iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** VII **Month of publication:** July 2015

DOI:

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Green Computing - An Efficient Computer Power Consumption Benchmarking

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Abstract— Computer power consumption is becoming a more important topic as electricity prices climb and as pollution is becoming a bigger problem in the world. It is common knowledge that most of the world's power plants emit pollution as they generate electricity. As computers become more powerful and plentiful, their electrical demand increases which creates a need for more pollution generating power plants. The overriding goal of this paper is to try to make some contribution to the computing sciences which will raise awareness and ideally reduce computing consumption and pollution caused by powering computers. Within computer science, benchmarks that measure various aspects of performance are common and widely used in the literature, yet benchmarking in order to measure power consumption of computers has not received the same attention. In this thesis, techniques for accurately measuring the impact of techniques that can be used to reduce the power consumption of computers are explored. Pertinent background information is presented to put power benchmarking within the proper context of Green Computing, and common techniques for reducing power use are surveyed. Power benchmarking tools and techniques are introduced; a number of new benchmarks are presented and evaluated. An analysis of these techniques and their impact is provided, demonstrating the importance of benchmarking as a key metric in the area of Green Computing.
Keywords— Green Computing, Benchmarking, Energy efficient computing.

I. INTRODUCTION

As population has increased, energy use has also increased. The widespread use of technology, particularly computers, means that computer power consumption is becoming a more important topic as the cost of energy rises and pollution, together with its side-effects, is recognized as an urgent challenge. Within computer science, benchmarks that measure various aspects of performance are common and widely used in the literature, yet benchmarking in order to measure power consumption of computers has not received the same attention.

One area of the computing sciences that is starting to become more important is computer power consumption benchmarking. *Benchmarking* is a general and widely known approach where a standard approach, or *benchmark*, is used to measure some desired aspect, behavior or other characteristic of the thing being observed. In computing, benchmarks are typically computer programs that are run on a system, enabling accurate and repeatable measurement of some specific characteristic of interest. Recently, various computer hardware review websites like Tomshardware.com and Anandtech.com have begun including power consumption results with their other computing results. This extra effort to include power consumption benchmarks shows that readers are becoming more interested in how much power our computing equipment can consume. While the early computing power consumption benchmarks show a lot of promise, there is little standardization going on among the various computer hardware review websites. Each hardware review site has their own methods for measuring power consumption. This makes cross site comparisons difficult for readers and researchers, alike.

One of the primary goals of this thesis is to develop a computer power consumption benchmarking toolkit. This toolkit is free for anyone to use and offers a standard approach to computer power consumption benchmarking. Our computer power consumption benchmarking toolkit contains benchmarks for different computing use patterns including web browsing, gaming, distributed computing, and various computer power states including Idle, Stand by, Hibernate, and Off modes. Computer users make use of computers in different ways so it should not be expected that a one-size-fits-all benchmark would accurately represent how much power every user would use. Another goal of our benchmarking toolkit is that it can be used to raise awareness of computer power consumption

II. LITERATURE SURVEY

Green computing is a general term describing a facet of computing that is interested in improving energy efficiency and reducing waste in the full life cycle of computing equipment [1]. The computing life cycle includes the energy consumed to create computing

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equipment, get the computing equipment to a consumer, used to run and maintain the computing equipment and discarding/recycling of computing equipment at the end of their life cycle [1]. Computing equipment can range from desktop personal computers, laptops, servers, networking equipment, cabling, and more. Green computing is an important realm of the computing sciences because of the significant demand computing requires of our resources.

A. Types of computing energy use

The University of California Energy Institute described direct energy use, indirect energy use and their relation to greenhouse gas emissions in a paper called "An Analysis of Measures to Reduce the Life-Cycle Energy Consumption and Greenhouse Gas Emissions of California's Personal Computers" [1]. In the University of California paper direct energy use and greenhouse gas emissions (GHG) are defined as energy use and greenhouse gas emissions attributable to the operational electricity consumption of California's PC stock [1]. This definition is also applicable to any state, country, or the entire world in general. Essentially direct energy use and greenhouse gas emissions come from the electricity requirements required to power a computer.

