MONITORING AND CHARACTERIZATION OF MISCELLANEOUS ENERGY AND BUSINESS-PROCESS LOADS: DEMONSTRATION OF FIELD METHODS FOR STUDYING DIVERSE COMMERCIAL ENVIRONMENTS

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National Renewable Energy Laboratory,

Oak Ridge National Laboratory, and

Pacific Northwest National Laboratory

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DISCLAIMER

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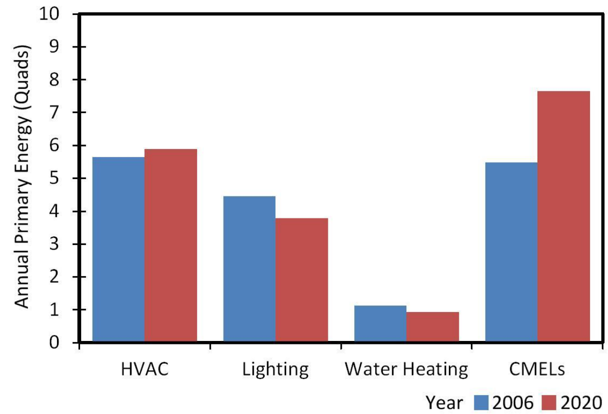
Background

Buildings account for 40% of the primary energy consumption in the U.S., with 22% consumed by the residential sector and 18% by the commercial sector. Of the primary energy used by commercial buildings, about 30% is used for heating, ventilation, and space cooling (HVAC), 25% for lighting, and 6% for water heating. These main, or primary, end-uses have received most of the attention for energy efficiency research and technology development. About 30% of the primary energy is consumed by miscellaneous energy loads (MELs), but this end-use has received far less attention. The Commercial MELs (CMELs) end-use includes a wide variety of devices -- major categories include electronics, computers, refrigeration, cooking, and "other," but there are hundreds of device types within these categories (US DOE 2009).

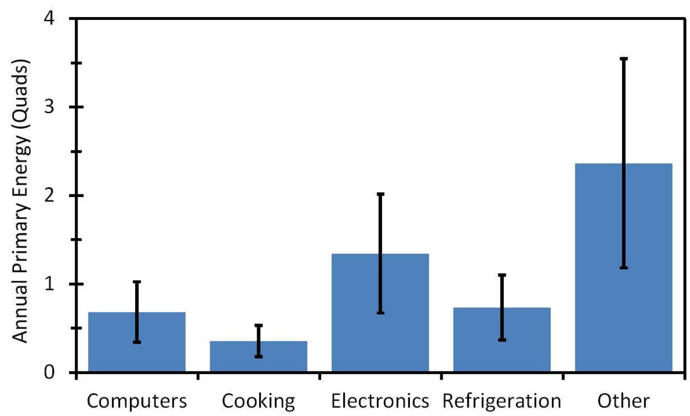
Figure ES-1 shows an estimated breakdown of the energy use for these end-uses in 2006 along with a forecast for 2020. MELs are an increasingly large percentage of building energy use, projected to grow from 30% to 35% of the commercial building total from 2006 to 2020. This growth is in small part due to advances in the energy efficiency of main building loads. The primary energy use of CMELs, however, is projected to grow by 40% to 7.7 Quads over the same period. This growth is due to an increase in the number of devices and the energy intensity of those devices, making CMELs the single fastest growing end-use in terms of relative percentage and absolute energy (McKenney et al. 2010). In order to meet DOE's long-term goals for reducing energy use and carbon emissions in the commercial sector, it is important that the energy efficiency community better understand the components and drivers of CMELS energy use, so that effective strategies can be developed to reduce this consumption.

Figure ES-1: Estimates of commercial building primary energy end-use splits. The primary end-uses are projected to decrease slightly. Essentially all of the growth in commercial building energy use is projected to occur in the CMELs end-use. (Source: US DOE 2009)



The CMELs end-use is also referred to as "business process" loads, because many types of CMELs equipment are used in essential business processes such as information processing, medical treatment, or food preparation. Because of this special relationship to the business function performed in a building, each type of commercial building is likely to have specific CMELs that are needed to perform those functions. In the United States, commercial buildings span a wide range of types, uses, sizes, and vintages. This diversity translates into a wide variation in the contribution of CMELs to energy use -- from 10% of whole-building consumption in warehouses to nearly 60% in food sales (US DOE 2009).

Figure ES-2: Estimates of commercial building CMELs equipment category breakdown in 2006. Large uncertainty exists in the relative contribution of different categories of end-use equipment to overall CMELs consumption. Note that the Other category is a residual remaining after all other end-uses have been estimated from the CBECS data. (Source: US DOE 2009 and National Lab uncertainty estimates)



Although there have been several studies of the CMELs end-use over the last ten years (summarized in this report), significant uncertainty remains about how much specific equipment types contribute to this energy use, as shown in Figure ES-2. This uncertainty makes it difficult to develop control strategies because the usage of CMELs are not well quantified. Few of these CMELs have been studied to date, and the diversity of usage patterns and power modes are not well understood. Information needed to develop effective control strategies includes knowing when devices tend to be providing useful service versus not, and why they are in each operating mode (by design, by use, by neglect, etc.). By understanding the usage in various modes, we can identify opportunities for savings or greater efficiencies.

Although the CMELs end-use is fragmented in a way that makes it more complex than the primary end-uses, recent studies have suggested that savings of over 35% of the CMELs total energy use are possible without depending on user behavior changes or controls (Kaneda et al. 2010, McKenney et al. 2010). To achieve this potential, prior studies have recommended some common actions, namely: improved data collection and monitoring methodologies, and evaluation of CMELs energy savings techniques.

To respond to the need for better data on CMELs energy use, this study focused on a proof-of-concept demonstration of methodology and technology for the identification, selection, metering, and analysis of MELs usage in commercial buildings. This work was jointly conducted by four national labs: Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL).

The primary research goals for this study were:

1. Define the scope of the problem—define what is a CMEL and what is not (develop a taxonomy for CMELs),
2. Develop and field-test methodologies for metering, monitoring, and analyzing CMELs,

3. Use this field experience to inform future research to characterize and reduce CMELs energy use. For instance, by understanding specific CMELs consumption in different modes, we can better determine if loads can be reduced during those modes, and if the devices can be switched into lower energy states sooner.

Methodology

The four national laboratories jointly selected ten buildings across the U.S. for this study, shown in Table ES-1 below, spanning a range of building types. Research teams identified CMELs that are typical of each building type, and addressed research concerns resulting from specialized space-types and energy end-uses.

A primary goal for this research was to test and assess various methodologies for each study phase: the inventory process, development of energy monitoring strategies, and data acquisition and analysis. This report highlights key elements for each study phase.

Inventory Process: In order to prioritize and develop strategies to reduce CMELs energy use, it is necessary to know the specific devices and categories of CMELS being used in each building. A consistent device taxonomy allowed parallel research teams both in the same building and across the labs to simultaneously count devices during the inventory phase and integrate or compare the data at a later time.

Starting with a taxonomy for miscellaneous and electronic devices developed by Nordman and Sanchez (2006), the study team expanded the taxonomy to include the CMELs that would be found in the more diverse building types included in this study (e.g. industrial ovens, conveyor belts, etc.). The inventory process was used to count and collect characteristics on CMELs devices in each building, and was critical for the following reasons:

1) To collect reliable data on CMELs densities and power ratings;
2) To obtain adequate information about a CMELs population to enable researchers to draw a representative sample for metering.

In addition to collecting data on CMELs characteristics and numbers by surveying the building, researchers collected additional information and used other inventory methods; below are selected examples:

- In the EMSL Bistro, the field research team reviewed electrical panel schematics, and identified CMELs on dedicated circuits. This information fed into the development of the monitoring plan, as these devices could be monitored by use of circuit level meters rather than plug-load meters.
- In response to hospital concerns regarding patient privacy, substantial data were gathered on health care CMELs by compiling and analyzing existing property-inventory databases: clinical technologies (traditional medical equipment), facilities (devices ranging from in-room televisions to vending machines), and information technology.

- Researchers inventoried retail CMELs in the Walmart, and over the course of two site visits researchers found that the inventory of CMELs had changed considerably due to stock turnover.

Monitoring Strategies: Once the devices in a building and their respective characteristics were identified, the study teams then collected the associated energy and power usage data for the CMELs in the building. This information addresses research questions related to energy consumption, such as *"What are the usage patterns and power modes for a particular CMELs device category?"* and *"Do the usage patterns for a particular CMELs device category vary between building or space types?"* and *"What CMELs devices use the most energy for each building type?"* Information addressing these questions will be needed to prioritize the development of effective reduction strategies and guide energy efficiency implementation programs across the U.S.

Table ES-1: Building included in this study

Building Type	Description	State	Research Issues
Food Service	PNNL/EMSL Cafeteria -- The Bistro	WA	Food service specific/kitchen CMELs, safety, access.
Food Sales & Food Service	Walmart Supercenter: Grocery, produce, bakery, deli, and restaurant	CO	Some devices were not accessible or measurable. Food service specific/kitchen CMELs, safety, access.
Health Care, Inpatient	Large teaching hospital	CA	Medical devices, health concerns, confidentiality and privacy, access.
Lodging	PNNL User Housing Facility	WA	Transient CMELs, with guest turnover, meter security.
Mercantile, Retail (Other than Mall)	Walmart Supercenter: retail sales, vehicle service garage, paint center, bank, photocenter, salons, pharmacy, and others.	CO	Mercantile specific Transient CMELs with stock turnover, confidentiality and security concerns.
Mercantile, Enclosed and Strip Mall	JCPenney	VA	Mercantile specific CMELs with confidentiality and security concerns.
Office, Small	ORNL Building 3156	TN	Meter deployment requiring manual data upload.
Office, Medium	LBNL Building 90	CA	Metering technology development, confidentiality, privacy, and security issues, multiple space types.
Public Assembly & Religious Worship	Central Baptist Church: Mahan Building, Family Life Center.	TN	Assembly, education, fitness facilities, reconfigurable spaces, and transient CMELs.
Warehouse & Storage	PNNL Technical Support Warehouse	WA	Warehouse-specific CMELs

Selecting the best available power and energy meter for a particular installation was an important initial step in developing a monitoring strategy. Panel / circuit metering can be used if a circuit exclusively powers one CMELs device, such as an industrial freezer or oven. Otherwise, device-level (i.e., plug-load) meters are needed for each device. Researchers bench tested five commercially available and one recently developed device-level meters. Each laboratory then tailored the meter selection for the building based on factors such as: the particular building circuits/electrical system, user concerns, accuracy, reliability, and cost effectiveness. Device-level meters selected for use include: WattsUp? Pro ES, WattsUp?.Net, and ACme meters. The first two are commercially available products, while the latter is a meter developed for this study by LBNL and UC Berkeley. Circuit level meters used include Smart Works Smart-PDU, and Johnson Controls Metasys. A summary of the meter used in each building and the scope of the metering is shown in Table ES-2.

WattsUp? Pro ES meters were used at the Walmart site, the small office building, and for spot metering at the hospital. This meter stores data internally; consequently field researchers manually uploaded the information into the database using batch files on a weekly basis, or as needed (dependent on the meter sampling rate).

Both the WattsUp?.Net, and ACme meters are networking meters with automatic data transmission capabilities, eliminating the need for field researchers to upload data. The WattsUp?.Net was used in the church buildings, EMSL Bistro, PNNL Guest House and Warehouse, and the JCPenney retail environment. WattsUp?.Net meters automatically uploaded data to either the vendor's FTP server or to a research database via either wired Ethernet or externally provided wireless networking capabilities. On a daily basis, researchers downloaded WattsUp?.Net files from vendor's FTP server, and loaded into the research MySQL database. In the medium office building, ACme meters transmitted information via wireless mesh networking and inserted data directly into the research database. The ACme meters are wireless by design and do not require any additional hardware or wires for network connectivity.

A number of metering issues surfaced during deployment and were addressed in various ways.

- *Metering Hardware*: Some of the commercial device-level meters had an internal relay for controlling loads, which unexpectedly activated and turned off loads. To resolve this, the manufacturer delivered custom meters with the relay bypassed. Other meters apparently caused feedback in the church A/V system, or tripped GFCI outlets, so had to be removed from service in those locations. The WattsUp Pro ES meters implement internal data logging, which requires manual upload of data and meter reset. The field teams found this process to be cumbersome, time consuming, and inappropriate for large-scale studies. Finally, meter testing showed that current and power factor readings for the Watts Up? meters are far less accurate than the power measurements, and all measurements suffer at low power levels.
- *Access*: User concerns resulted in excluding certain CMELs from metering. Confidentiality, privacy, and health information were cited as concerns by the hospital

Table ES-2 Summary of meter installations in each building. Meter installation is ongoing in some buildings (see section 2)

Building	Device Level Metering				Circuit Level Metering			
	Meter Model	No of Meters	Data Transmission	Metering Period	Meter Model	No of Points	Data Transmission	Metering Period
Food Service	WattsUp?.Net	15 [A]	Wireless [B]	1 year	Smart Works Smart-PDU	50 [A]	Wireless	1 year
Mercantile, Food Sales & Service	WattsUp? Pro ES	50 [D]	Data logging [C]	4 weeks[D]	Campbell Scientific	47	Wired	4 years
Health Care, Inpatient	WattsUp? Pro ES	15	Data logging [C]	Spot metering	N/A			
	ACMe	15	Wireless	4 weeks				
Lodging	WattsUp? .Net	50	Wireless [B]	1 year	Smart Works Smart-PDU	200	Wireless	1 year
Mercantile Enclosed and Strip Mall	WattsUp? .Net	50	Wireless [B]	3 months	Smart Works Smart-PDU	400	Wireless	1 year
Office, Small	WattsUp? .Net	25 [E]	Data logging	6 weeks[E]	Johnson Controls Metasys	36	Wired	1 year
Office, Medium	ACMe	500 [F]	Wireless	1 year	PSL PQube, Veris H80, Dent PowerScout	60	Wireless, wired	1 year
Public Assembly & Religious Worship	WattsUp?.Net	105	Wireless [B]	1 year	N/A			
Warehouse & Storage	WattsUp? .Net	15 [A]	Wireless [B]	1 year	Smart Works Smart-PDU	120 [A]	Wireless	1 year

[A] Some circuit level meters are used to meter individual CMELs where only a single device is on the circuit (common with cooking or other high-use equipment)

[B] Wireless data transmission for WattsUp? .Net and all circuit level metering devices used in this study require an external wireless device and sometimes includes wired data aggregation

[C] Data logging meters require researchers to manually download data from each meter approximately every week

[D] The total metering period was 8 months where each set of 50 devices was metered for four weeks.

[E] The total metering period is great than 6 weeks with meters rotated through different devices. Total number of devices to be metered TBD.

[F] 100 meters installed to date with an additional 400 planned in the medium office building

and Walmart. Because of restricted access -- plugs inside locked cabinets, reachable only by ladder, etc. some CMELs were not metered in the Walmart. Additionally, a number of CMELs could not be metered due to incompatibility with the device-level meters, for example appliances operating at 240V (e.g. cooking stoves, clothes dryers, etc.) could not be plugged into the meters. The study team does not believe that these access issues biased the results of this study, but future research is needed to develop strategies to mitigate these problems, such as developing 240V plug-load meters.

Data Acquisition, Storage, and Retrieval: The labs archived information in central data storage locations. Excel spreadsheets were used to collect inventory and attribute data, for convenient update and import into analytical tools. Energy monitoring data were transmitted via the Internet for database storage, if the meters were network connected, or manually uploaded if the meters used data logging. The team used MySQL databases to house the CMELs monitoring data.

Methodological Findings: Because the primary purpose of this study is to develop CMELs field research methods, some of the most important findings have to do with solutions the lab teams developed to address issues encountered in the field. These methodological findings fall generally into the following categories: study design, general protocol, device inventory, energy metering, data transmission, data analysis, and meter-specific hardware issues.

Many of the issues we encountered are due to the unique nature of CMELs compared to traditional building loads: 1) CMELS are often located near and controlled by the building occupants, 2) many CMELs are plug-based and can be unplugged, moved, or replaced during the monitoring period, and 3) some CMELs are critical loads—such as servers or medical equipment—that cannot be easily turned off or unplugged. Addressing the first issue required the consent and cooperation of both the building managers and occupants. It also was necessary in some cases to update the CMELs device inventory periodically during the study.The second issue was partially addressed by labeling meters with the associated CMELs device and educating occupants about plugging devices into the appropriate meter. For mobile devices (e.g., electric carts), in some cases the meter was permanently attached to the device so that the meter data could always be associated with the correct device. On the other hand, for hardwired devices the only approach tried was panel-level metering, although this only provides useful data when the CMEL device is the only one on the circuit. Despite some successes, more work is needed to develop robust solutions for metering CMELs that move or are unplugged routinely, or for hard-wired devices that are on circuits with other equipment. The third issue was addressed in some cases by installing meters during scheduled downtime for the critical devices, although this was not possible in all cases, especially in the hospital.

For inventorying CMELs, we found that using a formal and consistent device taxonomy streamlined data entry and analysis as well as allowed comparison of results across buildings. The taxonomy has been updated with new types of devices encountered in these buildings. The best inventory technique depends on the environment being studied—for smaller sites, recording the device data on paper for later electronic transcription proved to be the easiest approach, while larger sites required direct electronic data entry for greater time efficiency. Collecting photo or video data proved useful in some cases, e.g., to avoid duplicating data entry, although this is not possible in some environments due to privacy concerns. While a full inventory of all CMELs devices in a building is desirable, it may be necessary to conduct a partial inventory for practical reasons (e.g., in a large building or where there are access issues). The choice of whether and how to conduct a partial inventory should be based on factors such as the number of CMELs present and diversity of CMELs in the study space.

Identification and analysis of device operational modes (e.g., on, asleep, off) was a primary goal of this study, so the study teams spent considerable time designing the protocol to collect and analyze the proper data. The sampling frequency for energy monitoring is critical to mode identification of the CMELs measured. We found that data with smaller than 1 minute time resolution is required for accurate mode identification. In addition, automated mode identification software is crucial to understanding time and energy in power modes because of the large number of metered devices and the large number of data points for each device. We also found that automated detection of corrupt data (e.g., due to meter malfunction) was important for maintaining the integrity of the results.

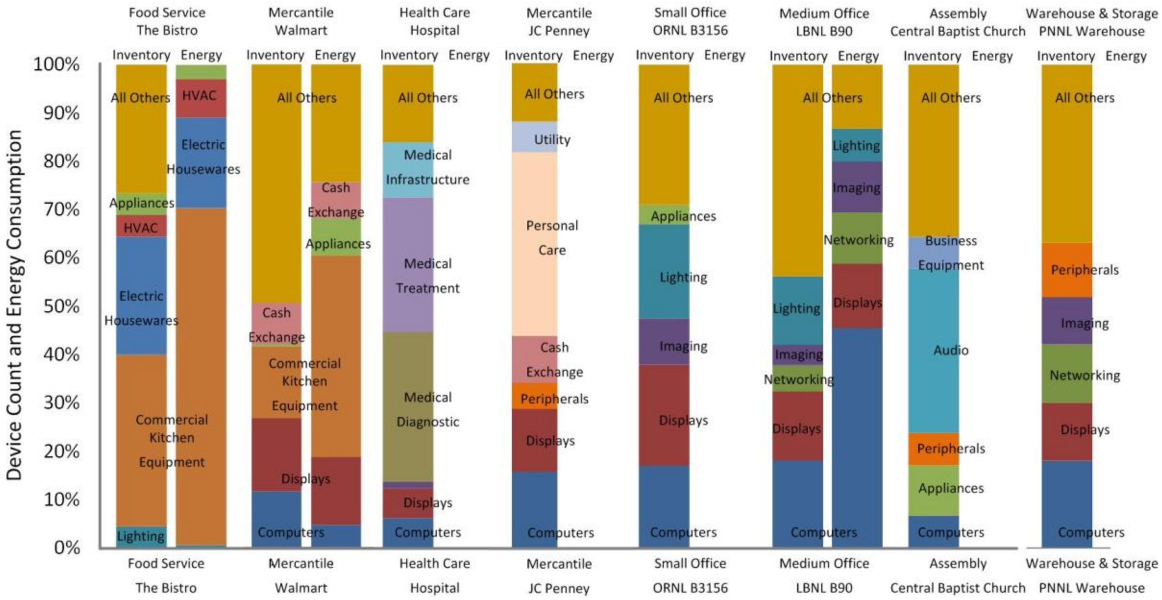
Given the amount of data being collected, we found that automated data collection over a network (preferably wireless) was very helpful in larger monitoring installations (>100 device-level meters). In some cases, we were able to use the host building network for data transmission over the network, while in other cases a separate Internet connection had to be installed. Having now worked with several of the commercially available device-level meters, we found that the WattsUp?.Net was the most appropriate for this type of study because of its ability to transmit data over the network and its relative accuracy. But it had several drawbacks due to the internal relay tripping inadvertently, and it occasionally tripped GFCI outlets in certain situations. The ACme meters largely met the requirements of this study, with their small form factor and wireless data transmission, but took significant effort to design and manage the production process, and network reliability is an ongoing issue that the study team is still working to improve.

Building Case Study Results

Besides the things the study team has learned that will help improve future CMELs field protocols, our analysis of the data gathered to date in this project shows that this type of study can help answer fundamental and critical research questions, such as:

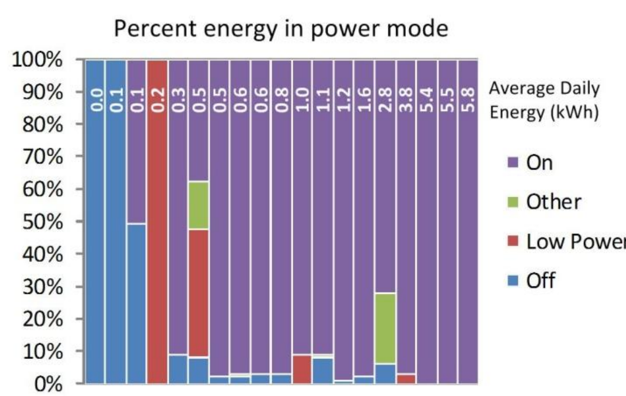
Variation in CMELs energy use by device category and building type: CMELs vary in number and energy intensity by building type. To develop CMELs reduction strategies, it is critical to understand how building or space type influences which CMELs are present and their energy use patterns. Similarly, comparisons between building types are important because they show which CMEL reduction strategies may apply across building types. Figure ES-3 presents the distribution of CMELs by device category for the buildings inventoried in this study. In addition, the top five energy consuming CMELs categories are shown for eight of the buildings. This figure shows that the CMELs that consume the most energy vary significantly depending on the building type.

