Pacific Northwest
NATIONAL LABORATORY

PNNL-29914

Characterizing Plug Load Energy Use and Savings Potential in Army Buildings

December 2022

RT Dahowski
GP Sullivan
AR Davila
BG Pennell

Prepared for the **Deputy Assistant Secretary of the Army for Energy and Sustainability** under a Government Order with the U.S. Department of Energy

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

PNNL-29914

Characterizing Plug Load Energy Use and Savings Potential in Army Buildings

December 2022

RT Dahowski[1]
GP Sullivan[2]
AR Davila[1]
BG Pennell[1]

Prepared for
the Deputy Assistant Secretary of the Army for Energy and Sustainability
under a Government Order with the U.S. Department of Energy
Contract DE-AC05-76RL01830, Related Services

Pacific Northwest National Laboratory
Richland, Washington 99354

[1] Pacific Northwest National Laboratory, Richland, Washington
[2] Efficiency Solutions, Richland, Washington

Executive Summary

The Assistant Secretary of the Army (Installations, Energy and Environment) tasked the Pacific Northwest National Laboratory to examine plug loads in typical Army buildings. Plug loads (also known as miscellaneous electric loads (MELs)) represent the electricity used by appliances and devices that are plugged in or hardwired and serve functions outside of a building's core end uses. Common plug loads include computers, printers, copiers, networking devices, refrigerators, and vending machines. They also include personal electronic devices such as televisions, smart phones, tablets, and gaming systems. Examples of hardwired MELs include elevators, air compressors, and security and fire alarm systems.

ES.1 Study Objectives

Plug loads and other MELs are growing to comprise a larger fraction of building energy use and costs. This growth is increasing the attention on evaluating approaches for managing their use. A better understanding of the magnitude and nature of key loads is important for developing and maintaining sound policy to manage energy use across the Army, and support efforts to enhance the energy efficiency and resilience of installations.

While numerous studies have looked at plug loads in commercial buildings, this is the first major study seeking to better understand plug load use patterns, energy consumption, and savings opportunities within a range of Army building types. The goal of this study was to evaluate plug load and MEL energy use to raise awareness and inform near-term actions as well as the development of future policy regarding management of loads at Army garrisons. The key questions this research aimed to begin to answer include:

1. How much do plug loads and MELs contribute to Army facility energy use?
2. Which device types consume the most energy in select Army buildings?
3. What types of strategies are available to manage these loads?
4. What measures may help to reduce energy consumption by MELs across the Army?

ES.2 Approach

PNNL identified five Army building types for which to evaluate plug load equipment and energy use. The selected building types represent one-fifth of the total Army-wide facility floor area and share similarities with additional Army category codes. The relevance of these building types and the selected host installation (Fort Carson) ensures that the results from this study are broadly applicable across a much larger number of facilities. Characteristics of each selected building are shown in Table ES.1.

PNNL developed and implemented a plan to inventory all devices and meter representative samples of the equipment within each building. The team inventoried a total of 878 MEL devices across the five representative study buildings, grouping them into eight primary categories as summarized in Table ES.2. The Admin building contained the highest number of devices, with 45% of the total. Across all five study buildings, the majority of devices belong to the Computing category which consists of desktop and laptop computers, monitors, and related equipment including computer speakers, and workstation uninterruptible power supplies (UPS).

Table ES.1. Basic Characteristics and EUIs for the Selected Buildings

Building	Floor Area (ft^2)	Vintage	EUI ($kBtu/ft^2$)
Administration General Purpose (Admin)	14,300	1988	64.7
Tactical Equipment Maintenance Facility (TEMF)	18,100	2010	109.6
Unaccompanied Enlisted Personnel Housing (UEPH)	63,800	2009	45.9
Battalion Headquarters (BN HQ)	14,000	2013	60.9
Company Operations Facility (COF)	32,300	2010	39.9

Table ES.2. Summary of Device Inventory by Building and Category

	Admin	TEMF	UEPH[(a)]	BN HQ	COF	ALL
AV/Communications	58	6	1	47	23	135
Breakroom	44	8	6	21	16	95
Computing	194	25	-	109	58	386
Documents/Imaging	30	6	-	17	16	69
Laundry	-	-	36	-	-	36
Occupant Comfort	68	14	-	31	12	125
Shop Equipment	-	29	-	-	1	30
Facility Loads[(b)]	-	-	-	2	-	2
TOTALS	**394**	**88**	**43**	**227**	**126**	**878**
Devices per ksf	**27.6**	**4.9**	**0.7**	**16.2**	**3.9**	**6.2**
Devices per Occupant	**10.4**	**5.9**	**0.3**	**6.3**	**3.6**	**3.4**

[(a)] Device inventory for UEPH represents common area devices only
[(b)] Facility load devices include the elevator and oil minder within the BN HQ. Additional facility loads such as networking infrastructure, fire alarm and security systems are omitted from this device inventory but included within the MEL energy consumption estimates.

A mix of panel and device-level energy monitoring was deployed to capture power and energy use data for the plug loads and MELs. A summary of the field metering deployed within each study building is listed in Table ES.3, including the duration of both device and panel metering. The data acquired within each building enabled estimation of annual MEL energy consumption and load profiles for typical day types and occupancy states to highlight savings potential. Metering within the COF was not installed; however, the inventory data was combined with unit energy consumption results from equipment in other buildings to estimate its plug load energy use.

Whole building interval-metered data from the Meter Data Management System and Fort Carson's energy management control system were analyzed to evaluate annual MEL energy consumption using an always-on estimation procedure. The results from this process provide a rough measure of validation for the results obtained from the device and panel metering. With some exceptions, this approach confirmed the value for using whole building interval-metered data as an initial step towards identifying Army buildings that may be candidates for implementation of MEL savings opportunities.

Table ES.3. Duration of Field Monitoring by Type and Building

Building	Device Monitoring	Panel Monitoring
Admin	20 weeks (May-September)	None
TEMF	22 weeks (May-October)	16 weeks (June-October)
UEPH	21 weeks (May-October)	16 weeks (June-October)
BN HQ[(a)]	18 weeks (October-March)	11 weeks (December-February)
COF[(b)]	None	None

[(a)] Listed period represents data analyzed for report; monitoring of BN HQ continued for six months beyond the analysis period as a result of access restrictions at Fort Carson in response to COVID-19
[(b)] Monitoring of COF not performed

ES.3 Results

Total plug load and MEL energy use is 25% of the combined annual electricity consumption for the five study buildings and is valued at nearly $15,000 per year based on the Fort Carson average electricity rate. This 248,500 kWh equates to an aggregate plug load energy density of 1.74 kWh per square foot. Scaling the individual study building energy densities to the floor area of each broader facility category results in an estimate of total annual MEL energy use of 420 million kWh for the Army within just these five facility categories. Annual Army-wide MEL utility costs for these building categories exceed $25 million when applying the same electricity rate assumption. The following sections further describe the key results from this study.

ES.3.1 MEL Energy Use by Building

Table ES.4 presents the MEL energy use for each of the five study buildings. The MEL energy density is compared for each building in Figure ES.1, in terms both annual kWh per thousand square feet and kWh per occupant. The contribution of MELs to total building electricity use ranges from 9% in the COF to 39% in the UEPH. While total plug load energy is highest in the UEPH, energy use per floor area is highest in the Admin and the consumption per occupant is greatest in the TEMF. Examining the MEL consumption as a percentage of total building energy should also consider other factors, such as building EUI. Observations and analysis of building metering data suggest that significant opportunities exist for improving the control and operation of other building systems (e.g., lighting and HVAC) in buildings such as the TEMF.

Table ES.4. Summary of Best Estimate Annual MEL Consumption by Building

Building	MEL Annual Electricity Consumption, kWh/yr	Percent of Total Building Electricity (%)	Percent of Total Building Energy Use (%)	Estimated Electricity Cost[(a)] ($/yr)
Admin	34,300	30%	13%	$2,100
TEMF	30,700	16%	5%	$1,800
UEPH	139,300	39%	16%	$8,400
BN HQ	26,200	21%	10%	$1,600
COF	18,000	9%	5%	$1,100
Total	**248,500**	**25%**	**11%**	**$14,900**

[(a)] Electricity cost based on recent blended average rate at Fort Carson of $0.06/kWh

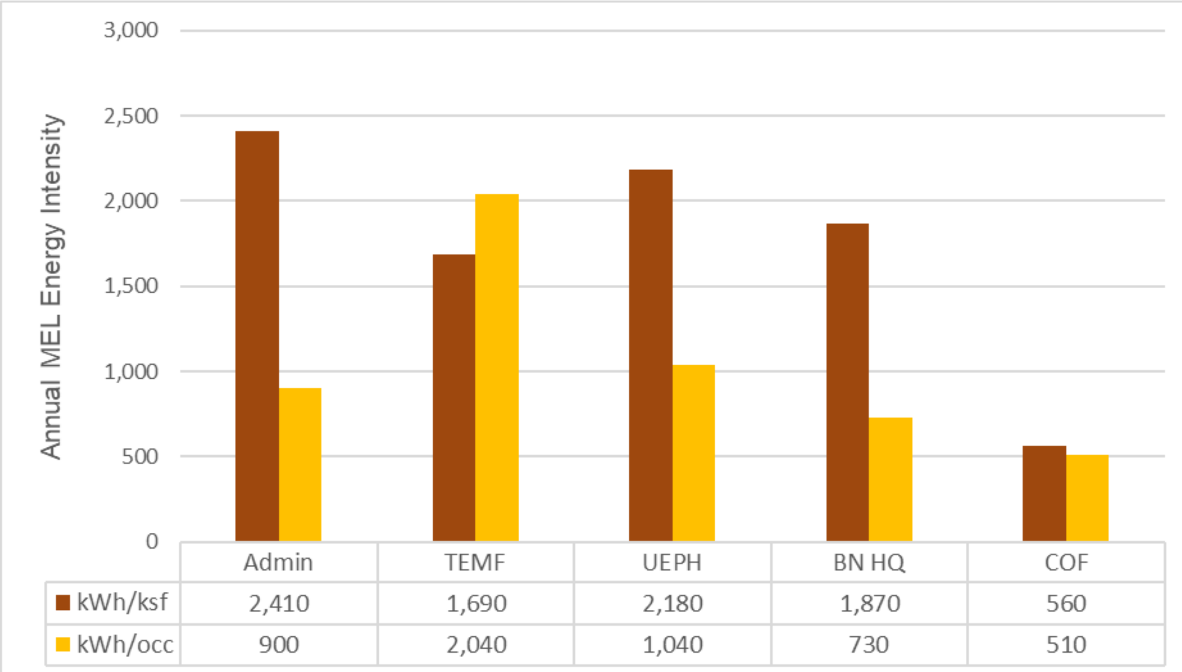


Figure ES.1. Annual MEL Energy Intensity by Building (kWh per thousand square feet and kWh per occupant)

Figure ES.2 presents the annual MEL energy use per thousand square feet by building type and device category. The density of energy use varies significantly by building type, from 560 kWh per thousand square feet in the COF to 2400 kWh per thousand square feet in the Admin.

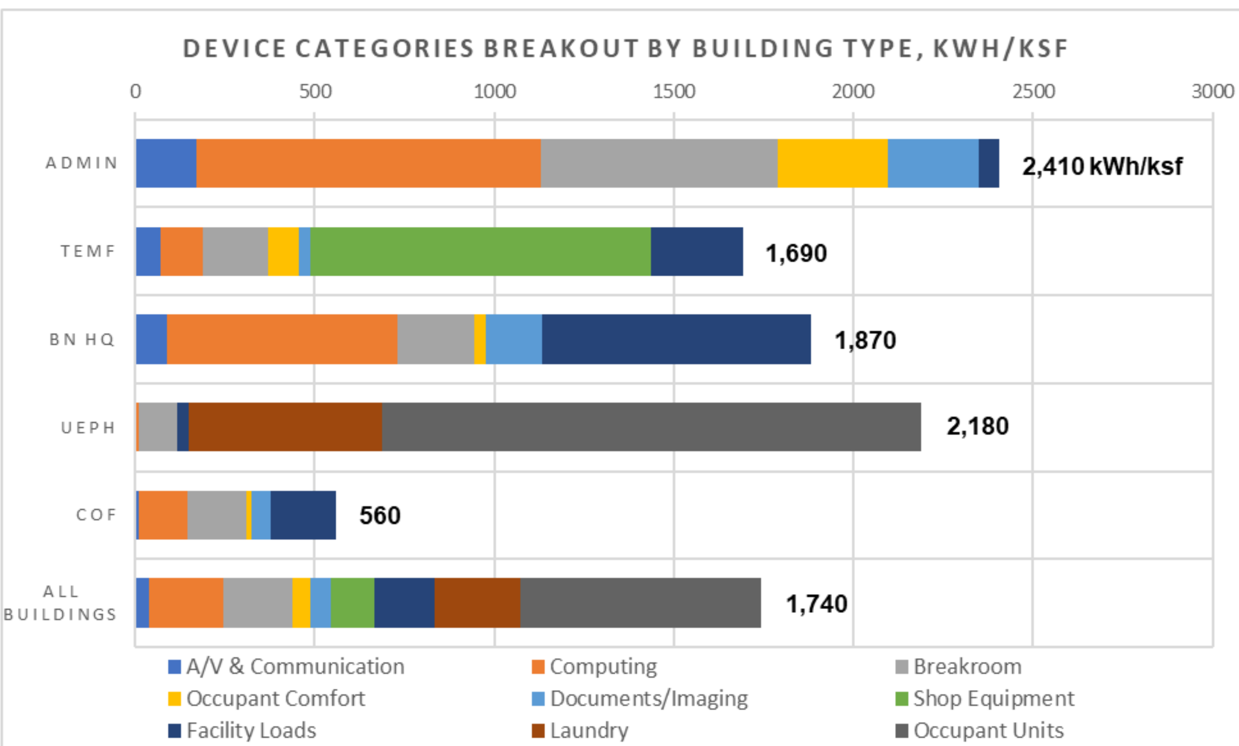


Figure ES.2. MEL Energy Use Density by Building Type and Category

ES.3.2 Largest Plug Load Energy Consumers

The UEPH living quarters consume the most plug load energy of all categories across the study buildings. However, because a detailed inventory and monitoring of equipment within these private spaces was not possible, this energy total is from an undetermined mix of kitchen appliances, computers, and other personal electronic equipment that, if known, would be allocated to other categories. Excluding the UEPH living quarters, the five categories with the highest energy use across the five study buildings are:

1. Laundry: 34,300 kWh/yr
2. Computing: 29,500 kWh/yr
3. Breakroom: 27,900 kWh/yr
4. Facility Loads[1]: 22,000 kWh/yr
5. Shop Equipment: 17,200 kWh/yr

Figure ES.3 identifies the 10 device types that use the most energy across the five buildings evaluated in this study. Together, the energy use from these device types represents 71% of all MELs within the five study buildings, excluding the UEPH occupant units.

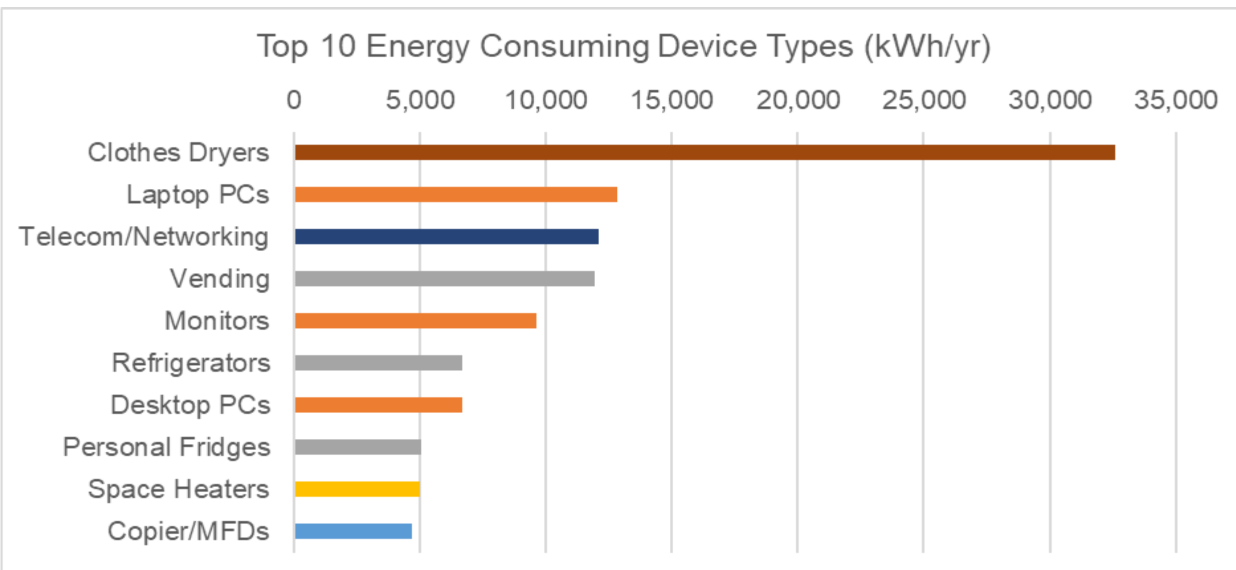


Figure ES.3. Top Ten Energy-Consuming Devices within the Study Buildings

Figure ES.4 presents the energy use for the 20 individual highest-consuming MELs. The aggregate use for BN HQ networking infrastructure is first, followed by large plug and hardwired devices such as refrigerated vending machines, the TEMF air compressor, BN HQ elevator, the average UEPH clothes dryer, the communications terminal in the TEMF, plus refrigerators, space heaters, and more. Collectively, these 20 MELs consume nearly 20% of the total MEL energy consumption from the five study buildings.

[1] Facility loads include a mix of MELs such as telecom and networking infrastructure, elevators, fire alarm and security systems, plus some loads from spaces that could not be disaggregated.

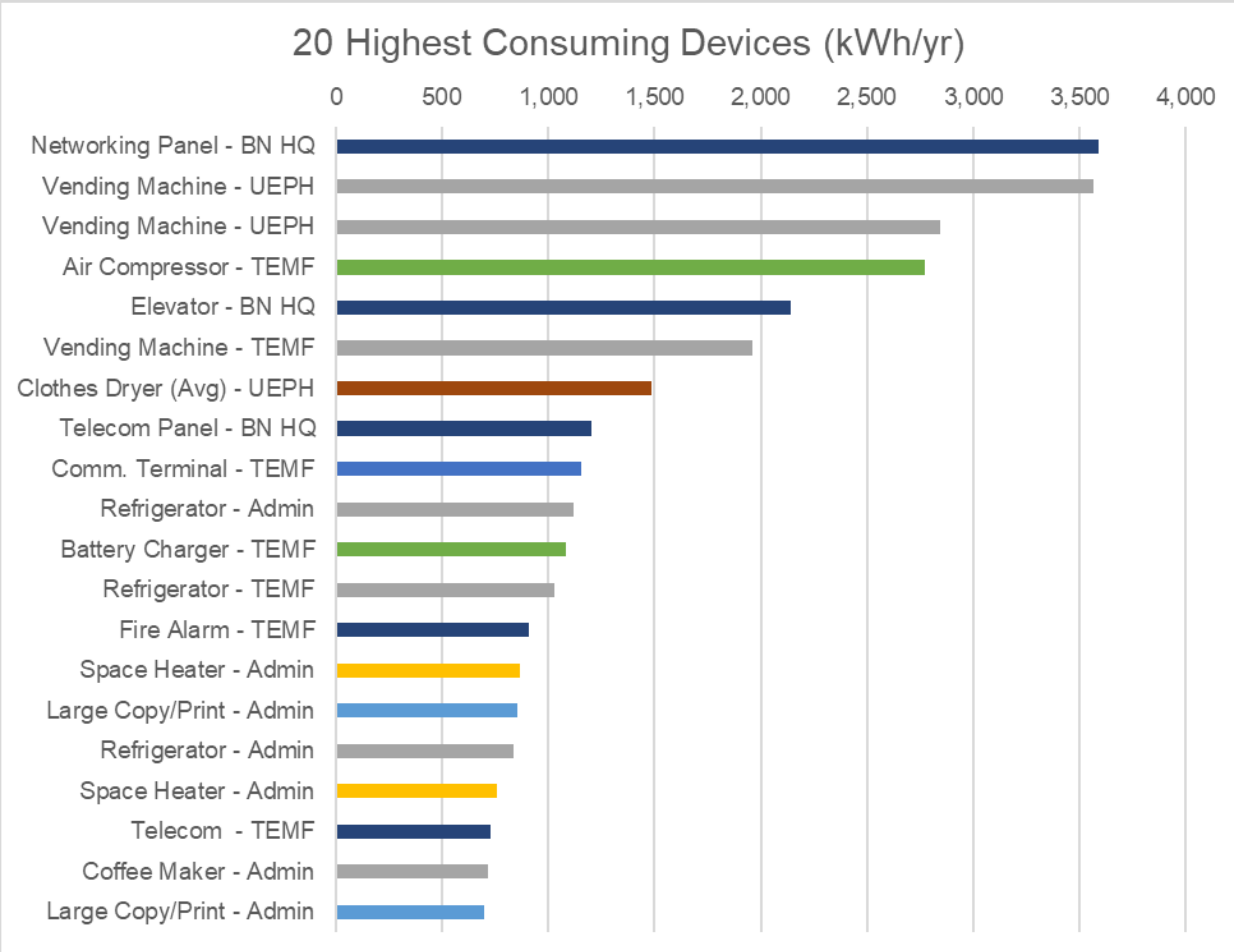


Figure ES.4. 20 Highest-Consuming Individual MELs within the Study Buildings

ES.3.3 Strategies to Manage Army Plug Loads and MELs

This study confirms that significant opportunities exist for reducing energy use from plug loads and MELs in Army buildings. A number of strategies and best practices for plug load device management are presented that may be useful for the Army. These are presented as a comprehensive lifecycle management process involving the following elements: **purchase, setup, operate, monitor, review, and engage**.

Purchase: Identify equipment purchase needs based on requirements for the application and integration with existing systems or technologies. Purchase energy efficient equipment with energy-saving settings appropriate for the intended use. If the equipment is not necessary, do not purchase.

- Existing policies require the purchase of Energy Star rated or otherwise energy efficient equipment for many of the categories investigated in this study. These purchasing policies are effective for most equipment types; however other equipment, including leased or contracted vending machines from outside vendors, are not required to meet similar standards.
- Policies that encourage or require more efficient types of equipment should also be considered. An example is the purchase of laptop computers over desktop machines

(many with UPS for backup power) where feasible. Thin client technology should be evaluated as an emerging option to save additional energy while improving cybersecurity.

- The proper excess or disposal of replaced equipment should further be considered as part of the overall purchase plan, to limit the repurposing of old and inefficient equipment to new locations on post.

Setup: Activate energy-saving features such as sleep mode. These settings should be based on guidance developed for the equipment type and application, in order to meet applicable Army regulations and mission requirements. Provide users with information on proper operation, how to override when necessary, and how to identify when the power saving modes are not engaging.

- Existing Army regulations specify that equipment including computers, printers, and copiers must be turned off or enter a low-power mode after 30 minutes of inactivity (15 minutes for monitors). However, results from this study indicate that the implementation of these requirements needs improvement.
- A conflict between energy and cybersecurity policies is acknowledged by the Army and is an issue that many installations likely struggle with. Personnel have been instructed to leave their computers on each night in order to expedite the processing of important security patches and system upgrades. Resolving this issue to enable computers to wake on demand to process system updates would save the Army over 31 million kWh of electricity valued at $2 million per year just within the five building categories evaluated in this study.
- Activating controls for appropriate sleep and other low-power modes is an easy way to reduce the energy use for many types of devices. It is recommended that the Army define power-saving settings for each device and application and require their implementation as part of the equipment install.

Operate: User education is important to ensure that the power-saving settings are maintained. Commands should be encouraged to foster an environment of diligence towards reducing energy waste from plug load equipment under their operation. This includes maintaining persistent power-savings through device settings, external controls, and awareness to identify and minimize unnecessary energy use.

- Turning off equipment for 12 hours each weekday and all weekend reduces operating hours by 64%.
- For devices that lack built-in power management capabilities, other energy management and control options are available and should be implemented. Commercial coffee makers offer one example that waste a lot of energy when not controlled. Findings suggest that a timer or other control method to turn the appliance off each night and all weekend would save 47% of the energy use of an uncontrolled device, and 37% for a coffee maker that occupants already turn off each weekend.
- Other options for managing the operation of plug load equipment include advanced power strips, occupant sensors, and devices like the commercial plug load management system used in this study to monitor and control equipment use and energy consumption. Controlled receptacles are another option that are beginning to be required by building codes in select states. These codes call for up to 50% of the electrical receptacles to be controllable. The implementation of this technology is meeting mixed review by building occupants; the Army may need to evaluate this for new construction, however other options are likely more flexible and cost effective for existing buildings.

- Instilling operational best practices means that personnel are aware of equipment operation and able to identify and correct off-normal events that may prevent normal energy management functions from engaging.

Monitor: Plug load equipment is all around us yet often taken for granted. Even those knowledgeable about energy management often have little idea about how common appliances or devices actually operate and how much power they draw under various conditions. Monitoring is often the only way to truly understand how devices behave and how to best manage their energy use.

- The extended monitoring performed within this study provided an understanding of the operation and energy use of plug load devices in the study buildings. However, even intermittent, short-duration monitoring can be beneficial to confirm equipment loads within various states of activity and validate that energy-saving settings are having the desired impact. It is therefore important to continue to monitor plug loads and other large MELs across the Army.

Review: It is important to review equipment settings, operation, behavior, and results from any monitoring on a regular basis. The review of equipment settings should be scheduled to occur twice per year to ensure that each device is set to enter power-saving mode after 15 or 30 minutes of inactivity and ensure that savings persist. Policies should be reviewed to keep up with emerging device types, capabilities, and mission needs. As should the adherence to policies and opportunities to learn from what is and what is not working.

- There are a variety of methods available to help manage plug load energy use and reduce waste. The first and best option is to review and identify equipment that is not being used and unplug it. The next best is to enable any existing power-saving features built into the device.
- The review of useful life of equipment and excess procedures should ensure that outdated or inefficient equipment (e.g., refrigerators older than 20 years) are replaced and removed and properly recycled rather than being moved and repurposed in another location.
- Device settings and operation should further be reviewed and validated on a recurring basis to ensure that optimal performance is sustained.

Engage: The goal of effective and sustainable plug load management is to reduce energy use without negatively impacting mission performance. Regardless of the policy and technology approaches employed, a strong foundation built on occupant engagement is critical. This engagement should permeate through each of the other best practice elements. Plug loads are unlike any other building end use; rather than being locked within mechanical rooms and operated, controlled, and maintained by a small team of experienced technicians, most plug load equipment is directly and regularly exercised by occupants in the course of completing their daily tasks. The success and sustainability of plug load management therefore relies on these occupants.

- Outreach should provide an understanding of existing policies and their drivers, while empowering staff with the knowledge and authority to review and maintain the desired power savings settings and systems to an appropriate degree.
- Educate building occupants on the necessary settings and operation of equipment and how to identify and remedy when power-saving modes are not working properly.

ES.3.4 Recommendations and Savings Potential

Results from this study and the detailed monitoring of plug load equipment and MELs suggest that coordinated policy and management can provide significant energy savings to the Army. A number of opportunities have been identified that should be broadly applicable to Army facilities. Table ES.5 presents the estimated savings potential for 10 plug load measures identified based on the study findings. The savings estimates for the five study buildings at Fort Carson are presented, with the percentage of existing energy use that each measure could save. Total savings potential for the Army is approximately 83 million kWh and $5 million per year. The recommendations are listed in order of savings potential extrapolated to the Army across the five building categories represented in this study. Most of these measures are applicable to other building types beyond these five categories, offering significantly higher annual savings potential beyond the 83 million kWh and $5 million presented here.

The top recommendation is to implement an effective computer security patching process that does not require computers to be continuously left in an active mode. A solution should be coordinated at the level of the CIO, G-6, and NETCOM, working with individual installation network enterprise centers. Given the number of networked computers in use across most building types, the savings from solving this challenge is likely to be significantly higher than the 31.6 million kWh and $1.9 million per year estimated based on the four study building categories evaluated in this study.

The recommendation offering the next highest savings potential is to increase the efficiency of the fleet of vending machines on installations. Most of these machines are owned and maintained by commercial vendors and managed through AAFES. Replacing old, refrigerated beverage machines with Energy Star certified units will provide significant savings. Further, the energy saving capabilities of these machines should be specified in contracts and set as appropriate for the location where each machine is installed. Even for the same model of Energy Star vending machine, energy use is shown to vary significantly depending on these settings which can control the lighting as well as the operation of the compressor during unoccupied periods. Contractors should be required to regularly inspect and maintain the equipment and settings. It is recommended that the Army work with AAFES to establish consistent guidelines for tracking vending machines and estimating the monthly energy consumed. This may require some additional monitoring and will help standardize the reimbursement process for the cost of electricity consumed by these machines.

The next group of recommendations focus on properly enabling existing power saving settings or adding external controls to turn devices off when not in use. Those measures have the potential to save around 12 million kWh and over $720,000 per year across these five building categories, with the greatest savings expected for large copy and print machines, commercial coffee makers, printers, and projectors. Measures that focus on the purchase of more energy efficient laptop and thin client computing equipment over desktop computers, and the replacement of older, inefficient refrigerators, are estimated to save 9.5 million kWh and $570,000 per year. The remaining measures recommend policy and technical reviews regarding the use of space heaters and fluid heaters for hydraulic elevators.

Table ES.5. Priority Plug Load Savings Opportunities and Scale of Potential Savings within the Study Buildings and their Categories Across the Army

Savings Measure	Study Building Findings: Device Savings (%)	Study Building Findings: Savings (kWh/yr)	Potential Army-Wide Savings: Energy (million kWh/yr)[(a)]	Potential Army-Wide Savings: Dollars ($K/yr)[(b)]
Implement Sustainable Computer Policy: Power Systems Down Each Night	46%	11,300	31.6	$1,900
Refrigerated Vending Machines: Energy Star with Custom Settings	57%	6,000	31.2[(c)]	$1,870
Improve Power Save Settings: Large Copy Print Devices	47%	2,500	7.6	$456
Refrigerators: Replace 20+ Year Old Units with New Energy Star Models	39%	2,600	6.3	$378
Computer Purchase Policy: Purchase Laptop PCs over Desktops + UPS	46%	2,000	3.2[(d)]	$192
Commercial Coffee Makers: Add Timer or Similar Controls	43%	490	2.6	$156
Space Heaters: Review Policy Enforcement and Exceptions for Reasonable and Responsible Use	50%	2,500	1.1[(e)]	$66
Printers: Enable Sleep Mode	14%	370	0.93	$56
Projectors: Turn Off When Not in Use	41%	300	0.75	$45
Elevators: Review and Remove or Adjust Hydraulic Fluid Heaters	62%	1,300	0.25	$15
TOTALS	**51%**	**29,360**	**82.9**	**$4,970**

(a) Army-wide savings are estimated based on savings per ft^2 in study building(s) multiplied by floor area of the study building cat code. Actual savings are likely higher but depend on other building types being relevant for the identified measure and how representative the study building(s) and device densities, usage, and settings are across the Army.

(b) Total Army dollar savings (thousands of dollars per year), assume a $0.06/kWh average electric rate.

(c) Savings estimates for refrigerated vending machines are extrapolated to the entire Army floor area, and not only the building categories assessed in this study.

(d) Savings are estimated only for general Admin buildings and assume that (1) a sustainable solution to allow computers to power down nightly has been implemented, and (2) the category average density of desktop computers is only 30% of that in the Fort Carson Admin building studied.

(e) Assumes a 50% overall reduction rate within these building types across the Army (to account for variations in climate, use, and policy exceptions to support occupant comfort and productivity)

ES.4 Path Forward

The findings from this study confirm that significant energy is consumed within Army buildings by plug load devices and hardwired MEL equipment. A number of opportunities are identified for reducing unnecessary energy use that could save the Army over $5 million per year when broadly applied. Army regulations clearly spell out expectations for the purchase and operation of information technology equipment (computers, laptops, monitors, printers, and multi-function devices). However, the policies regarding the shutdown or activation of sleep and other lower power modes after 30 minutes of inactivity (15 minutes for monitors) are not consistently followed. In some cases, this may be driven by decisions to prioritize cybersecurity over energy savings. But in other instances, the devices are simply not configured to take advantage of embedded power management features.

There are many effective approaches and pathways for impacting change as it relates to improving awareness, implementing measures, and adjusting behaviors to identify and reduce plug load energy use. The Army should prioritize and consider deploying all of these to better understand and manage plug load equipment to save energy and enhance resilience across their facilities. Engaging the building occupants who use these devices daily via outreach and education should be a strong component of the strategy. The focus should be on reducing waste without sacrificing productivity or the benefits that many of these devices provide. Continued monitoring and evaluation of plug loads beyond that performed here is important to gather lessons from additional building and equipment types, and to stay aware of evolving device technology and management options. This will highlight additional needs for policies, best practices, control technologies, and education of personnel to achieve real reductions in energy waste from plug load equipment. It is recommended that this study serve as the foundation for a broader and sustained focus on plug loads and MELs, towards simultaneously enhancing the productivity, readiness, and resilience of the Army while reducing energy use and demand, and freeing up resources to better support the mission.

Acknowledgements

The authors would like to acknowledge the Office of the Assistant Secretary of the Army (Installations, Energy and Environment) (ASA (IE&E)) and Paul Volkman for the support of this first-of-its-kind research for the Army. In addition, the project team received exceptional support from Fort Carson, without which this study would not have been possible. This includes the Fort Carson Directorate of Public Works Energy Team, Network Enterprise Center, and the facility managers and occupants of the buildings that were the focus of the study. Finally, we recognize Kopacz-Boyer Design Build Services for their outstanding collaboration and support to enable the electrical panel metering deployed by the study.

Acronyms and Abbreviations

AAFES	Army and Air Force Exchange Service
Admin	administration general purpose
AHU	air handling unit
ASA (IE&E)	Assistant Secretary of the Army (Installations, Energy and Environment)
BN HQ	battalion headquarters
COF	company operations facility
CY	calendar year
DPW	Directorate of Public Works
EMCS	energy management control system
ESTCP	Environmental Security Technology Certification Program
EUI	energy use intensity
FACP	fire alarm control panel
FY	fiscal year
H-Axis	horizontal axis (washing machine)
HDD	heating degree days
HVAC	heating, ventilation and air-conditioning
ksf	thousand square feet
kW	kilowatt
kWh	kilowatt-hour
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
MBtu	million British thermal units
MFD	multi-function device (copy, print, scan)
MDMS	Meter Data Management System
MDP	main distribution panel
MEL	miscellaneous electric load
NEC	Network Enterprise Center
NILM	nonintrusive load monitoring
PNNL	Pacific Northwest National Laboratory
TEMF	tactical equipment maintenance facility
UEC	unit energy consumption
UEPH	unaccompanied enlisted personnel housing
UPS	uninterruptible power supply
V-Axis	vertical axis (washing machine)
W	watt

Contents

Figures

Tables

1.0 Introduction

The Office of the Assistant Secretary of the Army for Installations, Energy and the Environment (ASA (IE&E)) requested that Pacific Northwest National Laboratory (PNNL) conduct a study to assess the magnitude and characteristics of miscellaneous electric loads (MELs), also commonly known as plug loads, within typical Army buildings. Growth in plug loads and other MELs, coupled with expanded focus on efficiency in other building systems, is increasing the attention on MELs and opportunities for improved management for reducing their energy use. A better understanding of the magnitude and nature of key loads is important for implementing sound policy to manage energy use across the Army, and support efforts to enhance the energy efficiency and resilience of installations.

1.1 Background and Description of Plug Loads and MELs

MELs represent the electricity used by appliances and devices that are plugged in or hardwired and serve functions outside of a building's core end uses of heating, ventilation, and air conditioning (HVAC); lighting; water heating; and commercial refrigeration. Common plug loads cover a broad range of equipment from computers, printers, copiers, networking devices, refrigerators, and vending machines to personal electronic devices such as televisions, smart phones, tablets, and gaming systems. Hard-wired loads can include elevators, air compressors, fire and security systems and other systems not associated with the core end uses noted above. These diverse miscellaneous loads are also referred to as plug and process loads. This report refers to MELs and plug loads somewhat interchangeably, although plug loads is used to describe devices that are typically plugged into an electrical outlet and MELs as the broader definition of electrical devices and loads that can be either plugged in or hardwired.

Studies in commercial buildings have shown that while efficiency gains have been realized for building systems such as HVAC, lighting, and thermal envelope, MELs continue to grow both in absolute and relative terms to comprise an increasingly significant and expanding fraction of building energy use. Studies have shown that MELs often comprise between 15% and 40% of a commercial office building's total energy use and that through the combined growth in equipment loads and further efficiency gains in other end uses, plug load consumption is anticipated to increase to 50% in more efficient buildings (Kaneda et al. 2010). The 2020 Annual Energy Outlook (EIA 2020) reports that computers and other office equipment are responsible for 16% of the electricity consumed by commercial U.S. buildings, and that other miscellaneous loads (including elevators, coffee makers, laundry equipment, and transformers) consume another 32%. The analysis also projects that, through mid-century, the energy use of computers and office equipment will increase 25% and other electrical loads 15% in terms of kWh per floor area, while the consumption for all other end uses declines. Thus, MELs represent an important focus for improved management, energy savings, and enhanced resilience.

The individual and collective energy use of MELs is impacted by a number of factors including equipment attributes, device density, use schedules, occupant interaction, and presence and use of controls. One challenge is that plug loads represent a very large and diverse set of distributed loads that can vary markedly by building function and activity level, and their use is typically driven to a significant degree by occupant needs and behaviors. Compared with other end uses such as lighting and HVAC, they are highly decentralized and more difficult to monitor, assess, and control. There has been growing interest in better understanding the energy used by MELs, as well as identifying best practices for reducing excess energy consumption. Most studies specific to plug loads and MELs to date have focused on commercial office and university buildings and none have attempted to look at buildings common to a typical Army installation.

1.2 Study Objectives

The objective of this study is to assist the Army in better understanding the magnitude and characteristics of MELs within Army facilities and inform the development and implementation of policy for the effective management and operation of plug load equipment.

The primary goal is to better understand how much MELs contribute to the energy use within a handful of buildings that are representative of a large cross section of the Army. Common building design practices assume a given load density for MELs; however, very little is understood regarding actual equipment diversity and density, the operation and energy consumption, nor the true nature of the load characteristics of these devices. The second goal is to evaluate the characteristics of the predominant loads and assess the potential opportunity for energy and demand savings that might be realized by improving the potential for technology, policy, and operational adjustments to realize more efficient use of plug load equipment.

In pursuit of these goals, the study focused on beginning to answer the following questions:

1. How much do plug loads and MELs contribute to Army facility energy use?
2. Which device types consume the most energy in select Army buildings?
3. What types of strategies are available to manage these loads?
4. What measures may help to reduce energy consumption by MELs across the Army?

1.3 Study Approach and Report Organization

Five representative buildings were selected to examine the plug loads and MELs within Army buildings. A mix of monitoring and evaluation approaches were implemented as suitable for each study building. The research team installed a combination of device- and panel-level energy monitoring equipment in most buildings to collect detailed data on the operation and energy use of equipment. The analysis of available whole building interval-metered data provided a basis for the total building energy use comparison and enabled a combination of top-down and bottom-up energy estimation approaches to be evaluated.

The study leveraged this mix of data to identify and analyze building loads to better frame MEL energy use during both occupied and unoccupied periods. As part of this effort, the team prepared and evaluated results from several different MEL energy consumption estimation methods. The evaluation of different methods allowed for greater confidence in the final estimates and allowed for the assessment of the validity and reliability of results obtained from high-level assessment of available whole building data relative to that resulting from the more detailed monitoring of major electrical panels, major circuits, and select plug load equipment. The purpose is to review such approaches and whether their deployment might aid in a more comprehensive effort to evaluate, identify, and implement opportunities for energy use reduction.

Section 2.0 of this report describes the selection of the five buildings and the relevant characteristics of each, including baseline energy consumption. The approach and results of the detailed inventory of more than 870 plug load and hard-wired MEL devices for each building are presented in Section 3.0. Section 4.0 reviews the data collection and energy consumption estimation methods, from high level top-down approaches using existing building-level interval-metered data, to more detailed top-down electrical panel and circuit monitoring. Bottom-up methods relying on the monitoring of loads at the individual device level are also presented. A review of the metering equipment and approaches deployed to measure electricity demand and estimate annual consumption is included.

The results of the energy monitoring and aggregation approaches are presented in Section 5.0, along with estimates of annual energy use by device type, category, and total MELs for each building. The results from the bottom-up evaluations are compared with the top-down approaches, using available whole building and circuit interval power data, to examine the validity of the bottom-up estimate, as well as to gauge the reasonableness of estimates performed strictly via the top-down methods. Section 6.0 extends the discussion of findings to specific device types, and what the characteristics of resulting load profiles suggest regarding potential savings opportunities, with specific observations and recommendations for reducing energy use from select device types. A review of findings and recommendations for a path forward are presented in Section 7.0, along with a discussion of life-cycle best practices for plug load equipment.

2.0 Buildings Studied

To meet the goals of this study, a handful of buildings was sought that represent a mix of common and prevalent Army facility types. Several criteria were identified, focused on the broader transfer of the findings across the Army. A host installation having numerous examples of buildings likely to meet these criteria and located in a relatively temperate climate zone rather than one dominated by hot or cold weather was desired.

Priority building types were identified via review of a recent summary of Army facilities. Data from the 2016 Army Building Category Code Summary covering all Army facilities, by facility category across all commands were evaluated to identify those building categories representing the largest portion of Army facilities that would be amenable to this study. The selected building types are listed in Table 1 and represent over 11,000 buildings and nearly 211 million square feet of floor area. Combined, the facilities represented by these category codes comprise over 19% of the total Army facility floor area and nearly 7% of the buildings covered by the 2016 summary. These totals do not include similar building types categorized under different codes, for instance other classifications of administration buildings, barracks, and maintenance facilities. The results of this study will therefore likely have much broader relevance regarding plug load equipment, energy use, and savings potential beyond the five selected categories.

Table 1. Building Selection Based on Relevance to Total Army Building Stock

Building Type	Cat Code	Army Total # Bldgs	Army Total Floor Area (Msf)	% of Total Army Floor Area	Average Floor Area (ksf)
Administration General Purpose	61050	5,291	76.4	6.9%	14.4
Unaccompanied Enlisted Personnel Housing	72111	2,083	72.4	6.6%	34.8
Company Headquarters	14185	1,412	25.6	2.3%	18.1
Vehicle Maintenance Shop	21410	1,439	23.5	2.1%	16.3
Battalion Headquarters	14183	803	12.8	1.2%	16.0

ksf = $ft^2 \times 1000$; Msf = $ft^2 \times 1,000,000$

Primary building selection criteria included:

- Representative of the larger Army building stock (e.g., in terms of typical use, size, and occupancy characteristics)
- Availability of reliable Army Meter Data Management System (MDMS) or other whole building interval-metered data for electricity and other fuels[1]
- Accessibility of most building spaces and devices for monitoring
- Supportive facility management
- Electrical configuration amenable to panel metering.

[1] Buildings using electricity plus natural gas were preferred over steam, hot water, or chilled water from a central plant for which accurate metering may not be available.

Fort Carson was selected as the study site because it has a good assortment of buildings that meet many of these criteria, along with a proactive and supportive energy management team and program. PNNL reviewed the project goals and desired criteria with Fort Carson Directorate of Public Works (DPW) personnel and visited a number of candidate buildings to identify the final choices for the study. Buildings were selected based on these criteria as well as preferences such as having centralized heating and cooling systems (rather than extensive use of packaged terminal units or ductless mini-split systems).

The final five buildings selected for the study are identified in Table 2 and described in the following sub-sections. These include an administration general purpose (Admin), tactical equipment maintenance facility (TEMF), unaccompanied enlisted personnel housing (UEPH), battalion headquarters (BN HQ), and company operations facility (COF). Each of these buildings use both electricity and natural gas, and recent average annual energy consumption for each building (obtained from MDMS for FY18 and FY19) is listed, along with resulting energy use intensity (EUI). The resulting EUIs also are compared in Figure 1 by fuel type.

Table 2. Basic Characteristics, Energy Consumption and EUIs for the Selected Buildings

Building	Floor Area (ft^2)	Vintage	Electricity (kWh/yr)	Natural Gas (MBtu/yr)	Total Energy (MBtu/yr)	EUI ($kBtu/ft^2$)
ADMIN	14,300	1988	113,512	535	922	64.7
TEMF	18,100	2010	188,420	1,345	1,988	109.6
UEPH	63,800	2009	360,317	1,700	2,929	45.9
BN HQ	14,000	2013	126,006	423	852	60.9
COF	32,300	2010	197,673	616	1,291	39.9

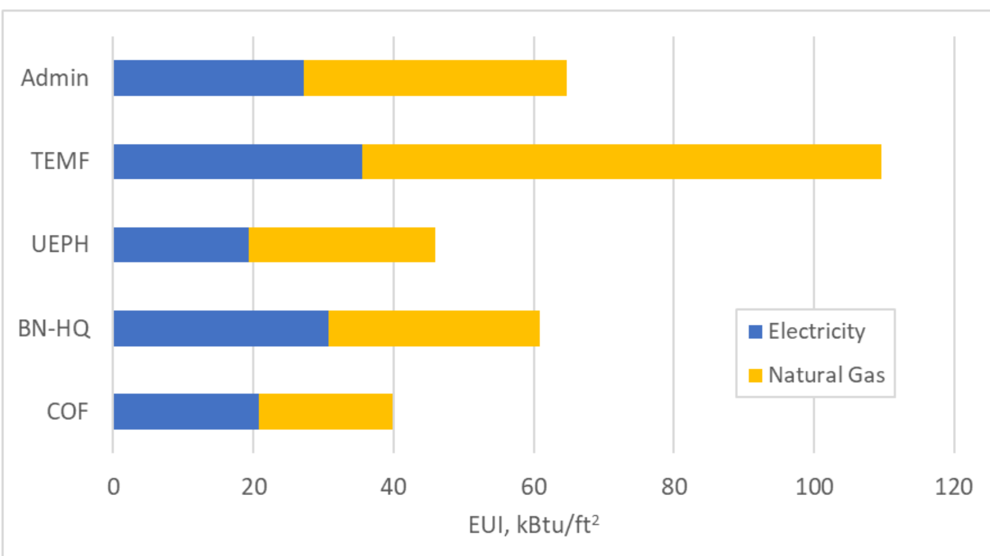


Figure 1. Study Building Energy Use Intensity by Fuel Type

2.1 Admin Building

The Admin building is a single-story 14,300 ft^2 structure that was built in 1988. It typifies the many smaller Army general administration buildings from this era. At the time of the study, it housed a primarily civilian-staffed support organization. The building contains a mix of private and open office spaces, one large and one small conference room, and a small networking infrastructure space. It has several small break areas intermixed within the office areas rather than a central breakroom.

The building is conditioned via two air-handling units with a natural gas boiler for heating and an air-cooled chiller for cooling. A single gas-fired water heater supplies hot water to the restrooms. Lighting is predominantly T8 fluorescent throughout, with occupancy sensors in most spaces. There are LED wall pack lights on the exterior walls; however, parking lot lighting is served from a different building. Most of the electrical panels are in the mechanical room; however, the panel with most of the plug-load receptacles is located in the main hallway, which made metering of its circuits impractical.

Total annual electricity consumption was 110,859 kWh in FY18 and 116,165 kWh in FY19. FY19 natural gas consumption totaled 535 MBtu. The FY18 natural gas use reported by MDMS was 809 MBtu, and the monthly totals showed summer use on par with winter use. This is unrealistic and could be a result of an abnormal situation or metered data issues. In either case the FY18 natural gas data was deemed unrepresentative, and therefore, the representative natural gas consumption was set equal to the FY19 value of 535 MBtu, with the electricity taking the average of 113,512 kWh, for a combined total energy consumption of 922 MBtu, as shown in Table 2. Natural gas and electricity use represent 58% and 42% of the total energy use, respectively. The resulting EUI for this Admin building is 64.7 kBtu/ft^2.

2.2 TEMF

The TEMF is a 18,100 ft^2 vehicle maintenance shop built in 2010 to Leadership in Energy and Environmental Design (LEED) standards. The design is common to many TEMF facilities at Fort Carson. It is predominately high bay shop space with six large vehicle bays, plus a battery charging space, an office area, conference/training room, and a storage room. A mobile trailer parked behind the facility contains an active and self-contained fuels laboratory that is powered by electricity from the building.

Space heating is supplied by natural gas boilers (a mix of rooftop unit air heating and radiant floor heating in the maintenance bays), and cooling is provided by a packaged rooftop unit. A natural gas water heater provides hot water to the restroom faucets and showers and the breakroom. Lighting consists of a mix of T8 fluorescent (interior) and metal halide (exterior).

Based on data from MDMS, the building consumed 187,682 kWh of electricity and 1371 MBtu of natural gas in FY18. FY19 consumption was 189,157 kWh of electricity and 1319 MBtu of natural gas. The recent average annual energy consumption is then 188,420 kWh and 1345 MBtu, or 1988 MBtu combined. Natural gas and electricity use represent 68% and 32% of the total building energy use, respectively. The EUI for the TEMF is 109.6 kBtu/ft^2, which is the highest of these buildings, mostly because of the significant air volume and air exchange resulting from exhaust fans and the opening of the large bay doors.

2.3 UEPH

The selected UEPH is a typical modern three-story, 63,800 ft^2 barracks built in 2009. The units are configured as double occupancy living quarters, each consisting of two bedrooms, a bathroom, and kitchen. Common spaces include a laundry room on each floor, a first-floor lobby with reception desk, and a nook with three vending machines.

The building is conditioned with large air-handling units and variable-air-volume boxes. Heat is provided by natural gas boilers and cooling by an air-cooled chiller. Hot water is heated with natural gas and circulated through the building to each kitchen and bathroom. High-efficiency equipment and systems including economizing, energy recovery, and variable speed drives aid in lowering building energy use. Lighting is a mix of linear and compact fluorescents in the rooms, and linear fluorescents in the hallways, stairwells, and common areas. In early CY19, the natural gas clothes dryers in the laundry rooms were replaced with electric units.

Typical annual energy use is 360,317 kWh of electricity and 1700 MBtu of natural gas, for an EUI of 45.9 kBtu/ft^2. Natural gas and electricity represent 58% and 42% of the total energy use, respectively. These values are the average from FY18 (355,259 kWh electricity and 2042 MBtu natural gas) and FY19 (365,375 kWh and 1358 MBtu). Part of this increase in electricity consumption, and decline in natural gas, is due to the change to electric clothes dryers. This impact is expected to grow in FY20 when this change will impact the full year.

2.4 BN HQ

The BN HQ selected for the study was built in 2013 to LEED standards. It is 14,000 ft^2, and two-stories in the front, with a single story in the back. The two-story section is mostly a mix of private and open office space, with a 24-hour duty desk, conference room, small breakroom, and telecommunications and network infrastructure spaces. The rear single-story space is split into training rooms consisting of a large meeting room, open flexible office area, and a computer lab.

The building is served by natural gas boilers for heating, an electric package unit for cooling, with an air-handling unit and variable-air-volume boxes, plus energy recovery units. Hot water is supplied to the restrooms and breakroom by a natural gas water heater. Lighting is predominantly T5 fluorescent.

Recent annual energy consumption averages 126,006 kWh of electricity (50%) and 423 MBtu of natural gas (50%). The EUI for this BN HQ is 60.9 kBtu/ft^2.

2.5 COF

The COF identified for the study is 32,300 ft^2 in area and was built to LEED standards in 2010. Like many COFs, it has admin space in the front and a large readiness and storage area, vaults, and supply cages in the back. It houses two Army companies, and occupancy levels can vary significantly according to needs and activities.

The building is heated with a natural gas boiler and cooled with an electric package unit. Hot water for the restroom faucets and showers is heated with natural gas. Lighting is a mix of T8 and T5 linear fluorescent. Two smaller maintenance and storage buildings are served with electricity from the COF.

Typical energy consumption, as determined by averaging FY18 and FY19 data from MDMS is as follows: 197,673 kWh of electricity (52% of total energy consumed) and 616 MBtu natural gas (48%). The resulting EUI is 39.9 kBtu/ft^2.

3.0 Plug Load Device Inventory

A critical step toward understanding plug-load energy use and savings potential is to identify the types of devices that are used within a building. The diversity of device types, characteristics, and use can be broad and vary significantly from one building to another, and particularly for different types of buildings and the missions that they serve. After identifying the five buildings to study, the team performed walk-through surveys to prepare inventories of the plug-load devices within each building.

The process of surveying plug-load devices and creating a detailed inventory provides several benefits:

- Categorizes and quantifies the equipment in typical Army buildings
- Provides a foundation for developing a metering strategy to help understand plug-load energy use
- Allows for the estimation of savings potential for the variety of methods that may be identified for reducing plug-load energy use.

3.1 Inventory Approach

The approach for performing a thorough survey of plug loads was to conduct a room-by-room review to identify, categorize, and count all miscellaneous electric devices that did not serve a major building end use. In addition to descriptions and categorization, manufacturers, model numbers, and notable features were also documented when possible. Notable features include Energy Star labels, enabled power saving settings, wattages of active modes vs. standby modes,[1] and attributes of the device such as a technology type, size, and vintage. These features were noted to provide context for how devices are being used (e.g., whether power saving settings are properly implemented) and to inform whether policy changes may be applicable for impacting the energy use of such devices. The inventory focused on plugged-in devices but also made note of hardwired MELs such as fire and security systems, elevators, and air compressors.

There is no universally accepted or standard categorization for plug loads and MELs (Butzbaugh et al. 2020). Part of the reason is due to the tremendous diversity of equipment types and the space types and missions they serve. For this study, the categorization approach was based on taxonomies of MEL categories and sub-categories from prior studies reported in the literature that share some similarities to the space and equipment types encountered in this study (e.g., Hafer 2017, Hafer 2015, and Lanzisera et al. 2013). The taxonomy examples from these studies provided a basis for the categorization and reporting of MELs and were subsequently tailored to fit the needs of the Army buildings in this study. The resulting MEL categories applied in this study are presented in Table 3 along with examples of the devices and equipment that fall under each category.

The initial inventory of each building was performed at the beginning of the project, immediately after the final buildings were selected. Because some time elapsed between the initial inventory and installation of metering equipment, each inventory was reviewed, verified, and updated as needed at the time that metering was installed.

[1] Power readings of select equipment in various modes of operation were measured using an Onset HOBO Plug Load Data Logger.

Table 3. Army MEL Categories and Typical Devices

Category	Typical Devices
Audio/Video & Communications	Projectors, Phones, Communications Terminals, Stereos, Radios, Cable Boxes, TV Displays, DVD, Speakers, Cell Phone Chargers
Computing	Desktop Computers, Laptop Computers, Monitors, Uninterruptible Power Supplies (UPS), Network Switches, External Hard Drives, Docking Stations, Computer Speakers
Breakroom	Vending Machines, Refrigerators (Large or Personal), Coffee Makers, Water Coolers, Microwaves, Toasters, Electric Kettles
Documents / Imaging	Personal Printers, Small Networked Printers, Large Copy/Print Devices, Shredders, Plotters, Scanners
Laundry	Washing Machines, Dryers
Occupant Comfort	Space Heaters, Fans (Personal or Industrial Stand), Task Lights, Air Purifiers, Standup Desks
Shop Equipment	Lift Cranes, Air Compressors, Air Dryers + Auto Purge Devices, Power Tools, Parts Cleaners, Battery Chargers, Ground Power Units, Portable Oil/Water Separators, Lab Trailer, Tool Charger, Portable Shop Lights
Facility Loads	Telecom and Networking Infrastructure, Elevators, Fire Alarm Systems, Security Access Control, Restroom Infrared Plumbing Fixture Controls, Hand Dryers

3.2 Inventory Results

The results of the inventories from each of the five study buildings are summarized in Figure 2. A total of 878 MEL devices were inventoried, across the buildings and categories shown. The Admin building has the most devices with 394, the majority of which are in the personal computing category. The BN HQ, COF, TEMF, and UEPH follow. Note that the inventory for the UEPH focused on the common spaces and excluded equipment located in private living quarters. More details on the inventory process and results for each building are presented in the following sections.

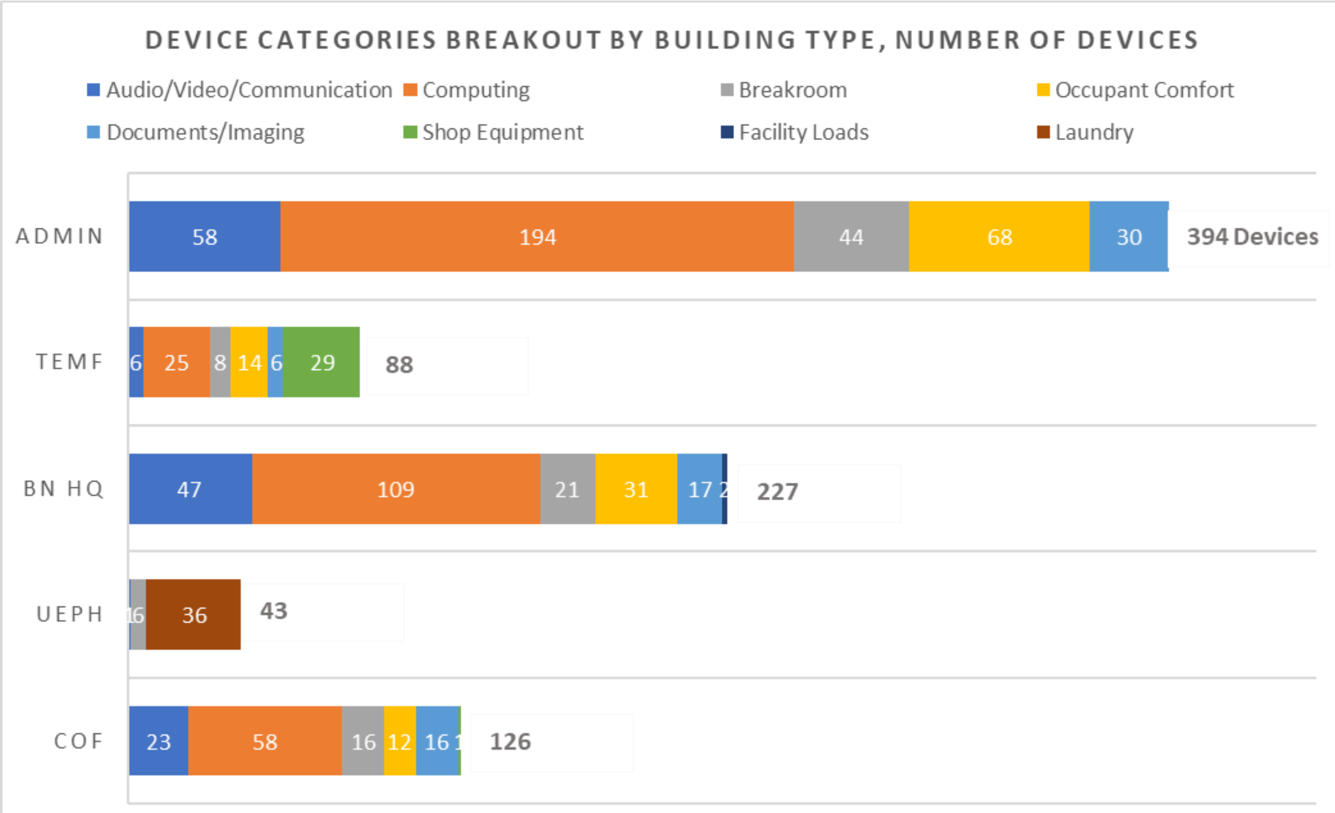


Figure 2. Number of Devices Inventoried by Category and Building Type

3.2.1 Admin

The device inventory for the Admin building is detailed in Figure 3 and Table 4. The inventory identified 394 devices across the categories shown. Nearly all spaces in the Admin building serve as a mix of open and private administrative offices. There is also an IT service room where computers are imaged. The primary devices inventoried in the Admin building include computer monitors, desktop computers, workstation UPSs, and task lights. Most workstations had two monitors, and there were several large refrigerators, personal mini-fridges, and coffee makers throughout the building. Of the five buildings studied, this is the only one that had mini-tower desktop computers, many with UPS units, whereas other buildings had only laptop computers.

The Admin building also had significantly more personal printers and televisions, occupant comfort and breakroom devices (e.g., space heaters, fans, water coolers, and microwaves) than the other buildings. These breakroom and occupant comfort devices account for approximately 28% of MEL devices in the Admin building. Based on the floor area of the building (14,300 ft^2) and number of devices, there are roughly 28 plug-load devices per thousand square feet, or approximately 10.4 devices per occupant. These metrics can be useful in comparing the density of devices between buildings of different sizes and occupancy levels, as well as different administrative building types. For example, the average density of computing equipment within 90 office buildings on the Stanford University campus is reported by Hafer (2015) as 6.8 devices per thousand square feet, compared with over 13 for this Admin building.

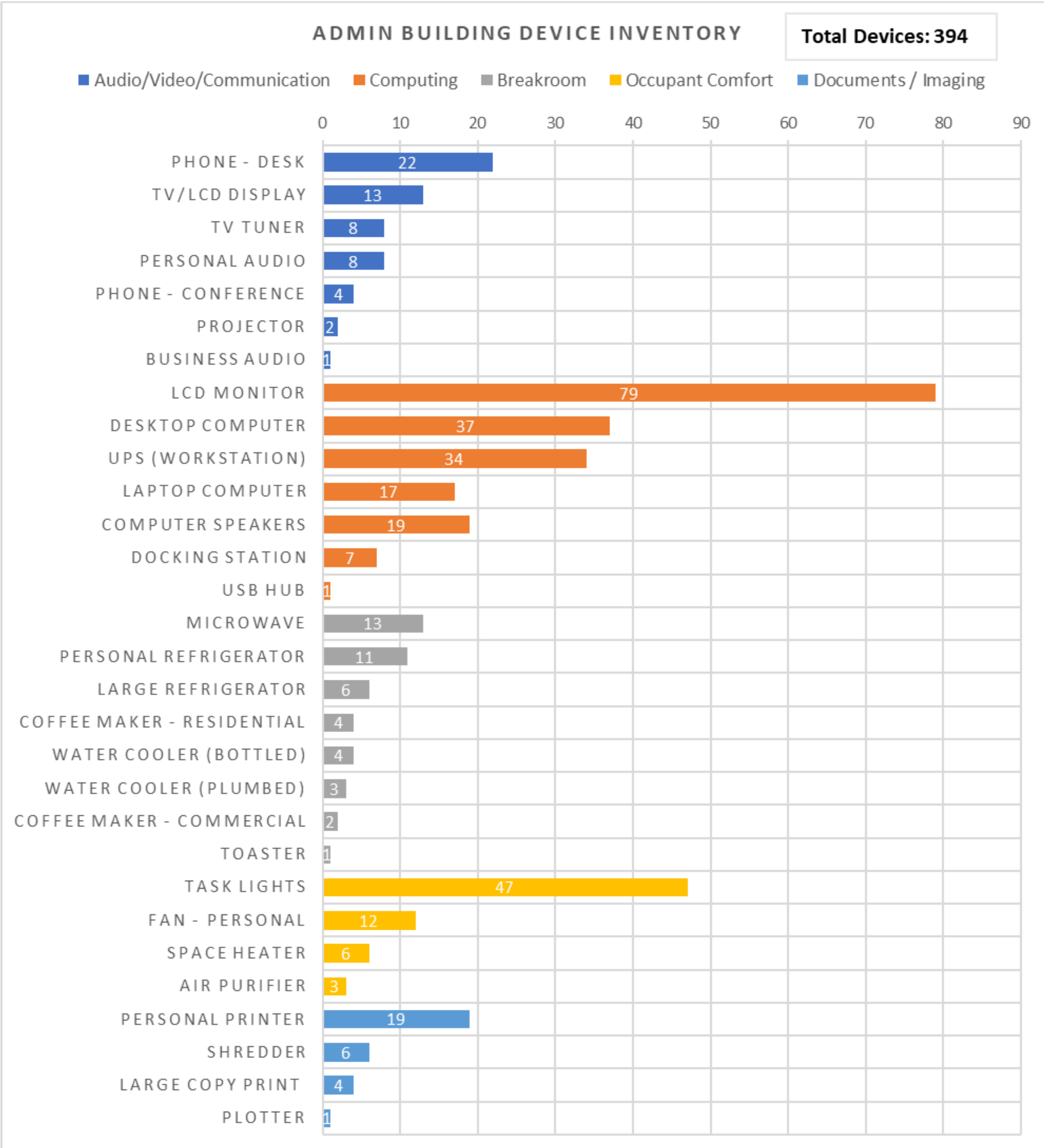


Figure 3. Admin Building Device Inventory

Table 4. Admin Building Device Inventory and Equipment Density

Category	Sub-Category	Count	% of Total	# per ksf	# per Occupant
Audio/Video / Communication	Projector	2	1%	0.14	0.05
	TV/LCD Display	13	3%	0.91	0.34
	Phone - Desk	22	6%	1.54	0.58
	Phone - Conference	4	1%	0.28	0.11
	Personal Audio	8	2%	0.56	0.21
	Business Audio	1	0%	0.07	0.03
	TV Tuner	8	2%	0.56	0.21
	CATEGORY TOTAL	**58**	**15%**	**4.1**	**1.5**
Computing	Desktop Computer	37	9%	2.59	0.97
	Laptop Computer	17	4%	1.19	0.45
	LCD Monitor	79	20%	5.54	2.08
	UPS (workstation)	34	9%	2.38	0.89
	Docking Station	7	2%	0.49	0.18
	USB Hub	1	0%	0.07	0.03
	Computer Speakers	19	5%	1.33	0.50
	CATEGORY TOTAL	**194**	**49%**	**13.6**	**5.1**
Breakroom	Large Refrigerator	6	2%	0.42	0.16
	Personal Refrigerator	11	3%	0.77	0.29
	Coffer Maker - Commercial	2	1%	0.14	0.05
	Coffee Maker - Residential	4	1%	0.28	0.11
	Water Cooler (Plumbed)	3	1%	0.21	0.08
	Water Cooler (Bottles)	4	1%	0.28	0.11
	Microwave	13	3%	0.91	0.34
	Toaster	1	0%	0.07	0.03
	CATEGORY TOTAL	**44**	**11%**	**3.1**	**1.2**
Occupant Comfort	Space Heater	6	2%	0.42	0.16
	Fan - personal	12	3%	0.84	0.32
	Air Purifier	3	1%	0.21	0.08
	Task Lights	47	12%	3.30	1.24
	CATEGORY TOTAL	**68**	**17%**	**4.8**	**1.8**
Documents/ Imaging	Personal Printer	19	5%	1.33	0.50
	Large Copy Print	4	1%	0.28	0.11
	Plotter	1	0%	0.07	0.03
	Shredder	6	2%	0.42	0.16
	CATEGORY TOTAL	**30**	**8%**	**2.1**	**0.8**
TOTALS		**394**	**100%**	**27.6**	**10.4**

3.2.2 TEMF

The TEMF functions primarily as a high bay vehicle maintenance shop but also has administrative, training, and storage spaces. Figure 4 and Table 5 detail the 88 devices inventoried in the TEMF. The primary plug-level devices encountered in the building's administrative areas include laptop computers, monitors, and task lighting built into the workstation furniture, plus a communications terminal. In the high bays, there is a variety of power tools, parts cleaners, and battery charging equipment. Hardwired MELs in this building consist of devices such as a lift crane, bay door openers, and air compressor. The air compressor provides air to pneumatic shop tools and also pressurizes the delivery of vehicle oils and fluids throughout the maintenance bays. The air dryer and auto purge unit operate in tandem with the compressor to ensure the air supplied is dry. Unique to this building is a small, self-contained mobile fuels laboratory trailer that connects to a 240 V outlet in the rear of the building. The trailer remained connected throughout the course of the study.

Based on the square footage of the building (18,100 ft^2) and number of devices, there are 4.9 plug load devices per thousand square feet, or roughly one device for every 204 ft^2. In the TEMF, there were 15 full-time occupants, translating to approximately 5.9 devices per occupant.

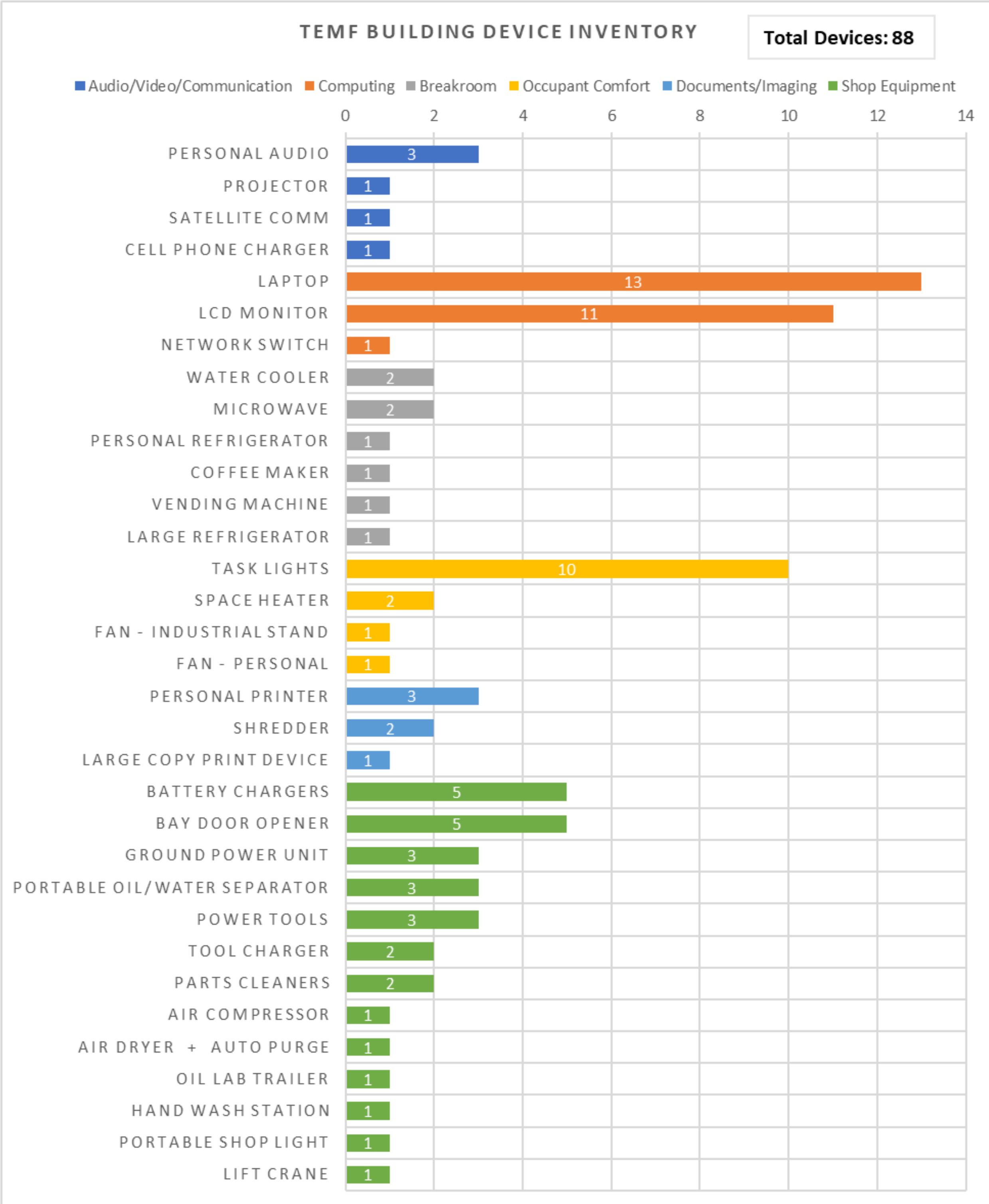


Figure 4. TEMF Building Device Inventory

Table 5. TEMF Building Device Inventory and Equipment Density

Category	Sub-Category	Count	% of Total	# per ksf	# per occupant
Audio/Video / Communications	Projector	1	1%	0.06	0.07
	Personal Audio	3	3%	0.17	0.20
	Comm. Terminal	1	1%	0.06	0.07
	Cell Phone Charger	1	1%	0.06	0.07
	CATEGORY TOTAL	**6**	**7%**	**0.3**	**0.4**
Computing	Laptop	13	15%	0.72	0.87
	LCD Monitor	11	13%	0.61	0.73
	Network Switch	1	1%	0.06	0.07
	CATEGORY TOTAL	**25**	**28%**	**1.4**	**1.7**
Breakroom	Vending Machine	1	1%	0.06	0.07
	Large Refrigerator	1	1%	0.06	0.07
	Personal Refrigerator	1	1%	0.06	0.07
	Coffee Maker	1	1%	0.06	0.07
	Water Cooler	2	2%	0.11	0.13
	Microwave	2	2%	0.11	0.13
	CATEGORY TOTAL	**8**	**9%**	**0.4**	**0.5**
Occupant Comfort	Space Heater	2	2%	0.11	0.13
	Fan - personal	1	1%	0.06	0.07
	Fan - industrial stand	1	1%	0.06	0.07
	Task Lights	10	11%	0.55	0.67
	CATEGORY TOTAL	**14**	**16%**	**0.8**	**0.9**
Documents / Imaging	Personal Printer	3	3%	0.17	0.20
	Large Copy Print Device	1	1%	0.06	0.07
	Shredder	2	2%	0.11	0.13
	CATEGORY TOTAL	**6**	**7%**	**0.3**	**0.4**
Shop Equipment	Bay Door Opener	5	6%	0.28	0.33
	Lift Crane	1	1%	0.06	0.07
	Air Compressor	1	1%	0.06	0.07
	Air Dryer + Auto Purge	1	1%	0.06	0.07
	Power Tools	3	3%	0.17	0.20
	Parts Cleaners	2	2%	0.11	0.13
	Hand Wash Station	1	1%	0.06	0.07
	Battery Chargers	5	6%	0.28	0.33
	Ground Power Unit	3	3%	0.17	0.20
	Portable Oil/Water Separator	3	3%	0.17	0.20
	Tool Charger	2	2%	0.11	0.13
	Oil Lab Trailer	1	1%	0.06	0.07
	Portable Shop Light	1	1%	0.06	0.07
	CATEGORY TOTAL	**29**	**33%**	**1.6**	**1.9**
TOTALS		**88**	**100%**	**4.9**	**5.9**

3.2.3 UEPH

As described previously, the UEPH contains 84 double occupancy living quarter units plus common spaces that include an entry lobby with reception desk, television, and vending area, and a laundry room on each of the three floors. To respect the privacy of the Soldiers in their living space, the team did not perform an inventory of personal plug load devices within the rooms. However, the team talked with some occupants about the types of electronic devices that typically are present in the rooms. These occupants reported that large television sets, computers, gaming consoles, and audio systems are common. In one unit, the occupant indeed had a large flat screen TV, a computer gaming system, and audio system; however, his suitemate simply had an acoustic guitar, proving that personal entertainment tastes do vary and not every room is stacked with high powered electronic equipment. Visiting these units also provided the opportunity to see the typical kitchen equipment in each unit:

- Refrigerator (medium size)
- Microwave
- Two-Burner electric cooktop
- Garbage disposal.

With limited access to the living quarters, the device inventory for the UEPH focused on the common area spaces as shown in Figure 5 and Table 6. The primary devices inventoried were laundry washing machines, dryers, and vending machines. Assuming an 80% occupancy rate, there are approximately 0.3 common area devices per occupant. Additionally, the floor area of 63,800 ft^2 translates to roughly 0.7 common area devices per thousand square feet.

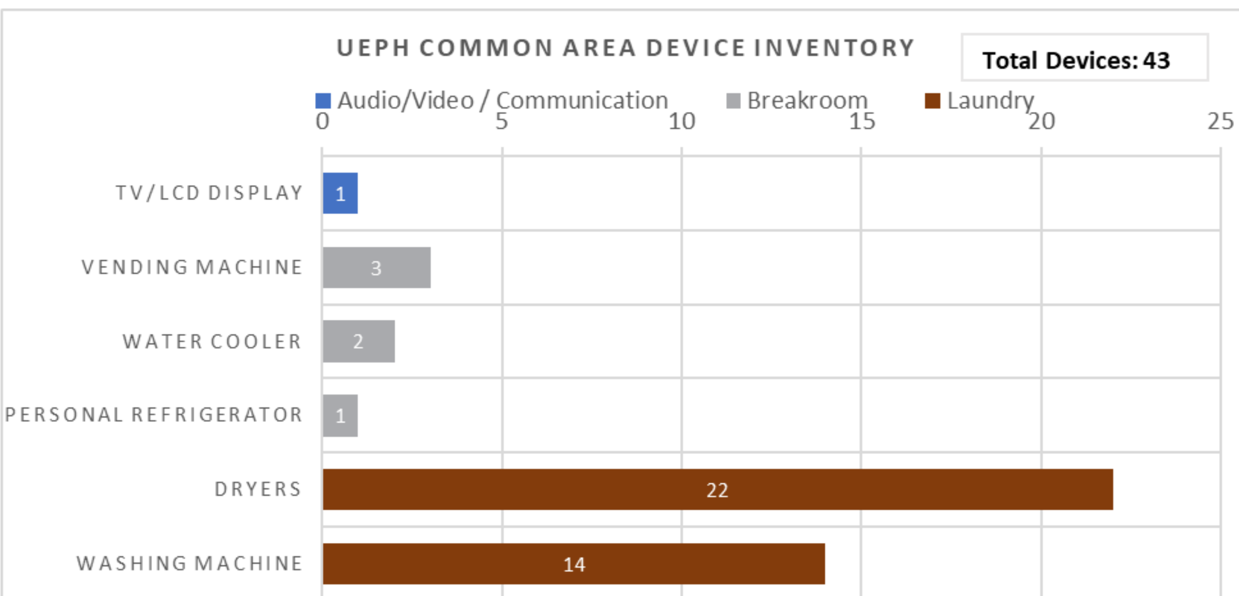


Figure 5. UEPH Common Area Device Inventory

Table 6. UEPH Common Area Device Inventory and Equipment Density

Category	Sub-Category	Count	% of Total	# per ksf	# per occupant
Audio/Video / Communications	Television	1	2%	0.02	0.01
	CATEGORY TOTAL	1	2%	0.02	0.01
Breakroom	Vending Machine – Refrigerated	2	5%	0.03	0.01
	Vending Machine – Non-Refrigerated	1	2%	0.02	0.01
	Personal Refrigerator	1	2%	0.02	0.01
	Water Cooler	2	5%	0.03	0.01
	CATEGORY TOTAL	6	14%	0.09	0.04
Laundry	Washing Machines	14	33%	0.22	0.10
	Dryers	22	51%	0.34	0.16
	CATEGORY TOTAL	36	84%	0.56	0.27
TOTALS		43	100%	0.7	0.3

3.2.4 BN HQ

Figure 6 and Table 7 detail the inventory in the BN HQ, which is primarily administrative space. The inventory accounted for 227 devices, the majority of which include workstation equipment such as laptop computers, monitors, and desk phones. A component unique within the study buildings are the training and computer lab rooms. These training rooms in the Battalion HQ are highly configurable and provide several rows of floor-mounted outlets for staff and Soldiers to use for laptop power and other equipment to meet different mixes of conference, training, computer lab, and temporary admin space requirements. Hardwired MELs in the building include a hydraulic elevator, restroom hand dryers, telecom and networking spaces, and fire alarm and security systems.

Based on the square footage of the building (14,000 ft^2) and number of devices, there are 16.2 plug load devices per thousand square feet, or roughly one device for every 60 ft^2. This equates to roughly 6.3 devices per occupant.

