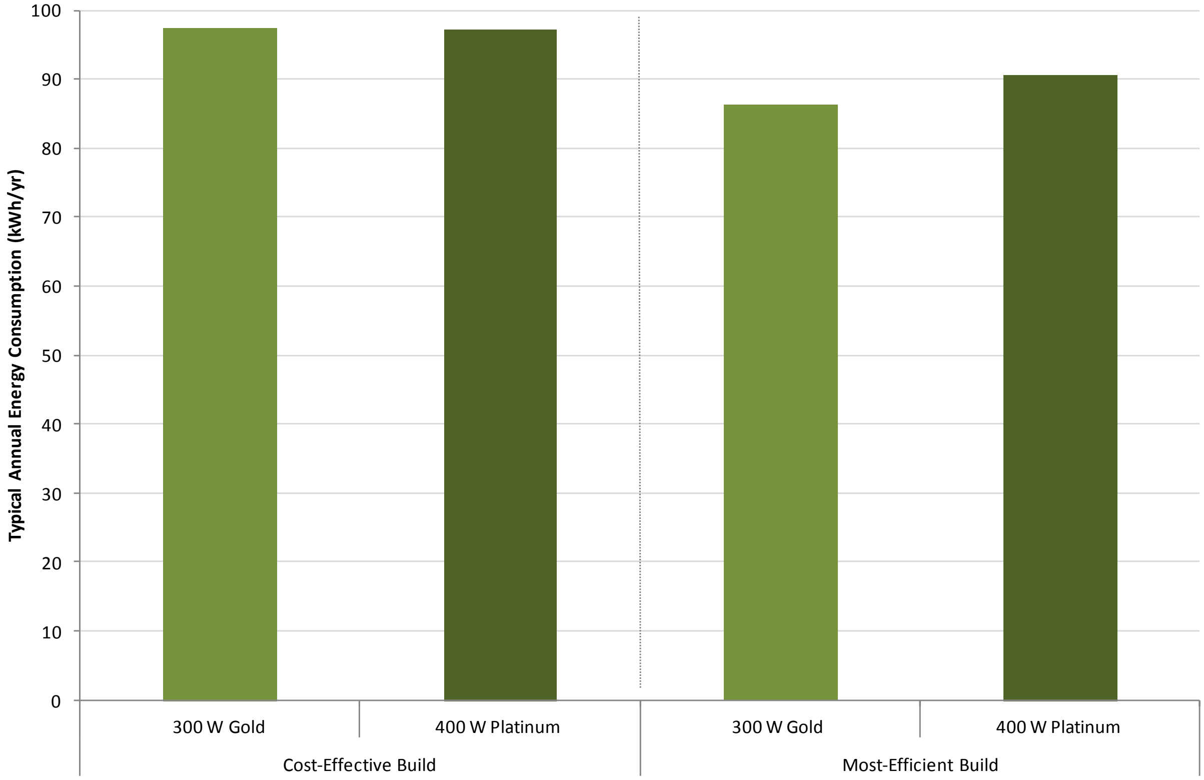


Figure 4: TEC Results for Cost-Effective and Most-Efficient Builds with Gold vs. Platinum supply

The reason for these counterintuitive results is a design convention that continues to plague new computers: power supply oversizing. Desktop computer manufacturers size their power supplies for possible user upgrades and expansion of the system. As a result, desktop power supplies may be able to provide several times more dc power than the system requires under normal operation. This has direct efficiency consequences, because power supply efficiency varies depending on the fractional loading of the unit. Supplies are typically most efficient at between 50% and 75% of rated load, with efficiency dropping off precipitously below 20% load. Note that power losses may be higher in this range of rated load because the power losses are dependent not only on efficiency, but also on the size of the load; the larger the load, the larger the power loss. To qualify for 80 PLUS certification, power supplies must achieve prescribed efficiency levels at 20, 50 and 100% of the unit's rated dc output. Specification levels are shown in Table10 below.