Figure ES-3: CMELs Device and Energy Distribution by Building Types and Device Category Uses. Preliminary data is used in this chart; data and missing buildings will be updated for final report.



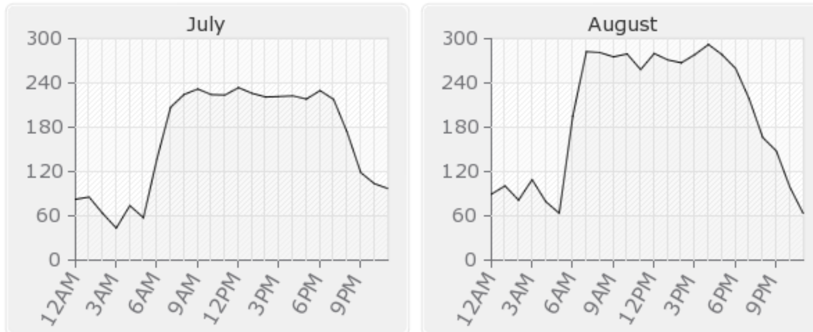
Breakdown of energy use by power mode: In order to improve CMELs device energy use, it is important to understand the time and energy that devices spend in various power modes. If devices are "on" even when they are unused, significant energy savings may be realized by adding automatic power down capabilities or other controls. If devices already sleep at low power levels, we can focus on improving on-state efficiency or reducing the number of devices in use. Figure ES-4 shows an example analysis on computers, and significant variation occurs in the usage pattern and energy use even though devices are in the same building. Without detailed information on the breakdown of energy use by power mode, decisions on potential control strategies cannot be made to maximize function while minimizing energy use.

Figure ES-4: Percent energy in power modes for 19 computers metered over a work week in the medium office building. Each column represents an individual computer sorted from left to right by increasing energy use. Time in mode is shown in section 3.2.



Weekday average profile for a given device CMELs loadshapes are useful to improve load modeling in new or retrofit designs and to improve utility forecasts for peak load or demand response planning. They also provide a way to observe the effectiveness of power management and low power modes enabling better upstream feedback to manufacturers, and efficiency standards or specifications. We expect that loadshapes for some devices will have seasonal dependencies. For example, as seen in Figure ES-5, the average weekday profile for an ice maker shows variations across different months. We expect to find more devices that exhibit these characteristics as the metering period extends into 2011.

Figure ES-5: Ice maker energy use over a two month period (average hourly load)



A more detailed discussion of the above and additional topics is found in section 3.2.

Current Project Research Plan

This is an interim report presenting initial findings for this study. In order to implement the original action plan and fully address the research questions for this study, the lab teams plan to continue metering through January, 2011, and deliver the Final Project Report to DOE at the end of February, 2011. This remaining research will be continued under current DOE funding in the areas described below.

To capture the seasonality of MELs use (particularly for devices with large seasonal variations such as space heaters and task lights) and to better capture usage of devices that may be episodic in nature (e.g., some types of food service equipment or holiday devices in the church and Walmart), the research teams will continue to collect data from the installed meters. There will be very little incremental cost to leaving the meters in the field collecting data as nearly all the remaining meters have automated data collection. Research teams are in the process of installing additional meters in several building types in order to complete the planned metering.

The lab teams will also expand the analysis of monitoring data to provide a more comprehensive statistical summary across building and device types, using data from the full monitoring period. The final report will include several additional types of analysis: power mode identification, mode transition identification, correlation of CMEL loads to temperature, and seasonal load variation.

Future Research

While this study provides an important foundation for better understanding the CMELs end-use, much work still remains in order to develop effective strategies for reducing that energy use. Based on our experience in this study, we believe that work is needed to collect additional field data, design and test energy reduction strategies, and implement policies and programs for CMELs.

Refine Methodology and Collect Data: This CMELs study focused on a proof-of-concept demonstration of methodology and technology for the selection, metering, monitoring, collection, and analysis of CMELs usage in commercial buildings. Based on the knowledge acquired during the first phase of our work we recommend methodology development and data collection efforts continue in the following areas.

Maximize use of existing monitoring systems. With current investments already made in deploying meters and data collection systems, the marginal cost is minimal for using the installed systems to continue to collect seasonal date and to track CMELs trends via longer time series data.

Meter additional building types, sizes, and vintages. Studying CMELs energy use in a representative sample of the building population is needed to inform technology development, policy decisions, and to prioritize promising and effective control measures. As part of these studies, whole-building energy use data is critical to determine what fraction of total energy use is contributed by CMELs. Future data collection should also expand to include additional data, such as occupancy monitors to determine how closely CMELs usage profiles reflect occupancy schedules in practice. As recommended in the TIAX study, future CMELs field studies should also expand to cover loads that are external to the building structures but integral to operations, such transformers, data center servers, etc..

Utilize Collected Data. The data collected in this and future studies can be leveraged to answer additional research questions that may not have been originally anticipated. To facilitate this, DOE should develop a repository of MELs consumption profiles and device densities that can be shared across laboratories and used to inform other areas of study, such as building modeling. To make optimal use of this data repository, data mining techniques should be developed to identify consistent patterns, including algorithms for: identification of power modes and transitions between modes; correlation of CMEL loads to temperature; identification of functional groupings of CMELs; correlation between building occupancy and user-directed CMELs; and identification of seasonal CMELs load variations.

Improve metering technology. Commercially available metering equipment needs to be improved to address research and industrial applications for large-scale, device-level energy monitoring. In particular, the size of the meters needs to be reduced and the data transmission methods made easier and more reliable. A product with the functionality of the ACme meters, but from a reliable commercial vendor, would be very appropriate for future studies (see Appendix B.1

Ideal Meter Specifications). In addition, other meter types need to be developed to address the full range of CMELs metering situations. For instance, a power strip-like device with LAN port and wireless capability that could monitor multiple CMELs individually would be useful in environments with dense CMELs saturations (e.g., offices). Also, methods are needed to meter multiple hard-wired CMELs on a single circuit.

Design and Test Strategies to Reduce CMELS Energy Consumption: Understanding CMELs energy use is the first step in developing strategies to reduce both energy usage and peak demands. A spectrum of approaches should be pursued, including: 1) working upstream with manufacturers, industrial groups and standards organizations to improve the design of CMELs devices, 2) matching the energy use of CMELS devices to their usage patterns, 3) testing consumer education techniques to effect behavior change, and 4) developing effective methods for CMELs energy-use feedback to users. The energy efficiency community should also undertake a concerted effort to identify other strategies for reducing CMELs energy use. With current investments already made in deploying meters and data collection systems for this study, the existing CMELs monitoring systems can serve as ready research platforms and test beds for measuring the impacts of CMELs energy reduction strategies. Most importantly, these are the only installations for which baseline data on CMELs usage and consumption already exist.

Control. Evaluate the methods, effectiveness, and savings of control strategies:

- Categorize CMELs for what can and should be controlled, and determine what types of controls make sense. Determine how to control the device so that the operating mode is at the lowest energy consumption state appropriate for the service demanded.
- Controls to reduce energy use of entire functional groups of CMELs when not in use.
- Integrate plug-load control with deployment of other control systems, i.e. existing occupancy sensors for lighting that are also used for occupant dependent HVAC control.

Efficiency. Develop more efficient CMELs devices:

- Develop technologies to improve the efficiency of targeted categories of CMELs equipment, such as the commercial cooking and laundry technologies identified by Navigant (Zogg et al. 2009).
- Improve designs of plug-in devices so that they interface more efficiently and seamlessly with other devices, and manage their power state to minimize energy use.
- Stimulate demand for more efficient CMELs devices by making CMELs energy use reduction an integral part of future development of highly efficient commercial buildings.

Education. Develop information and strategies to educate CMELs users:

- Target device types with high standby loads and infrequent usage to develop campaigns for the commercial building owners to purchase lower power consuming models (e.g. ATMs, photo kiosks).

- Survey building occupants about their usage of CMELs to gauge feasibility of energy savings implementation strategies.
- Test information strategies to address 24-hour retailers, where CMELs are on whether or not customers are usually purchasing items in these areas (e.g. electronics displays).

Feedback. Develop methods for feedback to CMELs users and purchasers about the energy use of specific CMELs devices:

- Develop and test a variety of techniques for real-time energy-use feedback to individual building occupants, groups of occupants, and building managers.
- Test the effectiveness of different types of product information for devices—including typical energy use and load profiles, or the existence of device features that allow better energy control—so that purchasers can make informed purchasing decisions.
- Improve and test the design of buildings (such as Commercial Building Partnership buildings) with a specific focus on reducing CMELs through control and behavior modification.

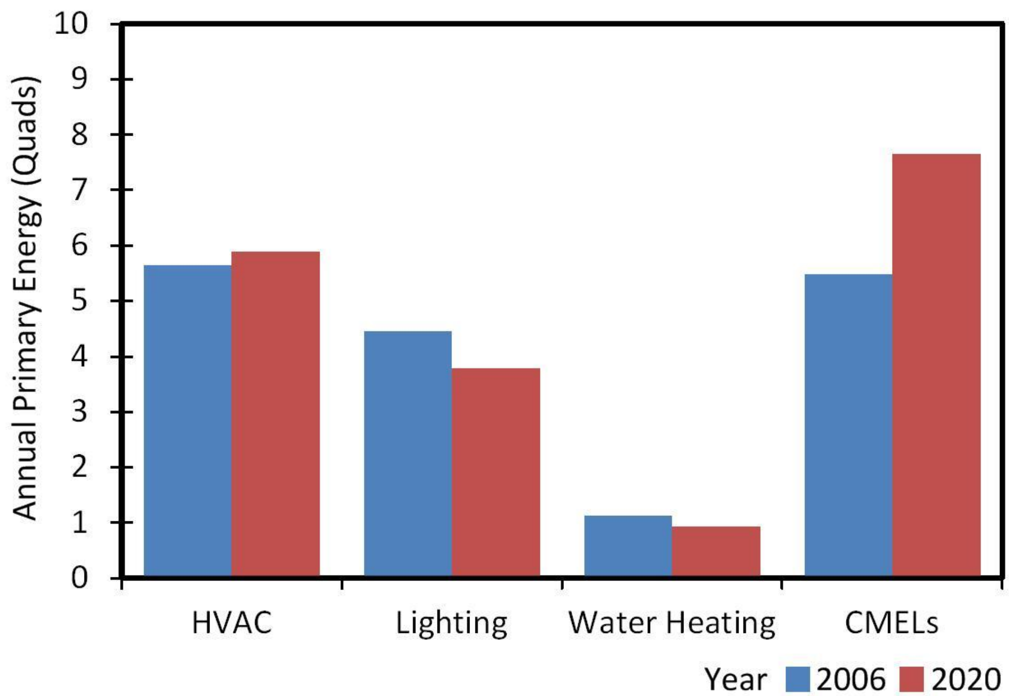
Develop Program and Policy Recommendations: The research and development agenda described above is ultimately intended to provide data to aid the development of effective public policies to reduce energy usage by CMEL devices. These policies include: equipment standards, utility energy programs, purchasing guidelines, Energy Star specifications, and building codes. Expenditure of public funds should be targeted to proven technologies with demonstrated efficiencies, based on field research of the type demonstrated in this study.

1.0 Introduction and Motivation

Buildings account for 40% of the total primary energy consumption in the U.S., with 22% consumed by the residential sector and 18% by the commercial sector. The vast majority of that energy is used in the form of electricity, with 79% of commercial building energy being consumed as electricity in 2006 (US DOE 2009).

Of the primary energy used by commercial buildings, the Building Energy Data Book states that about 30% is used for heating, ventilation, and space cooling (HVAC), 25% for lighting, and 6% for water heating. These main, or primary, end-uses have received most of the attention for energy efficiency research and technology development. About 30% of the primary energy is consumed by miscellaneous and electronic loads (MELs)[1], but this end-use has received far less attention. Figure 1 shows an estimated breakdown of the energy use for these end-uses in 2006 along with a forecast for 2020. MELs are an increasingly large percentage of building energy use, projected to grow from 30% to 35% of the commercial building total from 2006 to 2020. This growth is in small part due to advances in the energy efficiency of main building loads. The

Figure 1: Estimates of commercial building primary energy end-use splits. The primary end-uses are projected to decrease slightly. Essentially all of the growth in commercial building energy use is projected to occur in the CMELs end-use. (Source: US DOE 2009)



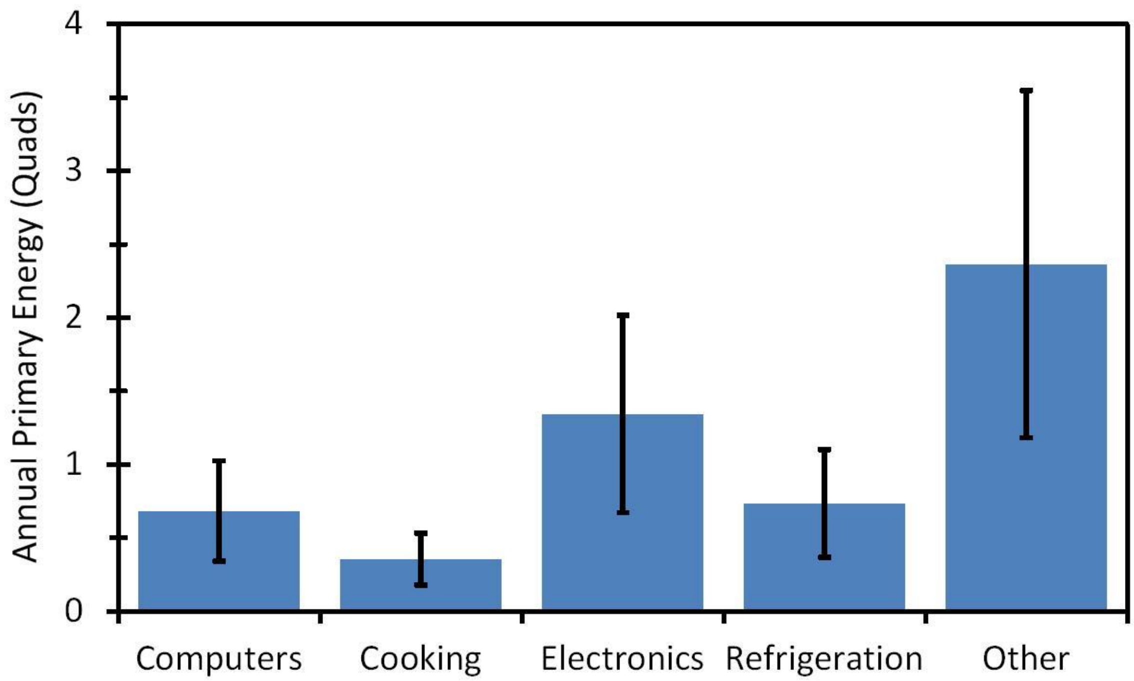
[1]In this study, we refer to MELs in commercial buildings as "CMELs." This end-use is also referred to as "business process" loads, because many types of CMELs equipment are used in essential business processes such as information processing or food preparation. In addition, all plug loads are often included in CMELs because they are typically not included in data collection or modeling of the primary end-uses.

primary energy use of commercial MELs (CMELs), however, is projected to grow by 40% to 7.7 Quads over the same period. This growth is due to an increase in the number of devices and the energy intensity of those devices (McKenney et al. 2010). CMELs are the single fastest growing end-use in terms of relative percentage and absolute energy, and they must be better understood and reduced in order to meet DOE's long-term goals for reducing energy use and carbon emissions in the commercial sector.

The CMELs end-use consists of a wide variety of equipment types, grouped by DOE into the categories shown in Figure 2 (US DOE 2009). These energy use values, based on EIA's Commercial Building Energy Consumption Survey (CBECS), are rough estimates with large uncertainties, as shown qualitatively in Figure 2[2].

Although the CMELs end-use is fragmented in a way that makes it more complex than the primary end-uses, recent studies have suggested that savings of over 35% of the CMELs total energy use are possible without depending on user behavior changes or controls (Kaneda et al. 2010, McKenney et al. 2010). The common recommendations of these studies are: improved data collection and monitoring methodologies, and evaluation of CMELs energy savings techniques. Improved data collection does not, in and of itself, save energy. But it informs energy use estimates, identifies priorities for targeting the development of control strategies, can improve building and CMEL device design, and provides the reliable CMELs baselines required to

Figure 2: Estimates of commercial building CMELs equipment category breakdown in 2006. Large uncertainty exists in the relative contribution of different categories of end-use equipment to overall CMELs consumption. Note that the Other category is a residual remaining after all other end-uses have been estimated from the CBECS data. (Source: US DOE 2009 and National Lab uncertainty estimates)



[2] The labs' assessment of CBECS end-use uncertainty is described in Section 1.1 below.

verify the savings of CMELs reduction strategies. This study addresses the request for improved data collection methodologies across the commercial building sector.

1.1 Previous Research

Recognizing the growing importance of the CMELs end-use, several studies have been conducted to better understand the magnitude and composition of this end-use and the potential to reduce the CMELs energy use in buildings. Initially, most of the focus was on information technology (IT) equipment, with the rapid penetration of personal computers into the commercial building stock in the 1980s and '90s. More recent research has expanded to also address miscellaneous devices in commercial buildings. We summarize the more significant MELs studies in the last ten years, to provide context for the current study.

TIAX, "Commercial Miscellaneous Electrical Loads," (2010)

The most recent and comprehensive study of CMELs was conducted by TIAX for the US DOE (McKenney et al. 2010). This study was intended to broadly estimate national CMELs energy use by device and building type, to identify data gaps, and to guide further research. The TIAX study only used secondary data; measurement and collection of data were outside the scope of the study. National energy estimates were made using the Commercial Buildings Energy Consumption Survey (CBECS) data to describe the population of buildings and energy breakdown by major end-use. The study estimated energy consumption for 28 key device categories by combining CBECS data with market and shipment data to estimate the stock of MELs devices in each building type and the average energy consumption values for each device type. The results of this analysis show that a handful of MELs categories dominate the energy consumption of this end-use, but some of the highest-consuming MELs categories, such as distribution transformers and wastewater treatment, are primarily industrial (data centers, water supply and treatment) or their energy use is accounted for in transmission and distribution losses (transformers), thus they are not strictly part of the commercial building sector. An important estimate from this study is that approximately 35% of the CMELs electricity consumption could be saved by replacing the entire installed stock of devices with best-in-class devices.

The TIAX study is probably the most rigorous that can be done by compiling and combining independent datasets. As the authors pointed out, however, the results have significant uncertainties because many important inputs to the analysis – particularly usage patterns of MELs and how usage and saturations vary between building types – are not well known and in many cases were simply assumptions made by the analysts. For instance, the annual energy use of the average PC was assumed to be the same in all building types. Data were not available on the stock of MELs devices by building type, so the study simply allocated the national stock to building type using a simple measure such as relative floor area. Finally, by including non-building MELs, such as data centers and wastewater treatment (classified as industrial facilities), in the study and allocating a portion of the estimated national commercial-building MELs electricity use to these categories, the TIAX study may have significantly underestimated the actual energy consumed by device categories that are much more common in commercial buildings, such as electronics and refrigeration.

Rumsey Engineering, "Plug Load Reduction: The Next Big Hurdle for Net Zero Energy Building Design," (2010)

This recent set of building case studies evaluated CMEL reduction strategies for office buildings and a commercial building server room. It found that 44% or more of the plug-load energy use could be saved primarily through equipment replacement (Kaneda et al. 2010). For each building, the team surveyed existing equipment, interviewed occupants to estimate equipment and occupant schedules, performed short term metering of representative MELs, estimated a baseline, installed energy saving alternatives, and estimated the achieved savings (savings were deemed not measured). This study used an evaluation method similar to that used in the current study, but because accepted protocols for CMELs data collection do not exist, the researchers had to develop *ad hoc* methods for deciding what information to gather, how to select devices for metering, and how long of a metering period to use. Metering was performed for one work day typically and up to five days for servers and audio/visual equipment. Although this is perhaps the best example of the application of field data to CMEL energy use estimation and savings strategy implementation, it did not use a robust strategy for estimating a building baseline or verifying savings.

Navigant, "Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances," (2009)

Another recent study conducted for the US DOE examined commercial appliances, which included several types of CMELs devices, such as cooking equipment, IT equipment, vending machines, and ATMs (Zogg et al. 2009). This study used a similar methodology to McKenney at al. (2009), by compiling secondary data on shipments, installed base, annual energy use, and other factors needed to estimate national energy use by device type. As such, it made many of the same compromises as the McKenney et al. (2010) report. The focus of the Zogg et al. study was somewhat different, though, in that its scope covered "appliances," which were defined to include water heating and exclude many CMELs devices of interest to the current study. The Zogg et al. report thoroughly describes the markets for different appliance device categories.

Ecos Consulting, "Office Plug Load Field Monitoring Report," (2008)

This study surveyed plug-load energy use in a sample of nearly 50 California office buildings (Moorefield et al. 2008). Based on an inventory of all the plug load devices in these buildings, the study found a total of about 7,000 devices. A sample of 450 of these devices was then energy monitored for a 2-week period. This appears to be the first study to measure, at the device level, the in-field energy use of a large sample of plug-load devices. The energy monitoring found that computers and monitors were the largest contributors to plug-load energy use, followed by office electronics. While an innovative and important study, several shortcomings limit its ability to inform DOE research and policy efforts:

1. It only collected data from one building type (offices) in a single state;
2. The office buildings were mostly small offices (<30,000 square feet);
3. The sample of devices metered was a relatively small fraction of the devices inventoried;
4. The metering period was relatively short and therefore the results may not be representative of long-term activity or seasonal patterns;

5. The study did not collect any data on hard-wired CMELs devices and did not compare plug loads to whole building energy use.

EIA, "Commercial Building Energy Consumption Survey (CBECS)," (2008)

The most recently released CBECS estimates the commercial building energy use by end-use for 2003. In line with the increasing energy use of CMELs, several CMELs categories are listed separately as shown in Figure 2. The CBECS energy-use estimates are based on a survey of attributes and utility bill data for a sample of approximately 1,500 commercial buildings. A basic model is used to allocate the whole-building utility bills to the end-uses. The primary sources of this model are regressions based on weather and engineering estimates using published analysis methods (e.g. from ASHRAE handbook). Due to the self-reported nature of the survey data and the inherent uncertainty in these engineering methods, large uncertainties exist in the breakdown of energy use to end-uses. This is particularly true for breakdown of CMELs energy use to device category; the labs estimate the CBECS methodology to be accurate to within 50% for each category in the CMELs end-use. This assessment is based on an evaluation of the quality of the inputs to the CBECS utility bill disaggregation model. Despite the uncertainties in the CBECS estimates, an important conclusion from CBECS is that the MELs fraction of whole-building energy use varies widely between building types, from 10% in warehouses to nearly 60% in food sales.

