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Abstract

Miscellaneous and electronic devices consume about one-third of the primary energy used in U.S. buildings, and their energy use is increasing faster than other end-uses. Despite the success of policies, such as Energy Star, that promote more efficient miscellaneous and electronic products, much remains to be done to address the energy use of these devices if we are to achieve our energy and carbon reduction goals. Developing efficiency strategies for these products depends on better data about their actual usage, but very few studies have collected field data on the long-term energy used by a large sample of devices due to the difficulty and expense of collecting device-level energy data.

This paper describes the development of an improved method for collecting device-level energy and power data using small, relatively inexpensive wireless power meters. These meters form a mesh network based on Internet standard protocols and can form networks of hundreds of metering points in a single building. Because the meters are relatively inexpensive and do not require manual data downloading, they can be left in the field for months or years to collect long time-series energy use data.

In addition to the metering technology, we also describe a field protocol used to collect comprehensive, robust data on the miscellaneous and electronic devices in a building. The paper presents sample results from several case study buildings, in which all the plug-in devices for several homes were metered, and a representative sample of several hundred plug-in devices in a commercial office building were metered for several months.

Key words: end-use metering, advanced meters, load research, wireless networking

Introduction and Motivation

Miscellaneous and electronic devices (also known as miscellaneous and electronic loads, or MELs) consume about one-third of the primary energy used in U.S. buildings, and their energy use is increasing faster than other end-uses [1]. Because the usage of these devices tends to be closely tied to the activities and lifestyles of a building's occupants, their energy use varies greatly between buildings and device types. In order to address the growing energy use of MELs, it is important to have empirical, field data on the energy use of these devices, for the purposes of policy development, product design and testing, and consumer information. These field data allow targeting energy efficiency activities at products that contribute the most to energy use, and also help guide the development of technologies to address the most consuming operational modes. Field data are also important for accurately measuring and verifying the savings from energy efficiency programs that address MELs products.

Previous Research

The most comprehensive studies of the MELs end-use in the U.S. are based on national surveys of a few thousand residential and commercial buildings, in which monthly, whole-building utility bills are collected. These monthly bills are then statistically disaggregated to estimate end-use energy consumption, using building characteristics, equipment ownership, and exogenous factors such as weather to explain variation in energy use. In these models, miscellaneous and electronic loads are included in the "Other" end-use, which is simply a statistical residual that cannot be attributed to one of the traditional end-uses (heating, cooling, lighting, etc.), and is therefore subject to errors due to data collection or model specification in these traditional end-uses. This type of whole-house metering has also been conducted in other countries, such as by Firth et al. [2] in the UK.

Another study approach is to use energy-consumption data from controlled, laboratory conditions, combined with shipment and stock data, to produce bottom-up estimates of MELs energy use by device type. These studies have been developed for the residential [3] and commercial [4] sectors in the U.S.

Starting in the 1980s, to avoid the uncertainties inherent in the whole-building disaggregation methods, U.S. electric utilities began conducting more detailed end-use metering studies to provide input data for load forecasting. This metering was typically conducted at the branch-circuit level in buildings, to identify large individual loads (e.g., furnaces). The largest such study was the End-Use Load and Consumer Assessment Program (ELCAP), conducted in the Pacific Northwest [5]. Other large-scale residential end-use metering studies have been conducted in northern California [6] and central Florida [7]. Similar residential studies have also been conducted in Europe [8] and New Zealand [9]. These studies typically monitored several hundred homes (ELCAP also monitored commercial buildings). Due to data storage and processing limitations, typically ten to fifteen circuits or devices were monitored in the homes and energy measurements were taken every ten to fifteen minutes. Depending on the study, monitoring lasted from one month to one year.

While these studies are still an important basis for our knowledge of energy use in buildings, they are best at identifying the consumption of large devices such as furnaces, water heaters, and refrigerators. With the proliferation of MELs over the last 20 years, a more intensive style of metering—at the individual device level—is needed to properly characterize energy use of this equipment. Several studies have been conducted in recent years to fill this gap. In California, MELs metering has been conducted in both residential [10] and commercial [11] buildings. The residential study sampled 50 homes, metering 17 devices per home, on average, for a period of one week. Meter readings were collected at one-minute intervals. The commercial building study sampled 47 office buildings, metering 10 devices per building, on average, for a period of two weeks. Meter readings were again collected at one-minute intervals. A third study of this type was recently completed in Minnesota. Detailed metering was conducted in about 50 homes, with 16 devices metered per home, on average, for a period of one month. Meter readings were collected at six-minute intervals (or 90-second intervals for computers). The data collected through these studies significantly improved the state of knowledge of MELs energy use in U.S. buildings. The main limitation is that the expense of the metering equipment (the last two studies used Watts Up Pro meters, www. wattsupmeters.com, which cost US$200-300 per metering point) limits the number of devices per building that can be metered. Because of the wide diversity of MELs devices found in buildings, it is important to be able to meter a large number of devices per building. Also, the meters all used on-board data storage, which limits the length of the metering period and the frequency of energy measurements.