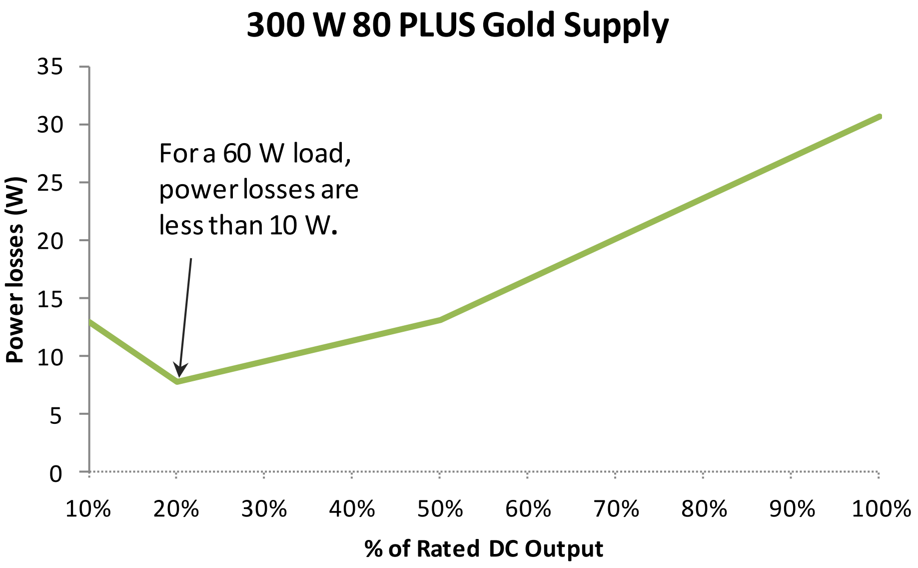
Table 10: 80 PLUS Efficiency Requirements

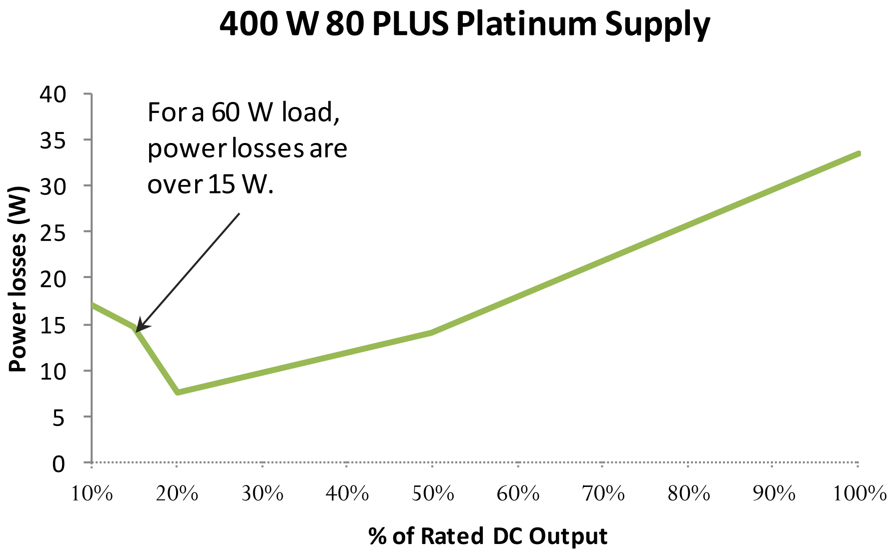
80 PLUS Certification	80 PLUS Efficiency Requirements by Percent of Rated Dc Load		
	20%	**50%**	**100%**
80 PLUS	80%	80%	80%
80 PLUS Bronze	82%	85%	82%
80 PLUS Silver	85%	88%	85%
80 PLUS Gold	87%	90%	87%
80 PLUS Platinum	90%	92%	89%

The 80 PLUS program does not set efficiency targets for load points below 20%, and yet in most systems, this is where typical operation occurs. Power supplies can operate at efficiencies significantly lower than those required by 80 PLUS when operating in this range.

