CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Plug Load Energy Testing to Inform Codes & Standards (PLETICS)

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency; renewable energy and advanced clean generation; energy-related environmental protection; transportation; and energy transmission and distribution.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities — Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company — were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increased safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emissions in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs, first with energy efficiency and demand response, next with renewable energy (distributed generation and utility-scale projects), and finally with a clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Plug Load Energy Testing to Inform Codes & Standards (PLETICS) is the final report for Contract Number EPC-20-010 conducted by the California Energy Alliance, the California Plug Load Research Center, the California Lighting Technology Center, and California State University, Northridge. The information from this project contributes to the Energy Research and Development Division's Electric Program Investment Charge Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

The Plug Load Energy Testing to Inform Codes & Standards project, funded by the California Energy Commission, sought to identify energy efficiency opportunities in noncovered plug load devices to inform future codes and standards. The project was conducted by the California Energy Alliance and its partners, and it targeted commercial office equipment, residential networking equipment, and laboratory equipment. The project's primary objectives were to identify devices with the highest potential for cost-effective energy savings, develop standardized test procedures to quantify their energy use, and model the impact of potential codes and standards recommendations to estimate statewide energy savings.

The project found that imaging devices, such as printers and multifunction devices, could benefit from improved energy efficiency by aligning with ENERGY STAR 3.0 standards. In the rapidly growing residential networking equipment sector, the project identified gaps in energy efficiency standards for devices like modems and routers, leading to the development of a comprehensive test methodology. For laboratory equipment, the project highlighted significant opportunities for energy savings through improved design and operational features in devices such as autoclaves and centrifuges.

The outcomes of the Plug Load Energy Testing to Inform Codes & Standards project include detailed recommendations for codes and standards improvements, supported by comprehensive analyses and modeling. These findings provide a robust dataset for future adoption through codes and standards. The California Energy Commission can leverage these insights to initiate new appliance standards rulemakings starting in 2026, while utility incentive programs and local sustainability efforts can also benefit.

Overall, the Plug Load Energy Testing to Inform Codes & Standards project has laid the groundwork for significant improvements in energy efficiency for plug load devices, aligning with California's goals of promoting energy efficiency, reducing environmental impact, and ensuring economic development. The project's outcomes offer a pathway toward more efficient use of plug load devices, benefiting both consumers and the environment.

Keywords: Plug loads, energy efficiency, codes and standards, commercial office equipment, residential networking equipment, laboratory equipment, ENERGY STAR, test procedures

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Executive Summary

The Plug Load Energy Testing to Inform Codes & Standards (PLETICS) project, sponsored by the California Energy Commission, aimed to identify energy efficiency opportunities in noncovered plug load devices to inform future codes and standards. The project was conducted by the California Energy Alliance, along with partners that included the California Plug Load Research Center, the California Lighting Technology Center, and California State University, Northridge, and it focused on commercial office equipment, residential networking equipment, and laboratory equipment. The goal was to develop codes and standards recommendations and standardized test procedures for these devices.

Project Purpose and Approach

Plug loads, which include various electronic devices and appliances, account for a significant portion of residential and commercial electricity consumption in California. These devices often lack power management features and are continuously powered, contributing to energy waste and greenhouse gas emissions. The PLETICS project aimed to reduce plug load energy use through the development of device-level appliance standards. By understanding the market and the manufacturing landscape of unregulated devices, the project sought to identify new opportunities for energy savings through codes and standards.

The approach involved a comprehensive assessment of plug load devices, focusing on three major subgroups: commercial office equipment, residential networking equipment, and laboratory equipment. The project aimed to identify devices with the highest potential for cost-effective energy savings, develop test procedures to quantify energy use, and model the impact of potential codes and standards recommendations to estimate statewide energy savings and related impacts.

Key Results

Commercial Office Equipment: The project evaluated imaging devices, including printers and multifunction devices, which are not covered by mandatory energy efficiency requirements. The research identified opportunities to improve energy efficiency by aligning with ENERGY STAR 3.0 standards. The project team developed test procedures to assess energy consumption in different operational modes, revealing potential savings in low power and average energy consumption.

Residential Networking Equipment: This category includes devices like modems, routers, and integrated access devices. The project found substantial growth in this market due to increased demand for internet services. Existing voluntary agreements were assessed, and the project identified gaps in energy efficiency standards. The team developed a comprehensive test methodology to evaluate devices under various traffic conditions, providing insights into real-world energy performance.

Commercial Laboratory Equipment: The project focused on devices like autoclaves, centrifuges, incubators, and water baths, which lack mandatory energy efficiency standards. The team identified significant opportunities for energy savings through improved design and operational features. Testing procedures were developed to evaluate energy consumption under different conditions, highlighting areas for potential codes and standards development.

Knowledge Transfer and Next Steps

The PLETICS project identified significant opportunities to improve energy efficiency in plug load devices across commercial office equipment, residential networking equipment, and laboratory equipment. The project provided a robust dataset of technologies that may be considered for future adoption through codes and standards. The California Energy Commission can leverage these findings to initiate new appliance standards rulemaking by 2026. Additionally, utility incentive programs and local sustainability efforts can benefit from the project's recommendations.

The project also emphasized public participation and stakeholder engagement to ensure that research findings are incorporated into energy policy and planning decisions. The knowledge transfer activities included industry outreach events and collaboration with manufacturers and policymakers to promote the adoption of energy-efficient technologies such as commercial office networking and laboratory plug load equipment.

The project's findings provide a foundation for future codes and standards development, with the potential to achieve substantial energy savings and greenhouse gas reductions. By aligning with emerging technologies and market trends, the project supports California's goals of promoting energy efficiency, reducing environmental impact, and ensuring economic development. The project's outcomes pave the way for more efficient use of plug load devices, benefiting both consumers and the environment.

CHAPTER 1: Introduction

Plug loads are one of the fastest growing categories of energy use in residential and commercial buildings. In 2022, plug and process loads accounted for 47 percent of U.S. commercial building energy consumption (Energy Solutions, 2022). With more and more devices being brought into and used in buildings, it is expected that the total energy use for plug loads will continue to increase. Plug load devices are typically not monitored or controlled. Many of these devices have no power management capabilities and are powered continuously at full output. In addition, many of these plug loads are not regulated at the state or the federal level. Lack of effective, cost-effective appliance standards for these devices contributes to energy waste, greenhouse gas (GHG) emissions and increased costs for business owners and consumers.

One of the most effective ways to reduce plug load energy use is through the adoption of device-level appliance standards. To identify achievable energy savings opportunities, however, research must be completed to develop a market and manufacturing understanding of each unregulated device type, its subsystems, potential and existing operating modes, and range of energy use and demand. This will lead to identification of new codes and standards opportunities focused on such things as maximum power ratings, mandatory operational states (for example, sleep or standby power use) and minimum component-level efficiencies. In addition, future codes and standards (C&S) will require specification of existing test procedures or development of new test or performance verification procedures to quantify energy use and, in the future, determine code compliance.

The goal of this project was to identify noncovered plug load devices with the most potential to inform future C&S for energy efficiency or load management and develop C&S recommendations and standardized test procedures to quantify their energy use for compliance purposes.

The project objectives are to:

- Identify plug load devices with the most potential for cost-effective energy savings achieved through state-level C&S development.
- Develop test procedures, when needed, to reliably quantify energy use and related performance attributes for compliance purposes.
- Test selected plug load devices to accurately determine energy consumption in active, standby, sleep, idle, and/or other operating modes.
- Analyze test data and extrapolate results to determine specific C&S opportunities.
- Model the impact of the C&S recommendations to determine statewide savings and related impacts.

The California Energy Alliance, in partnership with the California Plug Load Center, the California Lighting Technology Center, and California State University, Northridge, conducted research over the past three years focused on currently noncovered plug loads in California. The team focused on the three subgroups with the largest opportunities for future C&S development: commercial office equipment, laboratory equipment, and residential networking equipment. Based on these subgroups, the project team: studied and quantified the energy use and performance of individual devices within each category; identified device-level and subsystem-level opportunities for energy improvements as compared to commercially available, typical performance of the product category as a whole; developed or identified relevant test procedures necessary for quantifying performance; and modeled the proposed C&S improvements to estimate statewide savings impacts over time and under various, anticipated future market conditions.

The outcomes of the Plug Load Energy Testing to Inform Codes & Standards (PLETICS) project include a comprehensive set of recommendations for the three product categories, supported by detailed component-level analyses and modeling that provides a reliable estimate of energy savings over time. The California Energy Commission (CEC) Standards Branch will be able to use these recommendations to initiate new appliance standards rulemakings beginning no later than 2026. In addition, program recommendations and other outcomes can be leveraged by utility incentive programs and other local sustainability efforts should the CEC elect to pass on any of the recommendations provided under this project.

The project benefits California investor-owned utility (IOU) ratepayers by providing cost-effective, energy efficiency improvements for commercial and residential plug loads that can be achieved through state-level appliance regulations. The benefits include power reductions for common device types, which translates to annual energy and cost savings and to GHG reductions. In addition, the project addresses the potential for inclusion of load management strategies at the device level, which can further contribute to business owner and consumer bill savings should these groups elect to participate in forthcoming real-time pricing and similar dynamic-pricing utility tariffs that are expected as part of the CEC update to its load management standards.

This project completed the following activities:

- Analyzed devices not currently covered by California or US Standards.
- Determined total energy consumption that includes standby and active modes.
- Identified devices with the most potential for cost-effective energy savings.
- Developed new or improved existing testing procedures for measuring total energy consumption for future C&S consideration.
- Determined if it’s cost-effective to control low power and idle modes compared to total energy consumption.
- Determined the ability for managing devices for load flexibility.

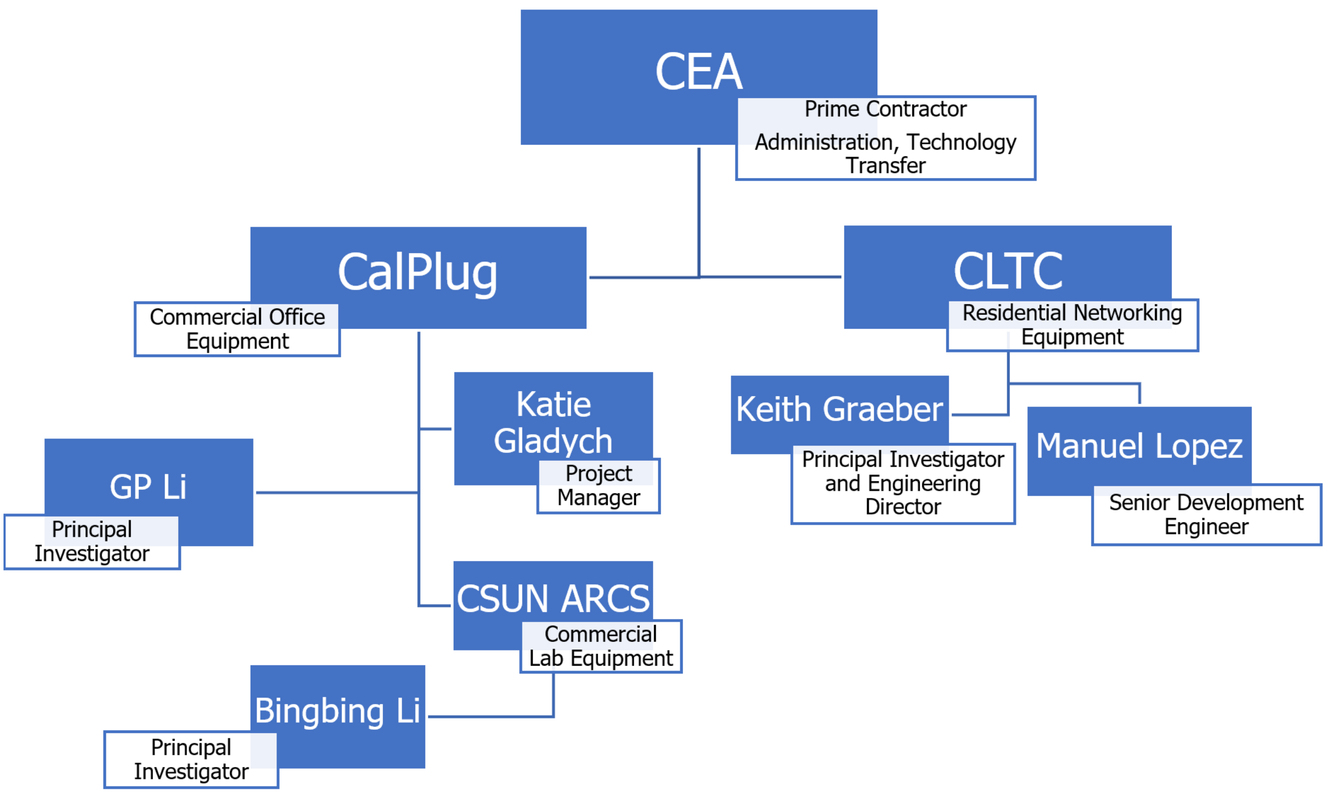
- Developed and tested improvements to plug load devices using developed test procedures.
- Developed a detailed dataset of technologies that may be considered for adoption through codes and standards.
- Justified recommendations for near-term code implementation for the tested plug load devices, including determination of cost effectiveness.

CHAPTER 2: Project Approach

Background

The PLETICS project includes the prime contractor California Energy Alliance (CEA) and subcontractors California Plug Load Testing Center (CalPlug), California Lighting Technology Center (CLTC), and California State University, Northridge (CSUN). Figure 1 shows the team organization structure. The PLETICS project evaluated the energy consumption of multiple plug load device types in various operating modes and configurations; and it quantified statewide market size and energy use to determine potential savings associated with their inclusion in futures energy codes and standards. The device types identified for this project include commercial office equipment, residential networking equipment, and laboratory equipment.

Figure 1: PLETICS Project Team



Source: California Energy Alliance

The project team evaluated devices from its three selected subgroups based on device energy consumption, product shipment and installed base information, market penetration of relevant ENERGY STAR products, and market growth potential. Products within these device categories were subjected to rigorous market and laboratory analysis to identify new opportunities for operational state energy savings (for example, sleep or standby power use), component efficiencies, and maximum power draw, and development of standardized test procedures for evaluating savings. Impacts of potential codes were estimated through modeling that considered market factors and new device adoption (due to market turnover). The effect of connectivity on power consumption for networked devices was also considered, as were opportunities to enable automatic load flexibility at the device level so that products are well positioned for the CEC's forthcoming load management standards.

At the project's conclusion, deliverables for each subgroup included proposed energy efficiency and other performance improvements, load management strategies, test procedures to inform future codes and standards efforts, and knowledge and technology transfer implementation for manufacturers, policymakers, and other stakeholders. Test methods have been developed and verified for repeatability in differing testing setups and assessed for relevancy across categories to support future C&S directives.

Subgroups and Device Analysis

To supplement the project team's expertise and existing knowledge, it performed a preliminary review of: relevant devices; existing C&S, including voluntary programs; and related market drivers. The project team's decision to pursue the three subgroups previously stated relied on multiple considerations and market factors. Key points are summarized below.

Commercial Office Equipment

Most devices under this subgroup are certified under ENERGY STAR 2.0 or 3.0 as part of the Imaging Devices product category. There is a gap where elements of 2.0-certfied products could be brought up in efficiency by complying with 3.0 requirements. This provides a potential opportunity for California to improve the energy performance of all devices in this subgroup by requiring that they comply with performance levels similar to ENERGY STAR 3.0. With respect to specific multi-function devices, such as multi-function copiers (MFC), market growth is expected, along with a related decrease in single-service alternatives. In the case of MFCs, standalone printer sales within California are expected to decrease; market turnover rates for these devices is yet to be determined.

The project team also identified potential opportunities with respect to specialized devices such as label printers, receipt printers, new-generation point-of-sale printers, and barcode marking devices. The influx of these devices within the California market is due primarily to the recent market availability of low-cost, imported devices catalyzed by the growth of online retailers that require product tracking and inventory tools. There are potential standardization opportunities related to sleep-mode controls and standby power with these products, especially related to document processing and networking functions that keep devices in active mode even when not in use.

CalPlug, with its extensive direct experience with consumer electronics, was the subcontractor tasked with the Commercial Office Equipment subgroup.

Residential Networking Equipment

Use of residential networking equipment (RNE) is expected to grow substantially over the coming years. Due to current environmental, economic, and health issues facing California and the country, people are spending more time at home and indoors. The demand for internet services, "internet of things" devices, and the networking equipment to enable these systems and services is high. Product prices are dropping; however, no existing codes and standards apply to this subgroup, and vendors are flooding the market with a range of products with varying quality, features, and performance. Given current and expected demand, this subgroup offers a lot of C&S opportunity. Existing ENERGY STAR programs and test procedures can be leveraged at the state level to ensure that only high-quality products are available for the California market.

CLTC, with its extensive experience evaluating these products as part of emerging technology demonstrations, product development, and related research efforts, was tasked with the Residential Networking Equipment subgroup.

Commercial Laboratory Equipment

Currently, there are no appreciable mandatory or voluntary C&S programs or requirements for commercial laboratory equipment. There are some standards for laboratory refrigerators and freezers; however, no state or federal standards or no ENERGY STAR category exist for other device types within this subgroup. This subgroup contains a large unexplored field with many opportunities to improve device efficiency and performance including reduction of overall standby load and inclusion of mandatory energy-saving modes of operation.

CalPlug brought on CSUN to complete the research tasks for this subgroup, since it is well versed in the use and evaluation of laboratory equipment common to this subgroup.

Project Focus

The project team targeted the three subgroups highlighted above because these are the three with the largest codes and standards opportunities now and in the near future. The following shows which device group each subcontractor leads, with CEA managing the overall project deliverables and timeline:

- Commercial Office Equipment – CalPlug
- Residential Networking Equipment – CLTC
- Commercial Laboratory Equipment – CSUN

The project schedule spanned over three years, from March 2021 to September 2024. During Year 1, the project team conducted all the required market and product assessments necessary for categorizing products within each selected subgroup according to architecture and features. This work ensured that commonalities were identified and variances in product performance were attributed to specific root causes. The outcome of Year 1 activities defined a roadmap for Year 2 testing and evaluation, which included the specific products tested, the specific performance attributes quantified, and the individual performance thresholds characterizing the standard and best-in-class product clusters and devices.

During Year 2 and Year 3, the project team conducted all necessary product testing to include multiple samples of each device. This work served to identify the energy-consuming components of each device, as well as those components with the largest opportunity for improvements in energy performance. Following this work, the team tested multiple units of each device to generate common ranges of performance and verify that improvements are replicable across multiple device types within a given subgroup.

The outcomes from Year 3 testing were used to develop product test procedures and C&S recommendations for each device type. All project data, analyses and recommendations are combined in this final project report, validated through multiple reviews with the Technical Advisory Committee for the project and shared with industry as part of technology transfer activities.

To gather feedback and share knowledge from the project findings, CEA managed and focused on industry outreach events and activities typical within the manufacturing and the codes and standards community.

Overall Research Methods and Objectives

The PLETICS team tackled this project using the following methods for each major task. When completed, each task constitutes a milestone and major deliverable for the project. The overall research methods and objectives for the PLETICS project are discussed in the following tasks. Each task pertains to all device subgroups.

Task 2: Preliminary Market Assessments and Product Selection

The goal of this task was to assess the three selected device types of commercial office equipment, residential networking equipment, laboratory equipment and to create a plan for the evaluation of energy savings opportunities and device sourcing. This included device review and assessment; segmentation and analysis; and development of a market assessment report with Technical Advisory Committee feedback.

The project team used the methods described in Task 2.1 and Task 2.2 to complete device review and market analysis.

Task 2.1: Device Review and Assessment

The project team leveraged prior work completed outside of this agreement by conducting a deep evaluation into the three specified subgroups to verify category breadth and common feature sets. Task 2.1 research included examining the current and projected future market for these devices and reviewing past and present domestic and international codes and standards, manufacturer voluntary agreements, and government-mediated voluntary agreements/labeling programs.

Task 2.2: Device Segmentation and Analysis

For each of the three plug load subgroups, the project team categorized and segmented the market to identify representative devices and models based on common features. The team used this information to collect energy and other relevant information on each device type to develop a representative model of each particular product category, its energy use, and its energy savings potential.

Highlights from Task 2 can be found in Chapter 3 of this report, and the key deliverables include: an initial Device Type List and the Plug Load Devices; a Market Assessment and Energy Savings Opportunities Report that identifies preliminary energy usage, device clusters, common features that impact energy use, and recommendations for relevant codes and standards (see the Project Deliverables section of this report).

Task 3: Develop Product Test Procedures

The goal of this task was to develop procedures for testing the three plug load device types and models identified and selected under Task 2. Considerations included common subsystems contributing to energy use within each device type and opportunities for savings at the device level, which can be achieved by adopting commonly available architectures, components, or operating modes.

The project team used the methods described in Task 3.1 through Task 3.3 to complete test planning, test procedure development, and source the devices to be tested in Task 4.

Task 3.1: Plug Load Device Testing – Planning

The project team developed a list of potential investigation points for evaluation of selected plug load devices. The list of potential test elements included energy-related factors in design, workflow, and usage of device subsystems common to each device type/product category. The team compared manufacturing designs and approaches and selected device performance thresholds that can be achieved using commonly available methods. For each component, the project team developed preliminary savings opportunities and test methods to quantify energy use and savings for both components and operating strategies.

Task 3.2: Test Procedure Development

The project team selected devices based on considerations developed in Task 3.1 and developed test procedures on a per-device-type basis but common to all devices within the same category. Testing included a functional usage period and a subsystem investigation. Values such as energy use in different modes as well as total energy use and switching states based on user's typical action (or inaction) were recorded.

Task 3.3: Device Sourcing

Based on results of previous tasks, the project team selected and procured specific devices for testing. Additional sample devices would also be purchased; where possible, this stage of testing would be conducted on rented equipment or currently owned devices in situ to reduce costs.

During this phase, the PLETICS team developed proposed testing procedures for each device group to guide the testing phase of the project. The proposed test procedures were reviewed by the Technical Advisory Committee and recommendations were incorporated into final test procedures. Throughout this phase of the project, the PLETICS team identified devices that could be tested in situ on university campuses and ones that need to be purchased. The team chose a final list of devices to test based on current market availability and started the purchasing process.

Highlights from Task 3 can be found in Chapter 3 of this report, and the deliverables include a Plug Load – Component Opportunities and Potential Savings Report, a Proposed Test Procedures for Plug Load Devices report, and a Product Test List and Inventory (see the Project Deliverables section of this report).

Task 4: Product Testing and Analysis

The overall goal of this task was to test the selected devices, analyze results, identify opportunities for C&S according to the test results, and model the energy impacts of code change recommendations to understand statewide impacts.

The project team used the methods described in Task 4.1 through Task 4.3 to complete device testing, to analyze results from the testing of each device group, and to develop recommendations for future C&S.

Task 4.1: Device Testing

The project team created test reconfiguration procedures and apparatuses, and specific device test automation processes and setups for each plug load device type. The project team completed the testing developed in Task 3. There were some differences observed across devices, and these were evaluated for root cause and noted in the results analysis.

Task 4.2: Results Analyses

The project team analyzed the test data for commonalities and differences among tested samples across each device type/product category and performed a gap analysis on the results to assess specific device features and components that differ, and which may be opportunities for new C&S. For device types or products where no variation in energy performance existed, the project team considered other opportunities to promote quality products such as labeling or manufacturer voluntary agreements to develop new and improved device features.

Task 4.3: Model Measures and Estimate Savings

Following testing and C&S development work, the project team incorporated C&S recommendations for each device type/product category into a market model that considered future levels of device replacement and growth for the current installed device base to determine energy savings potential and it reported the results.

For Task 4, the project team validated and confirmed testing methods and protocols for the devices, performed specified testing using the final procedures developed under Task 3.2, and created a Device Test Results report. Additionally, the project team analyzed the test data for commonalities and differences among tested samples across each device type and performed a gap analysis on the results to assess specific device features and components that differ, and which may be opportunities for new C&S. The team then incorporated C&S recommendations for each device type.

Highlights from Task 4 can be found in Chapter 3 of this report, and the deliverables include the Device Test Results report, the Final Technical Report on Testing Procedures for Plug Loan Devices, and the Plug Loads – Codes & Standards Impacts Report (see the Project Deliverables section of this report).

Tasks 5 and 6

In addition to the above tasks, the PLETICS team completed activities that included Benefits Questionnaires and Knowledge Transfer activities. The goal of these tasks was to ensure that the scientific and techno-economic analysis and tools developed under this agreement are utilized in the energy policy sector, and/or in connection with planning decisions at the state and/or local levels, in the academic community, and/or the commercial sector. These activities included:

- Industry feedback and development
- Stakeholder education
- Utility program assessment and development
- Codes and standards development.

A Knowledge Transfer Summary Report was developed to highlight the activities, results, and lessons learned from tasks performed relating to implementing the Final Knowledge Transfer Plan.

CHAPTER 3: Results

The PLETICS research team followed the approach laid out in Chapter 2 to conduct a market assessment, test procedure development, and test devices for all subgroups. The key results from these activities are detailed in the following sections. Additional details and results for deliverables from each subtask can be found in the Project Deliverables section of this report.

Task 2: Market Assessment and Product Selection

The CEC's mandate for this project was to assess devices not currently addressed by state regulations for which energy savings potentials could be identified, beyond any existing voluntary agreements or labeling requirements. The project team selected three product categories for evaluation: commercial office equipment, residential networking equipment, and laboratory equipment. For each category, the team developed a device selection database listing relevant devices for further examination and selection. Information collected for the spreadsheets included relevant aspects of energy usage, such as: unit energy consumption (UEC), or the annual energy consumed by a single device; average energy consumption, or the annual energy consumed by a device make and model multiplied by the installed base; and estimated standby load, or energy consumed while the device is in low power mode and/or not being used for its primary function. Other considerations included market assessment information such as product installed base (number of devices in operation in a given territory) and market trajectory or compound annual growth rate (CAGR), defined as the projected percentage growth over baseline during a specified timeframe. The team also considered the practicality and availability of each product type relevant to project scope of work and budget constraints.

At this project stage, information was sourced through a literature review of academic publications, market research analyses, and product nameplate information supplied by manufacturers and labeling programs such as ENERGY STAR®. Based on a holistic assessment of parameters relating to energy consumption, device prevalence and market growth potential, and feasibility for this project, the team identified the top five device types for each category for testing. The main goal was to target devices that are most likely to have significant energy savings opportunities, while also being relevant for future codes due to expected market penetration.

Commercial Office Equipment

Device Review

Many office devices are already regulated through federal code and California Title 20, such as computers, servers, monitors, and televisions/screens. This leaves imaging devices as the only common office devices that are not covered by mandatory energy efficiency requirements and that have sufficient energy consumption to consider. For the purpose of this report, imaging equipment includes products that print, scan, and/or copy, including all-in-one multifunction devices. The ENERGY STAR Imaging Equipment Program (Version 3.2) serves as a non-obligatory labeling guide to help consumers identify energy-efficient products in this category.

The selected five device types are shown in Table 1. These include desktop commercial inkjet and laser standalone printers, desktop commercial inkjet and laser multi-function devices (MFD), and large (floor-stand) laser MFDs. While large inkjet MFDs do exist, general models are uncommon; most large inkjet devices are specialized (for example, for poster printing).

The data in Table 1 show that, while standard-sized equipment has become much more efficient over the past decade, very-high-capacity devices still have relatively high unit energy consumption. Thus, one aspect of this project would be to assess opportunities for improving energy efficiency of these products.

