Principal-Agent Problems in Energy Efficient Computing in a University Setting

Marco Pritoni, Siva G Gunda, Tracy Hsieh
Energy Efficiency Center, University of California-Davis

ABSTRACT

About 10% of the energy usage on a typical university campus is spent to meet Information Technology (IT) demands such as powering desktops, severs, printers, laptops, and other peripheral equipment. At UC Davis, the annual energy expenditure on IT alone was approximately $3 million (~$1.3 million excluding servers and related usage) in 2008. This translates to nearly 12,800 equivalent tons of CO_2 per year. In light of California's greenhouse gas reduction goals such as AB 32, UC campuses are crafting detailed plans to reduce energy waste and improve efficiency across all domains; IT efficiency is recognized as an important area of focus. It is well documented that IT energy use can be significantly reduced through energy efficiency measures and best practices. However, these strategies when implemented have not been as successful as expected because they have not incorporated behavioral change, thereby missing the opportunity to maximize energy savings. Inherent principal-agent conflicts impede behavior change, notably in the form of consumers on campus not paying the electrical bill for their IT energy use.

The objective of the current work is to establish the PA problem with IT usage in a university setting and quantify the maximum potential savings possible by eliminating this behavioral component. Preliminary estimates have shown that the PA problem in computing amounts to $460,000 annually. It was found that lack of 1) incentives or policies, 2) collaboration amongst various stake holders and 3) awareness were some of the key barriers that need to be addressed to achieve any significant savings.

Background

Since the passage of the Global Warming Solutions Act of 2006 (Nunez & Pavley 2006), which mandates that by 2020 the state's greenhouse gas (GHG) emissions be reduced to 1990 levels, individuals and institutions in California have grappled with this challenge. The DOE estimates that electricity used in buildings accounts for 70% of the nation's total electricity use, which corresponds to nearly 40% of the total domestic GHG emissions. Within the context of buildings, energy efficiency is seen as the key element to achieve carbon neutrality. Furthermore, the McKinsey report on climate change (McKinsey & Company 2007) and the Energy Efficiency Strategic Plan (CPUC 2008) slated by California Public Utilities commission identifies efficiency measures as the number one strategy to realize the goals set by AB32.

Because of its size, the University of California is a considerable contributor towards GHG; hence, it has adopted a sustainability policy in 2003 and launched the greening of UC campuses. To date, it is projected that an estimated $15 million in annual cost savings have been realized across campuses via investment in energy efficiency projects. At the UC-Davis campus alone, nearly $3 million worth of annual energy savings were realized through efficiency measures that mainly focused around HVAC systems (UCD 2009). As more strategies to reduce energy usage in a cost effective manner are being researched, IT usage has been identified as one of the key areas of focus for the future.

At UC-Davis, around 10% of all campus' energy is spent to meet information technology (IT) demands such as powering laptops, desktops, severs, printers and peripheral equipment (Hobbs et al 2008). The annual energy expenditure on IT was approximately $3 million in 2008, which also included all usage linked to servers. The more relevant number for this study is the $1.3 million that was expended toward user based consumption such as workstations, desktops, and laptops. While historically, the primary focus for improving IT efficiency has been centered on technology upgrades, as reported by several other campuses such as Yale and UC Berkeley, an increasing number of current strategies are looking at impacting usage and behavioral patterns.

The current work complements several ongoing efforts at UC Davis by various independent student and staff teams attempting to develop conservation strategies for the campus. This study draws upon at least three other studies being conducted on the campus that directly relate to this work. These separate efforts are being conducted in a collaborative fashion to aid each others' work. The study by Dana Rowan (Rowan 2008) was the first to look at PA problems existing on campus. It was conducted in a graduate lab setting and included IT equipment, appliances, lighting and various other plug loads. The estimates of the case study were further scaled to the entire campus. Hobbs et al (Hobbs et al. 2008), a Graduate School of Management team, studied the cost effectiveness of technology upgrades relating to servers. During 2009, the UC Davis campus sustainability planner and several students conducted a pilot program to reduce waste generation, energy use, and travel behavior in two campus administrative offices with a total of 75 office workers. Measurements, surveys, and focus groups informed the design of the program, which included informational lunches and an action campaign. Some of the most popular actions piloted were computer-related energy conservation actions, including changing power management setting changes and shutting equipment off at the end of the work-day. Pre- and post-program measurements indicated a 22 percent drop in weekly plug load power use, although the share attributable to computer energy savings was not measured. The campus sustainability office plans to scale the project to several campus buildings that include other types of university affiliates and to study the persistence of behavioral change.

