

Study of Desktop Computer Energy Waste at Worcester Polytechnic Institute

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Abstract

This IQP sought to improve sustainability at WPI by reducing the energy wasted by the university's desktop computers. Energy waste was calculated by inventorying desktop computers, measuring their power draw, and estimating the ways in which they were used. It was found that the university's desktop computers waste approximately 300,000 kWh of electricity annually; however, a policy of putting idle computers to sleep with Windows 7 Power Options could reduce this waste by 69%.

Executive Summary

Problem

Desktop computers have become an integral component of modern life (Anderson 2015), (Fox 2014). Because of this, they have become a large source of energy consumption and—when used inefficiently—energy waste (Mills 2013). This is a global problem, but it is particularly relevant to organizations that house thousands of desktop computers (Hirst 2013). Many organizations leave desktop computers on at all times to ensure convenience for the desktop computer users; however, this means that the desktop computers are powered at all times, even when they are not in use (Hirst 2013), (Dupuis 2009). Worcester Polytechnic Institute (WPI) is not insulated from this source of energy waste. In 2009, a WPI IQP study found that the desktop computers in Higgins Laboratories were left on at all times (Hirst 2009). Another study was conducted in 2010 regarding WPI’s Atwater Kent Laboratories, and it had similar findings. (Newman 2010). Outside of these two past studies, little was known regarding WPI’s desktop computer energy consumption and energy waste. For this reason, further research into the desktop computers at WPI was needed.

Project Goals

The purpose of this IQP study was to improve the Sustainability of WPI by examining the energy consumption and energy waste of desktop computers at WPI. In doing so, two goals were outlined:

1. Measure the energy waste of desktop computers at WPI
2. Recommend a method to reduce the energy wasted by desktop computers at WPI

Measuring Energy Waste at WPI

To measure the energy waste of all desktop computers at WPI, energy waste was defined, equations to calculate energy waste were written, and data was collected to determine the values of all necessary parameters for these equations.

Energy waste was defined as the energy consumed by a desktop computer when it was not in active use, where active use meant the desktop computer was both awake and had a user logged in. From this definition followed five desktop computer states: (1) awake and logged in, (2) awake and logged out, (3) asleep and logged in, (4) asleep and logged out, and (5) shutdown. These desktop computer states are visually presented in *Figure 1*. As shown in *Figure 1*, energy consumed in states two through five was considered wasted because a desktop computer in these states was not in active use.



Figure 1. This figure illustrates the five desktop computer energy states and classifies each as either wasteful or non-wasteful.

Energy waste for a single desktop computer was calculated by the sum of the energy consumed in states two through five. The energy consumed in a state was found by multiplying the power drawn in that state by the time spent in that state. Energy waste for all desktop computers at WPI was calculated by summing the weighted average of energy consumed in states two through five, and multiplying the result by the total number of computers. Therefore, in order to measure the energy waste of all desktop computers at WPI, the following values were required: the total number of desktop computers, the power drawn by each desktop computer in each of the five states, and the proportion of time each desktop computer spent in each state.

The number of desktop computers at WPI was determined by inventorying the university’s desktop computers. This entailed categorizing computers by manufacturer, model, and location, and counting the number of computers in each category. 684 desktop computers were categorized across 10 academic buildings. 66 restricted laboratories were also documented and it was assumed that each lab had approximately 5 desktop computers. Additionally, it was assumed that each of WPI’s approximately 450 faculty have a desktop computer, and around 250 desktop computers are owned and operated by WPI staff. Thus the total number of desktop computers at WPI was estimated to be between 1000 and 1700 (approximated when accounting for the assumptions).

In order to determine the power draw of desktop computers at WPI, the Watts Up Pro energy monitor was used to measure the energy consumed over the course of 10 minutes for each model of desktop computer in each of the five states. It was found that on average, desktop computers at WPI draw 92.9 watts in State 1, 36.6 watts in State 2, 2.1 watts in State 3, 2.1 watts in State 4, and 0.5 watts in State 5.

The proportion of time desktop computers spend in each state was determined by analyzing the Windows 7 system logs of 19 desktop computers and by making assumptions. From the system logs it was found that desktop computers at WPI spend on average, 92.54% of the time awake, 7.45% of the time shut down, and 0.01% of the time asleep. It was assumed that of the time awake, approximately 25% is in active use.

From the values discussed above energy waste was calculated. It was estimated that desktop computers at WPI waste 300,000 kWh of electricity annually. This is equivalent to \$23,000 and 167,000 kg of CO₂ emissions.

Evaluating Energy Waste Reduction Methods for WPI

5 energy waste reduction methods were taken into consideration: (1) Windows 7 Power Options, (2) Commercial Power Management Software, (3) Network Connectivity Proxy, (4) Partial VM Migration, and (5) Thin Client Server Based Computing. In order to evaluate each for implementation at WPI, a greater understanding of the organization and technological structure of the WPI Office of Information Technology was needed. This understanding was gained through the modeling of stakeholders and through interviews with staff.

The stakeholders of an energy waste reduction method were modeled using a Stakeholder Onion Model as described by Ian Alexander (Alexander 2004). In doing so it was found that the WPI Office of Facilities will benefit financially, the WPI Office of Sustainability will benefit politically, and the WPI Office of information technology will not benefit in any direct way. Further it was found that all work needed to implement and maintain an energy waste reduction method would fall to the WPI Office of Information technology.

When taking into account the above stakeholder analysis, as well as the interviews conducted with Information Technology Staff, it was determined that energy waste reduction methods should be evaluated based on their ease of implementation, ease of maintenance, change to user experience, and ability to reduce energy waste. Each of the five energy waste reduction methods was evaluated against these criteria, the results of which are summarized in *Figure 2*. It was found that Windows 7 Power Options were the best option for immediate implementation at WPI, and the thin client server based computing should be considered as a future energy waste reduction method at WPI.

Energy Waste Reduction Method	Implementation	Maintenance	User Experience	Energy Waste Reductions
Windows 7 Power Options	Very Easy to Implement	Very Easy to Maintain	No Change in User Experience	Energy Waste Reduction
Commercial Power Management Software	Difficult to Implement	Easy to Maintain	No Change in User Experience	Energy Waste Reduction
Network Connectivity Proxy	Very Difficult to Implement	Very Difficult to Maintain	No Change in User Experience	Energy Waste Reduction
Partial VM Migration				
Thin Client Server Based Computing	Extremely Difficult to Implement	Very Easy To Maintain	Greatly Improved User Experience	Large Energy Waste / Consumption Reduction

Figure 2. This figure summarizes the findings from the evaluation of the five energy waste reduction methods. Green boxes correspond to positive effects, yellow to neutral, and red to negative. The Partial VM Migration strategy is grey because it was found to be not applicable to WPI.

Evaluating Windows 7 Power Options

Once it was determined that Windows 7 Power Options were the best energy waste reduction method for immediate implementation at WPI, they were explored further to determine the best configuration of these options. This involved investigating the time needed to and the energy consumed while transitioning between the states, and evaluating the potential savings of a plan set to shut down idle (State 2) desktop computers after 30 minutes of inactivity, versus a plan set to put idle desktop computers to sleep after 1 minute of inactivity.

It was found that transitioning desktop computers between awake and asleep consumes an insignificant amount of power and takes roughly two seconds. Additionally, it was found that transitioning desktop computers between awake and shut down consumes 2.16 Wh and takes on average 2.4 minutes. Because of this, it was determined that putting desktop computers to sleep would not inconvenience users, while shutting down desktop computers would.

When analyzing the savings data, it was found that the sleep plan would like reduce energy waste by 208,000 kWh which is equivalent to \$15,700 and 115,000 kg of CO₂ in savings. It was found that the shutdown plan would like reduce energy waste by 165,000 kWh which is equivalent to \$12,400 and 91,000 kg of CO₂ in savings. Because the sleep plan saved more energy and would be more convenient for users it was selected as the configuration for the Windows 7 Power Options.

Concluding Remarks

It was ultimately recommended that the WPI Office of Information Technology implement Windows 7 Power Options to put idle desktop computers to sleep after 1 minute. Additionally, further IQP studies should investigate the feasibility of a thin client server based computing strategy at WPI in a greater depth than this IQP study had the time to. If these recommendations are followed, WPI will reduce the energy waste by its desktop computers, and in doing so, it will become a more sustainable campus.

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1 Introduction

The Environmental Protection Agency defines energy waste as “the ability to maintain or improve standards of living without damaging or depleting natural resources for present and future generations” (Environmental Protection Agency, 2017). This IQP study was conducted at Worcester Polytechnic Institute (WPI) for the Sustaining WPI Project Center. Its intent was to improve sustainable practices at WPI with a focus on desktop computer energy consumption.

Overview

Desktop computers are a central part of most people’s personal and professional lives (Anderson 2015), (Fox 2014). The large majority of US adults either own or use a laptop or desktop computer on a daily basis (Anderson 2015), (Fox 2014). Although desktop computers have contributed greatly to the technological era, they have also contributed greatly to the global energy consumption (Mills 2013). It is estimated that desktop and laptop computers consume just over 3% of the global energy consumption (Mills 2013), (Imaizumi 2009), (Khan 2016).

Organizations that house thousands of desktop computers consume a great amount of electricity, and unfortunately a large portion of this energy is often wasted (Alliance to Save Energy 2009), (Bray 2006), (UWA 2017). These organizations often leave computers on when not in use for the sake of accessibility to users (Bray 2006), (Dupuis 2009), (Hirst 2013). This is an energy inefficiency because the computers are consuming energy when they do not need to be. Leaving computers on when not in use will be the primary source of energy waste considered in this IQP study.

This particular energy inefficiency impacts a number of Universities and Colleges across the U.S (Hirst 2013), including Worcester Polytechnic Institute (WPI) (Dupuis 2009). In an energy audit of WPI’s Higgins Laboratories, it was found that the building’s desktop computers used 97% less energy while asleep than while idle; however, despite this, the desktop computers in Higgins Laboratories were left on at all times (Dupuis 2009). A similar study was conducted of WPI’s Atwater Kent (Newman 2010), yet outside of these two studies, no information is available regarding desktop computers and their energy consumption at WPI. Further research was needed before the energy consumption and the associated energy waste of WPI’s desktop computers could be fully understood.

Project Statement

The purpose of this IQP study was to improve the Sustainability of Worcester Polytechnic Institute by examining the energy consumption and energy waste of desktop computers at WPI. In doing so, two goals were outlined:

1. Measure the energy waste of desktop computers at WPI
2. Recommend a method to reduce the energy wasted by desktop computers at WPI.

In achieving these two goals, this IQP study addressed four primary research questions.

1. How much energy is wasted by the desktop computers at WPI?
2. What are the financial and environmental impacts of the WPI desktop computer energy waste?
3. What factors does an energy waste reduction method at WPI need to accommodate?
4. How much energy can WPI expect to save with the recommended energy waste reduction method?

Through the successful implementation of this IQP study, a comprehensive profile of WPI's desktop computer energy consumption was developed, and a series of recommendations were made for the immediate and future computer infrastructure at WPI.

The problem addressed in this IQP study is not unique to WPI. As a result, the recommendations presented in this report are likely applicable to other organizations that manage a large number of desktop computers.

2 Background

In this chapter, relevant background information for the study of desktop computer energy waste at WPI is presented. Desktop computer use-trends and energy consumption are discussed, first on the global scale, and then for WPI. Energy waste measurement techniques and energy waste reduction methods are also presented. Lastly, organizational aspects of an energy waste reduction method at WPI are discussed. In doing so, this chapter presents (1) information supporting the need for a study of the desktop computer energy waste at WPI, and (2) the information needed to understand the techniques used and decisions made in the Methodology chapter.

2.1 Desktop Computers and Energy Waste

Desktop computers are an integrated component of modern society. This section will examine the prevalence of desktop computers in modern society, the energy consumed by desktop computers globally, and the amount of energy wasted by desktop computers, and the regulations for desktop computer energy consumption. In doing so, this section presents the information needed to understand desktop computer energy waste on a global scale.

2.1.1 Overview of Desktop Computer Energy Waste

Since the invention of the first digital computer in 1942, computers have become an integrated component of modern life (Computer History Museum 2006) (Anderson 2015), (Fox 2014). As of 2014, over 80% of U.S. adults used a laptop or desktop computer on a daily basis (Fox 2014), and as of 2015, 68% of U.S. adults own a smartphone, 73% own a desktop or laptop computer, and 45% own a tablet computer (Anderson 2015). The percentages for smartphones and tablets have sharply increased since 2004, while they have remained roughly the same for desktop computers and laptop computers (Anderson 2015). These trends can be seen in *Figure 3*.

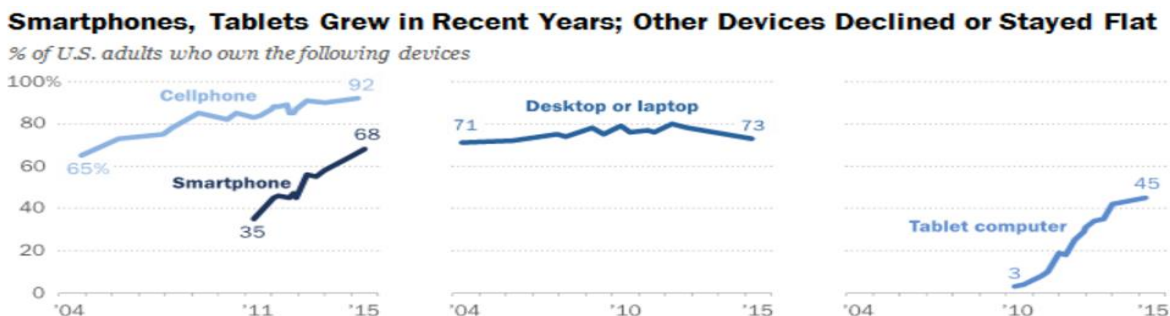


Figure 3. The ownership trends of computer devices from 2004 to 2015 (Anderson 2015).

While the sales of Smartphones and tablets steadily rise, the sale of desktop computers is expected to decline (Vandermeulen 2016). This is in part because of the saturation of the market, and also because of recent trends towards mobile and cloud computing (Vandermeulen 2016). Gartner, a technology research company, predicts that by 2018, laptop and desktop sales will drop from 244 million to 199 million per year (Vandermeulen 2016).

Although Desktop Computers are becoming less popular with the advent of mobile and cloud computing, they are—for the time being—still a large portion of the worldwide information technology infrastructure (Mills 2013, 3). It is estimated that worldwide information technology uses 1,500 TWh of electricity annually, which accounts for 10% of the global energy consumption (Mills 2013, 3). Of this, 49% is consumed in the manufacturing and operation of Desktop and laptop computers, of which 78% is consumed during operation (Imaizumi 2009, 1) (Khan 2016, 1).

While desktop computers consume a substantial quantity of electricity worldwide, not all of the energy consumed by desktop computers is used effectively. In a study of workplace computer usage, it was found that 50% of desktop computers in a U.S. corporate setting are left on overnight (Bray 2006). In addition, desktop computers are used for approximately three hours per day, yet remain on for the entirety of the work day (Bray 2006). Collectively, U.S. organizations leave approximately 108 million PCs on; this is estimated to cost \$2.8 billion and emit 20 million tons of carbon dioxide each year (Alliance to Save Energy 2009, 1). To put the potential energy savings in perspective, an organization with 10,000 desktop computers that powered down all its computers each night would save a quarter of a million dollars annually and reduce the emission of CO₂ by 1,800 tons (Alliance to Save Energy 2009). The energy wasted by desktop computers when powered on but unused was further substantiated by a second study, which found that a single computer being left on overnight generates approximately 535 kilograms of CO₂ more than a computer that is shut down overnight over the course of a year (UWA 2017).

2.1.2 Desktop Computer Energy Waste Standards

As desktop computers have become popular for consumer and commercial purposes, a number of standards have been implemented in an attempt to reduce the energy consumed and wasted by desktop computers. Energy Star Ratings were originally developed with the intention of improving desktop computer energy efficiency, and have worked towards this goal for over 20 years (Energy Star 2017). This movement has continued into recent years: in 2016 California passed a new standard regulating the energy consumption of desktop computers with the goal of reducing their energy waste (California Energy Commission 2016).

Energy Star Ratings

Energy Star is a voluntary label for electronic products that signifies that they are energy efficient (Energy Star 2017). Energy Star was created by the United States Environmental Protection Agency in 1992 in an attempt leverage energy efficiency to help individuals and business save money and protect the environment. (Energy Star 2017). As of December 2013, Energy Star has saved families and businesses approximately \$295 billion in utility bills and prevented more than 2.1 billion metric tons of greenhouse gas emissions through encouraging the use of energy efficient products, practices, and services (Energy

Star 2017). Products, homes, commercial buildings, and industrial plants can all receive the Energy Star Label; however vigorous testing is needed (Energy Star 2017). For a product to become certified it must meet per-product specifications when tested in EPA laboratories and when tested randomly, off-the-shelf. (Energy Star 2017).

For a Desktop Computer to receive the Energy Star Label it must meet the following criteria:

$$E_{TEC_MAX} \leq E_{TEC}$$

(Energy Star 2014). E_{TEC} is calculated based on the power consumed by the desktop computer in four different states and the percent of the time the desktop computer spends in that state during a year. The formula to calculate E_{TEC} is:

$$E_{TEC} = 8760/1000 * \\ \{(\text{Power in off mode} * \text{typical percent of time in off mode}) + \\ (\text{Power in sleep mode} * \text{typical percent of time in sleep mode}) + \\ (\text{Power in long idle mode} * \text{typical percent of time in long idle mode}) + \\ (\text{Power in short idle mode} * \text{typical percent of time in short idle mode})\}$$

(Energy Star 2014). E_{TEC_MAX} is the maximum allowable typical energy consumption and is calculated based on the base energy consumption of the desktop computer and power allowances based on performance requirements. The formula to calculate E_{TEC_MAX} is:

$$E_{TEC_MAX} = TEC_{BASE} + Allowances$$

(Energy Star 2014). Only after meeting this criteria will a desktop computer be labeled with the Energy Star.

California Standard

In late December of 2016, the California Energy Commission adopted a new set of energy efficiency standards for computers and monitors (California Energy Commission 2016). The standard sets a baseline energy use target for computers in idle, sleep, and off modes, with the focus of reducing energy waste when computers are on, but not in use (California Energy Commission 2016). The standard comes in two tiers: the first tier will come into effect in 2019 and the second in 2021 (California Energy Commission 2016). Each tier tightens the regulations on energy consumption of computers, and makes them more energy efficient (California Energy Commission 2016). This new standard is expected to save the amount of energy used to power nearly 350,000 homes (California Energy Commission 2016). Although only applicable to computers sold in California, the vast market share California holds mean this legislation will likely set a standard for energy consumption targets for computer manufacturers across the country.

2.2 Desktop Computer Energy Waste at WPI

WPI is not isolated from the desktop computer energy waste problem. While little research has been done of the energy consumed by desktop computers at WPI, three IQP studies have shown that there is energy being wasted by desktop computers. In this section information regarding the WPI electrical and computer infrastructure as well as the energy wasted by desktop computers on campus is provided.

2.2.1 The WPI Electrical and Computer Infrastructure

When considering the energy wasted by desktop computers at WPI, it is important to consider WPI's electrical and computer infrastructure. There is minimal information publicly available regarding these two frameworks. The information presented in this section does not represent the complete infrastructure; it instead represents only the information that is currently available.

Electrical Infrastructure at WPI

According to the *Energy Monitoring for Sustainability* IQP conducted at WPI in 2016, WPI's electricity monitoring system is minimal (Adams 2016, 21). The technology used to monitor electrical usage data is outdated and non-user-friendly (Adams 2016, 21). WPI is currently upgrading the energy meter infrastructure at individual circuit panels, and the institution has been recommend to adopt a centralized electricity monitoring system (Adams 2016, 22, 31). Although WPI is moving in the right direction, much is still unknown about the electrical consumption of the WPI campus.

In an IQP study that examined the energy consumption of Atwater Kent Laboratories, a sample WPI electrical bill was provided (Newman 2010, 40). This bill provides valuable information about the electricity usage of WPI. From this bill the following data is known regarding the 2009 Electrical Consumption of WPI's main campus: WPI's electricity Supplier was National Grid; WPI spent approximately \$45,000 a month on electricity; WPI consumed approximately 1,545,800 kWh of electricity a month; and WPI spent \$0.01192 per kWh of electricity (not factoring in various distribution charges) (Newman 2010, 40).

Desktop Computer Infrastructure at WPI

Microsoft Windows is the most widely used family of operating system amongst desktop computers; as of 2016, 90.3% of all desktop computers used a Windows operating system (NetMarketShare 2016). Since its founding in 1985, the Windows family of operating systems has collected 13 different operating systems from Windows 1.0 to Windows 10 (Chan 2016). Of the desktop computers maintained by the WPI IT department, Windows 7 is the primary operating system. The following three sections each provide information from separate IQP studies that addressed desktop computers and their energy consumption or use behavior.

2.2.2 Energy Waste of Desktop Computers in Higgins Laboratories

The energy waste of a desktop computer is directly related to the computer's' energy consumption and usage behavior. In order to understand the desktop computer energy waste at WPI, energy consumption and

usage behavior must be determined across all of WPI's computers. The 2009 IQP study, *Energy Audit of Higgins Laboratories* explored these two topics and researched the energy waste of desktop computers in Higgins Laboratories (Dupuis 2009). Of the Higgins Labs' 120 desktop computers, the IQP study measured the energy consumption for 41 computers located in HL230 (Dupuis 2009, 53 & 63). These computers consumed 70 watts while on and 2 watts while in sleep mode (Dupuis 2009, 53). Additionally, the typical weekly usage of each desktop computer (time spent awake) was 168 hours, or the equivalent of 24 hours a day, 7 days a week (Dupuis 2009, 53). The 41 computers had a calculated total wattage of 2870 watts and calculated weekly electricity consumption of 482.16 kWh (Dupuis 2009, 53). In *Figure 4* and *Figure 5*, respectively, these two statistics are compared against all the other components found in room 230 of Higgins Laboratories (Dupuis 2009, 53-54). As shown in these figures, desktop computers have both the greatest instantaneous watt draw and the greatest weekly energy consumption of all components found in room 230 of Higgins Laboratories.

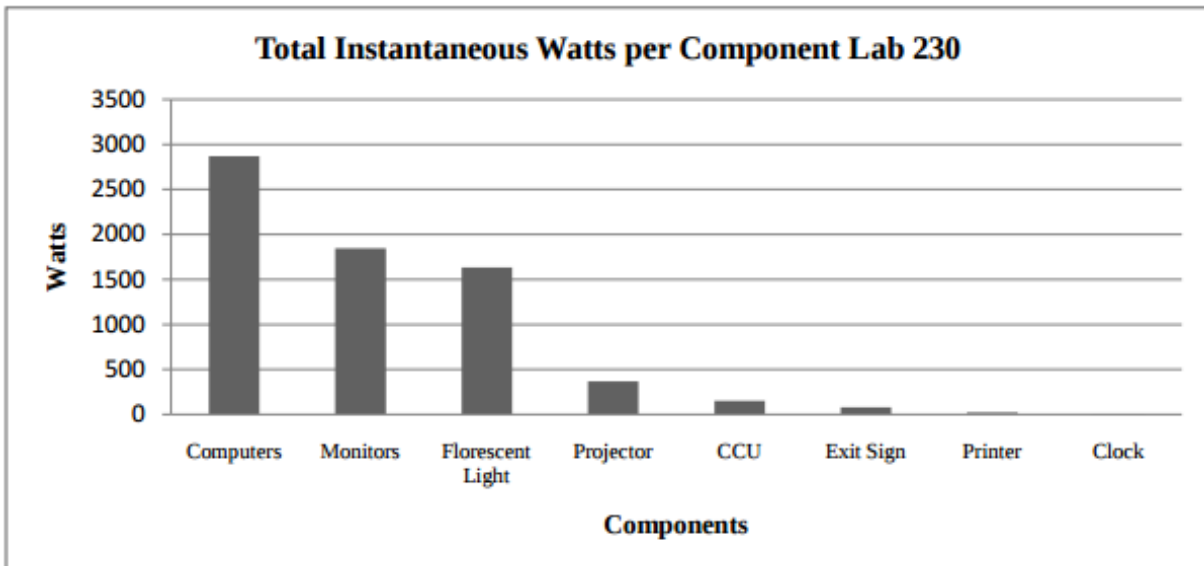


Figure 4. The total instantaneous watts for each component found in room 230 of Higgins Laboratories. The total Instantaneous Watts is the number of Watts drawn by all components (watts per component X * count of component X). Figure retrieved from Dupuis (2009), page 53.

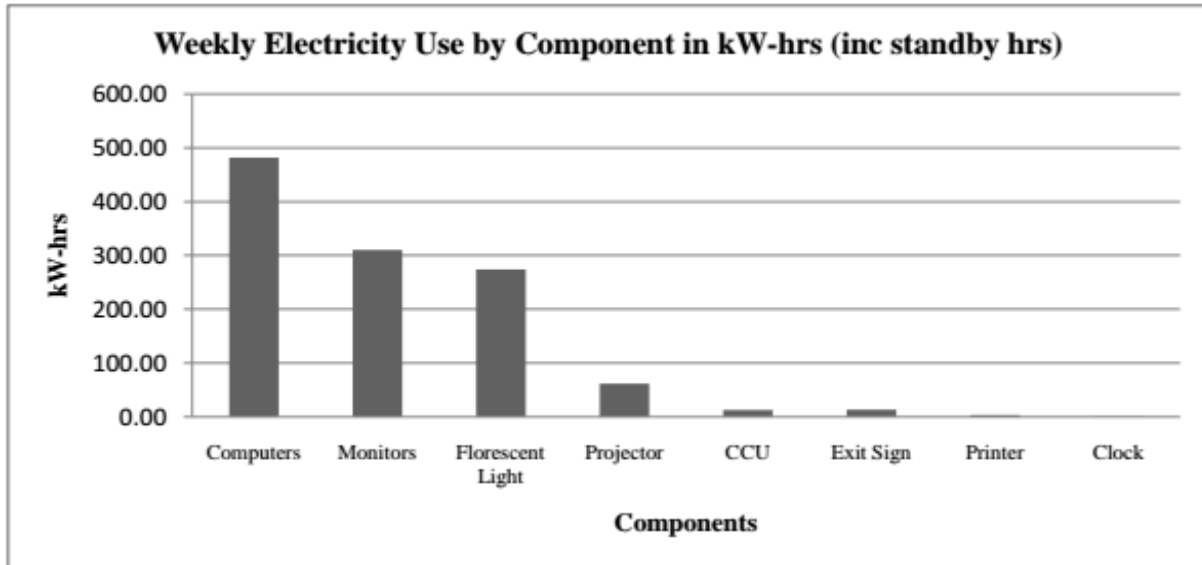


Figure 5. The weekly electricity consumption for each component found in room 230 of Higgins Laboratories. Figure retrieved from (Dupuis 2009, 54).

This group noted that leaving the desktop computers in Higgins Laboratories on for 168 hours a week is a large source of energy waste (Dupuis 2009, 79). This group made two recommendations: first implement the default power saving options available within Microsoft Windows to automatically shut down the desktop computers after some period of inactivity, and second install smart power strips to prevent electrical leakage while the desktop computers are powered off (Dupuis 2009, 79). Through these two recommendations, this group expected the building to save about \$4400 dollars annually in electricity, with a payback period of approximately 9 months (Dupuis 2009, 79).

2.2.3 Energy Waste of Desktop Computers in Atwater Kent Laboratories

In addition to the energy audit of Higgins laboratories, an energy audit of WPI's Atwater Kent Laboratories was conducted by the 2010 IQP study, *Atwater Kent Energy Audit and Solar Energy* (Newman 2010). In this study, desktop computer energy consumption and desktop computer use behavior at WPI was collected. In this study, the group performed a case study in which they explored the energy consumption of a single computer within Atwater Kent before and after implementing default power saving options offered by Microsoft Windows (Newman 2010, 18-20). These options were to turn the monitor off after 10 minutes, the hard drives off after 20 minutes, and enter sleep mode after one hour (Newman 2010, 19). Prior to the implementation of these power saving options, the computer consumed 15.3 kWh of electricity per week; after the implementation of these power saving options, the computer's energy consumption had been reduced by 1.4 kWh (Newman 2010, 22). If implemented on every desktop computer in the building, these power saving options would result in a total savings of \$55 per week (Newman 2010, 23). Because of this, the group recommended that all 328 desktop computers in Atwater Kent be configured to turn off the monitor after 10 minutes, turn off the hard drives after 20 minutes, enter sleep mode after 30 minutes, and hibernate after an hour (Newman 2010, 29). They also recommended using Wake-On-Lan technology to allow the IT department to update the desktop computers autonomously (Newman 2010, 29).

2.2.4 Personal Computer Use Behavior at WPI

The use behavior of desktop computers at WPI was also explored in the 2014 IQP study, *Energy Consumption of WPI Buildings*, in which the energy consumption was analyzed for three WPI residence halls (Giguere 2014). Surveys were distributed to the residents of the three buildings with the primary goal of gaining an understanding of general student energy use behavior (Giguere 2014, 20-24). The survey's included a few questions which regarded the students' personal computer usage (Giguere 2014, 74-106). The survey found that of the students who care about energy conservation, 47% left their laptops on, and 6% left desktop computers on, while the students who did not care about energy conservation left laptops and desktop computers on constantly (Giguere 2014, 31). These results indicate that computer users who care less about sustainability are less likely to use computers in sustainable ways (Giguere 2014, 31).

2.3 Measuring Desktop Computer Energy Waste

Many Factors influence the amount of energy that is consumed by a desktop computer. These factors include the state that the desktop computer is operating in (awake, asleep, shutdown), the hardware of the desktop computer, as well as the work being done by the desktop computer (Brink 2011), (Build Computers 2016), (Ahmed 2016, 438). To provide background information on how to measure energy consumption, this section will discuss the power states of a Windows 7 computer, Benchmark Tests as a means of maintaining a consistent desktop computer workload, the Watts Up Pro energy meter as a means of measuring energy consumption. Energy consumption alone, however, does not constitute energy waste; energy waste is dependent on the use behavior of the desktop computer. Thus this section will also discuss the Windows 7 Event Viewer software as a means of determining the use behavior of a desktop computer.

2.3.1 Windows 7 Power States

Computers running Windows 7 can be in one of six power states *S0-S5*, and these states drastically impact the power drawn by the desktop computer (Brink 2011).¹ *S0* represents that the computer is turned on and awake, *S1* through *S3* represent that the computer is in a sleep state, *S4* represents that the computer is hibernating and *S5* represents that the computer is shut down.

While awake (*S0*) the computer draws the maximum amount of power. In this state the many components of a computer may enter low power modes on their own accord; however, it is not strictly enforced by the operating system. Because the hardware is not forced into a low power mode, this state ensures that there is no hardware latency, where hardware latency means the time interval between the user issuing a request, and the hardware beginning to complete this request.