Study Purpose

To address the limitations of these earlier studies, we felt it was important to develop MELs field metering techniques that are more cost-effective and allow more frequent meter readings over longer time periods. The goal of this study was to take advantage of recent developments in wireless sensor networks to develop a MELs field study methodology that was relatively low-cost, reliable, and allowed metering all the MELs devices in a home and a representative sample in a commercial building. The resulting methodology is tested in several homes and a commercial office building. Another goal of this study was to further refine field methods for conducting an inventory of MELs devices and, where devices are too numerous to meter all of them, develop a method for selecting devices to meter.

Wireless Meters and Network

The wireless power meters used in this study are a research platform developed by the University of California, Berkeley. Called ACme ("AC meter"), these meters provide data readings as frequently as every 10 seconds, are accurate to about 0.5% of the reading, and wirelessly transmit the data back to a central database. These meters are ideally suited to research applications because they are based on an open platform that can be improved and adapted for a given project [12, 13]. The ACme system consists of three tiers: the ACme node (Figure 1, and shown installed in Figure 2) which provides a metering interface to a single AC outlet, a network fabric which allows the meter data to be communicated over an Internet Protocol (IP) network, and application software that collects the power and energy data, stores it in a database, and provides various data processing functions. The architecture used in residential buildings is summarized in Figure 3. Commercial building installations use the same architecture, except the TED meter is not present and multiple edge routers are used for greater floor-area coverage.

Figure 1 – ACme node (scale in inches)