Because of partial loading, it is quite possible for a “low-efficiency” supply to operate more efficiently than a “high-efficiency” supply when the more efficient unit is oversized. Take the example below comparing a 300 W Gold and a 400 W Platinum supply, both providing the same dc load of 60 W which is equal to 20% load of the 300 W Gold and 15% load of the 400 W power supply (Figure 4). At loads as low as 15%, even Platinum power supplies can experience severe drops in efficiency. The ac power draw is 75 W with the 400-watt Platinum supply and 65 W with the 300-watt Gold supply, a nearly 10% difference. As Figure 4 depicts, net losses — that is, power conversion losses caused by the power supply and dissipated as heat — in the oversized Platinum unit are over 15 W, whereas the more appropriately sized Gold unit consumes less than 10 W.

Figure 5: Net Power Losses in Power Supply





Thus, power supply rightsizing presents another strategy for improving operational efficiency of power supplies, without incurring significant incremental cost. In fact, rightsizing improves both energy savings and cost effectiveness, allowing lower efficiency power supplies to operate at higher efficiencies and reducing the bill of materials associated with oversized power electronics. Our team measured the impact of reducing power supply sizes on the DT 0 system. We measured the TEC and energy savings of a 300 W Gold and 250 W Bronze power supply. The 250 W Bronze supply generated roughly the same savings (24 kWh/yr) as the 300 W Gold supply in the same build (23 kWh/yr), with a smaller incremental cost. Here we have estimated a lower incremental cost for the bronze PSU based on the cost vs. efficiency relationships described in Section 3.4.1 that relate a power supply's average efficiency to overall cost. Incremental costs for the 250 W Bronze power supply would likely be even lower in reality due to its reduced output rating. Results are summarized in Table 11 below.

Table 11: DT 0: Power Supply Lifetime Savings and Cost Effectiveness

Build/Modifications	TEC (kWh/yr)	Savings (kWh/yr)	Lifetime Savings (kWh)	Lifetime Cost Savings (USD)	Incremental Cost (2013 USD)	Incremental Cost (2015 USD)	Benefit-Cost Ratio (2015 Cost)
220 W Baseline supply (non 80 PLUS)	110	-	-	-	-	-	-
+ 300 W 80 PLUS Gold supply	88	23	105	$16.19	$13.44	$12.60	1.3
+ 250 W 80 PLUS Bronze supply	87	24	109	$16.80	$8.43	$7.90	2.1
+ 250 W 80 PLUS Gold supply	84	27	123	$18.97	$13.76	$12.90	1.5

Table 11 demonstrates that system designers have multiple pathways at their disposal for improving power supply efficiency in computers. The path originally explored in the CASE report involved replacing the OEM power supply with a highly efficient 80 PLUS Gold power supply. However, our more recent tests on DT 0 show that a similar result could have been achieved with a less efficient, right-sized power supply, such as the 250 W 80 PLUS Bronze unit. For the DT 0 system, inclusion of the right-sized power supply in place of the original 300 W Gold unit chosen in the CASE report would have reduced the system's overall 2015 incremental cost by about $4.70. This, in turn, would have improved benefit-to-cost by ratios by over 60%. Even a smaller 250 W Gold unit would have provided slightly improved cost effectiveness.

Power supply rightsizing is a promising efficient design strategy, but it may not be appropriate in all situations. For example, OEMs may wish to oversize a model's power supply to allow for later hardware upgrades and expansion by the user. We highlight rightsizing here to demonstrate that even greater cost effectiveness may be achievable in situations where smaller power supplies do not compromise the OEM's overall design objectives.

