It's Not Easy Being Green: Understanding Home Computer Power Management

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ABSTRACT

Although domestic computer use is increasing, most efforts to reduce energy use through improved power management have focused on computers in the workplace. We studied 20 households to better understand how people currently use power management strategies on their home computers. We saw computers in the home, particularly desktop computers, are left on much more than they are actively used suggesting opportunities for economic and energy savings. However, for our most of participants, the economic incentives were too minor to motivate them to turn off devices when not in use, especially given other frustrations such as long boot up times. We suggest research directions for home computer power management that could help users be more green without having to dramatically change their home computing habits.

Author Keywords

Power management, home computer use, sustainability

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

As energy costs rise and adverse effects of energy production become more apparent, there is a growing interest in sustainability issues, e.g. designing persuasive technologies to motivate people to be more green using social networking tools [16] or incorporating values of sustainability from the onset of technology design [4]. Improving power management on computers in particular, has estimated savings of over a billion dollars per year [14] and research in this area has mostly concentrated on commercial or office settings. Some have created more energy efficient devices through dynamic power management [15] and others have studied whether users are already using power management effectively in the office [23]. The potential for saving power in residential settings may exist, but little has been said about how people are using power management at home. Given the lack of focus on domestic computer power management, we explored how and why people power down their machines and the potential for energy savings.

We conducted a field study of 20 family homes in a U.S. metropolitan area using software logs of computer usage for 2 weeks, interviews, and surveys about households' current power management behaviors for home computers. Our findings suggest that opportunities for economic and energy savings through improved power management on home computers exist because computers are left on more than they are actively used. However, our findings also show that currently economic and energy incentives are too minor to motivate users to change their behaviors. Further, other factors such as impatience over long boot up times mean users do not want to go through extra effort to turn their devices off when not in use. Our findings highlight the challenges of using persuasive interfaces to encourage people to reclaim "wasted" energy; instead we suggest creating greener home computing technologies that increase computer availability.

RELATED WORK

The CHI community has a growing interest in sustainability issues. For example, in the home, researchers have looked at how extremely motivated users engage in "green" practices [25] and how households generally understand and manage their resources [5]. Others have created visualizations of a building's energy footprint to motivate people to save energy in the workplace [12]. Fewer researchers have investigated how to reclaim energy lost through poor power management on computers, although estimated savings from improved computer power management is in the order of terawatts per year [13]. Existing research on computer power management tends to concentrate on the workplace in two areas: improving technologies to be more energy efficient and increasing peoples' use of power management options on computers.

Researchers working to make technologies more energy efficient have implemented *dynamic power management*

CHI 2009, April 4–9, 2009, Boston, Massachusetts, USA.

algorithms [15] to optimize how devices use power to prolong battery life and improve resource usage without degrading performance. Gupta and Singh discussed how improved power management on computers and routers may require rethinking of network protocols to enable computers that are in low power modes to still be responsive to network requests [9]. Agarwal *et al.* have prototyped a USB solution that allows a computer to "sleep talk" or appear to be on the network while in a low power mode, awakening to process network requests as needed.

Fewer studies explore what people would like their devices to do or account for user behaviors, although the importance of this perspective has been raised [20]. Bannerjee *et al*. [2] focused on power usage rather than savings, and studied how and when users recharge mobile devices to predict when laptops can use more resources because a battery recharge is imminent. Exploring the potential for energy savings, Harris and Cahill conducted a user study in an office setting to determine how well context aware power management (CAPM), or using information about a user's intent and context to switch the device off when not in use, works in this type of setting [11]. They compared different possible context based algorithms against an *oracle* power policy which would always ensure that any computer not being used is either off or in a low power mode. Achieving an oracle policy requires predicting user intent about machine use while taking *break-even* time—the minimum amount of time that a device needs to spend in a low power state to justify the cost of powering down—into account. Harris and Cahill found that different styles of computer usage, (e.g. using the computer often when near the device), affect which policies will minimize user frustration at not having the device on when needed. Our study builds on their work by adding an in-depth look into users' desires and behaviors for power management in the home.

Research on how many people use power management settings also tends be concentrated on the workplace. For instance, Lawrence Berkeley National Laboratory reported on people's turn off rates of office equipment when not in use and whether power management was enabled on equipment. Their results show only 44 percent of computers were turned off completely at night, and of those left on, only 38 percent of monitors were in low power mode [23]. Others focus on educating users on how effective power management can reduce energy costs. For example, Energy Star [8], a joint program of the US Environmental Protection Agency and US Dept of Energy, recommends changing power settings to turn both monitors and personal computers off or to low power modes after set periods of inactivity. Over the years, both device manufacturers and developers of operating systems have improved user controllable power settings and power management on computers [14]. Today, personal computers typically support an almost overwhelming variety of power management options from turning off screens after periods of inactivity to *sleep* (also known as *standby* where system context is saved to main memory and memory is kept in a low power mode while the system is asleep) and *hibernate* (where system context is saved on the system hard disk drive) modes and a combination called *hybrid sleep* (where context is saved both to memory and disk) [17]. Microsoft has also recently worked with Verdiem on the Edison tool to allow users more flexibility in controlling their power settings and to get more feedback on power usage [22].

