Exploring the Relevance and Energy Usage Implications of Fixed Computer Labs in Electrical Engineering Education

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***Abstract*—This Research Paper examines the question of whether fixed computer labs are still a necessary or important facet of the Electrical Engineering Laboratory Environment. Large academic computer labs stocked with high performance computing workstations have long been a major feature of Electrical and Computer Engineering programs. Historically they have been used throughout the curriculum for everything from running complex image processing algorithms in Matlab to simulating and synthesizing advanced digital designs with CAD tools like Vivado. As the cost of computation has declined, however, and as students increasingly bring their own high performance computing devices to the lab, it is no longer clear that workstation-based computer labs provide a significant benefit for student learning. This paper explores this topic by looking at student in-lab computer usage patterns and preferences for an introductory digital design course at California Polytechnic State University San Luis Obispo. Our research also quantifies the potential environmental savings institutions can achieve by moving away from workstation-based labs by comparing average energy usage from students using lab computers versus those using their own laptops.**

I. INTRODUCTION

Electrical and Computer Engineering laboratories stocked with high performance computer stations are a common feature found across University Campuses today. They support a variety of classes and laboratories, ranging from introduction to digital design to advanced signal processing and computer architectures. At the same time university campuses are increasingly pushing to become more energy efficient and sustainable.

As the cost of computation has declined, and as students are increasingly bringing their own computing devices to the laboratory, it is no longer clear that traditional work-station-based computer labs provide a significant benefit for student learning. In this paper, we investigate the tradeoffs and potential impacts when designing laboratory environments. Specifically, we conduct measurements of lab daily power usage across a variety of classes and devices (such as high performance computing workstations, monitors, and student's personal mobile/laptop machines).

Using laboratory power measurements we evaluate lab overall energy usage and potential energy savings from adopting work-station-less computing laboratories. Using data collected from an Electrical Engineering laboratory, we show that a workstation-less computing laboratory design can reduce total energy usage by over 10x as compared to a fixed workstation setup. We also discuss the implications of emerging computing trends on the design of electrical and computer engineering laboratories in the future.

Note that this paper focuses on the energy implications of laboratory design, specifically regarding hardware setups (e.g. fixed stations, mobile, thin clients, etc.) and the resulting energy profiles. In Section IV and V we provide a brief discussion on some of the other effects and design considerations for work-station-less computing laboratories (e.g. curriculum, social impact, etc.) Future work will continue to analyze other effects and design considerations for alternative work-station-less computing laboratories.

This paper is organized as follows. Section III provides a description of our laboratory setup and methodology. Section IV presents our experimental results and analysis. Section V discusses the impact of computer usage trends and our power analysis on laboratory design. Section VI concludes.

II. RELATED WORK

With process scaling, computing systems increasingly face tight power and energy budgets. Much research has been conducted on approaches to reduce the power and energy usage of computing systems, from embedded/mobile systems to high performance computing systems. Computing systems today dissipate the majority their power through device leakage currents (i.e. static power). Due to this fact, one of the most significant ways to conserve power in computing systems is to turn devices off or put them into low power modes when not in use. Note that for many consumer electronics, these low power modes can still consume significant amounts of power.

There have been several energy measurement studies in the context of university laboratories [1], [2]. These studies investigated the impact of sleep states and workloads on power usage and have made sleep-state recommendations for reducing the energy footprints of work-station-based labs. Unlike these papers, we investigate the impact of laboratory designs that do and do not contain sleep-state based workstation based computers. In this paper we also gather laboratory power measurements in the context of the most recent computing technologies. Previous work was primarily focused on machines from 5-7 years ago.

There has also been some related work on reducing the energy usage of academic computing labs by making use of minimal computing hardware and/or thin clients [3], [4]. However, our paper focuses on the energy implications of the increasing number of students who use their own laptops in class without making any changes to lab workstations.