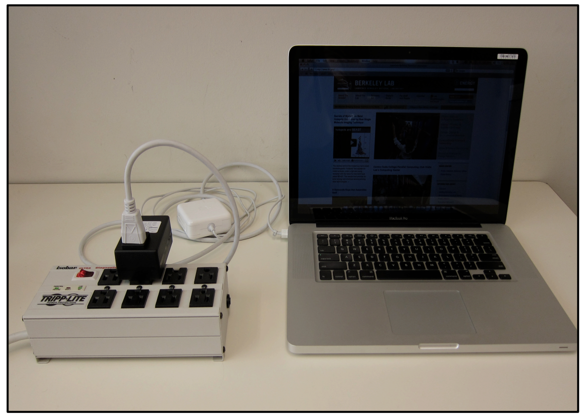

Figure 2 –ACme node (left), measuring laptop power

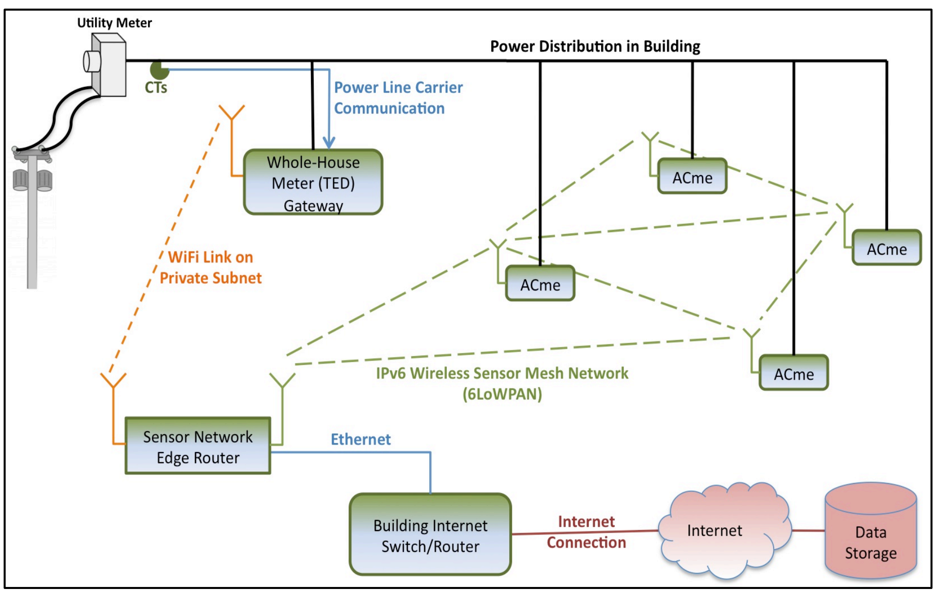

Figure 3 – Residential Metering Network Diagram

The ACme node integrates a wireless communications module with a dedicated energy metering IC to provide real, reactive, and apparent power measurements. The network comprises a complete IPv6 network stack on every node, based on the open-standard *6LoWPAN* network protocol and the *Hydro* routing protocol [14]. The nodes form a mesh network, in which they cooperatively route data packets through the network to an edge router, which provides bi-directional communication with other IP networks. The application tier receives and stores readings in a database and uses a web server for visualization. Nodes automatically join the IPv6 subnet after being plugged in, and begin interactions with the application layer. Due to the small size and use of commodity parts, the purchase cost of the ACme system is approximately $100 per node. The power draw of the ACme system is approximately 1W (constant) per node and a few watts per edge router, which sums to a few tens of watts for a residential installation and hundreds of watts for a commercial building. In addition to the ACme network for device-level metering, we also collect whole-building energy data to calculate the fraction of whole-building load due to MELs devices. In homes, we use a TED 5000 (www.theenergydetective.com) to collect whole-building data, as shown in Figure 3.

Commercial Building Deployment

The commercial study building, an office building located on the LBNL campus, is a 1960s era facility largely used as a traditional office space. It has a total floor area of 89,500 square feet, of which 62,100 square feet is considered net usable. Approximately 450 occupants in six working groups are located on four floors and a basement. The building has individual offices, cube farms, conference rooms, small kitchens or break rooms, a computer training facility, server closets, and network equipment.

MELS Device Inventory

We conducted a full inventory of the MELs devices in the office building. Although it may not be practical to do this in a larger building, we wanted a full inventory to serve as “ground truth” in comparing various sampling approaches.

Due to the diversity of devices, a standardized system of identifying and recording MELs is essential for inventory and energy data analysis. Nordman and Sanchez [15] developed a taxonomy of MELs for a California Energy Commission study, and we augmented this taxonomy by referencing other existing taxonomies (Energy Star product categories and California Energy Commission appliances list). The taxonomy consists of three levels - End Use, Category, and Product Type. MELs are divided into three major end uses – Electronics, Miscellaneous, and Traditional. Each end use is in turn composed of categories, and each category contains many product types. For example, a “LCD computer display” is a product type in the “Display” category, which is part of the end use “Electronics”. During the study, we expanded and fine-tuned the taxonomy, in order to describe certain devices in a more consistent way and as we encountered new device types during the inventory.

In addition to the device taxonomy, information recorded during the inventory included:

- Location and space type, Date and time of inventory, Manufacturer of device;
- Any device specific information, such as diagonal screen size of displays and form factor of computers;
- If device appears to be in use, if device is plugged in, power state and portability of device.

Before conducting the extensive whole-building inventory, we explored different inventory methods, seeking a compromise between time and effort, quality and quantity of information gathered, compliance with building security requirements, and occupant disruption.

Occupant Consent and Access

For the purposes of our study, the building occupants who use and interact with the MELs devices are considered research subjects and therefore protected by “human subjects” rules imposed by the U.S. federal government. Some guidelines that we followed are general in nature, such as providing occupants with advanced notice before inventory and not identifying any personal information. Others are more specific, such as the prohibition of videotaping during inventory (to protect occupant privacy).

Much of the inventory was performed after work hours, in the absence of building occupants in order to minimize disruption. Because the research team works in the study building, after hour access to the building was made easier in most cases. For some workspaces however, an escort by a representative was required because of security concerns or in sensitive areas such as computer server rooms.

Inventory Data Collection Method

Based on our inventory of a small area, we projected that the building might have roughly 5,000 devices. With so many devices in place, we experimented with the following data collection methods before one was selected for deployment:

- Voice recording, with electronic voice recognition and transcription,
- Paper, with manual entry at a later time,
- Direct electronic entry (typing in spreadsheet) in real-time.

The voice recognition method appeared to be promising at first, as the voice recognition software used is able to instantly convert spoken language into text. Using a wireless headphone, the researcher identified and spoke the inventory information, while the software recorded data directly into a spreadsheet. We found several drawbacks to this approach: transcription accuracy varied depending on the position of the microphone and the individual, and training the software to recognize an individual's speech pattern can be time consuming and may not be practical if multiple personnel are involved in the inventory activities. For these reasons, this method was not considered further.