5.3 Power Supply Power Factor Requirements

The CASE report provided recommendations both for internal power supply efficiency and power factor, mirroring requirements of the ENERGY STAR Version 6.0 computer specification and the 80 PLUS program. We would like to clarify and expand upon our recommendations in this regard. After further analysis, it appears desirable and possible to require a more comprehensive set of power factor requirements for computer internal power supplies that covers all major load conditions and harmonizes with ENERGY STAR Version 6.0 and 80 PLUS program requirements. Our proposed requirements, seen in Table 12 below, would cover 10, 20, 50, and 100% load points as with proposed efficiency levels. They would be identical to ENERGY STAR Version 6.0 and all levels of 80 PLUS PSU certification (Standard, Bronze, Silver, Gold, and Platinum). They would also extend modest power factor requirements down to lower load levels where computers are anticipated to spend most of their operational hours.

Table 12: Proposed Power Factor Requirements

	Load Condition			
	10%	**20%**	**50%**	**100%**
80 PLUS Standard requirements	-	-	-	0.9
80 PLUS Bronze/Silver/Gold/Platinum requirements	-	-	0.9	-
ENERGY STAR Version 6.0 requirements	-	-	-	0.9
CASE report proposed requirements	-	-	-	0.9
New IOU proposed requirements	**0.8**	**0.8**	**0.9**	**0.9**

A random sampling of 80 PLUS certification reports from the past year indicates that a wide variety of power supplies — varying in rated output wattage, efficiency level, form factor, and manufacturer — will be able to meet these requirements (see Table 18 in Appendix 8.4). Despite this widespread compliance, a more comprehensive power factor requirement is in the best interests of California's rate payers, utilities, and grid operators to encourage improved power quality on the grid. It would also prevent a possible loophole whereby power supplies could be designed to meet power factor requirements at 50% and 100% load, but switch off power factor correction at lower load levels in order to gain in efficiency. This behavior was recently observed in external power supplies in another jurisdiction.[11]

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[11] ITU-GeSI 2012: An energy-aware survey on ICT device power supplies

6 Conclusions

This report provided detailed documentation of testing of efficient desktop computer builds that helped form the basis for the California IOUs' Title 20 computer standards proposal. Supplemental analysis and test results were also included to provide additional support for the IOUs' August 2013 CASE report. The team also investigated the impact of alternate power supply configurations and next-generation processor architecture on the energy consumption of desktop systems.

The IOU technical team examined the possibility of using high-efficiency 80 PLUS Platinum power supplies in mainstream desktop systems, but found that many Platinum-rated power supplies were oversized for this application. Our research shows that additional cost-effective savings may be possible in desktop computer categories like DT0, DT1, DT2, and DT3, but would require OEMs to specify Platinum power supplies of lower rating than what is currently available on the market. Higher performance systems with discrete graphics (DT D1 and above) may see greater benefit from Platinum power supplies because their load requirements are more appropriately matched to current Platinum output.

Our latest analyses also include consideration of a 4% compound annual price decline for PSUs (the analysis presented in the August 2013 CASE report assumed flat prices). This assumption, based on input from power electronics industry stakeholders, further enhances the cost effectiveness of power supplies as a compliance path for desktop computers.

Additional supplemental testing of Intel's latest Haswell architecture indicates that OEMs should be able to realize approximately an additional 25% TEC reduction when Haswell's power-saving CPU modes are fully enabled.

Finally, we have also clarified our proposal for power factor requirements for desktop internal power supplies and have demonstrated the feasibility of those requirements using a random sample of units recently certified by the 80 PLUS program.