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TABLE I
LAB INSTRUMENTATION SETUP

Hardware Device	Number of Sensors
Dell Desktops (3.4 GHz Intel Core i5-3570) (16 GB RAM, Crucial 250 GB MX200 SSD)	5
Dell 23inch LCD Monitor (P2314H)	5
Student personal machines (e.g. laptops, chromebooks, mobile, etc.)	6

Finally, there are also has been much related work on the use of mobile devices for engineering education [5], [6], [7], [8]. Researchers are increasingly interested in the design of mobile applications based on the constructivist theory of learning, which provide scaffolding designed to assist and motivate students in using the applications and learning engineering/computing principles. In this paper, we focus on the energy implications of laboratory design, specifically regarding hardware setups (e.g. fixed stations, mobile, thin clients, etc.) and the resulting energy profiles.

III. METHODOLOGY

To get representative energy consumption model for a modern EE computer lab, we instrumented one of the most heavily scheduled EE classrooms at California Polytechnic State University with 16 Wemo Insight smart power monitoring plugs [9]. Some sensors were set up to measure the workstations and their monitors (separately), while others were left as open outlets for students to connect power adapters for their personal machines (e.g. laptops). Table I shows the distribution of sensors and the typical machines connected for each sensor. These sensors activate whenever a device is connected (i.e. plugged in) and begin to measure power usage. Each sensor was configured to connect over a wireless network to a Raspberry Pi [10] running the open source home automation tool, openHAB [11]. The Rasberry pi collected the raw real-time power measurements from all the Wemo power sensors in the laboratory, which we then aggregated and analyzed offline.

During the data collection period, the lab hosted classes in programming and interfacing with microprocessors, HDL-level processor design, and introductory digital circuit design. Sample workloads for these classes and their typical weekly workload distributions are shown in Table II.

The lab was highly utilized during the week for the Winter and Spring quarters of 2018, as shown in Table III. The number following each class specifies the number of students enrolled. On average, the instructors for these sections estimated that roughly 50% of students chose to use their personal laptops instead of the fixed desktop machines. Note that the percentage of college students who own laptops nationally, according to recent surveys, is at nearly 90% and other computing devices (e.g. tablets and other mobile devices) are also quickly approaching similar usage levels [12].

TABLE II
WORKLOAD DISTRIBUTION

Workload	In Class-Usage
Assembler/Assembly Simulator (Python)	10%
CAD Synthesis (Xilinx Vivado)	40%
CAD Simulation (Xilinx Vivado)	45%
Web browser (class Youtube videos)	5%

TABLE III
CLASSROOM SCHEDULE

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8:00 AM</td><td></td><td rowspan="3">Class F
17</td><td></td><td rowspan="3">Class F
17</td><td></td></tr>
<tr><td>9:00 AM</td><td rowspan="2">Class A
33</td><td rowspan="2">Class A
33</td><td rowspan="2">Class A
33</td></tr>
<tr><td>10:00 AM</td></tr>
<tr><td>11:00 AM</td><td rowspan="2">Class B
31</td><td></td><td rowspan="2">Class B
31</td><td></td><td rowspan="2">Class B
31</td></tr>
<tr><td>12:00 PM</td><td rowspan="3">Class G
26</td><td rowspan="3">Class G
26</td></tr>
<tr><td>1:00 PM</td><td rowspan="2">Class C
34</td><td rowspan="2">Class C
34</td><td rowspan="2">Class C
34</td></tr>
<tr><td>2:00 PM</td></tr>
<tr><td>3:00 PM</td><td rowspan="2">Class D
27</td><td rowspan="3">Class H
15</td><td rowspan="2">Class D
27</td><td rowspan="3">Class H
15</td><td rowspan="2">Class D
27</td></tr>
<tr><td>4:00 PM</td></tr>
<tr><td>5:00 PM</td><td rowspan="2">Class E
17</td><td rowspan="2">Class E
17</td><td rowspan="2">Class E
17</td></tr>
<tr><td>6:00 PM</td><td></td><td></td></tr>
</table>