B. Interpreting computer population data

The real focus of the University of California Energy Institute paper is to characterize the effectiveness of their data collection measures to inform PC-related policies for near-term energy efficiency improvements and GHG emissions reduction in California [1]. They gathered data (Table 2.1) about California's residential PC stock from information from the U.S. Census Bureau as well as other surveys [1].When taking data from different sources and comparing them to each other there can be some variation. In order to try to provide an accurate picture of what the PC stock projections look like in California, the authors tabulate the data into low and high scenarios [1]. These low and high scenarios provide boundaries which show the reader that they can be confident that the real PC stock lies somewhere in between these boundaries.

Year	California Population	Low Scenario				High Scenario			
		Total PCs	Notebook PCs	Desktop PCs		Total PCs	Notebook PCs	Desktop PCs	
				w/ CRT	w/ FPD			w/ CRT	w/ FPD
2005	37,005,000	12,102,422	2,987,441	5,651,521	3,463,460	12,398,645	3,060,563	5,789,849	3,548,233
2006	37,461,449	12,251,703	3,263,952	4,521,725	4,466,026	12,626,549	3,363,814	4,660,069	4,602,666
2007	37,917,899	12,400,984	3,585,559	3,563,154	5,252,271	12,856,280	3,717,201	3,693,973	5,445,106
2008	38,374,348	12,550,265	3,948,239	2,790,313	5,811,714	13,087,838	4,117,356	2,909,832	6,060,650
2009	38,830,798	12,699,546	4,348,121	2,166,738	6,184,688	13,321,222	4,550,973	2,272,805	6,487,444
2010	39,246,767	12,835,588	4,776,365	1,648,788	6,410,436	13,542,466	5,039,408	1,739,589	6,763,469
2011	39,703,216	12,984,869	5,238,323	1,227,347	6,519,199	13,779,424	5,558,860	1,302,449	6,918,114
2012	40,159,666	13,134,150	5,725,155	880,400	6,528,596	14,018,208	6,110,514	939,659	6,968,035

III. TECHNIQUES FOR MANAGING POWER CONSUMPTION

A. Energy saving primer

One of the primary goals of this research is to create practical and repeatable benchmarks for computer power consumption. The reason for this goal is to ultimately assist people in choosing more efficient computing equipment. We can tell immediately that by doing something as simple as shutting off your pc when it is not in use, significant energy and financial savings can be made. Over the course of a year around $50 is saved when turning off the computer/monitor only on the weekend, and around $150 is saved when turning off the computer/monitor on weekends and on weekdays when the computer is not in use.

Even more substantial savings can be seen while following some of the power savings guidelines discussed later (stand by, hibernate) in addition to turning off the computer outside of an eight hour work day. When comparing a task completed on a desktop pc to a standalone laptop pc, there is a huge difference in power usage. For example even if you leave your computer on 24 hours a day 365 days a year, you can save around $150 per year by switching to a laptop and following the same usage pattern.

The laptop in our study generally used about six times less electricity than our desktop, PC and monitor use.

B. Screen savers

Screen savers are a bit of a misnomer in green computing. A general misconception is that screen savers use less electricity. This is actually far from correct. Screen savers will use up just as much or more power as if your computer was idle [13]. Sometimes a complex screen saver or a 3D screen saver may use more power than your computer would normally use when idling. Screen savers can prevent the monitor and CPU from going to sleep which can waste a significant amount of power [13].

Screen savers do not put computers in an energy saving state. One common thought about screen savers are that they were designed to keep monitors from suffering from "burn-in" [13]. Burn-in occurs in monitors when the same image is displayed on the screen for a

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long period of time [13]. Burn-in has little affect on modern LCD monitors [13]. Plasma television screens can suffer from “burn-in” but they are generally not used with computers. As a rule of thumb, screen savers should be disabled. It is better to allow the monitor to fall asleep than to have a screen saver turn on after a period of idling.