7 References

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8 Appendices

8.1 Testing and Instrumentation

We used high precision laboratory-grade instruments for all testing. An ISO/IEC 17025 accredited calibration laboratory calibrated all the measurement equipment used in this project. This includes:

- Chroma Programmable AC Power Source 61602
- Yokogawa WT1600 Digital Power Meter

Testing complied with ENERGY STAR's instrumentation measurement accuracy requirements:

- Power measurements with a value greater than or equal to 0.5 W shall be made with an uncertainty of less than or equal to 2% at the 95% confidence level.
- Power measurements with a value less than 0.5 W shall be made with an uncertainty of less than or equal to 0.01 W at the 95% confidence level

8.2 Detailed Component Price Information

Table 13: Detailed Component Price information

Component Type	Model number/name	Description	Number of Data Points	Average Price
CPU	AMD A6-5400B APU 3.8 GHz	Next generation AMD CPU Dual core 1 M Cache; 3.8 GHz	6	$68.09
	Intel Celeron G465	Launched in Q3 2012 Single core 1.5 M Cache; 1.9 GHz	5	$47.56
	Intel Celeron G460	Launched in Q4 2011 Dual core 1.5 M Cache; 1.8 GHz	3	$56.31
	Intel Celeron G440	Launched in Q3 2011 Dual core 1 M Cache; 1.6 GHz	2	$75.92
	AMD A4-5300	Dual core 1 M Cache; 3.7 GHz	17	$58.38
	Intel Core i5 3570T	Launched in Q2 2012 Quad core 6 M Cache; 2.3 GHz	1	$261.00
	Intel Pentium G640	Launched in Q2 2012 Dual core 3 M Cache; 1.6 GHz; 2.8 GHz	18	$78.50
	Intel Pentium G640T	Launched in Q2 2012 Dual core 3 M Cache; 2.4 GHz	2	$86.43
GPU	Sapphire Radeon HD6570 100323L (G2)	Inexpensive GPU 1 GB	2	$49.99
	EVGA 02G-P4-2645-KR	Next generation, low –end graphics card 2 GB	7	$121.35
HDD	Western Digital WD5000AAKX	Conventional HDD 500 GB 3.5 inch	14	$63.64
	Seagate Barracuda ST500DM002	Conventional HDD 500 GB 3.5 inch	10	$60.69
	Western Digital WD Green WD5000AZRX	Conventional HHD 500 GB 3.5 inch	8	$66.50
SSD	Samsung 830 Series	Solid State Drive 2.5 inch 256GB	18	$230.36
	Seagate Momentus XT Hybrid	Solid State Hybrid Drive 2.5 inch 500 GB	17	$110.89

Component Type	**Model number/name**	**Description**	**Number of Data Points**	**Average Price**
	Samsung 840 Series	Solid State Drive 2.5 inch 250 GB	14	$179.69
PSU*	Dell H220NS-00	220 W Conventional PSU	n/a	n/a
	HP PS-5301-02	300 W Conventional PSU	n/a	n/a
	Coolmax CA-300	300 W Conventional PSU	n/a	n/a
	Seasonic SS-300ES Active PFC F3	300 W 80 PLUS certified	n/a	n/a
	Huntkey HK 340-72FP	240 W Conventional PSU	n/a	n/a
	Seasonic SS-300TGW Active PFC	300 W 80 PLUS Gold certified	n/a	n/a
	Athena Power AP-MFATX32	320 W Conventional PSU	n/a	n/a

*** Power supply price assumptions were informed by a cost model, as described in section 3.4.1.**

8.3 Efficient Build Detailed Results

Table 14: Power Draw and Energy Use of Baseline and Cost-Effective Efficient Desktop Computers for All ENERGY STAR Categories

	DT 0	DT I1*	DT I1 (Budget)	DT I2*	DT I3	DT D1	DT D2 (Typical)*	DT D3*
Baseline System TEC (kWh/year)	**110**	**130**	**143**	**125**	**199**	**162**	**225**	**368**
Standby Power (W)	0.35	0.14	0.27	0.88	1.65	0.27	0.13	1.49
Sleep Power (W)	1.54	1.49	1.79	2.10	2.49	1.80	2.46	3.09
Short Idle Power (W)	25.27	29.74	32.74	27.90	43.83	36.97	52.40	82.80
Long Idle Power (W)	23.51	28.86	30.92	26.50	43.06	35.86	47.65	81.74
Cost-Effective System TEC (kWh/year)	**88**	**95**	**98**	**117**	**142**	**113**	**147**	**278**
Standby Power (W)	0.2	0.17	0.15	0.89	1.64	0.15	0.19	2.34
Sleep Power (W)	1.4	1.53	1.64	2.10	2.48	1.64	2.74	4.05
Short Idle Power (W)	20.08	21.78	22.36	26.15	30.91	25.64	33.62	61.27
Long Idle Power (W)	18.77	20.59	21.06	24.79	29.93	24.88	32.27	60.15
Annual Energy Savings (kWh/year, %)	**23 [21%]**	**35 [27%]**	**45 [32%]**	**8 [6%]**	**57 [29%]**	**50 [31%]**	**77 [34%]**	**91 [25%]**