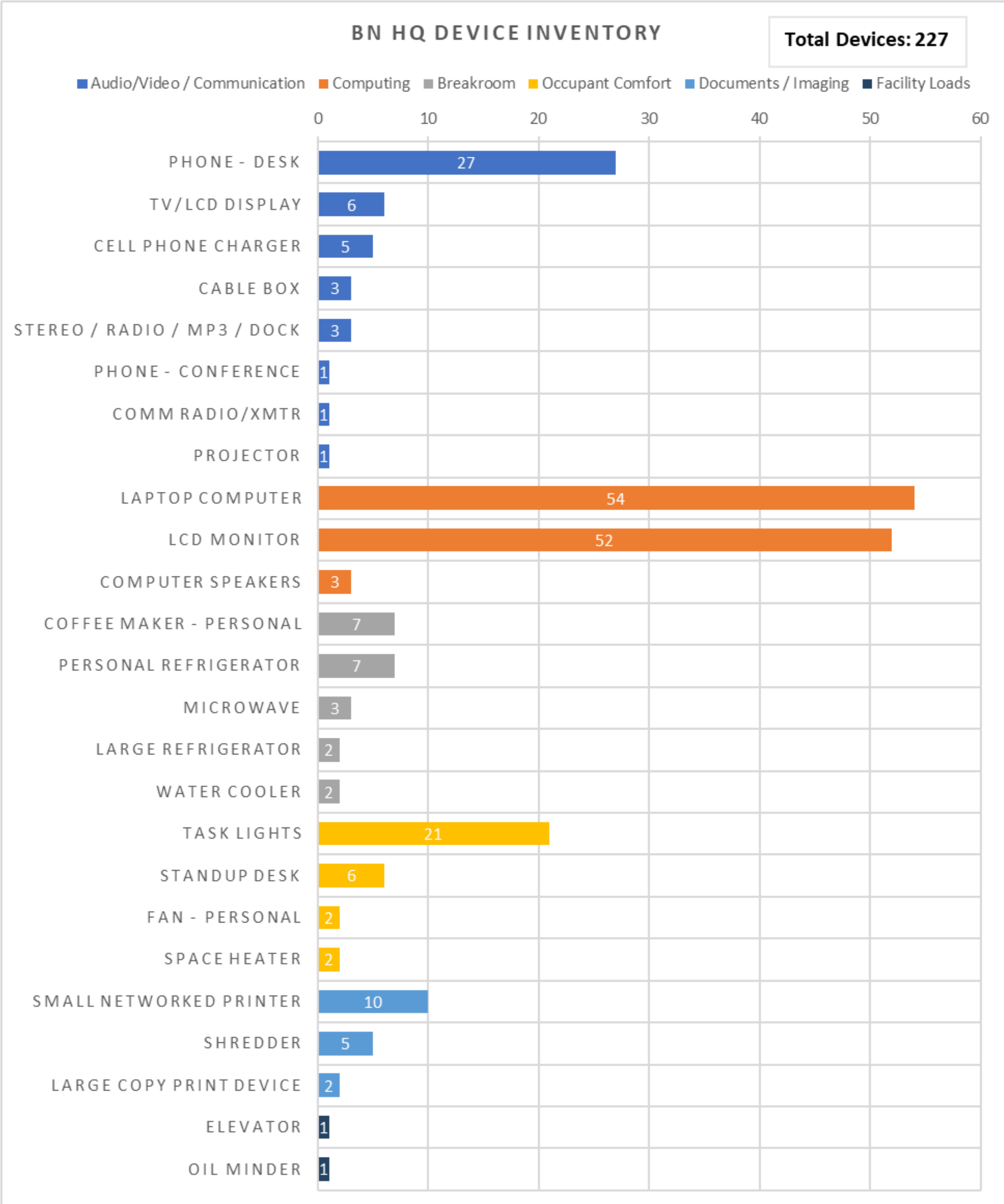


Figure 6. BN HQ Device Inventory

Table 7. BN HQ Device Inventory and Equipment Density

Category	Sub-Category	Count	% of Total	# per ksf	# per occupant
Audio/Video / Communications	Projector	1	0%	0.07	0.03
	TV/LCD Display	6	3%	0.43	0.17
	Phone - Desk	27	12%	1.93	0.75
	Phone - Conference	1	0%	0.07	0.03
	Personal Audio	3	1%	0.21	0.08
	Cable Box	3	1%	0.21	0.08
	Comm Radio/Transmitter	1	0%	0.07	0.03
	Cell Phone Charger	5	2%	0.36	0.14
	CATEGORY TOTAL	**47**	**21%**	**3.4**	**1.3**
Computing	Laptop Computer	54	24%	3.86	1.50
	LCD Monitor	52	23%	3.71	1.44
	Computer Speakers	3	1%	0.21	0.08
	CATEGORY TOTAL	**109**	**48%**	**7.8**	**3.0**
Breakroom	Large Refrigerator	2	1%	0.14	0.06
	Personal Refrigerator	7	3%	0.50	0.19
	Coffee Maker - Personal	7	3%	0.50	0.19
	Water Cooler	2	1%	0.14	0.06
	Microwave	3	1%	0.21	0.08
	CATEGORY TOTAL	**21**	**9%**	**1.5**	**0.6**
Occupant Comfort	Space Heater	2	1%	0.14	0.06
	Fan - personal	2	1%	0.14	0.06
	Standup Desk	6	3%	0.43	0.17
	Task Lights	21	9%	1.50	0.58
	CATEGORY TOTAL	**31**	**14%**	**2.2**	**0.9**
Documents / Imaging	Small Networked Printer	10	4%	0.71	0.28
	Large Copy Print Device	2	1%	0.14	0.06
	Shredder	5	2%	0.36	0.14
	CATEGORY TOTAL	**17**	**7%**	**1.2**	**0.5**
Facility Loads	Elevator	1	0%	0.07	0.03
	Oil Minder	1	0%	0.07	0.03
	CATEGORY TOTAL	**2**	**1%**	**0.1**	**0.1**
TOTALS		**227**	**100%**	**16.2**	**6.3**

3.2.5 COF

Figure 7 and Table 8 detail the inventory results for the COF building, covering 126 devices. The most prevalent devices inventoried at the COF are computing equipment, including laptops and monitors. The front section of the COF building includes administrative areas with offices, conference rooms, and breakrooms. These are the highest density plug load areas with devices common to these spaces such as computers, monitors, telephones, cell phone chargers, printers, coffee makers, and microwaves. Additionally, there are readiness/staging and storage areas that have limited plug-load devices. Notable devices in these areas consisted of a parts cleaner, a large refrigerator, a large fan, and a few additional workstations with computing equipment in the supply areas. Hardwired equipment that were not listed in the inventory but noted as MELs include security systems, access control equipment, restroom infrared controls, telecommunications and networking spaces, and a fire alarm system.

Based on the floor area of the building (32,300 ft^2) and number of devices, there are roughly four plug load devices per thousand square feet, or approximately 3.6 devices per occupant.

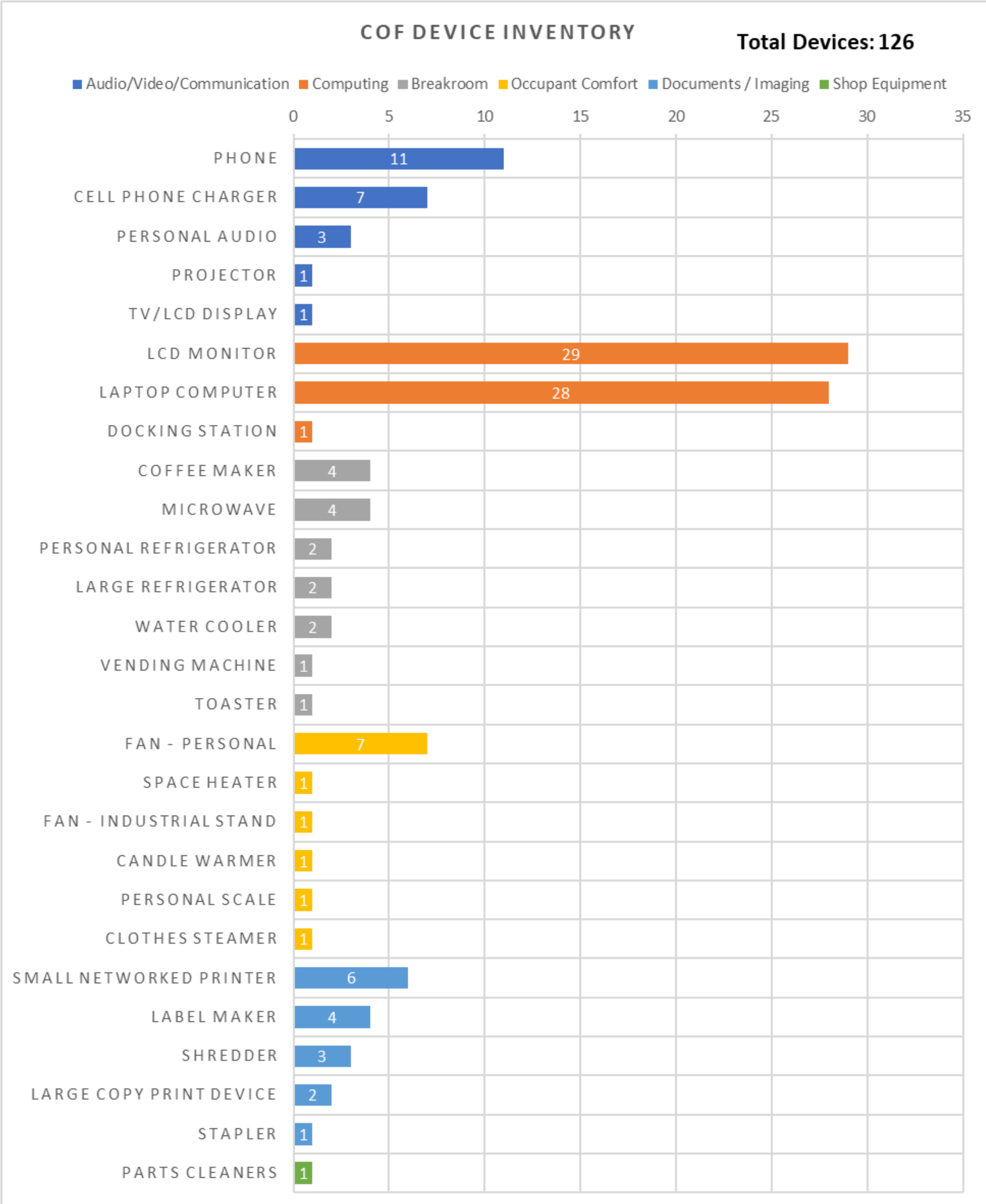


Figure 7. COF Building Device Inventory

Table 8. COF Building Device Inventory and Equipment Density

Category	Sub-Category	Count	% of Total	# per ksf	# per occupant
Audio/Video / Communications	Projector	1	1%	0.03	0.03
	TV/LCD Display	1	1%	0.03	0.03
	Phone	11	9%	0.34	0.31
	Personal Audio	3	2%	0.09	0.09
	Cell Phone Charger	7	6%	0.22	0.20
	CATEGORY TOTAL	**23**	**18%**	**0.7**	**0.7**
Computing	Laptop Computer	28	22%	0.87	0.80
	LCD Monitor	29	23%	0.90	0.83
	Docking Station	1	1%	0.03	0.03
	CATEGORY TOTAL	**58**	**46%**	**1.8**	**1.7**
Breakroom	Vending Machine	1	1%	0.03	0.03
	Large Refrigerator	2	2%	0.06	0.06
	Personal Refrigerator	2	2%	0.06	0.06
	Coffee Maker	4	3%	0.12	0.11
	Water Cooler	2	2%	0.06	0.06
	Microwave	4	3%	0.12	0.11
	Toaster	1	1%	0.03	0.03
	CATEGORY TOTAL	**16**	**13%**	**0.5**	**0.5**
Occupant Comfort	Space Heater	1	1%	0.03	0.03
	Fan - personal	7	6%	0.22	0.20
	Fan - industrial stand	1	1%	0.03	0.03
	Candle Warmer	1	1%	0.03	0.03
	Personal Scale	1	1%	0.03	0.03
	Clothes Steamer	1	1%	0.03	0.03
	CATEGORY TOTAL	**12**	**10%**	**0.4**	**0.3**
Documents / Imaging	Small Networked Printer	6	5%	0.19	0.17
	Large Copy Print Device	2	2%	0.06	0.06
	Label Maker	4	3%	0.12	0.11
	Stapler	1	1%	0.03	0.03
	Shredder	3	2%	0.09	0.09
	CATEGORY TOTAL	**16**	**13%**	**0.5**	**0.5**
Shop Loads	Parts Cleaner	1	1%	0.03	0.03
	CATEGORY TOTAL	**1**	**1%**	**0.0**	**0.0**
TOTALS		**126**	**100%**	**3.9**	**3.6**

4.0 Data Collection and Energy Consumption Estimation

A detailed metering plan was developed for each of the study buildings following the walk-through and comprehensive inventory of plug-load devices. The plan was designed for each building based on availability and quality of existing metered data, electrical system layout, individual building equipment characteristics, and identified areas of focus. Efficient approaches that would provide robust results at moderate cost were prioritized to maximize impact and understanding for the level of metering deployed. Therefore, the monitoring approach was different for each building and informed by the number and types of MELs in each building, along with the electrical wiring configuration and ability to monitor desired loads at the electrical panels and sub-panels.

A combination of device- and panel-level monitoring was performed to evaluate the magnitude of MELs and understand the characteristics of the loads. The monitoring of plug load devices and MELs occurred in two phases to reduce the need for metering equipment. The first phase occurred from May into early October, within the Admin, TEMF, and UEPH buildings. Phase two occurred within the BN HQ, from November through March. Because of time and budget constraints, no monitoring was performed in the COF; however available interval electricity data from the MDMS and the Fort Carson energy management control system (EMCS) were used along with the details from the building inventory to estimate plug-load energy use in that building.

For the Admin, TEMF, UEPH, and BN HQ buildings, a mix of electrical load monitoring was performed considering a combination of bottom-up and top-down methods. Energy-monitoring equipment was deployed at both the individual device level and within select electrical panels, sub-panels, and circuits. For all buildings, available whole-building interval-metered data from MDMS and/or the Fort Carson EMCS were evaluated to help validate the results of the team's metering and analysis efforts. The data were used to help bound the resulting energy use estimates and to assess the potential for using available building interval meter data to address potential plug loads more broadly in Army buildings going forward. The remainder of this section discusses the energy monitoring and data collection process and introduces the energy consumption estimation methods for the various bottom-up and top-down approaches performed in this study.

4.1 MEL Monitoring

As described below, a combination of device and panel load monitoring was performed within most of the study buildings. The technologies and general methods are described below, with additional detail in Appendix A.

4.1.1 Device-Level Load Monitoring

Upon completion of the initial inventory and categorization of plug load equipment, a metering plan was developed for each building. The focus of the plan was to balance costs with the desire to maximize the types and number of devices monitored with a sample size large enough to give a high confidence in the resulting data, with particular attention given to devices believed to contribute the most to energy use and/or offer high potential for reduction via policy or other changes. The literature provided some insight on the number of samples to monitor. Analysis by Lansizera et al. (2013) for their study in a commercial office environment suggests that an appropriate sample size to achieve a reasonably tight (±15–20%) confidence distribution of annual energy use for a device type ranges from 14–37% for most plug device categories, depending on the category as well as the total population size. Given the smaller number of devices in these Army buildings and the expected greater variability in use than in a typical commercial office environment, the higher end of sample size target of 30–40% was desired for most device types in this study.[1] Notable exceptions to this target include devices believed to have minor energy-use contribution, devices that are mobile in nature and difficult to effectively monitor, and devices believed to have less variation in load across the category. Given this approach, the method used to develop a feasible device-level monitoring plan considered the following criteria:

- Maximize type and quantity of devices to be monitored
- Capture a representative variation in device characteristics, use, and location within each building
- Prioritize high energy-consuming device types and those likely suitable for energy-reduction measures via policy changes or other drivers
- Include, as possible, a representative sample of all accessible devices without interfering with normal use or functionality.

Device-level monitoring was performed using a commercial plug load monitoring system from Ibis Networks.[2] The system includes a variety of data collection sockets and operates on a wireless Zigbee mesh network to transmit data regarding the voltage, current, power, and connectivity through each socket to a central gateway that then uploads the data to the cloud for storage, access, and analysis. The system uses a secure Zigbee protocol with AES-128 encryption to protect the data. Cellular modems were used to transmit the device power data to the cloud in order to maintain complete separation from Army networks. Figure 8 shows example photos of the Ibis Networks system components in use during this study.

Each device identified for monitoring was connected to an Ibis Networks socket to monitor its power draw. Data were measured in near real-time and made available for tracking at the one-minute interval. The resulting minute-interval load detail (in watts) for each monitored device was then used to calculate energy consumption and understand the nature of the load signature of each device.

[1] Actual percentages of devices monitored are presented in tables within Section 5.0 for each building (also Appendix C). Note that the 30-40% target was exceeded for some devices, and not attained for others.
[2] Ibis Networks commercial plug load monitoring system, see https://ibisnetworks.com/.

Figure 8. Ibis Networks Plug Load Monitoring System (top left: gateway and cellular modem; others: Ibis sockets connected to various devices – battery chargers in TEMF, parts cleaner and bench grinder, and workstation equipment)

4.1.2 Electrical Panel Load Monitoring

Monitoring of select building electrical panels and circuits also was performed to supplement data gathered at the device level. This metering falls into the category of “end-use metering” and was installed at the main electrical distribution panel, sub-panels, and individual circuit breakers. To assure reliable, accurate, and real-time communication, all metering was connected via cellular communications to operate autonomously of any other wired, wireless, or building system communications. Panels, sub-panels, and circuits amenable to monitoring were identified that would provide additional detail on MELs. Where possible, a mix of whole-building loads, major end-use loads, panels and circuits with MELs (including circuits with receptacle loads, hardwired MEL equipment, and spaces that were not accessible for device-level metering) were monitored. The deployment of panel metering was largely dictated by the wiring configuration within a building and the location of the electrical panels. The project-installed metering focused on the TEMF, UEPH, and BN HQ, and by design, each received a slightly different level of metering intervention.

The metering system installed within these buildings is the eGauge Pro, from eGauge Systems.[1] It consists of a 30-channel data logger that provides up to 30 connections to current transformers sized by code requirements for the loads to be monitored. Data are stored internally and also transmitted to the cloud for access and download via a cellular modem. Figure 9 shows examples of the eGauge system used in this study. Additional information about the technology including ancillary components, data collection, and communications protocols is available in Appendix A.

Figure 9. eGauge Data Logger Connected to TEMF Main Distribution Panel (left) and the Components Inside the Enclosure (right)

4.2 Metering Approach by Building

The application of metering within this study, and the mix of device- and panel-level monitoring, varied by building, and was driven by factors including the types of MELs, building wiring configuration and panel locations, and project budget and schedule. This section provides an overview of the metering strategy for each building, the drivers that contributed to the approach, and some of the metering challenges encountered. Table 9 summarizes the data available for each study building, and Table 10 lists the period and duration for which the device and panel monitoring was performed within each building.

[1] eGauge Systems LLC, commercial energy monitoring system. https://www.egauge.net/

Table 9. Summary of Load Data for each Building

Building	Device Monitoring	Panel Monitoring	MDMS Whole Building 15-Minute Interval	EMCS Whole Building 1-Minute Interval
Admin	✓		✓	✓
TEMF	✓	✓	✓	
UEPH	✓	✓	✓	✓
BN HQ	✓	✓	✓	✓
COF			✓	✓

Table 10. Duration of Monitoring by Type and Building

Building	Device Monitoring	Panel Monitoring
Admin	20 weeks (May-September)	None
TEMF	22 weeks (May-October)	16 weeks (June-October)
UEPH	21 weeks (May-October)	16 weeks (June-October)
BN HQ[(a)]	18 weeks (October-March)	11 weeks (December-February)
COF[(b)]	None	None

(a) Listed period represents data analyzed for report; monitoring of BN HQ has continued past report delivery due to access restrictions at Fort Carson in response to the COVID-19 pandemic
(b) Monitoring of COF not performed

4.2.1 Admin

The Admin building is the oldest of the study buildings, and its wiring configuration is not as amenable to panel monitoring of MELs as the other buildings. The primary sub-panel with receptacle circuits is located in the main hallway, making safe monitoring of its loads impractical. Therefore, monitoring of MELs within the Admin was limited to device-level metering using the Ibis Networks system. Because select panel and sub-panel loads would not be captured, a higher number of device meters were deployed to capture the variability of devices and use patterns. In total, over 140 device meters were installed, covering the range of device types that are present. A few staff office moves within the building complicated some of the device monitoring, but the team was able to reconcile the changes and identify the new equipment that was plugged into the meters.

4.2.2 TEMF

To capture the diversity of equipment and loads within the TEMF, a mix of device and panel monitoring was necessary in that building. Device-level meters were deployed on 44 plug-in devices ranging from laptop computers and other office equipment, the communications terminal, breakroom appliances, vehicle battery chargers, and other shop equipment.

Two eGauge panel metering systems were installed. One was installed to monitor the whole building and primary sub-loads from the main distribution panel (MDP). In addition to the building main feed, this system captured other key loads such as the air compressor, crane, HVAC equipment, lighting, and sub-panels that serve a mix of receptacles and other loads. The second eGauge data logger was installed on one of those sub-panels, recording loads for a mix of circuits including receptacles for the battery chargers, shop, administration spaces, the breakroom, the training room, and select hardwired facility loads. Hardwired loads include the fire alarm control panel, intrusion detection and access systems, telecommunications room, and infrared system for controlling auto-flush and faucet valves on restroom plumbing and shop handwash fixtures. Prior to installation, circuits on the sub-panel were traced to verify that the loads were labeled correctly. Because of safety requirements, all panel-level metering in the TEMF was limited to enclosed and secure electrical rooms; this precluded metering at panels located in the open-bay maintenance areas. Sixty channels of power were monitored in this building—10 three-phase sub-panels and 30 single/double-pole breakers.

The main challenge resulted from field exercises when many of the building occupants would leave and take equipment with them. Upon return with only minor exceptions, occupants reconnected the devices to the meters as they had been before departure. The PNNL team identified the few changes in load signatures being captured by the metering equipment and was able to resolve these discrepancies to align the collected loads for monitored devices prior to data analysis.

4.2.3 UEPH

As described in Section 3.2.3, the inventory and monitoring of plug load devices in the UEPH was limited to common areas so the privacy of Soldiers within their living quarters could be sustained. Device-level monitors were deployed on most common area equipment with the exception of the clothes dryers.[1] A total of 19 device meters were installed on common area equipment.

The UEPH presented metering challenges because of its size, the number of electrical panels, and the distribution of panels across electrical/HVAC rooms and within each of the barracks rooms. Electrical panels serving individual circuits within the barracks rooms are located within each private space in this building. To understand the magnitude and nature of the occupied unit loads, panel monitoring was installed on a sub-panel (load center) serving approximately one-third of the barracks rooms. The three-phase (120/208) wiring of the load center resulted in a distribution panel breaker allocation of three double-occupancy rooms per breaker, where each phase serves individual loads across the three rooms and the cook top would use two of the phases for its power. For the 10 three-phase circuits monitored, the actual loads of the three rooms are balanced across the supplying circuit, however, the equivalent of a single room's diversity of loads is included on each phase. As a result, load monitoring on each phase provides insight into the load for a representative, if not actual, occupant space, including kitchen appliances and receptacles, bathroom receptacles, bedroom receptacles, and lighting. Overall, the monitored circuits capture the loads from 30 of the 84 double-occupancy barracks units in the building (36% of the units).

4.2.4 BN HQ

As shown in Table 10, the BN HQ was the last building to have metering deployed. Inclement weather and ongoing mission activities within the building forced the installation of device-level

[1] The gas dryers were replaced with electric units in early CY19 after the initial inventory was performed, and no there are no Ibis Networks sockets compatible with dryer plugs. The energy use of dryers was therefore estimated by applying a typical dryer energy use of 2.897 kWh per dryer cycle to the number of washer cycles identified by the washer monitoring (per Bendt 2010).

metering to diverge from the planned approach. Thirty-nine device meters were installed, but they were not able to capture as representative a cross section of the plug load equipment types and use as in the other buildings. The impact of this more limited device-level metering became evident while compiling and analyzing the results, which tend to underestimate what is believed to be the true level of energy consumed by plug loads in this building. This lesson is notable because it underscores the importance of monitoring a sufficient and representative cross section of devices and use patterns to obtain the best results.

Fortunately, a highly robust panel metering strategy was deployed within this building to capture a detailed and comprehensive look at total MELs, as well as select hardwired loads and groups of receptacles. The BN HQ building metering design focused on the building MDP plus circuits within two key sub-panels. An effective “exception metering” approach was applied whereby all MDP breakers/sub-panels were metered as well as most non-MELs (e.g., electric unit heaters, small HVAC system pumps, controllers, and other process loads) on the MEL-dominated panels. Once aggregated, the non-MELs were subtracted from the MELs panels to arrive at the MELs-only loads. This “exception metering” approach was facilitated in the BN HQ building because, different than the TEMF, the BN HQ loads were more uniformly segregated across a typical panel structure, including three designated plug panels. Ninety channels of power were monitored in this building—10 three-phase sub-panels and 60 single/double-pole breakers.

4.2.5 COF

Because of budget and schedule constraints, no metering was deployed in the COF. However, the building remained in the study to demonstrate the potential for estimating plug load energy use based on a detailed device inventory coupled with equipment energy use obtained from metering in other buildings. Additionally, whole-building interval-metered data from MDMS and the Fort Carson EMCS were applied to perform a top-down assessment of the energy use from its plug loads.

4.3 Estimating Plug Load Energy Consumption

A core focus of this study was to estimate the aggregate energy consumption from plug-load devices and hardwired MELs. Several approaches have been evaluated and applied to estimate annual plug-load energy use. However, not every building is amenable to all types of methods because of factors such as the quality of available MDMS and EMCS data, electrical wiring and panel locations and circuits that are amenable to metering, etc. Multiple approaches have been applied to better estimate the energy consumption from plug loads rather than relying on a single method without validation. Additional benefits may be gained by estimating how well a given method may perform relative to cost. For example, better understanding of how well such loads can be estimated using MDMS data, compared to metering at the main distribution panel, specific circuits, and/or the device level, may help highlight some potential new uses for MDMS data, as well as when additional metering may be warranted. A summary of each approach is described here. Details on each estimation methodology are presented in Appendix B.

4.3.1 Bottom-Up Approaches

Two similar bottom-up approaches to estimate the annual consumption of plug load and MEL devices are applied in this study. The preferred approach follows the results from device-level metering that was used in four of the study buildings. A consumption-by-proxy approach also was applied in two of the study buildings where device-level metering was either not performed or is of questionable accuracy based on it not representing the breadth of equipment types and use present.

4.3.1.1 Device-Level Metering

The primary bottom-up methodology for estimating a building's energy consumption from plug loads and MELs relies on building up loads and energy use from a representation of the surveyed diversity of plugged-in and hardwired devices within the building. This approach therefore relies on device-level as well as select circuit-level metering of specific equipment. Energy use data collected over monitoring period are extrapolated to an estimate of annual energy consumption.

4.3.1.2 Consumption by Proxy

A consumption-by-proxy approach provides an estimate of annual MEL electricity consumption by applying unit energy consumption (UEC) values for equipment calculated in other buildings, to the detailed device inventory of the building in question. In the COF, no metering was performed; therefore, an estimate of MEL consumption was made by applying calculated UEC values from similar devices in other buildings to the results from the device inventory of the COF. Similarly, even though device-level metering was deployed in the BN HQ, the team realized that it did not capture the most representative mix of devices across some categories. Therefore, a consumption-by-proxy approach also was applied to select device types in the BN HQ to evaluate a possible improvement in the resulting bottom-up estimation of plug load and MEL consumption. In both cases, a representative UEC for similar devices metered in other buildings was multiplied by the number of devices of that type in the building under evaluation to estimate the total annual electricity consumption for the inventoried population of those devices.

4.3.2 Top-Down Approaches

Top-down estimates of plug load energy consumption can provide a cost-effective approach to understanding, at least at a high level, the magnitude of MELs and the energy they consume, by analyzing existing data or acquiring a limited amount of new data. Results offered by top-down methods are also important for validating and appropriately bounding results of bottom-up estimates. A few top-down consumption estimation approaches have been examined and applied in this study, with the goal of evaluating and comparing the results to better understand tradeoffs between the level of accuracy and cost of acquiring more detailed data.

A top-down MELs disaggregation was completed for each of the five study buildings. In two of the buildings (i.e., COF and Admin), the top-down approach relied solely on MDMS 15-minute and/or EMCS 1-minute interval data. In the other three building types (i.e., TEMF, BN HQ, and UEPH), the approach used both MDMS/EMCS data and project-installed panel-level metering that included some form of MDP, sub-panel (e.g., lighting, HVAC, plug-load, etc.), and/or breaker-level monitoring.

Each of the top-down methods applies a similar approach, with the main difference being the resolution of the data used in the assessment (e.g., standard 15-minute MDMS data, 1-minute whole-building interval data from the Fort Carson EMCS, 1-minute project-metered data from the MDP and select end-use panels). A variety of these methods were applied in each of the study buildings, as the metering approach and availability of reliable MDMS and EMCS interval data allowed. The potential benefit to the Army from these top-down estimations are to provide a comparison of the improvement in accuracy and detail from more disaggregated data. In some cases, a mix of bottom-up and top-down methods were necessary to maximize understanding for the amount of metering that was determined to be feasible for specific buildings and loads. This hybrid approach is described further in the next section.

4.3.2.1 Whole-Building Interval-Metered Data Analysis

In addition to the selective metering performed, two sources of whole-building interval-metered data were evaluated for the study buildings—MDMS 15-minute interval and 1-minute interval data provided by the Fort Carson EMCS. Both data types originated from the same building meter; although, each type was processed differently to compile at the different time intervals. Data from each source was available for each of the five study buildings and were evaluated to perform a high-level, top-down assessment of MELs as described in Appendix B.2.

Whole-building electric interval data offer a variety of benefits and challenges when attempting to disaggregate the whole-building load into the sum of its parts. Depending on factors including building characteristics, the systems contained within, usage patterns, data intervals, and metering system resolution, this exercise can be very productive for large, distinctive, and/or episodic loads. For smaller, less distinctive loads this process can be challenging. By definition, MELs fall into this smaller, less distinctive load category.

Nonintrusive load monitoring (NILM) is a process that has been under development to assist with load disaggregation through the monitoring of a whole-building electrical feed. The concept applies machine learning to identify signature load patterns from the analysis of the main distribution load without invasive end use and device-level metering. However, the vision for NILM has thus far outpaced reality. A recent demonstration under the DoD Environmental Security Technology Certification Program (ESTCP), evaluated a commercially available NILM technology within three facilities at Joint Base Lewis-McChord. The results suggest that the NILM technology is not yet ready for typical Army facilities, especially for smaller loads such as plug load devices, and failed to identify a reasonable number or diversity of equipment outside of a few major loads (Meier et al. 2019).

By applying a “minimum-load process” disaggregation approach, whole-building interval data is, to some extent, useful for estimating the magnitude of MELs within a building. This approach uses daily whole-building consumption profiles that are reviewed to identify a “profile minimum.” This minimum is assumed to encompass the building’s always-on loads, the majority of which are typically MELs. Acknowledging this is an approximate order-of-magnitude approach to estimating MELs and not ideal for higher-accuracy MEL assessments, it can be useful as a top-down MEL estimate for building-type comparisons or to identify ranges of estimated use. In general, the 1-minute interval data are most useful for MEL estimation, and they also provide much better definition of larger-system functions (e.g., HVAC, lighting, other process loads, etc.), operating profiles, and schedule confirmation. However, poor data resolution can present challenges in distinguishing load changes within a broad band. For example, the resolution of the 1-minute data captured at the 1 kWh resolution for the TEMF was so low it could not be used to distinguish loads within that building.

4.3.2.2 Detailed End Use Panel and Circuit Metering

If the metering approach allows sufficient data to be captured at the end use level, total MELs can be isolated from other end uses and more directly summed and extrapolated to an annual estimate of electricity consumption. Depending on the layout of the electrical panels and loads, this can be accomplished directly if all MEL circuits can be metered. A variance of this approach, metering by exception can be applied to specifically subtract individual loads from a sub-panel that may otherwise serve MELs. This latter approach was successfully applied in the BN HQ, where all MDP breakers/sub-panels were metered as well as most non-MELs (e.g., small HVAC equipment, pumps, controllers, and other process loads) on the MEL-dominated panels. Once aggregated, the non MELs are subtracted from the MEL panels to determine the MEL total.

The process is somewhat similar to the bottom-up approach described above, where total MELs electricity consumption is estimated by aggregating and extrapolating metered power and consumption data over the monitoring period to annual electricity consumption. This annual consumption is derived over the relevant circuits representing discrete and aggregate MELs and subtracting any non-MELs that are included. For seasonal loads such as those for electrical unit heaters, vestibule heaters, and heating water distribution pumps, the extrapolation to annual energy consumption was performed using a heating degree-day (HDD) adjustment based on the ratio of HDD over the monitoring period to the annual HDDs.

4.3.3 Hybrid Approach

A combination of some of these approaches is sometimes warranted depending on the level of data captured at the device and panel/circuit levels. A hybrid approach can be applied by combining elements of bottom-up and top-down methods in which both device-level and select panel meter data exists, but perhaps without complete coverage of loads for each. In this approach, load data from select panels and circuits can be compared with measured loads from the same panel or circuit and used to fill in gaps of missing data. This approach can be particularly useful to validate and estimate missing loads from an incomplete bottom-up approach, where not all plug loads were able to be captured at the device level.

For example, this hybrid method was used for the TEMF, where a number of the shop plug loads were not feasibly monitored because of their distributed and highly mobile nature. Detailed device-level load data were therefore augmented with targeted panel and circuit load data to provide a robust estimate of loads that could not be reliably captured at the device level. Similarly, the loads on select panels were able to be more effectively disaggregated by removing known loads captured at the device level. By combining elements of the bottom-up and top-down approaches, such hybrid methods combine the best of both approaches to arrive at an estimate of annual MEL energy consumption that is more complete than either method could achieve alone, especially when data coverage from one or both methods may be incomplete. Again, the suitability of each approach is influenced greatly by the nature of the building, its wiring configuration and loads, and accessibility of specific devices and electrical panels to be safely and cost effectively monitored. Overall, the approach may be best categorized as bottom-up, even though it applies data from some aggregated loads from select panels.

5.0 Plug Load Energy Use and Load Analysis

The results of the study provide insights into MELs energy use within each type of Army building evaluated. This section presents the results from the various top-down and bottom-up methods applied for estimating the annual energy consumption of plug loads within each building, along with details on the approximate energy use per device (unit energy), and for the entire population of devices of each type as inventoried in each building. Additionally, metrics such as energy consumption per thousand square feet and per occupant are noted to provide a starting point to interpret and extrapolate the results across other buildings of similar type and function.

5.1 Summary Results

This study applied up to five approaches for estimating annual MEL energy consumption for each study building. In all but one of the study buildings, the bottom-up/hybrid approach is deemed to offer the most robust estimate, based on the understanding of each approach and the underlying data. For the BN HQ, the detail captured by the panel and circuit metering allowed that top-down approach to provide the most accurate estimate for that building. The resulting estimates deemed most robust for each building are summarized in Table 11.

Table 11. Summary of Best Estimate Annual MEL Consumption by Building

Building	MELs Annual Electricity Consumption, Best Estimate, kWh/yr	Percent of Total Building Electricity (%)	Percent of Total Building Energy Use (%)	Estimated Electricity Cost[a] ($/yr)
Admin	34,300	30%	13%	$2,100
TEMF	30,700	16%	5%	$1,800
UEPH[a]	139,300	39%	16%	$8,400
BN HQ	26,200	21%	10%	$1,600
COF	18,000	9%	5%	$1,100
Total	**248,500**	**25%**	**11%**	**$14,900**

(a) Electricity cost based on recent blended average rate at Fort Carson of $0.06/kWh

In addition to the total magnitude of the plug load consumption, details from device-level monitoring provide valuable insight into the composition of the MEL end use. Figure 10 summarizes the plug load energy use by device category within each building, in kilowatt-hours per thousand square feet. This highlights the energy use intensity of plug load and MEL devices within these building types. Figure 11 identifies the ten device types that use the most energy across the five buildings evaluated in this study. Electric clothes dryers, which consume over 32,600 kWh/yr in the UEPH, are first.[1] Personal computing equipment (e.g., laptop and desktop computers and monitors), networking systems, vending machines, refrigerators, space heaters, and copiers round out the other top device types. Together, these 10 highest energy

[1] Clothes dryers were not metered in this study. This estimate is based applying a typical dryer energy use of 2.897 kWh per dryer cycle to the number of washer cycles identified from the washer monitoring (per Bendt 2010).

consuming plug-load device types represent 71% of all MELs within the five study buildings,[1] and certainly represent significant energy usage across Army installations.

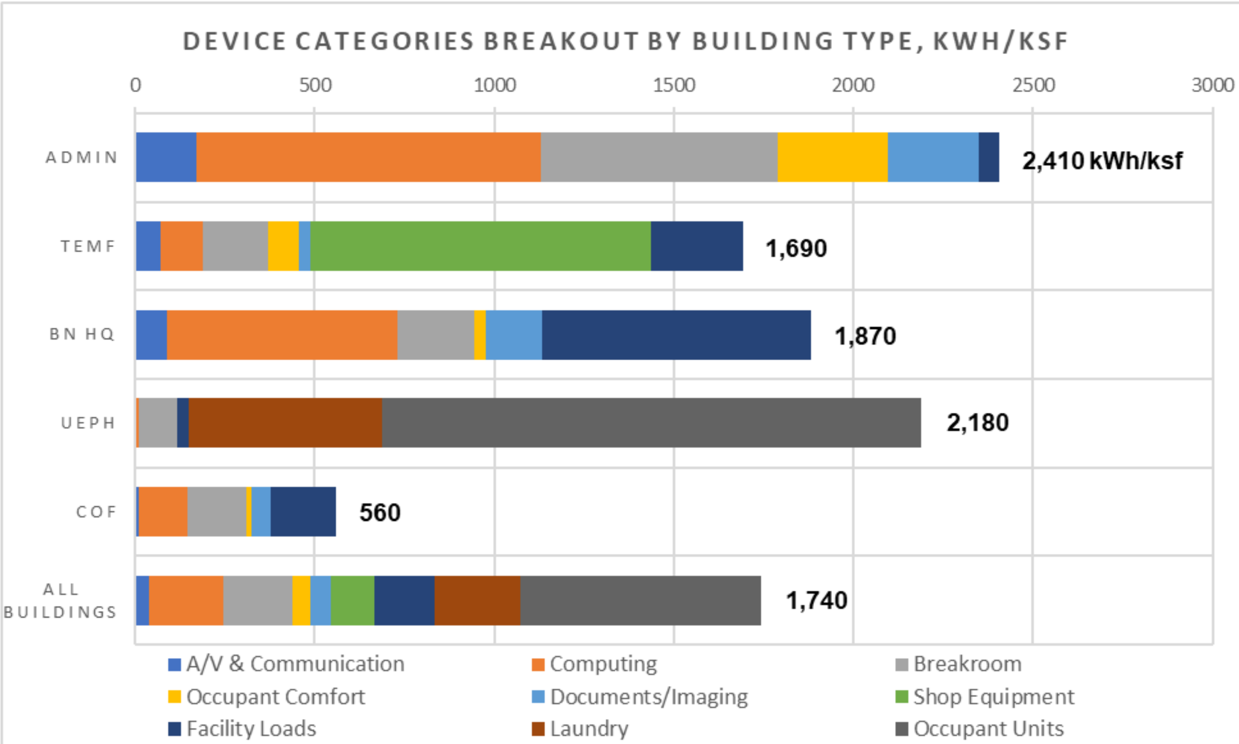


Figure 10. Electricity Use Per Thousand Square Feet by Building and Device Category

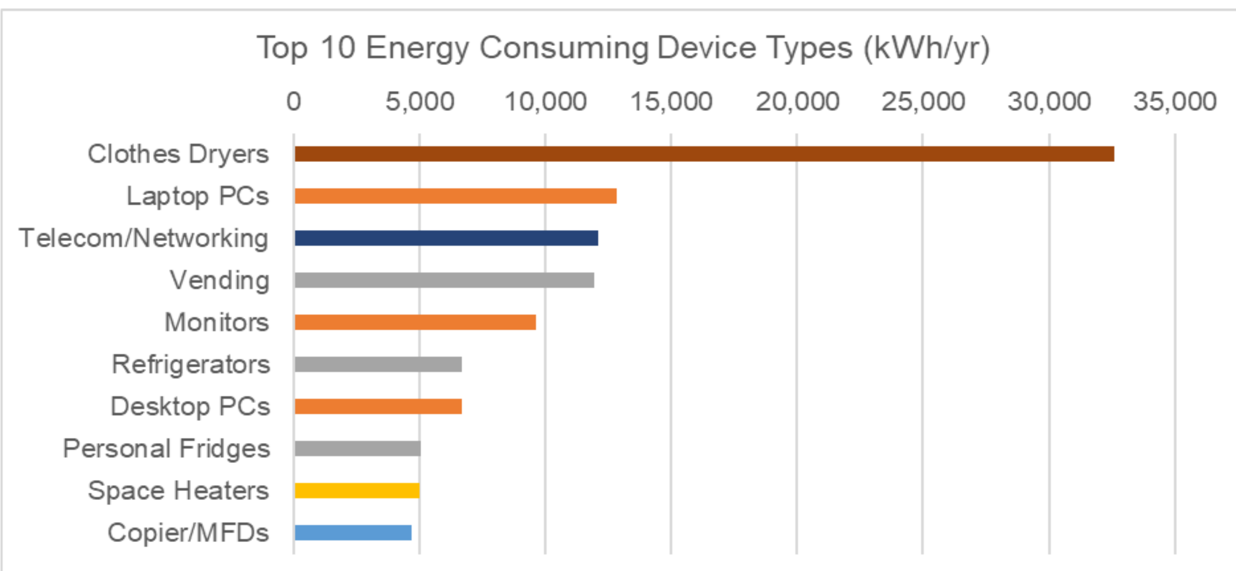


Figure 11. Top Ten Energy-Consuming Device Groups within the Study Buildings

[1] The energy use from these top ten MELs categories represents 71% of the total MELs consumption in these buildings, with the exception of the living quarters of the UEPH, as the breakout of those loads by device type is not known.

Similarly, Figure 12 identifies the 20 individual MEL devices that were found to consume the most electricity within the buildings included in this study. The networking and telecom panels actually represent a number of different devices that support these functions; however, they were metered together at the sub-panel level and therefore reported here in aggregate. The three refrigerated vending machines metered within the five core study buildings are each near the top of this list, with one consuming just 30 kWh less than the BN HQ networking infrastructure equipment per year.[1] Other high-energy-consuming equipment on this list include the air compressor, communications terminal, and battery chargers in the TEMF; BN HQ elevator; the average electricity use of the clothes dryers in the UEPH; the three oldest refrigerators; and space heaters, copiers, and a coffee maker in the Admin building.

Collectively, these 20 MELs consume nearly 20% of the total MEL energy consumption from the five study buildings (including only common area MELs in the UEPH). The following sections present additional results from the top-down and bottom-up monitoring and energy consumption results.

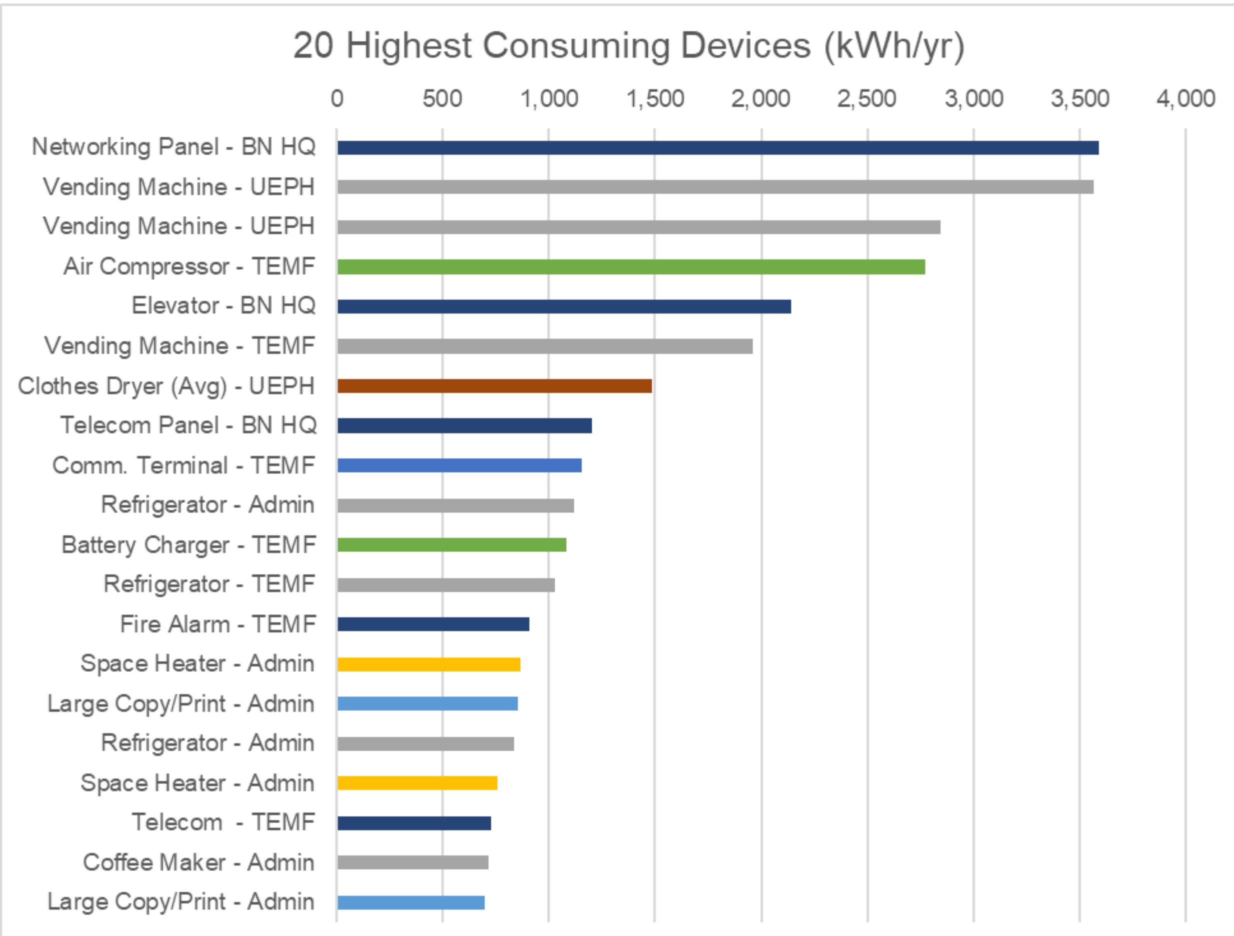


Figure 12. 20 Highest-Consuming Individual MELs within the Five Study Buildings

[1] In addition to these three refrigerated vending machines, five additional units were monitored outside of the primary study buildings. Three of those vending machines were found to use more energy than the highest shown here (as much as 4650 kWh/y). Additional details on the vending machines evaluated in this study are provided in Section 6.3.1.

5.2 Top-Down vs. Bottom-Up Results

A combination of up to five different approaches for estimating total annual MEL energy consumption was applied to the buildings in this study. These approaches rely on a mix of data sources, data resolution, and estimation methods, as described in Section 4.3. Up to four different top-down approaches were applied including the annual MDMS, seasonal MDMS, seasonal EMCS, and detailed panel/circuit monitoring. A bottom-up approach based on device-level monitoring and/or a hybrid approach combining elements of both device- and select panel/circuit monitoring was also applied to each building.

The resulting estimates for annual MELs energy consumption are presented in Figure 13 for each study building as a percentage of building total annual electricity use. These include the four top-down approaches (annual minimum load using MDMS data, seasonal always-on loads using MDMS and EMCS data, and the detailed panel and circuit monitoring approach), plus the bottom-up or hybrid approach. The variation in estimates for each building is the result of a combination of load characteristics (including the nature of plug load use, but also the scheduling of HVAC and lighting) and data resolution, among other possible factors. The bars outlined in green identify the estimates judged to be most robust based on completeness of data and accuracy of approach. The following sections present additional results from the top-down and bottom-up monitoring and energy consumption results in general and for each building.

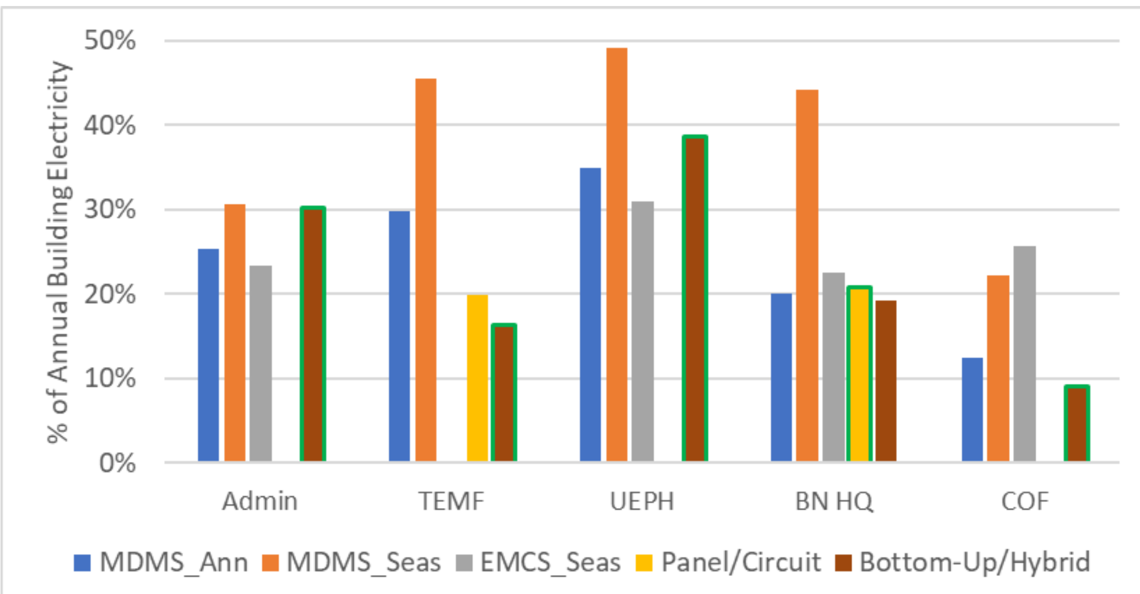


Figure 13. Compilation of Annual MEL Consumption by Building as a Percentage of Total Building Electricity Use (best estimate for each building outlined in green)

5.2.1 Top-Down Results

A number of top-down methods (described in Section 4.3.1) were applied to these buildings for estimating the plug-load/MEL energy use. The method of daily interval electricity profile review and aggregation across seasons and time affords a low-data-impact estimate of MELs. The benefits of higher resolution data (i.e., 1-minute vs. 15-minute) are evident in both estimating MELs, but perhaps more importantly, in identifying other larger system operating issues, potential maintenance problems, or scheduling opportunities. However, the nature of this approach is that it focuses on the lowest always-on load identified during each evaluated season. As a result, it can end up underestimating MELs that are not operating all the time and that vary with occupancy or other diurnal factors. Further, the minimum loads also can include some non-MELs, such as emergency and egress lighting or HVAC loads that were not removed. Therefore, there remains uncertainty on either end which is why a diversity factor is applied. With these caveats in mind, the approach can still offer value for estimating the magnitude of MELs and their contribution to annual energy use.

More robust estimates are obtained when more detailed end-use metering is applied at a combination of electrical panels, sub-panels, and circuits. The resulting estimates of plug load annual energy use, and percentage of total building electricity and total energy use, are presented in the following sections for each study building. Results from the different methods are compared and an assessment of greatest confidence provided based on known characteristics of the building and its operation, as well as the estimation process and quality of the underlying data.

5.2.2 Bottom-Up Results

The bottom-up method often yields the most robust results of annual MEL energy consumption. This is particularly so when the results of representative device-level monitoring are supplemented with data from detailed top-down monitoring at the sub-panel and circuit levels. For most of the study buildings, a hybrid approach such as this offers the most robust energy estimation approach. These methods are discussed in Sections 4.3.2 and 4.3.3. In addition to total annual energy use, the bottom-up approach provides further insight into the composition of the MELs by category and device type. Additional details for each building can be found in tables and figures in the sections that follow. For each building, a chart presents the energy use for each major plug load category and shows the device categories as a fraction of the total electricity use in the building. A detailed table reports the unit and total combined energy consumption by category and device type, along with metrics of kWh per thousand square feet (kWh/ksf) and kWh per occupant.

In the bottom-up energy consumption results tables presented, the analysis results provide the count of devices (inventories), the percent metered, estimates of unit energy, total energy, and other useful metrics. The unit energy is the energy use estimate of a single device, based on weighted average electric use of the devices metered. The total energy is an estimate of the energy used by all the devices of that type, based on the count of devices in the building (e.g., two projectors each use an average 84 kWh/yr, so the total energy that can be attributed to projectors in that building is 168 kWh/yr). Additional metrics include electricity use per thousand square feet, and electricity use per occupant (kWh/occupant). These metrics can be useful for comparing and/or extrapolating energy use to buildings with similar devices and functions.

5.3 Admin

The plug load and MEL energy consumption estimates for the Admin building are presented in Figure 14 for each of the methods applied. As described in Section 4.2.1, no panel or sub-panel metering was installed in this building; therefore, only top-down approaches using available whole-building (MDMS and EMCS) data were able to be performed, in addition to the hybrid bottom-up approach based on the extensive device-level metering plus proxy consumption values for select facility loads as determined from circuit metering in other buildings.

In the team's assessment of the underlying data and process, it is estimated that the bottom up/hybrid approach is the most robust for this building. This suggests that plug loads and other MELs consume approximately 34,300 kWh/yr or 30% of total annual electricity consumption and 13% of total annual energy consumption. However, results from each of the four approaches are relatively close and are separated by only 7% of electricity and 3% of total energy use. Results of the MDMS seasonal approach are the closest, at 34,900 kWh/yr. The EMCS seasonal approach may be lower given the poorer resolution of that whole building interval-metered data.

More details on each method, including the bottom-up energy use monitoring results by device and category type are described below.

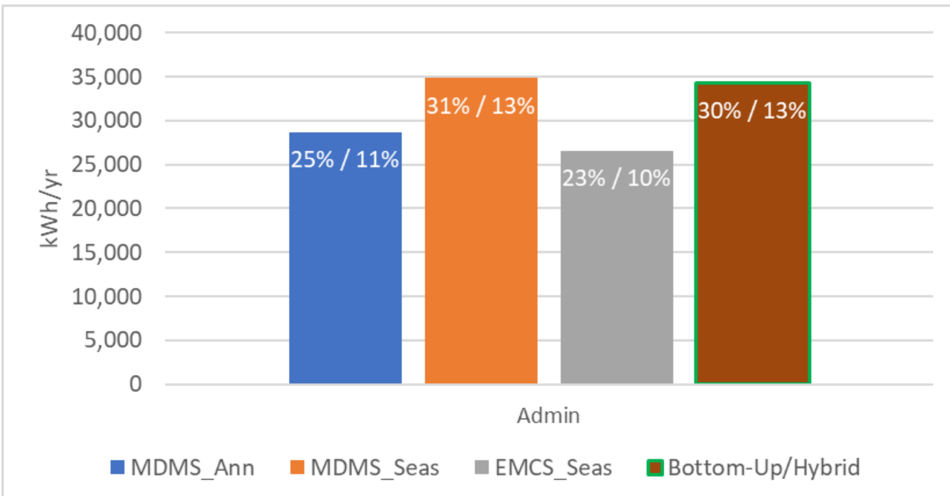


Figure 14. Comparison of Admin Annual MELs Consumption Estimates by Approach (percent values indicate % of annual electricity / % of annual total energy consumption)

5.3.1 Top-Down Energy Consumption Results

5.3.1.1 MDMS Annual Minimum Load

The global annual minimum load approach estimates 28,730 kWh in annual MEL electricity consumption from always-on loads. This represents 25% of the total building electricity consumption and 11% of total energy consumption for the Admin building.

5.3.1.2 MDMS/EMCS Seasonal Minimum Load Approach

Figure 15 and Figure 16 present the representative 15-minute and 1-minute interval data sets for the Admin building for the same summer season weekday. There are notable similarities between the profiles in overall shape and the 1-minute profile provided greater resolution and resulting detail. From the 1-minute data, specific start/stop events (e.g., HVAC and lighting systems) can be defined and more thoroughly explored. This profile allows a more refined estimate of the "always on" MELs of about 3.5 kW. This value and others across the data set were used to better estimate an annual top-down MEL use of 26,590 kWh/yr or about 23% total annual electric consumption (and 10% of total annual energy consumption). As highlighted in Figure 15, data quality issues are a concern with the MDMS data. Here, the data drops out twice during this particular day; for this and other buildings, longer stretches of missing data are not uncommon.

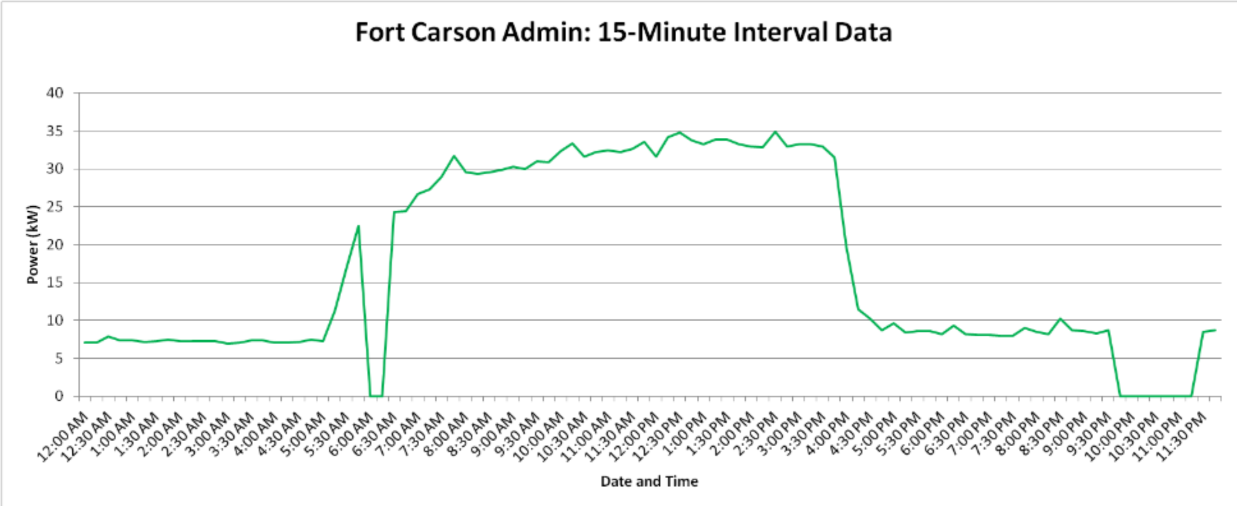


Figure 15. Admin Building Representative Daily MDMS 15-Minute Interval Profile (Summer Weekday)

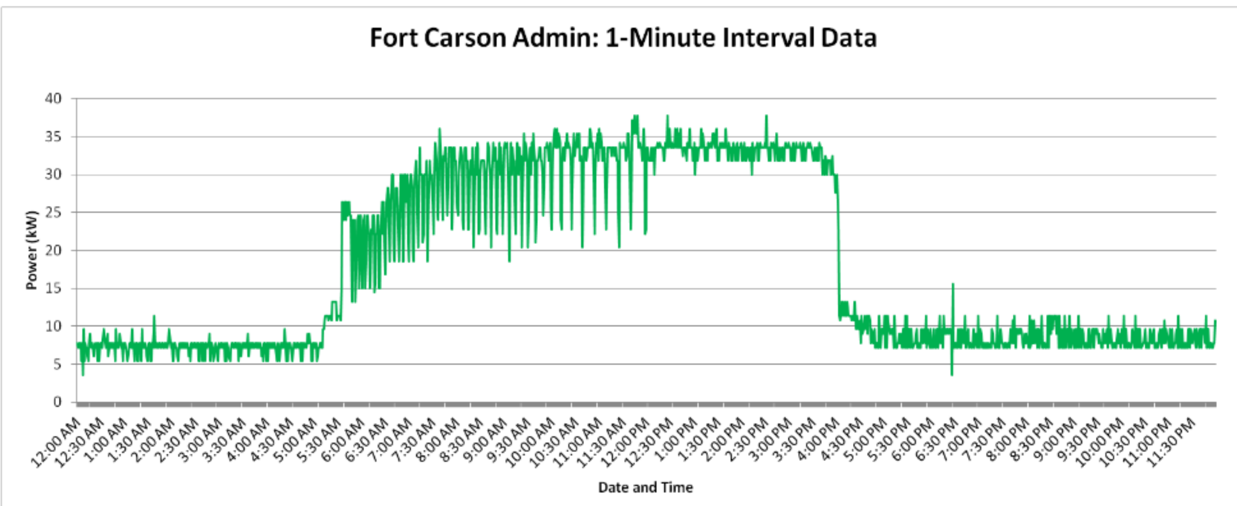


Figure 16. Admin Building Representative Daily EMCS 1-Minute Interval Profile (Summer Weekday)

5.3.2 Bottom-Up Energy Consumption Results

The Admin building has an average annual electric use of 113,512 kWh and total annual energy use of 922 MBtu. Based on the bottom-up approach, MELs account for 34,326 kWh/yr, or approximately 30% of total electricity use (and 13% of combined annual electricity and natural gas consumption). Figure 17 shows the MEL categories as a portion of the total electricity use, and the electric consumption within each major category. Personal computing systems (desktop and laptop computers and monitors) is the highest consuming category at 40% of total MELs, and breakroom equipment (i.e., refrigerators, coffee makers, water coolers, etc.) are second accounting for 27% of total MEL consumption for the building. Although hardwired facility loads such as telecom and networking infrastructure equipment, fire alarms, and security systems are not shown in the device inventory in Section 3.2.1, they represent a small portion (2%) of MEL consumption in the Admin building.

Table 12 details the Admin building device inventory, energy use, and relevant metrics by device type, category and entire building. Figure 18 highlights the 10 highest energy-consuming device types in this building. These are led by desktop computers, refrigerators, monitors, space heaters, and large copier/multi-function devices. Combined, the energy used by these 10 device types comprise 82% of the total annual plug load energy consumption for the building and offer good opportunities for reduction.

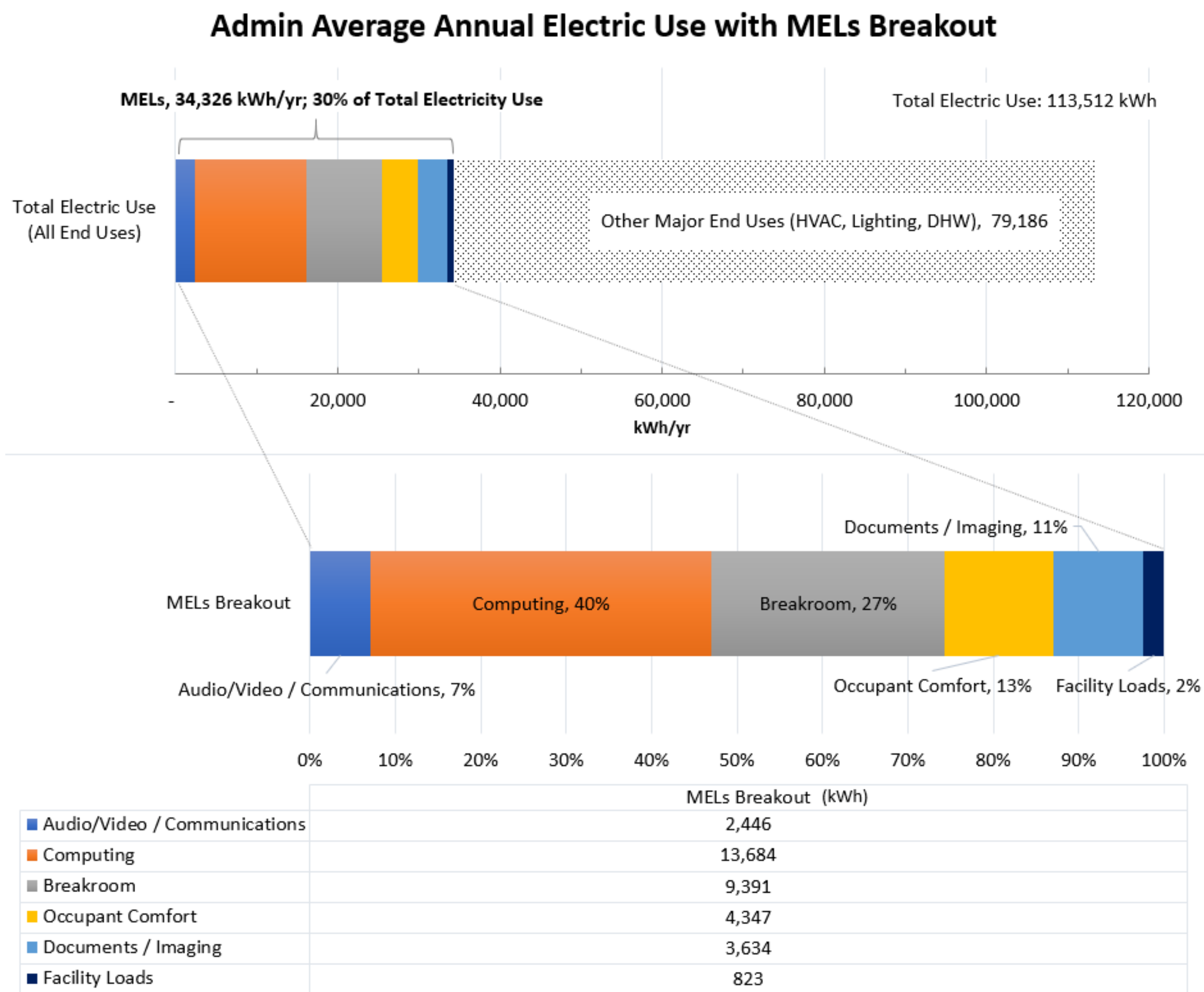


Figure 17. Admin Building MEL Electricity Use by Category Relative to Total Building Use

Table 12. Admin Building Plug Load Inventory with Electric Use Breakdown per Device

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/ksf	kWh/ Occupant
Audio/Video / Communication	Projector	2	100%	84	168	11.8	4.4
	TV/LCD Display	13	54%	75	975	68.4	25.7
	Phone - Desk	22	18%	14	297	20.8	7.8
	Phone - Conference	4	25%	4	15	1.0	0.4
	Personal Audio	8	38%	18	140	9.8	3.7
	Business Audio	1	100%	27	27	1.9	0.7
	TV Tuner	8	25%	103	824	57.8	21.7
	CATEGORY TOTAL	**58**	**34%**		**2,446**	**171.5**	**64.4**
Computing	Desktop Computer	37	38%	180	6,652	466.4	175.0
	Laptop Computer	17	41%	139	2,354	165.0	61.9
	LCD Monitor	79	43%	44	3,472	243.5	91.4
	UPS (workstation)	34	6%	17	581	40.7	15.3
	Docking Station	7	29%	32	222	15.5	5.8
	USB Hub	1	100%	5	5	0.3	0.1
	Computer Speakers	19	37%	21	400	28.1	10.5
	CATEGORY TOTAL	**194**	**35%**		**13,684**	**959.6**	**360.1**
Breakroom	Large Refrigerator	6	100%	682	4,090	286.8	107.6
	Personal Refrigerator	11	73%	223	2,448	171.6	64.4
	Coffee Maker – Commercial	2	100%	570	1,141	80.0	30.0
	Coffee Maker – Residential	4	50%	71	284	19.9	7.5
	Water Cooler – Plumbed	3	67%	46	139	9.8	3.7
	Water Cooler – Bottles	4	100%	240	960	67.3	25.3
	Microwave	13	54%	25	330	23.1	8.7
	Toaster	1	-	-	-	-	-
	CATEGORY TOTAL	**44**	**70%**		**9,391**	**658.5**	**247.1**
Occupant Comfort	Space Heater	6	83%	574	3,446	241.7	90.7
	Fan - personal	12	33%	18	211	14.8	5.6
	Air Purifier	3	33%	9	26	1.8	0.7
	Task Lights	47	21%	14	664	46.5	17.5
	CATEGORY TOTAL	**68**	**29%**		**4,347**	**304.8**	**114.4**
Documents / Imaging	Personal Printer	19	42%	50	956	67.0	25.2
	Large Copy Print	4	100%	630	2,521	176.8	66.3
	Plotter	1	100%	95	95	6.6	2.5
	Shredder	6	83%	10	63	4.4	1.6
	CATEGORY TOTAL	**30**	**60%**		**3,634**	**254.8**	**95.6**
Facility Loads	Telecom/Networking	-	-		601	42.1	15.8
	Fire Alarm System	-	-		222	15.6	5.8
	CATEGORY TOTAL	**n/a**	**n/a**		**823**	**57.7**	**21.6**
TOTALS		**394**	**40%**	**-**	**34,325**	**2,406.9**	**903.3**

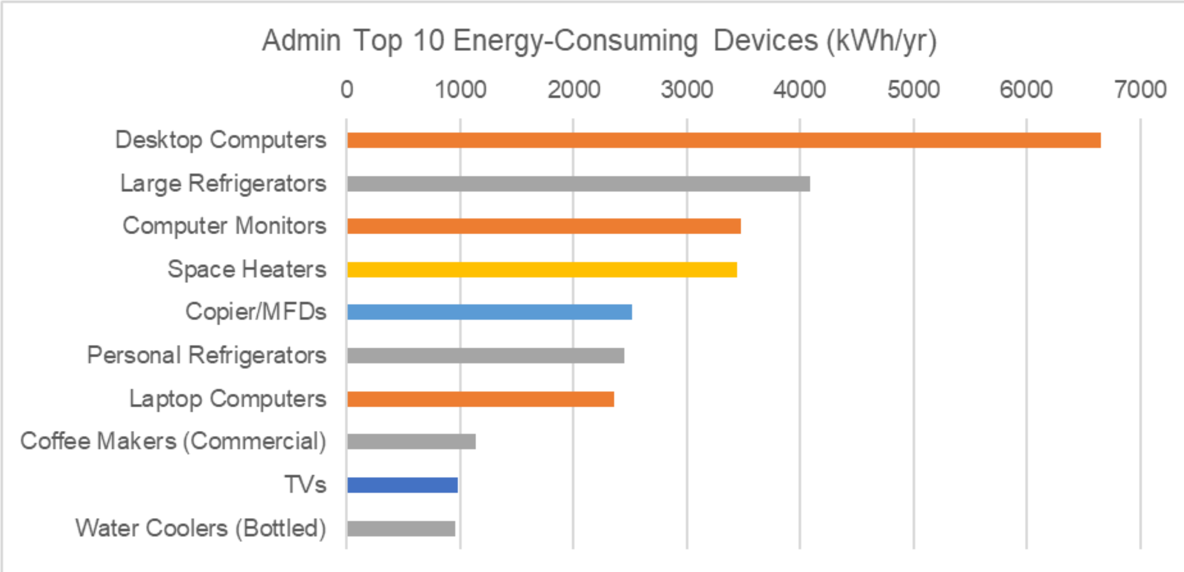


Figure 18. Top Ten Consuming Device Types in the Admin Building

5.4 TEMF

The TEMF plug-load and MEL energy consumption estimates are presented in Figure 19 for each of the four methods applied. As discussed below in Section 5.4.1, the poor resolution of the 1-minute EMCS data resulted in not being able to apply the seasonal 1-minute approach. Because of the nature of the shop loads in the TEMF and the inability to meter each of the sub-panels, a hybrid approach was required to combine elements of the deployed top-down and bottom-up metering.

In the team's assessment of the underlying data and process, the results from the bottom-up/hybrid approach are the most robust for the TEMF. While the panel and circuit monitoring provided good results, there was a mix of MELs and HVAC loads on the shop sub-panel that could not be monitored, and a mix of panel, circuit, and device metering was required to adequately estimate the mix of plug loads and other MELs (including general shop receptacles, portable ground power units, welding stations, and the fuels laboratory trailer that could not be metered individually). The results suggest that plug loads and other MELs in the TEMF consume approximately 37,600 kWh/yr or 16% of total annual electricity consumption and 5% of total annual building energy. The panel/circuit top-down approach probably provides a reasonable upper bound as it includes the bulk of the MELs but also some known non-MELs that could not be isolated. The estimates of energy consumption from the two approaches using the MDMS data are significantly higher, likely as a result of this building exhibiting a mix of intermittent MEL usage plus some significant 24/7 HVAC and lighting operation, the latter of which could benefit from improved scheduling. The remaining composition of the annual energy use by end use is shown in Figure 20.

More details on each method, including the hybrid top-down/bottom-up energy use monitoring results by device and category type for the TEMF are described below.

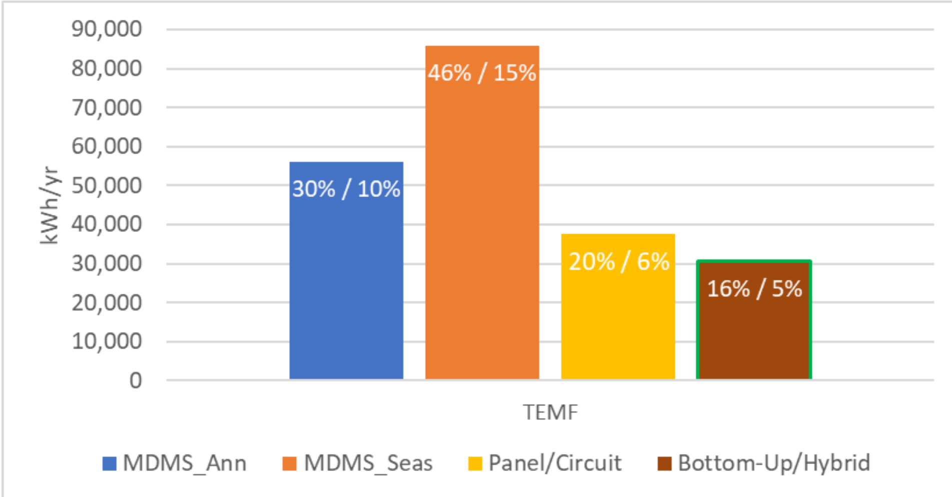


Figure 19. Comparison of TEMF Annual MEL Consumption Estimates by Approach (percent values indicate % of annual electricity/% of annual total energy consumption)

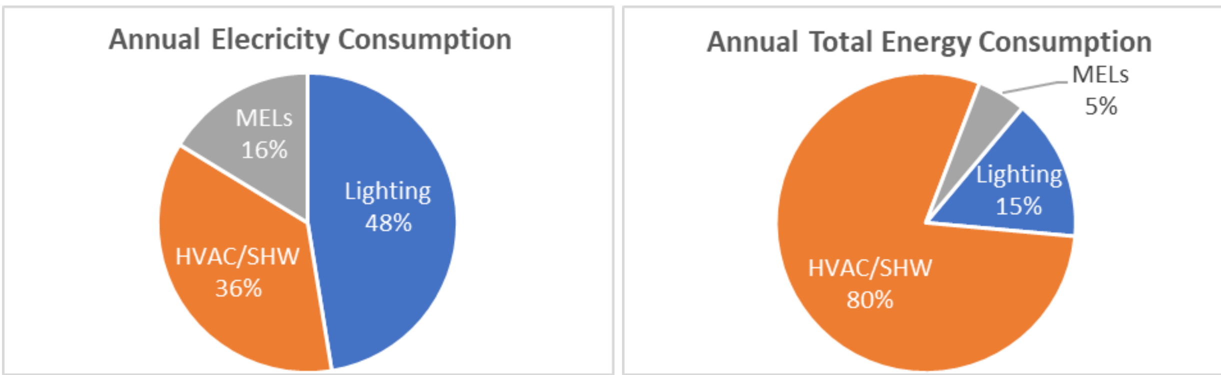


Figure 20. Best Estimate of TEMF Annual MELs Consumption Relative to Other End Uses; Annual Electricity Consumption (left) and Annual Total Energy Consumption (right)

5.4.1 Top-Down Energy Consumption Results

5.4.1.1 MDMS Annual Minimum Load

The global annual minimum load approach estimates an always-on load accounting for 56,000 kWh in annual MEL electricity consumption for the TEMF. This represents 30% of the total building electricity consumption and 10% of total energy consumption.

5.4.1.2 MDMS/EMCS Seasonal Minimum Load Approach

The whole building winter season 15-minute interval dataset for the TEMF is presented in Figure 21 for a representative winter weekday. Because of significant data resolution issues at the EMCS 1-minute interval (with time interval energy readings oscillating between 0 and 1 kWh), only the MDMS 15-minute data were useful. The resulting profile has an inverted shape; daytime loads are lower than nighttime loads, which is often characteristic of buildings with significant exterior lighting and a relatively flat diurnal profile. These attributes are true for the TEMF, which has a large number of exterior lights in the vehicle parking lot surrounding the building.

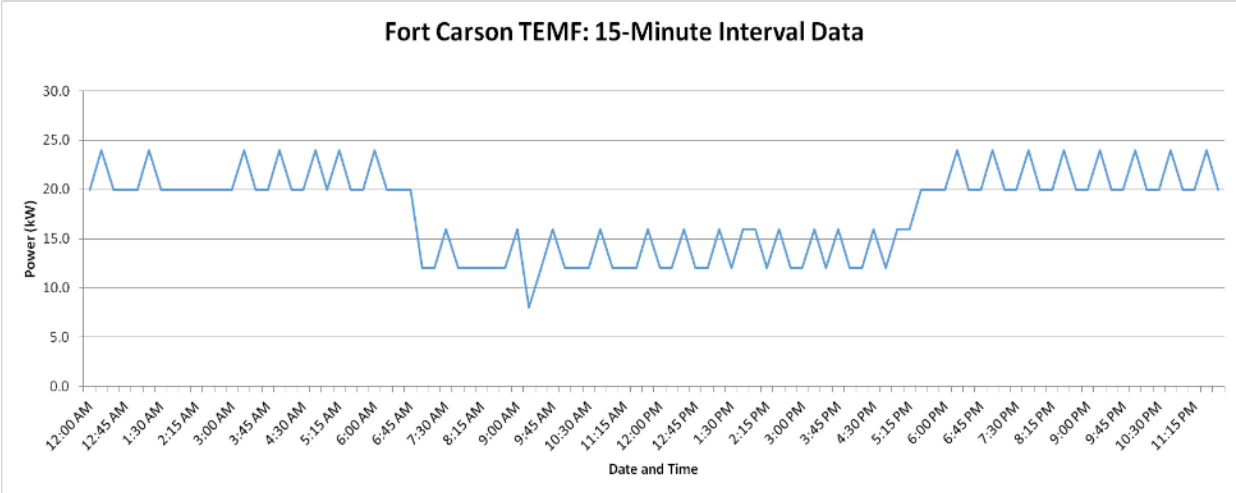


Figure 21. TEMF Representative Daily MDMS 15-Minute Interval Profile (Winter Weekday)

The winter season minimum 15-minute load is around 7.5 kW. This value and others across the data set were used to better estimate the annual top-down MEL use for this building of 85,850 kWh/yr, or about 46% of total annual electric consumption and 15% of total annual energy consumption.

5.4.1.3 Detailed Project-Installed Metering

While detailed panel and circuit metering offered unique views into individual MELs, it also highlighted the transitory nature of MELs. After thorough data review, the TEMF metering identified key end-use MELs captured at the breaker and quantified these. As a result of this analysis, it was noted that some devices had been moved from their original receptacles and were then unaccounted for in the metering mix, creating a challenge in effective aggregation from the circuits to a building MELs total. As such, attention turned to the MDP, the second source of MELs aggregation. At the MDP, all sub-panels were monitored, including three panels dominated by MELs. As a general finding, the TEMF panels were more dispersed (i.e. not only located in electrical rooms) and had a greater mix of loads (MELs and non-MELs) across panel types. To account for this challenge, a load profile isolation process was used to aggregate both known MELs and non-MELs, and these were then summed across the panels to arrive at a best-estimate whole-building MELs total.

The following figures highlight two sample daily MELs profiles for the TEMF building. Figure 22 presents a typical weekday and Figure 23 a typical weekend day. Notable in both profiles is their relative diurnal indifference (day vs. night) and striking similarity, weekday to weekend. MEL profiles such as these are typical of a facility that operates continually and do not have manual or automated turn-down or shut-off protocols implemented.

Aggregating the TEMF MELs over the metering duration and extrapolating across a typical year results in an estimated total MELs annual energy use of 37,620 kWh/yr or 20% of the total annual building electrical consumption (6% of total annual building energy use). This value is significantly less than annual and seasonal whole building MELs estimates, which likely include a greater proportion of non-MEL loads. Those results were also developed without the availability of 1-minute EMCS data, and only the 15-minute interval MDMS data. As such, more credibility is afforded to this MELs calculation based on the project metering than the other top-down approaches.