Table 1: Selected Commercial Office Equipment

Laser Printers

Device Type – TEC Method (EP)	Speed/Images per Minute (ipm) (ENERGY STAR categories)	UEC: TEC (kWh/yr) (Ranges per ENERGY STAR QPL)	Market Size ($ Millions)	Compound Annual Growth Rate (CAGR) 2021-2026
Monochrome Non-MFD	s ≤ 20	< 20	39,208 (All lasers)	3.6% (All lasers)
	20 < s ≤ 40	8.84 - 27.04		
	40 < s ≤ 60	18.2 - 46.28		
	60 < s ≤ 135	37.44 - 47.84		
	s > 135	>900		
Monochrome MFD	s ≤ 20	<15		
	20 < s ≤ 40	9.88 - 30.68		
	40 < s ≤ 60	20.8 - 49.92		
	60 < s ≤ 80	35.88 - 76.96		
	s > 80	75.4 - >100		
Color Non-MFD	s ≤ 20	17.68		
	20 < s ≤ 40	10.92 - 38.48		
	40 < s ≤ 60	22.88 - 45.76		
	s > 60	> 452		
Color MFD	s ≤ 20	9.88 - 10.4		
	20 < s ≤ 40	12.48 - 32.76		
	40 < s ≤ 60	23.92 - 50.44		
	60 < s ≤ 80	53.04 - 447.2		
	s > 80	>500		

kWh/yr=kilowatt-hours per year
Sources: EPA, 2022a; Technavio, 2022

Inkjet Printers

Device Type	Speed (ipm) (Ranges per ENERGY STAR QPL)	UEC: Power in Sleep Mode (W) (Ranges per ENERGY STAR QPL)	Market Size Estimate 2026 ($ millions)	CAGR 2021-2026
Monochrome Non-MFD	20-24 ipm	0.6 - 0.9	13,854 (All inkjets)	3.3% (All inkjets)
Monochrome MFD	20-24 ipm	0.6 - 1.1		
Color Non-MFD	01-25 ipm	0.5 - 1.6		
Color MFD	04-10 ipm	0.2 - 4.3		

Sources: EPA, 2022a; Technavio, 2022

Codes and Standards Analysis

There are several voluntary agreements (VA) and labeling programs identified for commercial office equipment, including imaging devices such as laser and inkjet printers and MFDs. In the United States, ENERGY STAR Version 3.0 and the EPEAT label (Electronic Product Environmental Assessment Tool, conforming to IEEE [Institute of Electrical and Electronics Engineers] Standard 1680.2) are the main programs pertaining to energy efficiency and, in the case of EPEAT, to non-energy environmental and life cycle standards. In Europe, the European Union Industry Voluntary Agreement (EU VA) and the German Blue Angel ecolabel adhere to and build upon U.S. EPA ENERGY STAR label requirements. Until recently, the EU VA also followed ENERGY STAR. However, in March 2022, the European Commission (EC) rejected the most recent version of EU VA, opting instead to pursue formalized code requirements for imaging devices. The project team is monitoring the development of EC codes and associated test methods and plans to update the research when these are published. Additionally, international standards such as IEC (International Electrotechnical Commission) 62301, ed. 2, and EN50643 provide requirements and test methods for standby power consumption for networked office equipment.

The national and international agreements and programs relevant to commercial imagining devices are shown in Table 2, along with the devices covered by each. Details regarding limits, allowances, adders, and requirements set forth by these VAs, programs, and standards are summarized in the Codes & Standards Comparison Matrix.

Table 2: Voluntary Agreements, Labeling Programs, and International Standards for Imaging Devices

Name	Type	Region/ Country	Year Last Updated	Devices Covered
ENERGY STAR® Product Specification for Imaging Equipment Eligibility Criteria Version 3.1	Label	Worldwide	2019	Printers, MFDs, scanners, digital duplicators, mailing machines, and

Name	Type	Region/ Country	Year Last Updated	Devices Covered
				professional imaging products (industrial printers)
EPEAT Ecolabel Conforms to: IEEE Standard for Environmental Assessment of Imaging Equipment Amendment 1 1680.2a™-2017 (Amendment to 1680.2™-2012)	Label	U.S., used in multiple other countries	2017	Printers, MFDs
Blue Angel - The German Ecolabel Office Equipment With Printing Function (Printers and Multifunction Devices)	Label	European Union	2017	Products with printing as the primary function; capable of printing monochrome or color; either inkjet or electrophotographic (EP)/laser print deposition
IEC 62301 Ed. 2.0 b:2011 Household Electrical Appliances – Measurement of Standby Power	Standard	Worldwide	2011	Electrical products with a rated input voltage or voltage range that lies wholly or partly in the range of 100V to 250V for single-phase products and 130V to 480V for other products
BS EN 50643:2018+A1:2020 Electrical and electronic household and office equipment. Measurement of networked standby power consumption of edge equipment	Standard	European Union	2018	Specifically refers to household appliances, information technology products, consumer electronics, audio, video, and multimedia systems. However, methodology may be applied to other electronics.
European Commission Regulation No. 1275/2008 of 17 December 2008,	Standard	European Union	2008	All electrical and electronic household and office equipment

Name	Type	Region/ Country	Year Last Updated	Devices Covered
implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment				
European Commission Regulation No. 278/2009 of 6 April 2009, implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign require-ments for no-load condition electric power consumption and average active efficiency of external power supplies	Standard	European Union	2009	External power supplies

Source: CalPLug

An ENERGY STAR label conveys that the product meets certain minimum requirements. ENERGY STAR maintains a qualified product list for imaging devices on its website, which includes intelligent power management and sleep mode energy usage of approved products. The EU VA requires manufacturers to provide information to the end user about energy consumption (in practice, the same data available from ENERGY STAR), enabling detailed comparison across products. The EU VA and the Blue Angel label require manufacturers to provide information and data sheets on energy consumption of the product to end users.

The EU VA requires signatories to submit annual "energy consumption reports" that include data on the total energy consumption of operational mode (OM) units and of typical energy consumption (TEC) units placed on the market each year (see EU VA section 8.3). This information is assembled by an independent inspector and is published in an annual energy usage report for the EU market. The EU VA functions as a de facto legislative requirement, and therefore it also has auditing and investigation mechanisms for verifying compliance.

The different approaches considered here formed the foundation of the PLETICS team's approach to informing the CEC on potential areas of exploration for future California Title 20 code cycles.

Device Selection

Devices in this category would be selected based on a combination of existing inventory (imaging devices available to test at the University of California, Irvine [UCI] and the University of California, Davis) and externally sourced products. For the inventories of devices, the research team collected all available data on the features identified in the earlier section, primarily through operating manuals. The externally sourced devices were chosen based on 1) their ability to fill gaps in the range of products that the project team already had access to, and 2) the popularity and market availability of representative products, as determined by market research reports and sales data. Commercial grade equipment in these categories is often leased rather than purchased; to save costs, devices would be rented (short-term) whenever possible. The final device list for testing is detailed in the Task 3 section of this chapter.

Residential Networking Equipment

Device Review

As with commercial office equipment, there are limited individual device types in the RNE category that are relevant for the current project scope. Residential networking equipment, or small network equipment (SNE), enables internet connection (typically broadband) and wireless functionality to pass between the internet service provider and the individual home or apartment building. SNE comprises the wide area network system, consisting of a broadband modem or integrated access device (IAD), and an optical network terminal (ONT). IADs, modems, and/or ONTs are usually provided as rental equipment from the internet service provider, but some residential users purchase equipment independently through traditional retail channels. The wide area network provides two-way connection between the internet service provider and the home local area network (LAN). Some residential users install additional local network equipment such as routers, range extenders, switches, access points, and Wi-Fi mesh systems to enhance the quality and range of the LAN (Dayem and Granda, 2020). SNEs are covered by an industry-led VA in the United States, which currently operates in lieu of formal federal or state regulation.

Considering the installed base, market growth potential, and opportunities for energy savings, the research team selected modems, IADs, routers, range extenders, and ONTs as primary devices for inclusion in enhanced energy-efficiency test procedure development. Installed base and UEC for the selected RNE categories are shown in Table 3. IADs are the most rapidly growing category in RNE over the last 10 years and recent studies show an installed base of 99 million. The growth of IADs and their prevalence in internet service provider stock have pushed the installed base of modems and routers downwards in recent years, but both categories still have a substantial 61 million units installed, according to the most recent reports, and they are favored over IADs by advanced users because they allow for easier upgrades and, often have more advanced capabilities. Optical network terminals and range extenders are both relatively new and growing categories. Optical network terminals are expected to grow substantially once more widespread adoption of fiber optic within homes occurs.

Table 3: Selected Residential Networking Equipment

Device	UEC	Installed Base	CAGR
Integrated Access Devices (IAD)	121 kWh/yr	99 million	4.4% 2022-2026 (for Global Networking equipment market)
Modem (DSL)	70 kWh/yr	6 million	
Routers (wireless)	59 kWh/yr	53 million	
Range Extenders	23 kWh/yr	2 million	
Optical Network Terminal (ONT)	142 kWh/yr	6 million	

Sources: 360Research, 2022; Urban et al., 2017; Horowitz, 2013

Wi-Fi mesh routers were also considered. However, this is still a relatively new technology and, while it is growing in market share, the current lack of available data on energy consumption makes addressing this device type premature given the requirements of the current project. Also, Wi-Fi mesh devices should ideally be tested at the system level rather than the individual device level, making them beyond the scope of PLETICS.

Codes and Standards Assessment

For residential networking equipment there are/have been a variety of existing codes and standards, including ENERGY STAR. However, participation within these codes and standards vary. While the ENERGY STAR program struggled to gather participation, eventually leading to the program ending, the Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Small Network Equipment has shown increasing participation throughout the last five years. This has caused Canada to recently adopt an identical VA as well. Compared to the ENERGY STAR procedure and the European Union Code of Conduct (EU CoC), the VAs characterize the unit under test (UUT) to a lesser extent, looking at a device solely in “idle” mode, and this could equate to missed opportunities for energy savings for products. However, industry experts noted that the VAs’ defined idle mode is an accurate reflection of how most SNE devices spend a significant amount of time, whereas the defined active mode in the EU CoC is unrealistic.

Table 4 summarizes the relevant agreements, standards, and test methodology for residential networking equipment. Most of these documents cover all five of our device types of interest but the VAs omit the regulation of ONTs. Further details regarding limits, allowances, adders, and requirements set forth by these VAs, programs, and standards are summarized in the Codes & Standards Comparison Matrix.

Table 4: Voluntary Agreements, Labeling Programs, and International Standards for Residential Networking Equipment

Name	Type	Region/Country	Year Last Updated	Device Types Covered
ENERGY STAR Product Specification for SNE Version 1.0	VA and Test Methodology	Open to North American, Taiwan, Europe, Australia, New Zealand, and Japan markets	2014	IADs, routers, modems, ONTs, range repeaters
Voluntary Agreement for Ongoing Improvement of SNE	VA	United States	2020	IADs, routers, modems, range repeaters
Code of Conduct on Energy Consumption of Broadband Equip-ment Version 7.0	Standard	European Union	2019	IADs, routers, modems, ONTs, range repeaters
Canadian Voluntary Agreement for SNE	VA	Canada	2020	IADs, routers, modems, range repeaters
ANSI/CTA-2049	Standard, Test Methodology	No Limitations	2020	IADs, routers, modems, ONTs, range repeaters

Source: California Lighting Technology Center

When assessing additional saving opportunities not covered by existing standards, the research team proceeded by comparing EU CoC-compliant products to VA-compliant products with comparable features. This helped the project team identify the relevant energy efficiency differences, if any, between the two codes. From there the team assessed whether additional restrictions or allowances based on these comparisons could benefit California C&S.

In addition, the team compared VA-compliant products with different features to each other to see if the allowances for various features were appropriate for devices or if they should be changed due to actual power draw from additional features. While the test procedure may be sufficient, the team could analyze whether the power allowances for each feature were appropriate and could identify features that may not be covered in the VAs but significantly influence power draw.

Device Selection

Selected RNE products are listed in the final device list in the Task 3 section of this chapter and is paired in the RNE features matrix. The matrix contains listed values for every relevant feature that has been elaborated on. Various features do not apply to certain device types and are listed as "N/A to device type" within the matrix. The products were selected based on creating a subsample of systems covering a variety of features that could improve energy efficiency. Furthermore, products were prioritized based on buyer popularity and voluntary agreement listings.

Commercial Laboratory Equipment

Device Review

In contrast to commercial office equipment and residential SNE, laboratory equipment spans a wide range of device types and functionalities. Only refrigerators and freezers have a dedicated ENERGY STAR program, and laboratory devices are not subject to any energy efficiency requirements under California state law or federal law. This leaves the majority of devices open to new test procedure development.

From an original list of 28 different device types, the research team selected floor-stand top-loading autoclaves, benchtop general purpose centrifuges, benchtop incubators, floor-stand incubators, and general-purpose water baths as the top five most relevant products for PLETICs. As shown in Table 5, these devices have reasonably high UEC estimates, broad distribution throughout different types of labs, product availability, and notable opportunities for energy savings through the adaptation of power management features and other best-in-class efficiency functions.

Table 5: Selected Laboratory Equipment Overview

Device	UEC	Installed Base	Market Share	CAGR
Floor Stand Autoclave	11,700 kWh/yr	16,000 (Calif.)	99% of all autoclaves	7% 2020-2024 (Global general laboratory equipment market)
Benchtop Centrifuge	91 kWh/yr	76,000 (Calif.) 740,000 - 1.49 million (U.S.)	60% of all centrifuges	
Benchtop Incubator	262 kWh/yr	60,000 (Calif.) 560,000 - 1.1 million (U.S.)	25% of all incubators	
Floor Stand Incubator	3,723 kWh/yr		75% of all incubators	
Water Bath	3,850 kWh/yr	52,000 (Calif.) 440,000 - 890,000 (U.S.)	80% of all water baths	

Sources: Nash, 2021; Paradise, 2015; Technavio, 2020

The team excluded laboratory-grade refrigerators and ultra-cold freezers, because while they do consume high amounts of energy, they must be left on at all times. The nonprofit My Green Lab (MGL) completed and published a thorough, definitive study of the efficiencies of ultra-low temperature laboratory freezers. Additionally, one way to further improve energy efficiency of low temperature storage is to set these units to -94 degrees Fahrenheit (°F) (-70 degrees Celsius [°C]) instead of -112°F (-80°C). That is often not done due to concerns about undetected failure. In that case, the question of whether a Stirling-cycle, ultra-low freezer has a higher reliability than a dual-compressor conventional refrigerant freezer is very pertinent, and Stirling lab freezers have been in wide use long enough to quantify their reliability, although it may not seem to be part of an "efficiency" evaluation. Similarly, whether an ultra-low freezer has effective, no-delay communications technology may determine whether users use the -94°F (-70°C) energy-saving recommendation. In this case, the net efficiency results are part mechanical, part behavioral, and risk-driven (or perceived risk-driven). This "always on" feature, combined with the fact that ENERGY STAR has already implemented a test method for laboratory refrigerators and freezers (Version 1.0) leaves almost no additional opportunities to improve energy savings outside of improvements in refrigerants and other manufacturer-level component redesigns, which are beyond the scope of this project. Similarly, fume hoods were not included because the main energy savings mechanism for these products is variable speed drive fans controlling the exhaust system, which are regulated separately through California Title 24 and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1, beyond the scope of plug load appliance efficiency.

The laboratory equipment category is also unique, in that project feasibility played a much larger role in ultimate device selection than in the other two categories. The research team consulted with laboratory experts and with a company that sells these products to estimate which device types, sizes, and subtypes were most commonly used. The team excluded fewer common types of centrifuges and other highly specialized, difficult-to-source lab devices. This criterion speaks to both the energy savings potential of addressing more common devices and also to the team's access to devices for testing during this project, given the prohibitive expense of purchasing new equipment in this category. The choice of equipment readily accessible to staff in multiple university research and medical labs at UCI and CSUN not only greatly reduced the cost of testing devices but also offered the researchers the opportunity to test products in situ, as they would be used in normal day-to-day operations.

Finally, some devices such as microscopes, grow lamps, vortex mixers, scales, shake tables, and hot plates either had too low individual UEC values or were not common enough across labs to be considered within the prioritized list of products with the most immediate potential to benefit from statewide codes and standards.

Codes and Standards Assessment

Out of the selected five commercial lab equipment, only autoclave has the developing standard testing method proposed by MGL in partnership with the National Renewable Energy Laboratory (NREL), as shown in Table 6. The testing method will be used to engage manufacturers in Accountability, Consistency, and Transparency (ACT)-labeling of autoclaves.

MGL also conducted some preliminary studies on commercial lab refrigerators/freezers, biosafety cabinets (BSCs), and microscopes. For the freezer, MGL recommends defrosting freezers and vacuuming coils on freezers and refrigerators, creating an inventory for cold storage units, adjusting set points on -112°F (-80°C) freezers to -94°F (-70°C), eliminating unneeded samples, sharing space with colleagues, and using room temperature sample storage whenever possible.

For the cabinets, MGL recommends turning off BSCs when not in use. BSCs can consume 15 kWh/day — about half of the energy consumption for a house. If one is working on a BSC with an ultraviolet (UV) light, UV sterilizers need only be turned on for 30 minutes at most in the tissue culture (TC) hoods. Leaving UV light on for longer can lead to the breakdown of any plastics in the hood, and it can affect people working in the area. Many recent models of TC hoods have timers on them to ensure that the UV light is turned off after 30 minutes.

For the microscope, MGL recommends light engines, LEDs, and solid-state devices, which are all better choices than mercury and metal halide light sources for microscopes. Not only do they not contain mercury, but they also use significantly less energy (considering the amount of heat put out by a mercury bulb; most solid-state devices work at room temperature).

Table 6: Voluntary Agreements, Labeling Programs, and International Standards for Laboratory Equipment

Name	Type	Region/Country	Year Last Updated	Devices Covered
My Green Lab	ACT Label	United States	TBD	Autoclave

Source: California State University, Northridge

MGL concluded that attempts to quantify the resource use by autoclaves have been sporadic and, unfortunately, not complete and universal enough in order for purchasers, organizations, scientists and engineers to truly understand the water and energy costs that will be associated with certain models or designs. Case studies are often well-intentioned but unable to provide the necessary consistency required for comparative conclusions. For example, the number of hours an autoclave is run does not correlate to the number of cycles; thus, one cannot directly compare between studies using inconsistent parameters. There is a need for a standardized system of resource quantification to assist buyers in purchasing the most resource-efficient model that fits their specific needs.

Device Selection

Devices in this category were selected based on a combination of existing inventory (commercial lab equipment available to test at CSUN, the Terasaki Institute for Biomedical Innovation, and UCI) and externally sourced products at the University of California, Los Angeles (UCLA) and VWR International customer in Southern California. For the inventories of devices, the research team collected all available data on the features identified in the earlier section. The externally sourced devices were chosen based on 1) their ability to fill gaps in the range of products that the teams already had access to, and 2) the popularity and market availability of representative products, as determined by market research reports and sales data. The team continuously sourced additional products to create a more robust profile of device types, particularly for floor stand incubators. The final device list used for testing is detailed in Task 3 section of this Chapter.

Additional findings from this task can be found in the Task 2.2: Market Assessment and Energy Savings Opportunities Report, located in the Project Deliverables section of this report.

Task 3: Develop Product Test Procedures

Task 3 for this PLETICS project was to develop procedures for testing the plug load devices selected in the previous stage and begin sourcing those devices. The team assessed a list of potential investigation points for evaluation of selected plug load devices. This list begins by summarizing the energy-related design features identified in Task 2 and further explores issues of design and device usage that can impact energy usage. For each element, the project team identified potential types of savings opportunity strategies. As the project focused on energy-saving solutions, the key driver for any of these strategies was to save energy. However, other drivers, including reducing water waste, reducing products' life-cycle environmental impacts, and improving user experience, were considered for their potential to further encourage improvement. Achieving higher energy efficiency while balancing potential increases in cost for device components and manufacturing was another important goal to be considered and kept in mind when recommending cost-effective codes and standards.

Barriers to adopting these strategies were considered to better understand why the changes have not already been widely instituted and to explore mechanisms for facilitating adoption. These investigation points and opportunities for savings can be found in the Task 3.1: Plug Load – Component Opportunities and Potential Savings Report in the Project Deliverables section of this report.

Finally, the team identified any existing testing protocols for testing these device aspects (especially for existing standards). This task included the development of preliminary test procedures to quantify energy use and savings for each device type. The project team used the following approach to develop the proposed test procedures to be used in Task 4. The final test procedures are documented in the Task 4 section of this report.

Commercial Office Equipment

The ENERGY STAR Specification for Imaging Equipment (Version 3.2) is the standard test method for commercial imaging equipment, including stand-alone printers and MFDs, across major international codes and standards for these products. Within the scope of this research, devices under testing include electrophotographic (EP) monochrome standalone printers, EP monochrome MFDs, EP color standalone printers, EP color MFDs, and ink-jet printers. Other standards and labeling programs assessed by the PLETICS team include the German Blue Angel Ecolabel and the EPEAT Ecolabel, which both conform to ENERGY STAR.[1] Therefore, ENERGY STAR will form the basis of the proposed test procedure.

There are several goals for this proposed test method. The main goal of the testing procedure is to verify and build upon the ENERGY STAR test method for imaging devices under different operational conditions. Additional test metrics for further characterizing certain states, such as low power modes, will be introduced.

The project team developed additional assessments combining the TEC and OM procedures to test and report data for all product types to reveal potential savings for low power modes and

[1] One of the codes previously assessed, the EU Industry Voluntary Agreement, is now defunct and will be re-introduced as a formal code under European Commission authority.

average consumption. As ENERGY STAR prescribes the OM and TEC methods on an exclusionary basis, applying both tests to each device may reveal additional opportunities for low power savings and average energy consumption that were previously unexplored. The following categories are addressed in the proposed test method (these are explained in more detail in the next section):

Average Power per Page of Printing:

- Takes into account the various states of the printer (printing, idle, sleep) and the time intervals between various states (as characterized through the ENERGY STAR TEC method).
- Incorporates the average power per page from initial start-up (from device "off" position) and average power per page from sleep settings.
- Provides information on comparing printers in terms of energy consumption.

Detailed Low Power Modes Power Profile Testing:

- Measures the accuracy of existing codes and standards, reports the power level of each state, and regulates the upper bound transition time between states.
- Builds on existing codes and standards to characterize the time and power profile between states to illustrate energy saving opportunities.

Harmonics and Power Factor With Single and Multiple Printers:

- Harmonics testing can determine whether the device is producing unusual voltage signals that may degrade the integrity of the device more quickly than normal or consume abnormally high amounts of electricity (decreasing product efficiency).
- The test procedure characterizes harmonics (specifically, distortions in the waveform of voltage signals) introduced by printers and the degradation to the power quality and its efficiency.
- The Harmonics analyzer performs detailed analysis of power quality to determine the wave shapes of voltage and current on respective frequency spectrums with single and multiple printers.

Another important goal was to improve product data reporting and make the energy efficiency data more informative for customers when comparing devices and choosing office imaging equipment. For instance, the manufacturer's product data sheet could include metrics that equalize OM and TEC reporting data to help consumers make decisions across device categories (specifically, inkjet vs. laser printers). This could be indicated as pages per watt-hour (Wh) or average Wh per page printed.

Finally, the research team characterized the product user interface to assess potential design features that lead to more or less efficient use of the device. While this task was mainly qualitative in nature, identifying user experience issues would provide additional insights into wasteful energy consumption. Therefore, these analyses would not be incorporated as formalized test methodology but will provide additional insights for exploration in future research.

Residential Networking Equipment

For residential networking equipment, the main goals for product testing were:

1. Compare products under the various existing standards, including the VA, EU CoC, and the upcoming Low Power Mode (LPM) Roadmap, to identify the inherent differences, limitations, and complexities associated with each testing methodology.
2. Characterize various products' energy performance with generated traffic and several types of connected devices to align more closely with homes with heavy utilization (10-plus connected devices).
3. Identify any out-of-the-box physical and software differences between products, including products sourced from outside the U.S.

In addition to this test methodology, the product's user interface would be assessed. The assessment would focus on understanding the available user settings for each product that may affect energy use or user experience, characterizing the ease of configuring the system, and verifying that any provided documentation, if available, matches the actual user interface.

Commercial Laboratory Equipment

For commercial laboratory equipment, the main goals for product testing were:

1. Compare products under the various existing standards, including ENERGY STAR, My MGL Certification, and the ACT Label, to identify the inherent differences, limitations, and complexities associated with each testing methodology.
2. Identify any out-of-the-box differences between products, including products sourced from outside the U.S.

In addition to this test methodology, the product's user interface was assessed. The assessment focused on understanding the available user settings for each product that may affect energy use or user experience, characterizing the ease of configuring the system, and verifying that the provided documentation, if available, matches the actual user interface.

Device Sourcing

Based on the results of Task 2, Task 3, and current market conditions, the project team chose the following devices for the Task 4 stage of testing. In addition, the project team procured these devices through purchase as well as identified ones that were owned and/or rented in situ.

Product Test List and Inventory

Commercial Office Equipment

For commercial office equipment, the project team selected the devices in Table 7 for testing and identified the current location.

Table 7: Commercial Office Equipment Device List

Category	Make	Line	Model	UCI Location
Desktop Laser Printers	HP	Laserjet	M607	Calit2
	HP		M554dn	Calit2
	Brother		hl-2320d	Calit2
	HP	Laserjet	m551	AIRB3000
	HP	Laserjet	m452	Aldrich Hall 4th Hall
	HP	Laserjet	p4014dn	111 Theory
Desktop Laser Multifunction Devices (MFDs)	Brother		L2550dw	Calit2
	HP	Laserjet	M428fdw	Calit2
	HP	Laserjet	M227fdw	Calit2
	Canon	imageclass	MF743cdw	Calit2
	HP	Laserjet	m426fdn	111 Beall Applied Innovation
Freestanding Color MFDs	Ricoh	IM	C6000	Calit2
	Xerox	Altalink	c8055	Calit2
	Xerox	AltaLink	c8055	111 Beall Applied Innovation
	Xerox	AltaLink	c8070	111 Beall Applied Innovation
	Xerox	WorkCentre	c7225	111 Beall Applied Innovation
	Xerox	VersaLink	c505	111 Beall Applied Innovation
	Xerox	WorkCentre	7845	Aldrich Hall 4th Hall
	Xerox	AltaLink	c8045	Aldrich Hall 4th Hall
	Xerox		c70	111 Theory
Freestanding Monochrome MFDs	Ricoh		MP 4002	AIRB3000
	Xerox			UCI Rental - TBA
	Xerox			UCI Rental - TBA
	Canon			UCI Rental - TBA
	Canon			UCI Rental - TBA
Inkjet Devices (Color)	Canon	Pixma MegaTank	G7020	To be purchased by CalPlug
	Canon	Maxify	MB2120	To be purchased by CalPlug

Category	Make	Line	Model	UCI Location
	Epson	Workforce PrWF-4830	To be pur-chased by CalPlug	
	Brother		MFC-J4535DW	To be purchased by CalPlug
	HP	OfficeJet	9012	To be purchased by CalPlug

Source: CalPlug

Residential Networking Equipment

For residential networking equipment, the project selected the devices in Table 8 for testing and identified the current location.

Table 8: Residential Networking Equipment Device List

Category	Make	Model	Voluntary Agreement (VA) Listed	Ordered
Router	Asus	RT-AC86U	Y	Y
	Asus	RT-AX56U	Y	
	Asus	RT-AX82U	Y	Y
	D-Link	AC2600	N	Y
	Netgear	RAX70	N	Y
	Tenda	AC23 AC2100	N	Y
	TP-Link	AX1800	N	Y
	TP-Link	MR6400	N	Y
	TP-Link	AC1750	N	
	Asus	AX6000	N	
	Asus	RT-AX3000	Y	
Modem	Arris	S33	Y	Y
	Arris	SB6183	Y	Y
	Arris	SB8200	Y	Y
	Motorola	MB8611	N	Y
	Netgear	CM1000	N	Y
	Netgear	CM1150V	Y	Y
	Arris	T25	Y	Y
Range Extender	Linksys	RE6500	N	
	Netgear	EX2700	N	Y
	Netgear	EX7300	N	Y

Category	Make	Model	Voluntary Agreement (VA) Listed	Ordered
	Rockspace	AC1200	N	Y
	TP Link	AC750	N	Y
	TP-Link	RE450	N	Y
	Linksys	RE7000	N	Y
Optical Network Terminal/Unit	CiscME4601	N/A		
	TP-Link	MC100CM	N/A	Y
	TP-Link	MC200CM	N/A	Y
	TP-Link	MC220L	N/A	Y
	Ubiquiti	UF-LOCO	N/A	Y
Integrated Access Device	Arris	G34	Y	Y
	Arris	SBG10	Y	Y
	Motorola	MG7700	N	Y
	Netgear	C7000	N	Y
	Netgear	C7800	N	Y
	Netgear	CAX80	N	Y
	TP-Link	MR6400	N	
	Motorola	MG8702	N	Y
	TP-Link	AX3000	N	Y
	TP-Link	AC2100	N	

Source: California Lighting Technology Center

Commercial Laboratory Equipment

For commercial laboratory equipment, the project team selected the devices in Table 9 for testing.