IV. RESULTS

A. Overall Lab Power Usage

We measured power usage across the same laboratory over a 2 week period. This was long enough to capture power data from 42 course meetings across 8 course offerings, as well as idle power draw from the lab overnight. The raw power usage for three different sensors (workstation, monitor, and laptop) over a period of a week are shown in Figure 1. These raw results are indicative of common usage patterns that we observed on the machines. For the workstation, Figure 1 (top) there was a large amount of standby power and frequent power changes throughout the week. For the monitor, Figure 1 (center) we saw lower standby power drain, but similar frequent spiking as students used the machines in the lab. Finally, for sensors measuring laptop power, Figure 1 (bottom) shows a typical pattern where the power was negligible for large periods of time due to the sensors being unused, and then a larger mount of power in short active periods.

These instantaneous power measurements were in-line with the expected active power usage of each device. A typical workstation can consume anywhere from 20-300W depending on the usage [13]. Many reasonably high-end laptops max out at about 90W power consumption (e.g. 15" macbook pro has 87W power supply and a Thinkpad T580 has a 65W power supply).

Figures 2, 3, and 4 show the distribution of power usage measurements over a 2 week period for each device using a boxplot (which shows the median, 1st and 3rd quartiles, and max/min values). In Figure 2, we observe that average power usage was fairly constant throughout the week. During the weekend, machines were powered off resulting in a gap in the readings for those days. The machines could also be seen to be reaching near zero power usage when in sleep modes. However, the average power usage was fairly constant (around

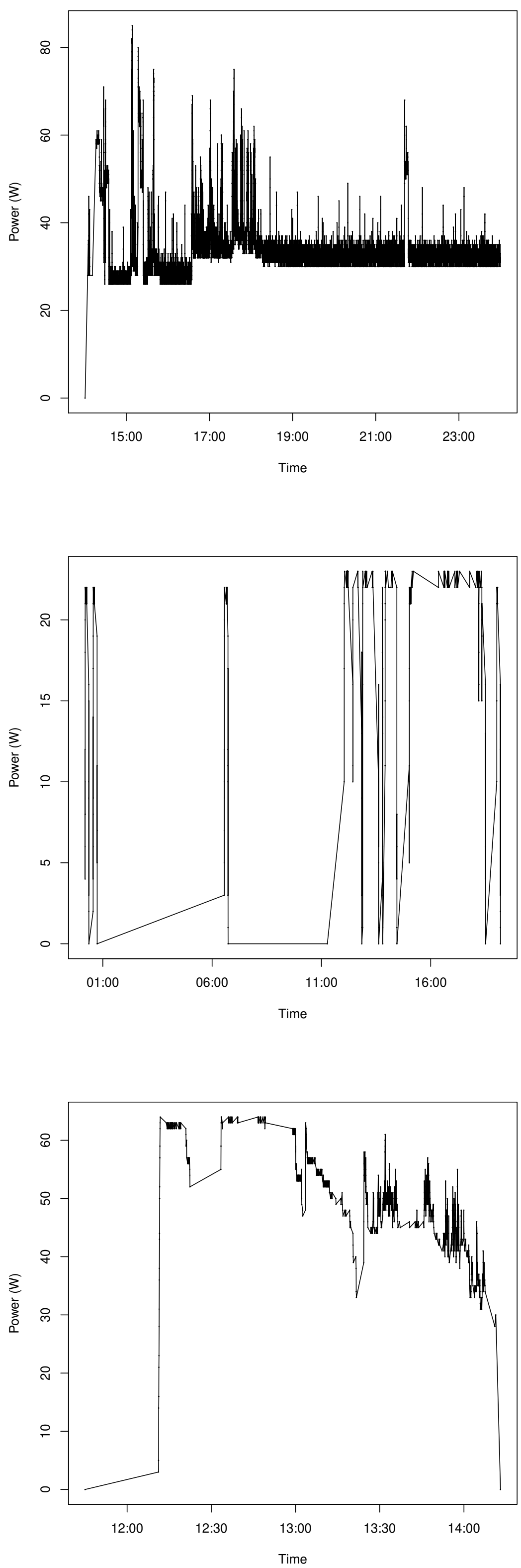

Fig. 1. Raw Power readings for single Workstation/Desktop (top), Monitor (center), and Laptop (bottom) (Power (W) on y-axis and time (s) on x-axis).