Previous research (all based on estimates and self reports) suggests energy savings can result if power management is correctly enabled and used properly. Yet, we know little about what is happening in people's homes. Are people really using power management? What are their perceptions of power management? Are there are factors influencing use of power management and what can the CHI community contribute? Most existing studies of power management usage in the home have been self-reported via surveys alone, such as the Residential Energy Consumption (REC) survey conducted by the Energy Information Administration [7]. The most recent REC survey suggests that most people leave their home computers off when not in use and the next most common behavior is manually switching the computer to sleep mode.

However, studies of actual observed computer use using sensor data about where people were in relation to their computers as well as logs of computer use [19,24], have indicated that availability, i.e. having a computer on and ready to use, is an important factor influencing power management. For instance, oftentimes laptops were not used when people did not want to wait for these machines to boot up in favor of machines that were already on. Further, these studies, particularly [19], have suggested that use of ultra-mobile and personal computers is *plastic* or massively interleaved with other activities in the home—meaning that optimal automatic power management may be difficult in practice.

Our work complements these previous studies by examining power management in family homes in depth. Specifically, we sought to further investigate how factors raised in previous work, such as the importance of computer availability, affect how much power we can reclaim with optimized computer use. In our study, we report on what people said about power management, and compare this with actual observed usage data. We also present detailed information about why people choose to use or not use power management on their devices and calculate actual savings that our sample set would have realized had they been using an *oracle* policy.

METHOD

We studied computer power management strategies employed by 20 households with 83 occupants from July 2008 to August 2008. We recruited 2 pools of participants: 8 households in Seattle, Washington, a major USA metropolitan area (*externals*) and 12 households affiliated with our technology company, Microsoft, in the USA (*internals*). We assumed the internals would be more likely to have multiple computers in their homes and be more familiar with and likely to employ computer power management strategies because of their affiliation. However, given the challenges of conducting field research we were able to collect data from a much larger group of households by including internals as they installed the logging software themselves.

We recruited households with a variety of machine types including desktops and at least one laptop, as well as at least one shared machine (used by more than 1 person in the home). All the machines logged were Windows XP or Vista machines because our logging software was platform specific. All households had 3 or more people and included at least 1 child. Most households were in a middle to high income bracket, but 3 were in a lower income bracket (under $50K annually). Each household was compensated with software (externals) or lunch coupons (internals) for their participation in the study.

Our main challenge in this study was to collect data on power management habits without biasing our subjects to the topic at hand. We thus used some deception. Our participants were initially told that the study was about home computer use in general, and while we provided participants with the complete information on what was logged (e.g. applications, account usage, on/off times) we did not emphasize power management. Only when we collected the logged data, did we reveal that we were interested in power management specifically. This was important to ensure that the data logged was not influenced by participants' knowledge of the study focus.

Installation: We visited the 8 external participants' homes and collected basic demographics, an inventory of computers and other technologies in a house and detailed information on how different computers in a household were used. Participants also sketched a home floor plan and indicated where devices were located. For these visits we requested, but did not require everyone in the family be present. We then installed our logging software on all desktop and laptops possible in the home. At installation, we also took a snapshot of basic information about the type of machine being logged and the current power management settings on the device. The 12 external participants were given a starter kit with a USB key containing our logging software, instructions for installation, a blank sketch page for drawing a floor plan and the same survey on their basic demographic information and computer use.

Data Collection: A minimum of 2 weeks after the initial installation date, we visited 10 households (8 external and 2 internal participants). During the visit we interviewed these participants about their computer power management strategies, collected data from their computers and had them complete a survey on power management habits. If at all possible, we had all computer users in each household complete the power management survey. Given that simple sensors to detect user context have shown potential to improve power management algorithms in the office [11], at the end of the interview we showed participants an application that used a motion sensor to turn on and off a computer monitor and asked them for feedback. The remaining 10 internal households were given collector kits, containing a USB key with a data extractor application to run on all the machines on which the software was installed, and the power management habits survey.

Logging Software

Our logging software tracked basic computer use such as which applications were used, which user account was currently active, duration and times of use as well as power state such as when the computer was on or off or in a low power mode. Due to privacy concerns, we did not log website urls, window titles, document names or any other data which would identify specific activities that a user was performing – rather all application use data was limited to the name of the application being used e.g. Internet Explorer and the time used. From this information, we could only infer high level activities—for example, we could track if a browser was open for 20 minutes but we could not determine if the user was reading a webpage, watching a video or sending an email specifically. All data was logged to a SQL database and text files stored locally on the machine.

Logging computer usage over time does have some limitations. Our logger relies on interaction (e.g. keyboard or mouse events) to indicate activity so could be imprecise in determining if someone is watching a video versus the computer being idle (both would have no user input for large portions of time). Also, if machines crash logging inaccuracies could occur until reboot. As such our logging data gets as close as possible to ground truth, but may have slight inaccuracies which we estimate to be small. For instance, even media players require some user interaction to keep the screensaver from turning on. Examining usage of the top 250 most used application over the course of the study showed that iTunes, Windows Media player and related applications only accounted for 0.5% of the usage time. So given the length of time for which we collected logging data we believe the trends to be representative of families' usage.

Analysis

In total, we performed 18 home visits, collected pre and post surveys as well as floor plan sketches from 20 households and interviewed 10 households in depth about their computer power management behaviors. During data analysis we triangulated data from logs, surveys and interviews. All 10 interviews on power management strategies were transcribed and coded using the affinity diagramming technique [3]. Locations of computers were coded public where access was freely available to everyone in the house (e.g. kitchen) and as private when access to a location was highly controlled (e.g. a bedroom) or partially controlled such as dens, or offices. Laptops used in multiple locations were coded as private.