While asleep (*S1-S3*) the computer draws less power than awake, but more power than when shut down. With each successive sleep state the operating system enforces more computer components to enter low

¹ The entirety of the information presented in this section was drawn from a forum post by Shawn Brink, an administrator on the Windows Seven Forum. See citation: (Brink 2011).

power modes. States $S1$ and $S2$ are not available sleep states at WPI. As shown in *Figure 6*, this was determined by viewing the available sleep states on a WPI desktop computer. For this reason, only the final sleep state ($S3$) is described.² While in state $S3$, the computer's processor and busses are off, as well as some system clocks and chips on the motherboard. The system has a hardware latency of roughly 2 seconds, and only the memory stored in RAM is retained.



```
C:\windows\system32\cmd.exe
Microsoft Windows [Version 6.1.7601]
Copyright (c) 2009 Microsoft Corporation. All rights reserved.

C:\Users\jamartin>powercfg -a
The following sleep states are available on this system: Standby < S3 > Hibernate Hybrid Sleep
The following sleep states are not available on this system:
Standby < S1 >
    The system firmware does not support this standby state.
Standby < S2 >
    The system firmware does not support this standby state.

C:\Users\jamartin>
```

Figure 6: The available sleep states on the desktop computers at WPI, as reported by the 'powercfg -a' command within the Windows 7 cmd program.

When a computer enters hibernation ($S4$) it creates a hibernate file and saves it to disk. The computer then turns off and consumes no power except for a few trickle devices (such as the power button or select system clocks). The computer can only be awoken by a physical interaction such as the user pushing the power button, BIOS timers, or a signal from a LAN (if Wake-on-LAN technology is present). When powered back on, the system resumes from the hibernation file. Because all hardware is shut off in $S4$, the hardware latency is long and undefined.

When a computer is shut down ($S5$) it is in a very similar state to $S4$. Unlike $S4$, however, a computer in $S5$ does not have a hibernation file to resume from. Additionally, a shutdown computer can only be awoken by the user pushing the power button or by a properly configured BIOS timer.

2.3.2 Benchmark Software

The power drawn by a desktop computer is greatly impacted by the workload it is under (Lewis n.d.), (Ahmed 2016, 438). This is largely because the workload impacts the utilization of computer components, and the utilization of a component is directly related to the power drawn by that component (Ahmed 2016). Each component within a desktop computer typically draws between fractions of a watt to over 300 watts (Build Computers 2016). The largest energy consumers within a PC are the CPU and the Video Card (Build Computers 2016). Thus the utilization of the CPU greatly impacts the power consumption of a desktop computer. Because of this, the CPU utilization should be standardized across energy consumption measurement. One Technique of standardizing the CPU utilization is through benchmarking software (Goebel n.d.). The primary purpose of CPU benchmarking software is to measure system performance by running a standardized computational task; however, because of the consistency between runs,

² Throughout the remainder of this paper, a 'sleeping' computer refers to a computer in $S3$.

benchmarking software can be used to ensure that the CPU utilization remains constant across multiple energy consumption measurements (Goebel n.d.).

SilverBench

SilverBench is a free, online benchmarking software hosted by urih.com that is intended to benchmark computers with multicore CPUs (SilverBench 2012). It puts a computational load on the computer by performing ray tracing (SilverBench 2012). Ray tracing is computational problem in computer graphics that involves tracing the path of pixels through light (Ward 2007). This task is computationally intensive³ and thus it is adequate task for benchmarking software (Ward 2007). The SilverBench software supports three different benchmark tests: Benchmark is intended for a quick benchmark test; Extreme Test is intended for a long term benchmark test; and Stress Test is intended to put the system under normal stress, and display performance figures throughout the test (SilverBench 2012). *Figure 7* shows the SilverBench menu where a test can be run, and *Figure 8* shows the Benchmark test being performed.



Figure 7. The main menu of the SilverBench benchmarking software hosted by urih.com. From this menu, the user can decide to run a Benchmark, and Extreme Test, or a Stress Test (SilverBench 2012).

³ Since 2007 a number of algorithms have been developed to reduce the computational resources needed to perform ray tracing; however, it still provides a computationally demanding, and consistent problem for the SilverBench benchmarking Software (Nikodym 2010, ix).

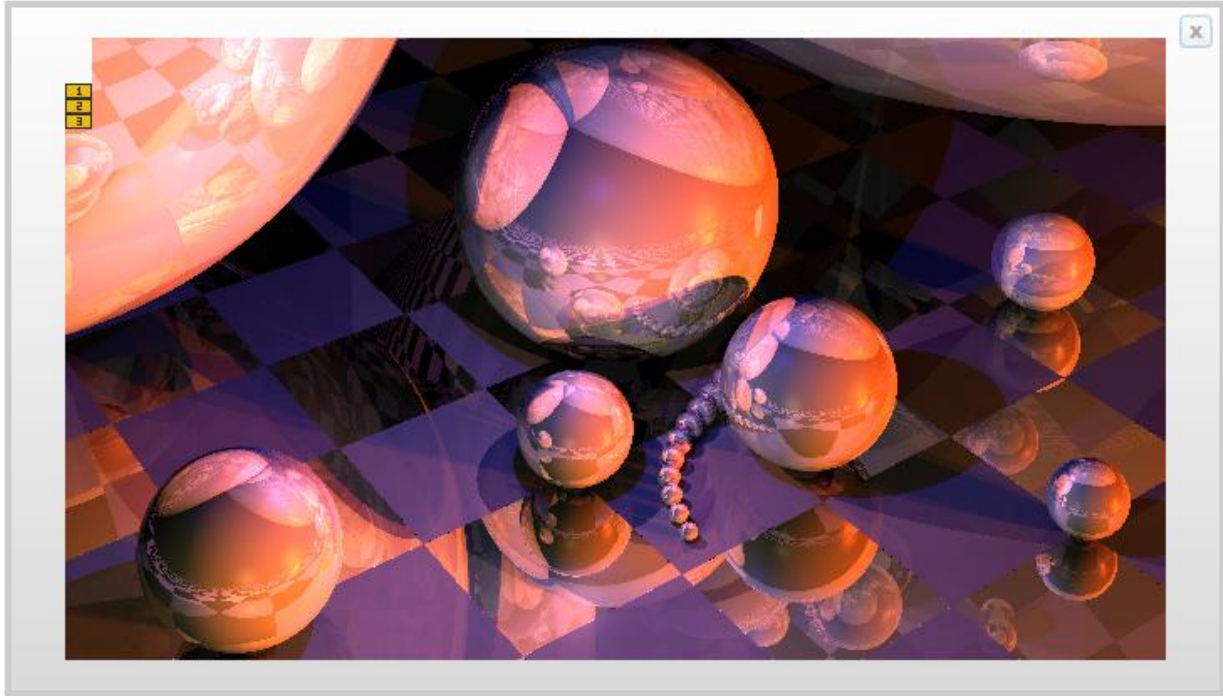


Figure 8. A partially completed SilverBench Benchmark Test. The small yellow boxes in the top left represent the portions of the image that the computer's three threads are working to render using ray tracing (SilverBench 2012).

2.3.3 Watts Up Pro

The Watts Up Pro energy meter provides a way to directly measure the energy consumption of desktop computers (Vernier 2015). It can be used in accordance with the Logger Pro® 3.8 or Lab Quest App 1.3 software to monitor real-time electricity usage and cost (Vernier 2015). A picture of the device can be seen below in *Figure 9*.



Figure 9. A picture of the Watts Up Pro Energy Monitor.

The Watts Up Pro can generate the following types of data:

- Real Power: The power currently being consumed by the device that is plugged into Watts Up Pro, measured in watts.
- Potential: The root mean squared (RMS) potential present on the power line.
- Current: The RMS current being drawn by the device that is plugged into Watts Up Pro, measured in amperes.
- Apparent Power: The product of the RMS potential and the RMS current.

(Vernier 2015). Used in junction with Logger Pro® 3.8 or Lab Quest App 1.3, these various type of data can be logged and displayed on a computer. Sample data from a basement Freezer is shown below in *Figure 10*.

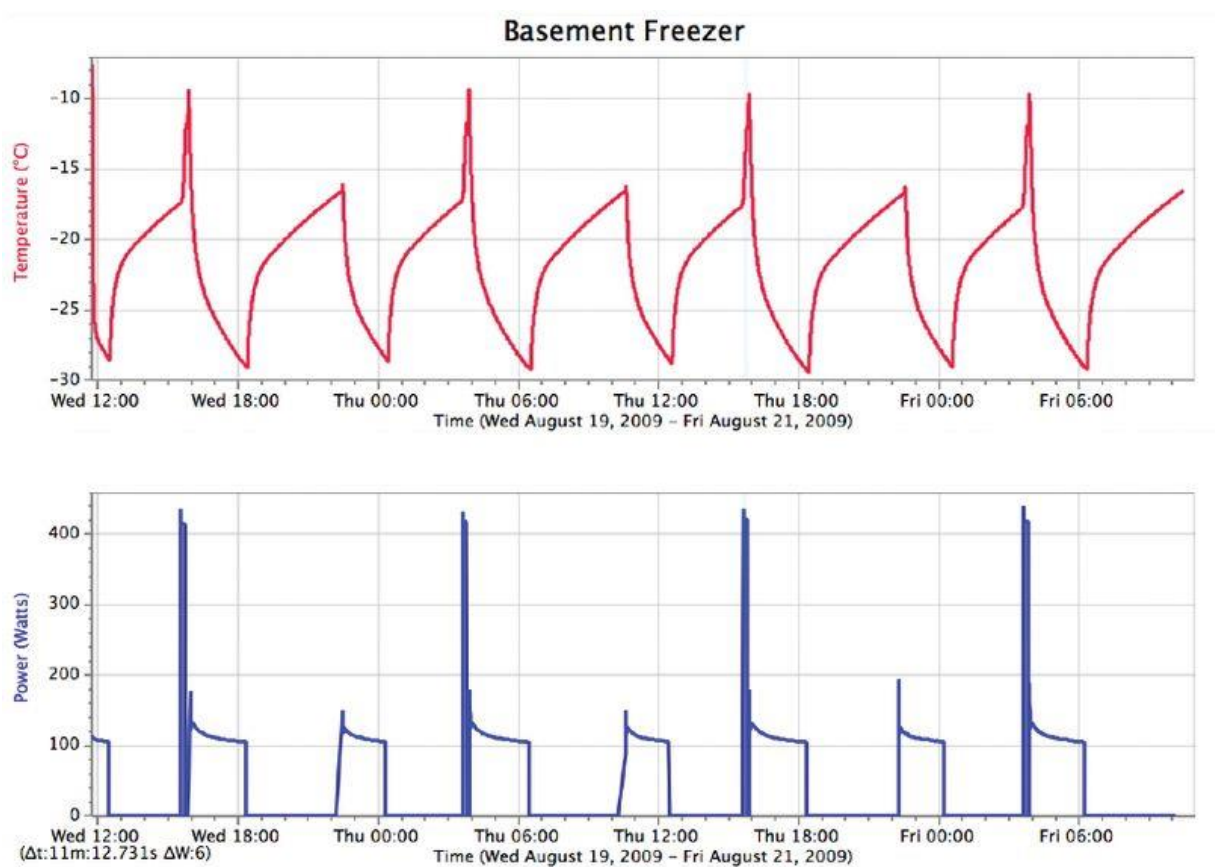


Figure 10. Sample data generated by the Watts Up Pro used in junction with the Logger Pro® 3.8 software. The top graph displays temperature (°C) measurements over a 48-hour period of a basement freezer. The bottom graph is the corresponding power draw (W) over the same period.

2.3.4 Windows Event Viewer

Windows Event Viewer is a default program that can be found on any computer running a Windows Operating System (TechNet 2017).⁴ Event Viewer is used to view and manage the program, security, and system event logs that are generated by Microsoft Windows throughout normal operation. This software is useful because it allows the user to track information about hardware and software problems, as well as monitor Windows security events. Additionally, Event Viewer can be used to track certain power events, and determine the power related use behavior of the computer.

Event Logs

The Event Viewer can be used view three types of Windows Logs:

- System Logs- events logged by the Windows system components. (i.e. failure of a driver or other system component to load during startup).
- Application Log- events logged by programs. (i.e. a database program file error)
- Security Log- security events. (i.e. valid and invalid logon attempts, and events related to resource use, such as creating, opening, or deleting files or other objects)

Each event log contains a header and a description of the event (based on event type). Additionally, more data may be provided. Event Viewer displays events from each log separately. Each line can display information in various categories about a single event. Although settings may be changed, each line typically provides the following information: date, time, source, event type, category, event ID, and event description. The format and contents of event descriptions depend on the event type. The description provides information on the significance of the event. The types of events recorded by the event logs are shown below in *Table 1*.

Table 1. Windows 7 Event Types

Event Type	Definition
Error	A significant problem, such as loss of data or loss of functionality.
Warning	An event that might not be significant, but might indicate a future problem.
Information	An event that describes the successful operation of an application, driver, or service.
Success Audit	An audited security access attempt that succeeds.
Failure Audit	An audited security access attempt that fails.

A list of the event types and their associated definitions that are logged by Microsoft Windows.

Viewing Events

In order view specific events, the log under which the event is categorized must be selected. Logs can be selected in the menu shown below in *Figure 11*. After a log is selected in Event Viewer, a user can filter

⁴ The entirety of the information presented in this section was drawn from the Microsoft TechNet Library. See citation: (Brink 2011).

and view details about specific events, as shown in *Figure 12*. Once a log is filtered, only the defined events will appear in the log window. According to the TechNet Library, “Filtering has no effect on the actual content of the log; it changes only the view”.

Power Events in Event Viewer

The events of particular interest to this IQP are those associated with power and use behavior. These include the desktop computer powering on, shutting down, entering sleep, and exiting sleep, as well as a user logging in and logging out. These events are summarized in *Table 2*.

Table 2. Windows 7 Power Events

Event	ID	Source	Log
Shut Down	6006	EventLog	System
Turn On	6005	EventLog	System
Sleeping	42	Kernel-Power	System
Awakening	1	Power-Troubleshooter	System
Log on	4624	Microsoft Windows Security Auditing	Security
Log off	4634	Microsoft Windows Security Auditing	Security

The events of particular interest to this project as well as their ID, source, and the log in which they are stored. (How-To-Geek 2010), (Kurshid 2013), (Smith 2017), (Grégory42 2011).

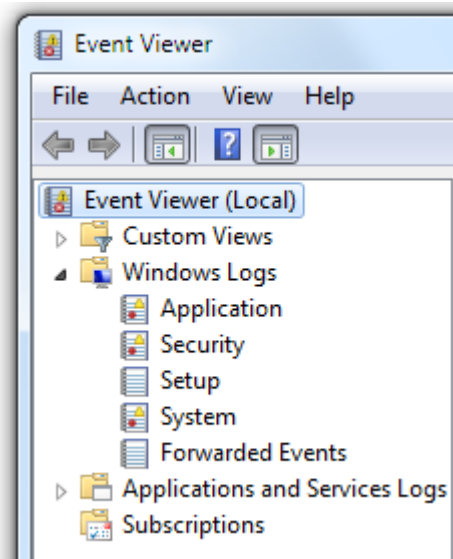


Figure 11. Primary menu for navigating between various log files. Within the expanded Windows Logs folder, Application, Security and System logs can be viewed.

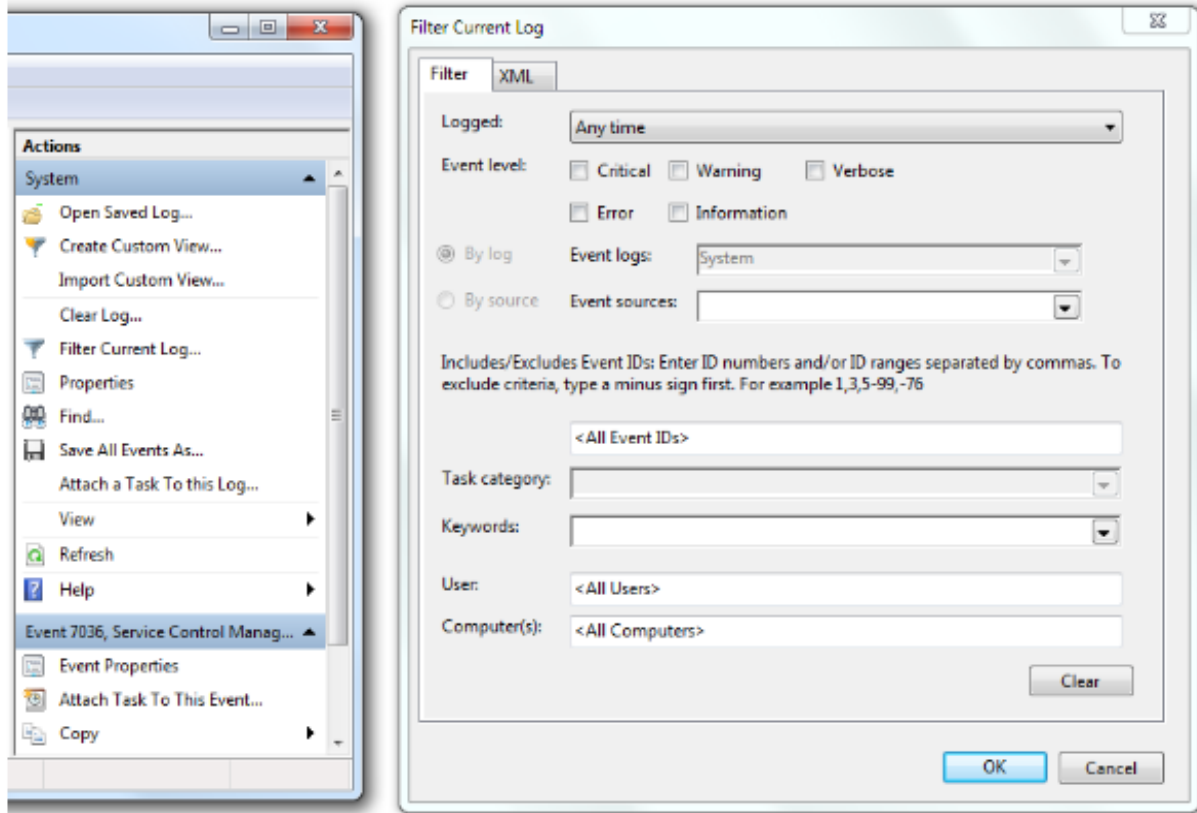


Figure 12. The menu on the left lists actions a user can perform once a particular log is selected. Selecting the 'Filter Current Log' option opens the view on the right. From this menu, events can be filtered by source, ID number, or keywords.

2.4 Desktop Computer Energy Waste Reduction Methods

There are a number of methods commonly used to reduce the energy wasted by desktop computers. Some of these methods include Windows 7 Power Options, commercial power management software, network connectivity proxies, VM migration, and thin client server based computing. In this section, each method is described, and for some, a case study is presented. Additionally this section discusses Wake-on-LAN, a technology that is used to remotely turn on a desktop computer that is shut down. The technology is discussed because the majority of the energy waste reduction methods conserve energy by turning off desktop computers, and they therefore need to use Wake-on-LAN to turn desktop computers back on.

2.4.1 Wake-on-LAN Technology

Wake-on-LAN is a technology that was invented in 1998 by the IBM/Intel Advanced Manageability Alliance (IBM 1998). This technology was invented as a means to improve management software for large networks of computers; and has since been used for a number of energy waste reduction software solutions. According to the IQP Study that conducted an energy audit of Atwater Kent Laboratories, WPI's network infrastructure does not support Wake-on-LAN technology (Newman 2010). However, it is referenced a

number of times in the energy waste reduction methods that are described below, therefore this section will describe Wake-on-LAN technology.

Wake-on-LAN is used to turn on a computer when a special Wake-on-LAN packet is received through a network connection (Arch Linux 2017). There are a number of criteria that a desktop computer must meet in order to support Wake-on-LAN: (1) The desktop computer must have a motherboard that supports Wake-on-LAN technology, (2) the desktop computer must be physically connected to the network (i.e. through an Ethernet cable. This is because wireless cards do not support Wake-on-LAN technology), (3) Wake-on-LAN must be enabled within the desktop computer's BIOS, and (4) Wake-on-LAN must be enabled in the desktop computer's network drivers (Arch Linux 2017).

2.4.2 Windows 7 Power Options

Built into Windows 7 is an energy saving tool called Power Options. This tool helps reduce the energy wasted by desktop computers by providing the user the ability to customize the power consumption of their PC.

Overview of Windows 7 Power Options

With the Windows 7 Power Options⁵ the user can customize their computers energy consumption with power plans. By default there are three power plans: performance, balanced, and power saver. The performance plan prioritizes the system's performance and disregards its energy consumption; the balanced plan attempts to balance the system's performance and power consumption; and the power saver plan prioritizes the system's energy consumption and disregards its performance. In addition to these three plans, the user can create custom power plans. *Figure 13* shows the default view of the Windows 7 Power Options tool.

⁵ The entirety of the information presented in this section was collected from the Power Options Software installed on the Windows 7 Dell OptiPlex 7020 desktop computer in WPI's Atwater Kent Laboratories, room 109 (service tag: CC0BW52).

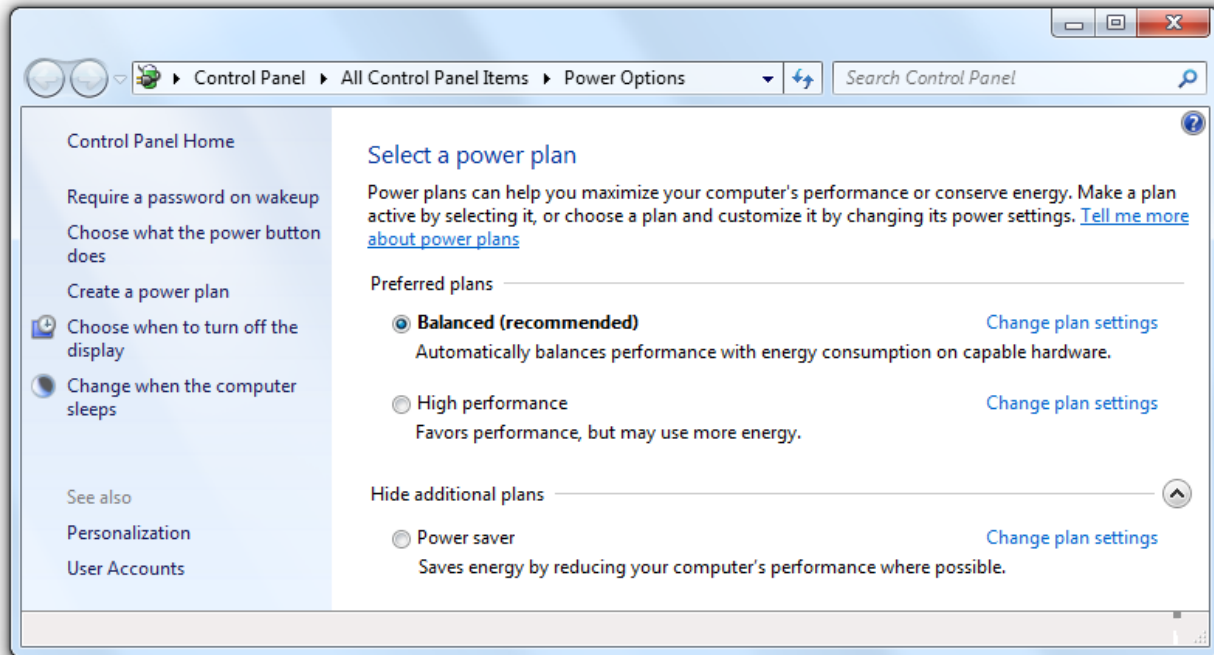


Figure 13. The primary view of the Power Options tool offered by Windows 7. This view allows the user to select either balanced, high performance, or power saver as the power plan for the computer. The user can create a custom power plan by selecting 'Create a power plan' from the left menu. The user can change the settings of a power plan by selecting the 'Change plan settings' option next to each power plan.

Within each plan (default or custom) the user can modify basic and advanced settings. The basic settings control how much time the computer will wait while inactive before turning off the monitor, or entering sleep mode. The view to edit the basic settings can be seen in *Figure 14*. The advanced settings allow the user to control the power related behaviors of the hard disk, system timers, wireless adapter, USB ports, power buttons, PCI express, processor, and the display. The view to edit the advanced settings can be seen in *Figure 14*. Through the basic and advanced settings, the user can control the balance between the power draw and performance of his/her computer.

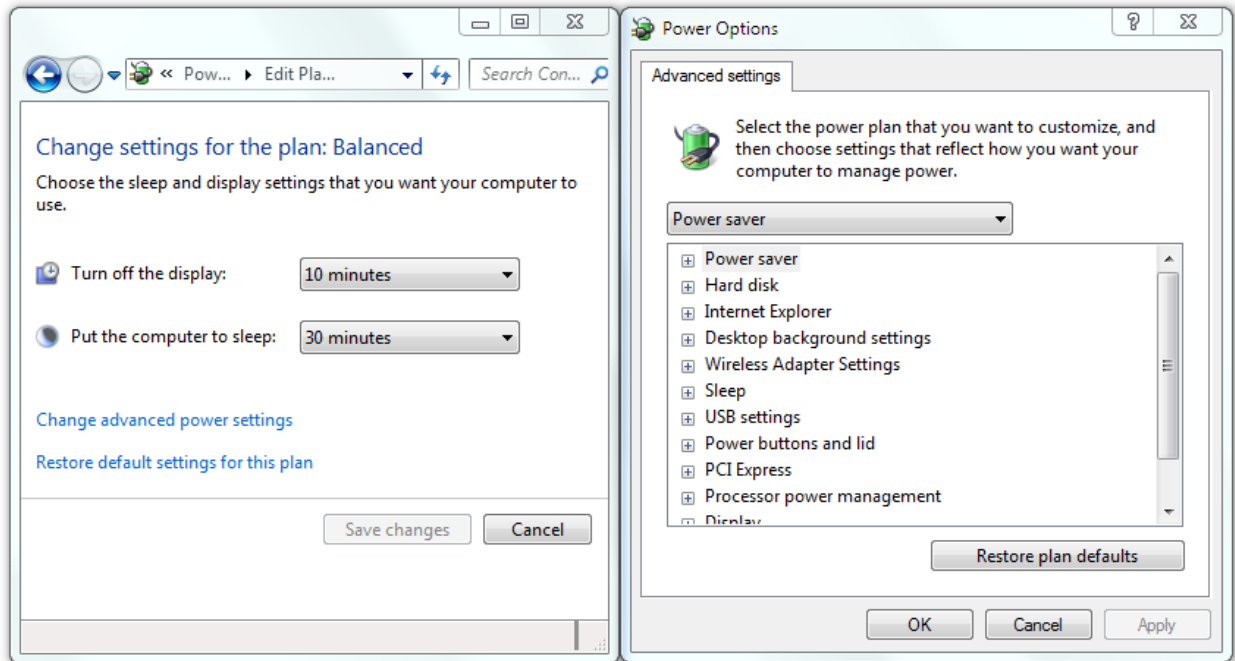


Figure 14. The views used to modify the basic (left) and advanced (right) settings for a power plan. The two drop down menus in the basic settings allow the user to change the automatic sleep and display settings. The user can view the advanced settings by selecting ‘Change advanced power settings’. Within the advanced settings window, the user can view and edit the power settings for particular computer components by clicking the plus sign next to that component.

Case Study: Windows 7 Power Options and the University Of Kansas

The University of Kansas houses 28,401 students and 22 computer labs (Kansas University 2017), (Kansas University: IT 2017). In 2013, the department of Applied Behavioral Sciences conducted a case study of the Windows 7 default power saving options (Hirst 2013). The study inspected a single computer lab, which contained 18 computers and was open between 9 and 12 hours per day (Hirst 2013, 341). They used the Watts up Pro power meter to record the energy consumed by the laboratory on a weekly basis (Hirst 2013, 342). The team collected data across four weeks, for four different conditions (Hirst 2013, 342). The first condition was a baseline, in which the computers and monitors were not configured to enter low power modes automatically, but users could manually put the computers and monitors in low power mode (Hirst 2013, 342). The second condition was the Windows 7 default power saving options, in which the monitor and computer were set to enter sleep mode after 10 and 20 minutes of inactivity, respectively (Hirst 2013, 342). The third condition was a prompt in which the desktop background was changed to a message that encouraged students to put the computers to sleep when not in use (Hirst 2013, 342-343). The fourth condition was the combination of Windows 7 Power Options and the prompt (Hirst 2013, 343). The energy consumption for each of the four tests is shown in *Figure 15*.

From this case study, the research team found that the desktop computers in this laboratory wasted energy; approximately 112 hours a week the computers were awake when not in use. They concluded that the

implementation of Windows 7 Power Options would reduce the cost of operating a 20-computer computer lab by approximately 79%, or \$61.28 per semester (Hirst 2013, 343). If the entire university were to adopt these settings, the report determined that large scale savings would be achieved (Hirst 2013, 343).

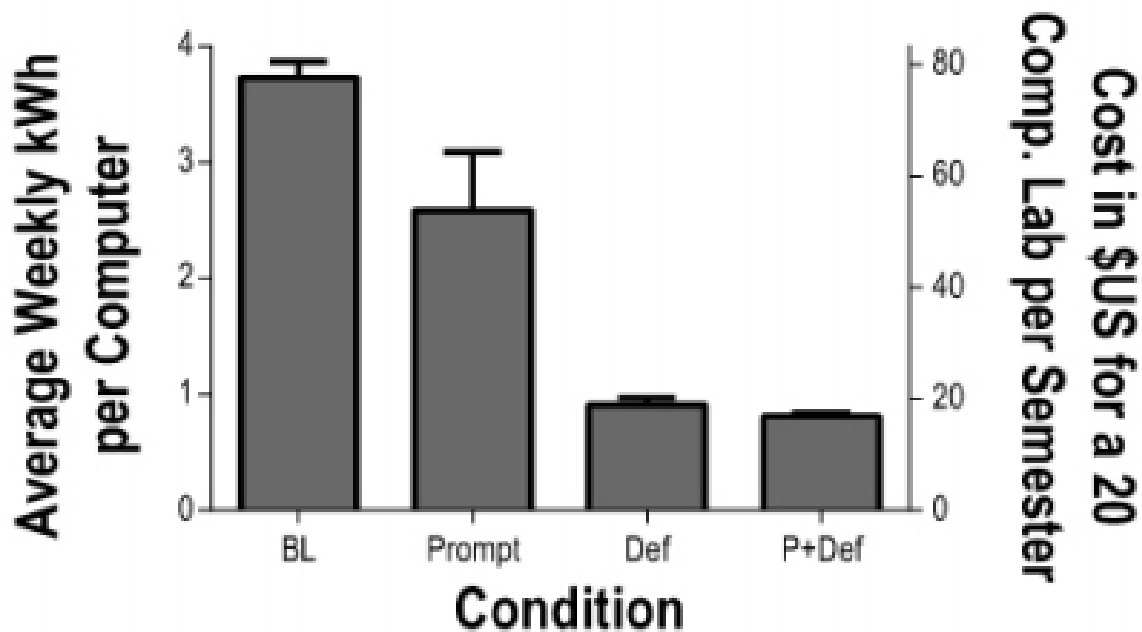


Figure 15. Findings from the University of Kansas Study. BL represents the baseline test, Prompt represents displaying a prompt suggesting that the user power off the machine when complete, and Def represents the default power settings built into Windows (Hirst 2013, 342).

