Methods, Metrics and Motivation for a Green Computer Science Program

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ABSTRACT

Computer science educators are uniquely positioned to promote greater awareness of Green Computing, using the academic setting to encourage environmentally conscious use of technology. This paper reports on practical techniques that can engage faculty and students, enabling Green Computing to be integrated into the classroom and research laboratory. Analysis and empirical evaluation of each reported technique is given, comparing the efficacy of each in terms of energy, environmental and financial cost savings. These results are provided as technological and economic evidence for the benefits of "Going Green," and to promote education in Green Computing in the classroom, department and research lab.

Categories and Subject Descriptors

K.4.1 [**Computing Milieux**]: COMPUTERS AND EDUCATION – *Public Policy Issues.* K.6.2 [**Computing Milieux**]: MANAGEMENT OF COMPUTING AND INFORMATION SYSTEMS – *Installation Management.*

General Terms

Economics, Measurement, Management.

Keywords

Green computing, classroom economics, environmental awareness

1. INTRODUCTION

"Green" has become a popular term for describing things that are good for the environment, generally healthful and, more recently, economically sensible [13]. "Going Green" implies reducing your energy use and pollution footprint. The technology community, specifically computer users, have popularized the term "Green Computing," which is the reduction of the pollution and energy footprint of computers [19]. While the goal of a truly paperless office [11] has yet to be realized, it certainly began a movement toward Green Computing. Technologies such as inexpensive scanners, large and affordable storage devices, and widespread use of PDF files have reduced paper in the modern office, although the truly paperless office is rarely realized even as interest in green approaches has risen.

With computing technology firmly woven into the fabric of daily life, computer science educators are ideally suited to contribute to Green Computing education and research. The introduction of green technology projects such as the Low Carbon ICT Project at the University of Oxford [8] are indicative of a positive trend, although there is significant opportunity for theoretical and experimental research to be performed by computer scientists. Computer science educators can lead the way by incorporating Green Computing ideas into the curriculum and by making these ideas and techniques accessible to educators in other disciplines.

This paper describes current Green Computing principles and approaches for reducing energy use and, ultimately, the carbon footprint. Practical methods are introduced, with analysis of an empirical evaluation to support their use in the department and classroom and to offer insight into paths for Green Computing research. Although this paper focuses on technical approaches, the authors acknowledge that there are many other aspects of Green Computing that deserve serious consideration.

2. GREEN COMPUTING

Green Computing is a discipline that studies, develops and promotes techniques for improving energy efficiency and reducing waste in the full life cycle of computing equipment from initial manufacture, through delivery, use, maintenance, recycling and disposal in an economically realistic way [9,13]. While it is daunting to consider the ways in which the widespread use of computers is contributing to waste, it is encouraging to recognize that computer science researchers and educators can pursue solutions to reduce this wastefulness.

2.1 Motivation

Due to the rising cost of energy, depletion of natural resources, and increasing concern for the environment by the general population, sensitivity to and interest in the issues of Green Computing are high [14]. While the Earth has existed for perhaps 4.5 billion years, in just the past 30 years one-third of the Earth's natural resources have been consumed [15]. Clearly, this pace of consumption is not sustainable from a practical perspective, suggesting that techniques for reducing consumption are needed.

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As population has increased, energy use has also increased. The widespread use of technology, particularly computers, means that computer power consumption is a topic of concern, with increases in computer energy consumption leading to increases in pollution and related side-effects. The negative side-effects of the computing life cycle include pollution in the form of carbon dioxide from power plants and transportation, lead and mercury from manufacturing processes and power plants, and other toxic materials used in the production, use and disposal of computers [6,7,9,14]. Computers that are less efficient use more electricity which leads to increased pollution. The need for Green Computing is thus quite clear, yet empirical studies and formalized recommendations have been slow in coming.

Energy efficiency is currently the easiest and cheapest way to reduce our use of fossil fuels, for both computers and other electrical devices. In the United States, where electricity costs are still relatively low compared with many other countries, alternative sources of electricity such as photovoltaics and wind turbines are still cost prohibitive for many. Although these technologies are likely to become more affordable, cost is still the primary factor inhibiting early adoption. [10]

There is a growing consensus that improving energy efficiency will reduce pollution and save money [10,13]. The matters in question are how to go about implementing efficiency improvements, how to improve these methods and create new methods, and how best to spread this knowledge by engaging computer experts and lay people.