The paper method involves writing down information during the inventory and transcribing it to an electronic format afterwards. The inventory is best done by a two-person team, with one person identifying the MELs devices and reading out relevant data, while the other person records data by hand. A printed form to fill in during the inventory helps ensure consistent data collection. The written entry also takes relatively little time, however, manual entry adds significantly to the inventory effort.

The method we found best suited for the study building is the direct electronic entry method. The same two-person team would take the same roles as with the paper method. However, the data entry person would now enter data directly into a spreadsheet using a laptop computer, combining data entry and transcription in one task. In addition, given the long lists of MELs included in the taxonomy, we found that the built-in taxonomy lists set up in the spreadsheet greatly facilitate the process of consistently identifying and recording MELs.

Mobile Devices

Aside from the diversity of devices, another challenge that the study of MELs present is their mobility. Devices such as computer notebooks and small electronic devices are moved between locations, and since we performed the inventory after work hours some devices might have been taken home by the occupants. If the mobile devices were not present during our inventory, we looked for other signs of their presence in the workspace, such as notebook docks, external power supplies for notebooks and small electronics, and connection cables for external displays. If we believed that a mobile device might be present, we returned during work hours to confirm the presence with the occupant.

Meter Sampling Methodology

With close to 5,000 MELs in our study building, metering all these devices would be time and cost prohibitive, and not all data generated would provide useful insights. The original study goal was to install 500 ACme meters—which is about a 10% sampling rate—for a 3-6 month period to capture usage patterns and any seasonal variation. The selection of an appropriate sampling method is driven by the multi-fold purpose of our energy data collection and analysis:

- Measure power consumption of MELs and capture the different power states;
- Derive usage patterns of MELs;
- Study usage correlations between devices, i.e. computer, display, and lighting within the same occupant's office;
- Provide a large survey of power and energy measurements of individual MELs devices while in actual use.

We used a stratified random sampling approach to select devices for metering. Devices were divided into strata several ways – by Device Type, by Organization, and by Space Type – to meet our data collection objectives listed above. We also divided the building inventory into stages, and each of the five floors was considered a separate sampling stage. Staging allowed the field team to build the network sequentially to ensure wireless connectivity as meters were deployed. Phasing deployment on one floor at a time was also more time efficient.

The first stratification method we used was by device category or product type, in which devices that we expected to have more variation in power levels or usage (such as computers) were placed in their own strata. Some device categories were assigned to a strata that was not sampled at all, if they were a device that consumes a constant amount of power with an insignificant or predictable usage pattern. For these devices, such as power strips, surge protectors, or staplers, it is not essential to measure their power consumption for long periods of time. Instead, we spot metered them with wired power meters to measure their typical power use and inferred these power levels in actual use. There are also a small number of MELs in the study building that are hard-wired or rated at more than 15-amps, making them unsuitable for use with the ACme meters.

The next stratification method we used is by organization. The study building is occupied by several organizations within LBNL, and the types of MELs used and their usage patterns are likely to differ by the type of organization.

The final stratification method was by space type. Different space types may have very different MELs categories in use, and stratification by space type helps ensure that the types of devices within each strata are more homogenous. For example, workspaces mostly contain office equipment such as computers, displays, and lighting. Common spaces, i.e. office common or hallways, contain shared MELs such as copiers and printers, whereas conference and server rooms contain yet different device types.

In some cases, we used a combination of these stratification methods to select samples for metering, to ensure that the final sample of devices accurately represents the whole building. For example, the first floor of the study building is occupied by workers from 4 different organizations. In this space, we first stratified by space type, then by organization, according to the floor area occupied by each organization. We installed an average of four meters per randomly-selected office/cubicle, with priority assigned to computer, display, and imaging devices, in order to study usage correlation between devices. Remaining meters were randomly installed on device(s) in the offices/cubicles. For meters assigned to common spaces, we stratified by device category and product type, focusing on office and kitchen equipment.

Residential Building Deployment

For our residential study, we selected 3 homes for a full MELs inventory and metering, with the meters remaining in place for 6 months to capture seasonal variation of devices. Two of the study homes are typical existing homes located in Oakland, California, and the third is a zero-energy new home located in Boston, Massachusetts. The homes were selected using a questionnaire that identified a number of household characteristics preferred for the study, such as having a broadband wireless Internet connection (needed to transmit ACme data back to LBNL), number of household members, and the variety of MELs in the home.

Inventory

Once the study homes were selected, we made one site visit to conduct an interview and guided walk-through of the home with the homeowner, a whole-house MELs inventory, and ACme meter installation. During the interview with the homeowner, we explained details of our study, and asked questions about their usage of MELs and the location of any unused and stored MELs that they might overlook. The homeowner then showed us the location of their electric panel, rooms in the house, and both in-use and unused MELs. During the walkthrough, one member of the field team took the role of interviewing the homeowner, while the other researcher sketched diagrams of the rooms, recorded the locations and quantity of electrical outlets, and noted locations of MELs as described by the homeowner.