LBNL, "After-hours Power Status of Office Equipment and Energy Use of Miscellaneous Plug-Load Equipment," (2004)

This study (Roberson et al. 2004) collected data on the after-hours power state of IT equipment, as well as data on the types and amounts of miscellaneous plug-load equipment, from sixteen commercial buildings in California, Georgia, and Pennsylvania: four education buildings, two medical buildings, two large offices (> 500 employees each), three medium offices (50-500 employees each), and five small business offices (< 50 employees each). The study surveyed approximately 450,000 square feet of commercial space and inventoried about 10,000 devices in total, comprised of about 4,000 electronic devices (including 1,700 computers) and 6,000 miscellaneous devices. For most types of miscellaneous equipment, the study also estimated typical unit energy consumption in order to estimate total energy consumption of the miscellaneous devices within the study sample. No devices were monitored for power use during the study; the energy consumption data were compiled from previous studies. The key finding of this study was that only 6% of the computers had power management enabled, which was significantly lower than previously assumed. The funding agency for the study, the EPA Energy Star program, used the study findings to redesign their program for IT equipment to emphasize enabling of power management and require lower power levels in active modes. While this study was the first to collect field data on miscellaneous equipment saturations in a large sample of buildings, it had several shortcomings:

1. The sample included only a small cross-section of the building types in the commercial sector;
2. No energy consumption data were collected;
3. The device power-state data only represented device usage at night;
4. The power-state data are a one-time data point so cannot describe trends.

AD Little, "Energy Consumption and Savings Potential by Office and Telecommunications Equipment in Commercial Buildings," (2002, 2004)

Roth et al. (2002) carried out a "bottom-up" study to quantify the national electricity consumption of more than thirty types of non-residential office and telecommunications equipment. This study used a similar methodology to the 2010 TIAX study, relying on secondary data for equipment stocks and annual consumption. The study found that office and telecom equipment in 2000 consumed approximately 97 TWh in the non-residential (i.e., commercial and industrial) sector, with 90% of that consumption due to just eight classes of equipment: monitors and displays, computers and workstations, servers, copiers, telecom networks, data networks, printers, and uninterruptable power supplies. This was just under 3% of US electricity consumption at that time. A subsequent report (Roth et al. 2004) evaluated 61 efficiency technologies for office equipment and found energy savings potential in 2000 of between 1 and 30 TWh/year for each of the most promising eleven technologies. Collectively, this potential could be as high as 50% or more of the baseline energy consumption by office and telecom equipment in 2000. The study also identified many RD&D activities that would be needed to realize these potentials, as well as barriers to adoption and implementation of the technologies.

Summary of Findings from Previous Studies

To summarize, previous studies of the CMELs end-use used two principal methods: 1) "secondary" studies that estimated national CMELs energy use by compiling existing data on building and equipment stocks (largely based on CBECS), combined with energy use data from laboratory measurements, and 2) field studies that collected device saturation data and metered energy use from actual buildings. The first type of study is useful in providing a high-level estimate of how energy is used in the commercial sector, and what types of devices may be most responsible for that energy use. The shortcomings of these studies, however, are that they nearly always study the devices in isolation (i.e., device by device) rather than as a collection of devices in a building (thereby missing the correlation between usage of devices), and the laboratory data on MELs energy use is collected under simulated usage conditions, not actual field usage patterns. The field studies, on the other hand, have shown promising results, but have been conducted on only a very small sample of buildings (concentrated in two building types—office and education), due to the labor required to conduct traditional field monitoring studies.

Research Recommendations from Previous Studies

The studies described above all recommended further research to better understand the CMELs end-use. In reviewing these recommendations, we concluded that a recurring topic in many of the recommendations is that better data is needed on the saturation and usage of MELs in actual buildings. This conclusion fundamentally shaped the research goals for this study—to develop more robust and cost-effective methods for collecting CMELs field data. The recommendations from previous studies fall into three general categories, which are summarized here:

Evaluate Rapidly Evolving MELs:
McKenney et al. (2010) recommended performing regular (e.g., every 3-4 years) evaluations of MEL energy consumption and energy savings potential. The benefits of this would be two-fold: 1) to understand how the evolution of MELs—particularly electronics—are affecting the overall

energy use of commercial buildings, and 2) to evaluate the feasibility of cost-effectively attaining DOE's building efficiency goals.

Fill Key Data Gaps for CMELs by Building Type:
TIAX found that a lack of current data, particularly by building type, for many CMELs made it difficult to develop accurate bottom-up estimates. One data gap is power measurements by mode for a sample representative of the installed base for key CMELs in key building types. They also identify a need for data to more accurately understand the usage patterns of key MELs in key building types (from interviews, surveys, or actual measurements). Because of the cost of collecting these data, they suggest a focused work plan to fill the largest data gaps with the largest impact on energy consumption, starting with large commercial buildings (i.e., greater than 50,000 square feet). (McKenney et al. 2010). Kaneda et al. (2010) recommended detailed monitoring studies to determine "where, when and how much energy is being used." They also suggested that monitoring will generate valuable data on usage patterns to help design better devices and systems, and can also be used to study the impact of feedback on plug-load energy use at the user level. Moorefield et al. (2008) suggested that servers and data centers should be studied in more detail because their study was not able to meter servers present in buildings, and also suggest that their field methodology should be applied to a larger, statistically representative sample of buildings. Roberson et al. (2004) recommended collecting data on computer power management in more types of buildings, as well as data on laptop computer usage. To assist with this data collection, they recommended using existing data networks to help collect data on IT equipment usage patterns and power management enabling rates. They also recommended collecting MELs energy use data on a larger sample of buildings, including data on MELs' share of whole-building energy use, and collecting data over a longer time frame to analyze changes in the types of devices in buildings and changes in their usage. Roth et al. (2002) advocated performing larger-scale equipment usage surveys to reduce uncertainties in usage data, and carrying out surveys over a broader geographic range to reduce possible geographic biases in the data sets. They also recommended further study to better understand the energy use of uninterruptible power supplies and communication networks, as well as to understand the peak load impact of IT equipment in commercial buildings.

Evaluate and Characterize MEL Energy-Saving Opportunities:
McKenney et al. (2010) recommended that DOE perform a study focused on a thorough characterization of commercial MEL energy savings opportunities with a realistic assessment of likely adoption rates. This study could inform a roadmap that identifies the technologies and policies needed to realize significant reductions in MELs energy use. The initial focus should be on large (>50,000 square feet) buildings, which consume 50% of the key MEL energy, but are only 5% of buildings (~250,000). In addition, a focus on high impact technology areas that apply to several product types, such as efficient display panels, is recommended. Kaneda et al. (2010) recommended evaluating occupancy-controlled outlets and plug strips, as well as DC microgrids for some office equipment and lighting. Zogg et al. (2009) recommended further research to develop and refine several new technologies: a reliable electric ignition system for use in all commercial cooking appliance types, broiler idle energy reduction controls, supercritical CO2 dishwashing, efficient data center cooling systems, efficient commercial clothes dryers using sensors and improved heat sources, ozone laundry systems, and smart control systems and proximity sensors for electrical equipment such as escalators. Moorefield et al. (2008) recommended that research be conducted to estimate the energy savings potential of

several MELs efficiency technologies, including automatic controls such as smart plug strips, other timer or occupancy sensing outlet controls, widespread use of devices' own power management settings, and equipment usage changes through consumer education campaigns. Roberson et al. (2004) recommended research to investigate the reasons why computer power management is not enabled more often, as well as looking at savings potentials for electronic equipment in educational buildings.

1.2 Research Purpose

Based on this review of the existing literature, we concluded that the current knowledge about energy use of miscellaneous devices in buildings is not adequate to develop and test effective strategies to reduce CMELs energy use across the wide variety of device- and building-types that are present in the U.S. building stock. In order to develop these energy reduction strategies, we need better data about about how CMELs are used, when, for what purpose, etc., which in turn requires that we first develop and test reliable field methods for collecting CMELs data in a wide variety of commercial buildings. Therefore, this FY10 CMELs study focused on a proof-of-concept demonstration of methodology and technology for the identification, selection, metering, and analysis of MELs usage in commercial buildings. This study was jointly conducted by four national labs: Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL).

The primary research goals for this study were:

1. Define the scope of the problem—define what is a CMEL and what is not (develop a taxonomy for CMELs),
2. Develop and field-test methodologies for metering, monitoring, and analyzing CMELs,
3. Use this field experience to inform future research to characterize and reduce CMELs energy use. For instance, when we are thinking about reducing the consumption we have to understand *when* the device is providing useful service versus not and why it is in each operating mode (by design, by use, by neglect, etc.). By understanding the consumption in different modes, we can better determine if loads can be reduced during those modes, and if the devices can be switched into lower energy states sooner.

These goals in turn led to high-level research questions:

1. What fraction of commercial building energy use and load results from CMELs?
2. How does building and space type affect CMELs energy use?
3. What is the breakdown of CMELs characteristics by power mode, energy use, and device category?
4. How much effort is required to assess the energy use of CMELs in a building?
5. How can we improve the data used in building modeling of CMELs to ensure other building systems are properly designed?

This phase of research has been very effective in developing efficient methodologies for quantifying CMELs energy use in diverse commercial environments. The next step is to better understand CMELs energy use and develop and test strategies to reduce energy consumption. With current investments already made in deploying meters and data collection systems, the marginal cost of using the installed systems is minimal to continue to collect seasonal and longer time series data. These existing CMELs monitoring systems will also serve as research platforms and test beds for measuring the impacts of CMELs energy reduction strategies.

2.0 Methodology

This chapter contains the research processes developed and used by the four national laboratories – building selection, inventory, monitoring, and data analyses. Experimentation has been a key element fundamental to this research effort. We demonstrate this exploratory approach through examples described in the text boxes featured in this chapter. Each box focuses on a specific research question in a specific building, describes the experiment, and summarizes conclusions. These examples are illustrative of the kind of work done by all the labs in all the buildings and are intended to provide a look at the type of work undertaken in this study.

2.1 Building Selection

For the proof-of-concept demonstration of field study methodologies, on-site protocols, and analytical frameworks, the four national labs jointly selected representative buildings across a broad range of building types. For logistical, budgetary, and practical reasons, the team selected buildings either on the individual lab campuses, nearby, or coordinated with related projects such as DOE's Commercial Building Partnership projects. The labs used the taxonomy for building types and space types from CBECS 2003 -- a comprehensive survey of commercial building energy use (US DOE 2006). Nine major categories of building types were included in this work, and research teams encountered building type-specific CMELs, specialized research concerns resulting from space and end uses, and other metering and fieldwork issues as shown in Table 1.

Table 1: Building types, descriptions, and characteristics

Building Type	Description	Square Feet	Construction Date	Research Issues	Laboratory
Food Service	*EMSL Cafeteria --* *The Bistro*	3,000	1997	Food service specific/kitchen CMELs, safety, access.	PNNL
Food Sales and Food Service	*Walmart Supercenter: Grocery, produce, bakery, deli, and restaurant*	218,400 total, 47,000 food sales and food service	2004	Some devices were not accessible or measureable Food service specific/kitchen CMELs, safety, access.	NREL
Health Care, Inpatient	*Large teaching hospital*	420,000	1959	Medical devices, health concerns, confidentiality and privacy, access.	LBNL
Lodging	*PNNL User Housing Facility*	29,108	2001	Transient CMELs, with guest turnover, meter security.	PNNL

Building Type	Description	Square Feet	Construction Date	Research Issues	Laboratory
Mercantile, Retail (Other than Enclosed Mall)	*Walmart Supercenter: retail, vehicle service, paint center, bank, photocenter, salons, pharmacy, and others.*	218,400 total, 171,400 retail	2004	Transient CMELs with stock turnover, confidentiality & security concerns.	NREL
Mercantile, Enclosed and Strip Mall	*JCPenney*	100,000	1989	Mercantile specific CMELs with confidentiality and security concerns.	PNNL
Office, Small	*ORNL Building 3156*	6,940	1994	Meter deployment requiring manual data upload.	ORNL
Office, Medium	*LBNL Building 90*	90,000	1960s	Metering technology development, confidentiality, privacy, and security issues, multiple space types.	LBNL
Public Assembly and Religious Worship	*Central Baptist Church:* *Mahan Building,* *Family Life Center.*	118,000 12,075 32,548	1941 with renovations in 1965, 1987, 1988 1985	Assembly, education, fitness facilities, reconfigurable spaces, and transient CMELs.	ORNL
Warehouse and Storage	*PNNL Technical Support Warehouse*	7,100	1960s	Warehouse-specific CMELs	PNNL

A primary goal for this research was to test and assess various methodologies to inventory, deploy meters, monitor energy use, and analyze data (e.g., optimizing inventory methods, experimenting with metering equipment, etc.). Thumbnail photographs for buildings are provided below, with both a building and interior image. Below is a brief description of each building in the study.

1. Food Service:

The Bistro at the Environmental Molecular Sciences Laboratory (EMSL) at PNNL is a food

service space. The Bistro is approximately 3,000 s.f. and was built as a tenant space within EMSL in 1997. The Bistro is open weekdays from 6:30 am to 2:00 pm; the maximum occupancy is 75 people with three staff members.

2. Health Care, Inpatient:

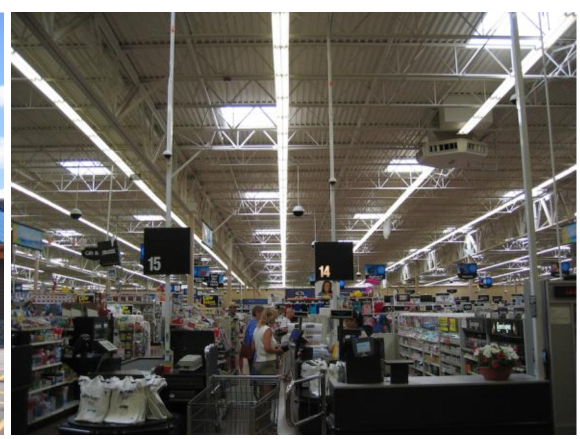
The hospital is a large teaching and research hospital with 420,000 s.f. of floor area on four floors and several wings. The original structure was built in 1959. The basement floor has no patient care function and houses building and equipment maintenance, administrative and physician offices, storage, and some laboratory facilities. The other floors are dominated by patient care and also contain a cafeteria and significant laboratory space. The hospital holds over 800 certified beds and employs more than 2,500 medical staff, residents and interns.

3. Lodging:

The User Housing Facility (UHF) on the PNNL campus is a 2-story motel-dormitory style building with 81 private rooms and a variety of amenities. The UHF was built in 2001, and measures 29,108 s.f. The facility is owned and managed privately.

4. Mercantile, Retail (Other Than Enclosed and Strip Mall), Food Sales, and Food Service

The Walmart Supercenter in Centennial, Colorado represents a conventional Walmart Supercenter design, with 171,400 sf of retail space and 218,400 sf of total space. The store also has the following areas: food sales, garden center, tire center and vehicle service garage, pharmacy, paint center, and photo center. The supercenter also houses the following



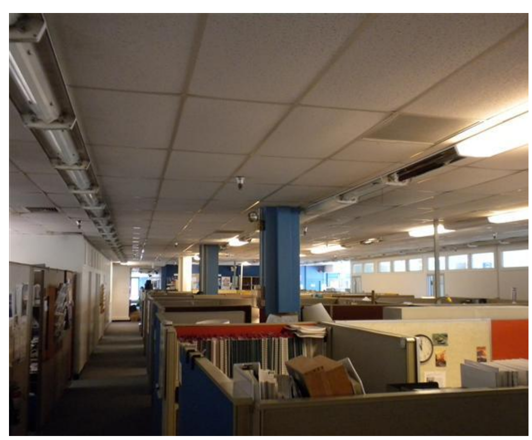
tenants: nail salon, bank, vision center, hair salon, and a McDonald's restaurant. The food sales and food service areas measure 47,000 sf, and include a full grocery store including a bakery, a deli, and a produce section.

5. Mercantile, Enclosed and Strip Mall:

In concert with related Commercial Building Partnership activities, CMELs monitoring is underway at a JCPenney store in Colonial Heights, Virginia. The building is divided among the four main use areas of retail/stocking, office, portrait studio, and hair salon. The building was constructed in 1989 and measures approximately 100,000 s.f. There are a variety of CMEL loads with concentrations located in the hair salon, back office, and point-of-sale areas.

6. Office:

LBNL Building 90 is a 90,000 sf, 1960s era facility largely used as a traditional office space. Approximately 450 occupants in six working and functional groups (two scientific divisions, Human Resources, LBNL Security, Environment, Health and Safety, and LBNL computer training facility) are located on four floors. The building has individual offices, cube farms, conference rooms, small kitchens or break rooms, a computer training and education facility, server closets, and network equipment.



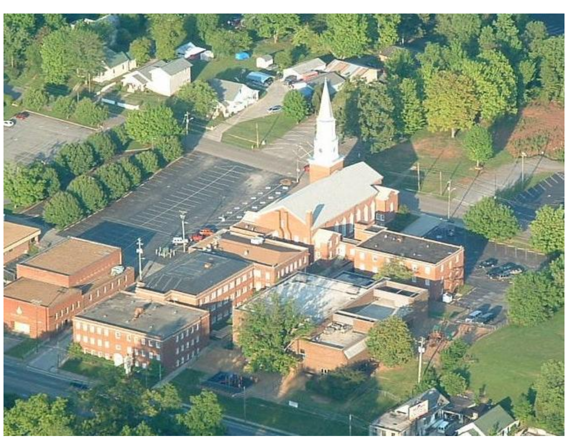

Building 3156 is a small office building located on the ORNL campus, with 23 offices and six additional rooms consisting of a kitchen, conference room, restrooms, and mechanical and electrical rooms. Building 3156 was constructed in 1994 and has 6,940 s.f. of floor space, housing some 30 researchers.

7. Public Assembly and Religious Worship:

The Central Baptist Church (CBC) of Fountain City is located in Knoxville, Tennessee. The CBC is a relatively large church complex consisting of six interconnected buildings on 6¼ acres. The first building in the complex was constructed in 1912. Along with a religious sanctuary, the complex includes business offices, assembly areas, a music center, daycare and educational facilities, and a community recreation and fitness center. Total floor area measures approximately 118,000 sf. Two buildings were selected for initial metering:

1. The newest and largest building of the complex at 32,548 s.f. is the Family Life Center (FLC). The FLC houses Church Ministries, Community Outreach (including a gymnasium, fitness facilities, track, racket ball courts, and game room), Early Childhood Center, School Age Program, and other Education Programs on two main levels. The FLC was constructed in 1985.

2. The 12,075 s.f. Mahan Building houses the music ministry and church administration offices on three levels. This building was originally constructed in 1941, and underwent renovations in 1965, 1987, and 1988.




Metering is currently being extended to the other buildings in the complex.

8. Warehouse and Storage:

The Battelle Shipping and Receiving Warehouse supports all of the activities for the PNNL campus as well as equipment excess and redistribution functions. There are six unique spaces within the building: receiving, shipping, janitorial storage, lunchroom, locker room, and offices. This 1960s single story facility measures 7,000 s.f. and operates on a standard 40 hour weekly schedule during the majority of the year; in August and September the building remains open for a 50 to 60 hour work week. The space houses an estimated 33 employees.

2.2 Inventory Process

The inventory of a building is critical for obtaining reliable data on the following:

- CMELs densities and power rating,
- Collecting adequate information about a CMELs population to enable researchers to draw a representative sample for metering.

2.2.1 CMELs Taxonomy

Nordman and Sanchez (2006) developed a taxonomy of miscellaneous and electronic devices for a California Energy Commission study. We augmented this taxonomy by referencing other existing taxonomies (Energy Star product categories and California Energy Commission appliances list), and by surveying a number of retailers (i.e. Best Buy, Walmart, McMaster-Carr, and Newark Electronics). A condensed version of the taxonomy used in this study in included in Appendix A.

In some cases, researchers expanded and fine-tuned the taxonomy to include specific considerations encountered in the field. For example, additional taxonomy categories were added to handle specific devices found in the retail environment being studied (e.g. cash registers, conveyor belts, etc.). All of the labs have contributed to extending the taxonomy to ensure that a more robust and complete version is used jointly in future studies. Additional changes to the taxonomy are anticipated in the continual study of CMELs, in order to further improve device categorization and subsequent energy data collection and analysis.

2.2.2 Methodology for Taking Inventory

Researchers selected an inventory method based on the building space type and number of CMELs devices in a building. In buildings with a small CMELs population, each device was inventoried, while in cases with extensive numbers of CMELs devices, researchers may have adopted a sampling strategy.

Field researchers collected attribute information on each CMELs inventoried; for example, manufacturer, model, production year, serial number, nominal voltage, rated current, rated

Table 2: Inventory Method and Number of CMELs

Building Type	Space Types (major categories, % area)	Inventory Sampling Method	No. of CMELs
Food Service	Food Prep- 39% Dining – 41%	Complete	45
Food Sales and Food Service		Complete	60
Health Care, Inpatient		Sub-Sample	
Lodging	Living 79% Common Space 18% Office 2%	Sub-Sample	TBD
Mercantile, Enclosed and Strip Mall	PNNL TBD		
Mercantile, Retail (Other Than Mall) or Enclosed and Strip Mall	Sales 77% Warehouse – Stock 10% Lunchroom 4% Other 9%	Complete	332
Office, Small	Office 61% Circulation 27% Conference 6% Facilities 6%	Manual Complete	200
Office, Medium	Office 56% Common 11% Facilities/Other 33%	Complete	4942
Public Assembly and Religious Worship	TBD	Manual Complete w/ exceptions noted	298
Warehouse and Storage	Materials Receiving – 38% Materials Shipping – 19% Office – 12% Janitorial Storage – 12% Lunchroom – 10% Locker Room/Break Room – 9%	Initial walkthrough of type of equipment by location complete.	140

power, electrical plug type, load type, external power supply specifications (if applicable), energy star rating (if applicable), space type and location in the building. Table 2 lists the building type, space types, inventory sampling method and number of CMELs counted in each building.