Objectives and Completeness of the Current Study

The primary objective of the current study is to measure the inefficiencies/wastage in computing energy *usage* that exist due to usage patterns influenced by the principal-agent (PA) problem. We believe that trying to understand the IT efficiency problem through the PA lens would offer new insights into solving this problem. Our objectives are to further establish that the PA problem exists and then quantify it through measurements augmented by survey data. This helped us to estimate the maximum potential for the savings as well as gain insights into information asymmetry that exists in a complex organizational structure such as a university.

The current study draws upon a number of strategies and methods developed by Rowan (Rowan 2008) in order to estimate the usage component of the PA problem. Although the scope of this paper is only limited to measuring the PA problem, the team intends to launch a program similar to the one developed by Kirk et al (2009), to affect behavior change and realize the potential saving estimated in this study.

Principal Agent Problem

According to Meier, "PA problems refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information". A very common example used to describe the PA problem is a landlord-tenant situation. Most of the appliances such as the refrigerator, laundry machines, stove, and water heater in the apartment are chosen by the landlord and typically the tenant does not have a say in this choice (although this is changing), while the tenant is responsible for the energy bill. This creates a situation where the incentives are split between the two parties involved where one (landlord) pays for the efficiency and the other (tenant) for usage; hence, from an economic perspective (assuming that there is good demand for rentals) the landlord does not have an incentive to offer more energy efficiency appliances (Meier 2007).

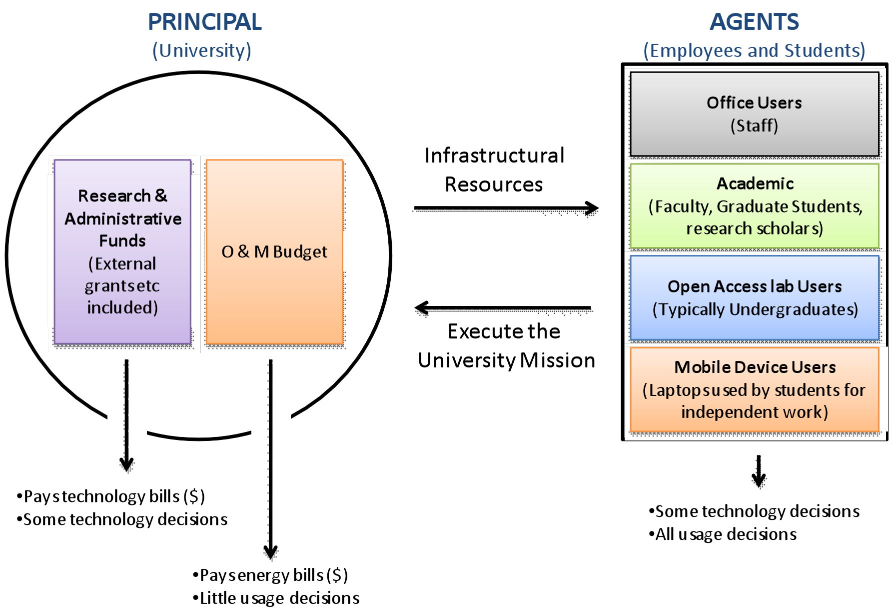

Figure 1: Principal Agent Diagram for Computing Usage in a University Setting

The end users of the computers in a university setting such as the students, researchers, and staff typically are not directly responsible or aware of their energy usage and bill. We found that 81% of survey correspondents did not know how much energy their computer uses and 67% do not know who is paying the energy bill. Though the end users are not responsible for paying the energy bill directly, a number of them are involved in the purchasing decisions of IT related equipment. Due to the robustness and the variety of users across the campus, there is information asymmetry across the various stakeholders. The general guidelines around IT efficiency often tend to a small subset of best practices that can be implementing across all of campus, and the local level policies are not necessarily communicated.

For the purpose of this study, as is noted in Figure 1, the principal is the university. The employees and the students act on behalf of the university in fulfilling its mission. The university provides all the infrastructural resources in terms of funds, office spaces, and a management structure to the agents in order for them to perform their duties.

Methodology

The current study follows the methodology outlined in Alan Meier's book, *Mind the Gap* (Meier 2007). As a first step toward estimating the PA problem, we categorized the entire university user population into four categories. These four user categories allow us to exemplify typical usage patterns by various types of users across campus.