C. Monitor sleep mode

Allowing the monitor to fall asleep after idling for some time period is a good start in improving energy efficiency [14]. A monitor falling asleep or entering Standby generally means the same thing. The monitor screen will go blank and no light will emit from the screen. There is usually a green light on the monitor that shows the user that the monitor is turned on. When the monitor is in sleep mode, the green light usually becomes amber.

Experiments performed for this research showed that a Dell 20” wide screen LCD uses around 55 watts of power when it is turned on. When the LCD goes into a sleep state, the power usage drops to around 3 watts resulting in significant energy savings. Using the monitor sleep mode can result in significant carbon dioxide reductions [14]. Major operating systems such as Microsoft Windows [14], Linux, FreeBSD, and Mac OS X have power options which allow users to modify the monitor sleep feature as well as other energy saving features we will discuss in the upcoming sections.

D. Hard disk sleep mode

Similar to the monitor sleep mode, a computer can place its hard disk drives in asleep mode when they are not in use [15]. Hard disk drives on desktop computers can use10 watts or more power when in use [16]. Hard disk drives on laptop computers tend to use less than desktop computers but the energy savings on a laptop may be more valuable, especially when the laptop is running on battery power. Some desktops, workstations, and servers have multiple hard disk drives. Hard disk drives that are not in use can be placed into Standby mode while hard disk drives that are in use can be left turned on. The operating system manages this automatically for the user.

E. System standby

System Standby is one of the most useful power saving features computers have to offer. After a preset time period of idling, a computer will shutdown most of its components [17] giving us significant energy savings. The memory will remain active so that whatever the user was working on will still be there when the computer wakes up from Standby mode [17]. The desktop computer that we tested used more than 100 watts idling and used as little as 5 watts when in Standby mode. That is more than 20 times less electricity used than when idling. Another advantage of the system Standby mode is that the computer can wake up within a few seconds. This is much faster than shutting down a computer completely and booting it back up. Another useful method of using Standby is to configure the computer's power button to send the computer into Standby mode instead of shutting it down. This feature will allow a user to send a computer into Stand by immediately, rather than waiting some time period idling before it is automatically put into Standby mode. Configuring a computer's power button
to act as a Standby button can be accomplished by changing the computer's power options in the control panel.

F. Hibernate

Hibernate feature is similar to the system Standby mode. The Hibernate feature can be enabled via the interface. Hibernate goes one step further than Standby and completely turns off the computer. Prior to turning the computer off, the Hibernate feature will save the memory state onto the hard disk drive. When the computer comes out of Hibernate mode, it will access the memory file which it stored on disk before hibernating and copy it back into memory. The desktop we tested used around 3 watts of power in Hibernate mode vs. the 5 watts of power the Standby feature uses. Why does the computer use 3 watt of power if Hibernate turns the computer completely off? The cause is due to phantom loads. A disadvantage of the Hibernate feature is that it takes slightly longer to Hibernate or wake up than it would to enter Standby mode or wake up from Standby. This is because it takes several seconds to save or load the memory's state onto the hard disk drive.

IV. COMPUTER POWER USE BENCHMARKING

A. General computer benchmarking

General computer benchmarking can usually be completed by using software tools or scripts. This is advantageous because everyone with a computer can download a free benchmarking program and run it on their machine to see how well their computer performs on that particular benchmark. There are benchmarks available to test a computer's performance in many areas including CPU throughput,

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memory bandwidth, video frames per second and more. General computer benchmarking has evolved over the past several decades. Products such as 3DMark2006 [23] can be downloaded for free and used to benchmark a computers graphics system. The benchmark's results can then be compared to online databases which contain the results of thousands of other machines.

B. Measuring power consumption

There is a variety of computer power consumption benchmarking techniques in practice today. Despite there being many available techniques, there is no universal one size fits all technique that is appropriate for every benchmarking situation. Different methods of benchmarking must be completed for different usage patterns. General computer benchmarks such as CPU or video benchmarks generally do not require any special tools. Since power consumption benchmarks require electricity measuring devices, it makes it harder for people to participate in the power consumption benchmarking area. The requirement and cost of a tool adds a burden to those who wish to run their own computer power consumption benchmarks. We discuss two electricity consumption meters in, the affordable **KILL A WATT** meter and the more expensive **watts up? PRO es** meter.