2.4.3 Commercial Power Management Software

In addition to the Microsoft Windows 7 Power Options, there are a number of commercial software solutions that reduce the energy waste of desktop computers. These software packages typically offer similar features to the Windows 7 Power Options: they allow schedules to be created for which the machines shut down, go to sleep, or turn off specific hardware components (Energy Star n.d.). Many such solutions wake computers remotely using Wake on LAN packets (Energy Star n.d.). Despite being similar, commercial power management software often offers one advantage over the Windows 7 Power Options; these software packages provide many extensive administrative tools (Energy Star n.d.). These tools serve a number of purposes, including intelligent management capabilities for thousands of computers, as well as detailed and customized reports of power savings that allow administrators to properly manage the power settings for thousands of computers (Energy Star n.d.). Commercial power management software is often more powerful than Windows 7 Power Options; however, it can be expensive and may present a large overhead to install on a complex system of computers. (Newman 2010). A list of commercial power management software can be found in Appendix A.

Case Study: Verdiem Surveyor and City of Spokane, Washington

Verdiem Surveyor is a commercial power management software developed by Aptean. It supports the accurate measurement of energy consumption, the enforcement of policies to reduce energy waste, and the optimization of savings (Verdiem 2017). It is intended for organizations with a large volume of computers that require consistent software updates and patches (Verdiem 2017). This software was implemented as an energy waste reduction solution for the city of Spokane in Washington State (Verdiem 2016).

Spokane, Washington is the second largest city in Washington state with a population of over 200,000 (U.S. Census Bureau 2010). The city⁶ has an IT infrastructure of approximately 1500 computers across 60 different sites (Verdiem 2016). The city explored using enterprise solutions available through Microsoft; however, Spokane found that a more configurable and robust system would be needed (Verdiem 2016). The city began with an audit and trial of the Verdiem Surveyor software to determine the potential return on investment (Verdiem 2016). The trial proved successful, and the city worked with Verdiem for approximately 30 days to tailor Verdiem Surveyor to the city's Exact Needs (Verdiem 2016). After the product was fully deployed, the software reduced the energy consumed by the city's computers by 34.4%, which annually saved the city 205,497 kWh, reduced greenhouse gas emissions by more than 280,000 pounds, and saved the city approximately \$15,000 in utility bills (Verdiem 2016).

2.4.4 Network Connectivity Proxy

A new technology that is being researched as a means to reduce the energy wasted by desktop computers and other network interfacing information technology is the Network Connectivity Proxy. A Network Connectivity Proxy is software that runs on low power hardware with the intent of maintaining a network connection for the desktop computer while the desktop computer is a low power state (Bolla 2013, 1). This software imitates the behavior of the awake desktop computer for a limited set applications that require the network, such as instant messaging services and system updates (Khan 2016, 2). The Software interfaces with network requests and only wakes the desktop computer briefly to process the request, before returning it to a low power state (Khan 2016, 2). The Network Connectivity Proxy wakes the computer using a Wake on LAN packet (Khan 2016, 2). Because Network Connectivity Proxies are still a relatively new technology, the software must be developed based on a customer to customer basis; there is no available generalized network connectivity proxy at this point in time (Khan 2016, 2). Additionally, this means case study data is unavailable for this method of desktop computer energy waste reduction.

2.4.5 Partial VM Migration

Another way to reduce the energy consumption of desktop computers is VM migration, or migrating the working state of a desktop computer to a virtual machine running on a server, and putting the desktop into sleep mode (Bila 2012, 211). This is used when a desktop computer is mostly inactive, but must remain on to service small and infrequent requests, such as instant messaging or system updates (Bila 2012, 211). When the desktop computer is ready to resume, it is awoken using Wake-on-LAN technology, and the contents of the VM are transferred back to the Desktop such that it can resume operation.

⁶ For the remainder of this section 'the city' will refer to the administration of the city and not the city inhabitants.

Transferring the entire working state of a desktop computer requires transferring large files which is energy inefficient and consumes valuable network bandwidth (Bila 2012, 211), (Baliga 2011, 1). To work around this issue, that concept of Partial VM Migration was developed (Bila 2012, 211). This technique migrates only the necessary, and much smaller, portion of the desktop computer's working state to a VM; In doing so less network traffic is generated resulting in a more efficient (when considering both energy and bandwidth) system (Bila 2012, 211).

This technique has seen positive energy saving results as a prototype; however, it has not be fully implemented as a energy waste reduction solution (Bila 2012, 218). In the prototyping stage, it has seen up to 90% energy waste reduction, while still taking into account the energy consumed by the server hosting the VMs (Bila 2012, 218, 212).

2.4.6 Thin Client Server Based Computing

A final way to reduce the energy consumption of desktop computers is to not use desktop computers. Thin client server based computing is an information technology strategy that removes desktop computers from the picture (Anderson n.d., 2), (Aung 2015, 22). The user interacts with a 'thin client' which is typically a low power computer used only to interface⁷ with the user, while all computation is routed to a back-end server (Anderson n.d., 2), (Aung 2015, 22). The client is typically only needed to record keystrokes and mouse movements, as well as update the display (Anderson n.d. 2).

Using thin client server based computing as a means to reduce energy consumption was explored in computer labs in developing nations by Win Win Aung (Aung 2015, 22). He found that standard desktop computers (and their associated monitor) drew 170 watts when in use, while a thin client only drew 25 watts (Aung 2015, 23). A similar study conducted by Greenberg, Anderson, and Mitchell-Jackson found that desktop computers drew an average of 69 watts and thin clients drew an average of 10 watts (Greenberg 2001, 9). This study also collected power consumption data for the servers and found that they drew between 145 watts and 316 watts (Greenberg 2001, 8). While accounting for power drawn by the servers, this study predicted that a network of 100 users could save between \$3,000 and \$6,000 when switching from a PC based infrastructure to a thin client server based infrastructure; this finding is shown in *Figure 16* (Greenberg 2001, 11). Ultimately, Greenberg, Anderson and Mitchell-Jackson assert that thin client server based networks are more power efficient than PC networks, and that this efficiency is saleable. (Greenberg 2001, 13).

⁷In this context, interface refers to recording inputs such as keystrokes and mouse movements, as well as displaying data to the

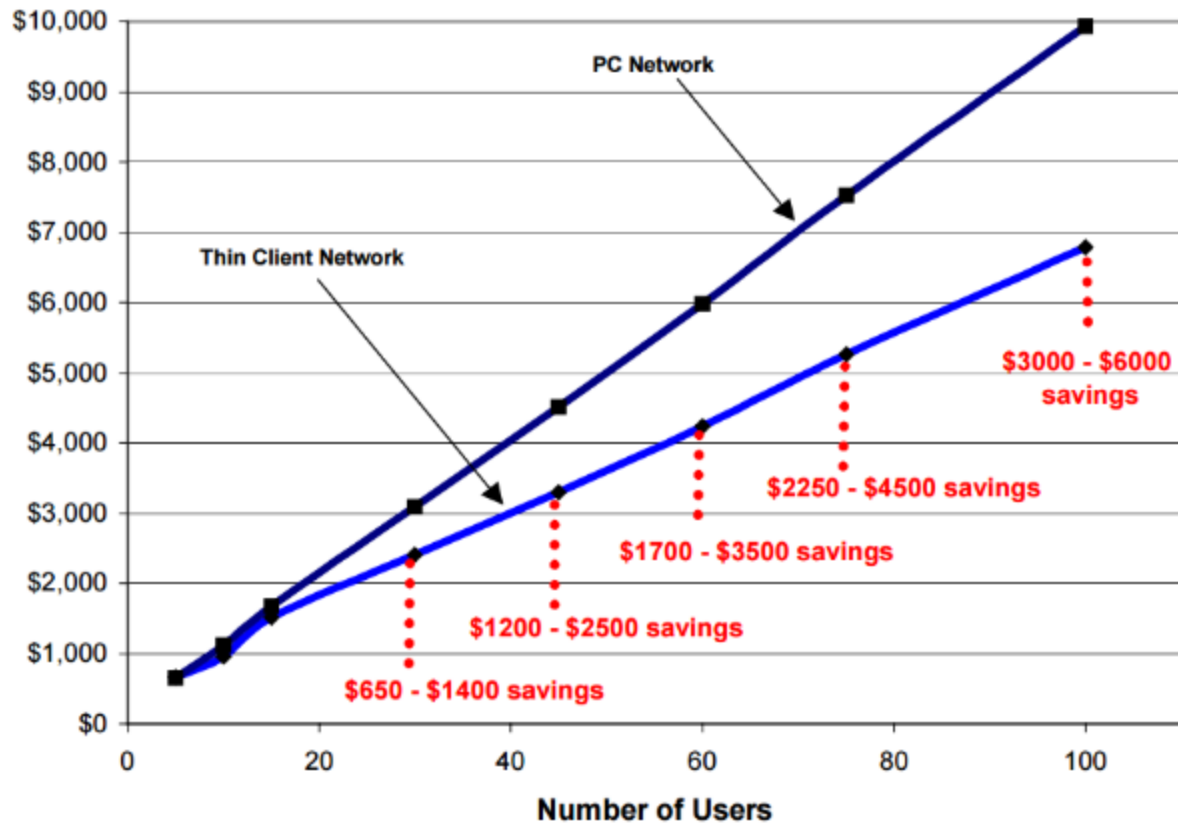


Figure 16. The predicted energy cost of a PC network vs. a Thin Client Network for between 5 and 100 nodes on the network. (Greenberg 2001, 11).

In addition to prospective energy savings, thin client server based computing is advantageous to traditional desktop computer IT infrastructures for the following reasons: (1) improved performance, (2) consolidated workload, (3), enhanced data sharing, (4) easier centralized management, (5) location independent data processing, (6) reduced implementation, operation, and maintenance costs, (7) reliability, and (8) enhanced security (Aung 2015, 22).

2.5 Organizational Aspects of Energy Waste Reduction

Much is unknown about the energy consumption of WPI’s desktop computers and the means that WPI has in place to reduce the energy wasted by these systems. Furthermore, little is known regarding the impacts of reducing the energy wasted by desktop computers at WPI. There are two information collection techniques that will prove useful for the understanding of the organizational implications of desktop computer energy waste reduction at WPI. Those two techniques are stakeholder modeling and conducting interviews.

2.5.1 Stakeholders and Stakeholder Modeling

Stakeholders determine to a great extent the development and outcome of a project. Stakeholders were a key component of the reduction of energy waste of the desktop computers in WPI's academic buildings. In this section the concept of a stakeholder is defined and methods of stakeholder modeling are described. Stakeholder modeling through an onion model is explored in depth.

The Stakeholder

In his book *Managing Project Stakeholders*, Tres Roeder defines the stakeholder of a project as any “individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project (Roeder 2013, 11). The stakeholder's of a project have the power to influence the projects development, implementation, and results, and they are therefore a key component of the project (Roeder 2013, 12). Through an analysis of the stakeholders, a project ensures that it is considering all who are impacted by the project and all who have the power to impact the project.

There are a number of methods used to model stakeholders; these methods include, but are not limited to, the Stakeholder Register (Roeder 2013, 39), the Stakeholder Engagement Assessment Matrix (Roeder 2013, 25), and the Stakeholder Onion Model (Alexander 2004, 1). This section will explore the Stakeholder Onion Model proposed by Ian F. Alexander in his paper, *A Better Fit - Characterizing Stakeholders* (Alexander 2004, 1).

Stakeholder Onion Model

The Stakeholder Onion Model proposed by Alexander is composed of four concentric layers. Layers are used to categorize similar roles, where a role is the categorization of similar stakeholders. The innermost layer, referred to as the ‘Kit’, represents the product that the project is developing. The next layer is called ‘Our System’, and it contains roles that directly interact with the Kit. The following layer is called the ‘Containing System’, and it contains roles that benefit from the direct interaction with the Kit. The outermost layer is called the ‘Wider Environment’, and it contains all roles that were not captured by the inner layers. Generally, this final layer represents roles that do not interact with the Kit on a day-to-day basis, but are still impacted by it (Alexander 2004, 1-3). An example Stakeholder Onion Model can be seen in *Figure 17*. A summary of the roles within each layer is shown in *Table 3*.

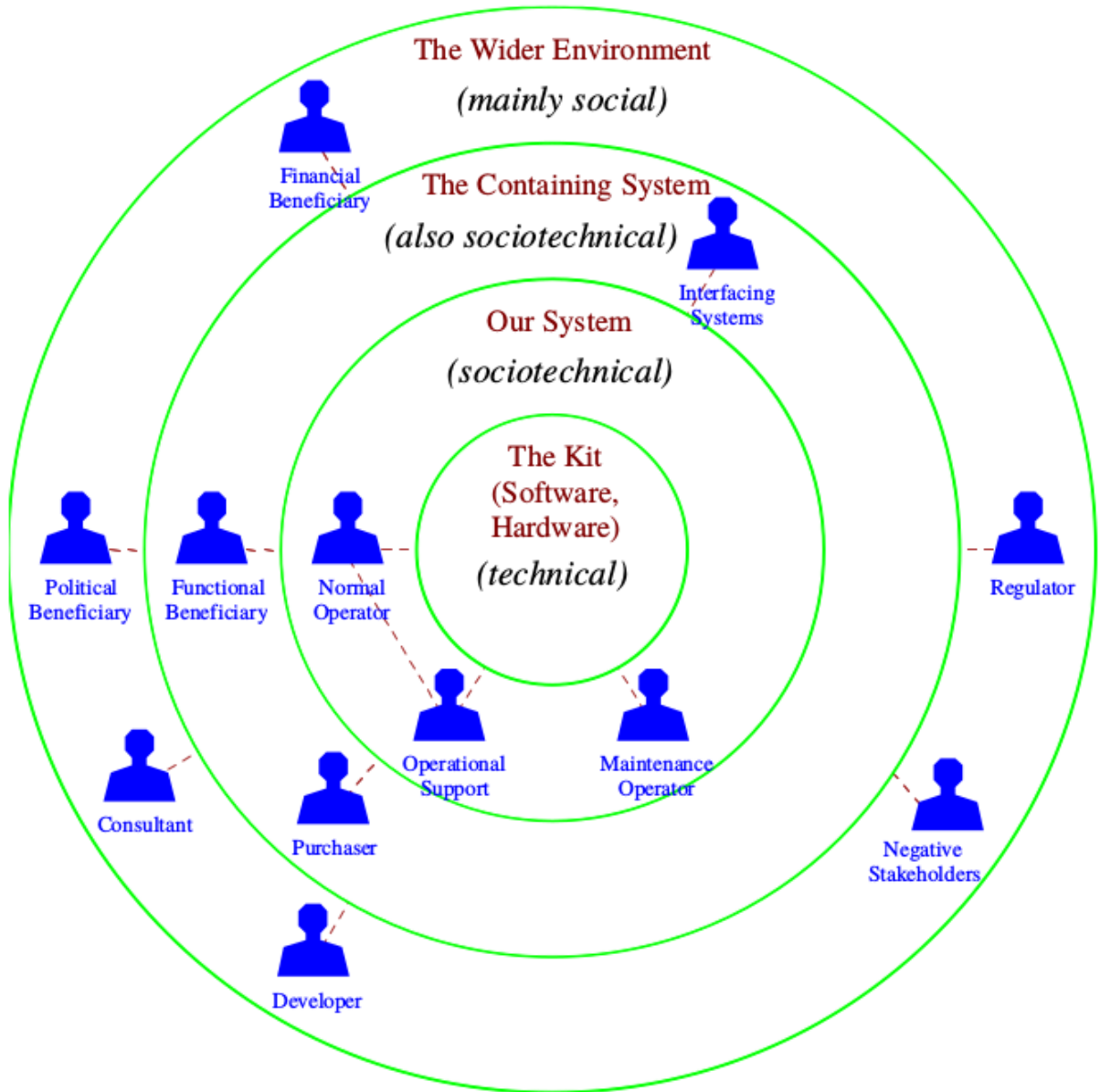


Figure 17. An example Stakeholder Onion Model from Ian F. Alexander's paper, *A Better Fit - Characterizing the Stakeholder*. This model shows the four layers and the roles within each layer. (Alexander 2004, 2)

Table 3. Stakeholder Roles

Layer	Role	Description
Our System	Normal Operator	Any stakeholder that routinely interacts with the 'Kit'.
	Maintenance Operator	Any stakeholder that maintains the 'Kit'.
	Operational Support	Any stakeholder that advises the interactions between the Normal Operator and the 'Kit'.
Containing System	Functional Beneficiary	Any stakeholder that benefits from the functionality of the 'Kit'.
	Interfacing System	Any stakeholder that is responsible for other products of technologies that interface with the 'Kit'.
	Purchaser	Any stakeholder that is responsible for the decision to develop or implement the 'Kit'.
	Champion	Any stakeholder that initiates and supports the development of the 'Kit'.
Wider Environment	Negative Stakeholder	Any stakeholder that is negatively impacted by the 'Kit'.
	Political Beneficiary	Any stakeholder that stands to gain power, influence, or prestige from the success of the 'Kit'.
	Financial Beneficiary	Any stakeholder that benefits financially from the success of the 'Kit'.
	Regulator	Any stakeholder that is responsible for the quality, cost, or user satisfaction of the 'Kit'.
	Developer	Any stakeholder that is directly involved with the development of the 'Kit'.
	Consultant	Any stakeholder responsible for supporting a specific aspect of the 'Kit'.

A description of each stakeholder role, organized by the layer to-which the role belongs. (Alexander 2004, 4-5).

2.5.2 Interview Techniques

Interviews are a powerful technique used to acquire information from human sources. Interviews with WPI staff provided useful information related to the reduction of energy waste of the desktop computers in WPI's academic buildings. As identified by Melvin Mencher, a professor at the Graduate School of Journalism at Columbia University, when conducting an interview there are four core principles to consider:

1. Prepare carefully, familiarizing yourself with as much background as possible.

2. Establish a relationship with the source conducive to obtaining information.
3. Ask questions that are relevant to the source and that induce the source to talk.
4. Listen and watch attentively.

(Mencher n.d.).

This section presents information on how to properly prepare for, conduct, and summarize an interview, such that these four principles can be achieved.

Interview Preparation

Prior to an interview, a successful interviewer will conduct extensive research on both the interview topic and the interviewee; according to the New York Times Columnist, Clyde Haberman, "exhaustive research is the basic building block of a successful interview" (Mencher n.d.). Research should be collected from academic sources, other published interviews, and people acquainted with the topic or the interviewee (Mencher n.d.). The purpose of interview preparation is threefold: first, interview preparations provides a useful background; second, interview preparation allows the reporter to understand the subject and the interviewee's background; and third, interview preparation allows the interviewer to develop useful questions and trace themes in the subject (Mencher n.d.).

In addition to research, it is important that an interviewer prepare the interview questions prior to the interview. These questions should collect the information that is needed from the interviewee in an unbiased way. In his article *General Guidelines for Conducting Research Interviews*, Carter McNamara recommends asking open ended, neutral, and clear questions (McNamara n.d.). Doing this allows the interviewee to respond on his/her own terms. McNamara also warns against asking 'why' questions, for these questions imply a 'cause-effect' relationship that may not actually exist (McNamara n.d.).

It is important to not only prepare proper interview questions, but also order the questions appropriately. When ordering questions, McNamara recommends beginning with engaging questions to get the interviewee interested in the interview right away (McNamara n.d.). Additionally, it is important to maintain this interest throughout the interview by diffusing any fact based questions amongst engaging questions (McNamara). Finally, as the end of the interview is approached, the questions should become more open ended to allow the interviewee to include any information that they feel is relevant to the interview (McNamara n.d.).

Conducting the Interview

The beginning of an interview requires that the interviewer set the scene for the interviewee. McNamara suggests this can be accomplished with the following eight guidelines:

1. Conduct the interview in a comfortable setting within minimal distraction. Consider allowing the interviewee to pick the location to maximize his/her own comfort.
2. Explain the purpose of the interview.
3. Address the confidentiality of the interview. If the contents of the interview will be published, inform the interviewee of this and to what extent the information will be published. Receive written consent to publish information from the interview.

4. Explain the interview structure. This includes the types of questions that will be asked and the topics that the interview will cover.
5. Inform the interviewee of the expected duration of the interview.
6. Provide contact information such that the interviewee can contact the interviewer following the interview.
7. Ask if the interviewee has questions regarding the interview.
8. Inform the interviewee of how the interview will be recorded (written notes, audio recording, video recording, etc.), and receive consent to record the interview through that medium.
(McNamara n.d.).

Additionally, there are a number of things to keep in mind throughout an interview. According to McNamara, it is essential that an interviewer maintain control of the interview throughout its duration (McNamara n.d.). This means ensuring both that the interview stays on topic and that time is used responsibly and efficiently (McNamara n.d.). Furthermore, it is the responsibility of the interviewer to remain neutral at all times; to avoid appearing biased, the interviewer should not jump to take notes, as such an action indicates that the answer is surprising, pleasing, or important, and may influence the interviewee's future answers (McNamara n.d.). Lastly, it is important that the interviewer informs the interviewee of transitions throughout the interview. Doing so improves the clarity of the interview (McNamara n.d.).

Summarizing an Interview

It is important to document an interview following its completion. This is often done by summarizing the interview and highlighting the key points of discussion. As described in the article *Summaries and Transcriptions*, The purpose of an interview summary is to “gather key basic information about the circumstances of the interview and give a concise guide to its contents” (Learning and Teaching Committee 2012). The summaries should introduce the interviewee, describe the purpose of the interview, and provide a clear overview of what was discussed in the interview (Learning and Teaching Committee 2012). The topics of the interview should be consolidated where appropriate, but not compressed to the extent that important information is lost (Learning and Teaching Committee 2012). Interview summaries should be written within 24 hours of the interview such that the information is still fresh in the interviewer's mind.

2.6 Summary of Background

In this chapter, relevant background information for the study of desktop computer energy waste at WPI was presented. It was shown that desktop computers are a widely and often inefficiently used resource both globally and at WPI. Additionally, methods of desktop computer energy waste measurement, and reduction were presented and discussed within the Scope of WPI. From this chapter it is clear that there is a need for a desktop computer energy waste study at WPI.

Methodology

This chapter presents the methodology used throughout the duration of this IQP study. The concepts of power draw, energy consumption, and energy waste are defined for desktop computers, and equations are presented that allow for the calculation of these figures. In presenting these equations, a number of variables are introduced. These variables were determined for WPI's desktop computers by developing an inventory of, collecting power draw data for, and collecting use behavior data for WPI's desktop computers. The methods used to do each of these things are presented in this chapter. Further, this chapter addresses that the IQP study's focus shifted towards Windows 7 Power Options, and presents aspects of evaluating Windows 7 Power Options.

3.1 Defining Desktop Computer Energy Waste

In order to measure and reduce the energy wasted by desktop computers at WPI, the energy waste of a desktop computer must first be defined. In this section, the definition of energy waste within the context of this IQP study is formalized. Additionally, the equations used to calculate energy waste are presented. These equations introduce a number of variables which were used to guide the data collection process of this IQP study.

3.1.1 Definition of Desktop Computer Energy Waste

The energy consumption of a desktop computer is the total energy, in watt hours, used by the desktop computer over a given period of time. The power draw of a desktop computer is the instantaneous wattage drawn by the system, and it is directly related to the energy consumption through the variable of time. However, unlike energy consumption or power draw, the energy waste of a desktop computer is not commonly defined. For the purpose of this IQP study, energy waste was defined as any energy that a desktop computer consumes while not actively being used. The active use of a desktop computer requires that a user be logged in and that the desktop computer is awake. By defining energy waste in this way, it is dependent on the power state⁸ of the desktop computer, as well as the user mode of the machine. For this IQP study, the power states of interest are awake, asleep, and shut down, and the user modes of interest are logged in and logged out. From these two factors, five desktop computer states were defined: (1) Awake & Logged In, (2) Awake & Logged Out, (3) Asleep & Logged In, (4) Asleep & Logged Out, and (5) Shut Down. As shown in *Figure 18*, any energy consumed while in state one is not considered energy waste because the computer is in active use; however, any energy consumed in states two through five is considered energy waste because the computer is not in active use. Thus, the energy consumed by a desktop computer is the sum of the energy consumed in states one through five, while the energy wasted by a desktop computer is the sum of the energy consumed in states two through five.

⁸ Power states described in Section 2.3.1.



Figure 18: A visual representation of the five desktop computer states and their respective categorization as wasteful or non-wasteful.

3.1.2 Calculating Desktop Computer Energy Waste

In this section variables are defined and equations are presented that will allow for the calculation of energy waste at WPI. Throughout the remainder of the Methodology Chapter, the terms model and category of desktop computer are used. To clarify, a ‘model’ of desktop computers refers to a group of desktop computers identified by their manufacturer and model number. Desktop computers are grouped by model because the power draw of a desktop computer is dependent on its model. A ‘category’ of desktop computers refers to a group of desktop computers identified by their manufacturer, model number, and location. Desktop computers are grouped by categories because the use behavior, or proportion of time spent in each of the five states, of a desktop computer is dependent on its category. Additionally, a number of the following equations define variables for an ‘average computer’; this means that the variable is the weighted average across all models / categories of desktop computers with respect to the model / category size.

Variables and Equations Related to the Inventory of Desktop Computers

Let N_M be the number of model M desktop computers. Let N_C be the number of category C desktop computers. Then, the total number of computers, N , is defined as:

$$N = \sum_{M=First\ Model}^{Last\ Model} N_M = \sum_{C=First\ Category}^{Last\ Category} N_C \quad \text{Equation 1}$$

Variables and Equations Related to the Power Draw of Desktop Computers

Let $P_{I,M}$ represent the power draw, in watts, of a model M desktop computer in state I . Then, the power draw, in watts, of an average desktop computer in state I , P_I , is defined as:

$$P_I = \sum_{M=First\ Model}^{Last\ Model} (P_{I,M} * N_M) \div N \quad \text{Equation 2.}$$

Variables and Equations Related to the Use Behavior of Desktop Computers

Let $T_{AW,C}$, $T_{AS,C}$, and $T_{SH,C}$ be the proportion of time that a category C desktop computer spends awake, asleep, and shutdown, respectively. Let $T_{AWLI,C}$ and $T_{ASLI,C}$ be the proportion of time that a category

C desktop computer spends logged in when awake and asleep, respectively. Then, the proportion of time that an average desktop computer spends awake, T_{AW} , is defined as:

$$T_{AW} = \sum_{C=First\ Category}^{Last\ Category} (T_{AW,C} * N_C) \div N \quad \text{Equation 3.}$$

The proportion of time that an average desktop computer spends asleep, T_{AS} , is defined as:

$$T_{AS} = \sum_{C=First\ Category}^{Last\ Category} (T_{AS,C} * N_C) \div N \quad \text{Equation 4.}$$

The proportion of time that an average desktop computer spends shutdown, T_{SH} , is defined as:

$$T_{SH} = \sum_{C=First\ Category}^{Last\ Category} (T_{SH,C} * N_C) \div N \quad \text{Equation 5.}$$

The proportion of time that an average desktop computer spends logged in when awake, T_{AWLI} , is defined as:

$$T_{AWLI} = \sum_{C=First\ Category}^{Last\ Category} (T_{AWLI,C} * N_C) \div N \quad \text{Equation 6.}$$

The proportion of time that an average desktop computer spends logged in when asleep, T_{ASLI} , is defined as:

$$T_{ASLI} = \sum_{C=First\ Category}^{Last\ Category} (T_{ASLI,C} * N_C) \div N \quad \text{Equation 7.}$$

The proportion of time that an average desktop computer spends logged out when awake, T_{AWLO} , is defined as:

$$T_{AWLO} = 1 - T_{AWLI} \quad \text{Equation 8.}$$

The proportion of time that an average desktop computer spends logged out when asleep, T_{ASLO} , is defined as:

$$T_{ASLO} = 1 - T_{ASLI} \quad \text{Equation 9.}$$

The proportion of time that an average desktop computer spends in state 1, T_1 is defined as:

$$T_1 = T_{AW} * T_{AWLI} \quad \text{Equation 10.}$$

The proportion of time that an average desktop computer spends in state 2, T_2 is defined as:

$$T_2 = T_{AW} * T_{AWLO} \quad \text{Equation 11.}$$

The proportion of time that an average desktop computer spends in state 3, T_3 is defined as:

$$T_3 = T_{AS} * T_{ASLI} \quad \text{Equation 12.}$$

The proportion of time that an average desktop computer spends in state 4, T_4 is defined as:

$$T_4 = T_{AS} * T_{ASLO} \quad \text{Equation 13.}$$

The proportion of time that an average desktop computer spends in state 5, T_5 is defined as:

$$T_5 = T_{SH} \quad \text{Equation 14.}$$

Equations to Calculate Power Draw, Energy Consumption, and Energy Waste

The power drawn, in watts, by an average desktop computer, P , is defined as:

$$P = \sum_{I=1}^5 (P_I * T_I) \quad \text{Equation 15.}$$

The energy consumed, in watt hours, over H hours by an average desktop computer, E_H , is defined as:

$$E_H = P * H \quad \text{Equation 16.}$$

The energy wasted, in watt hours, over H hours by an average desktop computer, W_H , is defined as:

$$W_H = \sum_{I=2}^5 (P_I * T_I) * H \quad \text{Equation 17.}$$

The power drawn, in watts, all desktop computers, \underline{P} , is defined as:

$$\underline{P} = P * N \quad \text{Equation 18.}$$

The energy consumed, in watt hours, over H hours by all desktop computers, \underline{E}_H , is defined as:

$$\underline{E}_H = E_H * N \quad \text{Equation 19.}$$

The energy wasted, in watt hours, over H hours by all desktop computer, \underline{W}_H , is defined as:

$$\underline{W}_H = W_H * N \quad \text{Equation 20.}$$

Equations 16, 17, and 18 define the total power draw, energy consumption and energy waste, respectively, of WPI's desktop computers. In order to calculate these two values, the values of $N_M, N_C, P_{I,M}, T_{AW,C}, T_{AS,C}, T_{SH,C}, T_{AWLI,C}$, and $T_{ASLI,C}$ must be determined for all models / categories of desktop computers at WPI. These values were determined using the methodology described in Section 3.2.

3.2 Measuring Desktop Computer Energy Waste

As shown in Section 3.1, in order to calculate the energy consumption and energy waste of desktop computers at WPI, the values of $N_M, N_C, P_{I,M}, T_{AW,C}, T_{AS,C}, T_{SH,C}, T_{AWLI,C}$, and $T_{ASLI,C}$ must be determined for all models / categories of desktop computers at WPI. In this section, the methodology used to determine the values of these variables is presented. As described in Section 3.2.1, N_M and N_C were determined by inventorying WPI's desktop computers. As described in Section 3.2.2, $P_{I,M}$ was determined by measuring the power draw of WPI's desktop computers with the Watts Up Pro energy meter. As described in Section 3.2.3, $T_{AW,C}, T_{AS,C}, T_{SH,C}, T_{AWLI,C}$, and $T_{ASLI,C}$ could not be determined; however, $T_{AW}, T_{AS}, T_{SH}, T_{AWLI}$, and T_{ASLI} (The corresponding weighted averages) were estimated by examining the Windows 7 system files as well as by making educated assumptions.