After the walk-through, the field team performed a full inventory of the MELs devices in the home while installing meters at the same time. In addition to the inventory methods considered for the commercial building, we also tested a video data collection method, in which the field team videotaped the MELs being inventoried and narrated relevant information for recording on the video. The recorded video was then transcribed into electronic record after the field visit. We found that videotaping in the field takes relatively little time, but the manual transcription afterwards makes the whole process time consuming. Therefore, we decided to use the same direct electronic entry method that we used for the office building.

Metering Methodology

Since we were interested in the fraction of energy use contributed by MELs, our goal was to install meters for all MELs that were in-use in the homes. We assigned 75-80 meters for each home. If the number of MELs in the home exceeded 80, the preference was to meter devices that were expected to be bigger energy users and/or have variable usage patterns. In some cases, we combined multiple similar loads, such as a cable modem and a network switch, for metering by a single ACme.

To capture the energy use of devices that are only periodically plugged in, we also installed meters on sockets that the homeowners indicated were used periodically but had no device plugged in during our visit. The homeowners were instructed to plug devices into a meter wherever possible. To identify these transient devices that are not plugged in at the time of our visit, we provided the homeowners with instructions and a log book to make an entry when they connect these devices to an available meter. We also provided homeowners with extra ACmes for use with any new or seasonal devices.

In addition, because we wanted to quantify the fraction of overall home energy consumption due to MELs, we installed a TED whole-house energy monitor in each home. This device contains current transformers that are installed in the home's electric panel and uses power-line carrier communication to transmit data to a gateway that communicates via WiFi to the ACme edge router for relay to LBNL via the homeowner's internet connection (as shown in Figure 3).

Methodological Findings

In addition to the study findings listed later, we have accumulated extensive lessons learned and experience from the inventory and metering activities that will be useful in future studies.

Building Sub-metering Data

A key question for MELs research and evaluations is what is the fraction of total building electricity used by MELs. As traditional building systems become more efficient, the fraction used by MELs will increase. In the office building, because of the incomplete building sub-metering data available, determining the MELs fraction of energy use proved to be difficult. When the building was first built, electrical panels were set up to serve distinct end uses, and MELs consumption in the building could be obtained by subtracting all the primary end-use consumptions (i.e. lighting, HVAC) from the whole-building load.

Over the years, however, as new services were added, multiple end-uses were extended from these single-voltage panels. In recent years, a sub-metering project has been launched for the building, and a large number of power meters and an extensive network reporting system were commissioned to measure energy consumption of each end use over time. But because of the highly intertwined end uses at the panel level, the MELs portion of energy consumption, which is obtained by measurement subtractions, is mixed in with small amounts of other end uses.

Electrical systems in buildings are continually changing to meet occupants' needs, and this phenomenon is probably not uncommon in buildings older than a few years. But this mixed end-use issue makes it difficult to obtain reliable sub-metering information in a building, and building managers are advised to avoid this if they expect to install a building metering system in the future.

Power Meters

Much of the metering equipment available in the market either has limited internal storage or requires connection to a computer for continuous data storage, making large-scale deployment labor-intensive and difficult. Power meters with wireless data transmission have recently become commercially available in a few form factors, such as plug meters or power strips. The ACme meters have several advantages over most commercially available meters that make them appropriate for large-scale deployment:

- Small form factor is unobtrusive and fits well into the building environment,
- In-house developed meters are less expensive than commercially available meters and allow flexibility for software and hardware upgrades and adjustments,
- Real-time data collection over a wireless network eliminates the need to manually download data and allows for real-time analysis,
- Relatively high sampling frequency of 10 seconds facilitates power-mode identification.

The ACmes also present some challenges:

- As a research platform the ACme system has not been as extensively tested as some commercial products, so is not as stable and reliable as one would like for a research study,
- Meeting Underwriters Laboratory (UL) safety standards takes substantial verification and testing,
- Managing the manufacturing, programming, testing, and calibration process for hundreds or thousands of measurement devices is time-consuming.

Preliminary Findings

Below we present our findings from the inventory and metering data we collected thus far in the study. Figure 4 presents the device distribution based on a full inventory in our commercial study building. The wide diversity of devices in the building is apparent from the number of device categories present. Moreover, the "Other" category contains 127 device types.