KILL A WATT POWER CONSUMPTION METER

In order to use KILL A WATT, you must plug it into the wall and then plug a device into KILL A WATT. KILL A WATT can be connected directly to the wall outlet or can be connected to an extension cable or power strip which is then connected to the wall outlet. While conducting this research, we found it easier to work with KILL AWATT with an AC extension cable so that it could be positioned closer to the experimenter for easier viewing.

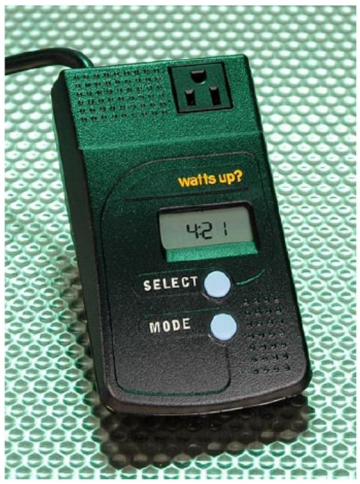


KILL A WATT has several modes including Volt (voltage), Amp (amperes),Watt (wattage), VA (volt-amperes), Hz (hertz), PF (power factor), KWH (kilowatt-hours), and Hour (the length of time the device has been connected to a power source)[25]. The voltage tends to approximately 120 volts for most devices and appliances. Some heavy appliances like electric stoves and electric dryers use 240 volts of alternating current (VAC). This research deals with the standard American wall plug voltage of 120VAC. KILL A WATT is not able to be used with 240 VAC wall outlets.

The Amp mode records amperes, a unit of electric current or amount of electric charge per second [26]. The VA mode measures volt-amperes, the SI unit of apparent power measurement [27]. The Watt mode displays how many watts are being consumed through the device at the moment of time the wattage value is recorded. This value tends to fluctuate with most devices as the electrical loads vary.

1) *WATTS UP? Power Consumption Meter:* The watts up? Power consumption meter (Figure 5.3) features the same functionality as the KILL A WATT meter and more. In addition to the KILL A WATT features, the watts up? meter can record power measurements over time in watt hours sensitively enough to use for computer power consumption measurements. In addition to recording the amount of power consumed over time, the meter comes with memory which saves the data that is recorded during measurements. The data can then be accessed by loading software from the watts up? website [29] and connecting the meter to a Windows computer with an included USB cable.

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There are several watts up? meter models available. The model that we tested was the watts up? PRO es model which included extra memory for saving measurements that are taken over long periods of time. The watts up? meter has several advantages over the KILL A WATT meter. It has more complex features than the KILL A WATT meter such as more sensitive measurements and memory for data storage.

V. EVALUATIONS OF POWER BENCHMARKS

A. *Implementation of benchmarks*

The power consumption benchmarks for green computing that we implemented must pass the following criteria:

1) The benchmark should be straightforward to use. This means that there should not hav
2) e to be any complicated configuration files to configure and each iteration of the benchmark should be easy to run. The benchmark should be reasonably inexpensive to obtain. Another indirect cost would be the cost of the software which the particular benchmark runs from. Our gaming benchmark runs off of a proprietary game called Team Fortress 2. Team Fortress 2 cost around $30 at the time of this writing.
3) The benchmark should be reasonably practical. There are synthetic benchmarks that can be downloaded on the Internet for free which give no inherently useful results such as 3DMark06. The reason we argue that synthetic benchmarks give no inherently useful results is because synthetic benchmarks are not programs which are used in the real world. Synthetic benchmarks attempt to perform tasks similar to real world program but their results cannot be interpreted clearly on their own.