*** Indicates results obtained in 2012 under PG&E technology funding (PG&E, 2012).**

Table 15: Power Draw and Energy Use of Baseline and Most-Efficient Desktop Computers for All ENERGY STAR Categories

	DT 0	DT I1*	DT I1 (Budget)	DT I2*	DT I3	DT D1	DT D2 (Typical)*	DT D3*
Baseline System TEC (kWh/year)	**110**	**130**	**143**	**125**	**199**	**162**	**225**	**368**
Standby Power (W)	0.35	0.14	0.27	0.88	1.65	0.27	0.13	1.49
Sleep Power (W)	1.54	1.49	1.79	2.10	2.49	1.80	2.46	3.09
Short Idle Power (W)	25.27	29.74	32.74	27.90	43.83	36.97	52.40	82.80
Long Idle Power (W)	23.51	28.86	30.92	26.50	43.06	35.86	47.65	81.74
Most-Efficient System TEC (kWh/year)	**78**	**92**	**86**	**75**	**134**	**103**	**127**	**275**
Standby Power (W)	0.2	0.17	0.12	0.73	1.62	0.14	0.15	1.49
Sleep Power (W)	1.55	1.52	1.62	1.79	2.47	1.63	2.57	3.19
Short Idle Power (W)	17.83	21.00	19.81	16.67	29.08	23.28	28.80	60.03
Long Idle Power (W)	16.61	19.79	18.51	15.07	28.11	22.71	27.89	63.86
Annual Energy Savings (kWh/year, %)	**32 [29%]**	**39 [30%]**	**57 [40%]**	**50 [40%]**	**65 [33%]**	**60 [37%]**	**98 [44%]**	**93 [25%]**