PNNL: Food Service, Lodging, Mercantile, and Warehouse and Storage:

In the above buildings researchers used a three-step integrated protocol to inventory all CMELs. First, researchers reviewed the layouts of the electrical panels serving each building or space, and estimated the CMELs on dedicated circuits, other loads in the building or space, and the number of electrical outlets. In the second step the field researchers visited each building to better understand the occupancy and key functions of the spaces. They also recorded the location, circuit number, circuit amp ratings, the number of occupied plugs, and a description of the type of load on each outlet. From this information, a circuit level and plug-level metering plan was created. In the final step researchers installed the meters, and recorded the manufacturer, model number, and power rating of each appliance, as well as the corresponding meter number. Field researchers verified recorded loads, thus providing quality assurance for data collection.

LBNL: Health Care, Inpatient:

Researchers walked through the hospital and observed equipment in use in several situations to inform the inventory process, but information gathering was limited. Privacy requirements restricted researchers from entering occupied patient rooms except under very limited circumstances. Instead, inventory data was collected from existing hospital databases: clinical technologies (traditional medical equipment), facilities (devices ranging from in-room televisions to vending machines), and information technology. These databases were combined and analyzed in accordance with the taxonomy used in this study.

NREL: Mercantile and Food Sales and Service:

Researchers inventoried all CMELs in retail and food outlets using a two-phase approach. In the first phase, researchers cataloged each CMEL instance in the store, regardless of repeated manufacturer and model combinations. During the second phase, field researchers recorded the quantity of CMELs of each device model, in order to determine the total CMEL load for the entire store

Question: *What inventory protocol is most cost-effective, efficient, and accurate for the medium office building?*

Researchers tested and compared three protocols for conducting an inventory in an office building:

Video recording with manual data transcription -- employee privacy was a significant concern.

Audio recording with automated software transcription – the voice recognition software did not have adequate accuracy to transcribe the data.

Pen and paper recording – Using pre-printed forms resulted in complete data, but transcription was very time consuming. Difficult to read writing led to some accuracy problems.

Real-time direct data entry – Two-person teams were assembled, one person surveying all CMELs devices in each space, the second person recording the data by entering the information directly into the attribute database.

Conclusion: Real-time direct data entry eliminated the transcription process and possibility of transcription errors, encouraged collection of complete attribute data, and allowed real-time truth checking of data entries.

from a limited number of metered CMELs. In addition, researchers took three photographs of each CMEL: one of the nameplate(s), one of the plug, and one of the entire CMEL. Owing to confidentiality, privacy, or security concerns several areas of the store were off limits, including the bank, the pharmacy, and the security monitoring room. The lack of metering in these areas limited the accuracy in calculating the whole building energy use.

LBNL: Medium Office:

Researchers conducted a complete inventory of a medium office building in order to generate an accurate tabulation of the CMELs devices present. To minimize any disruption of the workplace, inventory activities were conducted after normal working hours. Researchers formed two-member teams and built the inventory by walking through the building and surveying the plug-in devices in each work space. One person identified all CMELs devices and attributes in a space, and the second team member entered the information directly into the attribute database. If laptops, cell phones, or other mobile devices were likely but not present in the work space, researchers returned during working hours to record device details. Almost 5,000 CMELs were inventoried. The inventory protocol was developed in conjunction with the LBNL human subjects committee, lab site security, and lab environmental health and safety personnel.

ORNL: Public Assembly and Religious Worship and Small Office:

Researchers collected CMELs inventories by investigating each building space and manually recording all CMELs information on pre-prepared inventory sheets. The data was transferred to Excel spreadsheets, and metering information was subsequently added. Researchers searched the internet to obtain any additional information needed to complete the inventory. As meters were installed, field researchers recorded the meter serial number, Electronic Educational Devices (EED, the company that makes the WattsUp? meters) account number, and installation date.

2.3 Monitoring Strategies

Across the study buildings, researchers tested a range of monitoring strategies – selecting meters, choosing which CMELs devices to monitor, and installing and operating meters. Many of these strategies are described in this section.

2.3.1 Power and Energy Meter Selection

Researchers can monitor CMELs at either the panel/circuit level or the device level. Panel/circuit metering is effective if the circuit exclusively powers one CMELs device, such as an industrial freezer or oven. If a circuit powers more than one CMEL, device level meters are needed for each device. Panel/circuit level data also contribute to whole building energy use calculations.

When selecting a device level meter for a specific application, researchers considered the following:

- Number of devices to be metered, and cost effective meters that fit the commercial environment;

Table 3: Summary of meter installations for each building in this study.

Building	Description	Device Level Metering					Circuit Level Metering					Status
		Meter Model	No of Meters	Data Transmission	Sampling Interval	Metering Period	Meter Model	No of Points	Data Transmission	Sampling Interval	Metering Period	
Food Service	The Bistro	WattsUp?.Net	15 [A]	Wireless [B]	15s	1 year	Smart Works Smart-PDU	50 [A]	Wireless	3 min	1 year	In Progress
Mercantile, Food Sales & Service	Walmart	WattsUp? Pro ES	50 [D]	Data logging [C]	30s	4 weeks[D]	Campbell Scientific	47	Wired	15 minutes	4 years	In Progress
Health Care, Inpatient		WattsUp? Pro ES	15	Data logging [C]	30s	Spot metering	N/A					Complete
		ACMe	15	Wireless	10s	4 weeks						Planned
Lodging	PNNL User Housing	WattsUp? .Net	50	Wireless [B]	15s	1 year	Smart Works Smart-PDU	200	Wireless	3 minutes	1 year	Planned
Mercantile Enclosed and Strip Mall	JCPenney	WattsUp? .Net	50	Wireless [B]	15s	3 months	Smart Works Smart-PDU	400	Wireless	3 minutes	1 year	Planned
Office, Small	ORNL Building 3156	WattsUp? .Net	25 [E]	Data logging	Variable	6 weeks[E]	Johnson Controls Metasys	36	Wired	15 minutes	1 year	In Progress
Office, Medium	LBNL Building 90	ACMe	500 [F]	Wireless	10s	1 year	PSL PQube, Veris H80, Dent PowerScout	60	Wireless, wired	1 minute	1 year	In Progress
Public Assembly & Religious Worship	Central Baptist Church	WattsUp?.Net	105	Wireless [B]	Variable	1 year	N/A					In Progress
Warehouse & Storage	PNNL Technical Support Warehouse	WattsUp? .Net	15 [A]	Wireless [B]	15s	1 year	Smart Works Smart-PDU	120 [A]	Wireless	3 minutes	1 year	In Progress

[A] Some circuit level meters are used to meter individual CMELs where only a single device is on the circuit (common with cooking or other high-use equipment)
[B] Wireless data transmission for WattsUp? .Net and all circuit level metering devices used in this study require an external wireless device and sometimes includes wired data aggregation
[C] Data logging meters require researchers to manually download data from each meter approximately every week
[D] The total metering period was 8 months where each set of 50 devices was metered for four weeks.
[E] The total metering period is great than 6 weeks with meters rotated through different devices. Total number of devices to be metered TBD.
[F] 100 meters installed to date with an additional 400 planned in the medium office building

- Ability to measure electrical variables for each CMEL: power, voltage, current, energy consumption, and power factor;
- Programmable sampling rate as fast as each second to capture transient load behavior (e.g. microwaves, conveyor belts, etc.);
- Automatic time stamp;
- Real time data collection;
- Ability to collect data for extended metering periods to reduce the labor resources required to upload data and service meters;
- Adequate internal memory to buffer at least one week of data storage, in the event of communication outage or other system malfunction; internal memory also needed if data transmission is not possible or not desirable because of security concerns or location;
- Wireless or LAN data transmission capability to a local or remote repository;
- Wireless mesh capability;
- Non-invasive load meters would be desirable in cases of sensitive CMELs where unplugging for data upload or meter installation is intrusive (e.g. cash registers, servers, refrigerators, etc.);
- UL listing, or other certification as required by host institution;
- Minimally invasive meters with low physical profile so as not to create a hazard (e.g. tripping, electrical shock, etc.);
- Concealable with low physical profile to reduce the chances of tampering or vandalism;
- Barriers to theft
- Meter with medical device approval for usage in series with medical devices.
- Meter accuracy

Each metering situation presented its own challenges, and the labs agreed to try a diverse set of metering methods to compare and contrast the difficulty and effectiveness of each technique. A summary of the types and numbers of meters deployed is shown in Table 3 for each building in this study.

PNNL: Food Service, Mercantile (Enclosed Mall), and Warehouse and Storage:

The WattsUp? .Net meters were selected for their autonomous reporting capability and relative accuracy, and these meters were combined with external wireless adapters to provide wireless data reporting. Several CMELs in the Food Service and Warehouse buildings are the only devices on a circuit, and panel level metering from Smart Works was selected. Smart Works provides a flexible, large Current Transformer (CT) count metering

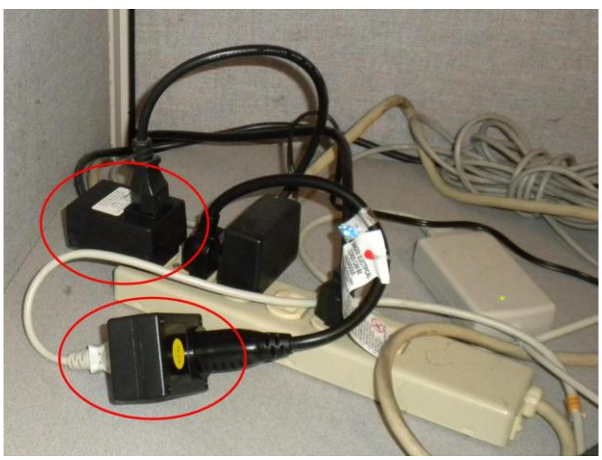
Figure 3 Typical Installation for Food Service (and other PNNL buildings) of branch circuit power metering (left) with CTs on circuits, and a WattsUP? .Net plug load meter with wireless data logging (right).

option with wireless network communication capability as an add-on device. A typical installation of these devices is shown in Figure 3.

LBNL: Medium Office:

Custom designed meters, the ACme devices, were used in the medium office building. These meters form a wireless mesh network and report data over this network without the need for wires, additional external wireless devices, or manual data downloading. Data appears in the database in real time allowing for monitoring of systems. Real time feedback to users could be provided using these devices. These meters were originally designed by UC Berkeley and were updated substantially for this study. They provide almost all of the features desired in a meter (small form factor, relatively low cost, accurate measurement and wireless data reporting), but they are not a commercial product. Substantial resources went into their development for this study. A typical ACme device installation is shown in Figure 4.

Figure 4 Typical installation of ACme meters showing improved form factor without need for Ethernet cables or additional wireless hardware. Two acmes are shown (circled).



LBNL: Health Care, Inpatient:

The hospital decided that the safest course of action for metering would be to require in-line meters used on medical equipment to be approved in the same process as the medical devices themselves. No such meter exists on the market at this time, and it appears FDA approval would be the required hurdle in most cases. WattsUp? Pro ES (WUPE) meters were used for spot metering of devices to ensure the user could record energy use from the screen, and ACMes will be used in the training facility to eliminate additional wires and to eliminate the problems with meter resets observed with the WattsUp? devices.

ORNL: Mercantile and Food Sales and Service:

Researchers chose the WattsUp? Pro ES for the Walmart environment because of its internal logging capabilities and the meter's accuracy.

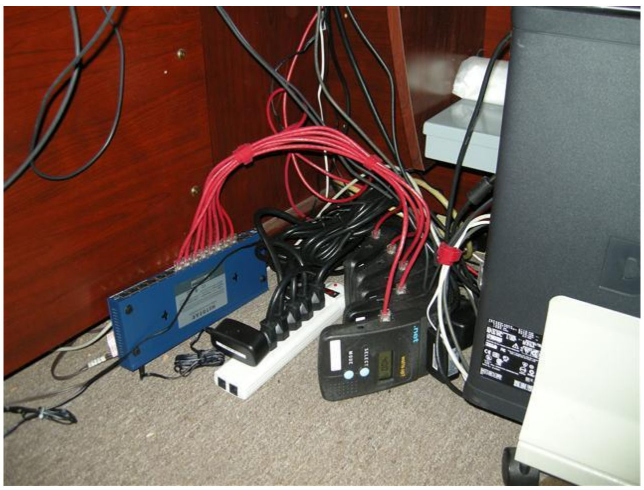
ORNL: Small Office:

Submetering on a circuit level provides composite CMELs data on a whole-building basis or circuit-level basis. Whole building energy data is important in assessing the CMELs energy use. The percentage of energy used by CMELs can be compared against the building total. Also building submetering data is used in verifying and cross checking meter data. ORNL chose Metasys by Johnson Controls for circuit-level and end use-level circuit monitoring.

ORNL: Public Assembly and Religious Worship and Office:

The WattsUp?.net meter was chosen for the church because it featured most of the important attributes listed above, particularly its internet-ready capability and the availability of the manufacturer's server to receive and store the multiple-millions of data records that will be generated in the course of this study. A typical meter installation is shown in Figure 5.

Figure 5 Typical installation of WattsUp? .Net device at the church showing wired data aggregation followed by wireless data transmission. Five meters are shown in this figure with associated hardware.



2.3.2 CMELs Device Selection for Monitoring

Researchers selected the CMELs devices for monitoring based on the total number of devices and the type of space found in each commercial environment:

Meter all CMELs:

If the number of CMELs devices was relatively few, field researchers monitored all or nearly all CMELs devices. For example, in the Food Service building (Bistro), current transformers (CTs) were installed on 48 circuits in two panels containing CMELs, and when multiple devices were plugged into 15 amp circuits WattsUp meters were used to disaggregate the loads.

Meter Most CMELs:

A small number of CMELs devices could not be metered in some buildings. For example, the Family Life Center in one of the Religious Worship buildings included both daycare and school rooms. Researchers elected not to meter in these rooms because of difficulty keeping instrumentation and ancillary equipment operational in the presence of multitudes of curious children. In addition, Researchers had difficulties with some of the plug level meters that caused equipment to turn off. In this instance the building manager did not want the meters installed on "critical" equipment (e.g. refrigeration, credit card swiper).

The CBC sanctuary balcony and gym each contain audio/visual systems with over 30 individual devices each. Considering that the systems are used only intermittently, it was decided to meter each system as a whole for this initial phase of the study. It may be decided later to monitor each of the A/V devices separately. Finally, the meters are rated for 1800 watts/15 amps. While this covers the vast majority of CMELs at the test sites, there are several 240V devices, namely ranges and clothes dryers, which draw higher currents. At this point, those devices are not being monitored. Since those are chiefly resistance loads, current transformers with loggers may be installed at a later date.

Selected CMELS Not Metered – Confidentiality, Privacy, Security, Access, Policy, or Health Concerns:

In a number of building types, a number of concerns resulted in excluding certain CMELs from metering. In the Walmart Superstore, confidentiality, privacy, health, and security concerns limited the number of CMELs that were metered in the bank, security monitoring room, and pharmacy.

Access limitations also restricted the number of devices that could be metered at Walmart, and elsewhere: inaccessible plugs behind immovable objects, inside locked cabinets, reachable only with ladder, etc.

In the hospital, device metering was severely restricted as a result of institutional policies reflecting health, privacy, and confidentiality concerns. A corporate policy in the Walmart hair salon required employees to unplug any CMELS devices (e.g. clippers, curling irons, etc.) unless actively in use. An unexpected result of this policy was that sparse metering data was collected from a few CMELs devices in the salon.

Extensive Numbers of CMELs:

In a few building types, metering all CMELs proved impractical, as a result of the sheer number of CMELs devices present. For example, the CMELs population in the medium

Office building numbered nearly 5,000 devices, and researchers employed stratified random sampling to select the CMELs devices for metering. Similarly, the Warehouse had intensive CMELs usage and many power strips. Consequently meters were installed on all outlets and on a sub-sample of the equipment. A third example is the Walmart consumer electronics section, with a rapid turnover of inventory, such as televisions, radios, and notebook computers. In each of these cases, researchers selected a sub-sample of devices for metering.

> **Question:** *Would random sampling or stratified random sampling yield more representative CMELs meter data, especially in buildings with a large number and wide variety of CMELs?*
>
> Researchers compared two sampling methods to select CMELs devices from the inventory for monitoring from the inventory:
>
> - Random sample, and
> - Stratified random sample, in which researchers divided the inventory into nine strata: computers, imaging equipment, displays, lighting, refrigerators, water fountains, fans, space heaters, and other devices. Devices in each stratum were assigned a probability of selection, and a predetermined number of devices were selected from each strata.
>
> Conclusion: One goal in this study is to collect CMELS data on less common and building-specific devices. The random sample yielded many devices with low energy use (e.g. pencil sharpeners, disk drives, etc.); few energy intensive devices were included in the original random sample. The stratified random sampling method included devices in each stratum, and was selected for use in the study.

2.3.3 Meter Deployment

Research teams implemented a number of meter deployment configurations and data collection strategies. Table 3 in section 2.3.1 summarizes the meters used at each study site, data transmission methods, sampling intervals and monitoring period. This section provides a further description.

PNNL: Food Service, Lodging, Mercantile, and Warehouse and Storage:

Researchers used a two-tier approach to capture MEL loads. Circuit level metering captured energy used by individual pieces of equipment that resided on a single breaker, as well as the total CMELs loads. An additional advantage of circuit level data allowed researchers to identify new CMELs devices in use. (For example, portable fans and extra pieces of kitchen equipment were brought into the Food Service space during the monitoring period.) Researchers installed CTs on all circuits in the retail, food service, warehouse spaces as well. In cases where individual CMELs shared a circuit, field researchers installed device level metering to understand the energy use patterns.

The Warehouse and Storage building had a high density of CMELs per workstation and a large number of power strips. Field researchers installed CTs on all circuits to capture lighting, HVAC, water heating, and CMELs. Researchers then plugged Watts Up meters into all of the outlets, and then on a sample of the equipment.

The Food Service meter deployment is described in Section 2.3.2. After the first month of downloading data manually from the meters in the food service space, researchers installed single-port wireless bridges on the meters. By connecting the wireless bridges to the WattsUp.net meters, data was automatically inserted into a central database, removing the need for field staff to manually download data.

NREL: Mercantile, Food Sales, and Food Service:

Fifty WUPE meters were deployed throughout the store. Each meter recorded measurements every 30 seconds and stopped recording when the internal memory was full. Researchers fitted WUPEs with adaptors as needed to plug into the CMELs device and the wall outlet. For example, at the checkout stands a NEMA L5-15R adapter was needed to monitor the cash registers and a NEMA L5-20R was needed to monitor the conveyor belts. Field researchers recorded the start time, and the meter collected data for one week.

To retrieve data from the WUPE, field researchers connected a USB cable from a laptop to the meter. Using the "WattsUpUSB" program, data was transferred from the meter to the laptop and saved as a text file. Researchers then cleared the meter and recorded a new start time. This entire process was repeated for a total of four weeks per CMEL.

LBNL: Medium Office:

In the LBNL Building 90 deployment, the AC meters (ACme) were customized for use in this study by LBNL and UC Berkeley, building on a design developed for a previous project. The ACme devices form an Internet Protocol (IP) based wireless mesh network and report data over the Internet to a database.

The entire building inventory was subdivided, and each of the five floors was considered a separate sampling stage. Staging allowed the field team to build the mesh meter by meter and ensure wireless network connectivity as meters were deployed. Phasing deployment on one floor at a time also afforded efficiency gains as researchers could focus their efforts within a small local area. Initially 100 meters were deployed on the third floor, and devices from all nine strata were selected for monitoring to ensure sufficient coverage of key CMELs. Device-level wireless meters collected information at a ten second sampling interval. The information packets were transmitted via edge router and deposited in the database on the CMELs server.

ORNL: Small Office:

In ORNL Building 3156 researchers installed 25 WattsUp?.net meters using internal memory. IT restrictions prevented using the internet capability, thus the time stamp feature was not available. Installation and removal times must be carefully recorded and merged with the data upon download. Periodically, field staff uploaded data, reset the time stamp, and configured the meters to record data internally. Recorded data must be analyzed for power interruptions and meter resets, and adjusted accordingly. Internal meter data storage, while adequate on a small scale, does not provide for the volume of data that can be obtained via internet reporting, and proved to be cumbersome and time consuming in comparison. It is not recommended for large scale deployment.

CMELs were also monitored in Building 3156 on a circuit by circuit basis. Researchers installed current transformers on each circuit in the breaker panels. The CTs are connected to a Johnson Controls internet-based building energy monitoring system – Metasys. Energy usage data for individual circuits and clusters of like-type circuits, including CMELs circuits, are collected, stored, and analyzed.

ORNL: Public Assembly and Religious Worship:

The ORNL deployment of meters attempted to minimize human involvement in the data gathering. Since network enabled meters were used, an accurate time stamp was provided.

Remote administration of meter reporting was also supported that allowed the data interval to be custom tailored to meet analytical needs. With the data acquisition process essentially automated, higher data rates were possible since human intervention in the reading of the information was not required.

Deployment of the initial "shakedown" phase focused upon developing an efficient installation process as well as troubleshooting problems. After achieving success with the initial trials, custom manufactured WattsUp?.net meters with bypassed relays (to avoid relays from switching off loads on occasion) were procured for the next phase of the trial. EED professional accounts were set up to receive and store the data. Field researchers installed 125 meters at the CBC using 802.11n protocol wireless connectivity. Several of the

Question: *Which metering protocol provides the best fit for the Walmart retail environment using the Watts Up Pro ES (WUPE) meters?*

Four metering protocols were designed and tested:

1. Three Watts Up Pro ES WUPE meters continuously uploaded data to a laptop via direct USB connection. The "WattsRealUSB" program successfully logged data from all three meters every ten seconds for a period of three weeks.
2. Wireless USB (wUSB) adapters from Cables Unlimited transmitted meter data continuously and wirelessly. Since the wUSB adapters behave like a physical USB cable, researchers followed essentially the same procedures for continuous data collection, with a few minor adjustments. This method ran successfully in a small scale, non-commercial environment for 48 hours.
3. The CMELS devices were plugged into adaptors, and then into the WUPE. The WUPE, in turn, was plugged into a NEMA 5-15P wall outlet. Field researchers cleared the memory on the meter, recorded the start time, and the meter logged data for the next week. To retrieve data from the WUPE, researchers attached a USB cable to upload data from the meter to the laptop as a text file, cleared the data from the meter, and recorded a new start time. This entire process was repeated for each CMEL.
4. A WattsUp?.net meter was substituted in place of the WUPE; as a result, the CMELs data was stored online rather than on the meter. Netgear Powerline AV Ethernet Adapters transmitted data every 15 minutes from the meter to a modem, and ultimately to the wattsupmeters.com server for storage. This method ran successfully in a small scale, non-commercial environment for 48 hours.