B. *Internet web surfing benchmark*

The Internet web surfing benchmark attempts to simulate the power consumption of a machine whose user is surfing the Internet through a web browser. The Villanova AutoSurf benchmark is an HTML and JavaScript based benchmark. Using HTML and JavaScript is ideal because they allow the benchmark to be browser neutral.
In order to run a power benchmark with the Villanova AutoSurf benchmark, follow these Steps:

1) Have the computer and monitor, or laptop connected to a power measuring device which measures in watt hours or a similar power measurement over time.
2) Start the computer and load the Villanova AutoSurf page in a web browser.
3) Type in a time interval for page loads. The default is 5 seconds.
4) Start the benchmark by clicking the “Start Surfing” button.
5) Record measurements after the amount of time required for the benchmark is reached.

Once the watt hours are recorded, you can convert to average watts by multiplying the watt hours value by [60 minutes (minutes in an hour) / n minutes (amount of minutes spent benchmarking].

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C. 3D Gaming benchmark

The 3D gaming benchmark is designed to give a benchmark user an accurate measurement of how much electricity is consumed when a computer user plays a game. The selected gaming benchmark is Team Fortress 2 [30], a game developed by Valve Corporation for the Microsoft Windows platform.

In order to record power consumption from a Team Fortress 2 time demo, follow these steps:

1) Connect the computer and monitor, or laptop to a power measuring device which measures in watt hours or a similar power measurement over time.
2) Start the computer and copy the time demo file to: C:\Program Files\Steam\SteamApps\[USER PROFILE]\team fortress 2\tf\
3) Open the console by pressing the tilde key [~] key on the keyboard.
4) Type playdemo [demoname]. Replace [demoname] with the name of the demo.
5) Press enter to start the time demo, record the start watt hours. Use a stopwatch or other timing device to measure how much time has passed.
6) When the amount of time required for the benchmark is reached, record the end watt hours.
7) Subtract the end watt hours from the start watt hours to get the watt hours for the time interval that was spent benchmarking.

D. System power mode benchmarks

The System Power Mode Benchmarks are the easiest tests of our benchmark toolkit to run. The tester simply needs to turn off the computer, set it to Standby or Hibernate and then measure the wattage. In all of the computers that have been tested for this research, the amount of power used by the system power saving modes is constant.

In order to record power consumption for a system power saving mode benchmark, follow these steps:

1) Connect the computer and monitor, or laptop to a power consumption meter that displays wattage.
2) Turn on the computer and place the computer in the off, Stand by, or Hibernate power saving mode. For Windows machines this can usually be done by clicking on the start menu and clicking on “Turn Off Computer”.
3) The wattage consumed should not fluctuate. Record the value. This value represents how much wattage is consumed in one hour.

E. Distributed application benchmark

Our distributed application benchmark makes use of a program called Folding@home. Folding@home is a Stanford University distributed networking project which uses massive amounts of computing power to solve protein folding problems. Folding@home has clients available for many major operating systems including Windows, Linux, Mac OS X, and more.

In order to record power consumption for a system power saving mode benchmark, follow these steps:

1) Connect the computer and monitor, or laptop to a power consumption meter that displays wattage.
2) Turn on the computer, and start the Folding@home application. A straightforward guide on configuring and using Folding@home can be found in Appendix C for Windows and Appendix D for Linux.
3) Record the wattage displayed by the meter.

VI. RESULTS

A. Inter web surfing benchmark – Villanova Autosurf benchmark

Villanova Autosurf benchmark test results (watts used in 5 minutes) Desktop (windows XP) Desktop (Ubuntu 7.0) Laptop (windows XP):

	Desktop (Windows XP)	Desktop (Ubuntu 7.10)	Laptop (Windows XP)
Run 1 Watts / 5 Minutes	13.8	12.5	2
Run 2 Watts / 5 Minutes	13.8	12.4	2
Run 3 Watts / 5 Minutes	13.9	12.4	2.1
Average Watts / 5 Minutes	13.8	12.4	2

