AUTOMATIC POWER MANAGEMENT FOR INSTRUCTIONAL COMPUTERS AT HUMBOLDT STATE UNIVERSITY: A CALCULATION OF POTENTIAL ENERGY SAVINGS AND GREENHOUSE GAS EMISSIONS REDUCTIONS

By

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ABSTRACT

AUTOMATIC POWER MANAGEMENT FOR INSTRUCTIONAL COMPUTERS AT HUMBOLDT STATE UNIVERSITY: A CALCULATION OF POTENTIAL ENERGY SAVINGS AND GREENHOUSE GAS EMISSIONS REDUCTIONS

Nicholas Flenghi

Computers consume an estimated 5,610 GWh per year in California alone. Much of that energy is consumed by computers that are not being used. In this project, detailed user login data are used to estimate the energy consumption of instructional computers at Humboldt State University (HSU) over the course of one semester. The data are also used to estimate the potential energy savings from automating the shutdown process. Potential cost savings and greenhouse gas (GHG) emissions reductions resulting from implementing an automatic-shutdown power management plan are also calculated.

There are approximately 1,000 computers used for teaching and learning purposes at HSU. In their current configuration, they consume an estimated 35.4 MWh each semester. However, 56% of that energy is wasted, powering computers that are not being used. By automatically powering down unused computers after 30 minutes of inactivity, significant energy, cost, and GHG emissions reductions could be realized. Energy consumption could be reduced by 45% or 15.9 MWh per semester, saving $1,935 in electricity costs. Consequently, GHG emissions could be reduced by four metric tons per semester, with little to no additional costs and minimal impact to users.

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AEF	Average emissions factor
AR5	Fifth Assessment Report
CFL	Compact fluorescent
CO_2e	Carbon dioxide equivalent
CPU	Central Processing Unit
eGRID	Emissions & Generation Resource Integrated Database
GHG	Greenhouse Gases
GPU	Graphics Processing Unit
GWP	Global Warming Potential
HDD	Hard Disk Drive (conventional)
HSU	Humboldt State University
IPCC	Intergovernmental Panel on Climate Change
ITS	Information Technology Services
LED	Light-emitting diode
MEF	Marginal emissions factor
MT	Metric Tons
NWPP	Northwest Power Pool
SSD	Solid State Drive
TEC	Typical Energy Consumption
WoL	Wake-on-LAN

CHAPTER 1: INTRODUCTION

In California, computers and monitors use an estimated 5,610 GWh of energy per year (California Energy Commission, 2016). Universities use an ever-increasing number of computers for instructional activities, yet they often do not take full advantage of computer energy management solutions. This project aims to estimate the energy consumption of campus computers and quantify the potential for energy savings and greenhouse gas emissions reductions at Humboldt State University through computer power management.

Humboldt State University (HSU) is a public university in the far northern California town of Arcata. HSU has a reputation for promoting sustainability through both academic programs and campus procedures. In March 2017, the university released a Climate Action Plan with the goal of reducing greenhouse gas emissions (GHG) to 1990 levels by the year 2020 (HSU Office of Sustainability, 2016). In the fall semester of 2016 there were 8,503 students enrolled (Humboldt State University, 2016), and there are nearly 1,000 computers in labs across campus available to students and faculty (classified as being use for “teaching and learning” purposes).

Computers make up a significant portion of plug loads in both commercial and educational buildings. Various studies estimate that computers account for about 2 percent of California’s electricity end-use consumption (Pixley & Ross, 2014). Educational institutions differ from much of the commercial sector in that they provide computers that are primarily used by transient users, rather than computers at dedicated desks or in private offices. Additionally, computers at universities are used at varied times throughout the day and late into the night by students and faculty. Apart from new technology purchases, the simplest and most effective way to reduce computer power consumption is to ensure that they are turned off when not being used.

Currently, approximately two-thirds of campus instructional computers at HSU are set to remain on until they are automatically shut down at 11:00 PM each night; one third of instructional computers are never automatically shut down. This configuration reduces the amount of time that computers would otherwise spend powered on and unused overnight, but there are still significant energy savings to be had during the rest of the day. In the past, the extra time required to wait for a computer to boot was considered too inconvenient for users, but upgrades over the years have resulted in significantly faster boot times. Setting the computers to shut down a short period after logout would further reduce energy consumption, electricity costs, and associated greenhouse gas emissions.

In this project, real user login data and information about computer power consumption were used to estimate computer usage patterns and to calculate the current energy usage of instructional computers on campus. The effect of implementing an automatic-shutdown power management policy was simulated and the associated energy, cost, and greenhouse gas emissions reductions were analyzed. Chapter 1 introduces the scope and setting of the project. In Chapter 2, similar studies are reviewed and compared to the current project. Chapter 3 lays out the methods used to estimate energy usage and savings as well as the method used to calculate avoided greenhouse gas emissions.

Results are presented in Chapter 4 and further discussed in Chapter 5. Conclusions and recommendations for future action are discussed in Chapter 6.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

There has been significant research aimed at computer energy efficiency technologies and computer energy usage and behaviors in the commercial sector, but relatively little has focused on computer usage on university campuses. A consistent conclusion across similar studies is that automatic power management settings have the greatest potential to reduce computer energy consumption, yet they are often disabled or altered (Moorefield et al., 2011; Barr et al., 2010; Bishop et al., 2013; Mercier & Moorefield, 2011; Cabrera & Zareipour, 2011; Luberus & Nyandoro, 2014).

Commercial plug load energy consumption has increased dramatically in recent decades, with the now ubiquitous presence of computers, peripherals, and IT infrastructure in offices around the world. Plug load energy usage in California’s small offices (<30,000 square feet) is estimated to be about 1,000 GWh per year (Moorefield et al., 2011; Itron, Inc., 2006), and office equipment and miscellaneous plug loads make up about 12.9% of all commercial energy usage in the state (Itron, Inc., 2006). In a 2011 study of 47 California offices, computers accounted for 48% of the total plug load energy use (Moorefield et al., 2011). Similarly, in a case study of a LEED certified public library and small office in California, computers were the largest plug loads, accounting for nearly 70% of plug load energy consumption (Mercier & Moorefield, 2011).

The power requirement of a computer depends strongly on its configuration and form factor. An average ENERGY STAR qualified desktop computer uses approximately 310 kWh per year, while integrated desktops and notebooks use 250 and 75 kWh per year, respectively (Dewart et al., 2013). The introduction of the 80 PLUS labeling program has helped to make efficient internal power supplies the norm, though there is still room for improvement. Similarly, desktop CPU (central processing unit) efficiency has increased dramatically because of policy focus on idle power requirements. To qualify for an ENERGY STAR label, computers must meet a maximum Typical Energy Consumption (TEC) per year for various configurations. In the latest version, TEC is calculated using both *short idle* and *long idle* power states (i.e. accounting for the contributions of power scaling technologies) (ENERGY STAR, 2016). When intensive graphics performance is not required, integrated graphics processing can be used either solely or through graphics switching technology to reduce power requirements. Additionally, many computers are now shipping with higher performance solid state drives (SSDs) that often use less than 1 Watt of power (compared to about 4 to 8 Watts for conventional hard disk drives [HDDs]) (Dewart et al., 2013). A summary of several computer components' share of energy use and their associated energy savings opportunities is presented in Table 1. The power supply, display, and motherboard make up the bulk of energy use, but the graphics processing unit (GPU, or "graphics card") can account for up to 50% of computer energy use.

Table 1: Share of computer energy use and range of potential energy-savings improvements. Table adapted from an EPRI & Ecos 2008 study (as included in Dewart et al., 2013)

Component	**Share of energy use**	**Savings opportunities**
Power Supply	15-35%	80-Plus Bronze: <70% to 82% efficiency
Display	15-30%	LED backlighting, more efficient panel technology
Motherboard	15-20%	More efficient chipsets, voltage regulators and other components, mobile-on-desktop design
GPU	0-50%	Higher power proportionality: low power in idle
CPU	5-15%	Low power CPUs, voltage and frequency scaling
Disks	5-10%	“Green” drives, solid state drives (SSD)
Memory	5-10%	“Green” memory
Networking	2-8%	

The average power levels of all ENERGY STAR labeled desktop computers currently on the market are presented in Table 2, and the average power level of 19-inch monitors is presented in Table 3. Computers with integrated graphics use around 20 Watts while active (long idle and short idle modes), 1.3 Watts in sleep mode and 0.5 Watts while off. On average, desktops with discrete graphics use about 42 Watts in active modes; more than twice as much as their integrated counterparts (ENERGY STAR, 2017). Much of the difference may also be due to other high performance components used in computers with discrete graphics cards. The average power consumption of ENERGY STAR labeled monitors is 12.2 Watts in on mode, 0.3 Watts in sleep mode, and 0.1 Watts in off mode (ENERGY STAR, 2017).

Table 2: Average power consumption of ENERGY STAR labeled desktop computers. Averages were calculated based on computer models that meet version 6.1 requirements as of April 2017 (ENERGY STAR, 2017).

Type	**Off (W)**	**Sleep (W)**	**Long Idle (W)**	**Short Idle (W)**
Desktop (integrated graphics)[1]	0.5	1.3	18.8	20.1
Desktop (discrete graphics)[2]	0.5	2.1	42.0	42.5

Table 3: Average power consumption of a 19-inch ENERGY STAR labeled computer monitor in off, sleep, and on modes (as of April 2017) (ENERGY STAR, 2017).

Monitor Size	**Off Mode (W)**	**Sleep Mode (W)**	**On Mode (W)**
19 inches[3]	0.1	0.3	12.2

Computer operating efficiency can be increased with small technology investments. In research carried out in 2008, off-the-shelf components were used to exceed ENERGY STAR Idle Mode requirements by 40% to 50%; ultra-efficient components in a small form factor mobile-on-desktop platform exceeded them by 70% (California Energy Commission, PIER, 2012). Supported by these results, in 2016, the California Energy Commission adopted the first mandatory computer and monitor efficiency standards in the nation (California Energy Commission, 2016).

Though computer efficiency has improved, computers still spend much of the time turned on, whether they are being used or not. ENERGY STAR 6.0 specifies an estimated duty cycle for desktop computers of 45% in off, 5% in sleep, 15% in long idle,

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[1] Average includes computers in ENERGY STAR 6.1 categories I1, I2, and I3.

[2] Average includes computers in ENERGY STAR 6.1 categories D1, and D2.

[3] 19-inch monitors are shown here because it is the most common monitor size in use at HSU.

and 35% in short idle modes (Dewart et al., 2013). Several studies focus on PC user behavior, with computers found to spend between 39% and 94% of their time in active or idle modes (Table 4). Many studies fail to differentiate between active and idle modes because it is more difficult to determine when a computer is being actively used and because it has been assumed in the past that power consumption remains essentially constant between active and idle modes. However, modern computers are better equipped to scale power down when idle, leading to a more significant difference between idle and active power (Itron, Inc., 2006).