Conclusion: Option number one was abandoned due to concerns about leaving multiple laptops unattended for weeks in the store. With option one, the CMELs had to be within a distance of less than the length of the USB cable which limited the usefulness of this option. The second option was also abandoned due to the application only being able to support three wireless clients. The wUSB had a limited range of five to ten feet, with connectivity issues even at these close ranges. The fourth option was also abandoned due to the difficulty of redirecting the data stream out of the building. Due to the reliability and connectivity issues of the previously mentioned options, the third option was selected for this study.

meters were initially connected to the internet through the CBC's LAN but were subsequently moved to wireless bridges to relieve the congestion on the CBC LAN. Ultimately, to completely eliminate any burden on CBC's network, a separate internet drop was installed for ORNL.

Researchers used wireless N-band networking technology to minimize the amount of cabling that was required. Data was acquired and managed at several levels. Vendor servers were used as the primary acquisition point for all network enabled meters. Data was saved at the vendor site for a year for a nominal charge. Access to the data was via a standard web interface and an FTP server. The vendor's web site offered data access pages that work well for quick-look viewing and downloads that were useful during initial deployment of a meter. For automated processing, the vendor implemented an FTP server where daily csv files of meter data were stored. Researchers accessed this FTP server and downloaded the files to a laboratory Linux server on a daily basis. The daily files were backed up on a Windows file server. The manufacturer was forthcoming in helping resolve issues that surfaced during use of these meters. Automating the data acquisition process resulted in higher data collection rates; as of September 15, 2010, there were well over 50 million records in the CBC database.

2.4 Data Acquisition, Storage, and Retrieval

All of the research programs archived information in central data storage locations:

- o Attribute data -- Attribute data all buildings was stored in a master Excel spreadsheet for convenient update and import into analytical tools;
- o CMELs monitoring data was housed in MySQL databases;
- o Panel/circuit level monitoring for ORNL Building 3156 is stored in Metasys.

The MySQL databases were tailored to interface closely with the meter being used. For example, the database structure for the Public Assembly and Religious Worship CMELs data mimicked the architecture assigned by the WattsUp.net server site. The medium Office building database was developed in parallel with the ACme meters. The Warehouse and Food Service data was integrated into an existing flexible format buildings metering database. Similarly, the Walmart database was adapted from an existing database, affording the researchers the opportunity to leverage prior work.

CMELs data was inserted into the central databases using a number of methods:

- Manual upload -- WattsUp Pro ES meters were used at the Walmart site and the small Office building; consequently field researchers uploaded the information stored in the meters into the database using batch files on a weekly basis.
- Daily download -- Researchers studying the Public Assembly and Religious Worship building downloaded WattsUp.net files on a daily basis from vendor's FTP server, unzipped, and loaded into the master MySQL database.
- Real-time electronic transmission and incorporation into database, as data collected. ACme meters transmitted information packets via wireless router and inserted data directly into the database. Similarly, in the Bistro Food Service and Religious

Worship buildings, researchers connected wireless bridges to the WattsUp.net meters and were able to collect data automatically in the central database, eliminating the need for manual download. The Smart Works circuit level metering at the Bistro Food Service and Warehouse were uploaded in real time via wireless router.

Meters reporting over networks sometimes dropped packets. Additionally, some received data was corrupted. Researchers developed adaptations to handle these issues; see section 3.1 for further details.

The experimental nature of this project is reflected in the diversity of analyses applied to the CMELs data. Researchers employed a number of analytical tools:

- R (R Development Core Team, 2010)
- Excel
- Python
- MATLAB

3.0 Findings

Chapter 3 discusses preliminary findings from this study. This chapter is broken into two sections: Section 3.1 addresses methodological findings, and Section 3.2 describes the initial results of the CMELs characterization research to date.

3.1 Methodological Findings

Based on the research activities conducted, a list of methodological findings was developed which related to 1) study design, and 2) study protocol. Identifying and incorporating these findings into the next phase of research would maximize data quality, provide economies of scale and improve data collection methods and efficiencies, and ultimately test the effectiveness of energy reduction strategies for CMELs.

3.1.1 Study Design

A list of study design findings are described in this section. These are planning level questions and issues rather than those encountered while carrying out specific research tasks.

1. **Single building vs. building population study**

   This study developed methods for evaluating the CMELs energy use in a commercial building of virtually any type. A meter based study of all CMELs energy use in buildings would need to be built differently for cost reasons.

2. **Stakeholder approval for field research**

   Proper planning and allotting adequate time in obtaining approval(s) for inventory and meter installations in the commercial environment is crucial in avoiding project delays and maintaining good relationships with stakeholders.

3. **Building sub-metering data**

   a. Sub-metering data compares CMELs energy consumption with electricity use in traditional categories such as lighting, HVAC, and refrigeration, and informs energy savings opportunities. In order for sub-metering data to be useful, the metering system should be installed such that each end use is metered separately.

   b. In the medium office studied, it was observed that multiple end uses are being extended from single-voltage panels and metered aggregately in some locations. This makes it difficult if not impossible to obtain accurate sub-metering data. It is important for electricians and building managers to be aware of this issue for better building energy management. New buildings under design may benefit from incorporating building metering in the design and construction to save on installation costs and avoid mixed panel issues described above.

   c. Sub-metering of CMELs would benefit from the addition of occupancy trending.

4. **Plug load vs. hard wired CMELs**

   A majority of CMELs encountered in this study are plug-loads; however, some CMELs such as elevators, security cameras, and exit signs/emergency lights are hard-wired devices. In some buildings studied, hard-wired loads are simply not measured, whereas in other buildings, different types of meters with current transformers were selected to meter hard-wired devices.

5. **Full vs. partial building/space inventory**

   The decision about whether a full or partial CMELs inventory should be conducted in a study building is based on considerations including the number of CMELs present and diversity of CMELs in the study space.

6. **CMELs that cannot be unplugged**

   a. Some CMELs such as medical and networking devices cannot be taken out of service, and meter installation on these devices becomes a challenge as they cannot be unplugged. A robust solution has not been found for this issue— the proper solution would probably be situation specific. For example, researchers could request a temporary after-hour shut down of equipment for meter installation.

   b. In the Hospital selected for the study, however, meter installation is not possible for CMELs used for patient treatment, as the hospital requires all devices connected in series to be FDA approved and our meters do not meet this requirement. Researchers instead installed meters on medical devices in the staff training area which did not involve patient treatment.

7. **Meter sampling frequency**

   a. Sampling frequency of selected meters is important in mode identification of the CMELs measured. Sampling period would have to be significantly less than the time spent in each mode for the CMEL, in order to capture the change in operating modes. Automated mode identification software is also crucial to understanding time and energy in power modes because of the large number of metered devices and the large number of data points for each device.

   b. We found that data with smaller than one minute time resolution is required for accurate mode identification. Longer sample periods result in blurring between modes for devices that change mode often (e.g. microwave ovens) because some portion of many samples is in more than one power mode. The sampling frequency selected is a compromise between data quality and the volume of data required for storage and analysis and is also an important consideration for meter selection.

3.1.2 Protocol – General Findings

A list of protocol findings are described in this section. These are issues and observations encountered while carrying out specific research tasks.

1. **General**

   a. CMELs baseline energy consumption is crucial in determining measurable goals for energy reductions.

    i. Information about building occupancy and CMELs operation schemes is beneficial in building energy reduction or control strategies.

b. Coordination with stakeholders, such as building occupants and managers and electricians, is critical in completing research tasks.

c. Older buildings with outdated panel schedules make it difficult to know what is on every circuit.

d. Some building owners show high interest in understanding CMEL loads to meet energy reduction goals. They have upgraded traditional loads and are in search of where more efficiency investments can be made.

2. Inventory

a. Taxonomy

   i. The use of formal and consistent device taxonomy streamlines data entry and analysis. Using electronic data entry at time of data collection forces consistent use of taxonomy.

   ii. Adjustments and improvements must be made to the taxonomy as new devices are encountered in the inventory.

b. Methods

   i. To avoid missing data entries, a form is needed (preferably electronic) that reminds field workers about data fields to collect.

   ii. Direct-entry data collection using a laptop worked well in an office environment, and a two-person inventory team is an efficient approach. Automated voice recognition for inventory did not work well.

   iii. Manual data entry onto printed forms by two-person teams proved efficient for the public and religious assembly buildings.

c. Video and photo inventory methods are not allowed in some buildings due to privacy concerns. When allowed, photographing the CMEL in its location reduces the chance of it being inventoried as two different items by different researchers, especially in the retail environment.

d. Assigning CMELs a phonetical ID is beneficial in collecting data, navigating around the retail environment, and sorting and analyzing the data.

e. Devices used by building occupants change with time, particularly during changes of season; it is necessary to check the inventory periodically and make adjustments.

   i. The turnover in consumer electronics sales areas is such that maintaining an accurate inventory in these locations is cost prohibitive.

f. Challenges
    i. Performing extensive inventories can be time intensive.
    ii. Some study spaces require multi-tenant permissions.
    iii. Working in occupied buildings with occupant-controlled devices.
    iv. Inventory process made more difficult when occupants requested to be present.
    v. Turnover in space occupancy during the study.

3. Metering

It is important to bring the facility management and staff onboard with the CMELs metering program early in the process. Installation of meters can be intrusive and disruptive to staff, and the staff's understanding of the research and their contribution to the research will go a long way in gaining their support.

Planning and thoroughly preparing for meter installation is vital. Where possible, meter installation activities should be scheduled to minimize interruptions in the staff's work days. Depending on the building type and use, there can be physical barriers or other concerns such as security, safety and privacy that can make metering certain CMELs devices difficult or totally impractical. CMELs teams should bring adequate tools and supplies to the research sites to provide for overcoming as many obstacles as practicable.

Careful recordkeeping and periodic inspections are necessary to ensure that meters are monitoring their corresponding CMELs devices. For meters using internal memory without the benefit of timestamps, installation and removal times must also be recorded. Many CMELs are transient and it can be difficult to ensure that the CMELs remain plugged into the correct meter by the user. Every meter should be clearly labeled with the corresponding CMEL device name, and the CMEL user should be briefed on the importance of plugging into the correct meter. CMELs teams should inspect the installations periodically to ensure the accuracy of the meter to device correlation.

In some environments, for example retail, the challenges of devices being frequently removed or exchanged while being metered can be pervasive. The regular unplugging of CMELs posed two problems – (1) how to meter devices that do not remain plugged in for the duration of the study and (2) how to meter devices that may be moved about the area and plugged in to multiple outlets during the study. In order to meter mobile devices, the meter had to stay with the device and be constantly plugged in. Due to the large and variable staff at the Large Retail Store, the local staff could not be relied on to return CMELs to the metered outlet. For perspective, a full 10% of the devices inventoried are known to be moved or regularly unplugged (e.g. electric cart and floor sweepers). An additional two dozen CMELs have the potential to be moved on occasion during the course of daily business (e.g. fans in the bakery, blow dryer in the paint center).

The manual data collection process employed at the Large Retail Store, Church, and Small Office is time consuming and susceptible to human error, and not suitable for large scale deployment; wireless internet data collection is much preferred.

4. Data Transmission

a. Wireless vs. wired, recording intervals (i.e. 3 minutes vs. 15 seconds), and onboard memory are important criteria in selecting meter(s) for data collection.

b. In some cases, researchers are not allowed to use facility owners' wired or wireless networks because of security or performance issues, and setting up a separate wireless network can be costly or prohibited.

c. Wireless technology can greatly facilitate deployment of the metering system and collection of data. The amount of LAN cabling that needs to be installed is minimal, consisting of trunks between wireless access points and the router.

d. Concrete walls and floors can limit wireless transmission range.

e. When using a static IP address to provide for remote access to a router, the Internet Service Provider's (ISP) gateway firewall smart packet detection may block data transmission. To prevent this problem the ISP should disable smart packet detection.

f. In some cases, the transmission of meter data may slow the data flow of the host's LAN. An immediate fix is to extend meter reporting increments (e.g. from 1-second to 15-seconds) and disconnect clusters of meters that are hardwired to the host's LAN. The long term solution is to install a separate LAN and gateway totally independent of the host's LAN. It is recommended that due consideration be given to installing an independent LAN for monitoring studies to help maintain a good relationship with the host staff. A trunk cable can be installed to connect directly to the independent LAN router and relieve congestion on the host's LAN.

5. Data Analysis

a. Automated detection and removal of corrupted data by a data analysis script was difficult, as many different failure modes must be checked. In addition, sometimes data corruption may be detected only subjectively. At present, visual inspection of CMELs data is being used to determine data corruption.

b. The following analysis goals have been met using R and Python:

   i. Identification of Missing or Corrupt Data: Built-in functions were used to automatically skip missing data without compromising the results. A mechanism for manually flagging and removing corrupt data has been implemented as well as an internal consistency check that can determine if the various measured values (voltage, current, power, and power factor) make sense in relation to each other. Various linear and nonlinear filtering techniques have been evaluated for noise removal with some success.

ii. Computation of Key Statistics: The scripts that have been written can compute basic statistical quantities on demand for any given CMEL, including average power, total energy used, extrema in the data, and measures of variance. It is straightforward to evaluate and report additional statistical quantities built-in commands. Scripts have been implemented which compute quantities of specific interest in the analysis of electrical loads given the set of measured quantities, such as device reactive and apparent power.

iii. Identification of Transitions between Operational Modes: In order to identify usage patterns and device duty cycle, it is advantageous to know when transitions between operational modes occur. The most basic of such transitions is an on/off change, but transitions between modes are also of interest (e.g. standby to active). Image sharpening algorithms have been implemented to detect edges (transitions) in time series data. Preliminary testing shows promising results.

iv. Identification of Operational Modes: Techniques have been developed for detecting and extracting operational modes in CMELs. The desired outcome of mode analysis is to classify device behavior into operational modes, or states, with distinct characteristics. This analysis is critical not only for computing such metrics as duty cycle and standby time, but also for adequate modeling of CMELs in building simulations.

c. The following goals have been met using an ODBC/JBC database connection and MATLAB:

i. To facilitate the analysis of the meter data, all the meter data has been consolidated into a single database. MATLAB, an ODBC/JBC compliant tool, is then able to mine this data by setting criteria that can utilize any of the field records as arguments. SQL access is possible using the Database Toolbox.

ii. To facilitate the speed of database fetches, timemarker values which are stored as DATETIME values are cast into unsigned integers during the query and then these values are converted to floating point time values with MATLAB scripts after the data is gathered. It was found that acquiring the DATETIME information in the default mode, which is ASCII, was too inefficient for timely processing of the results. By casting DATETIME data into unsigned integers, the processing time is improved by two orders of magnitude when compared to normal ASCII based DATETIME processing.

3.1.3 Protocol – Meter Specific Findings

1. ACme meters have several major benefits over commercially available meters, including:

    a. Small form factor meters are unobtrusive and fit well into the environment;
    b. Real time data collection over a wireless network eliminates the need for manual download and allows for real time analysis;

    c. In house developed meters are less expensive ($80/unit) than commercially available meters ($300/unit) and better match the needs of this study.

2. ACme meters present some challenges, however:
    a. Achieving a reliable, stable network is an ongoing challenge requiring substantial software and networking expertise;
    b. Designing for UL level safety requirements requires substantial verification and testing;
    c. Managing the manufacturing, programming, testing, and calibration process for hundreds of electronic devices requires a very large time commitment.
3. WattsUp? meters in general have several benefits over competing commercial products:
    a. The meters measure and record a wide spectrum of energy consumption data;
    b. All models are equipped with internal memory;
    c. The meters are more accurate in most ranges that other commercially available products;
    d. The meters are rugged.
4. WattsUp? Meters do have some disadvantages:
    a. The form factor is too bulky for commercial installation; owners or tenants take them out of service;
    b. The accuracy of the current and power factor measurements is poor at low power levels.
5. WattsUp? Pro ES meters have several negative issues specific to that model:
    a. Meters exhibited a number of failure modes, including application of incorrect calibration constants, recording constant power when power was not constant, or recording highly noisy time series.
    b. All-in-all, 31% of the CMELs metered at the Large Retail Store had some significant portion of their data series that was considered inaccurate during their metered period. Twenty-one meters (41% of deployed meters) were responsible for these inaccuracies, suggesting a problem with the meter model rather than individual meters.
    c. The lack of an internal real-time clock meant that metered data must be manually tagged with a timestamp during the data download process and also would not accurately reflect the gaps in data in a time series. This process afforded opportunity for human error, in particular by incorrect assignment of timestamps to the data files, resulting in overlapping or shifted data points in the time series. This was an issue with the WattsUp?.net meters as well when used in internal logging mode.
6. Wattsup? .Net meters had additional advantages:

   a. The internet-ready capability was invaluable in automating data collection for a large number of meters;
   b. Internal memory provided a buffer in case of network outages;
   c. The meter could be programmed remotely via internet.

7. Several negative issues came to light during deployment of the **WattsUp?.net** meters:
   a. This meter was prone to tripping GFCI outlets.
   b. Early in the initial trials it was discovered that these meters randomly switched off their loads on occasion. The meters are equipped with an onboard relay that provides the capability to switch loads remotely. To expedite delivery of suitable meters, a special run of meters manufactured with the relays physically bypassed with a jumper. This allowed for the meters to be deployed and the host's facility without the risk of inadvertently switching off the host's devices.
   c. Several meters had duplicate MAC addresses and/or external serial numbers that did not match the programmed serial numbers. This caused conflicts on the network until the offending meters were removed.
   d. The wireless data collection capability requires additional outlets to power each the wireless access point.

3.2 Building Case Study Results

This section discusses preliminary results from the building case studies performed as part of this study, and the section is structured to answer the research questions raised in section 1. Although data were collected in each building type that could be used to answer many of these questions, selected data are presented here to highlight the types of results that this study and those that follow will generate. More complete and detailed results will be presented in the final report.

3.2.1 Fraction of commercial energy use that results from MELs

A key question for MELs research and evaluations of commercial buildings in the field is what is the fraction of total building electricity used by MELs. As traditional building systems (e.g. HVAC, lighting) become more efficient, the fraction used by MELs will increase. The energy use of MELs is also increasing in real consumption, and it is becoming more critical to address MELs.

The primary tool for addressing this question is the use of circuit level submetering, but very few buildings are in a condition such that this metering is practical given time and budget constraints. For example, the medium office building has more than 40 panels and breakers with multiple metering points installed per panel, and this coverage is insufficient to fully extract the circuits that are labeled as plug loads or that fall into the miscellaneous category. To further complicate things, many circuits are mixed use: some lighting or HVAC is mixed together with MELs. Buildings are continually changing, and changes to the electrical system are surprisingly regular. The metering system and calculations would need to be updated regularly even if all of the required metering points were in place.

We used two methods to evaluate the fraction of building electricity used by MELs: 1) standard submetering and 2) projections based on individual MELs metering coupled with whole building energy data. Using MELs device level metered data, it is possible to either directly sum or project a building MELs total, and this method provides a second way of looking at this problem.

In the Walmart store, existing submetered data was utilized. The category containing MELs was responsible for 29% of the total building electricity use from 2006 to 2008, but the fraction of building energy use resulting from MELs cannot be exactly determined due to the issues identified earlier.

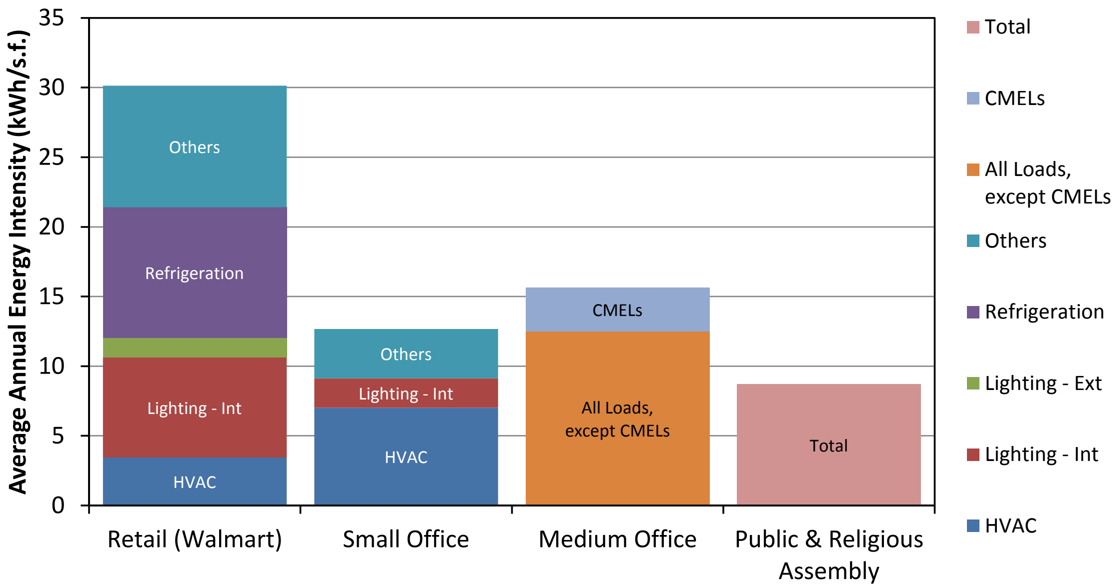
Using a similar submetering installation, the small office building at ORNL uses approximately 29% of its electricity for MELs. ORNL did not experience the issues with multiple use circuits as described above for some of the other building types; CMELs, HVAC, and lighting were all on dedicated circuits. This is an accurate indication of composite CMELs consumption in the building, but does not give a breakout of individual CMELs. Therefore, CMELs are being individually meter as discussed previously.

Although submetered data is available for the medium office building, it is of insufficient quality at this time for reporting MELs energy use. Based on a sample of MELs device level metering, we estimated the whole building MELs consumption and compared this to the whole building consumption in a typical summer week. We found that the MELs consumed over 20% of the building total, but we expect this fraction to increase when chillers are not in use and we meter server closets and other large loads.

Data are unavailable at this time for the other buildings in this study. Some of these missing data will be available in the final report. For example the Bistro Food Service is a tenant in a larger laboratory building with shared HVAC facilities. The required submetering data is unavailable as a result. The intention is to use whole building data and the metered CMELs data to come up with estimates similar to that found for the medium office building if no submetering data are available. An advantage of this technique is that we know exactly what is being metered and can be sure that no primary lighting or HVAC are included in the CMELs total, but results will not be perfect if only a sample of devices are metered.