Table 9: Commercial Office Equipment Device List

Category	Make	Model	Location	Subtype
Centrifuges (Benchtop)	Eppendorf	Multipurpose 5810R	CSUN (JD1115)	
	Beckman Coulter	Allegra 6R	Terasaki Institute (Biomedical Lab)	
	Eppendorf	5417R	Terasaki Institute (Biomedical Lab)	

Category	Make	Model	Location	Subtype
	Eppendorf	5430R	Terasaki Institute (Biomedical Lab)	
	Eppendorf (Fisher Scientific)	5424	Terasaki Institute (Biomedical Lab)	
Incubators (Floor Stand)	Boekel	CO2 Water Jacketed Incubator	Terasaki Institute (Biomedical Lab)	
	VWR / Shel Lab	2300-MP CO2 Water Jacketed Incubator	Terasaki Institute (Biomedical Lab)	
	Thermo Scientific	Forma Steri-Cycle i160 CO2 165 L Incubator	UCLA	
	Thermo Scientific	Forma Series II Water-Jacketed CO2 Incubator	UCLA	
	Fisher Scientific	Isotemp Gravity Oven, 100 L	Terasaki Institute (Biomedical Lab)	
Water Baths	Kendal	Commercial Grade Ultrasonic Cleaner – 6 L	CSUN (JD1115)	
	VWR	Fisher Scientific Isotemp Dual Digital Water Bath Model 2322	CSUN (JD1115)	
	Benchmark	SB-12 L Shaking Water Bath	Terasaki Institute (Biomedical Lab)	
	Fisher Scientific	Emerson CPX1800H 1.9 L Ultrasonic Cleaning Bath	Terasaki Institute (Biomedical Lab)	
	Fisher Scientific	Isotemp General Purpose Deluxe Water Bath	Terasaki Institute (Biomedical Lab)	

Category	Make	Model	Location	Subtype
Autoclaves	Thermo Scientific	ST75925 Sterilemax Benchtop Steam Sterilizer	CSUN (JD1115)	Benchtop
	Tuttnauer	3870EA Autoclave	Terasaki Institute (Biomedical Lab)	Benchtop
	Steris	Amsco Century V120	UCLA (Room 13-281)	Floor Stand
	Steris	Reliance 400	UCLA (Room 13-281)	Glassware Washer
	Consolidated Sterilizer Systems	Tower Autoclave	UCLA (Room 10-622)	Floor Stand
-13°F (-25°C) Freezers	VWR	Minifridge	CSUN (JD1115)	Undercounter Refrigerator
	Thermo Scientific	Value Lab Upright Freezer	Terasaki Institute (Biomedical Lab)	General Purpose Freezer
	Insignia	21 Cu. Ft. Garage Ready Convertible Upright Freezer	Terasaki Institute (Biomedical Lab)	Freezer/Refrigerator
	Insignia	21 Cu. Ft. Garage Ready Convertible Upright Freezer	Terasaki Institute (Biomedical Lab)	Freezer/Refrigerator
	Insignia	21 Cu. Ft. Garage Ready Convertible Upright Freezer	Terasaki Institute (Biomedical Lab)	Freezer/Refrigerator

Source: California State University, Northridge

Task 4: Product Testing and Analysis

Task 4 included testing of devices under the test procedures developed in Task 3.2, refinement of those procedures, development of a detailed dataset that may be considered for adoption through codes and standards, power consumption of the specific devices during low power and idle modes, total energy consumption, connected devices interactions power consumption, and any differences observed across devices and the root cause.

The PLETICS project team segmented this section into the following device categories: commercial office equipment, residential networking equipment, and laboratory equipment. Each subsection covers the testing equipment used, device testing procedures, and datasets of total power consumption, baseline power use, annual energy use, and so on. The analysis and recommendations from the testing results are presented in the Codes and Standards Impact subsection.

Final Procedures and Test Results

Commercial Office Equipment

As specified by ENERGY STAR, test setup and instrumentation are in accordance with the requirements of International Electrotechnical Commission (IEC) Standard 62301, Ed. 2.0, "Measurement of Household Appliance Standby Power," Section 4, "General Conditions for Measurements" for all products. The following test method steps shall be implemented:

1. Connect AC power mains to voltage source.
2. All products shall be tested in their "as-shipped" configuration unless otherwise specified by this test method.[2]

The product speed for all calculations and reporting shall be the highest speed as claimed by the manufacturer, as expressed in images per minute and rounded to the nearest integer.

1. Test Image: Test Pattern A from ISO/IEC Standard 10561:1999 shall be used as the original image for all testing. Test images shall be rendered in 10-point size in a fixed-width Courier font (or nearest equivalent).
2. Print jobs for the test shall be sent over the network connection designated in Table 6 immediately before printing each job. Each image in a print job shall be sent separately (specifically, all images may be part of the same document) but shall not be specified in the document as multiple copies of a single original image.

Table 10 enumerates the test method steps. This method follows the combined TEC and OM tests per ENERGY STAR. According to the official ENERGY STAR methodology, TEC applies only to laser printers and MFDs, and OM applies only to inkjet products. However, the project team tested each device in both TEC and OM configurations to capture a more detailed profile of energy consumption in active, sleep, and sleep-to-off modes.

Table 10: Test Methodology

Initial State	Action	Record	Unit of Measure	States Measured	Metrics Calculated
Off	Connect the UUT to the meter. Ensure the unit is powered and in Off mode. Zero the meter; measure energy over 5 minutes	Off energy	Watt-hours (Wh)	Off	
		Testing Interval time	Minutes (min)		

[2] Devices tested in situ were tested with existing internet configurations. This will be explored in greater detail in Report 4.2.

Initial State	Action	Record	Unit of Measure	States Measured	Metrics Calculated
	or more. Record both energy and time.				
Off	Turn on unit. Wait until unit indicates it is in Ready mode.	–	–	–	
Ready	Measure Ready power. Record power profile from OFF mode to Ready mode.	Ready power, $^{P}READY$	Watts (W)	Ready	Detailed power profile in LPM transitions
Ready	Print a job of at least one output image but no more than a single job per Table 11. Measure and record time to first sheet exiting unit. Measure harmonics during printing.	Active0 time	Seconds (s)	–	
Ready (or other)	Wait until the meter shows that the unit has entered its final Sleep mode or the time specified by the manufacturer.	Default delay time to Sleep, $^{t}DEFAULT$	Minutes (min)	–	Harmonics and Power factor
Sleep	Zero meter; measure energy and time for 1 hour. Record the energy and time. Measure Sleep power.	Sleep energy, $^{E}SLEEP$	Watt-hours (Wh)	Sleep	
		Sleep power, $^{P}SLEEP$	Watts (W)		
		Sleep time, $^{t}SLEEP$ (≤ 1 hr)	Minutes (min)		
Sleep	Zero meter and timer. Print one job (calculated above). Measure energy and time. Record time to first sheet exiting unit. Measure energy over 15 minutes from job initiation. The job must	Job1 energy, $^{E}JOB1$	Watt-hours (Wh)	Recovery, Active, Ready, Sleep	Wh per print; Average power at printing
		Active1 time	Seconds (s)		

Initial State	Action	Record	Unit of Measure	States Measured	Metrics Calculated
	finish within the 15 minutes.				
Ready (or other)	Repeat Step 6.	Job2 energy, E_{JOB2}	Watt-hours (Wh)	Same as above	Same as above
		Active2 time	Seconds (s)		
Ready (or other)	Repeat Step 6 (without Active time measurement).	Job3 energy, E_{JOB3}	Watt-hours (Wh)	Same as above	Same as above
Ready (or other)	Repeat Step 6 (without Active time measurement).	Job4 energy, E_{JOB4}	Watt-hours (Wh)	Same as above	Same as above
Ready (or other)	Zero meter and timer. Measure energy and time until meter and/or unit shows that unit has entered Sleep mode or the final Sleep mode for units with multiple Sleep modes, or the time specified by the manufacturer, if provided. Record energy and time.	Final energy, E_{FINAL}	Watt-hours (Wh)	Ready, Sleep	
		Final time, t_{FINAL}	Minutes (min)		
Sleep	Wait and measure default delay time to Auto-off. (Disregard if no Auto-off mode). Record power profile from Ready to Auto-off/Sleep	Auto-off default-delay time	Minutes (min)		Detailed power profile in LPM transitions
Auto-off	Measure Auto-off power. (Disregard if no Auto-off mode).	Auto-off power $P_{AUTO\text{-}OFF}$	Watts (W)	Auto-off	Detailed power pro-file in LPM transitions
Auto-off	Manually turn device off and wait until unit is off. (If no manual on-off switch, note and wait for lowest-power	–	–		

Initial State	Action	Record	Unit of Measure	States Measured	Metrics Calculated
	Sleep state). Record power profile from Auto-off to Off.				

Source: CalPLug

The following equation show how to calculate the EMERGY STAR TEC calculation for printers, fax machines, digital duplicators with print capability, and MFDs with print capability:

$$TEC_{2018} = \left[5 \times \left(E_{JOB\_DAILY} + (2 \times E_{FINAL}) + \left[24 - \frac{N_{JOBS}}{16} - (2 \times t_{FINAL}) \right] \times \frac{E_{SLEEP}}{t_{SLEEP}} \right) + 48 \times \frac{E_{SLEEP}}{t_{SLEEP}} \right]$$

Where:

- TEC2018 is the typical weekly energy consumption for printers, digital duplicators with print capability, and MFDs with print capability, expressed in kWh and rounded to the nearest 0.01 kWh for reporting;
- EJOB_DAILY is the daily job energy, in kWh.
- EFINAL is the final energy, as measured in the test procedure, converted to kWh.
- NJOBS is the number of jobs per day, as calculated in the test procedure.
- tFINAL is the final time to Sleep, as measured in the test procedure, converted to hours.
- ESLEEP is the Sleep energy, as measured in the test procedure, converted to kWh.
- tSLEEP is the Sleep time, as measured in the test procedure, converted to hours.

Test Datasets and Results

Before commencing testing, the team collated relevant information about the selected devices, including the power consumption data advertised in the manufacturer's product manual, and the TEC value listed in the ENERGY STAR qualified product guide. ENERGY STAR results are confirmed through third-party testing approved by the U.S. Environmental Protecting Agency (U.S. EPA). The following tables for each device group list the make and the model (unit-under-testing), accompanied by their ENERGY STAR approved images per minute (ipm), ENERGY STAR TEC metrics, and the available data provided by the manufacturer on power consumption (Table 11 through Table 25).

After conducting ENERGY STAR testing, the project team compiled datasets summarizing the most salient aspects of the TEC calculation. Active average is the average energy usage (W) of the four "jobs" required for each device test (each job is conducted for 15 minutes). Sleep average is the average energy draw (W) during the one-hour "sleep" test. Off energy is the power profile from "ready" to off. These results are shown in the "Measured Energy Consumption" tables.

Freestanding Color Multifunction Device

Table 11: ENERGY STAR IPMs and Associated TEC values, Laser Color MFDs

Speed/Images per Minute (ipm)	Maximum Typical Energy Consumption (TEC), kWh/wk
s ≤ 20	0.254
20 < s ≤ 40	0.024 x s + 0.250
40 < s ≤ 60	0.011 x s + 0.283
60 < s ≤ 80	0.055 x s – 2.401
s > 80	0.118 x s – 7.504

Source: CalPlug

Table 12: Selected Devices and Manufacturer Provided Information, Large Color MFDs

UUT	Mfr.	Model	Speed (ipm)	Advertised Power Consumption	Energy Star TEC (kWh/wk)
Large Color MFD 1	Ricoh	IM C6000	60	Active: <1,584 W; LPM: 0.59W Auto Off: N/A	0.762 (Mfr) 0.89 (Energy Star)
Large Color MFD 2	Xerox	AltaLink C8055	55	Active: 787 W avg. LPM: 95 W avg. Auto Off: 1.2 W avg.	0.81 (Energy Star)
Large Color MFD 3	Ricoh	IM C300	31	Active: < 1,300 W; Sleep Mode: 0.65 W	0.37 (Mfr; Energy Star)
Large Color MFD 4	Xerox	VersaLink C405	36	Active: <750 W LPM: <82 W Auto Off: <4 W	0.52 (Energy Star)
Large Color MFD 5	Xerox	C8055	55	Active: 787 W avg. LPM: 95 W avg. Auto Off: 1.2 W avg.	0.81 (Energy Star)

avg=average; Mfr=Manufacturer
Source: CalPlug

Table 13: Measured Energy Consumption, Large Color MFDs

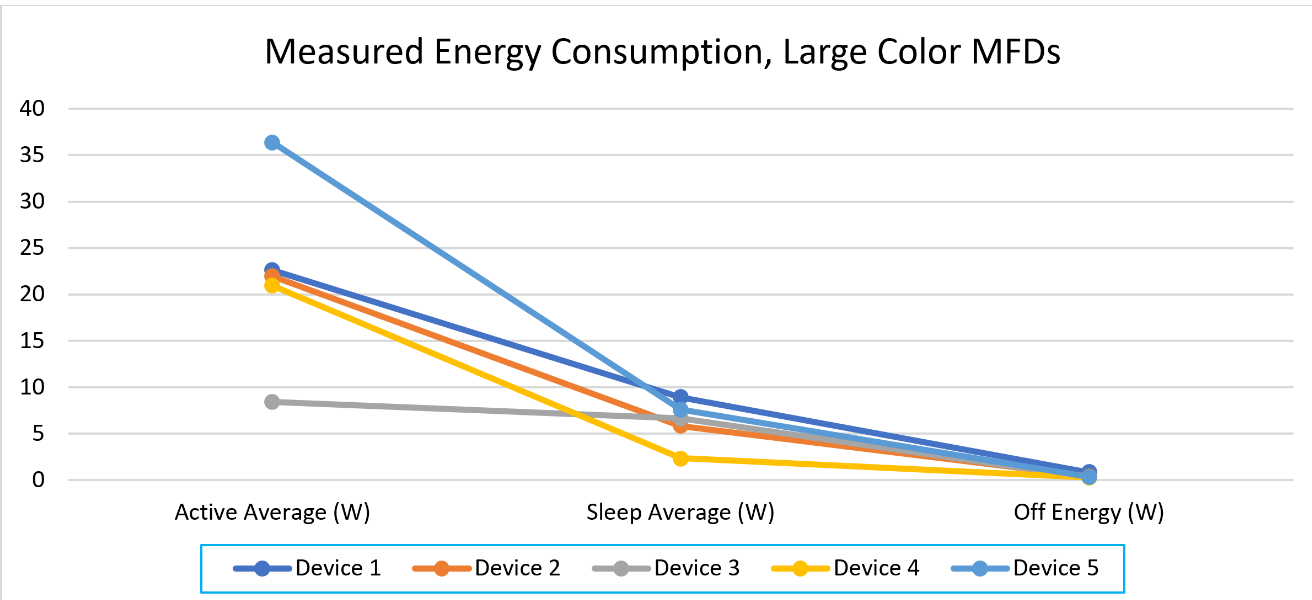
UUT	Active Average (W)	Sleep Average (W)	Off Energy (W)	TEC (kWh/wk)
Large Color MFD 1	22.63	8.926	0.849	2.35
Large Color MFD 2	22.0	5.85	0.43	1.87
Large Color MFD 3	8.44	6.67	0.31	1.43

UUT	Active Average (W)	Sleep Average (W)	Off Energy (W)	TEC (kWh/wk)
Large Color MFD 4	20.96	2.36	0.27	1.42
Large Color MFD 5	36.38	7.6	0.34	3.51

Source: CalPlug

The graph below plots the profiles of each device across active, sleep, and off modes (Figure 2).

Figure 2: Energy Consumption of Large Color MFDs Across Active, Sleep, and Off Modes



Source: CalPlug

Freestanding Monochrome Multifunction Device

Table 14: Selected Devices and Manufacturer Provided Data, Large Monochrome MFDs

UUT	Manufacturer	Model	Speed (ppm)	Advertised Power Consumption	Energy Star TEC (kWh/wk)
Large Mono MFD 1	Sharp	MX M4071	40	Active: < 1500 W	0.55 (Energy Star)
Large Mono MFD 2	Ricoh	MP 4002	40	Active: 2.7 W (avg) Sleep: 1 W (avg)	2.87

Source: CalPlug

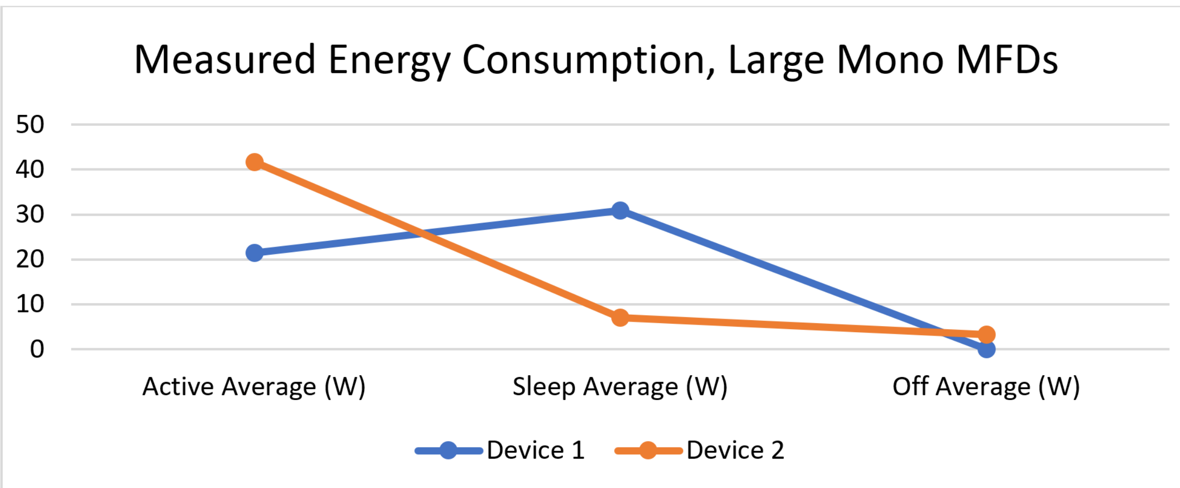
Table 15: Measured Energy Consumption

	Active Average (W)	Sleep Average (W)	Off Average (W)	TEC (kWh/wk)
Large Mono MFD 1	21.41	30.91	0.01	5.7
Large Mono MFD 2	41.71	7.11	3.31	3.86

Source: CalPlug

This graph plots the profiles of each device across active, sleep, and off modes (Figure 3).

Figure 3: Energy Consumption of Large Mono MFDs Across Active, Sleep, and Off Modes



Source: CalPlug

Desktop Laser Multifunction Device

Table 16: ENERGY STAR ipms and Associated TEC Values, Laser Color MFDs

Speed/Images per Minute (ipm)	Maximum Typical Energy Consumption (TEC), kWh/wk
s ≤ 20	0.254
20 < s ≤ 40	0.024 x s + 0.250
40 < s ≤ 60	0.011 x s + 0.283
60 < s ≤ 80	0.055 x s – 2.401
s > 80	0.118 x s – 7.504

Source: CalPlug

Table 17: ENERGY STAR ipms and Associated TEC Values, Laser Monochrome MFDs

Speed/Images per minute (ipm)	Maximum Typical Energy Consumption (TEC), kWh/wk
s ≤ 20	0.263
20 < s ≤ 40	0.018 x s – 0.115
40 < s ≤ 60	0.016 x s – 0.033
60 < s ≤ 80	0.037 x s – 1.314
s > 80	0.086 x s – 5.28

Source: CalPlug

Table 18: Selected Devices and Manufacturer Provided Information

UUT	Mfr.	Model	Speed (ppm)	Advertised Power Consumption	ENERGY STAR TEC
Desktop Laser MFD 1	HP	LaserJet m426fdn	40	Print/Copy: 583 W Ready: 9.1 W Sleep: 2.7 W Auto-On/Auto-Off, via USB connectivity: 0.7 W Shutdown or Off: 0.1 W	N/A
Desktop Laser MFD 2	HP	LaserJetPro m283cdw	22	Active printing: 361 W Ready: 7.8 W Sleep: 0.8 W Manual-Off: 0.05 W Auto-off/Manual-on: 0.05 W Auto-Off/Wake on LAN: 0.06 W	0.25
Desktop Laser MFD 3	HP	LaserJetPro M283fdw	22	Active printing: 361 W Ready: 7.8 W Sleep: 0.8 W Manual-Off: 0.05 W Auto-Off/Manual-On: 0.05 W Auto-Off/Wake on LAN: 0.06 W	0.25
Desktop Laser MFD 4	Canon	ImageClass MF751cdw	35	Maximum: Approx. 1610 W Standby: Approx. 24 W Sleep Mode: Approx. 1 W	0.34
Desktop Laser MFD 5	Brother	HL-L3290CDW	25	Active: 430 W Ready: 75 W Sleep: 10.1 W Deep Sleep: 1.2 W Power Off: 0.02 W	

Source: CalPlug

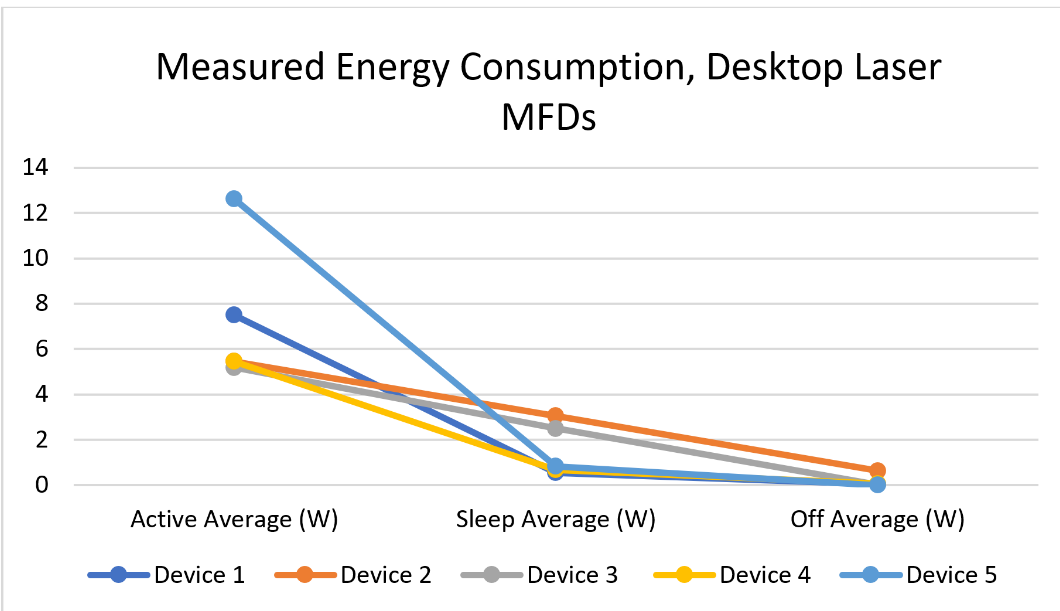
Table 19: Measured Energy Consumption

	Active Average (W)	Sleep Average (W)	Off Average (W)	TEC (kWh/wk)
Desktop Laser MFD 1	7.5	0.55	0.04	0.4
Desktop Laser MFD 2	5.45	3.05	0.04	0.64
Desktop Laser MFD 3	5.19	2.5	0.03	0.59
Desktop Laser MFD 4	5.46	0.68	0.07	0.4
Desktop Laser MFD 5	12.61	0.84	0.00	0.47

Source: CalPlug

Figure 4 plots the profiles of each device across active, sleep, and off modes.

Figure 4: Energy Consumption of Desktop Laser MFDs Across Active, Sleep, and Off Modes



Source: CalPlug

Desktop Laser Printer

Table 20: ENERGY STAR ipms and Associated TEC Values, Laser Color Printers

Speed/Images per minute (ipm)	Maximum Typical Energy Consumption (TEC), kWh/wk
s ≤ 20	0.275
20 < s ≤ 40	0.032 x s – 0.397
40 < s ≤ 60	0.002 x s + 0.833
s > 60	0.100 x s – 5.145

Source: CalPlug

Table 21: ENERGY STAR ipms and Associated TEC values, Laser Monochrome Printers

Speed/Images per Minute (ipm)	Maximum Typical Energy Consumption (TEC), kWh/wk
s ≤ 20	0.226
20 < s ≤ 40	0.018 x s – 0.152
40 < s ≤ 60	0.025 x s – 0.439
60 < s ≤ 135	0.049 x s – 1.903
> 135	0.183 x s – 20.127

Source: CalPlug

Table 22: Selected Devices and Manufacturer Provided Information

UUT	Mfr.	Model	Speed ppm)	Advertised Power Consumption	ENERGY STAR TEC
Desktop Laser Printer 1	HP	LaserJet M607	55	Printing: 780 W Ready: 15.3 W Sleep: 3.1 W Auto Off/Manual On: < 0.1 W Manual Off: < 0.1 W	0.6
Desktop Laser Printer 2	HP	LaserJet M551	32	Printing: 780 W Ready: 15.3 W Sleep: 3.1 W Auto Off/Manual On: < 0.1 W Manual Off: < 0.1 W	1.36
Desktop Laser Printer 3	HP	LaserJet M452	28	Active: 570 W Ready: 17.6 W Sleep: 2.4 W Auto-Off: 0.6 W Off: 0.05 W	N/A
Desktop Laser Printer 4	HP	LaserJet M401dne	35	Printing: 570 W Ready: 7.3 W Sleep 1.68 W Off: 0.1 W	1.39

Source: CalPlug

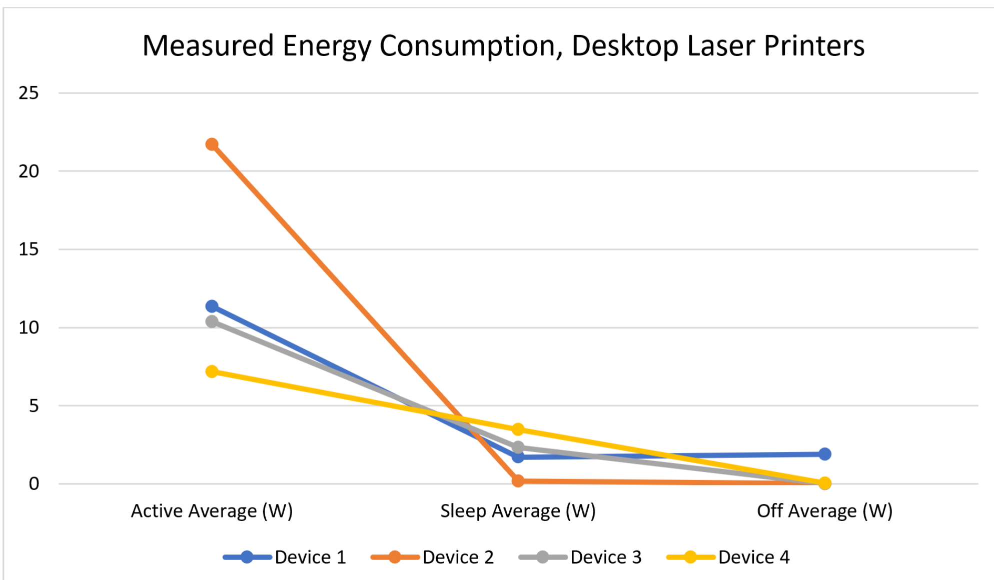
Table 23: Measured Energy Consumption, Desktop Laser Printers

UUT	Active Average (W)	Sleep Average (W)	Off Average (W)	TEC (kWh/wk)
Desktop Laser Printer 1	11.37	1.71	1.91	0.72
Desktop Laser Printer 2	21.70	0.18	0.01	1.01
Desktop Laser Printer 3	10.38	2.33	0.02	0.87
Desktop Laser Printer 4	7.19	3.46	0.07	0.85

Source: CalPlug

Figure 5 plots the profiles of each device across active, sleep, and off modes.