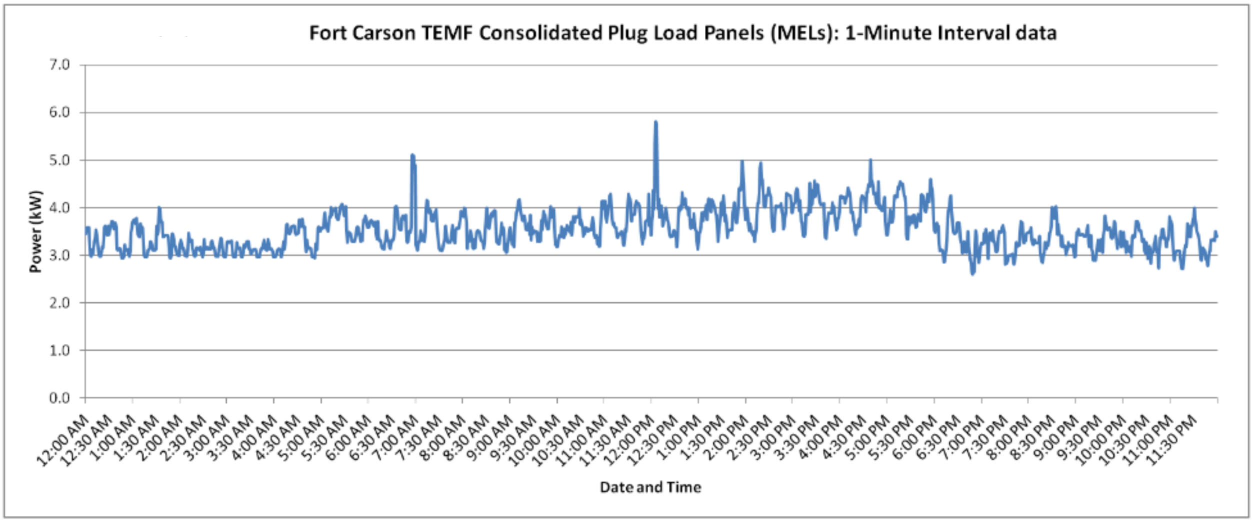


Figure 22. TEMF Typical MELs Weekday Load Profile

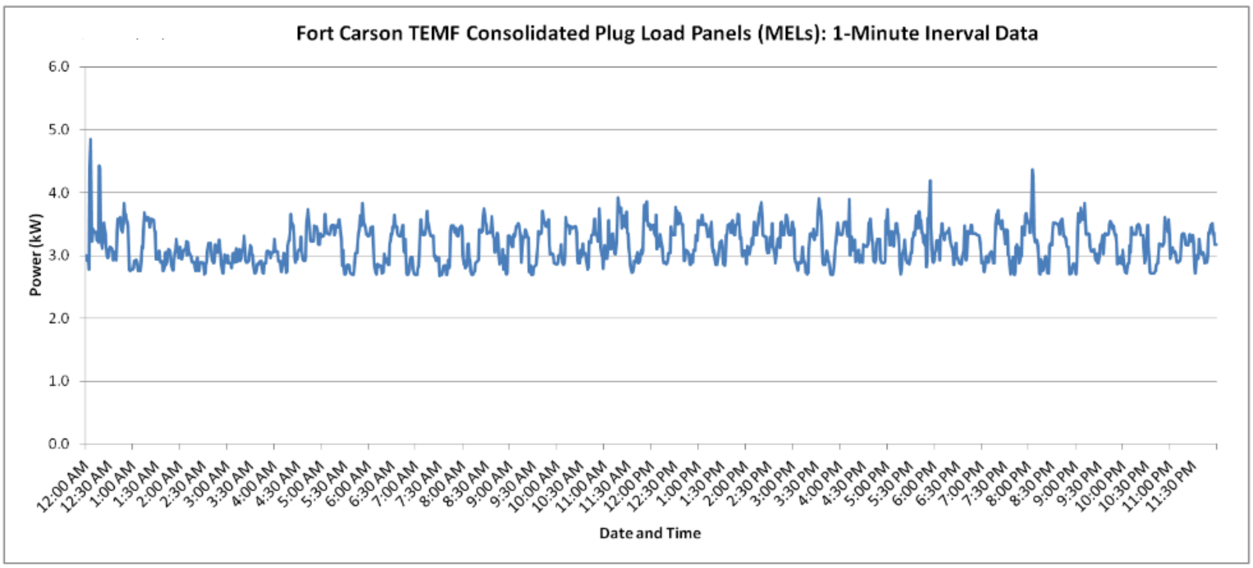
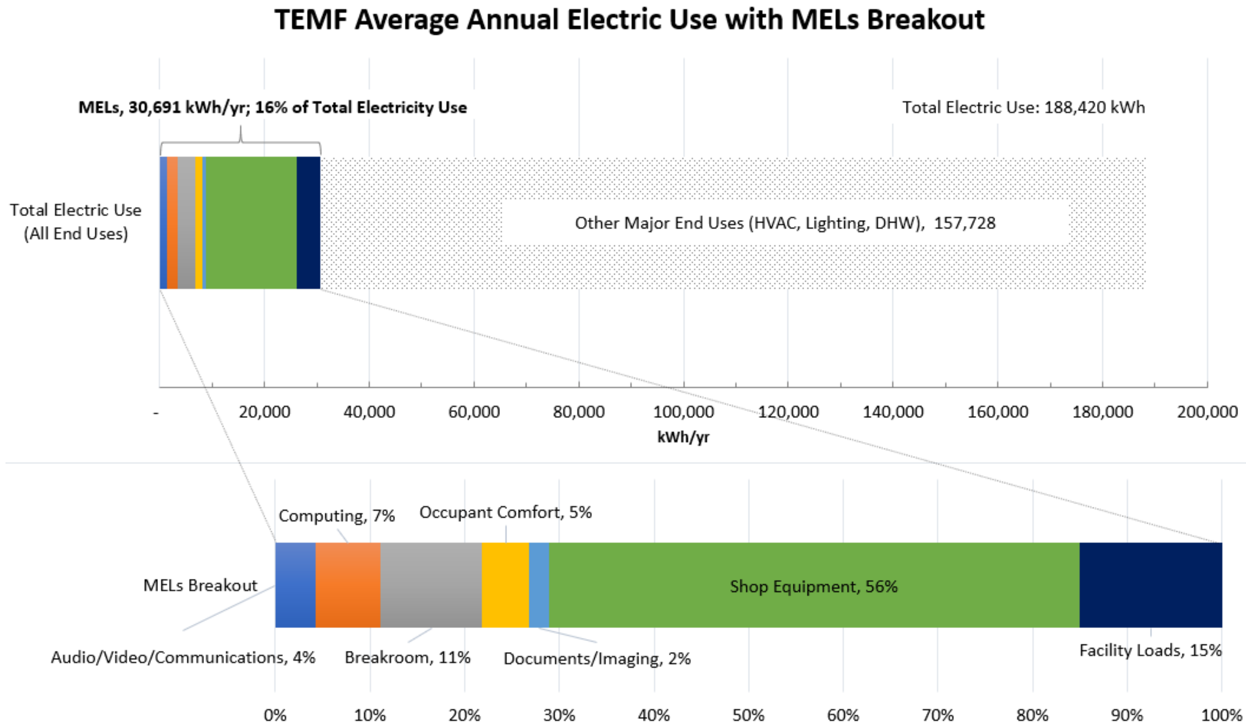


Figure 23. TEMF Typical MELs Weekend Load Profile

5.4.2 Bottom-Up Energy Consumption Results

As noted above, the bottom-up approach for the TEMF required a hybrid method that supplemented device-level monitoring data with that from select sub-panels and circuits, to cover the breadth and diversity of plug loads and MELs within the space. For instance, select circuit and panel data were used to fill gaps in distributed shop loads that were not able to be captured with the device-level monitoring system, in addition to hardwired MELs. This hybrid approach provides a reasonable estimate of total MEL annual energy consumption of 30,657 kWh/yr – 16% of total annual electricity use and 5% of total combined energy use in the TEMF. As a percentage of total building energy use, this is relatively small, and explained by the high heating load resulting from the large air volume and air exchange rate, plus lighting and HVAC systems that operate a large percentage of the time, as highlighted above in Figures 21, 22, and 23.

A more detailed view of the MELs component categories is presented in Figure 24, which shows that the Shop Equipment category dominates, consuming over 56% of the total from all MELs. These loads include the air compressor, battery chargers, the fuels lab trailer, and various maintenance bay tool and receptacle loads. Table 13 lists the count, percentage monitored, and unit and total energy use for each device type and category. Resulting plug load energy use is also presented in terms of kWh per thousand square feet and per occupant, for comparison to and extrapolation of results to other buildings.



	MELs Breakout (kWh)
Audio/Video/Communications	1,302
Computing	2,100
Breakroom	3,299
Occupant Comfort	1,534
Documents/Imaging	626
Shop Equipment	17,207
Facility Loads	4,623

Figure 24. TEMF MEL Electricity Use by Category Relative to Total Building Use

The 10 highest-consuming MEL device types are identified in Figure 25. These devices account for 41% of the total annual plug load energy consumption in the TEMF. The highest consumers include the air compressor, refrigerated vending machine, laptop computers, communications terminal, battery chargers, and refrigerator. Many of these devices represent good energy reduction opportunities.

Table 13. TEMF Inventory with Electric Use Breakdown Per Device

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/kSF	kWh/ Occupant
Audio/Video / Communication	Projector	1	100%	141	141	7.8	9.4
	Personal Audio	3	67%	2	7	0.4	0.5
	Comm. Terminal	1	100%	1,152	1,152	63.5	76.8
	Cell Phone Charger	1	100%	1	1	0.1	0.1
	CATEGORY TOTAL	**6**	**83%**		**1,302**	**71.8**	**86.8**
Computing	Laptop Computer	13	77%	96	1,215	68.9	83.2
	LCD Monitor	11	55%	76	840	46.3	56.0
	Network Switch	1	100%	12	12	0.7	0.8
	CATEGORY TOTAL	**25**	**68%**		**2,067**	**114.0**	**137.8**
Breakroom	Vending Machine	1	100%	1,963	1,963	108.3	130.9
	Large Refrigerator	1	100%	1,028	1,028	56.7	68.6
	Personal Refrigerator	1	100%	113	113	6.3	7.6
	Coffee Maker	1	100%	9	9	0.5	0.6
	Water Cooler	2	100%	65	129	7.1	8.6
	Microwave	2	100%	13	25	1.4	1.7
	Receptacles	0	0%	-	31	1.7	2.1
	CATEGORY TOTAL	**8**	**100%**		**3,299**	**181.9**	**219.9**
Occupant Comfort	Space Heater	2	50%	402	803	44.3	53.5
	Fan - personal	1	100%	401	401	22.1	26.7
	Fan - industrial stand	1	0%	-	-	-	-
	Task Lights	10	30%	33	330	18.2	22.0
	CATEGORY TOTAL	**14**	**36%**		**1,534**	**84.6**	**102.3**
Documents Imaging	Personal Printer	3	100%	45	136	7.5	9.1
	Large Copy Print Device	1	100%	477	477	26.3	31.8
	Shredder	2	100%	6	13	0.7	0.9
	CATEGORY TOTAL	**6**	**100%**		**626**	**34.5**	**41.7**
Shop Equipment	Lift Crane	1	100%	301	301	16.6	20.1
	Air Compressor	1	100%	2,528	2,528	139.4	168.5
	Air Dryer+Auto Purge	1	100%	246	246	13.5	16.4
	Power Tools	3	67%	0	1	0.0	0.1
	Parts Cleaners	2	100%	23	47	2.6	3.1
	Hand Wash Station	1	100%	261	261	14.4	17.4
	Battery Chargers	5	100%	228	1,141	62.9	76.1
	Ground Power Unit	3	0%	-	-	-	-
	Portable Oil/Water Separator	3	100%	15	46	2.5	3.1
	Fuels Lab Trailer	1	0%	-	-	-	-
	Tool Charger	2	0%	-	-	-	-
	Portable Shop Light	1	0%	-	-	-	-
	Bay Door Opener	5	0%	-	-	-	-
	Maintenance Bay Receptacles and Other Loads (Lab Trailer, Welding, Tire Changing Station)	0	0%	-	12,637	696.9	842.5
	CATEGORY TOTAL	**29**	**55%**		**17,207**	**948.9**	**1,147.1**

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/kSF	kWh/ Occupant
Facility Loads	Telecom & Networking	-	100%	-	781	43.1	52.1
	Fire Alarm System	-	100%	-	907	50.0	60.5
	Security Access Control	-	100%	-	58	3.2	3.9
	Restroom Infrared Controls	-	100%	-	45	2.5	3.0
	Restroom Receptacles	-	100%	-	127	7.0	8.5
	Other (Telcom, receptacles, other)	-	-	-	2,704	149.1	180.3
	CATEGORY TOTAL	**5**	**83%**		**4,623**	**254.9**	**308.2**
TOTALS		**88**	**58%**		**30,657**	**1,690**	**2,040**

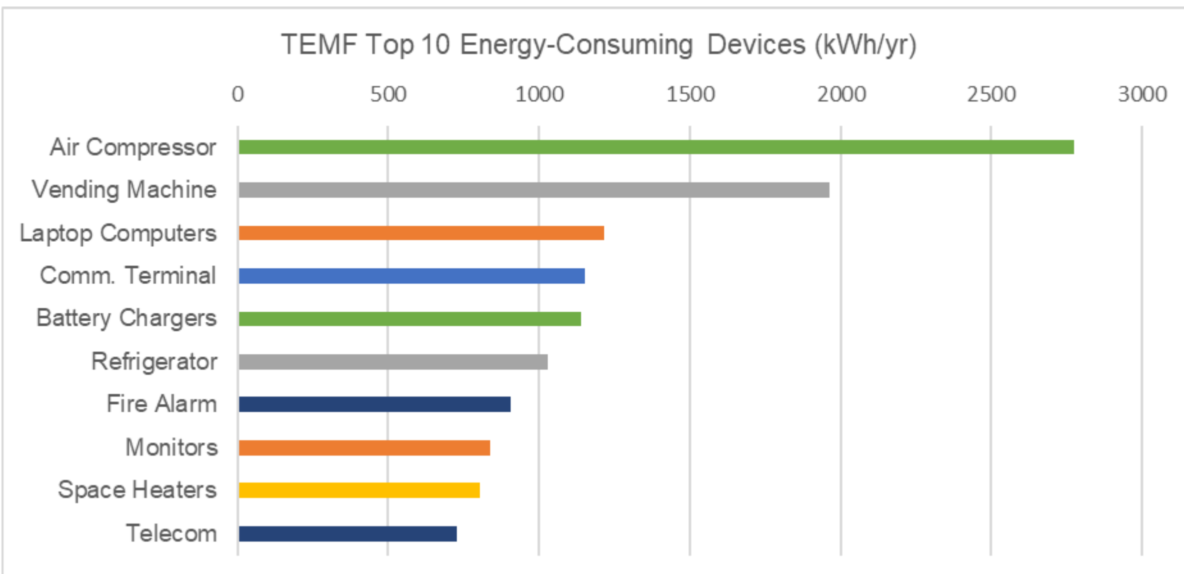


Figure 25. Top Ten Consuming Device Types in TEMF

5.5 UEPH

The plug-load energy consumption estimates for the UEPH are presented in Figure 26 for each of the four methods applied. Both MDMS annual and seasonal methods, plus the EMCS 1-minute seasonal estimates, were performed. Additionally, a hybrid approach using bottom-up device-level results for common space equipment and load center metering representing 30 of the 84 occupant rooms was followed. Typical in-unit lighting energy was estimated and subtracted from the total energy for the occupancy units based on the load center monitoring.

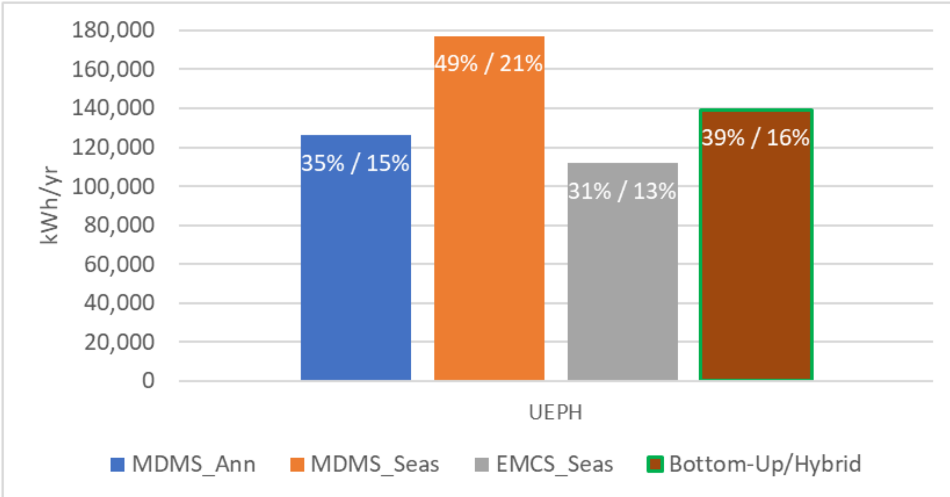


Figure 26. Comparison of UEPH Annual MELs Consumption Estimates by Approach (percent values indicate % of annual electricity/% of annual total energy consumption)

The characteristics of plug loads within the UEPH are significantly different than for the other building types. The vast majority of plug loads are within the private living quarters and their use is strongly dictated by occupancy patterns and behaviors, more than any of the other buildings in the study. Most of the plug load equipment is personally owned and can exhibit a greater diversity in type, characteristic, and level of use. Overall, loads are highest during the evenings and in some cases in the middle of the night. For these and other reasons, the nature of plug loads in the UEPH are significantly different than the plug loads and MELs in other building types and the assessment of always-on load approaches for estimating should be applied with greater care.

This analysis suggests that plug loads and other MELs consume approximately 139,000 kWh/yr or up to 39% of total annual electricity consumption and 16% of total annual energy consumption. More details on each method, including the energy use monitoring results by location are described below.

5.5.1 Top-Down Energy Consumption Results

5.5.1.1 MDMS Annual Minimum Load

The global annual always-on minimum load approach estimates 126,140 kWh in annual MEL electricity consumption for the UEPH. This represents 35% of the total building electricity consumption and 15% of total energy consumption.

5.5.1.2 MDMS/EMCS Seasonal Minimum Load Approach

Figure 27 and Figure 28 present representative summer season 15-minute and 1-minute weekday interval data sets for the UEPH. As with the previous buildings, notable are the similarities between the profiles in overall shape; however, the 1-minute profile provided greater resolution and resulting detail. Because of the building size and the diversity of occupants and their schedules, defining anything beyond major HVAC events is difficult. The EMCS 1-minute summer profile provides an estimate of the always-on MEL of about 17 kW. This value and others across the data set were used to estimate an annual top-down MELs use of 111,690 kWh/yr, or about 31% of total annual electric consumption (13% of total energy use), the lowest of the four approaches. While the 1-minute EMCS data may provide good detail for this and the other buildings, for the UEPH the always-on approach may miss a large portion of the variable plug load use, and for this building type, offer a questionable estimation of total MEL consumption, again highlighting the challenges and limitations of using whole-building data to estimate MELs.

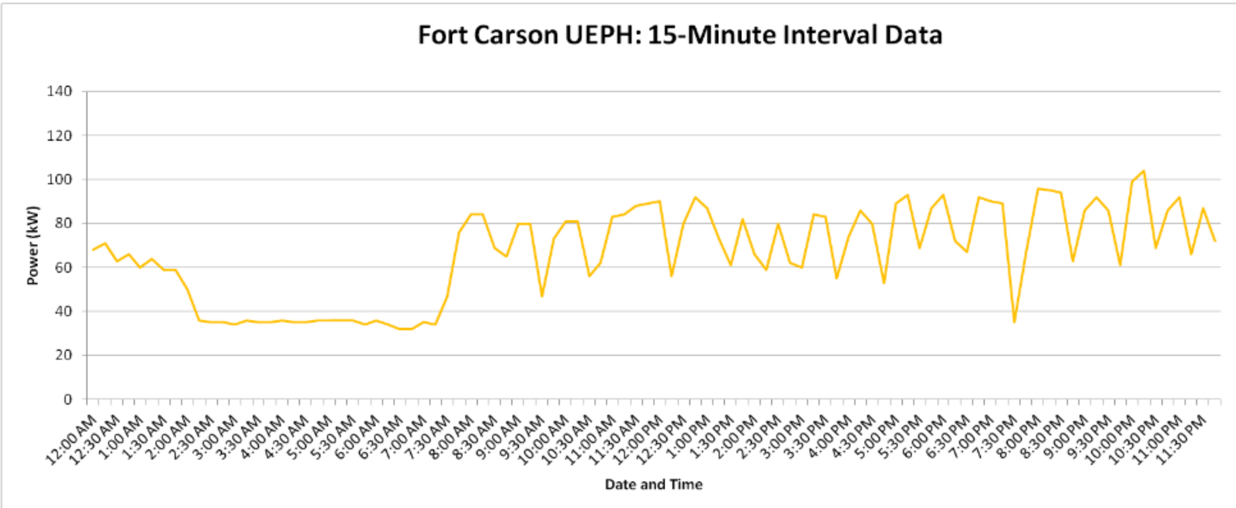


Figure 27. UEPH Representative Daily MDMS 15-Minute Interval Profile (Summer Weekday)

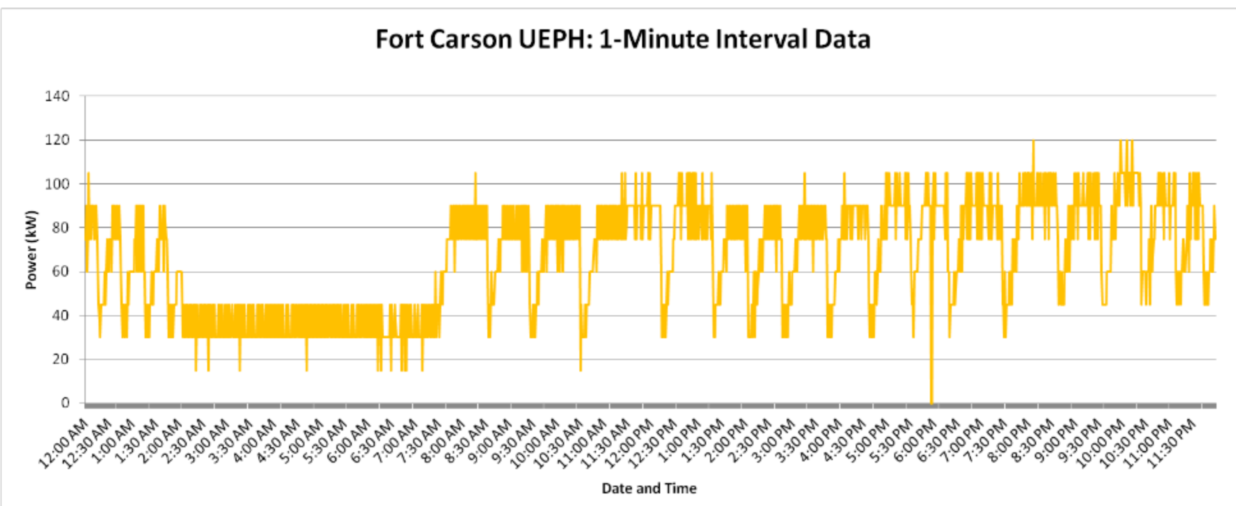


Figure 28. UEPH Representative Daily EMCS 1-Minute Interval Profile (Summer Weekday)

5.5.2 Bottom-Up Energy Consumption Results

The metering of the UEPH focused on two separate approaches. In the common spaces such as laundry rooms and lobby, device-level metering was deployed to monitor the loads from washing machines, vending machines, water fountains, and the lobby television. The energy from electric clothes dryers was estimated based on the recorded number of washer cycles, as described in Section 4.2.3. The energy use of private living quarters was captured at the load center for over a third of the occupancy units.

5.5.2.1 Detailed Load Center Metering

The monitoring of representative occupancy unit loads at the load center provided an opportunity to understand energy use within private living quarters without requiring in-unit metering. While the results cannot differentiate loads from specific devices or equipment types, they do highlight the total load resulting from the mix of lighting and plug load devices in use within representative spaces. Figure 29 shows the distribution of resulting aggregated annual energy use estimates for each of the 30 representative occupancy units monitored. Individual results range from 785 to 3179 kWh/yr, and average 1855 kWh/yr. Across the 30 monitored units, 80% use less than 2500 kWh/yr, equivalent to an average continuous load of no more than 285 watts, for all internal lighting, appliance, and personal plug loads.

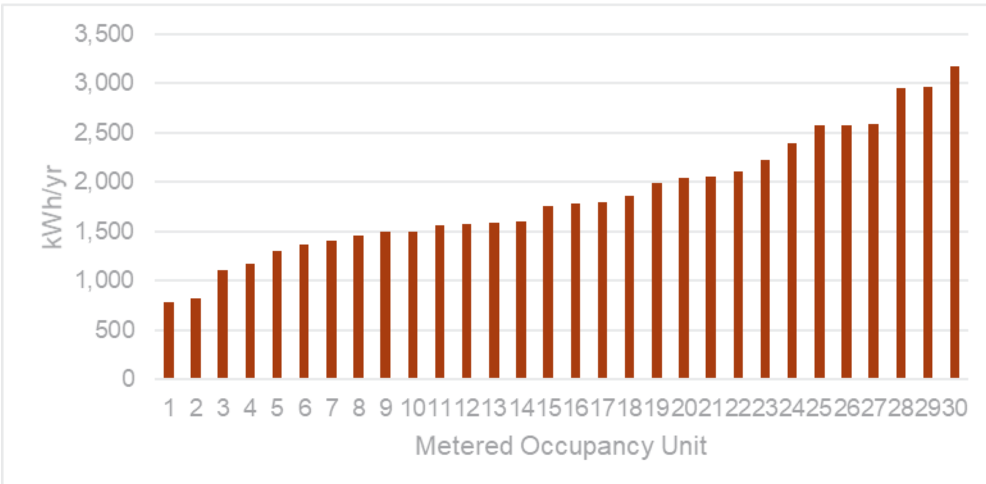


Figure 29. Distribution of Annual Energy Use for 30 Representative Occupancy Units in UEPH

Figure 30 highlights the occupancy unit load profiles as captured at the load center. Four panels are presented, each representing the 15-minute load profile over an average week, based on the 1-minute data collected over the monitoring period. The top profile shows the average across all 30 monitored phases, representing the diversity of loads within each double-occupancy unit. The grey bands highlight nighttime hours for each day, from 6 P.M. to 6 A.M. with midnight in the center. The white bands indicate the daytime hours (6 A.M. to 6 P.M. daily), with noon at their center. The typical pattern shows significant diurnal variation in load, from about 160 watts in early morning to approximately 300 watts in late evening, with smaller morning and midday peaks. For comparison with the average, the second profile highlights the actual profile for the lowest energy-consuming set of loads, using 785 kWh/yr, while the third is for the highest energy-consumer, using 3179 kWh/yr and having about 200 watts always-on and average peaks reaching 800 watts. Together, these first three profiles highlight the diversity in range of load magnitudes, as well as the average nature of the combined loads.

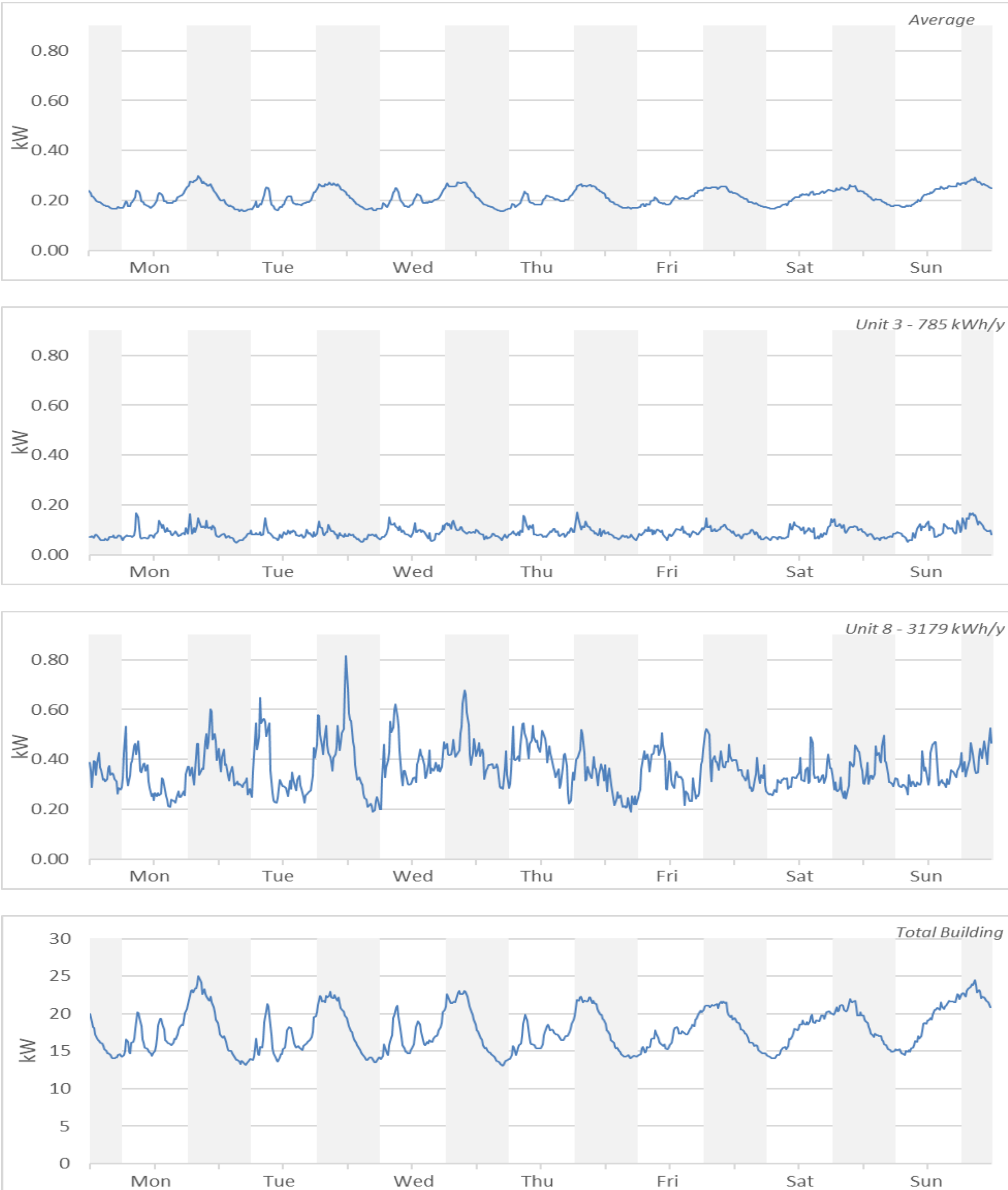


Figure 30. Average Aggregate 15-Minute Interval Weekly Load Profiles for Representative UEPH Occupancy Units; Average over All Units (top), Lowest-Consuming Unit (next), Highest-Consuming Unit (next), Total Occupancy Unit Load for Building (bottom). Note: the grey bands represent the period from 6 P.M. – 6 A.M. each day.

The bottom profile shows the combined magnitude and variation estimated for all 84 living quarters in the building, ranging between approximately 13 and 25 kW, with different patterns between weekdays and weekends. Extrapolating the metered energy use to an entire year, and all 84 living quarters suggests a total occupant unit annual energy use of 155,800 kWh/yr. This assumes that 1) the average magnitude of loads within the section of 30 monitored units is representative of the rest of the units in the building and 2) that the monitored loads from the study period are representative of loads across the rest of the year, with minimal seasonal variation. It is difficult to provide validation of these assumptions without a longer study or obtaining details regarding actual occupancy rates over time. If accepted, this estimation approach suggests an average annual load of just over 200 W per unit or 100 W per Soldier assuming full occupancy (or 130 W per Soldier if 80% occupied), including room lighting, kitchen appliances, and personal plug loads.[1]

An estimate of typical lighting energy consumption based on the hardwired lighting fixtures in each unit and the physical layout of units (including the natural light limited to the bedrooms) suggests that a typical unit likely consumes approximately 700 kWh per year for lighting (with some units using more and others less). The peak power demand of all installed lighting is 270 watts, so the estimated energy represents a 30% average utilization over the year. Summing across all 84 units suggests that occupant unit lighting uses approximately 60,000 kWh/yr and that plug loads account for the remaining 96,000 kWh/yr of in-unit electricity use. Therefore, it is estimated that the plug loads in the average occupant unit uses 1100 kWh/yr.

Results from the load center monitoring are combined with the results from the device-level monitoring of plug loads in the common areas and discussed the following section.

5.5.2.2 Common Area Device-Level Metering

Results from the energy monitoring of plug load devices within common areas of the UEPH are highlighted in Figure 31, along with the magnitude of the occupant quarters energy use. Table 14 details the results of the device-level monitoring of common area washing machines, vending machines, water fountains, and lobby television, including number of devices, and the unit and total energy consumption. Dryer energy was estimated based on the number of washer loads observed from the washer data. Figure 32 presents the top energy-consuming devices of those monitored. These include the two refrigerated vending machines, the average annual per-unit energy consumption for the clothes dryers, the snack vending machine, lobby television, followed by the washing machines, led by the most-used vertical axis machine which consumes about 200 kWh/yr.

The magnitude and variation of the resulting common area device loads are compared to occupant unit loads in Figure 33. The combined loads for the washers and vending machines are displayed at the bottom of the chart. The orange line shows the total of all common area loads including the clothes dryers, whose weekly average energy use was allocated to the profile to coincide with the monitored operation of the washers. This confirms that the clothes dryers are the highest energy consumer of the common area devices. Shown in green however are the resulting load from the building's occupant quarters.

[1] The complete set of average weekly 15-minute interval load profiles, for all 30 representative occupant units monitored in the UEPH, are presented in Appendix E.8.

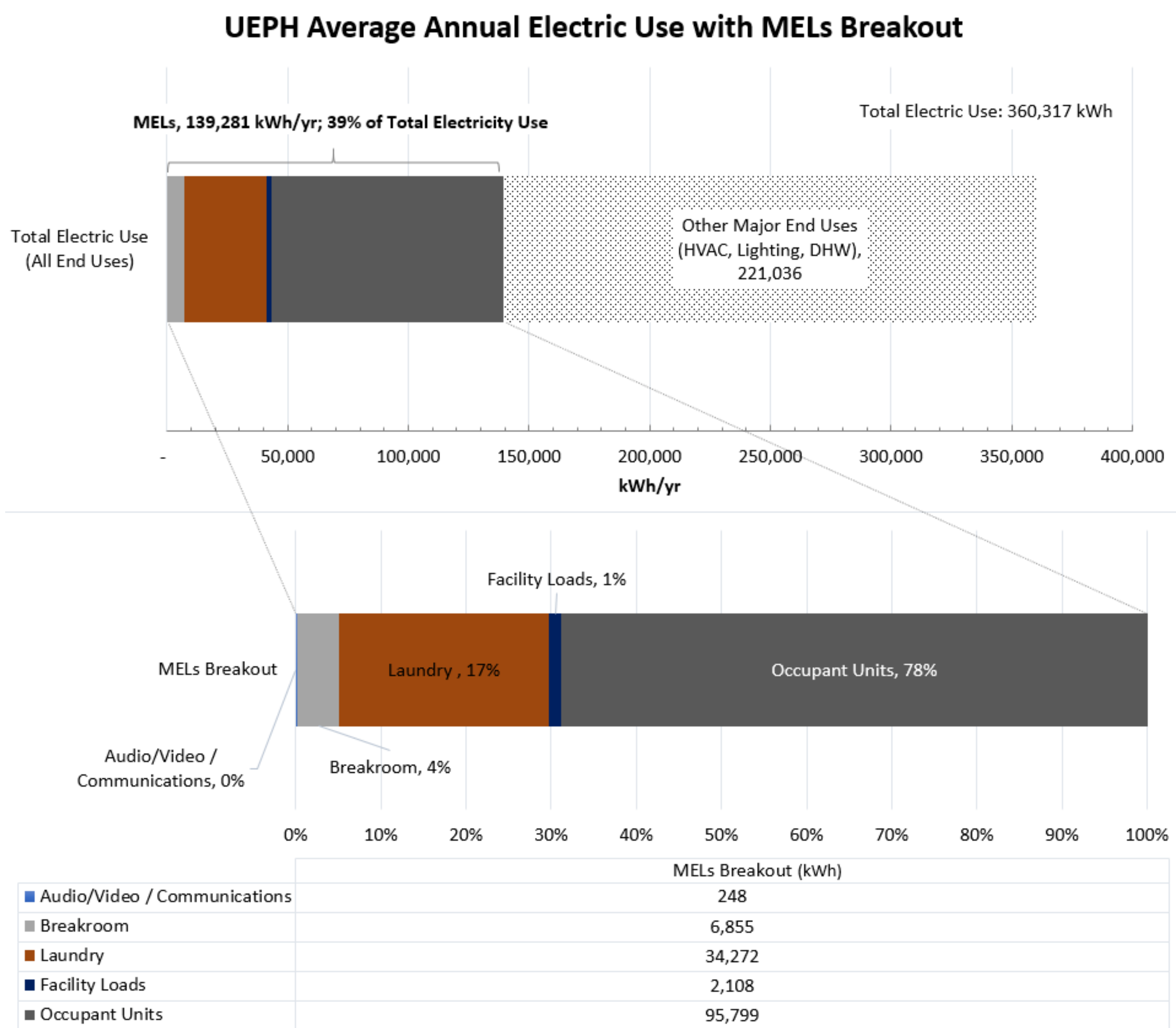


Figure 31. UEPH MEL Electricity Use by Category Relative to Total Building Use

Table 14. UEPH Inventory with Electric Use Breakdown per Device

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/ ksf	kWh/ Occupant
Audio/Video / Communications	TV/LCD Display	1	100%	248	248	4	2
	CATEGORY TOTAL	**1**	**100%**		**248**	**4**	**2**
Breakroom	Vending Machine	3	100%	2,260	6,779	106	51
	Personal Refrigerator	1	0%	-	-	-	-
	Water Cooler	2	100%	38	76	1	1
	CATEGORY TOTAL	**6**	**67%**		**6,855**	**107**	**51**
Laundry	Washing Machine	14	100%	118	1,649	26	12
	Dryer	22	0%	1,483	32,623	511	243
	CATEGORY TOTAL	**36**	**50%**		**34,272**	**537**	**256**
Facility Loads	Telecom / Wifi	1	0%	-	1,201	19	9

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/ ksf	kWh/ Occupant
	Fire Alarm System	1	0%	-	907	14	7
	CATEGORY TOTAL	2	0%		2,108	33	16
Occupancy Units	Living Quarters	84	36%	1,140	95,800	1,502	715
	CATEGORY TOTAL	84	36%		95,800	1,502	715
TOTALS		129	48%		139,281	2,183	1,039

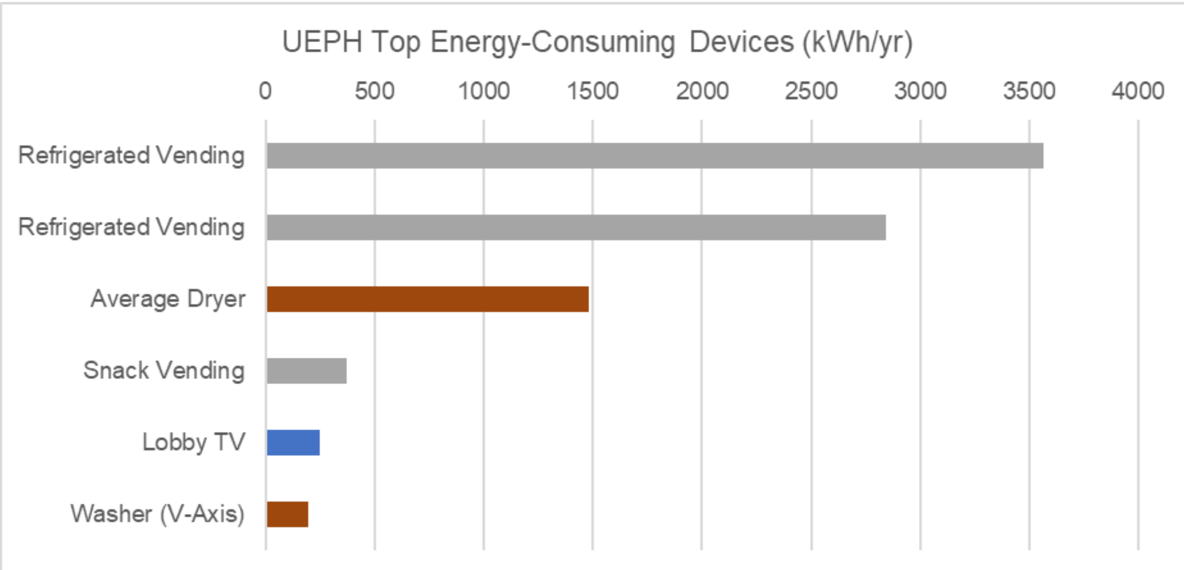


Figure 32. Top Energy-Consuming Common Area Devices in the UEPH

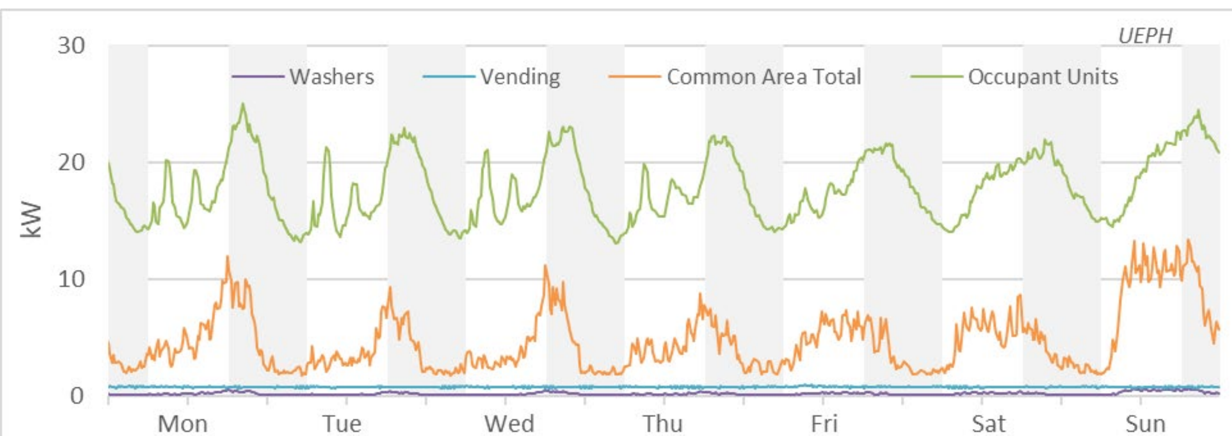


Figure 33. Resulting Average Weekly Load Patterns for the Common Area Devices and Occupant Units in the UEPH

Compiling the 15-minute interval MDMS whole building data into this same average weekly profile format allows a comparison of the profiles shown above to the whole building electricity profiles, and derive the combined typical HVAC+Lights profiles as the difference. Figure 34 shows the resulting profiles comparing total common area loads, occupancy unit loads, total MELs, and HVAC+Lights, for typical summer, winter, and shoulder periods.

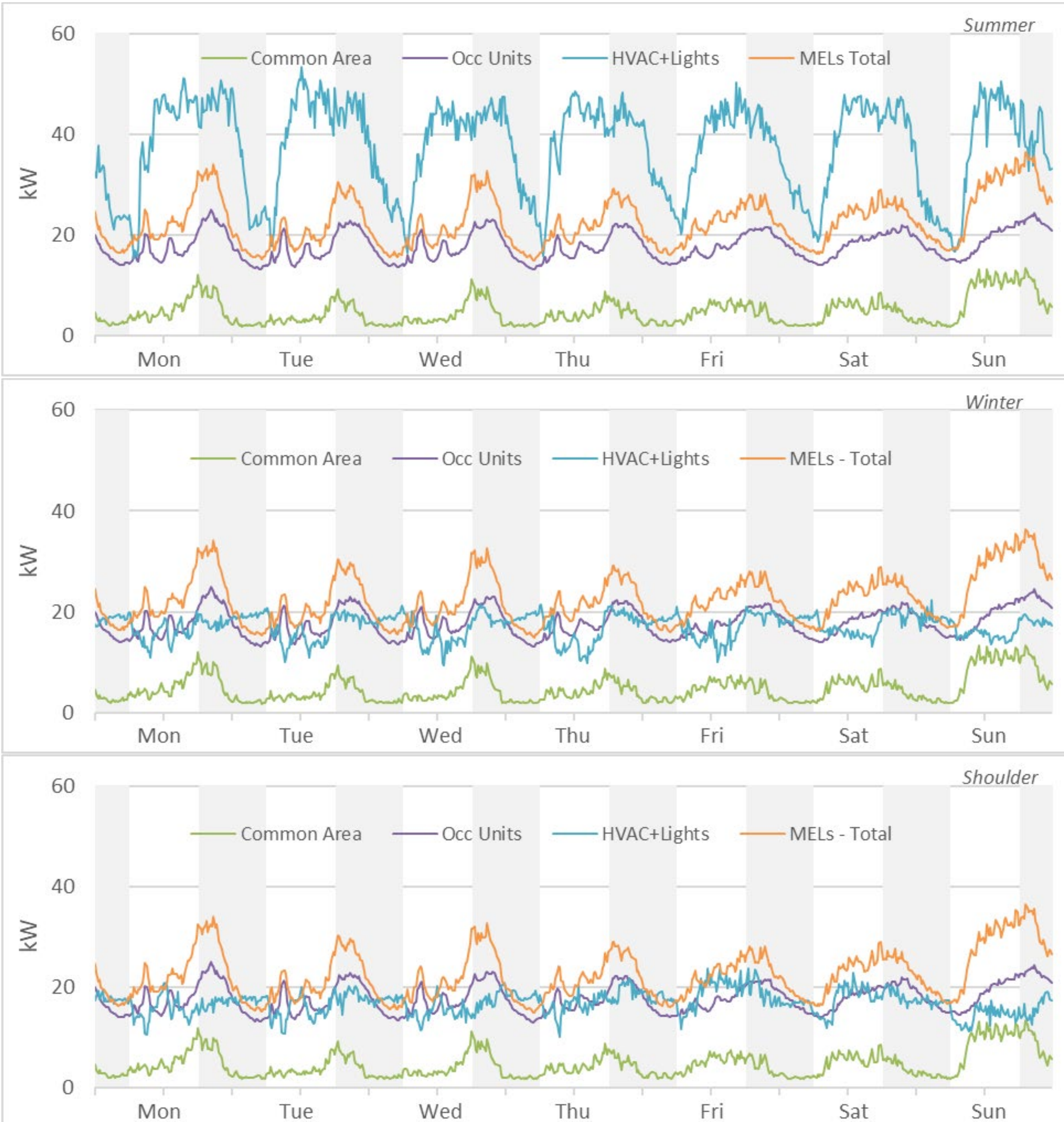


Figure 34. Average Aggregate 15-Minute Interval Weekly Load Profiles for Representative UEPH Common Area Plug Loads, Occupancy Units, Total MELs, and HVAC+Lights by Season

Figure 35 compares just the resulting HVAC+Lights profiles for each season. The high loads in the summer period represents the operation of the cooling system that reaches peak operation from mid-morning into the middle of the night. However, the primary contributors to the winter and shoulder season loads include fans to ventilate and move air within the building. These two profiles align remarkably well, which suggests that the general magnitude and nature of the occupancy unit and common area devices captured during the summer monitoring period appear reasonably consistent across the other seasons.

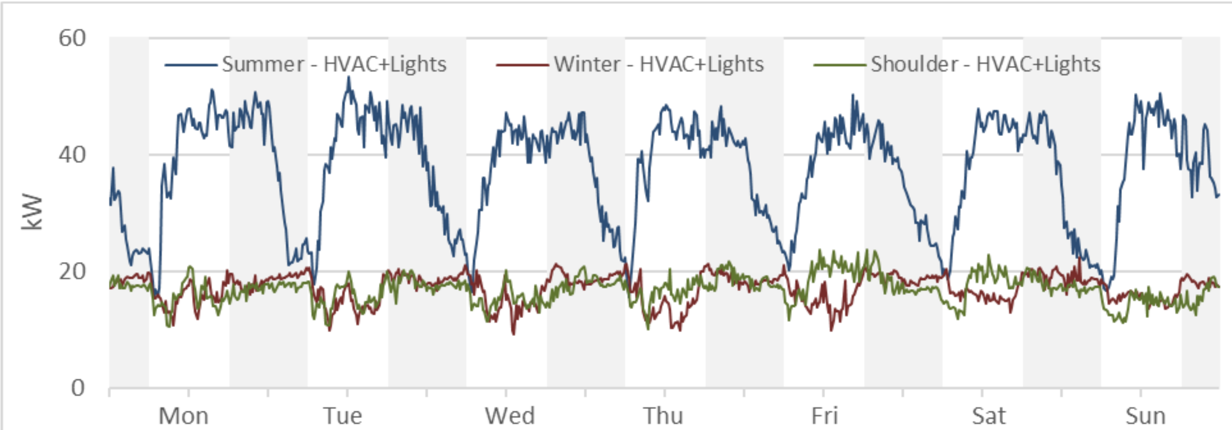


Figure 35. Average Aggregate 15-Minute Interval Weekly Load Profiles for Representative UEPH HVAC+Lights by Season

5.6 BN HQ

The plug load and MEL energy consumption estimates for the BN HQ are presented in Figure 36 for each of the five methods applied. As described in Section 4.2.4, the layout and locations of electrical panels in the BN HQ allowed for the deployment of a highly robust panel metering strategy to capture a detailed and comprehensive look at total MELs. The resulting estimate from the detailed panel/circuit top-down approach is therefore recognized as the most complete and robust estimate of annual energy use for the building's plug loads and MELs. This 26,190 kWh/yr usage represents 21% of annual electricity consumption, and 11% of total annual building energy use. All other methods except for the seasonal MDMS always-on approach provide a reasonably similar result, within just a percentage point or two in terms of annual energy use. The annual end use energy breakdown for the BN HQ is presented in Figure 37, based on the results of the detailed panel and circuit metering.

As described below in Section 5.5.2, the initial bottom-up approach was deemed inadequate due to an inability to perform device-level monitoring across a representative cross-section of devices. As a result, a hybrid bottom-up approach was applied combining elements from the device-level metering in the building plus a consumption-by-proxy approach for devices where monitoring was believed to not capture the true diversity of use. The hybrid approach resulted in a much better approximation of total energy use. More details on each method, including the bottom-up energy use monitoring results by device and category type are described below.

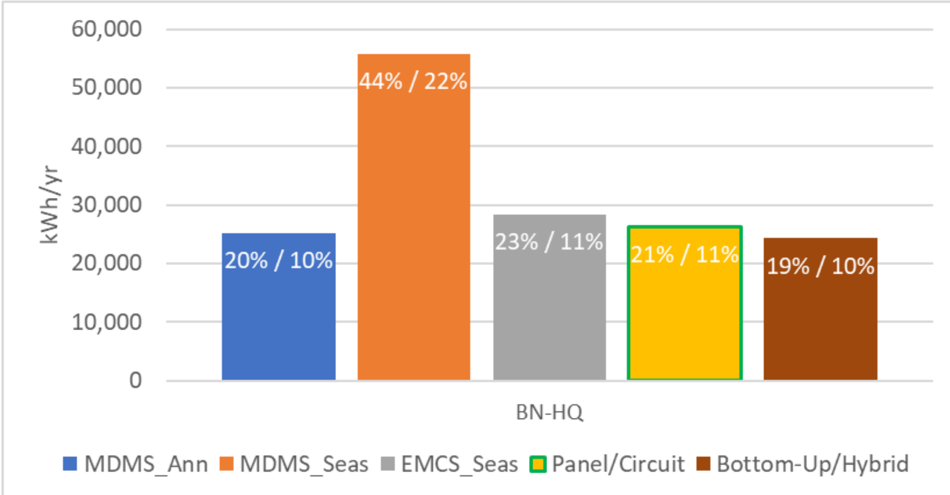


Figure 36. Comparison of BN HQ Annual MELs Consumption Estimates by Approach (percent values indicate % of annual electricity/% of annual total energy consumption)

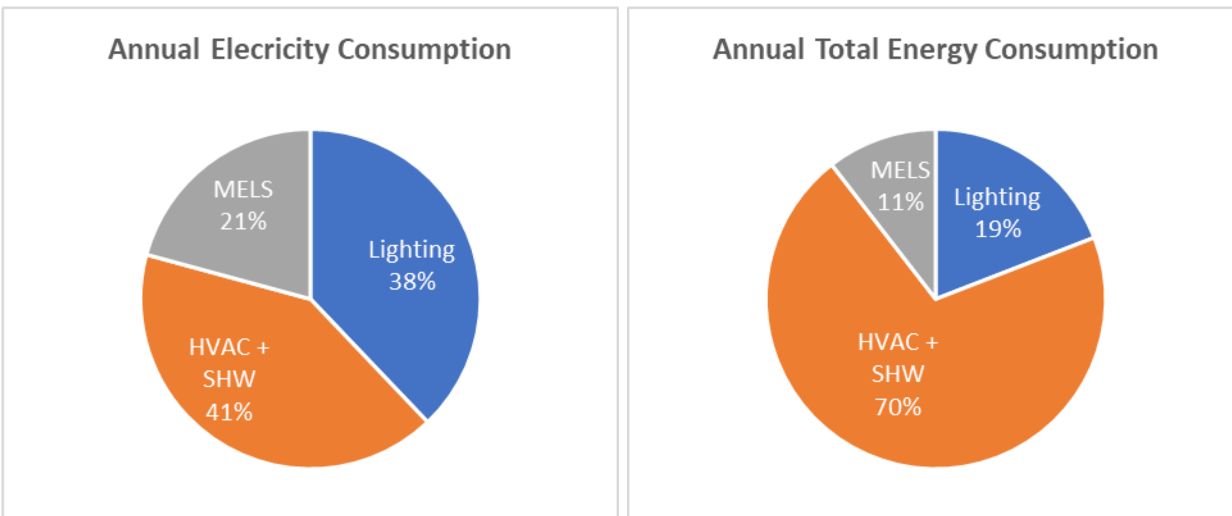


Figure 37. Estimate of BN HQ Annual MELs Consumption Relative to Other End Uses

5.6.1 Top-Down Energy Consumption Results

5.6.1.1 MDMS Annual Minimum Load

The global annual minimum always-on load approach estimates 25,230 kWh in annual MEL electricity consumption. This represents 20% of the total building electricity consumption and 10% of total energy consumption.

5.6.1.2 MDMS/EMCS Seasonal Minimum Load Approach

Figure 38 presents a typical MDMS 15-minute daily profile for the BN HQ building for a winter weekday. Of interest in the profile is the well-defined and fairly consistent always-on loads with a daily minimum estimated at 7.5 kW. Also noted in this profile is its inverted nature; that is, the daytime energy use is less than the nighttime energy use. An inverted profile is often seen in buildings that have relatively flat diurnal profiles and have significant outdoor/parking lot lighting loads. Both of these attributes are true of the BN HQ where the diurnal profile is relatively flat and has an exterior lighting load of between 4 and 5 kW, turning off at roughly 7 A.M. and back on at about 5 P.M. at the time of year shown.

Figure 39 presents a typical EMCS 1-minute daily profile for the BN HQ building for the same day as shown by the MDMS data. Highlighted in this profile is the greater definition of individual events, including the exterior lighting on/off events. This profile allowed a more refined estimate of the “always on” MELs of about 4.5 kW. This value and others across the dataset were used to better estimate an annual top-down MELs use of 28,380 kWh/yr, or about 23% of total annual electric consumption and 11% of total annual energy consumption.

Also noted in this profile are four defined power spikes occurring regularly throughout the day – these are also visible in the 15-minute profile, yet less pronounced. These power spikes have been traced back to the elevator circuit and are likely the electrical energy used by the hydraulic-fluid tank heater. A more detailed look at the elevator loads is presented in Section 6.5.1.

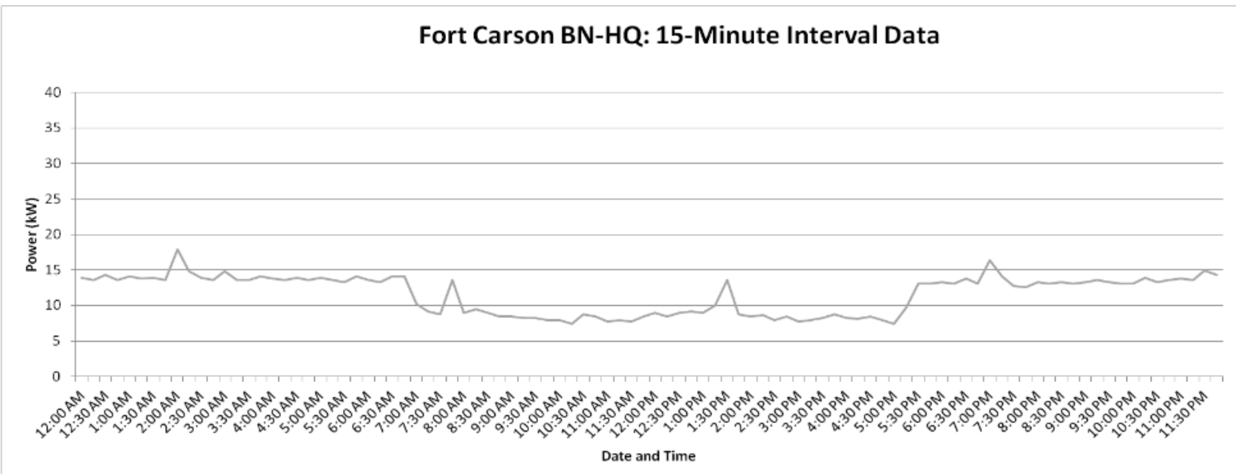


Figure 38. BN HQ Representative Daily MDMS 15-Minute Interval Profile (Winter Weekday)

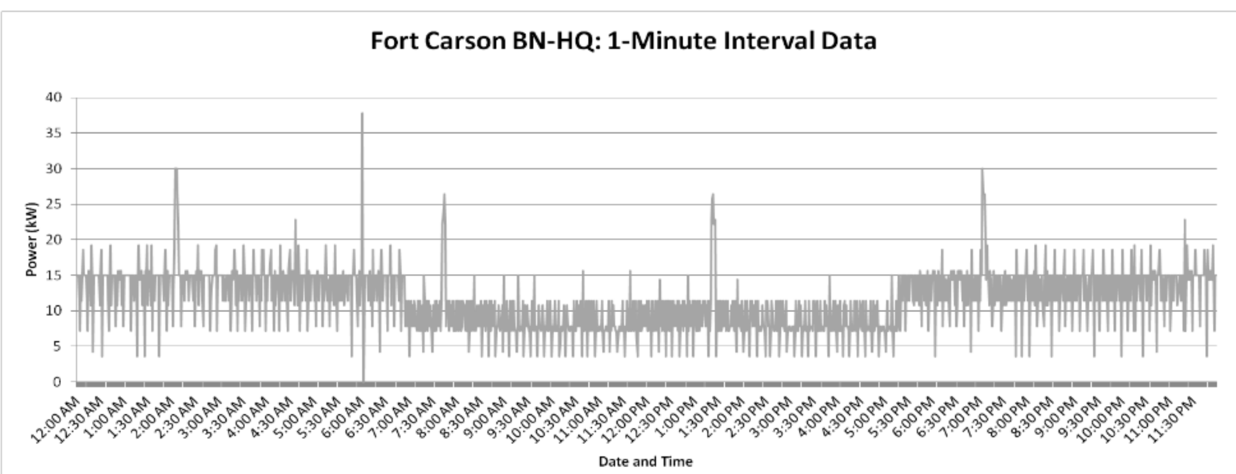


Figure 39. BN HQ Representative Daily EMCS 1-Minute Interval Profile (Winter Weekday)

5.6.1.3 Detailed Project-Installed Metering

Figure 40 presents a typical winter weekday and Figure 41 a typical winter weekend day from the detailed panel and circuit metering installed in the BN HQ building. Starting with Figure 40, notable is the relative increase in MEL energy use during business hours and then a reduction at night. This is a fairly typical profile and highlights some degree of manual or automated turn-down or shut-off protocols have been implemented. Figure 41 highlights the expected flatness of a weekend MELs profile. There is most likely opportunity in both profiles to reduce the base load consumption.

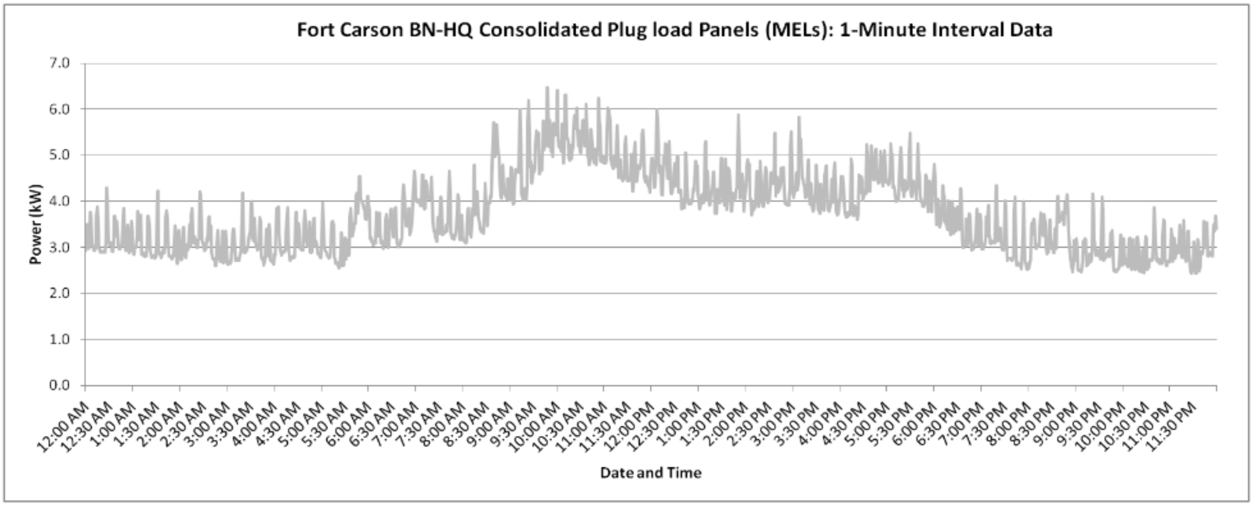


Figure 40. BN HQ Typical Detailed MELs Weekday 1-Minute Load Profile (Winter Weekday)

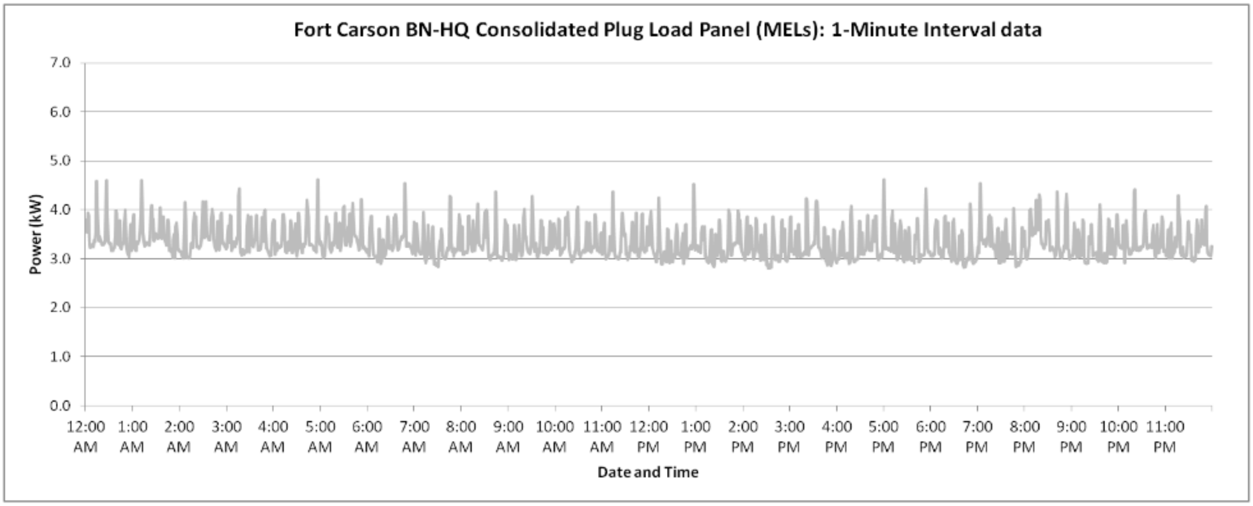


Figure 41. BN HQ Typical Detailed MELs Weekend 1-Minute Load Profile (Winter Weekend Day)

Aggregating the BN HQ MELs over the metering duration and extrapolating across a typical year results in an estimated total MEL annual energy use of 26,191 kWh/yr or 21% of the total annual building electrical consumption and 11% of total annual energy consumption. This value corresponds well with the whole-building MEL estimate. The electrical panel configuration in the BN HQ allowed for detailed MEL monitoring and enabled effective exception metering to remove non-MELs from sub-panels otherwise serving receptacles and other plug loads. Based on this approach, the team is confident that this application of detailed top-down monitoring and estimation provides not only the most robust result for the BN HQ, but also the most robust and accurate MELs estimation for any of these five study buildings.

5.6.2 Bottom-Up Energy Consumption Results

The application of bottom-up, device-level monitoring within the BN HQ reaffirmed the importance of developing and following a metering strategy and plan focused on monitoring a sample of devices that is of sufficient size and representation to adequately capture the diversity of characteristics and use for each set of devices. Overall metering penetration was lower and across fewer and less diverse spaces than desired based on site-specific challenges. The team was asked to avoid certain areas where higher device density and use was concentrated. As a result, the initial bottom-up results showed significantly lower UECs for many device types than seen within similar spaces of other study buildings. Even with the best efforts to combine results from this bottom-up approach with select MELs from the detailed top-down approach, the final resulting estimate of total MELs annual electricity consumption was 19,325 kWh/yr. Having high confidence in the detailed top-down result of 26,191 kWh/yr, this resulted in an underestimate of close to 6900 kWh or 26% of the total annual value.

In response to this lower than anticipated result, the team reviewed the device energy use estimates and monitoring percentages and decided to recalculate the bottom-up estimates using a slightly different approach. For devices deemed to have poor or non-representative monitoring coverage from installed device-level metering, unit energy values were replaced with proxy estimates developed for similar devices in other buildings. Some of the devices for which proxy energy use estimates were applied include televisions, laptop computer and monitors, mini-fridges, personal coffee makers, and large copy/print multi-function devices. As a result of this application of proxy consumption data where judged appropriate, the new total MEL annual energy consumption estimate increased to 24,300 kWh/yr, with only 1890 kWh (7%) remaining unknown when compared to the results from the detailed top-down results. Pie charts of the MEL contributions by category from each of these two bottom-up approaches are shown in Figure 42.

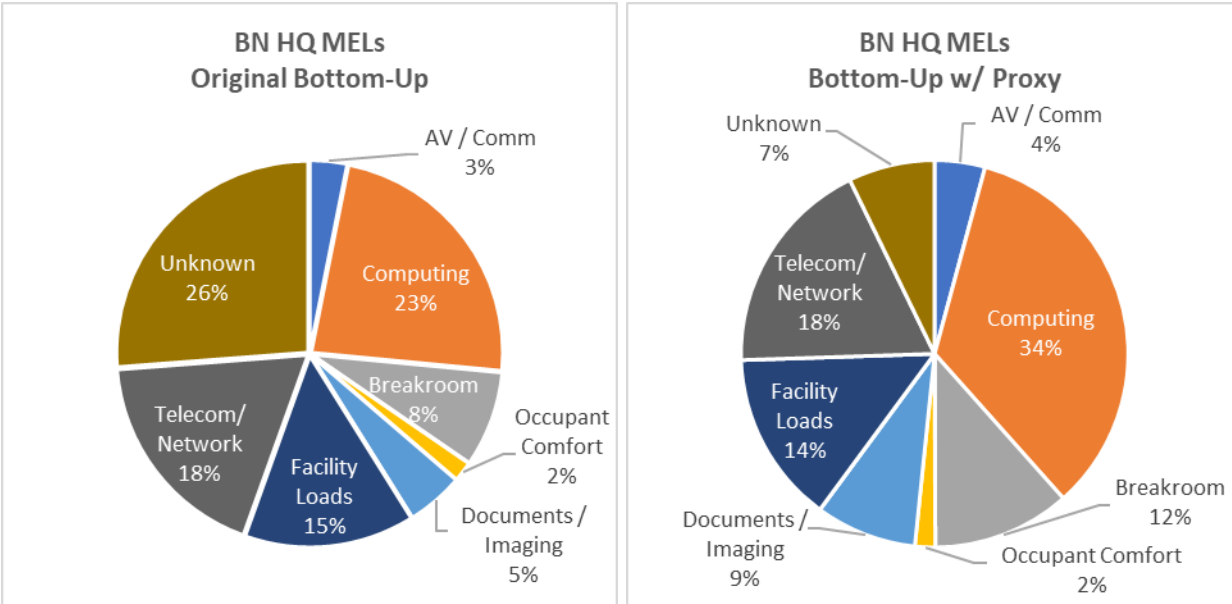


Figure 42. Comparison of Two Bottom-up Results for the BN HQ Building. Original Bottom-up (left) and Bottom-up with Proxy Unit Energy Results for Select Devices (right)

The results highlight the value that a carefully executed consumption-by-proxy approach can offer, when a detailed inventory and set of representative device UECs are available from similar spaces. Based on the improvement of results for the hybrid approach that applies proxy energy use estimates, this method was selected to represent the most robust bottom-up results.

The best overall estimate of annual MEL energy use was still provided by the detailed top-down panel and circuit monitoring. The breakout of MEL energy use by equipment category is represented in Figure 43. MELs use approximately 26,190 kWh/yr, or 21% of total electricity use in the building. The highest energy-consuming category is facility loads (40%), personal computing equipment (34%), followed by breakroom (12%), and documents and imaging (8%). The facility loads include a number of larger MELs including telecom and networking equipment, the elevator, plus the 1890 kWh of unknown energy representing the gap between the best MEL energy estimate and the results of bottom-up approach combining device-level metering with proxy results for select device types. Additional detail for each category and subcategory is provided by Table 15.

A MELs component unique to this facility compared to the others in the study are the training rooms. This space consists of a mix of conference rooms, versatile offices, and computer lab and also includes several rows of floor-mounted outlets for Soldiers to use for equipment and laptop computer power needs. While these receptacle loads are true plug loads, the transient nature of their use did not allow for bottom-up, device level monitoring; instead, the plug loads within this area were captured through panel monitoring. Results suggest that this area uses 1174 kWh/yr, or accounts for approximately 5% of MELs electric use, and is listed as a facility load.

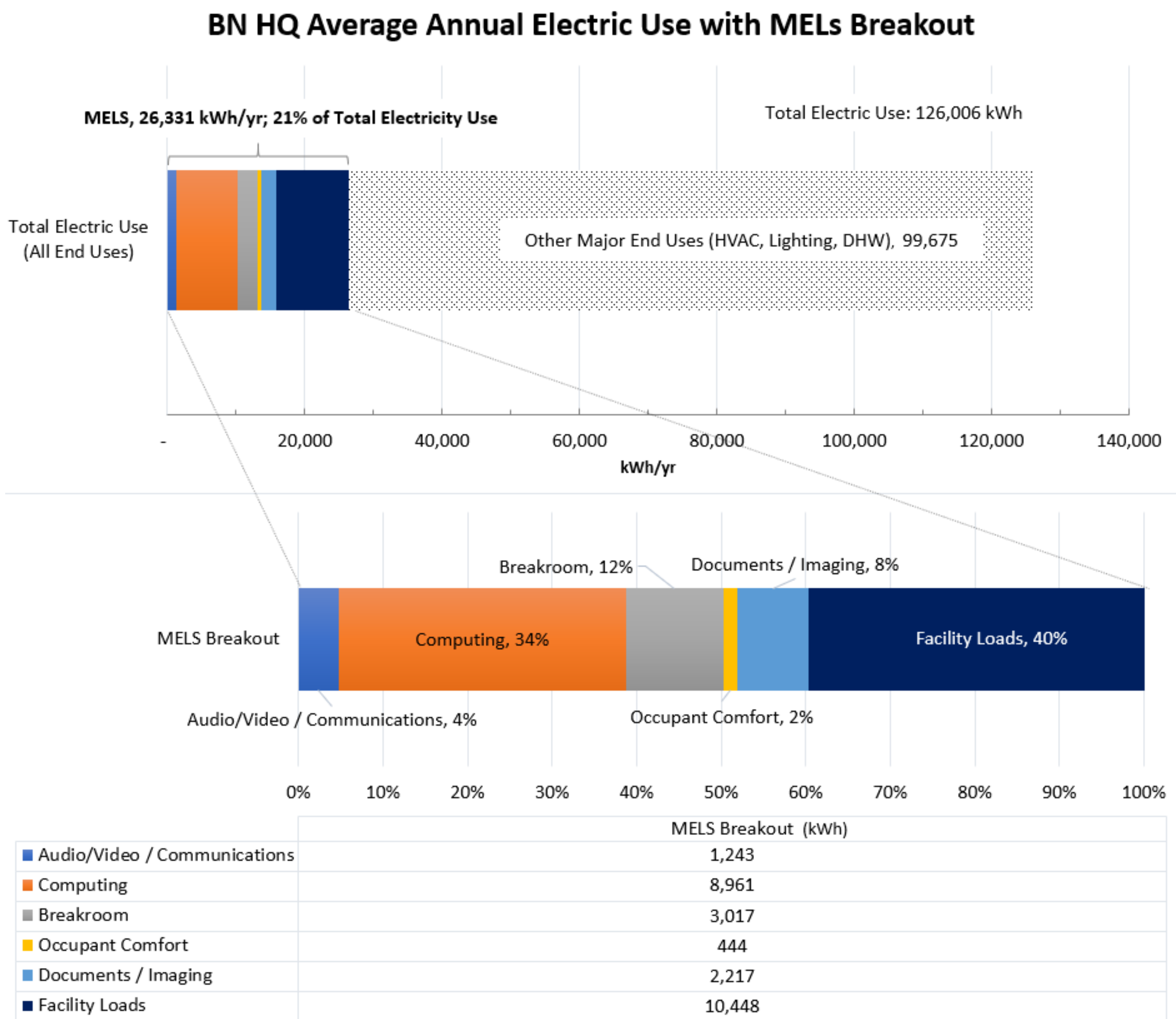


Figure 43. BN HQ MEL Electricity Use by Category Relative to Total Building Use

Table 15. BN HQ Inventory with Electric Use Breakdown per Device

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/kSF	kWh/ Occupant
Audio/Video / Communications	Projector	1	0%	141	141	10.1	3.9
	TV/LCD Display	6	50%	75	450	32.1	12.5
	Phone - Desk	27	7%	5	132	9.4	3.7
	Phone - Conference	1	0%	4	4	0.3	0.1
	Personal Audio	3	0%	18	53	3.8	1.5
	Cable Box	3	33%	53	159	11.4	4.4
	Comm Radio/XMtr	1	100%	305	305	21.8	8.5
	Cell Phone Charger	5	0%	-	-	-	-
	CATEGORY TOTAL	**47**	**15%**	**-**	**1,243**	**88.8**	**34.5**

Category	Sub-Category	Count	% Metered	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/kSF	kWh/ Occupant
Computing	Laptop Computer	54	17%	119	6,112	457.8	178.1
	LCD Monitor	52	17%	54	2,785	198.9	77.4
	Computer Speakers	3	0%	21	63	4.5	1.8
	CATEGORY TOTAL	**109**	**17%**	**-**	**8,961**	**640.1**	**248.9**
Breakroom	Large Refrigerator	2	100%	395	790	56.4	21.9
	Personal Refrigerator	7	29%	223	1,558	111.3	43.3
	Coffee Maker - Personal	7	29%	71	497	35.5	13.8
	Water Cooler	2	0%	38	76	5.4	2.1
	Microwave	3	33%	32	96	6.9	2.7
	CATEGORY TOTAL	**21**	**33%**	**-**	**3,017**	**215.5**	**83.8**
Occupant Comfort	Space Heater	2	50%	184	369	26.4	10.2
	Fan - personal	2	0%	-	-	-	-
	Standup Desk	6	0%	-	-	-	-
	Task Lights	21	5%	4	75	5.4	2.1
	CATEGORY TOTAL	**31**	**6%**	**-**	**444**	**31.7**	**12.3**
Documents/ Imaging	Small Networked Printer	10	30%	117	1,174	83.9	32.6
	Large Copy Print Device	2	0%	477	954	68.1	26.5
	Shredder	5	60%	18	89	6.4	2.5
	CATEGORY TOTAL	**17**	**35%**	**-**	**2,217**	**158.4**	**61.6**
Facility Loads	Telecom	-	100%	1,201	1,201	85.8	33.4
	Networking	-	100%	3,592	3,592	256.6	99.8
	Elevator	1	100%	2,140	2,140	152.9	59.5
	Fire Alarm System	-	100%	444	444	31.7	12.3
	Security System	-	100%	7	7	0.5	0.2
	Oil Minder	1	0%	-	-	-	-
	Restroom Hand Dryer	-	0%	-	-	-	-
	Training Rooms	-	-	-	1,033	73.7	28.7
	Unknown	-	-		1,890	135.0	52.5
	CATEGORY TOTAL	**2**	**63%**	**-**	**10,307**	**736.2**	**286.3**
TOTALS		**227**	**19%**	**-**	**26,190**	**1,870**	**730**

Figure 44 reports the 10 highest-consuming MELs within the BN HQ. Together, these comprise 77% of the total annual plug-load energy consumption for this building. The largest consumers include the personal computing devices (laptops and monitors), telecom and networking loads, the elevator, printers, and refrigerators. Many of these devices offer potential for reducing unnecessary energy use.

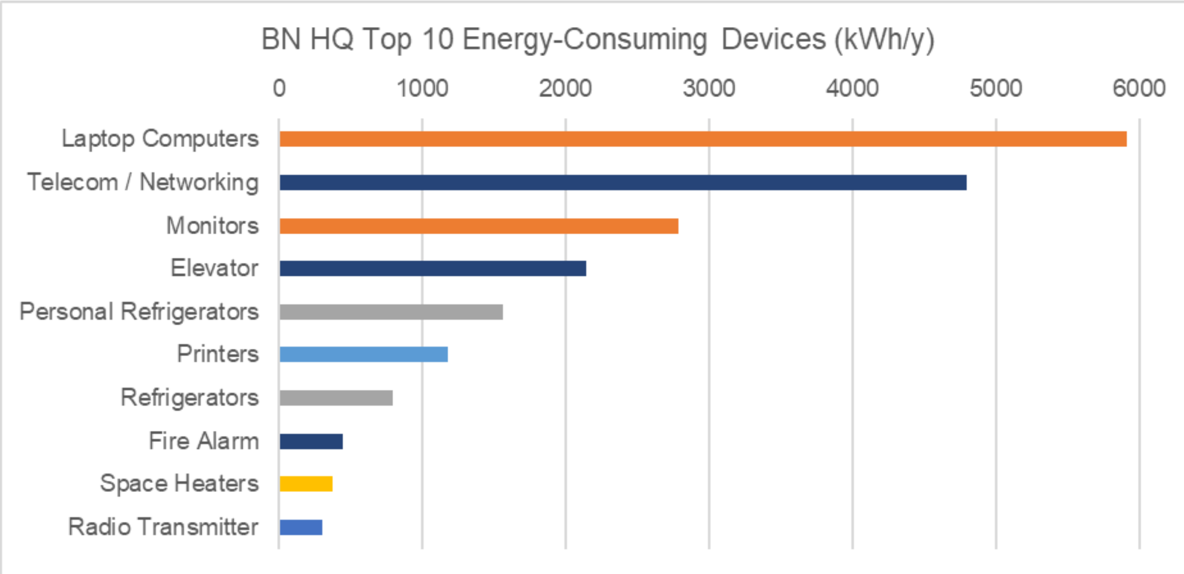


Figure 44. Top Ten Consuming Device Types in the BN HQ Building

5.7 COF

Even though no energy monitoring was performed in the COF, an assessment of the magnitude of MELs was performed using available data. Top-down assessments were performed using whole-building MDMS and 1-minute interval electricity data. A proxy-based bottom-up assessment also was performed by taking the building's equipment inventory results and applying UECs determined for similar devices from the metered buildings, primarily the Admin, TEMF, and select devices from the BN HQ. These results are presented and compared here to review how applicable and reasonable the methods and results might be.

The resulting plug load and MEL energy consumption estimates for the COF are presented in Figure 45 for the four methods applied. Lacking any detailed end use or device-level metering, it is more difficult to assess the results for the COF than for the other buildings. However, because the consumption-by-proxy approach is a bottom-up method based on the actual inventory of devices and energy use from similar spaces, it is believed that this offers a reasonably robust method for estimating MEL consumption. This success in applying a similar approach as part of the bottom-approach in the BN HQ also supports this belief. As part of the inventory process, the team was able to visit most spaces in the building and not only count devices but also see how they are used and select the energy use for comparable devices in similar settings from other buildings to build up the energy use estimate.

This consumption-by-proxy approach suggests an energy consumption for MELs of 18,000 kWh/yr, 9% of annual electricity, and 5% of total annual energy use. The annual MDMS approach estimate is just slightly higher, at 24,530 kWh/yr, with the two seasonal whole building interval data approaches resulting in estimates approximately twice as high. Those higher seasonal estimates are likely driven by a larger contribution of always-on non-MELs in this building. For example, there is likely frequent or continuous operation of some HVAC and lighting systems (e.g., within the readiness area), in addition to lighting and other loads within a couple of smaller storage/shop buildings served by electricity from the COF. More details on each method, including the bottom-up energy use estimates by device and category type from the consumption-by-proxy approach are described below.

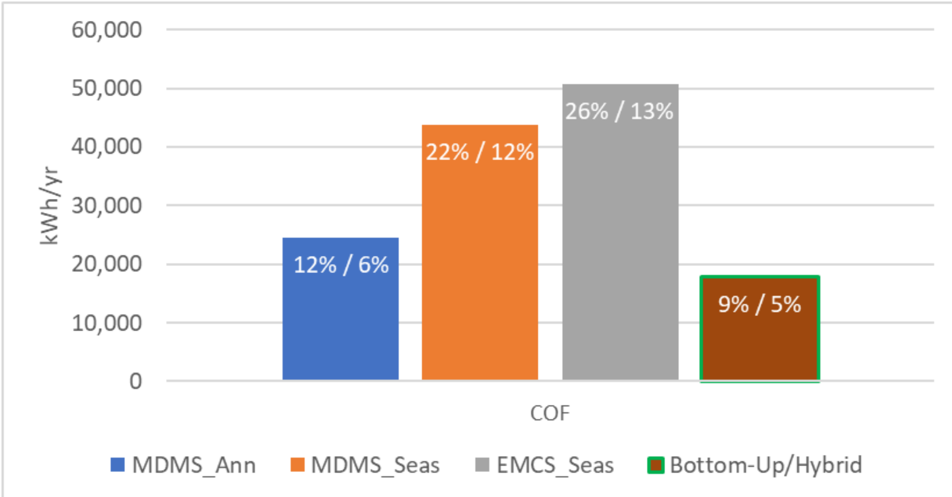


Figure 45. Comparison of COF Annual MELs Consumption Estimates by Approach (percent values indicate % of annual electricity/% of annual total energy consumption)

5.7.1 Top-Down Energy Consumption Results

5.7.1.1 MDMS Annual Minimum Load

The global annual minimum load approach estimates 24,530 kWh in annual MEL electricity consumption based on the always-on load. This represents 12% of the total building electricity consumption and 6% of total energy consumption.

5.7.1.2 MDMS/EMCS Seasonal Minimum Load Approach

Figure 46 and Figure 47 present the 15-minute and 1-minute interval data sets for the COF for the same summer weekday. Note the similarities in overall shape between the profiles, however, the 1-minute profile provided greater resolution and resulting detail. From the 1-minute data, specific start/stop events (HVAC and lighting systems) can be defined and more thoroughly explored. This profile allowed a more refined estimate of the always on MELs of about 6.5 kW. This value and others across the data set were used to better estimate an annual top-down MELs use of 50,720 kWh/yr or about 26% of total annual electric consumption.