3.2.1 Developing an Inventory of Desktop Computers

In order to determine N_m and N_C an inventory⁹ of the desktop computers at WPI was developed. The inventory recorded the number of desktop computers at WPI for each category of desktop computer. Desktop computers were categorized by manufacturer, model, and location. The inventory was developed for ten of WPI's academic buildings: Alden Hall (AH), Atwater Kent Laboratories (AK), Fuller Laboratories (FL), Gordon Library (GL), Higgins Laboratories (HL), Kaven Hall (KH), Olin Hall (OH), Salisbury Laboratories (SL), Stratton Hall (SH), and Washburn Shops (WB). The inventory was developed by categorizing and counting the desktop computers as each building was walked through. During walkthroughs, desktop computer laboratories were encountered that required restricted access. These laboratories were primarily professor operated research laboratories. These laboratories were recorded, but not included in the primary inventory. Additionally, an inventory of desktop computers in WPI's general purpose laboratories was provided by the WPI Office of Information Technology. This inventory was cross referenced with the inventory developed during walkthroughs to create a final inventory. Computers that used operating systems other than Windows 7 were included in the inventory, but excluded from the remainder of the IQP study. From this inventory, N_C was retrieved directly, and N_m was found by summing all N_C that had model M desktop computers. This inventory is only a sample of the entire population of desktop computers at WPI. Because of this, assumptions¹⁰ were made regarding the population of desktop

⁹ Inventory discussed in Section 4.1 and presented in Appendix D.

¹⁰ Assumptions discussed in Section 4.4.1.

computers at WPI such that the energy waste of desktop computers could be analyzed more accurately. To do this, conservative, probable and optimistic assumptions were made regarding the total number of desktop computers at WPI. An empty entry in the inventory of desktop computers is shown in *Figure 19*.

Manufacturer	Model Number	Building	Room	Number of Computers

Figure 19: An empty category entry in the inventory of desktop computers.

3.2.2 Measuring the Power Draw of Desktop Computers

In order to determine $P_{I,M}$ the power drawn¹¹ by each model of desktop computer at WPI was measured and recorded. For each model, three desktop computers were selected, and the energy consumed, in watt hours, across a duration of 10 minutes was measured for each of the five states. A 10 minute long measurement was adequate to obtain an accurate measurement (Fitzpatrick 2012). Measurements were collected with a Watts Up Pro¹² provided by Professor Looft in accordance to the user manual (Vernier, 2015). Measurements were precise to a tenth of a watt hour. The power consumption, in watts, as well as averages were calculated from the measured energy consumption.

When the desktop computers were awake and logged in, the SilverBench benchmarking software was used to ensure that the desktop computers had a consistent workload. It was set to perform the ‘Extreme Test’ which meant the desktop computers were under a consistent workload for the entirety of the 10 minute trial. Additionally, when collecting data in states three and four (the sleep states), the desktop computer’s mouse, keyboard, and Ethernet cable were unplugged. This is because each of these devices was capable of waking the desktop computer, and could have woken the desktop computer in the middle of the trial. To improve the rate of data collection, multiple measurements were sometimes taken at once. This was done by connecting multiple computers to a power strip, and connecting the power strip to the Watts Up Pro. To determine the energy consumption for each of the desktop computers, the resulting energy consumption was divided by the number of computers that were connected to the power strip. This did not reduce the accuracy of the measurement, because the power strip was found to consume 0.0 watt hours over the course of 10 minutes. This measurement technique was done only when multiple desktop computers of the same model were near each other and unoccupied. An empty model entry from the compiled power draw data is shown in *Figure 20*.

¹¹ Power draw data discussed in Section 4.2 and presented in Appendix F.

¹² Watts Up Pro described in Section 2.3.3.

Manufacturer		Model Number		Number of Computers		Computer Service Tag			Average
State	Description	Data Type							
1	Awake & Logged In	Energy used in 10 min (Wh)							
		Power (W)							
2	Awake & Logged Out	Energy used in 10 min (Wh)							
		Power (W)							
3	Asleep & Logged In	Energy used in 10 min (Wh)							
		Power (W)							
4	Asleep & Logged Out	Energy used in 10 min (Wh)							
		Power (W)							
5	Shutdown	Energy used in 10 min (Wh)							
		Power (W)							

Figure 20. An empty power draw data entry for a single model of desktop computer.

3.2.3 Calculating the Use Behavior of Desktop Computers

Unfortunately, the values of $T_{AW,C}$, $T_{AS,C}$, $T_{SH,C}$, $T_{AWLI,C}$, and $T_{ASLI,C}$, were not determined in the course of this IQP study. This was because the intended methodology could not be followed due to concerns of exposing confidential information. Instead, the values of T_{AW} , T_{AS} , T_{SH} , T_{AWLI} , and T_{ASLI} (and by extension, T_{AWLO} and T_{ASLO}) were estimated by analyzing available data, and making educated assumptions. In doing so, Equations 3-7 were bypassed¹³ (all other equations were still followed). This section will discuss the intended methodology, why this methodology could not be followed, and finally the adapted methodology used to determine the values of T_{AW} , T_{AS} , T_{SH} , T_{AWLI} , and T_{ASLI} .

Intended Methodology

Windows 7 maintains a system log and a security log¹⁴, and together they contain the information needed to determine $T_{AW,C}$, $T_{AS,C}$, $T_{SH,C}$, $T_{AWLI,C}$, and $T_{ASLI,C}$. The system log file records information about power events; this information includes a timestamp for every time the desktop computer shuts down, turns on, enters sleep mode, or exits sleep mode. With these timestamps, it is possible to determine what proportion of time the desktop computer spends awake, asleep, and shut down, or $T_{AW,C}$, $T_{AS,C}$, and, T_{SH} . The security log file records information about user events; this information includes a timestamp for every time the desktop computer is logged into or out of. With these timestamps (cross referenced with the timestamps from the system log), it is possible to determine what proportion of time that the computer is logged in when awake, and what proportion of time the computer is logged in when asleep, or $T_{AWLI,C}$ and $T_{ASLI,C}$. This IQP study intended to collect multiple log files from each category of desktop computers and analyze the log files using a C program. However, due to the confidential nature of the information present in these files, administrative access is needed to view them. Unfortunately, this IQP study was not able to gain the required permissions to view these files, and thus the values of $T_{AW,C}$, $T_{AS,C}$, $T_{SH,C}$, $T_{AWLI,C}$, and $T_{ASLI,C}$ could not be determined.

¹³ These equations were bypassed because they were used to calculate T_{AW} , T_{AS} , T_{SH} , T_{AWLI} , and T_{ASLI} .

¹⁴ Windows log files described in Section 2.3.4.

Adapted Methodology

Because administrative privileges could not be obtained, no security logs were available for analysis; however, for unknown reasons, there were four categories of desktop computers at WPI where system logs were not restricted. Within these four categories, system log data¹⁵ was collected from 19 desktop computers. These system logs were analyzed¹⁶ as intended using a C program¹⁷ to calculate the proportion of time that each desktop computer spent awake, asleep, and shutdown. A weighted average was calculated for these three proportions by taking into consideration the length¹⁸ of the system log. The resulting values were used as the estimations of T_{AW} , T_{AS} , and T_{SH} . These calculations are shown in equations 19, 20, and 21.

Let $S_{AW,K}$ be the total number of seconds that desktop computer K spent awake, $S_{AS,K}$ be the total number of seconds that desktop computer K spent asleep, and $S_{SH,K}$ be the total number of seconds that desktop computer K spent shutdown. Then,

$$T_{AW} = \sum_{K=1}^{19} S_{AW,K} \div \sum_{K=1}^{19} (S_{AW,K} + S_{AS,K} + S_{SH,K}) \quad \text{Equation 21.}$$

$$T_{AS} = \sum_{K=1}^{19} S_{AS,K} \div \sum_{K=1}^{19} (S_{AW,K} + S_{AS,K} + S_{SH,K}) \quad \text{Equation 22.}$$

$$T_{SH} = \sum_{K=1}^{19} S_{SH,K} \div \sum_{K=1}^{19} (S_{AW,K} + S_{AS,K} + S_{SH,K}) \quad \text{Equation 23.}$$

Additionally, assumptions¹⁹ were made to estimate the values of T_{AWLI} and T_{ASLI} (and by extension, T_{AWLO} and T_{ASLO}). To do this, conservative, probable and optimistic assumptions were made regarding the proportion of time that an awake computer spends logged in and logged out, and the proportion of time that an asleep computer spends logged in or logged out.

3.3 Organizational Aspects of Energy Waste Reduction

In this section, the methods used to investigate the organizational aspects of energy waste reduction methods are presented. These methods including communicating with WPI Faculty and staff either through email or via an interview, as well as developing a model of stakeholders. Through these methods an understanding of how an energy waste reduction method will impact WPI was obtained.

3.3.1 Communicating with WPI Faculty & Staff

Throughout this IQP study, a number of WPI Faculty and Staff were reached out to²⁰ with the purpose of developing a greater understanding of the organizational impacts of an energy waste reduction method. This included learning about past, present and future desktop computer energy waste reduction methods; the direction of desktop computers in the WPI IT department; the challenges associated with a desktop computer energy waste reduction method; and the WPI energy profile.

¹⁵ Sample system log presented in Appendix H.1.

¹⁶ Use behavior data discussed in Section 4.2 and presented in Appendix H.3.

¹⁷ C Program is presented in Appendix H.2.

¹⁸ Here, length refers to how far back in time events were documented in the file.

¹⁹ Assumptions discussed in Section 4.4.1.

²⁰ Communications presented in Appendix C.

Email Communications

Elizabeth Tomaszewski from the WPI Office of Facilities and WPI Office of Sustainability, and Siamak Najafi from the WPI Office of Information Technology were communicated with through email. Ms. Tomaszewski is the systems manager and Associate Director of Sustainability and had an understanding of WPI's total energy consumption. Siamak Najafi is the Executive Director of Research Computation and Academic Information Technology Support and had an understanding of past energy waste reduction methods at WPI.

Interview Subjects

Three staff within the WPI Office of Information Technology were interviewed. These staff were Jim McDonald, Galen Lipin, and Steve Tanpoco. Jim McDonald was a desktop support technician and had an understanding of the desktop computers currently in use at WPI. Galen Lipin was an Application Engineer and had an understanding of the current software systems in place at WPI and how new software systems were implemented. Steve Tanpoco was the manager of Systems Operations and had an understanding of the overall infrastructure of the WPI office of Information Technology.

Conducting Interviews

Interviews²¹ were carefully prepared for, conducted, and summarized to ensure that meaningful information was collected. When preparing for interviews, clear and purposeful questions²² were developed, the topic of discussion was researched in depth, and the interview subjects were researched to help tailor questions to their expertise. At the start of an interview, the interviewer introduced himself, explained the goals of this IQP study, and clarified how the interview would help achieve this IQP study's goals. The interviewer maintained a balance of open ended questions and closed ended questions. Open ended questions were asked to ensure that the interviewees could respond on their own terms, and closed ended questions were asked to acquire specific information. Throughout the duration of the interview, notes were diligently taken by group member who was not the interviewer. At the end of each interview, the subjects were thanked, and their permission was requested to publish the information from the interview in this IQP report. Following the interview (within a 24 hour period), the interview notes were reviewed and a summary was written to synthesize and consolidate the interview findings.

3.3.2 Stakeholder Modeling

The Stakeholder Onion Model presented by Ian F. Alexander was used to model the stakeholders for this IQP study.²³ To complete this model, the 'Kit' was defined, and stakeholders were assigned to the various roles within the Stakeholder Onion Model. The kit was defined as the recommended energy waste reduction method, because it is the product that resulted from this IQP study. The assignments were made based on information collected from interviews with Jim McDonald, Steve Tanpoco, and Galen Lipin, as well as email correspondence with Elizabeth Tomaszewski.

²¹ Interview techniques discussed in Section 2.5.2.

²² Prepared interview questions presented in Appendix B.

²³ Stakeholder Onion Model described in Section 2.5.1. and discussed in Section 4.5.

3.4 Evaluating Windows 7 Power Options

As discussed in Section 4.6, Windows 7 Power Options²⁴ are the most feasible energy waste reduction method for immediate implementation at WPI. This was determined after carefully evaluating all energy waste reduction methods against the criteria learned from the Stakeholder Onion Model and the interviews. Through this evaluation, it was found that Windows 7 Power Options have the ability to greatly reduce desktop computer energy waste, are easy to implement and maintain, and do not require any additional purchases for the institution. Because of this, Windows 7 Power Options were deemed most appropriate for immediate implementation at WPI, and the focus of this IQP shifted towards how to tailor this energy waste reduction method to WPI. With these options, the main source of energy waste reduction is transitioning idle²⁵ computers to low power modes, such as sleeping or shutting down. Because of this, the associated costs of transitioning between states should be considered, and the methodology used to measure these costs is presented in this section. Further, the concept of energy savings is defined and an equation to calculate energy savings is presented in this section. This allowed the various Windows 7 Power Options to be compared such that the best configuration was selected for recommendation to WPI.

3.4.1 Collecting State Transition Energy Consumption Data

Because the Windows 7 Power Options require transitioning a desktop computer between the five desktop computer states, the cost of transitioning between states was explored. The cost was quantified both as energy consumption, in watt hours, and as elapsed time, in seconds. This is because the energy consumption correlates to a financial and environmental cost, and the elapsed time correlates to a convenience cost for the user. When collecting energy consumption data, the computer was connected to the Watts Up Pro, and the difference in watt hours between the start and end of the transition was recorded. A stopwatch was used to collect the elapsed time data.

Alpha Test & Results

An initial alpha state transition test was conducted on two desktop computers to determine which state transitions, if any, had a significant cost. Only energy consumption data was collected in this alpha state transition test, and therefore a significant cost was defined as an energy consumption of greater than 0.1 watt hours to transition between states. Data was collected for turning on the computer, turning off the computer, entering sleep while logged out, exiting sleep while logged out entering sleep while logged in, exiting sleep while logged in, logging in, and logging out. The results are presented in *Table 4*.

Table 4. Alpha State Transition Results

Manufacturer	Model	Turn On	Turn Off	Log In	Log Out	Enter Sleep While Logged In	Enter Sleep While Logged Out	Exit Sleep While Logged In	Exit Sleep While Logged Out
Dell	OptiPlex 5040	1.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Alienware	X51 R2	2	1	2.8	0.2	0.1	0.1	0.1	0.1

The results from the alpha state transition data collection.

²⁴ Windows 7 Power Options described in Section 2.4.2.

²⁵ Idle computers are computers in desktop computer state 2 (Awake and Logged Out).

From *Table 4* it is clear that the turn on, turn off, login, and logout transitions are the only costly state transitions. However, the Windows 7 Power options will not control when a computer is logged into or logged out of. Thus, it was determined that turning on and turning of were the only transitions worth considering when examining a configuration of the Windows 7 Power Options.

Final Data Collection

Because of the findings from the alpha state transition test, turning on a computer and turning off a computer were the only state transitions that were measured in depth. These two transitions were measured from the same sample of desktop computers as the power draw data. For this test, both energy consumption and elapsed time were measured such that the cost of the transition could be more accurately analyzed. *Figure 21* shows a sample entry in the table of compiled state transition data²⁶.

Manufacturer	Model Number	Number of Computers		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
Average				

Figure 21. An empty state transition data entry for a single model of desktop computer.

3.4.2 Calculating Energy Savings

In order to compare the energy savings of various configurations of the Windows 7 Power Options, the concept of energy savings for desktop computers must first be defined. In this section a definition for desktop computer energy savings is formalized. Additionally, an equation used to calculate the energy savings of desktop computers is presented, and in doing so, a number of variables are introduced.

Energy saved is defined as the difference in energy consumption before and after the implementation of an energy waste reduction method. This means that the energy saved for an average desktop computer, E_S , over the course of H hours is defined as:

$$E_S = E_{H,BEFORE} - E_{H,AFTER} \quad \text{Equation 24.}$$

Although *Equation 21* is conceptually very simple, $E_{H,BEFORE}$ and $E_{H,AFTER}$ are each rather complicated to compute. E_S can be expressed in a more computationally concise way, as follows. Let C be a Windows 7 Power Options configuration that transitions T_{TRAN} percent of the time spent in state X to time spent in state Y . Then the total time, in hours, transitioned from state X to state Y through the implementation of C over the course of H hours is defined as:

²⁶ State transition data discussed in Section 4.7.1 and presented in Appendix G.

$$T_{X,Y} = T_{TRAN} * T_X * H \quad \text{Equation 25.}$$

And the energy saved, in watt hours, through the implementation of C over the course of H hours is defined as:

$$E_S = (T_{X,Y} * P_X) - (T_{X,Y} * P_Y) \quad \text{Equation 26.}$$

From this it follows that the energy saved, in watt hours, across all desktop computers, \underline{E}_S is defined as:

$$\underline{E}_S = E_S * N \quad \text{Equation 27.}$$

In order to define equations for energy savings, the variable of T_{TRAN} was introduced. The value of this variable is completely dependent on the configuration of the Windows 7 Power Options. For this reason, the value of this variable was estimated using assumptions²⁷ made for aggressive, moderate, and conservative power options.

3.5 Summary of Methodology

In this chapter, the methodology used throughout the duration of this IQP study was presented. The concept of energy waste was defined and equations were outlined that allowed for the calculation of energy waste of desktop computers. Through these equations a number of variables were introduced, and the methods used to determine the values for these variables were outlined. These included developing an inventory, collecting power draw data, collecting use behavior data, and making assumptions. Additionally, the methods used to investigate the organizational aspects of energy waste reduction methods were presented. Finally, the chapter outlined the shift in focus towards Windows 7 Power Options as the primary energy waste reduction method, and provided aspects of these Power Options worthy of consideration, as well as a definition of energy savings within the scope of these power options. The results of this methodology are outlined in the following chapter.

²⁷ Assumptions described in Section 4.4.1.

4 Results and Analysis

In this chapter the results of this IQP study are presented and analyzed. These results are organized with respect to the project goals. The first set of results, including the desktop computer inventory, the power draw data, and the desktop computer use behavior were combined and analyzed to determine the desktop computer energy waste at WPI. The second set of results, including the Stakeholder Onion Model and criteria of an energy waste reduction method, were combined and analyzed to evaluate desktop computer energy waste reduction methods. It was ultimately determined that Windows 7 Power Options would be the best energy waste reduction method for immediate implementation at WPI, and a savings analysis was performed with this in mind. The analysis conducted in this chapter provides support for the recommendations made in Chapter 5.

4.1 Desktop Computer Inventory

In order to determine N_M and N_C ²⁸ for all models/categories of desktop computers, an inventory of desktop computers at WPI was developed. In this inventory, desktop computers were organized by their category, a unique combination of the desktop computer manufacturer, model, and location. For each category, the number of computers was counted, thus the category lists all the N_C values. The desktop computer inventory established the physical scope of this IQP study and was essential in determining both the energy waste currently being produced as well as the potential savings of an energy waste reduction method. The complete inventory developed for this project can be found in Appendix D.

The inventory data was organized by model, which allowed for the values of N_M to be calculated. This organization of the desktop computers is shown in *Table 5*. Additionally, desktop computers were organized by building as shown in *Table 6*. By applying Equation 1, it was found that the total number of desktop computers at WPI, N , was 684. This data was collected from 10 academic buildings across 11 different computer models. 38 desktop computers were encountered that did not run the Windows 7 Operating System; these computers are shown in the inventory in Appendix D, but they were not considered in this IQP study. Additionally, while collection inventory data 66 inaccessible computer labs were encountered. These labs are reported in Appendix E.

²⁸ N_M and N_C are defined in Section 3.1.2.

Table 5. Desktop Computers by Model

Desktop Computers by Model			
Manufacturer	Model	Locations	Computers
Dell	OptiPlex 980	3	4
Dell	OptiPlex 990	5	12
Dell	OptiPlex 5040	6	125
Dell	OptiPlex 7010	17	319
Dell	OptiPlex 7020	6	110
Dell	OptiPlex 7040	1	11
Dell	Precision T3620	1	22
Dell	Precision T7600	1	12
Dell	Precision Tower 5810	2	5
HP	Z640	1	9
Alienware	X51 R2	2	55
All Desktop Computers			684

Desktop computer inventory information organized by the desktop computer manufacturer and model (N_M).

Table 6. Desktop Computers by Building

Desktop Computers by Building		
Building	Locations	Computers
Atwater Kent Laboratories	8	95
Fuller Laboratories	6	70
Goddard Hall	2	42
Gordon Library	10	135
Higgins Laboratories	4	81
Kaven Hall	3	75
Olin Hall	4	60
Stratton Hall	2	27
Salisbury Laboratories	2	39
Washburn Shops	4	60
All Desktop Computers		684

Desktop computer inventory information organized by building.

4.2 Desktop Computer Power Draw

In order to determine $P_{I,M}$ for all models of desktop computers in each of the five states, the power draw of the desktop computers at WPI was measured. For each of the 11 models of desktop computers, measurements were taken from three desktop computers; this raw data is presented in Appendix F. In this section the compiled power draw results are presented and analyzed.

4.2.1 Desktop Computer Power Draw Results

The average power draw for each of the 11 computer models in each of the five states, or $P_{I,M}$, is presented in *Table 7* and displayed in *Figure 22*. From these values the average power draw across all models of desktop computers, P_I , was computed using Equation 2. These results are shown in *Figure 23*.

Table 7. Average Power Draw Data by Desktop Computer Model

Computer Model	State 1	State 2	State 3	State 4	State 5
Dell OptiPlex 980	80.8	33.6	1.2	2	1.4
Dell OptiPlex 990	101	50.4	1.6	2.4	0.2
Dell OptiPlex 5040	83	34	1.38	1.6	0.6
Dell OptiPlex 7010	95.2	30.2	2.4	2.2	0.2
Dell OptiPlex 7020	74	38.4	1.2	1.2	0.4
Dell OptiPlex 7040	40	19	1.4	1	0.4
Dell Precision T3620	74.4	37.4	2	1	0.4
Dell Precision Tower 5810	101.4	69.6	3.6	3.6	0
Dell Precision T7600	217.2	96.2	6	5.2	0.42
Alienware X51 R2	117.8	51.6	2.8	2.8	1.6
HP Z640	159.8	90	4	5.4	1

The average power draw data for each model of desktop computers considered in this IQP study.

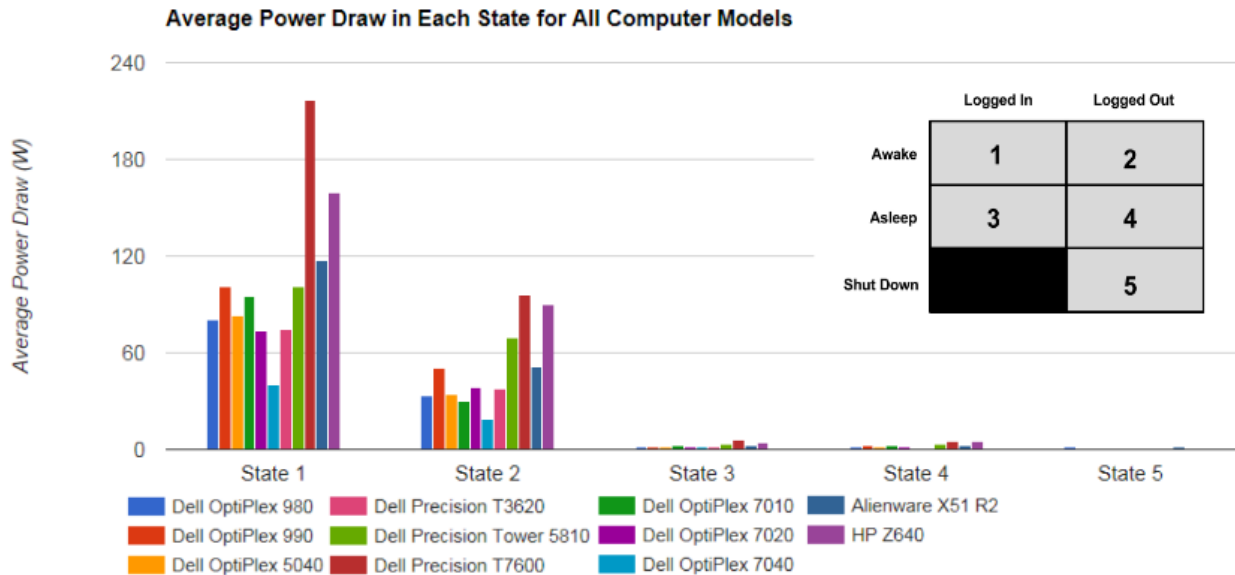


Figure 22. The average power draw data for each model of desktop computers in each of the five states ($P_{I,M}$). The definition of desktop computer states is provided as a reference.

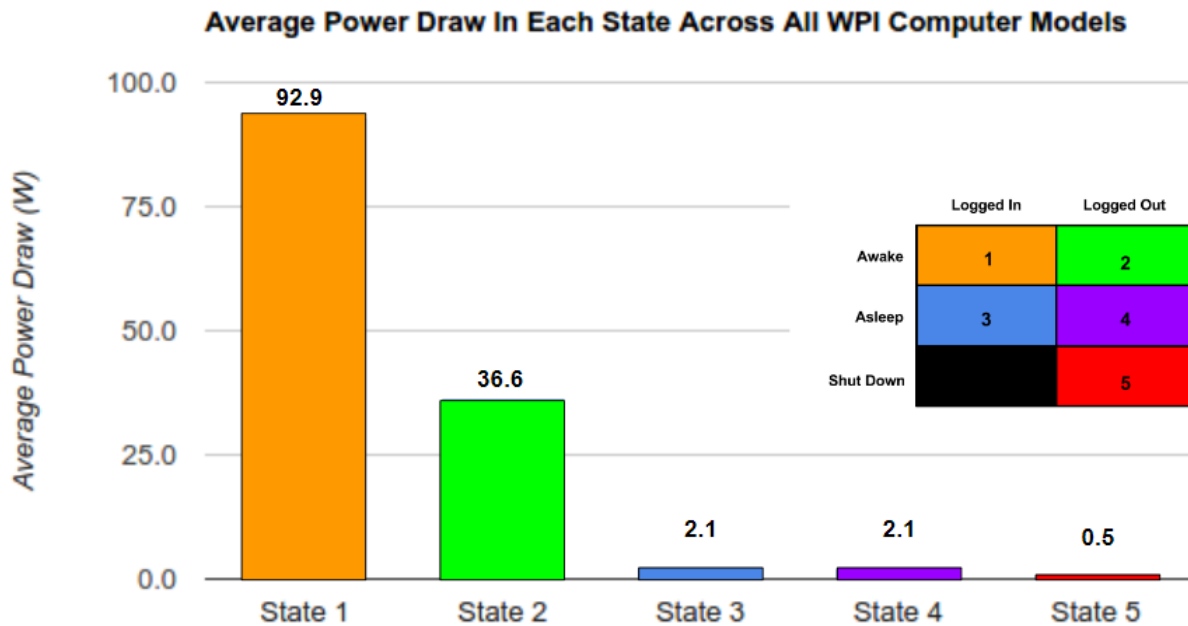


Figure 23. The average power draw in each state across all models of desktop computers (P_1). The definition of desktop computer states is provided as a reference.

4.2.2 Analysis of Desktop Computer Power Draw

The desktop computer power draw data allowed this IQP study to calculate desktop computer energy waste and energy savings. The findings presented in this analysis allowed this IQP study to select an energy waste reduction method.

A Desktop Computer In State 1 Draws Significantly More Power Than Any Other State.

When in State 1, the desktop computer may be performing a large number of computationally intensive tasks, and it is known that the workload of a desktop computer directly impacts its power draw. When in States 2, 3, 4, and 5, the desktop computer is not performing any user tasks that may increase the energy consumption. Because the power draw is affected by each user, this is not an area of focus for the scope of this project.

An Idle (State 2) Desktop Computer Draws As Much As 17 Times More Power Than A Desktop Computer In A Low Power Mode (States 3, 4, or 5).

When a computer is idle, it still requires a large amount of power to run a number of system tasks. These system tasks are not run in the low power modes. Because idle desktop computers consume much more energy than computers in low power modes, energy waste reduction methods that transition idle desktop computers to a low power mode will greatly reduce the desktop computer's energy consumption.

An Asleep Desktop Computer Draws Nearly As Little Power As A Shutdown Desktop Computer.

The processes run by an asleep desktop computer do not require a large power draw. Because asleep and shut down desktop computers draw similar power, shifting an idle computer (State 2) to sleep (State 4)

saves almost as much energy as shutting down the computer; while mitigating the inconvenience of an energy waste reduction method. The recommendations presented in section 5 take this into account.

4.3 Desktop Computer Use Behavior

The use behavior of a computer within the scope of this project is the proportion of time the computer spends in each of the five states. As mentioned in section 3.2.3, access to security logs of WPI's computers was not granted for this study. Additionally, only a small sample of system logs were available for analysis. Therefore, the values of $T_{AW,C}$, $T_{AS,C}$, $T_{SH,C}$, $T_{AWLI,C}$ and $T_{ASLI,C}$ (and by extension, $T_{AWLO,C}$ and $T_{ASLO,C}$) were not calculated. Instead, the corresponding averages, T_{AW} , T_{AS} , T_{SH} , T_{AWLI} , and T_{ASLI} (and by extension, T_{AWLO} and T_{ASLO}) were estimated through partial data analysis and assumptions. These values were used to calculate energy consumption, energy waste, and energy savings. This section presents the results of the data collected as well as the the assumptions made in order to determine the use behavior of desktop computers at WPI. A sample system log, the system log analysis program and the full results of the system log data can be found in Appendix H.

4.3.1 Educated Assumptions Regarding Desktop Computer Use Behavior

In this section, the assumptions made to approximate the values of T_{AWLI} , and T_{ASLI} are outlined. In order to ensure accuracy, a conservative, probable, and optimistic case was considered for each of the assumptions. This widened the range of the calculated results to account for inaccuracies of the assumptions. Each assumption is outlined and discussed in depth below. A full explanation of the following assumptions can be found in Appendix K.

T_{AWLI}

- Conservative- On average, of the time spent awake, 45% is in State 1.
- Probable- On average, of the time spent awake, 25% is in State 1.
- Optimistic- On average, of the time spent awake, 5% is in State 1.

T_{AWLO} (These estimates were calculated using *Equation 8*).

- Conservative- On average, of the time spent awake, 55% is in State 2.
- Probable- On average, of the time spent awake, 75% is in State 2.
- Optimistic- On average, of the time spent awake, 95% is in State 2.

T_{ASLI}

- On average, of the time spent in state 3, 50% is in State 3. (Because states 3 and 4 have nearly identical power draw and this power draw is significantly below that of states 1 and 2, a three-tiered assumption was unnecessary as changing the proportion of time spent between states 3 and 4 had little to no effect on the overall energy consumption.)

T_{ASLO} (These estimates were calculated using *Equation 8*).

- On average, of the time spent in state 3, 50% is in State 4.

4.3.2 Desktop Computer Use Behavior Results

Access to the system log portion of the use behavior data was granted for four different categories on campus. Of these 4 categories, 19 desktop computers were sampled. The usage of each of the 19 desktop computers is divided into three categories: proportion of time shut down, asleep, and awake. The compiled Log Data is presented in Appendix H.3. From the data of these 19 computers, the values of T_{AW} , T_{AS} , and T_{SH} were estimated. These represent the proportion of time an average desktop computer spends awake, asleep and shutdown. They are presented in *Table 8* and displayed in *Figure 24*.