Figure 6 shows the electricity use breakdown for the buildings in this study where data was available. We note that preliminary data show buildings use 20% to 30% of their electricity to power MELs, and this is consistent with other estimates. This estimate will be updated in the final report with more complete data across building types as available. As noted in chapter 1, we expect this percentage to grow as a relative fraction of electricity use not only as other end-uses become more efficient but as the energy intensity and number of CMELs continues to increase.

Figure 6: Combined figure showing each building with some breakdown of energy use.



3.2.2 Variation in CMELs energy use by device category and building type

The CMELs that are the most numerous or the most energy intensive vary from building type to building type. It is critical to understand how building type and space type influence which CMELs are the most important to address. Similarly, comparisons between building types are important because they show which CMEL reduction strategies may apply across building types and which are building type or space type specific.

Figure 7: CMELs Device and Energy Distribution by Building Types and Device Category Uses. Preliminary data is used in this chart; data and missing buildings will be updated for final report.

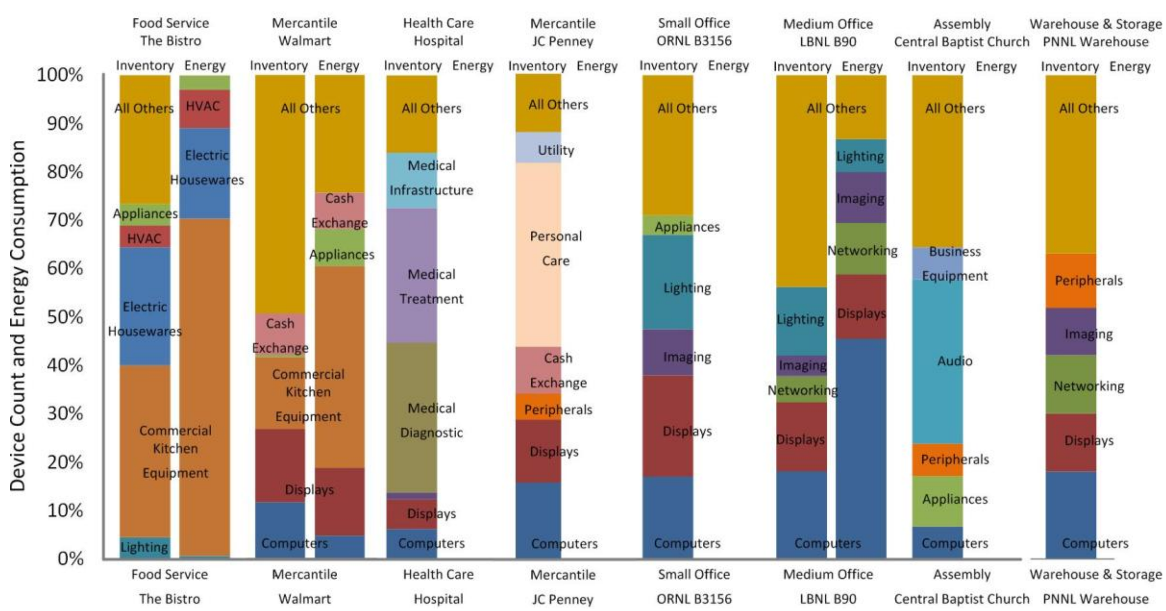


Figure 7 presents the distribution of CMELs by device category and building type to provide comparisons between CMELs distribution for buildings inventoried in this study. Each building for which data were available is shown with the top five energy consuming CMELs categories. Both the faction of CMELs energy use and the fraction of CMELs devices are shown to illustrate that the CMELs that consume the most energy depend on the building type. In offices, computers consume the most. In other buildings, this is not the case, however. Commercial kitchen equipment is the largest consumer on both the retail and food services buildings. There are 16 categories of devices shown in the figure, and eight of these categories are only a top five energy user in one building. This illustrates how different the CMELs are from building to building and shows the long tail of the distribution of CMELs. In a given building type, there are not simply five major players with everything else having a minimal contribution. There are several dozen device types found in each building, and many of these devices are captured in the "All Others" category. There are too few of that particular device type to consume much, but many such situations exist making this category larger than some of the top five categories.

The density of CMELs devices and their corresponding energy density is highly variable from building type to building type. When modeling a building for renovation or new construction, CMELs energy densities are important to improve modeling. When building an energy estimate based on best in class technology, the device density is critical because it can be scaled with updated energy estimates to predict the reduction in energy use. Figure8 shows the density of MELs by end use per 1000 s.f. of floor area, and Figure 9 shows the corresponding energy density for these devices. These charts divide the MELs by enduse, the highest level in the taxonomy. From these charts we see that not only do the number of devices vary significantly by building type, the density is also highly variable. Low device density (the commercial kitchen or retail store) does not correspond with low energy density. These charts are preliminary and new data and analysis will be included in the final report to revise existing and add incomplete data.

Figure 8: CMELs Device Density (Devices per 1000 sf) by Building Type and End Use

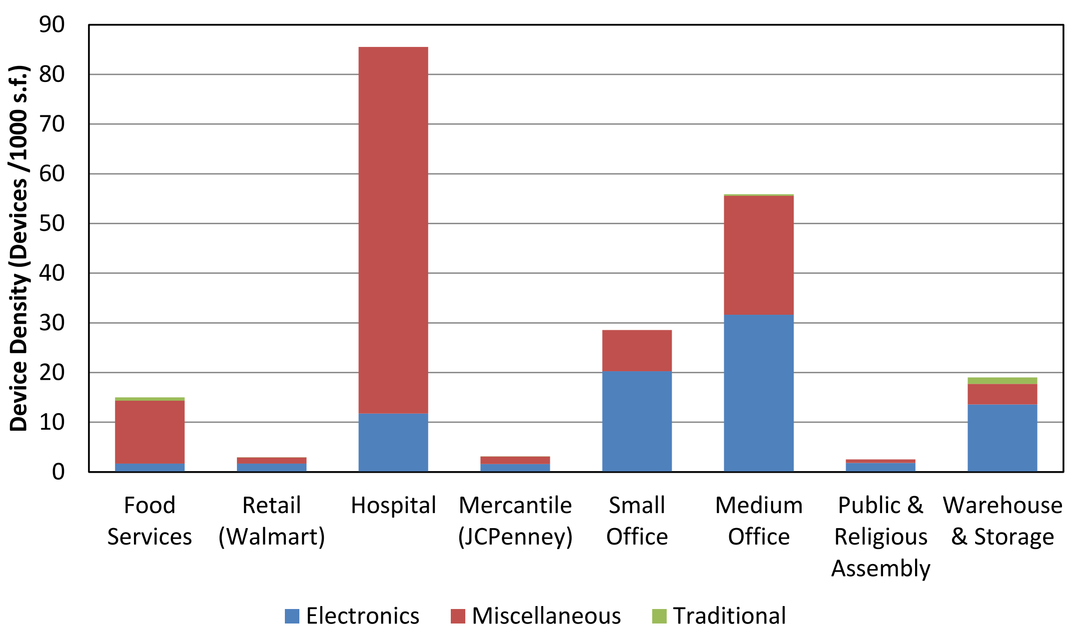
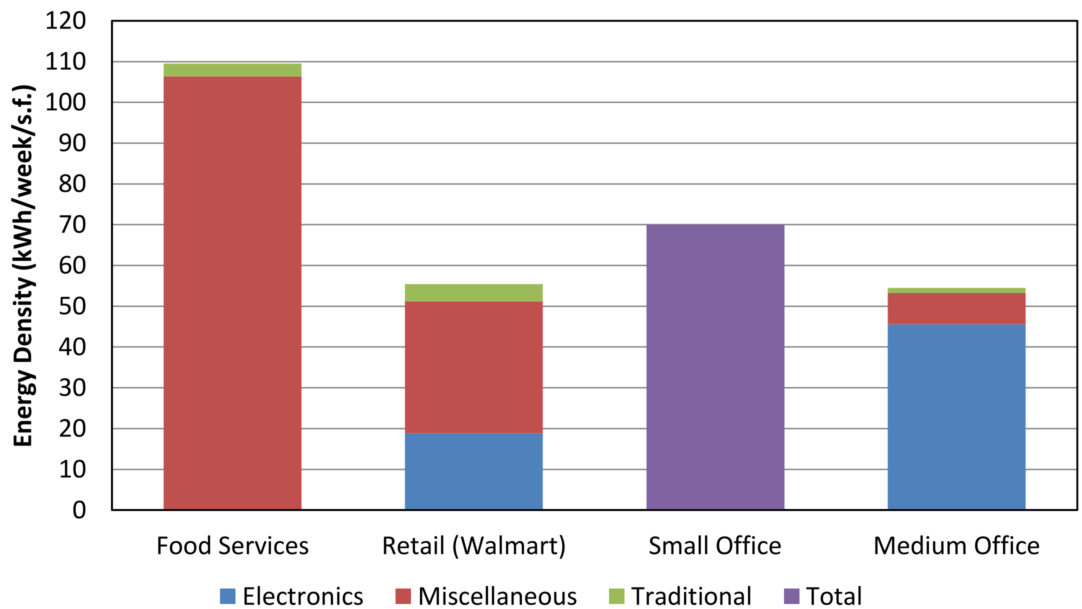
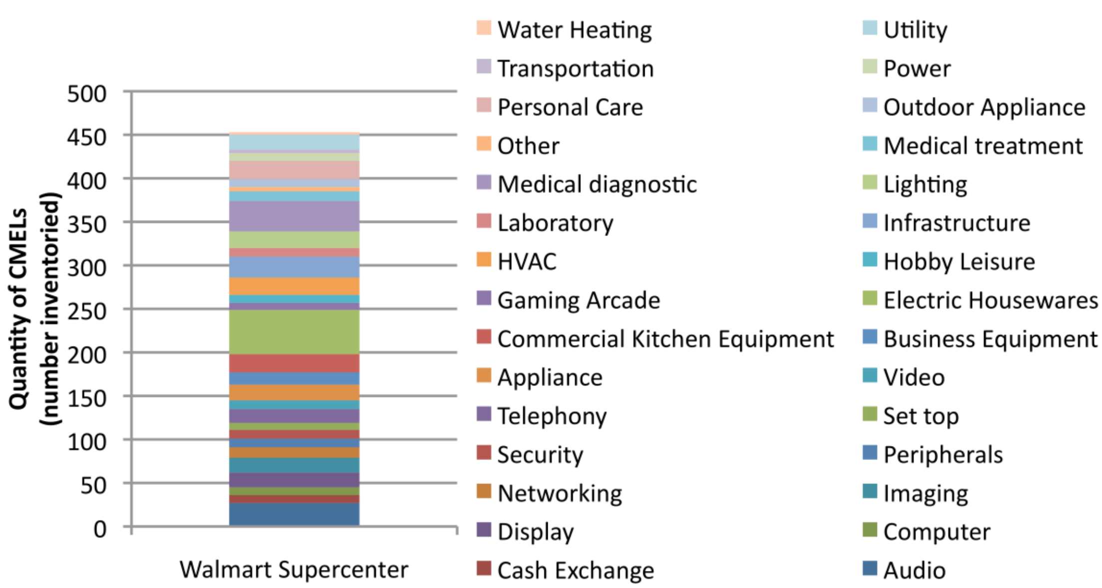


Figure 9: CMELs Energy Density (Energy per 1000 sf) by Building Type and End Use



Hospital MELs are very different from the MELs found in other buildings, and the study of them is particularly challenging for several reasons. Because we do not work in the medical field, we are unfamiliar with medical equipment in a way that is unique to the building type. Less information is available, and the names of devices do not intuitively inform us of device function. The medical inventory is built from several hospital managed databases that store inventory data. A total of almost 36,000 MELs are included in our hospital inventory analysis,

Figure 10 : CMELs Distribution by Device Type in Walmart (Mercantile)

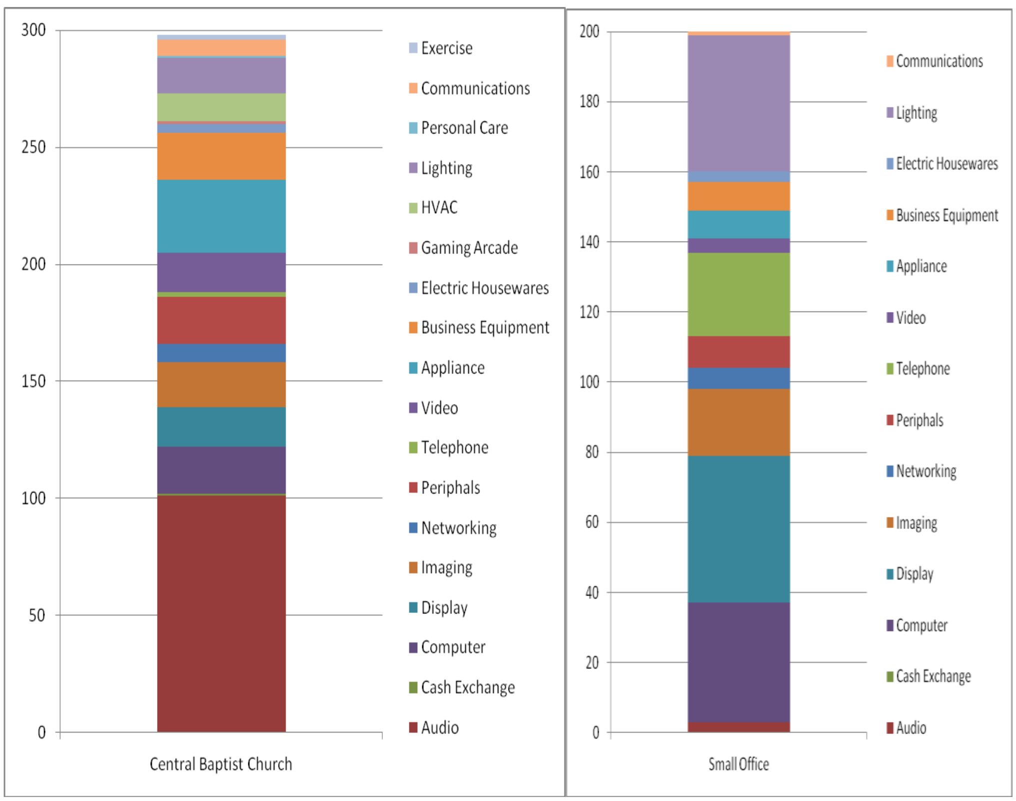


and this includes devices in storage or maintenance. More analysis and research is required to gather information equivalent to that available in the other buildings.

Figure 10 shows the breakdown of the CMELs inventory by device type in the retail store. Of the 453 CMELs inventoried in the Walmart, we see that no two or three categories make up more than 20% of the total devices found. This figure highlights the diversity and quantity of CMELs in a large retail outlet environment, and a similar situation is found in other building types. Such a diverse set of CMELs makes addressing CMELs energy use challenging.

Figure 11 shows the breakdown of the CMELs inventory by device type in the church and the small office building. Most notable is the high proportion of audio devices in the church. Almost a third of the CMELs are in audio devices, most of them being in three separate systems consisting of mixer boards and component racks. As would be expected, the largest segment of CMELs in the small office consists of computers and related equipment.

Figure 11 CMELs Distribution by Device Type in the church (Public & Religious Assembly) and the small office building.



3.2.3 Breakdown of energy use by power mode

In order to improve CMELs device energy use and evaluate the potential efficacy of controls for CMELs, it is important to understand how devices are used. A key component of use is the time that devices spend in various power modes. If devices are left on all of the time even when it is unlikely they are used, improving behavior or adding automatic power down capabilities can save significant energy. If devices already sleep at low power levels much of the time, we must focus on improving the on-state efficiency of the device or reducing the number of devices in use. Without detailed information on the breakdown of energy use by power mode, these sorts of decisions cannot be made to maximize function while minimizing energy.

Figure 12: Percent time and energy in power modes for 19 computers metered over a work week in the medium office building. Each column represents an individual computer sorted from left to right by increasing energy use. Energy use is dominated by time in the "on" (active) mode, even when time in that mode is small.

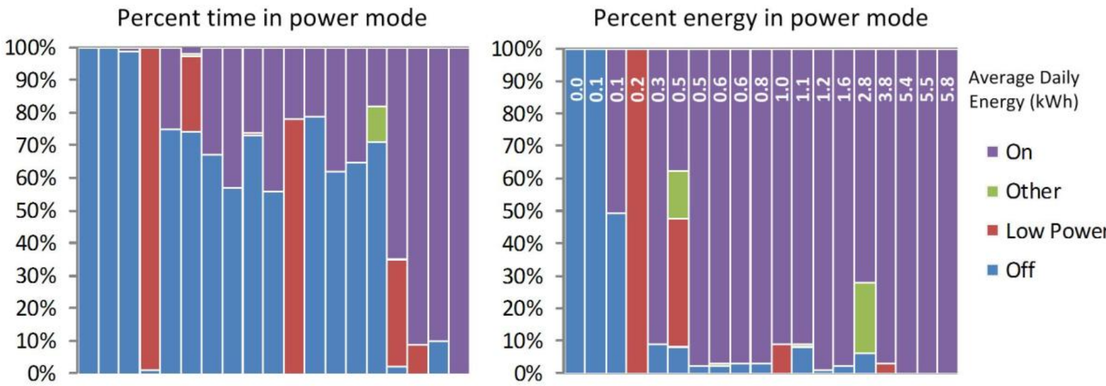
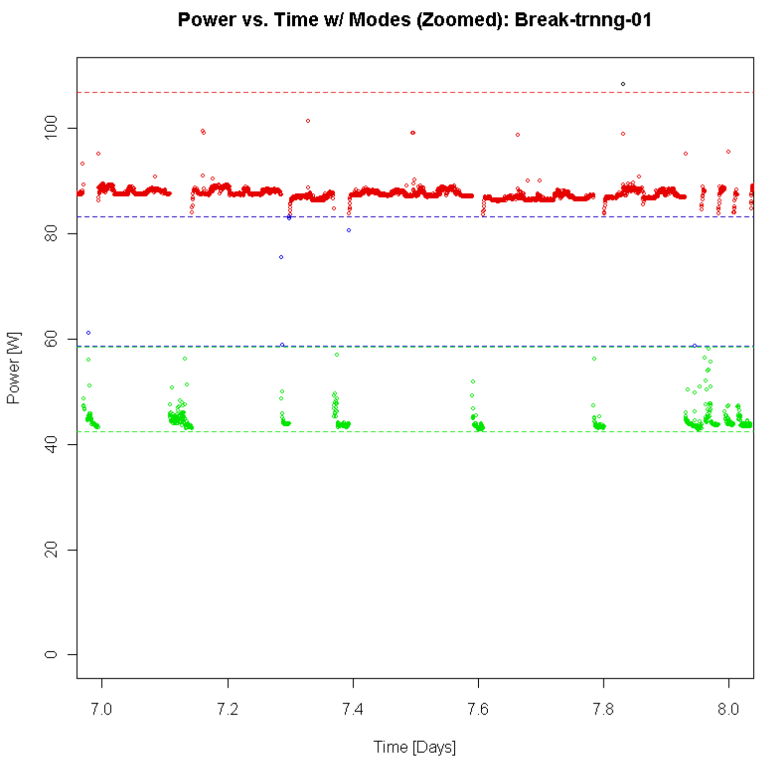


Figure 13: Time series plot showing the power of a desktop computer used for training in the Walmart. Two different power modes were identified and are highlighted on the chart.



The usage patterns of CMELs vary not only device type to device type and building type to building type but also significant variability occurs within particular device types in the same building. CMELs have a distributed nature and close ties to users that cause this high degree of variability. Increasing the time devices spend sleeping or off is a primary opportunity for saving CMELs energy, and we found that devices often spend far more time in high-power states than is required. Further, we identified some low-power modes that may be higher than necessary.

Figure 12: shows the high degree of power mode variation between typical office computers in the medium office 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 those 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 reducing energy use for devices that are left on. 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 carry over to other devices in other buildings as well.

Figure 13 shows 24 hours of power data from a desktop computer tower used for training employees in a retail environment. Automated mode identification identified two modes: a low power mode averaging 44 W, and a high power mode averaging 87 W. This computer spends 15% of the time in its low power mode, and, in the four weeks that this computer was metered, it was never turned off. This computer is only used 16 hours per day, on average, typically resulting in significant wasted energy. The low power mode of 44 W is ten times higher than required for an unused computer.

3.2.4 Correlations between CMELs energy use in a space

CMELs are often used together to assist users in performing a task, and we expect to see energy use of devices in the same space correlated in time as a result. Figure 14 shows the aggregate power load over one week (Saturday to Saturday) for one office at the church. The individual loads vary from very low levels such as for the power supply for a PC speaker to large loads such as for a space heater or PC. The individual using this office normally works full time and has an office intense work assignment (accounting).

This particular office has nine CMEL loads that are metered. Determining correlation could reduce the number of meters that need to be deployed in some cases where the correlation is known to be very strong. In other cases the correlations are not very strong, but we can learn more about how devices are used together informing technology improvement strategies. Figure 15 shows the power load divided by device type over the same week for one office at the church. This office is used full time and contains nine metered CMELS. Some of the loads did not use significant energy over this period (adding machine, speakers, heater, and electric pencil sharpener). One thing that is quickly obvious is the periodic load that occurs around 10pm each evening. This is a backup job that runs each night to copy files from this computer to a server. This type of office usage pattern may prevent some types of energy minimization schemes from being implemented since the device must remain energized for the off-normal event to function properly. The space heater was not used during the metering to date, but is expected to become a major portion of the load during winter months. The PC, monitor and printer have highly correlated power consumption, and the statistical evaluation of this correlation (and for other similar situations in buildings) will be included in the final report.