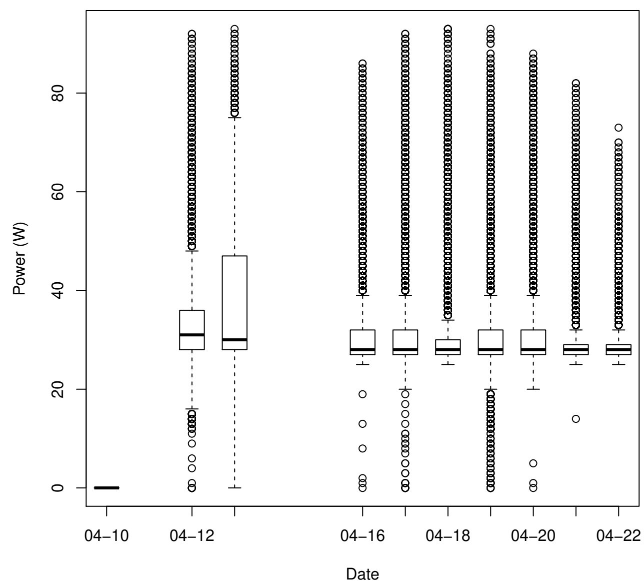

Fig. 2. Workstation/Desktop power usage over 2 week period. Boxplot shows the distribution (i.e. median, 1st & 3rd quartile, max/min) of power readings over all measured machines in one day.

30W) throughout the week. For monitor usage, Figure 3, we observed lower average power usages during the week (around 20W), mainly due to the lower standby power needed for these particular monitors. For students personal machines (mobile/laptops), Figure 4, we observed slightly less average power usage compared to desktops ($< 30W$), however the largest difference was that there were larger gaps in the power usage periods and much lower swings (peaks) in the power readings. Note that the laptops also did not require separate monitors, so even if power usage was similar for the laptops we would still see energy reductions by saving on monitor power dissipation.

Another important observations from these results is the large amount of power usage even outside regular classroom hours. While this laboratory is also used by students outside regular classroom hours for running experiments, the lab is locked in the evening and these machines typically sit idle over night and on weekends.

While some of the workstation energy could possibly have been mitigated with more aggressive power management features, the computers were already set to stop displaying on the monitors after a few minutes of idling. Short of manually shutting the desktops and monitors off when not in use, there appears to be no easy way to mitigate the 1-2KWh of idle energy usage consumed by these devices each day.

By integrating the power readings over the measurement period we were also able to investigate the energy usage of the laboratory over the 2 week period. Figure 5 shows the total energy usage, in units of kWh, for each type of device used in the laboratory (i.e. fixed desktop machines, fixed

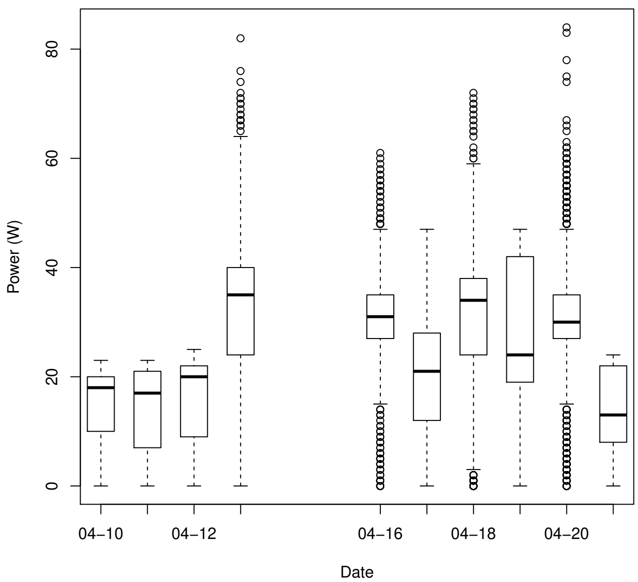

Fig. 3. Monitor power usage over 2 week period. Boxplot shows the distribution (i.e. median, 1st & 3rd quartile, max/min) of power readings over all measured machines in one day.