Table 4: Comparison of studies investigating computer duty cycles. Table adapted from the *Response to California Energy Commission 2013 Pre-Rulemaking Appliance Efficiency: Invitation to Participate* (Dewart et al., 2013).

	Active-idle	**Sleep**	**Off**	**Date**	**Segment**	**Sample Size**
PG&E / Barr, Harty & Nero	94%	1%	5%	2010	Enterprise (Thin-client, Cross-sector, U.S.)	110,000
Ecma-383, 3rd Edition, Annex B	50%	5%	45%	2010	Enterprise (International, technology companies)	500
Microsoft, Customer Experience Report	41%	5%	54%	2008	?	75,000
Pigg & Bensch	49%	51%	n/a	2010	Residential (Wisconsin)	81 computers in 50 homes
Fraunhofer / CEA	39%	25%	36%	2010	Residential (U.S.)	1,000 homes
Chetty et al.	75%	25%	n/a	2009	Residential (U.S.)	59 computers in 20 homes

University campus computer labs exhibit strong seasonal and diurnal usage patterns, which result in large periods of underutilization, particularly on nights, weekends, and academic breaks (Spennemann et al., 2007; Cabrera & Zareipour, 2011; Bishop et al., 2013). In a three-year study of several university campuses in Australia, 86% of all logins occurred during typical business hours (Monday to Friday, 07:00 to 18:00) during a semester. Computer utilization ranged from 13.3% to 38.5% during the semester. Figure 1 shows the typical diurnal nature of computer lab access observed in that study. Logins increase rapidly in the mornings and decrease somewhat less rapidly in the evenings as students leave campus (Spennemann et al., 2007).

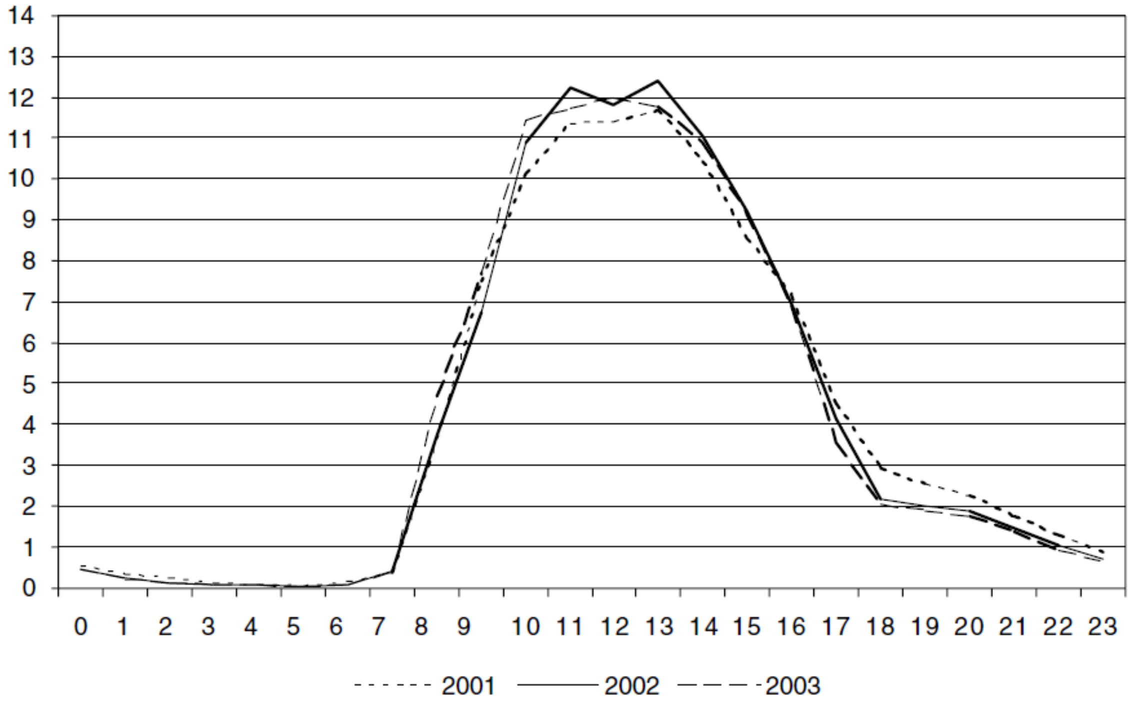

Figure 1: Access of Charles Sturt University computer labs by hours of the day, 2001-2003 all laboratories (in %). Figure taken from *Sessional, weekly and diurnal patterns of computer lab usage by students attending a regional University in Australia* (Spennemann et al., 2007)

Despite large periods of underutilization, many university IT departments have not configured computer power management settings to automatically put computers into standby or sleep mode when idle. In several cases computers were set to stay on indefinitely (Cabrera & Zareipour, 2011; Luberus & Nyandoro, 2014; Bishop et al., 2013). Similarly, power management settings were disabled in commercial settings (Mercier & Moorefield, 2011). University IT departments are often distanced from the energy saving policies of their university (Sheehan, 2010). Concerns over staff accessing computers remotely (Mercier & Moorefield, 2011), class time wasted waiting for computers to power on, and interference with computer updates (Bishop et al., 2013) are often cited as reasons for disabling power management settings. However, there are many network-based power-management systems that utilize Wake-on-Lan (WoL) technology to manage laboratory updates regardless of the power state of the computers (Mercier & Moorefield, 2011),[4] and higher performance SSDs have improved boot times.

Information about HSU's computer stock was provided by David Marshall, the head of Student Computing/Labs for HSU Information Technology Services (ITS). HSU operates about 1000 computers for "teaching and learning" purposes. The stock is generally composed of four types of PCs: (1) PCs with an SSD and integrated graphics, (2) PCs with an SSD and discrete graphics, (3) PC with a HDD and integrated graphics, and (4) PCs with a HDD and discrete graphics. The university is in the process of

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[4] See: https://www.energystar.gov/products/low_carbon_it_campaign/implementation_resources_enterprises/commercial_software

replacing all conventional HDDs with SSDs for the associated performance improvements; because of this, it was assumed that all PCs have SSDs in calculations for this project. Approximately 311 computers (or 30%) have discrete graphics cards installed. Additionally, approximately 10% of the computer stock on campus is made up of Apple Macintosh integrated desktops. Due to technological constraints, only Windows PCs were measured for this project.

The instructional computers on campus are set to a consistent power management plan. All computer displays are set to go to sleep after three hours of inactivity. Additionally, a majority of the computers are automatically shut down at 11:00 PM every night; ITS provided a list of 279 computers that are excluded from any automatic shutdown. ITS is interested in pursuing a more aggressive power management plan, but would like to justify any potential inconvenience imposed on users. Faronics Deep Freeze software is used to manage the instructional computers on campus. Every time a computer is restarted it is reset to a standard configuration. Because of this, a policy with automatic shutdowns, rather than sleep or standby, is preferred.

CHAPTER 3: METHODS

The analyses in this project can be broken into roughly five parts: (1) computer power consumption measurements, (2) monitor power consumption measurements, (3) usage pattern analysis, (4) simulations of baseline and alternate power plans, and (5) emissions reductions and cost savings estimates.

3.1 Computer Power Consumption Measurements

The computers' power consumption was analyzed in four states, which, for the purposes of this report, are referred to as: *active*, *short idle*, *long idle*, and *off* (see Table 5 for definitions). *Active* and *idle* power measurements were made using a "Watts-Up? Pro" data-logging power meter. *Off* mode power measurements were made using a "Kill-A-Watt" meter (meter specifications are listed in Appendix A).

Table 5. Definitions of the four computer power states referred to in this report. Definitions are adapted from *ENERGY STAR® Program Requirements for Computers, v6.1* (ENERGY STAR, 2016)

Power State Name	*Definition*
Active	A user is logged in to the computer and assumed to be performing general computing tasks (e.g. web browsing, word processing, etc.).
Short Idle	The computer is logged out and powered on; the computer display is still in active mode (i.e. backlight is powered on)
Long Idle	The computer is logged out and powered on; the computer display is in a low power state (i.e., backlight has been turned off)
Off	The computer is in its lowest power mode which cannot be switched off (influenced) by the user.

Active power consumption was measured for a period of 10 minutes while performing a sequence of basic computer tasks[5]. *Idle* power consumption was measured for a period of 5 minutes with the computer sitting at the login screen. In *long idle* mode its current draw was low enough to not register on the meter[6] and assumed to be 0. All measured values were sampled with a 1 second resolution and averaged over the 10-minute measurement period. An additional long-term measurement was made, with data loggers on the monitor and PC for 24 hours to compare the short-term tests to real-world usage.

Measurements were made on two computers representative of the majority of computers on campus. Information about these computers was presented in CHAPTER 2:. Both types of machines have SSD drives, one type has a discrete graphics card while the other does not. See Table 6 for detailed specifications of the computers used for testing.

Table 6. Specifications of computers chosen for testing.

Make/Model	**CPU**	**Storage**	**Graphics**
Dell Precision 3420	Intel® Core i5™-6500 @ 3.20 GHz	SanDisk X400 256GB SSD	Intel HD graphics 530, 1 GB (integrated)
Dell Optiplex 3020	Intel® Core i5™-4570 @ 3.20 GHz	Crucial M500 240GB SSD	AMD FirePro v4900, 1 GB (discrete)

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[5] Details of the test procedure are in Appendix B.

[6] The Watts Up? Pro meter reportedly has ±1.5% accuracy down to 0.5W (Hirst et al., 2013).

Boot up and login times for each computer were recorded by restarting and logging in to each computer three times. The *boot time* measures the elapsed time from pushing the power button to the computer displaying a login prompt. The *login time* measures the time required, after entering a username and password, for the computer to display the desktop and all icons. These values give some perspective on the potential inconvenience imposed on users who encounter a powered down computer.

3.2 Monitor Power Consumption Measurements

Computer monitor power consumption can vary dramatically between different models and with different brightness settings. Due to the lack of a complete inventory of computer monitors on campus, an ad hoc survey of a subset of computer labs was conducted. Approximately 125 computer monitors in six labs were surveyed. Monitor power consumption for each model was measured at five brightness levels (0%, 25%, 50%, 75%, and 100%), and the current brightness setting of every unoccupied station was recorded. The results of this survey were used to determine a range of power levels to use in a corresponding sensitivity analysis presented in Appendix C-2.

3.3 Usage Pattern Analysis

I based my analysis on computer login data logs that were provided by HSU ITS. See Appendix D for a sample of the type of login data that were provided. The logs record user login and logout times for all the campus computers during fall semester of 2016. With 304,477 entries, it was necessary to first clean up and sort the data. Any computers whose next login event occurred before the previous session ended (indicating a possible crash or other login error) were removed. In total, 10,598 entries were removed using these conditions (about 3% of the dataset).

The primary goal of the analysis was to estimate the amount of time each computer spends in each of the power states identified in Table 5, to be combined with measurements of power in those states for estimating campus-wide demand. Additionally, analysis was performed to develop a time of day usage profile and to gain statistical insight into the frequency of use of individual computer stations. The results of the former were used to make estimates of computer power usage and potential savings, while the results of the latter were used to identify the most effective energy reduction scheme balanced against an estimate of impact to user convenience.