Figure 14: Aggregate load in accountant's office

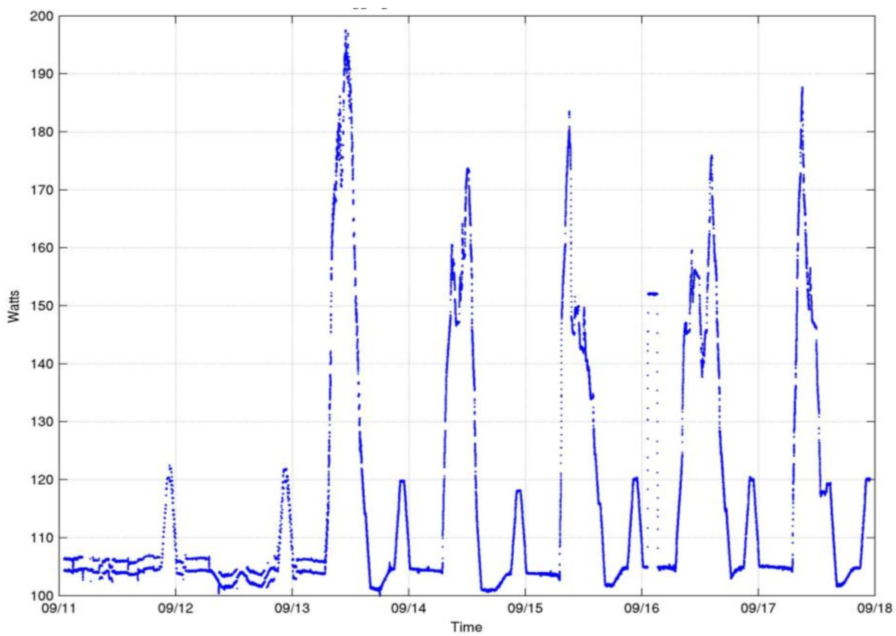


Figure 15 CMEL device level power consumption for an office in the church

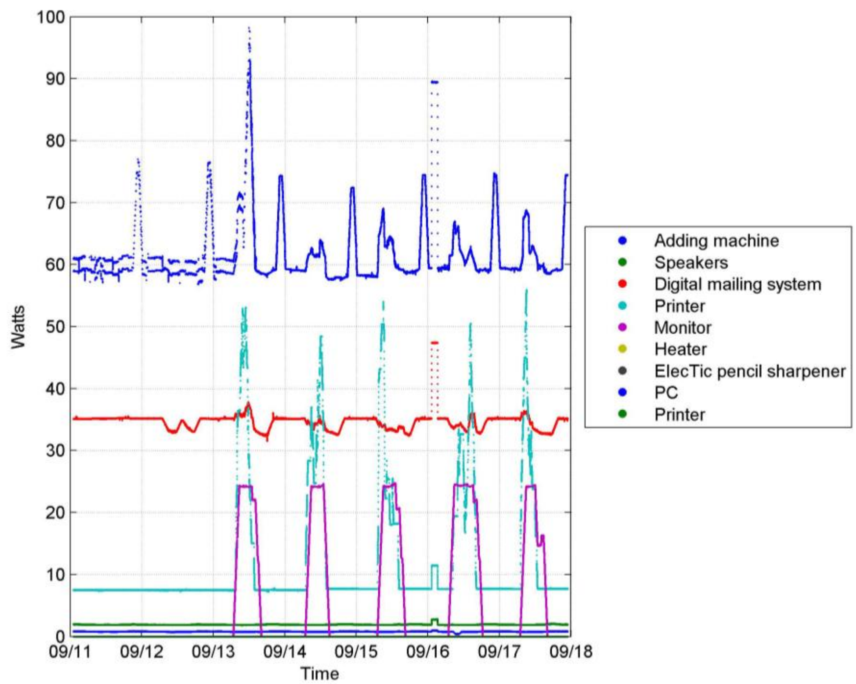
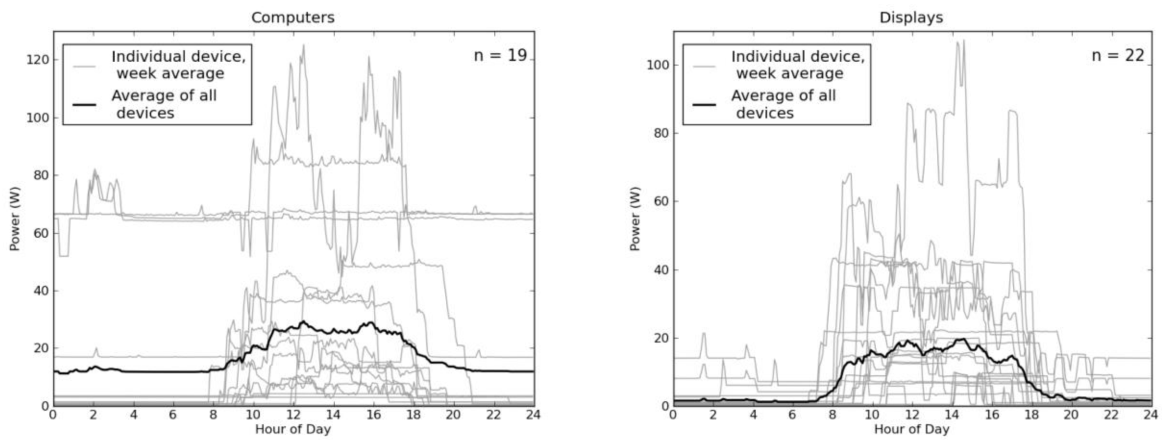


Figure 16: Weekday average power consumption for computers (left) and computer displays (right) taken from the medium office building. Power management is used more effectively on displays than on computers.

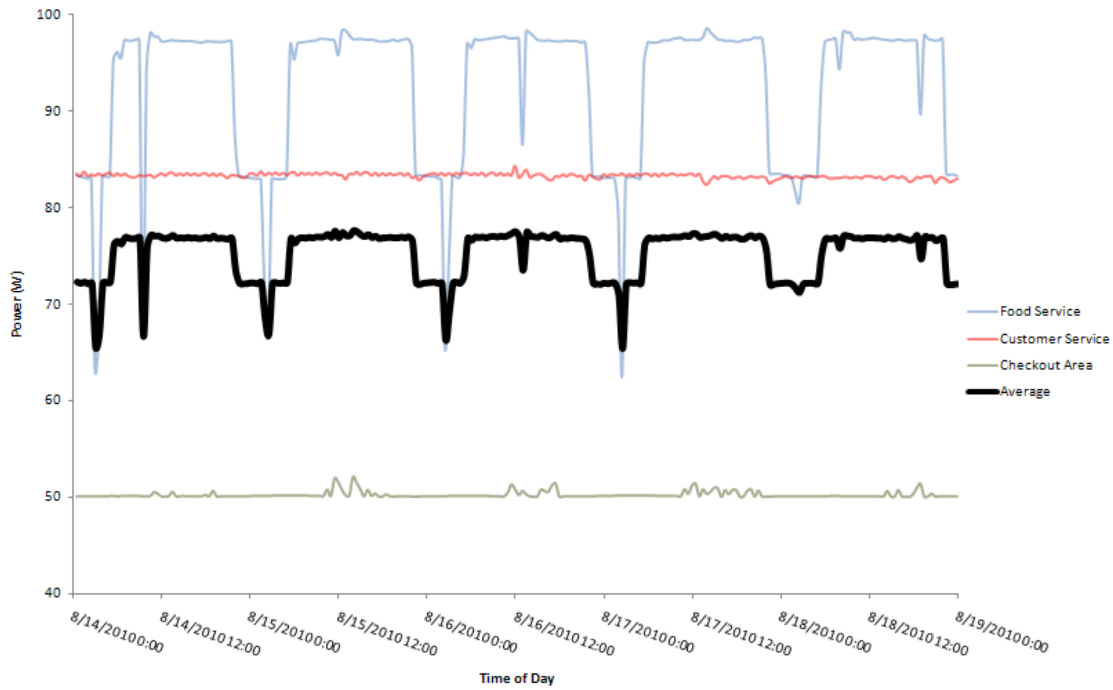


3.2.5 Weekday average profile for a given device

CMELs loadshapes 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 loadshapes for some devices will have seasonal dependencies. For example, space heaters may be used more during the winter in some buildings but the summer (to combat over cooling) in others Figure 16 shows the average weekday power consumption for computers (left) in the medium sized office building, and the light traces represent the average consumption of the individual computers Figure 16 (right) is a similar figure for computer displays. The individual device traces have significant roughness primarily because of the short period over which these data were collected (5 days), and longer metering periods will result in more accurate results. From these figures we see that power management is not used as effectively on computers as on displays. There is a great deal of variation from device to device and significant usage during off-hours, but there is a clear shape showing the most common building occupancy trends.

Loadshapes also show the on-mode efficiency and the effectiveness of low-power mode use in devices. Figure 17 shows load profiles for three cash registers in three different locations in the Walmart store. The cash registers in the checkout and customer service areas were in operation 24 hours a day and were never powered off. On the other hand, the food service area operates from 6 AM to 9 PM daily. The cash register in this area is switched into a low power mode during unused hours. From these plots, we observed that even unused devices remain in relatively high power mode. Cash register low power modes are much higher than those for comparable computers showing that improved low-power mode design and utilization of cash registers is a significant opportunity for savings in retail environments. The distribution of power consumption when active for these three devices varies by almost a factor of two, but the devices nominally perform similar functions. It is likely that purchasing guidelines for equipment could result in the purchase of more efficient equipment both in terms of on-mode

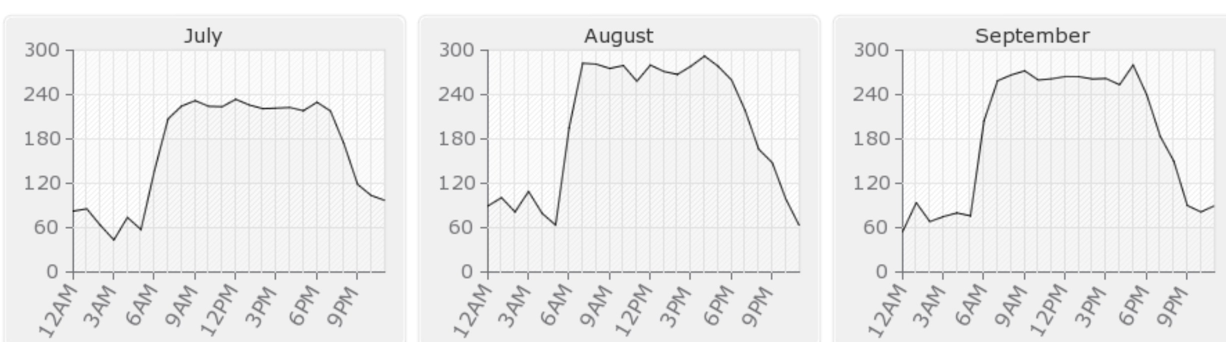
Figure 17: Power draw of three different cash registers in three different space areas. Five days of data is shown with 30 minute averaged data.



and low-power mode consumption.

Although we have not collected enough data to show seasonal changes in energy use to our satisfaction, Figure 18 shows ice maker energy use traces over a three month period. In these plots we see that energy use was higher in August than neighboring months. This small change noted here is expected to be more pronounced in other circumstances, and we expect to have more results showing this effect moving forward.

Figure 18: Ice maker energy use over a three month period (average hourly load)



3.2.6 Evaluation of meter accuracy

Meter accuracy can be an important issue to consider when performing a distributed metering study such as this one, but the accuracy of the meter is just one of the many factors that influence the accuracy of the energy evaluation of CMELs. Because it is often not practical to meter every device, variation in device types and usage patterns will contribute errors that are likely greater than those contributed by meters that are a few percent from accurate. At the same time, data collected in a study like this one can be useful outside this immediate context. Low power mode studies require high accuracy at the low end, and we have found that inexpensive meters perform most poorly below 5W.

For aggregation studies and for comparing usage patterns across devices, relatively coarse accuracy is all that is required. If, on average, the meters are close to correct, then the aggregated values (e.g. all computers in a building) will be close to correct as well even if individual meters produce results that are less than ideal. Determining usage patterns and variations in usage also only require meters with coarse accuracy. Detection of power mode changes requires repeatability rather than high accuracy. Analyzing individual traces for power levels in depth, however, requires meters with higher accuracy to ensure the validity of the conclusions. It is likely that a balance between meter accuracy, expense, and sample rate that is particular to the study objectives is the best choice.

The labs evaluated the accuracy of a wide set of meters for this study including several commercially available meters and the custom meters used by LBNL. Each lab conducted a series of meter studies to ensure that the team had broad knowledge and understanding of these issues.

Table 4 shows a comparison of five commercially available power meters to provide an example of the types of evaluations done. These meters were compared to a Fluke power meter which is a higher-end power meter considered to be well calibrated with high accuracy. Voltage, current, power, and power factor were measured in the power range from 0 to 500W in order to test the common power ranges of CMELs. Based on bench testing, the meters had an overall error in current readings of 5% over the entire meter range. The largest current error, 19%, was found in the 5 to 25 W range. Power factor error was found to be 3% accurate over the entire meter range.

Table 4 Accuracy of five different power meters, from 0 to 500W

Meter Type		**Watts Up? Pro ES and .Net**	**Teridian OMU1-S-RF**	**Kill-A-Watt P4400**	**Wattstopper PL-100**
# of Meters Tested		38	1	1	3
<5W Range Avg % Errors (Compared to Fluke)	**Voltage**	0.03%	0.00%	-0.08%	-0.79%
	Current	-12.03%	-47.58%	-20.42%	34.58%
	Power	2.46%	-2.17%	-11.11%	-3.13%
	P.F.	20.14%	94.12%	3.92%	-2.59%
5-25W Range Avg % Errors (Compared to Fluke)	**Voltage**	0.03%	-0.08%	0.08%	-0.85%
	Current	-18.83%	-1.73%	-18.55%	-9.53%
	Power	0.47%	-0.81%	-19.35%	-3.48%
	P.F.	3.91%	1.04%	-7.29%	1.04%

25-100W Range Avg % Errors (Compared to Fluke)	**Voltage**	0.02%	0.08%	0.17%	-0.48%
	Current	5.48%	-0.57%	-2.99%	-0.92%
	Power	-0.51%	0.88%	-2.94%	-1.90%
	P.F.	-6.73%	1.82%	-5.56%	-2.45%
100-500W Range Avg % Errors (Compared to Fluke)	**Voltage**	0.04%	0.09%	0.34%	-0.68%
	Current	0.40%	-0.05%	0.22%	1.50%
	Power	-0.46%	1.72%	1.56%	0.00%
	P.F.	-2.04%	0.40%	-2.04%	0.00%
100-500W Range Avg % Errors (Compared to Fluke)	**Voltage**	0.38%	0.53%	2.76%	-0.30%
	Current	-1.81%	-0.39%	3.48%	-33.86%
	Power	-1.59%	0.34%	7.13%	-0.08%
	P.F.	-0.61%	0.00%	0.00%	0.00%
Overall Avg % Errors (Compared to Fluke)	**Voltage**	0.10%	0.12%	0.65%	-0.62%
	Current	-5.36%	-10.06%	-7.65%	-1.64%
	Power	0.07%	-0.01%	-4.94%	-1.72%
	P.F.	2.94%	19.48%	-2.19%	-0.80%

Figure 19: Power measurement accuracy of 50 WattsUp? Pro ES Meters

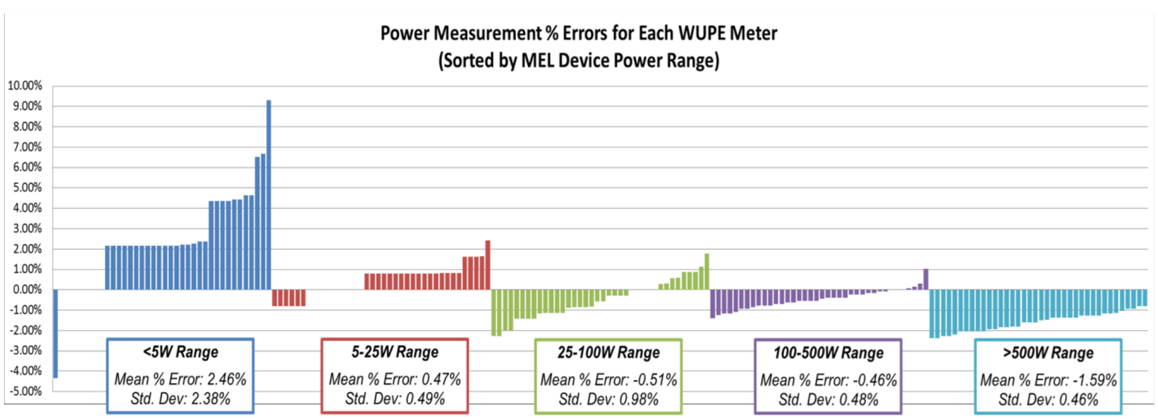
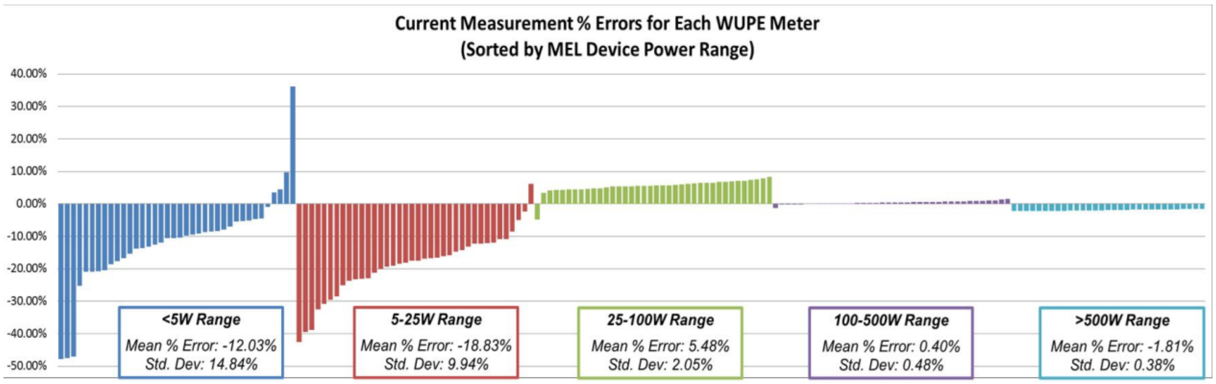


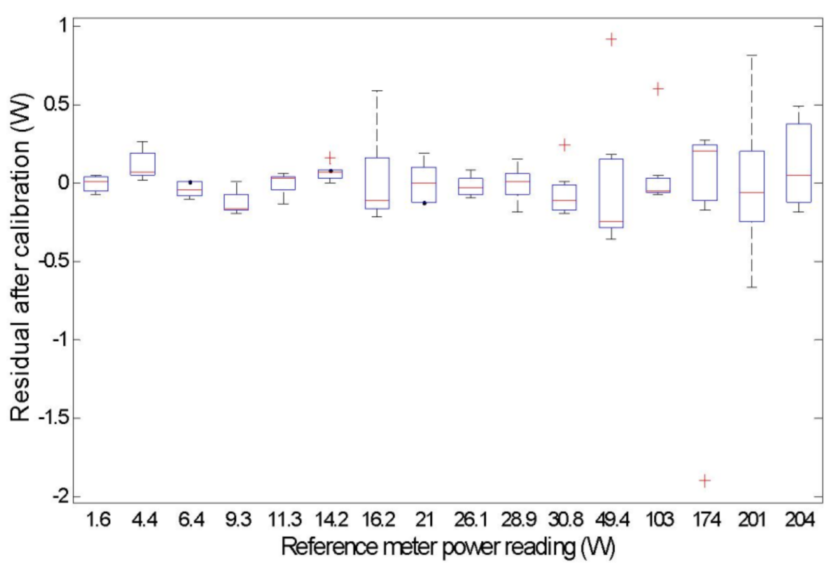
Figure 20: Current measurement accuracy of 50 WattsUp? Pro Es Meters



The primary meter used in this study was the Watts Up? Pro ES or .Net meters. These meters have very similar performance because the designs are highly similar, and the metering results for a set of these meters in shown in Figure 19. These meters were found to be the most accurate of the tested meters, an unexpected result because the Watts Up? meters were selected based on considerations other than accuracy. Figure 20 shows the accuracy of the same meters for measuring current. Note that the worst case accuracy for power was less than 10%, but current measurement errors up to almost 50% exist, showing a limitation of current, low-cost metering technologies.

The ACme wireless meters are custom devices, and the accuracy of the meters was determined at the time of calibration. Typical accuracy of better than 0.5 W or 1% of reading was observed as shown in Figure 21. This chart plots the residuals after calibration for seven meters at the

Figure 21: Box plot showing the residuals after calibration for seven ACme meters. Typical accuracy is better than 0.5 W or 1% of the reading, which is similar to the WUPE meters commonly used in this study.



calibration points used. Similar to the WattsUp? meters, fraction accuracy suffers at the low end, but overall accuracy is acceptable for most purposes. The ACme devices are comparable to the WattsUp? meters in terms of accuracy.

4.0 Research Plan

This is an interim report presenting initial findings for this study. In order to implement the original action plan and fully address the research questions for this study, the lab teams plan to continue metering through January, 2011, and deliver the Final Project Report to DOE at the end of February, 2011. This remaining research will be continued under current DOE funding in the areas described below.

- Continue to collect data from the installed meters in order to capture the seasonality of MELs use (particularly for devices with large seasonal variations such as space heaters, dehumidifiers, and task lights) and to better capture usage of devices that may be episodic in nature (e.g., some types of food service equipment or holiday usage of devices in the church). The study team plans to continue collecting meter data for the time periods shown previously in Table 3. There will be very little incremental cost to leaving the meters in the field collecting data in several of the sites because the meters have automated data collection. In some sites, manual download is required and data collection is ending shortly.
- Install additional meters in certain building types to achieve the broad cross-section of metering situations originally envisioned in the study plan. Buildings requiring meter installation include the church, lodging, hospital, and the medium office.
- Expand the analysis of the monitoring data to provide a more comprehensive statistical summary across building and device types, using data from the full monitoring period. Also analyze data sets to try to answer methodological questions, such as: what fraction of a building's MELs must be sampled to produce an accurate analysis of MELs energy use?; what meter sampling rates are needed to accurately determine device power modes?; what length of metering period is needed to accurately describe annual device energy consumption? Analysis tools and results planned for inclusion in the final report are mode identification, mode transition identification, correlation of CMEL loads to temperature, and seasonal load variation analysis.

Research plans for each building are described below.

Public Assembly and Religious Worship

ORNL plans to deploy additional meters at the CBC in the immediate future to cover all CMELs at the facility, with the exceptions mentioned previously. This will include over 200 individual CMELs. It is recommended that the CMELs program support continue until at least one year of data is obtained to quantify usage through the various seasons, including the holiday season.

Small Office

ORNL will continue to monitor CMELs on a small scale at Building 3156 on the ORNL campus. Data will continue to be manually downloaded, and enhancements to that process will be sought. Energy savings strategies will be tested in the building using the current metering protocol.

Medium Office

LBNL will deploy 200 to 400 additional meters leading to a building total of 300 to 500 meters installed. The larger number will depend on ACme meter production schedules. This device sample size will provide the most comprehensive, long term metering study of CMELs in a commercial office building. LBNL plans to leave the meters installed and collecting data after the project's conclusion because the cost for leaving the meters installed is minimal due to automated data collection. When funding is available, we will analyze the resulting data to provide the recommended longer term view of the data.