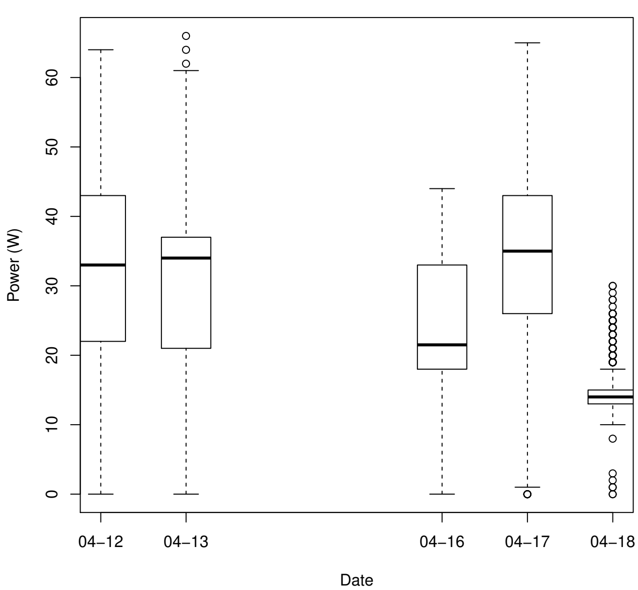

Fig. 4. Laptop power usage over 2 week period. Boxplot shows the distribution (i.e. median, 1st & 3rd quartile, max/min) of power readings over all measured machines in one day.

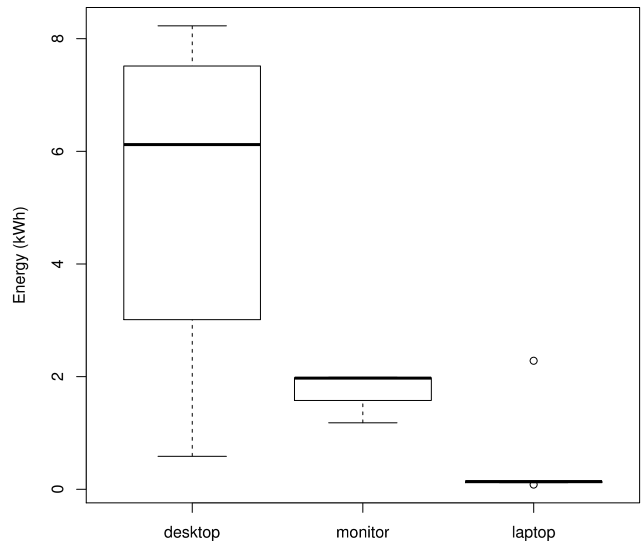

Fig. 5. Total Energy usage over 2 week (in units of kWh) for all measured machines. Fixed machines showed a 10X increase in energy usage for similar workloads over students personal machines.

monitors, and students personal machines). The boxplots show the distribution of energy measurements across the different sensors used in the experiment for each device class (i.e. desktop, monitor, laptop). These results suggest that there is a 10X reduction in energy usage from students using their personal machines vs the fixed machines. Similarly monitors were observed to utilize about 3X-4X less energy vs the fixed machines.

Figure 6 shows the projected energy usage based on these measurements (Assuming similar energy usage for the rest of the year and a laboratory with 16 machines). Nearly 5000 kWh ($1000) are consumed for the fixed-workstations vs 400 kWh ($80) for the laptop machines. This is over an order of magnitude reduction in energy usage for computing. To put this in perspective, university electricity budgets include many items other than computers (lighting, cooling, heating, refrigeration, ventilation, etc.) However, computers alone, on average, represent about a quarter of the total energy budget, which may be over $100,000 per year [14]. In light of the increasingly significant environmental and social costs of energy usage (and e-waste), we believe these savings are significant.