Figure 5: Energy Consumption of Desktop Laser Printers Across Active, Sleep, and Off Modes



Source: CalPlug

Desktop Inkjet Color Multifunction Device

Table 24: Selected Devices and Manufacturer Provided Information, Inkjet Color MFDs

UUT	Mfr.	Model	Speed (ppm)	Advertised Power Consumption	Energy Star OM (W)
Inkjet MFD 1	HP	Envy 7955e	15	N/A	1.67
Inkjet MFD 2	Canon	Maxify MB2120	19	Copying: 27.0 W (Standby: 0.9 W)	1.17
Inkjet MFD 3	Epson	WorkforcePro WF-4830	25	Active: 22 W Power Off: 0.2 W	0.88

UUT	Mfr.	Model	Speed (ppm)	Advertised Power Consumption	Energy Star OM (W)
Inkjet MFD 4	Brother	MFC-J4535DW	35	Active: 20 W Ready: 3.5 W Sleep: 1.2 W Off: 0.2 W	0.94
Inkjet MFD 5	HP	OfficeJet 9015	22	N/A	1.08

Source: CalPlug

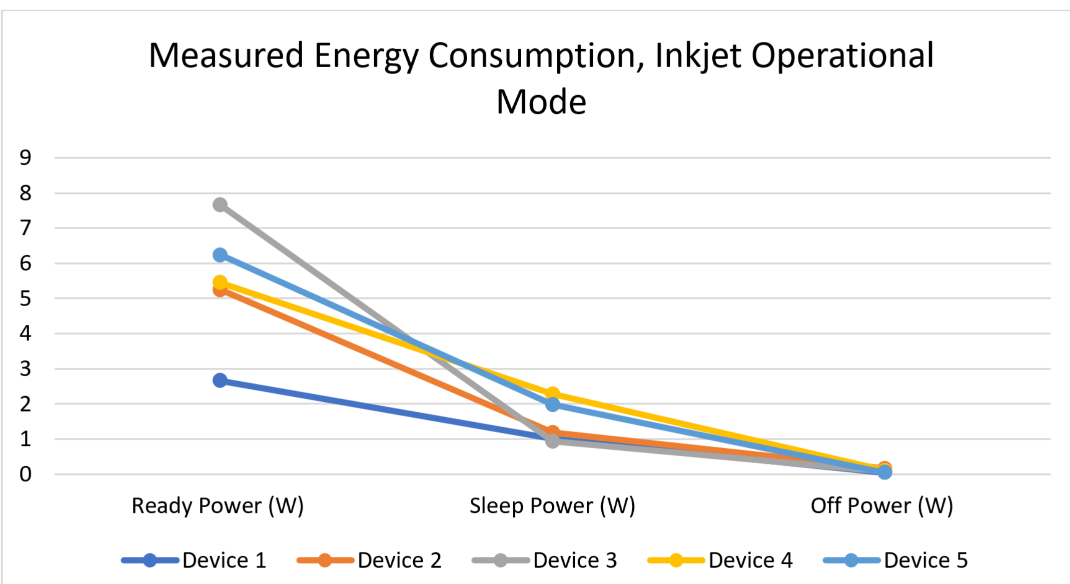
Table 25: Measured Energy Consumption, Inkjet Operational Modes

UUT	Ready Power (W)	Default Delay (Minutes)	Sleep Power (W)	Auto-Off Delay (Hours)	Auto-Off Power (W)	Off Power (W)
Inkjet MFD 1	2.66	5	1.00	8	N/A	0.04
Inkjet MFD 2	5.24	5	1.18	4	N/A	0.16
Inkjet MFD 3	7.65	1	0.93	N/A	0.15	0.07
Inkjet MFD 4	5.45	5	2.28	8	N/A	0.10
Inkjet MFD 5	6.23	5	1.98	8	N/A	0.04

Source: CalPlug

Figure 6 plots the profiles of each device across active, sleep, and off modes.

Figure 6: Energy Consumption of Inkjet Operational Mode Across Active, Sleep, and Off Modes



Source: CalPlug

Residential Networking Equipment

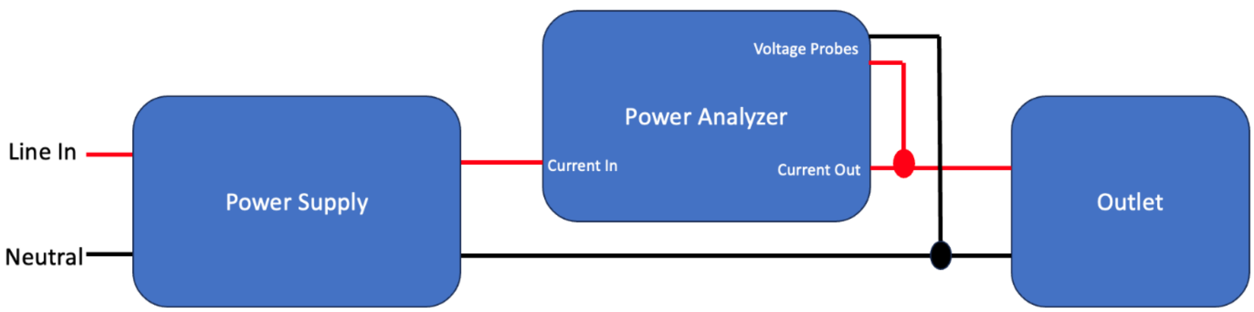
Each product of interest underwent three rounds of testing, two of which followed existing/upcoming standards/methodologies, including:

- The Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Small Network Equipment & ANSI/CTA-2049-A
- The EU Code of Conduct on Energy Consumption of Broadband Equipment: Version 7.1

The third round of testing followed the methodology expanded below, which includes expansion to cover multiple active states and settings configurations to assess characteristics likely to be seen in real-world scenarios and not captured in existing standards. Testing environment, product preparation, and connections are heavily based on the aforementioned three methodologies with minor adjustments to further increase repeatability by reducing specified condition ranges.

To connect the UUT to the testbed first, the power supply and power analyzer should be wired in line with Figure 7. In the diagram, the power analyzer is utilizing a direct current input, but an external current transformer can also be utilized with minor adjustments. Wiring should be rated to support the maximum expected electrical characteristics of the UUTs. Wiring should terminate into an appropriate outlet in line with what the UUT is compatible with.

Figure 7: Power Equipment Wiring Configuration



Source: California Lighting Technology Center

Connecting the UUT to the networking portion of the testbed will vary based on the category of device. In this methodology five categories are explored but the procedure can be easily adapted to support other existing or future categories.

For devices that require a cable modem termination system (CMTS), the equipment settings should be set as follows to allow for DOCSIS 3.0 or 3.1 connections:

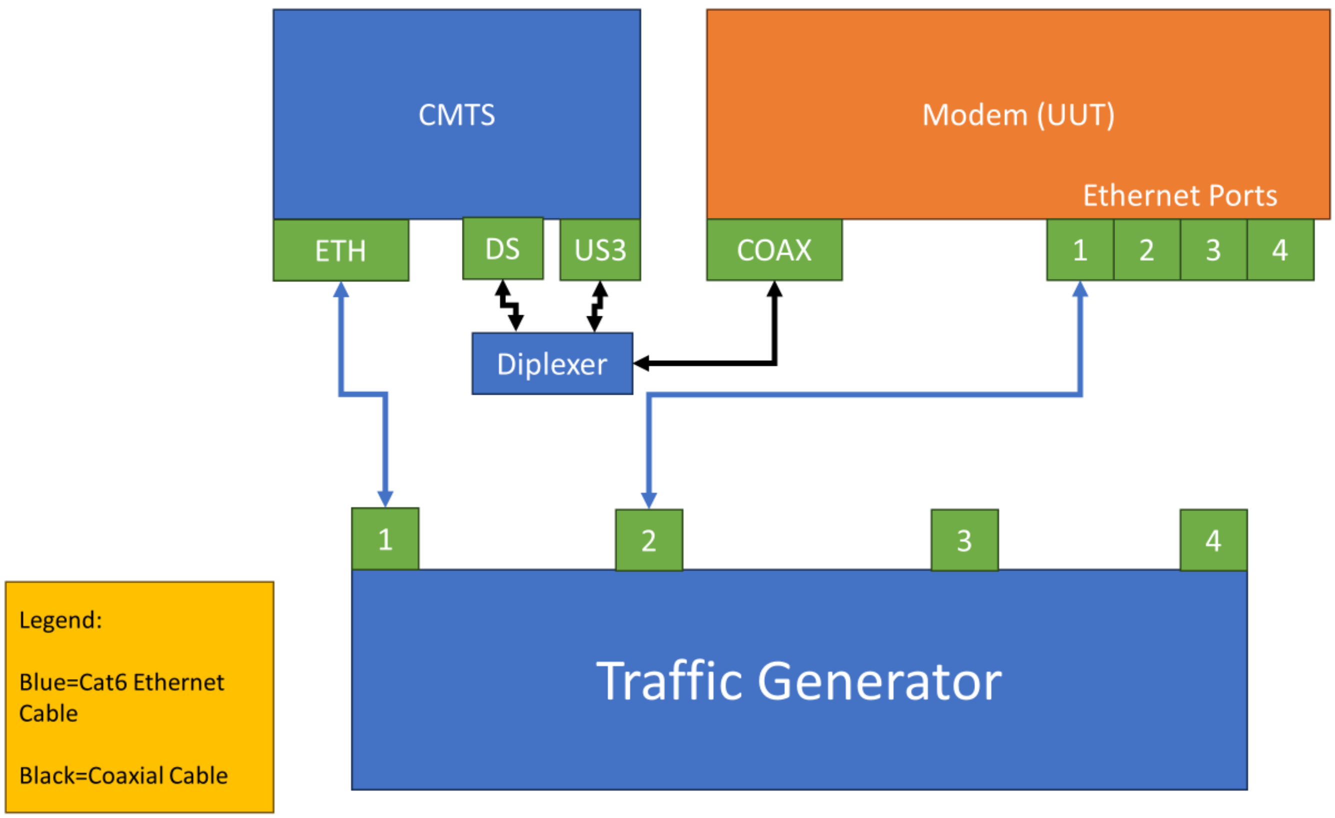
- DCHP Relay:
    - All options set to Snooping
    - Cable Source Verify set to On
- Local Provision Management:
    - Global DHCP: On
    - CPE Switch: On

- Local-Provision Client-Class: Used D_BT_cm31.cfg for client-class 1 with media access control (MAC) range 0000.0000.0000 – FFFF.FFFF.FFFF
  - Contact the manufacturer of your CMTS for a general purpose .cfg file

Modem Configuration

Modem UUTs should be connected to the network testbed following Figure 8. If multiple ports exist on the UUT port, priority should be given to the highest throughput capable port or primary cable port, if specified.

Figure 8: Modem Networking Testbed Configuration



Source: California Lighting Technology Center

The traffic generator should be configured with a BERT pattern of 2^9-1, the Traffic type set as constant rate with frame size of 1518 bytes, and with the following layering configuration:

- Layer 2 = Ethernet
- Layer 2.5 = None
- Layer 3 = None
- Layer 4 = None

The networking equipment's MAC addresses should be set automatically using address resolution protocol or set manually to allow for proper traffic destination alignment. Additionally, IP addresses, subnet mask, and default gateways for the UUT and networking testbed should be configured and aligned to allow for communication.

Additional configurations for each category of device can be found in the Task 4.2 Final Technical Report on Testing Procedures for Plug Load Devices in the Project Deliverables section of this report and in Appendix A.

Once the UUT is appropriately configured in one of the possible defined physical configurations and the equipment is set up, the unit is ready to be tested. The number of tests is based on the number of traffic conditions to be identified. It is recommended that 30 equal distant data throughput configurations throughout the UUTs range be accessed for a full performance characterization.

To test UUT configuration:

1. Energize Device Under Test (DUT), allowing a 5-minute start-up interval.
2. Confirm proper communication with testbed.
3. Begin recording of power analyzer.
4. Set the relevant traffic generator ports to target download or upload speed.
5. With no traffic flowing, measure the power consumption of the UUT for 5 minutes to determine the idle state power draw of the configuration.
6. Note the end of the test duration.
7. Turn traffic flow on, then measure the power consumption of the UUT for 5 minutes.
8. Turn off traffic flow.
9. Note the test duration and total bits received by the traffic generator ports.
10. Set the traffic generator ports to the next target configuration, then repeat steps 7–10 until all configurations of interest are tested.

After testing completes, calculations should be done to determine the average of the total bits received by each download and upload port by dividing them by the testing duration to get an average data throughput speed in Mbps (megabits per second).

Test Datasets and Results

In Task 4, proposed testing was modified to align with acquired equipment and associated limitations. The project team utilized a network traffic generator to generate a series of demand traffic conditions instead of utilizing a bank of connected devices to emulate heavy utilization. The network traffic generator allowed the project team to create more replicable and controllable test conditions compared to what was feasible with multiple connected devices.

Table 26 through Table 38 show the testing results for each RNE device subgroup, and they highlight the specifications from the manufacturer’s data displayed on the box or on the manufacturer’s website, measured idle power for each DUT, reported idle power for devices that are VA compliant, and the overall comparison between allowances and measured power. The latter are listed with a green highlighted value indicating that the DUT is under the associated power allowance, while a red highlighted value indicates that it would fail.

Modems

Table 26: Tested Modems Specifications and Product Key

DUT	Manufacturer	Modem	DOCSIS	Advertised Speed	Date Ordered
Modem 1	Motorola	MB8611	3.1	2.5 Gbps Download	April 2023
Modem 2	Netgear	CM1150V	3.1	2.5 Gbps Download	April 2023
Modem 3	Arris	S33	3.1	3.5 Gbps Download	April 2023
Modem 4	Arris	SB6183	3.0	686 Mbps Download	March 2023
Modem 5	Arris	SB8200	3.1	10 Gbps Download	April 2023
Modem 6	Arris	T25	3.1	2 Gbps Download	April 2023

Source: California Lighting Technology Center

Table 27: Measured and Listed Idle Power for Tested Modems

DUT	Measured Idle Power	Listed Idle Power
Modem 1	7.16	N/A
Modem 2	7.40	7.50
Modem 3	7.33	10.20
Modem 4	9.86	8.45
Modem 5	6.88	10.80
Modem 6	8.66	9.40

Source: California Lighting Technology Center

Table 28: Percent of Power Utilized by Tested Modems for Each VA Tier

DUT	% of Tier 1 Allowance	% of Tier 2 Allowance	% of Tier 3 Allowance
Modem 1	42.24%	46.80%	50.42%
Modem 2	41.81%	46.54%	50.00%
Modem 3	42.62%	47.29%	50.90%
Modem 4	90.05%	97.62%	128.05%
Modem 5	40.00%	44.39%	47.78%
Modem 6	48.65%	53.79%	57.73%

Source: California Lighting Technology Center

Integrated Access Devices

Table 29: Tested IADs Specification and Product Key

DUT	Manufacturer	Model	Wireless Protocol	Advertised Download Speeds	Date Ordered
IAD 1	Motorola	MG7700	WiFi 5	1000 Mbps	April 2023
IAD 2	Motorola	MG8702	WiFi 5	1000 Mbps	March 2023
IAD 3	Netgear	C7000	WiFi 5	1.9 Gbps	April 2023
IAD 4	Arris	G34	WiFi 6	4 Gbps	April 2023

Source: California Lighting Technology Center

Table 30: Measured and Listed Idle Power for Tested IADs

DUT	Measured Idle Power	Listed Idle Power
IAD 1	13.48	N/A
IAD 2	10.62	N/A
IAD 3	16.55	18.13
IAD 4	14.28	14.10

Source: California Lighting Technology Center

Table 31: Percent of Power Utilized by Tested IADs for each VA Tier

DUT	% of Tier 1 Allowance	% of Tier 2 Allowance	% of Tier 3 Allowance
IAD 1	71.70%	79.76%	98.39%
IAD 2	50.57%	56.19%	60.34%
IAD 3	81.93%	90.93%	112.59%
IAD 4	65.50%	72.86%	77.61%

Source: California Lighting Technology Center

Wireless Routers

Table 32: Tested Wireless Routers Specification and Product Key

DUT	Manufacturer	Model	Wireless Protocols	Advertised Download Speeds	Date Ordered
WR 1	Asus	RT-AC86U	WiFi 5	1600 Mbps	April 2023
WR 2	Asus	RT-AX82U	WiFi 6	5400 Mbps	April 2023
WR 3	Netgear	RAX70	WiFi 6	6.6 Gbps	April 2023
WR 4	Tenda	AC23	WiFi 5	1 Gbps	April 2023
WR 5	TP-Link	Archer AX21	WiFi 6	1.8 Gbps	March 2023
WR 6	TP-Link	Archer AX55	WiFi 6	3000 Mbps	April 2023

Source: California Lighting Technology Center

Table 33: Measured and Listed Idle Power for Tested Modems

DUT	Measured Idle Power	Listed Idle Power
WR 1	8.79	10.72
WR 2	6.15	6.50
WR 3	7.03	N/A
WR 4	5.80	N/A
WR 5	5.95	6.63
WR 6	6.29	6.81

Source: California Lighting Technology Center

Table 34: Percent of Power Utilized by Tested Wireless Router for each VA Tier

DUT	% of Tier 1 Allowance	% of Tier 2 Allowance	% of Tier 3 Allowance
WR 1	72.64%	80.64%	87.90%
WR 2	53.95%	59.71%	64.74%
WR 3	55.35%	62.21%	67.60%
WR 4	66.29%	72.50%	84.06%
WR 5	62.63%	69.19%	74.38%
WR 6	65.52%	72.30%	77.65%

Source: California Lighting Technology Center

Wireless Range Extenders

Table 35: Tested Range Extenders Specification and Product Key

DUT	Manufacturer	Model	Wireless Protocol	Advertised Download Speeds	Date Ordered
RE 1	Linksys	RE7000	WiFi 5	1.9 Gbps	April 2023
RE 2	Netgear	EX2700	WiFi 5	300 Mbps	April 2023
RE 3	Netgear	EX3700	WiFi 5	750 Mbps	April 2023
RE 4	Netgear	EX7300	WiFi 5	2.2 Gbps	April 2023
RE 5	Rockspace	RSD0608	WiFi 5	867 Mbps	April 2023
RE 6	TP-Link	RE220	WiFi 5	433 Mbps	April 2023
RE 7	TP-Link	RE315	WiFi 5	867 Mbps	April 2023
RE 8	TP-Link	RE450	WiFi 5	1300 Mbps	April 2023

Source: California Lighting Technology Center

Table 36: Measured and Listed Idle Power for Tested Range Extenders

DUT	Measured Idle Power	Listed Idle Power
RE 1	4.37	4.28
RE 2	1.56	1.64
RE 3	2.95	2.85
RE 4	4.01	4.60
RE 5	3.10	N/A
RE 6	2.51	N/A
RE 7	2.59	N/A
RE 8	3.09	N/A

Source: California Lighting Technology Center

Table 37: Percent of Power Utilized by Tested Range Extenders for Each VA Tier

DUT	% of Tier 1 Allowance	% of Tier 2 Allowance	% of Tier 3 Allowance
RE 1	59.05%	64.26%	71.64%
RE 2	31.20%	33.19%	35.45%
RE 3	34.30%	38.31%	41.55%
RE 4	44.07%	49.51%	54.93%
RE 5	45.26%	49.21%	53.45%
RE 6	36.64%	39.84%	43.28%
RE 7	34.53%	37.54%	39.85%
RE 8	43.52%	47.54%	51.50%

Source: California Lighting Technology Center

Optical Network Terminals

Table 38: Tested ONTs Specification and Product Key

DUT	Manufacturer	Model	Date Ordered
ONT 1	AD-net	AN-UMGSM-AS-20J	July 2023
ONT 2	StarTech	MCMGBSCMM055	July 2023
ONT 3	TP-Link	MC100CM	April 2023
ONT 4	TP-Link	MC200CM	April 2023
ONT 5	TP-Link	MC220L	April 2023
ONT 6	StarTech	IMC1GSFP	July 2023

Source: California Lighting Technology Center

Unlike other devices, ONTs are not listed as a part of the VA for Ongoing Improvement to the Energy Efficiency of Small Network Equipment. However, they were in scope for the initial ENERGY STAR methodology that the VA is based on and still in scope of the European Union Code of Conduct. Data from the tested ONTs is shown in Table 39 through Table 44 for each tested product and condition.

Table 39: Traffic Throughput Test Data for ONT 1

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
ONT 1	1	0 Mbps	0.00	0 Mbps	0.00	2.15
	2	10 Mbps	9.50	10 Mbps	9.49	2.22
	3	0 Mbps	0.00	0 Mbps	0.00	2.21
	4	100 Mbps	94.99	100 Mbps	94.98	2.20
	5	0 Mbps	0.00	0 Mbps	0.00	2.78
	6	1,000 Mbps	95.56	1,000 Mbps	95.58	2.77

Source: California Lighting Technology Center

Table 40: Traffic Throughput Test Data for ONT 2

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
ONT 2	1	0 Mbps	0.00	0 Mbps	0.00	1.61
	2	10 Mbps	9.52	10 Mbps	9.49	1.67
	3	0 Mbps	0.00	0 Mbps	0.00	1.68
	4	100 Mbps	95.02	100 Mbps	95.02	1.67
	5	0 Mbps	0.00	0 Mbps	0.00	1.91
	6	1,000 Mbps	950.20	1,000 Mbps	950.18	1.90

Source: California Lighting Technology Center

Table 41: Traffic Throughput Test Data for ONT 3

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
ONT 3	1	0 Mbps	0.00	0 Mbps	0.00	0.89
	2	10 Mbps	9.51	10 Mbps	9.51	0.93
	3	0 Mbps	0.00	0 Mbps	0.00	0.93

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
	4	100 Mbps	94.93	100 Mbps	94.93	0.93
	5	0 Mbps	N/A	0 Mbps	N/A	N/A
	6	1,000 Mbps	N/A	1,000 Mbps	N/A	N/A

Source: California Lighting Technology Center

Table 42: Traffic Throughput Test Data for ONT 4

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
ONT 4	1	0 Mbps	0.00	0 Mbps	0.00	1.27
	2	10 Mbps	9.53	10 Mbps	9.53	1.34
	3	0 Mbps	0.00	0 Mbps	0.00	1.35
	4	100 Mbps	94.99	100 Mbps	94.99	1.33
	5	0 Mbps	0.00	0 Mbps	0.00	1.70
	6	1,000 Mbps	948.86	1,000 Mbps	948.88	1.69

Source: California Lighting Technology Center

Table 43: Traffic Throughput Test Data for ONT 5

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
ONT 5	1	0 Mbps	0.00	0 Mbps	0.00	0.96
	2	10 Mbps	9.54	10 Mbps	9.54	1.01
	3	0 Mbps	0.00	0 Mbps	0.00	1.34
	4	100 Mbps	95.00	100 Mbps	95.02	1.32
	5	0 Mbps	0.00	0 Mbps	0.00	1.68
	6	1,000 Mbps	950.79	1,000 Mbps	950.80	1.67

Source: California Lighting Technology Center

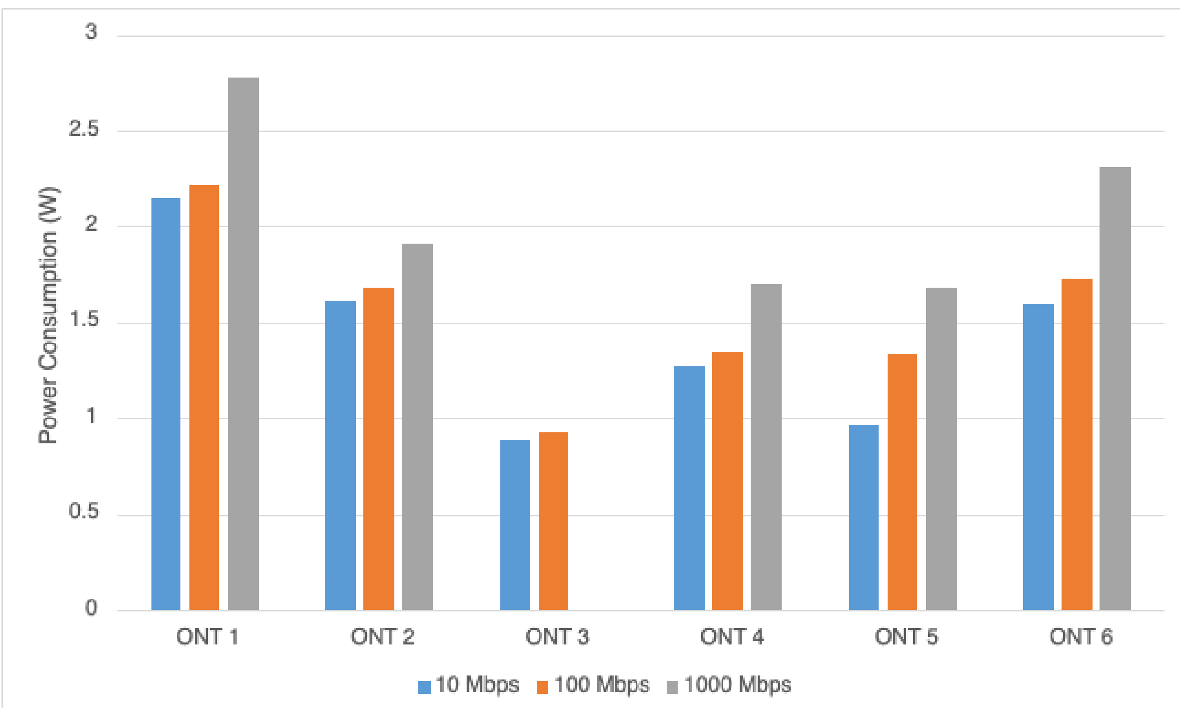
Table 44: Traffic Throughput Test Data for ONT 6

DUT	Test Condition	Target Download Speed	Average Download Speed	Target Upload Speed	Average Upload Speed	Measured Average Power
ONT 6	1	0 Mbps	0.00	0 Mbps	0.00	1.59
	2	10 Mbps	9.51	10 Mbps	9.51	1.66
	3	0 Mbps	0.00	0 Mbps	0.00	1.73
	4	100 Mbps	95.01	100 Mbps	95.04	1.70
	5	0 Mbps	0.00	0 Mbps	0.00	2.31
	6	1,000 Mbps	948.95	1,000 Mbps	948.95	2.32

Source: California Lighting Technology Center

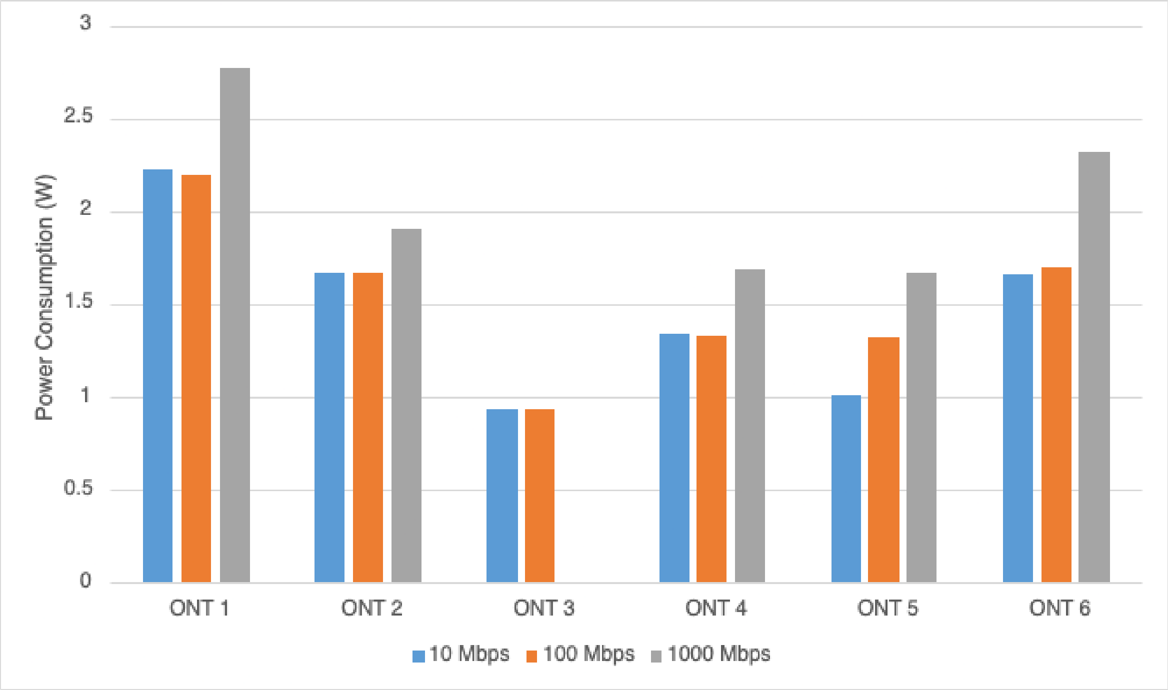
Lastly, Figure 9 and Figure 10 compare the power utilized between tested ONTs with each ethernet standard applied.