It was assumed that if a user is logged in, then the computer is in use and performing general light-duty tasks such as web browsing and word processing. The power management plan described in the background section will be referred to as the *baseline* configuration. To estimate the amount of time spent in *short idle* and *long idle* states, it was assumed that every computer stayed powered on after its first login each day, entering the *short idle* state for three hours followed by the *long idle* state until another user logged into the same computer or it reached the shutdown time of 11:00 PM. Computers indicated by ITS to never automatically shut down were assumed to stay on overnight. These assumptions fail to account for computers that are manually switched off by users, though they are expected to be in the minority. A sensitivity analysis was performed to quantify the impact manual shutdowns would have on overall energy consumption (see Appendix C-1).

To create a profile of computer usage throughout the day, the number of concurrent logins was averaged over the entire semester on a per-minute basis. The results were grouped by day of the week to reveal typical peak usage periods.

I determined the time between logins only during the hours of 8:00 AM – 6:00 PM, since it encompasses the majority of computer use during the day and avoids skewing the results with the long periods of inactivity overnight. The goals were to find the amount of time that a computer typically goes unused before another person logs in and to provide an estimate of the likelihood that the next user encounters a computer that has turned off automatically.

3.4 Simulations of Baseline and Alternate Power Plans

The same login data were used to simulate the effects of alternate computer power management plans. It was assumed that the computers were used for the same duration and at the same time of day (i.e. the *active* time did not change). However, the time spent in *short ide* and *long idle* were reduced, with the computers set to turn off completely if enough time passed before another user logged in. In this way, the effects of different timeout limits could be directly compared to the *baseline* configuration described above.

3.5 Emissions Reductions and Cost Savings Estimates

Greenhouse gas (GHG) emissions due to electricity usage can be estimated using an emission factor for the electricity supplier. The emission factor is the average emissions per unit of energy produced for all sources from which electricity is purchased.

HSU purchases electricity through an agreement with Shell Energy. The 2014 power content label for Shell Energy[7] was used to estimate the appropriate emissions factor. In 2014, 34.5% of the energy sold to HSU was produced by renewable generators (wind, solar, etc.). An additional 9.4% was produced by other carbon-neutral generators (large hydroelectric and nuclear), 32% by natural gas generators, and 24.1% from unspecified sources. Renewable sources, large hydroelectric, and nuclear were all assumed to have net zero GHG emissions, consistent with California state GHG reporting policy (California Air Resources Board, 2015). An emission factor of 0.553 metric tons of CO_2 per MWh, based on the average heat rates for gas-fired steam-electric generators in California in 2014 (7,760 Btu/KWh), was used for natural gas (Nyberg, 2016). The California Air Resources Board specifies a standard emission factor of 0.428 metric tons of CO_2e per MWh for unspecified sources (California Air Resources Board, 2015). The total emission factor for electricity purchased by the university is therefore 0.280 metric tons of CO_2e per MWh.

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[7] The 2014 power content label was the most recent at the time of writing. A copy is included in Appendix E.

The avoided GHG emissions were calculated using the following equation:

$$\mathrm{CO_2}e = kWh \times TL \times EF_i$$

Where:

- CO_2e = Annual CO_2 equivalent mass emissions
- kWh = Kilowatt-hours
- EF_i = 0.280 MT CO_2e/MWh
- TL = 1.0576; Transmission loss correction factor, using eGRID2012 Western US gross grid loss factor (The Emissions & Generation Resource Integrated Database, 2012)

HSU's electricity service is billed by time-of-use with additional peak demand charges. Morgan King, the HSU Sustainability & Waste Coordinator, provided an estimate of the average electricity prices paid by HSU based on energy bills from the 2015/2016 school year. For cost savings calculations, the average price of \$0.1215 per kWh was used.

CHAPTER 4: RESULTS

4.1 Computer Power Consumption

For the two computer models that were measured directly, electrical power consumption was found to be between 22 and 30 Watts when powered on (see Table 7). There was a small difference observed between computers with and without discrete graphics cards. A weighted average of the two types of computers measured was used to estimate energy consumption across all instructional computers on campus.

Table 7. Computer power requirements (not including monitor). The weighted average is calculated by assuming 70% of computers have integrated graphics and 30% have discrete graphics cards based on estimates of computer stock provided by ITS.

Computer Model	**Active (Watts)**	**Idle (Watts)**	**Off (Watts)**
Dell Precision 3420 (integrated graphics)	24.8	22.0	0.9
Dell Optiplex 3020 (discrete graphics card)	30.4	28.0	0.9
Weighted Average	**26.5**	**23.8**	**0.9**

4.2 Monitor Power Consumption

In the subset of computer labs surveyed, computer monitor power consumption varied from as low as 4.5 W to as high as 28.8 W across different models and different brightness settings. Some of the monitors surveyed were newer LED (light emitting diode) backlit models, but many had older CFL (compact fluorescent) backlights. The

LED monitors generally consumed less power despite having larger displays than the CFL-backlit models.

The power consumption of the monitors varies in a roughly linear fashion as the brightness is changed. The profile for each of the tested monitors is shown in Figure 2. The 27-inch Dell P2717H was the only LED monitor to use more power than a CFL monitor, but it was also the largest monitor tested by a wide margin. The range of power consumption between the lowest and highest brightness settings was significant. At 100% brightness, the monitors consumed between two and five times as much power as they did at 0%. In one case (the Dell P2717H, 27” LED monitor) there was a 19 Watt difference between 0% and 100% brightness settings. Additional information about monitor power consumption measurements is included in Appendix F.

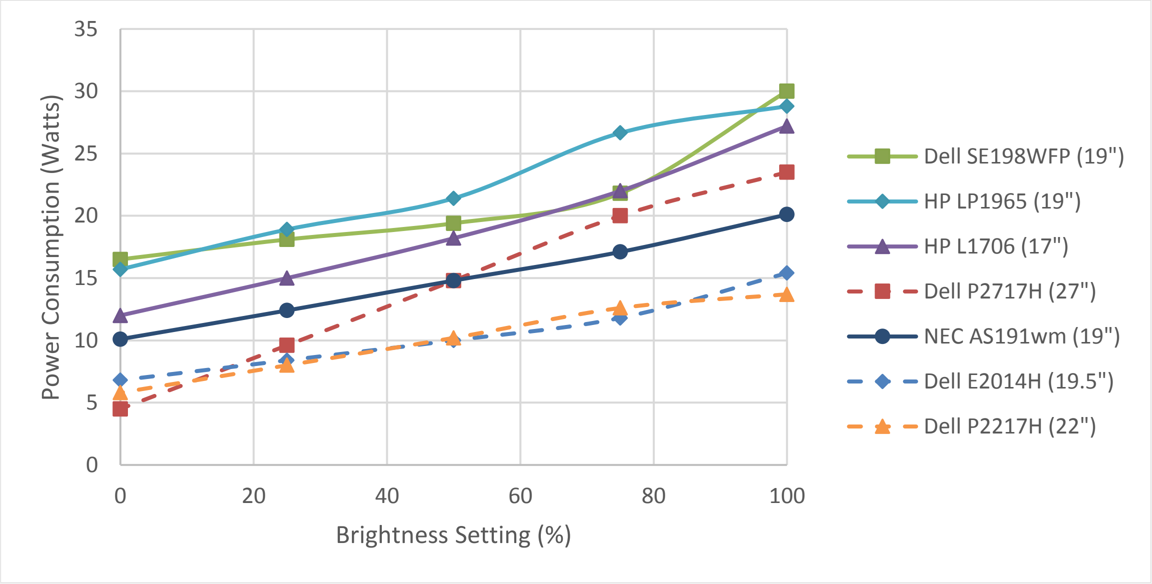

Figure 2: Computer monitor power consumption at various brightness settings. LED-backlit monitors are represented by dashed lines and CFL-backlit monitors are represented by solid lines.

The brightness setting of the monitor is set using the buttons on the panel by individual users; on a desktop computer, the computer itself cannot control the monitor's brightness. As such, many monitors may have been changed from the factory default brightness setting. To gain a general sense of the habits of users, a sample of 60 monitors from six computer labs were inspected and their brightness settings were recorded. The factory default brightness for the tested monitors ranged from 75% to 90%. A majority of the observed monitors had been set to brightness levels higher than the default; the median monitor brightness setting was 81% and the average was 77%. The distribution of brightness settings in the sampled group is shown in Figure 3.

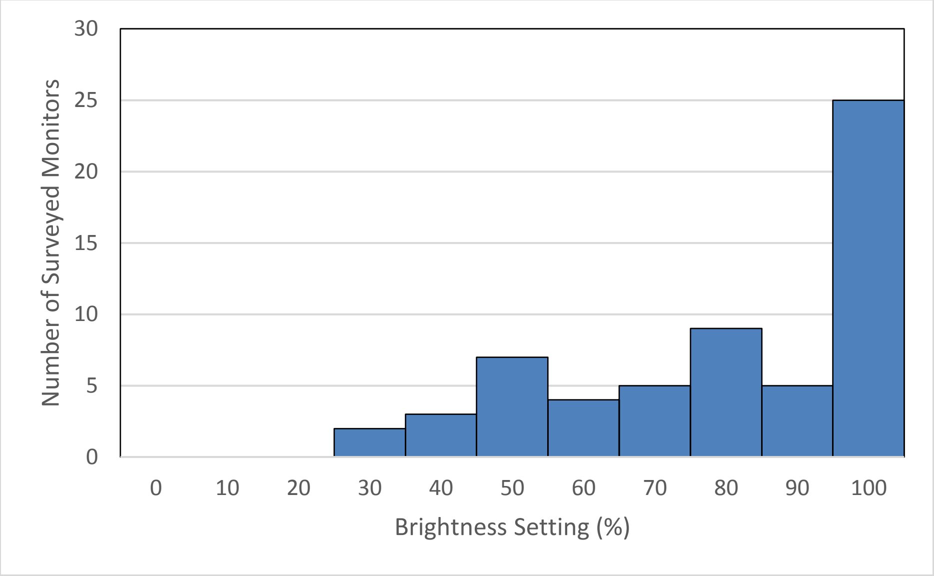

Figure 3: Distribution of computer monitor brightness settings among surveyed monitors.

Based on this, the average power consumption of the monitors at 75% brightness (20 Watts) was used for the baseline energy consumption calculations. Additionally, a sensitivity analysis was performed for monitor power consumption values between 10 and 30 Watts.

4.3 Usage Pattern

Typical computer usage patterns were found by analyzing the login data for all of fall semester 2016. Figure 4 shows the average number of computers in use by time of day throughout the month. Looking at this plot, some common patterns become apparent. Computer usage on Monday through Thursday is largely the same, with the bulk of users logging in around 9:00 AM, peaking around noon, and steadily dropping off after 6:00 PM (18:00). Friday’s usage profile is similar to the rest of the week, but there are significantly fewer computers in use and usage drops off earlier in the day. Weekend usage is lower still and peaks later in the day (around 3:00 to 4:00 PM). This usage profile closely resembles the results of a similar study discussing in Chapter 2 (see Figure 1). Additional plots showing usage profiles are presented in Appendix G.