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Villanova Autosurf benchmark test results (Appr. watts used in 1 hour) Watts up? Desktop (windows XP) Desktop (Ubuntu 7.0) Laptop (windows XP):

watts up?	Desktop (Windows XP)	Desktop (Ubuntu 7.10)	Laptop (Windows XP)
Run 1 Appr. Watts / Hr	165.6	150.0	24
Run 2 Appr. Watts / Hr	165.6	148.8	24
Run 3 Appr. Watts / Hr	166.8	148.8	25.2
Average Appr. Watts / Hr	166	149.2	24.4

B. 3D Gaming benchmark – Team Fortress 2

We ran the Team Fortress 2 benchmark with the computer monitor and speakers turned on. Games are played with the monitor turned on and most of the time with a set of speakers or headphones. Each benchmark was run for 5 minutes. We ran the Team Fortress 2benchmark natively in Windows XP and through WINE [32]. The watts up? meter was used for measuring power consumption. Table contains the video settings which were used for each configuration.

	Desktop (Windows XP 1680x1050)	Desktop (Windows XP 1024x768)	Desktop (Ubuntu 7.10 1024x768)	Laptop (Windows XP 800x600)
Video Settings				
Resolution	1680x1050	1024x768	1024x768	800x600
Aspect Ratio	Widescreen 16:10	Normal (4:3)	Normal (4:3)	Normal (4:3)
Display Mode	Full screen	Full screen	Full screen	Full screen
Video Advanced				
Model detail	High	Medium	Medium	Medium
Texture detail	High	Medium	Medium	Medium
Shader detail	High	High	High	High
Water detail	Reflect all	Reflect all	Reflect all	Reflect all
Shadow detail	High	Medium	Medium	Medium
Color correction	Enabled	Enabled	Enabled	Enabled
Anti-aliasing mode	None	None	None	None
Filtering mode	Anisotropic 8x	Trilinear	Trilinear	Trilinear
Wait for vertical sync	Disabled	Disabled	Disabled	Disabled
High Dynamic Range	Full (if available)*	Full (if available)*	Full (if available)*	Full (if available)*
Motion Blur	Enabled	Disabled	Disabled	Disabled
Use 'bloom' effect when available	Unchecked (disabled)	Unchecked (disabled)	Unchecked (disabled)	Unchecked (disabled)
Hardware Direct X level:	DirectX v9.0+	DirectX v9.0+	DirectX v9.0	DirectX v9.0
Software Direct X level:	DirectX v9.0	DirectX v9.0	DirectX v9.0	DirectX v9.0

Fig: Team Fortress 2 benchmark test combinations

watts up?	Desktop Recording Demo (Windows XP 1680x1050)	Desktop Playing Demo (Windows XP 1680x1050)	Desktop Playing Demo (Windows XP 1024x768)	Desktop Playing Demo (Ubuntu 7.10 1024x768)	Laptop Playing Demo (Windows XP 800x600)
Watts / 5 Minutes	18	18	16.6	15.7	4
Appr. Watts / Hr	216	216	199.2	188.4	48

Fig: Team Fortress 2 benchmark test results

C. System power mode benchmarks – Off, Standby, Hibernate and Idle

We ran each system power mode benchmark with the monitor left off except for the Idle benchmark. Certain modes such as the Off state would force the monitor into its own sleep state. The Dell 20" 2005FPW used 2 watts in its sleep state.

The Off, Stand by, and Hibernate states have constant levels of power consumption so we used the simpler KILL A WATT tool for that purpose. The results of these tests are shown in Table.