Categorization of Users

In order to categorize the user population, we identified seven key attributes that typically contribute to the usage pattern of a typical campus computer user. Three of these attributes are computer specific such as the owner of the computer and four of the attributes are user specific. Table 1 lists these seven key attributes and their associated weight-factors. The weight-factor for a specific attribute is calculated as the normalized ratio between the stocks that affect the attribute to the total available stock. For example, the total number of university-owned computers on campus is approximately 21,000 and the total number of all computers at anytime on campus is approximately 24,000. The ratio of these numbers defines the weighting factor for that specific attribute. As can be seen from Table 1, we assumed that only a few users have multiple computing devices; therefore, it was excluded as a key attribute of categorization.

Table 1: Key attributes and weights

Attribute	Weight
Computer is owned by the university (A1)	0.895
Computer is used by a single user (A2)	0.853
Computer is mobile within campus (A3)	0.105
User is an university employee (A4)	0.853
User has predictable work schedule (A5)	0.625
User typically works from a fixed location (A6)	0.895
User has multiple computing devices (A7)	0.002

Table 2: Category and attributes

	Categories			
Attribute	**C1**	**C2**	**C3**	**C4**
A1	1	1	1	0
A2	1	1	0	1
A3	0	0	0	1
A4	1	1	0	0
A5	1	0	0	0
A6	1	1	1	0

The remaining six independent attributes, with two distinct possible values per attribute ("yes" or "no") gives rise to a total of 64 (2^6) unique categories. However, once the redundancies and the impossible combinations were removed, the total size of categories was reduced to four. The specific combinations of attribute values for the four categories are listed in Table 2. A value of "1" represents "yes" and a value of "0" represents a "no" for each related attribute. The qualities of the four categories are described below:

- ***Category 1****(Office/Administrative Users)*: The users in this category are university employees with predictable work schedules. Users in this group include administrative employees, student assistants and part-time lecturers whose computer usage tends to be very regular and predictable.
- ***Category 2*** *(Academic Users)*: Users in this category are university employees as well, but their usage pattern tends to be highly erratic. These include faculty, researchers, and graduate students who use the computers extensively and work hours past a typical job. The kinds of computers used by this group tend be more computing intensive and hence

are typically on the higher end in terms of their processing capabilities. It should be noted that there is high variation across disciplines in the typical intensity of computer usage.

- ***Category 3*** *(Open Access Users)*: Users in this category typically are undergraduate and graduate students using campus-owned computers that are not designated for single-person use. The facilities catering to these users are very diverse and spread across the campus. For example, UC Davis has at least 5 different sub-categories of open access labs, catering to different populations that fall under this group, such as graduate computer labs for graduate students in every department, undergraduate education labs scattered across campus, general purpose computer spaces available in libraries and student centers, etc. In the current study, we estimated the number of users in this category as the total number of computers available in such spaces across the campus. Then we captured a "***full-time equivalent user***" per computer by combining the usage patterns of all subcategories of computers in this group using a weighting factor that captures their usage pattern from our measurements.
- ***Category 4*** *(Mobile Device Users)*: The users in this category typically bring their personal laptops to the university. Users mainly include undergraduate, graduate, professional students and a small number of campus visitors who use the laptops for completing their class work and for personal use. Though a number of graduate students use their personal laptops also for research purposes, we assume that a minority of graduate students employed by the university actually use their personal laptops for research.

As can be seen in Figure 1, firstly, none of the users included in this study pay for their computing energy bills. Secondly, a fraction of the end users choose the technology. In particular, users in academia such as the faculty and researchers, often choose the IT equipment for their use. This situation creates both an efficiency and usage problem as described by Meier (Meier 2007).

The situation currently being described can be visualized using a PA matrix that can be seen in Figure 2. For the case of this paper we consider quantifying the part of the PA problem which is purely affected by the behavior of the users, which is the usage problem, categorized by cases 3 and 4. In order to estimate the stock that is being affected in these two cases we followed the method described in the following section.