The maximum number of concurrent users during the semester was 506, yet the number of unique computers used during a day was regularly over 900. That is, the number of computers turned on each day is often over 170% of the peak number of computers concurrently in use at any one time. This is to be expected with fixed computers installed in labs throughout campus, but when computers are not automatically shutdown this results in hundreds of extra computers running during the day.

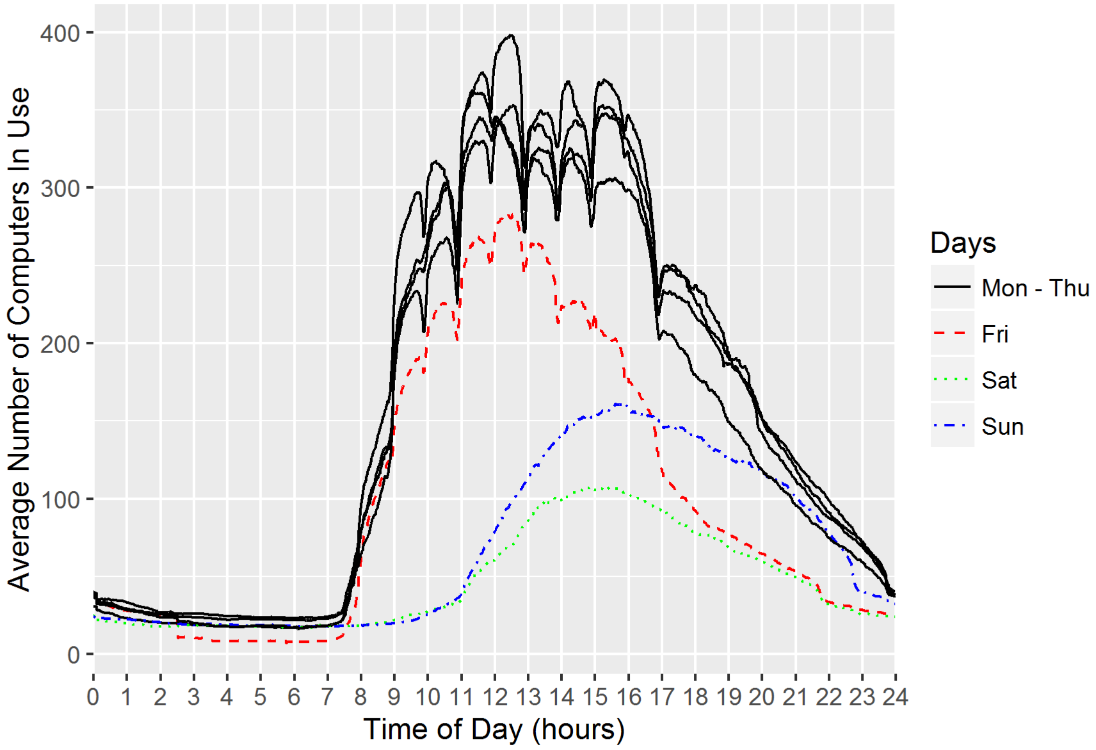

Figure 4. The average number of computers in use throughout the day during the fall semester of 2016.

Since the majority of computer use occurs on weekdays between 8:00 AM and 6:00 PM, this time range was used to investigate the amount of time computers spend inactive between individual users. Figure 5 shows a cumulative distribution of the time between logins during working hours. Approximately 49% of logins occur within 10 minutes of the previous logout, 69% within 30 minutes, and 81% occur with an hour.

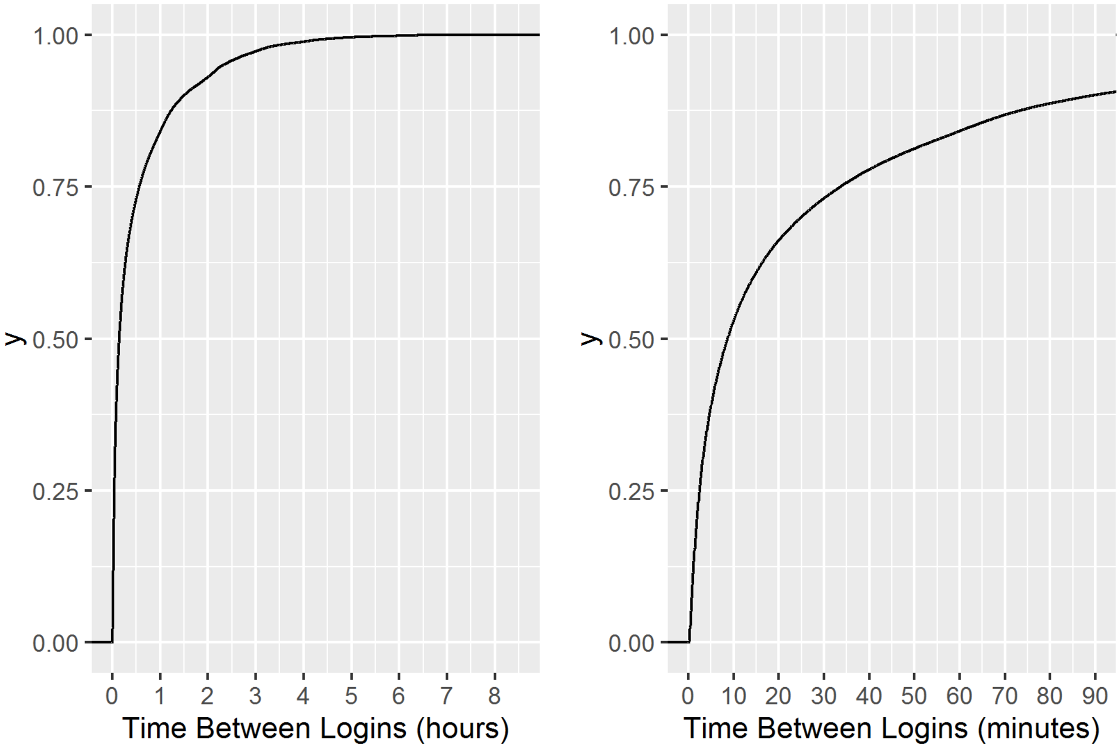

Figure 5. A cumulative distribution of the time between logins on weekdays between 8:00 AM and 6:00 PM. The full distribution is shown on the left; the plot on the right is enlarged to show additional detail for time intervals of 90 minutes and less.

One potential drawback of implementing an automatic shutdown power plan is that more students and faculty would have to wait for computers to turn on before using them. The startup times of several computers were measured and are presented in Table 8. On the computers tested, booting the computer added 25 to 34 seconds to the total log in time. However, the total time to boot and log in was still only approximately one minute.

Table 8. Time required to power on and log in to computers.

Computer Model	**Boot Time (seconds)**	**Log in Time (seconds)**	**Total (mm:ss)**
Dell Precision 3420	25	42	1:07
Dell Optiplex 3020	34	25	00:59

During working hours, the average computer session duration was 43 minutes. The maximum boot time of 34 seconds represents 1.3% of that time. With a timeout period of 30 minutes, users would only have to wait for computers to startup an average of 31% of the time, meaning the average additional delay per login is only 9 seconds.

4.4 Energy Consumption

The primary motivation for implementing a computer power management plan is energy conservation and the associated reductions in GHG emissions and cost. To estimate the energy savings we must first calculate a baseline energy consumption value for the campus computers.

The total baseline weekly computer energy consumption is shown in Figure 6, assuming all computers use the existing power management plan described in Chapter 2. On average, 56% of the total energy consumed each week was used to power computers not being used (i.e. those in *short idle* and *long idle* states). Throughout the semester, the computers are estimated to use 35,391 kWh. HSU Facilities Management provided monthly utility billing information for the 2015/2016 school year; by interpolating for the fall semester of 2015, the total electricity consumption of the campus for that semester was estimated to be 4.5 TWh (4,500,000 kWh). Therefore, the consumption of instructional computers represented only 0.8% of the total electricity consumption of the campus.

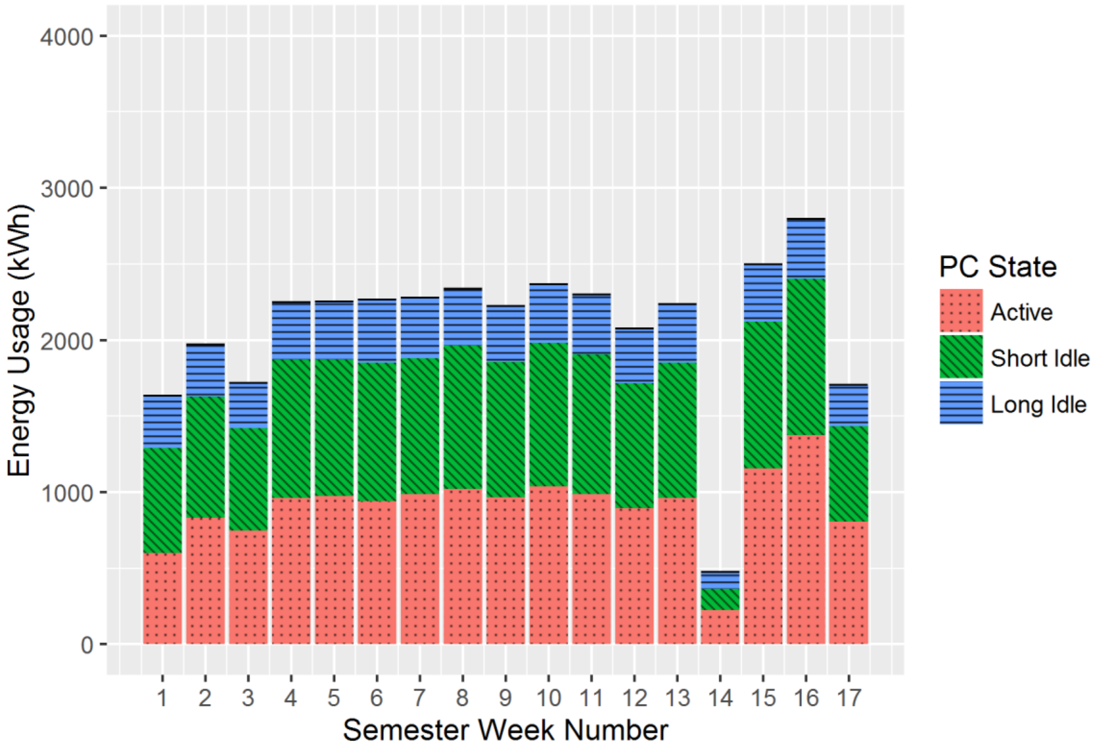

Figure 6. Estimated *baseline* weekly energy usage throughout the semester. Week 14 corresponds to the Thanksgiving holiday break, week 17 is finals week.