*** Indicates results obtained in 2012 under PG&E emerging technology funding (PG&E, 2012).**

Table 16: Cost-Effective Builds – Cost-Effectiveness and Lifetime Savings

	Measured Baseline TEC (kWh/yr)	Measured Cost-Effective TEC (kWh/yr)	Annual Savings (kWh/yr)	Lifetime Savings (kWh)	Lifetime Cost Savings (USD)	Base Component Cost (USD)	Efficient Component Cost (USD)	Incremental Cost (2013 USD)	Base Component Cost (2015 USD)	Efficient Component Cost (2015 USD)	Incremental Cost (2015 USD)
DT 0	**110**	**88**	**23**	**105**	**-$16.59**			**$13.44**			**$12.30**
PSU	-	88	23	105	-$16.59	n/a	n/a	$13.44	n/a	n/a	$12.30
DT I1*	**130**	**95**	**35**	**161**	**-$25.54**			**$16.01**			**$0.24**
CPU	-	119	12	53	-$8.43	$50.00	$55.00	$5.00	$39.70	$43.67	$3.97
HDD	-	98	32	148	-$23.43	$75.91	$81.91	$6.00	$58.68	$50.37	-$8.32**(1)**
PSU	-	99	31	144	-$22.79	n/a	n/a	$5.01	n/a	n/a	$4.59
DT I1 (Budget)	**143**	**98**	**45**	**209**	**-$33.04**			**$16.30**			**$14.67**
HDD	-	133	10	45	-$7.06	$63.64	$66.50	$2.86	$52.71	$55.08	$2.37
PSU		107	36	166	-$26.20	n/a	n/a	$13.44	n/a	n/a	$12.30
DT I2*	**125**	**89**	**36**	**167**	**-$26.42**			**$54.54**			**$24.21**
HDD	-	111	14	65	-$10.26	$69.79	$110.89	$41.10	$53.95	$65.85	$11.90
PSU		106	19	88	-$13.97	n/a	n/a	$13.44	n/a	n/a	$12.30
DT I3	**199**	**142**	**57**	**260**	**-$41.19**			**$47.25**			**$25.45**
HDD	-	181	18	81	-$12.74	$63.64	$110.89	$47.25	$52.71	$65.85	$13.14
PSU	-	160	38	177	-$27.94	n/a	n/a	$13.44	n/a	n/a	$12.30
DT D1	**162**	**113**	**50**	**229**	**-$36.17**			**$2.86**			**$14.67**
HDD	-	153	10	45	-$7.06	$63.64	$66.50	$2.86	$52.71	$55.08	$2.37
PSU	-	126	36	166	-$26.20	n/a	n/a	$13.44	n/a	n/a	$12.30
DT D2*	**225**	**147**	**77**	**356**	**-$56.34**			**$26.08**			**$14.31**
CPU	-	225	0	2	-$0.26	$209.00	$189.00	-$20.00	$165.93	$150.06	-$15.88
GPU	-	177	48	220	-$34.79	$169.89	$266.13	$96.24	$120.98	$189.52	$68.53
HDD	-	198	26	121	-$19.20	$173.17	$120.02	-$53.16	$133.87	$92.78	-$41.09
PSU	-	216	9	43	-$6.76	$57.00	$60.00	$3.00	$52.17	$54.92	$2.75
DT D3*	**368**	**278**	**91**	**417**	**-$65.92**			**$55.78**			**$43.90**
GPU	-	323	46	210	-$33.26	$196.10	$230.00	$33.90	$139.65	$163.79	$24.14
HDD	-	359	10	45	-$7.04	$118.14	$120.02	$1.88	$91.33	$92.78	$1.45
PSU	-	323	46	211	-$33.37	$90.00	$110.00	$20.00	$82.38	$100.69	$18.31

* Indicates results obtained in 2012 under PG&E emerging technology funding (PG&E, 2012).

(1) With the applicable experience curves, the more efficient component would be less expensive than the base component. Even if no incremental cost is assumed for this component, the efficient build will be cost-effective.