Overall, we collected general information on 59 unique machines (Desktops:24, Laptops:35), power settings from 51 machines (D:22, L:29) and logs of detailed application use from 38 machines (D:15, L:23). Unfortunately, we were not able to install logging software on every machine, often because the machines were too old or unable to run our software (for instance 64 bit machines). On average we logged 17.5 days per machine. In a few cases households had other machines that they chose not to report on, typically because they were not used frequently. Power settings were examined for changes to default Windows profiles (for the monitor settings or hard drive settings e.g. increased/decreased timeout to switch off or to low power mode) and the active profile. We collected 40 responses on the power management survey (out of a possible 70), and in some cases we had people reporting on multiple computers for a total of 89 per computer responses.

RESULTS

We present our results by first outlining how people set their automatic power management settings and how they used their computers. Next, we discuss their reported reasons for their behavior and factors that may have affected what we observed in the logs. Finally, we outline the possibilities for reclaiming wasted energy and what participants desired in home computer power management.

What People Did

We examined our data to determine what people set their power management profiles to and their computer usage.

Perceived and Actual Automatic Power Settings

Table 1 summarizes a snapshot of the "plugged-in" or Adaptive Current (AC) power management settings we recorded for all machines at the beginning of the study, excluding 7 cases where we recorded "Not supported" or "unknown" settings. Note, Woodruff *et al.* [24] have found that laptops are mostly used plugged in at home and thus for simplicity we only report on these settings. For desktops, only AC settings are relevant since they do not run on batteries. Examining this snapshot, we find that most desktops have low power modes (standby and hibernate) turned off (timeouts set to "Never") as compared to laptops. Generally, for both types of machines, most are set to turn off monitors after a fairly short period (30 minutes or less).

Overall, 47% (D:16, L:8) of 51 computers had no power management settings turned on at all (i.e. all AC standby and hibernate settings set to "Never"). Not surprisingly, desktops are less likely to have efficient power management settings. In our interviews, one participant highlighted that power and battery awareness is very apparent on laptops but not on desktops: *"Everybody is always looking at the battery power on a laptop but on a desktop there's absolutely no concern with that at all. It's not even part of the picture. Yet it's an integral part of a laptop's picture, so it's kind of odd that there's two separate norms with the desktop and laptop when it comes to energy use" (H8).*

On the power survey, respondents were split about whether they had altered power settings (e.g. standby and hibernate times) in general on their machines, 45% (N=89) said "No," 39% said "Yes," while 11% reported that they did not know. However, changing monitor settings was slightly more common, with more than half of the respondents, 56%, reporting they had altered their monitor settings. Reasons for the changes included preventing screen burn, saving battery power, and energy. Similarly, 54% of respondents said they had set up a screen saver to prevent screen burn or because they liked the effect.

We observed in the power settings snapshot that 47% of all machines had their default AC or Direct Current (DC) settings slightly tweaked and 20% were on non-standard Windows profiles. Although the option exists in both XP and Vista to create new power schemes, we did not find evidence that people created their own schemes. Rather, they seemed to alter default schemes for their needs. Looking at those using standard Windows profiles, 41% of desktops and 52% of laptops, had their settings altered from the default values for the profiles chosen. Out of the 24 total machines with the power settings changed, 12 of the machines were from 5 internal households and 12 were from 7 external households, which was unexpected since we assumed the internal households would be more technically savvy and likely to alter power settings.

We examined machines with altered settings to see if the settings were made more power efficient, for example, by decreasing timeout values e.g. turning off the monitor after 5 minutes instead of 15 minutes. In general, about half the time settings were changed (38 cases over 24 machines), low power mode settings were made more power efficient and half the time, timeouts were increased, we assume to make machines more available. For example, in 8 cases, laptop's settings had been adjusted to make them go to sleep faster and in 6 cases were adjusted to do the opposite. Similarly, only a third of desktops with altered low power settings were adjusted to power down the machines quicker.

N=51 (L=29, D=22)	Type	≤ 15 min	16-30 min	>30 min	Never
Monitor Off	L	**48%**	28%	0%	21%
	D	18%	**68%**	0%	14%
Standby	L	3%	**41%**	17%	31%
	D	9%	0%	14%	**73%**
Hibernate	L	0%	0%	31%	**62%**
	D	0%	5%	0%	**91%**

Table 1. Machine Power Management AC Settings L=Laptop, D=Desktop

All this suggests that people do not necessarily choose their automated power management settings to make their machines as power efficient as possible.

Home Computer Usage

While 47% of computers, mostly desktops, had no automatic power management turned on at the start of the study, it is possible people only turn these computers on for use and then shut them down. We explored whether computers are being left on while not being used from the logging data. We calculated *active* use as periods where there were mouse and keyboard inputs (with contiguous sessions having inputs not separated by more than 5 minutes) and *on* but non-active times of each computer, i.e., when there was no mouse or keyboard inputs. On time does not include periods when the computer was in a low power state (standby or hibernate).