Figure 7 shows the estimated weekly energy consumption in each state if the computers were set to turn off automatically after 30 minutes[8] of idle time. In this case, the portion of energy wasted in idle states would be reduced to only 20% of the total.

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[8] ENERGY STAR default sleep time is 30 minutes, with monitor going into sleep mode after 15 minutes of inactivity (Computer Key Product Criteria, 2017).

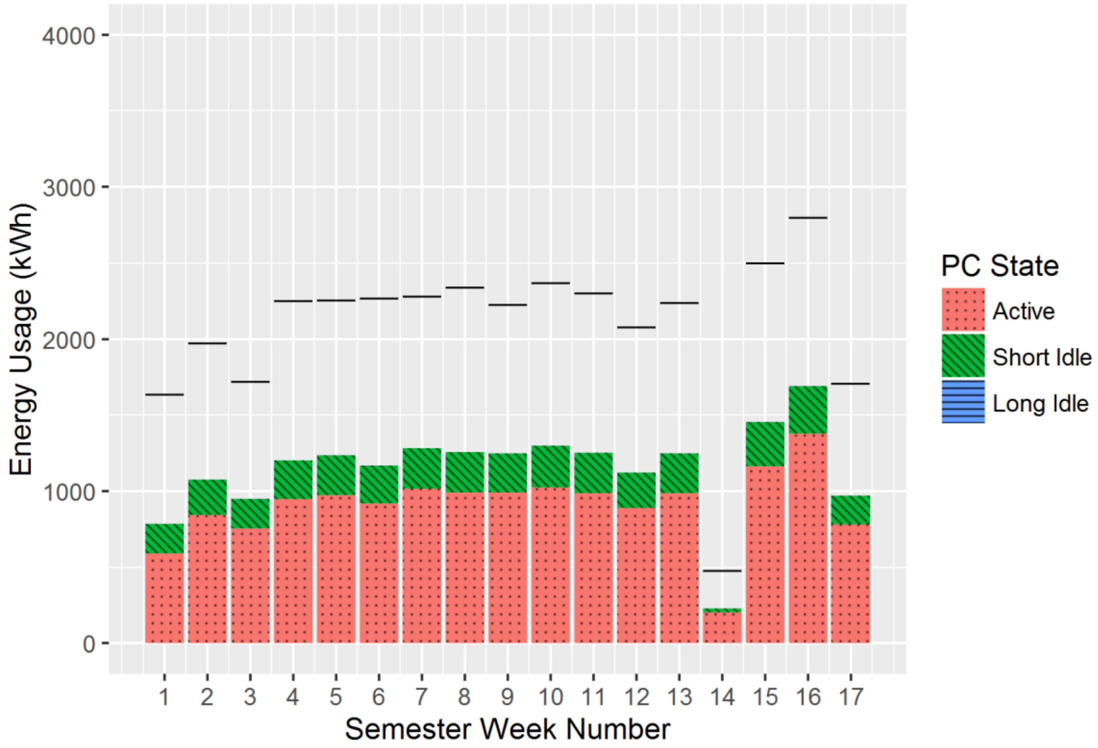

Figure 7. Estimated weekly energy usage throughout the semester with computers set to turn off after 30 minutes. The baseline energy usage is marked with horizontal black lines. Week 14 corresponds to the Thanksgiving holiday break, week 17 is finals week.

4.5 Emissions Reductions and Cost Savings

In Table 9, the energy consumption, costs, and associated GHG emissions of each simulated power management plan are compared with the baseline. Even relatively long timeout periods yield significant cost and GHG emissions reductions. Even a long 90-minute timeout period reduces computer electricity costs end associated emissions by 42% or $1,337 and 5.2 metric tons per semester.

Table 9. Estimated energy consumption, cost, and CO_2e emissions associated with each power plan for fall semester 2016.

Power Plan	**Energy Usage (kWh)**	**Energy Cost**	**GHG Emissions (MT CO_2e)**	**Cost Savings**	**GHG Reduction (MT CO_2e)**	**Percent Change in GHG Emissions**
Baseline	35,391	$4,300	8.8	--	--	--
90 Minute	24,391	$2,963	6.1	$1,337	2.7	-31%
60 Minute	22,209	$2,698	5.5	$1,602	3.3	-37%
30 Minute	19,466	$2,365	4.8	$1,935	4.0	-45%
20 Minute	18,372	$2,232	4.6	$2,068	4.2	-48%
10 Minute	17,110	$2,079	4.3	$2,221	4.5	-52%

As the timeout period shortens, energy consumption falls more rapidly. The results of a sensitivity analysis are shown in Figure 8. An automatic shutdown timeout of nearly any length offers significant energy savings, but the shorter the timeout is, the more effective it becomes. Though the shortest possible timeout results in the most energy savings, it must be balanced with the impact to user convenience.

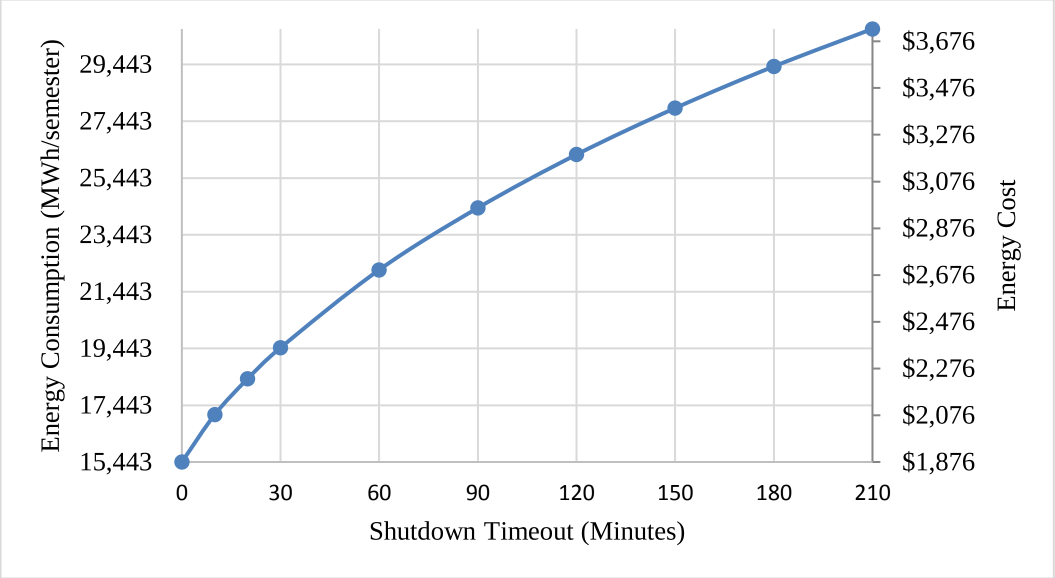

Figure 8: Sensitivity analysis of the effect of shutdown timeout lengths on total semester energy consumption and energy cost.

CHAPTER 5: DISCUSSION

The results of this project indicate that, in their current configuration, instructional computers at HSU waste more than half of the electrical energy that they consume while sitting idle and unused. There are significant energy savings to be had through no- to low-cost automatic power management.

The electricity consumption of the instructional computers at HSU is surprisingly small when compared to the total consumption of the campus (only 0.8%). However, the scope of this project covers only computers used for teaching and learning purposes. It does not consider other administrative computers, servers, printers, and similar electronics being used on campus. Though their consumption is small when compared to the campus as a whole, it should not be considered insignificant. An average American home consumes 901 kWh per month (U.S. Energy Information Administration, 2016). Over the four months of fall semester, HSU instructional computers consumed an estimated average of 8,850 kWh per month, enough electrical energy to power 9.8 homes for the same four months.[9]

There are several steps that could be taken to reduce computer energy use on campus. The single most cost effective solution would be to implement an automatic power management policy for idle computers. With no additional equipment investments

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[9] For the purposes of this project, no estimate was made for energy consumption during the summer session or winter break; therefore, no annual total has been calculated. However, it should be safe to assume that spring semester closely resembles fall semester.

and minimal user inconvenience, the energy use of instructional computers could be halved.

The large variance in computer monitor power usage makes it difficult to precisely calculate their impact on overall computer energy use at HSU. It is clear that significant energy gains could be made by replacing CFL-backlit monitors with newer LED-backlit models and by encouraging lower brightness settings. Mercier & Moorefield (2011) came to similar conclusions, where monitor brightness changes, in one case, reduced consumption by 27% while maintaining full readability. However, it is difficult to know how long changes in monitor brightness would persist. It is unlikely that cost savings alone would justify the replacement of monitors, but it should easily make it beneficial to invest in LED models when it comes time for regularly scheduled replacement.

The computer usage pattern on campus resembles results of similar studies discussed in the background section. The computers on campus are never 100% utilized; usage follows a distinct diurnal and weekly pattern, and, at most, only half of the available computers are ever in use concurrently. Arguments could be made in favor of mobile computers rather than desktops, both for energy efficiency and for increased utilization rate. However, such a change poses significant security and management challenges.

The next user of each computer usually logs in shortly after the logout of the previous user, which makes even relatively short timeout periods have little effect on users. To balance between user impact and energy savings I recommend a timeout of around 30 minutes. At 30 minutes, 69% of users logging into computers during business hours would notice no difference from the baseline configuration (computers should still be available and powered on) and energy consumption is still reduced by a substantial 45% compared to the baseline. The cumulative distribution in Figure 5 shows that longer timeout periods would have diminishing returns in terms of increased user convenience.

The total weekly and semester energy consumption are also enlightening. After the first few weeks of the semester, it appears that computer usage levels off. As expected, during break there is a dramatic decrease in the number of students on campus and consequently much less computer use. I did not attempt to extrapolate the results of this project to include summer session and the winter break. Computer use would likely be substantially lower in both cases, but it is difficult to estimate without additional data about the number of students on campus.

The total cost savings and emissions reductions associated with automatic power management plans are small when compared to the university's total energy usage, but should not be overlooked. Implementing a 30-minute timeout results in energy savings 16 MWh per semester, the equivalent of 4.4 houses' electricity usage. The cost savings of $1,935 are also small but not insignificant. It should be possible to implement an automatic power management policy with existing technology in use on campus and with minimal impact to IT staff.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

In their current configuration, the instructional computers at HSU are estimated to consume 35,391 kWh and indirectly emit 8.8 metric tons of CO_2e per academic semester. Approximately 56% of the energy consumed by computers each week is wasted keeping unused computers powered on. By setting computers to automatically shut down after 30 minutes of inactivity, CO_2e emissions could be reduced by 4 metric tons per semester while saving $1,935 in electricity costs.

The wide variation in computer monitor power consumption had a larger impact on the results than anticipated. Brightness adjustments and the difference between LED and CFL backlit monitors result in potential power levels between 4.5 W and 28.8 W, a difference of 600%. Reducing the power level of monitors by 10 Watts would result in a 21% reduction in overall computer energy consumption in the current configuration.