Table 8. Proportion of Time Awake, Asleep, and Shutdown

	Time (Seconds)	Percentage
Awake	206990782	92.54%
Shut Down	16662102	7.45%
Asleep	16364	0.01%
Total	223669248	100.00%

The proportion of time that an average desktop computer spends awake, asleep, and shutdown.

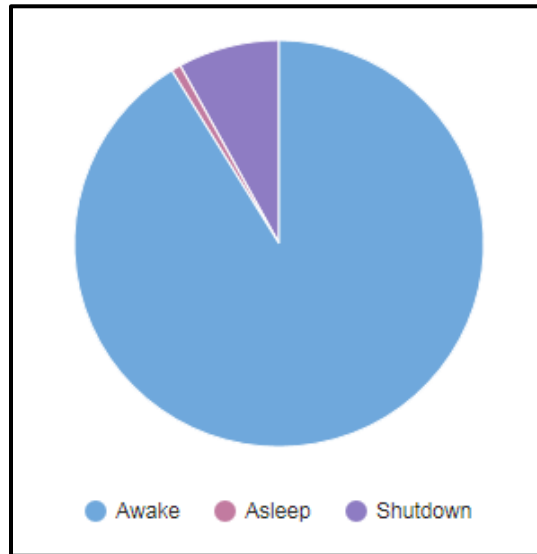


Figure 24. *The proportion of time that an average desktop computer spends awake, asleep, and shutdown.*

The proportion of time that an average desktop computer spends in each state was calculated from the system log data and the assumptions by using *Equations 10-14*. The results are presented in *Table 9*, and displayed in *Figure 25*. Note that in *Table 9* and *Figure 25* States 3 and 4 were merged because their proportion was insignificantly small.

Table 9. Proportion of Time Active, Idle, Asleep and Shutdown

State	Percentage
Active	23.14%
Idle	69.41%
Asleep	0.01%
Shut Down	7.45%
Total	100.00%

The proportion of time that an average desktop computer spends awake, idle, asleep, and shutdown.

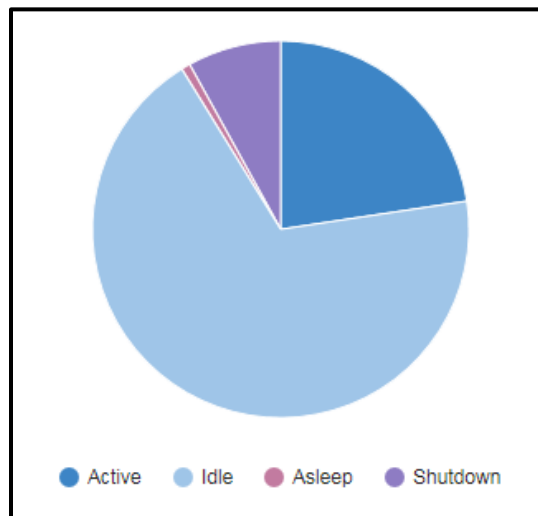


Figure 25. *The proportion of time that an average desktop computer spends awake, idle, asleep, and shutdown.*

4.3.3 Analysis of Desktop Computer Use Behavior

The desktop computer use behavior data allowed this IQP study to calculate desktop computer energy consumption, waste, and savings. The findings presented in this analysis allowed this IQP study to select an energy waste reduction method.

Desktop Computers At WPI Almost Never Sleep.

WPI computers, on average, spend 0.01% of the time asleep. Additionally, it is important to note that this data dispels the misconception that computers on campus currently sleep after being inactive for an extended period of time. In actuality, only the monitors enter sleep mode; the computer remains on (State 2). Seeing as monitors currently support a power saving option, this demonstrates the opportunity of applying power saving options to computers through shifting the time spent idle (State 2) to sleep time (State 4).

4.4 Desktop Computer Energy Waste

As previously stated in this report, energy waste is defined as any energy a computer consumes while not being operated by a user. The calculation for energy waste of any given desktop computer is represented by *Equation 17*. This entails multiplying the power draw in each wasteful state first by the proportion of time spent in those states and then by the desired time frame for which energy waste is being calculated (i.e. monthly, yearly, etc.).

4.4.1 Educated Assumptions Made

In order to determine the overall desktop computer energy waste at WPI, it was necessary to make several new assumptions. First, it is important to note that the assumptions made in section 4.3.1 are carried over and affect the desktop computer energy waste calculations. Additionally, the number of computers on campus maintained by the IT department was estimated. This was necessary due to the fact that the inventory compiled in this study did not encompass all of the computers on campus that are maintained by the IT department (this is because there were many labs and computers to which access was restricted). Following the same three-tiered format as section 4.3.1, a conservative, probable, and optimistic estimate was made.

Estimated Number of Computers:

- Conservative- 684
 - This estimate was based solely on the computers in the inventory of this study.
- Probable- 1000
 - This estimate was made with the assumption that there are an average of 5 computers in each special access lab found in Appendix E.
- Optimistic- 1700
 - This estimate was made with the assumption that in addition to the 5 computers in each special access lab, there are 450 faculty computers (based on the student population number of 6,500 and a 14:1 student to faculty ratio) and 250 additional employee desktop computers.

4.4.2 Desktop Computer Energy Waste Results

Based on the information collected from the inventory, power draw measurements, and use behavior measurements, the desktop computer energy waste was calculated. Nine total scenarios were accounted for based on the conservative, probable, and optimistic estimates for both the number of computers and the use behavior assumptions. The nine scenarios are presented in *Table 10*. The calculations for each scenario were done with *Equations 10 - 20* and are presented in Appendix I.

As expected, the quantity of energy waste has a direct correlation with the number of assumed computers as well as the proportion of time the computers spend in State 1. In the most probable scenario, desktop

computers at WPI waste around 300,000 kWh of electricity per year, which is approximately equivalent to \$23,000²⁹ of waste and 211,000³⁰ kg of CO₂ emissions.

Table 10: Energy Waste Results From Nine Possible Scenarios

Estimates and Respective Waste		Proportion of Awake Time in Active Use		
		0.45	0.25	0.05
Number of Computers	1000	163,400 kWh	220,600 kWh	277,800 kWh
	1350	222,700 kWh	300,700 kWh	378,700 kWh
	1700	282,100 kWh	380,800 kWh	479,500 kWh

Estimate	
	More Conservative
	More Optimistic

The most optimistic estimate for the desktop computer energy waste at WPI.

4.5 Stakeholder Onion Model

The Stakeholder Onion Model³¹ proposed by Ian F. Alexander was used to model the stakeholders for this IQP study. Within the scope of this project the ‘Kit’ was defined as the recommended energy waste reduction method. In this section, the Stakeholder Onion Model created for this IQP study is presented and analyzed.

4.5.1 Stakeholder Onion Model Results

In this section, The Stakeholder Onion Model created for this project is presented and described. This model, as shown in *Figure 26*, displays the four layers, the roles for each layer, and the stakeholder assigned to each role. The reasoning used to assign stakeholders to roles is presented in the following subsections.

Our System

Within the scope of this IQP study, the Normal Operators are the WPI students, faculty, and staff that regularly use the desktop computers within WPI’s academic buildings.

Within the scope of this IQP study the Maintenance Operator is the Hosting Infrastructure & Services division within the IT Department. Because this division maintains all of WPI’s software infrastructure, the recommended energy waste reduction method, if implemented, will fall under their domain (Tanpoco 2017).

²⁹ The cost of electricity was found to be \$0.076/kWh from the WPI energy data in Appendix K.

³⁰ Assuming 0.703 kg of CO₂ are emitted for every kWh produced (Environmental Protection Agency 2017).

³¹ The Stakeholder Onion Model is described in Section 2.5.1.

Within the scope of this IQP study, the Operational Support is the Help Desk team within the Services and Support division of the IT department. This is because the Help Desk team is responsible for supporting the students, faculty, and staff of WPI with the normal operation of all computer systems.



Figure 26: The onion model used to analyze the stakeholders of this IQP project. This model shows the four layers, and the roles that each layer contains. The Stakeholders are color coded to indicate stakeholders that have multiple roles.

Containing Systems

Within the scope of this IQP study, the Champion is the Sustaining WPI IQP Project Center. This center encouraged, and provided the resources for, the development and recommendation of an energy waste reduction method.

Within the scope of this IQP study, the Purchaser is the IT Governance committee. This committee will ultimately be responsible for the decision to implement the energy waste reduction method that is recommended by this IQP project.

Within the scope of this IQP study, the Interfacing System is the Hosting Infrastructure & Services division of the IT department. The energy waste reduction method, if implemented, will interface with much of the software overseen by this department, particularly the software that falls under the Microsoft Enterprise Management Suite (Tanpoco 2017).

Within the scope of this IQP study, the Functional Beneficiary is the Desktop Support Technician team within the Services and Support Division of IT. This team is responsible for maintaining and replacing the hardware for the desktop computers in academic buildings. If implemented, the energy waste reduction method may reduce the workload of these desktop computers and thus improve the longevity of their components. This may reduce the maintenance work needed from the Desktop Support Technicians (McDonald 2017).

Wider Environment

Within the scope of this IQP study, the Financial Beneficiary is the WPI Office of Facilities. This office is responsible for the payment of all utilities, including electricity; thus through the energy waste reduction method, the Office of Facilities will spend less money paying for electricity (Tomaszewski 2017).

Within the scope of this IQP study, the Political Beneficiary is the WPI Office of Sustainability. If implemented, the energy waste reduction method will improve the overall sustainability of WPI, which will bestow prestige upon the University's Sustainability Office.

Within the scope of this IQP study, the Regulator is the Hosting Infrastructure & Services division of the IT Department. If implemented, the energy waste reduction method will be regulated by this division; This division will ensure the quality of the method and adjust the method as needed (Tanpoco 2017).

Within the scope of this IQP Study, the Negative Stakeholder is National Grid. National Grid is the supplier of electricity for the university, and if the energy waste reduction method is implemented, their business with WPI will be reduced (Adams 2016).

Because Our group is responsible for the development of the recommendation for any energy waste reduction method, the Developer role was excluded from the Stakeholder Onion Model for this IQP project.

All aspects of the the recommended energy waste reduction method fall within the domain of other roles within the stakeholder analysis, therefore the Consultant role was excluded from the Stakeholder Onion Model for this IQP project.

4.5.2 Analysis of Stakeholder Onion Model

The Stakeholder Onion Model allowed this IQP study to understand the impacts that the implementation of an energy waste reduction method will have at WPI. The findings presented in this analysis allowed this IQP study to select the energy waste reduction method that is best suited for WPI.

The Implementation Of An Energy Waste Reduction Method Will Impact Many People.

As shown in the Stakeholder Onion Model, there are eight unique stakeholders spread across the eleven roles. None of the stakeholders are a single person; each is an organization composed of tens, hundreds, and even thousands of people.

The Implementation Of An Energy Waste Reduction Method Will Be Most Beneficial To The Office of Facilities and the Office of Sustainability.

Within the Stakeholder Onion Model, there are three beneficial roles: the Functional Beneficiary, the Financial Beneficiary, and the Political Beneficiary. The Functional Beneficiary is the Services and Support Division within the Office of Information Technology; however, as stated by Jim McDonald in an interview, this benefit is only a possibility, and is by no means guaranteed (McDonald 2017). The Office of Facilities is guaranteed to benefit financially because this office is responsible for the payment of the electricity bills (Tomaszewski 2017). The Office of Sustainability is guaranteed to gain prestige because the implementation of an energy waste reduction method will improve the sustainability of WPI.

The Implementation Of An Energy Waste Reduction Method Will Not Benefit The Office Of Information Technology.

Within the Stakeholder Onion Model, the only beneficial role for which the Office of Information Technology is a stakeholder is the functional beneficiary. However, as stated by Jim McDonald in an interview, this benefit is only a possibility, and is by no means guaranteed (McDonald 2017).

The Implementation Of An Energy Waste Reduction Method Will Create More Work For The Office Of Information Technology.

The roles within the Stakeholder Onion Model that will support the implementation and use of the energy waste reduction method are all held by Divisions within the Office of Information Technology. These roles are the Regulator, the Interfacing Systems, the Maintenance Operator, and the Operational Support.

4.6 Evaluation of Energy Waste Reduction Methods

In this section, an evaluation of potential energy waste reduction methods was performed. This included discussing the foreseeable problems associated with energy waste reduction methods; presenting the criteria used to assess energy waste reduction methods; and finally, assessing all energy waste reduction methods against these criteria. It was ultimately determined that Window 7 Power Options were the best energy waste reduction method for immediate implementation at WPI.

4.6.1 Potential Problems of Energy Waste Reduction Methods at WPI

During the course of this IQP study, two problems were uncovered that may impact the implementation of an energy waste reduction. The first was that desktop computers at WPI may have a defective sleep mode, which results in them shutting down instead of sleeping. The second was that WPI's network infrastructure does not support Wake-on-LAN technology; thus, computers that are shut down can not be turned on remotely. In this section, each of these problems is described and the resulting implications for energy waste reduction methods are discussed.

WPI Does Not Support Wake-on-LAN Technology.

The WPI network does not support Wake-on-LAN Technology; this was stated in the 2010 IQP study that conducted an energy audit of Atwater Kent Laboratories (Newman 2010), and confirmed by Mr. Lipin via email (Tanpoco 2017). According to Mr. Lipin, this is because WPI's "network architecture does not allow wake-up packets to traverse our network hardware. In essence we can send wake-up packets all we want, but we can't actually get them to a hibernating computer in a meaningful way" (Tanpoco 2017). This was investigated further, and it was found that Wake-on-LAN technology is a feature of desktop computers that can be enabled/disabled in the system BIOS (Arch Linux, 2017). Five desktop computers in Atwater Kent Laboratories 113 were sampled and it was found that Wake-on-LAN technology was disabled in the BIOS for each. It is possible that the reason the Wake-on-LAN packets cannot be sent on the WPI network is because this feature is disabled in the BIOS; however this will have to be investigated further before it can be confirmed.

The fact that WPI's network does not support Wake-on-LAN technology is problematic for the university's Office of Information Technology, because desktop computers cannot be turned on remotely. In order to turn desktop computers on, the IT department would have to send someone to manually push the power button, and this is a large inconvenience for an office that manages, likely, over a thousand computers. Instead, because desktop computers cannot be remotely turned on, they will likely miss important system updates if turned off. For this reason it is important that desktop computers at WPI not be shut down.

WPI's Desktop Computers May Enter And Exit Sleep Modes Improperly.

In the past, desktop computers at WPI have had defective sleep modes. As learned from Mr. Najafi the WPI Office of Information Technology has, in the past, implemented Windows 7 Power Options to put idle computers to sleep; however, "not all PCs came out of the sleep mode properly. Sometimes necessitating a reboot" (Najafi 2017). When researched further, it was found that this is a common problem on Windows 7 support forums with a number of potential causes. These causes include, defective motherboard hardware, hardware software incompatibility, defects in Windows 7 hybrid sleep, and disabled USB power in sleep (prevents USB peripherals such as keyboard or mice from waking the system)(Khanse 2015),(Dena 2010), (Unknown 2010) . This issue does seem to still be a problem at WPI; all models of desktop computers were put to sleep during our power draw data collection, and only one had an issue resuming from sleep. This computer, in AK113, was set to allow hybrid sleep mode. This was disabled in the advanced Windows 7 Power Options. Following this change, the desktop computer no longer had issues resuming from sleep.

If, however, desktop computers still have defective sleep modes, it will be problematic for all energy waste reduction methods that put desktop computers to sleep. When Windows 7 Power Options were used in the past, it was this defect was largely inconvenient for the students, faculty, and staff of WPI; as stated by Mr. Najafi, this problem "adversely affected classes scheduled in these labs and took time away from class time" (Najafi 2017). Additionally, if computers can't wake from sleep then the Office of Information Technology would have to send someone to manually reboot the computer. As stated previous this is not feasible for an office that likely manages over a thousand desktop computers.

4.6.2 Criteria of an Energy Waste Reduction Method

When evaluating energy waste reduction methods for implementation at WPI, a number of criteria were considered. In this section, these criteria are presented, and explained.

The Recommended Energy Waste Reduction Method Must Be Easy To Implement And Maintain.

As stated by Mr. Tanpoco in a personal interview, the most limited resource of the Office of Information Technology is the human resource (Tanpoco 2017). This fact was confirmed by Mr. McDonald, as well (McDonald 2017). Clearly, the Office of Information Technology does not have people needed to implement an energy waste reduction method with a lot of overhead and maintenance. Additionally through the stakeholder analysis, it was learned that if an energy waste reduction is implemented, the WPI Office of Information Technology will not directly benefit, yet will still be responsible for all the work of implementation and maintenance. For these reasons, the burden that is placed on the Office of Information technology must be considered seriously when evaluating energy waste reduction methods.

The Recommended Energy Waste Reduction Method Must Not Inconvenience The Normal Operators.

As learned from Mr. Najafi, Windows 7 Power Options were implemented at WPI in the past; however, the policy was quickly removed because the students faculty and staff of WPI were largely inconvenienced (Najafi 2017). This history demonstrates that energy waste reduction methods that inconvenience the normal operators will not remain in place. Additionally, Jim McDonald warned that their may be backlash from faculty at WPI if the recommended energy waste reduction method interferes with their work (McDonald 2017).

The Recommended Energy Waste Reduction Method Must Have Significant Results.

As indicated by Jim McDonald, the recommended energy waste reduction method should have significant monetary benefits for WPI (McDonald 2017). When asked what quantity of savings would be needed for an energy waste reduction method to be implemented, none of the staff interviewed had a concise answer; however, it was the consensus among Mr. McDonald, Mr. Tanpoco, and Mr. Lipin that an energy waste reduction method that saved thousands annually would be worth considering (McDonald 2017), (Tanpoco 2017).

4.6.3 Analysis of Energy Waste Reduction Methods at WPI

In this section, an analysis is presented of each energy waste reduction method against the criteria presented in the previous section. It was ultimately found that Windows 7 Power Options are the best energy waste reduction method for immediate implementation at WPI. A summary of how each energy waste reduction method impacts each criteria is presented at the end of this section.

Windows 7 Power Options

The implementation of Windows 7 Power management software would not require much work from the WPI Office of Information Technology. This energy waste reduction method could be implemented by issuing a command to all desktop computers at WPI. Additionally, because the method is built into the Windows 7 operating system, it would not cause any problems when interfacing with other software.

Windows 7 Power Options would not inconvenience the WPI students, faculty, and staff because it would not change the user experience of the normal operators. This claim is based on the assumption that the desktop computers at WPI can properly enter and exit sleep modes.

Windows 7 Power Options have the potential to eliminate the majority of desktop computer energy waste at WPI, because they would put desktop computers to low power modes when inactive.

Commercial Power Management Software

The implementation of commercial power management software will require a substantial amount of work from the WPI Office of Information Technology. This is because the power plan would have to be tailored to WPI, which would require a large amount of consulting with the software provider. Additionally, as learned from Mr. Tanpoco and Mr. Lipin, a commercial software product would have to interface with the existing commercial software that WPI has in place (Tanpoco 2017). This fact would make it difficult to implement a commercial power management software without disrupting the current technology at WPI. Because of this, it is unlikely that a commercial power management software would be approved for implementation from the IT Governance Committee. (Tanpoco 2017).

A commercial power management software would not inconvenience the WPI students, faculty, and staff. This is because it would not change the experience of the normal operator. This claim is based on the assumption that the desktop computers at WPI can properly enter and exit sleep modes. Additionally, it would likely make it easier for the IT Office of Information Technology to manage and monitor the desktop computers at WPI because most commercial power management software solutions offer management tools.

A commercial power management software would have the potential to eliminate the majority of desktop computer energy waste at WPI, because it would be able to put desktop computers to low power modes when they become inactive, and re-wake them as needed.

Network Connectivity Proxy

The implementation of a network connectivity proxy solution at WPI would require a substantial amount of work from the WPI Office of Information Technology. This is because this method of energy waste reduction has been researched, but not formalized. Thus the solution would have to be largely ‘invented’ or tailored to the WPI information technology infrastructure.

A network connectivity proxy would not inconvenience the WPI students, faculty and staff. This is because it would not change the experience of the normal operator. This claim is based on the assumption that the desktop computers at WPI can properly enter and exit sleep modes.

A network connectivity proxy would have the potential to eliminate the majority of desktop computer energy waste at WPI because it would be able to put desktop computers to low power modes when they become inactive, and re-wake them as needed.

Partial VM Migration

The implementation of a partial VM migration strategy is not applicable to WPI. This solution is ideal for desktop computers that need to run minimal background tasks, such as emailing / messaging services. It saves energy by moving these services to a VM on a server and puts the host desktop computer to sleep. This solution would not be effective at WPI because the majority of the university's desktop computers are within labs, available to all students, and not used to run background tasks of this nature.

Thin Client Server Based Computing

The implementation of a thin client server based computing strategy at WPI would require a substantial amount of work from the WPI office of information technology. This is because this strategy would require replacing the entire information technology infrastructure: all desktop computers would be replaced with low powered clients, and multiple large servers would be installed at WPI. This process would likely need to be done gradually over the course of many years.

A thin client server based computing strategy would not inconvenience the WPI students, faculty and staff. The normal operators would no longer interface with desktop computers, but with low powered clients. These clients would outsource all computation to a high performance server, which would likely improve the user experience. Additionally, the low powered clients are far cheaper than desktop computers, thus the WPI Office of Information technology would have extra budget that they could spend on a greater quantity of clients, better quality monitors, or any other technology to improve the user experience. Additionally once fully implemented, a thin client server based computing strategy would be easier for the Office of Information Technology to manage than the current network of desktop computers.

A thin client server based computing strategy would eliminate desktop computer energy waste because it would eliminate desktop computers. Additionally, it would lower the energy consumption while in active use by as much as 300% (Aung 2015), (Greenberg 2001). Even when accounting for the energy consumption of the high performance servers, it is expected that this infrastructure would reduce the energy waste and energy consumption of WPI's information technology infrastructure the greatest out of all energy waste reduction methods considered.

Summary

Table 11 summarizes the analyses of each energy waste reduction method. From this table, it is evident that the Windows 7 Power Options are the only energy waste reduction method that is both easy to implement and easy to maintain. For this reason, it is the primary energy waste reduction method that is explored in the remainder of this report. However, it is also important to note that thin client server based computing models have many benefits aside from the extreme difficulty in implementation. For this reason, this method will be considered as a long term recommendation for an energy waste reduction method at WPI.

Table 11. Summary of Analysis of Energy Waste Reduction Methods

Energy Waste Reduction Method	Implementation	Maintenance	User Experience	Energy Waste Reductions
Windows 7 Power Options	Very Easy to Implement	Very Easy to Maintain	No Change in User Experience	Energy Waste Reduction
Commercial Power Management Software	Difficult to Implement	Easy to Maintain	No Change in User Experience	Energy Waste Reduction
Network Connectivity Proxy	Very Difficult to Implement	Very Difficult to Maintain	No Change in User Experience	Energy Waste Reduction
Partial VM Migration				
Thin Client Server Based Computing	Extremely Difficult to Implement	Very Easy To Maintain	Greatly Improved User Experience	Large Energy Waste / Consumption Reduction

A summary of the analysis of the energy waste reduction methods at WPI. Green, yellow, and red regions mean the energy waste reduction methods are good neutral and bad, respectively, for the given criteria.

4.7 Evaluation of Windows 7 Power Options

This section considers the various configurations of Windows 7 Options. First, data collected on the energy used by desktop computers while transitioning between states is presented. Next, several assumptions are discussed in order to continue into the calculation and analysis of energy savings. Energy savings are calculated for a plan that transitions idle computers to sleep and a plan that transitions idle computers to shut down; these are referred to as the sleep plan and the shutdown plan, respectively.

4.7.1 Desktop Computer State Transitions

The desktop computer state transition data was collected for each of the 11 desktop computer models on campus. The full results of the state transition data collection can be found in Appendix G. As determined in the alpha test shown in section 3.4.1, the only significant energy consumption and transition time occurred while turning the computer on and off so data was only collected for these two transitions.

Energy Consumption During State Transition

The average energy consumption in transition from State 5 to State 2 (Turning on) was 1.7 Wh. For the transition from State 2 to State 5 (Turning off), the average was 0.46 Wh. Therefore, the average energy consumption for one restart cycle is 2.16 Wh. This means it is more energy efficient to shut down a computer if the computer is expected to be idle for more than 3.5 minutes.

Time Required to Transition Between States

The average time required to transition from State 5 to State 2 (Turning on) was 111 seconds. For the transition from State 2 to State 5 (Turning off), the average was 35 seconds. Therefore, the time required to perform one full shutdown and turn on cycle is roughly 2.4 minutes. This is a significant amount of time meaning there is a relatively large inconvenience factor associated with turning computers off often. This is something that was considered when selecting the recommendations put forth in section 5.1.

4.7.2 Assumptions

In order to calculate the potential energy savings of the sleep plan and the shutdown plan, several assumptions were made. These assumptions are presented in this section.

Shutdown Plan

First, a plan for shutting down idle computers was examined. This plan would entail shifting a computer's time spent in the idle state (State 2) to the shutdown state (State 5.) Due to the inconvenience factor associated with the length of time required to turn on one of WPI's computers, the plan entailed turning computers off only after 30 minutes of inactivity. Because there is an allowed period of inactivity, not all of the proportion of time spent in State 2 can be changed to State 5. Therefore, the assumption that 75% of the proportion of awake time spent in State 2 could be shifted to State 5 was made.

Sleep Plan

Next, a plan for putting idle computers to sleep was examined. This plan would entail shifting a computer's time spent in the idle state (State 2) to the asleep logged out state (State 4). Because transition between

states 2 and 4 can occur in under five seconds, there is a relatively low inconvenience factor associated with this. As such, a much lower period of inactivity prior to transition was chosen. The assumption was made that 99% of the proportion of time spent in State 2 could be shifted to State 4. *Table 12* and *Figure 27* present the proportion of time that desktop computers will spend active, idle, asleep, and shutdown, if the sleep plan is implemented.

Table 12. Proportion of Time Active, Idle, Asleep and Shutdown

State	Percentage
Active	23%
Idle	1%
Asleep	69%
Shut Down	7%
Total	100%

The proportion of time that an average desktop computer spends awake, idle, asleep, and shutdown.

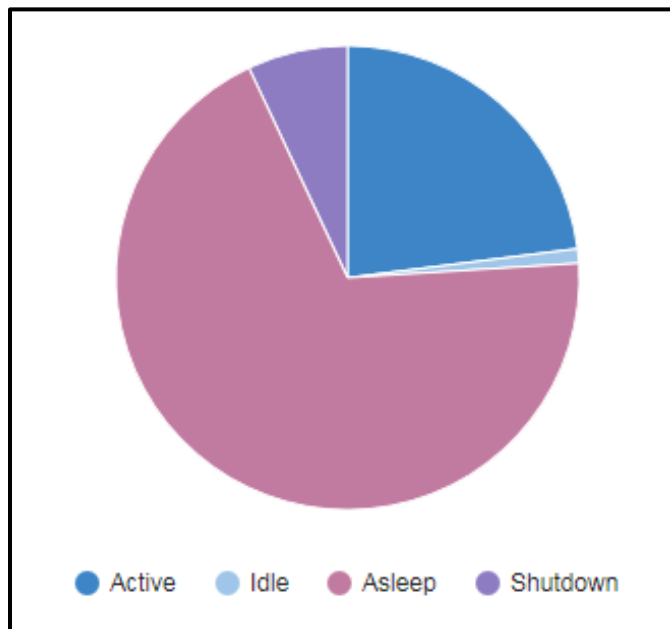


Figure 27. *The proportion of time that an average desktop computer spends awake, idle, asleep, and shutdown.*

4.7.3 Analysis of Savings

The savings of each Windows 7 Power Options energy waste reduction plan was calculated for each of the 9 scenarios introduced in section 4.4.2. These calculations were made following *Equations 24-27* outlined in section 3.4.2. The full list of calculated scenarios for each of these plans can be found in Appendix J. *Table 13* displays the expected savings for the shutdown plan, and *Table 14* displays the expected savings for the sleep plan.

Table 13: Expected Savings of Shutdown Plan

Estimates and Respective Savings		Proportion of Awake Time in Active Use		
		0.45	0.25	0.05
Number of Computers	684	82,600 kWh	112,700 kWh	142,700 kWh
	1000	120,800 kWh	164,700 kWh	208,700 kWh
	1700	205,400 kWh	280,000 kWh	354,700 kWh

Estimate	
<input type="checkbox"/>	More Conservative
<input checked="" type="checkbox"/>	More Optimistic

The summary of all 9 scenarios for the savings of the shutdown plan.

Table 14: Expected Savings of the Sleep Plan

Estimates and Respective Savings		Proportion of Awake Time in Active Use		
		0.45	0.25	0.05
Number of Computers	684	104,100 kWh	141,900 kWh	179,800 kWh
	1000	152,200 kWh	207,500 kWh	262,800 kWh
	1700	258,700 kWh	352,700 kWh	446,800 kWh

Estimate	
<input type="checkbox"/>	More Conservative
<input checked="" type="checkbox"/>	More Optimistic

The summary of all 9 scenarios for the savings of the sleep plan.

In the most probable scenario of the shutdown plan around 165,000 kWh of electricity per year would be saved, which is approximately equivalent to \$12,400 of savings and 115,000 kg of reduced CO₂ emissions. This is a reduction of 55% of the total probable energy waste. In the most probable scenario of the sleep plan around 208,000 kWh of electricity per year would be saved, which is equivalent to \$15,700 of savings and 146,000 kg of reduced CO₂ emissions. This is a reduction of 69% of the total probable energy waste.

The calculations of the potential savings demonstrates of each of these Windows 7 Power Options configurations reveals that the sleep plan can yield 25-30% more potential savings. In order for a shutdown plan to match or surpass the savings of a sleep plan, a more aggressive configuration must be implemented. This means shutting down computers after a much smaller period of inactivity, thus increasing the proportion of time shifted from State 2 to State 5. However, it is important to note that with a more aggressive shutdown plan, the inconvenience factor for the user becomes a larger issue.

4.8 Summary of Results and Analysis

In this chapter, the results and subsequent analysis of the data collected in this IQP study was presented. The calculation of energy waste at WPI was made from the results of the inventory of desktop computers at WPI, the power draw data, and the use behavior data. The results of the stakeholder analysis and the evaluation of waste reduction methods led to the selection of Windows 7 Power Options as the only viable short term solution. Finally, the chapter focused on Windows 7 Power Options as the primary energy waste reduction method, and provided two configurations as and analyzed the savings of each plan. The recommendations based on these results are presented in the following chapter.

5 Recommendations

In this section, the recommendations of this IQP study are outlined. The primary recommendation is that the Office of Information Technology implement the Windows 7 Power Options to put idle computers to sleep. In addition to this, multiple secondary recommendations are discussed as well as a single long term recommendation. The primary and secondary recommendations can be carried out at WPI immediately because they do not require drastic changes to the WPI information technology infrastructure. This however, is not the case for the long term recommendation. If followed, these recommendations will reduce the energy wasted by desktop computers at WPI, and ultimately make WPI a more sustainable university.