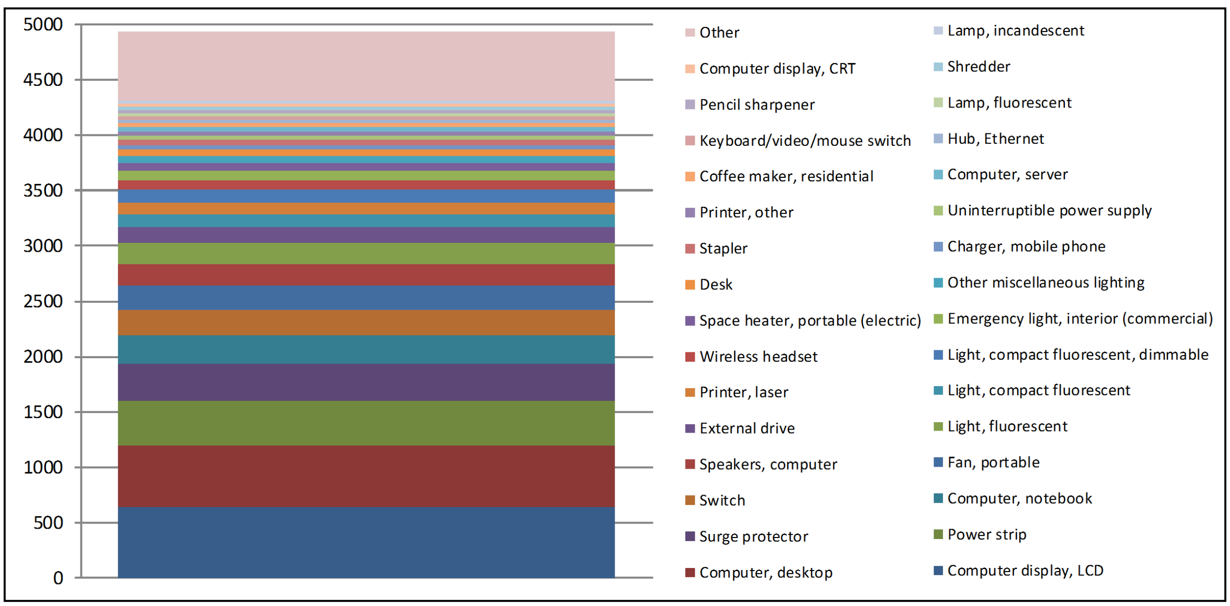

Figure 4 – MELs distribution in sample office building

An interesting use of the inventory and metering data is to compare the count and energy use between devices. Figure 5 presents the count of the top five energy users and all other devices, scaled with their respective energy usage in annual energy terms, for the commercial study building. Note that the annual energy consumption shown is based on a month of metering for the third floor of the building (the first to have a complete sample of meters installed). Energy estimates for the entire floor are projected from the metered sample of devices using sample probability weights. Computers use the most energy compared to their count in the building, whereas the "Other" devices show just the opposite. Because the building is mostly used as office space, displays, imaging, lighting, and networking are the next largest energy users. The energy breakdown shows that information technology equipment is the largest target for energy efficiency improvements.

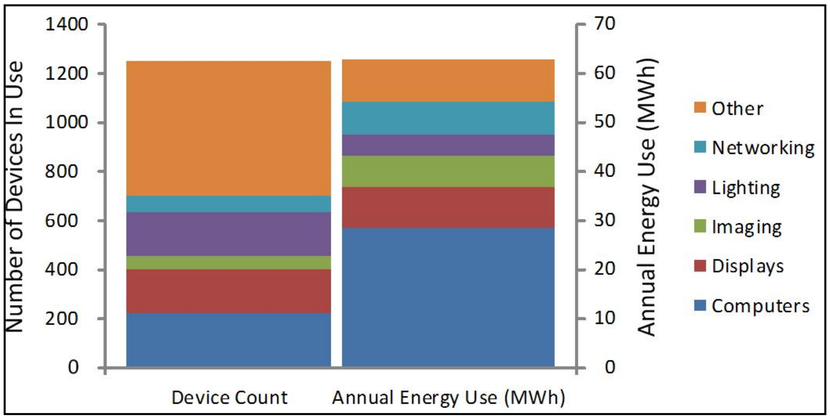

Figure 5 – Office building Device Count & Energy Use, 3rd floor

Figure 6 presents a similar plot, for one of the two study houses located in the San Francisco bay area, in which all plug-load devices are being monitored in real-time. In this home, plug lighting is the biggest energy using device category and also contributes to the highest count of devices. Just like the commercial building, computers consume a large amount of energy relative to their saturation. Other device types that dominate this particular home are entertainment, appliances, and kitchen devices.