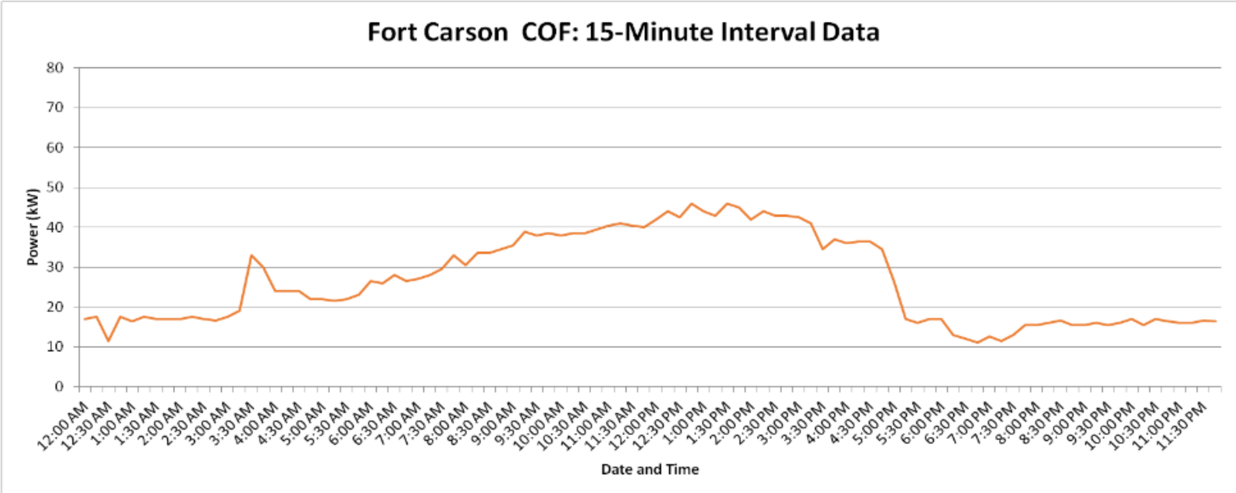


Figure 46. COF Representative Daily MDMS 15-Minute Interval Profile (Summer Weekday)

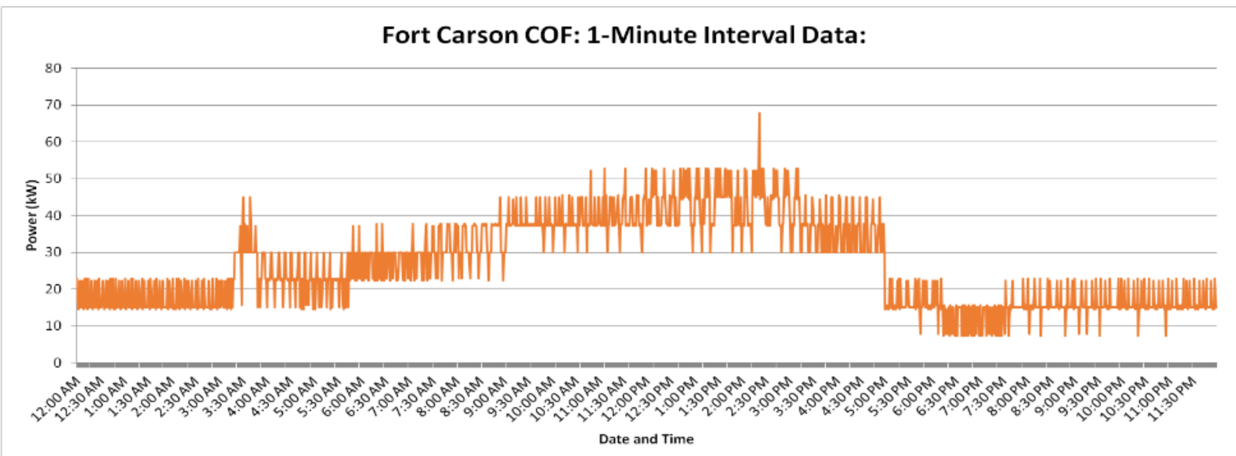


Figure 47. COF Representative Daily EMCS 1-Minute Interval Profile (Summer Weekday)

5.7.2 Bottom-Up Energy Consumption Results

As noted, no metering was performed by this project within the COF. However, by taking advantage of the comprehensive device inventory performed along with the results of device-level metering in other buildings, a bottom-up “consumption-by-proxy” approach was applied. This was performed by applying the unit energy consumption values from the most similar devices monitored in other buildings to the device population within the COF. The resulting breakout of MELs consumption by category and device types are presented here.

Figure 48 presents the resulting estimate of annual MELs energy consumption, by major category. Facility loads, breakroom, and personal computing categories combine to contribute an estimated 86% of the MELs total. Table 16 presents these results in greater detail, highlighting the number of devices and unit and total energy estimates by device and category. Figure 49 highlights the ten highest-consuming devices with the COF. Together, these comprise 94% of the total annual plug load energy consumption, led by telecom and networking, vending, laptops, refrigerators, and monitors. Based on what was observed in the other study buildings, it is believed that many of these devices are ripe for measures and approaches that can effectively reduce their energy use without negatively impacting the mission.

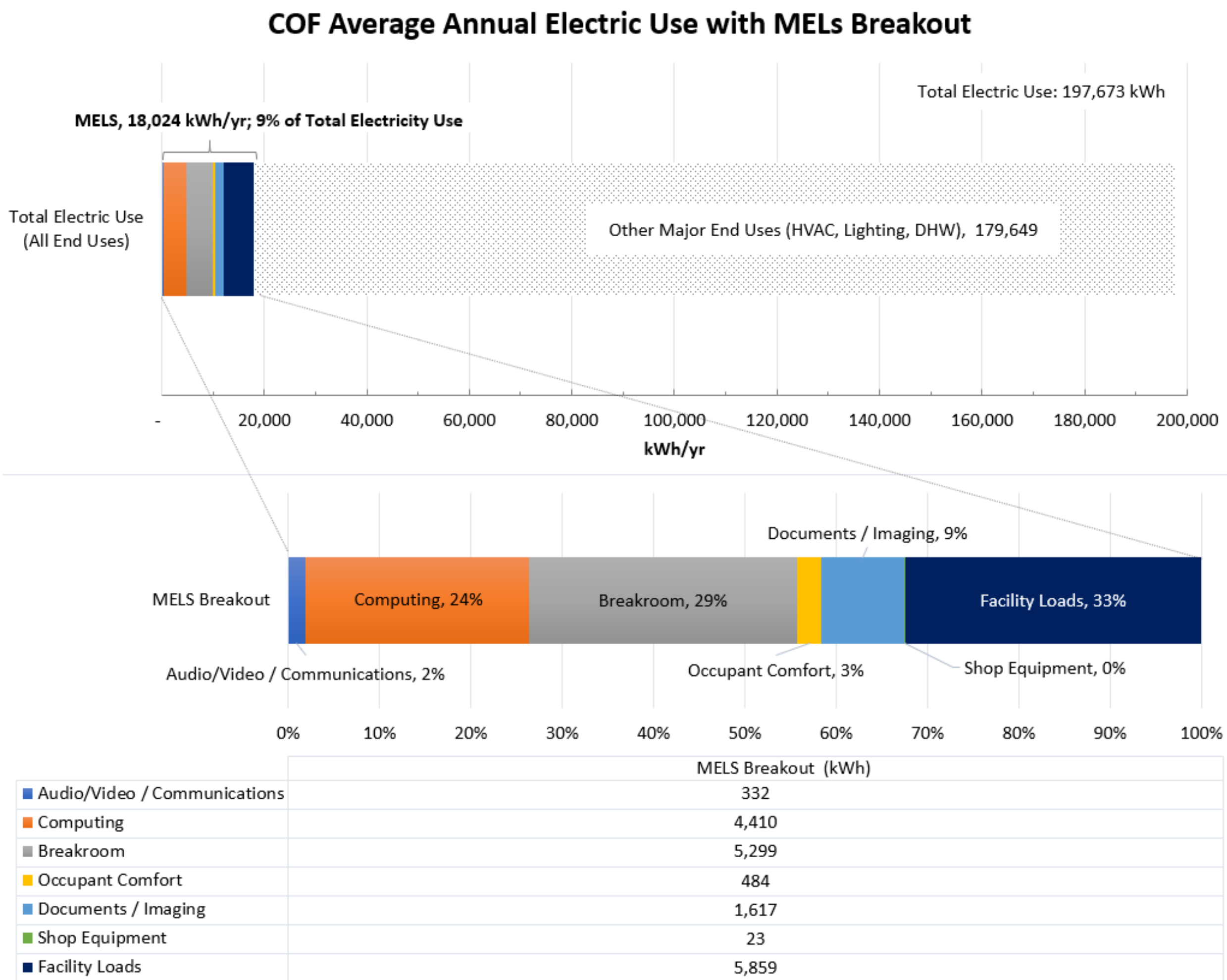


Figure 48. COF MEL Electricity Use by Category Relative to Total Building Use

Table 16. COF Inventory with Electric Use Breakdown per Device

Category	Sub-Category	Count	% Metered[(a)]	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/ ksf	kWh/ Occ
Audio/Video / Communications	Projector	1	0	141	141	4	4
	TV/LCD Display	1	0	76	76	2	2
	Phone	11	0	5	54	2	2
	Personal Audio	3	0	18	53	2	2
	Cell Phone Charger	7	0	1	9	0	0
	CATEGORY TOTAL	**23**	**0**		**332**	**10**	**9**
Computing	Laptop Computer	28	0	108	3,030	94	87
	LCD Monitor	29	0	47	1,349	42	39
	Docking Station	1	0	32	32	1	1
	CATEGORY TOTAL	**58**	**0**		**4,410**	**136**	**126**

Category	Sub-Category	Count	% Metered[(a)]	Unit Energy (kWh/yr)	Total Energy (kWh/yr)	kWh/ ksf	kWh/ Occ
Breakroom	Vending Machine – Refrigerated	1	0	3,203	3,203	99	92
	Large Refrigerator	2	0	682	1,363	42	39
	Personal Refrigerator	2	0	196	393	12	11
	Coffee Maker	4	0	42	170	5	5
	Water Cooler	2	0	38	76	2	2
	Microwave	4	0	24	94	3	3
	Toaster	1	0	-	-	-	-
	CATEGORY TOTAL	16	0		5,299	164	151
Occupant Comfort	Space Heater	1	0	184	184	6	5
	Fan – personal	7	0	18	123	4	4
	Fan – industrial stand	1	0	176	176	5	5
	Candle Warmer	1	0	-	-	-	-
	Personal Scale	1	0	-	-	-	-
	Clothes Steamer	1	0	-	-	-	-
	CATEGORY TOTAL	12	0		484	15	14
Documents / Imaging	Small Networked Printer	6	0	64	382	12	11
	Large Copy Print Device	2	0	600	1,199	37	34
	Label Maker	4	0	-	-	-	-
	Stapler	1	0	-	-	-	-
	Shredder	3	0	12	36	1	1
	CATEGORY TOTAL	16	0		1,617	50	46
Shop Equipment	Parts Cleaner	1	0	23	23	1	1
	CATEGORY TOTAL	1	0		23	1	1
Facility Loads	Telecom	-	0	1,201	1,201	37	34
	Networking	-	0	3,592	3,592	111	103
	Access Control	-	0	55	55	2	2
	Fire Alarm System	-	0	907	907	28	26
	Security System	-	0	58	58	2	2
	Restroom Infrared Controls	-	0	45	45	1	1
	CATEGORY TOTAL	0	0		5,859	181	167
TOTALS		**126**	**0**		**18,024**	**557**	**515**

(a) No monitoring was performed in the COF. Energy consumption was estimated by proxy; that is, by applying unit energy consumption results for similar devices obtained in other buildings with similar spaces and applications.

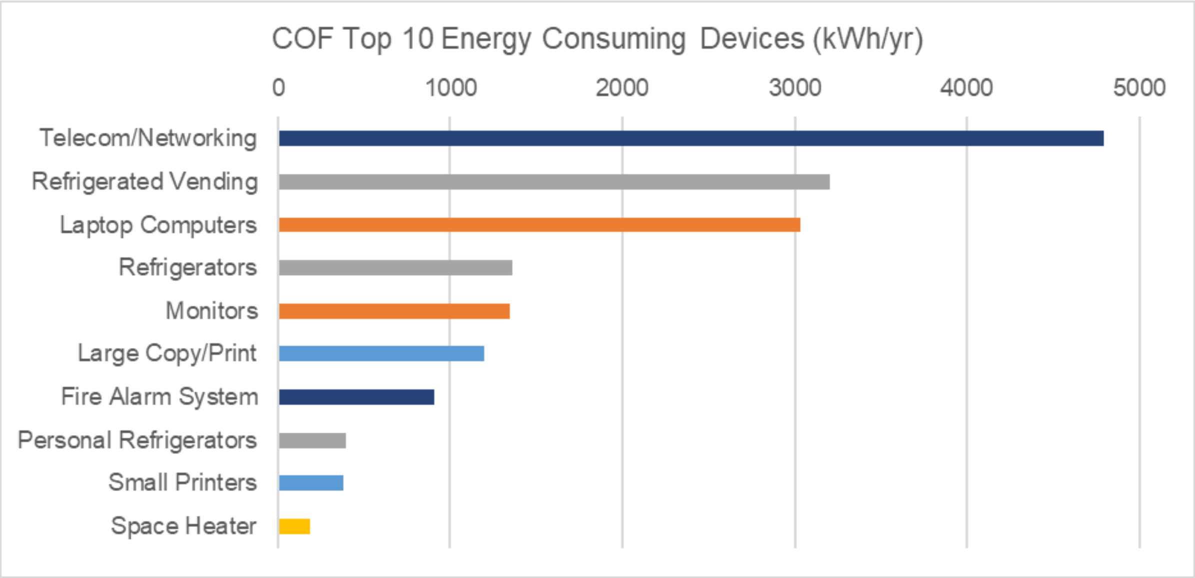


Figure 49. Top Ten Consuming Device Types in the COF (estimated based on the COF's device inventory and energy use of devices monitored in other buildings)

6.0 Savings Potential for Select Plug Load Devices

The importance of monitoring plug load devices extends beyond the ability to estimate annual energy consumption and build up to the magnitude of energy used by this end use category. It also enables an understanding of the nature of the loads and their variation over time. It is the characteristics of the load that describes the power demand over occupied and unoccupied periods and helps to identify energy savings potential. It is more than just the total energy that is consumed but rather how much of that is wasted when the device is not being used or needed.

For most of the devices monitored during this study, 1-minute power data was acquired and compiled into profiles of power demand over time to help visualize the characteristics of each plug load device. Data were aggregated into 15-minute interval power profiles that represent the typical characteristics of use over an average week. These plots differentiate each day type as well as daytime vs. nighttime periods and are useful in visualizing as well as calculating the energy savings opportunities from improved control of these devices. For each of the profile charts presented, alternating bands of white and grey differentiate between daytime and nighttime hours of each date. The transition occurs at 6 A.M. and 6 P.M. for each day, with the center of each white band representing noon and the center of each grey band midnight.

Equipment that operates during unoccupied periods such as nights and weekends often represent strong candidates for a variety of improved management and control approaches to reduce waste.[1] These measures include improvements to procurement and excess processes, setup of built-in power saving options, external controls, as well as education and shaping of occupant awareness and behavior. Many of these measures could be influenced via review of policy, both existing and new, to encourage and realize significant energy use reduction within these and similar buildings across the Army. However, as discussed further in Section 7.3, an occupant education and outreach component is critical, because unlike other major building end uses, the majority of plug loads are directly operated by building occupants.

The 15-minute power profiles compiled from the device- and circuit-level data were introduced in Section 5.4.2 when discussing the common space and living quarter loads in the UEPH. Profiles for additional device types are presented in this section to highlight the savings potential for select plug load and MEL devices that were metered and evaluated in this study. A more complete presentation of the profiles compiled from the metered power data, and how to interpret them, is presented within Appendix E.

Initial estimates of savings from the identified measures discussed below are summarized in Table 17 for the study buildings and also extrapolated to the relevant building floor area across the Army according to the category code of each applicable study building. The total estimated annual savings within these five study buildings is over 29,000 kWh and valued at nearly $1,800. When extrapolated across the Army within just these category codes the annual savings increases to nearly 83 million kWh and $5 million (assuming the same electricity cost of $0.06/kWh). The actual savings potential is expected to be much higher when these measures are also applied to other buildings beyond the five categories represented by these study buildings.

[1] The mission of the building and its systems must be understood prior to controlling devices as some equipment may need to operate during traditionally unoccupied periods.

Table 17. Priority Plug-Load Savings Opportunities and Scale of Potential Savings across the Five Study Buildings and their Categories across the Army

Savings Measure	Study Building Savings (kWh/yr)	Device-Level Savings (%)	Potential Savings Across Army (million kWh/yr)[a]
Implement Sustainable Computer Policy: Power Systems Down Each Night	11,300	46%	31.6
Refrigerated Vending Machines: Energy Star with Custom Settings	6,000	57%	31.2[b]
Improve Power Save Settings: Large Copy Print Devices	2,500	47%	7.6
Refrigerators: Replace 20+ Year Old Units with New Energy Star Models	2,600	39%	6.3
Computer Purchase Policy: Purchase Laptop PCs over Desktops + UPS	2,000	46%	3.2[c]
Commercial Coffee Makers: Add Timer or Similar Controls	490	43%	2.6
Space Heaters: Review Policy Enforcement and Exceptions for Reasonable and Responsible Use	2,500	50%	1.1[d]
Printers: Enable Sleep Mode	370	14%	0.93
Projectors: Turn Off When Not in Use	300	41%	0.75
Elevators: Review and Remove or Adjust Hydraulic Fluid Heaters	1,300	62%	0.25
TOTALS	**29,360**	**51%**	**82.9**

[a] Army-wide savings are estimated based on savings per ft^2 in study building(s) multiplied by floor area of the study building cat code. Actual savings are likely higher but depend on other building types being relevant for the identified measure and how representative the study building(s) and device densities, usage, and settings are across the Army.
[b] Savings estimates for refrigerated vending machines are extrapolated to the entire Army floor area, and not only the building categories assessed in this study.
[c] Savings are estimated only for general Admin buildings and assume that (1) a sustainable solution to allow computers to power down nightly has been implemented, and (2) the category average density of desktop computers is only 30% of that in the Fort Carson Admin building studied.
[d] Assumes a 50% overall reduction rate within these building types across the Army (to account for variations in climate, use, and policy exceptions to support occupant comfort and productivity)

6.1 Personal Computing

Personal computing equipment has the largest device inventory and is the second-highest energy-consuming plug load category across all five of these representative buildings.[1] There are 386 computing devices (40% of total equipment inventory across these five buildings) which together consume an estimated 29,000 kWh per year. This represents 10% of the total energy consumed by MELs in these five buildings and 27% of the MEL consumption within the Admin, TEMF, BN HQ, and COF combined (no personal computing devices were inventoried within the common areas of the UEPH). The primary contributors are laptop computers (112), desktop

[1] The laundry category is the highest energy-consuming category, using an estimated 34,000 kWh/yr. driven by the energy-intensive clothes dryers.

computers (37) and monitors (171), plus some auxiliaries such as personal UPS units (34) and computer speakers (22).

Army policy regarding the purchase and operation of information technology equipment such as computers, monitors, and other office equipment is described within Army Regulation 25-1 (2019). However, based on the data collected during this study, it appears that some of these regulations are not being followed. Here, the energy savings potential within this category is evaluated based on actual usage and load patterns from these devices, captured by the device-level monitoring during this study. Existing policies should be reviewed, and perhaps better communicated and enforced as appropriate in these areas as it pertains to personal computing to ensure that the desired energy savings are achieved. And some new policies could be considered where they don't currently exist.

Significant savings can be achieved by enhancing the effective power management of workstations (laptops, desktops, and monitors). Enabling power saving options of monitors and powering down computers each night could save 31.6 million kWh per year, just within the building categories specific to Admin, TEMF, BN HQ, and COF. Savings accruing to other facility categories would increase this estimate substantially. Additional savings associated with purchasing laptops over desktops (often with individual workstation UPS devices) would conservatively save an additional 3.2 million kWh/yr within Admin buildings alone.

Recommendations:

- Establish an effective, secure, and sustainable cybersecurity update process for computer systems that does not conflict with existing energy policy (by taking advantage of approaches to wake-on-update or schedule updates)
- Encourage the use of laptops over desktop computers (and investigate the potential for thin clients as that technology and application continues to be proven)
- Eliminate personal UPS devices except as required for more critical systems (laptops with batteries will assist in protecting systems and data from loss in power outages, and thin client technology will offer even greater protection)
- Strengthen policies and outreach regarding the setting and maintenance of personal computer power saving modes and screen brightness (e.g., see Energy Star program recommendations)

6.1.1 Computer Energy Policy

The largest potential for reducing personal computer energy waste across the Army exists in reviewing the effective and sustainable implementation of current policy as outlined by Army Regulation 25-1 (2019), regarding the powering down of equipment when inactive. The energy conservation guidelines for information technology equipment states that "All computers, desktops, laptops, and tablets must have energy-saving features, such as ENERGY STAR® certification. These features, if configurable, shall be configured to be activated after no more than 30 minutes of inactivity." Also, "Monitors and laptops displays will enter energy-savings mode after 15 minutes of inactivity." The Army has established computer use policies which encourage users to power down their workstation at night with reminders that pop-up on their monitors. However, as seen from the data collected on computers and monitors, nearly all workstations are left on all the time. The reason is that this policy conflicts with current implementation of cybersecurity policy and processes that requests users to leave systems running in order to effectively provide and install operating system and other important updates on a recurring and as-needed basis. These updates are critical from a cybersecurity standpoint to protect Army computing systems and resources, and as a result the update policy has been prioritized over the energy policy.

Discussions with site personnel within the study buildings as well as the Fort Carson NEC confirmed that the focus on ensuring a strong cybersecurity posture have come at the expense of energy savings. Contacts at the NEC confirmed that they have asked staff to leave their computers on all the time in order facilitate more rapid updates. Several staff we spoke with in the study buildings confirmed this. They further said that they typically never turn them off as reconnecting a computer or other connected device to the network after a period of disconnect is a time-consuming and non-trivial process that often requires assistance from the NEC. This posed some challenges for the team when installing meters to monitor the energy use of desktop computers, to ensure that the user was aware that their computer would need to be powered off and then turned back on.

The solution to this conflict between computer energy policy and cybersecurity requirements may not be simple, but it is possible. It is recommended that the Army prioritize and coordinate the evaluation and implementation of suitable processes that will enable computer workstations to be powered off or down each night, while not impeding the rollout and installation of critical updates. Many organizations have found and deployed solutions to this challenge. Representatives from the NEC confirmed that they have tried implementing a wake-on-demand approach, but a lingering port security issue has held that back. A consistent approach coordinated by the CIO, G-6, and NETCOM may be necessary to ensure that an effective and secure solution is deployed across the Army, rather than having each installation NEC work to identify their own solutions.

Results outlined below for the primary types of personal computing devices suggest that total annual savings across the Army within just the four building types with these devices in the study could reach 31.6 million kWh annually. In fact, the savings would be much higher when expanded to all cat codes that have personal computing devices connected to the network.

6.1.1.1 Desktop Computers

Desktop computers were found only in the Admin building, where 37 were inventoried and 14 monitored. These are all Dell OptiPlex model 7040 and 7050 Energy Star certified minitower devices. The average weekly 15-minute interval profile for these desktop computers is presented in Figure 50. This chart shows that the average desktop computer active workday load is generally between 23-34 watts, and slightly lower on Fridays, within the Admin building. The typical minimum power draw averages about 20 watts across all day types and hours. This is consistent with the rated short idle state power as published by Dell and Energy Star, but considerably higher than the sleep or off state power reported as 1.2 watts and 0.3 watts, respectively.[1] Some exceptions to the lower unoccupied period power draw are clearly evident from the weekly profile. At approximately the same time on Wednesday, Friday, and Saturday evenings around 8 P.M. a spike in desktop power is seen, along with smaller spikes each day around 5 P.M. These spikes are believed to represent occurrences of system updates being pushed out to these desktop computers over the network, with the Wednesday events causing the most activity and power response by the desktop computers.

[1] https://www.energystar.gov/productfinder/product/certified-computers/details/2330565/export/pdf

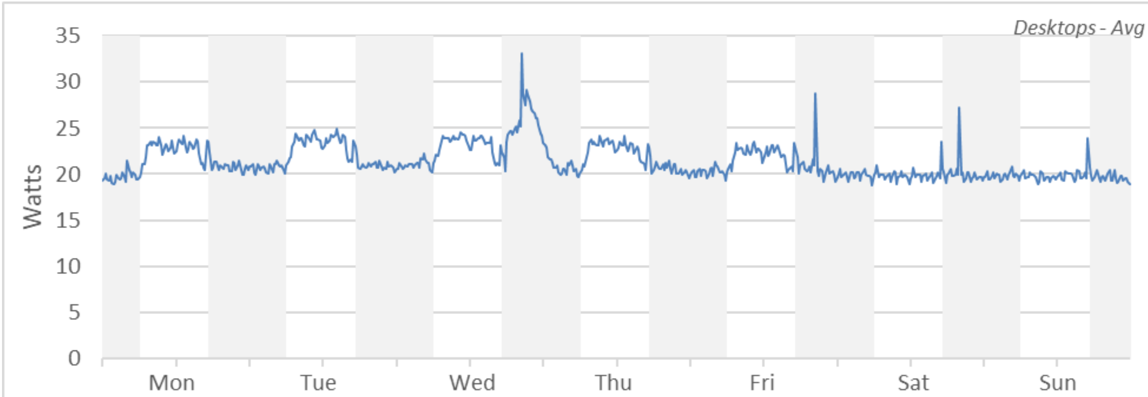


Figure 50. Average Weekly 15-Minute Interval Load Profile for the Average Desktop Computer (grey bands indicate daily night-time hours between 6 P.M. and 6 A.M.)

This weekly profile not only highlights the nature of the current electricity load of the average desktop PC, but also provides an opportunity to evaluate potential savings. To estimate the impact of an improved approach for pushing updates to these desktop computers, a scenario was modeled that allows the desktops to power down to full sleep mode each night and all weekend, waking only to accept and perform system updates. The resulting profile for the typical desktop computer that powers down each night is shown as Figure 51. On an annual energy consumption basis, this shows that the average desktop PC could save 97 kWh/yr (52% of its current energy use) by implementing an effective approach to balance energy and cybersecurity policies. This is a conservative savings estimate, as PCs would also be able to realize additional savings at other times when not being used. Cumulative savings for this Admin building would be 3600 kWh/yr, based on the overall reduction in desktop electrical demand as shown in Figure 52, by the difference in the base and power-save scenarios.

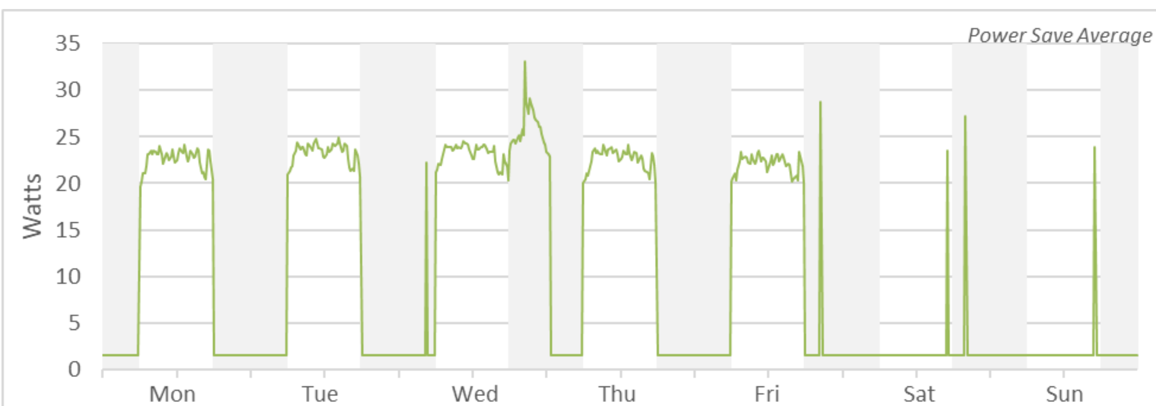


Figure 51. Average Weekly 15-Minute Interval Load Profile for the Average Desktop Computer under Power Saving Scenario

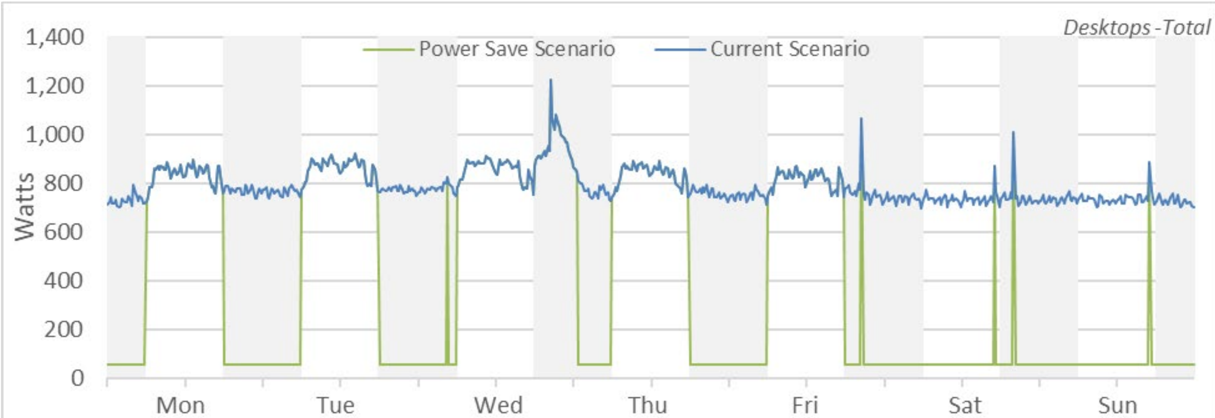


Figure 52. Total Admin Building Savings Potential from Applying Robust Power Saving to All Desktop Computers (3600 kWh/yr)

If all Army Admin buildings had a similar density of desktops PCs, these savings could scale to over 19 million kWh per year. Assuming a more reasonable density of desktop computers in the typical Admin building as 30% of what was found in this Admin, the savings potential for desktop computers across all Army Admin buildings would exceed 5.7 million kWh annually.

6.1.1.2 Laptop Computers

Overall, laptop computers outnumbered desktops within the study buildings by a ratio of more than 3:1, with 112 inventoried. The Admin had 17, TEMF 13, BN HQ 54, and COF 28. Laptops in general are more energy efficient and use less power than comparable desktop computers. In fact, results from the monitoring performed in this study show that on average, the desktop computers use twice the energy of the laptops (180 kWh/yr vs. 90 kWh/yr).[1] Figure 53 highlights the distribution of laptop annual energy consumption in a box plot for the 26 monitored laptops, by building.[2] This shows that with the exception of a couple of outliers in the TEMF with high energy use, the energy use of laptops in the Admin is higher than in the TEMF or BN HQ. However, as shown in Figure 54, the same issue applies to laptops in each of these buildings as was noted for desktop computers; laptops are left running all the time, using over nine watts on average in active standby when they could be using less than one watt in sleep mode.

[1] This average annual use for laptops may be skewed lower from the monitoring of a non-representative sample of laptops within the BN HQ. Comparing results for just the Admin, the desktop PCs consume 1.5 times that of the laptops, which use an average of 120 kWh/yr.

[2] Additional box plots for other plug load devices, along with an explanation of how to read a box plot, are presented in Appendix D.

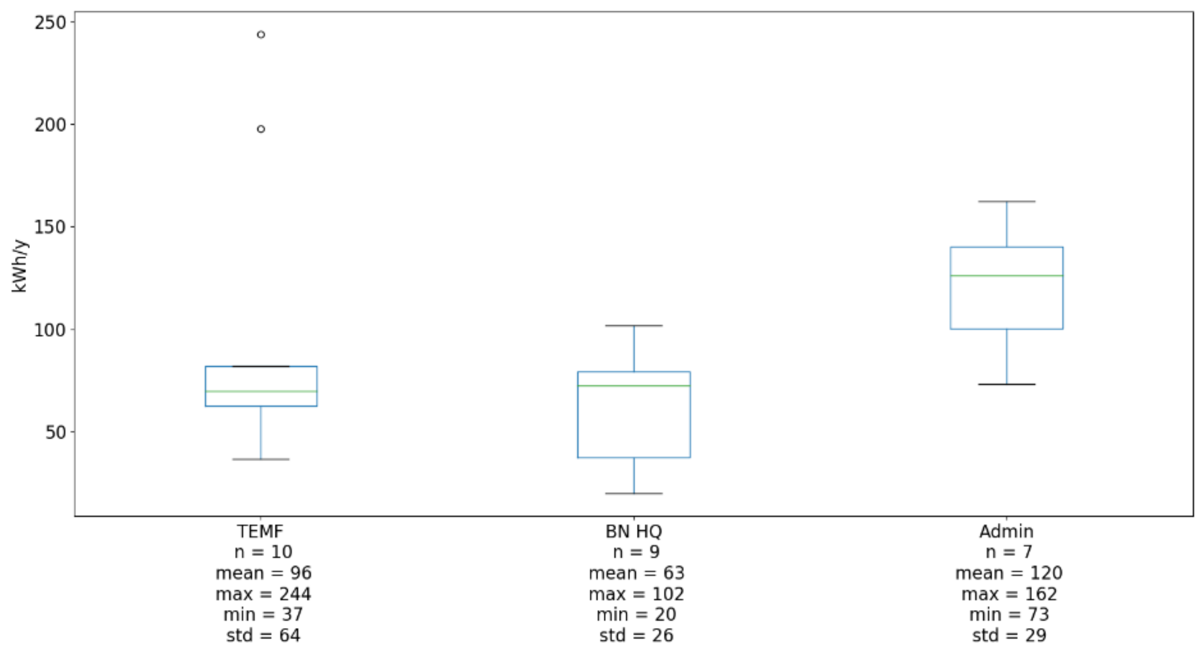


Figure 53. Box Plots of Monitored Laptop Annual Electricity Consumption for the TEMF, BN HQ, and Admin Buildings

The profiles in Figure 54 show spikes during unoccupied periods which also likely correspond to system updates for the laptops. They appear to occur most prominently late Friday evenings, as well as to a lesser degree on Tuesday, Wednesday, Saturday, and Sunday. Average savings by applying a lower power sleep mode for weekends and each weeknight from 6 P.M. to 6 A.M. are 44 kWh/yr per laptop, or 48% of average annual energy use. Scaling to all laptops within the study buildings will save 4900 kWh/yr. Extrapolating Army-wide based on the similar device densities and loads as determined in these buildings suggests that annual savings from applying current energy policy to laptops in these building types could save an additional 17.2 million kWh per year.[1] Figure 55 highlights the total savings potential for the four buildings with laptops in this study, by comparing the current profile for all laptops to the resulting profile that under the scenario that all laptops turn off or enter sleep mode at the end of each work day while allowing for system updates to proceed.

[1] This considers only these four building types and assumes that the average density of laptops in Admin buildings is increased by the same proportion that they were reduced when estimating the savings attributed to desktops above.

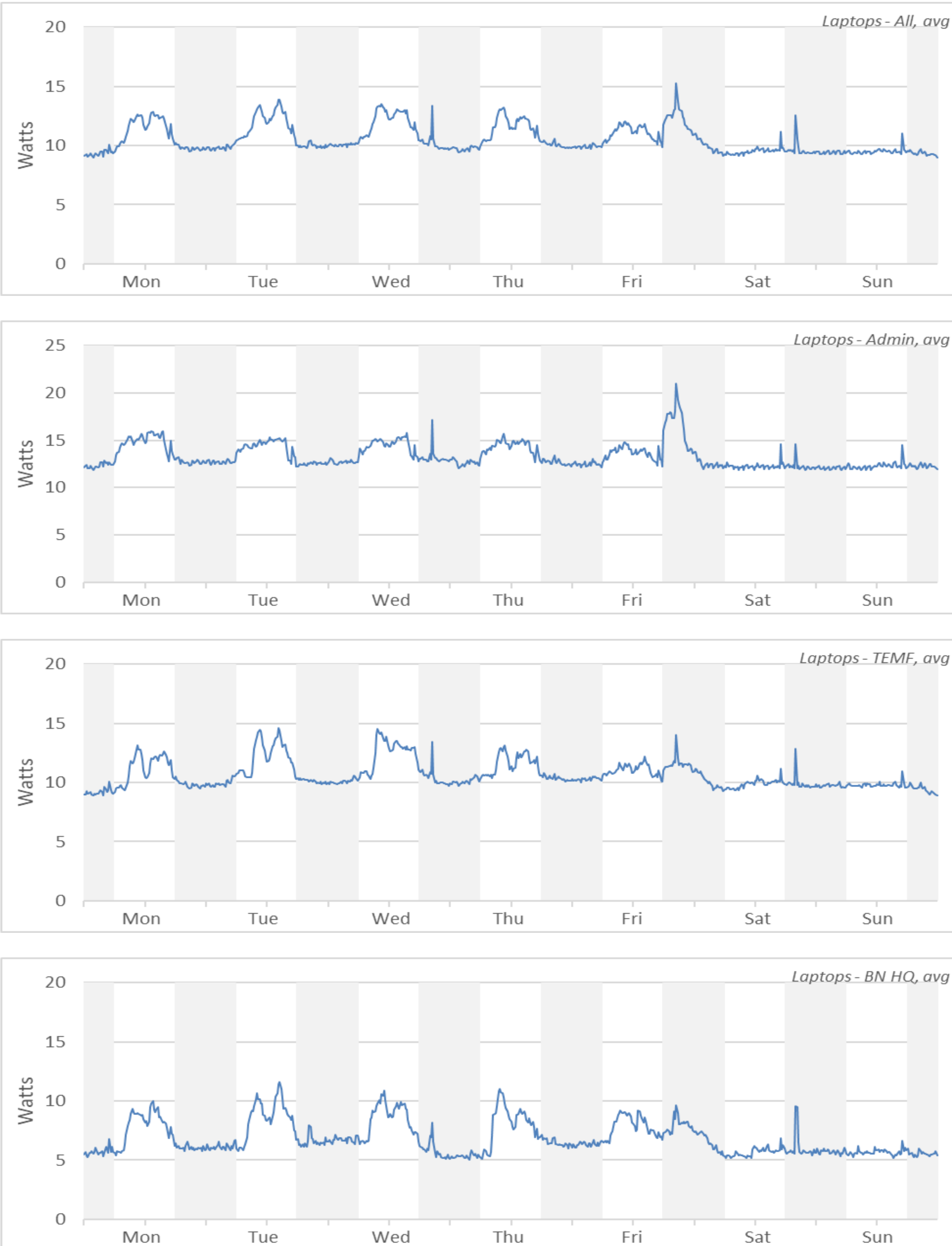


Figure 54. Average Weekly 15-Minute Interval Load Profiles for the Average Laptop Computer by Building

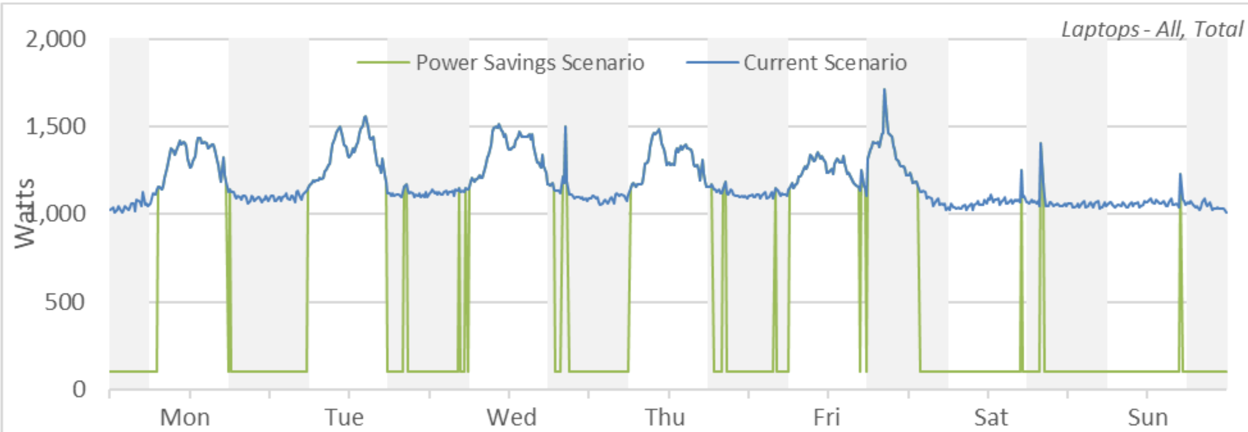


Figure 55. Total Savings Potential from Applying Robust Power-Saving to All Laptop Computers (4900 kWh/yr)

6.1.1.3 Computer Monitors

There are 171 computer monitors within the study buildings, excluding the UEPH. Seventy-nine of these are in the Admin building where most workstations had dual monitors. In all, 49 of the 171 were monitored for energy use with device-level metering. The average annual energy use for these monitors is 47 kWh/yr with a distribution within each building shown in Figure 56.

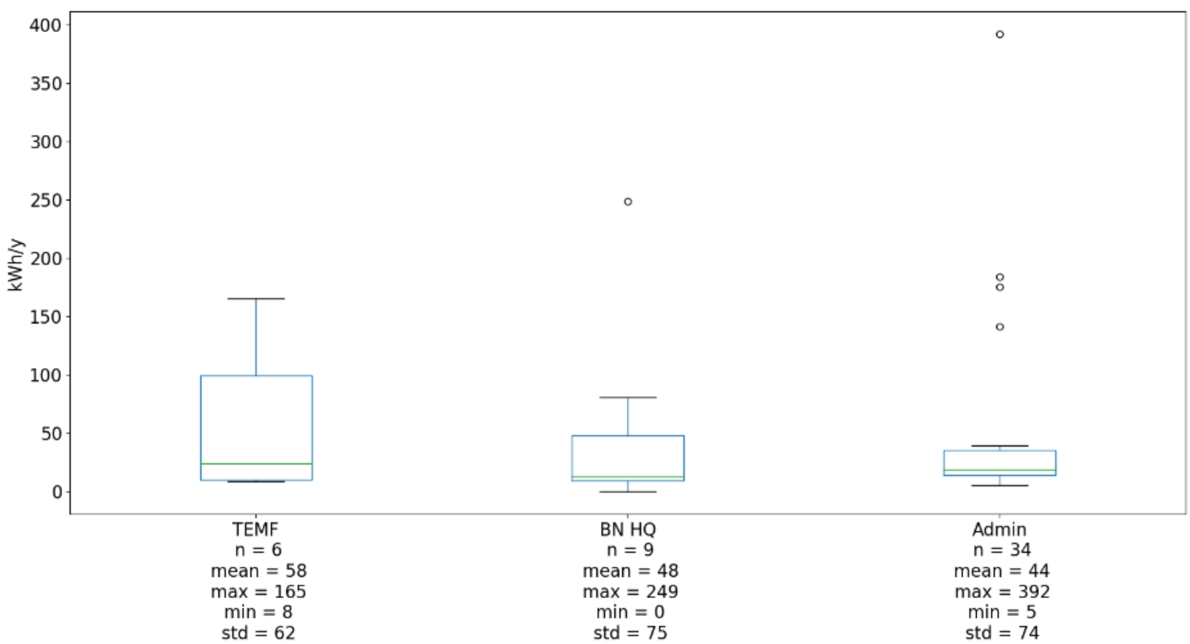


Figure 56. Box Plots of Computer Monitor Annual Electricity Consumption for the TEMF, BN HQ, and Admin Building

The average peak load for these monitors is 30 watts, with a maximum of 84 watts. Many of these monitors are configured to enter a low power state after a period of inactivity, however, opportunities for improvement exist. Figure 57 presents the average weekly 15-minute interval load profiles for the average monitor across all buildings, as well as within each of the three buildings where monitors were metered.

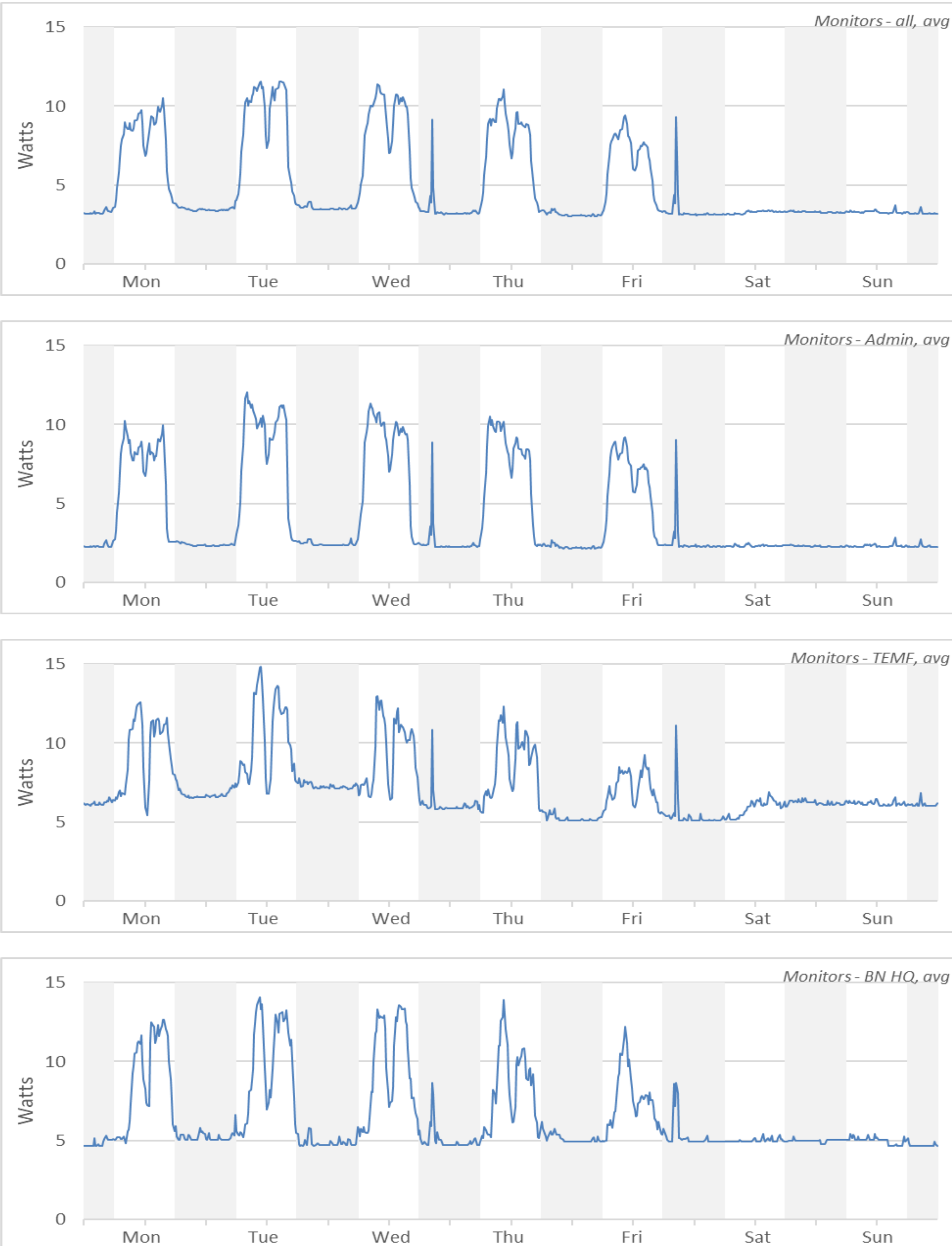


Figure 57. Average Weekly 15-Minute Interval Load Profiles for the Average Computer Monitor by Building

These load profiles confirm that many of the monitors are set to go into sleep mode based on the consistent reduction in power use both at lunchtime and each evening. However, the typical power draw in sleep mode is about a third of a watt and therefore evening and weekend power level averages show that a number of monitors are not properly configured to enter low power mode. Including a focus on monitor power management in the communication of computer policy will go a long way to achieving improved success. All monitors should be set to power down after 10–15 minutes of inactivity either via individual system operating system display settings or preferably set centrally by the NEC. Active screen savers should be disabled and instead the monitors should be powered down. And users should be made aware of screen brightness settings. Maintaining a brightness higher than necessary will waste energy and can lead to eye strain; however, the proper setting will vary based on the user and surrounding workstation lighting.

The savings potential for instituting more comprehensive display power management within the Fort Carson study buildings is 2800 kWh/yr or about 38% overall savings in monitor energy use. Figure 58 presents a pair of profiles that represent the current average weekly 15-minute load for the typical monitor compared with the savings potential from applying low-power mode consistently across all monitors in these buildings. Extrapolating these results across the Army would result in annual savings of 8.6 million kWh, for just these four building categories.

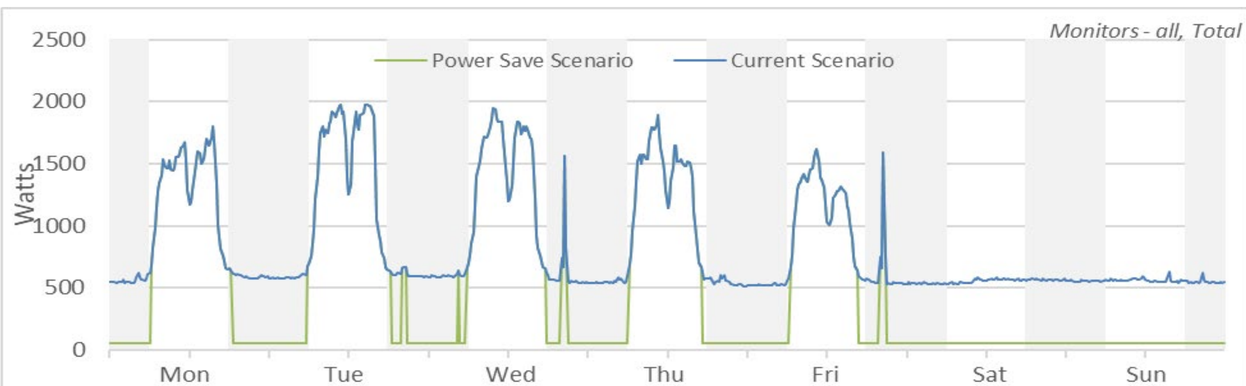


Figure 58. Total Building Savings Potential from Applying Robust Power Savings to All Computer Monitors (2800 kWh/yr)

6.1.2 Computer Purchase Policy

The decision to purchase a desktop or laptop computer has significant energy implications. Desktop computers use significantly more energy than laptops; as noted in Section 6.1.2, for the devices metered in this study, the average desktops use 1.5-2 times the energy of a laptop computer. Figure 59 shows a box plot of the annual energy use of all laptop and desktop computers monitored during the study.

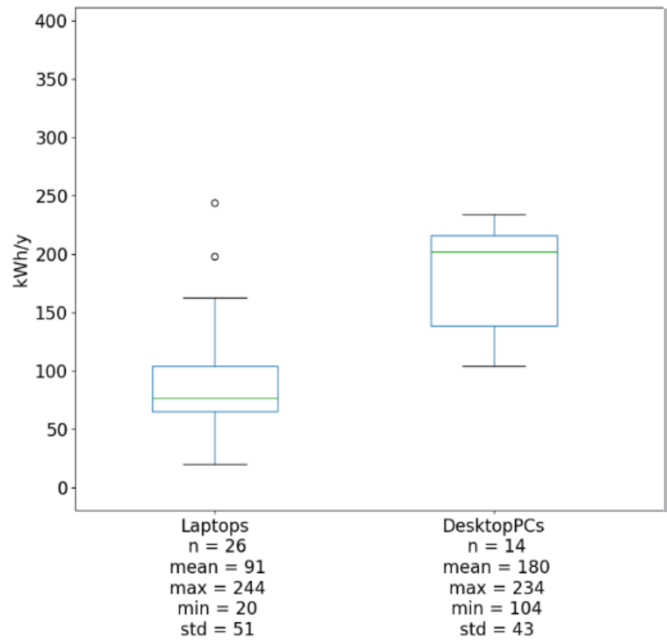


Figure 59. Box Plots of Monitored Laptop and Desktop Computer's Annual Consumption

The Admin building was the only one of the study buildings where desktop computers were found, and they were the predominant computer in use in that building. In addition to extra energy consumed by the desktop computer itself, most of the desktop computers were also connected to a small workstation UPS. On average, these UPS units added another 27 kWh/yr to the desktop PC energy consumption. Because laptops have a built-in battery, they can provide a buffer to protect the system and data in the event of a power outage. Therefore, it is recommended that the Army review purchasing policies for new personal computer systems and encourage, if not require, the purchase of laptops over desktops and UPS devices, except where the applications and mission dictate a need for a desktop system. Replacing the 37 desktop computers and companion UPS units with laptop computers within the Admin building would save 3300 kWh/yr (42%) against the current baseline where systems are left on all the time. If centralized computer power management and system update practices are first enabled, the savings from replacing the 37 desktop computers and UPS units with laptops will be 2000 kWh/yr over and above the savings achieved from improved power management practices (representing 46% savings over the lower baseline). Extrapolating to all general Admin buildings in the Army, and assuming just a 30% rate of desktop penetration relative to the Admin study building suggests that total savings are at least 5.3 million kWh/yr without comprehensive power management and 3.2 million kWh above and beyond the savings achieved with a more effective computer update approach.

Beyond encouraging the purchase of laptop computers over desktops (many with individual UPS devices), additional attention should soon be given to thin client or virtual desktop infrastructure. This technology moves data storage and processing to a centralized server in a data center and provides user access via a much lower energy-consuming client device. This is the next trend that is on the near horizon and will offer efficiencies by concentrating processing and storage and related energy use to the data center. Another benefit is that operating system and other software upgrades could be managed in a more centralized fashion.

6.2 Office Equipment

A significant number and variety of office equipment was evaluated in this study. The following are some of the lessons learned and recommendations for reducing unnecessary energy use. It is estimated that these lessons can save more than 10 million kWh/yr of electricity use across the Army.

Recommendations:

- Review technology selection, procurement, and use (encourage shared centralized equipment over individual units, define needs and equipment size/type requirements)
- Understand and enable appropriate power management features according to Army Regulation 25-1
- Educate staff to be aware of issues that may prevent equipment from entering sleep mode (e.g., device alerts such as an ink/toner or paper outage, or a tray has been removed)
- Turn off equipment when not in use and be aware of phantom loads (electricity use that continues when devices are off)

6.2.1 Large Copy/Print Multi-Function Devices

Within the study buildings there are a total of nine large multi-function devices that provide copy, print, and scanning services. Five of these were monitored for energy use, the four in the Admin plus the one in the TEMF. Photos of two examples are shown in Figure 60. Based on observation and brief discussion with occupants, these are used primarily for shared printing as well as copying. Based on the results of the metering, the average energy use of these machines is 600 kWh/yr across these five devices, and ranges from 420 to 850 kWh/yr. This distribution of annual energy consumption is highlighted in Figure 61, which also presents the annual energy use for smaller printers and document shredders.

Figure 60. Two of the Large Copy/Print Multi-Function Devices

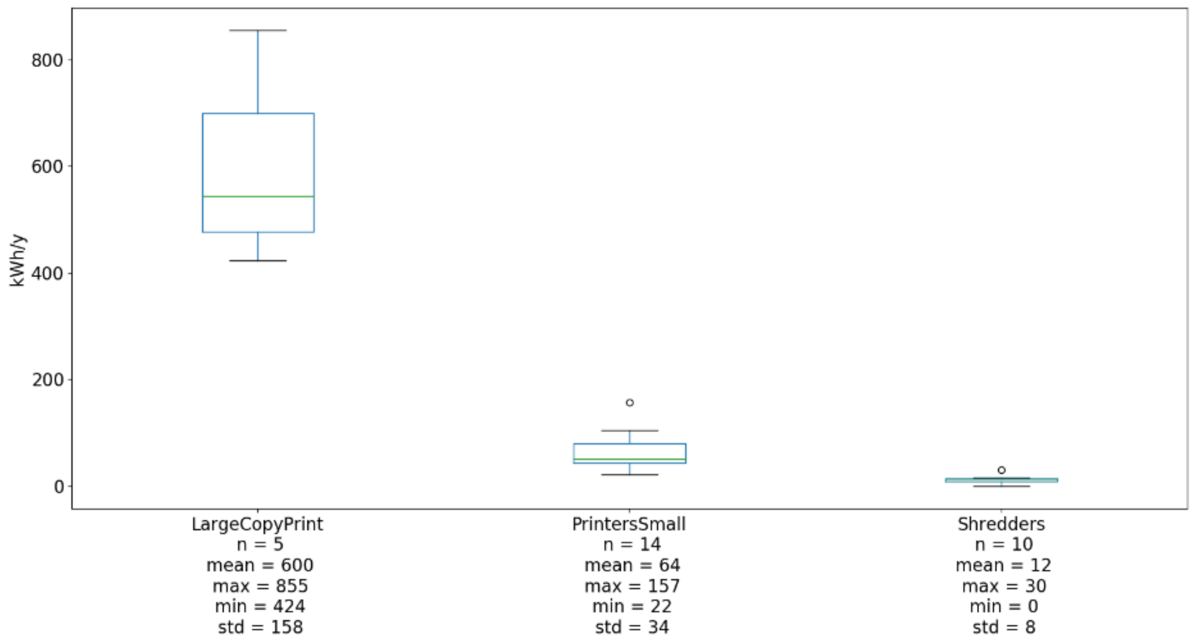


Figure 61. Box Plot of Monitored Documents and Imaging Devices' Annual Electricity Consumption

Current Army Regulation 25-1 states that "General-purpose office equipment, copiers, printing devices, faxes, all-in-one devices, and similar equipment, if configurable, will be configured to enter energy-saving mode (such as "sleep" or "standby"), after no more than 30 minutes of inactivity, or will be turned off at the end of every business day." However, the actual behavior for the devices monitored in this study was found to be quite different. The machine in the TEMF comes closest to compliance; as seen in Figure 62 it has settings that put the unit into a low power state at 6 PM each day. This control is effective however the device returns to active mode just 6 hours later rather than remaining in sleep state the entire night and all weekend. While imperfect and offering room for improvement, the behavior of this equipment demonstrates that built-in scheduling capabilities can be effective.

Average weekly profiles for each of the four devices in the Admin are shown in Figure 63. These show that these four devices remain in active mode during all hours and cycle continuously to keep warm, thereby wasting a significant amount of energy.

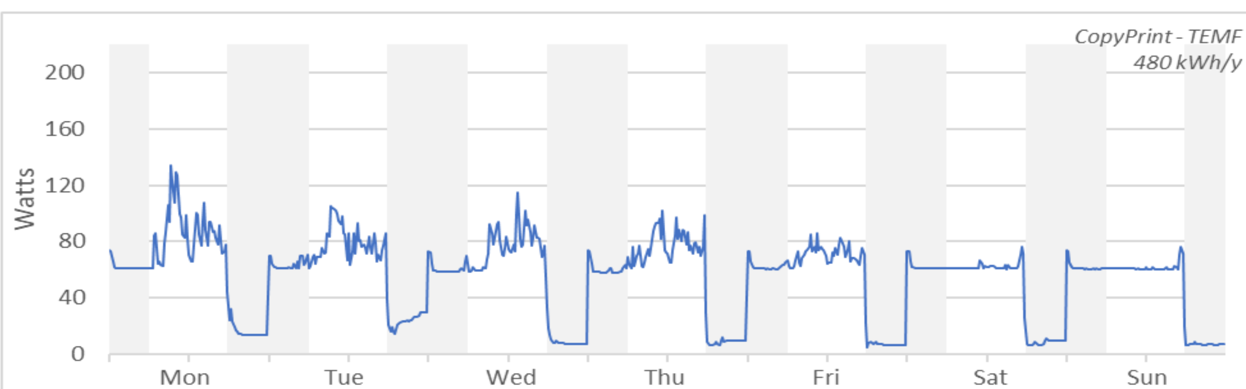


Figure 62. Average Weekly 15-Minute Interval Profile for the Large Copy/Print Device in the TEMF

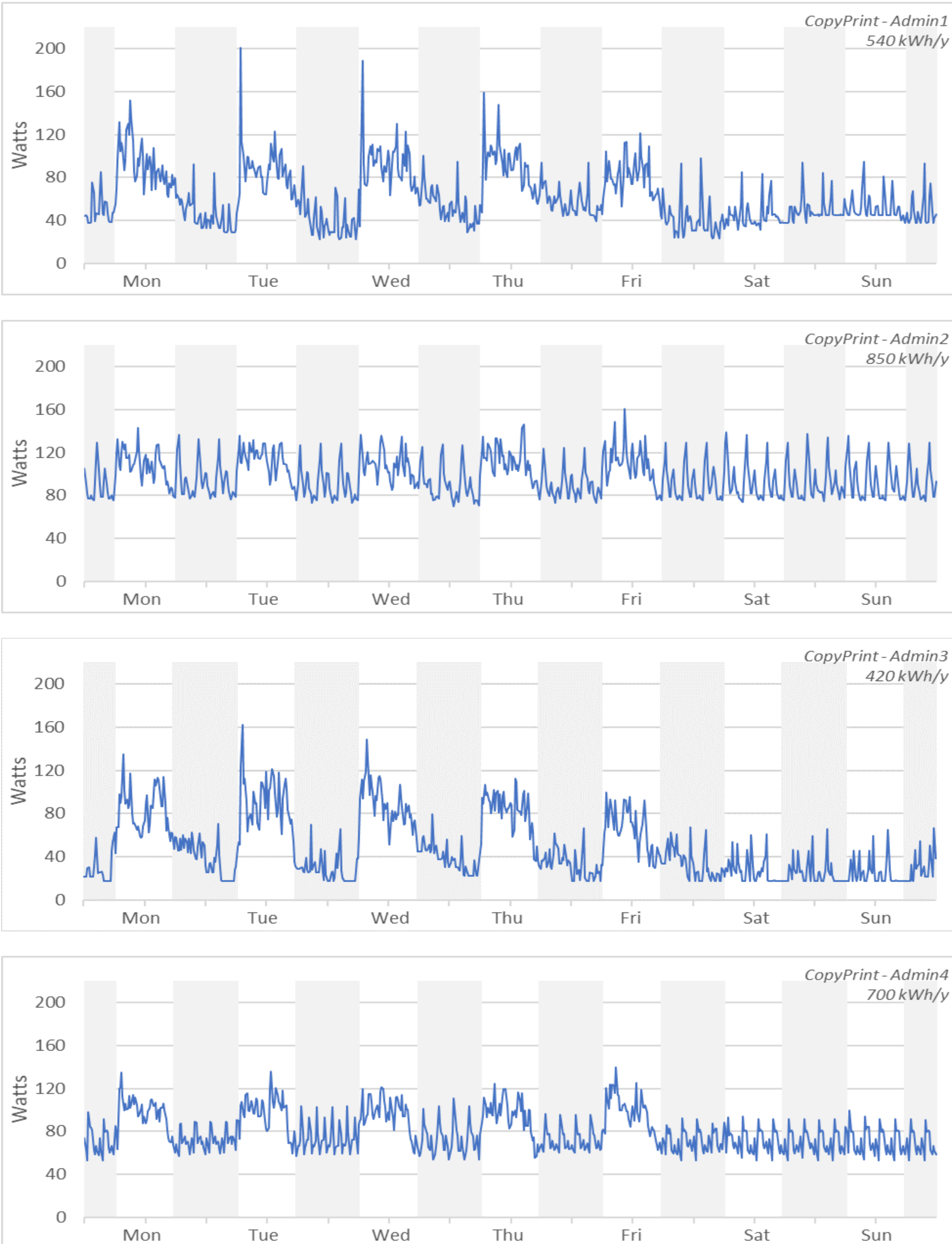


Figure 63. Average Weekly 15-Minute Interval Profile for the Large Copy/Print Devices in the Admin

It is estimated that setting and maintaining appropriate built-in power settings for the five monitored devices could save 1400 kWh annually, and 2500 kWh/yr over all nine devices within the study buildings. This 47% average savings is conservative as it is simply based on setting each device into sleep mode each night and over each weekend. Setting these to sleep after 30 minutes of inactivity would significantly increase the savings, especially for lesser used devices. Further, a sleep power of 6.5 watts was assumed here; however, for the majority of devices located in these buildings, the manufacturer reports that power used in sleep mode can be as low as less than 1 W. Figure 64 shows the reduction in power consumption for the devices in both the TEMF and Admin buildings. Extrapolating these findings to the four building types across the Army suggests that savings from following existing Army regulations could exceed 7.6 million kWh/yr.

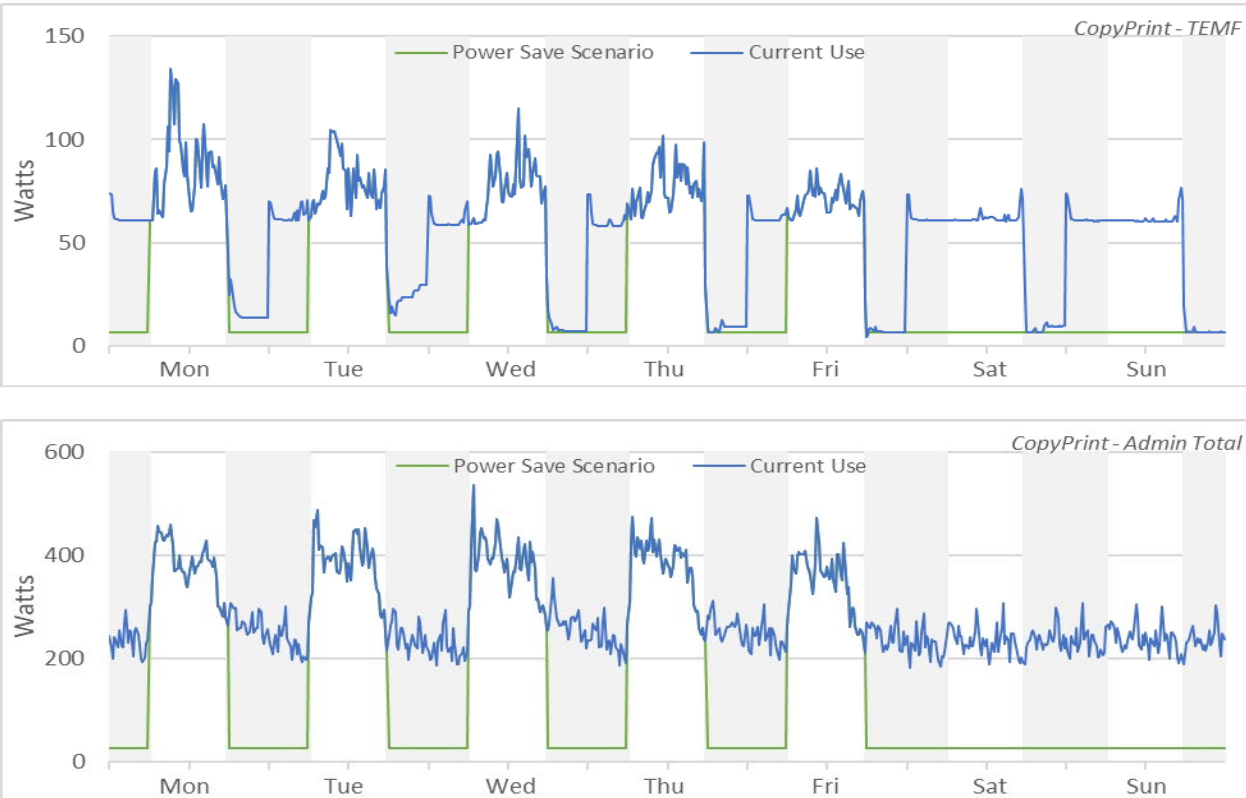


Figure 64. Average Weekly 15-Minute Interval Profiles for all Large Copy/Print Devices in the TEMF (top) and Admin Building (bottom) Highlighting the Savings Potential from Enabling Power Save Features

To achieve these savings, it is recommended that these devices be set up when installed to utilize the built-in energy-saving features as required by AR 25-1. Facility managers should be educated on the Army policy and the features and benefits of the settings. Signage could be added to instruct users how to enable required settings and how to override temporarily as needed. Further, the settings and resulting response of the machines should be subsequently checked to verify that they continue to operate as desired. Experience with similar equipment at PNNL shows that some devices will behave differently even for identical models under the same settings; status monitoring is therefore recommended.

6.2.2 Printers

In addition to the large multi-function devices, there were 38 smaller printers (some with multi-function capabilities) inventoried within the study buildings. Most are small, networked group printers while others serve individual staff. Of the 38 smaller printers, 14 were monitored at the device level: three each in the TEMF and BN HQ and eight in the Admin building. Photographs of three of these printers are shown in Figure 65. Average unit energy consumption is 65 kWh/yr, with a range of 20 to 160 kWh/yr (as highlighted in Figure 61). The highest consumers had poor to non-existent power saving features enabled, yet still used significantly less electricity than the large multi-function devices. Therefore, one recommendation is to purchase smaller multi-function printers instead of large copy/print devices, wherever feasible. It does appear that this is starting to happen in a couple of the study buildings.

Figure 65. Photos of Example Printers Inventoried in the Study Buildings

Average weekly electricity load profiles for select printers are shown in Figure 66. These highlight the variation in use and power management settings, and the impact that the standby power level has on total annual electricity use. The top profile is for a printer with a combination of low usage and sleep mode properly engaged at 2.5 W. This is the lowest energy-consuming printer using just 20 kWh/yr. The next profile is for the highest-consuming printer. It used less frequently but sleep mode is not engaged and the printer is always in ready mode of 17-18 W. The third profile is for a printer with significant use but with a 9 W active power at other times. The printer shown by the bottom profile has the highest use and average printing loads but consumes just 12% more than the third due a sleep mode that uses just 4 W.

Figure 67 shows the total combined average weekly load profile over all 14 printers that were monitored. This highlights the magnitude of energy savings, assuming that each can be set to a sleep mode that averages just 4 watts of power.[1] Given the variation in printer use, this represents a close approximation of overall savings potential of 14%. Applying this savings estimate across all 38 inventoried printers suggests that 370 kWh/yr could be saved in the study buildings. Extrapolating this to all Admin, TEMF, BN HQ, and COF buildings across the Army would result in savings on the order of 930,000 kWh per year.

[1] Most Energy Star rated printers use less than this in sleep mode. Three Lexmark models that represent half of the metered printers are reported by the manufacturer to use the following range of power in each mode: 0.2-0.5 W (hibernate); 1.44-2.5 W (sleep); 7-100 W (ready); 460-600 W (printing).

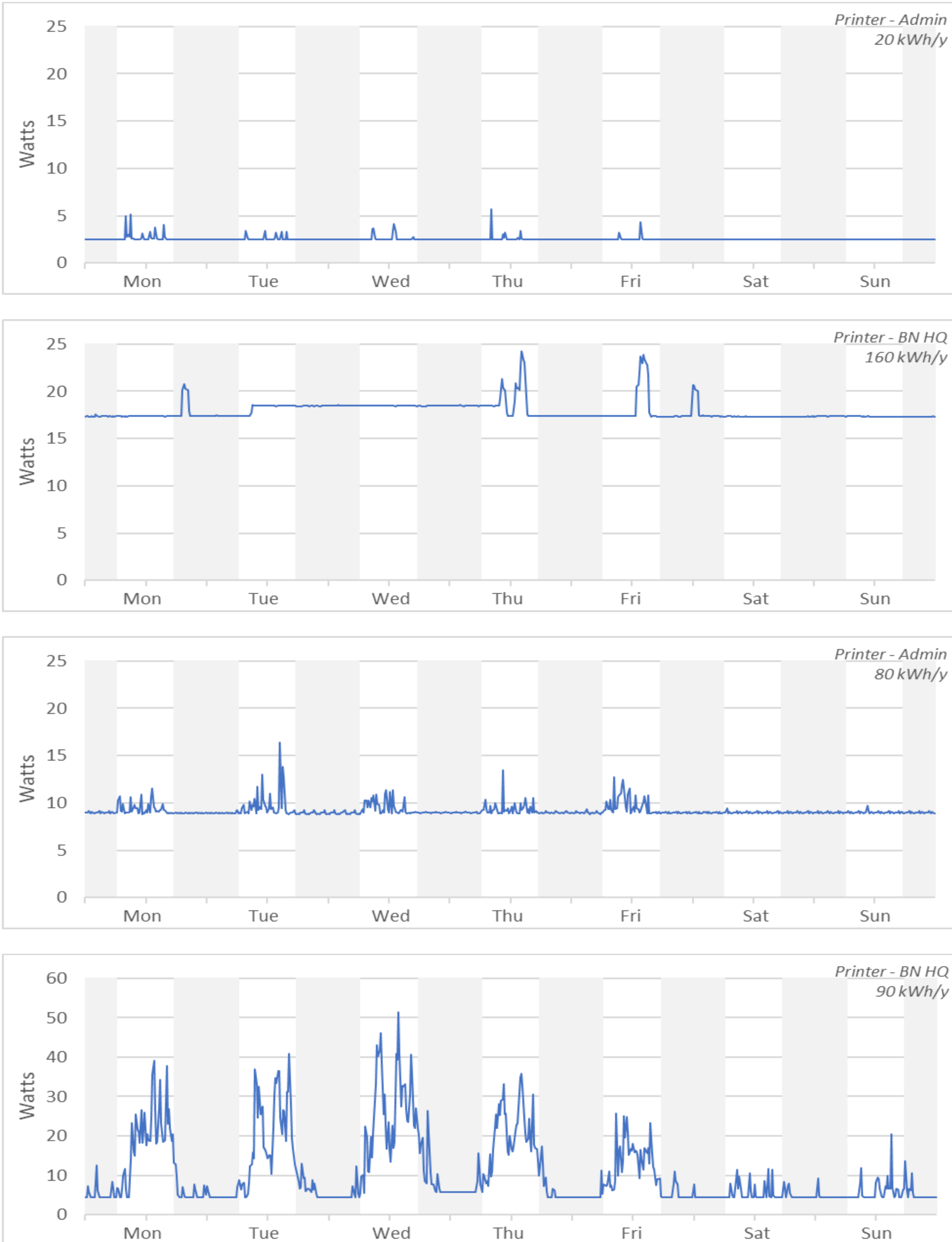


Figure 66. Average Weekly 15-Minute Electricity Profiles for Four Printers

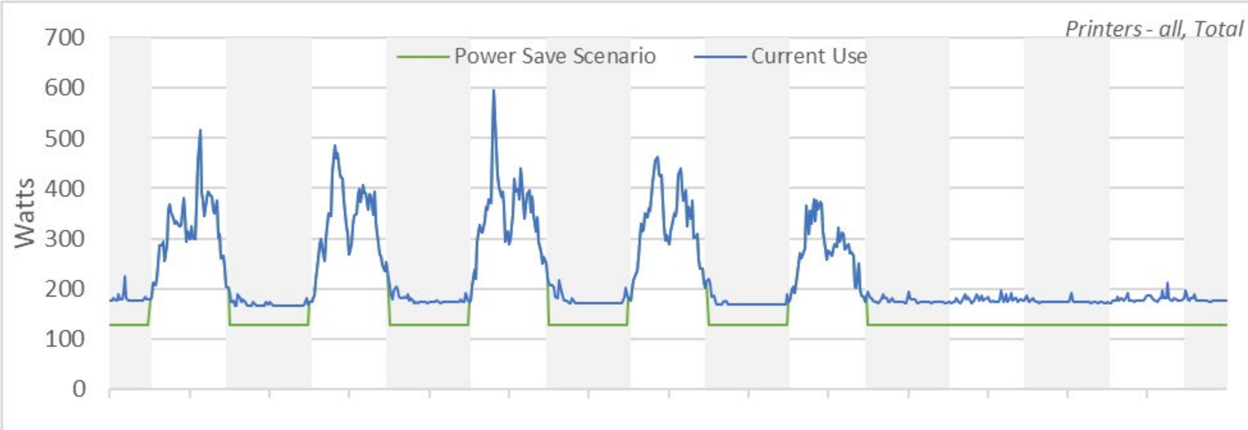


Figure 67. Average Weekly 15-Minute Interval Profiles for all Monitored Printers Highlighting the Savings Potential from Improving Power Management Settings

While many of these printers have a lower-power mode engaged when not in use, there is room for improvement. All printers should have the proper sleep mode engaged upon initial install and this should be reviewed on a recurring basis to ensure proper operation continues. Users should be engaged and educated on the benefits of proper power management as well as the types of scenarios that can prevent printers from engaging the low-power mode. Examples include alert states such as a print error, paper jam, out of paper or ink/toner, or a paper tray that has been removed.

6.2.3 Other Office Equipment

Several other types of office equipment within these buildings are noted to consume more energy than necessary. Many of these are commonly left on all the time and draw consistent power loads day and night. Some have built-in power management functions, but most do not and require some form of external control to limit their use during off hours. Modest amounts of load reduction and energy savings can be achieved by identifying this equipment and applying reasonable control options or simply turning them off when not needed. Examples of these devices are described here. Figure 68 presents the distribution of annual energy use for projectors, televisions, and television tuners.

6.2.3.1 Projectors

There are five projectors in the study buildings, located within conference and training rooms. Three were monitored for energy use. The highest energy use, 140 kWh/yr, was by the projector in the training room of the TEMF, which experienced significant use and was typically unplugged between uses. One projector in the Admin building was rarely used yet left on; it consumes 110 kWh/yr. The third projector also is in the Admin building and has its auto-power-off feature enabled. It is used frequently, yet consumes just 60 kWh/yr. The projector in the BN HQ was configured to never shut off, as shown in the photo in Figure 69. Together, for these five projectors, it is estimated that the savings potential is close to 300 kWh/yr. For these facility categories Army-wide, savings could be expected to reach over 750,000 kWh per year.

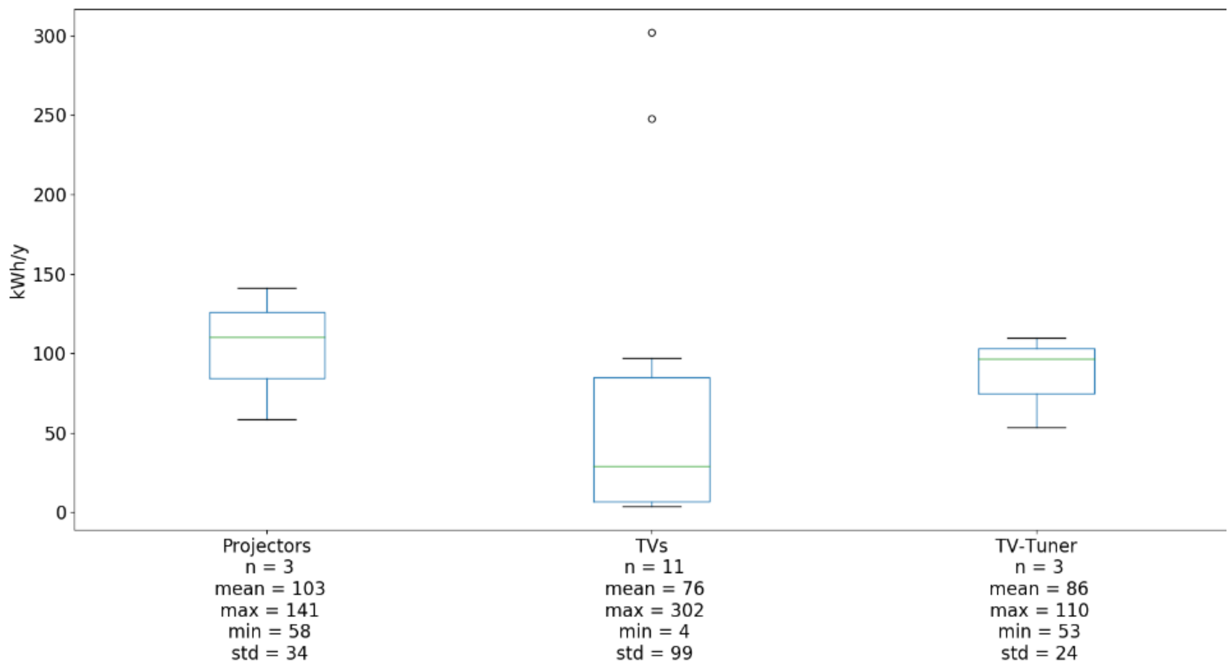


Figure 68. Box Plots of Monitored Audio/Visual Communication Devices Annual Electricity Consumption

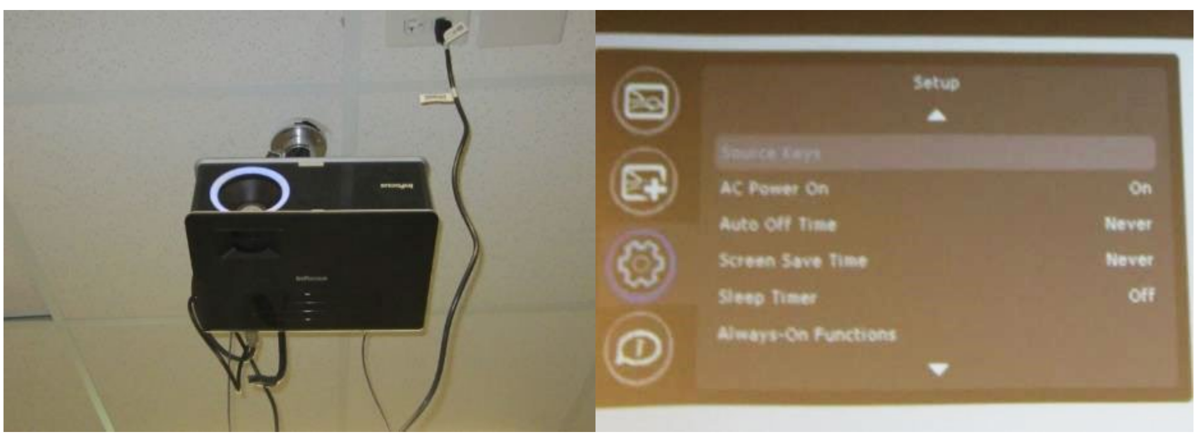


Figure 69. Always-on Ceiling-Mounted Projector in BN HQ, with Power Savings Options Available

6.2.3.2 Televisions

There are 20 flat screen LCD televisions in the buildings studied and 11 were monitored. Energy use averages 75 kWh/yr and ranges from 4 to 300 kWh/yr, depending on use. There is not a lot of savings potential as the most used televisions were turned off regularly at the end of each day. Staff turned these off manually, however most modern televisions have the capability to schedule automated device on and off schedules, making it even easier. Phantom loads (the power use when turned off) are also quite low on most modern Energy Star devices. The biggest opportunity is to make sure that televisions are only used where and when needed.

6.2.3.3 Television Tuners

While the energy use and savings potential for televisions is fairly modest, the small boxes that supply the input signal can in many cases use more energy than the televisions themselves. Three television signal input tuners were monitored within the study buildings. One used 6 W of power and the other two averaged 12 W. While low, these loads are typically always on and can add 100 kWh to overall system annual electricity use while sitting quietly in the background. In buildings with a high number of televisions, the standby energy of the tuners can add up quickly.

6.2.3.4 Shredders

There are 16 document shredders located within the study buildings. Ten of these were monitored and show a total combined annual electricity use of 120 kWh. The average electricity use of 12 kWh/yr is negligible. However, given their high density within some spaces, it is worth noting that some units have zero standby load while others are always using a small amount of electricity.