We found that the 38 household computers logged were *actively* being used for 1.7 hours per day (s=1.8) but were left *on* for an average of 12.4 hours per day (s=12.4). Put another way, the ratio of *active* to *on* times for the machines we logged, had a mean of 22%, i.e. on average the computers in our study were only being used for under a quarter of the time they were left on. We found no statistically significant difference between the average time active per day, length of sessions or time between sessions between laptop and desktop computers. However, we did find a statistically significant difference in the amount of time the computers are left on overall ($t(36) = 5.59$, $p < 0.001$) and per day ($t(36) = 2.46$, $p < 0.019$). On average, desktop computers were left on 18.1 hours per day while laptops were left on 8.7 hours.

Table 2 shows that only one computer in our sample had an active/on ratio above 76%. To be this *power-efficient,* this computer could either have efficient power settings or be used most of the time it was on and then manually turned off. In fact, in this case the computer in question had inefficient power management settings at the study onset (i.e. long timeout values) suggesting a focused usage style where the computer is only turned on to be used, which some participants described to us in interviews. In Figure 1, the upper activity graph illustrates this laptop's usage style which led to its 79% active/on ratio.

Active/On Time Groups	0-25%	26-50%	51-75%	76-100%
Laptop (23)	**44% (10)**	44% (10)	9% (2)	4% (1)
Desktop (15)	**80% (12)**	13% (2)	6.7% (1)	0% (0)
Total % of PCs	**58% (22)**	32% (12)	8% (3)	3% (1)

Table 2. Percentage of Computers in each Active/On Times percentage group

However, most of the computers are active less than half the time that they are left on (see Table 2) regardless of their type. These 34 *power-hungry* computers spend considerable time on when not in use, possibly because power management settings are turned off (19 computers) or the settings are mismatched with the time between active sessions so that we would expect power management timeouts do not often occur automatically. The bottom of Figure 1 shows the activity graph for a desktop with a 10% active/on ratio. Clearly the light gray on times overwhelm the dark gray active times. Given the intermittent use of this computer, it is clear that a considerable amount of power could possibly be reclaimed for this usage style.

Over the study period, in the 14 households where we successfully logged multiple computers (34 computers total), on average each computer was on at the same time with at least one other computer in the household 32 times (s=34, m=21). There was a wide range in the number of times pairs of computers were on at the same time (2 to 138). Variation occurred within households as well—for instance, during the study, 3 households had a pair of computers that were on simultaneously at least 60 times, but 2 of these same households also had a pair of computers that only overlapped 2 times in total.

Reasons for (Not) Using Power Management

Given the automatic power management settings people had on their home computers and that the logs show people are leaving computers on, we now discuss reasons for people's behaviors. First, we note our survey and interview

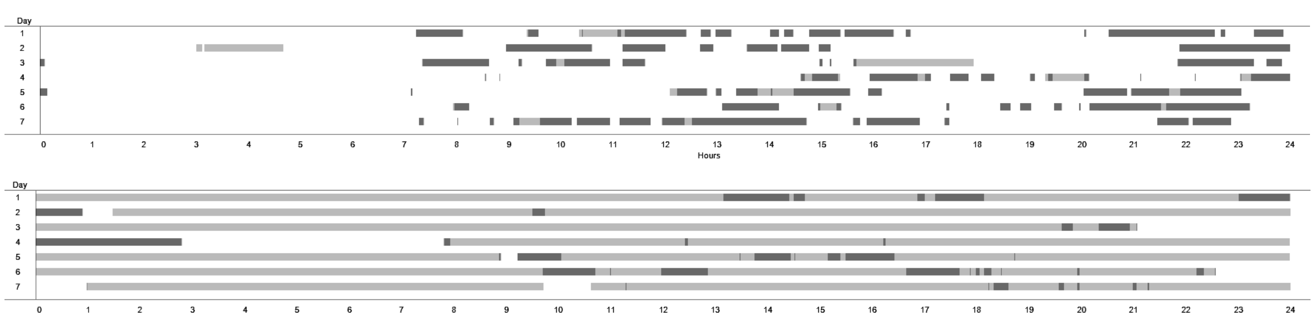

Figure 1: Example Activity graph for two computers for one week. Rows are logged days, light gray is on time, dark gray is active time. Bars show the duration of the activity during the day, with midnight starting on the left side. Top computer is typically only on when being used. Bottom computer is left on most of the time and rarely active.

findings confirmed, similar to [19,24], a desire for computers to be readily available for use and impatience with long boot up times meant that people often left their devices on more often that they actively used them. For instance, a participant in H1 said *"It's important because the calendar is right there. And if I have to make an appointment or something…if you have to sit there and boot your machine, and wait even 30 seconds…45 seconds, that is not a cool thing. So, basically in my case it's always on."* Other reasons for not using optimal computer power management included the situation of use, whether the device is shared, where devices are located, and technical challenges, as discussed below.

Situation

On the power survey, for each computer they used, we asked participants what they do when leaving the computer in a variety of situations (e.g. not using the computer for 10 minutes or less, more than 30 minutes, when leaving home for part of the day, at night or when they leave on vacation.). Table 3 shows the percentage of the 89 per computer responses where people said they would leave the computer either on, put it in low power modes, or turn it off for each situation. The table suggests that people are more actively managing power on their devices when they anticipate longer non-use periods.