Figure 9: Power Consumption of Tested ONTs for Each Ethernet Standard in Idle Conditions



Source: California Lighting Technology Center

Figure 10: Power Consumption of Tested ONTs for Each Ethernet Standard in Max Conditions



Source: California Lighting Technology Center

Commercial Laboratory Equipment

For commercial laboratory equipment, the project team measured and debugged each device and compared the ENERGY STAR, MGL, and ACT environmental impact factor labels. The project team found the differences in the test methods. The team's test method is aimed at power consumption under stable conditions, focusing on equipment that does not change status frequently. The project team did not conduct too many energy loss tests such as opening and closing doors, and the advantage of the team's testing is that the team could test the average power consumption of machines that work for a long time. The project team compared the catalysts, heaters, and sensors used in different models and compared and optimized some of the parts. It verified and provided relevant documents to match the actual situation.

For water baths, the working energy consumption of the water bath ultrasonic instrument is divided mainly into heating and ultrasonic waves. Because these are laboratory instruments, there is still no established measurement standard, so the working principle of the insulating layer and the ultrasonic wave is relatively important.

Proposed ways to test water baths:

1. Test the power consumption of the water bath heater at 99°F (37°C) and test the consumption at the highest temperature.
2. Test the consumption after reaching a stable state or heating is completed.
3. Test the consumption in ultrasonic state.

Additional configurations and testing procedures for each category of device can be found in the Task 4.2 Final Technical Report on Testing Procedures for Plug Load Devices in the Project Deliverables section of this report and in Appendix A.

The electricity meter uses real-time data collection, and the meter is placed where the equipment is connected to the power line. The equipment will record the current, voltage, and power of the power supply. Confirm the current state of the device through the camera and, finally, adjust and study the device data against the time. Table 45 details the testing states.

Table 45: Laboratory Equipment Testing States

Device Type	State 1	State 2	State 3	State 4
Insignia – 13.8 Cu. Ft. Upright Convertible Freezer/Refrigerator	25°F (-4°C)	N/A	N/A	N/A
VWR® Freestanding Undercounter Laboratory Freezer, (–20°C)	14°F (-10°C)	32°F (0°C)	N/A	N/A
VWR 4CF	25°F (-4°C)	N/A	N/A	N/A
Frigidaire	-4°F (-20°C)	N/A	N/A	N/A
Thermo Freezer	32°F (0°C)	14°F (-10°C)	N/A	N/A
Kenmore	25°F (-4°C)	N/A	N/A	N/A
Eppendorf Centrifuge 5417R	standby	1000, 2000, 4000, 8000 rpm with 99°F (37°C)	N/A	N/A
Eppendorf Centrifuge 5430R	standby	1000, 2000, 4000, 8000 rpm with 99°F (37°C)	N/A	N/A
Eppendorf Centrifuge 5424	standby	1000, 2000, 4000, 8000 rpm with 99°F (37°C)	N/A	N/A
accuspin micro 17r	standby	1000, 2000, 4000, 8000 rpm with 99°F (37°C)	16°F (-9°C), 32°F (0°C), 50°F (10°C), 68°F (20°C) with 2000 rpm	N/A
J15	standby	1000, 2000, 4000, 8000 rpm with 99°F (37°C)	16°F (-9°C), 32°F (0°C), 50°F (10°C), 68°F (20°C) with 2000 rpm	N/A

Device Type	State 1	State 2	State 3	State 4
KENDAL Ultrasonic Cleaner	Off or standby	Heating with 99°F (37°C) and ultrasound	Heating with max temperature and ultrasound	N/A
Fisher Scientific Isotemp Dual Digital Water Bath Model 2322	Off or standby	Heating with 99°F (37°C) and ultrasound	Heating with max temperature and ultrasound	N/A
Emerson CPX1800H device1	Off or standby	Heating with 99°F (37°C) and ultrasound	Heating with max temperature and ultrasound	N/A
Emerson CPX1800H device2	Off or standby	Heating with 99°F (37°C) and ultrasound	Heating with max temperature and ultrasound	N/A
DK SONIC	Off or standby	Heating with 99°F (37°C) and ultrasound	Heating with max temperature and ultrasound	N/A
Benchmar Roto-Therm Incubated Rotators	50°F (10°C) heating	99°F (37°C) heating	N/A	N/A
Benchmark INCU SHAKER Mini & 10L Shaking Incubators	39°F (4°C) heating	50°F (10°C) heating	N/A	N/A
NUAIRE NU-8700 Incubator	99°F (37°C) heating	N/A	N/A	N/A
PHCBI CO2 Incubators Double Stacked TESTED with Warranty SEE VIDEO	99°F (37°C) heating	N/A	N/A	N/A
vwrmini_incubator	50°F (10°C) heating	99°F (37°C) heating	N/A	N/A
Midmark M11 Autoclave1	Unwrapper	Handplace	N/A	N/A
Midmark M11 Autoclave2 (different device)	Unwrapper	Handplace	N/A	N/A
Consolidated_hinded_autoclave (Host part)	Unwrapper	N/A	N/A	N/A
Consolidated_hinded_autoclave (Vacuum pump part)	Unwrapper	N/A	N/A	N/A
Ritter M11 UltraClave Automatic Sterilizer	Unwrapper	Handplace	Pounches	Packs

rpm=revolutions per minute
Source: California State University Northridge

Datasets and Results

The testing of the laboratory equipment lasted two months and tested experimental equipment for different species, including water baths, freezers, incubators, centrifuges, and autoclaves. The test method was to insert the HOBO meter into the socket and insert the device plug into the meter so that the current could pass through the meter, the meter could record, and the meter could test the voltage, current, power, and energy. The cycle used in this experiment was one day for freezers and incubators and one hour for other equipment to test the energy usage in different states, respectively. Only the freezer testing can meet ENERGY STAR standards. Therefore, using a large amount of data to compare and find deviations is feasible.

Highlights of the testing results and datasets for the laboratory equipment are shown in Table 46, segmented by each device subgroup.

Freezers

Table 46: Freezer Average Power and Power Consumption

	Temperature (°C)	Capacity (cu ft)	Average Power (W)	Power Consumption (Wh)
24 hours				
Kenmore	-4	13.8	25.97	2243.64
VWR 4cf		5	44.55	3849.07
Insignia		13.8	33.43	2888.39
VWR Undercounter	-10	4.2	25.05	2103.93
Thermo Freezer		1.8	18.74	1574.36
Frigidaire	-20	16.6	73.85	6852.03
9 hours				
VWR Undercounter	0	4.2	51.5892	1878.43
Thermo Freezer		1.8	22.31	722.73

cu ft=cubic feet
Source: California State University Northridge

The project team found the refrigerant for each machine and surveyed and ranked the refrigerants. The survey found that R600 can be used in a broader range but has a relatively low price and energy consumption efficiency. R290 is a replacement for the R-134; the R290 is more outstanding in performance and efficiency. Table 47 shows the rankings.

Table 47: Efficiency Ranking of Refrigerants Used in Freezers

	Refrigerant	Efficiency Rank
Frigidaire FFH17F7HW 16.6 cu ft	R-134a	1
Insignia™ - 13.8 cu ft Garage Ready Convertible Upright Freezer	R600a	3

	Refrigerant	Efficiency Rank
Kenmore 22442 13.8 cu ft Frost-Free Upright Freezer - White	R-134a	2
Thermo Scientific Value Series Laboratory Freezer -11°F (-24°C), 1.8 cu ft	R290/ R170+R290 Mix	1
VWR - Undercounter Freezer General Purpose 4 cu ft 1 Solid Door	R-134a	2
VWR FREEZER UC MAN DEFROST FS S 4CF	R290	2

Source: California State University Northridge

Centrifuges

Compared with freezers and incubators, centrifuges require more attention to the equipment's energy mode and heat preservation capabilities. In laboratory use, most of the centrifuge's working state is standby, so keeping warm and automatically shutting down after sleep standby is the most critical part. In addition, the energy consumption generated by the centrifuge during cooling or heating and operation is also a part that must be addressed. The approximate energy consumption comes from these two parts.

This testing included 1,000 rpm, 2,000 rpm, 4,000 rpm, and 8,000 rpm at 99°F (37°C) (Table 48). When the rotational speed was 2,000, the project team tested the energy consumption generated at 16°F (-9°C), 32°F (0°C), 50°F (10°C), and 68°F (20°C).

Based on the test results, the team could analyze the working efficiency by comparing the rotation energy consumption in the equipment with that of different equipment, and it could explore the energy consumption required for cooling and heating can be analyzed.

Table 48: Average Power Consumption of Centrifuges in Various States

2000 rpm			
Device	**Temperature (°C)**	**Power (W)**	**Power Consumption (Wh)**
17R	-9	17.04	61.34
J15		352.04	1267.68
17R	0	30.12	108.48
J15		382.77	1378.37
17R	10	13.41	42.14
J15		409.15	1472.52
17R	20	10.94	39.41
J15		444.43	1600.39
17R	37	22.69	81.71
J15		460.98	1695.99

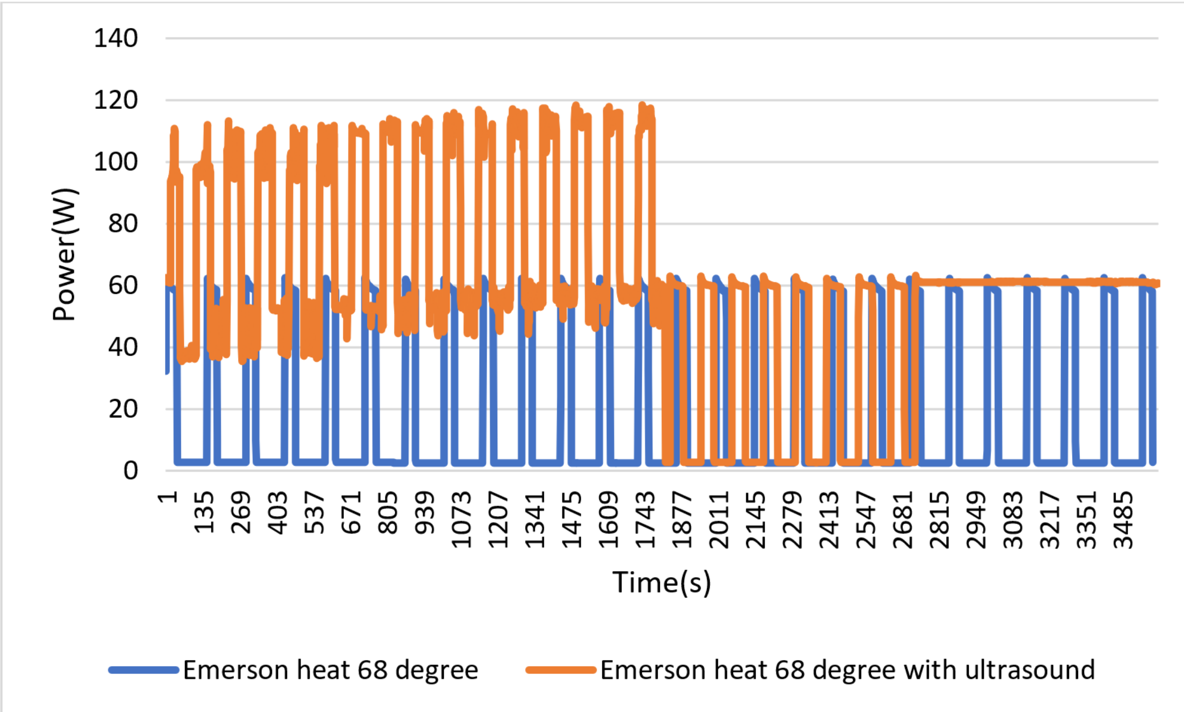
37°C			
Device	**Speed (rpm)**	**Power**	**Power Consumption (Wh)**
5417R	1000	452.01	1637.7
17R		24.82	89.37
5424		21.53	77.56
5430R		129.03	464.64
J15		451.96	1627.5
5417R	2000	460.83	1659.43
17R		22.69	817.13
5424		20.5	73.84
5430R		198.68	711.88
J15		460.98	1659.99
5417R	4000	473.05	1703.44
17R		27.37	98.55
5424		25	90.06
5430R		843.5	3037.46
J15		473.22	1704.05
5417R	8000	516.35	1859.36
17R		516.27	1863.72
5424		52.8	190.18
5430R		1194.28	4288.67
J15		516.35	1859.36

Source: California State University Northridge

Water Baths

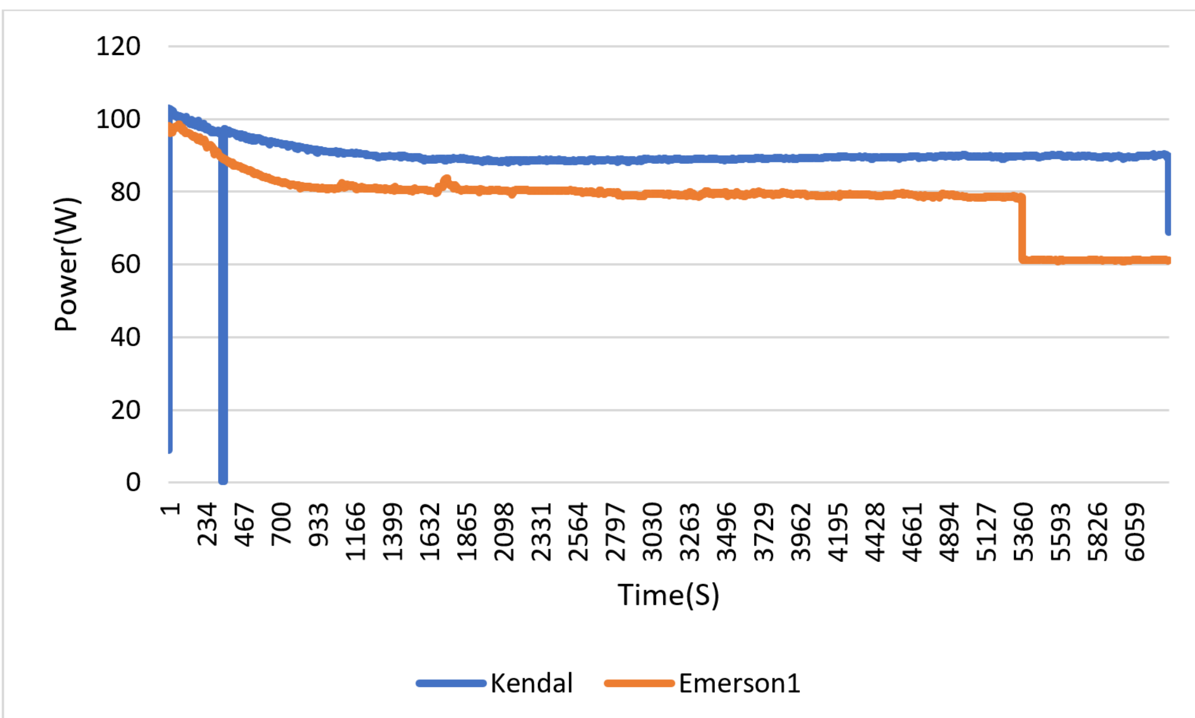
Water baths are not frequently used in the laboratory, so laboratory personnel usually choose to turn them off when not in use, but a small number of water baths are often in standby mode. In the test observation of water baths, the team's main research was divided into three parts: energy consumption in standby state, energy consumption in heating state, and energy consumption generated by ultrasonic waves (Figure 11 through Figure 13).

Figure 11: 154°F (68°C) State for Heating State With Ultrasound for One Cycle



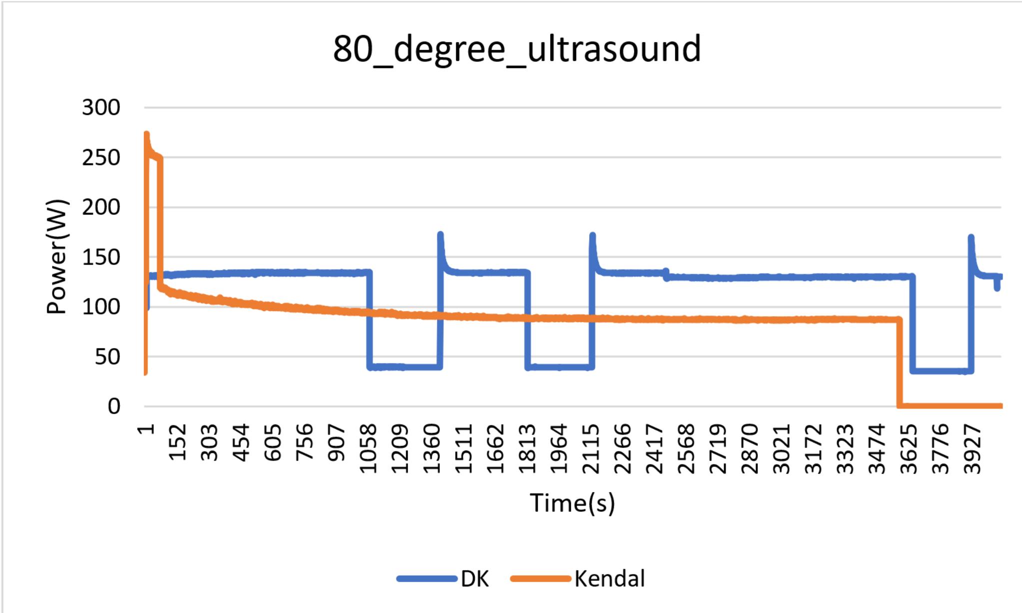
Source: California State University Northridge

Figure 12: 99°F (37°C) With Ultrasound State for One Cycle



Source: California State University Northridge

Figure 13: 176°F (80°C) With Ultrasound State for One Cycle



Source: California State University Northridge

Incubators

The frequency of use of the benchtop incubator is not high, so here the team mainly discussed the standby to shutdown of the benchtop and the long-term use of the floor stand, as shown in Table 49. The energy usage of the incubator mainly comes from reheating, so there may be some research on the control range of the sensor. The survival temperature of most cells exists between 97°F (36°C) and 99°F (37°C). Figure 14 shows the power for the incubator in 39°F (4°C) state. Figure 15 shows the power for the incubator in 50°F (10°C) state. Figure 16 shows the power for the incubator in 99°F (37°C) state for 24 hours.

Table 49: Average Power of Incubators in Various States

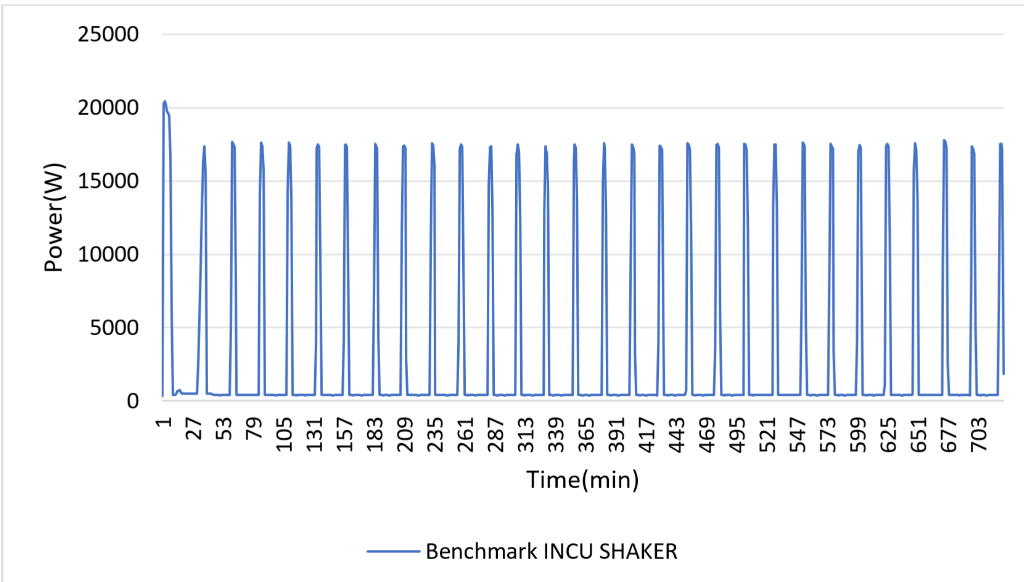
Devices	Test Time (h)	Heat 39°F (4°C)	Heat 50°F (10°C)
		Average Power (W)	Average Power (W)
Benchmark_Sharker	12	51.51	
	24		27.31
Benchmar Rot24	24		30.67
vwrmini_incubator	24		27.32

Heat 99°F (37°C) for 24 hours	
Devices	Average Power (W)
PHCBI CO2 Incubators	82.2
Benchmar Roto	12.15

Heat 99°F (37°C) for 24 hours	
Devices	**Average Power (W)**
vwrmini_incubator	56.66
NUAIRE NU-8700 Incubator	26.00

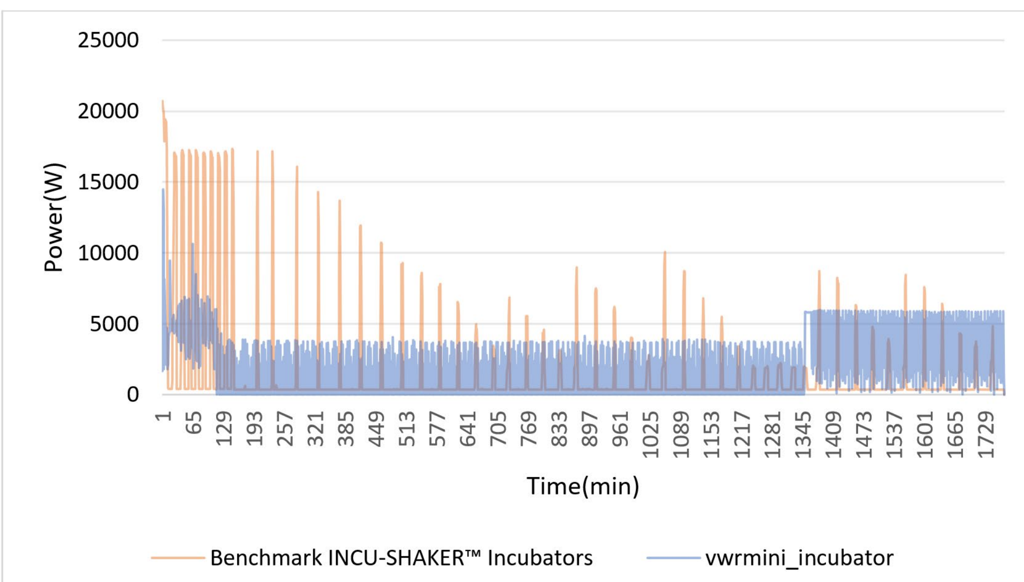
h=hours
Source: California State University Northridge

Figure 14: Data for Incubator 39°F (4°C) State



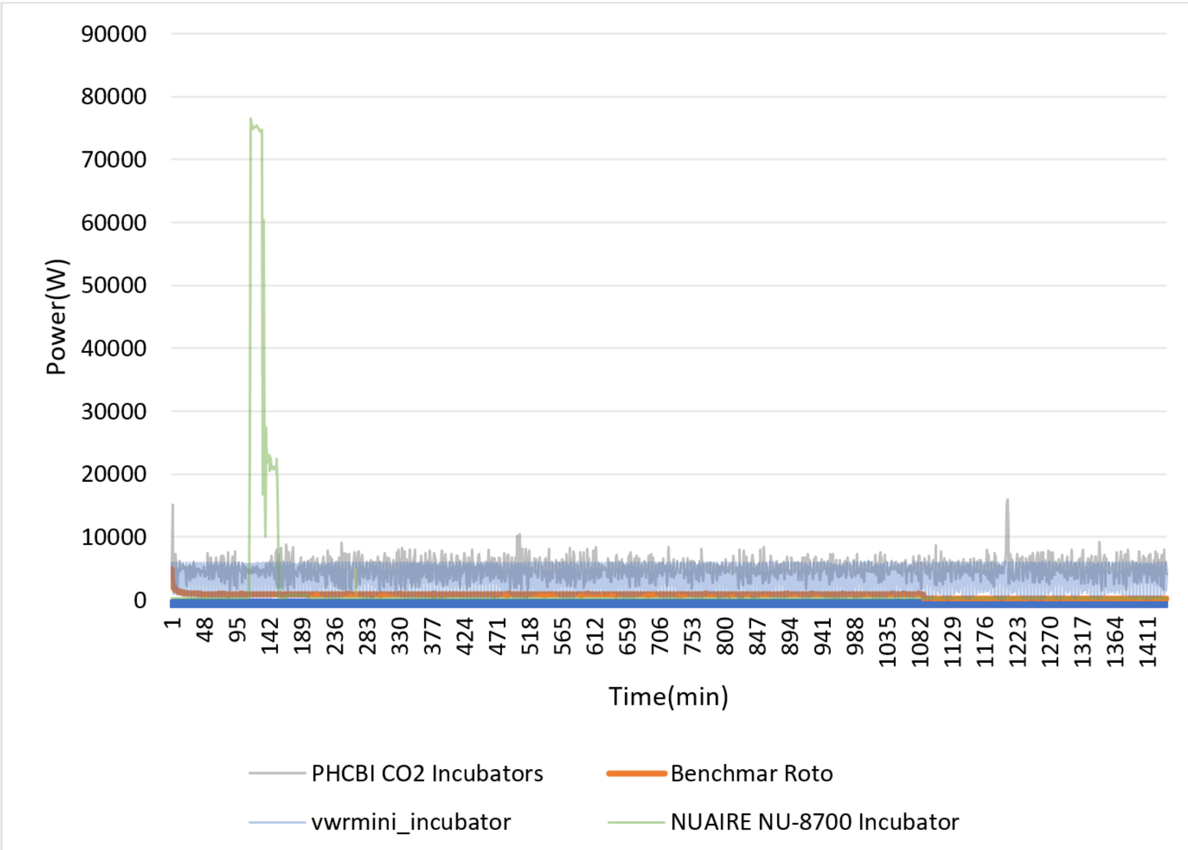
Source: California State University Northridge

Figure 15: Data for Incubator 50°F (10°C) State



Source: California State University Northridge

Figure 16: Data for Incubator 99°F (37°C) State for 24 Hours



Source: California State University Northridge

Autoclaves

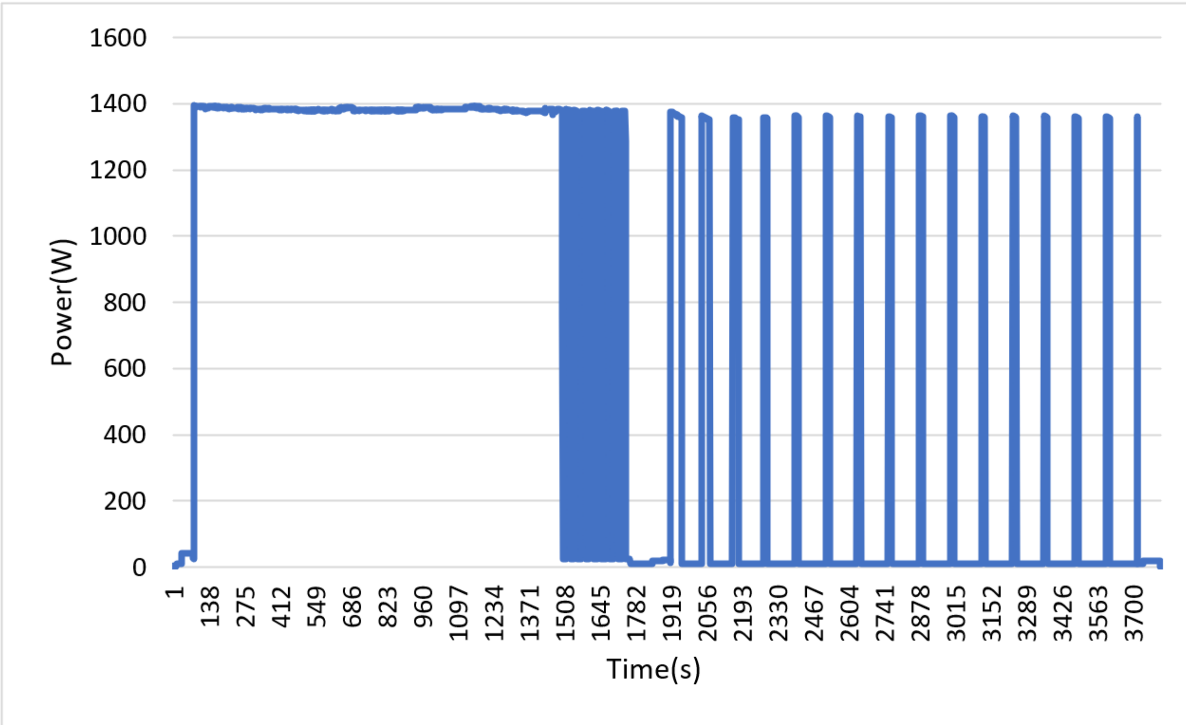
The use of the benchtop autoclave was carried out according to the cycle, and most of the use cycles were within one hour. An autoclave is mainly used for high-temperature sterilization of instruments. The machine liquefies water to achieve high-temperature effects in a closed space. Here, the heating efficiency of the centrifuge and the recycling of liquefied water were the main issues. Table 50 lists the autoclaves and their different states. Figure 17 through Figure 21 show the power of the different types of autoclaves tested.