6.2.3.5 Plotters

There was a large plotter (hp Design Jet 4500 PS) in the Admin building that was not used during the monitoring period while connected to the Ibis plug load metering socket. For the first month, the plotter drew a pretty constant 56 watts of standby load, after which it was disconnected from the monitoring device. Sitting in this state over the course of a year would consume 490 kWh of electricity. This provides a useful reminder to be sure to turn off equipment that is not being used.

6.3 Breakroom Equipment and Appliances

Breakroom is the third highest-consuming plug load category within the study buildings, consuming 28,000 kWh/yr. There are several areas to save significant energy within this category of equipment. Vending machines, refrigerators, coffee makers, water coolers, and other appliances for storing, delivering, cooking food and beverages are abundant in Army facilities and collectively use significant amounts of energy. The following recommendations are provided for specific device types based on the findings from this study. Those that have been quantified are estimated to save the Army well over 40 million kWh/yr in reduced electricity consumption, if broadly implemented.

Vending Machine Recommendations:

- Partner with the Army and Air Force Exchange Service (AAFES) and encourage vending machine contractors to provide only the latest Energy Star refrigerated vending machines on Army installations; requiring that all newly installed machines meet that criteria, while moving to replace the oldest non-Energy Star machines. De-lamp and consider VendingMiser or similar control technology to reduce energy use from non-Energy Star machines until they can be upgraded to more efficient models.
- Require vendors to deactivate fluorescent machine lighting and program machines to set back the temperature or deactivate the compressor for an amount of time each day suitable to the location each is installed in (i.e., machines in locations that typically don't operate 24 hours are amenable to set back)

- Develop consistent vending machine energy reimbursement guidance for installations, based on more accurate assessments of machine counts and energy use

Refrigerator Recommendations:

- Review refrigerator purchasing policies and ensure that Energy Star rated or equivalent models are being purchased and that the size and features are appropriate for the intended application.
- Consider policy or guidelines to replace refrigerators as they reach a certain age (e.g., 20 years).
- Review policies for the use of personal mini refrigerators in the workplace, and encourage where possible the use of efficient, shared refrigerators instead.
- Review equipment excessing and disposal requirements and practices to discourage and minimize the re-allocation and continued use of old, inefficient equipment intended for proper disposal and recycling.
- Coordinate large upgrade cycles with vendors and/or serving electric utility to identify proper disposal steps and possible incentives.
- Communicate policies to Army and contractor personnel to educate on their importance.

Coffee Maker Recommendations:

- Evaluate coffee maker needs, weighing number of coffee drinkers, typical demand, plus energy use and waste when selecting a coffee maker. Where possible, use single serve options or small non-commercial machines.
- For commercial coffee makers, use a timer to turn the entire machine off each night and over weekends and other unoccupied periods.

Water Cooler Recommendations:

- Follow Energy Star guidelines when purchasing bottled water coolers; and purchase cool-only units unless heat and cool is required for the application
- Unplug bottle water coolers when not in use for extended periods and especially when empty; unplug building water fountains if occupants confirm they are not used
- Educate users to avoid using cooled water for making coffee or other cooking applications.

6.3.1 Vending Machines

Vending machines use a lot of energy. They are the fourth highest energy-consuming type of MEL in the five buildings studied at Fort Carson and are the highest-consuming individual plug load devices. Within these five buildings there are five vending machines; four refrigerated beverage machines and one snack machine. Together, they consume nearly 12,000 kWh each year, and one of the machines consumes 3600 kWh/yr by itself. Of the three refrigerated vending machines that were monitored, one is Energy Star certified. It consumes 2000 kWh/yr, compared to 6400 kWh for the other two combined. There is significant room for improvement in each of these. By comparison the non-refrigerated snack vending machines that were monitored consume between 160 and 430 kWh/yr (the low end being non-lighted).

Throughout Fort Carson there are an estimated 300 vending machines on post managed by AAFES.[1] Sixty are snack machines and for the refrigerated beverage machines, AAFES reports that 200 (83%) are Energy Star qualified and the remaining 40 are not. Many are located within barracks, and others are found within exchange buildings, TEMFs, COFs, and many other building types. Vending machines are typically owned by third-party vendors, managed by AAFES, but they use installation electricity. They are not metered and therefore it is up to the site (DPW) to estimate consumption and coordinate reimbursement for electricity costs via AAFES. The Fort Carson Utility Program Manager estimates the energy use based on sample spot metering and the information provided by AAFES, and this appears typical for other installations that seek reimbursement for vending machine energy costs.

However, concerns arose over the completeness and reliability of some of the information provided by AAFES. Not all vending machines observed within the sampled buildings were found on the AAFES list. And the accuracy of the noted Energy Star status was questionable as well. For example, the two beverage machines in the UEPH are identified by AAFES as Energy Star certified but they are not labeled as such and their energy use (3560 kWh/yr and 2840 kWh/yr) strongly suggests that they do not meet current Energy Star standards.

In light of Fort Carson's interest in better understanding the energy use of vending machines, their high energy consumption, and to expand the sample size beyond those in the study buildings, a limited survey of vending machines in other buildings was performed. Seven additional buildings (four barracks and a COF) were visited to identify vending machines and compare observations against the list maintained by AAFES. Within these 10 total buildings having vending machines, 34 machines were found (27 refrigerated beverage and 7 snack). Of the beverage units, nine or one-third were Energy Star rated, although at least four of them were 10 years old, lighted, and not operating at current Energy Star levels. A comparison of the observed machines and those listed by AAFES is shown on Table 18, for the units in these ten buildings.

Table 18. Number of Listed vs. Observed Vending Machines within Expanded 10 Buildings

	AAFES List	Observed
Refrigerated – Energy Star	21	9[(a)]
Refrigerated – Non-Energy Star	1	18
Snack	3	7
Total	**25**	**34**

(a) At least four of these vending machines were 10 years old and not performing to current Energy Star standards; all were lighted.

In addition to the survey of the number of vending machines in these other buildings, limited device-level monitoring was deployed within two of the buildings (a barracks and COF). This provided minute-level power data for seven additional machines (five beverage and two snack), and similar results were obtained as in the primary study buildings. One of these four refrigerated vending machines is Energy Star certified and some of the others use as much as 4460 and 4650 kWh/yr. The average weekly 15-minute load profile for the non-Energy Star refrigerated vending machines that were monitored is shown in Figure 70 (with an average annual energy consumption 3640 kWh/yr). Figure 71 shows the average weekly profile for the highest energy consumer (4650 kWh/yr). Figure 72 highlights the resulting energy use

[1] Per DPW, based on a list maintained by AAFES.

distribution across these two Energy Star and six non-Energy Star beverage machines that were metered.

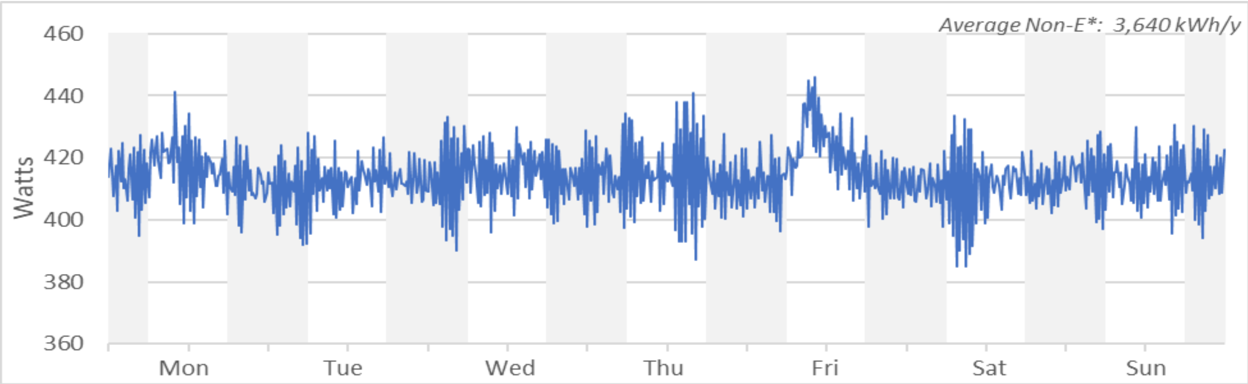


Figure 70. Average Weekly 15-Minute Load Profile for Six Monitored Non-Energy Star Refrigerated Vending Machines (3640 kWh/yr average annual electricity use)

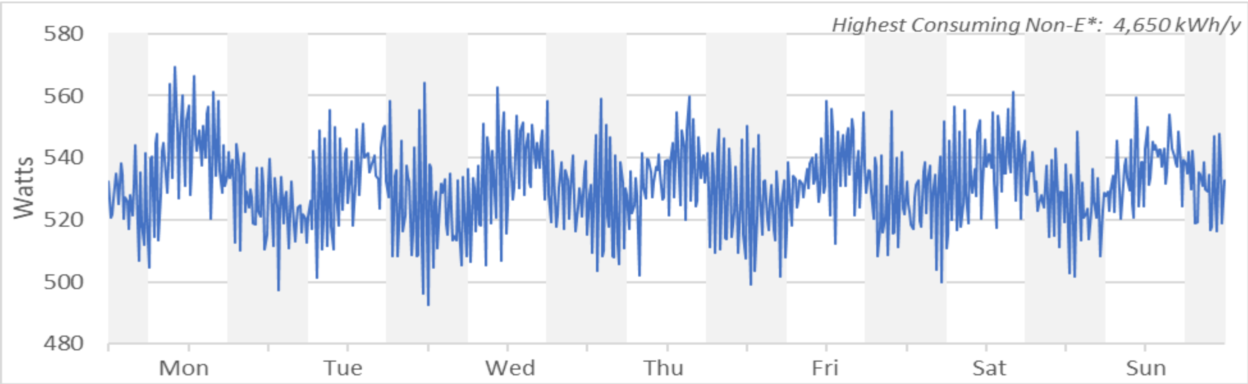


Figure 71. Average Weekly 15-Minute Load Profile for the Highest Consuming Non-Energy Star Refrigerated Vending Machine Monitored (4650 kWh/yr annual electricity use)

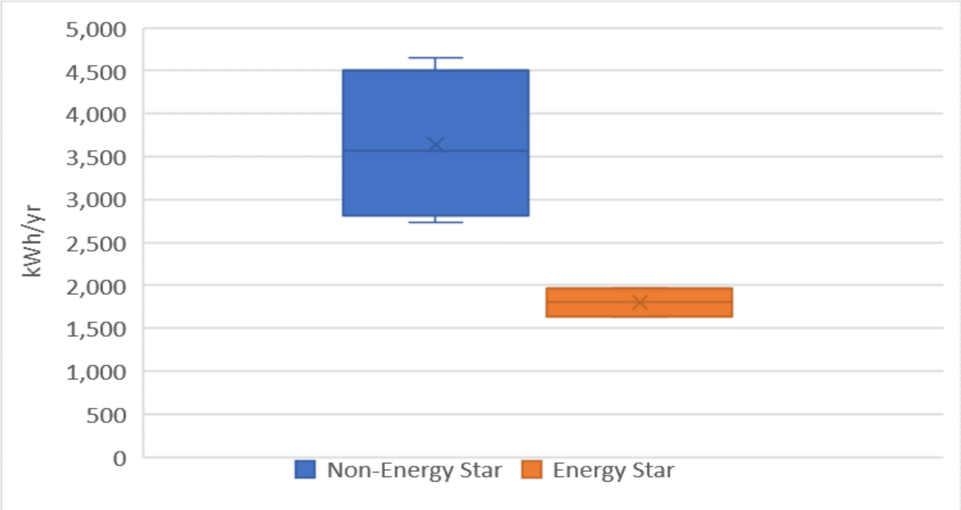


Figure 72. Annual Energy Use of Eight Refrigerated Vending Machines

Figure 73. Photographs of the Four Highest-Consuming Monitored Vending Machines – Coca-Cola machine in barracks (left), Coca-Cola and Full Throttle machines in COF (center), and Coca-Cola machine in UEPH (right)

On average, the Energy Star rated machines use fully half the energy of the others, with an average annual electricity consumption of 1800 vs. 3600 kWh. The average estimated age of the non-Energy Star machines is 20 years, and 5 years for the Energy Star. The oldest machine was manufactured in 1996 and is the highest energy-consumer. Photos of the four highest-consuming beverage machines, with an average vintage of 1999, are shown in Figure 73. These machines use an average of 4065 kWh/yr.

Sites should work with AAFES and vending contractors to replace these old and inefficient vending machines with newer Energy Star models. However, even the Energy Star certified vending machines have room for improvement. While the difference in electricity use between the two metered Energy Star machines is fairly small, the technology and operation is somewhat different, as shown when comparing the top two average weekly profiles in Figure 74. The top profile is for the machine in the TEMF which appears to be programmed to turn off the compressor or raise the temperature setpoint for a couple hours each night at around 2 am. This is good but the nightly setback could be extended and the T8 fluorescent lamps powered off or removed to reduce energy use further. The middle profile is for the newer Energy Star beverage machine in the barracks, which has LED lighting but is not programmed to set back (possibly because of its location in a 24-hour occupancy building). It uses 16% less energy than the one in the TEMF. For comparison, the average weekly profile for a third Energy Star beverage machine is shown at the bottom of Figure 74. This particular vending machine is not located at Fort Carson but within an office building at PNNL. The reason for including it here is that it is the exact same model and year as the machine in the TEMF (see photos in Figure 75). As can be seen from its profile, the PNNL machine is not programmed for nightly setback, but the lights have been deactivated. The annual energy use for this machine is 1290 kWh, 34% less than the one in the TEMF. The lack of lighting energy contributes to a significant part of that savings, but the PNNL machine is also located in a workspace which likely stays cleaner and may help it to operate more efficiently.

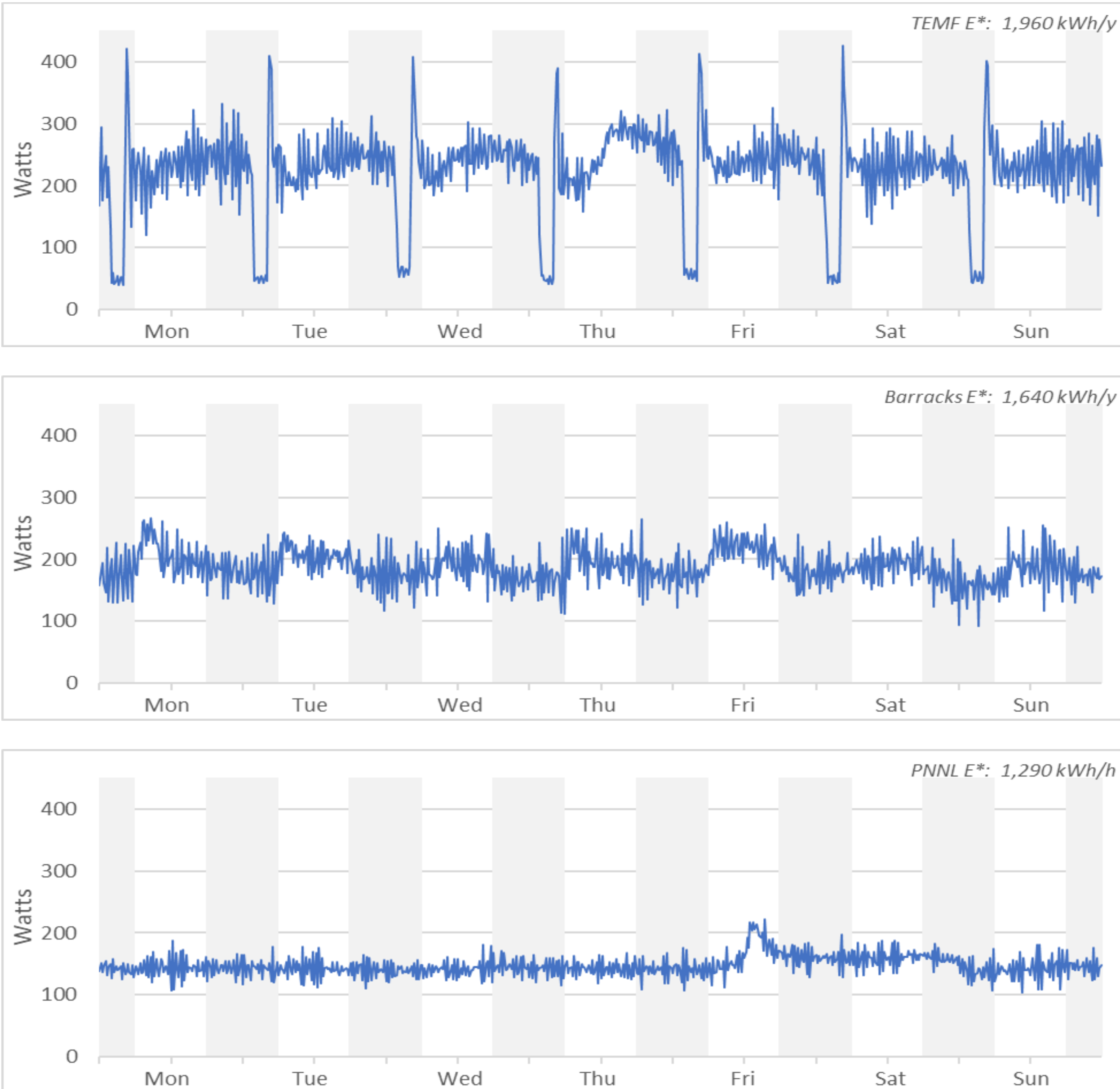


Figure 74. Average Weekly 15-Minute Load Profile for Different Three Energy Star Refrigerated Vending Machines – TEMF (top), Barracks (middle), PNNL Office (bottom)

Figure 75. Photos of Three Energy Star Refrigerated Vending Machines – TEMF (left), Barracks (center), PNNL (right)

As shown, there are significant opportunities to reduce the large energy footprint of refrigerated vending machines. Policies should be considered to encourage the use of the latest Energy Star technology. Contracts with vendors should require only new Energy Star equipment to be installed, while working to replace the oldest existing non-Energy Star equipment. Manual de-lamping and the application of VendingMiser or similar control technology can provide interim reductions in the energy used by these non-Energy Star vending machines while waiting to be phased out.

Vendor contracts should also require that built-in energy-saving options in the newer vending machines be set, consistent with the location and application of each machine, focused on reducing unnecessary energy while maintaining the quality of the product. Lighting should be disabled except in otherwise unlit locations, and schedules for setting back the temperature or locking out the compressor should be enabled to the maximum extent possible consistent with the operation of the facility in which the machine is located. For example, machines within Admin or TEMF facilities should be set back every night while units in barracks may be exempted or set back for a shorter time. In all cases, a consistent policy should be established and followed for the operational temperature setting of each beverage machine. Observations from machines surveyed across Fort Carson suggest that a range of non-standardized temperature settings are in place. Locating refrigerated machines outside should also be minimized but when necessary they should be located in a shaded location. Vending contractors have little incentive to keep machines clean and operating efficiently, as long as they continue operating. Cleaning the condenser coils regularly will help the machines run more efficiency and last longer. Considering an annual or semi-annual verification of appropriate settings and maintenance within contracts would help ensure implementation and persistence of savings.

At Fort Carson, replacing the six non-Energy Star refrigerated beverage machines that were monitored with Energy Star units and adjusting the operation of the two existing Energy Star machines all to use 1300 kWh/yr would save 15,000 kWh/yr in just these four buildings. Expanding this across the installation at Fort Carson, by adjusting the total number of refrigerated vending machines and portion of existing Energy Star based on the findings from the survey of ten buildings relative to the list maintained by AAFES, suggests that total savings from these actions could save Fort Carson over 500,000 kWh of electricity each year. That would provide an average savings of 28% for existing Energy Star machines and 64% for existing non-Energy Star machines. Even an 80% success rate translates into a savings potential exceeding 400,000 kWh/yr of electricity or 28 kWh/ksf-yr based on Fort Carson's total facility floor area. Extrapolating across the Army suggests that annual savings on the order of 31.2 million kWh may be possible across all building types.

6.3.2 Refrigerators

6.3.2.1 Full-Size Refrigerators

Full-size breakroom refrigerators consume 6700 kWh/yr within the four study buildings excluding the UEPH, making them the sixth highest energy-consuming device type in these buildings. In the three non-barracks buildings evaluated in detail in this study, there were nine refrigerators (approximately 10-21 cubic feet each), as summarized in Table 19. The ages of these refrigerators range from 9 to 35 years, with an average of 22 years. Some of the ages are estimated – including the oldest, a Hotpoint unit with exposed coils – though most have been in use for many years. The energy use of these refrigerators ranges from 260 to 1120 kWh per year, with an average of over 650 kWh. Figure 76 presents photos of the two oldest and highest energy-consuming refrigerators encountered in these buildings.

As shown in Figure 77 the electricity consumption of the monitored refrigerators is strongly correlated to the age of the device, with newer refrigerators being significantly more efficient than older models. Also shown on that chart are the estimated annual electricity use values for typical top-freezer refrigerators in residential use from the Energy Star Flip Your Fridge Calculator[1], which shows a similar trend of annual electricity use vs. refrigerator age. However, the measured energy use in these buildings is consistently lower for the metered devices as compared to the results reported by the calculator, likely due to their application within commercial office and shop settings where refrigerators are opened only on workdays rather than in residences where they are accessed daily. Actual energy use of refrigerators will vary based on a number of factors including their ambient and internal temperatures, the how full they are, how frequently they are accessed and for how long, and their size. The three monitored refrigerators aged 15-16 years are only 10 cubic feet; the others are 16-19 cubic feet.

Table 19. Summary of Full-Size Refrigerators Metered within Study Buildings

	#Devices	#Monitored	Avg. Age (yrs)	kWh/yr	Avg. kWh/yr
Admin	6	6	24	4090	682
BN HQ	2	2	12	790	395
TEMF	1	1	30	1,028	1,028
COF	2	0	15		
Total	**11**	**9**	**22**	**5,909**	**657**

[1] https://www.energystar.gov/index.cfm?fuseaction=refrig.calculator

Figure 76. Examples of 30+ Year Old Refrigerators in TEMF (left) and Admin (right)

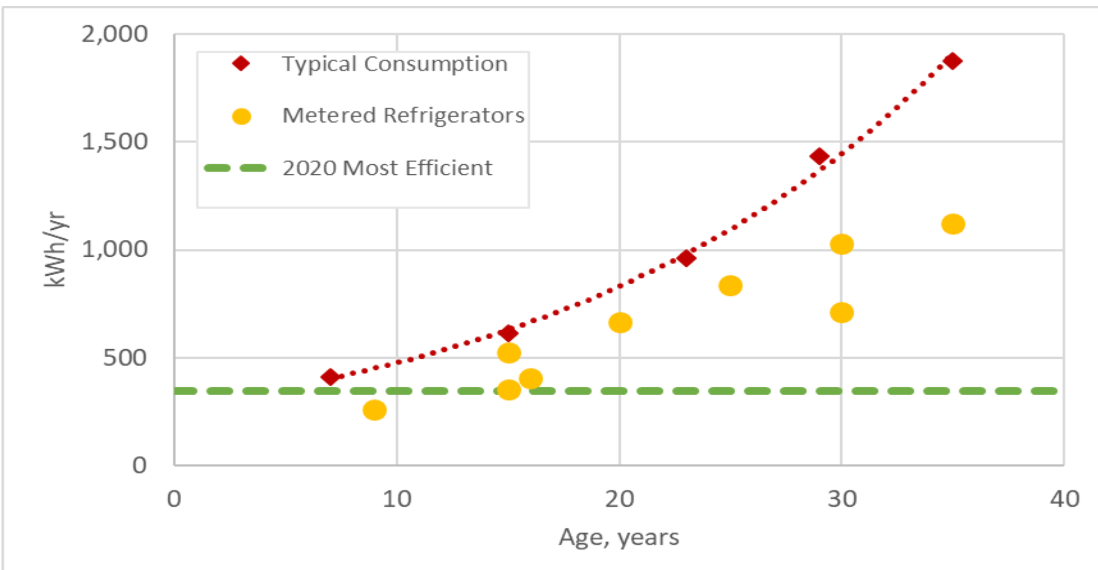


Figure 77. Refrigerator Annual Energy Use by Age Compared to Estimates of Typical Refrigerators and 2020 Most Efficient Models[1]

Also included on Figure 77 is a green line at 348 kWh/yr, representing the most efficient refrigerator available currently for this size range (again, based on standard test procedures) per the Energy Star website. Based on the other data sets it can be imagined that a similar Energy Star certified refrigerator would consume even less than this within these buildings and similar use. But even assuming that each would achieve the rated result, the savings for replacing the five refrigerators 20 or more years old would be 2622 kWh annually (39% of total refrigerator consumption in the four study buildings). Extrapolating this Army-wide, assuming a similar distribution of refrigerators in buildings of the same cat code, would suggest that savings on the

[1] 348 kWh/yr, based on Energy Star Most Efficient 2020 Refrigerators (https://www.energystar.gov/most-efficient/me-certified-refrigerators) for top-freezer models 15-17.9 cu ft.

order of 6.3 million kWh per year may be possible, within just Admin, BN HQ, and TEMF buildings.

6.3.2.2 Personal Refrigerators

As highlighted in Table 20 there are 21 mini-refrigerators in the study buildings, most within private offices of the Admin and BN HQ. That equates 1 for every 3.4 occupants in the Admin and 1 for every 5.1 occupants in the BN HQ. Personal refrigerators are often used for convenience but can also be important for meeting special medical or dietary needs. However, from an energy perspective the density of these appliances is fairly high and leads to extra energy use. On average these use a third of the electricity of the larger refrigerators, but typically with considerably less than a third of the space and are therefore not as efficient. Therefore, the Army should discourage the use of personal refrigerators in most settings, favoring the use of more efficient Energy Star shared breakroom refrigerators.

Table 20. Summary of Mini-Refrigerators Located in Study Buildings

	#Devices	#Monitored	kWh/yr	Avg kWh/yr
Admin	11	8	1,780	223
BN HQ	7	2	268	134
TEMF	1	1	113	113
COF	2	0		
Total	**21**	**11**	**2,161**	**197**

Another observation is that many of the mini-refrigerators appear to have been units that were rescued from disposal after being removed from a barracks that was upgrading its stock of refrigerators. While this may seem convenient and economical to the user, it is not from an energy, electrical demand, nor energy resilience perspective and should be discouraged. The Army may want to review policies governing the disposal or excessing of equipment that is being replaced to prevent or limit its acquisition and repurposing in other buildings on the installation. Ensuring proper disposal and recycling of outdated equipment is responsible from a lifecycle perspective and may be rewarded with rebates or other incentives in some instances.

6.3.3 Coffee Makers

A total of 21 coffee makers were inventoried and seven were monitored for electricity use in this study, as shown by Table 21. Four of the monitored units are located in the Admin building, two in the BN HQ, and one in the TEMF. Two of the four in the Admin building were commercial 2-pot Bunn VPS units. Of the non-commercial units, three were single serve models made by Keurig, with the others being a smaller single pot plus a small combination single brew plus pot coffee maker. The average energy use of the commercial coffee makers is more than 14 times higher than that of the non-commercial units, even though one of the commercial units was manually turned off each Friday afternoon by staff. Photos of example commercial and single serve units in the Admin are shown in Figure 78. Average weekly profiles for all commercial (top) and residential units (bottom) inventoried in the study are shown in Figure 79.

Table 21. Monitored Coffee Maker Energy Use by Type

	#Devices	#Monitored	Total kWh/yr	Avg kWh/yr
Commercial	2	2	1,140	570
Non-Commercial	19	5	210	40
Total	**21**	**7**	**1350**	**190**

Figure 78. Examples of Typical Coffee Makers in these Buildings: Commercial 2-Pot (left) and Single Serve (right)

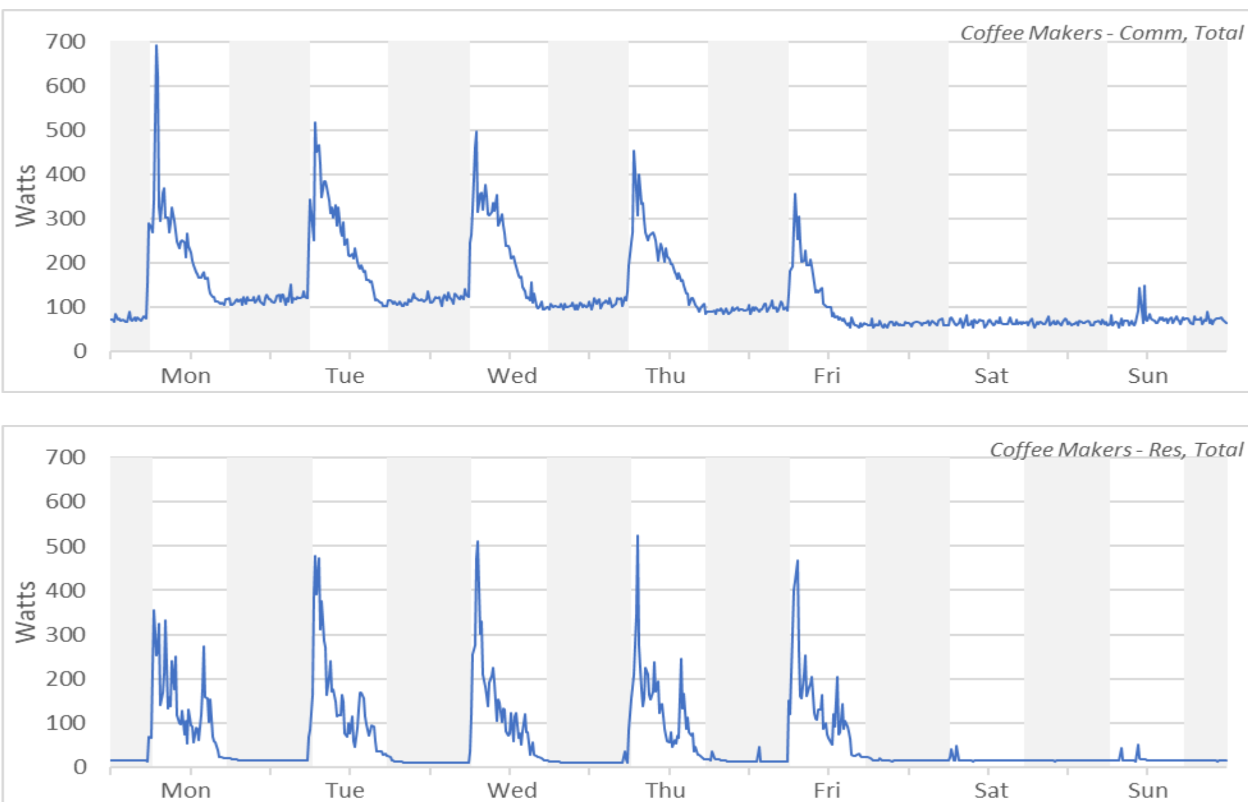


Figure 79. Average Weekly 15-Minute Coffee Maker Load Profiles: Commercial Units (top) and All Inventoried Residential Units (bottom)

The highest energy-consuming commercial unit uses over 700 kWh of electricity per year. In comparison, the highest-using residential coffee maker – a single-serving Keurig unit serving an open office area in the Admin – consumes 80 kWh/yr. While no data was collected on the number of servings brewed by each machine, the single brew devices appear to use significantly less energy and may be better options from an energy use perspective in most instances; perhaps except in areas with consistently high coffee demand.

Figure 80 presents a typical week of minute-level power use from the two commercial Bunn coffee makers in the Admin. These are each for the same week in June. The top profile shows the typical operation for the highest consumption coffee maker, using over 700 kWh per year. This profile suggests that coffee is brewed each morning Monday-Thursday and kept warm into the afternoon. However, throughout each night and weekend from Friday-Sunday when no one is around a heating element appears to create recurring power spikes approximately every hour and a half. The bottom profile is for the other commercial coffee maker during that same week. This unit serves occupants in a separate open office area and while there is similar power profile during the weekdays, a big difference is that the power drops to zero at noon on Friday and remains there until Monday morning. This is the result of the occupants' efforts to turn off the power to this coffee maker every weekend. This awareness and action by the occupants in this space result in an annual savings of approximately 280 kWh or 40% when compared to the coffee maker that is left on all the time.

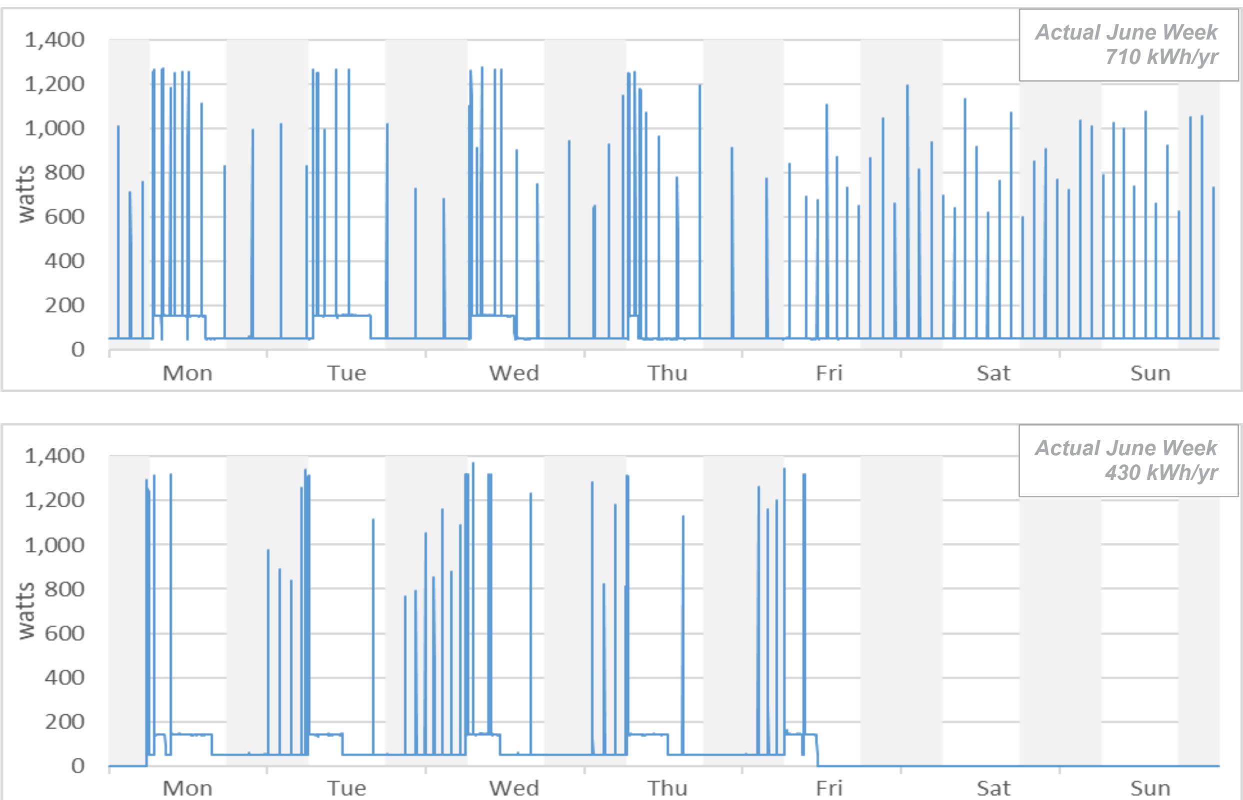


Figure 80. Actual Weekly 1-Minute Interval Load Profile for the Two Commercial Coffee Makers in the Admin (for the same June week) – highest energy-consuming unit (top) and unit manually turned off each weekend (bottom)

Figure 81 presents similar profiles and the same time period for two of the single serve Keurig coffee makers in the Admin, one that uses 80 kWh/yr and the other 60 kWh/yr. For these units, the power spikes are limited to times when a cup of coffee is being brewed. Also, the standby load during all other times is approximately 1.3 watts, compared to around 50 watts for the commercial Bunn units. Interestingly, the Keurig unit represented by the bottom profile is located in the same space and immediately next to the highest using commercial Bunn unit and each shows a markedly different use profile, especially on Friday of that June week, suggesting that certain staff may have used the Bunn while others the Keurig.

Based on these results, it is apparent that timers or other means to consistently turn off commercial coffee makers each night can save significant energy. For the two units in this study, both in the Admin building, total annual savings of 490 kWh (43% of current use) are possible, simply by turning them off for 12 hours each weekday and all weekends. This includes 330 kWh/yr for the Bunn unit that is currently left on all the time and 160 kWh/yr for the unit that is already turned off each weekend. This combined savings is highlighted by the difference in the two lines in the average weekly profiles shown in Figure 82. Extrapolating these savings to all Admin buildings across the Army, considering the same 34.3 kWh savings per thousand square feet, suggests that the savings potential from adding a timer or similar control option to all commercial coffee makers could reach 2.6 million kWh/yr.

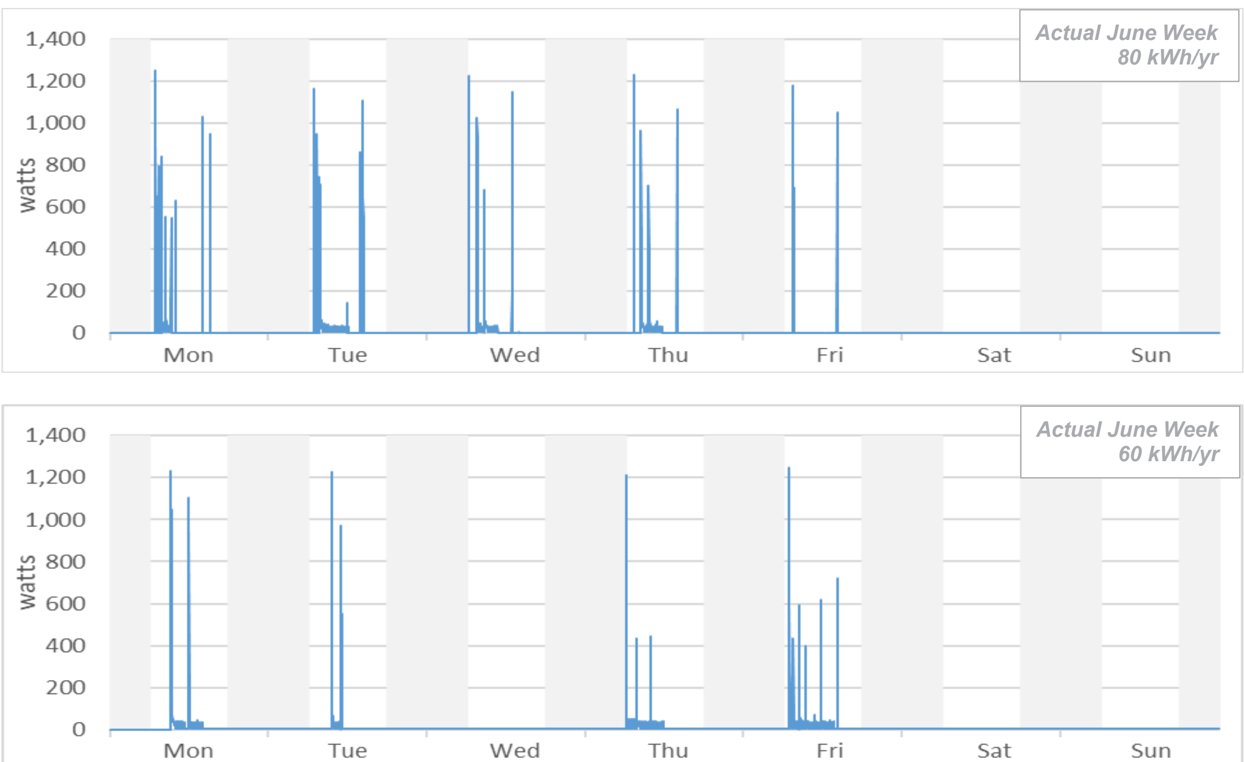


Figure 81. Actual Weekly 1-Minute Interval Load Profile for Two Single-Serve Coffee Makers in the Admin (same June week)

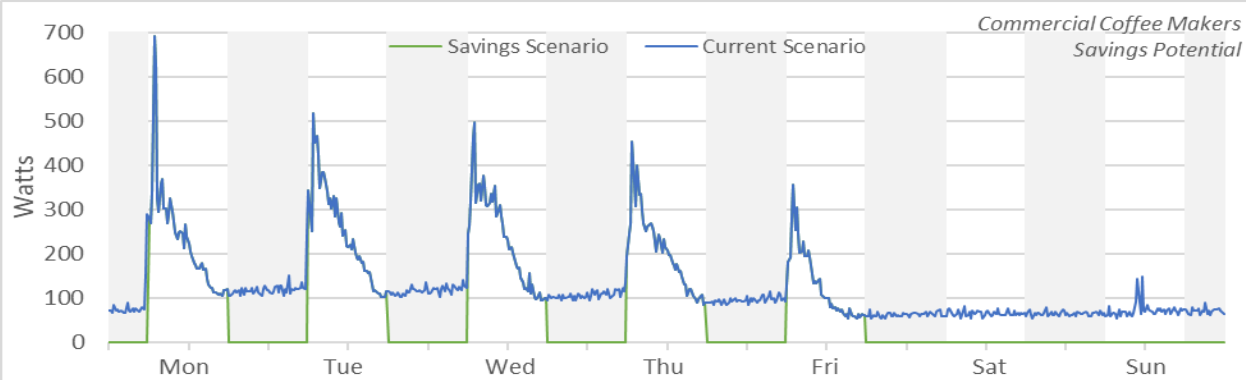


Figure 82. Average Weekly 15-Minute Commercial Coffee Maker Load Profile Highlighting Current Load and Expected Adjusted Load After Applying Timers or Other Control

6.3.4 Water Coolers

There are two types of water coolers encountered within these buildings. The first are the plumbed water fountains that are typically hanging from the walls within hallways in most buildings and were at least two in each of the study buildings. The other are portable bottled water coolers that plug in and provide cooled water as well as sometimes heated water. Four of these bottled water coolers were found in the Admin building. Examples of each area shown in Figure 83.

Figure 83. Three Types of Water Dispensers: Plumbed (left), Cool-Only Bottle (center), Heat and Cool (right)

Ten water coolers were metered: six plumbed devices and four of the bottled units. The total combined annual energy use for these ten units is 1,260 kWh/yr, with the four bottled water units accounting for 74% of the total. The average annual energy use for the plumbed units is 50 kWh/yr, ranging from 36 kWh/yr for a lightly used water fountain in the Admin to 65 kWh/yr for a more heavily used unit in the TEMF, which was loud and running rough. The average electricity for the bottled versions is 240 kWh/yr, and ranges from 85 kWh/yr to 450 kWh/yr. The two cool-only bottled water dispensers consumed an average of 86 kWh/yr, while the two heat and cool units consume an average of 390 kWh/yr.

Figure 84 presents the average weekly 15-minute interval profiles for the pair of metered plumbed water fountains in the Admin, UEPH and TEMF. The units in the Admin are considerably older than those in the other buildings, and based on the power profile appear to see little use and use more energy under no use than the others. The units in the UEPH appear to see some use with peaks typically early morning Monday-Wednesday plus midday and evenings most weekdays. In the TEMF, the water fountains clearly get a lot of use, as shown by the high peaks in compressor use during the core work hours, with noticeable drops during lunchtime, and a relatively flat base load of around 9 watts, about half of that of the older units in the Admin. For comparison, examples of average weekly profiles for cool-only and heat and cool bottled water dispensers are shown in Figure 85. Note that the cool-only dispenser is located next to two coffee makers; the peak in compressor activity each weekday morning suggests that staff may be using cooled bottled water to make coffee.

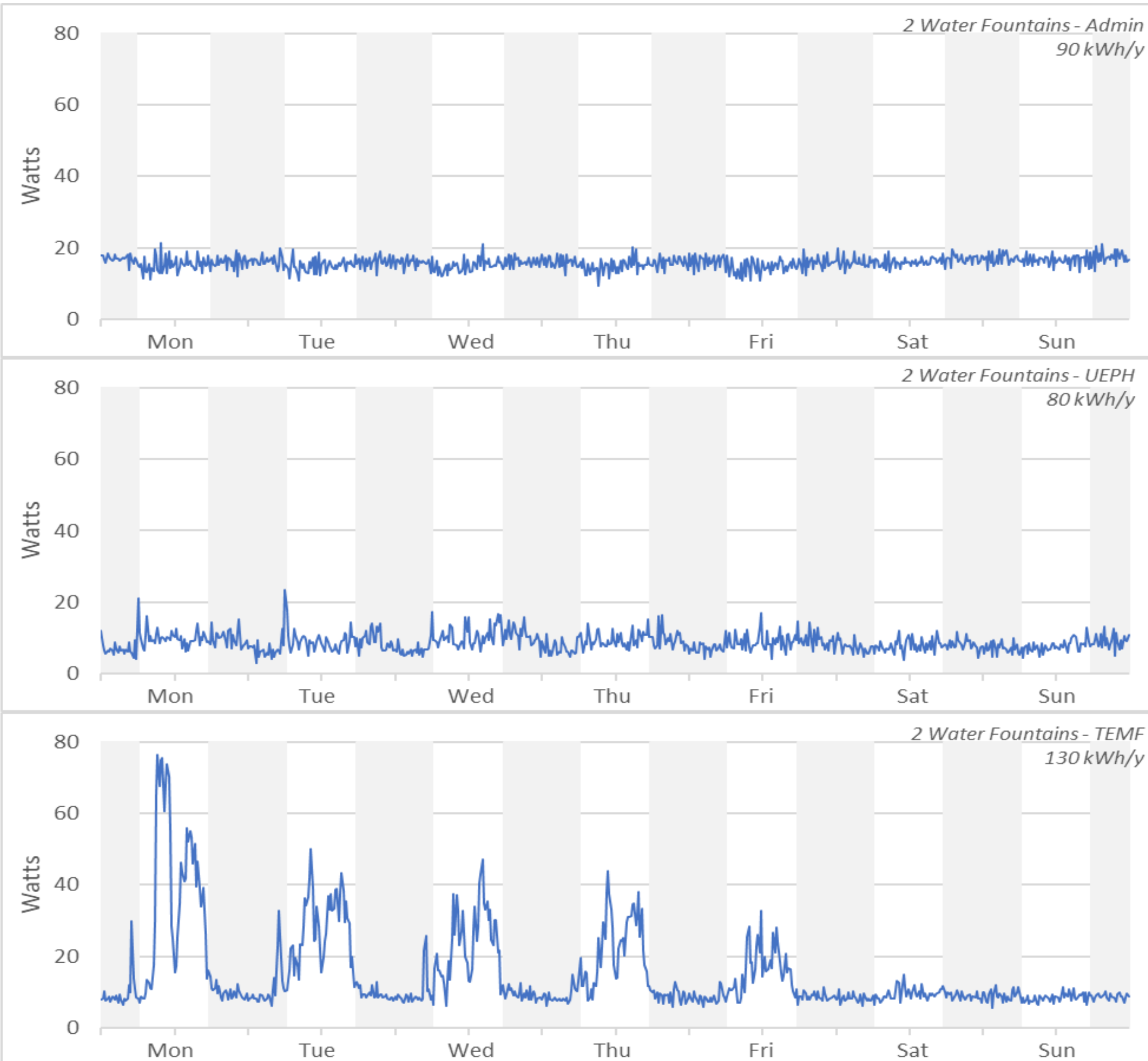


Figure 84. Average Weekly 15-Minute Interval Load Profiles for Plumbed Water Fountains

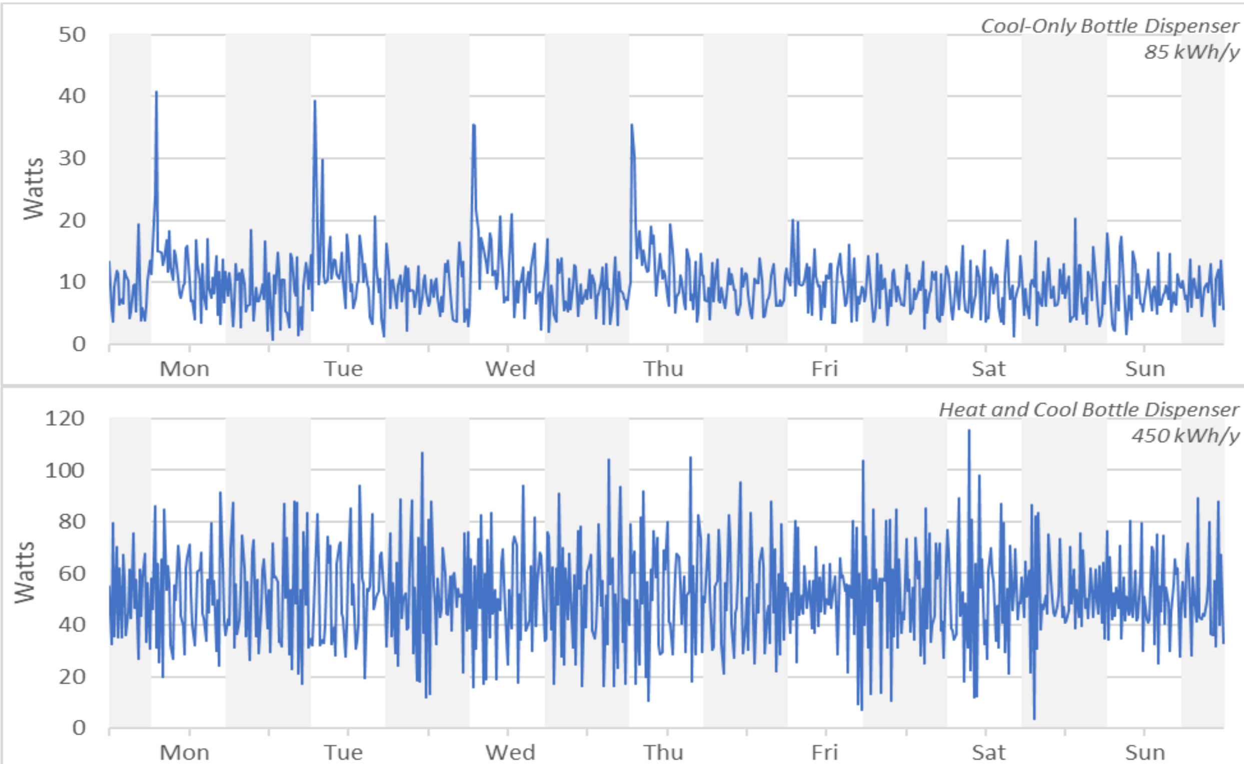


Figure 85. Average Weekly 15-Minute Interval Load Profiles for Bottled Water Dispensers

Water coolers (both cool-only and heat and cool) are tracked and certified by Energy Star. For information on the current standard as well as purchasing guidelines visit the Energy Star web site.[1] Recommendations for the Army regarding water coolers include purchasing Energy Star units when needed; avoiding heat and cool units unless required; turning them off if unused for an extended time; and avoid operating without water. For plumbed water fountains, units can be unplugged to avoid running the compressor if it can be confirmed with occupants that the fountains are not used.

6.4 Laundry

Laundry represents the highest energy-consuming plug load category across the five study buildings, responsible for an estimated 34,000 kWh/yr. Washing and drying clothes is a necessity. The efficiency of laundry equipment has improved over the past couple decades and there aren't a lot of widely proven approaches for reducing energy use further while minimizing the impact on time and convenience. However, some may be on the horizon.

Lessons & Recommendations:

- Energy Star rated washers do not always result in the lowest energy use (but they typically represent the best choice for overall energy and water savings).
- Water use, durability, and serviceability are other important factors to consider when purchasing equipment.

[1] https://www.energystar.gov/products/other/water_coolers

- All else equal, seek out Energy Star rated washing machines with zero or very low standby load.
- Watch for game-changing advances in technology (e.g., ultrasonic dryers).

6.4.1 Washing Machines

There are 14 operational washing machines in the UEPH (five on each floor, except for one which was out of order and non-operational). These are all commercial washers; 12 are Maytag, and there is one Speed Queen and one Frigidaire. The three oldest units are vertical axis (V-axis) Maytag machines (2003 vintage), and the remaining are Energy Star rated horizontal axis (H-axis) washers with known dates of manufacture ranging from 2009-2016. A photo of the mix of machines in two of the laundry rooms is shown in Figure 86.

Energy was monitored with an Ibis Networks socket for each operable unit for a duration that lasted up to 21 weeks. Over 3,500 washer cycles were recorded consuming a total of 514 kWh of electricity. Results are presented in Table 22 for each washer type, including the three operable H-axis units that were not used during the study.

Figure 86. Laundry Rooms in UEPH Showing a Mix of Washing Machines

Table 22. UEPH Washing Machine Results by Washer Type

Type	Count	Avg. Standby Load (W)	Avg. Operating Load (W)	Avg. Cycles per Week	Avg. Cycle Duration (minutes)	Avg. Cycle kWh	Total kWh per Cycle[(a)]	Avg. Annual kWh
V-Axis	3	0	270	22.4	28	0.122	0.129	151
H-Axis (Use)	8	4.8	129	18.6	41	0.091	0.134	129
H-Axis (No use)	3	6.1	NA	0	0	0	NA	54

[(a)] Total kWh divided by number of active cycles (includes impact of standby power)

All Energy Star H-axis machines except one had a standby load ranging from 4.4 to 7.6 watts. The Frigidaire and each of the V-axis units had zero standby load. The average peak load of the V-axis washers is 626 watts and 590 watts for the H-axis units, with average operating loads of 270 watts and 129 watts, respectively. However, recorded cycle times were significantly longer for the H-axis machines. While each of the H-axis washers operated at lower power during the wash cycle, the longer cycle times combined with their standby power draw resulted in a slightly greater net electricity use per wash cycle over the course of this study than the V-axis machines (as highlighted by Figure 87). Further, as shown in Figure 88 the V-axis washers seemed to be favored by occupants, seeing an average of 4 more cycles per week per machine (22.4 vs. 18.6 for the H-axis units). One of the three V-axis machines had the highest average use at 28.5 cycles per week (over 13% of total use), followed by the Speed Queen H-axis at 27.5 cycles per week.

Figure 89 presents the average weekly load profiles for V-axis and H-axis washers. This highlights the difference in average peak and standby loads, as well as the preferred days and time for washing laundry.

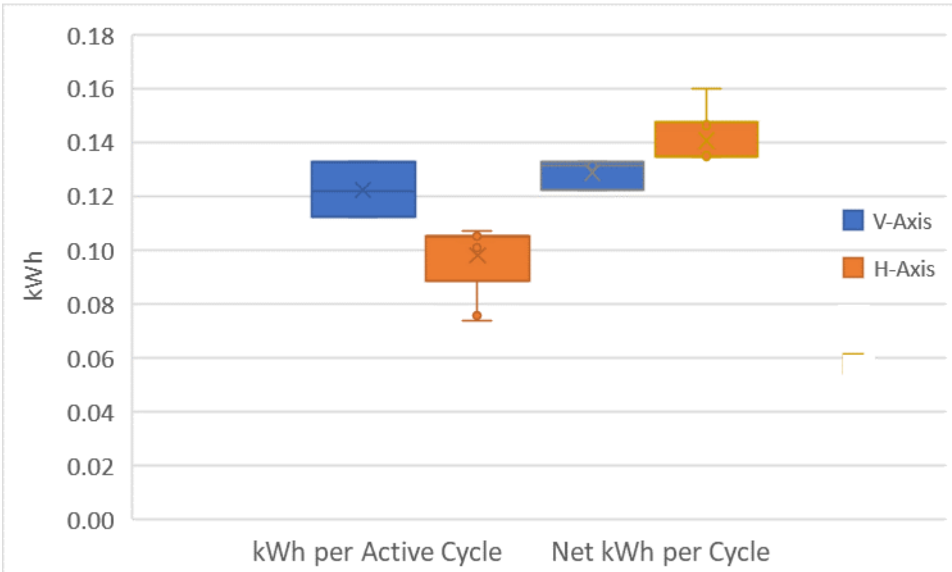


Figure 87. Comparison of Active Cycle and Net Energy Use Per Cycle for V-axis and H-axis Washing Machines

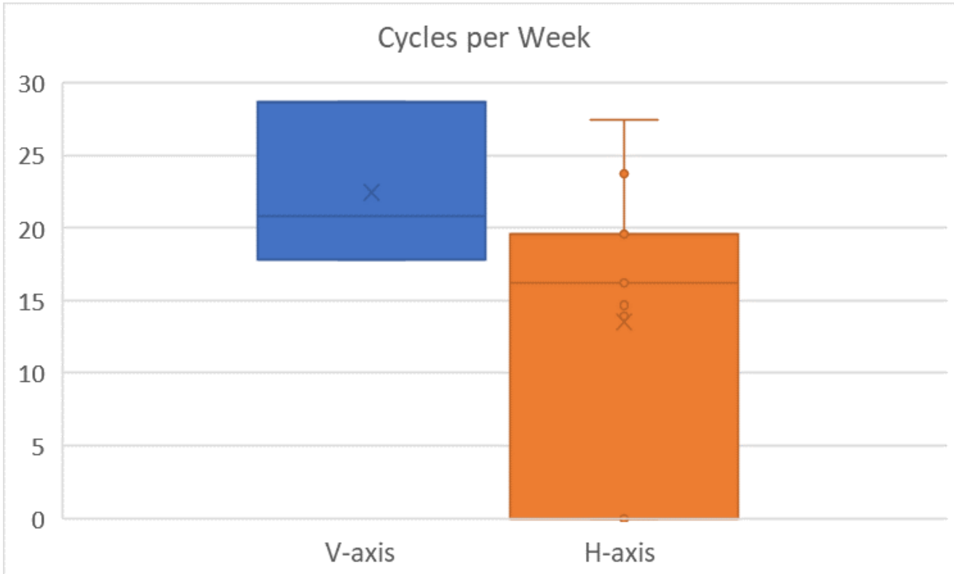


Figure 88. Average Use in Cycles per Week for V-axis and H-axis Washing Machines

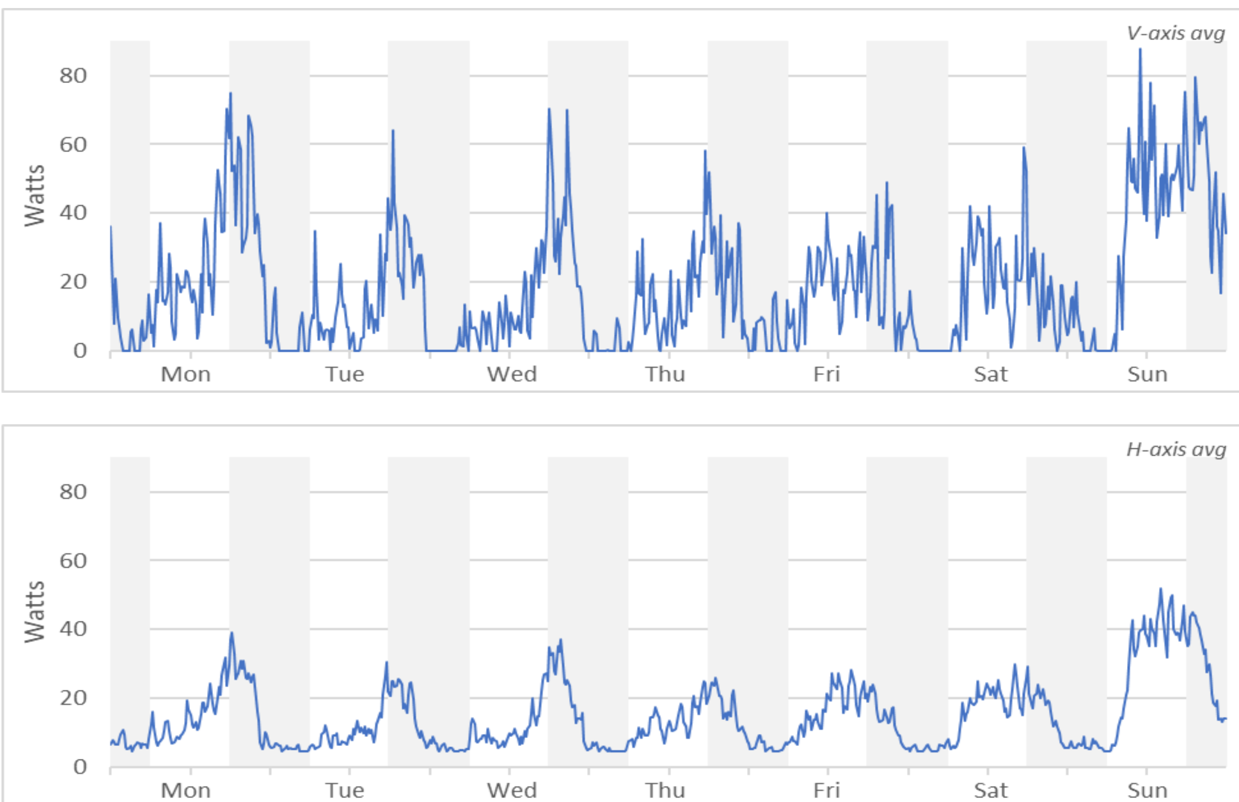


Figure 89. Average Weekly 15-Minute Interval Load Profiles for Washing Machines: V-axis (top) and H-axis (bottom)

Three of the operable washers had no recorded use during the 21-week monitoring period, one on each floor. They are all Maytag H-axis units, and in the first and second floor laundry rooms they are the first operable unit closest to the door (with the inoperable unit located nearest to the door on the first floor). On the third floor, it is the middle machine that was not used. As each of these are H-axis units with standby load averaging 6.1 watts, the average annual electricity use of 54 kWh (and ranging from 31 to 66 kWh) is equivalent to 42% of the average annual energy use of the H-axis washers that were used, and 35% of the average annual energy use of the V-axis machines. Combined, this is 161 kWh/yr of electricity for three washers that were not used and 9.8% of the total combined electricity consumption of all 14 washers. This could easily be saved if there were a reliable way to identify and power down machines that were not being used.

6.4.2 Clothes Dryers

The electric clothes dryers in the UEPH were not able to be metered due to an unforeseen change from natural gas to electrically heated units between the date of the equipment inventory and installation of metering equipment. However, energy use was estimated based on the number of washer cycles recorded. The result shows that clothes dryers are the single largest energy user of all plug load and MEL device types in these buildings, consuming over 30,000 kWh/yr. This is over 2.5 times that of the next highest device sub-category, laptop computers. However, short of requiring Soldiers to line dry their clothes, there are not currently a lot of options for significantly reducing this energy use. Energy Star clothes dryers should be investigated; however, durability and reliability of the machines may be comparatively more valuable than marginal gains in efficiency. Emerging technologies such as ultrasonic dyers, which dry clothes using sound waves rather than heat and significantly reduce both energy use and drying time[1], provide hope that a breakthrough may be on the horizon.

6.5 Other MELs

6.5.1 Elevators

It has been reported that elevators and escalators consume around a 0.3-0.5 quadrillion Btu in U.S. commercial buildings each year, or roughly the same amount of electricity as is used for electrically heating and cooling those buildings, excluding ventilation (Sachs, et al. 2015). The buildings evaluated in this study have just one elevator. It is a hydraulic elevator located in the 2-story BN HQ. Analysis suggests that this elevator consumes approximately 2,100 kWh of electricity per year. As shown in Section 5.6.2, it ranks as the fourth-highest energy-consuming MEL identified in the BN HQ by this study and represents approximately 8% of the MELs and 1.7% of the building's total annual electricity consumption. For comparison, Sachs et al. (2015) report that typical energy use by elevators and escalators is about 2-5% of the total energy consumption of modern commercial U.S. buildings.

Monitoring of the circuits at the building's main distribution panel included capturing the elevator load at 1-minute intervals. Analysis of the captured data revealed a very high repeating load of 13-14 kW over the duration of the monitoring period. As shown in Figure 90 for a typical winter week this load occurs repeatedly, typically 3 times per day regardless of occupancy – day and night including weekends and holidays. This recurring load is so large that it is also clearly visible on the total building electrical load as shown in Figure 91 for the very same week, and is itself on the order of the peak load from the remaining building systems. The elevator conveyance loads during operation are also visible on this chart. They occur most frequently

[1] https://www.fanaticalfuturist.com/2018/02/ornls-new-super-fast-ultrasonic-dryer-uses-70-percent-less-energy/

during the normal occupancy hours (and also into Wednesday evening) and are considerably lower in magnitude, typically 0.8-3.5 kW. These conveyance loads typically last approximately 1 minute while the 13-14 kW loads last approximately 5 minutes per episode.

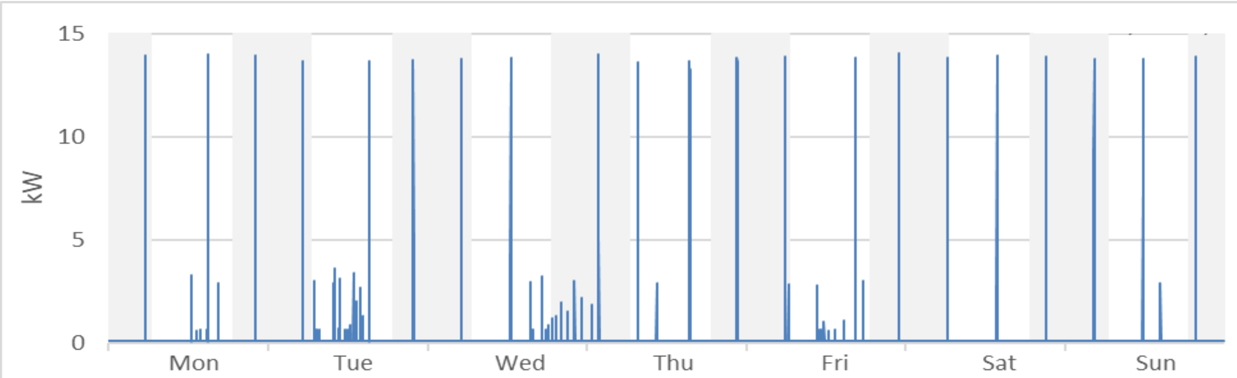


Figure 90. 1-Minute BN HQ Elevator Load Data for a Week in Winter

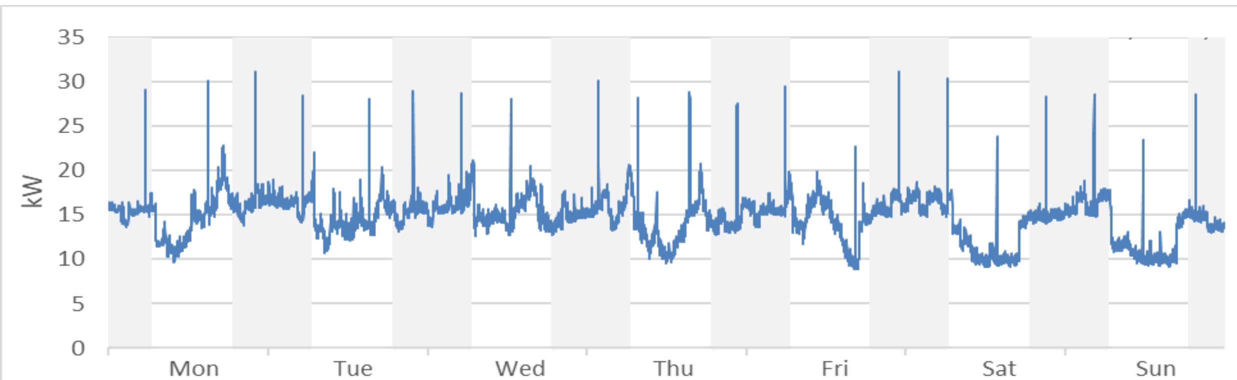


Figure 91. 1-Minute BN HQ Total Electric Load Profile for a Week in Winter

Upon review and consultation with elevator experts, this high periodic load has been identified as a heater for the hydraulic fluid reservoir. The purpose of an oil heater is to maintain an appropriate temperature and therefore viscosity of the oil to prevent operational problems. Various sources[1] suggest that the optimal temperature to maintain the oil is between 80-110ºF. However, others note that is typically only necessary for elevator machine rooms that are not weatherized or not conditioned (e.g., Nationwide Lifts, 2020, Sachs et al., 2015), and even then, only during winter months (Colley Elevator, 2016). The Northern Illinois University Design and Construction Standards for Elevators (NIU, 2018) require tank heaters only for elevators in parking garages, unheated buildings, or where exposed to freezing temperatures. A representative from Otis Elevator Company confirmed that the elevator should operate properly as long as the machine room is maintained within a range of 45-115ºF (Enevold, 2020). The elevator in question is located in the center of the BN HQ building, which is conditioned year-round, and therefore should not see temperatures outside of those bounds. Based on this, it is believed that the elevator will operate safely without a hydraulic tank heater, and at minimum the heater should not need to operate year-round.

[1] E.g., www.kja.com/hydraulic-oil-temperatures-p142271, www.transittraining.net/images/uploads/document_previews/218_Coursebook_with_Cover.pdf

Analyzing the elevator load data more closely revealed three states of operation: standby, conveyance, and oil heating. All elevators spend most of their time in standby mode and that is especially true for this elevator, with 98% of the time sitting idle during the initial monitoring period from December through February. Typical standby loads range from 0.085-0.087 kW. The conveyance mode is when the elevator performs the job it was designed for – carrying people and goods between floors. As shown in Table 23, this elevator was operating in conveyance mode only 0.6% of the time. Observed conveyance loads ranged from 0.8-3.5 kW. The total duration of the periodic oil heating during the study was found to be twice that of conveyance, at 1.3%, with typical measured 1-minute loads of 13-14kW.

As highlighted by Table 23 and Figure 92, the oil heating mode accounts for over 60% of the energy use, with standby mode energy contributing another 35%. Conveyance mode contributes only 3% of the energy consumed by the elevator, even though the number of uses or episodes of conveyance were over twice the number episodes of oil heating. Disabling the hydraulic fluid heater would therefore save 1,300 kWh of electricity annually, and equally if not more important, would eliminate the recurring 13-14kW spikes in electric demand. The year-round operation of the heater has been confirmed by reviewing available 1-minute electricity data captured by the EMCS, and makes sense given that the temperature of the building is maintained well under the likely setpoint temperature of the fluid heater.

Table 23. Elevator Use and Energy Breakout by Mode

Mode	# Episodes	Avg kW	% Time	Study kWh	kWh/yr	% Energy
Standby	NA	0.086	98.2%	151	739	35%
Conveyance	593	1.40	0.6%	14	68	3%
Oil Heating	268	12.2	1.3%	272	1,333	62%

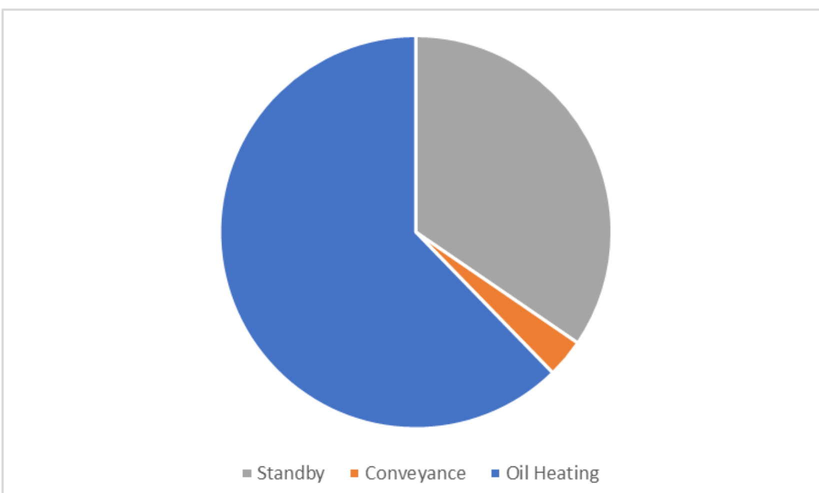


Figure 92.   Elevator Energy Use by Mode

The operation of elevators in conveyance mode increases the temperature of hydraulic fluid as potential energy is converted to heat energy. This explains why periods of more frequent use of the elevator result in delaying the next oil heating cycle and load spike. This can be seen in Figure 90 above. The elimination of these frequent and unnecessary peaks in load will reduce electric demand charges and also enable improved energy resilience by facilitating better design and operation of backup power systems in buildings with hydraulic elevators.

Assuming that 20% of the total BN HQ floor area across the Army exists within multi-story buildings with an elevator, the savings Army-wide to review, remove, or adjust hydraulic elevator oil tank heaters could be as much as 245,000 kWh/yr. The potential savings for all buildings with hydraulic elevators would be much higher. The review of hydraulic fluid heaters across the Army may also be significant from a peak demand reduction and mission resilience perspective. Such high and recurring peak demand behavior not only impacts an installation's electrical demand charges, but also the potential design and operation of backup generation for assuring mission resilience in buildings with these types of loads.

Elevator Recommendations:

- Confirm the presence and operation of hydraulic oil heaters for elevators in Army buildings where machine rooms are expected to maintain a temperature in the appropriate range (approximately 45-115ºF).
- Disable the heater if deemed unnecessary to maintain the required hydraulic oil viscosity.
- Otherwise consider lowering the setpoint temperature, turning off outside of winter months, and/or replacing with a lower power heater that will still provide necessary protection but over a longer duration to reduce the magnitude of the electric load, reducing potential demand impacts and challenges to backup power system design and operational stability, for improved resilience.

6.5.2 Air Compressors

The TEMF has a 25-hp air compressor (shown in Figure 93) to provide compressed air throughout the shop area for pneumatic tools as well as to pressurize lines that deliver various automotive fluids throughout the shop.

Figure 93. Air Compressor in TEMF

A review of 1-minute interval data for the air compressor suggests that it is actively compressing air roughly 1.7 – 3.3 percent of the time. Weekend cycling (during which the TEMF is unoccupied) indicates that there is some portion of compressed air that is being lost through leaks. In the data collected from July to October, the weekend-only data suggests a run time of approximately 2.0 percent. A comparison of the data for all hours during that period, including occupied hours, shows a runtime of 3.2 percent. The difference between these suggests that the air compressor cycles roughly 1.3 percent of the time during normal use. This indicates a low demand on the system over this period. Additionally, this indicates that the system does not have significant losses to air leaks and can be considered well-maintained.[1]

Figure 94 shows the 1-minute interval power profile for the compressor during a higher-activity summer week. During this period, the compressor ran extensively during operating hours Monday-Thursday, but only once every 4-8 hours each night and over the weekend.

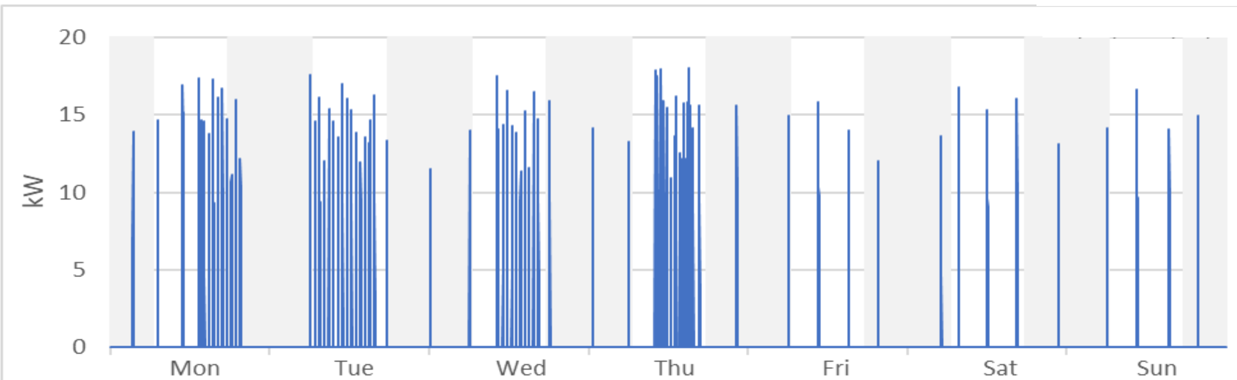


Figure 94. TEMF Air Compressor 1-Minute Interval Power Profile for 1 Week in July

The Admin building also had an air compressor. It is a smaller unit that serves the pneumatic HVAC controls for the building and therefore was viewed to be outside of the scope of this study and was not evaluated. However, observations of its frequent cycling suggest that the system in that building was particularly leaky and used significant energy to maintain proper pressurization. Further, during the study it was noted that the initial air compressor had failed and was replaced, potentially influenced by the frequent cycling rate.

Air compressors are a common source of energy waste in buildings, particularly for older buildings where piping has developed significant leaks over time. The Army has an abundance of compressed air systems, particularly within buildings such as vehicle maintenance and similar facilities, and maintaining such systems is important. Even though the system within the TEMF studied at Fort Carson was operating well with minimal leaks, there remains a large potential for energy reduction in identifying and addressing poorly operating systems.

Recommendation:

- Evaluate compressed air systems to ensure that they are well-maintained and are not cycling frequently when no or low load exists on the system.

- Review compressors to minimize over-sizing especially at part-load conditions which can lead to very inefficient operation.

---

[1] The percentage lost to leakage should be less than 10 percent in a well-maintained system per guidance from DOE's Operations & Maintenance Best Practices – A Guide to Achieving Operational Efficiency (Sullivan et al, 2010).

6.5.3 Space Heaters

Within the study buildings at Fort Carson, personal space heaters were observed to be operating to varying degrees within each of the four non-barracks buildings (examples shown in Figure 95). The team inventoried 11 space heaters, including six in the Admin, two each in the BN HQ and TEMF, and one in the COF. Overall, space heaters ranked ninth on the top 10 energy-consuming device types encountered in this study (Figure 11) with a combined annual energy use of nearly 5000 kWh. However, of all of the plug load devices, space heaters were the most challenging to estimate annual energy consumption for. There are a number of reasons for this, however, it is primarily that their operation is so dependent on the occupant and their perception of comfort. Use of space heaters is likely to be most frequent during the winter months but that is also dependent on the performance of the HVAC system within each building and the variation in airflow and other heat sources from one area to the next. If buildings are kept too cool for an occupant's comfort, heaters can be found to run during the summer as well.

Figure 95. Examples of Space Heaters in the Admin Building

Further compounding the challenge of estimating space heater energy use is that the energy monitoring within two of the buildings with these devices was performed during the warmer months. The period of the initial install in early May was quite cool and therefore significant space heater use was observed during that week and the following week, and then again just before the metering was removed in October. One space heater was also used for several days in August. During the winter portion of the study, one space heater in the BN HQ was monitored. For each of these space heaters, annual use was extrapolated using HDD data for Fort Carson and applying the ratio of monitored energy use to the HDDs coinciding with the days of use, to the number of HDDs occurring on weekdays throughout 2019. This provides a reasonable estimate of annual consumption but is still rather uncertain. Based on assessment via observation, the estimates of energy use in the TEMF and BN HQ are likely reasonably accurate, while the estimate for the Admin may underestimate actual use.

Army regulation AR 420-1 Chapter 22 (Army Energy and Water Management Program) covers the use of personal space heating and cooling devices. Such devices are prohibited from circumventing the allowable space temperature set point ranges but may be approved for use under two scenarios. First, such devices may be used for cost-effective conditioning of select spaces (e.g., where only a small portion of a building is occupied) enabling conditioning to be reduced for the remainder of the space. Additionally, “supplemental heating and cooling may be used … when personal comfort levels cannot be achieved by reasonable adjustments of the primary system.” Supervisor approval is required, and devices may operate only when the space is occupied. Such restriction combined with allowance for exceptions is common across many organizations. Worker comfort levels can vary significantly and if reasonable adjustments to the HVAC system or space configuration cannot adequately address an ongoing issue, accommodations are often made to allow for exceptions to balance productivity and morale with energy use.

The PNNL team did not investigate and verify that each space heater within the study buildings had documented supervisor approval. Nor was operation closely tracked to occupancy. The team did note that some space heaters were left operating while the occupant was away from their workspace for at least short periods but did not track the duration. The plug-level monitoring however did allow verification that none of the studied space heaters were left on overnight or over weekends. As noted, the annual energy consumed by the space heaters within these four study buildings is estimated at 5000 kWh. Extrapolating these results Army-wide within these four building categories suggests that space heater energy use could be on the order of 2.2 million kWh/yr. Accounting for variation of use with climate and other factors, and the ability to affect change, the effective savings potential may be around half that, or 1.1 million kWh annually. The bottom line is that space heaters consume a lot of energy and should be assessed more closely for compliance with existing policy. Processes and conditions for evaluating and documenting exceptions to support occupant comfort and productivity should be reviewed and communicated, along with safety and energy awareness expectations and responsibilities.

Recommendations:

- Review the personal space heater approval process relative to AR 420-1 and investigate occupant comfort complaints and possible building HVAC solutions, prior to approving exceptions.

- Require safe and responsible use of heaters (e.g., only operated when present, do not plug into a power strip, and all units must have a safety tip-over shut-off) when exceptions are granted as a condition for their use.

6.5.4 Disconnect Hard-Wired MELs When Not in Use

Similar to turning off plug load devices such as computers, projectors, and televisions when not in use, hard-wired loads should also be powered off when not being used or needed. The elevator hydraulic tank heater is one example of this that was described above. Another is noted for the TEMF. The design of the building included two Arms vaults with access control systems. The vaults in this particular TEMF are no longer being used for secure storage but rather for vehicle parts storage. The doors are left open, yet the access control system is still powered on. A similar situation was found with the access control for one of the network spaces which is unused in the TEMF.

This example serves as a reminder that unused hard-wired loads should be identified, disabled and powered off when they are serving no useful purpose.

Recommendation:

- If not in use, power it off, even for hardwired devices.

6.5.5 Distribution Transformers

Distribution transformers are a major MEL category that were not evaluated in this study. According to the EIA (2017) and Kwatra et al. (2013), distribution transformers rank as the highest consuming MEL in commercial buildings, as a result of the losses involved in transforming high voltage electricity supply to lower voltages used within buildings. Given their ubiquity across Army installations, these losses add up. Most buildings have at least a primary transformer and many have multiple. For the buildings that were metered in this study, three of the four had multiple transformers including the TEMF, UEPH, and Admin.

Given their continuous operation, even small increases in efficiency result in significant savings potential. With well over a hundred thousand Army facilities, if transformer efficiency has not been evaluated broadly it should be. A recent ESTCP study by Meier et al. (2019) looked at the transformer serving an Army vehicle maintenance facility and concluded that the losses exceed 15 MWh per year. The Energy Star program covered transformers until 2007, when a new minimum federal efficiency standard went into effect. The newer, more efficient transformers provide the greatest savings benefit when the average load it sees is less than 50 percent of its rated capacity (Thomas et al., 2002). As most of the buildings in this study were built after 2007, most of the transformers are already efficient. For example, the four transformers in the UEPH were made in 2010 and have a rated efficiency of 98.3% at a load of 35% (Figure 96). Transformer efficiency varies across building load with higher net losses often increasing with building energy consumption. Older buildings are likely to have older and less efficient transformer technology; thus the highest savings opportunity may lie in older and higher-consuming buildings where transformers are oversized for the typical or average load.