5.1 Primary Recommendation

Based on the information collected in this study, it is recommended that WPI implement a configuration of Windows 7 Power Options as an effective short term method to reducing energy waste. More specifically, idle (State 2) desktop computers should be set to enter sleep mode after 1 minute of inactivity. It is important to note, that when computers are awake and logged in (state 1) they will not be put to sleep with this plan. The recommendation to put inactive computers to sleep rather than shut them down comes from the results of the state transition data in section 4.7.1 and the desktop power draw data in section 4.2: the time needed to shut down and turn on desktop computers would pose as a significant inconvenience for users; and the power draw while asleep (State 4) is very similar to the power draw while shut down (State 5). Essentially, the slightly reduced power draw was determined to be less important than the significant difference in the convenience of each configuration. Furthermore, the inactivity period of 1 minute was selected based on the analysis of savings in section 4.7.3 and the alpha test state transition data in section 3.4.1. Since transitioning between asleep and awake takes only a few seconds, it was determined to not be an inconvenience and was selected such that energy waste could be minimized.

5.2 Secondary Recommendations

In addition to the implementation of Window 7 Power Options across campus, this IQP study makes a number of secondary recommendations. These recommendations, as presented in this section, will complement the Windows 7 Power Options and ultimately further reduce the energy wasted by desktop computers at WPI.

The WPI Office Of Information Technology Should Buy Energy Efficient Desktop Computers When Replacing Current Desktop Computers.

The Desktop Computers at WPI are currently replaced every 3 years by the Office of Information Technology. This replacement should occur with energy efficiency in mind; this means the power drawn by a desktop computer when awake, asleep, and shut down should be considered before it is purchased as a replacement. Doing so will ensure that the energy consumed by desktop computers at WPI is reduced every time old desktop computers are replaced. Additionally, because it would simply reduce the power drawn in each of the five states of operation, this strategy will not interfere with the primary recommendation of Windows 7 Power Options. Further, this recommendation is relevant not only to desktop computers, but to all information technology. The Office of Information Technology should

consider energy efficiency before purchasing devices such as monitors, servers, modems, routers, mice, and keyboards.

WPI Students, Faculty, and Staff Should Put Desktop Computers To Sleep When Not In Use.

WPI students, faculty, and staff have the power to reduce the energy wasted by desktop computers. They could do so simply by putting desktop computers to sleep when the computers is left or when the computer is inactive for an extended period of time. Although, with the primary recommendation, Windows 7 Power Options will automatically put desktop computers to sleep after 1 minute, the user has the ability to put the desktop computer to sleep immediately when it is no longer needed. Doing so will reduce the amount of time that desktop computers spend idle, and reduce the energy wasted by desktop computers at WPI. In order to implement this recommendation, awareness must be spread; WPI students, faculty, and staff need to be made aware of the energy wasted by desktop computers when idling.

The WPI Office Of Information Technology Should Ensure That WPI's Desktop Computers Are Capable Of Properly Entering And Exiting Low Power Modes.

As learned from Mr. Najafi, Windows 7 Power Options were used, unsuccessfully, in the past as a means to reduce the energy wasted by desktop computers (Najafi 2017). The issue was that some desktop computers would automatically shut down when put into sleep mode, which was largely inconvenient for the WPI Office of Information Technology as well as WPI students, faculty and staff (Najafi 2017), (Tanpoco 2017). As shown in Section 4.6, this is typically caused either by settings within the Windows Operating System, or by defective hardware in older models of desktop computers. The WPI Office of Information Technology can ensure that its desktop computers are capable of properly sleeping by the Advanced Windows 7 Power Options, and by purchasing desktop computers that do not have the defective sleep hardware. In doing so, WPI's desktop computers will be able to enter sleep mode without inconvenience to the Office of Information Technology, or the WPI students, faculty, and staff. This will allow the successful use of Windows 7 Power Options to reduce the energy wasted by desktop computers at WPI.

The WPI Office Of Information Technology Should Enable Wake-on-LAN Technology.

Currently the Network infrastructure at WPI does not support Wake-on-LAN Technology (Tanpoco 2017). As stated in Section 4.6, this is because of inadequate network hardware, as well as improper BIOS configurations. It is recommended that the WPI Office of Information Technology properly configure the BIOS of all desktop computers to support Wake-on-LAN technology, and, when replacing network hardware, purchase hardware that supports Wake-on-LAN technology. In doing so, the Office of Information Technology will allow desktop computers to be woken remotely. With this capability, the Windows 7 Power Options power plan could be modified to including shutting down computers overnight, which would further reduce the energy wasted by desktop computers at WPI.

5.3 Long Term Recommendation

Although there are a number of actions that can be taken immediately to reduce the energy wasted by desktop computers at WPI, there are also some long term changes that can be made to reduce the overall energy consumption of WPI's desktop computers. From the research conducted in this IQP study, it is believed that switching to a thin client server based computing structure would support WPI's Information

Technology needs, while drastically reducing the energy consumed by desktop computers. Doing so, would alter the entire WPI Information Technology infrastructure, thus it is something that should be considered in depth before being implemented and it is something that will take many years to fully implement. It is recommended that the WPI Office of Information Technology, as well as future IQP studies, examine the feasibility of a thin client server based computing strategy at WPI. In doing so, the following research questions should be considered:

1. To what degree will the energy consumption of WPI's information technology be reduced with a thin client server based computing strategy?
2. Can the normal computer operations of WPI be sustained by a thin client server based computing strategy?
This means, will students have the same access to computers, computer resources, and computer programs?
3. Can the normal computer operations of WPI be modified to be more energy efficient while still meeting the needs of WPI students, faculty, and staff?
This means, are there ways to change the way computers are used at WPI to reduce the total energy consumed by WPI's information technology? For example, because most students own their own laptop computer, it is possible that the the total number of computers at WPI could be reduced.
4. What is the expected timeline of implementing a thin client server based computing strategy?

5.4 Summary of Recommendations

In this section a number of recommendations were made regarding the energy waste of desktop computers at WPI. The primary recommendation was that idle desktop computers be put to sleep after 1 minute of inactivity using Windows 7 Power Options. The secondary recommendations were to purchase information technology with energy efficient hardware, which is capable of properly sleeping, and supports Wake-on-LAN technology. The secondary recommendations also included increasing awareness of desktop computer energy waste at WPI. Additionally, a long term recommendation was set for the WPI information technology infrastructure. It was advised that WPI consider transition to a thin client server based computing strategy. Through following these recommendations WPI will reduce the energy wasted by its desktop computers and become a more sustainable university.

6 Conclusion

The two goals of this IQP study were successfully achieved: the desktop computer energy waste at WPI was measured, and a number of energy waste reduction methods were recommended to WPI. It was found that the desktop computers at WPI waste an estimated 300,000 kWh of energy each year, which is approximately equivalent to \$23,000 in electricity costs and 167,000 kg in CO₂ emissions, annually. This was equivalent to 0.5% percent of WPI's total yearly energy consumption. In order to reduce the desktop computer energy waste at WPI, it was recommended that the Windows 7 Power Options be used to put idle desktop computers to sleep after 1 minute. It was estimated that, if implemented, this energy waste reduction method will reduce desktop computer energy waste by 69% percent, which would intern reduce the energy consumption by 208,000 kWh, electricity costs by \$15,700, and CO₂ emissions by 115,000 kg, annually. In doing so, WPI would become a more sustainable campus and set the path for other universities to follow.

Future Developments

A number of aspects of desktop computer energy waste were discovered throughout the course of this project; however, they could not be fully explored within the time frame of this study. It is encouraged that future research teams explore these topics in greater detail such that the understanding of desktop computer energy waste and energy waste reduction methods may be furthered. Doing so will provide the groundwork needed for large organizations to make sustainable choices for their information technology infrastructure.

These topics are:

- Thin client server based computing as a sustainable information technology strategy.³²
- Confidential methods to examine and analyze Windows 7 log files such that accurate use behavior data can be obtained for the desktop computers at WPI.
- Commercial power management software solutions that would allow for the real time monitoring and management of WPI's computers and their energy consumption.
- The need for computer systems at WPI and the potential of using student owned laptops to meet computational needs.
- Increasing awareness of desktop computer energy waste and encouraging students, faculty, and staff, to make sustainable choices regarding their desktop computer use behavior.

Concluding Remarks

WPI can greatly reduce its desktop computer energy waste through the immediate implementation of Windows 7 Power Options. As a long term goal, this IQP study recommends that WPI investigate a thin client server based computational strategy for its information technology infrastructure. Doing so would likely have numerous benefits including a reduction in energy consumption.

By following these recommendations, WPI will become a more sustainable university, and mark the path for other large organizations to follow.

³² This is recommended and explained in Section 5.3.

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A. Commercial Power Management Software

In this section, a table listing and describing commercial power management software solutions is presented.

Software Package:	Description
Absolute Manage <i>Absolute Software</i>	<p>“Absolute Manage is the World’s only persistent computer lifecycle management solution. Using our patented Computrace persistence technology, Absolute Manage is able to self-heal if the application agent is removed from a computer, providing you with a constant connection to each device in your deployment” (Energy Star n.d.).</p> <p>https://www.absolute.com/en/products</p>
Adaptiva Companion <i>Adaptiva</i>	<p>“Adaptiva Companion’s features include instant or scheduled power off, hibernate, or sleep and Wake On LAN to perform maintenance” (Newman 2010, 11).</p> <p>http://www.adaptiva.com/green-planet/</p>
ANSA PC Power Manager <i>Autonomic Software</i>	<p>“ANSA PC Power Manager is an easy to deploy, easy to manage, and cost effective solution for 100 to over 100,000 nodes, all from a centralized console. Autonomic Software’s ANSA PC Power Management Software has been awarded and recognized by major utility companies including PG&E and Entergy, and was named ‘Best Power Management Technology of the Year’ by InfoWorld” (Energy Star n.d.).</p> <p>http://autonomic-software.com/products/power-manager.html</p>
Auto Shutdown Manager <i>EnviProt</i>	<p>“Auto Shutdown Manager is a centrally managed and network enabled PC Power Management solution for enterprises, governments, educational institutions, NGOs, and private users. Auto Shutdown Manager allows an intelligent startup of necessary computers and shutdown of unused computers — but unlike other solutions, it never interrupts working users or productive systems” (Energy Star n.d.).</p> <p>http://www.enviprot.com/en/</p>
BigFix	<p>“BigFix enforces power saving options, uses Wake On LAN for IT maintenance, and reports accurate cost and energy savings” (Newman 2010).</p> <p>http://www-03.ibm.com/software/products/en/tivoendpmanaforpowemana</p>

Software Package:	Description
Cisco Energy Management	<p>“Cisco Energy Management helps customers reduce energy costs and carbon emissions by automatically monitoring, analyzing and controlling the energy consumed by all devices connected to their networks—without agents, hardware meters, or changes to their network or security. Cisco Energy Management provides organizations unprecedented visibility and control over the consumption and utilization of energy throughout their distributed office environments, data centers, and facilities management systems” (Energy Star n.d).</p> <p>http://www.cisco.com/c/en/us/products/switches/energy-management-technology/index.html</p>
EiPower Saver Solution <i>Enterprise Infrastructure Partners LLC</i>	<p>“EiPower Saver Solution is an enterprise desktop power management application that monitors the power events of PCs. Administrators can view power events, set, enforce, and fine tune Windows power settings from a central location to save power, and not interfere with PC software administration” (Energy Star n.d.).</p> <p>http://www.entisp.com/products/eipower-enterprise/</p>
Energy Saver <i>AVOB</i>	<p>“AVOB Energy Saver is the only solution on the market able to reduce PCs' (laptops & desktops) and Cisco network devices' (routers, switches, IP phones, wireless access points) energy consumption by 50% to 85%” (Energy Star n.d).</p> <p>http://avob.com/</p>
KACE <i>Dell</i>	<p>“Dell KACE Appliances allows system managers to create and enforce power management policies across both local and remote environments, and provides visibility into compliance and savings information with customizable reports” (Energy Star n.d.).</p> <p>https://www.quest.com/kace/</p>
KAR Energy Software	<p>“KAR Energy Software is the leading solution in the market which drastically reduces the power consumption (-48%) of your computer, laptop, by reducing the consumption of RAM, the CPU cooling requirements, the frequency of the processor, and by placing the computer into standby mode. Thus, through KAR Energy Software, you save money when you use your computer” (Energy Star n.d.).</p> <p>http://www.ia-kar.com/en/software-energy-saver.php</p>

Software Package:	Description
LANDesk Management Suite <i>Avocent</i>	<p>“LANDesk Management Suite’s features include comprehensive reporting, custom wattage settings, flexible power policy management, and chronological variability” (Newman 2010, 11). http://www.landesk.com/</p>
LANRev Power Management	<p>“LANrev's Power Management allows creation and enforcement of power saving policies and reporting” (Newman 2010, 11). https://heatsoftware.com/software-solutions/unified-endpoint-management/lanrev/power-management/</p>
NightWatchman Enterprise <i>IE</i>	<p>“NightWatchman Enterprise is licensed on 10 million PCs around the world, saving on average \$26 per PC per year. Since inception, it has cumulatively saved customers \$1.3B in energy savings, which is the equivalent of 12.7 million tons of CO2 emissions. NightWatchman allows you to reliably apply the right power policies to your clients, safely shutting them down aggressively or passively as appropriate, and waking them whenever needed” (Energy Star n.d.). https://www.ie.com/products/nightwatchman-pc-power-management/</p>
Power Management <i>SyAM Software</i>	<p>“SyAM Software is power management solution used by private and public institutions to reduce energy costs on their desktops, servers and notebooks. Users can schedule policies to wake up and turn off computers on a schedule. These intelligent policies also provide the ability to delay shutdowns when users still need to keep working, or when updates and patches need to be deployed” (Energy Star n.d). http://www.syamssoftware.com/solutions-power-management.html</p>
Power Manager <i>Verismic</i>	<p>“Power Manager manages servers, desktops, and notebooks to reduce energy waste and save up to \$60 per computer per year. Implemented worldwide, Verismic Power Manager is highly scalable, multi-currency, and multi-lingual; making it the perfect solution for Green IT cost savings” (Energy Star n.d.). https://www.verismic.com/power-manager</p>

Software Package:	Description
Power Save Enterprise <i>Faronics</i>	<p>“Power Save Enterprise delivers desktop computer energy management that doesn’t interfere with user or IT needs. Faronics Power Save keeps computers running when users need them, accurately determines when computers are inactive so they can be powered down, and can prove its rapid return-on-investment through power consumption and savings reports” (Energy Star n.d.).</p> <p>http://www.faronics.com/products/power-save/enterprise/</p>
PwrSmart <i>New Boundary Technologies</i>	<p>“PwrSmart is a simple PC power management solution that maximizes your energy efficiency by automatically powering down inactive PCs. Utilizing patented technology, PwrSmart creates a self-monitoring, self-maintaining PC power environment that enables you to reduce PC related energy costs by as much as 60%” (Energy Star n.d.).</p> <p>https://www.newboundary.com/products/pwrsmart</p>
SmartShield Suite <i>Centurion Technologies</i>	<p>“SmartShield Suite gives network administrators the power to quickly and efficiently manage all aspects of their workstations' energy usage” (Energy Star n.d.).</p> <p>http://centuriontech.com/</p>
SysTrack Power Management <i>Lakeside Software Inc.</i>	<p>“SysTrack Power Management actively manages system power states through dynamic power schedule discovery based on actual use and without requiring Wake-on-LAN technology. SysTrack Power Management helps organizations reclaim budget wasted on energy bills and reduce their carbon footprint, with savings beginning in as little as three days” (Energy Star n.d.).</p> <p>http://lakesidesoftware.com/</p>
Verdiem Surveyor <i>Aptean</i>	<p>“Surveyor allows the central administration of power management settings for networked PCs. Intelligent policies maximize energy savings by placing machines into a lower power states without interfering with end-user productivity, desktop maintenance or upgrades. With over 700 customers and 2 million devices, Verdiem Surveyor is enterprise-proven, delivering hard ROI in as little as 3 months. Verdiem Surveyor is the only independently verified and validated solution making it easy to qualify for utility rebates” (Energy Star n.d.).</p> <p>http://www.aptean.com/products/verdiem/surveyor</p>

Software Package:	Description
Wave PowerSteward	<p>“Wave PowerSteward is a smart power management tool that applies power settings based on an organization's unique behavior and usage patterns. Wave PowerSteward runs as a background service to quietly measure each computer's electrical usage and aggregate this data into analytical dashboards, proving significant cost avoidance and energy conservation. Wave’s tool allows for all IT maintenance windows” (Energy Star n.d.).</p> <p>http://wavepowersteward.com/</p>

B. Interview Questions

In this section, the interview questions asked throughout the course of this IQP study are presented. These interviews were conducted with Jim McDonald, Steve Tanpoco, and Galen Lipin.

1. Does the WPI Office of Information Technology maintain an inventory of desktop computers on campus? If so, may this IQP study have access to said inventory?
2. Does the WPI Office of Information Technology maintain information regarding the power draw or energy consumption of desktop computers on campus? If so, may this IQP study have access to said information?
3. Does the WPI Office of Information Technology maintain records of computer purchases? If so, may this IQP study have access to these records?
4. Does the WPI Office of Information Technology maintain a list of the owners/managers of each computer lab on campus? If so, may this IQP study have access to this list?
5. Does the WPI Office of Information Technology have the means to compile the system logs from a large sample of desktop computers on campus? If so, would the WPI Office of Information Technology be willing to provide this information to this IQP study?
6. Does the WPI Office of Information Technology have the means to compile the security logs from a large sample of desktop computers on campus? If so, would the WPI Office of Information Technology be willing to provide this information to this IQP study?
7. What approaches (if any) has WPI implemented in the past to reduce the energy wasted by desktop computers on campus?
8. What criteria should an energy waste reduction method take into account? What foreseeable challenges are there with implementing an energy waste reduction method at WPI?
9. Who stands to benefit from the implementation of an energy waste reduction method at WPI?
10. Who has the jurisdiction to approve a method to reduce the energy waste of desktop computers at WPI?
11. Which division within the WPI Office of Information Technology is responsible for maintaining the desktop computer hardware at WPI?
12. Which Office at WPI would be responsible for deciding to implement an energy waste reduction method at WPI?
13. If a commercial power management software solution were selected as the recommended energy waste reduction method, which Office at WPI would fund this purchase?
14. If an energy waste reduction method were implemented which division within the WPI Office of Information Technology would oversee its regulation and maintenance?
15. What technological systems would an energy waste reduction method have to interface with, and what divisions within the WPI Office of Information Technology is responsible for these systems?
16. Does WPI currently have any methods in place to reduce the energy wasted by desktop computers on campus?
17. Does WPI have any plans in place to implement an energy waste reduction method at WPI?
18. How significant would the energy savings need to be in order for WPI to consider implementing an energy waste reduction method?
19. May this IQP study be granted access to the security logs on a sample of desktop computers on campus?
20. Is there anything that we haven't asked that you feel we should know for the sake of this IQP study?

C. External Communications

In this section the communications with WPI faculty and staff throughout the duration of this IQP study are outlined. These Communications were primarily email, informal interviews, or formal interviews.

C.1. Elizabeth Tomaszewski

Elizabeth Tomaszewski is the Associate Director of Sustainability for the WPI Office of Sustainability as well as the Systems Manager for the WPI Office of Facilities.

First Contact

Mon 2/20/17, 10:23 AM

Hello Elizabeth,

I am a member of one of the Sustaining WPI IQP groups for this upcoming D term. Our project will be exploring the energy inefficiencies of computers on campus. We would like to get in touch with someone from Information Technology or Network Operations, such that we can determine what policies/procedures WPI currently has in place. Our adviser, Suzanne LePage, said that you may have information on this topic, or know someone who does. Any help you could give us would be greatly appreciated. Thanks so much, and have a great day!

Best,

Jeff Martin

Mon 2/20/17, 11:27 AM

Hi Jeff,

Happy to help. The best person to contact in IT is Deborah Scott; she is the CIO. I know that Deborah has a keen interest in energy efficiencies, as she is a member of the Sustainability Advisory Committee. If she doesn't have the answers you need, I'm sure that she will direct you to someone who does. If you need any additional help, please let me know.

Liz Tomaszewski

Second Contact

Thu 3/23/17, 10:43 AM

Hello Liz,

I am a member of an IQP team for the Sustaining WPI project center. In February we exchanged emails regarding our project of reducing the energy wasted by desktop computers at WPI and you pointed us in the direction of Deborah Scott in the IT department. This was very helpful to our project. Currently we are looking to explore the energy distribution system at WPI such that we may add context to our project. In particular we are interested in how much energy WPI consumes on a yearly basis, how is this energy supplied, and who pays for this energy. Because of your role as Facilities System Manager, we were hoping you could help us answer these questions, or perhaps direct us to someone who would be able to help answer the questions. Thank you for your time, and we greatly appreciate any information you are able to provide.

Sincerely,

Jeff Martin

Thu 3/23/17, 1:42 PM

Happy to help.

The department of facilities pays all WPI utility bills, including, of course, electric bills. We have spreadsheets of electric bills for the past few years. Some buildings, such as the ones which are around the quad, are all on one meter, and there are others that are on separate meters. We can share those spreadsheets with you.

Liz Tomaszewski

C.2. Deborah Scott

Deborah Scott is the Chief Information Officer for the WPI Office of Information Technology.

Thu 3/16/17, 4:43 PM

Hello Ms. Scott,

I am a member of an IQP team for the Sustaining WPI project center. Our project is exploring the energy consumption of desktop computers within WPI's academic buildings. The project goals are to develop a catalog of the desktop computers and their energy consumption, as well as recommend a method to reduce the energy wasted by these computers. My partner, Thomas Roberti, and I would like to speak with you to gain a greater understanding of WPI's current policies and procedures related to the energy consumption of desktop computers. Would you be willing to meet with us to discuss this topic in greater detail? Sometime early next week would be ideal for our group, but we will work around your availability. Please let us know if you would be willing to meet, and if you would like further information regarding our project and the information we need to know.

Thank you for your time,
Jeff Martin

Tue 3/21/17, 11:27 AM

Hello Jeff,

Thanks for contacting me about your Sustaining WPI IQP. I have forwarded your message around to the relevant people in IT, and have identified the following people who have responsibilities for the desktop environment can work with you.

- Steve Tanpoco, Manager System Operations, ad interim
- Galin Lipin, Application Engineer
- Jim McDonald, IT Services Desktop Support (Jim is a WPI Alum)

You may contact them directly to setup a time to discuss your project, and/or ask the IT Office Coordinator, Lisa Atwell to assist with scheduling.

All the best,
Deborah

C.3. Jim McDonald

Jim McDonald is a desktop support technician for the WPI Office of Information Technology.

Interview

An Informal Interview with Jim McDonald on March twenty third 2017 at 2:00 PM in Fuller Labs Room A16. The interview was conducted by Jeff Martin and Tom Roberti and lasted approximately 45 minutes.

Jeff Martin and Tom Roberti met informally with Jim McDonald, a desktop support technician for the WPI Office of Information Technology. Jeff and Tom were referred to Jim in an email communication with Deborah Scott, the Chief Information Officer for the WPI Office of Information Technology. The information collected in this interview helped develop the inventory of desktop computers within WPI's academic buildings, as well as contributed to the understanding of the WPI information technology organization and infrastructure.

The first portion of the interview focused on the IT department's inventory of desktop computers. Mr. MacDonald presented Jeff and Tom with some pre-prepared information regarding the energy consumption of the most popular desktop computers and monitors on campus (see *Figure 28*). He retrieved all figures for Apple products from the data sheets provided by Apple; all other figures were manually acquired with a multimeter. The inventory that had been collected by Jeff and Tom was shown Mr. McDonald. He offered to compile an inventory of desktop computers within the general purpose labs within WPI's academic buildings, and stated that he would provide Jeff and Tom with this information through email within the next few days; however, he stated that the list compiled by Jeff and Tom was likely more accurate and up-to-date.

Following the discussion of the department's inventory of desktop computers, the conversation shifted towards the policies that WPI's IT department uses to reduce the energy consumption of desktop computers. Mr. MacDonald noted that the department does not implement an overarching policy to induce low power modes with PCs. He stated that at the start of the 2016-2017 academic year, a sleep schedule policy was implemented on some, but not all, of the desktop computers at WPI. Additionally, he noted that during the summer of 2017 a desktop computer management policy would be implemented at WPI. Mr. MacDonald was not able to provide further details regarding this change.

Mr. MacDonald indicated that the department would be receptive to recommendations of new energy saving policies. He thought the best method would be to enforce various sleep/shutdown policies that are tailored towards groups of desktop computers at WPI. He advocated that by grouping desktop computers the various needs of all desktop computer users could be met, while still reducing the amount of energy consumed at WPI. He warned that if the policy were to interfere with the needs of users, faculty in particular, there would be a large amount of backlash. He stated that in order to be implemented, an energy waste reduction method would need to be easy to deploy and maintain, while still having significant monetary benefits for WPI. Mr. McDonald believed this because the WPI Office of Information Technology is primarily limited by its size of its staff. When asked who, within WPI, would likely make the decision to implement an energy

waste reduction method, Mr. McDonald stated that it would likely be either Steve Tanpoco, the Manager of System Operations for the WPI Office of Information Technology, or someone within the WPI Office of Facilities.

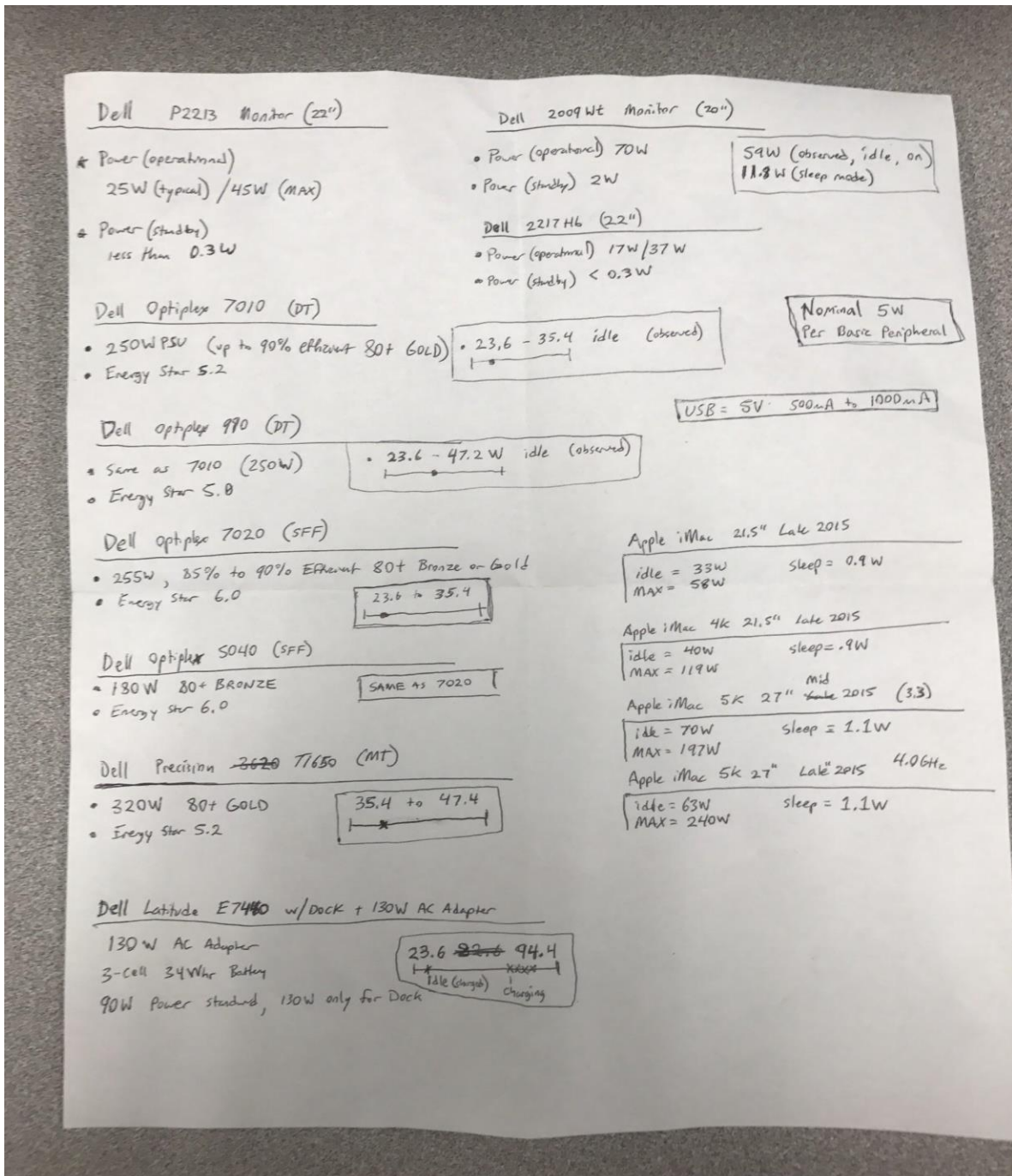


Figure 28. Jim MacDonald's power draw data on several common desktop computer models.

Additionally, the electrical infrastructure at WPI was discussed. Mr. McDonald noted that the Facilities Department maintains the meters, and that they likely pay for the electricity. He also stated that he believed WPI has an independent power feed; however, he reiterated that we would need to speak with the Office of Facilities to obtain more concrete information regarding WPI's electrical infrastructure.

Overall, the interview was very informative. The information Mr. MacDonald provided regarding power draw data was compared to our own findings, and the compiled list he sent us following the interview was used to verify the inventory that was manually developed throughout the course of this IQP study. Further, He provided information regarding past and present energy waste reduction methods at WPI as well as information regarding what criteria are important for an energy waste reduction method. Finally, he referred Tom and Jeff to a number of persons and departments within WPI that were relevant to this project.

Follow Up

Thu 3/23/17, 9:51 AM

Hi Jim,

Thomas and I would like to thank you for meeting with us the other day. This discussion, as well as the figures that you prepared will be invaluable to our project. Additionally, we wanted to request your permission to include within our report the information that you provided as well as cite you as the source of this information. Once again, thank you for your help!

Sincerely,

Jeff Martin

Thu 3/23/17

Hi Jeff,

I'm fine with all of that!

Here's a list of most of the machines we manage. This information will be accurate until this summer, when some of the labs will be updated on their 3-year rotation. I left off labs run by a single professor, though some of these still have card access: (See *Table 15*). Let me know if you need anything else!

-Jim

Table 15. Inventory of Desktop computers Provided by IT

Room	Number of Computers	Model
GL003	9	OptiPlex 7010
GL114	17	OptiPlex 7020
GL117	15	OptiPlex 7020
GL2	47	OptiPlex 7010
GL3	6	OptiPlex 7010
GLMM	20	OptiPlex 7010
GH012	31	OptiPlex 7010
OH114	13	OptiPlex 7020
OH117	17	OptiPlex 7010
OH208	15	OptiPlex 7010
OH211	16	OptiPlex 7010
HL031	20	OptiPlex 5040
HL230	41	7010 MT
SL123	28	OptiPlex 7010
KH203	26	OptiPlex 5040
KH202	29	OptiPlex 7010
KH207	22	T3620 MT
SH003	26	OptiPlex 7010
FL222	32	Alienware X51 R2
FLA21	28	Alienware X51 R2
AK113	19	OptiPlex 5040
AK227	26	OptiPlex 7020
AK317	19	OptiPlex 5040
AK120	16	OptiPlex 7020
AK013	12	OptiPlex 9020
WB228	25	OptiPlex 7020
AHB30	26	21.5" iMac
SL412	12	OptiPlex 5040
WB107	32	OptiPlex 5040
WB107	8	OptiPlex 9020
FL222/A21 (VR)	5	T5810 M

List of desktop computers within WPI's general purpose laboratories. This list was provided by Jim McDonald in an email.