For shorter periods of non-use (e.g. 10 minutes or less) reasons cited for leaving the computer on were because of long boot up times or if the computer was likely to be used again soon. Other less common reasons included *"inconvenient to turn back on and I will use remote desktop to access it later" (H18)* or *"usually doing something (job running)" (H14).* For longer periods of time, like leaving the computer for part of the day or at night, most people said they would leave it off. Reasons included: *"Save power/conserve power supply" (H9),* or because of noise: *"It's too loud (fan) and power" (H8)*. One unexpected reason emerging from our interviews for turning off the computer at night was to be more secure, as one grandmother told us: *"we used to leave it on all the time but it got a virus. Someone told me you can get viruses that way" (H7*). For vacation periods those who reported their computers were left on or in low power mode said that they had house sitters—"*grandma takes care of dog and reads blogs" (H11)* —or left computers on to record TV shows.

We conducted a two-way contingency table analysis to see if the type of computer affected people's responses about what they would do when leaving the computer. The only situation that had a significant affect was when leaving the computer for part of day, Pearson χ^2 (2, N=88) = 8.82, $p < 0.012$, Cramer's V = 0.317. Of the computers left on, in low power mode and off, laptops comprised 26%, 58%, and 64%, respectively. The only significant pair wise difference was between leaving computers on or off. Computers turned off were significantly more likely to be laptops, Pearson χ^2(1, N=62) = 8.36, $p < 0.004$.

Situation (N = 89)	On	Low power	Off
10 minutes or less	**61%**	28%	10%
30 minutes or more	**48%**	33%	18%
Part of day	26%	29%	**44%**
Night	27%	24%	**48%**
Vacation	9%	8%	**74%**

Table 3. Self reported power management behaviors when leaving the computer in different situations

Sharing

One of the largest potential differences between a home and work setting is the amount of sharing. Of the 59 computers, 37% were personal computers and 63% were shared computers (used by more than one person). In our interviews, people told us how they would not switch off desktops and laptops that were shared because they were not certain when other people in the house might want to use the computer. For example, *"it would waste time if you turned it off and started turning it back on because everyone wants to get on there" (H6).*

Oftentimes, family members said they were reluctant to turn off a computer that was shared if they knew other people were logged into the machine, for fear of disrupting applications they were running. In one household (H7), a participant told us how she would notice the main living room computer was on in the middle of the night and that her grandkids were still logged into the machine. She would then wake up her grandkids to get their passwords so she could log them out before shutting off the machine. In the case of shared machines, often one person eventually switched the device off because of concern for energy savings. Usually, this was a parent, e.g. a mom or dad switching off the main computer once the kids had gone to bed (H6). For personal devices, such as a personal laptop, the owner of the device usually switched it on and off.

Location

Of the 59 computers, 25% of these machines were in a private location, 36% were in a semi-private location and 39% were in a public location. Participants spoke of how when computers were located in bedrooms or living spaces where the computer could be seen or heard, they turned them off at night time to avoid being disturbed by the sound of the computer or lights on the computer box. They also confirmed that where devices were located also affected frequency or desire to switch them off. One family (H6) told us they did not unplug their computer when they went out for long periods because it was difficult to physically access the plugs, located behind a large cabinet. Another family told us that they would not turn off their server even if it would still record shows because it was located in garage so that meant extra effort to switch it off (H19).

We also explored whether location of the computer might affect power management responses on the survey, as we hypothesized that computers in public locations might be left on more than those in private areas. There was not strong support in the survey data for this. A two-way contingency table analysis showed an affect of location only when leaving the computer for more than 30 minutes (Pearson χ^2 (2, N=88) = 7.01, $p < 0.03$, Cramer's V = 0.282). The only significant pairwise difference was between leaving computers on or in low power mode. Computers left in low power mode were more likely to be in private locations (Pearson χ^2(1, N=72) = 6.01, $p < 0.014$). We also compared the average on and active times between computers in public and private locations, but did not find any significant differences.

Technical Challenges

Several technical challenges hampered the use of power management. First, many people we interviewed claimed they did not know how to alter their power settings to be more energy efficient. One family member in H9 wanted the options to be preconfigured for him: *"if it came out the box and it was kind of like that then I would probably leave it*". The power survey data suggests, not surprisingly, that not everyone may fully understand what different power settings can do. Generally people seemed to have an accurate understanding of "sleep" or "standby" mode with 88% on our survey reporting that this meant a low power mode. When asked about "hibernate", the responses indicated less clarity about what this particular power mode means, with only 30% reporting that it meant the computer saved all documents and shut down. Despite being somewhat unclear about power settings, in our interviews, the most commonly spoken about techniques were standby because of the fast resume time or hibernate because it saved the state of applications.

Second, participants complained that shutdown and hibernate power settings often did not work very well. One family told us how they often shutdown their machines and walk away at night but return to find them on in the morning because certain applications caused shutdown to hang. Another family complained that they had problems with hibernate not saving their documents and applications state properly: *"I turn mine off because I've had bad experiences in the past with the power save mode and getting it to come back. Sometimes computers lock up and don't come back well from hibernate" (H2).* Another participant said: "*Any power saving mode is too flaky and wastes too much time" (H1).*

Third, participants often left computers on to run general "maintenance tasks," with 43% in our surveys agreeing that they left the computer on because they had applications running. In our interviews, one dad told us how he often started a system defragmentation before heading to bed. Other people left backup applications running.