Recommendation:

- Review the age, sizing, and efficiency of transformers serving Army buildings to identify cost-effective replacement opportunities.

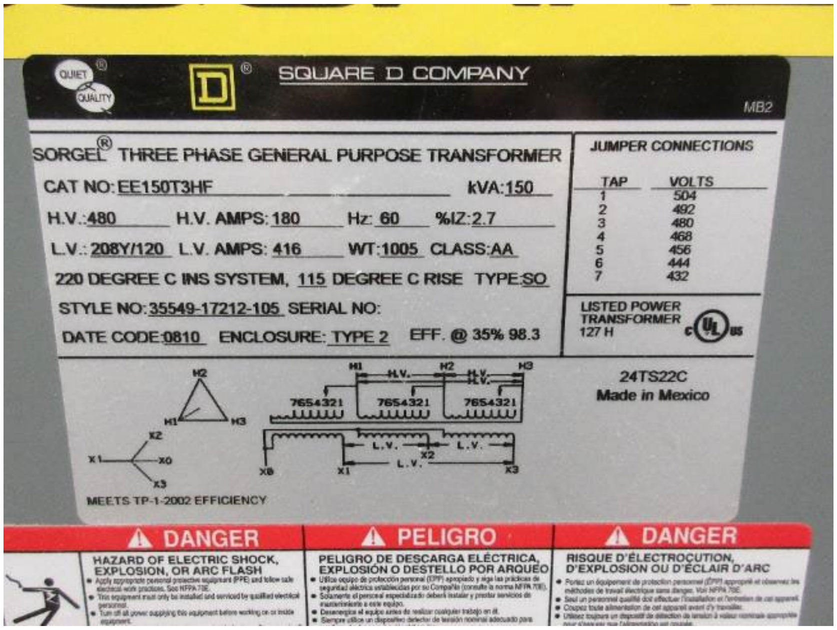


Figure 96. Example of a High Efficiency Transformer in the UEPH

7.0 Findings and Recommendations for Path Forward

This study for the Army assessed the magnitude and characteristics of plug load energy use within five representative buildings located at Fort Carson. Results provide estimates of total plug load and MEL electricity consumption for each building, as well as by device category and for many individual devices. These findings help to better understand the contributions to total building energy use, relative to other end uses, and help to identify the magnitude of savings that are possible from focusing on improved management and operation of these plugged-in and hardwired devices, which can contribute to overall efficiency and resilience of Army facilities, and better focus resources on the mission.

7.1 Findings

Key findings from the study are summarized here, highlighting results obtained from the inventory, metering, and analysis performed for the five study buildings: Admin, TEMF, UEPH, BN HQ, and COF.

7.1.1 Number of Plug Load Devices

A total of 878 MELs devices were inventoried across the five representative study buildings and grouped into eight primary categories. These are shown in Table 24 with the calculated metrics of devices per thousand square feet and devices per occupant.

Table 24. Summary of Device Inventory by Building and Category

	Admin	TEMF	UEPH[a]	BN HQ	COF	ALL
AV/Communications	58	6	1	47	23	135
Breakroom	44	8	6	21	16	95
Computing	194	25	-	109	58	386
Documents/Imaging	30	6	-	17	16	69
Laundry	-	-	36	-	-	36
Occupant Comfort	68	14	-	31	12	125
Shop Equipment	-	29	-	-	1	30
Facility Loads[b]	-	-	-	2	-	2
TOTALS	**394**	**88**	**43**	**227**	**126**	**878**
Devices per ksf	**27.6**	**4.9**	**0.7**	**16.2**	**3.9**	**6.2**
Devices per Occupant	**10.4**	**5.9**	**0.3**	**6.3**	**3.6**	**3.4**

[a] Device inventory for UEPH represents common area devices only
[b] Facility load devices include the elevator and oil minder within the BN HQ. Additional facility loads such as networking infrastructure, fire alarm and security systems are omitted from this device inventory but included within the MEL energy consumption estimates.

7.1.2 Energy Use of MELs

The energy consumption of MELs was estimated using a number of top-down and bottom-up methods. A summary of the resulting best estimate of annual MELs' energy consumption for each building is presented in Table 25, with the percentage of total building electricity and total building energy, and the value of the energy consumed.

Table 25. Summary of Best Estimate Annual MEL Consumption by Building

Building	MELs Annual Electricity Consumption, Best Estimate, kWh/yr	Percent of Total Building Electricity (%)	Percent of Total Building Energy Use (%)	Estimated Electricity Cost[(a)] ($/yr)
Admin	34,300	30%	13%	$2,100
TEMF	30,700	16%	5%	$1,800
UEPH	139,300	39%	16%	$8,400
BN HQ	26,200	21%	10%	$1,600
COF	18,000	9%	5%	$1,100
Total	**248,500**	**25%**	**11%**	**$14,900**

[(a)] Electricity cost based on recent blended average rate at Fort Carson of $0.06/kWh

Figure 97 presents the resulting energy use density for MELs in each building, in terms of both annual kWh per thousand square feet and per occupant. The Admin has the highest density per floor area, while the TEMF has the highest MELs consumption per occupant. Figure 98 highlights the annual MEL energy use density per floor area for each building by equipment category. Details of plug load energy use and energy density by floor area and number of occupants, for each building and by major plug load equipment category, are presented in Appendix C.

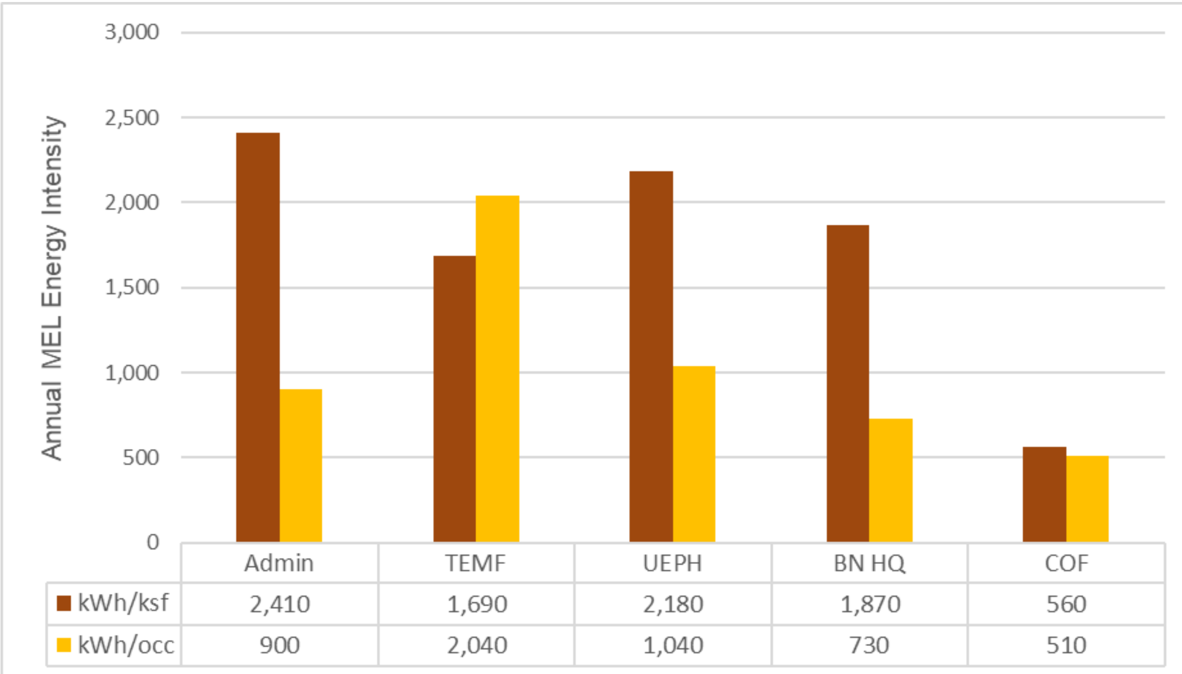


Figure 97. Annual MELs Energy Intensity by Building

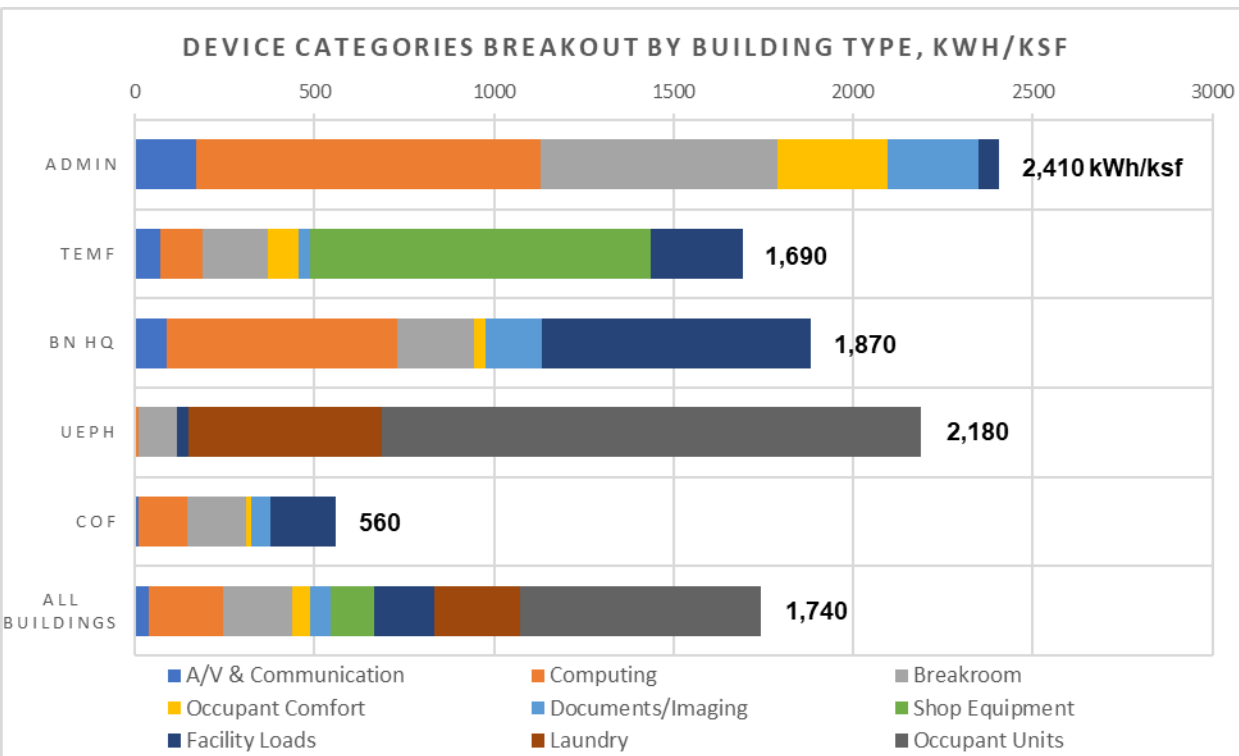


Figure 98. MEL Energy Use Density by Building Type and Category

The 10 highest energy-consuming device types, over all five study buildings, are identified in Figure 99. Together, these contribute 71% of the MEL energy use, excluding that from the UEPH occupant living quarters. Figure 100 highlights the 20 individual MELs and plug load devices that consume the most energy.

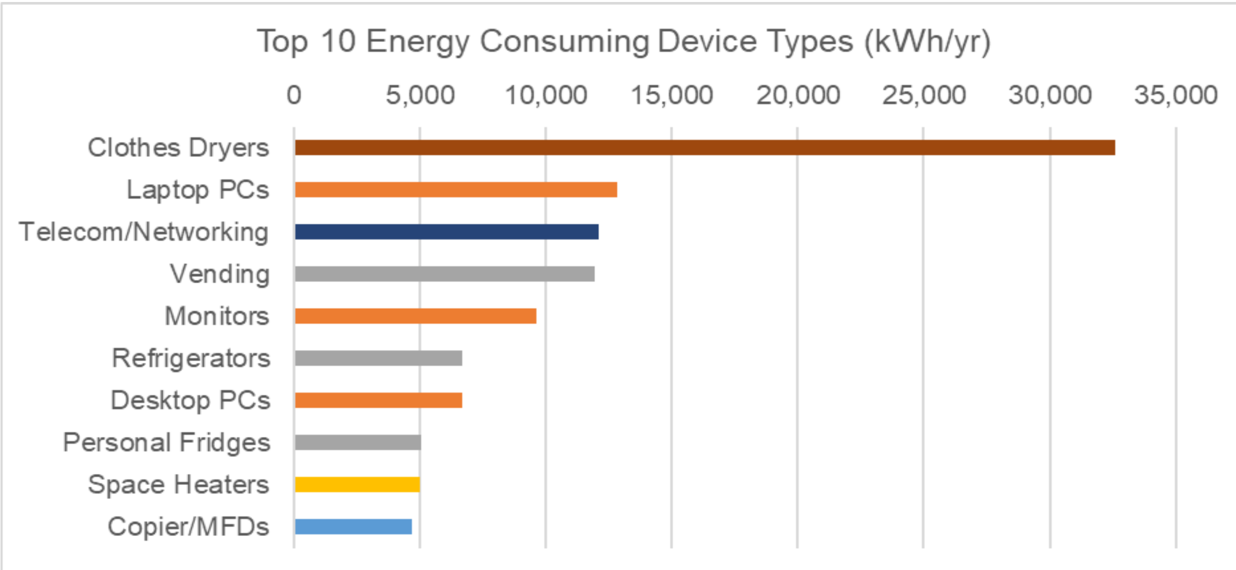


Figure 99. Top 10 Energy-Consuming Device Types Within the Study Buildings

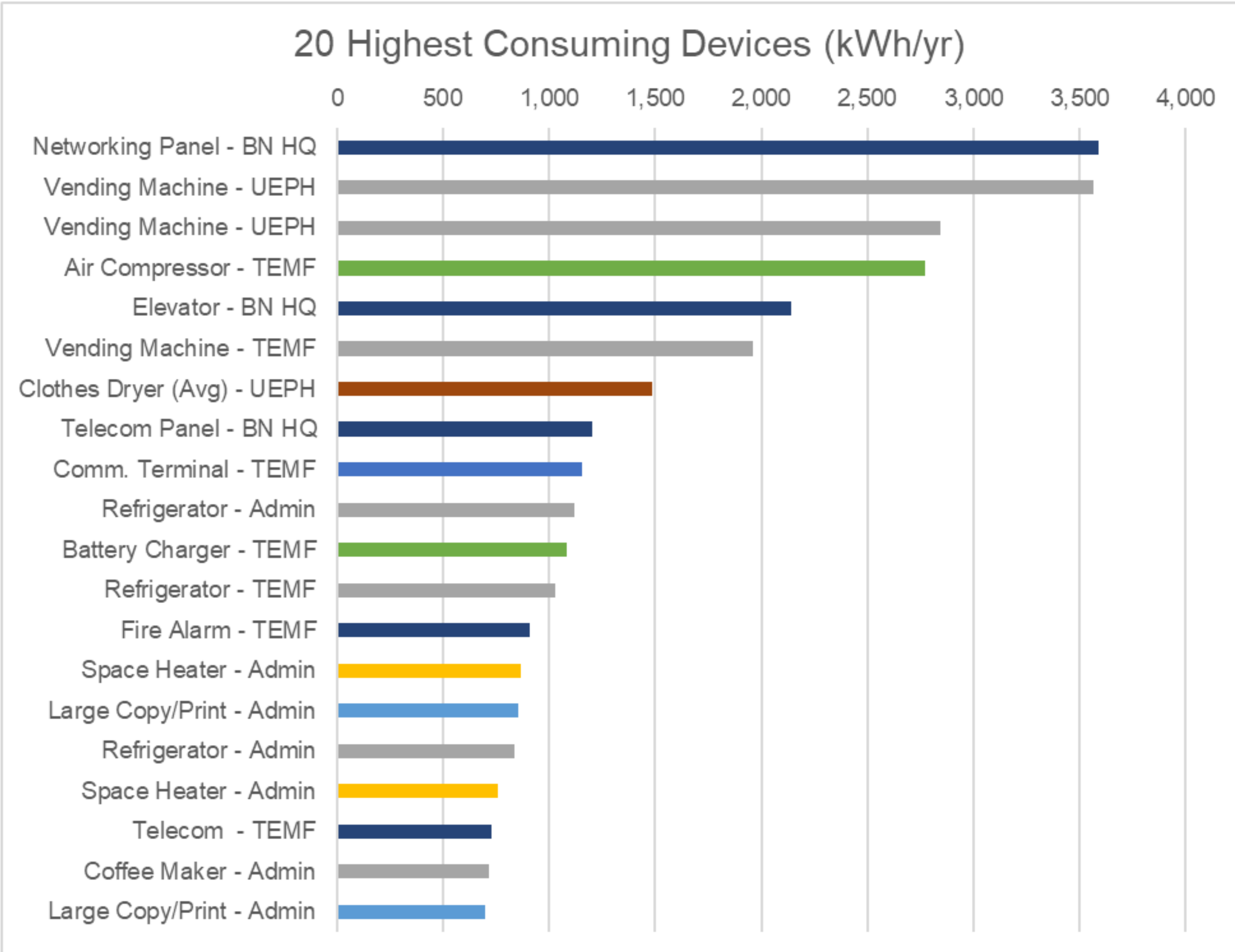


Figure 100. 20 Highest-Consuming Individual MELs Within the Study Buildings

7.1.3 Magnitude of Potential Savings

The results from the monitoring of plug load devices contribute to the best estimates of energy consumption at the device, category, and total building levels. The largest plug load contributors to energy use within these representative study buildings consist of a mix of different types of devices. Figure 100 highlights the 20 individual devices that were found to use the most energy. These include each of the three refrigerated vending machines, the TEMF air compressor, BN HQ elevator, UEPH clothes dryers, TEMF communications terminal and battery chargers, refrigerators, and more. Additionally, there are types of devices that use significantly less energy per device, but due to their high population within these buildings makes them some of the largest overall energy users. As was shown by Figure 99, these device types primarily include personal computing (laptops, desktops, and monitors), but also personal and regular refrigerators, space heaters, and large multifunction copy/print devices.

The value of monitoring plug load devices goes well beyond estimating total energy use. It also helps to understand the nature of the loads over time, and how the devices are operated both during occupied and unoccupied periods. This provides great value in determining whether a variety of energy-saving measures may be viable for reducing plug load and MEL device energy use. Such measures can include improved equipment purchase and excess processes, setup of built-in power saving options, external controls, as well as education and shaping occupant awareness and behavior. Many of these measures could be influenced via review of policy, both existing and new, to encourage and realize significant energy use reduction within these and similar buildings across the Army.

Army Regulations regarding the energy use of information technology equipment (computers, laptops, monitors, printers, multifunction devices) are spelled out clearly in AR 25-1. However, the policies regarding shut down or sleep power mode after 30 minutes of inactivity (15 minutes for monitors) do not appear to be consistently followed. In some cases it is a decision based on supporting a strong cybersecurity posture, but in other instances the devices are just not being set up to take advantage of such power management settings.

As presented in Section 6.0 the estimated annual savings for identified savings measures in the study buildings is over 29,000 kWh and close to $1800. Extrapolating Army-wide for just these five building categories, the savings potential expands to nearly 83 million kWh and $5 million per year.[1] This is conservative as similar opportunities exist within many of other building categories. A summary of the identified measures and savings potential is presented again here as Table 26.

[1] Dollar savings based on a rate of $0.06/kWh.

Table 26. Priority Plug Load Savings Opportunities and Scale of Potential Savings

Savings Measure	Study Building Findings Device Savings (%)	Study Building Findings Savings (kWh/yr)	Potential Army-Wide Savings Energy (million kWh/yr)[a]	Potential Army-Wide Savings Dollars ($K/yr)[b]
Implement Sustainable Computer Policy: Power Systems Down Each Night	46%	11,300	31.6	$1,900
Refrigerated Vending Machines: Energy Star with Custom Settings	57%	6,000	31.2[c]	$1,870
Improve Power Save Settings: Large Copy Print Devices	47%	2,500	7.6	$456
Refrigerators: Replace 20+ Year Old Units with New Energy Star Models	39%	2,600	6.3	$378
Computer Purchase Policy: Purchase Laptop PCs over Desktops + UPS	46%	2,000	3.2[d]	$192
Commercial Coffee Makers: Add Timer or Similar Controls	43%	490	2.6	$156
Space Heaters: Review Policy Enforcement and Exceptions for Reasonable and Responsible Use	50%	2,500	1.1[e]	$66
Printers: Enable Sleep Mode	14%	370	0.93	$56
Projectors: Turn Off When Not in Use	41%	300	0.75	$45
Elevators: Review and Remove or Adjust Hydraulic Fluid Heaters	62%	1,300	0.25	$15
TOTALS	**51%**	**29,360**	**82.9**	**$4,970**

[a] Army-wide savings are estimated based on savings per ft^2 in study building(s) multiplied by floor area of the study building cat code. Actual savings are likely higher but depend on other building types being relevant for the identified measure and how representative the study building(s) and device densities, usage, and settings are across the Army.
[b] Total Army dollar savings (thousands of dollars per year), assume a $0.06/kWh average electric rate.
[c] Savings estimates for refrigerated vending machines are extrapolated to the entire Army floor area, and not only the building categories assessed in this study.
[d] Savings are estimated only for general Admin buildings and assume that (1) a sustainable solution to allow computers to power down nightly has been implemented, and (2) the category average density of desktop computers is only 30% of that in the Fort Carson Admin building studied.
[e] Assumes a 50% overall reduction rate within these building types across the Army (to account for variations in climate, use, and policy exceptions to support occupant comfort and productivity)

7.2 Plug Load Equipment Best Practices

In order to achieve and sustain these types of savings throughout the Army, the recognition and implementation of best practices regarding plug load devices is important. The following sections outline some of the key elements of these best practices. These should be viewed as a continuous set of processes over the equipment lifecycle.

7.2.1 Purchase

Equipment purchase is often regarded as the first if not only step of the plug load best practice cycle. However, it should be viewed as a continuation of previous steps, though a convenient place to initiate the discussion. Importantly, the review of equipment and capability needs should take place prior to the point of purchase. Not understanding the capabilities required to meet the needs of the task and mission can lock in potential inefficiencies and waste for years to come.

Per federal and Army regulations[1], most office and other equipment purchases must follow Energy Star rated or qualified energy efficiency guidelines. The Army appears to be doing well on this front, however, needs regarding the type of equipment and features should still be reviewed prior to purchase. As examples, policies and guidelines should be reviewed against requests for equipment such as personal printers; where feasible the use of shared networked printers should be encouraged. Similarly, the purchase of laptop computers should be encouraged if not required over a comparable desktop computer, as long as it meets mission needs. Thin client technology should be evaluated as it becomes more available for energy and other benefits. Individual UPS devices should also require additional authorization to be sure they are required for meeting a critical need, when laptops with embedded batteries are not suitable.

In some instances, the need for equipment purchases should be driven based on the poor energy performance of otherwise operating devices. Good examples of this include establishing policies or recommendations to replace refrigerators that are more than 20 years old with new Energy Star qualified units – with only the features that are needed for the intended application. Vending machines typically aren't purchased by the Army but provided by vendors contracted through AAFES. The Army should partner with AAFES to ensure that all new refrigerated vending machines comply with the latest Energy Star standards, while proactively replacing the oldest and most inefficient existing machines.

7.2.2 Setup

As noted, the purchase of energy efficient equipment is required; but that alone is not sufficient to ensure efficient operation. The equipment must be set up with energy saving features configured in order to be effective. In order to comply with regulations for office equipment described in AR 25-1, the energy saving features must be understood and configured properly during the equipment install. As shown by the energy monitoring results captured in this study, the energy wasted by equipment not engaging in appropriate power management and sleep modes is significant and can be equal to or greater than its energy used for meeting mission needs. This is unacceptable, especially as most equipment has energy saving settings available. The settings just need to be understood and engaged. Most common office equipment such as computers, printers, large multi-function devices, and projectors have power management settings. Device monitoring results show that many monitors and printers are configured to enter sleep or other low-power mode after a certain time of inactivity. And one large multi-function device was being scheduled to turn off each night. But in the case of that device as well as a number of printers and other equipment, significant room for improvement remains. Other equipment such as modern Energy Star refrigerated vending machines can be programmed to reduce energy use by turning off the lighting and even the compressors for

[1] Federal Acquisition Regulation (FAR) 52.222-15, Energy Efficiency in Energy- Consuming Products and Army Regulation 25-1

periods of time unlikely to impact service to users. Vendors of these machines should be required to de-lamp and program these energy saving features based on the active operating hours where the machine is located. The Army should work with AAFES to develop and implement such guidelines.

Equipment without built-in power saving features, should be evaluated for installation with an advanced power strip, timer, or other control mechanism to help turn equipment down or off when not needed. One of the best examples of this are commercial coffee makers, which don't have built-in controls but can save close to 50% by simply turning them off each night. Other devices that would benefit from this type of control include television tuners also known as set-top boxes, older printers, scanners, water coolers, and other devices with significant standby load that do not need to operate all the time. Fort Carson DPW has demonstrated success in using advanced power strips to help turn off workstation peripherals when not in use.

As part of the setup process, personnel who will use the device should be engaged and educated on its proper use and the importance of the power saving features. The benefits of power management should be communicated, along with the required settings and how to use the equipment at off hours when needed. Further, it is important to be clear that the settings do not harm the equipment or reduce its life.

7.2.3 Operate

Following the best practices regarding equipment purchase and setup will facilitate efficient operation. User education is an important aspect of that to ensure that the power-saving settings are maintained. Commands should be encouraged to foster an environment of diligence towards reducing energy waste from plug load equipment under their operation. This includes maintaining power-saving behavior through device settings, external controls, and even behaviors to identify and minimize unnecessary energy use. Simply turning off equipment for 12 hours each weekday and all weekend will reduce operating hours by 64%.

Instilling operational best practices also means that personnel are aware of equipment operation and identify off-normal events that may prevent normal energy management functions from engaging. From experience in monitoring various plug load equipment at PNNL, the authors have become aware of easily over-looked events that can keep equipment from entering sleep mode. For example, printers that are out of paper or ink/toner, have a paper jam, or simply have one of many paper trays removed and otherwise remains fully operational, have been observed to fail to enter the programmed sleep mode as a result of these scenarios.

7.2.4 Monitor

The maxim that you can't effectively manage what you don't understand is especially appropriate for plug loads. Plug load equipment is all around us yet is not a focus of energy use. And even for those knowledgeable about energy management often have very little idea about how common appliances or devices are actually operating and how much power they are drawing. Most equipment of this nature do not have displays that report their current or cumulative power use, and it can be extremely difficult to assess how well or efficiently a device is performing. Monitoring is often the only way to truly understand how devices are behaving, which can lead to more effective management and energy savings.

It is therefore important to continue to monitor plug loads and other large MELs across the Army. Commercial plug load monitoring options can be a significant investment, but under well-planned and executed they can pay for themselves by identifying improvement opportunities, scheduling operation, alerting staff to off-normal status or events, and even the tracking the utilization and management of equipment assets. Even without broad and full-time implantation, plug load power monitors can be useful for both one-time readings as well as limited scale and duration deployment. Each time our team has deployed plug load monitoring, we have been surprised at some of the findings and have identified additional savings opportunities. Even intermittent monitoring of devices will reinforce each of the other best practices while identifying new lessons learned and savings opportunities.

7.2.5 Review

The final step in the cycle is to review settings, operation, behavior, and results from any monitoring on a regular basis. The review of equipment settings should be scheduled to occur twice per year to ensure that each device is set to enter power-saving mode after 15 or 30 minutes of inactivity and ensure persistence in savings. Policies should be reviewed to ensure it is keeping up with device types, capabilities, and mission needs. As should the adherence to policies and opportunities to learn from what is and what is not working. For example, while strong policies regarding the purchase of energy efficient equipment are in place, guidelines and expectations governing the repurposing of old equipment or excessing and disposal of equipment may be less clearly defined. The transfer of refrigerators being upgraded with more efficient units in one building, for use in another, should be reviewed from an energy and sustainability perspective. Where a need is determined, in most cases the purchase of new efficient equipment should be encouraged.

The plug load opportunity with the largest savings potential for the Army is to identify and implement an effective and sustainable approach to power down networked computers in accordance with Army regulations. This is not being done consistently due to conflicts with the cybersecurity requirements. Computers must be able to receive and install updates to operating systems and applications in an expedient and comprehensive manner. To date, an effective solution that allows computers to enter low-power sleep mode after 30 minutes of inactivity yet wake on demand when updates need to be installed, has not been identified or broadly deployed. This should be a top priority for the Army CIO, G-6, NETCOM, and installation NECs to work out together, to ensure the cybersecurity of Army computing systems while also enabling significant energy savings and enhanced resilience. Electricity savings of more than 30 million kWh per year are estimated from within the four building categories evaluated within this study, yet given the broad use of computers in most buildings the potential is clearly much greater.

The need and required features of new equipment should be reviewed prior to purchase. New equipment purchases should be reviewed carefully, identifying needs and matching device specifications and capabilities to those needs as well as the compatibility with other existing equipment and systems. A recent lesson learned at PNNL is to make sure the power-saving features are compatible for the intended use and with any integrated technology.[1]

---

[1] Four large-screen LCD displays were purchased at PNNL to serve as message board displays. While they had a built-in scheduling capability to automatically turn the units on and off each day, it was not compatible with the device supplying the video stream, and so when the displays would turn on, the video signal was not viewable. The scheduling of different models had been proven to work with the video system, but compatibility with the new display model was not validated prior to purchase, thus wasting a significant and enduring savings opportunity.

However, the easiest ways to reduce plug load energy use and waste remain as follows, which can be identified via recurring review:

1. Avoid purchasing new equipment that is not required, and
2. Identify existing equipment that is not being used, and turn it off (or better yet, unplug it).

7.3 Pathways for Affecting Change

Beyond the best practices to support a sustainable plug load lifecycle, pathways must be identified and developed for encouraging and affecting desired change. These pathways can and should manifest in multiple forms and approaches, including policy, technology, and outreach.

Policy: Policies governing the expectations of plug load equipment purchase and use are important. They provide clear guidelines but alone are insufficient.

Technology: Technology has a significant supporting role to play. Advances in technology are enabling devices to provide the required services to completing a task or supporting a mission at lower and lower energy use. Technology is also important for managing power use and turning equipment off when not in use – with built-in settings or external timers, switches, or other controllers. And as noted, monitoring technology is critical for understanding how plug load equipment is really behaving and how much energy is being consumed, and how much could be saved.

Outreach: This pathway is critical. Unlike most other building end use equipment which is managed and operated centrally with limited occupant input, plug loads are typically operated directly by building occupants. Therefore, building occupants must be viewed and treated as partners in plug load management efforts. Without the effective engagement and education of end users, the impacts of policies and technology will be limited and short-lived. Effective communication of the goals and benefits of operating and managing common devices such as office equipment, appliances, and electronics, is critical to sustained success. Many of these needs require behavior to align with goals – not from a small subset of skilled equipment operators as for HVAC equipment, but by all Army and contractor personnel occupying Army facilities. Investing in transparency and partnership with staff will be necessary and go a long way to achieving success.

Like the monitoring deployed by this study, effective pathways for change can follow both top-down as well as bottom-up approaches, and the best results often come with a combination of the two. Top-down approaches include policies and other similar measures. Several examples highlighting bottom-up methods were witnessed at Fort Carson during the performance of this study. These include the occupants in the Admin showing the awareness and taking the initiative to turn off the commercial coffee maker before leaving ahead of each weekend. Also, DPW personnel have demonstrated the value that technology can provide in using advanced power strips to easily turn equipment off when not in use. The eagerness of Army personnel to learn more about reducing energy waste was also displayed by a number of people encountered during the course of the study. One staff duty sergeant who escorted the research team in one building showed great interest in the study and learning what he could do to help save energy both at work and at home. This highlights the potential for the greatest resource to impact change, every day. The Army should invest in finding new ways to engage and empower inquisitive and enthusiastic Soldiers to identify and address waste as they serve their primary missions. That will have a compounding effect, raising awareness and impacting change not only in the workplace, but also within the barracks, on-post housing, and within the broader communities.

This study focused on understanding the magnitude and characteristics of plug loads within representative Army buildings. Savings opportunities were identified, and savings estimated, but no savings measures were enacted. However, anecdotal evidence from another study points to the promise of combining top-down and bottom-up drivers that is likely able to be successfully replicated and expanded throughout the Army. A recent ESTCP technology demonstration study at Joint Base Lewis McChord reported (Meier et al. 2019) that a facility manager initiated an ad hoc campaign within his building to raise the awareness of plug load equipment energy use and requested that occupants adjust behaviors to switch off office equipment before leaving or whenever it was not being used. The building occupants reportedly responded by shutting down a variety of office equipment and breakroom appliances and unplugging other machines that were rarely used. As a result, a 25% reduction in equipment electricity consumption was measured, which exceeded the researchers' estimate of what might be possible, demonstrating the power of an informed and engaged Army workforce.

There are many effective approaches and pathways for impacting change as it relates to improving awareness, implementing measures, and adjusting behaviors to identify and reduce plug load energy use. And the Army should deploy all of these to better understand plug loads, save energy, and enhance resilience across their inventory of facilities.

7.4 Next Steps

The use of plug load equipment has increased significantly to enhance personal and professional connectivity, productivity, convenience, and comfort. Projections (e.g., EIA 2020) forecast a continuation of this growth trend for the foreseeable future accelerated in part by efficiency gains in other building end uses. The Army is already working hard to improve the design and performance of its building energy systems. As these efforts progress, the fraction of total building energy consumed by plug loads and MELs will continue to increase across the Army. Therefore, a focus on MELs is important and its significance will grow.

This study was the first of its kind for the Army to examine plug loads at this scale and in this variety of buildings. Through a mix of panel and device-level monitoring, along with top-down and bottom-up energy estimation methods and characterization of device load profiles, it has identified some very positive findings (including effective systems and behaviors) as well as many areas for improvement. However, the study represents a single snapshot of the behavior within five representative buildings. While the results are intended to be (and are believed to be) broadly applicable to large swaths of Army facilities worldwide, the sample size is insufficient to fully or adequately capture the full breadth, magnitude, and nuance of the opportunity. Every building is different and variations the types of equipment and their operation matter. While the findings and recommendations presented here may be broadly applicable to the Army, more review is necessary for continued revelation, mitigation, and review, to ensure real and sustained progress.

The goal of effective plug load management is to reduce plug load energy use without negatively impacting mission performance. There are several effective approaches and pathways for impacting change as it relates to improving awareness, implementing measures, and adjusting behaviors to identify and reduce plug load energy use. The Army should prioritize and consider deploying all of these to better understand and manage plug load equipment to save energy and enhance resilience across their facilities. Engaging the building occupants who use these devices daily via outreach and education should be a strong component of the strategy. Continued evaluation of plug loads beyond that performed here is important to gather lessons from additional building and equipment types, and to stay aware of evolving device technology and management options. This will highlight additional needs for policies, best practices, control technologies, and education of personnel to achieve real reductions in energy waste from plug load equipment. It is recommended that this study may serve as the foundation for a broader and sustained focus on plug loads and MELs, towards simultaneously enhancing the productivity, readiness, and resilience of the Army while reducing energy use and demand, and freeing up resources to better support the mission.

8.0 References

Army Regulation 25-1 (AR 25-1). 2019. Army Information Technology. Headquarters Department of the Army, Washington, DC. 15 July 2019.

Army Regulation 420-1 (AR 420-1). 2019. Army Facilities Management. Headquarters Department of the Army, Washington, DC. 24 August 2012.

Bendt, P. 2010. Are We Missing Energy Savings in Clothes Dryers? 2010 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, D.C., ACEEE.

Butzbaugh, J., R. Hosbach, and A. Meier. 2020. Miscellaneous Electric Loads: Characterization and Energy Savings Potential. Manuscript submitted for publication. Pacific Northwest National Laboratory, Richland, WA. Lawrence Berkeley National Laboratory, Berkeley, CA.

Colley Elevator. 2016. Hydraulic elevator maintenance - cold temperatures. Colley Elevator. December 12, 2016. Accessed January 16, 2020. http://colleyelevator.blogspot.com/2016/12/hydraulic-elevator-maintenance-cold.html

Enevold, D. 2020. Personal communication. 3/5/20.

Hafer, M. 2017. Quantity and electricity consumption of plug load equipment on a university campus. *Energy Efficiency* 10, 1013–1039. https://doi.org/10.1007/s12053-016-9503-2

Hafer, M. 2015. Inventorying Plug Load Equipment and Assessing Plug Load Reduction Solutions on a University Campus. Stanford University, Stanford, CA. https://sustainable.stanford.edu/sites/default/files/resource-attachments/Plug%20Load%-20White%20Paper%20FINAL.pdf

U.S. Energy Information Administration (EIA). 2020. Annual Energy Outlook 2020 with projections to 2050. U.S. Department of Energy, Washington, DC. https://www.eia.gov/outlooks/aeo/

EIA. 2017. Analysis and Representation of Miscellaneous Electric Loads in NEMS. U.S. Energy Information Administration. Washington DC. https://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf

Energy Star. 2020. Flip Your Fridge Calculator. https://www.energystar.gov/index.cfm?fuseaction=refrig.calculator (Accessed 3/12/20)

Kaneda, D, B Jacobson, and P Rumsey. 2010. Plug Load Reduction: The Next Big Hurdle for Net Zero Energy Building Design. 2010 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, D.C., ACEEE.

Kandt, A, and R. Langner. 2019. Golden, CO. https://www.nrel.gov/docs/fy19osti/72028.pdf

Kwatra, S, J Amann, and H Sachs. 2013. Miscellaneous Energy Loads in Buildings. American Council for an Energy-Efficient Economy. Report A133. Washington DC. https://www.aceee.org/sites/default/files/publications/researchreports/a133.pdf

Lanzisera, et al. 2013, Methods for detailed energy data collection of miscellaneous and electronic loads in a commercial office building. *Building and Environment 65* (2013) 170-177. https://doi.org/10.1016/j.buildenv.2013.03.025

Meier, A., O Jahromi, and D Cautley. 2019. Real-Time Itemized Electricity Consumption Intelligence for DoD Bases. Lawrence Berkeley National Laboratory. September 2019. ESTCP Project EW-201335.

Nationwide Lifts. 2020. How to Keep Commercial Elevator Running During Cold Weather. Accessed January 16, 2020. https://www.home-elevator.net/info-keeping-commercial-elevators-running-cold-weather.php

Northern Illinois University (NIU). 2018. NIU Design and Construction Standards. Rev. 4/2018 - Elevators Div 14 2000. Accessed May 4, 2020. https://www.niu.edu/facilities/pdf/standards/Div-14-2000-Elevators.pdf

Sachs, H., H Misuriello, and S Kwatra. 2015. Advancing Elevator Energy Efficiency. American Council for an Energy-Efficiency Economy. Washington DC. Report A1501. https://www.aceee.org/sites/default/files/publications/researchreports/a1501.pdf

Sachs, H. 2005. Opportunities for Elevator Energy Efficiency Improvements. American Council for an Energy-Efficiency Economy. https://pdfs.semanticscholar.org/5332/82876691428fd5bd3179e26dc5e0896d04f2.pdf

Sullivan, G, R Pugh, A Melendez, and W Hunt. 2010. Operations & Maintenance Best Practices – A Guide to Achieving Operational Efficiency (Release 3.0). Pacific Nortwest National Laboratory. Richland, WA. PNNL-19634. www.pnnl.gov/main/publications/external/technical_reports/PNNL-19634.pdf

Sullivan, G, G Parker, and J Jenkins. 2004. Resource-Efficient Laundry Room Demonstration and Evaluation: A Holistic Approach to Maximizing Energy, Water and Cost Savings in Multifamily Laundry Rooms. 2004 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, D.C., ACEEE.

Thomas, A, M Shincovich, S Ryan, D Korn, and J Shugars. 2002. Replacing Distribution Transformers: A Hidden Opportunity for Energy Savings. 2002 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, D.C., ACEEE.

Appendix A – Metering Equipment

The energy monitoring equipment used for both the panel-level and device-level metering are described as follows.

A.1 eGauge Systems Commercial Energy Monitoring

Website: https://www.egauge.net/commercial-energy-monitor/#overview

The eGauge multi-channel energy meter (eGuage Pro) combines an energy meter, a data logger, and a web server into one packaged device. This combination allows measurement, storage and retrieval of data directly from the device or from a remote location. The meter calculates power and other metrics including Volts, Amps, VAR/kVAR, Watts and kWh.

The eGauge Pro reports 0.5 percent revenue-grade accuracy compliance and the ability to measure residential or commercial circuit panels, up to three-phase 277/480 VAC and 6900 amperes (A). It is ANSI C12.20 Revenue-Grade Accuracy Compliant. Current transformers, manufactured by Continental Controls and J&D Electronics, have accuracy ratings of 1 to 2 percent of load when measuring current levels of 10 percent of full load or higher.

Historical and real-time data can be downloaded and viewed for up to 30 years with the unit's web-based user interface (UI). The UI can be accessed on a local network or via the internet from a computer, tablet, or smartphone. Once connected, access is gained to real-time values or long-term reports through graphical interface.

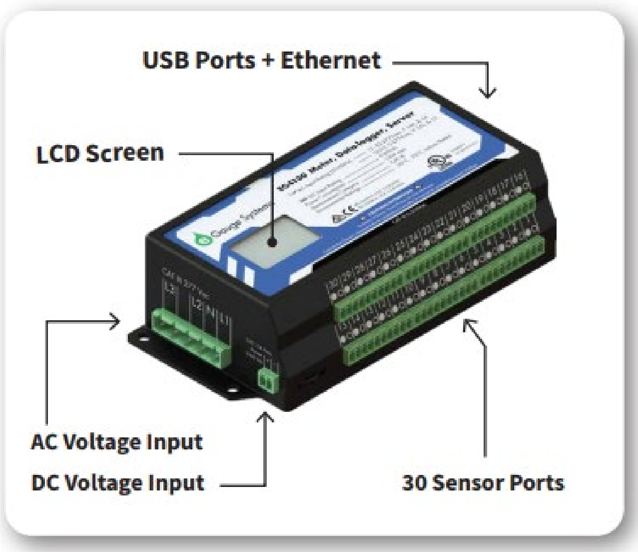


Figure A.1. eGauge Pro Data Logger

Figure A.2. eGauge Pro Typical Split-Core Current Transformers

Figure A.3 eGauge Data Logger and Cellular Modem Mounted within Enclosure

eGauge Pro Specifications

Measurement
AC Voltage – single and three-phase measurements
L1: 85-277 Vrms
L2: 0-277 Vrms
L3: 0-277 Vrms

Current:
30 channels
5-6900A max per channel
Fully isolated inputs

Frequency: 50 or 60 Hz

Logging Values: Volts, Amperes, Watts, Watt-hours/Kilo Watt-hours, Frequency (hertz), Volt-amps, Volt-amps reactive, Total Harmonic Distortion

Data Logger Capacity
Register Count: 64 (data storage points)
Granularity: 1 second to 1 hour
(duration/avg)
1 year/1 minute
10 yrs/15 minute
Device Lifetime/1 Day

Safety and Regulatory
Safety: IEC/UL 61010-1 Ed. 3.0 B:2010
CE: IEC 61000-6-1 Ed. 3.0 B:2016
IEC 61000-6-3 Ed. 2.1 B:2011
FCC: FCC Title 47 CFR Part 15-Subpart B Class B
ICES-003 Information Technology Equipment Class B

Communication
To assure reliable communication a stand-alone cellular protocol was used. Each eGauge Pro made use of MultiTech cellular modem and T-Mobile data plan for communication, access, and downloading data.

Figure A.4. MultiTech Cellular Modem

A.2 Ibis Networks Commercial Plug Load Monitoring

Website: https://ibisnetworks.com/[1]

The Ibis Networks commercial plug load monitoring system is designed for the monitoring and control of a variety of plug load equipment at the enterprise level. The system monitors energy use, power, voltage, current of plug load devices every 15 seconds. InteliSockets are installed between the equipment to be monitored and the electrical outlet. These gather energy data on the monitored device and transmit it to the InteliGateway via a secure Zigbee Pro wireless mesh. The InteliGateway connect to an external network to transmit data collected from the InteliSockets to the InteliNetwork for data storage, download, and reporting. Photos of the key components are presented in Figure A.5. Characteristics of the hardware components are as follows:

InteliGateway™

- ZigBee Pro Coordinator
- 128 bit AES Security
- 17dBm RF Power
- RoHS Compliant

InteliSocket™

- UL certified
- ZigBee Pro
- 128 bit AES Security
- Surge Protected
- RoHS Compliant
- Multiple Configurations Available:
  - Single sockets
    - 120V 12A
    - 17dBm RF Power
  - Dual sockets
    - 120V 12A
    - Title 24 Part 6 Compliant
    - Built-in load-sensing control capability
  - High power sockets
    - 120V 20A
    - 240V 15A
    - 240V 20A

[1] Ibis Networks recently rebranded as WattIQ (https://wattiq.io/)

Figure A.5. Components of the Ibis Networks Plug Load Monitoring System (top left: InteliGateway; top right: dual InteliSocket; bottom left: single InteliSocket; bottom right: 20-amp InteliSocket)

Communication

To assure reliable communication a stand-alone cellular protocol was used. Each Ibis InteliGateway was connected to a MultiTech cellular modem with a T-Mobile data plan for communication and transfer of collected energy data to the InteliNetwork for data storage, reporting, and download.

Appendix B – Methodologies for Estimating Plug Load Energy Consumption

A core focus of this study was to estimate the aggregate energy consumption from plug-load devices and hardwired MELs. Several approaches have been evaluated and applied for estimating annual plug-load energy use, including a bottom-up approach based on 1-minute metered energy use data from individual devices, to top-down methods using building and panel interval meter data including 15-minute whole building MDMS data, 1-minute whole building data from the EMCS, and 1-minute data from select electrical panels, sub-panels, and circuits that were metered as part of this study.

Not every building is amenable to all types of methods because of such things as the quality of available MDMS and EMCS data, electrical wiring and panel locations and circuits that are amenable to metering, etc. Different approaches are applied to better estimate the energy consumption from plug loads rather than relying on a single method without validation. Additional benefits may be gained by estimating how well a given method may perform relative to cost. For example, better understanding how well such loads can be estimated using MDMS data, compared to metering at the main distribution panel, specific circuits, and/or the device level, may help highlight some potential new uses for that data, as well as when additional metering may be warranted. A summary of each approach is described here.

B.1 Bottom-Up Approaches

Two similar bottom-up approaches to estimate the annual consumption of plug load and MEL devices are applied in this study. The preferred approach follows the results from device-level metering that was used in four of the study buildings. A consumption-by-proxy approach also was applied in two of the study buildings where device-level metering was either not performed or is of questionable accuracy based on it not representing the breadth of equipment types and use present.

B.1.1 Device-Level Metering

The primary bottom-up methodology for estimating a building's energy consumption from plug loads and MELs relies on building up loads and energy use from a representation of the surveyed diversity of plugged-in and hardwired devices within the building. This approach therefore relies on device-level as well as select circuit-level metering of specific equipment. The process applied in this study is as follows:

- *Sample size:* Based on the equipment inventory, diversity of use, and desired confidence (as discussed in Section 4.1.1), identify the target sample of devices to be monitored.
- *Device selection*: Randomly select devices for installation of device-level monitors, capturing a mix of space types (i.e., shop, open office, private office, meeting rooms, etc.), applications, and level of use. In some instances, device selection was influenced by accessibility for installing the meters and was therefore not completely random, but efforts were made to capture devices that were located in a variety of space types and that represented the range of likely applications within each building.
- *Monitoring duration*: Findings reported by Lanzisera et al. (2013) suggest that for device types with limited variability in a typical office building, a metering duration exceeding a few months provides little improvement in estimating annual energy use. The typical duration

of monitoring with the Ibis system was approximately 18–22 weeks in each building (as shown previously in Table 10). The monitoring period for this study was extended to capture some of the additional variability anticipated in Army facilities but also to fit with site travel and access logistics. Additionally, a small percentage of devices were monitored for shorter periods of time due to staff and device moves, and occupants plugging new equipment into the meters. The load signatures for each device were frequently evaluated to identify changes and document anomalies so that the new devices could be identified and tracked separately and the data for each device could be maintained without interference from other devices. These changes were also confirmed by interim visits to the buildings and during the removal of the meters.[1] Data for the few devices monitored for less than 4 weeks were excluded from the analysis, except for select devices with consistent loads (e.g., select phones, workstation UPS devices).

- *Energy consumption calculation*: For each metered device having at least four weeks of reliable data, the 1-minute interval power data captured over the monitoring period was converted into energy consumption for the period. The electricity consumption for the study period was then extrapolated to annual kWh, and averaged across all monitored devices of that type, resulting in the mean annual unit energy consumption (AUEC) for each type of device. The AUEC can then be multiplied by the total inventory of those devices in the building to reach an estimate for annual energy consumption (EC_{total}), in kWh/yr. These calculations are described by Equations (1–3).[2]

$$MEC_d = \left(\frac{\sum_{t=0}^{m} power_d}{60 \times 1000}\right) \tag{1}$$

$$AUEC_{mean} = \frac{\sum_{d=1}^{n}\left\{ MEC_d \times \frac{525{,}600}{m_d}\right\}}{n} \tag{2}$$

$$EC_{total} = AUEC_{mean} \times devices_{total} \tag{3}$$

[1] Challenges with new devices being plugged into select meters were experienced in all but one of the study buildings that were metered. This was most commonly the result of occupants returning from the field and inadvertently plugging devices (e.g., laptops) back into a different meter and in one building the result of select office moves. However, such occurrences overall were minimal, and we found that occupants were remarkably diligent about using the meters and maintaining and returning equipment to the correct plug upon return.

[2] This approach works best for devices with a good sample size, a good representation of use and load characteristics within the monitored sample, and minimal seasonal variation in load. For devices that exhibit strong seasonal use and load variation (e.g., personal space heaters) the monitoring period energy use was extrapolated using a ratio of the heating degree days (HDD) coinciding with the use of the space heater during the study period, to annual weekday HDD. Because the use of space heaters is driven by a number of variables (including weather conditions, efficacy of building conditioning systems, perceived comfort by occupants, and other factors) and because the device-level monitoring of three buildings occurred outside of the core heating season, the reasonable extrapolation of use and electricity consumption from the metered data to an annual estimate results in greater uncertainty than for other devices that operate more uniformly throughout the year.

where MEC_d = monitored energy consumption for device d, over the monitoring period, kWh
d = device
t = time duration of monitoring for device d
$power_d$ = power of device d at time t (watts)
n = number of monitored devices, d, of a given type
60 = minutes per hour
1000 = watts per kW
$AUEC_{mean}$ = mean annual unit energy consumption for a type of device, kWh/yr
$525{,}600$ = minutes per year
m_d = duration of monitoring for device d (minutes)
$devices_{total}$ = total number of devices (total population) of this type inventoried
EC_{total} = total energy consumption over all devices of this type, kWh/yr

B.1.2 Consumption by Proxy

Rather than relying completely on device-level metering, a consumption-by-proxy approach provides an estimate of annual MEL electricity consumption by applying unit energy consumption (UEC) values for equipment calculated in other buildings, to the detailed device inventory of the building in question. In the COF, no metering was performed; therefore, an estimate of MEL consumption was made by applying calculated UEC values from similar devices in other buildings to the results from the device inventory of the COF. Similarly, even though device-level metering was deployed in the BN HQ, the team realized that it did not capture the most representative mix of devices across some categories. Therefore, in an attempt to improve the resulting bottom-up estimation of plug load and MEL consumption, a consumption-by-proxy approach also was applied to select device types in the BN HQ, In both cases, a representative UEC for similar devices metered in other buildings was multiplied by the number of devices of that type in the building under evaluation to estimate the total annual electricity consumption for the inventoried population of those devices.

B.2 Top-Down Approaches

Top-down estimates of plug load energy consumption can provide a cost-effective approach to understanding, at least at a high level, the magnitude of MELs and the energy they consume, by analyzing existing data or acquiring a limited amount of new data. Results offered by top-down methods are also important for validating and appropriately bounding results of bottom-up estimates. A few top-down consumption estimation approaches have been examined and applied in this study, with the goal of evaluating and comparing the results to better understand tradeoffs between the level of accuracy and cost of acquiring more detailed data. Each of the top-down methods applies a similar approach, with the main difference being the resolution of the data used in the assessment (e.g., standard 15-minute MDMS data, 1-minute whole-building interval data, 1-minute MDP data, and select end-use panel data). A variety of these methods were applied in each of the study buildings, as the metering approach and availability of reliable MDMS and EMCS interval data allowed. The potential benefit to the Army from these top-down estimations are to provide a comparison of the improvement in accuracy and detail from more disaggregated data. Further, these top-down approaches provide a valuable method for both validating and bounding the results from the bottom-up estimations. In some cases, a mix of bottom-up and top-down methods were necessary to maximize understanding for the amount of metering that was determined to be feasible for specific buildings and loads. This hybrid approach is described further in the next section.

Nonintrusive load monitoring (NILM) is a process that has been under development to assist with load disaggregation through the monitoring a whole-building electrical feed. The concept applies machine learning to identify signature load patterns of select equipment and appliances to be able to identify when they are operating and track their electricity consumption by device and end use. The potential of NILM technology is to allow for the analysis of the main distribution load to provide disaggregated detail without costly and intrusive end use and device-level metering. Unfortunately, the vision for NILM has thus far outpaced reality, and test results have been disappointing. A recent demonstration under the DoD Environmental Security Technology Certification Program (ESTCP), evaluated a commercially available NILM technology within three facilities at Joint Base Lewis-McChord. The results suggest that the NILM technology is not yet ready for typical Army facilities, especially for smaller loads such as plug load devices, and failed to identify a reasonable number or diversity of equipment outside of a few major loads (Meier et al. 2019).

At the whole-building level, and with limited access to end-use MEL operational data, disaggregating MELs for this study makes use of a “minimum-load process” approach. This approach uses daily whole-building kilowatt profiles that are reviewed to identify a “profile minimum.” This minimum is assumed to encompass the building’s always-on loads, the majority of which are typically made up of MELs. Acknowledging that this is an approximate order-of-magnitude approach for estimating MELs and is not ideal for higher-accuracy MEL assessments, it can however be useful for developing top-down MEL estimates for building-type comparisons or to set ranges of estimated MEL usage. When using this method, it is recommended to have at least one complete year of building electricity use data available for comparison and, importantly, for calculating the MEL percentage of total electricity use.

This metric, along with other common building/system operating information, can be used to validate the MEL estimate. For example, in a building with mainly process loads, multiple shifts, and few MELs, one would expect to see this MEL contribution to total building electricity consumption to be rather low, perhaps in the 5%–10% range. Conversely, if the building is a commercial admin-style facility with higher populations of computers, monitors, printers, and other office devices, this MEL percentage may range from 20% to as high as 40% or 50% in otherwise efficient buildings. Common sense becomes the best guide and can be used to determine reasonableness of the estimate and predicate the need to better understand the building (or supplement the collected data) before reporting estimated MELs.

At the 15-minute interval, two MEL estimation processes were applied using available MDMS data. Additional approaches using 1-minute interval whole-building data captured from the Fort Carson EMCS and select project-installed metering were applied, and each approach is described in the following sections.

B.2.1 Whole-Building Interval Data: Annual Always-On Load

This estimation approach is the simplest, requires the lowest resolution of data and analysis, and can be applied using available 15-minute MDMS interval electricity data.

- Acquire and quality assure available interval electricity data and convert if necessary to kilowatts. At least 9 months of data is preferred, if available, to capture a mix of summer, winter, and shoulder season loads.
- Examine a representative winter, summer, and shoulder period.

- Review representative daily profiles for weekdays (workdays) vs. weekend days (non-workdays).
- Review occupied (typically daytime) hours vs. unoccupied (typically nighttime) hours.
- Identify the lowest (global minimum) load greater than zero. This represents a first-cut estimate at the always-on miscellaneous electric load.
- Estimate annual electricity consumption by MELs by multiplying this value by 8760 hours per year and 1 minus a diversity factor of approximately 20%, to account for unknowns such as a portion of the base load contributed by non-MELs, as shown in Equation (4).[1]

$$MEL_{ann} = load_{min} \times 8760 \times (1 - diversity) \quad (4)$$

where MEL_{ann} = estimated annual consumption by MELs, kWh/yr
$load_{min}$ = minimum observed building load, kW
8760 = hours per year
$diversity$ = diversity factor

B.2.2 Whole-Building Interval Data: Seasonal Always-On Loads

The next set of top-down energy consumption estimation follows the same general process and can be applied with a variety of available interval-data resolutions (e.g., 15-minute MDMS, 1-minute total building load data). This approach is not as prescriptive as the method described above. It takes some skill and understanding of building system behavior and the resulting load patterns:

- Acquire and quality assure available interval electricity data and convert if necessary to kilowatts. At least 9 months of data is preferred, if available, to capture a mix of summer, winter, and shoulder season loads.
- Examine a representative winter, summer, and shoulder period. While the representative heating and cooling seasons highlight the peak HVAC periods, the shoulder season when HVAC-related loads should be relatively low is usually most insightful. Depending on location, this often includes the March/April and September/October time periods but can be determined more accurately from outside temperature or HDD and cooling degree day data for the location. For each season:
- Identify representative daily profiles for weekdays (workdays) vs. weekend days (non-workdays)
- Review occupied (typically daytime) hours vs. unoccupied (typically nighttime) hours, comparing what the load data suggests against reported building operating hours.
- For each of these profiles, attempt to identify the following:
  - *HVAC loads*: Any electric heating or cooling, and fan operation (either cycling or continuous).

[1] An important caveat to this approach is that any always-on non-MEL load will be interpreted as part of the total MELs, so it is important to understand lighting and HVAC schedules. Additionally, MELs that vary with occupancy or other factors will not be fully captured with this method. These are reasons why the application of a diversity factor is important and the result from this approach provides an approximate, lower confidence estimate of MELs energy consumption.

- *Interior lighting*: Look for operating profile coinciding with known or expected building occupancy schedules. Watch for constant lighting load (a savings opportunity).
- *Exterior lighting*: Look for signature "inverted" profile based on known or expected exterior loads and schedules (may follow a timer, photocell, or astronomical clock).
- *Process/other loads*: Look for unexplainable loads, large demand spikes, abnormal patterns, and review building details and discuss non-standard loads with knowledgeable building contact.
- *Miscellaneous loads*: By default, the remaining unidentified loads are predominantly MELs.

- Based on the above information, identify the always-on load, and subtract any constant loads from fans and in some cases interior lighting. The remaining load provides an estimate of the MELs (typically in kW). Capture differences in this load by day type, reflecting variations in occupied and unoccupied days.
- Calculate the representative MEL load for each season, taking the weighted average of load values across occupied and unoccupied days.
- Estimate the annual electricity consumption for the building MELs by multiplying the resulting MEL value from each season by the number of hours falling within that season, summing the results, and applying a diversity factor, as shown in Equation (5).

$$MEL_{ann} = \left(\sum_{s=1}^{4}\{load.MEL_s \times hrs_s\}\right) \times (1 - diversity) \tag{5}$$

where MEL_{ann} = estimated annual MEL consumption, kWh/yr
s = season (winter, spring, summer, fall)
$load.MEL_s$ = identified representative MEL load for season s
hrs_s = number of hours in season s
$diversity$ = diversity factor

The end use panel approach is similar to this whole building approach but takes advantage of additional detail from monitored sub-panels and specific circuits.

- Select panels to meter judiciously (depending on how the building wiring is configured) so as to either capture most/all plug loads or capture total panel loads plus non-MEL loads that can be subtracted from the totals in a metering by exclusion data post-processing.
- Acquire and quality assure interval electricity data from selected panels. At least 9 months of data is preferred, when feasible, to capture a mix of summer, winter, and shoulder seasons.
- If the metered loads are predominantly MELs, follow a similar process as described above.
- Assign a best estimate of connected load and scale by hours of operation multiplied times diversity by load type to estimate annual energy consumption.

B.2.3 Detailed End Use Panel and Circuit Metering

If the metering approach allows sufficient data to be captured at the end use level, total MELs can be isolated from other end uses and more directly summed and extrapolated to an annual estimate of electricity consumption. Depending on the layout of the electrical panels and loads, this can be accomplished directly if all MEL circuits can be metered. A variance of this approach, metering by exception can be applied to specifically subtract individual loads from a sub-panel that may otherwise serve MELs. This latter approach was successfully applied in the BN HQ, where all MDP breakers/sub-panels were metered as well as most non-MELs (e.g., small HVAC equipment, pumps, controllers, and other process loads) on the MEL-dominated panels. Once aggregated, the non MELs are subtracted from the MEL panels to determine the MEL total.

The process is therefore somewhat similar to the bottom-up approach described above, where total MEL electricity consumption is estimated by aggregating and extrapolating metered power and consumption data over the monitoring period to annual electricity consumption. This annual consumption is derived over the relevant circuits representing discrete and aggregate MELs and subtracting any non-MELs that are included. For seasonal loads such as those for electrical unit heaters, vestibule heaters, and heating water distribution pumps, the extrapolation to annual energy consumption was performed using a HDD adjustment based on the ratio of HDD over the monitoring period to the annual HDDs.

B.3 Hybrid Approach

A combination of some of these approaches is sometimes warranted depending on the level of data captured at the device and panel/circuit levels. A hybrid approach can be applied by combining elements of bottom-up and top-down methods in which both device-level and select panel meter data exists, but perhaps without complete coverage of loads for each. In this approach, load data from select panels and circuits can be compared with measured loads from the same panel or circuit and used to fill in gaps of missing data. This approach can be particularly useful to validate and estimate missing loads from an incomplete bottom-up approach, where not all plug loads were able to be captured at the device level. For example, this method was used for the TEMF, where a number of the shop plug loads were not feasibly monitored because of their distributed and highly mobile nature. Detailed device-level load data were therefore augmented with targeted panel and circuit load data to provide a robust estimate of loads that could not be reliably captured at the device level. Similarly, the loads on select panels were able to be more effectively disaggregated by removing known loads captured at the device level. By combining elements of the bottom-up and top-down approaches, such hybrid methods combine the best of both approaches to arrive at an estimate of annual MEL energy consumption that is more complete than either method could achieve alone, especially when data coverage from one or both methods may be incomplete. Again, the suitability of each approach is influenced greatly by the nature of the building, its wiring configuration and loads, and accessibility of specific devices and electrical panels to be safely and cost effectively monitored. Overall, the approach may be best categorized as bottom-up, even though it applies data from some aggregated loads from select panels.

Appendix C – Energy Use by Building and Category

Table C.1. Summary of MELs Annual Energy Use Density (kWh/ksf) by Building and Category

	Admin	TEMF	UEPH	BN HQ	COF	ALL
AV/Comm	172	72	4	89	10	39
Breakroom	659	182	107	215	164	195
Computing	960	114	-	640	136	204
Documents/Imaging	255	35	-	158	50	57
Laundry	-	-	537	-	-	240
Occupant Comfort	305	85	-	32	15	48
Shop Equipment	-	949	-	-	1	121
Facility Loads	58	255	33	736	181	166
UEPH Occupant Units	-	-	1,500	-	-	672
TOTALS	**2,410**	**1,690**	**2,180**	**1,870**	**557**	**1,740**

Table C.2. Summary of MELs Annual Energy Use Density (kWh/occupant) by Building and Category

	Admin	TEMF	UEPH	BN HQ	COF	ALL
AV/Comm	64	87	2	35	9	22
Breakroom	247	220	51	84	151	108
Computing	360	138	-	249	126	113
Documents/Imaging	96	42	-	62	46	31
Laundry	-	-	256	-	-	133
Occupant Comfort	114	102	-	12	14	26
Shop Equipment	-	1,147	-	-	1	67
Facility Loads	22	308	16	286	167	92
UEPH Occupant Units	-	-	715	-	-	371
TOTALS	**900**	**2,040**	**1,040**	**730**	**515**	**960**

Table C.3. Summary of Devices Counted, Metered, and Energy Use by Building

	Count	% Metered	Total Energy (kWh/yr)	kWh/KSF	kWh/Occupant
Admin	**394**	**55%**	**34,326**	**2,410**	**900**
Audio/Video / Communication	58	51%	2,446	172	64
Breakroom	44	78%	9,391	659	247
Computing	194	42%	13,684	960	360
Documents / Imaging	30	81%	3,634	255	96
Facility Loads	-	-	823	58	22
Occupant Comfort	68	43%	4,347	305	114
TEMF	**88**	**58%**	**30,660**	**1,690**	**2,040**
Audio/Video / Communication	6	92%	1,302	72	87
Breakroom	8	86%	3,299	182	220
Computing	25	77%	2,100	114	138
Documents / Imaging	6	100%	626	35	42
Facility Loads	-	-	4,623	255	308
Occupant Comfort	14	45%	1,534	85	102
Shop Equipment	29	59%	17,207	949	1,147
UEPH	**43**	**48%**	**139,280**	**2,180**	**1,040**
Audio/Video / Communication	1	100%	248	4	2
Breakroom	6	67%	6,855	107	51
Facility Loads	-	-	2,108	33	16
Laundry	36	50%	34,272	537	256
Occupancy Units	-	-	95,799	1,500	715
BN HQ	**227**	**34%**	**26,190**	**1,870**	**730**
Audio/Video / Communication	47	24%	1,095	89	30
Breakroom	21	38%	3,017	215	84
Computing	109	11%	9,258	661	257
Documents / Imaging	17	30%	2,217	158	62
Facility Loads	2	50%	8,558	237	59
Occupant Comfort	31	14%	444	32	12
COF	**126**	**0%**	**18,020**	**560**	**510**
Audio/Video / Communication	23	0%	332	10	9
Breakroom	16	0%	5,299	164	151
Computing	58	0%	4,410	136	126
Documents / Imaging	16	0%	1,617	50	46
Facility Loads	-	-	5,859	181	167
Occupant Comfort	12	0%	484	15	14
Shop Equipment	1	0%	23	1	1
Grand Total	**878**	**39%**	**248,480**	**1,740**	**960**

Appendix D – Box Plots of Device Electricity Use

The following box plots present the distribution of the annual unit electricity consumption values (UEC, in kWh per year) for a selection of monitored device types. These plots highlight the variability of the monitored energy consumption, resulting from variables such as equipment characteristics, application, use intensity, user behavior, and presence and use of power saving modes. Except as noted, these plots show the distribution of devices across all study buildings.

The key components of the box plots are as follows:

- Blue box: the box represents the interquartile range (IQR, 25^{th} – 75^{th} quartile) of values, or the middle 50% of consumption values for the sample of devices being evaluated, where n is the number of monitored samples for each device subcategory.
- Mean: the mean of the UEC values for the set of monitored devices is indicated by the center of the box.
- Median: the median UEC value for the group of monitored devices is shown as the green line.
- Min/Max: the minimum and maximum values (excluding outliers) are shown by the black lines above and below the box. The maximum is determined as the 75^{th} quartile value plus 1.5 times the interquartile range (max = Q3 + 1.5*IQR). The minimum is similarly: min = Q1 – 1.5*IQR.
- Outliers: any values that are outside of the min/max lines are shown as circles and highlight any devices whose UEC lies outside of the distribution for the other devices in the group.

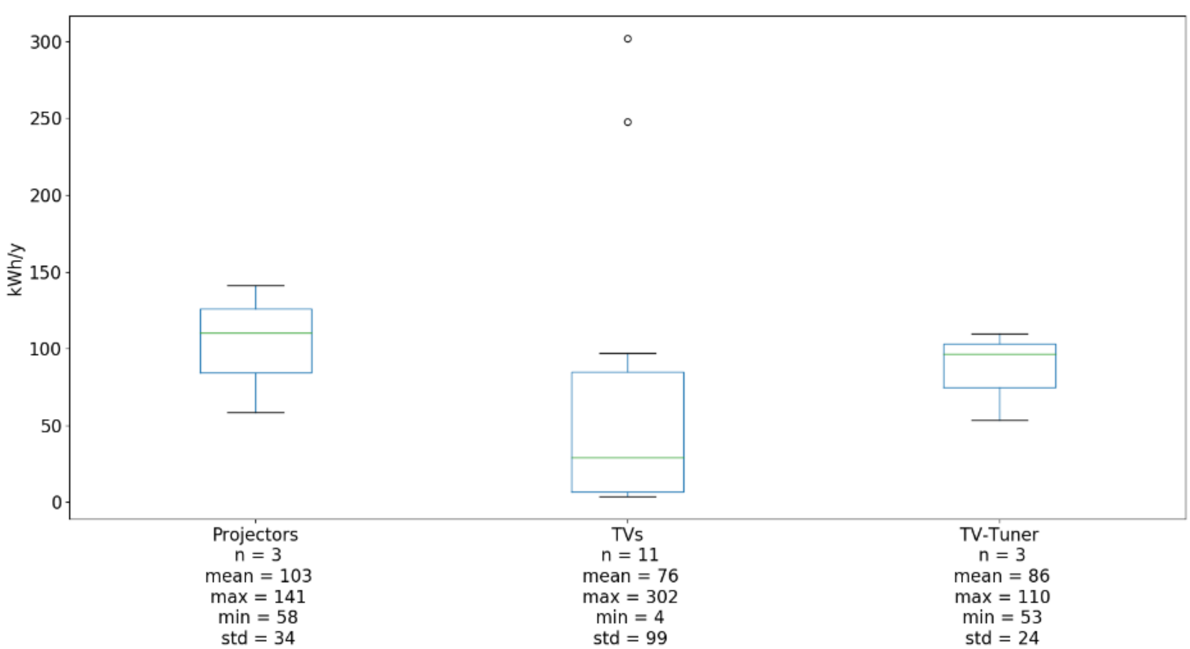


Figure D.1. Box Plot of Monitored A/V & Communication Devices Annual Electricity Consumption

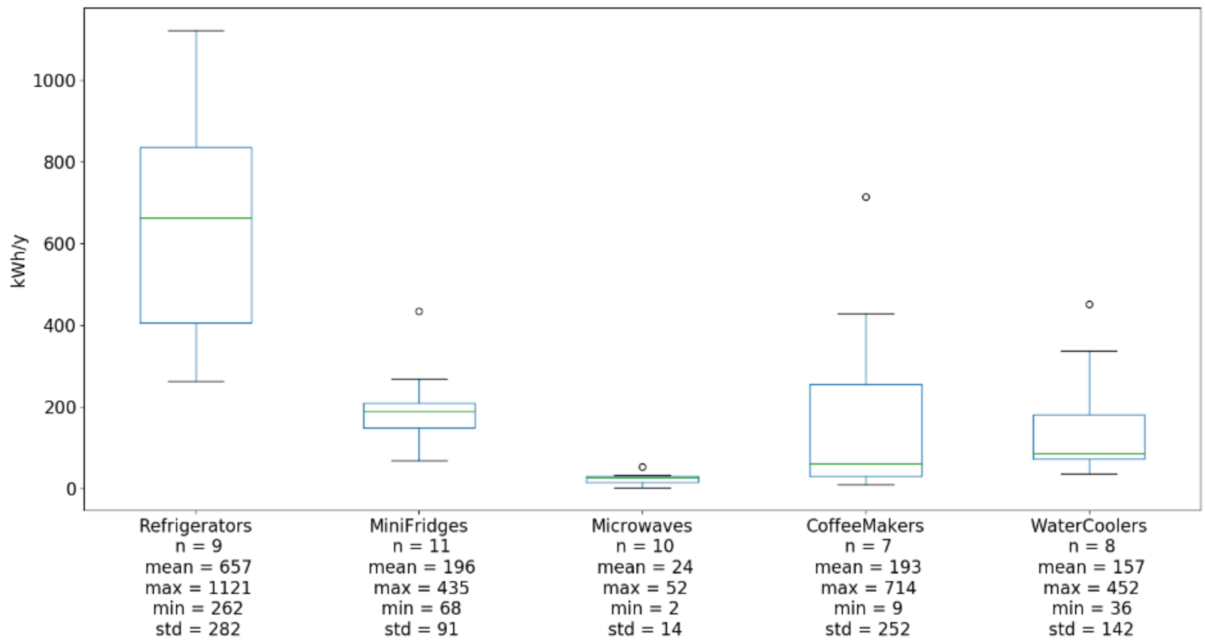


Figure D.2. Box Plot of Monitored Breakroom Devices Annual Electricity Consumption

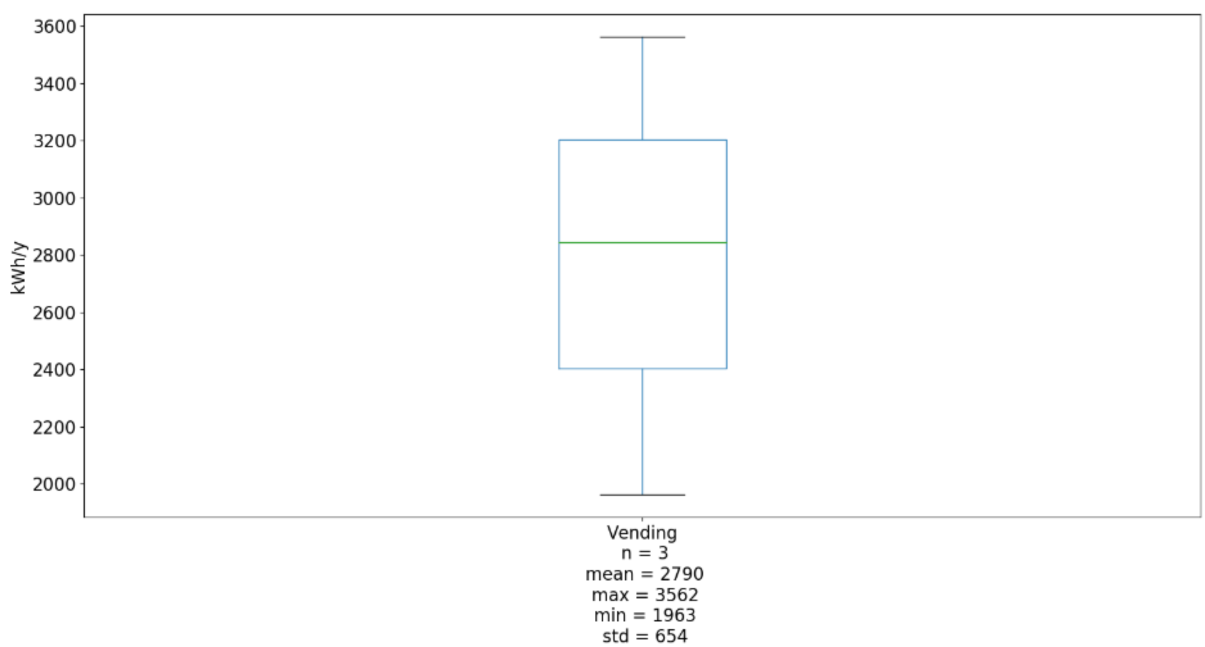


Figure D.3. Box Plot of Monitored Refrigerated Vending Machines Annual Electricity Consumption

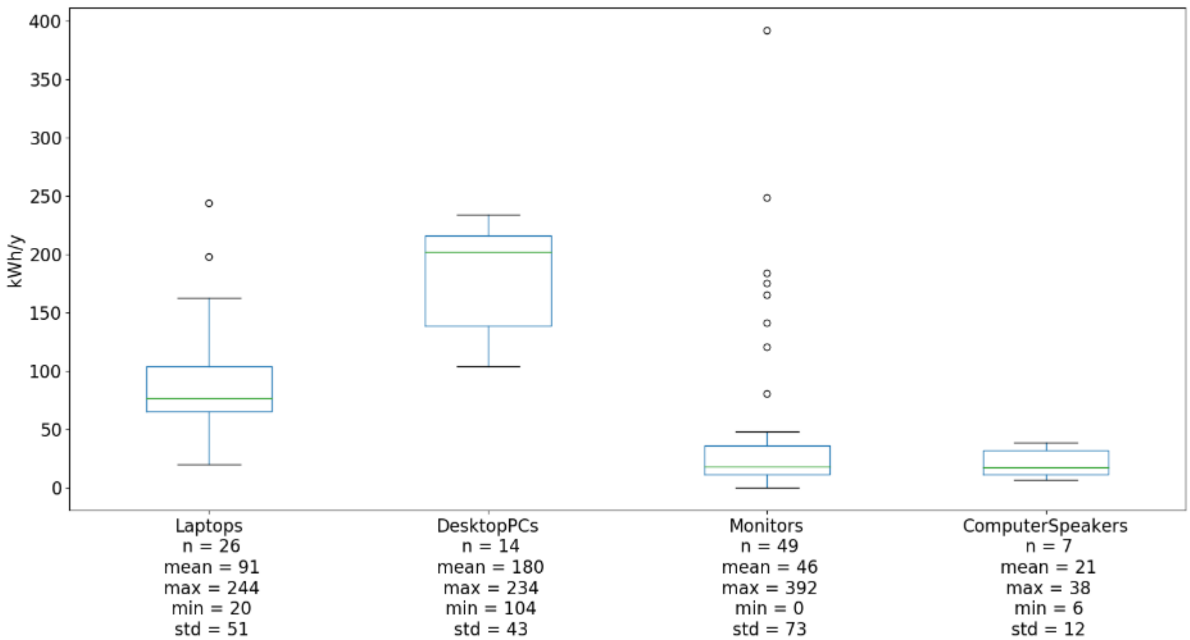


Figure D.4. Box Plot of Monitored Computing Devices Annual Electricity Consumption

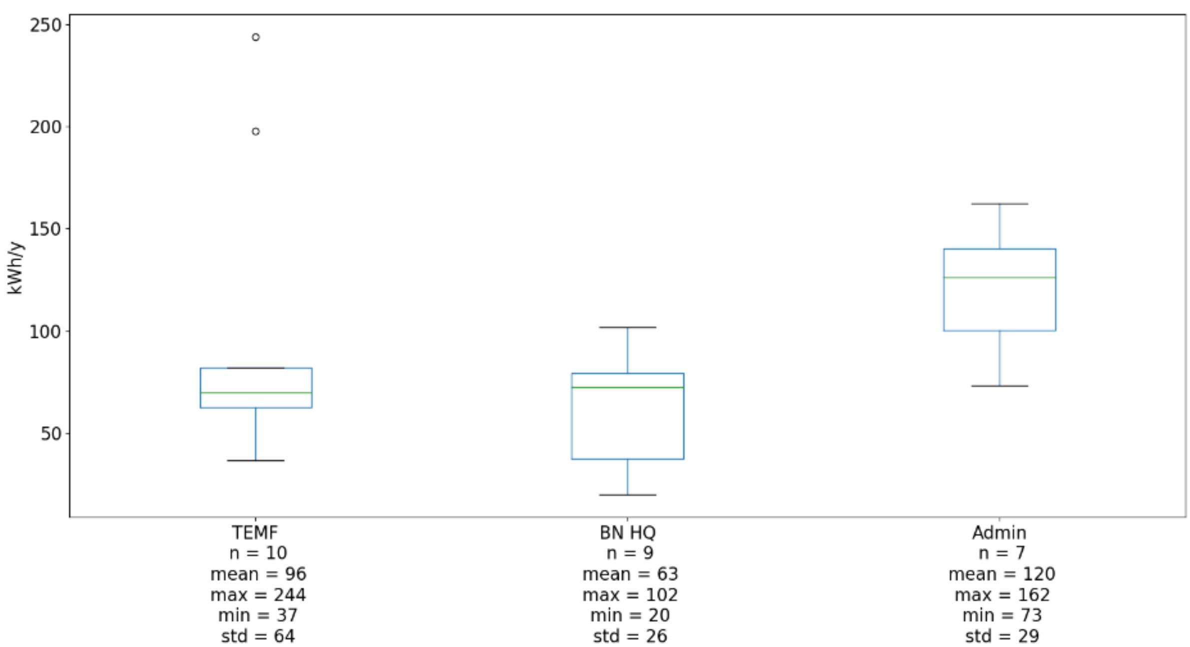


Figure D.5. Box Plot of Monitored Laptops Annual Electricity Consumption by Building

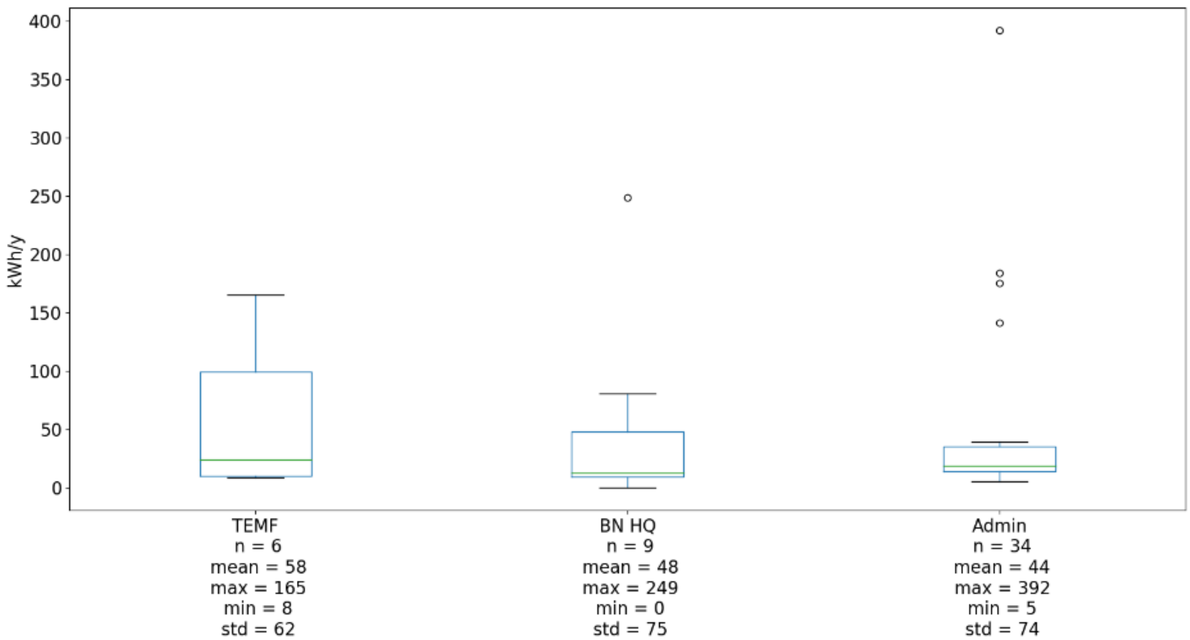


Figure D.6 Box Plot of Monitored Monitors Annual Electricity Consumption by Building

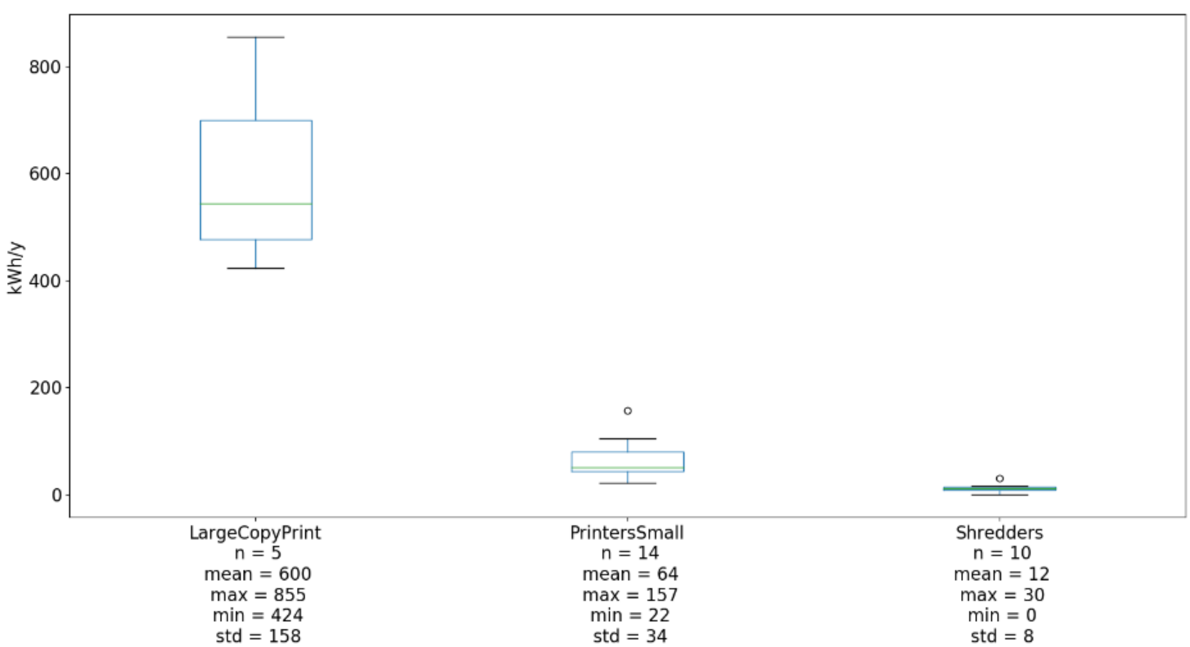


Figure D.7 Box Plot of Monitored Documents & Imaging Devices Annual Electricity Consumption

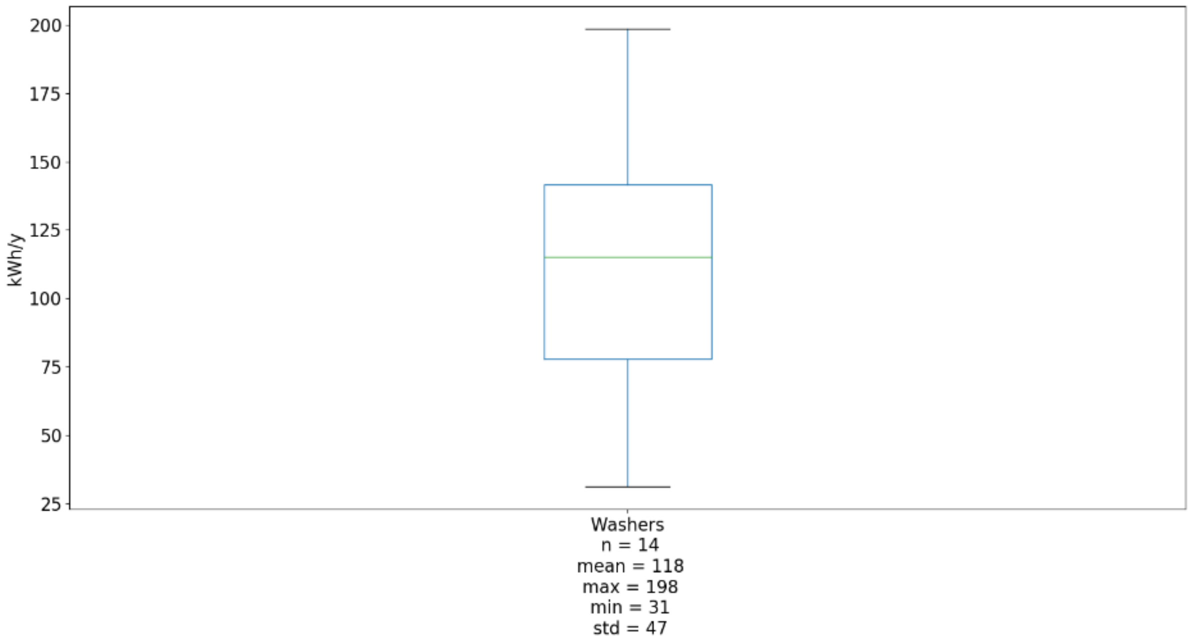


Figure D.8 Box Plot of Monitored Washing Machine Annual Electricity Consumption

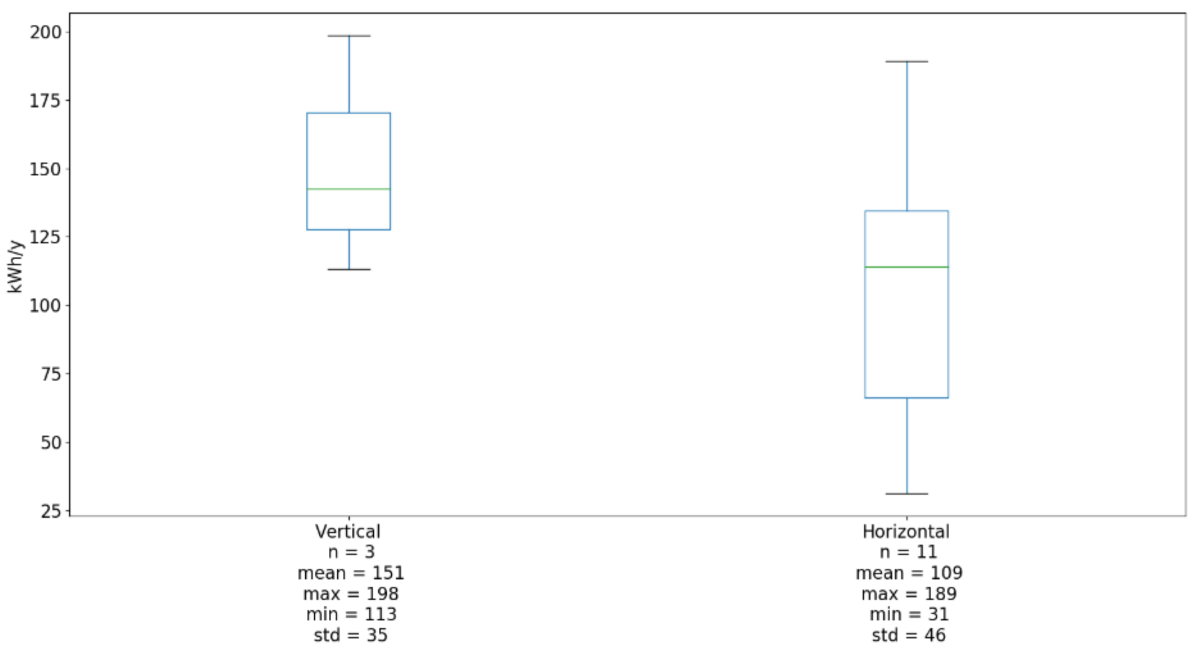


Figure D.9 Box Plot of Monitored Washing Machine Annual Electricity Consumption, by Washer Type (Vertical Axis vs. Horizontal Axis)

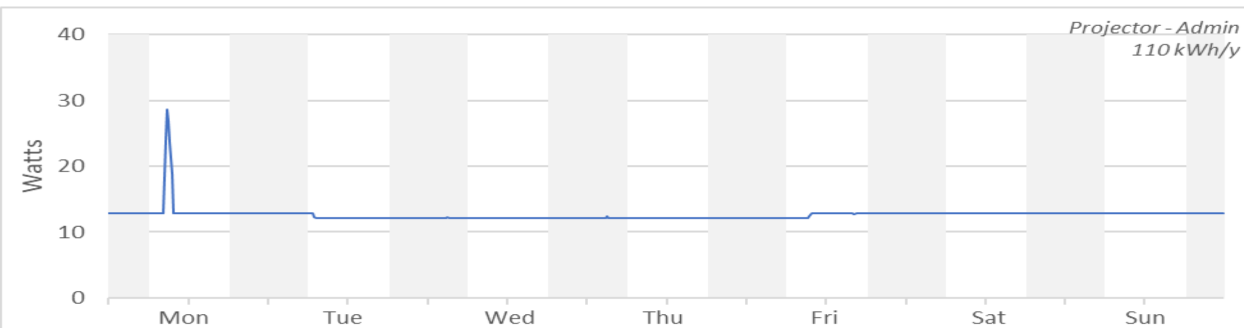
Appendix E – Load Profiles by Category

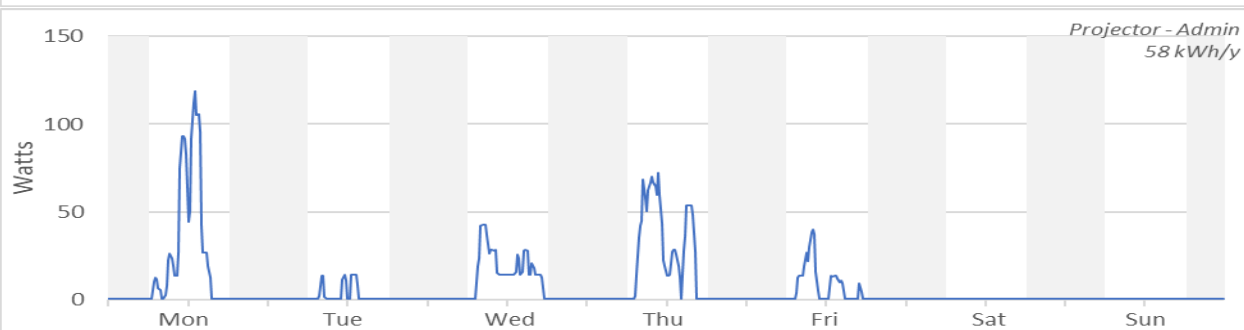
This appendix presents aggregate 15-minute weekly load profiles compiled from the monitoring of devices and select electrical panel circuits. Presented here are a subset of the data that were collected and compiled into these aggregate 15-minute interval weekly profiles, representing the behavior of each device or group of devices over a typical week. The grey bands on each chart highlight the nighttime hours of each day, from 6 P.M. to 6 A.M., with midnight at the center of each grey band. The white bands show the daytime hours (6 A.M. to 6 P.M.) with noon marked at the center. The devices presented highlight a subset of each type that was metered. Annual energy use is reported on each chart for the device or, for total profiles, the total estimated annual energy use for all devices in each building where any were monitored.