	End User Can Choose Technology	**End User Cannot Choose Technology**
End User Pays For Energy Usage	**Case 1: No PA Problem**	**Case 2: Efficiency Problem**
End User Does Not Pay For Energy Usage	**Case 3: Efficiency and Usage Problem**	**Case 4: Usage Problem**

Figure 2: PA Matrix

Estimating the number of end-users / stock affected by the PA problem

In order to estimate the number of users affected under PA problems in each *case*, we first need to quantify the number of users (or full-time equivalent users) in each category and then ascribe the categories to the cases they belong to. The number of users in case 1 is approximately 1% of the campus users that pay their energy bills and the number of users in case 2 is estimated to be negligible. The number of users affected under PA problem in case 3 is the sum of users in categories 2 & 4. And the number of users affected under case 4 is the sum of users in categories 1 & 3. In order to estimate the number of users (or full-time equivalent users) in each category, the census data from the university was used (UCD 2009). The data used to estimate each category of users is as follows:

- Category 1 users: The total number of users in this category is assumed as the subtotal of the headcount of full time equivalent (FTE) number of university employees excluding non-administrative employees such as faculty, student assistants, researchers etc. This number according to the university fact sheet for 2009 was 14,913.
- Category 2 users: The total number of users in this category is assumed as the head count of full time equivalent (FTE) number of university employees who are involved in academic roles that focus on academic deliverables. This number according to the university fact sheet for 2009 was 5,438.
- Category 3 users: In order to estimate users in this category, we defined a "***full-time equivalent user***" per computer by combining the usage patterns of all subcategories of computers in this group using a weighting factor that captures their usage pattern from our measurements. Hence each computer over a day is counted as an equivalent of a user per day. From information gathered from UC Davis IT services, this number is estimated to be 1,119.
- Category 4 users: We took a top down approach to approximate the number of students carrying a laptop on any given day using weighting factors similar to category 3. Additional input and weights came from a compilation of in-house survey data as well as the "EDUCause IT study" (ECAR Research Study 2007). For example, the total number of undergraduate personal laptop users on campus was estimated using the undergraduate head count (24,209 for 2009) and factoring in the results from "EDUCause IT study," which estimates that nearly 75% of all undergraduate students own a personal laptop and only about 14.5% bring them to class weekly or more often. Similar factors were used for estimating graduate and professions students. By combining all these different mobile device users, it is approximated that on any given day, 2,544 students carry laptops to campus. This number is in close agreement with the actual average number of laptops that connect to the university's wireless network. The compound usage pattern for this category was generated by combining usage patterns of all sub-categories using a weighting fraction, which is the percentage of users in each sub-category.

	End User Can Choose Technology	End User Cannot Choose Technology
End User Pays For Energy Usage	Case 1: ~200 (1%)	Case 2: Negligible
End User Does Not Pay For Energy Usage	Case 3: ~7,932	Case 4: ~16,032

Figure 3: Affected User Stock in Each Case

Figure 3 lists the number of users calculated per case as detailed above. These values are approximate and should be used to gain a general understanding about what is at stake. As far as the usage problem is concerned the total number of users is the sum of case 3 and 4, which is equal to a total of 23,964 users.

Measurement and Analysis

The current work is solely focused on quantifying the *usage component* of the PA problem. Energy savings that can be realized by technology improvements or conversely, the inefficiencies that exist due to purchase of inefficient technologies, were not considered in this study. The methodology outlined by Meier was used to quantify the possible efficiency gap that exists due to usage patterns in relation to IT equipment at UC Davis. The steps followed to estimate the potential savings are:

- Estimate the total number of users affected under each *case* in the PA matrix.
- Select a random sample of users under each category and measure their usage pattern.
- Estimate the savings possible for each user category by virtue of implementing simple conservation measures such as the ones tabulated in Table 2.
- Calculate the total potential savings by extrapolating savings potential at individual user level estimates to the entire campus stock.

Spot Measurements

This analysis considers IT equipment as all desktop and laptop computers, monitors and all the peripherals connected to them such as speakers and printers. The potential savings quantified in this section are probably unrealistic to achieve and are preliminary; nevertheless, they provide the upper boundary achievable by measures easy to implement and essentially without any capital cost.