2.2 Approaches and Issues

The motivation to reduce waste through Green Computing is clear, although identifying appropriate Green techniques for a given situation from among the many available is challenging. One of the easiest ways to reduce consumption and pollution is to reduce use [11]. Reducing consumption by printing documents double-sided, viewing documents on-screen, powering off electrical devices that are not in use, placing a computer in sleep mode or powered off when not in use, and similar techniques are effectively free, save for the minimal extra effort involved [14].

Computers in particular are ideal candidates for reducing power consumption, with easy-to-use features such as automatic sleep mode which shuts down an idle computer after a configurable period of inactivity. Using power management settings is a common strategy for reducing energy consumption and carbon dioxide emissions [9,19]. Replacing computers less frequently can also significantly reduce energy and environmental waste because manufacturing PCs is an energy intensive process and many old computers are still sent to landfills in the United States [7,9].

Although the technical challenges of Green Computing are not overly complex, perhaps the largest issue is that of changing the behavior of computer users. Technical challenges include finding the optimum system configuration settings and balancing energy efficiency with classroom or business requirements, which are within reach of a deliberate research and administrative effort. Computer users, however, are often used to leaving machines powered on as a convenience, and system administrators often count on this situation to conduct automated software updates and nightly file system backups. Although solving the social and behavior issues involved with Green Computing pose a significant challenge, there can be little forward movement without concrete and workable solutions to the technical issues. While individual effort is important, organized research activities are vital if these solutions are to be found.

2.3 Applicability to Computer Science

Computer science plays a crucial role in the research, teaching, and promotion of Green Computing techniques. With the ubiquity of computing, it is incumbent on computer science researchers and educators to lead the way in research and education in this emerging discipline. Given their necessary technological expertise, computer science students and faculty are uniquely positioned to learn, research and educate others about Green Computing. Students who graduate from programs which have Green Computing components will be able to share their knowledge to corporations, nonprofit organizations, government and in their communities. Research and education in the area of Green Computing is underway [8,12,17], with the focus on technical issues. Educators in particular can benefit from understanding the techniques currently available to them as a starting point for educating their students.

3. GREEN COMPUTING TECHNIQUES

Understanding the ways in which power consumption impacts the "greenness" of any technology, and specifically computing technology, is an essential step toward reducing this consumption and educating others. This section describes the various specific techniques that can be used to reduce power consumption.

3.1 Turn Off Equipment When Not In Use

Powering down equipment is the simplest, most effective and most obvious way to reduce computing power consumption. Computers have become such a standard part of daily life that many computers are left powered on around the clock, and is often done as a convenience to the user. This convenience is costly since the simple act of powering off a computing device will significantly reduce its power consumption, although it is important to note that many devices may still consume a small amount of power or "phantom load." [12]

3.2 Computer Power Savings Modes

Management of power consumption is a standard, yet often overlooked, feature of most computers and operating systems on the market today. Typically, one changes settings that control the behavior of various software and hardware components, thereby reducing power consumption. The barrier to wider adoption is that many find power savings modes to be inconvenient as there can be a brief delay in exiting a power saving mode back to normal use. Resistance is understandable, although with careful system configuration and gradual acclimation to a different way of working, this hesitancy can be overcome. [12]

3.2.1 Screen Savers

One of the simplest and most familiar power saving methods is the proper use of screen savers. The typical graphical screen saver, originally designed to minimize "burn-in" of computer monitors, actually increases power consumption [18]. Rather than using a 3D graphics screen saver, and with screen burn-in no longer a concern, power use easily can be reduced by disabling screen savers [18]. In this way, power consumed by intensive graphics is eliminated, leading to the monitor "falling asleep" after a period of idling, automatically conserving still more power.