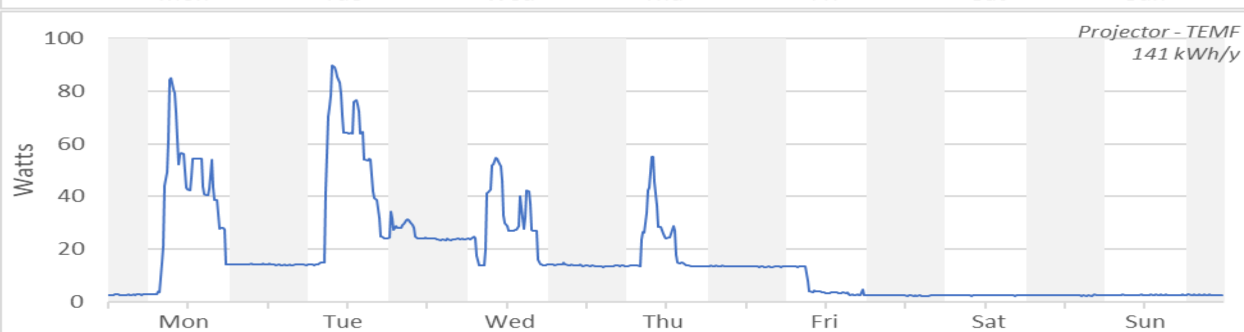
These profiles show average power by day type and time over the entire monitoring period. Depending upon the consistency of use, actual peak device loads can be much higher than shown by these profiles. The difference between daytime and nighttime loads is a strong indicator of the savings potential from improved plug load management.

E.1 Audio / Video & Communication

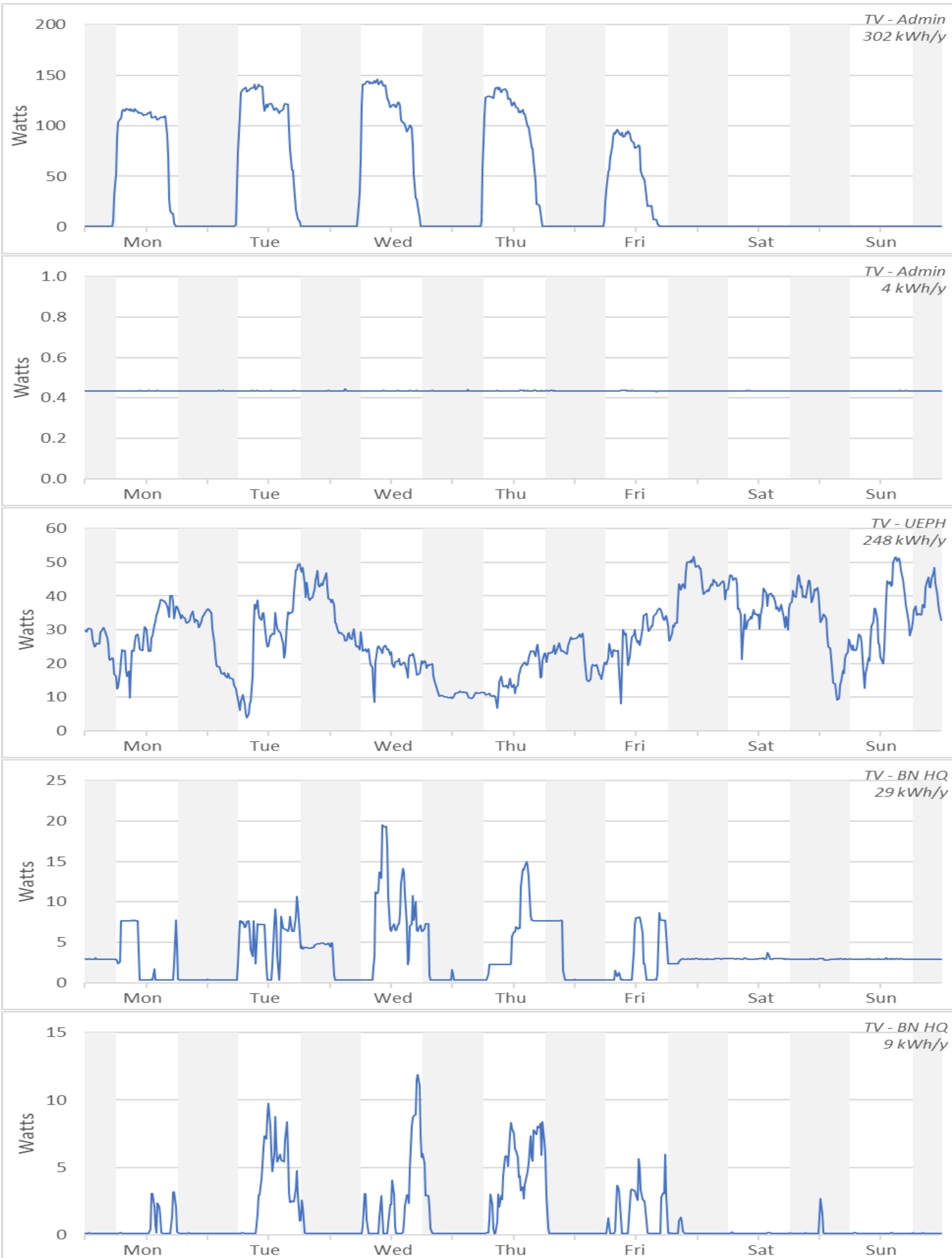
E.1.1 Projectors (Admin, TEMF)



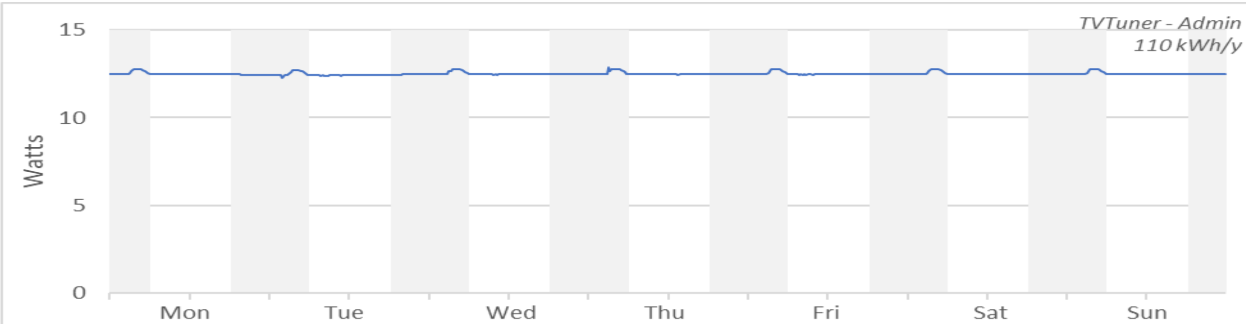


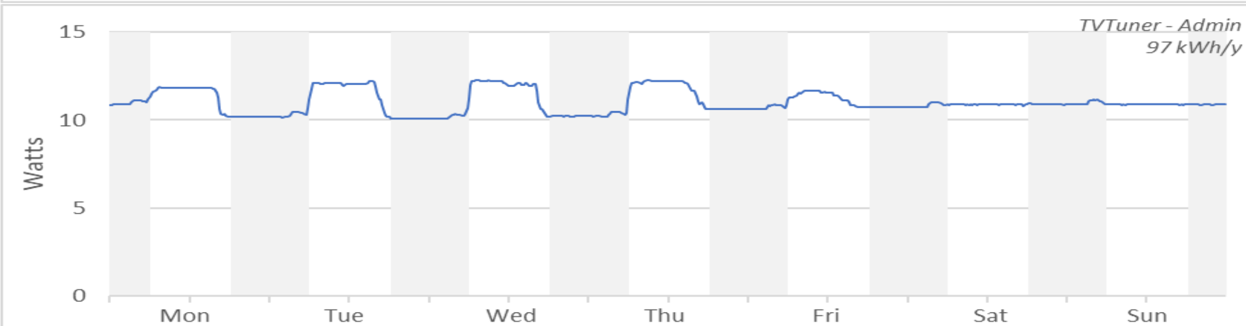


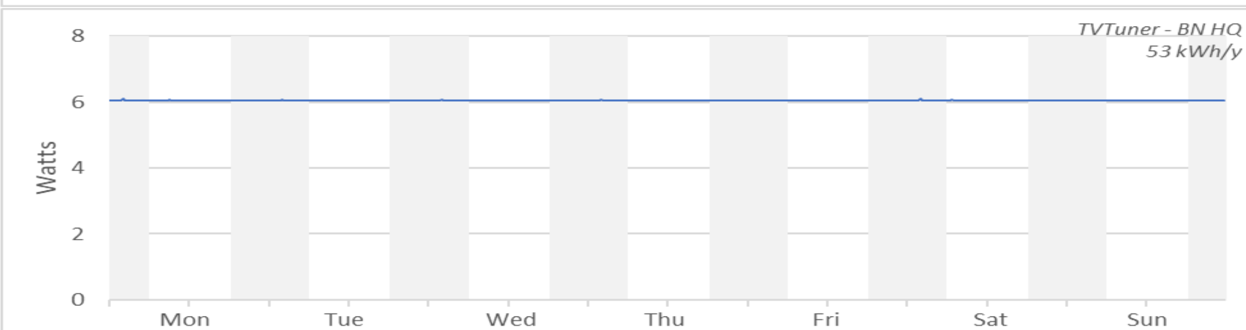
E.1.2 Televisions (Admin, UEPH Lobby, BN HQ)



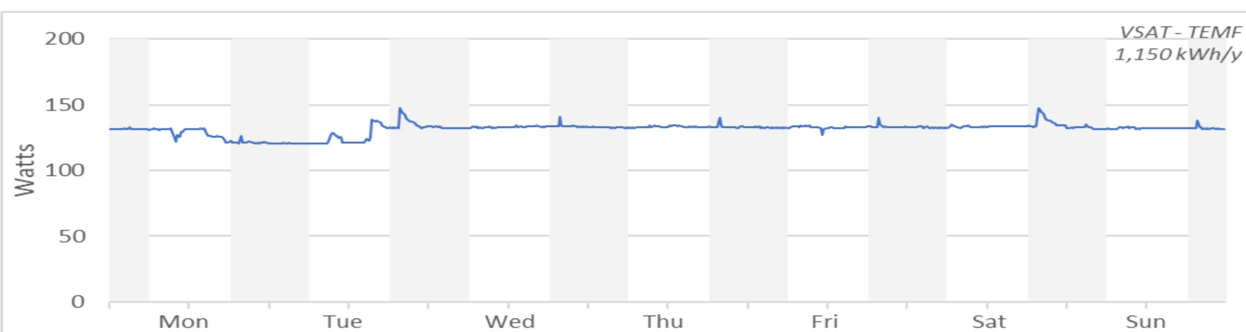
E.1.3 Television Tuners (Admin, BN HQ)





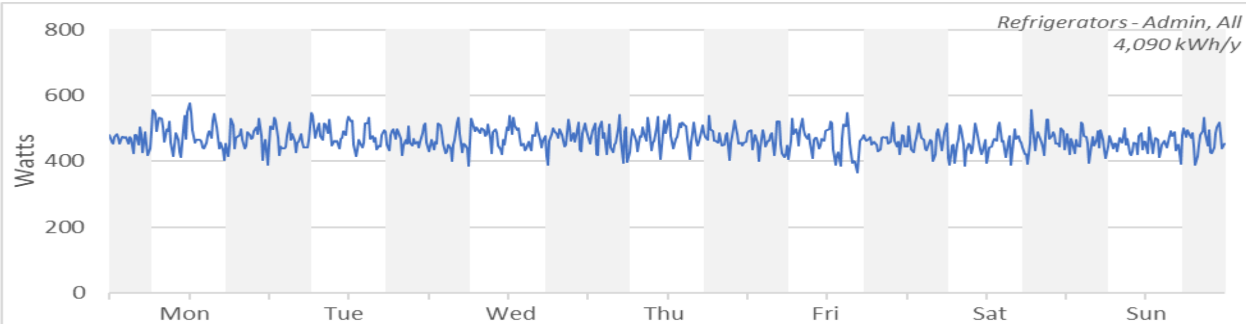


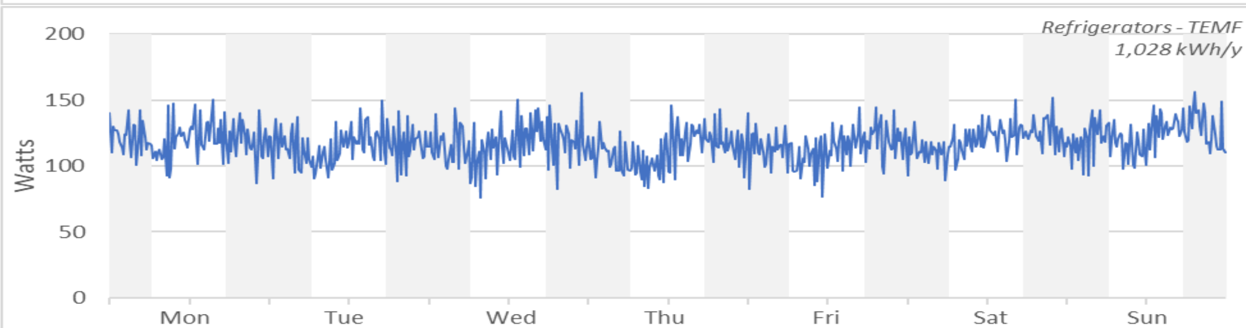
E.1.4 Communications Terminal (TEMF)

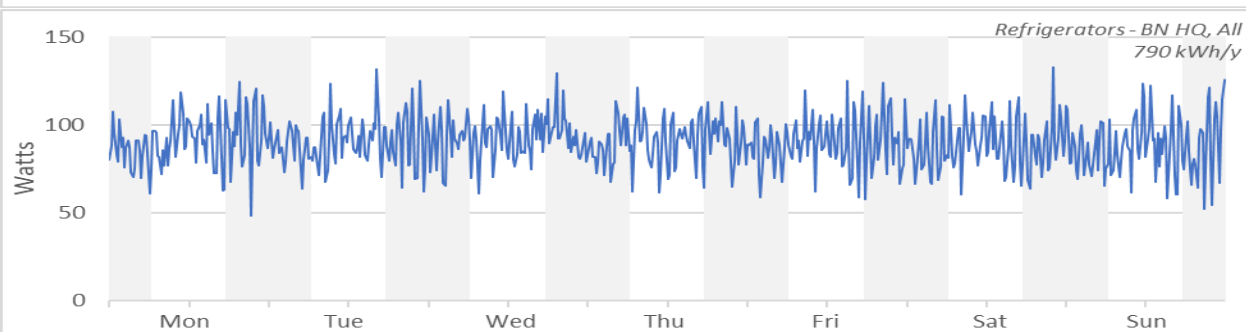


E.2 Breakroom Equipment

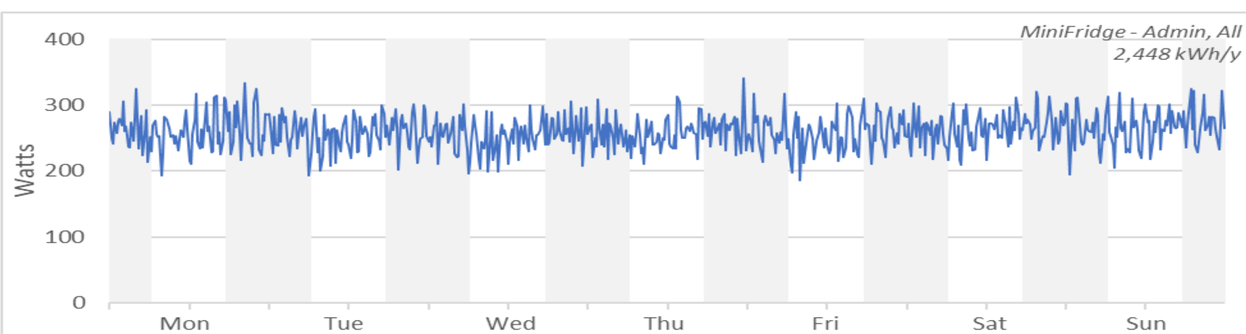
E.2.1 Refrigerators (Admin, TEMF, BN HQ)

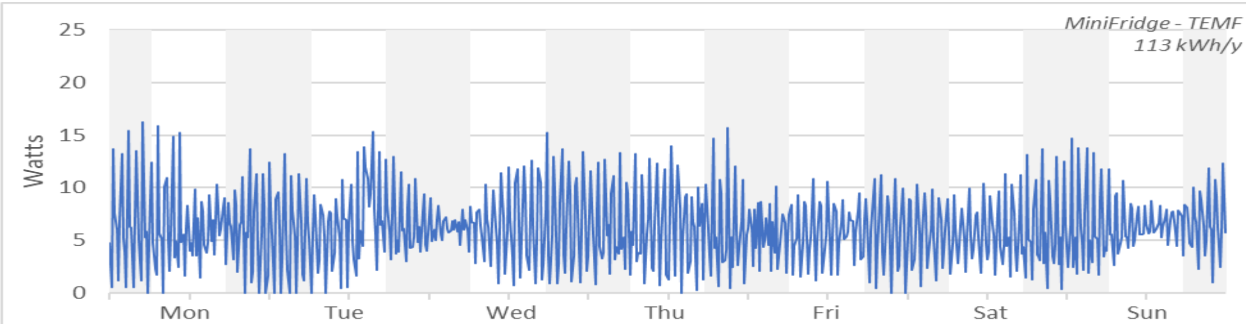


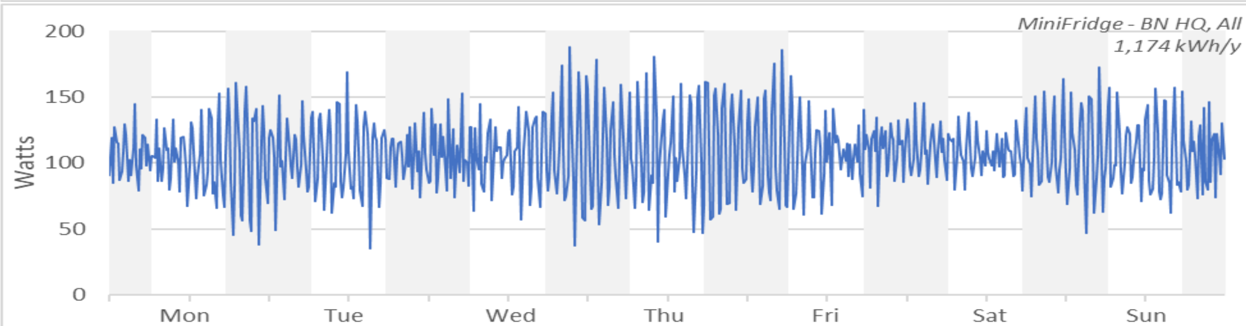




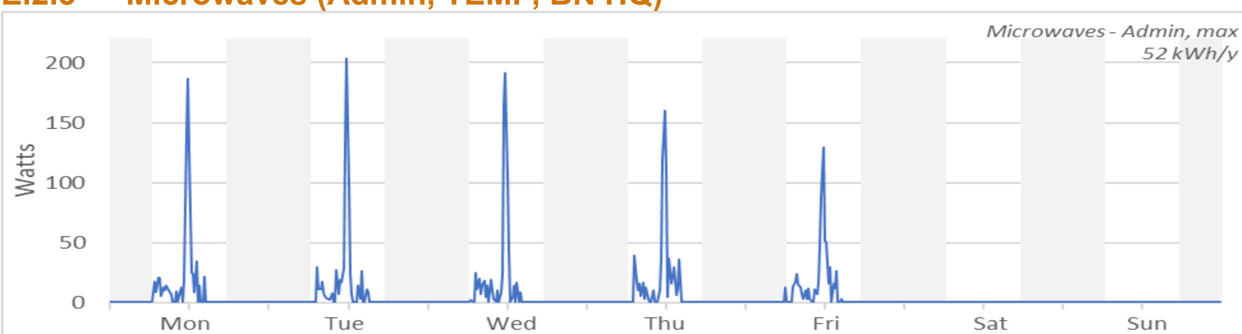
E.2.2 Mini-Refrigerators (Admin, TEMF, BN HQ)

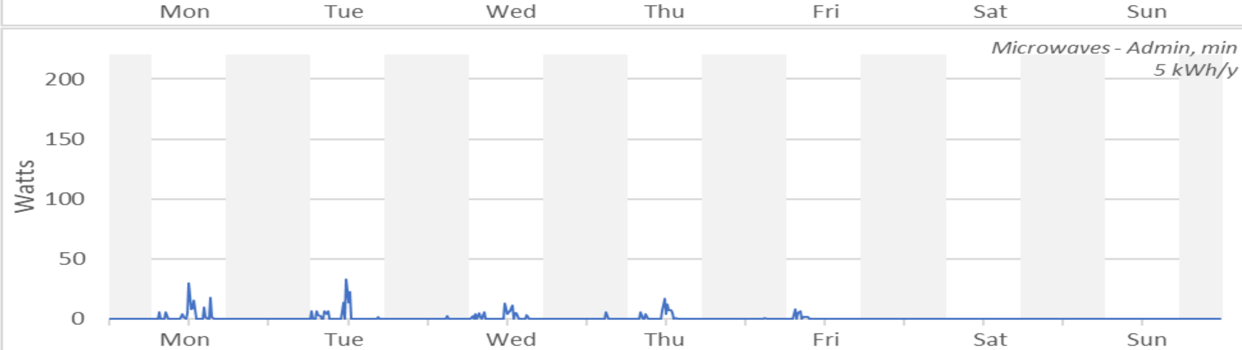


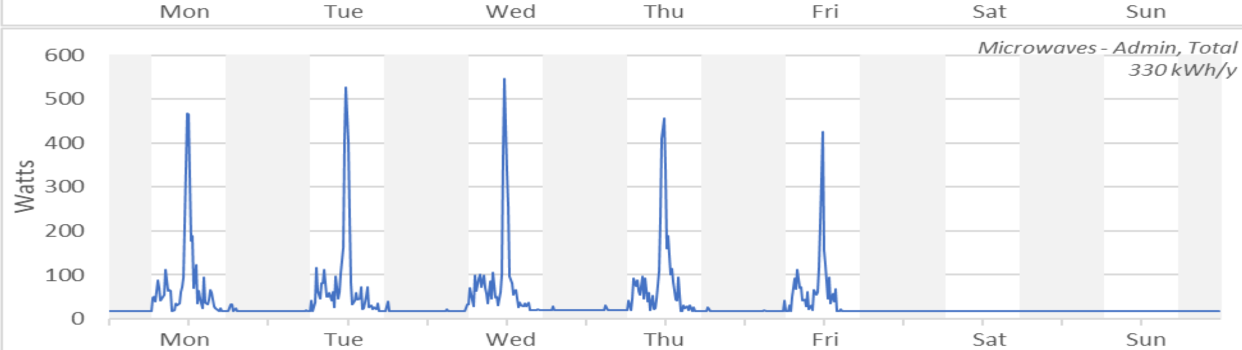


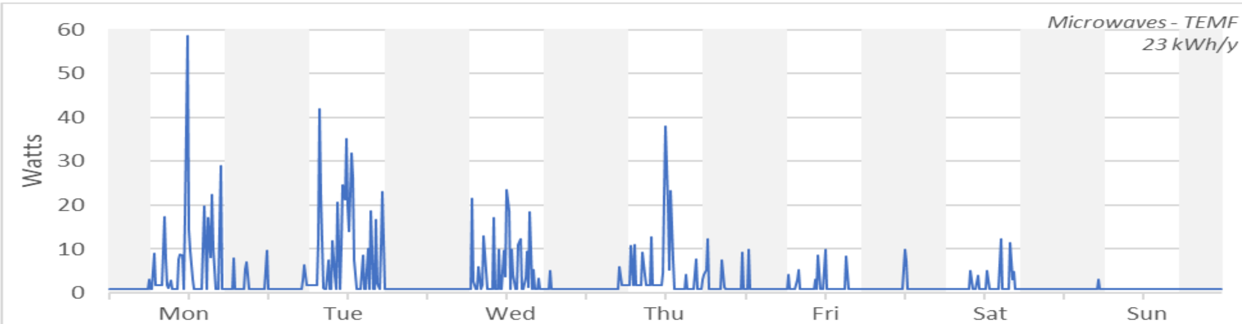


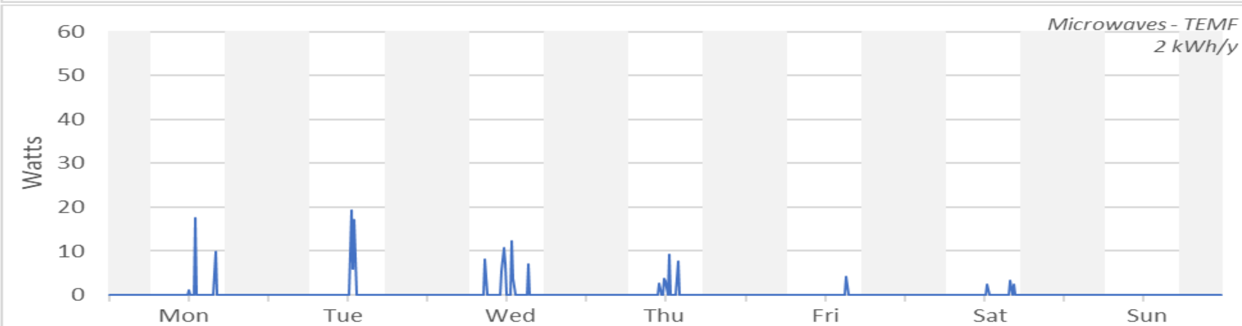
E.2.3 Microwaves (Admin, TEMF, BN HQ)

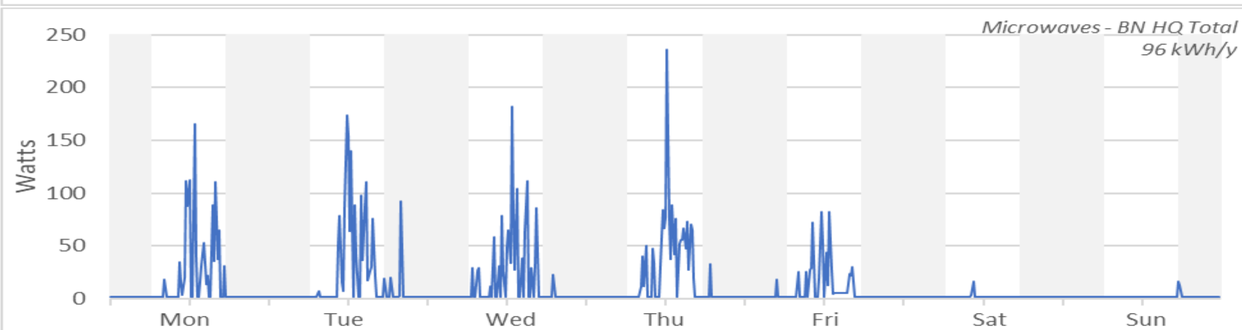




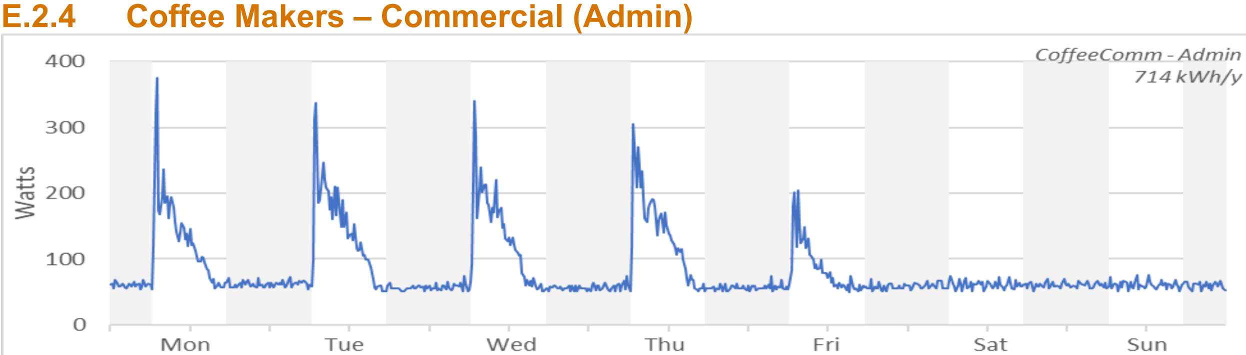


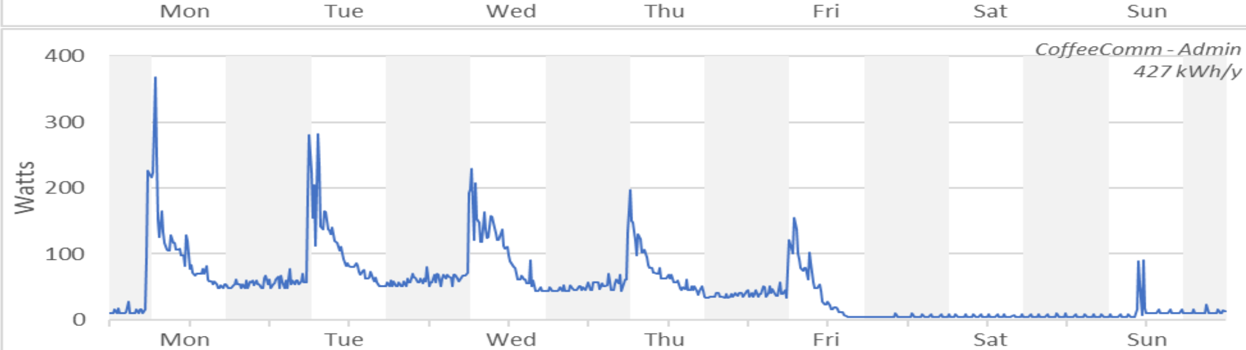




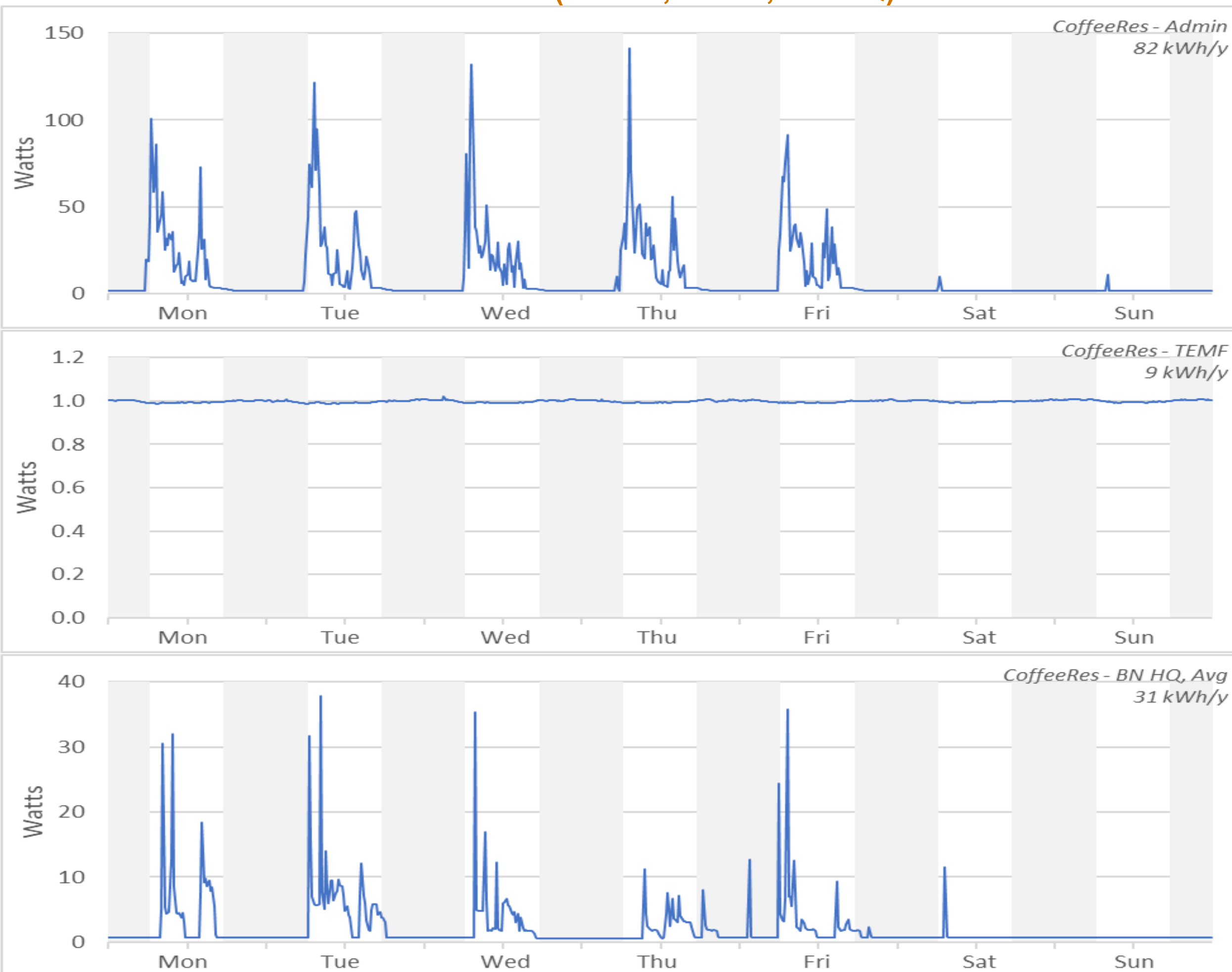


E.2.4 Coffee Makers – Commercial (Admin)

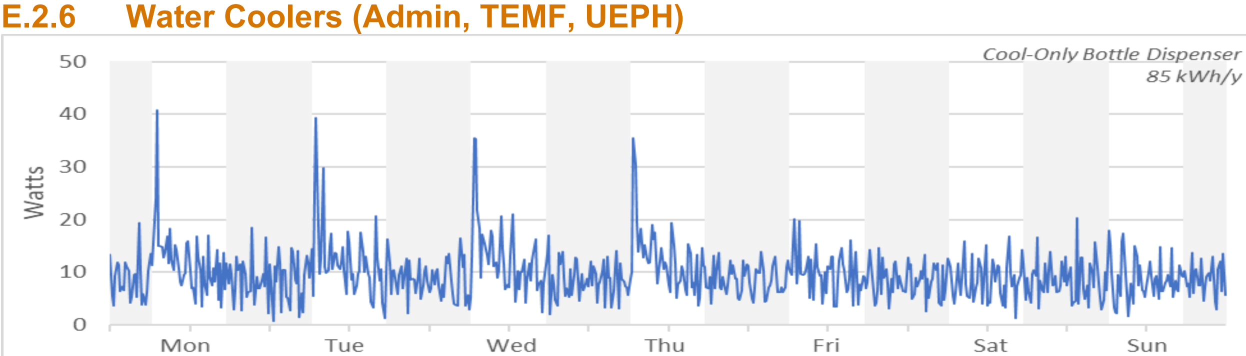


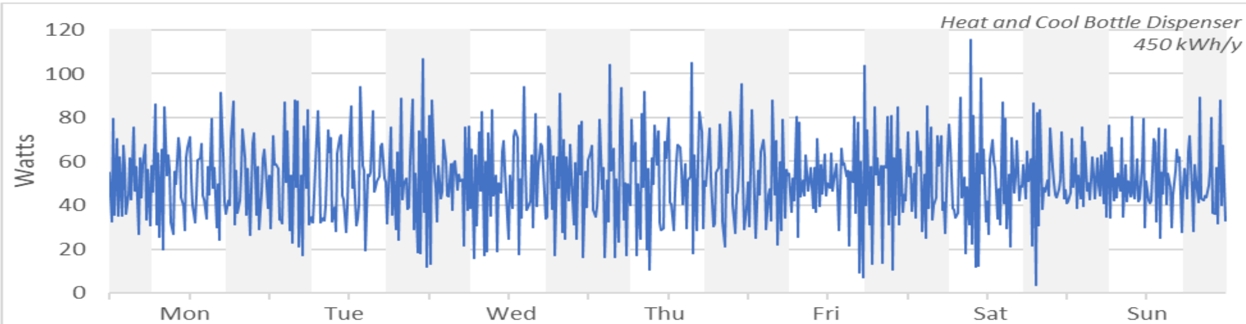


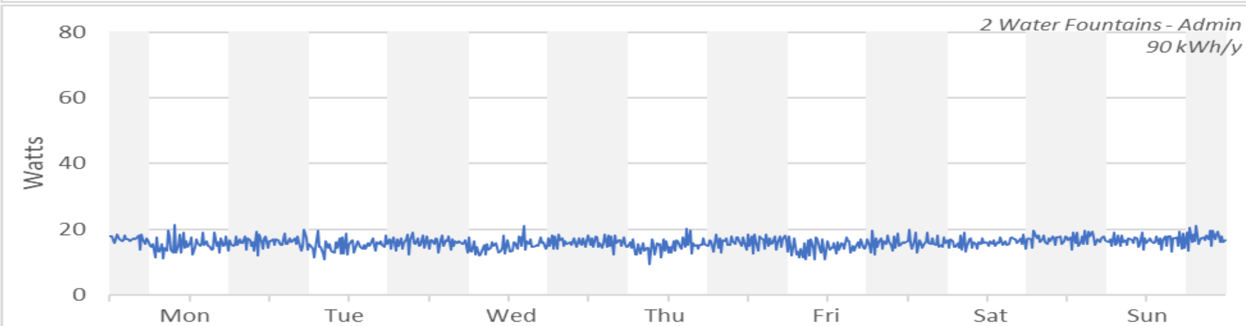
E.2.5 Coffee Makers – Residential (Admin, TEMF, BN HQ)

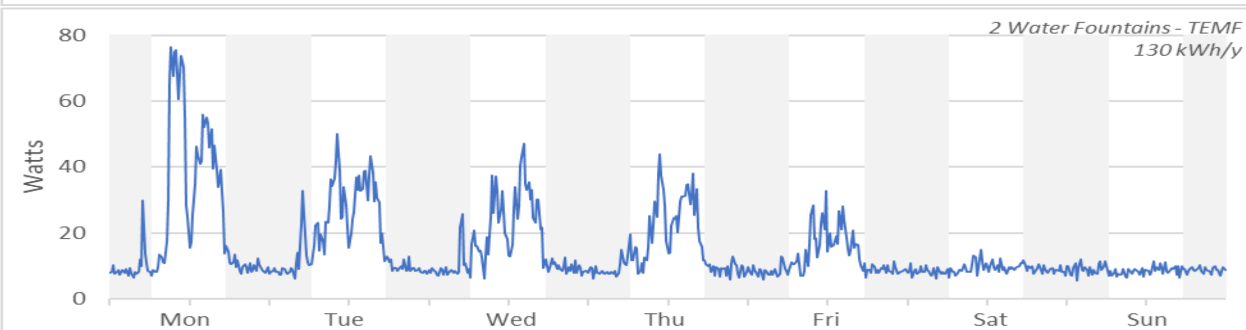


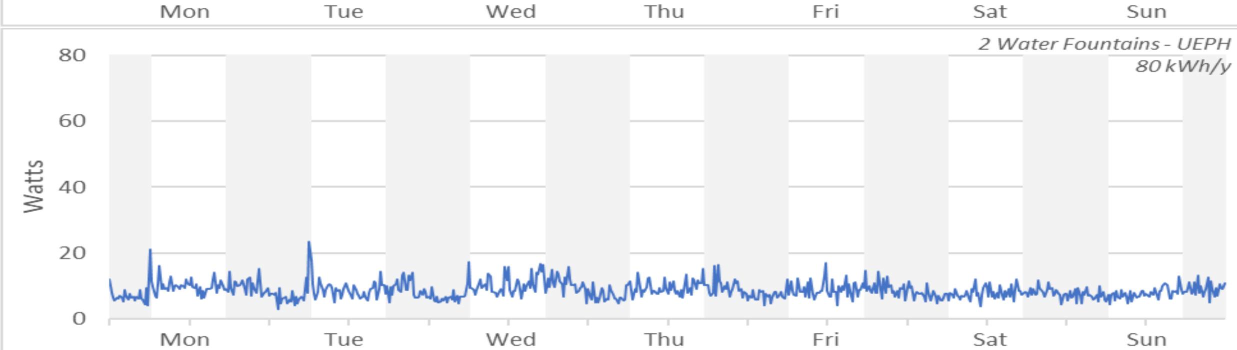
E.2.6 Water Coolers (Admin, TEMF, UEPH)



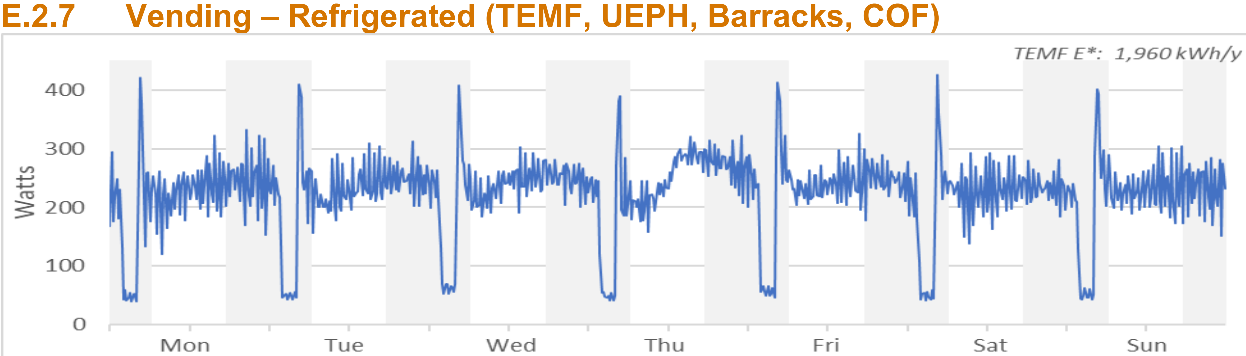


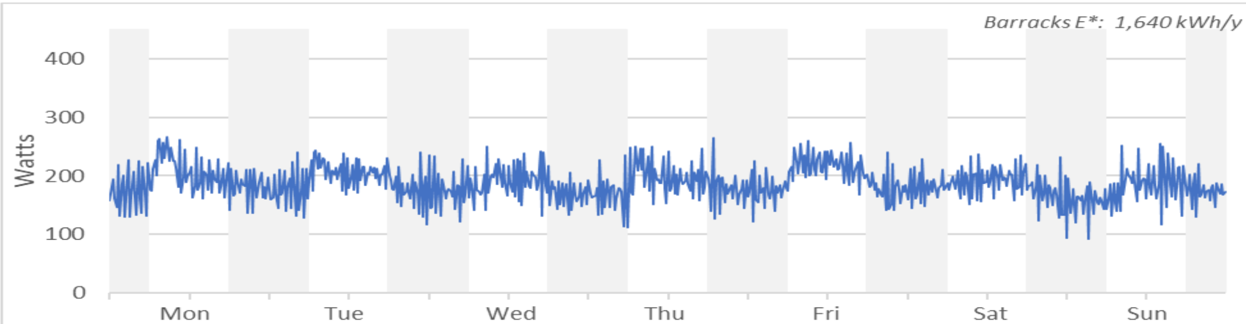


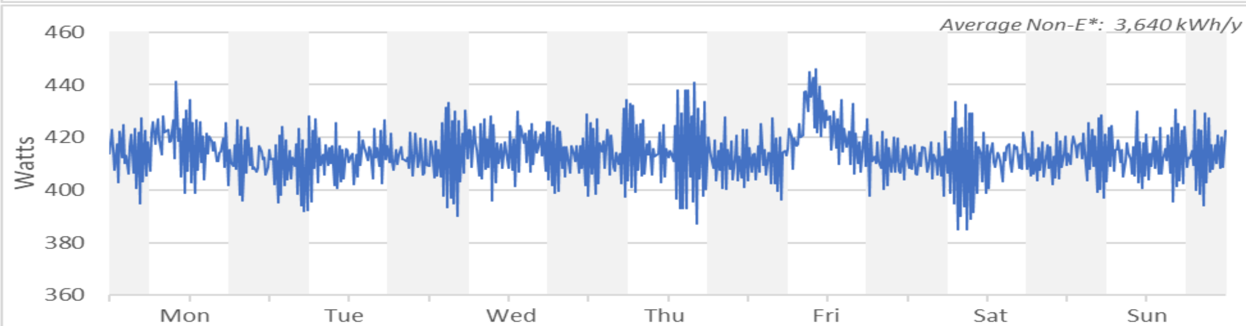


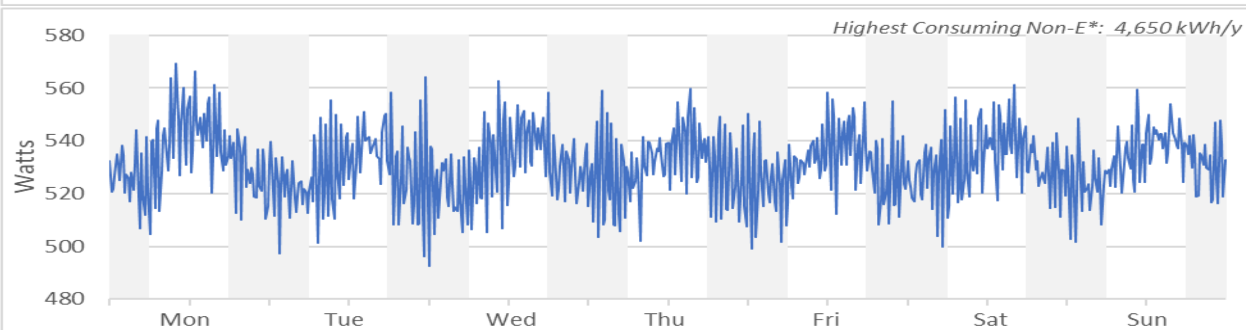


E.2.7 Vending – Refrigerated (TEMF, UEPH, Barracks, COF)

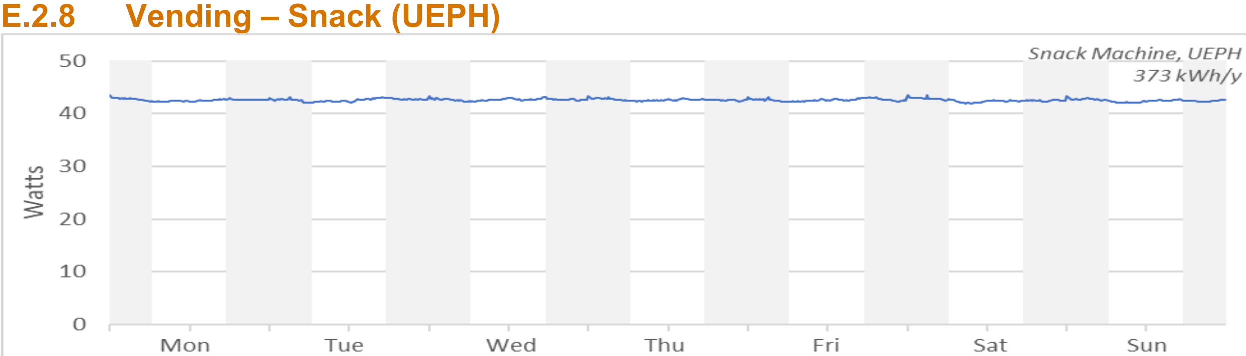






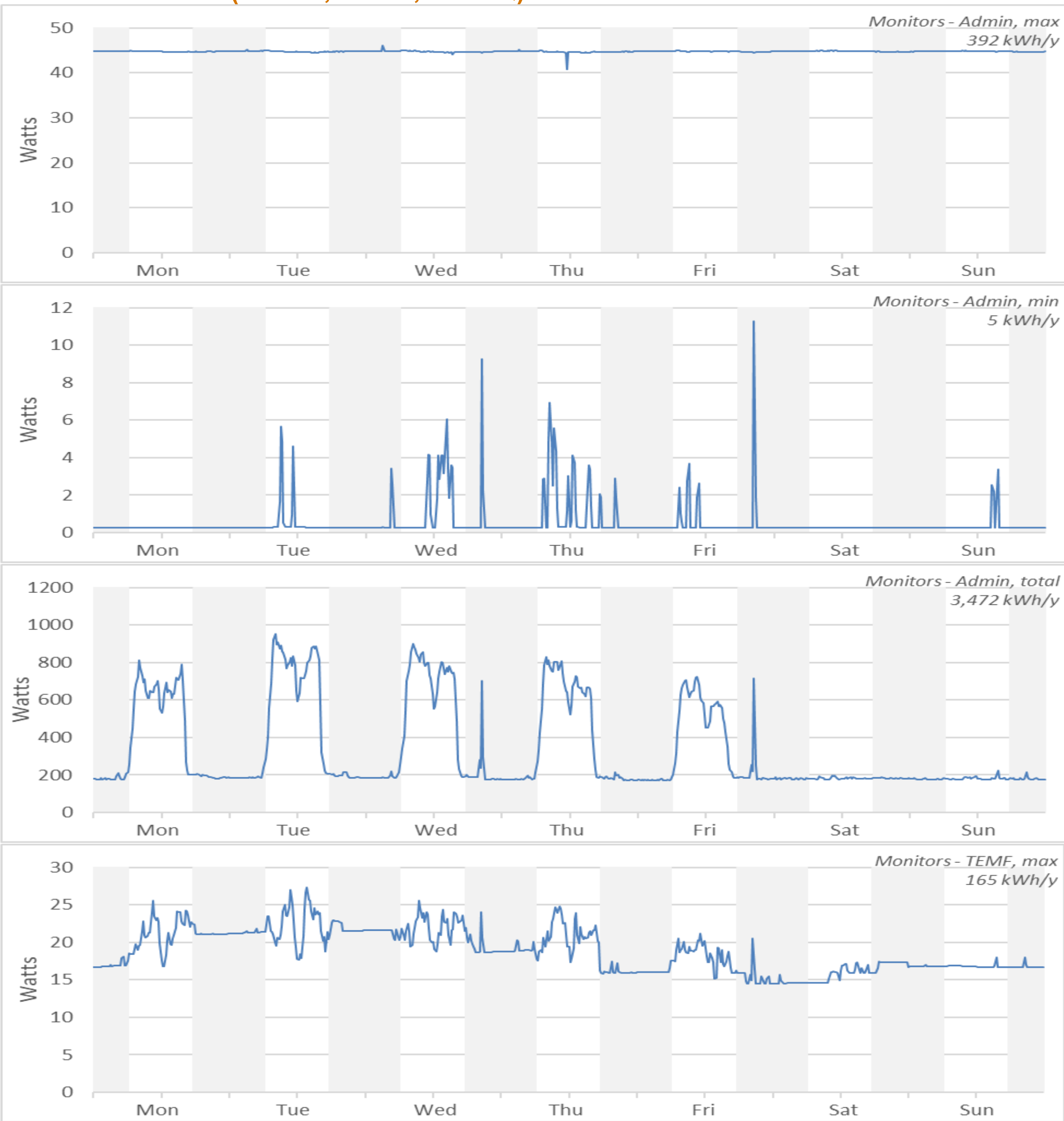


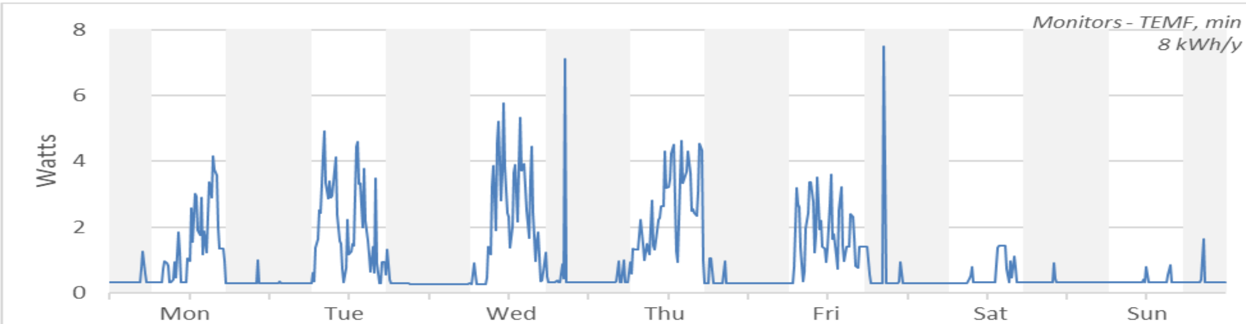
E.2.8 Vending – Snack (UEPH)

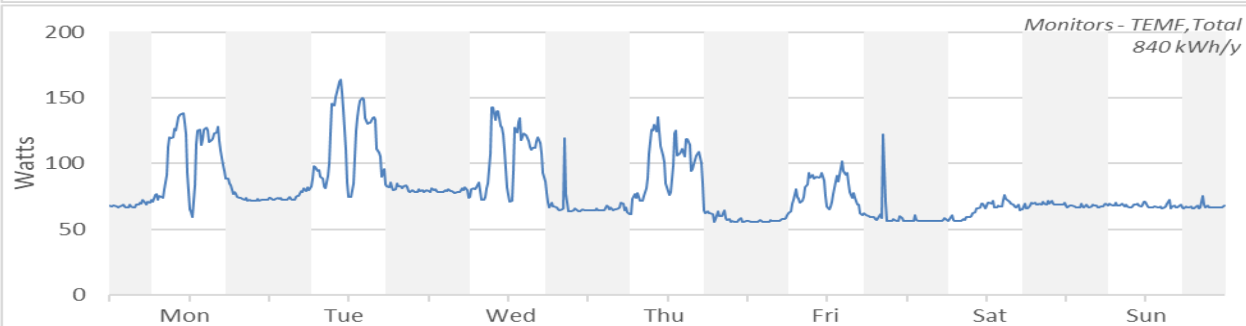


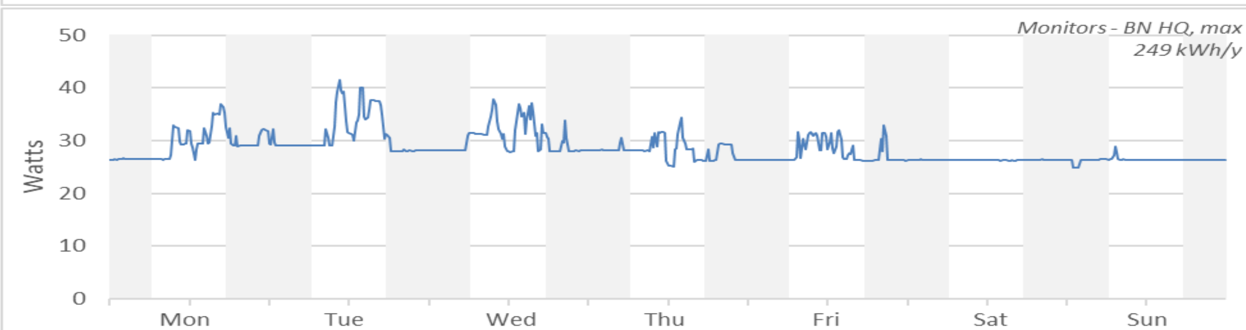
E.3 Computing

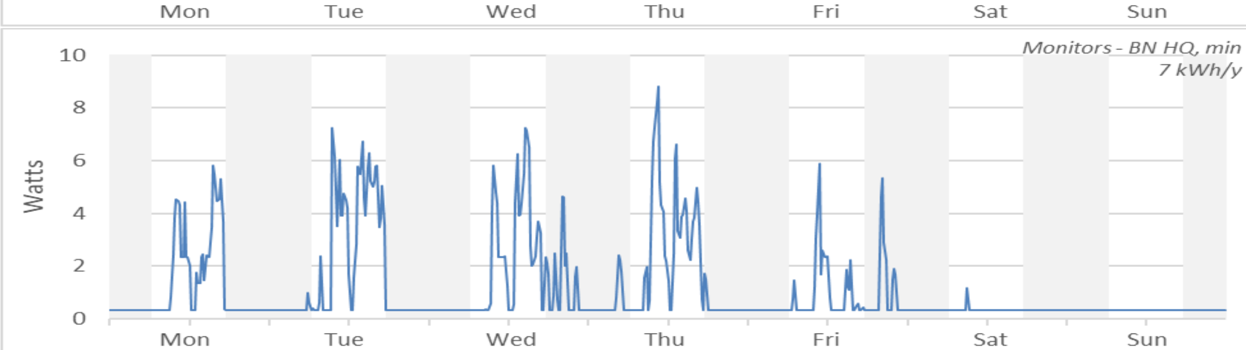
E.3.1 Monitors (Admin, TEMF, BN HQ)

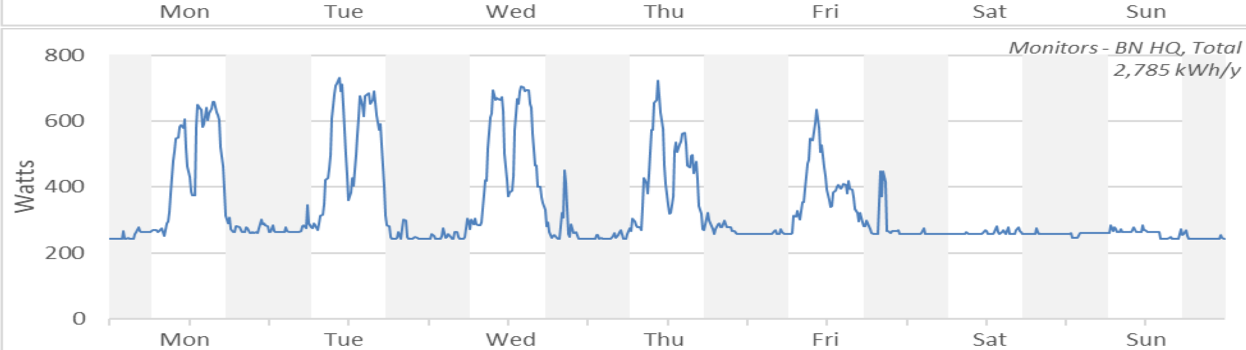



Monitors - TEMF, min
8 kWh/y
Watts
8
6
4
2
0
Mon
Tue
Wed
Thu
Fri
Sat
Sun

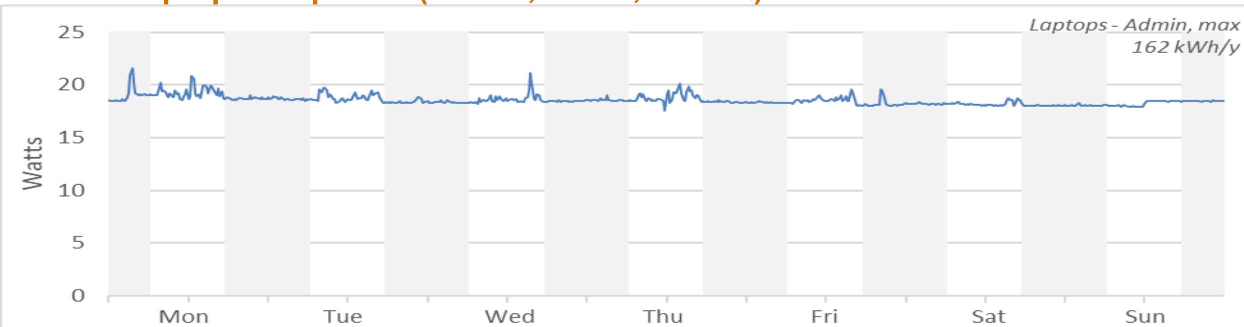

Monitors - TEMF, Total
840 kWh/y
Watts
200
150
100
50
0
Mon
Tue
Wed
Thu
Fri
Sat
Sun

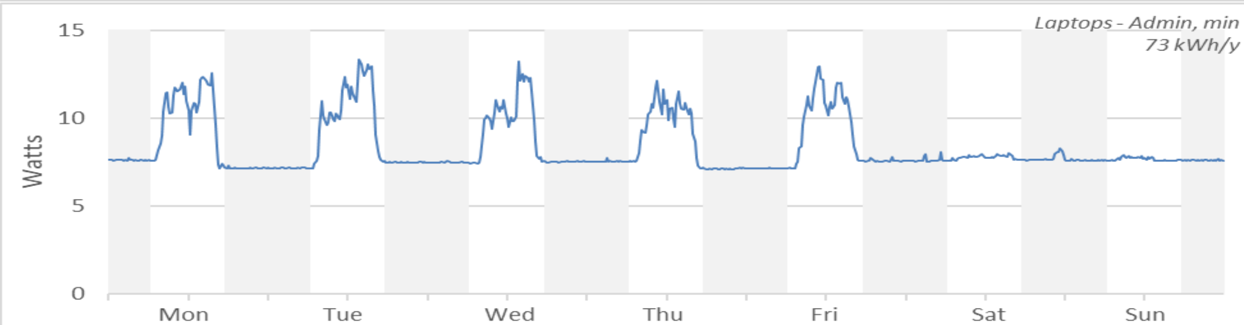

Monitors - BN HQ, max
249 kWh/y
Watts
50
40
30
20
10
0
Mon
Tue
Wed
Thu
Fri
Sat
Sun

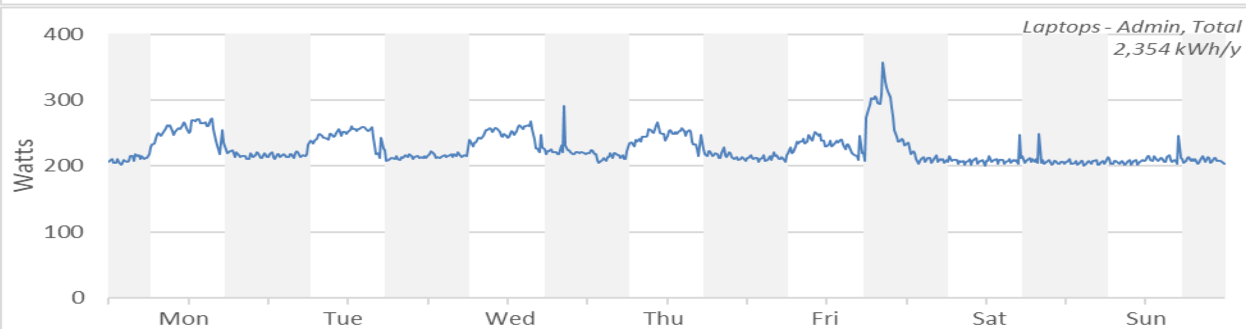

Monitors - BN HQ, min
7 kWh/y
Watts
10
8
6
4
2
0
Mon
Tue
Wed
Thu
Fri
Sat
Sun

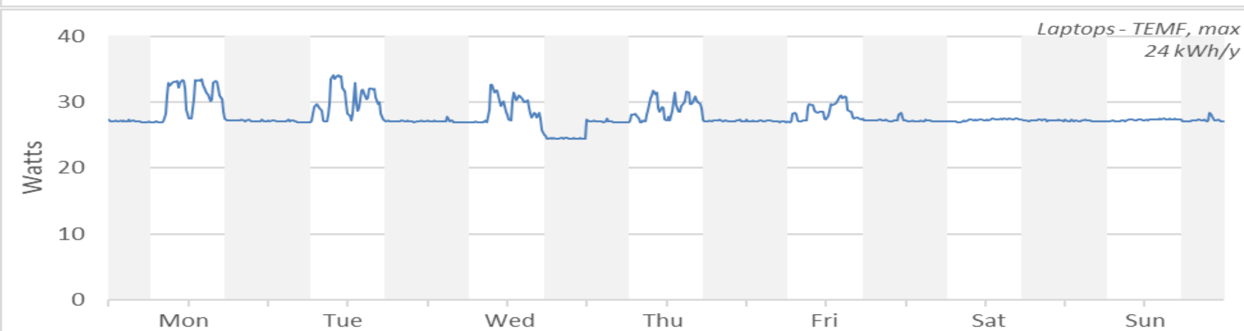

Monitors - BN HQ, Total
2,785 kWh/y
Watts
800
600
400
200
0
Mon
Tue
Wed
Thu
Fri
Sat
Sun

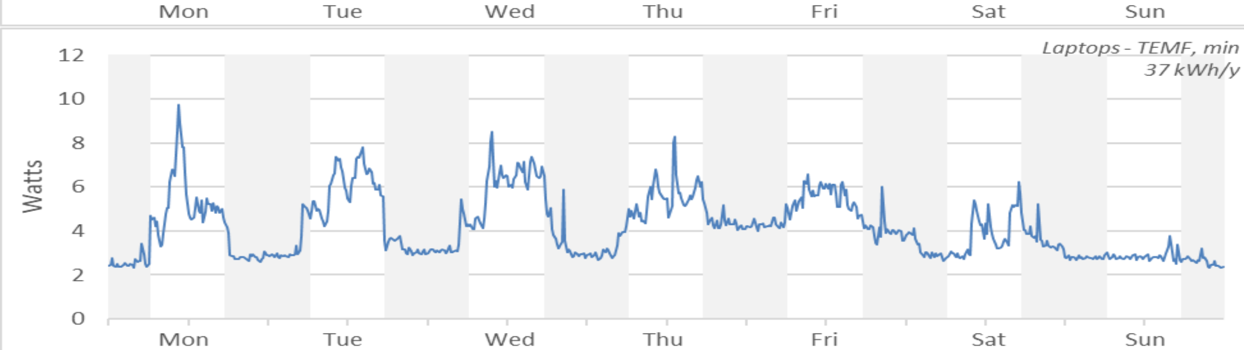
E.3.2 Laptop Computers (Admin, TEMF, BN HQ)

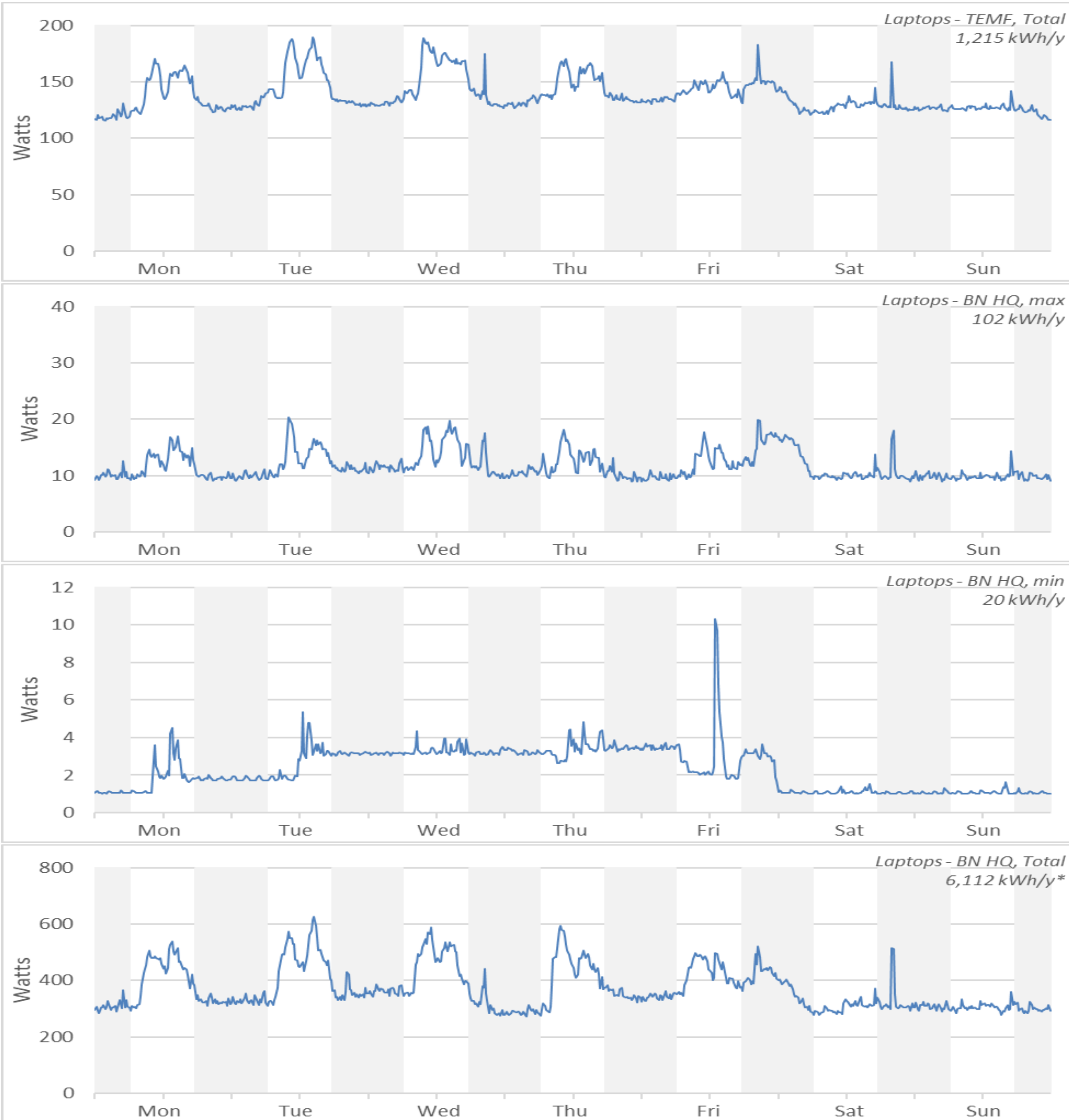




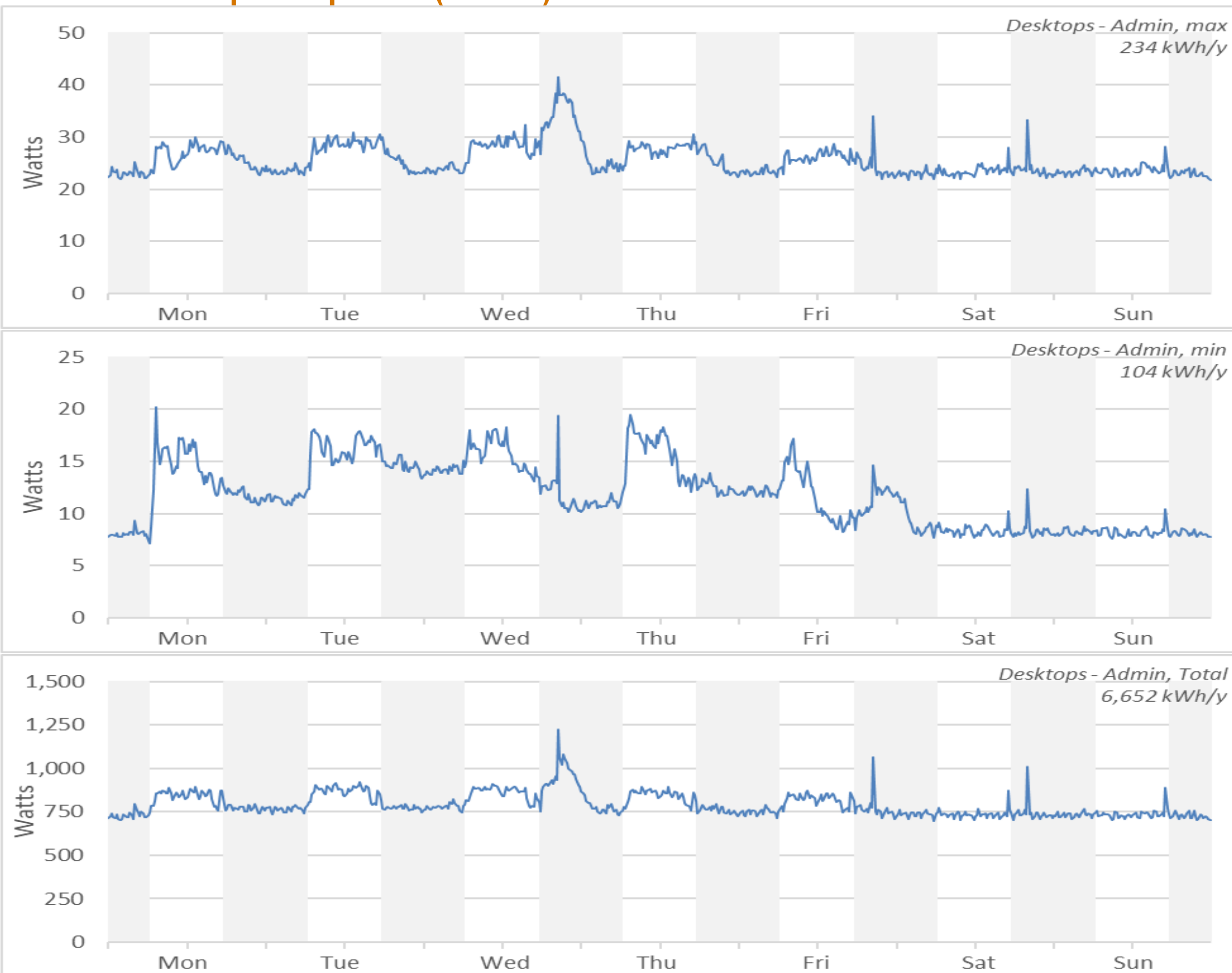




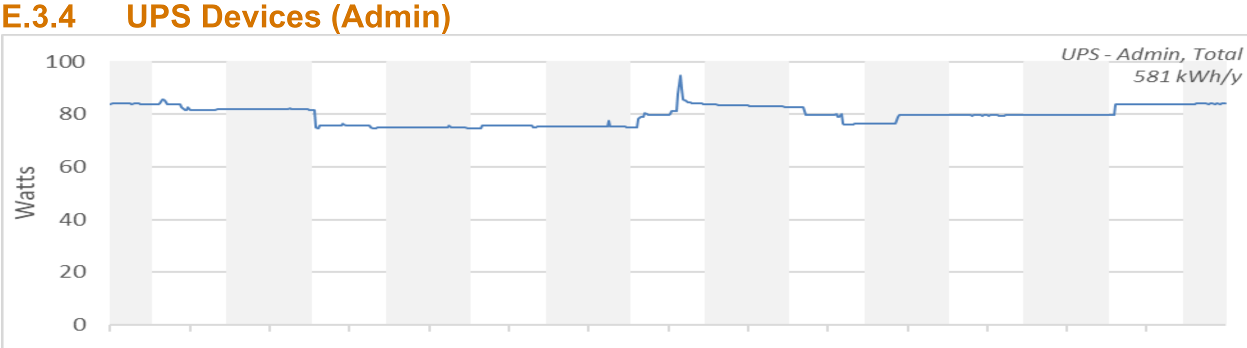



Laptops - TEMF, Total
1,215 kWh/y
Laptops - BN HQ, max
102 kWh/y
Laptops - BN HQ, min
20 kWh/y
Laptops - BN HQ, Total
6,112 kWh/y*
Watts
Mon
Tue
Wed
Thu
Fri
Sat
Sun