Looking Ahead: Savings and Home User Desires

Knowing now that people are not necessarily using the most power efficient management strategies, we outline the potential savings for reclaiming wasted energy and how our participants would like power management to be improved.

Reclaiming Wasted Energy

We asked participants on the power survey how much they thought they would save per month if they put their computer in a low power mode (off or standby/hibernate) when not using it. While 11 participants (27.5%) answered they did not know, many others thought large savings were possible. Fifteen participants (37.5%) thought they would save \$6 per month or more while the rest (12 participants, 30%) thought savings would be less than \$6 dollars. We also asked participants how much money they would have to save per month to convince them to turn off their computers when they were not using them, and half the respondents (20) said more than \$10 a month.

For the 23 respondents that answered both questions without choosing '*I don't know*' on either, we compared what respondents thought they could save and what they said they needed to save to change their behavior. Fourteen respondents wanted to save more than they thought they could, while 7 thought they would save the same amount they claimed they needed to save. This mismatch between what participants think they can save and what would motivate them to change their behavior suggests the economic incentives are currently not there for minimizing computer power use. As one participant in H1 said: *"if it was costing me like 10 or 20 bucks every time I left it on yeah I'd do something about it"*. Notably, our lower income families felt more strongly that saving even a few dollars a month would be worth switching their computers off.

In addition to the potential lack of strong economic incentive, many participants rightly did not perceive computers to be power hogs and prioritized power management of other power hungry devices or systems in the house like heating/cooling. As one household commented: *"We did a kind of mental calculation with some friends and we figured it's not using that much power and I realized that the bigger energy savings is making sure we turn the TV on and off" (H8).* When asked to rank the power usage of 7 different appliances in the home (desktop computer, hair dryer, laptop computer, light bulb, refrigerator, television, washing machine), from most to least usage the median ranking for laptop computers was 6 of 7 (N=38) and 4 of 7 for desktop computers (N=37). Clearly, participants were aware that computers do not use much energy in comparison to other household appliances.

The logging data collected allows us to roughly estimate the energy and cost savings possible from improved power management. While we collected point samples of power usage data for computers when possible, given that we did not visit all households, we opted to use estimates of power usage for computers based on [8] for our calculations. We calculated our saving estimates using 30 watts for a laptop and 150 for a desktop computer, which obviously does not represent all variation in power used by a computer (e.g. hard disk powered down, battery charging time on a laptop), but serves as a reasonable approximation.

We calculated the maximum possible savings based on an *oracle* power management strategy that would reclaim all possible wasted power. For each computer in the sample we computed the difference between its 'on time' and 'active time.' Any time in a low power state (standby or hibernate) was treated as being off, given the typically very low power requirements of those states. For the 38 computers this difference was 5,424 hours over 664 days of logging (3505 hours over 270 days for desktops, and 1918 over 393 days for laptops). This is a total of 583 kWh that could be reclaimed over the study period which would add up to 15,130 kWh per year for those 38 computers. Or, on average, desktop machines are left on 52 minutes extra each day and laptops 13 minutes. When that extra time is multiplied out for the year each desktop is consuming an extra 47.5 kWh and each laptop uses 2.4 kWh. For monetary cost, we used pricing rates from the Puget Sound Energy electrical company in our region to estimate a price of 10 cents per kWh. This amounts to an average savings of $4.75 (US) per desktop and $0.24(US) per laptop for a year.

These calculations support the sense of many of our participants that the energy saving and economic incentives through better power management are not very powerful on a per computer or per household basis, particularly for laptops. However, this does not mean the potential for savings is not quite large in the aggregate. Clearly these are very optimistic calculations assuming a perfect oracle strategy that reclaimed all lost power. However, given that the 2005 REC survey [7] estimates the 111.1 million housing units in the U.S. have 58.6 million desktop computers and 16.9 million laptop computers, the potential collective savings is large (about 2.8 TWh per year at a cost of $278 million dollars per year in the U.S.). Even if one assumes only some of this power could be reclaimed, there is still a considerable opportunity.

Our participants themselves did seem to recognize that the collective savings might matter more than their individual savings. Several participants expressed interest in knowing the collective savings or benefit to the larger community. For example, *"Everybody needs to realize too that if you have this household times 50 million others, it is a significant energy savings if things are optimized. So it may not be a monetary incentive per household but collectively, it can save a lot of energy. People need to realize that they may not be saving much [of their] own money but they're in a society and they can collectively do things to improve it" (H6).*

Desired Power Management Improvements

At the end of the interviews we asked participants about what they would like to help them with power management. Almost all participants wanted the resume or boot up time for the computer to be in a usable state to be faster, again highlighting the desire for instant availability. Our participants also expressed an interest in feedback about power usage, from insight into how much energy a single computer consumes over time and the cost of that in terms of their local electricity price to power consumption of computers on their network. Some participants also wanted more control of their computers including the ability to schedule tasks and wake their computers for remote access, some of these features are currently available in commercial products mostly targeted at business.

When we showed participants a motion based application for switching the monitor on and off as a demonstration of the possibilities of sensor based power management, many people did not see much advantage over a simple timeout strategy. Some felt that a proximity sensor may be better suited to power management since often computers (especially shared ones) are located in public spaces. In such high traffic areas, participants were concerned that the computer would switch on and off even if they entered the room for another purpose: *"well we walk past that computer about a hundred times a day so every time we walk past it would turn it on" (H7).* Those with computers in dedicated or more private rooms like an office or bedroom thought that motion sensors would be better suited to these locations. Participants commented that motion would be particularly well suited for leaving the home for an extended period of time, when they often forget to turn the computers off or at night.