Table 50: List of Autoclaves Tested

Devices List	State 1	State 2	State 3	State 4
Midmark M11 Autoclave1	Unwrapper	Handplace		
Midmark M11 Autoclave2 (different device)	Unwrapper	Handplace		
Consolidated_hinded_autoclave	Unwrapper			
Consolidated_hinded_autoclave (same device)	Unwrapper			
Ritter M11 UltraClave Automatic Sterilizer	Unwrapped	Pouches	Packs	Handplace

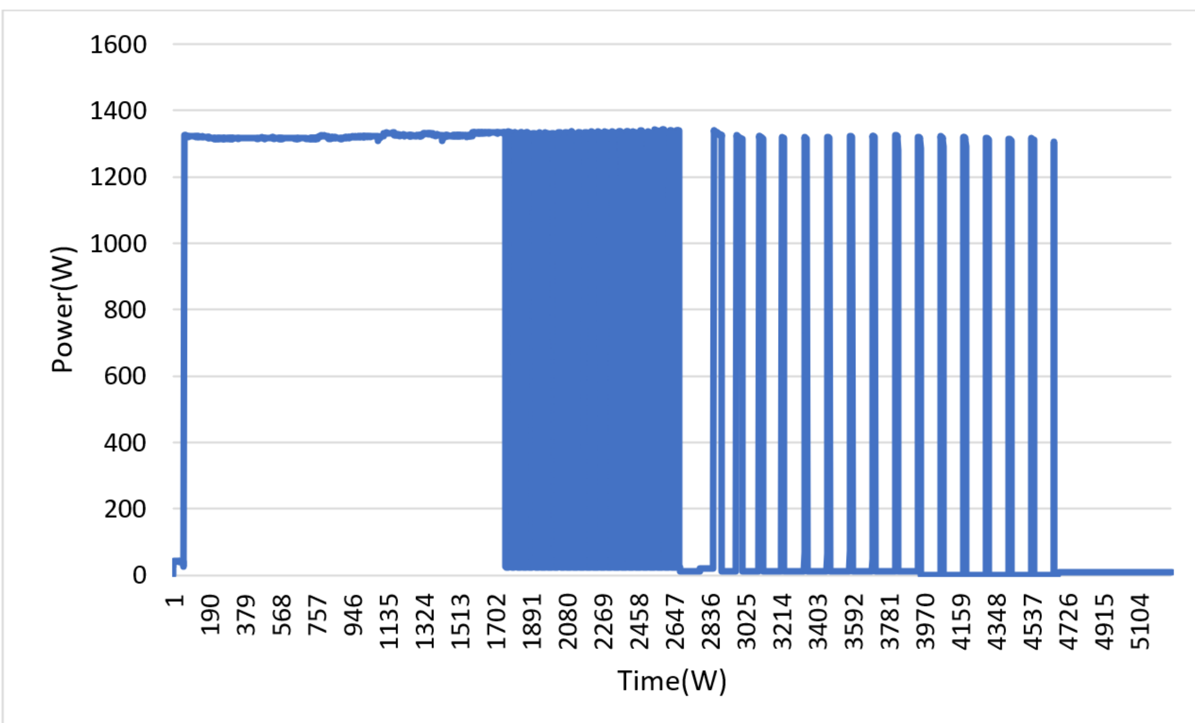
Source: California State University Northridge

Figure 17: Data for Midmark M11 Autoclave1 Data for Cycle 1 in Unwrapper and Handplace States



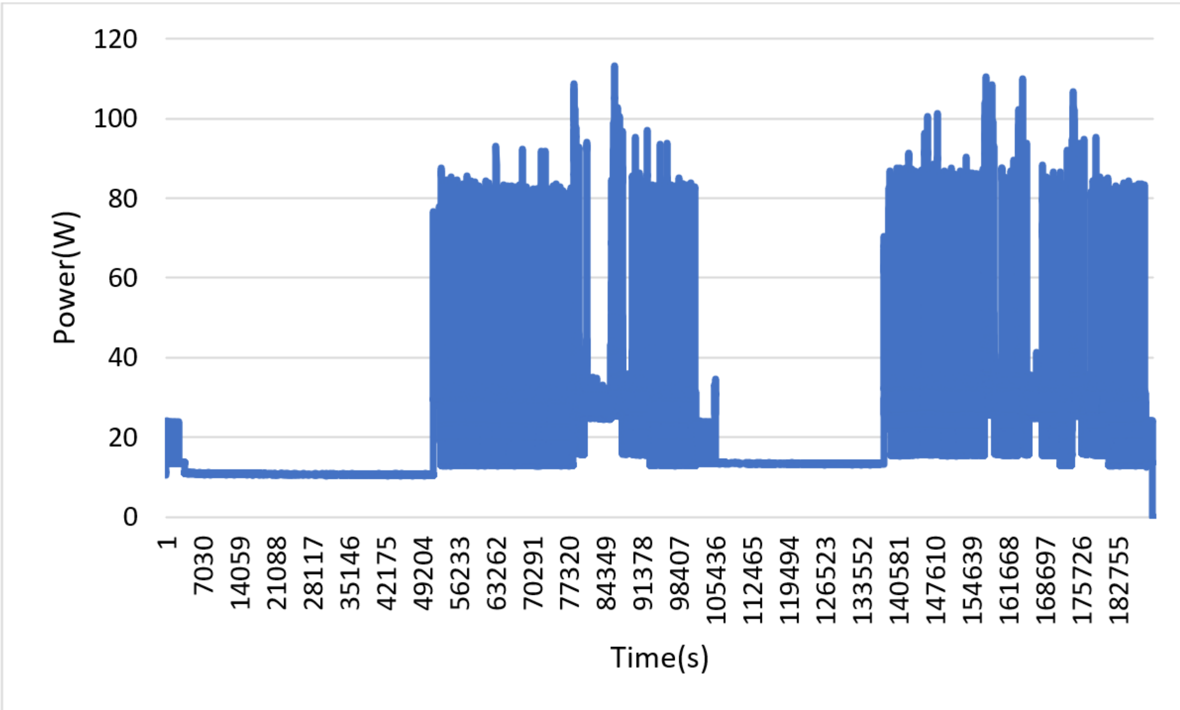
Source: California State University Northridge

Figure 18: Data for Midmark M11 Autoclave2 Data for Cycle 2 in Unwrapper and Handplace States



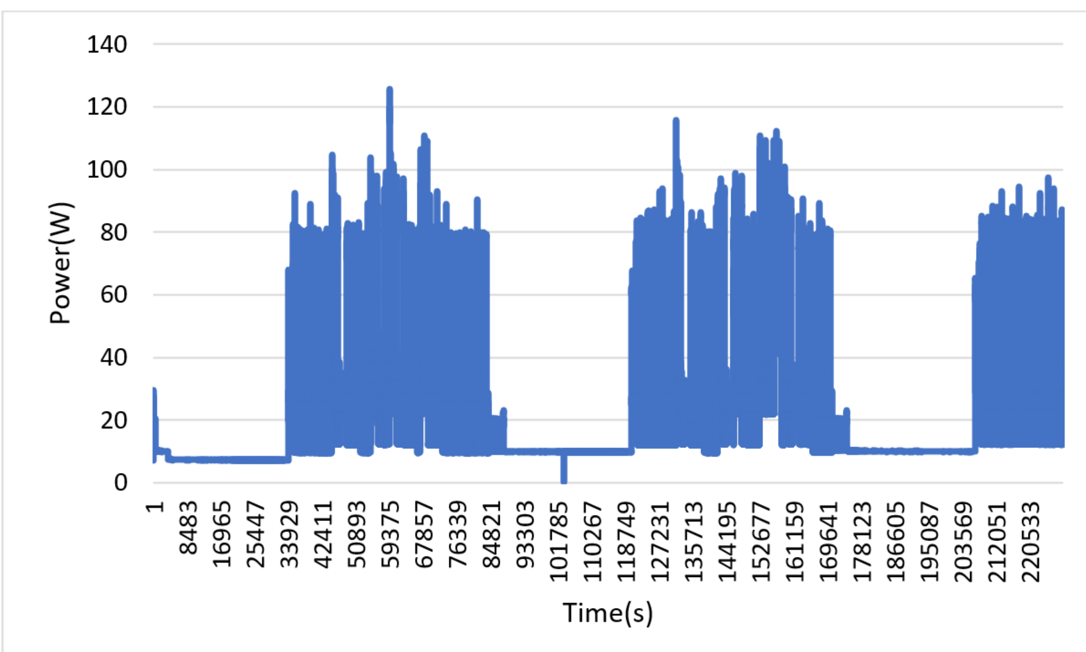
Source: California State University Northridge

Figure 19: Data for Consolidated_Hinded_Autoclave Data for Cycle 1



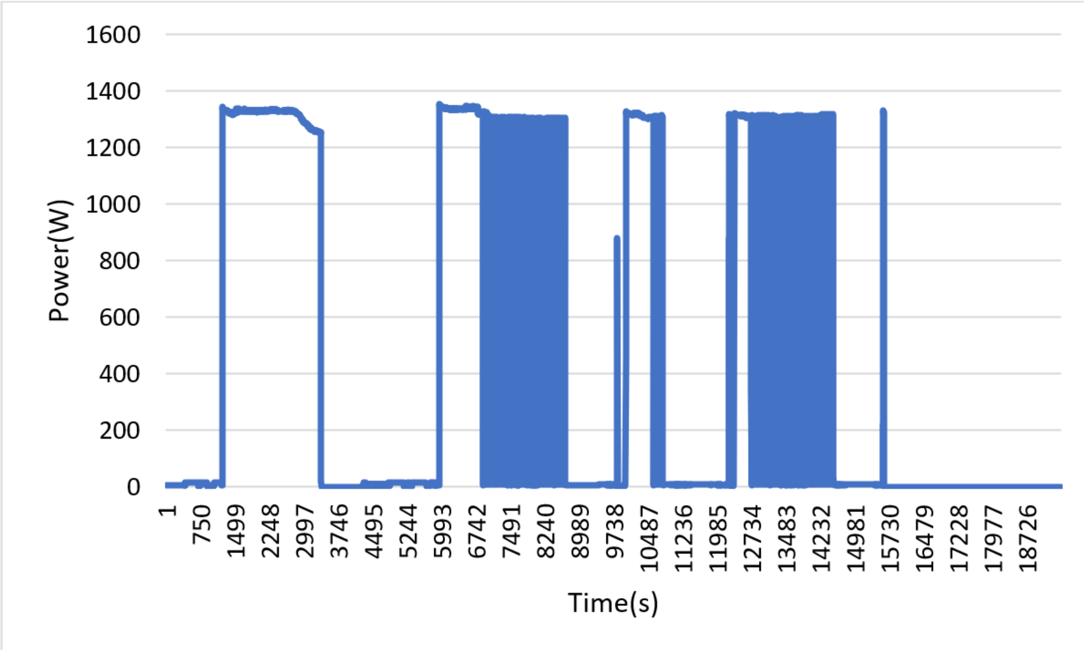
Source: California State University Northridge

Figure 20: Data for Consolidated_Hinded_Autoclave Data for Cycle 2



Source: California State University Northridge

Figure 21: Data for Ritter M11 UltraClave Automatic Sterilizer in Unwrapped, Pouches, Packs, and Handplace States



Source: California State University Northridge

Additional test results, datasets, and evaluated energy use for each device category can be found in the Task 4.1 Device Test Results and Task 4.3 Codes & Standards Impacts reports located in the Project Deliverables section of this report and in Appendix B.

CHAPTER 4: Conclusion

The PLETICS project concluded with the evaluation of energy usage for device operations, the range of expected energy savings from recommended codes and standards updates, and cost-effectiveness analyses for near-term code implementation. Additionally, where possible, the project team assessed the impacts on the estimated cost of improvements to manufacturers and corresponding increase in retail prices.

The PLETICS project team divided this Conclusion section by device category: commercial office equipment, residential networking equipment, and laboratory equipment. Each subsection highlights recommended codes and standards as well as the impacts of the codes and standards. The Laboratory Equipment subsection is unique in that there are no current regulatory or voluntary standards to start with, so the team provided novel ideas to include in future codes and standards.

Further analysis on the recommended codes and standards and the impacts of evaluated energy use can be found in the Task 4.3 Plug Loads – Codes & Standards Impacts Report in the Project Deliverable section of this final report.

Commercial Office Equipment

Recommendations for future codes and standards are twofold: 1) the CEC is encouraged to collaborate with ENERGY STAR or to design a separate testing mechanism to understand and record the effects of internet connectivity on device performance in active, low power, and soft-off modes (specifically, connected to a power source); and 2) the CEC is encouraged to design a labeling program for consumers to better compare typical energy consumption between products.

When designing a future test method for imaging devices incorporating internet connectivity, it will be important for the CEC to be mindful of the fast-paced nature of the imaging product industry and to require reviews of the product market every two to three years to ensure that the regulatory body is keeping pace with industry, while not stifling product innovation. The goal should be to sweep older, less efficient products out of the market, rather than to get ahead of industry and prevent it from introducing novel device features that may ultimately enhance energy savings and consumer comfort.

Finally, the CEC may also want to consider how imaging devices fit into future regulations and voluntary agreements around grid flexibility and demand response capability. Although the market for DR-capable appliances and load flexibility is still emerging and is currently restricted to large household appliances such as heating, ventilation and air conditioning (HVAC) units, dishwashers, and clothes washers/dryers, the goals of decarbonization in California require an aggressive approach to grid management. Indeed, early work from the CalFlexHub at the Lawrence Berkeley National Laboratory envisions new ways to integrate home electronics to the grid, for example, through smart hubs. Full integration of small household electronics may require new thinking that incorporates interoperability standards into small electronics, including printers. Although many current interoperability standards are led mainly by industry (specifically, CTA2045), the CEC and the California Independent System Operator (CAISO) will be responsible for ensuring that communication with the grid provides safe, secure, and effective connections for all customers.

Residential Networking Equipment

The team's recommendations for future codes and standards emphasize the need for adaptability to keep pace with the rapid evolution of RNE. Given the short two- to three-year lifespan of these devices, any new standard must be flexible enough to address frequent technological advancements, such as higher data throughput, mesh networking, and smart home integration.

Through discussions with representatives from the VA, the team confirmed that the VA does not intend to evolve into a mandatory state requirement. As a result, any new code or standard for RNE will need to start fresh rather than build upon the existing VA framework. This approach allows for the creation of standards that better reflect modern usage patterns and emerging technologies without being constrained by the limitations of voluntary agreements.

The team recommends scalable frameworks that allow incremental updates as technologies evolve, reducing the need for frequent, resource-intensive revisions. Standards should also emphasize performance metrics that capture both idle and active states, along with dynamic load conditions, to provide a more accurate representation of real-world energy performance.

Enhanced labeling and reporting practices are strongly recommended to provide consumers with actionable information about device energy usage, encouraging informed purchasing decisions and pushing manufacturers to prioritize energy efficiency. Collaborative efforts with policymakers, manufacturers, and researchers are also advised, to ensure that the standards remain relevant and adaptable to future market trends.

Commercial Laboratory Equipment

For freezers, the objective was to evaluate the effects of novel refrigerants and insulation technologies on manufacturing costs and market pricing, while establishing a baseline standard and proposing a testing methodology to inform the development of comprehensive standards.

Although the use of higher-efficiency refrigerants and advanced insulation materials may initially increase manufacturing costs, the long-term benefits — such as enhanced energy efficiency and reduced environmental impact — offer substantial savings to consumers. Compared to other refrigerants, R600 demonstrates superior energy efficiency; however, due to certain environmental hazards, it is commonly used in larger freezer units. Standardization of refrigerants for freezers across various sizes is recommended. As indicated in the experimental data from Task 4.2, the Energy Efficiency Index (EEI) ranges from a maximum of 2,103.93 watt-hours per cubic foot (Wh/Cu) to a minimum of 162.58 Wh/Cu. It is noteworthy that the unit with the highest energy efficiency was neither the largest nor the smallest by volume, suggesting a considerable potential for improving energy efficiency. Due to limited evaluations of laboratory equipment, it is advisable to control freezer models with identical capacities during testing. Where feasible, testing should include scenarios in which refrigerants are interchangeable, to accurately assess energy consumption efficiency.

For centrifuges, the objective was to evaluate the impact of fan optimization and intelligent standby modes on equipment costs and market adoption. Another objective was to improve the cooling capacity, storage space, and standby energy consumption of the equipment.

Although initial manufacturing costs may increase due to new design requirements, the overall improvement in energy efficiency will reduce long-term operational costs. The new standard should encourage the broad adoption of intelligent standby modes to minimize energy waste from idle equipment. Future testing should prioritize centrifuges of identical capacity to validate operational performance. Additionally, standby modes should be optimized to minimize energy consumption while ensuring cell viability during dormancy.

For water baths, the project team identified the impacts of developing a new standard mandating more efficient heating systems and improved insulation for water baths, to minimize energy waste, along with providing detailed recommendations for the standard's specifications.

While implementing a more efficient system may initially raise manufacturing costs, the energy savings over time are expected to compensate for the investment within two to three years. The standard should require that water baths maintain consistent temperatures, reduce unnecessary heating cycles, and ensure that large water baths do not exceed one watt of power consumption when insulated. Future testing should involve a wide range of large water baths of various capacities, to assess and compare their insulation materials and energy consumption.

For incubators, the new standard should mandate improvements in temperature control and insulation performance to enhance energy efficiency. Future testing should compare different models of similar capacities, with a tiered approach for different capacity ranges to account for cost considerations.

Small incubators often lack insulation requirements, leading some manufacturers to prioritize cost savings over insulation performance. To address this, a minimum insulation standard should be introduced for small incubators. For large incubators, regulating the frequency of heat cycles is essential to reduce unnecessary energy consumption.

Given the complexity of autoclaves, evaluations should focus on the entire operational cycle. A standardized, tiered assessment system should be established to compare and rank different models, based on their volume and overall performance.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
ACT Label	Accountability, Consistency, and Transparency Label
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
avg	average
BSC	biosafety cabinet
°C	degrees Celsius
C&S	codes and standards
CAGR	compound annual growth rate
CAISO	California Independent System Operator
CalPlug	California Plug Load Testing Center
CEA	California Energy Alliance
CEC	California Energy Commission
CLTC	California Lighting Technology Center
CMTS	cable modem termination system
CPE	customer premises equipment
CSUN	California State University, Northridge
cu ft	cubic feet
DR	demand response
DSL	digital subscriber line
DUT	Device Under Test
EC	European Commission
EEI	Energy Efficiency Index
EP	electrophotographic
EPA	Environmental Protection Agency
EPEAT	Electronic Product Environmental Assessment Tool
EPIC	Electric Program Investment Charge
EU	European Union
EU CoC	European Union Code of Conduct
EU VA	European Union Voluntary Agreement
°F	degrees Fahrenheit
GHG	greenhouse gas

Term	Definition
h	hours
HVAC	heating, ventilation and air conditioning
IAD	Integrated Access Device
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IOU	investor-owned utility
ipm	images per minute
kWh, kWh/wk, kWh/yr	kilowatt-hours, kilowatt-hours per week, kilowatt-hours per year
LAN	local area network
LED	light emitting diode
LPM	Low Power Mode
Mbps	megabits per second
MFC	multi-function copiers
MFD	multi-function devices
Mfr	manufacturer
MGL	My Green Lab
min	minute
NREL	National Renewable Energy Laboratory
OM	operational mode
ONT	optical network terminal
PLETICS	Plug Load Energy Testing to Inform Codes & Standards
RNE	residential network equipment
rpm	rotations per minute
s	second
SNE	small network equipment
TC	tissue culture hoods
TEC	typical energy consumption
UCI	University of California, Irvine
UCLA	University of California, Los Angeles
UEC	unit energy consumption
U.S. EPA	United States Environmental Protection Agency
UUT	unit under test

Term	Definition
UV	ultraviolet
V	volts
VA	voluntary agreement
W	watts
Wh	watt-hour
Wh/Cu	watt-hour per cubic foot
wk	week

References

Blue Angel German Ecolabel. 2017. *Office Equipment with Printing Function (Printers and Multifunction Devices).* Basic Award Criteria Version 4, Edition January 2017. Report Number DE-UZ 205. Available at https://web.archive.org/web/20210301011952/https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20205-201701-en%20Criteria-2020-06-02.pdf.

Blue Angel German Ecolabel. 2019. *Office Equipment with Printing Function (Printers and Multifunction Devices)*. Basic Award Criteria Version 4, Edition 2021. Report Number DE-UZ 219. Available at https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20219-202101-en%20Criteria-V4.pdf.

California Energy Commission. 2021. "California Investor Owned Utilities Comments - Cover Letter and Data Collection Procedure: Data Collection Procedure for Inactive State Power." May 14, 2021. Available at https://efiling.energy.ca.gov/GetDocument.aspx?tn=237807&DocumentContentId=71046.

Chiang, T., S. Natarajan, and I. Walker. 2012. "A laboratory test of the efficacy of energy display interface design." *Energy and Buildings*, 55: 471–480. Available at http://dx.doi.org/10.1016/j.enbuild.2012.07.026.

Dayem, K., and C. Granda. 2020. *Small Network Equipment: Energy Savings Opportunities and Test Procedure Needs for the LPM Roadmap*. California Statewide Investor-Owned Utilities Codes and Standards Program. Available at https://efiling.energy.ca.gov/GetDocument.aspx?tn=235563&DocumentContentId=68495.

Deloitte Center for Technology, Media & Telecommunications. 2021. "How the pandemic has stress-tested the crowded digital home." *Deloitte Insights.* Available at https://www2.deloitte.com/content/dam/insights/articles/6978_TMT-Connectivity-and-mobile-trends/DI_TMT-Connectivity-and-mobile-trends.pdf.

Durand, J.B., S. Girard, V. Ciriza, and L. Donini. March 2013. "Optimization of power consumption and device availability based on point process modelling of the request sequence." *Journal of the Royal Statistical Society Series C (Applied Statistics),* 62(2): 151–165. Available at https://doi.org/10.1111/j.1467-9876.2012.01053.x.

Elliott, I. 2018. "Why is a transition from laser to inkjet printers going to take place?" September 4, 2018. Available at https://blog.eandssolutions.com/blog/why-is-a-transition-from-laser-to-inkjet-printers-going-to-take-place.

Elmirghani, J., T. Klein, K. Hinton, L. Nonde, A. Lawey, T. El-Gorashi, M. Musa, and X. Dong. 2018. "GreenTouch GreenMeter Core Network Energy-Efficiency Improvement Measures and Optimization." *Journal of Optical Communications and Networking*, 10(2): A250–A269. Available at https://doi.org/10.1364/JOCN.10.00A250.

Energy Solutions. 2022. *2022 Plug Loads & Appliances Technology Priority Map*. CalNEXT. December 15, 2022. Available at https://calnext.com/wp-content/uploads/2022/12/2022-Plug-Loads-Appliances-TPM-December-15-2022.pdf.

Environmental Protection Agency. 2019. "Version 3.0 Imaging Equipment Test Method Draft 1 Comment Summary." Available at https://www.energystar.go.jp/document/pdf/Image_Equipment/3.0/IE30D1_TestMethod_comment.pdf.

Environmental Protection Agency. 2019a. *ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2019 Summary*. Available at https://web.archive.org/web/20211218142047/https://www.energystar.gov/sites/default/files/asset/document/2019%20Unit%20Shipment%20Data%20Summary%20Report.pdf.

Environmental Protection Agency. 2019b. *ENERGY STAR Program Requirements for Imaging Equipment*. Available at https://web.archive.org/web/20201019042654/https://www.energystar.gov/sites/default/files/FINAL%20Version%203.0%20ENERGY%20STAR%20Imaging%20Equipment%20Program%20Requirements.pdf.

Environmental Protection Agency. 2021. *ENERGY STAR Imaging Equipment Program Requirements Version 3.1*. Available at https://web.archive.org/web/20220119013102/https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Version%203.1%20Imaging%20Equipment%20Specification.pdf.

Environmental Protection Agency. 2022a. "ENERGY STAR Certified Imaging Equipment Qualified Product List." Accessed September 9, 2022. Available at https://web.archive.org/web/20220326171155/https://www.energystar.gov/productfinder/product/certified-imaging-equipment/results.

Environmental Protection Agency. 2022b. "Imaging Equipment Qualified Products." Available at https://www.energystar.gov/productfinder/product/certified-imaging-equipment/results.

European Commission. 2013. "Commission Regulation No 801/2013 of 22 August 2013 Amending EC 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment." Official Journal of the European Union. Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R0801.

European Commission. 2019. *Revision of Voluntary Agreement on Imaging Equipment Task 1-7 Final Report*. Available at https://circabc.europa.eu/d/a/workspace/SpacesStore/e8502596-432a-4991-807b-340e7f3d6171/Lot%204%20-%20Imaging%20equipment%20-%20Revision%20Task%201-7.pdf.

EuroVAPrint. 2015. *Industry Voluntary Agreement to Improve the Environmental Performance of Imaging Equipment Placed on the European Market,* VA v. 5.2. April. Available at https://www.stp.de/fileadmin/user_upload/stp-de/07_Downloadcenter/Broschueren__Factsheets__Studien/Studien/Selbsterklaerung_OEM.pdf.

EuroVAPrint. 2019. *Imaging Equipment Voluntary Agreement Annual Compliance Report of the Independent Inspector — Period 9 (1 January — 31 December 2018).* Report Number: 2019-0230. April 24, 2019. Available at https://www.eurovaprint.eu/fileadmin/eurovaprint_files/pdfs/2019/REG02009-001_EuroVAprint-9th_period_repf1.pdf.

EuroVAPrint. 2020. *Imaging Equipment Voluntary Agreement Annual Compliance Report of the Independent Inspector — Period 10 (1 January — 31 December 2019).* Report Number: 2020-0031. April 21, 2020. Available at https://www.eurovaprint.eu/fileadmin/eurovaprint_files/Member_Only/Reports/REG03418-001_EuroVAprint-10th_period_repf1.0.pdf.

EuroVAPrint. 2021. *Imaging Equipment Voluntary Agreement Annual Compliance Report of the Independent Inspector — Period 11 (1 January — 31 December 2020).* Report Number: 2021-0190. April 19, 2021. Available at https://www.eurovaprint.eu/fileadmin/eurovaprint_files/Member_Only/Reports/Independent_Inspector/REG45422-001_EuroVAprint-11th_period_repf1.0.pdf.

IDC Corporate. 2022. "Worldwide Hardcopy Peripherals Shipments Contracted 3.9% Year Over Year in the Second Quarter of 2022, According to IDC." June 1, 2022. Available at https://web.archive.org/web/20220623141300/https://www.idc.com/promo/hardcopy-peripherals.

IndustryARC. 2021. *Laboratory Equipment Services Market - Forecast (2022 - 2027).* Available at https://www.industryarc.com/Report/16800/laboratory-equipment-services-market.html.

Globe Newswire. 2021. *Analytical Laboratory Instrument Global Market Report 2021: COVID19 Impact and Recovery to 2030.* May 17, 2021. Available athttps://www.globenewswire.com/de/news-release/2021/05/17/2230884/0/en/Analytical-Laboratory-Instrument-Global-Market-Report-2021-COVID-19-Impact-and-Recovery-to-2030.html?f=22&fvtc=5&fvtv=32464777.

Goetzler, W., M. Guernsey, K. Foley, J. Young, and G. Chung. 2016. *Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances (2015 Update).* Available at https://www.energy.gov/sites/prod/files/2016/06/f32/DOE-BTO%20Comml%20Appl%20Report%20-%20Full%20Report_0.pdf.

Graham, L., and J. Gros-Burdet. 2021. "Sustainable Centrifuges: Greener, Cost-Effective, and Performance-Enhanced." Lab Manager Academy, Thermo Fisher Scientific. October 7, 2021. Available at https://web.archive.org/web/20220517070303/https://www.labmanager.com/insights/sustainable-centrifuges-greener-cost-effective-and-performance-enhanced-26826.

Hafer, M. 2017. "Quantity and electricity consumption of plug load equipment on a university campus." *Energy Efficiency,* 10(4): 1013–1039. https://doi.org/10.1007/s12053-016-9503-2.