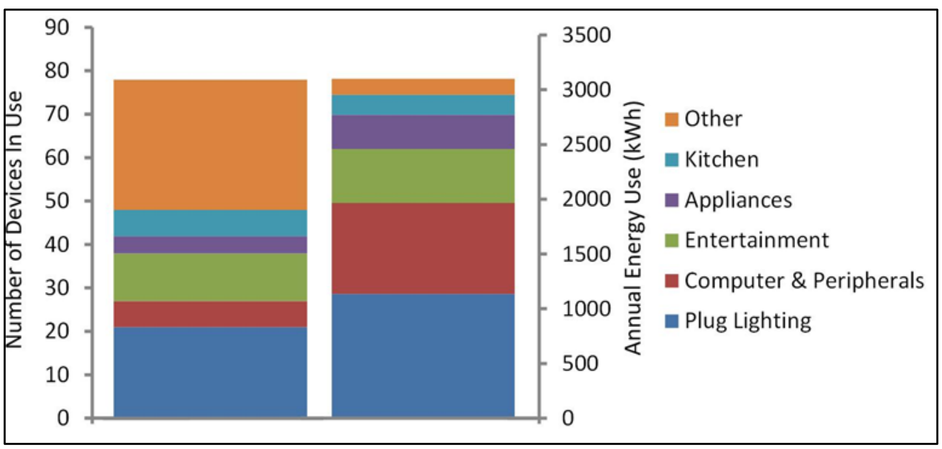

Figure 6 – Residential device count and energy use, Home #2

Figure 7 shows the high degree of power mode variation between typical office computers in the commercial study building. Some computers were never used during the week in question while others were left on almost the entire time as shown in the left hand chart. The right chart shows that energy use is dominated by time in the "on" (active) mode, even when time in that mode is small—computers with even relatively small on times consumed most of their energy in the on mode. Therefore, increasing device sleep time will be an effective means of improving energy efficiency for devices that are not routinely turned off. Computers that are left on 6-10 hours per day vary in typical energy use by almost ten times. Improving the on-state efficiency of devices will also be an effective means of reducing energy use. These findings are shown for computers, but they apply to other devices in this building as well.

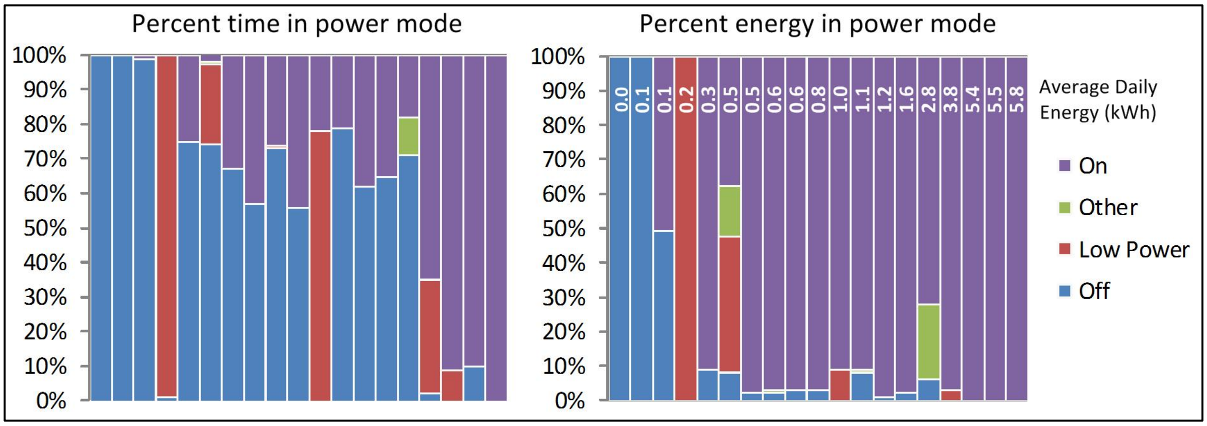

Figure 7 - Percent time and energy in power modes for 19 computers metered over a workweek in office building. Each column represents an individual computer, sorted from left to right by increasing energy use. Device ordering is the same in both charts.

MELs load shapes are useful to improve load modeling in new or retrofit designs and to improve utility forecasts for peak load or demand response planning. We expect that load shapes for some devices will have seasonal dependencies. For example, space heaters may be used more during the winter in some buildings but more in the summer (to prevent overcooling) in others. Figure 8 shows the average weekday power consumption for computers in the office building, with a one-minute sampling period. The light traces represent the average consumption of the individual computers. From this figure, we see that there is a great deal of variation from device to device and significant usage during off-hours, but the average load shape reflects the most common building occupancy periods.