Our participants also raised concerns about how sensor based power management would affect computer availability. For example, they would not want the computer to switch off if they left for a short bathroom break or if they interleaved other household tasks with their computer use e.g. going off to do laundry or to tend to the kids, before resuming the original task. Some participants also expressed concern at the machine switching off when there was little motion, but when the computer was being used such as when watching a video or having the screen up with documents open for reading but which are not directly being manipulated. One household spoke of how they opened up documents on their laptops for their role playing games just to look at as a reference, but not to actively manipulate. In all cases, the fear was that if the computer switched off at an inappropriate time, it would cause annoyance, frustration and inconvenience. Users were also concerned with the form factor of the sensor—they did not want to invest in additional devices for their computers, and would prefer built-in motion sensing for aesthetic reasons.

DISCUSSION: TOWARDS GREENER TECHNOLOGIES

Our results show that improved power management (switching devices to low power modes when they are inactive) could yield energy and monetary savings for home computer users. However, on a per household basis our data suggests these potential savings are very small and are outweighed by peoples' impatience with waiting for computers to start up, and complicated by shared usage patterns—often leading to computers being left on. As a first step, companies and researchers have begun working on persuasive visualizations that provide feedback on monetary and energy savings from using optimized power management (e.g. [22]) and persuasive ambient displays (e.g. the Power Aware cord [10]).

While these types of persuasive interfaces are a logical first step for the CHI community, our data (e.g. logs showed minor per household savings and some participants moved to more power inefficient settings) emphasize the challenges of this approach and the importance of making visible savings by groups of people or leveraging collective action, another difficult problem [18]. We are also skeptical of this approach for power management alone, since computer power usage only accounted for 3% of overall residential electricity consumption in the US in 2007 [6]. Persuasive visualizations will therefore have to show feedback on energy consumption beyond just computers and there are no guarantees that comparative information will not backfire—for example when people know they are below a neighborhood average for energy consumption, they may increase their own consumption [21].

More generally, since our data suggests people may not be easily motivated to change their computer usage behaviors, we as a community might concurrently explore how to create greener technologies and improve power management interfaces. First and possibly the easiest direction to pursue is for greener computing technologies to reduce the cost perceived by users of using low power modes and turning computers off. Providing users with more control and insight into which programs may be slowing down boot up, such as instant messaging clients that can be disabled, might ensure only the most important programs (e.g. email and a web browser) run at start up, thereby reducing the perceived cost of turning off the computer. Other minor power management fixes might include better interfaces to engage low power modes quickly and ensuring these modes minimize user frustration which may cause them to turn these settings off (e.g. not turning off the screen when users are watching a video).

Second, we believe that physical sensors for user presence and near-presence on computers may help improve computer availability (by being able to switch computers on as well as off) and save power and energy for minimal investment much like in the workplace [11]. As our participants noted, because of key differences between the office and the home, such as the placement of machines in high traffic public areas or multiple users per machine, domestic sensors based on motion or on personal devices (e.g. Bluetooth) may not be sufficient for better power management. Instead future research could explore sensors that use proximity or face detection, as well as whether one sensor per computer or a single central sensor somewhere in the home would improve upon power management timeouts for maximum availability and provide energy and monetary savings. Studies of prototypes could determine how well physical sensors work in practice and how to overcome situations when presence or near-presence does not indicate computer use as we observed in a desire for glance-able displays (e.g. calendars) and using personal computers to play music.

Aside from user availability, computers (and other home electronics) with physical sensors could be augmented with low powered devices that allow machines to be responsive to network requests in low power modes (e.g. [1]). Further research could investigate which applications should take advantage of this network responsiveness (e.g. we saw participants leave on computers that were print servers or personal video recorders) and how to transparently display this low power functionality to the user.

Beyond physical sensors, our data showed some evidence that learning multiple computer usage patterns in a home could be a valuable way to predict when a computer should be on or be used to change defaults for standard power management timeout settings. However, larger data sets are necessary to fully determine what patterns exist and how to leverage them for power management. Given the research effort needed for such an endeavor and the low payback we are reluctant to suggest this direction for computer power management alone.

Finally, given the shared nature of devices in the home that we observed (and the increasing prevalence of home networks), an interesting longer term direction to explore for improving both power management and computer availability is changing the paradigm of home computing away from the desktop model to a client-server model. For example, if families kept data and programs running on a central server and used lightweight low power thin client devices to access applications and data. The client devices could then address people's desire for availability by providing near instant access to the most frequently desired programs (email and a web browser for our participants) while having the server as a single heavy power user could allow for easier power management.

Equally important, this type of model could address the complications we saw associated with shared computers where people felt they needed to leave devices on when other people were logged in or had applications running. In a client server paradigm, people could switch off client devices guilt free, knowing that other peoples' applications and files were secure on the home server. However, switching home computer usage to this model will not be trivial, and requires research into network management and developing models of application and device sharing for the home that leverage home networks and optimize availability while improving overall computer power usage.