Hamid, E., N. Bahaman, A. Jaafar, A. M. Choo, and A. A. Malek. December 2019. "Development of Home Network Sustainable Interface Tools." *International Journal of*

Advanced Computer Science and Applications, 10(2). Available at https://doi.org/10.14569/IJACSA.2019.0100210.

IEEE. 2017. "1680.2a - 2017 – IEEE Standard for Environmental Assessment of Imaging Equipment 1680.2a Amendment 1." Available at https://ieeexplore.ieee.org/document/8237223.

International Electrotechnical Commission. 2011. "IEC 62301: 2011, Household Electrical Appliances - Measurement of Standby Power." Available at https://webstore.iec.ch/en/publication/6789.

Liu, D., Z. Liu, Z. Li., and K. Liu. 2015. "Research on the Energy Load During Incubation and the Energy-saving Potential of the Traditional Incubator." *Procedia Engineering,* 121: 1757–1763. Available at https://doi.org/10.1016/j.proeng.2015.09.148.

Mahadevan, P., P. Sharma, S. Banerjee, and P. Ranganathan. 2009. "A Power Benchmarking Framework for Network Devices." *Networking '09: Proceedings of the 8th International IFIP-TC Networking Conference:* 795-808. Available at https://dl.acm.org/doi/10.1007/978-3-642-01399-7_62.

Marcus, A., and W. Wang, eds. 2018. "*Design, User Experience, and Usability: Users, Contexts and Case Studies*." 7th International Conference, DUXU 2018, Las Vegas, NV, July 15-20, 2018, Proceedings, Part III. Available at https://link.springer.com/book/10.1007/978-3-319-91806-8.

Montalvo, J., J. Torrijos, J. Xia, and Y. Ye. 2013. "Energy Efficiency in PON Home Network Scenarios With Network Enhanced Residential Gateways." IEEE Xplore. Available at https://ieeexplore.ieee.org/document/6548726/similar#similar.

Nash, C. 2021. Personal communication. B. Li, Interviewer.

Nishihara, S., N. Miura, H. Nomura, N. Tanaka, K. Suzuki, and N. Yoshimoto. 2013. "Quantitative analysis of optical network unit sleep technique with maintained latency for asymmetric usage by residential users." *The Journal of Engineering*, 2013(11): 58–60. Available at https://doi.org/10.1049/joe.2013.0099.

Paradise, A. 2015. *Market Assessment of Energy Efficiency Opportunities in Laboratories*. March 12, 2015. ET Project Number: ET14PGE7591, ET15SCE1070, ET14SDG1111. Available at https://etcc-ca.com/sites/default/files/reports/ceel_market_assessment_et14pge7591.pdf

Ricoh. 2012. "Preventing Global Warming by Saving Energy." Available at https://web.archive.org/web/20230926213853/https://www.ricoh.com/sustainability/environment/product/energy/01_01_01.

Thermo Scientific. 2020. "How is it possible to reduce energy consumption and environmental impact with production-level centrifuges?" *Smart Notes*. Available at https://web.archive.org/web/20211202161752/https://tools.thermofisher.com/content/sfs/brochures/sustainability-large-capacity-centrifuge-smart-note-PFCFGSNSUSTAIN-EN.pdf.

Shen, L., Z. Zhou, X. Su., J. Wang, and M. M. Soares. 2020. "A Usability Study of a Brother Printer and Improvement with Ergonomic Recommendations." In *Design, User Experience, and Usability: Design for Contemporary Interactive Environments*: 322–334. Springer International Publishing. Available at https://doi.org/10.1007/978-3-030-49760-6_2.

Szepessy, S., and P. Thorwid. 2018. "Low Energy Consumption of High-Speed Centrifuges." *Chemical Engineering & Technology,* 41(12): 2375–2384. Available at https://doi.org/10.1002/ceat.201800292.

Technavio. 2019. "Global Laser Printer Market 2019-2023: 5% CAGR Projection Over the Next Five Years." *BusinessWire.* Available at https://www.businesswire.com/news/home/20200211005691/en/Global-Laser-Printer-Market-2019-2023-5-CAGR-Projection-Over-the-Next-Five-Years-Technavio.

Technavio. 2020. "Global General Laboratory Equipment Market Research 2020-2024: Post-Pandemic Impact and Analysis Report." Available at https://www.businesswire.com/news/home/20201229005409/en/Global-General-Laboratory-Equipment-Market-Research-2020-2024-Post-Pandemic-Impact-and-Analysis-Report-Technavio.

Technavio. 2021. "5G Equipment Market to grow by USD 24.26 billion through 2025: Key Drivers, Trends, and Market Forecasts: 17000+ Technavio Research Reports." *PR Newswire.* Available at https://www.prnewswire.com/news-releases/5g-equipment-market-to-grow-by-usd-24-26-billion-through-2025key-drivers-trends-and-market-forecasts17000-technavio-research-reports-301281983.html.

Technavio. 2022. *Global Printers Market 2022-2026.* Available at https://www.technavio.com/report/printers-market-industry-analysis.

Urban, B., K. Roth, M. Singh, and D. Howes. 2017. *Energy Consumption of Consumer Electronics in U.S. Homes in 2017.* Consumer Technology Association. Available at https://doi.org/10.13140/RG.2.2.30252.69766.

Valor, C., C. Escudero, V. Labajo, and R. Cossent. 2019. "Effective design of domestic energy efficiency displays: A proposed architecture based on empirical evidence." *Renewable and Sustainable Energy Reviews*, 114, 109301. Available at https://doi.org/10.1016/j.rser.2019.109301.

Project Deliverables

The PLETICS project deliverables are included in the bulleted list below. The products produced are deliverables noted in the technical tasks with key deliverables located in the Appendices.

- Task 2
  - Task 2.1: Device Type List and Codes & Standards Comparison Matrices
  - Task 2.2: Market Assessment and Energy Savings Opportunities Report
- Task 3
  - Task 3.1: Plug Load - Component Opportunities and Potential Savings Report
  - Task 3.2: Proposed Test Procedures for Plug Load Devices
  - Task 3.3: Product Test List and Inventory
- Task 4
  - Task 4.1: Device Test Results
  - Task 4.2: Final Technical Report on Testing Procedures for Plug Load Devices
  - Task 4.3: Plug Loads – Codes & Standards Impacts Report
- Task 6
  - Knowledge Transfer Summary Report

Project deliverables, including interim project reports, are available upon request by submitting an email to pubs@energy.ca.gov.

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Final Technical Report on Testing Procedures for Plug Load Devices

May 2025 | CEC-500-2025-018

APPENDIX A: Final Technical Report on Testing Procedures for Plug Load Devices

Commercial Office Equipment

Device Testing

Test set-up and configuration for all printers and MFDs follows the ENERGY STAR Test Method for Determining Imaging Equipment Energy Use (Nov. 2018). As our testing was conducted in part *in situ*, using existing equipment internet connections, there were some slight alterations to the official test method, as noted below.

General Test Setup and Configuration

As specified by ENERGY STAR, test setup and instrumentation are in accordance with the requirements of International Electrotechnical Commission (IEC) Standard 62301, Ed. 2.0, "Measurement of Household Appliance Standby Power", Section 4, "General Conditions for Measurements" for all products.

1. Connect AC power mains to voltage source
2. All products shall be tested in their "as-shipped" configuration unless otherwise specified by this test method.[1]
3. The product speed for all calculations and reporting shall be the highest speed as claimed by the manufacturer per the following criteria, expressed in images per minute (ipm) and rounded to the nearest integer
4. Test Image: Test Pattern A from ISO/IEC Standard 10561:1999 shall be used as the original image for all testing. 1) Test images shall be rendered in 10-point size in a fixed-width Courier font (or nearest equivalent).
5. Print jobs for the test shall be sent over the network connection designated in Table 6 immediately before printing each job. Each image in a print job shall be sent separately, (i.e., all images may be part of the same document) but shall not be specified in the document as multiple copies of a single original image.

Table A-1 enumerates the test method steps. This method follows the combined Typical Energy Consumption (TEC) and Operational Mode (OM) tests per ENERGY STAR. According to the official ENERGY STAR methodology, TEC applies only to laser printers and MFDs, and OM only to inkjet products. However, our team tested each device in both TEC and OM configurations, in order to capture a more detailed profile of energy consumption in active, sleep, and sleep-to-off modes.

[1] Devices tested in situ were tested with existing internet configurations. This will be explored in greater detail in Report 4.2

Table A-1: Test Methodology

Initial State	Action	Record	Unit of Measure	States Measured	Metrics Calculated
Off	Connect the UUT to the meter. Ensure the unit is powered and in Off Mode. Zero the meter; measure energy over 5 minutes or more. Record both energy and time.	Off energy	Watt-hours (Wh)	Off	
		Testing Interval time	Minutes (min)		
Off	Turn on unit. Wait until unit indicates it is in Ready Mode.	–	–	–	
Ready	Measure Ready power. Record power profile from OFF mode to Ready mode.	Ready power, $^{P}READY$	Watts (W)	Ready	Detailed power profile in LPM transitions
Ready	Print a job of at least one output image but no more than a single job per Table 11. Measure and record time to first sheet exiting unit. Measure harmonics during printing.	Active0 time	Seconds (s)	–	
Ready (or other)	Wait until the meter shows that the unit has entered its final Sleep Mode or the time specified by the manufacturer.	Default delay time to Sleep, $^{t}DEFAULT$	Minutes (min)	–	Harmonics and Power factor
Sleep	Zero meter; measure energy and time for 1 hour. Record the energy and time. Measure Sleep power.	Sleep energy, $^{E}SLEEP$	Watt-hours (Wh)	Sleep	
		Sleep power, $^{P}SLEEP$	Watts (W)		
		Sleep time, $^{t}SLEEP^{(\leq 1\ hr)}$	Minutes (min)		
Sleep	Zero meter and timer. Print one job (calculated above). Measure energy and time. Record time to first sheet exiting unit. Measure energy over 15 minutes from job initiation. The job must finish within the 15 minutes.	Job1 energy, $^{E}JOB1$	Watt-hours (Wh)	Recovery, Active, Ready, Sleep	Wh per print; Average power at printing
		Active1 time	Seconds (s)		
Ready (or other)	Repeat Step 6.	Job2 energy, $^{E}JOB2$	Watt-hours (Wh)	Same as above	Same as above
		Active2 time	Seconds (s)		
Ready (or other)	Repeat Step 6 (without Active time measurement).	Job3 energy, $^{E}JOB3$	Watt-hours (Wh)	Same as above	Same as above

Initial State	Action	Record	Unit of Measure	States Measured	Metrics Calculated
Ready (or other)	Repeat Step 6 (without Active time measurement).	Job4 energy, E_{JOB4}	Watt-hours (Wh)	Same as above	Same as above
Ready (or other)	Zero meter and timer. Measure energy and time until meter and/or unit shows that unit has entered Sleep Mode or the final Sleep Mode for units with multiple Sleep modes, or the time specified by the manufacturer, if provided. Record energy and time.	Final energy, E_{FINAL}	Watt-hours (Wh)	Ready, Sleep	
		Final time, t_{FINAL}	Minutes (min)		
Sleep	Wait and measure default delay time to Auto-off. (Disregard if no Auto-off Mode). Record power profile from Ready to Auto-off/Sleep	Auto-off default-delay time	Minutes (min)		Detailed power profile in LPM transitions
Auto- off	Measure Auto-off power. (Disregard if no Auto-off Mode).	Auto-off power $P_{AUTO\text{-}OFF}$	Watts (W)	Auto-off	Detailed power profile in LPM transitions
Auto- off	Manually turn device off and wait until unit is off. (If no manual on-off switch, note and wait for lowest-power Sleep state). Record power profile from Auto-off to Off.	–	–		

Residential Networking Equipment

Goals for Test Procedure

For residential networking equipment, the main goals for product testing are:

1. Compare products under the various existing standards, including the Voluntary Agreements (VA), European Union Code of Conduct (EU CoC), and the upcoming Low Power Mode (LPM) Roadmap, to identify the inherent differences, limitations, and complexities associated with each testing methodology.
2. Characterize various products' energy performance with several levels of generated traffic to align more closely with homes with heavy data utilization.
3. Identify any out-of-the-box physical and software differences between products, including products sourced from outside the U.S.

In addition to this test methodology, the product's user interface will be assessed. The assessment will focus on understanding the available user settings for each product that may affect energy use or user experience, characterizing the ease of configuring the system, and verifying that any provided documentation, if available, matches the actual user interface.

Test Procedure

Each product of interest will undergo three rounds of testing, two of which will follow existing/upcoming standards/methodologies, including:

- The Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Small Network Equipment & ANSI/CTA-2049-A
- The EU Code of Conduct on Energy Consumption of Broadband Equipment: Version 7.1

The third round of testing will follow the methodology expanded below, which includes expansion to cover multiple active states and settings configurations to assess characteristics likely to be seen in real-world scenarios and not captured in existing standards. Testing environment, product preparation, and connections are heavily based on the aforementioned three methodologies with minor adjustments to further increase repeatability by reducing specified condition ranges.

Test Environment

Based on ANSI 2049-A, the test environment will have an ambient temperature maintained at 24±3°C throughout testing. The area around the UUT will have an airspeed under 0.5 m/s. Relative Humidity for the environment will be held between 10-80%. The UUT will be mounted/seated on a thermally non-conductive surface for the duration of testing.

Instrumentation

Instrumentation will be in accordance with IEC 62301, ed 2.0, "Household electrical appliances – Measurements of standby power," Section 4. In the event of conflicting requirements, this methodology shall take precedence.

Power Supply

A precision alternating current (AC) power source is needed to provide repeatable, stable power to the UUT during testing. Specifications from ANSI c12.1 (§3.10.1) will be the minimum baseline used to select the AC power source for the testbed.

- ±1% Voltage
- ±1% Current
- ±0.2% Frequency
- ±2° Phase angle
- THD < 2% in current and voltage

Input voltage from the supply to the UUT will be adjusted to suit the market in which the UUT was intended to be sold, as seen in Table A-2.

Table A-2: Input Voltages for RNE Markets

Market	Voltage	Frequency
North America	115 Vac	60 Hz
Europe	230 Vac	50 Hz
China	220 Vac	50 Hz
Japan	100 Vac	50 or 60 Hz
Australia & New Zealand	230 Vac	50 Hz

Power Analyzer

A power analyzer will be used throughout testing between the power supply and the UUT to monitor the UUT's power consumption throughout the various testing stages. The power analyzer will have the following characteristics in line with ANSI c12.1 (§3.10.2) portable standard, in Table A-3.

Table A-3: ANSI c12.1 Portable Standard Error Characteristics

Standard	Percent Error	
	@ 1.00 PF	@ 0.5 PF
Portable Standard	0.1%	0.2%

Traffic Generator

Traffic generators may be composed of various discrete hardware and software components or dedicated traffic generator devices. The traffic generator must be able to do the following:

- Establish traffic conditions utilizing standard bit error rate testing with the following parameters:
    - BERT Pattern: 2^9-1
    - Traffic Type: Constant Rate
    - Frame Size: 1518 Bytes
- Traffic generator must have sufficient upload and download ports to allow for traffic flow. Limits are based on devices of interest. See the physical connections section below.
- The traffic generator shall be sized properly to allow for maximum data throughput of interest. Recommended minimum of 1 Gbps.

Networking Testbed

For devices that have Wide Area Network (WAN) connectivity additional equipment or components may be needed to allow for data throughput, such as Modems and IADs. This methodology only explores DOCSIS 3.0 and 3.1 devices, but other WAN connectivity methods can be easily adapted to allow for bit error rate testing.

For DOCSIS 3.0 and 3.1 devices a CMTS must be utilized to allow for DOCSIS communications to be established and data to flow through the devices. The CMTS must have the following capabilities:

- DOCSIS 3.0 compatibility
- 32 downstream channels, 16 upstream channels
- Downstream frequency range: 5 – 85 MHz
- Upstream frequency range: 54 – 1000 MHz

Cabling

Cabling to connect the UUT to connected testing devices through ethernet ports will meet ANSI/TIA-568.2-D category 6 specifications and will be less than 2 meters long.

UUT Receival and Startup:

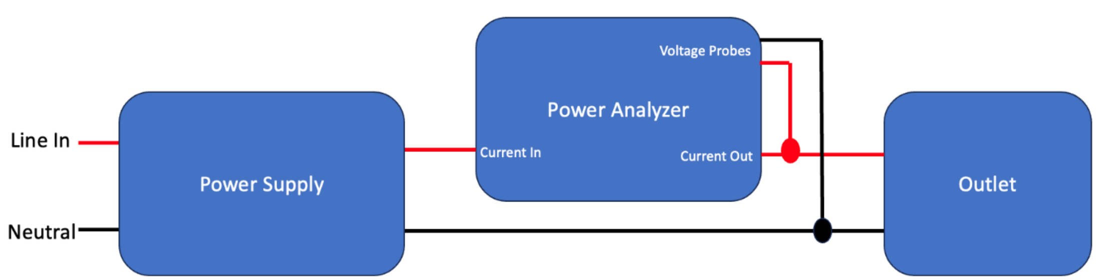
Once the UUT is received, the team will capture images of the outer package and inner packing material, noting the information consumers would see before purchasing. If the UUT contains parts such as antennas and an SFP module that are not installed by default, and are required for recommended operation, then the items will be installed. If multiple configurations exist for installable items, then the test report will note the differences between configurable options. If an external power supply powers the UUT, the test report will log the power supply characteristics such as output voltage, output current, frequency, and class.

The UUT will then be energized with the included external power supply, and the manufacturers' recommended/default practice for setup will be followed. The default settings will be logged for each device and maintained throughout testing, except for tests that explore configuration modifications. In those cases, the test report will note the configuration change. If default or recommended settings do not exist, the UUT will be configured in line with ANSI/CTA-2049, section 7.3. If the version of the UUT's software is apparent, it will be noted in the testing report.

Physical Configurations

To connect the UUT to the testbed first the power supply and power analyzer should be wired in line with Figure A-1. In the diagram, the power analyzer is utilizing a direct current input, but an external current transformer can also be utilized with minor adjustments. Wiring should be rated to support the maximum expected electrical characteristics of the UUTs. Wiring should terminate into an appropriate outlet in line with what the UUT is compatible with.

Figure A-1: Power Equipment Wiring Configuration



Connecting the UUT to the networking portion of the testbed will vary based on the category of device. In this methodology five categories are explored but the procedure can be easily adapted to support other existing or future categories.

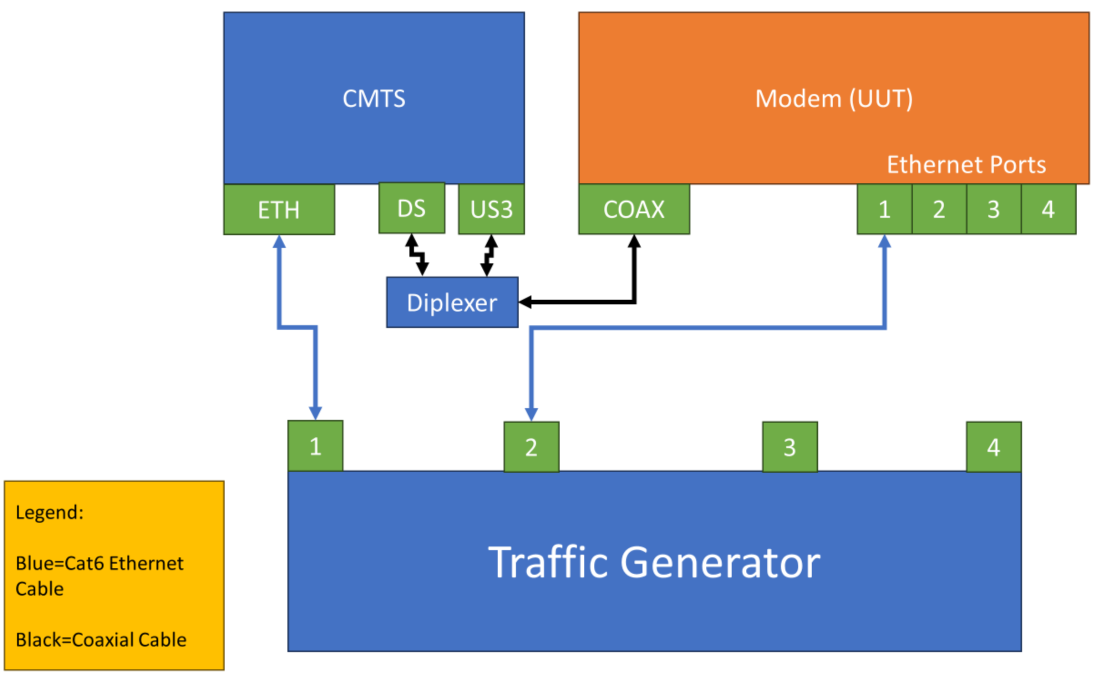
For devices that require a CMTS the equipment settings should be set as follows to allow for DOCSIS 3.0 or 3.1 connections:

- DCHP Relay:
    - All options set to Snooping
    - Cable Source Verify set to On
- Local Provision Management:
    - Global DHCP: On
    - CPE Switch: On
    - Local-Provision Client-Class: Used D_BT_cm31.cfg for client-class 1 with MAC range 0000.0000.0000 – FFFF.FFFF.FFFF
        - Contact the manufacturer of your CMTS for a general purpose .cfg file

Modem Configuration

Modem UUTs should be connected to the network testbed following Figure A-2. If multiple ports exist on the UUT port priority should be given to the highest throughput capable port or identified primary if specified.

Figure A-2: Modem Networking Testbed Configuration



The traffic generator should be configured with a BERT pattern of 2^9-1, Traffic type set as constant rate with frame size of 1518 bytes, and with the following layering configuration:

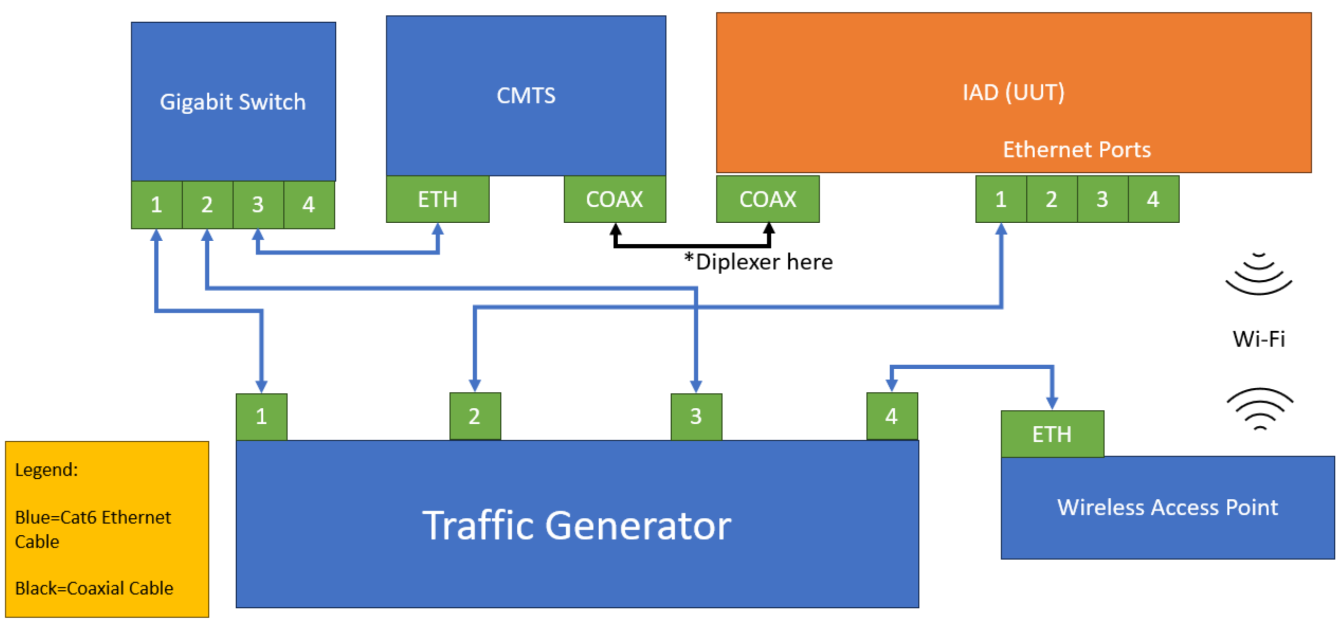
- Layer 2 = Ethernet
- Layer 2.5 = None
- Layer 3 = None
- Layer 4 = None

The networking equipment's MAC addresses should be set automatically using address resolution protocol or manually set to allow for proper traffic destination alignment. Additionally, IP addresses, subnet mask, and default gateways for the UUT and networking testbed should be configured and aligned to allow for communication.

IAD Configuration

IAD UUTs should be connected to the network testbed following Figure A-3. If multiple ports exist on the UUT port priority should be given to the highest throughput capable port or identified primary if specified.

Figure A-3: IAD Networking Testbed Configuration



The traffic generator should be configured with a BERT pattern of 2^9-1, Traffic type set as constant rate with frame size of 1518 bytes, and with the following layering configuration:

- Layer 2 = Ethernet
- Layer 2.5 = None
- Layer 3 = IP
- Layer 4 = UDP

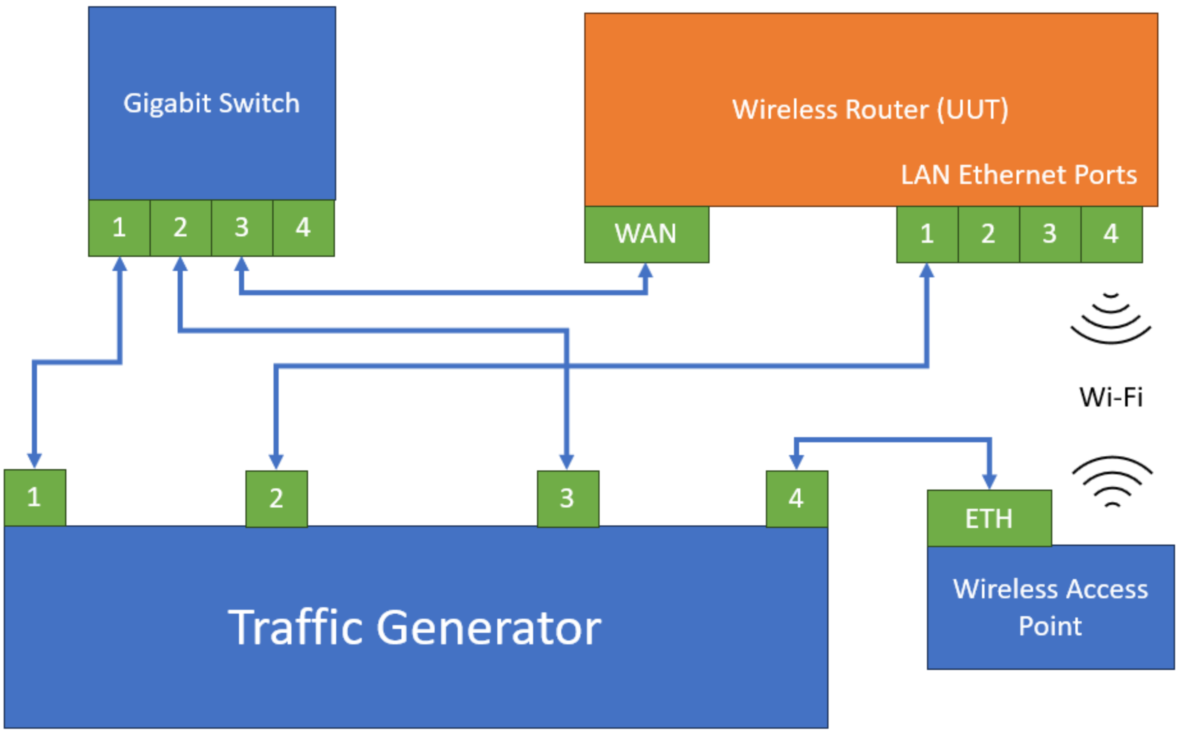
The networking equipment's MAC addresses should be set automatically using address resolution protocol or manually set to allow for proper traffic destination alignment.

Additionally, IP addresses, subnet mask, and default gateways for the UUT and networking testbed should be configured and aligned to allow for communication.

Wireless Router Configuration

Wireless Router UUTs should be connected to the network testbed following Figure A-4. If multiple ports exist on the UUT port priority should be given to the highest throughput capable port or identified primary if specified.