I recommend further investigation of the current stock of monitors on campus and of techniques to encourage lower brightness settings to further increase energy savings. Replacing older CFL-backlit monitors with new LED-backlit models would likely save energy in addition to providing larger, higher resolution displays. Depending on the current refresh cycle at HSU, it may also prove to be cost effective to perform early replacement of monitors. Simply setting the brightness level of monitors to a lower level could also save a considerable amount of energy, though users may manually readjust the brightness setting to a higher level. A study of user behavior, acceptance, and the usability of lower monitor brightness levels may help in estimating the permanence of such changes.

Common-sense computer power management at HSU has the potential to save money and to reduce the carbon footprint of the university. This represents a low-cost energy efficiency measure with the potential to save 16,000 kWh per semester.

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APPENDIX A: TEST EQUIPMENT SPECIFICATIONS

The manufacturer’s specifications for the power meters used are listed in section A-1 and A-2 below.

A-1 Watts-Up Pro

- Model: WU-PRO
- Operating Voltage: 120 V
- Maximum current: 15 A
- Maximum sampling speed: 1 sample per second
- Accuracy: ±1.5%, + 3 counts of the displayed value
    - Below 60 watts, current and power factor decrease in accuracy
- Minimum measurable power: 0.5 watts
    - Note: at 0.5 watts, the accuracy is ±0.3 watts

A-2 Kill-A-Watt Meter

- Model: P4400
- Maximum Voltage: 125 VAC
- Maximum Current: 15 A
- Display Update: 1 second
- Accuracy: Typ. 0.5%, Max 2%

APPENDIX B: ACTIVE/IDLE POWER TEST PROCEDURE

To simulate a typical computer session, the sequence of actions listed in Table B-1 was performed on the test computer while logging power consumption. The results are presented in Section 4.1.

Table B-1: Test sequence used to simulate active and idle modes while measuring computer power consumption.

Duration (minutes)	**Test State**	**Action**
1	Active	Browse Humboldt.edu website
1	Active	Browse Wikipedia.org website
1	Active	Edit Word document
1	Active	Edit Excel document
1	Active	Edit PowerPoint document
5	Active	Idle desktop, applications minimized in background
5	Idle	Login screen

APPENDIX C: SENSITIVITY ANALYSES

Additional sensitivity analyses were performed to estimate the effect of users manually shutting down computers and of variable computer monitor power consumption. Both variables are difficult to measure accurately and have the potential to change the total estimated energy consumption. The sensitivity analyses are presented in Section C-1 and C-2 below.

C-1 Manual Shutdown

Undoubtedly, some people will manually shutdown their computer after logging out, resulting in lower energy consumption in both the baseline and power management plan scenarios. However, the probability of users manually shutting down their computer is outside the scope of this project. A sensitivity analysis (Figure C-1) was performed to estimate the potential impact manual shutdowns would have on the energy consumption estimates presented in this report. A pseudo random number generator was used to simulate a portion of computer sessions being ended with a shutdown rather than just a logoff. Probabilities between 0% and 20% were simulated. The overall effect was moderate; for example, a 10% probability of manual shutdown results in a 6% drop in energy consumption.

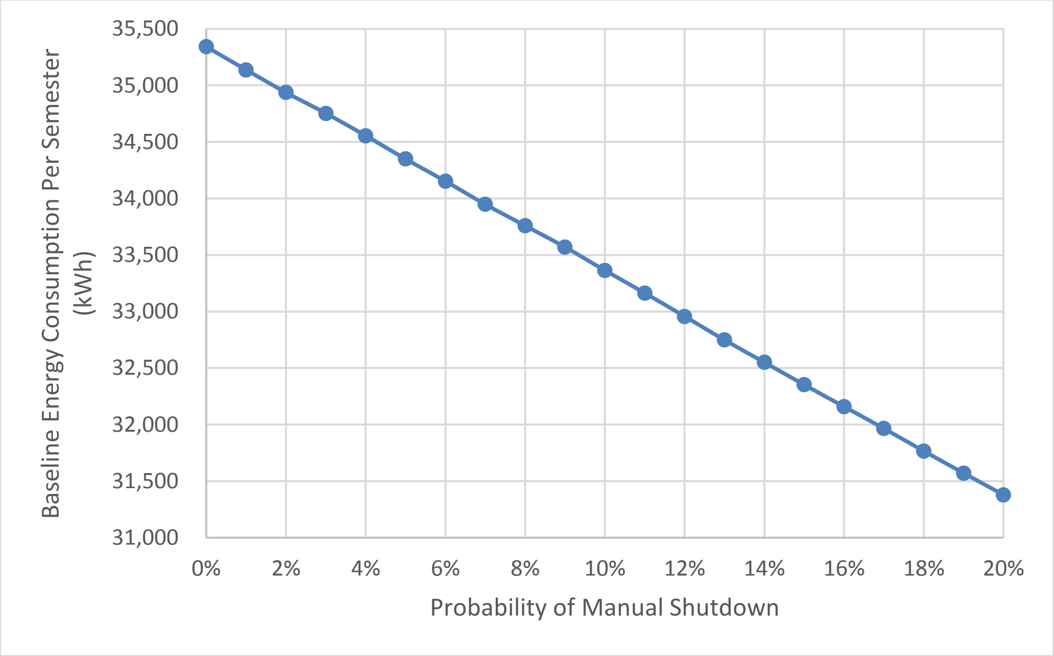

Figure C-1: Sensitivity analysis of manual computer shutdowns.

C-2 Monitor Power Consumption

Since monitor power consumption was found to have wide variation from model to model, a sensitivity analysis was performed to examine the effect on total energy consumption (Figure C-2). The relationship between monitor power consumption and overall computer energy consumption is linear. A change of 10 Watts in power consumption results in a 21% change in overall computer station energy consumption. Two of the low-power LED-backlit monitors tested use approximately 10 Watts at a 50% brightness setting, while others consume up to 21 Watts at the same brightness setting. Actual brightness was not quantitatively measured for this project.

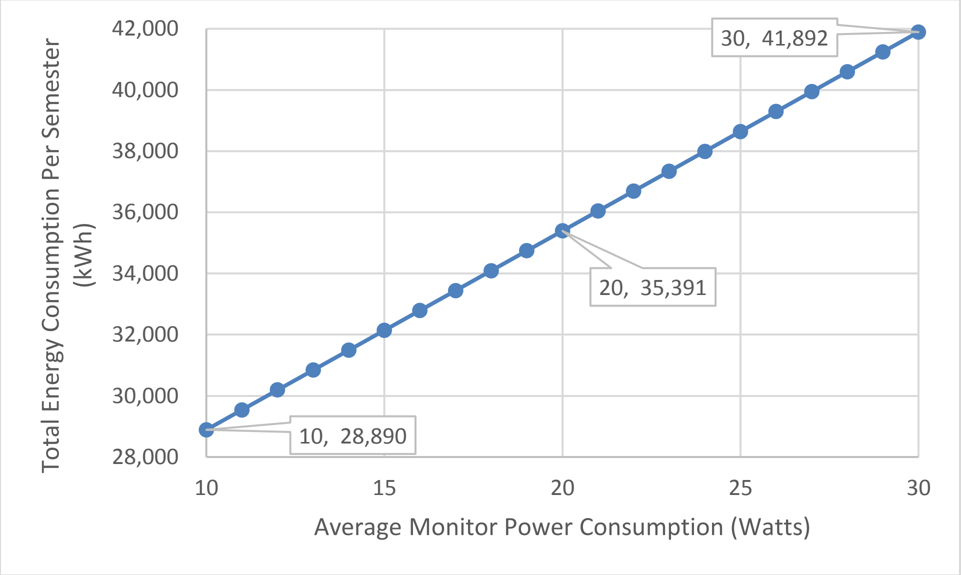

Figure C-2: Computer monitor power consumption sensitivity analysis.

APPENDIX D: SAMPLE LOGIN DATA

A sample of the user login data provided by ITS is shown in Table D-1.

Table D-1: Sample login data with unique computer name, anonymized user ID, login start and end timestamps, and duration of session in seconds.

Machine	User ID	Start	End	Duration
LIB120-LAB01-M	119095	8/17/2016 8:00	8/17/2016 8:16	970
LIB120-LAB01-M	327509	8/17/2016 8:17	8/17/2016 8:54	2200
LIB122-LAB40W	551929	8/17/2016 8:47	8/17/2016 9:24	2224
LIB122-LAB20W	197977	8/17/2016 8:59	8/17/2016 9:58	3582
LIB122-LAB20W	197977	8/17/2016 8:59	8/17/2016 9:58	3582
Lib122-lab06W	598779	8/17/2016 9:13	8/17/2016 10:21	4103
LIB122-LAB40W	442882	8/17/2016 9:34	8/17/2016 9:41	431
LIB122-LAB09W	535120	8/17/2016 9:42	8/17/2016 9:57	922
LIB122-LAB09W	535120	8/17/2016 9:42	8/17/2016 9:57	922
LIB122-LAB40W	300972	8/17/2016 9:58	8/17/2016 10:02	260
Lib122-Lab18W	130263	8/17/2016 10:44	8/17/2016 11:47	3737
LIB122-LAB40W	417002	8/17/2016 10:52	8/17/2016 10:54	140
LB301-CLB08W	66057	8/17/2016 10:53	8/17/2016 11:00	420
LB301-CLB06W	66057	8/17/2016 10:54	8/17/2016 11:01	420
LIB122-LAB32W	37756	8/17/2016 10:54	8/17/2016 11:55	3694
LIB122-LAB20W	197977	8/17/2016 11:00	8/17/2016 11:03	190
LIB122-LAB20W	197977	8/17/2016 11:00	8/17/2016 11:03	190
LIB122-LAB09W	7467	8/17/2016 11:18	8/17/2016 11:35	1011
LIB122-LAB09W	7467	8/17/2016 11:18	8/17/2016 11:35	1011
SCIA565-LAB07W	552755	8/17/2016 11:53	8/17/2016 15:56	14544
LIB122-LAB20W	197977	8/17/2016 11:58	8/17/2016 11:59	90
LIB122-LAB20W	197977	8/17/2016 11:58	8/17/2016 11:59	90
SCIA565-LAB05W	284935	8/17/2016 12:01	8/17/2016 15:52	13872
LIB122-LAB40W	51234	8/17/2016 12:12	8/17/2016 12:14	110
LIB122-LAB40W	250306	8/17/2016 12:16	8/17/2016 12:36	1181
LIB122-LAB12W	598776	8/17/2016 12:34	8/17/2016 12:48	819
LIB122-LAB12W	598776	8/17/2016 12:34	8/17/2016 12:48	819
LIB122-LAB40W	426488	8/17/2016 12:42	8/17/2016 12:55	781

APPENDIX E: SHELL POWER CONTENT LABEL

HSU purchases electricity through a contract with Shell Energy. As a result, the power mix is different from that provided by the local utility. The power content label in Table E-1 indicates the actual mix of power sources used by Shell Energy in 2014.