Figures 7, 8, and 9 show the density of the power measurements for each of the device types. In Figure 7 we observed the largest spike in power for desktops was around 25-30W, due to the large number of readings when the desktops were idle. Figure 8 also shows are large spike around 20-25W for when monitors where primarily in active states, and a second spike around near zero for their sleep states. Figure 9 shows large spikes around 20W and 40W. For the desktops, Figure 7

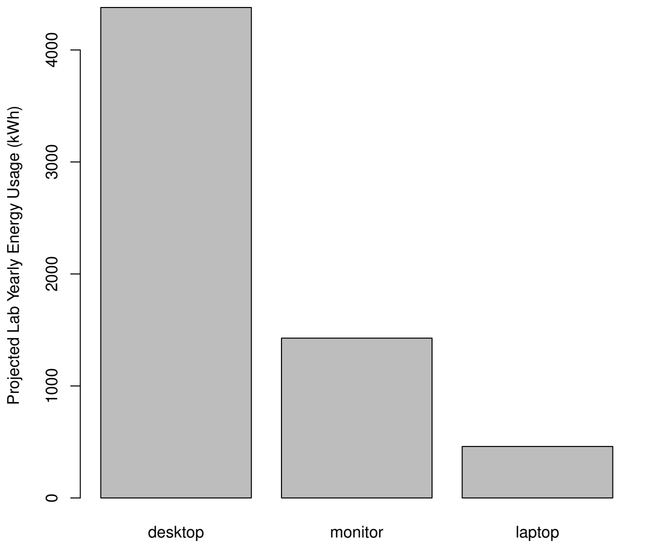

Fig. 6. Projected Yearly Energy usage (in Units of kWh) for single lab with 16 shared workstations. Nearly 5000kWh would be used for this lab alone with fixed workstations vs 400kWh for a laptop/mobile-based only laboratory. Fixed monitors would consume roughly 1400kWh.

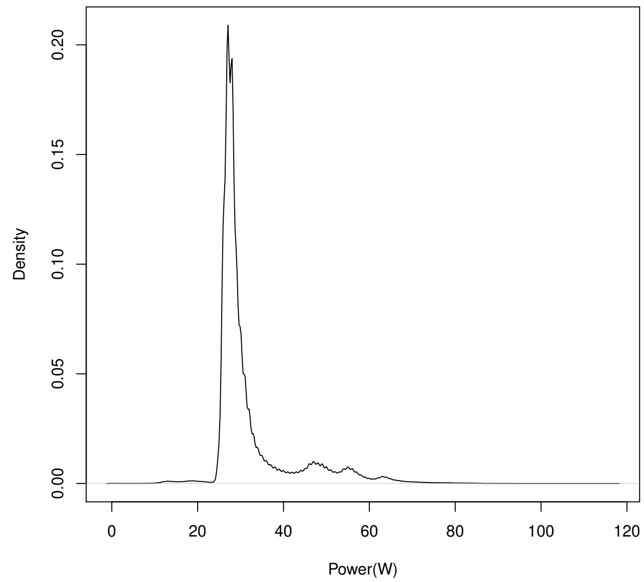

Fig. 7. Desktop power density. X-axis shows the power (W) and y-axis shows the probability (frequency) of the particular power reading.

we observed the largest range of measurements from 20W to over 100W.

Figure 10 shows the average power usage over a 24 hour day for all the data measurements for each of the device types. The blue dots and line (top) shows the average power (in 10 minute intervals) for the desktops. The red dots and line (bottom) shows the average power for the monitors in the lab. Finally, the green dots and line (middle) show the power for the laptops used in the lab. We observe significant variations in the power usages of all the devices. During the day, as we expected, there were large increases in power consumption for all devices due to scheduled classes/laboratories. There was also a large increase at night on average, most likely due students conducting homework assignments and projects.