3.2.2 Monitor Sleep Mode

Allowing the monitor to fall asleep after idling for some time period is another easily employed method for improving energy efficiency. When a monitor falls asleep or enters a “stand by” mode, it enters a low power consumption state. The monitor screen will be blank, with no light emitting from it. For example, a Dell 20” widescreen LCD uses approximately 55 watts of power when it is on. In sleep mode, the power use drops to around 3 watts, resulting in significant energy savings [18]. Setting the sleep mode is done via an operating system’s power options control panel, with a sleeping monitor able to be woken within a couple of seconds by moving the mouse or typing a key on the keyboard. Monitors should be configured to fall asleep in the classroom, office and at home.

3.2.3 Hard Disk Sleep Mode

A computer can place its hard disk drives in a low power sleep mode when they are idle. Hard disk drives on desktop computers can use 10 watts or more when in use [18], while notebook computer drives use less but energy savings have the benefit of extending battery charge life. Operating system settings again manage this mode automatically once configured. A hard disk drive that falls asleep is awakened within a couple of seconds by moving the mouse or typing a key on the keyboard. This setting provides a small savings and is minimally intrusive, with more significant savings possible using system standby mode.

3.2.4 System Standby Mode

System standby is one of the most effective power saving features. After a preset idling period, a computer will shutdown most of its components significantly reducing power use. Volatile memory remains active so that whatever the user was working on will still be there when the computer wakes up from standby mode. A desktop computer that uses more than 100 watts idling can use as little as 5 watts when in standby mode, using one twentieth of the electricity it used when idling [18]. Wake up time for system standby mode requires a few seconds, a delay that users may not be accustomed to. Standby mode is much faster than shutting down and later powering on the computer, and it preserves the computer’s state in memory, making it preferable for users seeking a balance between convenience and greenness. The power button of most computers can also be configured to send the computer into standby mode rather than shutting it down, further enabling users to conveniently save power.

3.2.5 Hibernate Mode

The hibernate mode goes one step further than standby mode by completely powering off the computer. Invoking the hibernate mode causes the memory state to be saved onto the hard disk before powering down. When coming out of hibernate mode, the computer restores the memory state, returning the computer to its pre-hibernate state. A desktop computer will consume approximately 3 watts in hibernate mode vs. 5 watts for standby [18]. A disadvantage of the hibernate mode is that it takes slightly longer to enter and exit hibernate than standby, the result of saving and restoring the memory state to and from the disk.

3.3 Eliminate Phantom Loads

Phantom loads, such as the 3 watts used by the hibernate mode, occur when electrical devices appear to be powered off but continue to consume electricity [10]. Many electrical devices exhibit phantom loads because they do not have a physical switch that disconnects the electrical connection to an electrical socket [10]. For example, most computers exhibit a phantom load of 1-3 watts due to a constant draw by AC/DC adapters or LAN-friendly wake up functionality, among other causes. Wake up on LAN allows a completely shut off computer to be turned on remotely from a machine on its network, an important capability when administering a network. The computer that is shut off uses a small amount of power to drive sensor circuits that detect a wake up signal received by the network interface. Though seemingly insignificant, phantom loads can cost a surprising amount. The following equation approximates the cost that a user who has 10 electrical devices, each consuming as little as 3 watts when “off,” will incur in one year:

$$Power_{year} = \frac{10 \text{ devices} * 3 \text{ W} * 24 \text{ hours} * 365 \text{ days} * 1 \text{ kW} / 1000 \text{ W}}{263 \text{ kWh}} \quad (1)$$

At the rate of 9.26 cents, the average price of electricity in the United States per kilowatt hour (kWh) in April 2008 [5], the total cost of phantom loads for this user is about $26 for the year. Of course, electricity rates vary widely, so the cost could be much higher in some areas. The solution to the phantom load problem is to pull the plug from the wall when the electrical device is not in use [10], with a more convenient alternative being the use of a switchable power strip. More sophisticated power strip devices are available that can automatically power off any devices plugged into the strip when a specific device, such as the computer, is powered off [4].