Table E-1: Shell Energy power content label for 2014 sales to the California State University system.

ENERGY RESOURCES	2014 POWER MIX (Actual)	2014 CA POWER MIX**
Eligible Renewable	**34.5%**	**20%**
-- Biomass & waste	3.8%	3%
-- Geothermal	3%	4%
-- Small hydroelectric	2%	1%
-- Solar	3.7%	4%
-- Wind	22%	8%
Coal	0%	6%
Large Hydroelectric	3.9%	6%
Natural Gas	32%	45%
Nuclear	5.5%	9%
Other	0%	0%
Unspecified sources of power*	**24.1%**	**14%**
TOTAL	**100%**	**100%**

* "Unspecified sources of power" means electricity from transactions that are not traceable to specific generation sources and ISO imports.

** Percentages are estimated annually by the California Energy Commission based on the electricity sold to California consumers during the previous year

2014 Power Mix represents Shell Energy purchases from specific eligibile renewable energy resources and ISO System Power on behalf of the California State Universities.

APPENDIX F: MONITOR POWER CONSUMPTION MEASUREMENTS

The computer monitors' power consumption was measured through a range of backlight brightness settings, from 0% to 100%, in 25% increments. The full measurements, as well as sleep mode power measurements are presented in Table F-1.

Table F-1: Summary of sampled monitors and measured power consumption at brightness settings from 0% to 100%.

Model	Backlight	Size (in)	Default Setting	Power at 100% (W)	Power at 75% (W)	Power at 50% (W)	Power at 25% (W)	Power at 0% (W)	Sleep (W)
Dell E2014H	LED	19.5	75%	15.4	11.8	10	8.4	6.8	0.4
Dell P2217H	LED	22	75%	13.7	12.6	10.2	8	5.8	0.0
Dell P2717H	LED	27	75%	23.5	20	14.8	9.6	4.5	0.6
Dell SE198WFP	CFL	19	75%	30	21.8	19.4	18.1	16.5	0.4
HP L1706	CFL	17	90%	27.2	22	18.2	15	12	0.4
HP LP1965	CFL	19	90%	28.8	26.65	21.4	18.9	15.7	1.3
NEC AS191wm	CFL	19	80%	20.1	17.1	14.8	12.4	10.1	0.3

APPENDIX G: DAILY USAGE PROFILES

The average daily usage profiles for each day of the week are presented in Figures G-1 through G-7. The profiles were created by averaging all concurrent logins by minute over fall semester 2016.

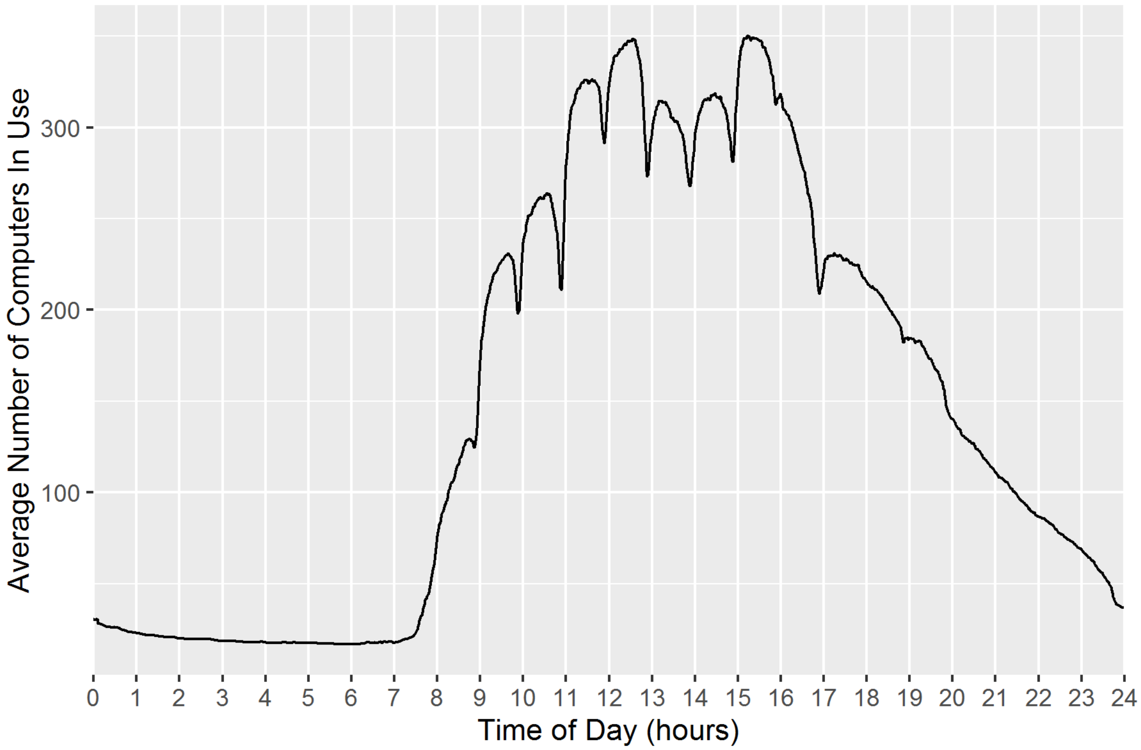

Figure G-1: Average usage profile for Monday.

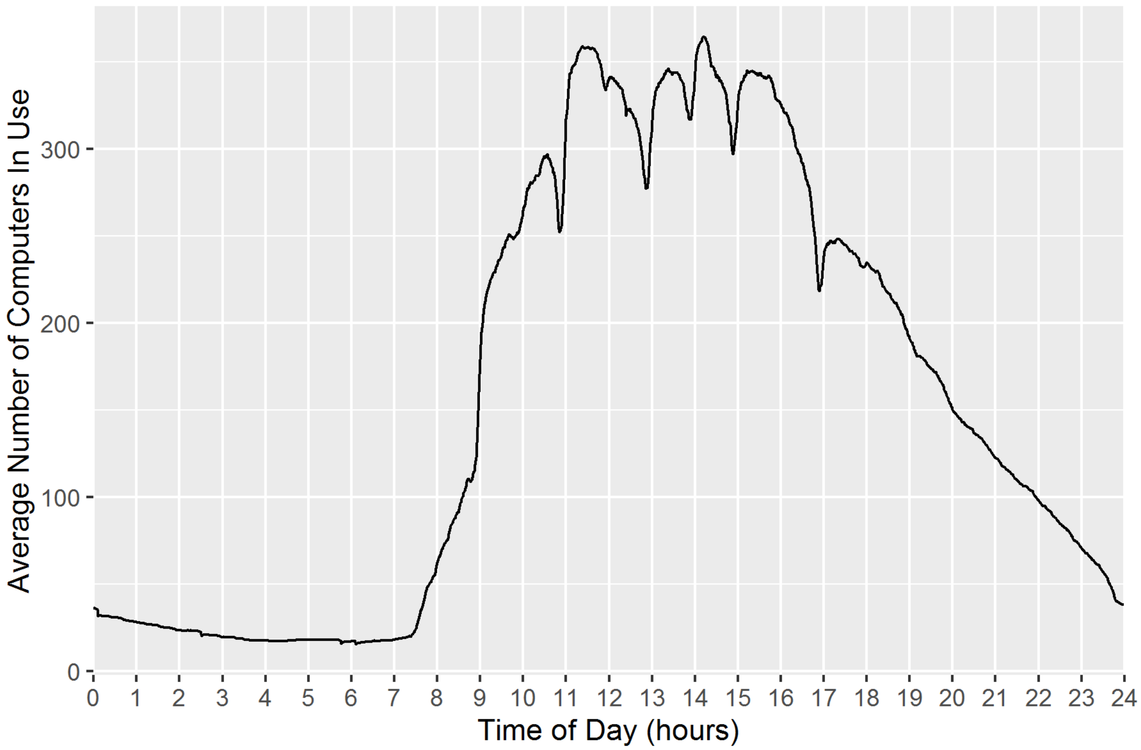

Figure G-2: Average usage profile for Tuesday.

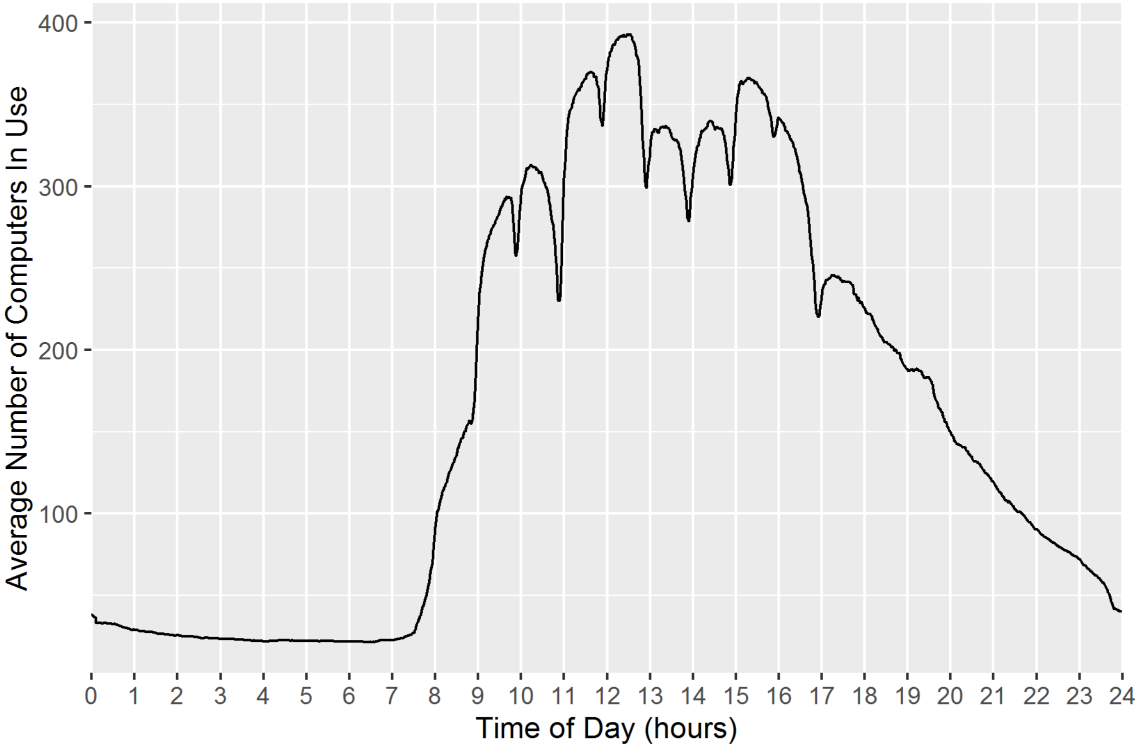

Figure G-3: Average usage profile for Wednesday.