Mercantile, Food Sales, and Food Service -- Walmart

NREL has nearly completed the metering effort in Walmart, and continued metering would be at significant cost because of the required manual data downloading. A significant effort has already occurred on the data analysis front. We plan to wrap up this effort and provide more detailed analysis of the collected data.

Food Service -- EMSL Bistro

PNNL plans to continue metering in the Bistro at the circuit level and the plug level and provide more detailed data analysis for the final report on the usage patterns and CMELs consumption as a function of the service provided in the space.

Warehouse and Storage

PNNL plans to continue metering in the warehouse at the circuit level to inform the selection of the sample of plug level meters to be installed. A more detailed inventory of equipment will occur when the plug level meters are installed. Techniques for installing a large number of plug meters in tight spaces will be explored and deployed. PNNL will provide more detailed data analysis for the final report.

Lodging

PNNL plans to install circuit level and plug level meters in the guest house and test out various methods for collecting information on transient loads. All data will be collected wirelessly. PNNL will provide detailed data analysis of the inventory and energy consumption for the final report.

Mercantile -- JCPenney

PNNL plans to meter this as part of the CBP Technical Assistance project. An agreement is in place for the scope of the metering and a cost share for meter installation at the panel level. Circuit level metering will be installed to inform the selection of the plug level metering. PNNL will provide more detailed data analysis for the final report.

Health Care, Inpatient -- Hospital

LBNL will expand the monitoring effort in the hospital to include power metering of equipment in use for training purposes. These data, combined with the spot metered data and interviews with equipment users, will be used to generate an estimate of the CMELs energy for this facility. Part of this effort requires an improved mapping of the available equipment inventories to the device taxonomy and the spot metered data. The other key component is gathering usage information from equipment users in the hospital.

5.0 Recommendations

Based on the field research to date and the research purpose (as described in Section 1.2) there are a number of areas where inferences can be drawn and recommendations made. In order to meet DOE's long term goals for low-energy commercial buildings, it is imperative that the growth in CMELs energy use be better understood and strategies developed and tested to reduce this energy use. The recommendations that follow are categorized into a number of different thrusts.

5.1 Further Methodology Development and Data Collection

This CMELs study focused on a proof-of-concept demonstration of methodology and technology for the selection, metering, monitoring, collection, and analysis of MELs usage in commercial buildings. Based on the knowledge acquired during the first phase of our work we would recommend methodology development and data collection efforts in the following areas.

Further refinement of study methods and protocols

- Combine CMELs metering with occupancy monitoring to assess opportunities for energy savings.
- Determine how closely current usage profiles reflect occupancy schedules in practice and the potential for better matching device consumption with occupancy.

Continued data collection—Current buildings

- The upfront cost for installation and equipment has been incurred and the cost of data collection is low compared to the value.
- Buildings with existing CMELs metering are already configured for testing of energy reduction methods, because good baseline data already exist and the installed meters provide a means to monitor changes in consumption.

Expanded data collection—Additional building types, sizes, and vintages

- In order to inform policy and technology development, a reasonable sample of buildings representative of the population is needed. One sample is not enough.
- CMELs metering needs to include the whole building and all other end uses in order to determine what fraction contribute to the total building load.
- Metering of CMELs should be expanded into buildings where submetering of the other building systems is on-going.
- As recommended in the TIAX study, future CMELs field studies should also expand to cover loads that are external to the building structures but integral to operations, such transformers, data center servers, etc.

Need for improved metering technology

- Commercially available metering equipment needs to be improved to address research and industrial applications for large-scale, device-level energy monitoring. In particular, the size of the meters needs to be reduced and the data transmission methods made easier and more reliable.

- A product with the functionality of the ACme meters, but from a reliable commercial vendor, would be very appropriate for future studies (see Appendix B.1 Ideal Meter Specifications).
- Develop a power strip-like device that could monitor multiple loads individually, as well as methods to meter multiple hard-wired CMELs on a single circuit.

Utilize Collected Data

- Improve the methods for estimating CMELs consumption over their lifetime.
- Develop a repository of MELs consumption profiles and device densities that can be shared across laboratories and used to inform other areas of study, such as building modeling.
- Data mining techniques should be developed to identify consistent patterns, including algorithms for: identification of power modes and transitions between modes; correlation of CMEL loads to temperature; identification of functional groupings of CMELs; correlation between building occupancy and user-directed CMELs; and identification of seasonal CMELs load variations.

5.2 Research Strategies to Reduce CMELS Energy Consumption

Understand the magnitude of the load that MELs represent is the first step in the effort to reduce these loads, next is developing informed recommendations on how to reduce CMELs consumption through control, efficiency improvements, or design changes.

Control

- Categorize and look at CMELs in terms of what can and should be controlled and determine what types of controls make sense. Determine how to control the device so that the operating mode is at the lowest energy consumption state appropriate for the service demanded.
- Additional control to eliminate parasitic loads while equipment is in low power modes would further reduce energy consumption.
- Evaluate the methods, effectiveness, and savings of control strategies (for both energy savings and peak demand reduction).
- Determine how these controls should be implemented for each category of CMELs (Standards, Energy Star, etc.).
- Device specific CMELs research, such as device control and inter-device communication to reduce energy use.

Efficiency

- Develop technologies to improve the efficiency of targeted categories of CMELs equipment, such as the commercial cooking and laundry technologies identified by Navigant (Zogg et al. 2009).
- Improve designs of plug-in devices so that they interface more efficiently and seamlessly with other devices, and manage their power state to minimize energy use.
- Stimulate demand for more efficient CMELs devices by making CMELs energy use reduction an integral part of future development of highly efficient commercial buildings..

Education

- Survey building occupants about their usage of CMELs to gauge feasibility of energy savings implementation strategies.
- Providing input to consumer information and education to reduce plug-in device(s) energy consumption and save money.
- Test out information strategies that address 24-hour retailers specifically. The CMELs in these spaces are on whether or not customers are usually purchasing items in these areas (e.g. electronics displays).
- Single out device types with high standby loads and infrequent usage and develop campaigns for the commercial building owners to purchase lower power consuming models (e.g. ATMs, photo kiosks).

Feedback

- Develop and test a variety of techniques for real-time energy-use feedback to individual building occupants, groups of occupants, and building managers.
- Test the effectiveness of different types of product information for devices—including typical energy use and load profiles, or the existence of device features that allow better energy control—so that purchasers can make informed purchasing decisions.
- Improve and test the design of buildings (such as Commercial Building Partnership buildings) with a specific focus on reducing CMELs through control and behavior modification.

Testing

- Need more developed methods for measurement and verification of CMELs reduction strategies.
- Improve the design of buildings (such as Commercial Building Partnership buildings) with a specific focus on reducing CMELs through control and behavior modification and verify with testing.

5.3 Program and Policy Recommendations

Changes to building codes, equipment standards, and public policies have the potential to reduce CMELs energy consumption.

- Require CMELs manufacturers to submit typical load profiles with the manufacturing specifications for their devices so that consumers can make informed decisions about their products.
- Revise building codes for the deployment of control systems, i.e. existing occupancy sensors for lighting that are also used for occupant dependent HVAC control could be integrated with plug load control.
- Provide data to aid the development of effective public policies to reduce energy usage by plug-in devices.
- Make CMELs energy use reduction central to the development of highly efficient commercial buildings.

6.0 Summary

This multi-lab research project advanced the understanding of how to best measure CMELs energy consumption in a number of different commercial building types using a variety of metering equipment and data collection protocols. The key tasks accomplished in FY2010 on this research project were:

1. Select buildings representative of the range of building types existing in the U.S.;
2. Develop and implement a means of inventorying CMELs in the selected buildings;
3. Determine what CMELs to meter, whether it be near 100% or some representative sample;
4. Select or develop suitable metering equipment;
5. Design data collection schemes (manual downloads or automated);
6. Perform preliminary analysis of data collected.

A diverse array of building types were selected and divided up between the four labs. Several methods of inventorying CMELs were tried, along with technical enhancements to increase productivity and minimize errors, e.g. audio recording with voice recognition. It was concluded that teams of two researchers entering data either directly into a laptop, or manually recording data on forms for subsequent entry were most productive. One lab found that photographing each CMEL device provided a useful record and helped to avoid duplication.

While essentially all CMELs could be metered in some facilities, 100% metering is not practical in others. For example, the medium office building contains approximately 5,000 individual CMEL devices. In such cases, a stratified random sampling protocol was used to select CMELs to monitor. There are a number of reasons why certain CMELs cannot be metered in certain facilities; most notably, the hospital cannot have meters in series with life-saving equipment.

All of the labs concluded that of the commercially available plug-level metering products, the WattsUp? meters manufactured by EED were the clear choice. Although these meters do not have all of the attributes desired, they provided the most functionality and accuracy of currently available products. LBNL developed the ACme metering system in-house which uses wireless data transmission and has proven very successful. In addition to individual device metering, several of the buildings were outfitted with circuit-level metering. This gives an indication of composite CMELs consumption or large CMELs on dedicated circuits, but generally does not break consumption down to the device level.

Two general means of data collection were used on the various projects. The most basic method was to use onboard memory in the metering devices and manually download the data periodically. This method works reasonably well for small samples over short metering periods, but falls short for wider deployments. It is very labor intensive, limited by internal memory, and automated time stamping is not available.

Larger deployments of meters used wireless data transmission and internet connectivity. This provided for automated data collection, automated time stamping of each data record, and the ability to record data records at intervals as short as 1 second. The frequent reporting capability is particularly useful in characterizing loads that fluctuate widely in short periods of time, e.g., laser printers, or devices that run intermittently. This automation provides for collecting large volumes of data; on one building over 50-million records were collected during the first 3 months.

For all of the means of data collection, the data ultimately resides on MySQL databases; although the routes to MySQL vary. The data analysis tools used include R, Python, MATLAB, and of course Excel. Most of the year was spent developing the means to collect CMELs data. Analysis activities so far have focused on system “shakedown” and data quality verification. Some preliminary analysis results for CMELs consumption are presented in preceding sections.

As a result of the FY2010 efforts, several of the buildings are equipped with infrastructure for continued automated data collection with minimal onsite intervention. It is anticipated that data collection will continue through at least the 2010-2011 winter to develop a characterization of seasonal variations in CMELs consumption. These infrastructures may prove valuable in service as test beds for ongoing research into CMELs energy efficiency concepts.

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Appendix A: Taxonomy

The taxonomy used in the study is divided into three end use types – Electronics, Miscellaneous, and Traditional. Each end use subsequently contains different device categories, and finally each device category contains various product types that improve product categorization. The taxonomy's end use and category types are listed in the following table, with examples product types from each category provided to show the diversity of devices covered.

Since this study was only concerned with the interior of the store, the taxonomy excludes exterior spaces and CMELs, such as: parking lot, parking lights, exterior lights, and signage. Additional changes to the taxonomy are anticipated in the continual study of CMELs, in order to further improve device categorization and subsequently energy data collection and analysis.

Category	Product Type (not an exhaustive list)
End Use - Electronics	
Audio	Audio minisystem, CD player, Radio, Powered/wireless speakers, Receiver, Other audio
Cash Exchange	Automated teller machine, Bar code scanner, Cash register, Credit card reader, Other cash exchange
Computer	Desktop, Integrated-CRT/LCD, Notebook, Server, Dock, Pen tablet, Other computer
Display	CRT/LCD/plasma screen computer display, LED display, portable game console, Slide/screen/video projector, television/VCR, Other display
Imaging	Copier, inkjet/laser/thermal fax, inkjet/laser multi-function device, printer (various), flatbed/multi-sheet/slide scanner, Other imaging
Networking	Ethernet/USB hub, DSL/POTS modem, Ethernet router, Switch, Wireless access point, Other networking
Peripherals	CD recorder, Disk storage, External drive, KVM switch, Computer speakers, Other peripherals
Security	Card reader, Intercom, Security system, Surveillance system, Video surveillance console, Other security
Set-top	Set-top box (various, i.e. analog/digital cable, satellite, internet, etc.), Other set-top

Category	Product Type (not an exhaustive list)
Telephony	Answering machine, Caller ID unit, Mobile phone charger, Phone (various), Wireless headset, Other telephony
Video	Still camera/video camera charger, DVD player/recorder, Game console, VCR/DVD, Videocassette rewinder, Other video
End Use - Miscellaneous	
Appliance	Fan range hood, Garbage disposal, Wine cooler refrigerator, Trash compactor, Other miscellaneous appliance
Business Equipment	Adding & binding machine, Desk, hole punch, Laminator, projector (various), Pencil sharpener, Shredder, Stapler, Other miscellaneous business equipment
Commercial Kitchen Equipment	Commercial coffee/espresso maker, freezer & refrigerator (various), Ice maker, Commercial oven/range/cooktop, Vending machine (various), Water cooler, Other miscellaneous commercial kitchen equipment
Electric Housewares	Blender, Can opener, Coffee & espresso maker (residential), Corn popper, Grill, Kettle, Microwave oven, Rice maker, Sewing machine, Toaster, Vacuum (various), Bottled water dispenser, Other miscellaneous electric housewares
Gaming/Arcade	Air hockey table, Arcade game, Photo booth, Pinball, Slot machine, Other
Hobby/leisure	Aquarium, Treadmill, Stairmaster, Exercise machine (various), Pool, Electric sauna, Spa/hot tub, Other miscellaneous hobby/leisure
HVAC	Air cleaner, Evaporative cooler - air conditioning, Ceiling fan, Dehumidifier, Fan (various), Fireplace heating, Portable space heater, Other miscellaneous HVAC
Infrastructure	AFI/GFCI Breaker, Smoke/CO detector, Door (various), Elevator (various), Escalator, Garage door opener, GFCI outlet, Other miscellaneous infrastructure
Laboratory	Autoclave, Blood culture instrument, Centrifuge, Incinerator, Incubator, Microscope, X-ray film processor, Other laboratory
Laboratory Integrated	High performance liquid chromatography (HPLC) system, Processor (various)
Lighting	Dimming switch, Emergency light (various), Lamp/Light (various - decorative, fluorescent, halogen, incandescent, LED, etc.), Motion sensor, Night light, Lighted sign, Other miscellaneous lighting

Category	Product Type (not an exhaustive list)
Medical Diagnostic	Analyzer (various), Blood culture instrument, Camera (various), Chart illuminator, Meter (various), Monitor (various), Scanner (various), X-ray system (various)
Medical Infrastructure	Bed, Bed locator/bumper, Call system (patient side/nurse side), Patient Lift, Other
Medical Treatment	Anesthesia delivery machine, Auto transfusion unit, Delivery system (various), Laser (various), Pacemaker, Pump (various), Ventilator, Surgical tool (various)
Medical Integrated Systems	Endoscopy system, Integrated diagnostic system, Mapping system, Other miscellaneous integrated systems
Other	Mobile bookshelves, Indoor fountain, Heat sealer, Self-cleaning litter box, Waterbed, Other miscellaneous
Outdoor Appliances	Charger (hedge/weed trimmer), Snow melting coil, Outdoor grill, Lawn mower, Pond pump, Irrigation timer, Other miscellaneous outdoor appliances
Personal Care	Air freshener, Curling iron, Hair dryer, Hand dryer, Massage chair, Shaver, Toothbrush, Water softener, Other miscellaneous personal care
Power	External power supply, Plug-In transformer, Power line conditioner, Power strip, Surge protector, Uninterruptible power supply, Other miscellaneous power
Transportation	Auto engine heater, Electric bicycle, Car/wheelchair/golf cart, Other miscellaneous transportation
Utility	Bicycle light, Battery charger, Power tool, Pump (industrial, sump, well), Saw, Water purifier/deionization unit, Wet/dry vacuum, Other miscellaneous utility
Water Heating	Water heating (instantaneous single point of use or point of use tank), Other miscellaneous water heating
End Use - Traditional	
Appliance	Clothes dryer & washer, Cooktop, Dishwasher, Freezer, Oven, Refrigerator, Other miscellaneous traditional appliance
HVAC	Air conditioning (central, heat pump, room/wall), Heating (various), Other miscellaneous traditional HVAC
Lighting	Commercial, Residential, Other miscellaneous traditional lighting
Water Heating	Water heating (various), Other miscellaneous water heating

Appendix B: Ideal Meter Specifications

Meters selected for power measurement affect different aspects of the study, including data quality and accuracy, measurement intervals (which affect the mode detection of CMELs), data storage and collection, among others. It was found that most power meters available commercially have shortcomings in fulfilling the data collection demands required by research studies such as this one. Below is the start of a list of meter specifications in an ideal commercial power meter that meets the demand of this research study. This list will be expanded to a full specification in the final report.

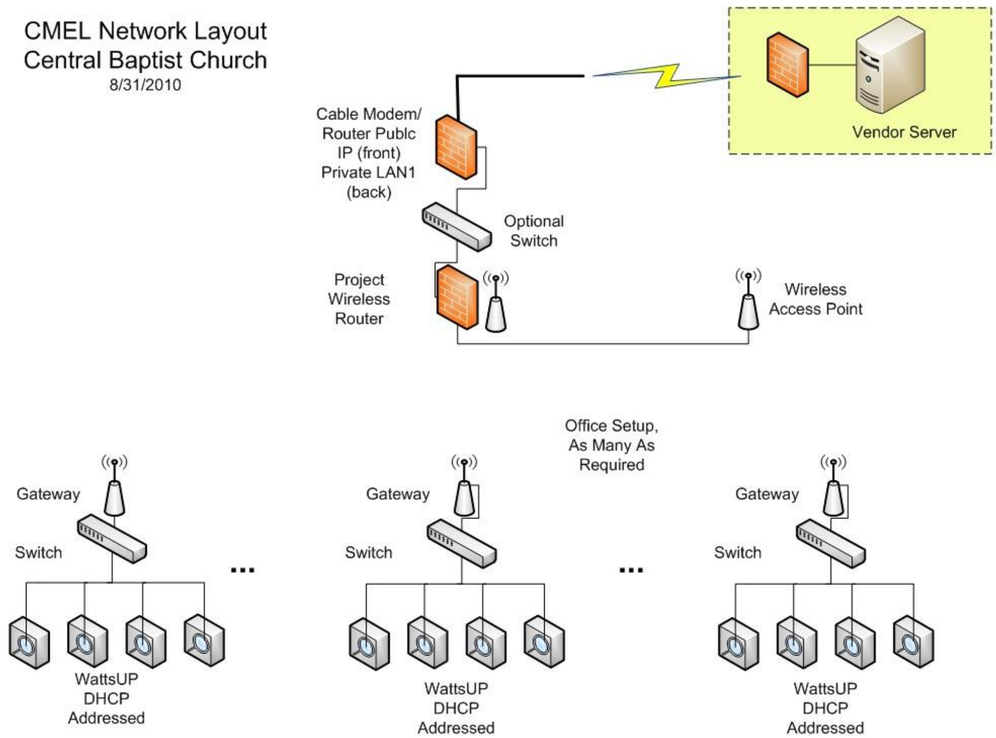
1. Real time, network synchronized clock
2. Internal battery backup
3. Accurate current and power factor measurement at low power (1-50W)
4. Low parasitic draw
5. Reliable to retain calibration settings
6. Sufficient storage to record 5 variables at 30-second intervals for a month
7. Capable of being attached or secured to CMELs that are routinely unplugged when not in use to eliminate lost data

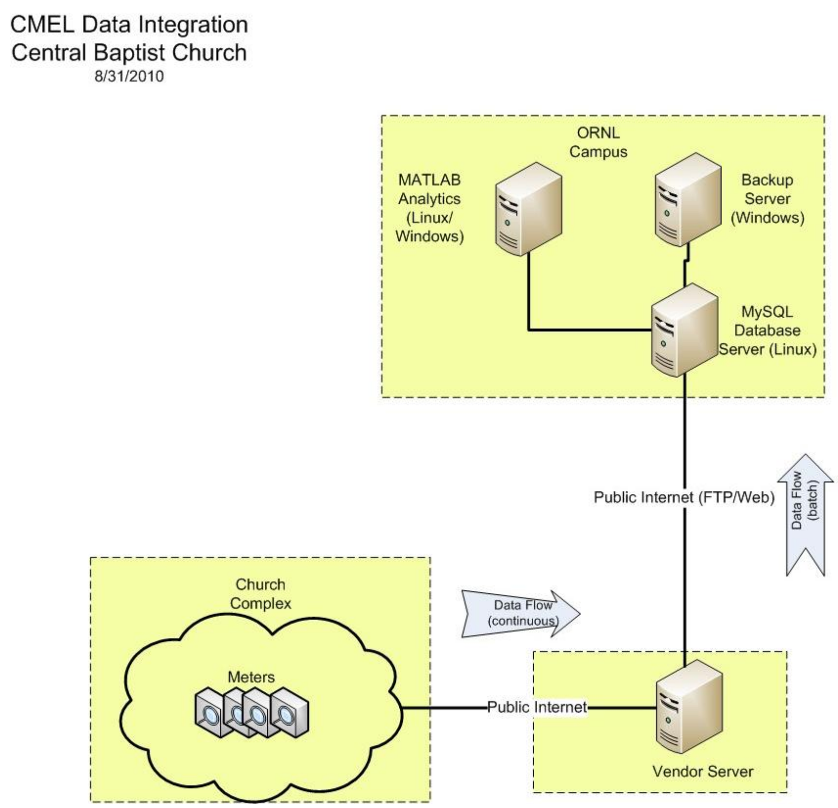
Appendix C: Meter Accuracy: Test Methods and Results

This appendix will be included in the final report of this research study.

Appendix D: Field Monitoring Details

This section covers more detailed information and methodological findings from the field studies, including layout of the power meter and data collection system. The diagrams below are examples of the types of detailed material that will be included in the final report. They present the structure for data transmission used at the public assembly and religious worship buildings. The first figure shows the network layout at the church and the second describes the data flow from the church to ORNL local servers.


CMEL Network Layout
Central Baptist Church
8/31/2010
Vendor Server
Cable Modem/
Router Publc
IP (front)
Private LAN1
(back)
Optional
Switch
Project
Wireless
Router
Wireless
Access Point
Office Setup,
As Many As
Required
Gateway
Switch
WattsUP
DHCP
Addressed
Gateway
Switch
WattsUP
DHCP
Addressed
Gateway
Switch
WattsUP
DHCP
Addressed


CMEL Data Integration
Central Baptist Church
8/31/2010
ORNL
Campus
MATLAB
Analytics
(Linux/
Windows)
Backup
Server
(Windows)
MySQL
Database
Server (Linux)
Public Internet (FTP/Web)
Data Flow
(batch)
Church
Complex
Meters
Data Flow
(continuous)
Public Internet
Vendor Server