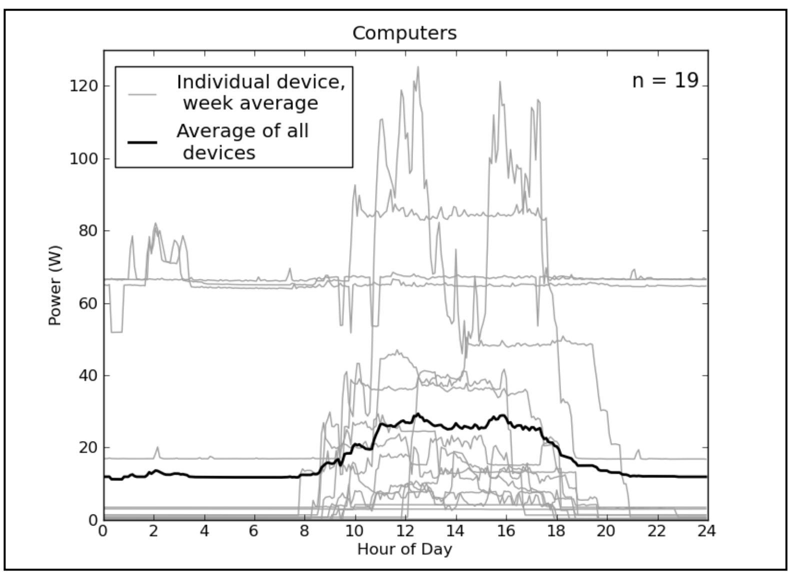

Figure 8 - Weekday average power consumption for computers in office building

Future Work

Further refinement of study methods and protocols. To improve the value of the field data collected, it would be useful to collect additional data beyond just energy and power, for example, occupancy monitoring to assess opportunities for energy savings. It also would be very helpful to develop reliable methods to identify and meter devices that move between power outlets in the building.

Expanded data collection. Due to the small number of buildings in this study, it is necessary to meter additional building types, sizes, and vintages, in order to make the results more representative of the building population.

Improved metering technology. The ACme metering platform provides a cost-effective way to deploy large-scale energy measurements and also offers an open platform for software upgrades and network controls. However, further development of the platform is needed for easier deployment and management, improved communication reliability, and lower-cost hardware (we estimate that the hardware cost could be cut in half with modest design changes). For permanent, non-research installations of wireless metering (or if integral to products), lower power-use metering hardware would help mitigate the direct energy use of the metering system. In addition, for situations where devices cannot be unplugged (as with servers or medical equipment), a non-intrusive power meter that could be clamped onto the power cord would be very useful.

MELs Product Development. Using real-time wireless sensors simply for monitoring baseline conditions is useful, but misses a lot of the potential of this technology. The monitoring and communication capabilities inherent in the ACme platform could be easily extended to provide MELs device management and control for the purpose of improving energy efficiency. Ultimately, power sensing and communication need to be built into all devices to enable this type of functionality and allow devices to cooperatively manage their power state to minimize energy use.

Summary

Unlike appliances in traditional end uses, the diversity of plug-in devices has made it difficult for policy makers to apply uniform standards to reduce their energy use. As efficiency improvements in the traditional end uses become more and more successful, plug-in devices will continue to increase their share of energy use in buildings. To develop effective strategies to reduce MELs energy use, large-scale data collection is needed to understand the areas of improvement available. The development of power meters with wireless mesh-networking technology (using the ACme system) has made large-scale data collection possible in a cost-effective way. The relatively high measurement accuracy and sampling frequency permit new types of analysis, such as accurate power-mode identification and approximate device-type identification.

Although our metering effort is still ongoing, the data generated thus far has provided valuable insight about the inventory, usage patterns, and device correlations for MELs in the residential and commercial buildings studied. Moreover, the collected data has informed the data collection strategies and meter specifications needed to improve our understanding of MELs. For example, from the collected data, we learned that a sampling frequency of no longer than 1 minute is needed in order to capture the rapid change in power mode in some devices, and a prolonged metering period is needed to understand device usage pattern and seasonal variation. In addition, due to the diversity of models for some device types such as computers, a large sample is needed for results representative of the entire product type.

Since the ACme meters are developed using an open platform, the meters and their mesh network are highly adaptable to meet research and individual project needs. In the future, improvements to the stablility and usability of the ACme system, new form factors, and the integration of occupancy sensing would be useful additions to improve future MELs studies.

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