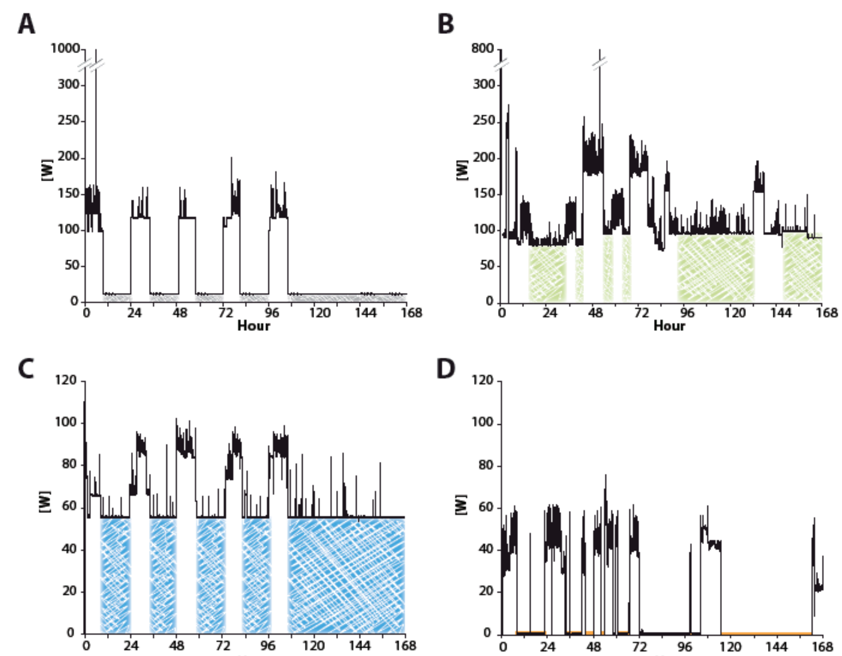

Figure 4: Typical Power Curves Measures for the four Categorical Users; A) Office, B) Academic, C) open Access and D) Mobile device

In the process of estimating the savings, a convenient sample of 30 users in each category were selected across a few departments and an inventory of all IT related equipment used by these users was collected. Using WattsUp ® Pro meters, various IT equipment of each user were monitored for duration of one week each. These data were stored in the meter's log and then extracted and analyzed to obtain power curves and usage patterns for all the devices. Monitors, hard disks, printers and other peripherals were measured separately and then combined to obtain the total consumption for each individual user.

Table 3: Observations and Survey Responses

User Category	"Status quo": area to improve
Office Users	• Almost every user with an independent office space has a personal printer • In office spaces shared by multiple users approximately 1 central printer served every 4-5 users • All printers and connecting peripherals were almost never turned off • No easy way to turn off the entire system and its peripherals was observed • Monitor Screen brightness was typically set high (past 50%) • 38% of the users claimed that they do not usually turn off the monitor or CPU at the end of the day, 30% turn off only the monitor and 69% do not turn off the peripherals • As expected schedules are pretty predictable
Academic Users	• Extremely erratic usage pattern, with schedules that are difficult to predict • Computers are typically more powerful (use more energy) on average compared to other user categories • While there is variance between powers consumed by computers used within this group, we observed that it has little effect on the overall usage in this category compared to the pattern of usage • Faculty and full-time researchers in this category typically have access to a personal printer • Most users have 2 monitors and a laptop turned on at the same time • Printers and other peripherals are almost never turned off (printer only standby) • Computers were mostly left turned on for remote access (Wake on LAN* not used) • Screen brightness is typically set high • 94% of users responded that they have no external pressure to reduce computer energy use
Open Access Users	• Monitors are set to go to standby after 15 minutes (though users tend to change them) • No standby for computers (always on) to allow updating software restoring settings • Brightness set at 50% when the computer was installed then left to users (some were set at 100%) • Issues: 1) lack of overall campus computer sustainability mandate and 2) no structure for replication of successful sustainable best practices
Mobile Device Users	• Most difficult user type to monitor • Usage is extremely unpredictable • Users typically have no awareness of the fact that they are using campus resources to power their system • 28% of users think that screen savers actually save energy • While all the people surveyed think that enabling power management software or turning off computers saves energy, 22% of users did not make this connection with an environmental impact • 75% of users responded that they have no external pressure to reduce computer energy use • Users rarely follow the university recommendations when purchasing their laptops

*Wake-On-LAN is a computer network standard that allows a computer to be turned on or *woken up* by a network message. The "message" is usually sent by a simple program executed on another computer on the local area network

Power-related settings of the devices monitored have been collected at the same time with the intent of supplementing and explaining quantitative data collected. A set of interviews were also conducted to help fill holes in the data as required. Figure 4 depicts a set of representative power curves for each category of users.