E.3.3 Desktop Computers (Admin)



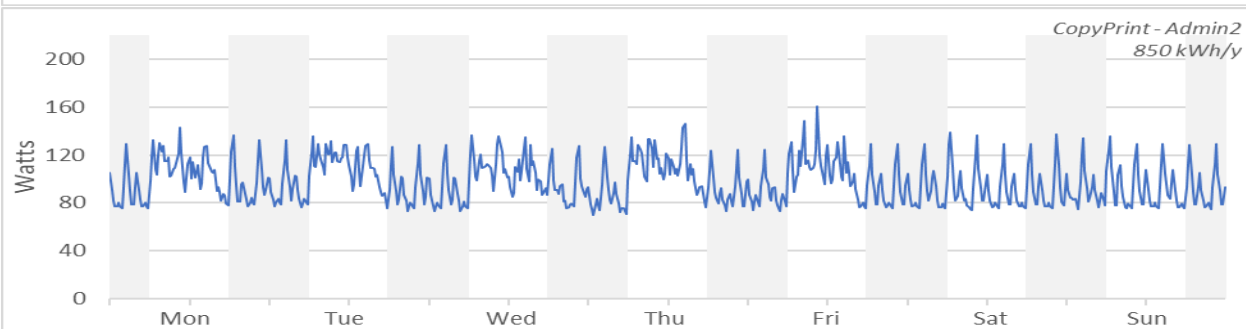
E.3.4 UPS Devices (Admin)

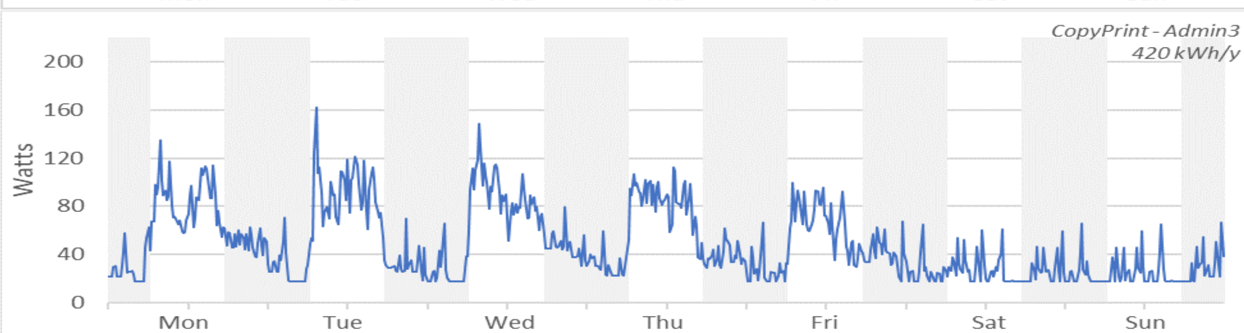


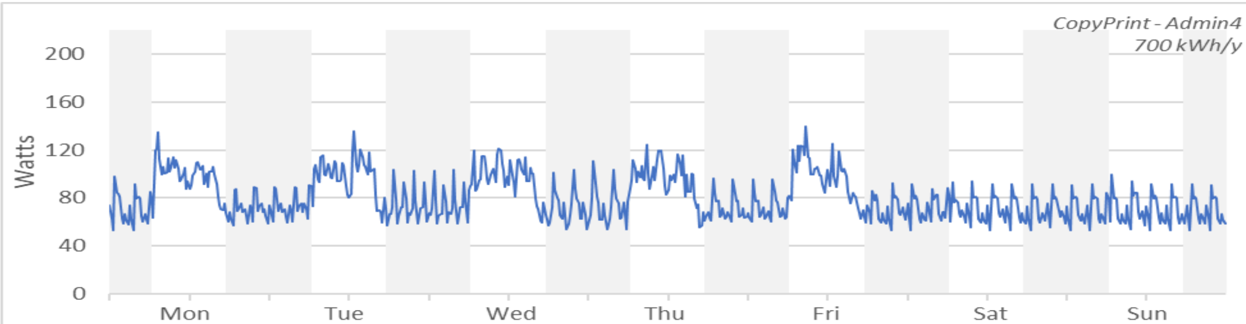
E.3.5 Computer Speakers (Admin)

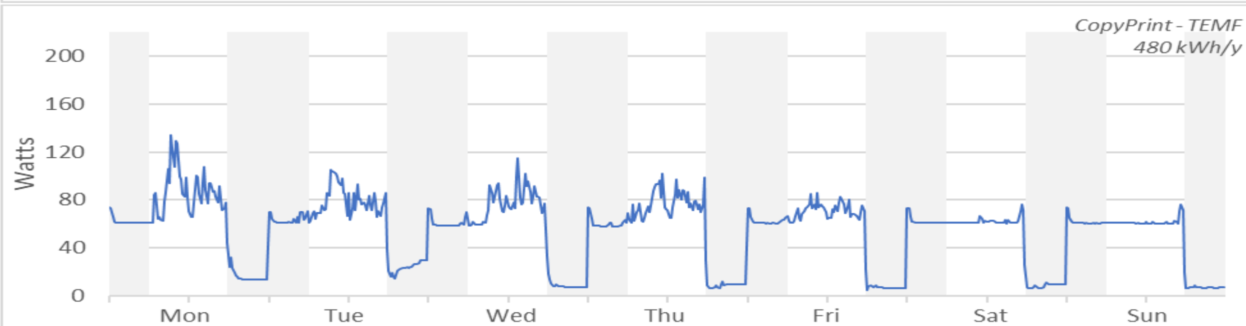
E.4 Documents / Imaging

E.4.1 Large Copy/Print Multi-Function Devices (Admin, TEMF)

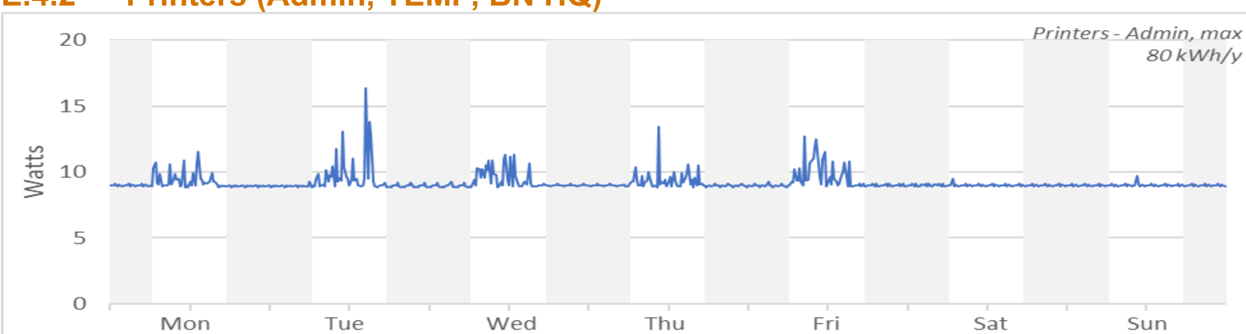


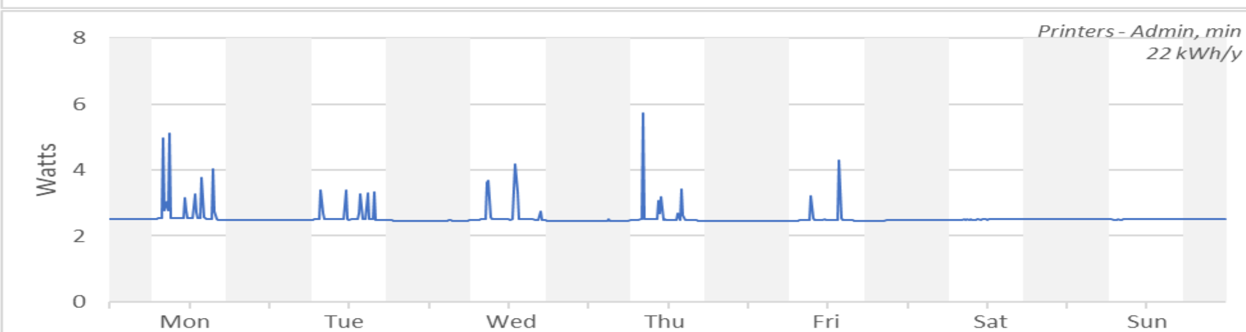


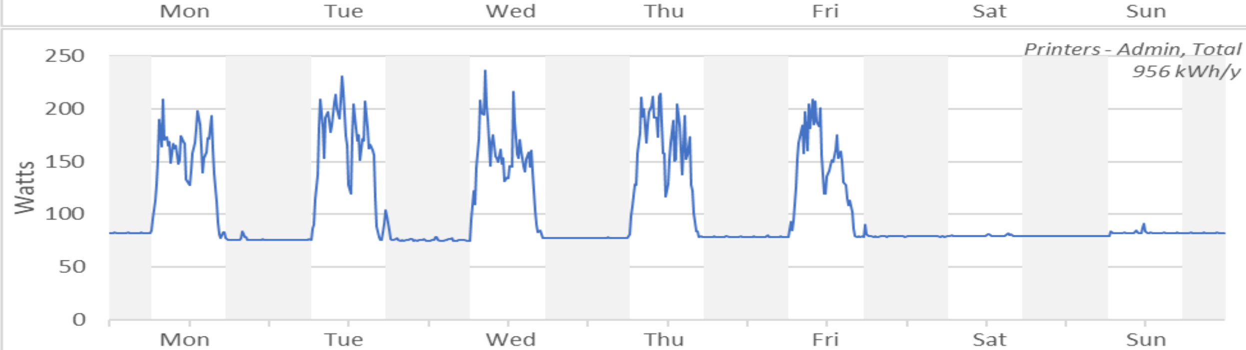


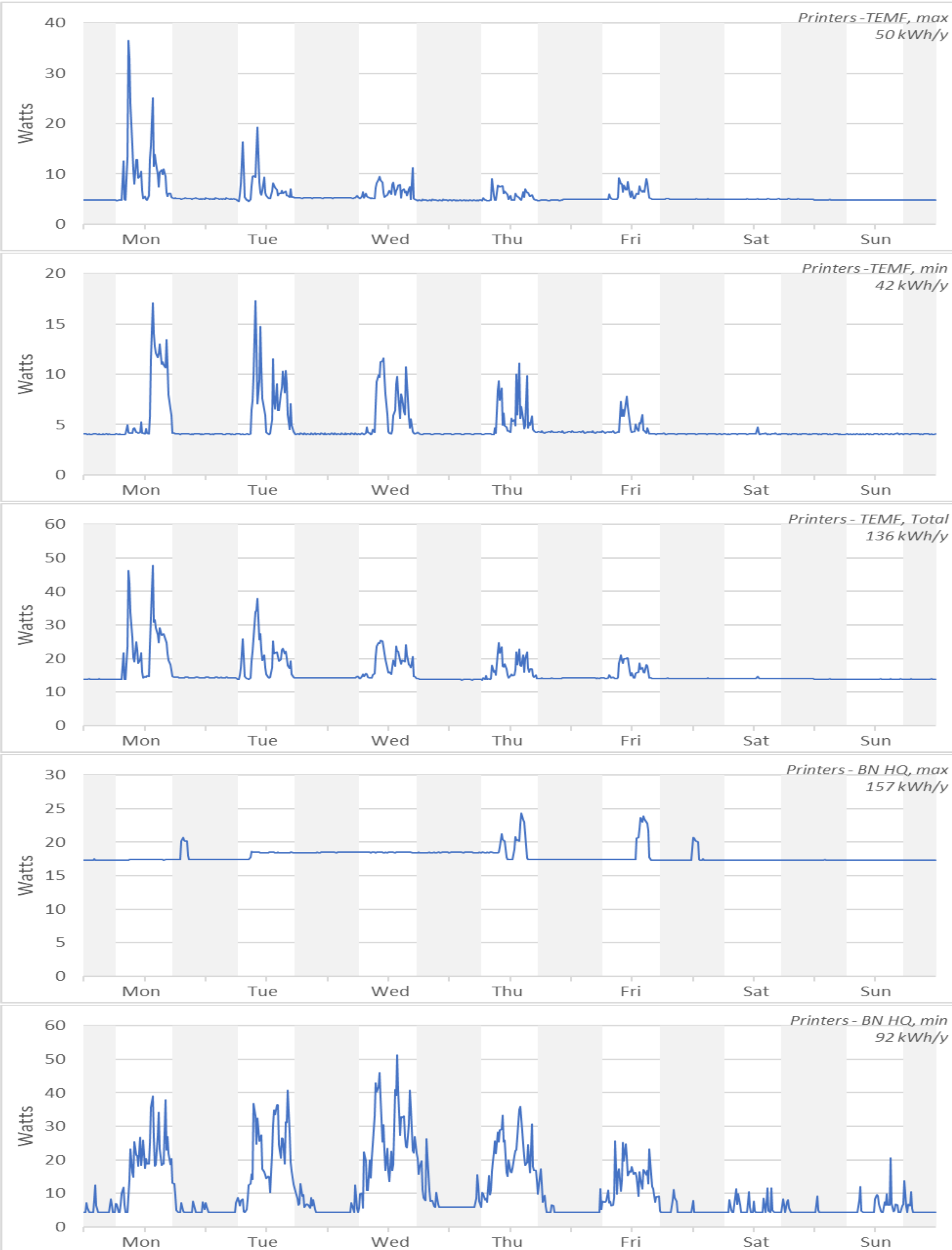


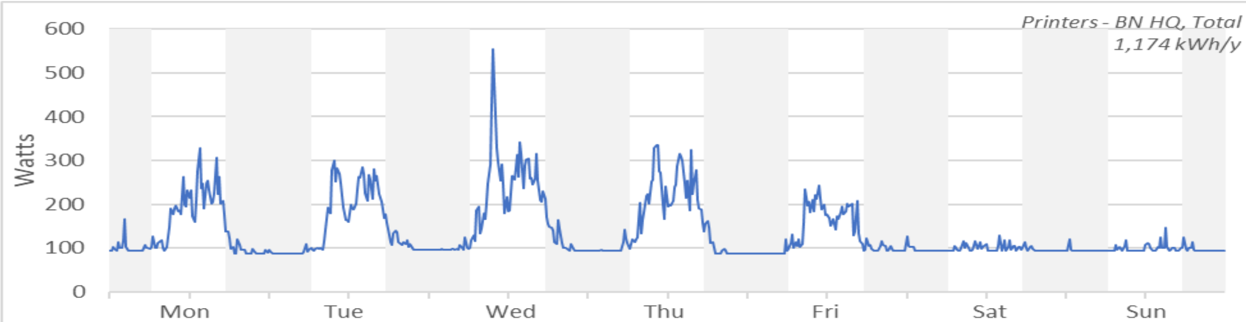
E.4.2 Printers (Admin, TEMF, BN HQ)



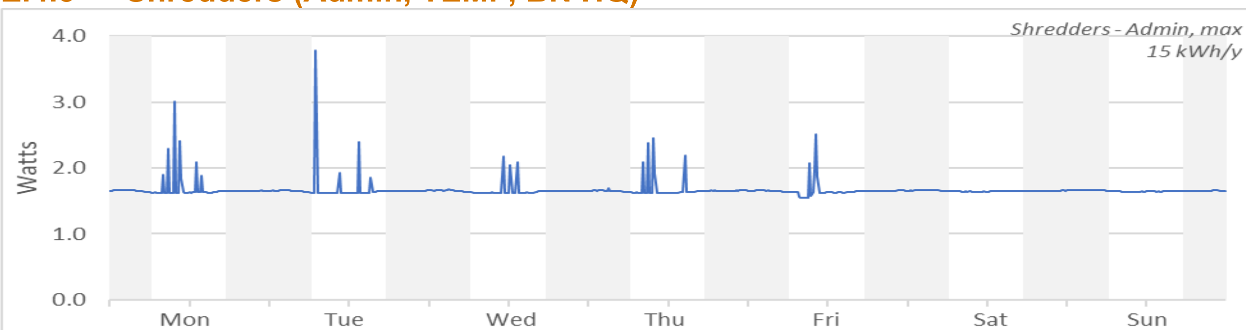


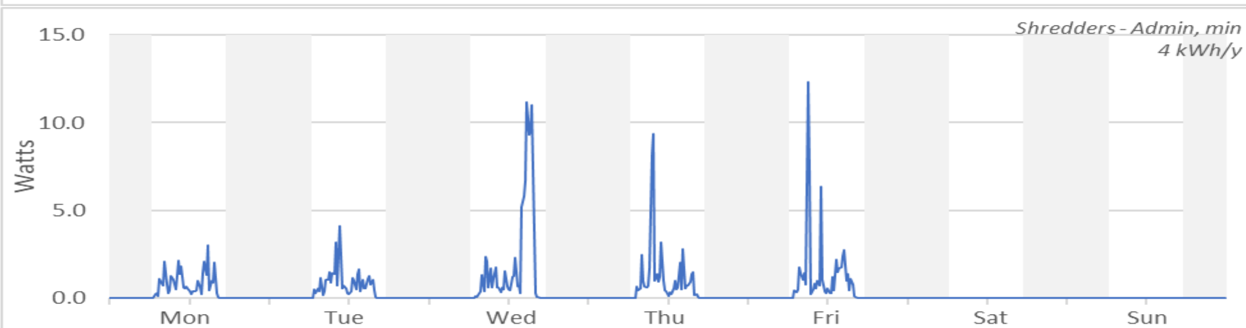


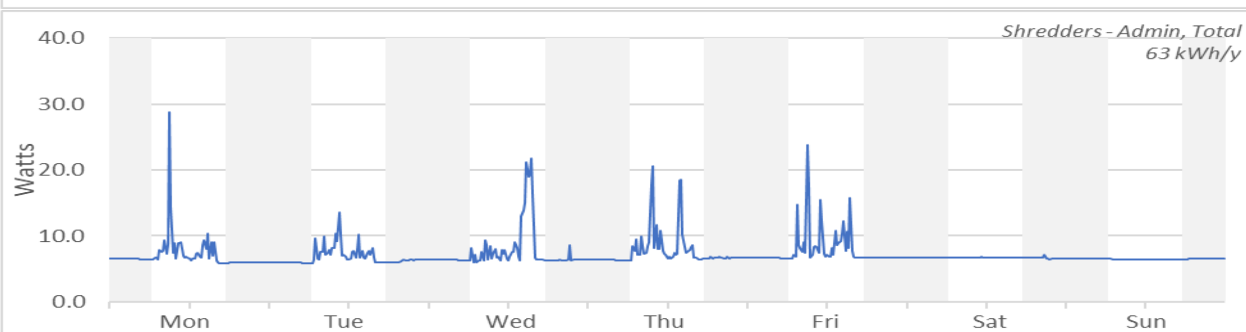

Printers -TEMF, max
50 kWh/y
Printers -TEMF, min
42 kWh/y
Printers - TEMF, Total
136 kWh/y
Printers - BN HQ, max
157 kWh/y
Printers - BN HQ, min
92 kWh/y
Watts
Mon
Tue
Wed
Thu
Fri
Sat
Sun

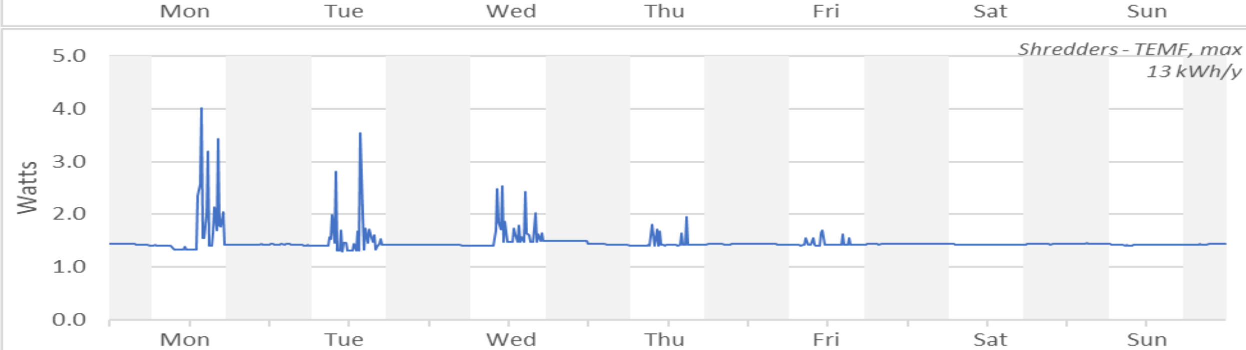


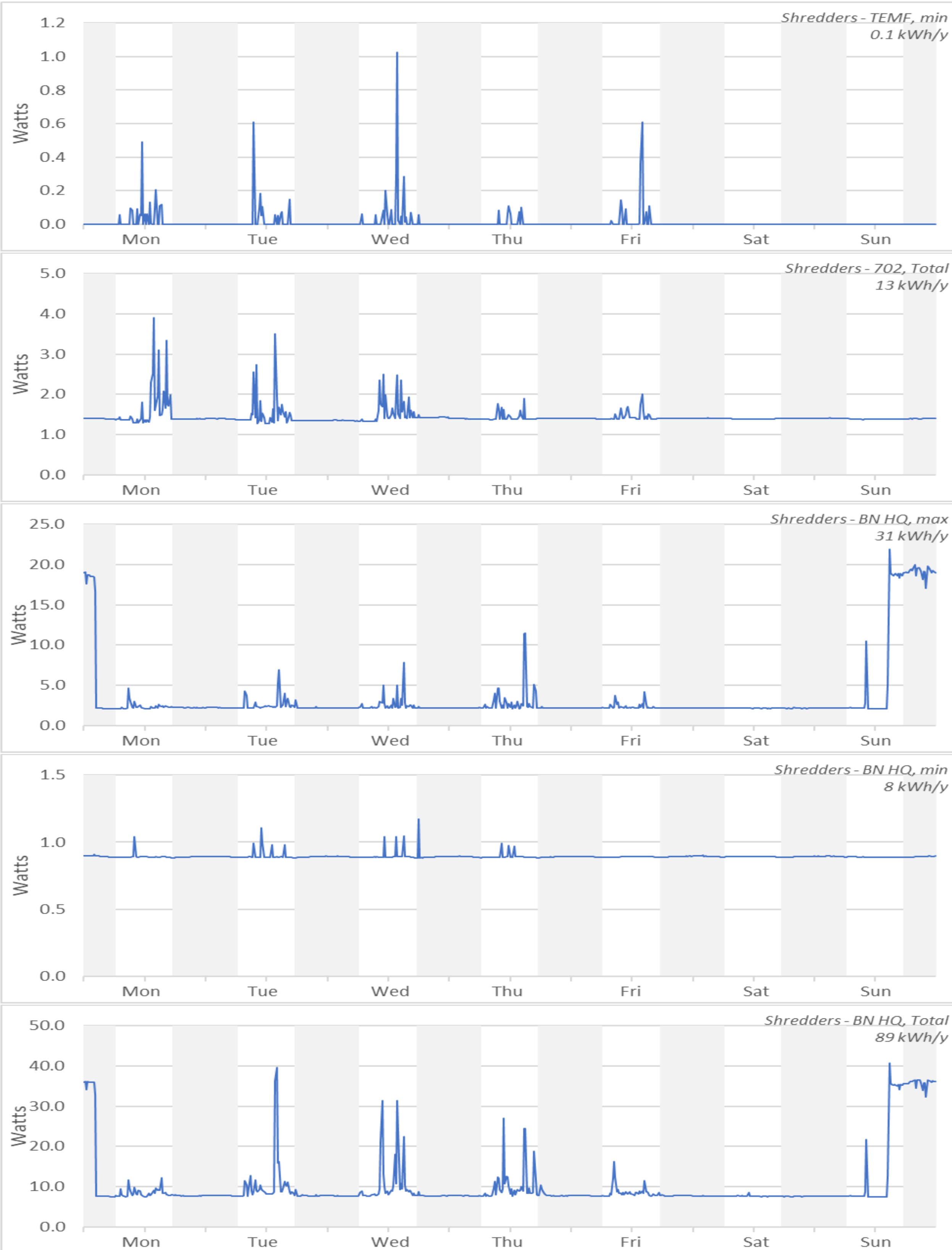
E.4.3 Shredders (Admin, TEMF, BN HQ)





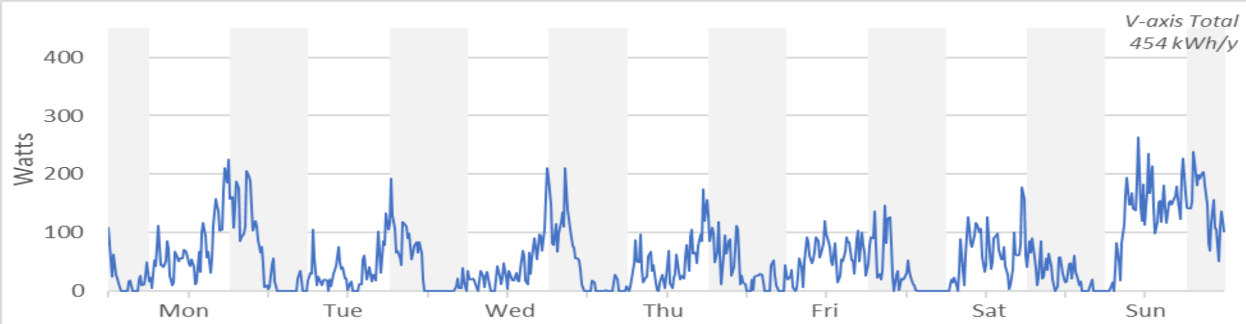


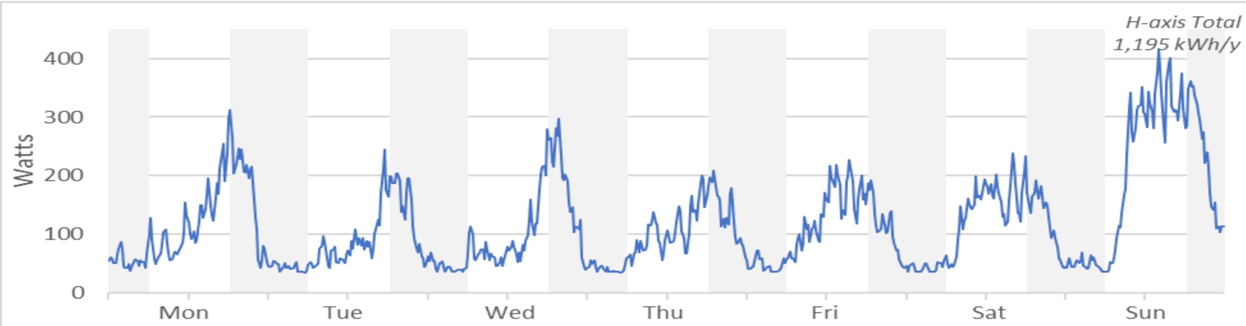



Shredders - TEMF, min
0.1 kWh/y
Watts
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Shredders - 702, Total
13 kWh/y
Watts
5.0
4.0
3.0
2.0
1.0
0.0
Shredders - BN HQ, max
31 kWh/y
Watts
25.0
20.0
15.0
10.0
5.0
0.0
Shredders - BN HQ, min
8 kWh/y
Watts
1.5
1.0
0.5
0.0
Shredders - BN HQ, Total
89 kWh/y
Watts
50.0
40.0
30.0
20.0
10.0
0.0

E.5 Laundry

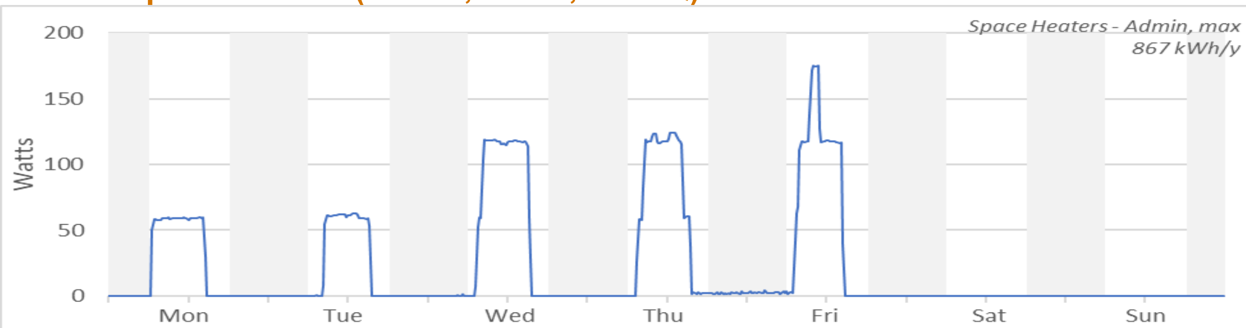
E.5.1 Washing Machines (UEPH)

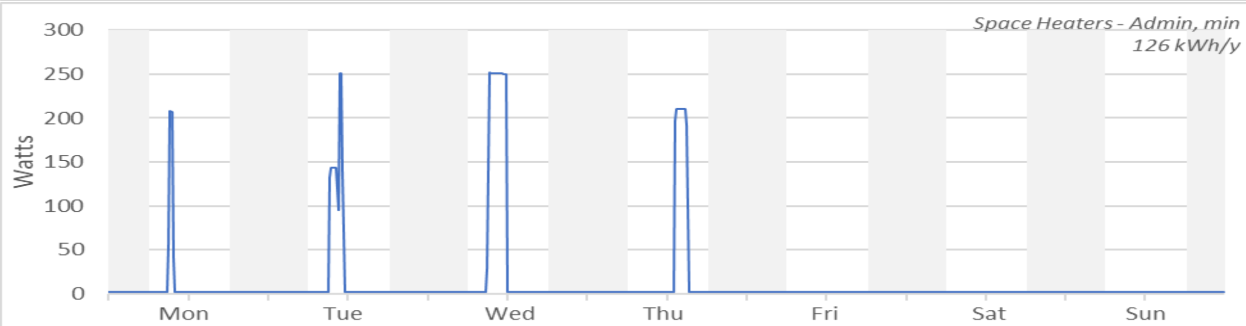


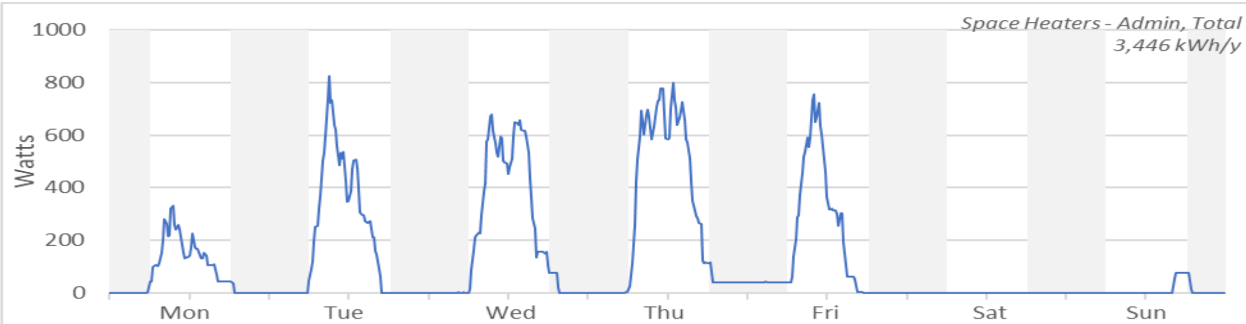


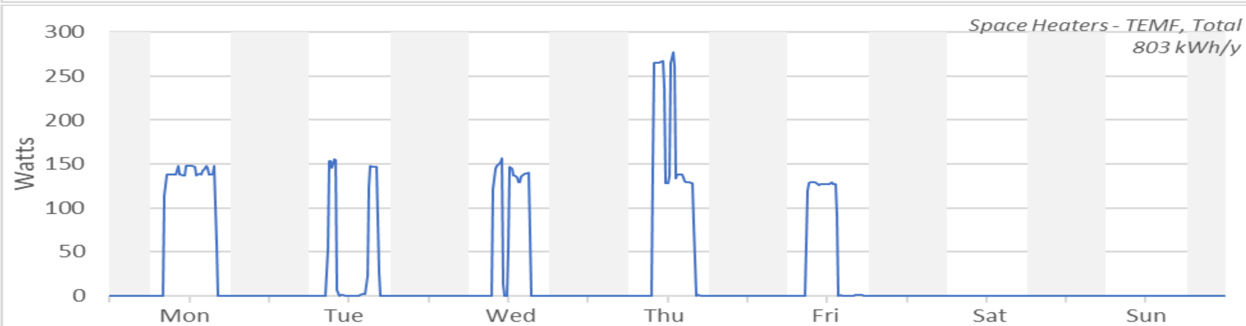
E.6 Occupant Comfort

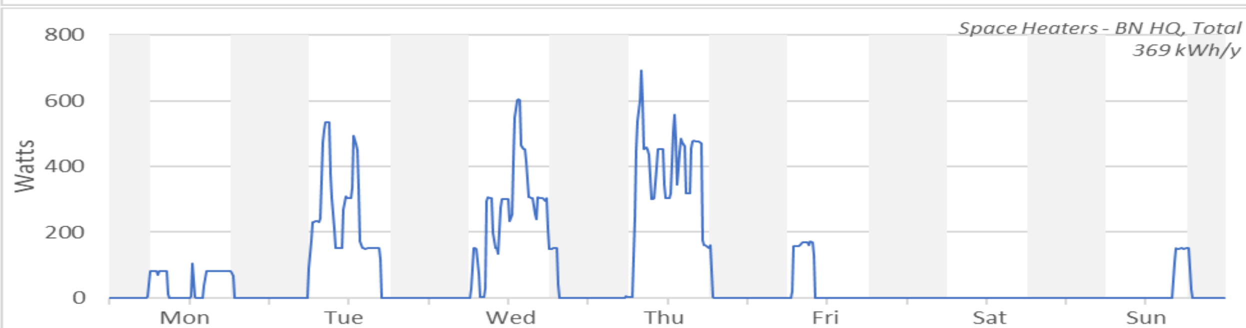
E.6.1 Space Heaters (Admin, TEMF, BN HQ)





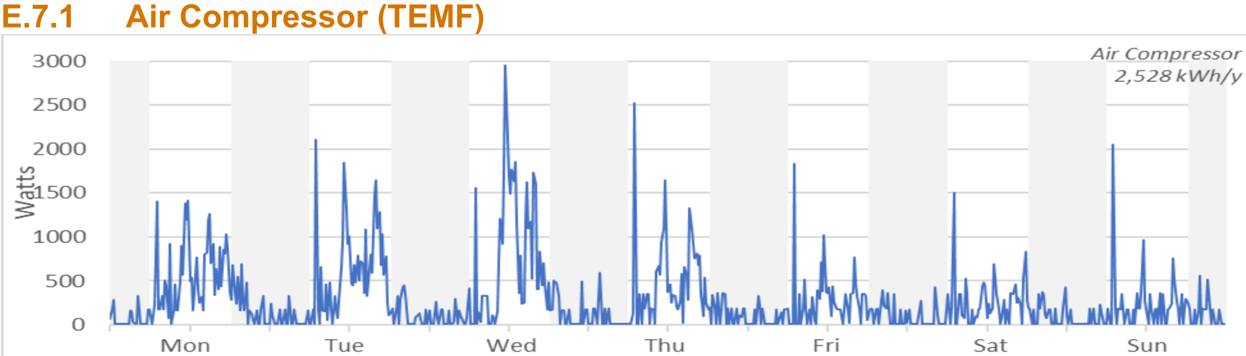


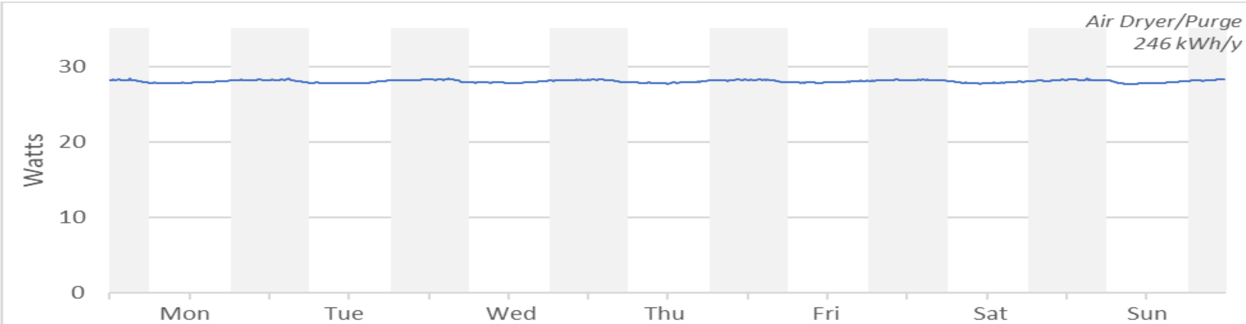




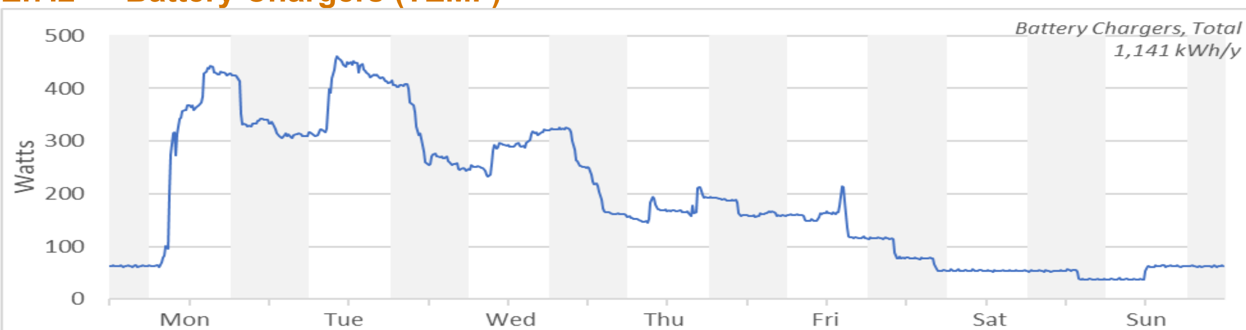
E.7 Shop Equipment

E.7.1 Air Compressor (TEMF)

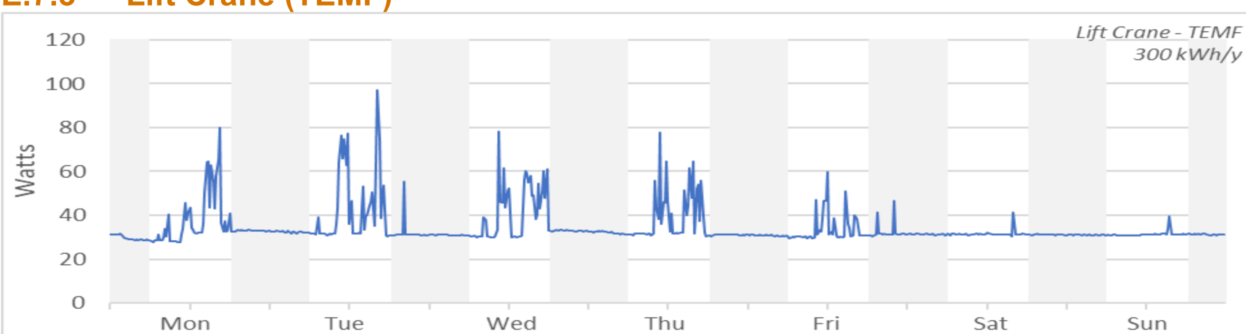




E.7.2 Battery Chargers (TEMF)



E.7.3 Lift Crane (TEMF)

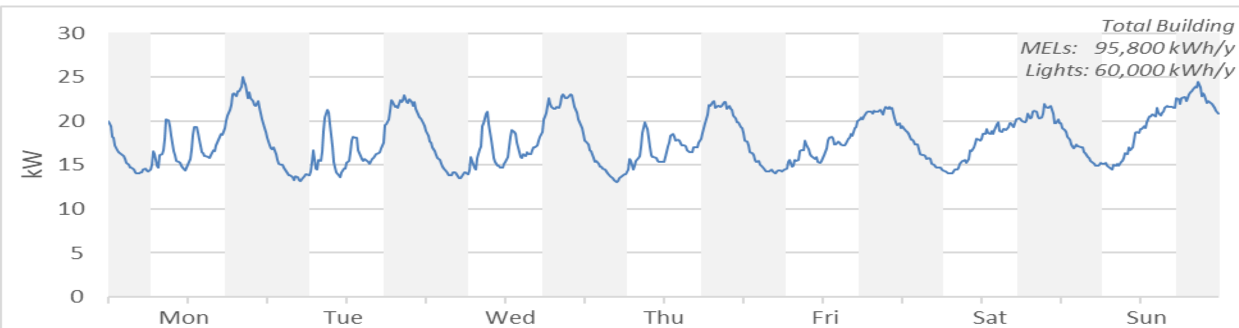


E.7.4 Parts Cleaners (TEMF)

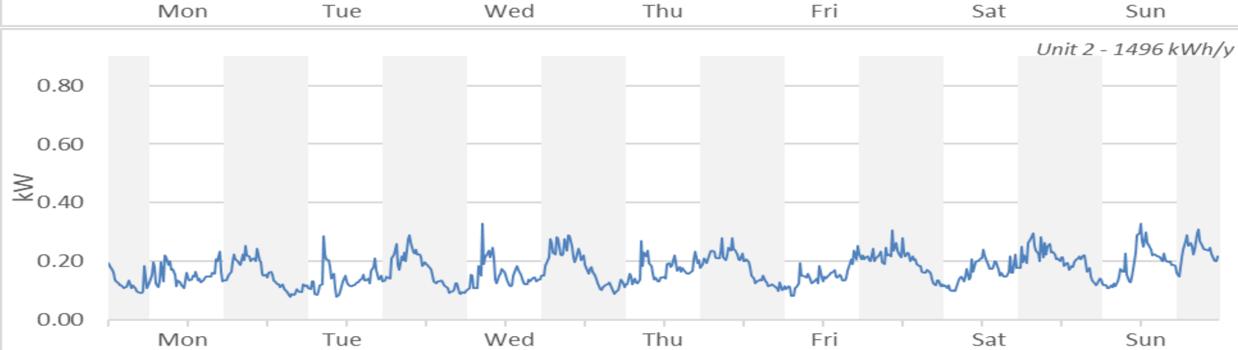
E.8 UEPH – Occupant Units

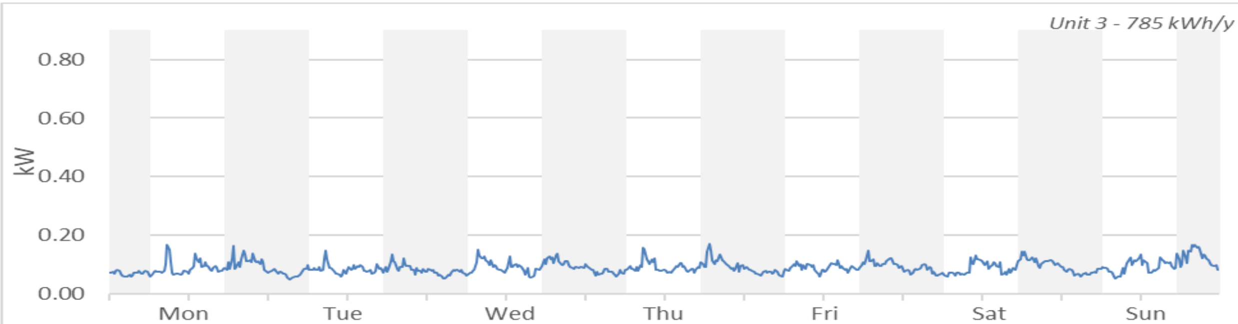
These profiles present the average weekly load at a 15-minute interval, for each of the occupant quarters that were monitored during the study. Due to privacy concerns, no metering was installed within occupied spaces. However, loads were captured at an electrical panel covering 30 of the 84 double-occupancy rooms. The resulting loads include a mix of loads from the rooms on floors 1-3, in order to balance the loads each phase. The combination of the load on the three phases does represent the total load for each stack of three living quarters, and each largely represents the diversity of loads within a single unit, but are from different parts of the three units. Therefore, the results provide a good indication of the magnitude of loads with units, but does not provide detail on the loads within any specific unit, which is still useful for the objective of this study to better understand the magnitude and variation of loads within typical occupancy units. In addition to personal plug loads for each occupant (e.g., TVs, computers, audio systems, gaming systems, clocks, coffee makers, personal grooming equipment, and other electronic devices), the captured loads also include lighting (a mix of T8 linear fluorescent and CFL) and standard kitchen equipment (refrigerator, microwave, and cooktop).

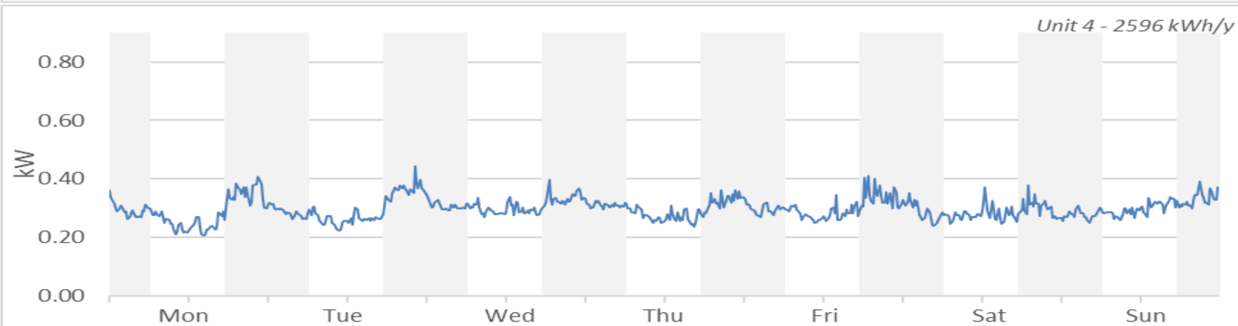
E.8.1 Building Total

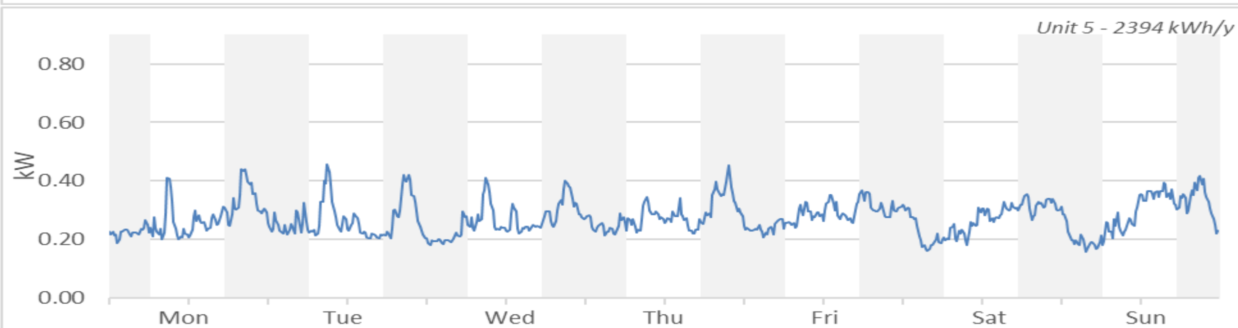


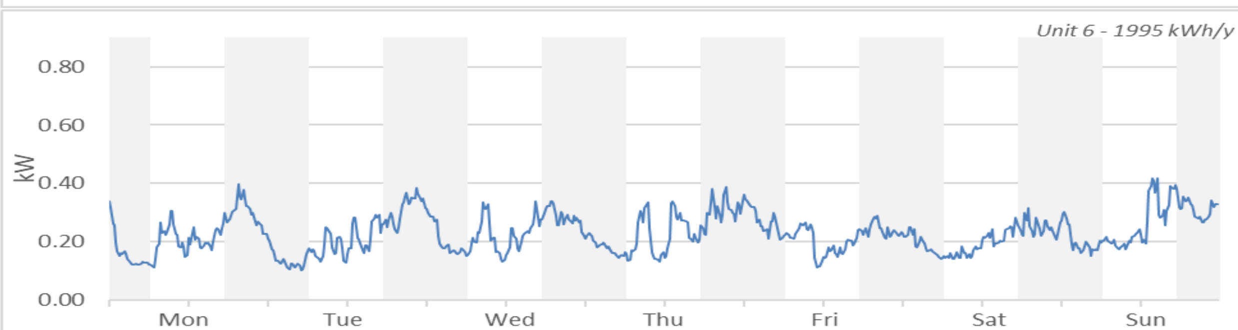
E.8.2 Individual Representative Units

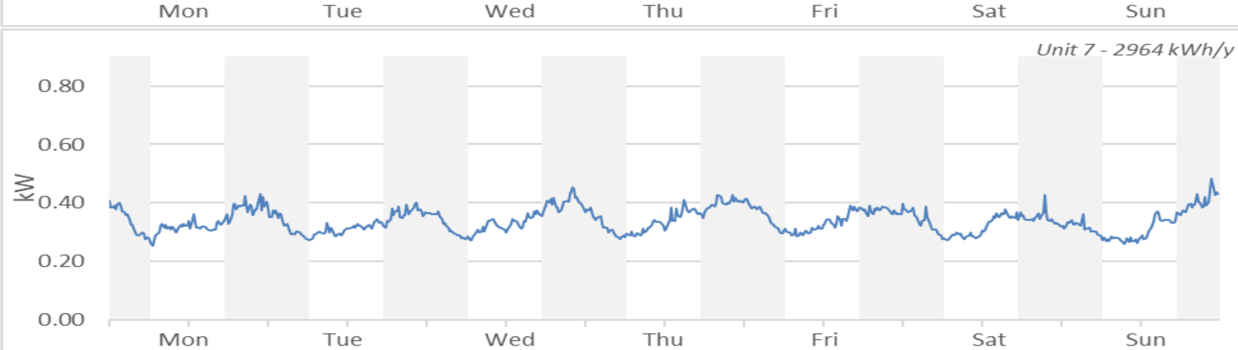


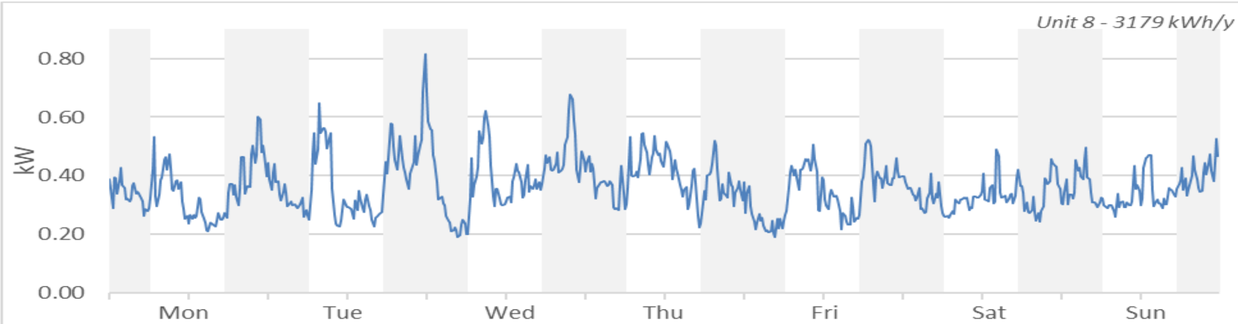

Unit 3 - 785 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

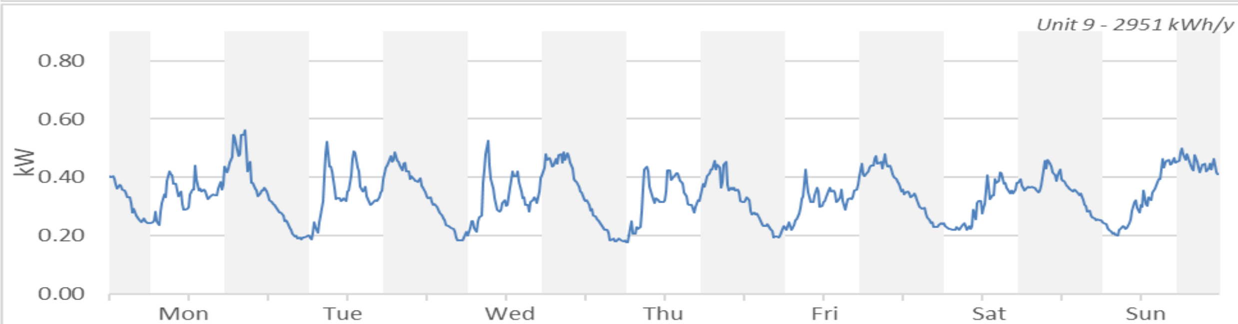

Unit 4 - 2596 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

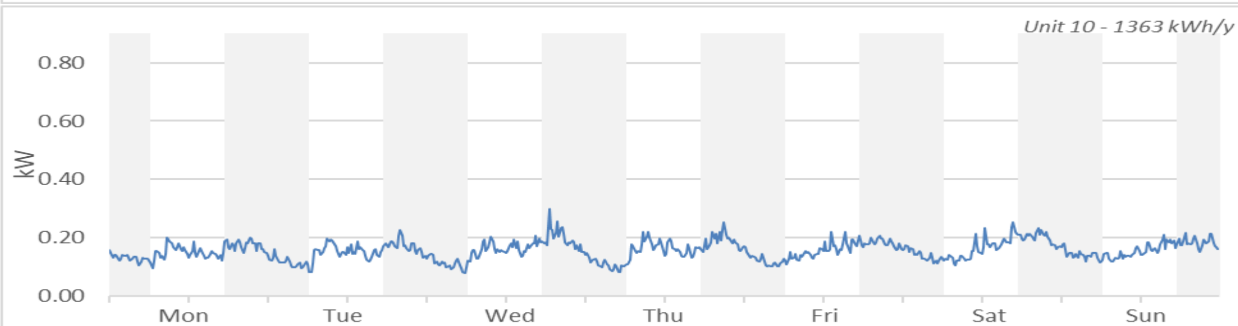

Unit 5 - 2394 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

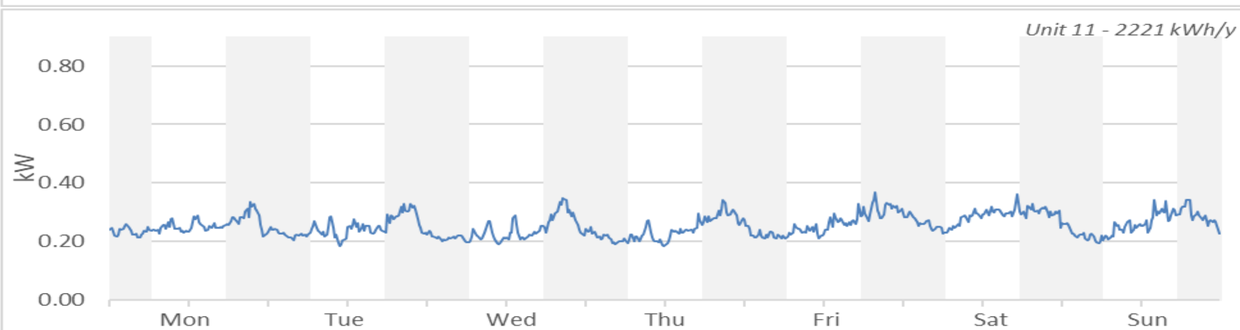

Unit 6 - 1995 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

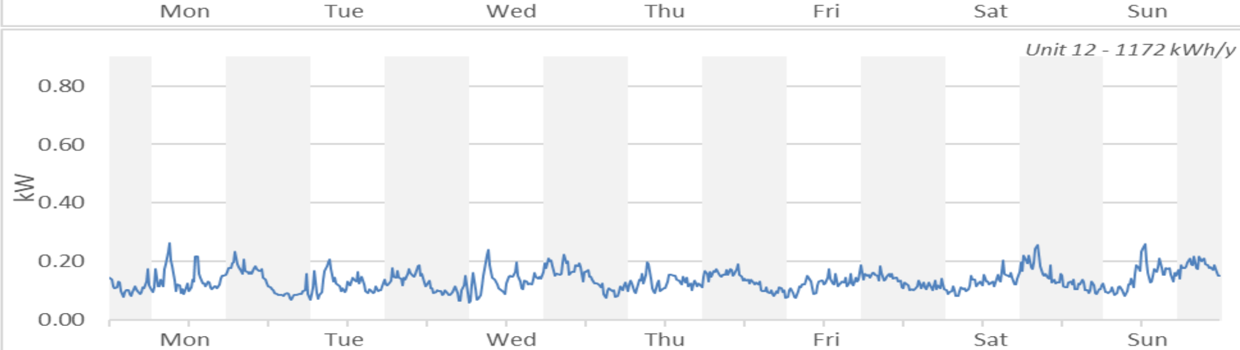

Unit 7 - 2964 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

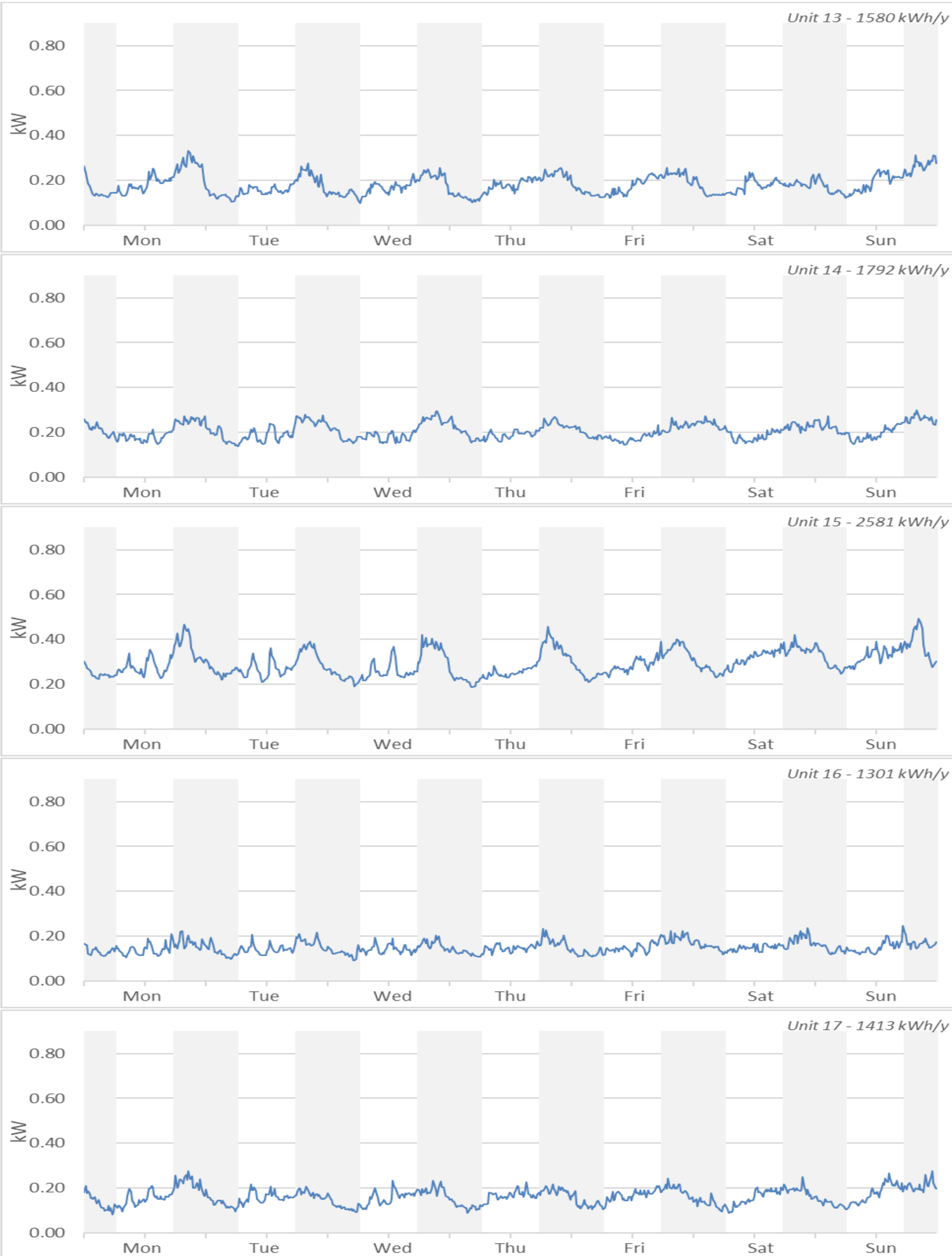

Unit 8 - 3179 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

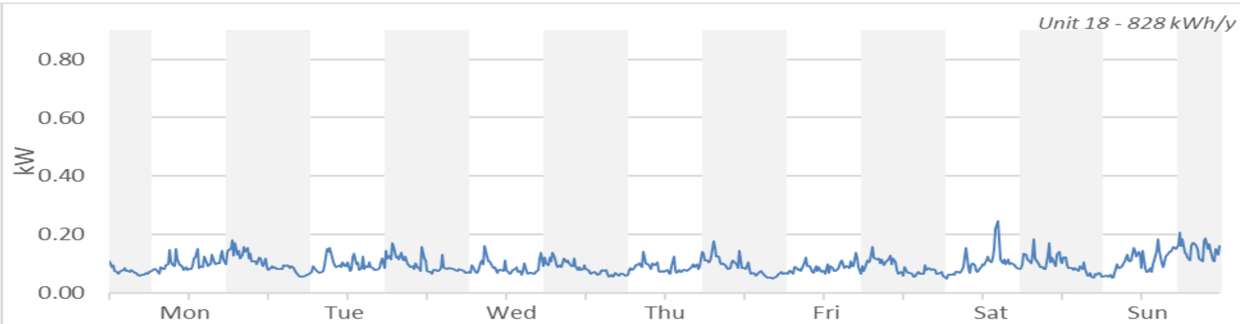

Unit 9 - 2951 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

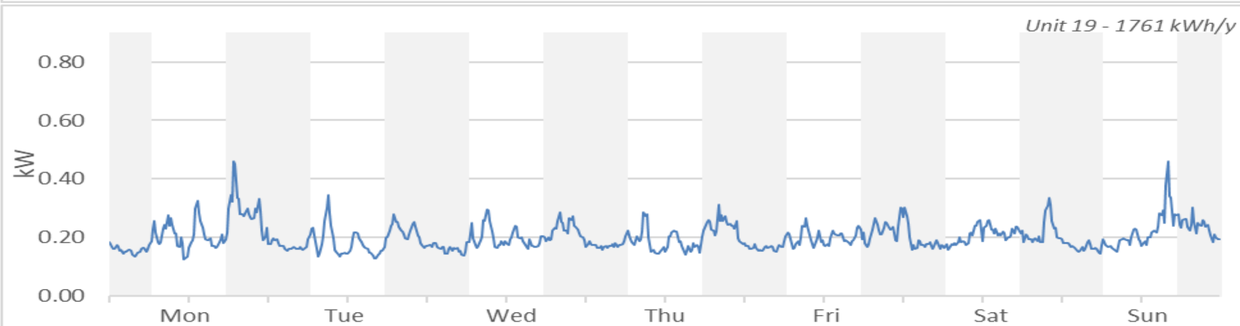

Unit 10 - 1363 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

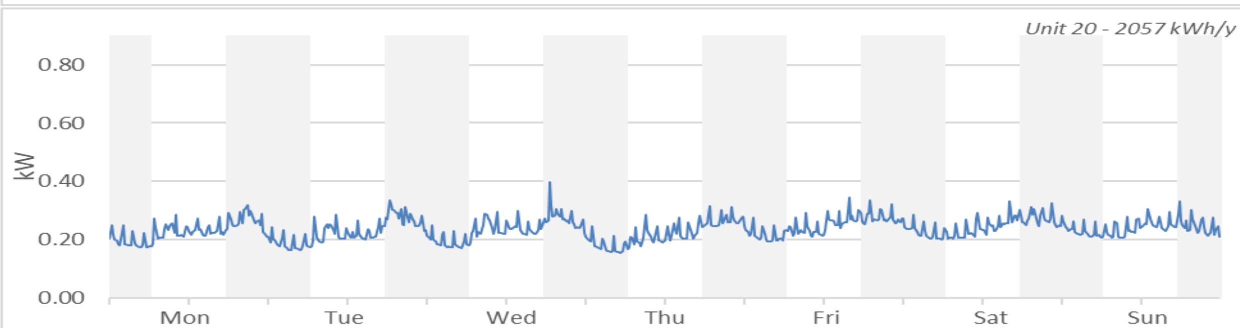

Unit 11 - 2221 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

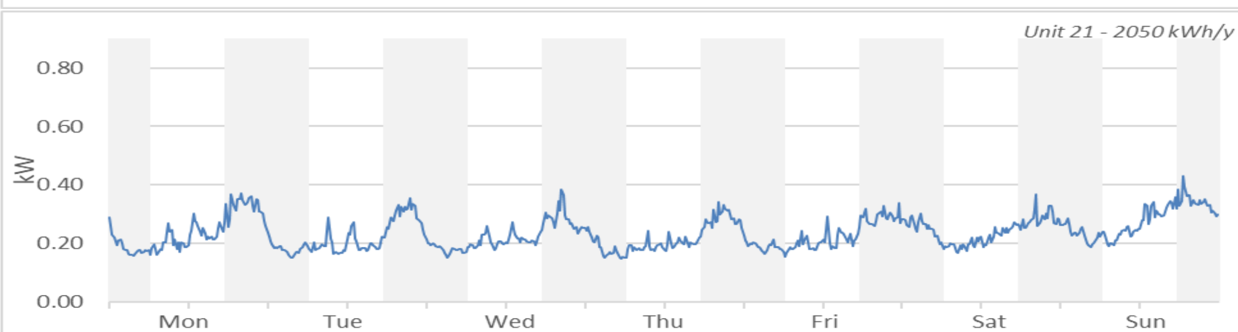

Unit 12 - 1172 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

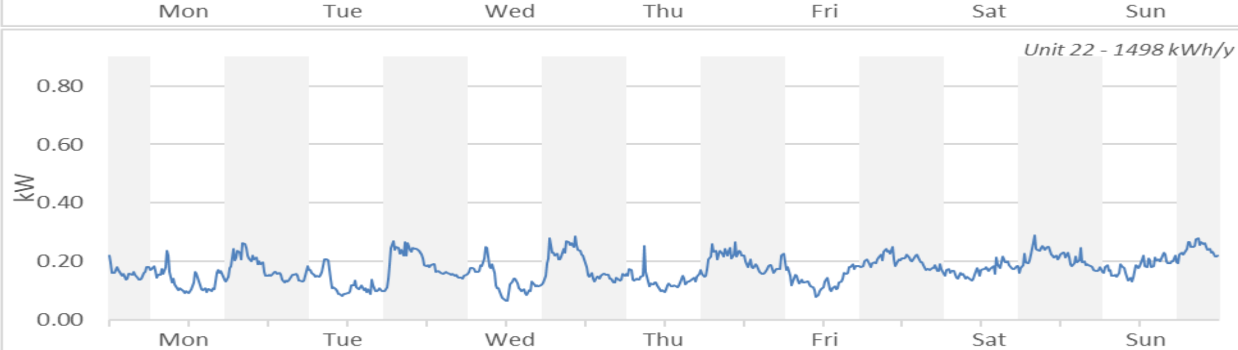

Unit 13 - 1580 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Unit 14 - 1792 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Unit 15 - 2581 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Unit 16 - 1301 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Unit 17 - 1413 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

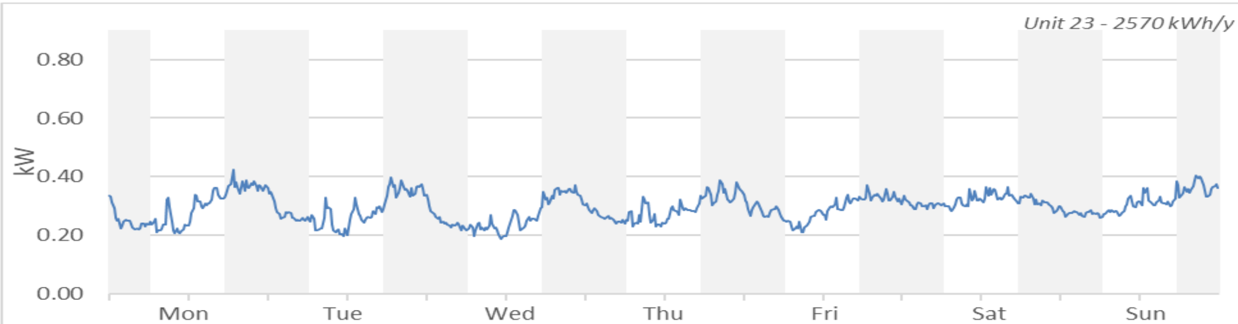

Unit 18 - 828 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

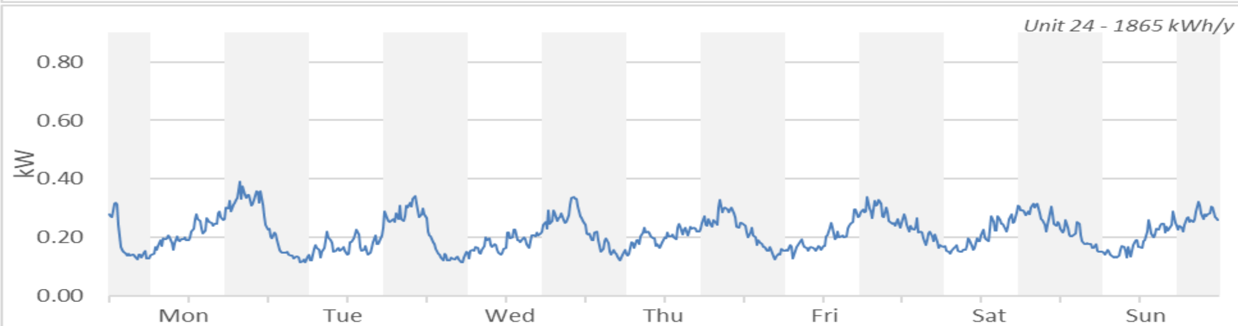

Unit 19 - 1761 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

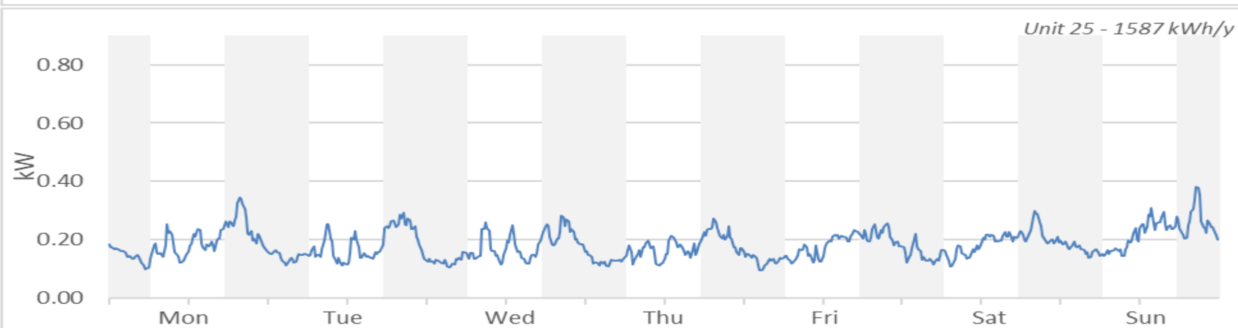

Unit 20 - 2057 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

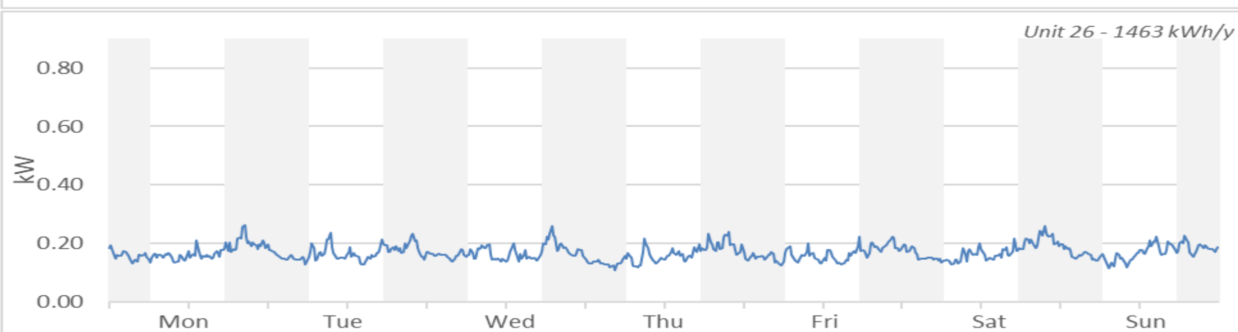

Unit 21 - 2050 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

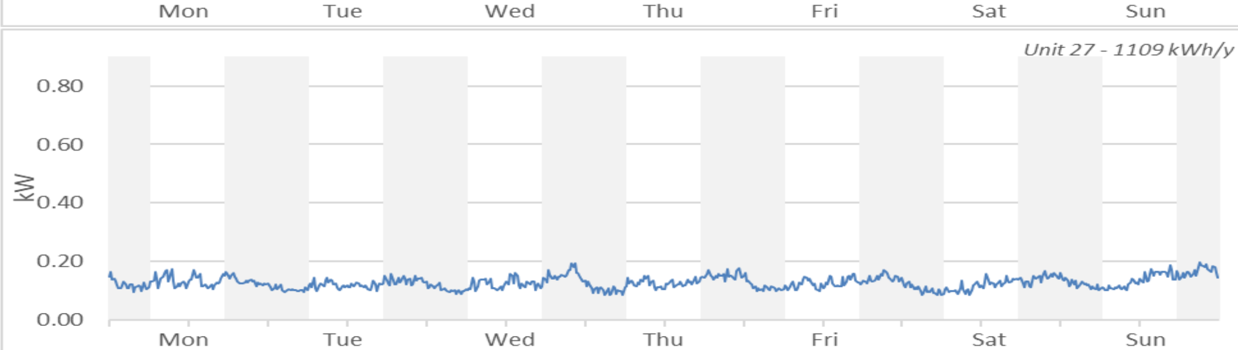

Unit 22 - 1498 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

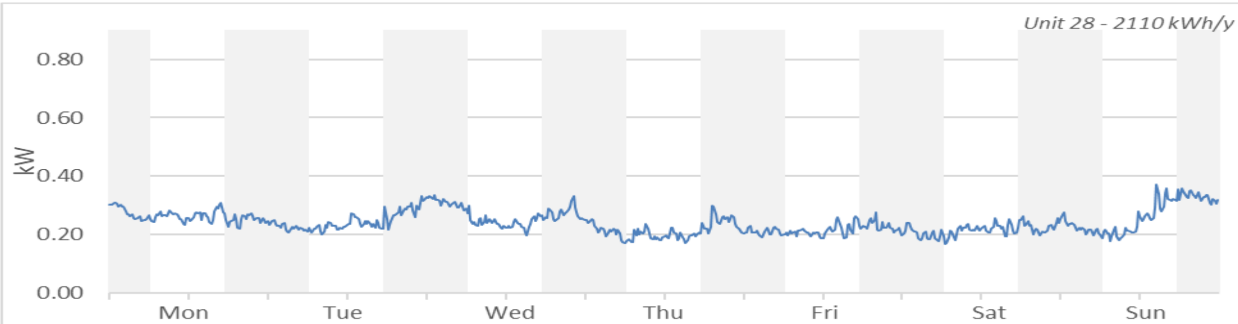

Unit 23 - 2570 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

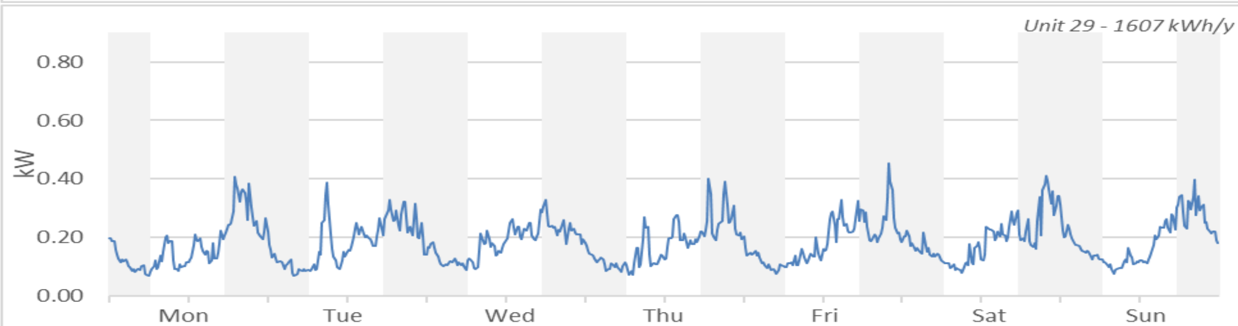

Unit 24 - 1865 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

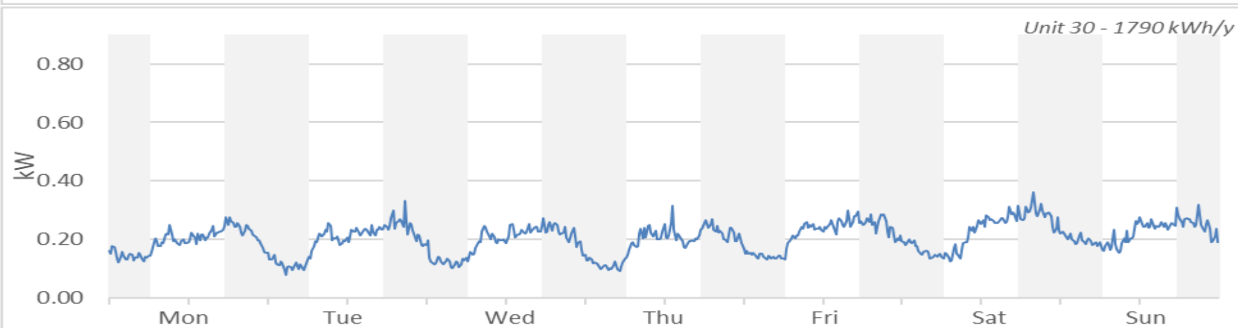

Unit 25 - 1587 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun


Unit 26 - 1463 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun


Unit 27 - 1109 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun


Unit 28 - 2110 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun


Unit 29 - 1607 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun


Unit 30 - 1790 kWh/y
kW
0.80
0.60
0.40
0.20
0.00
Mon
Tue
Wed
Thu
Fri
Sat
Sun

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov

For the Office of the Assistant Secretary of the Army (Installations, Energy and Environment)