V. Discussion

From our analysis, workstations use 10x more energy than individual student laptops. To make things worse, 20% of this power is effectively phantom energy, consumed after hours. At the same time, based on our classroom observations our benchmarks have shown that for moderate EE/CPE design work, a moderately priced laptop performs well enough for regular use. Therefore, moving away from work-station based computers in electronics labs could represent a substantial savings in both energy and provide an environmental benefit. Note that in addition to environmental benefits from lower energy energy usage, there is also a critical environmental benefit to producing less e-waste from having to replace workstations every few years.

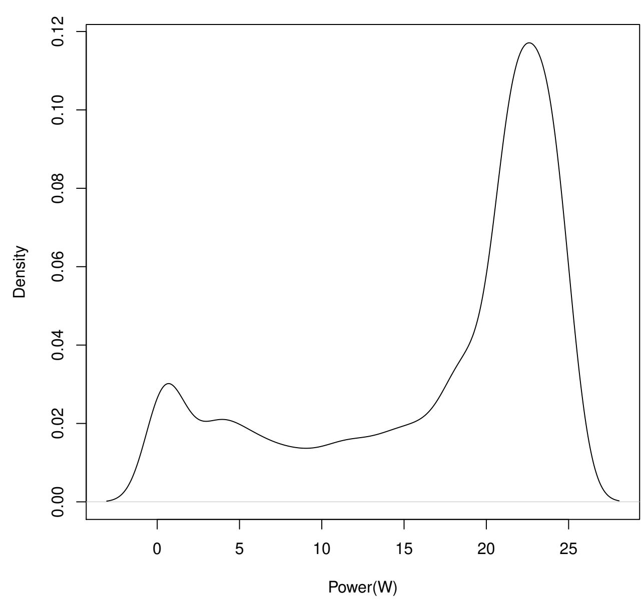

Fig. 8. Monitor power density. X-axis shows the power (W) and y-axis shows the probability (frequency) of the particular power reading.

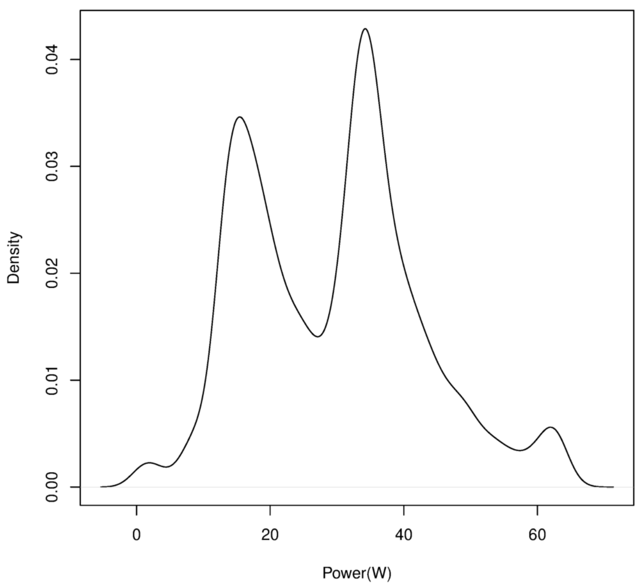

Fig. 9. Laptop power density. X-axis shows the power (W) and y-axis shows the probability (frequency) of the particular power reading.