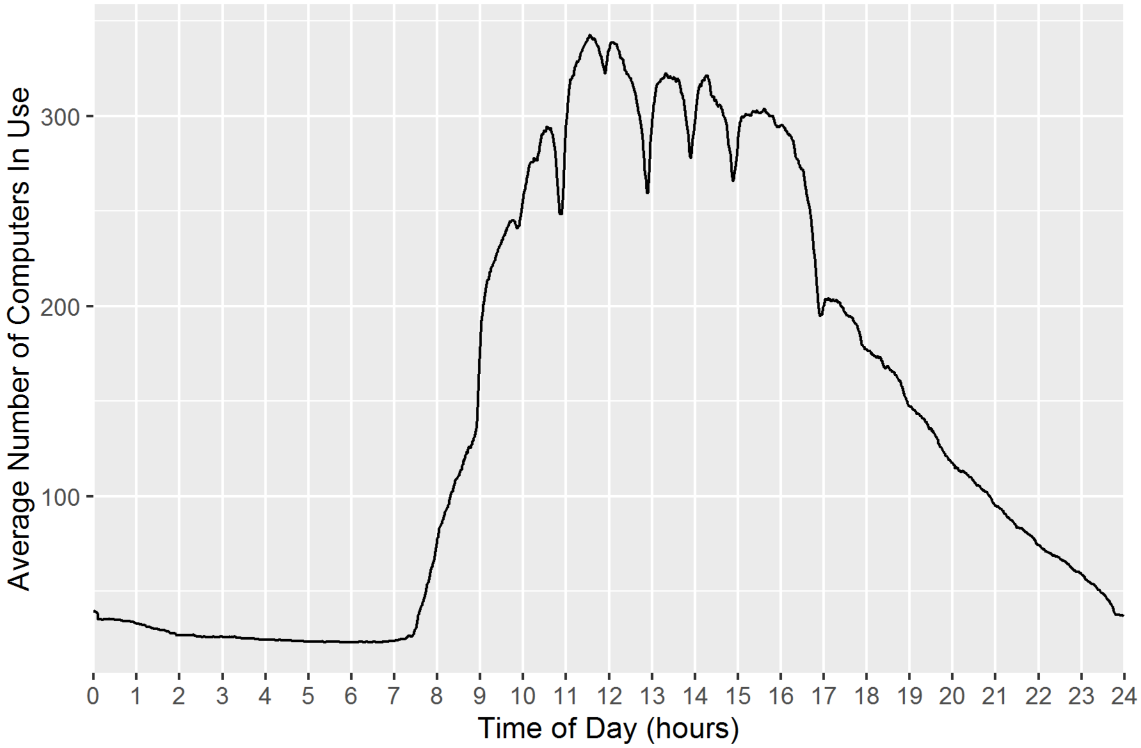

Figure G-4: Average usage profile for Thursday.

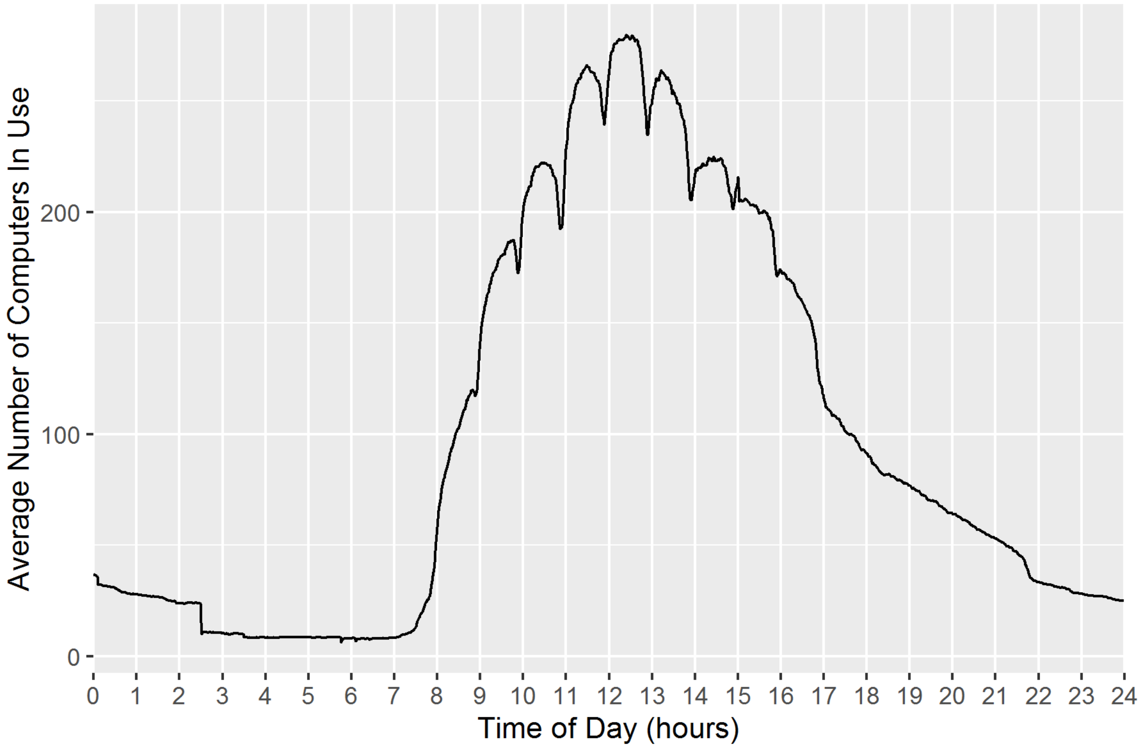

Figure G-5: Average usage profile for Friday.

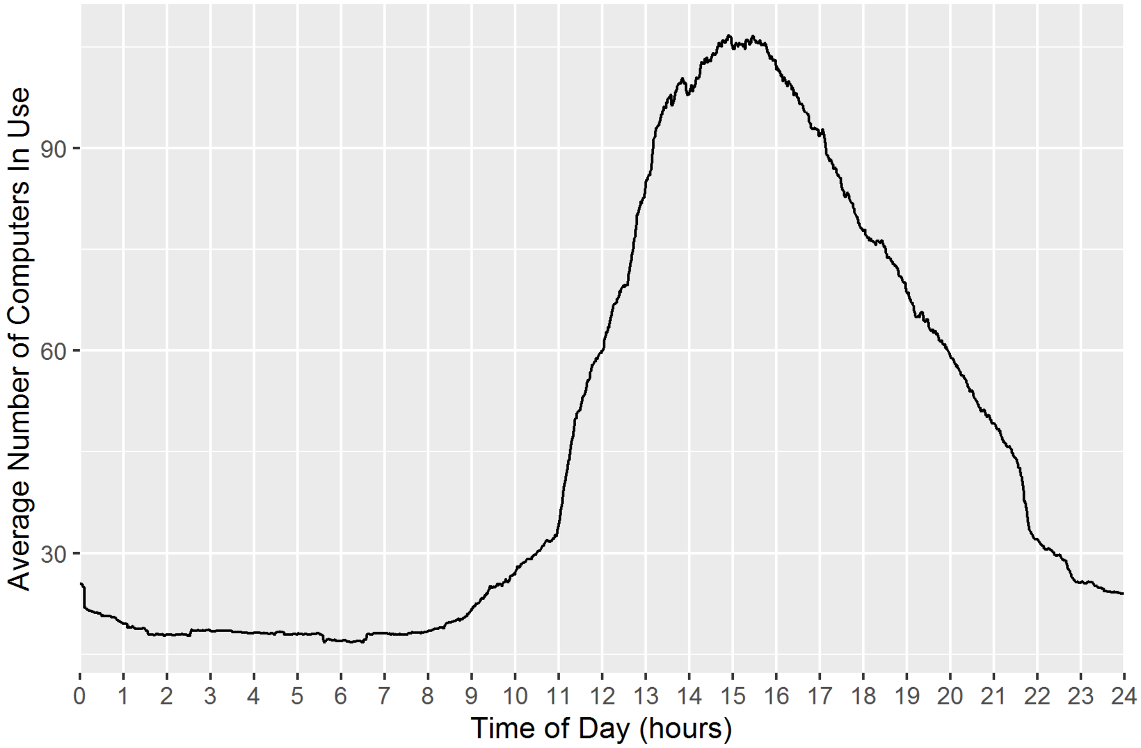

Figure G-6: Average usage profile for Saturday.

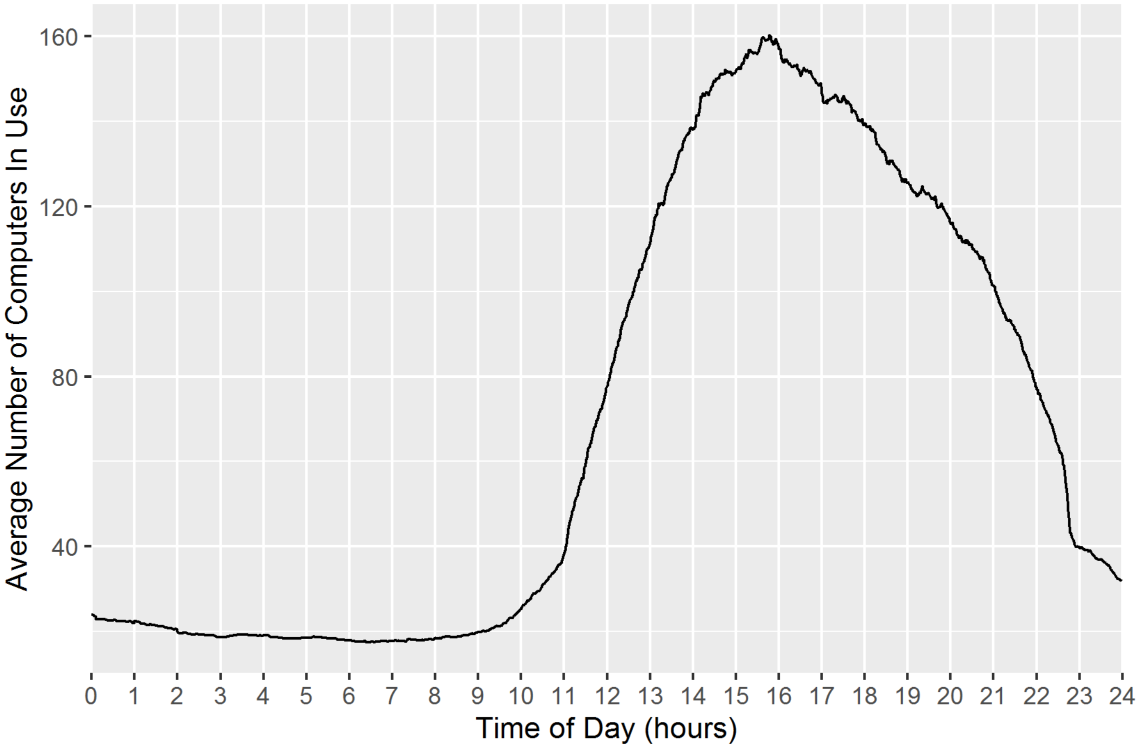

Figure G-7: Average usage profile for Sunday.