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Volume 3 Issue VII, July 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

watts up?	Desktop (Windows XP)	Desktop (Ubuntu 7.10)	Laptop (Windows XP)
Run 1 Watts / 3 Minutes	8.1	7.2	.9
Run 2 Watts / 3 Minutes	8.1	7.2	.9
Run 3 Watts / 3 Minutes	8.1	7.2	1.0
Average Watts / 3 Minutes	8.1	7.2	.9

Fig: System Idle benchmarks test results (watts used in 3 minutes)

The desktop using Windows XP is the worst performer in this test. Ubuntu performs slightly better on the same hardware. The laptop is the best performer once again. The gaps widen significantly when the hour long approximation is calculated. The desktop using Windows XP uses around 18 more watts than the desktop using Ubuntu Linux 7.10 at idle. The laptop uses 19 watts which is less than the power consumed by a typical 60W incandescent light bulb. This Idle benchmark shows us that a lot of power can be wasted when an unused computer is left on for extended amounts of time.

watts up?	Desktop (Windows XP)	Desktop (Ubuntu 7.10)	Laptop (Windows XP)
Run 1 Appr. Watts / Hr	162	144	18
Run 2 Appr. Watts / Hr	162	144	18
Run 3 Appr. Watts / Hr	162	144	20
Average Appr. Watts / Hr	162	144	19

Fig: System Idle benchmark test results (App. Watts used in 1 hour)

The Off state and the Hibernate state used the exact same amount of power. This is expected because Hibernate saves the computer's memory state to the hard disk drive and then shuts off the computer. Stand by in all cases uses 1 more watt than the Off and Hibernate states. Windows XP and Ubuntu did equally well in these power savings modes while the laptop was outstanding, using around 0 watts when it was Off or in Hibernate and 1 watt during Stand by. Savings of 158 watts for the Windows desktop,140 watts for the Ubuntu desktop, and 19 watts for the laptop can be observed simply by using the Hibernate feature instead of leaving the machine idling.

KILL A WATT	Desktop (Windows XP)	Desktop (Ubuntu 7.10)	Laptop (Windows XP)
Off	4	4	0
Stand by	5	5	1
Hibernate	4	4	0

Fig: System Off, Standby and Hibernate benchmark test results

D. Distributed application benchmark – Folding@home

We ran each test configuration with the monitor turned on and off. The KILL A WATT meter was used to get the results because when Folding@home is run by itself, the power usage is constant. If a benchmarker finds a case where the power usage is not constant, a watts up? meter may be used to record watts consumed over time. Here are the results of our tests:

KILL A WATT	Desktop (Windows XP)	Desktop (Ubuntu 7.10)	Laptop (Windows XP)
F@H With Monitor	186	187	38
F@H Without Monitor	133	134	34

Fig: Folding@home benchmark test results (Appr. Watts used in 1 hour)

Folding@home did not make use of both processor cores on the desktop system, so the CPU usage was pegged at 50%. This issue did

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not affect the laptop because the laptop only had a single processor core. If the Folding@home client supported symmetric multi processing (using more than one CPU), the power consumption would have been higher.

VII. CONCLUSIONS

Desktop computers require external monitors which consume more raw materials due to their size. All of these matters and more must be taken into account when looking at the impact of purchasing a desktop or a laptop computer. Even if a person determines that a laptop is better for the environment, another important consideration is that laptops sometimes do not perform as well as desktops in certain tasks. For mundane tasks such as web browsing and office work, laptops are usually more than adequate. However for 3D gaming, animation rendering, and other resource intensive programs a desktop may perform much better. Laptops have come a long way in the past decade with the advent of gaming laptops and solid state drives, but despite their advances sometimes laptops simply cannot compete with a performance desktop.

The overriding goal for this paper is to help people reduce electricity consumption which in turn reduces pollution. Saving money is a secondary benefit which is also important. Many people may not be willing to reduce consumption based on purely green reasons but maybe interested in learning how to save money. By reducing the amount of power computers consume there is a direct benefit in the form of lower electricity consumption. A side benefit occurs in warmer climates where air conditioning is used. If computers generate less waste heat, the air conditioners used to cool rooms that contain computers will work less hard. This reduces electricity consumption further. By using our green computing benchmarking toolkit folks can have a better idea of how much power their computers use in different scenarios. In order to deal with the electrical inefficiencies of computers we must first learn where the inefficiencies lie. Only then can we understand that there is a problem and work to solve the problem. We believe that our green computing benchmarking toolkit can be used to show the world computer power consumption in simple terms most people should be able to understand. By getting knowledge about computer electrical consumption out in the open, we will have completed the first steps to reduce pollution and greenhouse gas emissions due to computing.