3.4 Upgrade with Efficient Components

Upgrading inefficient components inside of a computer can improve a computer’s overall efficiency, although higher cost is sometimes a prohibiting factor, with component upgrades sometimes requiring other prerequisite components to be replaced first. A more cost effective alternative to component upgrades is to deliberately seek the greenest computer available when it comes time for replacement. [17]

3.5 Upgrade to Extend Computer Lifecycle

While upgrading computers to improve their efficiency may not be cost effective, upgrading with the intention to extend their life cycle is more worthwhile. Upgrading the system memory or CPU will improve performance without requiring additional component upgrades. This type of upgrade frequently is less expensive than system replacement, prolongs system life cycle, and reduces the waste issues of discarded computers. [9,17]

3.6 Purchase Efficient Devices to Begin With

Inevitably, a computer will need replacement. When purchasing a new computer, special attention should be paid to several criteria. First, the computer should be energy efficient, following a compliance standard such as Energy Star [12], indicating a recognized conformance to low energy use goals. Second, the manufacturer of the new computer should have a recycling program for used computers to reduce waste. Third, the computers themselves should be made up of as few toxic materials as possible [6,7]. Clearly, exposure to toxic materials can be detrimental to human health and to the environment.

3.7 Supporting Approaches

Powering computers using green electricity generated from sources such as solar, wind, bio-fuels, and others may reduce pollution and greenhouse gases, although improving the efficiency of electrical devices remains more cost effective at present. For every dollar spent improving the efficiency of electricity consuming devices, 3-5 dollars must be spent to obtain the same savings with generating equipment like solar panels[10].

Moving toward a paperless office and classroom is another approach that can benefit computer science researchers and educators [1], with institutional buy-in and individual reluctance remaining as hurdles [16]. Using electronic handouts, via PDF or HTML for instance, online forms, tests and quizzes, scanning archival copies of documents rather than printing, and printing those documents that must be printed double-sided when possible are techniques that can reduce paper waste and energy use [1,2].

4. EVALUATION

Formal and repeatable power consumption benchmarks of a number of power saving techniques were developed [18], and results are summarized and expanded upon here. Measurements of power consumption were performed using two commercially available devices (Figure 1).

Figure 1. Kill A Watt™ and Watts Up?™ devices [3].

Monitor power consumption tests were performed using a 20" Dell 2005FPW wide screen LCD monitor. As a control, the unplugged state exhibited the expected 0 watt draw. When the monitor was plugged in but powered off, the draw was 1 watt, a phantom load. In sleep mode, monitor drew 3, and drew 55 watts when powered on. This difference in power use highlights the power savings that are available. Enabling monitor sleep could result in approximately a 94% reduction in power use for the monitor tested, with comparative results shown in Figure 2 [18].

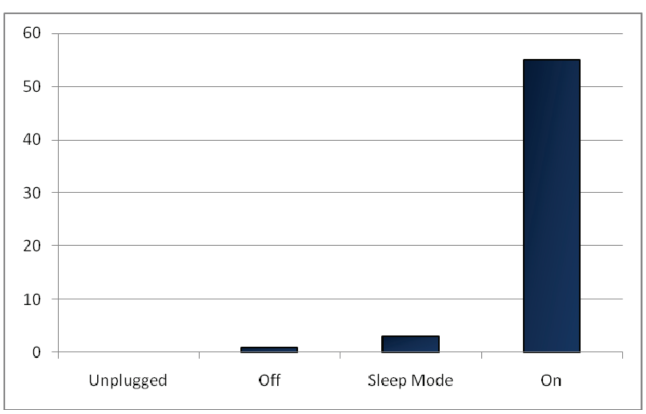

Figure 2. Dell 20" LCD monitor power consumption (watts).

Measurements of desktop computer power use were performed using a custom built AMD Athlon x2 5000+ computer, with laptop tests using an Acer Travelmate 3200 laptop. Results of measuring power consumption for different power modes using these two computers are shown in Figure 3 [18]. The most striking result is the large difference in efficiency between the desktop and laptop computer, with the desktop exhibiting a 4 watt phantom load vs. 0 watts for the laptop. The desktop drew about 4-5 times more power than the laptop when idling and under maximum use. From a power savings perspective, the case easily could be made in favor of equipping a lab with laptops rather that desktop computers.