C.4. Steve Tanpoco and Galen Lipin

Steve Tanpoco is Manager of System Operations for the WPI Office of Information Technology. Galen Lipin is an Application Engineer for the WPI Office of Information Technology.

Interview

An interview with Steve Tanpoco and Galen Lipin on March twenty seventh 2017 at 3:00 PM in Fuller Labs Room 212. The interview was conducted by Jeff Martin and Tom Roberti and lasted approximately 45 minutes.

Jeff Martin and Tom Roberti met with Steve Tanpoco, the Manager of System Operations for the WPI Office of Information Technology and with Galen Lipin, an Applications Engineer for the WPI Office of Information Technology. Jeff and Tom were referred to Steve and Galen in an email communication with Deborah Scott, the Chief Information Officer for the WPI Office of Information Technology. The information collected in this interview served four purposes: (1) it helped develop the stakeholder analysis, (2) it provided an understanding of the energy consumed by desktop computers within WPI's academic buildings, (3) it provided information regarding past, present, and future energy waste reduction methods at WPI, and (4) it contributed to the understanding of the information technology infrastructure and organization at WPI.

The beginning of the interview focused on the structure of the IT Department and information pertaining to the stakeholder analysis. Mr. Tanpoco and Mr. Lipin indicated that the hardware maintenance operators for an energy waste reduction method would be the desktop support technicians. Further they stated that the Hosting and Infrastructure division within the WPI office of Information Technology would be responsible for maintaining and regulating the software aspects of an energy waste reduction method. They informed Jeff and Tom that the energy waste reduction system would have to interface with the Microsoft Enterprise Management Software, which was overseen by the Hosting and Infrastructure division. Additionally, Mr. Tanpoco was able to provide a little insight as to which person/division within IT has the jurisdiction to implement a new product or policy for the computer systems. According to Steve, this would depend on the nature of the recommendation. If a third party software was proposed, it might be relatively easily implemented, but a campus-wide application of this software would affect many people/departments and therefore would require the approval of an IT governance committee. Mr. Tanpoco indicated that a windows power settings solution would most likely not require the approval of a committee and could receive the stamp of approval within the IT department itself.

Next, the focus of the interview shifted towards energy policies within the IT department. Both Mr. Tanpoco and Mr. Lipin stated that they have only been at WPI for a few years and they could not testify as to the history of WPI's energy saving policies in regards to the computers. However, Mr. Lipin mentioned was the IT department's policy of a 3-year rotation of computer systems on campus. Every three years, the university purchases new desktop computers. Mr. Lipin indicated that while the primary motivation behind this policy is not to improve energy efficiency, there is likely a strong correlation between newer computers and energy efficiency. Additionally, when asked why idle desktop computers are not currently put to sleep, neither had an answer, and both were surprised that this was not already in place. Mr. Lipin indicated that

it would be easy to implement this campus wide, by issuing a command to all desktop computers to update their default Windows power options.

Following the discussion of policies, Jeff and Tom briefly discussed their intentions to recommend a solution to WPI. Mr. Tanpoco and Mr. Lipin then gave insight on potential challenges to consider. First, they reiterated their apprehensions about a third party software. They mentioned that a low resource solution like windows default power settings would most likely not see many obstacles and that this type of solution could likely be implemented quite quickly. They stated that the main challenge would be waking up the computers at night in order to roll out a software update.

Next, Jeff and Tom asked what it would take to get a policy implemented. Mr. Tanpoco stated that it was difficult to give a good estimate as there was no set dollar amount that is required to get a new policy passed. He restated that a lot of this has to do with ease of implementation. Mr. Tanpoco elaborated further by saying that the IT Department's most limited resource is human resource. For instance, if a recommendation entailed having a technician install hardware in each lab, this would mean the expenditure of significantly more human resource than a digital application that could be done remotely during the night.

Towards the end of the interview, Jeff and Tom provided both Mr. Tanpoco and Mr. Lipin with some of the IQP study's preliminary results. Additionally, Jeff and Tom discussed one difficulty they had encountered in the project, particularly that their ticket with Network Operations regarding access to the security logs has yet to yield any response. Mr. Tanpoco offered to develop a small sample of security log files that Jeff and Tom could analyze for the sake of the project. Finally, Jeff and Tom explained the appendix of restricted access computers labs and asked Mr. Tanpoco and Mr. Lipin to cross reference this list with theirs to ensure that these labs were in fact computer labs. Mr. Lipin assured Jeff and Tom that he could do this over the next few weeks.

Overall, the interview provided valuable information to further this IQP study. One of the most important things learned was their advice on a potential recommendation. This was strongly considered when analyzing potential energy waste reduction methods at WPI. Not only was the lack of existing desktop computer energy saving policies learned, but also an understanding of the structure of the WPI Office of Information Technology was gained. This information was essential to the development of this IQP study's stakeholder analysis.

Follow Up

Mon 4/3/17, 10:33 AM

Hello Galen and Steve,

We spoke last Monday about my IQP study, which is examining the energy waste of desktop computers at WPI. A portion of our project requires a sample of Windows Security Logs from various computers. As discussed on Monday, Administrative privileges are needed to access these files, and this is something neither my partner nor I has. Towards the end of our discussion, you offered to pull together a sample of security logs from the computers on campus. Does this offer still stand? If so, what will be the approximate sample size / timeline? I only ask because our IQP is time sensitive and we would need this information before April 14th in order to make use of it. Please let us know if this is something you are still able to do, and if you have any questions don't hesitate to ask.

Sincerely,
Jeff Martin

Mon 4/3/17, 11:14 AM

Hi Jeff.

Apologies as we were getting guidance and also out of the office on Friday. Initial feedback is negative on providing access logs. I don't know if they are provided at the "status" level (logged in versus not logged in, asleep, awake) without user names. Galen, is it possible to do that?

Thanks,
Steve

Mon 4/3/17 11:23 AM

Hi Jeff,

Our Information Security team gave a no on parsing/providing additional access to logs. In doing further research on "wake-on LAN," that strategy has come up cyclically over the last 10 years, and from my current understanding our network architecture does not allow wake-up packets to traverse our network hardware. In essence we can send wake-up packets all we want, but we can't actually get them to a hibernating computer in a meaningful way. I would like to investigate this further when time allows. RE: citations, feel free to quote away! I hope our input reflected our desire to use energy in a responsible manner, and desire to find a pragmatic approach to doing things more efficiently. We'll try to get the lab vs broom closet information to you later this week.

Thanks and best,
-Galen

Tue 4/4/17, 8:45 AM

Hello,

Thanks for trying to gain access to the security logs, and for investigating the wake-on-LAN technology. We greatly appreciate all that you have contributed to this project. We look forward to hearing from you with regards to the appendix of computer labs.

Best,
Jeff Martin

D. Inventory of Desktop Computers

In this section the complete inventory of Desktop Computers within the public computer labs in WPI's Academic buildings is presented. Yellow rows indicate computers that were inventoried by the WPI Office of Information Technology, but were not manually verified in this IQP study. Red rows indicate computers that do not use the Windows Operating System, and were thus excluded from this IQP Study.

Manufacturer	Model Number	Building	Room	Number of Computers
Apple	iMac (21.5")	AH	B30	26
Dell	OptiPlex 9020	AK	013	12
Dell	OptiPlex 990	AK	111	1
Dell	OptiPlex 7010	AK	111	4
Dell	OptiPlex 5040	AK	113	18
Dell	OptiPlex 7020	AK	120	14
Dell	OptiPlex 980	AK	120	1
Dell	OptiPlex 7010	AK	210	12
Dell	OptiPlex 7020	AK	227	26
Dell	OptiPlex 5040	AK	317	19
Alienware	X51 R2	FL	A21	23
Dell	Precision Tower	FL	A21	1
Dell	OptiPlex 7010	FL	A22	8
Dell	Precision Tower	FL	222	4
Alienware	X51 R2	FL	222	32
Dell	OptiPlex 980	FL	223	2
Dell	OptiPlex 7010	GH	007	12
Dell	OptiPlex 7010	GH	012	30
Dell	OptiPlex 7010	GL	GF	8
Dell	OptiPlex 7020	GL	114	17
Dell	OptiPlex 7020	GL	117	15
Dell	OptiPlex 7040	GL	Tech Suits 111, 111A,112,112A,120, 121,206A,206B,212,217,316	11
Dell	OptiPlex 7010	GL	Multimedia Lab	23
Dell	OptiPlex 990	GL	Print Center	5
Dell	OptiPlex 7010	GL	F2	35
Dell	OptiPlex 990	GL	F2 Help Desk	2
Dell	OptiPlex 990	GL	F2 Scanner Station	1
Dell	OptiPlex 7010	GL	F3	18

Dell	OptiPlex 5040	HL	031	20
Dell	OptiPlex 7010	HL	230	40
HP	Z640	HL	234	9
Dell	Precision T7600	HL	234	12
Dell	OptiPlex 7010	KH	202	28
Dell	OptiPlex 5040	KH	203	25
Dell	Precision T3620	KH	207	22
Dell	OptiPlex 7020	OH	114	13
Dell	OptiPlex 7010	OH	117	17
Dell	OptiPlex 7010	OH	208	15
Dell	OptiPlex 7010	OH	211	15
Dell	OptiPlex 7010	SH	003	26
Dell	OptiPlex 980	SH	014	1
Dell	OptiPlex 7010	SL	123	27
Dell	OptiPlex 5040	SL	412	12
Dell	OptiPlex 5040	WB	107	31
Dell	OptiPlex 990	WB	107	3
Dell	OptiPlex 7010	WB	107	1
Dell	OptiPlex 7020	WB	228	25
Total				722

E. Special Access Computer Laboratories

In this section, special access laboratories are listed. Although these laboratories contain computers, they were not included in this IQP study because they are not open to the public.

Atwater Kent Laboratories (AK)

AK 013	Data Science Innovation Laboratory
AK 123	Data Science Ph.D. Laboratory
AK 208B	Sensory and Physiology Signal Processing Lab
AK 209	Embedded Computing Laboratory
AK 211A	Ultrasound Research Laboratory & Secure Cyber-Physical Systems Laboratory
AK 212A	Applied Crypto and Secure Embedded Systems Laboratory
AK 212C	MITRE-WPI Collaboratory
AK 221	Ultrasonic Research Laboratory
AK 314	Signal Processing & Information Networking Laboratory
AK 315	Convergent Technology Laboratory
AK 317B	New England Center for Analog & Mixed Signal IC Design
AK 318A	Wireless Innovation Laboratory
AK 320	Center For Wireless Information Network Systems
AK 320C	Wireless Antenna Laboratory

Fuller Laboratories (FL)

FL A17	IMGD Digital Production Studio
FL A20	IMGD Audio Recording Room
FL A23	Bioinformatics and Computational Biology
FL A24	Computer Science Machine Room
FL A25	Graduate Student Space
FL B16	Interactions Laboratory
FL B17	Systems and Security Laboratory
FL 312	AI and Intelligent Tutoring Laboratory
FL 314	ASSISTments

FL 316	DSRG II
FL 317	Supported Graduate Student Lounge
FL 318	Bioinformatics, Big Data Management and Mining Laboratory Center
FL 319	Database Systems Research Laboratory
FL 322	IMGD Laboratory

Goddard Hall (GH)

GH 006	No Description
GH 112A	Equipment Room
GH 116	No Description
GH 205	Teaching Laboratory
GH 206	Teaching Laboratory
GH 207	Biomedical Engineering Laboratory
GH 221	No Description
GH 222	No Description
GH 308	Equipment Room

Higgins Laboratories (HL)

HL 017	Course Project Laboratory
HL 019	Course Project Laboratory
HL 026	Nano Energy Laboratory
HL 027	Optomechanics Laboratory
HL 028	Structures and Materials Laboratory
HL 047	Scanning Electron Microscopy Laboratory
HL 124	Small Systems Laboratory
HL 127	Soft Robotics Laboratory
HL 248	Multi Scale Heat Transfer Laboratory
HL 312	Laboratory for Control of Systems and Robots
HL 314	No Description

Kaven Hall (KH)

KH 010	Environmental Infrastructure Laboratory
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KH 210A ABET

Olin Hall (OH)

OH 004 Order Disorder Phenomena Laboratory
OH 009 Atomic Force and Microscopy Laboratory
OH 10L No Description
OH 10R No Description
OH 014 Radiation Laboratory
OH 015 No Description
OH 017 Popovic Laboratory
OH 025 PH 2651 Laboratory
OH 026 Nuclear Physics Laboratory
OH 028 No Description
OH 204 Center for Computational Nanoscience
OH 205 Photonics Laboratory

Salisbury Laboratories (SL)

SL 133 Educational Psychology and Mathematics Learning Laboratory
SL 219 No Description
SL 412 Math Department Sloan Lab

Washburn Shops (WB)

WB 212 UDXM Laboratory
WB 216B UDXM Research Laboratory

F. Power Draw Data

In this section, a table of power draw data collected throughout this IQP study is presented.

Manufacturer		Model Number	Number of Computers	Computer Service Tag			Average
Dell		OptiPlex 980	4	Computer Service Tag			Average
State	Description	Data Type		HPYDLM1	433DPM1	HDKLLM1	Average
1	Awake & Logged In	Energy used in 10 min (Wh)		12.90	12.90	14.60	13.47
		Power (W)		77.40	77.40	87.60	80.80
2	Awake & Logged Out	Energy used in 10 min (Wh)		5.30	5.30	6.20	5.60
		Power (W)		31.80	31.80	37.20	33.60
3	Asleep & Logged In	Energy used in 10 min (Wh)		N/A	N/A	0.20	0.20
		Power (W)		N/A	N/A	1.20	1.20
4	Asleep & Logged Out	Energy used in 10 min (Wh)		0.40	0.40	0.20	0.33
		Power (W)		2.40	2.40	1.20	2.00
5	Shutdown	Energy used in 10 min (Wh)		0.30	0.30	0.10	0.23
		Power (W)		1.80	1.80	0.60	1.40
Manufacturer		Model Number	Number of Computers	Computer Service Tag			Average
Dell		OptiPlex 990	12	Computer Service Tag			Average
State	Description	Data Type		9XM9HQ1	FF5F4V1	1P3DQG1	Average
1	Awake & Logged In	Energy used in 10 min (Wh)		14.70	17.90	17.90	16.83
		Power (W)		88.20	107.40	107.40	101.00
2	Awake & Logged Out	Energy used in 10 min (Wh)		5.50	9.85	9.85	8.40
		Power (W)		33.00	59.10	59.10	50.40
3	Asleep & Logged In	Energy used in 10 min (Wh)		0.20	0.30	0.30	0.27
		Power (W)		1.20	1.80	1.80	1.60
4	Asleep & Logged Out	Energy used in 10 min (Wh)		0.50	0.35	0.35	0.40
		Power (W)		3.00	2.10	2.10	2.40
5	Shutdown	Energy used in 10 min (Wh)		0.00	0.05	0.05	0.03
		Power (W)		0.00	0.30	0.30	0.20
Manufacturer		Model Number	Number of Computers	Computer Service Tag			Average
Dell		OptiPlex 5040	125	Computer Service Tag			Average
State	Description	Data Type		6N5WPD2	6N4ZPD2	6N3ZPD2	Average
1	Awake & Logged In	Energy used in 10 min (Wh)		13.83	13.83	13.83	13.83
		Power (W)		82.98	82.98	82.98	82.98
2	Awake & Logged Out	Energy used in 10 min (Wh)		5.66	5.66	5.66	5.66
		Power (W)		33.96	33.96	33.96	33.96
3	Asleep & Logged In	Energy used in 10 min (Wh)		0.23	0.23	0.23	0.23
		Power (W)		1.38	1.38	1.38	1.38
4	Asleep & Logged Out	Energy used in 10 min (Wh)		0.26	0.26	0.26	0.26
		Power (W)		1.56	1.56	1.56	1.56
5	Shutdown	Energy used in 10 min (Wh)		0.10	0.10	0.10	0.10
		Power (W)		0.60	0.60	0.60	0.60

Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Dell	OptiPlex 7010	319	3Z82BZ1	594QW12	58VQW12	Average
State	Description	Data Type	3Z82BZ1	594QW12	58VQW12	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	15.00	16.30	16.30	15.87
		Power (W)	90.00	97.80	97.80	95.20
2	Awake & Logged Out	Energy used in 10 min (Wh)	5.00	5.05	5.05	5.03
		Power (W)	30.00	30.30	30.30	30.20
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.50	0.35	0.35	0.40
		Power (W)	3.00	2.10	2.10	2.40
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.50	0.30	0.30	0.37
		Power (W)	3.00	1.80	1.80	2.20
5	Shutdown	Energy used in 10 min (Wh)	0.00	0.05	0.05	0.03
		Power (W)	0.00	0.30	0.30	0.20
Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Dell	OptiPlex 7020	110	76LVR52	76MVR52	76PWR52	Average
State	Description	Data Type	76LVR52	76MVR52	76PWR52	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	12.33	12.33	12.33	12.33
		Power (W)	73.98	73.98	73.98	73.98
2	Awake & Logged Out	Energy used in 10 min (Wh)	6.40	6.40	6.40	6.40
		Power (W)	38.40	38.40	38.40	38.40
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.20	0.20	0.20	0.20
		Power (W)	1.20	1.20	1.20	1.20
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.20	0.20	0.20	0.20
		Power (W)	1.20	1.20	1.20	1.20
5	Shutdown	Energy used in 10 min (Wh)	0.07	0.07	0.07	0.07
		Power (W)	0.42	0.42	0.42	0.42
Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Dell	OptiPlex 740	11	1NXNJB2	HYDCQD7	HYDCQD2	Average
State	Description	Data Type	1NXNJB2	HYDCQD7	HYDCQD2	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	6.90	6.60	6.50	6.67
		Power (W)	41.40	39.60	39.00	40.00
2	Awake & Logged Out	Energy used in 10 min (Wh)	2.80	3.40	3.30	3.17
		Power (W)	16.80	20.40	19.80	19.00
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.10	0.30	0.20	0.20
		Power (W)	0.60	1.80	1.20	1.20
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.10	0.20	0.40	0.23
		Power (W)	0.60	1.20	2.40	1.40
5	Shutdown	Energy used in 10 min (Wh)	0.00	0.10	0.10	0.07
		Power (W)	0.00	0.60	0.60	0.40

Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Dell	Precision T3620	22	1F58QD2	1F57QD2	GPD2L6V	Average
State	Description	Data Type	1F58QD2	1F57QD2	GPD2L6V	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	12.40	12.40	12.40	12.40
		Power (W)	74.40	74.40	74.40	74.40
2	Awake & Logged Out	Energy used in 10 min (Wh)	6.23	6.23	6.23	6.23
		Power (W)	37.38	37.38	37.38	37.38
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.33	0.33	0.33	0.33
		Power (W)	1.98	1.98	1.98	1.98
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.60	0.60	0.60	0.60
		Power (W)	3.60	3.60	3.60	3.60
5	Shutdown	Energy used in 10 min (Wh)	0.10	0.10	0.10	0.10
		Power (W)	0.60	0.60	0.60	0.60
Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Dell	Precision T5810	5	GWQXPD2			Average
State	Description	Data Type	GWQXPD2			Average
1	Awake & Logged In	Energy used in 10 min (Wh)	16.90			16.90
		Power (W)	101.40			101.40
2	Awake & Logged Out	Energy used in 10 min (Wh)	11.60			11.60
		Power (W)	69.60			69.60
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.60			0.60
		Power (W)	3.60			3.60
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.60			0.60
		Power (W)	3.60			3.60
5	Shutdown	Energy used in 10 min (Wh)	0.00			0.00
		Power (W)	0.00			0.00
Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Dell	Precision T7600	12	1HFCX12	1HF6X13	1HFDX14	Average
State	Description	Data Type	1HFCX12	1HF6X13	1HFDX14	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	36.20	36.20	36.20	36.20
		Power (W)	217.20	217.20	217.20	217.20
2	Awake & Logged Out	Energy used in 10 min (Wh)	16.03	16.03	16.03	16.03
		Power (W)	96.18	96.18	96.18	96.18
3	Asleep & Logged In	Energy used in 10 min (Wh)	1.00	1.00	1.00	1.00
		Power (W)	6.00	6.00	6.00	6.00
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.87	0.87	0.87	0.87
		Power (W)	5.22	5.22	5.22	5.22
5	Shutdown	Energy used in 10 min (Wh)	0.07	0.07	0.07	0.07
		Power (W)	0.42	0.42	0.42	0.42

Manufacturer	Model Number	Number of Computers	Computer Service Tag			
Alienware	X51 R2	55	74X2T52	74Z8T52	74X6T52	Average
State	Description	Data Type	74X2T52	74Z8T52	74X6T52	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	19.63	19.63	19.63	19.63
		Power (W)	117.78	117.78	117.78	117.78
2	Awake & Logged Out	Energy used in 10 min (Wh)	8.60	8.60	8.60	8.60
		Power (W)	51.60	51.60	51.60	51.60
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.47	0.47	0.47	0.47
		Power (W)	2.82	2.82	2.82	2.82
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.47	0.47	0.47	0.47
		Power (W)	2.82	2.82	2.82	2.82
5	Shutdown	Energy used in 10 min (Wh)	0.27	0.27	0.27	0.27
		Power (W)	1.62	1.62	1.62	1.62
Manufacturer	Model Number	Number of Computers	Computer Service Tag			
HP	Z640	9	2UA6272BJ3	2UA6272BJ5	2UA6272BJ4	Average
State	Description	Data Type	2UA6272BJ3	2UA6272BJ5	2UA6272BJ4	Average
1	Awake & Logged In	Energy used in 10 min (Wh)	26.63	26.63	26.63	26.63
		Power (W)	159.78	159.78	159.78	159.78
2	Awake & Logged Out	Energy used in 10 min (Wh)	15.00	15.00	15.00	15.00
		Power (W)	90.00	90.00	90.00	90.00
3	Asleep & Logged In	Energy used in 10 min (Wh)	0.67	0.67	0.67	0.67
		Power (W)	4.02	4.02	4.02	4.02
4	Asleep & Logged Out	Energy used in 10 min (Wh)	0.90	0.90	0.90	0.90
		Power (W)	5.40	5.40	5.40	5.40
5	Shutdown	Energy used in 10 min (Wh)	0.17	0.17	0.17	0.17
		Power (W)	1.02	1.02	1.02	1.02
Total Number of Computers		684				

G. State Transition Data

In this section, a table of state transition data collected throughout this IQP study is presented.

Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 980	4		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
HPYDLM1	0.70	52	0.13	10
433DPM1	1.10	66	0.27	20
HDKLLM1	1.00	64	0.20	23
Average	0.93	61	0.20	18
Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 990	12		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
9XM9HQ1	1.30	92	0.40	39
FF5F4V1	2.05	135	0.70	57
1P3DGQ1	2.05	135	0.80	57
Average	1.80	121	0.63	51
Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 5040	125		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
6N5WPD2	1.90	190	0.20	22
6N4ZPD2	1.60	162	0.20	21
6N3ZPD2	1.60	167	0.20	23
Average	1.70	173	0.20	22
Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 7010	319		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
3Z82BZ1	0.60	47	0.20	28
594QW12	1.60	175	0.10	14
58VQW12	1.00	107	0.30	21
Average	1.07	110	0.20	21

Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 7020	110		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
76LVR52	1.10	161	0.10	14
76MVR52	1.20	78	0.20	21
76PWR52	1.70	128	0.20	19
Average	1.33	122	0.17	18
Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 7040	11		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
1NXNJB2	0.70	141	0.20	44
HYDCQD7	1.20	210	0.20	55
HYDCQD2	0.60	101	0.10	42
Average	0.83	151	0.17	47
Manufacturer	Model Number	Number of Computers		
Dell	OptiPlex 990	12		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
9XM9HQ1	1.30	92	0.40	39
FF5F4V1	2.05	135	0.70	57
1P3DGQ1	2.05	135	0.80	57
Average	1.80	121	0.63	51
Manufacturer	Model Number	Number of Computers		
Dell	Precision T3620	22		
Computer Service Tag	Turn On (S5 to S2) Transition		Turn Off (S2 to S5) Transition	
	Energy (wH)	Time (s)	Energy (wH)	Time (s)
1F58QD2	1.33	82	0.50	50
1F57QD2	2.19	135	0.50	47
GPD2L6V	2.48	153	0.40	46
Average	2.00	123	0.47	48

H. System Log Data

In this Section, a sample system log, the C program used to analyze system logs, and the data collected from the system logs are presented.

H.1. Sample System Log

In this section, a sample system log file is presented. This system log was collected from an OptiPlex 7020 Desktop Computer in AK 227. It is one of many system logs that was analyzed throughout the course of this project. The others were excluded from this appendix for the sake of brevity.

```
AK227 7020 HP8WS52
Information 3/17/2017 1:22:36 PM      EventLog      6005  None
Information 3/17/2017 1:27:15 PM      Kernel-General 1      None
Information 3/17/2017 1:27:15 PM      Kernel-General 1      None
Information 3/17/2017 1:27:53 PM      EventLog      6006  None
Information 3/17/2017 1:29:18 PM      EventLog      6005  None
Information 3/17/2017 1:29:06 PM      Kernel-General 1      None
Information 3/17/2017 1:29:06 PM      Kernel-General 1      None
Information 3/17/2017 12:31:00 PM     Kernel-General 1      None
Information 3/17/2017 12:31:00 PM     Kernel-General 1      None
Information 3/19/2017 4:41:21 PM      EventLog      6006  None
Information 3/19/2017 4:42:32 PM      EventLog      6005  None
Information 3/19/2017 4:41:32 PM      Kernel-General 1      None
Information 3/20/2017 12:57:49 AM     EventLog      6006  None
Information 3/20/2017 12:59:18 AM     EventLog      6005  None
Information 3/20/2017 12:57:58 AM     Kernel-General 1      None
Information 3/20/2017 1:02:11 AM      EventLog      6006  None
Information 3/20/2017 1:03:06 AM      EventLog      6005  None
Information 3/20/2017 1:02:16 AM      Kernel-General 1      None
Information 3/22/2017 11:41:20 PM     EventLog      6006  None
Information 3/22/2017 11:42:46 PM     EventLog      6005  None
Information 3/22/2017 11:41:32 PM     Kernel-General 1      None
Information 3/26/2017 5:22:39 PM      Kernel-General 1      None
Information 3/27/2017 3:17:49 AM      EventLog      6006  None
Information 3/27/2017 3:17:58 AM      Kernel-General 1      None
Information 3/27/2017 3:41:35 PM      EventLog      6005  None
Information 3/27/2017 3:43:02 PM      EventLog      6006  None
Information 3/27/2017 5:07:57 PM      EventLog      6005  None
Information 3/30/2017 9:50:16 AM      EventLog      6006  None
Information 3/30/2017 9:50:26 AM      Kernel-General 1      None
Information 3/30/2017 9:52:30 AM      EventLog      6005  None
Information 4/3/2017 8:46:24 AM      EventLog      6006  None
Information 4/3/2017 8:46:35 AM      Kernel-General 1      None
Information 4/3/2017 9:55:36 AM      EventLog      6005  None
Information 4/6/2017 10:02:03 AM     Kernel-General 1      None
```

H.2. System Log Analysis Program

In this section, the C program used to analyze the system log files is presented.

```
//Author: Jeff Martin
//Date: April 10, 2017
//
//This program was written to analyze the system files that are supplied on
//Windows 7 computers. It opens a file containing a number of these system logs,
//and outputs the proportion of time that that computer spends awake, asleep
//and shut down.

#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#define LINE_BUFF_SIZE 1000
#define FIELD_BUFF_SIZE 200

int main(int argc, char* argv[]){
    //Open file containing the system log files
    FILE* file = fopen("system_log_files.txt", "r");

    //initialize buff and buff start
    char* line_buff = (char*) calloc(LINE_BUFF_SIZE, sizeof(char));

    //Keep track of the line number in the file
    int line_num = 0;

    //Variables used to store data for a computer entry
    int within_header = 0;
    char* header_location = (char*) calloc(FIELD_BUFF_SIZE, sizeof(char));
    char* header_model = (char*) calloc(FIELD_BUFF_SIZE, sizeof(char));
    char* header_tag = (char*) calloc(FIELD_BUFF_SIZE, sizeof(char));

    int first_event_time = 0;
    int last_event_time = 0;

    long time_sleep = 0;
    long last_sleep_time = 0;
    long last_sleep_event = 0;

    long time_shutdown = 0;
    long last_shutdown_time = 0;
    int last_shutdown_event = 0;

    //For every line in the file
    while(1){
        //Update the line number
        line_num++;

        //Load this line into the buffer
        fgets(line_buff, LINE_BUFF_SIZE, file);
        if(feof(file)) break; //Terminate at the end of the file

        //Declare two dimensional character array to store fields.
        // (max of 5 fields)
        char** field_buff = (char**) calloc(5, sizeof(char*));
        for(int i = 0; i < 5; i++){
            field_buff[i] = (char*) calloc(FIELD_BUFF_SIZE, sizeof(char));
```

```

}

//Store fields in field buffer, count the number of fields.
int tab_count = 0;
int field_index = 0;
for(int i = 0; i < LINE_BUFF_SIZE; i++){
    //Detect end of lines / tabs and handle appropriately
    char c = line_buff[i];
    if(c == 0 || c == '\n') break; //End of line
    if(c == '    '){
        tab_count++;
        field_index = 0;
        continue;
    }
    //Copy the character into the field buffer
    field_buff[tab_count][field_index] = c;
    field_index++;
}
//Determine the Type of Line
int header = 0;
int event = 0;
int new_line = 0;
if(tab_count == 2){ //Header
    header = 1;
}else if(tab_count == 4){ //Event
    event = 1;
}else if(tab_count == 0){ // New Line ... skip
    new_line = 1;
}else{ //Invalid line format
    printf("Error: Invalid line format at line %d.\n", line_num);
    continue;
}

// If new line, print the results from the previous computer & reset vars
if(new_line){
    if(within_header){
        //Print results for previous header
        long total_time = last_event_time - first_event_time;
        long time_awake = total_time - time_shutdown - time_sleep;
        double prop_shutdown = (double)time_shutdown / total_time;
        double prop_asleep = (double)time_sleep / total_time;
        double prop_awake = (double)time_awake / total_time;

        printf("%s %s %s\n", header_location, header_model, header_tag);
        printf(" [shutdown: %08lds - %03f%%]\n", time_shutdown, prop_shutdown * 100);
        printf(" [asleep:   %08lds - %03f%%]\n", time_sleep, prop_asleep * 100);
        printf(" [awake:    %08lds - %03f%%]\n", time_awake, prop_awake * 100);
        printf(" [total:    %08lds]\n", total_time);

        //Reset variables for computer entry
        within_header = 0;
        for(int i = 0; i < FIELD_BUFF_SIZE; i++){
            header_location[i] = 0;
            header_model[i] = 0;
            header_tag[i] = 0;
        }
        time_awake = 0;
        time_sleep = 0;
        time_shutdown = 0;
        last_event_time = 0;
        first_event_time = 0;
        continue;
    }
}

```

```

    }else{
        printf("Error: Unneeded new line at line %d.\n", line_num);
        continue;
    }
}

// Handle if this line is a header
if(header){
    if(within_header){
        printf("Error: Missing new line at line %d.\n", line_num);
        continue;
    }else{
        //prepare variables for computer entry
        within_header = 1;
        for (int i = 0; i < FIELD_BUFF_SIZE; i++){
            header_location[i] = field_buff[0][i];
            header_model[i] = field_buff[1][i];
            header_tag[i] = field_buff[2][i];
        }
    }
}

// Handle if this line is an event
if(event){
    if(within_header){
        //Determine if the event is the proper type
        if(!strcmp("Information", field_buff[0])){
            //Determine the time of the event.

            //allocate array to hold month, day, year,
            //hour, minute, second, PM
            int time[7];
            for(int i = 0; i < 7; i++){
                time[i] = 0;
            }

            //Store Values in time array
            int time_count = 0;
            for(int i = 0; i < FIELD_BUFF_SIZE && time_count < 7; i++){
                char c = field_buff[1][i];
                if(c == '/' || c == ':' || c == ' ' || c == 0){
                    time_count++;
                    continue;
                }
                if(time_count == 6){
                    if(c == 'P') time[6] = 1;
                    break;
                }
                char character_buff[2];
                character_buff[0] = c;
                character_buff[1] = 0;

                time[time_count] *= 10;
                time[time_count] += atoi(character_buff);
            }

            //Convert time to seconds since year 0.
            int month[12] = {0, 31, 59, 90, 120, 151, 181, 212, 243, 273, 304, 334};
            long time_sec = 0;
            time_sec += time[5]; // add seconds
            time_sec += time[4] * 60; // add minutes
            if(time[3] == 12) time[3] = 0; // convert 12 to 0

```


H.3. System Log Data

In this section, a table of data collected from the system logs is presented.