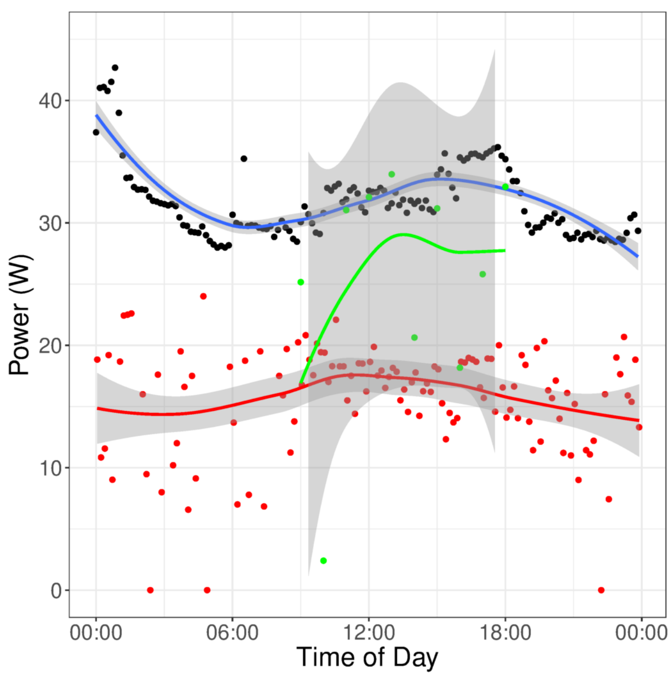

Fig. 10. Average power usage over 24hr day. Black (top) line and dots represent desktop measurements. Red (bottom) line and dots represent monitor measurements. Green (middle) line and dots represent laptop measurements.

Although university electricity budgets include many items other than computers (lighting, cooling, heating, refrigeration, ventilation, etc.), computers on average still represent a large portion of campus power usage (on average about a quarter of total campus energy budgets [14]) and is only growing with advances in computing technology.

Additionally, going this route, of a laptop/mobile only laboratory, may even provide a benefit for student learning . For future work, we plan to investigate student success and learning objectives, especially related to retention, with more hands on experiments and time with the machines/equipment.

Emerging computing devices and environments are also increasingly heterogeneous. Today, electrical and computer engineering laboratories use a variety embedded equipment (e.g. TI launchpads and boosterpacks, Arduinos and shields, Raspberry Pis, etc.), reconfigurable boards (FPGAs and System-on-Chips), tablets, etc., lessening the importance of having a single fixed high performance machine where all experiments are conducted.

Trends in open-source software also make the move toward laboratory spaces designed around mobile and students personal machines an attractive option. Another significant technology trend that is enabling even greater laptop/mobile usage in laboratories has been the standardization of USB ports as a way to power, program, and debug/communicate with development boards. In the past, multiple specialized serial programmers were needed for chips. With greater system integration, it has become increasingly easy and cost-effective to use personal mobile devices with digital lab equipment.

Of course, such a laboratory design would also entail making additional computing resources available for students on campus, in the face of both reliability issues that may arise during classes, as well ensuring general accessibility for the all students.

Thin clients with docking stations for students' personal devices may be another promising configuration for designing computing laboratories. Allowing students to leverage larger displays fixed in the laboratory, easy docking capabilities, and the mobility/flexibility of using their own machines would have numerous benefits. Our future work includes the investigation of energy implications and tradeoffs for such hardware setups.

VI. Conclusions

Fixed computing stations popularly found in electrical and computer engineering laboratories across Universities have several limitations, including inefficient power usage. We showed that a laboratory using fixed desktop computing stations can draw nearly 120kWh a week.

While there are some policies and configurations (e.g. sleep modes) for reducing the power usage and cost of operating these types of fixed labs, we found that a fixed workstation laboratory still drew significantly more energy vs. mobile/laptop machines. At the same time, as the cost of computation has declined, students increasingly bring their own high performance devices to the laboratory. Mobile/laptop oriented laboratories provide an attractive alternative to fixed-workstation laboratories in face of the changes in the computing landscape and significant sustainability challenges. When students use their own personal machines, challenges of synchronizing files, working with different versions of software suites, and classroom availability are avoided. Unless specific and common hardware is required for all lab stations, laptops can functionally replace common computer labs. We showed that by leveraging students' personal devices in the laboratory vs fixed workstation, there was a 10x reduction in energy usage for the laboratory.

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