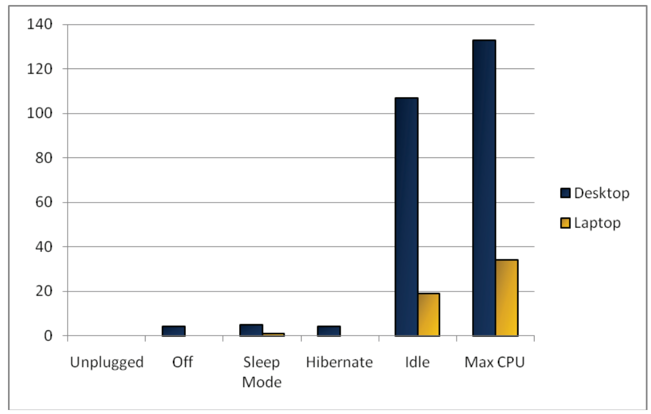

Figure 3. Desktop and laptop power consumption (watts).

It is possible to reduce power use by nearly 97% when using the sleep or hibernate modes rather than leaving computers idling when not in use. Although using hibernate mode offers the greater savings of the two, it takes significantly longer (~30 secs) to wake up from hibernate mode than it does from sleep mode (~3 secs). However, if power is disconnected while a computer is in hibernate mode, no information is lost, while a power loss in sleep mode would cause the computer to lose its current state from memory. Thus, for absolute electricity savings the hibernate feature is slightly better, while the sleep mode provides slightly less savings with a much faster wake up time.

The following equation has been devised to estimate how much power a PC will use, and can also be used for any electricity consuming device. The amount of power a computer, or other device, consumes depends on the type of work that it does. A computer being used to browse the Internet will use less power on average than one being used for computer gaming. The average watts/hour can be used to estimate how much it costs to run a PC in the average case. Given the local cost of electricity per kWh, the cost to run a computer for one year is calculated as:

$$\text{Cost}_{\text{year}} = \left[\frac{\text{Average Watts}}{\textit{hour}}\right] * \left[\begin{matrix}\text{Hours run}\\ \text{in 1 year}\end{matrix}\right] * \left[\frac{1\text{ kWh}}{1000\text{ W}}\right] * \left[\begin{matrix}\text{Cost of}\\ \text{electricity}\\ \text{per kWh}\end{matrix}\right] \quad (2)$$

To calculate the cost for a computer lab of N computers, simply calculate the cost for one computer and multiply by N.

5. INVOLVING STUDENTS & FACULTY

Computer science departments can lead by example to encourage students and faculty to learn more about Green Computing. By instituting one or more green practice or policy for labs, classes or offices, students and faculty will gain practical experience and knowledge. The result may be that some students and faculty will decide to pursue further learning about or application of Green Computing in their classes or research labs.

Introductory CS courses, and courses in computer systems or operating systems, are ideal places to incorporate Green Computing into a curriculum, as these students already are being exposed to system concepts, either at the application or operating systems levels. Lab assignments can be given where students would use electricity testing meters and power benchmarking techniques to measure computer power consumption under different system run levels and power saving modes. Faculty can research areas of power optimization in compilers or other areas where further research is needed, using these same power benchmarking techniques. Because these research projects can be limited in scope, they are appropriate for undergraduate or early graduate students.

6. CONCLUSIONS & FUTURE WORK

Incorporating the Green Computing techniques discussed in this paper into classrooms can have an immediate impact by reducing power consumption of entire labs of computers. Over the longer term, students and faculty will share their knowledge with others, increasing the reach of Green Computing ideas. Power management features such as the sleep and hibernate modes are most likely to be effective because computers can automatically go into low power states after a preset idle time without human intervention. Techniques such as unplugging a computer or using a lab-wide "kill switch" to eliminate phantom loads are less effective because they require constant action by the user. Using intelligent power strips help to reduce user interaction since they can automatically shut down peripherals when a computer shuts down, thereby reducing phantom loads.

In the future, we plan to conduct a more comprehensive series of case studies in classrooms to improve the understanding of how these techniques perform in real world scenarios. Information on repeatable power use benchmarking, including an automated web browsing benchmark, are available online (actlab.csc.villanova.edu). Additional guideline development is planned, with the goal of engaging more faculty, staff and students in Green Computing research, application and education.

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