The colored areas in Fig 4 represent the amount of energy used to power the devices when the device was not performing any function, while further savings can are attained by reducing settings such as monitor brightness or powering off unused peripherals. At first glance, it is evident that a conspicuous percentage of energy was being wasted due to behavior. This data is specific and does not necessarily represent the pattern of all users. Some of the immediate observations from measured data and surveys relating to configuration and usage pattern are listed in Table 1.

Survey and Interviews

A survey was launched to further understand the user behavior across the four categories. Using a Gmail survey format, 22 carefully selected questions were posed. These questions helped us understand the user's nature of work, their knowledge and awareness about their consumption and energy in general. 1500 survey links were sent out to a randomly selected sample that consisted of 350 faculty and researchers in 14 different departments, 150 staff, 250 graduate students and 750 undergraduate students. The survey was conducted over a period of two weeks with a 7% completion rate and a total of 106 responses were received. In addition we interviewed three IT computer lab managers and had conversations with several people belonging to each category. The results from the surveys and observations from the measurements are listed in Table 3.

Estimating potential savings

In order to estimate the potential savings for each category of users we supplemented the power measurements with survey results. Table 4 shows the estimated annual savings possible via various simple measures on a categorical basis. The results combine spot measurements with user responses such as how often they are present on campus, actually using their computers while they are turned on, and any alterations in efficiency settings.

Table 4: Savings potential and corresponding measures

Action / Measure	Office Users	Academic Users	Open Access Users	Mobile Device Users
Reduce Monitor Brightness	17 kWh/y	16 kWh/y	19 kWh/y	1 kWh/y
Turn off all the peripherals when leaving	31 kWh/y	14 kWh/y	3 kWh/y	-
15 min of inactivity stand-by option set	131 kWh/y	371 kWh/y	167 kWh/y-	12 kWh/y
Turn off computer when leaving[1]	9 kWh/y	33 kWh/y[2]	2 kWh/y[2,3]	4 kWh
Total	188 kWh /y	433 kWh /y	190 kWh/y	14 kWh/y

[1] These savings are calculated after strand-by option is activated

[2] need for Wake on LAN tools to use or update computers remotely (already available in other departments)

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Figure 5 shows the estimated percentage savings potential per category by implementing the measures listed in Table 4. At 52%, office users offer the most potential for savings. While the scope for savings is high for this category and survey responses indicate that the majority (more than 80%) of users would change their settings to save energy, there is currently no mechanism in place to translate the willingness to a change in usage behavior. Furthermore an overwhelming 93% of respondents said that they do not feel any kind of pressure from their supervisors to change their behavior in this regard.

Extrapolating to Campus Scale

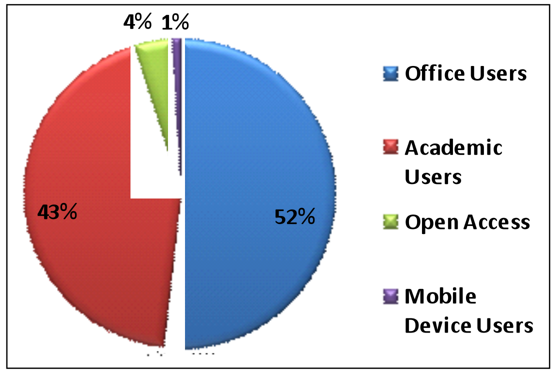

Figure 5: % of saving by category

In the final step, we combined the potential savings per categorical user with the total number of users in the category. Table 5 shows the total estimated values of potential savings at the campus level if the PA problem can be completely eliminated on an annual basis. The total savings potential across all users that can be achieved by completely eliminating the usage component of the PA problem is approximately $460,000 (1961 eq. tons of CO_2). It needs to be noted that the estimated $460,000 is based on a price of $0.085 per kWh (based on WAPA contract). In comparison to the $1.3 million annual energy bill in computing, the *usage component* of the PA problems accounts for a significant portion of nearly 33%.

Table 5: Potential campus scale energy Savings

	Energy wasted under the usage component of PA problem [kWh / y]	Total number of Users	Campus Savings [kWh / y]	Campus Savings [$]	Campus Savings CO2e [Metric Tons]
Office Users	188	14,913	2,803,000	238,000	1015
Academic Users	433	5,438	2,354,000	200,000	853
Open Access Users	190	1,119	212,000	18,000	77
Mobile Device Users	17*	2,544	44,000	4,000	16

* Difficult to monitor, may vary in other departments (School of Management, Law School, etc.)