CONCLUSION

Our field study of 20 households' computer power management habits suggest opportunities for energy and monetary savings exist because devices are left on more than they are being actively used. Yet, given the relatively small energy and monetary savings suggested by our data and peoples' desire for always available computing in the home, this is a challenging area for persuasive technologies. Instead we encourage researchers to explore interfaces that reduce the perceived costs of turning off computers, utilize sensors to ensure computers are available when people want to use them, and contemplate new computing paradigms for the home that could provide increased availability and better power management.

ACKNOWLEDGMENTS

We thank our participants and Danyel Fisher.

REFERENCES

1. Agarwal, Y., Hodges, S., Scott, J., Chandra, R., Bahl, V. and Gupta, R. *Somniloquy: Maintaining network connectivity while your computer sleeps.* Microsoft Research, 2008. http://research.microsoft.com/research/pubs/view.aspx?type=Technical%20Report&id=1458.
2. Banerjee, N., Rahmati, A., Corner, M.D., Rollins, S. and Zhong, L. Users and Batteries: Interactions and Adaptive Energy Management in Mobile Systems. *Ubicomp 2007*, Springer, Innsbruck, Austria, 2007, 217-234.
3. Beyer, H. and Holtzblatt, K. *Contextual Design: Defining Customer-Centered Systems*. Morgan Kaufmann Publishers Inc., San Francisco, CA., 1998.
4. Blevis, E. Sustainable Interaction Design: Invention & Disposal, Renewal & Reuse *CHI 2007*, ACM, Florence, Italy, 2007.
5. Chetty, M., Tran, D. and Grinter, R.E. Getting to Green: Understanding Resource Consumption in The Home. *Ubicomp 2008*, Springer, Seoul, Korea, 2008.
6. Energy Information Administration. http://www.eia.doe.gov/oiaf/aeo/pdf/appa.pdf.
7. Energy Information Administration. *Residential Energy Consumption Survey.* 2005. http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html.
8. Energy Star. http://www.energystar.gov/index.cfm?c=power_mgt.pr_power_management.
9. Gupta, M. and Singh, S. Greening of the Internet. *SIGCOMM 2003*, ACM, New York, NY, 2003, 19-26.
10. Gustafsson, A. and Gyllenswärd, M. The Power-Aware Cord: Energy Awareness through Ambient Information Display. *CHI 2005 Extended Abstracts*, ACM, Portland, USA, 2005, 1423-1426.
11. Harris, C. and Cahill, V. An Empirical Study of the Potential for Context-Aware Power Management. *Ubicomp 2007*, Springer, Innsbruck, Austria, 2007, 235-252.
12. Holmes, T.G. Eco-visualization: Combining Art and Technology to Reduce Energy Consumption. *Creativity and Cognition 2007*, ACM, Washington, DC, USA, 2007.
13. Kawamoto, K., Koomey, J.G., Nordman, B., Brown, R.E., Piette, M.A., Ting, M. and Meier, A.K. *Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendices.* Ernest Orlando Lawrence Berkeley National Laboratory. 2001. http://enduse.lbl.gov/Info/LBNL-45917b.pdf.
14. Korn, D., Huang, R., Beavers, D., Bolioli, T. and Walker, M. Power Management of Computers *International Symposium on Electronics and the Environment (ISEE'04)*, IEEE, 2004.
15. Lu, Y.-H., Chung, E.-Y., Simunic, T., Benini, T. and de Micheli, G. Quantitative comparison of power management algorithms. *Design, Automation and Test in Europe Conference and Exhibition 2000*, IEEE, Paris, France, 2000, 20-26.
16. Mankoff, J., Matthews, D., Fussell, S.R. and Johnson, M. Leveraging Social Networks to Motivate Individuals to Reduce their Ecological Footprints. *HICSS 2007*, Hawaii, 2007.
17. Microsoft. *Application Power Management Best Practices for Windows Vista.* 2007. http://www.microsoft.com/whdc/system/pnppwr/powermgmt/PM_apps.mspx.
18. Olson, M. *The Logic of Collective Action: Public Goods and The Theory of Groups*. Harvard University Press, Cambrigde, Massachusetts, 1965.
19. Rattenbury, T., Nafus, D. and Anderson, K. Plastic: A Metaphor for Integrated Technologies. *Ubicomp 2008*, ACM, Seoul, Korea, 2008.
20. Satyanarayanan, M. Pervasive Computing: Vision and Challenges. *IEEE Personal Communications*, *8*, 4 (2001), 10-17.
21. Schultz, P.W., Nolan, J.M., Cialdini, R.B., Goldstein, N.J. and Griskevicius, V. The Constructive, Destructive, and Reconstructive Power of Social Norms. *American Psychological Science*, *18*, 5 (2007), 429-434.
22. Verdiem. http://www.verdiem.com/edison/.
23. Webber, C.A., Roberson, J.A., Brown, R.E., Payne, C.T., Nordman, B. and Koomey, J.G. *Field surveys of office equipment operating patterns.* Lawrence Berkeley National Laboratory. 2001.
24. Woodruff, A., Anderson, K., Mainwaring, S. and Aipperspach., R. Portable, But Not Mobile: A Study of Wireless Laptops in the Home. *Pervasive*, ACM, Toronto, Ontario, 2007, 216-233.
25. Woodruff, A. and Hasbrouck, J. A Bright Green Perspective On Sustainable Choices. *CHI 2007*, ACM, Florence, Italy, 2008.