Location	Model	Computer Service Tag	Shut Down		Asleep		Awake		Total Time (s)
			Time (s)	Proportion	Time (s)	Proportion	Time (s)	Proportion	
AK 317	Dell OptiPlex 5040	CS82JB2	27439	0.15%	0	0.00%	18716380	99.85%	18743819
AK 317	Dell OptiPlex 5040	CS63JB2	1662392	8.58%	18	0.00%	17704522	91.42%	19366932
AK 317	Dell OptiPlex 5040	CS6BJB2	1517239	8.32%	17	0.00%	16723794	91.68%	18241050
AK 317	Dell OptiPlex 5040	CS84JB2	1669402	9.54%	0	0.00%	15823207	90.46%	17492609
AK 317	Dell OptiPlex 5040	CS69JB2	1879561	10.34%	0	0.00%	16299197	89.66%	18178758
AK 227	Dell OptiPlex 7020	HP8WS52	54393	3.17%	0	0.00%	1661574	96.83%	1715967
AK 227	Dell OptiPlex 7020	HP7WS52	474	0.03%	0	0.00%	1655214	99.97%	1655688
AK 227	Dell OptiPlex 7020	HP2XS52	164375	9.90%	0	0.00%	1496672	90.10%	1661047
AK 227	Dell OptiPlex 7020	HP5VS52	278	0.02%	0	0.00%	1209171	99.98%	1209449
AK 227	Dell OptiPlex 7020	J2NZS52	65629	4.77%	0	0.00%	1309873	95.23%	1375502
AK 113	Dell OptiPlex 5040	CS78JB2	2907095	15.30%	0	0.00%	16099081	84.70%	19006176
AK 113	Dell OptiPlex 5040	CS5CJB2	2236995	11.47%	102	0.00%	17269923	88.53%	19507020
AK 113	Dell OptiPlex 5040	CS6DJB2	1512548	7.88%	15	0.00%	17671547	92.12%	19184110
AK 113	Dell OptiPlex 5040	CS75JB2	1631624	8.32%	2429	0.01%	17979306	91.67%	19613359
AK 113	Dell OptiPlex 5040	CS62JB2	1020830	5.32%	17	0.00%	18179434	94.68%	19200281
FL A21	Alienware X51 R2	74Z0T52	10803	0.16%	0	0.00%	6574036	99.84%	6584839
FL A21	Alienware X51 R2	7507T52	81062	1.12%	4811	0.07%	7180779	98.82%	7266652
FL A21	Alienware X51 R2	7505T52	114839	1.70%	0	0.00%	6660351	98.31%	6775190
FL A21	Alienware X51 R2	74ZCT52	105124	1.53%	8955	0.13%	6776721	98.34%	6890800

I. Energy Waste Data

In this section the calculations for each case of energy waste are presented.

To download the fully interactive spreadsheet online, visit:

https://docs.google.com/spreadsheets/d/1n4q16vwXKqa1C0aos0iAgWokSr_qYeRhF3NlzWJ3d8w/edit?usp=sharing

Conservative Estimate									
Number of Computers		1000							
Before	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	338760.7	N/A	N/A	
(2) Idle	36.58	0.55	N/A	0.51	163.1	163118.7	163.1	163118.7	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	0.0	0.7	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	0.0	0.7	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	0.3	299.5	
Totals				1.000	502.2	502200.2	163.4	163419.6	

Probable Estimate									
Number of Computers		1000							
Before	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	188211.5	N/A	N/A	
(2) Idle	36.58	0.75	N/A	0.69	222.4	222434.6	222.4	222434.6	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	0.0	0.7	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	0.0	0.7	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	0.3	299.5	
Totals				1.000	410.9	410946.9	222.7	222735.5	

Optimistic Estimate									
Number of Computers		1000							
Before	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	37642.3	N/A	N/A	
(2) Idle	36.58	0.95	N/A	0.88	281.8	281750.5	281.8	281750.5	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	0.0	0.7	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	0.0	0.7	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	0.3	299.5	
Totals				1.000	319.7	319693.7	282.1	282051.4	

Conservative Estimate									
Number of Computers		1350							
Before	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	457353.9	N/A	N/A	
(2) Idle	36.58	0.55	N/A	0.51	163.1	220210.3	163.1	220210.3	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.9	0.0	0.9	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.9	0.0	0.9	
(5) Off	0.46	N/A	N/A	0.07	0.3	404.3	0.3	404.3	
Totals				1.000	502.2	677970.3	163.4	220616.4	

Probable Estimate										
Number of Computers		1350								
Before	Awake	Shut Down	Asleep	Total						
Seconds	206990782	16662102	16364	223669248						
Proportion of Time	0.93	0.07	0.00	1.00						
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year		
(1) Active Use	92.87	0.25	N/A	0.23	188.2	254085.5	N/A	N/A		
(2) Idle	36.58	0.75	N/A	0.69	222.4	300286.7	222.4	300286.7		
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.9	0.0	0.9		
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.9	0.0	0.9		
(5) Off	0.46	N/A	N/A	0.07	0.3	404.3	0.3	404.3		
Totals				1.000	410.9	554778.4	222.7	300692.9		

Optimistic Estimate										
Number of Computers		1350								
Before	Awake	Shut Down	Asleep	Total						
Seconds	206990782	16662102	16364	223669248						
Proportion of Time	0.93	0.07	0.00	1.00						
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year		
(1) Active Use	92.87	0.05	N/A	0.05	37.6	50817.1	N/A	N/A		
(2) Idle	36.58	0.95	N/A	0.88	281.8	380363.2	281.8	380363.2		
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.9	0.0	0.9		
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.9	0.0	0.9		
(5) Off	0.46	N/A	N/A	0.07	0.3	404.3	0.3	404.3		
Totals				1.000	319.7	431586.4	282.1	380769.4		

Conservative Estimate										
Number of Computers		1700								
Before	Awake	Shut Down	Asleep	Total						
Seconds	206990782	16662102	16364	223669248						
Proportion of Time	0.93	0.07	0.00	1.00						
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year		
(1) Active Use	92.87	0.45	N/A	0.42	338.8	575927.1	N/A	N/A		
(2) Idle	36.58	0.55	N/A	0.51	163.1	277301.8	163.1	277301.8		
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	0.0	1.1		
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	0.0	1.2		
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	0.3	509.1		
Totals				1.000	502.2	853740.4	163.4	277813.3		

Probable Estimate										
Number of Computers		1700								
Before	Awake	Shut Down	Asleep	Total						
Seconds	206990782	16662102	16364	223669248						
Proportion of Time	0.93	0.07	0.00	1.00						
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year		
(1) Active Use	92.87	0.25	N/A	0.23	188.2	319959.5	N/A	N/A		
(2) Idle	36.58	0.75	N/A	0.69	222.4	378138.9	222.4	378138.9		
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	0.0	1.1		
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	0.0	1.2		
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	0.3	509.1		
Totals				1.000	410.9	698609.8	222.7	378650.3		

Optimistic Estimate										
Number of Computers		1700								
Before	Awake	Shut Down	Asleep	Total						
Seconds	206990782	16662102	16364	223669248						
Proportion of Time	0.93	0.07	0.00	1.00						
State	Power Draw (W)	% of AwakeTime	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Wasted kWh/Year/Computer	Wasted kWh/Year		
(1) Active Use	92.87	0.05	N/A	0.05	37.6	63991.9	N/A	N/A		
(2) Idle	36.58	0.95	N/A	0.88	281.8	478975.9	281.8	478975.9		
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	0.0	1.1		
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	0.0	1.2		
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	0.3	509.1		
Totals				1.000	319.7	543479.2	282.1	479487.3		

J. Energy Savings Data

In this section the calculations for each case of energy savings are presented, first for the shutdown plan, then for the sleep plan.

To download the fully interactive spreadsheet online, visit:

https://docs.google.com/spreadsheets/d/1n4q16vwXKqa1C0aos0iAgWokSr_qYeRhF3NlzWJ3d8w/edit?usp=sharing

J.1 Shutdown Plan Savings

Conservative Estimate									
Number of Computers Affected		684							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	231726.0	\$25.56	\$17,480.48	
(2) Idle	36.58	0.55	N/A	0.51	163.1	111573.2	\$12.31	\$8,416.64	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.00	502.2	343505.0	\$37.88	\$25,912.64	
	Awake	Shut Down	Asleep	Total					
Seconds	121607084	102045800	16364	223669248.00					
Proportion of Time	0.54	0.46	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.77	N/A	0.42	338.8	231726.0	\$25.56	\$17,480.48	
(2) Idle	36.58	0.23	N/A	0.13	40.8	27893.3	\$3.08	\$2,104.16	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.46	1.8	1254.6	\$0.14	\$94.64	
Totals				1.00	381.4	260874.8	\$28.77	\$19,679.35	
Savings					120.8	82,630.1	\$9.11	\$6,233.29	

Probable Estimate									
Number of Computers Affected		684							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	128736.6	\$14.20	\$9,711.38	
(2) Idle	36.58	0.75	N/A	0.69	222.4	152145.3	\$16.78	\$11,477.23	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.00	410.9	281087.7	\$31.00	\$21,204.13	
	Awake	Shut Down	Asleep	Total					
Seconds	90558467	133094417	16364	223669248.00					
Proportion of Time	0.40	0.60	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.57	N/A	0.23	188.2	128736.6	\$14.20	\$9,711.38	
(2) Idle	36.58	0.43	N/A	0.17	55.6	38036.3	\$4.19	\$2,869.31	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.60	2.4	1636.4	\$0.18	\$123.44	
Totals				1.00	246.2	168410.2	\$18.57	\$12,704.20	
Savings					164.7	112,677.5	\$12.43	\$8,499.94	

Optimistic Estimate									
Number of Computers Affected		684							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	25747.3	\$2.84	\$1,942.28	
(2) Idle	36.58	0.95	N/A	0.88	281.8	192717.4	\$21.25	\$14,537.83	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.00	319.7	218670.5	\$24.12	\$16,495.63	
	Awake	Shut Down	Asleep	Total					
Seconds	59509850	164143034	16364	223669248.00					
Proportion of Time	0.27	0.73	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.17	N/A	0.05	37.6	25747.3	\$2.84	\$1,942.28	
(2) Idle	36.58	0.83	N/A	0.22	70.4	48179.3	\$5.31	\$3,634.46	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.73	3.0	2018.1	\$0.22	\$152.24	
Totals				1.00	111.0	75945.7	\$8.38	\$5,729.04	
Savings					208.7	142,724.8	\$15.74	\$10,766.59	

Conservative Estimate									
Number of Computers Affected		1000							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	338780.7	\$25.56	\$25,556.26	
(2) Idle	36.58	0.55	N/A	0.51	163.1	163118.7	\$12.31	\$12,305.02	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.00	502.2	502200.2	\$37.88	\$37,883.98	
	Awake	Shut Down	Asleep	Total					
Seconds	121607084	102045800	16364	223669248.00					
Proportion of Time	0.54	0.46	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.77	N/A	0.42	338.8	338780.7	\$25.56	\$25,556.26	
(2) Idle	36.58	0.23	N/A	0.13	40.8	40779.7	\$3.08	\$3,076.26	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.46	1.8	1834.2	\$0.14	\$138.37	
Totals				1.00	381.4	381395.9	\$28.77	\$28,770.98	
Savings					120.8	120,804.3	\$9.11	\$9,112.99	

Probable Estimate									
Number of Computers Affected		1000							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	188211.5	\$14.20	\$14,197.92	
(2) Idle	36.58	0.75	N/A	0.69	222.4	222434.6	\$16.78	\$16,779.58	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.00	410.9	410946.9	\$31.00	\$31,000.19	
	Awake	Shut Down	Asleep	Total					
Seconds	90558467	133094417	16364	223669248.00					
Proportion of Time	0.40	0.60	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.57	N/A	0.23	188.2	188211.5	\$14.20	\$14,197.92	
(2) Idle	36.58	0.43	N/A	0.17	55.6	55608.7	\$4.19	\$4,194.89	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.60	2.4	2392.3	\$0.18	\$180.47	
Totals				1.00	246.2	246213.8	\$18.57	\$18,573.39	
Savings					164.7	164,733.1	\$12.43	\$12,426.81	

Optimistic Estimate									
Number of Computers Affected		1000							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	37642.3	\$2.84	\$2,839.58	
(2) Idle	36.58	0.95	N/A	0.88	281.8	281750.5	\$21.25	\$21,254.13	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.00	319.7	319693.7	\$24.12	\$24,116.41	
	Awake	Shut Down	Asleep	Total					
Seconds	59509850	164143034	16364	223669248.00					
Proportion of Time	0.27	0.73	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.17	N/A	0.05	37.6	37642.3	\$2.84	\$2,839.58	
(2) Idle	36.58	0.83	N/A	0.22	70.4	70437.6	\$5.31	\$5,313.53	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.73	3.0	2950.4	\$0.22	\$222.57	
Totals				1.00	111.0	111031.7	\$8.38	\$8,375.79	
Savings					208.7	208,662.0	\$15.74	\$15,740.63	

Conservative Estimate									
Number of Computers Affected		1700							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	575927.1	\$25.56	\$43,445.64	
(2) Idle	36.58	0.55	N/A	0.51	163.1	277301.8	\$12.31	\$20,918.54	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	502.2	853740.4	\$37.88	\$64,402.76	
	Awake	Shut Down	Asleep	Total					
Seconds	121607084	102045800	16364	223669248.00					
Proportion of Time	0.54	0.46	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.77	N/A	0.42	338.8	575927.1	\$25.56	\$43,445.64	
(2) Idle	36.58	0.23	N/A	0.13	40.8	69325.5	\$3.08	\$5,229.64	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.46	1.8	3118.2	\$0.14	\$235.22	
Totals				1.00	381.4	648373.1	\$28.77	\$48,910.67	
Savings					120.8	205,367.3	\$9.11	\$15,492.09	

Probable Estimate									
Number of Computers Affected		1700							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	319959.5	\$14.20	\$24,136.47	
(2) Idle	36.58	0.75	N/A	0.69	222.4	378138.9	\$16.78	\$28,525.28	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	410.9	698609.8	\$31.00	\$52,700.33	
	Awake	Shut Down	Asleep	Total					
Seconds	90558467	133094417	16364	223669248.00					
Proportion of Time	0.40	0.60	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.57	N/A	0.23	188.2	319959.5	\$14.20	\$24,136.47	
(2) Idle	36.58	0.43	N/A	0.17	55.6	94534.7	\$4.19	\$7,131.32	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.60	2.4	4067.0	\$0.18	\$306.79	
Totals				1.00	246.2	418563.5	\$18.57	\$31,574.75	
Savings					164.7	280,046.3	\$12.43	\$21,125.58	

Optimistic Estimate									
Number of Computers Affected		1700							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248.00					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	63991.9	\$2.84	\$4,827.29	
(2) Idle	36.58	0.95	N/A	0.88	281.8	478975.9	\$21.25	\$36,132.03	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	319.7	543479.2	\$24.12	\$40,997.90	
	Awake	Shut Down	Asleep	Total					
Seconds	59509850	164143034	16364	223669248.00					
Proportion of Time	0.27	0.73	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.17	N/A	0.05	37.6	63991.9	\$2.84	\$4,827.29	
(2) Idle	36.58	0.83	N/A	0.22	70.4	119744.0	\$5.31	\$9,033.01	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.73	3.0	5015.7	\$0.22	\$378.36	
Totals				1.00	111.0	188753.9	\$8.38	\$14,238.84	
Savings					208.7	354,725.4	\$15.74	\$26,759.06	

J.2 Sleep Plan Savings

Conservative Estimate									
Number of Computers Affected		684							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	231726.0	\$25.56	\$17,480.48	
(2) Idle	36.58	0.55	N/A	0.51	163.1	111573.2	\$12.31	\$8,416.64	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.000	502.2	343505.0	\$37.88	\$25,912.64	
	Awake	Shut Down	Asleep	Total					
Seconds	94284301	16662102	112722845	223669248					
Proportion of Time	0.42	0.07	0.50	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.99	N/A	0.42	338.8	231726.0	\$25.56	\$17,480.48	
(2) Idle	36.58	0.01	N/A	0.01	1.6	1115.7	\$0.12	\$84.17	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	1.0	0.50	9.3	6376.9	\$0.70	\$481.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.00	350.0	239423.9	\$26.41	\$18,061.18	
Savings					152.2	104,081.1	\$11.48	\$7,851.46	

Probable Estimate									
Number of Computers Affected		684							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	128736.6	\$14.20	\$9,711.38	
(2) Idle	36.58	0.75	N/A	0.69	222.4	152145.3	\$16.78	\$11,477.23	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.000	410.9	281087.7	\$31.00	\$21,204.13	
	Awake	Shut Down	Asleep	Total					
Seconds	53300126	16662102	153707020	223669248					
Proportion of Time	0.24	0.07	0.69	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year		Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.97	N/A	0.23	188.2	128736.6	\$14.20	\$9,711.38	
(2) Idle	36.58	0.03	N/A	0.01	2.2	1521.5	\$0.17	\$114.77	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	1.0	0.69	12.7	8695.6	\$0.96	\$655.96	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.00	203.4	139159.0	\$15.35	\$10,497.60	
Savings					207.5	141,928.7	\$15.65	\$10,706.54	

Optimistic Estimate									
Number of Computers Affected		684							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	25747.3	\$2.84	\$1,942.28	
(2) Idle	36.58	0.95	N/A	0.88	281.8	192717.4	\$21.25	\$14,537.83	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.5	\$0.00	\$0.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.000	319.7	218670.5	\$24.12	\$16,495.63	
	Awake	Shut Down	Asleep	Total					
Seconds	12315952	16662102	194691194	223669248					
Proportion of Time	0.06	0.07	0.87	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year		Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.84	N/A	0.05	37.6	25747.3	\$2.84	\$1,942.28	
(2) Idle	36.58	0.16	N/A	0.01	2.8	1927.2	\$0.21	\$145.38	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	0.5	\$0.00	\$0.03	
(4) Asleep Log Out	2.11	N/A	1.0	0.87	16.1	11014.3	\$1.21	\$830.87	
(5) Off	0.46	N/A	N/A	0.07	0.3	204.9	\$0.02	\$15.45	
Totals				1.00	56.9	38894.1	\$4.29	\$2,934.01	
Savings					262.8	179,776.4	\$19.83	\$13,561.61	

Conservative Estimate									
Number of Computers Affected		1000							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	338780.7	\$25.56	\$25,556.26	
(2) Idle	36.58	0.55	N/A	0.51	163.1	163118.7	\$12.31	\$12,305.02	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.000	502.2	502200.2	\$37.88	\$37,883.98	
	Awake	Shut Down	Asleep	Total					
Seconds	94284301	16662102	112722845	223669248					
Proportion of Time	0.42	0.07	0.50	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.99	N/A	0.42	338.8	338780.7	\$25.56	\$25,556.26	
(2) Idle	36.58	0.01	N/A	0.01	1.6	1631.2	\$0.12	\$123.05	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	1.0	0.50	9.3	9322.9	\$0.70	\$703.28	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.00	350.0	350034.9	\$26.41	\$26,405.24	
Savings					152.2	152,165.3	\$11.48	\$11,478.74	

Probable Estimate									
Number of Computers Affected		1000							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	188211.5	\$14.20	\$14,197.92	
(2) Idle	36.58	0.75	N/A	0.69	222.4	222434.6	\$16.78	\$16,779.58	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.000	410.9	410946.9	\$31.00	\$31,000.19	
	Awake	Shut Down	Asleep	Total					
Seconds	53300126	16662102	153707020	223669248					
Proportion of Time	0.24	0.07	0.69	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.97	N/A	0.23	188.2	188211.5	\$14.20	\$14,197.92	
(2) Idle	36.58	0.03	N/A	0.01	2.2	2224.3	\$0.17	\$167.80	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	1.0	0.69	12.7	12712.8	\$0.96	\$959.00	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.00	203.4	203448.8	\$15.35	\$15,347.36	
Savings					207.5	207,498.1	\$15.65	\$15,652.83	

Optimistic Estimate									
Number of Computers Affected		1000							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	37642.3	\$2.84	\$2,839.58	
(2) Idle	36.58	0.95	N/A	0.88	281.8	281750.5	\$21.25	\$21,254.13	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	0.7	\$0.00	\$0.05	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.000	319.7	319693.7	\$24.12	\$24,116.41	
	Awake	Shut Down	Asleep	Total					
Seconds	12315952	16662102	194691194	223669248					
Proportion of Time	0.06	0.07	0.87	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.84	N/A	0.05	37.6	37642.3	\$2.84	\$2,839.58	
(2) Idle	36.58	0.16	N/A	0.01	2.8	2817.5	\$0.21	\$212.54	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	0.7	\$0.00	\$0.05	
(4) Asleep Log Out	2.11	N/A	1.0	0.87	16.1	16102.7	\$1.21	\$1,214.73	
(5) Off	0.46	N/A	N/A	0.07	0.3	299.5	\$0.02	\$22.59	
Totals				1.00	56.9	56862.7	\$4.29	\$4,289.49	
Savings					262.8	262,831.0	\$19.83	\$19,826.92	

Conservative Estimate									
Number of Computers Affected		1700							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.45	N/A	0.42	338.8	575927.1	\$25.56	\$43,445.64	
(2) Idle	36.58	0.55	N/A	0.51	163.1	277301.8	\$12.31	\$20,918.54	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.000	502.2	853740.4	\$37.88	\$64,402.76	
	Awake	Shut Down	Asleep	Total					
Seconds	94284301	16662102	112722845	223669248					
Proportion of Time	0.42	0.07	0.50	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.99	N/A	0.42	338.8	575927.1	\$25.56	\$43,445.64	
(2) Idle	36.58	0.01	N/A	0.01	1.6	2773.0	\$0.12	\$209.19	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	1.0	0.50	9.3	15849.0	\$0.70	\$1,195.58	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	350.0	595059.4	\$26.41	\$44,888.90	
Savings					152.2	258,681.0	\$11.48	\$19,513.86	

Probable Estimate									
Number of Computers Affected		1700							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Asleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.25	N/A	0.23	188.2	319959.5	\$14.20	\$24,136.47	
(2) Idle	36.58	0.75	N/A	0.69	222.4	378138.9	\$16.78	\$28,525.28	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	410.9	698609.8	\$31.00	\$52,700.33	
	Awake	Shut Down	Asleep	Total					
Seconds	53300126	16662102	153707020	223669248					
Proportion of Time	0.24	0.07	0.69	1.00					
State	Power Draw (W)	% of Awake Time	% of Aleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.97	N/A	0.23	188.2	319959.5	\$14.20	\$24,136.47	
(2) Idle	36.58	0.03	N/A	0.01	2.2	3781.4	\$0.17	\$285.25	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	1.0	0.69	12.7	21611.8	\$0.96	\$1,630.31	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	203.4	345863.0	\$15.35	\$26,090.52	
Savings					207.5	352,746.8	\$15.65	\$26,609.81	

Optimistic Estimate									
Number of Computers Affected		1700							
	Awake	Shut Down	Asleep	Total					
Seconds	206990782	16662102	16364	223669248					
Proportion of Time	0.93	0.07	0.00	1.00					
State	Power Draw (W)	% of Awake Time	% of Aleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.05	N/A	0.05	37.6	63991.9	\$2.84	\$4,827.29	
(2) Idle	36.58	0.95	N/A	0.88	281.8	478975.9	\$21.25	\$36,132.03	
(3) Asleep Log In	2.09	N/A	0.5	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	0.5	0.00	0.0	1.2	\$0.00	\$0.09	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	319.7	543479.2	\$24.12	\$40,997.90	
	Awake	Shut Down	Asleep	Total					
Seconds	12315952	16662102	194691194	223669248					
Proportion of Time	0.06	0.07	0.87	1.00					
State	Power Draw (W)	% of Awake Time	% of Aleep Time	% of Total Time	kWh/Year/Computer	kWh/Year	Cost (USD)/Year/Computer	Cost (USD)/Year	
(1) Active Use	92.87	0.84	N/A	0.05	37.6	63991.9	\$2.84	\$4,827.29	
(2) Idle	36.58	0.16	N/A	0.01	2.8	4789.8	\$0.21	\$361.32	
(3) Asleep Log In	2.09	N/A	0.0	0.00	0.0	1.1	\$0.00	\$0.09	
(4) Asleep Log Out	2.11	N/A	1.0	0.87	16.1	27374.6	\$1.21	\$2,065.03	
(5) Off	0.46	N/A	N/A	0.07	0.3	509.1	\$0.02	\$38.41	
Totals				1.00	56.9	96666.6	\$4.29	\$7,292.14	
Savings					262.8	446,812.7	\$19.83	\$33,705.76	

K. Explanation of Assumed Variables

This section presents the assumptions made and the math used to determine a number of variables for energy consumption, savings, and waste. These variables are the proportion of time that a computer is active when awake (T_{AWLI}), and the number of desktop computers, N .

K.1 Usage Assumptions

Library (represents 19.7% of computers on campus)

M-F 8-00 60% of Computers in the Library are used.

22.21 hours a day computer is on.

6.21 hours idle + (40% of 16 hours (6.4))= 12.61 hours idle.

Idle/On = 12.61 / 22.21 = 56.8% of time awake is idle.

S-S 8-00 20% of Computers in the Library are used.

22.21 hours a day computer is on.

6.21 hours idle + (80% of 16 hours (12.8))= 19.01 hours idle.

Idle/On = 19.01 / 22.21 = 85.6% of time awake is idle.

Taking the average across the 2 categories weighting them by percentage of 1 week:

M-F represents 5/7 (71.43%) of one week.

S-S represents 2/7 (28.57%) of one week.

$56.8*(.7143)+85.6*(.2857)=65.0\%$

All Other Labs (remaining 80.3% of computers on campus)

M-F 8-00 20% of Computers in every lab are used. 3hrs a day, 100% of Computers in every lab are used. (Due to Classes/Labs)

22.21 hours a day computer is on.

6.21 hours Idle + (80% of 13 hours (10.4 hours))= 16.61 hours idle.

Idle/On = 16.61 / 22.21 = 74.8% of time awake is idle.

Sat 8-00 5% of Computers in every lab are used.

22.21 hours a day computer is on.

6.21 hours Idle + (95% of 16 hours (15.2)) = 21.41 hours idle.

Idle/On = 21.41 / 22.21 = 96.4% of time awake is idle.

Sun 8-00 10% of Computers in every lab are used.

22.21 hours a day computer is on.

6.21 hours Idle + (90% of 13 hours (11.7)) = 20.61 hours idle.

Idle/On = 20.61 / 22.21 = 92.8% of time awake is idle.

Taking the average across the 3 categories weighting them by percentage of 1 week:

M-F represents 5/7 (71.43%) of one week.

Sat & Sun each represent 1/7 (14.29%) of one week.
 $74.8*(0.7143)+96.4*(0.1429)+92.8*(0.1429)=80.5$

Weighted Average of Library and All other Labs:
 $65*(.197)+80.5*(.803)=77.4$

K.2 Number of Computers Assumptions

For the Calculation of Energy Waste:

Low

1000: inventoried computers + 5 computers per restricted laboratory

Probable

1350: middle ground between high and low estimates

High

1700: inventoried computers + 5 computers per restricted laboratory + 450 faculty computers (Number of faculty = 6200 Students w/ 14:1 Student to Faculty Ratio = 450), and 250 staff computers.

For the Calculation of Potential Savings:

(These values are lower because an energy waste reduction method likely would not reach all of the computers on campus that are wasting energy)

Conservative

684: Only inventoried computers

Probable

1000: inventoried computers + 5 computers per restricted laboratory

Optimistic

1700: inventoried computers + 5 computers per restricted laboratory + 450 faculty computers (Number of faculty = 6200 Students w/ 14:1 Student to Faculty Ratio = 450), and 250 staff computers.

L. Energy Profile

In this section, the energy consumption data for WPI over the 2015 and 2016 fiscal years is presented. This table was generated from data provided by Amy Rajotte.

Fiscal Year (Jul - Jun)	2016			2015		
	Cost	kWh	Rate	Cost	kWh	Rate
July	\$ 363,300.75	4,842,680	0.075	\$ 318,947.13	5,045,853	0.063
August	\$ 393,324.35	5,276,830	0.075	\$ 316,893.05	5,096,340	0.062
September	\$ 428,661.15	5,856,160	0.073	\$ 335,269.45	5,315,057	0.063
October	\$ 374,600.05	4,911,181	0.076	\$ 300,858.14	4,814,875	0.062
Novemeber	\$ 368,811.27	4,853,261	0.076	\$ 302,963.43	4,723,114	0.064
December	\$ 340,064.75	4,537,453	0.075	\$ 378,689.45	5,089,409	0.074
January	\$ 320,040.74	4,182,350	0.077	\$ 337,502.01	4,368,848	0.077
February	\$ 381,328.89	5,115,124	0.075	\$ 415,932.48	5,595,414	0.074
March	\$ 330,040.48	4,271,104	0.077	\$ 329,337.93	4,600,950	0.072
April	\$ 388,245.34	5,153,728	0.075	\$ 388,320.55	5,064,197	0.077
May	\$ 325,895.77	4,278,683	0.076	\$ 338,224.92	4,504,629	0.075
June	\$ 332,028.92	4,337,735	0.077	\$ 331,973.17	4,410,472	0.075
Total	\$4,346,342.46	57,616,289		\$4,094,911.71	58,629,158	
Average	\$ 362,195.21	4,801,357	0.076	\$ 341,242.64	4,885,763	0.070