It should be noted that there is a tremendous potential for savings with the office and academic users, while the open access labs and mobile users do not contribute significantly to the PA problem. It is also important to note that the estimations for the mobile device users are highly variable and it is extremely difficult to assess their full impact. As seen in Figure 6, though the academic users are only 21% of the total number of users, they represent nearly 43% of the total saving opportunity.

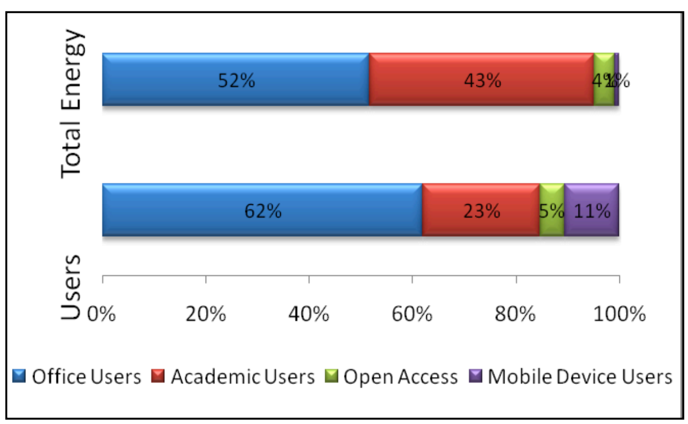

Figure 6: Affected User Stock in Each Case

This means in order to gain realistic savings in computer efficiency, this category needs to be addressed.

Lessons Learned: Affecting Behavioral Change

Existing literature and our personal experience made clear that it is very difficult to affect behavioral change in a decentralized institution such as UC Davis. The complex organizational structure of IT services, professors being funded by external sources and most departments not being directly responsible for paying their energy bills makes the implementation of a global strategy nearly impossible. Small scale IT efficiency projects that have been successfully implemented by several groups cannot be easily replicated on a campus scale without strong leadership. University leadership needs to have a long term vision for the campus and provide resources and support all the stakeholders involved in the process. Computer users, IT lab and network administrators, purchasing departments and supervisors all have an impact on computer efficiency and need to cooperate to achieve the common goal of saving energy. The principal-agent framework adopted in our analysis provides insight on how split incentives and information asymmetry can lead to misaligned objectives. To overcome these barriers we propose a top-down approach that includes:

- Provide feed-back on personal energy consumption to increase awareness.
- Provide best practice guidelines and recommendations to users on computer efficiency such as enabling power management (such power management software) and turning off devices when not in use.
- Implement passive marketing strategies that include posters, fliers, stickers, technical bulletin reports and online resources and help emphasize the relationship between energy usage and negative environmental impact.
- Make department and lab level energy usage available to management in order to create awareness and help develop incentives to promote energy efficiency initiatives.
- Make grant funding available and accessible to departments that want to implement computer efficiency programs.
- Mandate curriculum requirements for students that educate them in the basics of energy efficiency and conservation.
- Involve mid-level IT professionals in policy making in order to reduce information asymmetry and eliminate conflicting initiatives (such as the need of updating software during the night).

Conclusions

Keeping in mind the objectives of this study, the current work was successful in establishing the inefficiencies in the computer usage in a university setting through the framework of a principal agent problem. The study was focused only on the *usage* component of the PA problem. In estimating the total energy wastage, the users were broadly classified into four categories based on their usage patterns. The total amount of *usage* inefficacies at the campus levels was estimated to be costing the university approximately $460,000 annually, which amount to nearly 33% of annual computing energy cost on campus and corresponds to 1961 eq. tons of CO_2. It needs to be noted that these estimates are preliminary and were subject to a number of assumptions. It was observed that two categories of users, namely the office and academic users contribute to nearly 95% of the usage problem. While at any given time nearly 16% of on campus users are laptop users, mobile computers amount to only 1% of the PA problem.

When developing strategies to reduce this wastage, decision makers should prioritize the office user category as their usage patterns are very regular and predictable. Furthermore, nearly 80% of users in this category responded that they are willing to change behavior to conserve energy. On the other hand, affecting the behavior of academic users will be challenging due to their extremely erratic usage pattern. Open access labs users currently correspond to 4% of energy usage. In order to realize savings in this category, it is essential to remove conflicting policies and improve communication amongst various IT personnel. Though laptop users amount to only 1% of the current PA problem, it is a rapidly expanding sector and could become significant in time. Moving forward, we hope to develop and implement category specific strategies to affect behavior and realize a part of the potential savings.

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