Table 17: Most-Efficient Builds – Cost-Effectiveness and Lifetime Savings

	Measured Baseline TEC (kWh/yr)	Measured Most-efficient TEC (kWh/yr)	Annual Savings (kWh/yr)	Lifetime Savings (kWh)	Lifetime Cost Savings (USD)	Base Component Cost (USD)	Efficient Component Cost (USD)	Incremental Cost (2013 USD)	Base Component Cost (2017 USD)	Efficient Component Cost (2017 USD)	Incremental Cost (2017 USD)
DT 0	**110**	**78**	**32**	**149**	**-$24.20**			**$132.44**			**$26.98**
HDD		95	16	73	-$11.80	$60.69	$179.69	$119.00	$39.62	$55.27	$15.64
PSU	-	88	23	105	-$17.03	n/a	n/a	$13.44	n/a	n/a	$11.34
DT I1*	**130**	**92**	**39**	**178**	**-$28.84**			**$164.46**			**$19.72**
CPU	-	119	12	53	-$8.65	$50.00	$55.00	$5.00	$32.07	$35.28	$3.21
HDD	-	95	35	162	-$26.37	$75.91	$230.36	$154.45	$46.26	$58.55	$12.29
PSU	-	99	31	144	-$23.38	n/a	n/a	$5.01	n/a	n/a	$4.23
DT I1 (Budget)	**143**	**86**	**57**	**261**	**-$42.36**			**$129.49**			**$25.05**
HDD	-	125	18	84	-$13.60	$63.64	$179.69	$116.05	$41.55	$55.27	$13.72
PSU		107	36	166	-$26.89	n/a	n/a	$13.44	n/a	n/a	$11.34
DT I2*	**125**	**75**	**50**	**231**	**-$37.50**			**$174.01**			**$27.36**
CPU		124	1	4	-$0.67	$125.00	$130.00	$5.00	$80.19	$83.39	$3.21
HDD	-	106	19	85	-$13.82	$69.79	$230.36	$160.57	$42.53	$58.55	$16.02
PSU		106	19	88	-$14.34	n/a	n/a	$13.44	n/a	n/a	$11.34
DT I3	**199**	**134**	**65**	**299**	**-$48.56**			**$116.05**			**$25.05**
HDD	-	174	25	113	-$18.38	$63.64	$179.69	$116.05	$41.55	$55.27	$13.72
PSU		160	38	177	-$28.69	n/a	n/a	$13.44	n/a	n/a	$11.34
DT D1	**162**	**103**	**60**	**275**	**-$44.67**			**$116.05**			**$25.05**
HDD	-	125	18	84	-$13.60	$63.64	$179.69	$116.05	$41.55	$55.27	$13.72
PSU	-	107	36	166	-$26.89	n/a	n/a	$13.44	n/a	n/a	$11.34
DT D2*	**225**	**127**	**98**	**452**	**-$73.33**			**$76.08**			**$49.56**
CPU	-	225	0.4	2	-$0.27	$209.00	$189.00	-$20.00	$134.07	$121.24	-$12.83
GPU	-	177	48	220	-$35.71	$169.89	$266.13	$96.24	$88.41	$138.48	$50.08
HDD	-	198	26	121	-$19.71	$173.17	$120.02	-$53.16	$105.53	$73.14	-$32.39
PSU	-	191	34	157	-$25.52	$57.00	$110.00	$53.00	$48.08	$92.78	$44.70
DT D3*	**369**	**275**	**93**	**429**	**-$69.70**			**$55.78**			**$35.66**
GPU	-	323	46	210	-$34.14	$196.10	$230.00	$33.90	$102.04	$119.68	$17.64
HDD	-	359	10	45	-$7.23	$118.14	$120.02	$1.88	$71.99	$73.14	$1.14
PSU	-	323	46	211	-$34.25	$90.00	$110.00	$20.00	$75.91	$92.78	$16.87

* Indicates results obtained in 2012 under PG&E emerging technology funding (PG&E, 2012)

8.4 Power Factor Measurements

Table 18: Power Factor Measurements of Recently Certified 80 PLUS Power Supplies

Manufacturer	Model	Size (W)	Label	Power Factor at % of Rated Load				Meets Proposed PF Levels?
				10%	20%	50%	100%	
AcBel	FSB009	250	Bronze	0.83	0.94	0.99	0.99	YES
AcBel	POB002-280G	200	Gold	0.93	0.98	0.98	0.99	YES
Antec	EA-750 Platinum	750	Platinum	0.94	0.96	0.99	1	YES
Antec	VP630F	630	Standard	0.98	0.99	0.99	1	YES
Dell	D300EM-01	300	Bronze	0.96	0.99	1	1	YES
Dell	D315ES-00	315	Gold	0.95	0.97	0.98	0.99	YES
Delta	DPS-300AB-70 A	300	Bronze	0.96	0.98	0.99	0.99	YES
Delta	DPS-250AB-88A	250	Gold	0.88	0.95	0.97	0.98	YES
FSP	FSP500-50ERN	500	Silver	0.96	0.98	1	1	YES
FSP	FSP1200-50AAG	1200	Gold	0.95	0.97	1	1	YES
Seasonic	SS-400FL2	400	Platinum	0.93	0.97	0.99	0.99	YES
Seasonic	SSR-550RM	550	Gold	0.98	0.99	1	1	YES