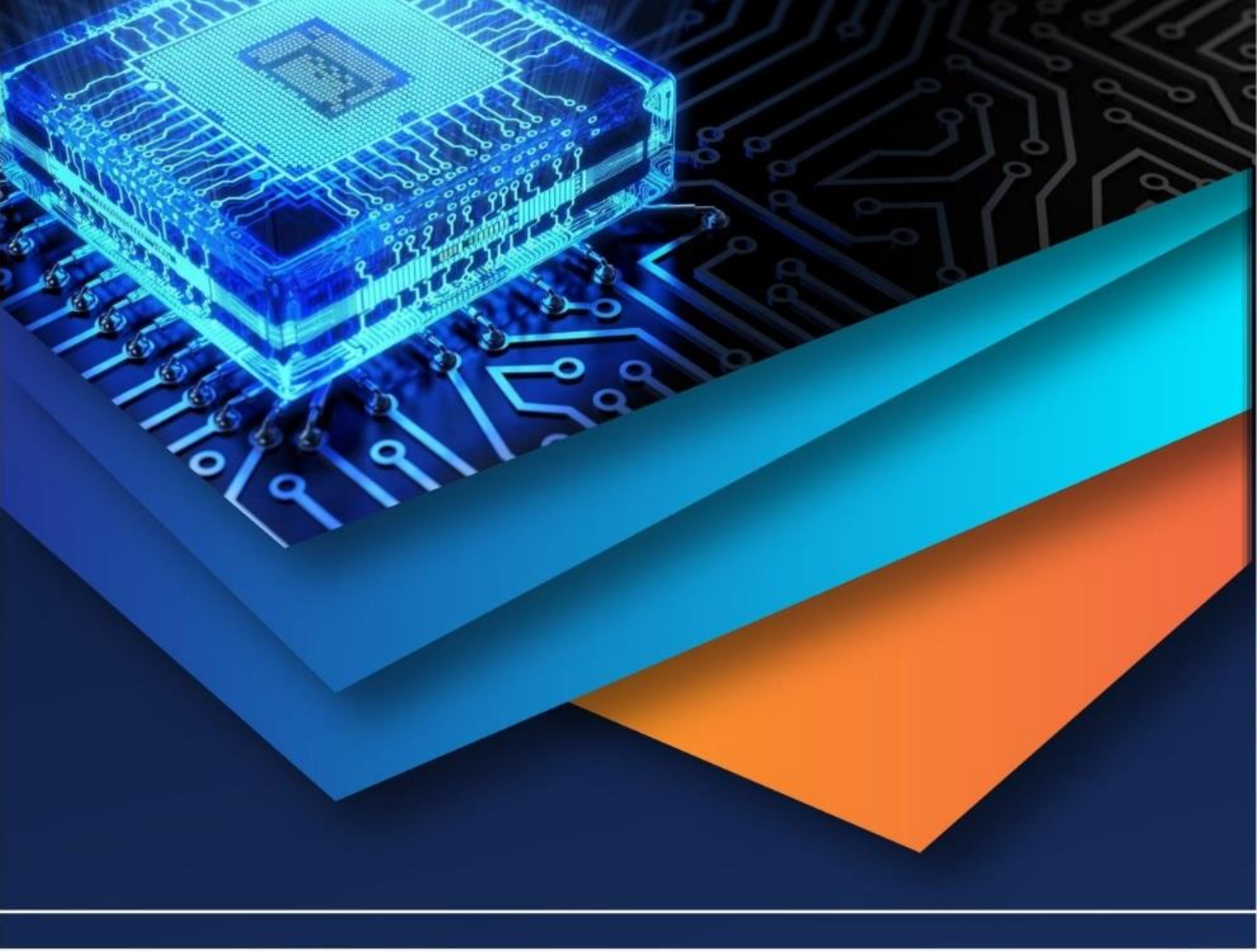
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