Figure A-4: Wireless Router Networking Testbed Configuration



The traffic generator should be configured with a BERT pattern of 2^9-1, Traffic type set as constant rate with frame size of 1518 bytes, and with the following layering configuration:

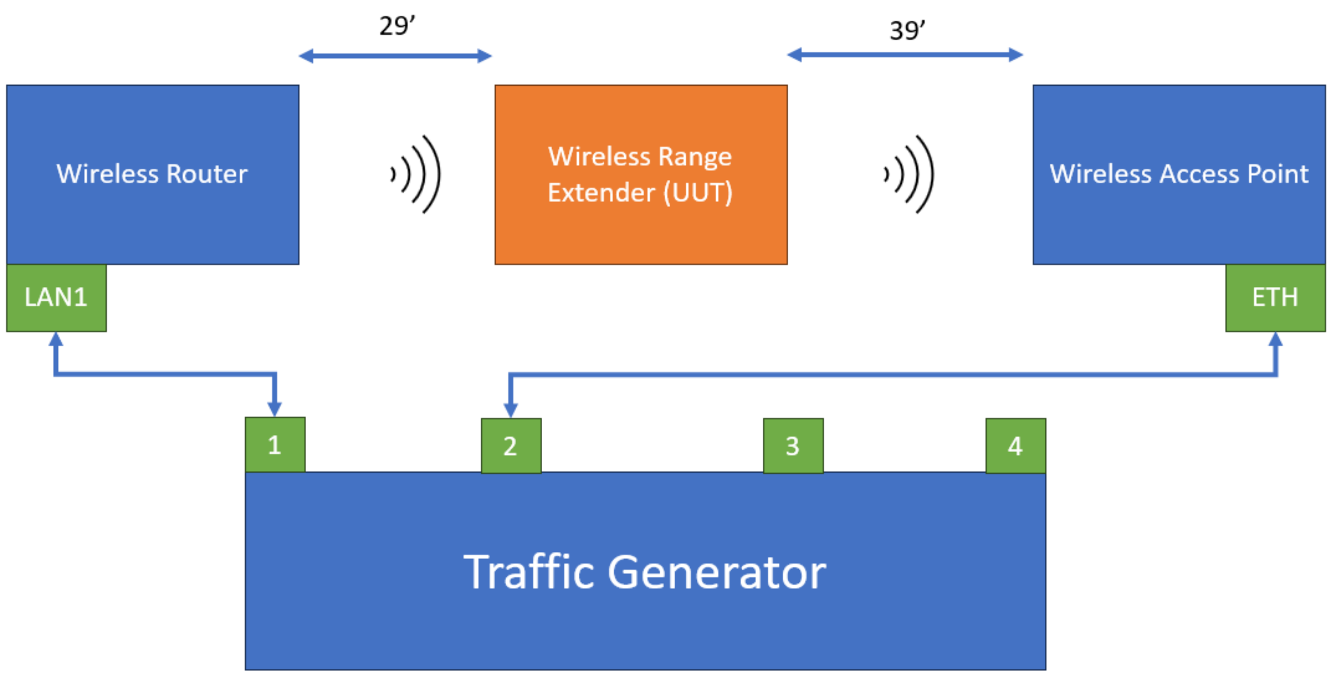
- Layer 2 = Ethernet
- Layer 2.5 = None
- Layer 3 = IP
- Layer 4 = UDP

The networking equipment's MAC addresses should be set automatically using address resolution protocol or manually set to allow for proper traffic destination alignment. Additionally, IP addresses, subnet mask, and default gateways for the UUT and networking testbed should be configured and aligned to allow for communication.

Range Extender Configuration

Range Extender UUTs should be connected to the network testbed following Figure A-5. If multiple ports exist on the UUT port priority should be given to the highest throughput capable port or identified primary if specified.

Figure A-5: Range Extender Networking Testbed Configuration



The traffic generator should be configured with a BERT pattern of 2^9-1, Traffic type set as constant rate with frame size of 1518 bytes, and with the following layering configuration:

- Layer 2 = Ethernet
- Layer 2.5 = None
- Layer 3 = IP
- Layer 4 = UDP

The networking equipment’s MAC addresses should be set automatically using address resolution protocol or manually set to allow for proper traffic destination alignment. Additionally, IP addresses, subnet mask, and default gateways for the UUT and networking testbed should be configured and aligned to allow for communication.

Optical Network Terminal Configuration

Optical network terminals UUTs should be connected to the network testbed following Figure A-6 or Figure A-7 depending on whether the ONT features an SFT module as those devices do not require connection of fiber optic cables. Instead, an SFP to RJ45 converter module is inserted into the SFP port of the ONT. If multiple ports exist on the UUT port priority should be given to the highest throughput capable port or identified primary if specified.

Figure A-6: ONT Networking Testbed Configuration A

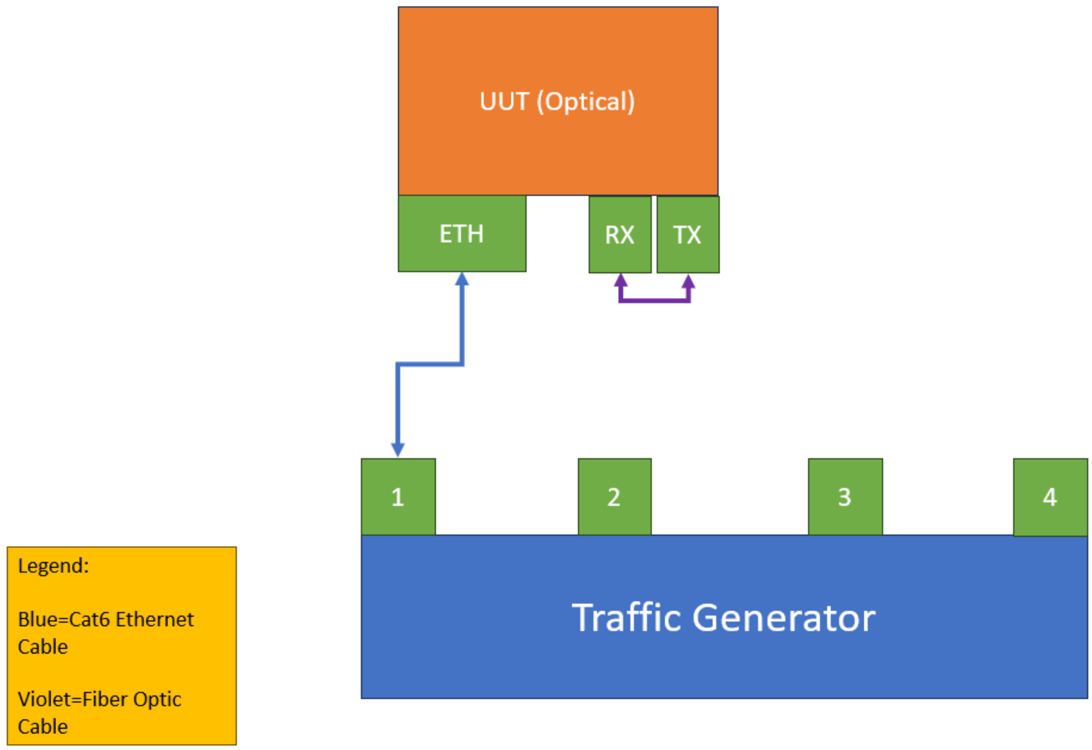
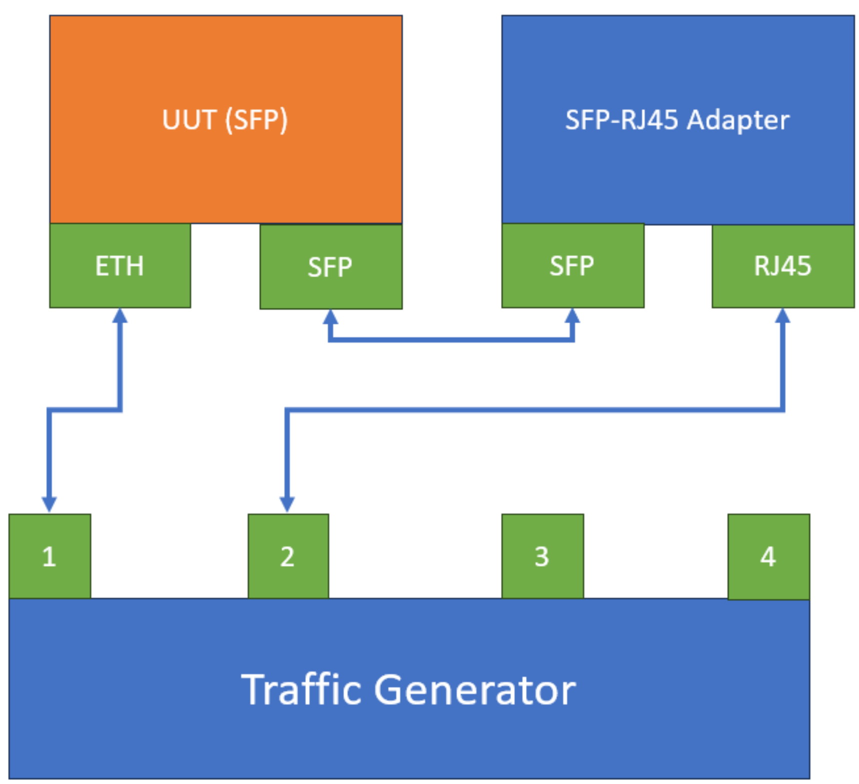


Figure A-7: ONT Networking Testbed Configuration B



The traffic generator should be configured with a BERT pattern of 2^9-1, Traffic type set as constant rate with frame size of 1518 bytes, and with the following layering configuration:

- Layer 2 = Ethernet
- Layer 2.5 = None
- Layer 3 = IP
- Layer 4 = UDP

The networking equipment's MAC addresses should be set automatically using address resolution protocol or manually set to allow for proper traffic destination alignment. Additionally, IP addresses, subnet mask, and default gateways for the UUT and networking testbed should be configured and aligned to allow for communication.

ONTs are unique in that these devices have set ethernet standards that limit data throughput. ONTs will need to additionally have these settings manipulated to fully characterize the device.

Testing the UUT

Once UUT has been appropriately configured in one of the possible defined physical configurations, and the equipment has been set up, the unit is ready to be tested. The number of tests will be based on the number of traffic conditions to be identified. It is recommended that 30 equal distant data throughput configurations throughout the UUTs range should be accessed for a full performance characterization.

To test UUT configuration:

1. Energize DUT, allowing a 5-minute start-up interval.
2. Confirm proper communication with testbed
3. Begin recording of power analyzer
4. Set the relevant traffic generator ports to target download or upload speed.
5. With no traffic flowing, measure the power consumption of the UUT for 5 minutes to determine idle state power draw of the configuration.
6. Note end of test duration.
7. Turn traffic flow on, then measure the power consumption of the UUT for 5 minutes.
8. Turn off traffic flow.
9. Note the test duration and total bits received by the traffic generator ports.
10. Set the traffic generator ports to the next target configuration then repeat steps 7 – 10 until all configurations of interest have been tested.

After testing completes calculations should be done to determine the average of the total bits received by each download and upload port by dividing them by the testing duration to get an average data throughput speed in Mbps.

Commercial Laboratory Equipment

Goals for Testing Procedure

1. We measured and debugged each device and compared the ENERGY STAR, My Green Lab and ACT environmental impact factor labels. We found the differences in the test methods. Our test method is aimed at power consumption under stable conditions, focusing on equipment that does not change status frequently, such as laboratories. We did not test too many energy loss tests such as opening and closing doors, and the advantage of our test is that we can test the average power consumption of machines that work for a long time.
2. We compared the catalysts, heaters, sensors, etc. used in different models, and compared and optimized some parts. Verify and provide relevant documents to match the actual situation. In addition to this test methodology, the product's user interface will be assessed. The assessment will focus on understanding the available user settings for each product that may affect energy use or user experience, characterizing the ease of configuring the system, and verifying the provided documentation, if available, matches the actual user interface.

In addition, regarding the user experience interface, with the popularization of LCD control pages, the old user interface is gradually being eliminated. Therefore, it is not tested as an evaluation criterion here. The reason is that the newer the product, the more convenient the user interface is. However, this depends on the cost of the user interface.

Freezer (-25°C [-13°F])

In June 2021, the Federal Energy Plan emphasized the importance of laboratories prioritizing energy-efficient products when purchasing refrigerators and freezers. It recommended that these products meet the ENERGY STAR certification or conform to the Performance Evaluation and Measurement Plan (PEMP) guidelines. Traditional ultra-low temperature (ULT) freezers are particularly energy-intensive, using around 20 kWh of energy per day, which is equivalent to the daily energy consumption of an average household. This significant energy draw highlights the necessity of choosing more efficient models. By selecting ENERGY STAR certified ULT freezers or those meeting PEMP standards, laboratories can drastically reduce their energy consumption, thereby supporting sustainability efforts and lowering operational costs. The aim of the Federal Energy Plan's directives is to encourage the adoption of energy-efficient technologies in laboratory environments, ultimately minimizing the environmental footprint and financial burden associated with high energy use.

There are several types of freezer tests:

1. Test the power consumption at different temperatures, 0 degrees Celsius, -4 degrees Celsius, -10 degrees Celsius and -20 degrees Celsius.
2. Test the power consumption of different devices at the same temperature.

Possible ways to save energy:

1. Power consumption at different temperatures: Control the temperature at the same time and compare the different internal space sizes and power consumption to measure the efficiency relationship between the compressor and the refrigerant.
2. In terms of investigating the temperature processor, we can derive the sensor's fluctuation frequency based on the frequency of energy fluctuations, and the optimal refrigeration frequency and efficiency based on the temperature prompt on the screen
3. Innovative refrigerants: We conducted comparative investigations on different types of refrigerants. We found that the mixed R170 and R290 has a good cooling effect as well as the R134.

Centrifuge

The centrifuge has no measured standard for comparison, but it has more potential for improvement

Ways a centrifuge can be tested:

- Test the energy consumption status of different machines in standby state
- Test the state of energy consumption at different temperatures and speeds

Possible ways to save energy:

According to experimental data, the differences between different centrifuges are significant.

1. The differences in the working state of the centrifuge. Different centrifuges have huge differences at the same temperature and the same speed. The main difference comes from the control of the speed. Some machines take continuous acceleration and maintenance. This kind of data will consume a lot of energy and generate a lot of heat, which needs to be cleaned. The other friction is relatively small, so it only needs to be based on kinetic energy when it is just started, and it will continue to run at a constant speed after that
2. In the test of more than 12 hours, most centrifuges will not work for more than 1 hour per day on average, so most of the time they will be powered off or in standby mode. We tested the power consumption in standby mode and found that some centrifuges will choose to maintain a constant temperature in standby mode. The power consumption here is huge, and how to efficiently maintain the temperature of the internal space and minimize the loss of power requires strict requirements from the manufacturer. For example, standby mode and sealing, etc.

Water Baths

The working energy consumption of the water bath ultrasonic instrument is mainly divided into heating and ultrasonic waves. Because it is a laboratory instrument, there is still no established measurement standard, so the working principle of the insulating layer and the ultrasonic wave is relatively important.

Ways to test water baths:

1. Test the power consumption of the water bath heater at 37 degrees and test the consumption at the highest temperature.
2. Test the consumption after reaching a stable state or heating is completed.
3. Test the consumption in ultrasonic state.

Possible ways to save energy:

1. The main problem is how to maintain the temperature in standby mode, or how to reduce the power consumption. The conclusion here is that since the power consumption required to maintain the temperature is very small, the water bath does not need to be turned off within two days.
2. Most of the ultrasonic states are only used for a few minutes to tens of minutes, so the frequency of use is not very high. Not many improvement methods for ultrasonic waves can be found here
3. It was found that the power required for heating is much higher than the power required for standby, so the heating efficiency of the water bath is not very high, and the manufacturer needs to optimize the power consumed during heating

Incubator

The main job of the incubator is heating and heat preservation, so heating is the main energy consumption. Since most incubators keep warm for more than 12 hours, checking their working status is the main purpose.

Ways to test incubators:

1. Test the energy consumption status at different temperatures
2. Test the energy consumption of different machines at the same temperature

Possible ways to save energy:

1. According to the test results, we found that different heating frequencies bring different energy consumption. We put two large incubators together for comparison. Under the same temperature, without affecting the incubation, the power consumption of the different heating frequencies is twice that of the other. This means that this is a factor that cannot be ignored.
2. At the same time, we found that different equipment has different performances at different temperatures. It is more energy-efficient when it is close to room temperature. Therefore, better materials are needed in terms of insulation materials to ensure the insulation effect.

Autoclave

There is no national standard for autoclave energy performance.

Ways to test autoclaves:

1. Test multiple modes separately and collect energy consumption

Possible ways to save energy:

Since most autoclaves do not provide self-service temperature, only the four modes provided can be measured.

1. Compare the heating efficiency under different volumes.
2. Some machines have excessive steam pressure, which is very dangerous, so recovering steam cold energy will also be a good method.
3. Under the same conditions, the heating efficiency of different brands is also different. The newer the autoclave, the higher the heating efficiency.

Proposed Testing Procedure

The electricity meter uses real-time data collection, and the meter is placed where the equipment is connected to the power line. The equipment will record the current, voltage and power of the power supply. Confirm the current state of the device through the camera, and finally adjust and study the device data against the time. Table A-4 details the testing states.

Table A-4: Laboratory Equipment Testing States

Device Type	State 1	State 2	State 3	State 4
Insignia – 13.8 Cu. Ft. Upright Convertible Freezer/Refrigerator	-4 degree	N/A	N/A	N/A
VWR® Freestanding Undercounter Laboratory Freezer, (–20°C [-4°F])	-10 degree	0 degree	N/A	N/A
VWR 4CF	-4 degree	N/A	N/A	N/A
Frigidaire	-20 degree	N/A	N/A	N/A
Thermo Freezer	0 degree	-10 degree	N/A	N/A
Kenmore	-4 degree	N/A	N/A	N/A
Eppendorf Centrifuge 5417R	standby	1000,2000,4000,8000rpm with 37 degree	N/A	N/A
Eppendorf Centrifuge 5430R	standby	1000,2000,4000,8000rpm with 37degree	N/A	N/A
Eppendorf Centrifuge 5424	standby	1000,2000,4000,8000rpm with 37degree	N/A	N/A

Device Type	State 1	State 2	State 3	State 4
accuspin micro 17r	standby	1000,2000,4000,8000rpm with 37degree	-9,0,10,20 degree with 2000rpm	N/A
J15	standby	1000,2000,4000,8000rpm with 37degree	-9,0,10,20 degree with 2000rpm	N/A
KENDAL ultrasonic cleaner	Off or standby	Heating with 37°C and ultrasound	Heating with max temperature and ultrasound	N/A
Fisher Scientific Isotemp Dual Digital Water Bath Model 2322	Off or standby	Heating with 37°C and ultrasound	Heating with max temperature and ultrasound	N/A
Emerson CPX1800H device1	Off or standby	Heating with 37°C and ultrasound	Heating with max temperature and ultrasound	N/A
Emerson CPX1800H device2	Off or standby	Heating with 37°C and ultrasound	Heating with max temperature and ultrasound	N/A
DK SONIC	Off or standby	Heating with 37°C and ultrasound	Heating with max temperature and ultrasound	N/A
Benchmar Roto-ThermIncubated Rotators	10 degree heating	37 degree heating	N/A	N/A
Benchmark INCU SHAKER Mini & 10L Shaking Incubators	4 degree heating	10 degree heating	N/A	N/A
NUAIRE NU-8700 Incubator	37 degree heating	N/A	N/A	N/A
PHCBI CO2 Incubators Double Stacked TESTED with Warranty SEE VIDEO	37 degree heating	N/A	N/A	N/A
vwrmini_incubator	10 degree heating	37 degree heating	N/A	N/A
Midmark M11 Autoclave1	Unwrapper	Handplace	N/A	N/A
Midmark M11 Autoclave2 (different device)	Unwrapper	Handplace	N/A	N/A

Device Type	State 1	State 2	State 3	State 4
Consolidated_hinded_autoclave (Host part)	Unwrapper	N/A	N/A	N/A
Consolidated_hinded_autoclave (Vacuum pump part)	Unwrapper	N/A	N/A	N/A
Ritter M11 UltraClave Automatic Sterilizer	Unwrapper	Handplace	Pounches	Packs

Notes

1. During the testing of refrigerators, different target temperatures need to be tested separately to observe whether there is a state that can save energy.
2. When testing the centrifuge, compare the difference in energy consumption from the off state to the working state and from the standby state to the working state. Used to find and join power saving modes
3. Ultrasonic water baths need to measure the temperature change before and after the test to control the experimental variables.
4. The CO2 incubator needs to compare the energy consumption of heating to the target temperature by different methods after the test.
5. The autoclave needs to measure the water level before and after use to compare the water energy consumed in the experiment.

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APPENDIX B: Codes and Standards Impacts

May 2025 | CEC-500-2025-018

APPENDIX B: Codes and Standards Impacts

The Codes and Standards Impacts Report for the Plug Load Energy Testing to Inform Codes & Standards (PLETICS) Project includes details of evaluated energy usage for device operations, the range of expected energy savings from recommended codes & standards updates, and cost-effectiveness analyses for near-term code implementation. Additionally, this report highlights the impacts on estimated cost of improvements to manufacturers and corresponding increase in retail prices where possible.

The PLETICS project team has segmented this report into the device categories commercial office equipment, residential networking equipment, and laboratory equipment. Each section will be a deeper dive into each device category to evaluate energy use found in Task 4.2 test results and develop a range of expected energy savings from recommended codes and standards as well as the impacts from the codes and standards. The Laboratory Equipment section is unique in that there are no current regulatory or voluntary standards to start from, so the team provided novel ideas to include in future codes and standards.

Commercial Imaging Devices

Goals

In Task 4.3, we identified several main goals. These included evaluating energy use based on current ENERGY STAR minimum performance standards and testing procedures, identifying the settings and attributers that contribute to energy savings or excessive energy consumption, and considering the annual energy savings and potential costs to manufacturers and consumers based on potential codes and standards improvements.

Evaluated Energy Use

Energy usage evaluated during the testing phase revealed that commercial imaging products across specific device types displayed similar patterns. While devices overall conformed to energy usage ranges published in the ENERGY STAR qualified products database, we observed anomalies in the way devices entered low power mode and off mode. Specifically, Typical Energy Consumption (TEC) metrics for several laser MFDs and printers were higher than ENERGY STAR allowances for power consumption used during periods of inactivity (low power) and several devices did not enter into final off mode in a timely fashion. In particular, two color MFDs and one monochrome MFD took longer than 5 hours to proceed from low power mode to final off mode.

Range of Expected Energy Savings

The PLETICS team recommends that the efficiency standards for all five categories of commercial imaging devices conform to the ENERGY STAR minimum energy usage thresholds. The ultimate goal is to sweep older, less efficient models out of the market in order to reduce unnecessary energy usage for the consumer. The team also suggests that manufacturers be required to ship products with low power modes enabled by default. Testing revealed that the effective use of low power modes was the main contributor to energy savings for imaging devices. Although many manufacturers already ship their products with default low power modes, this is not currently required by regulation, and some products tested required additional set-up to access low power modes. Developing such a regulation would ensure uniform device performance and energy savings with minimal costs to industry or end-users.

To determine a range of expected energy savings, it is necessary to compare current market saturation data with savings that would occur if all devices on the market met ENERGY STAR energy usage standards.

ENERGY STAR data for imaging device market penetration has not been published since 2019, when the ENERGY STAR 3.0 test method went into effect. The stated reason for lack of data provided by manufacturers is that the new method dramatically changed the requirements to meet ENERGY STAR standards, resulting in many products becoming ineligible to be certified.

Lacking exact data, it is difficult to make assumptions about how many devices currently qualify for ENERGY STAR. However, one manufacturer, HP, published a press release in 2023[4] stating that 87% of their printers shipped in the U.S. were ENERGY STAR certified. Therefore, using 85% as the median, for the purposes of this report, we assume that between 75% and 95% of imaging products shipped in the U.S. are currently ENERGY STAR certified. According to ENERGY STAR,[5] each qualified device saves between 25% and 35% of energy over non-certified products.

Assuming an average consumption of a large color laser MFD at 34.02W/yr (average of the published ENERGY STAR data for the devices tested in this project), a non-ENERGY STAR version of the product would consume between 42.53W/yr and 45.93 W/yr.

The following serves as an example of potential energy savings for the category of color laser MFDs, which are currently the most commonly purchased commercial imaging devices. If California were to implement a requirement that 100% of color laser MFDs sold in the state met ENERGY STAR certification standards, this would correspond to a savings of 8.51-11.91 W/year for each device not currently eligible for ENERGY STAR.

Thus, if there are 50,000 color laser MFDs sold each year in California, between 12,500 and 2,500 are not currently certified. Thus, requiring all devices to meet ENERGY STAR certification standards would save 21kW-30kW per year on the low end and 102kW-143kW on the high end.

Codes & Standards Impacts

Energy efficiency for imaging devices is currently assessed under the ENERGY STAR test method and qualified products list. All devices tested for this project conformed to ENERGY STAR minimum performance standards at the time of testing. Nevertheless, during testing the

[4] HP Sustainability and Compliance Center. 2024 "Are HP products Energy Star certified?" August 29, 2024. Available at https://sustainability.ext.hp.com/en/support/solutions/articles/35000061787-are-hp-products-energy-star-certified-.

[5] Environmental Protection Agency. n.d. "Imaging Equipment." Energy Star. Available at https://www.energy star.gov/products/imaging_equipment.

PLETICS team discovered anomalous behavior in devices across category types that led to deviations from ENERGY STAR published QPL data. Specifically, low power modes were not correctly engaged during shut-down sequences, and higher than expected energy usage was recorded while devices were in low power mode.

The team suggests that the effect of internet connectivity on device function may need further characterization as an additional variable that is not currently captured by the ENERGY STAR test method. The team theorizes that one possible reason for higher-than-normal energy usage in low power modes could be that network activity through the device's wi-fi connection may be disrupting device shut-down sequences and causing surges of energy usage at times when the network is highly congested.

Therefore, before designing specific codes and standards for commercial imaging devices (e.g., under CA Title 20) the PLETICS team suggests that the Energy Commission develops a framework for evaluating the effects of internet connectivity on energy consumption for this category of products. There are several avenues that this endeavor may be pursued. One method would be to consult directly with ENERGY STAR to improve their test method. Working with ENERGY STAR would have the advantage that the test method would be updated at the federal and international level, as the ENERGY STAR method is currently the worldwide gold standard for qualifying energy efficiency for printers.

Alternatively, the Energy Commission may decide to develop an independent test metric to assess internet connectivity effects on energy efficiency. This would allow the state of California to introduce a cohesive framework for understanding and measuring internet connectivity not only for printers, but for other consumer electronics as well. This study may be conducted through the state CASE team, in a similar fashion to the low power mode methodology that is currently under development. The PLETICS team similarly finds close potential synergy with the Low Power Mode methodology. For example, there may be significant opportunity for an internet connectivity CASE study to align, complement, and be integrated with the Low Power Mode methodology.

Cost-Effectiveness Models

Cost-effectiveness for implementing codes and standards for imaging devices will largely depend on the type of regulatory process the Energy Commission chooses to employ. Codes and standards based on current ENERGY STAR methodology will be easier and less costly to implement, as manufacturers largely already conform to ENERGY STAR for new products.

ENERGY STAR benefits methodology technical notes, states that the "total incremental

cost is calculated by multiplying the number of units purchased in a given year by the incremental unit cost of a particular product." For commercial printers, the incremental cost to produce an ENERGY STAR certified product is about 10% more than a non-certified product. Manufacturers have been successful in harnessing economies of scale to drive down the cost of compliance.

Alternatively, as recommended here, the Energy Commission may decide to devise a new test methodology either through engagement with the ENERGY STAR program, or as an independent enhanced methodology building on ENERGY STAR, that explicitly measures the energy usage effects of internet connectivity. This test procedure would require costs including dedicated laboratory space and staff, acquiring a sufficiently large range of products across device types and manufacturers, and sophisticated metering instruments to accurately measure device energy usage during different use modes, measure Wi-Fi internet traffic, and account for any impacts from the power factor supplied by the building.

Initial costs of developing a new test methodology would mainly be borne by the Energy Commission through state-allocated funds, or through federally-funded EPA ENERGY STAR programs. It is difficult and premature to calculate a precise increase in cost to manufacturers and ultimately consumers based on a test methodology that has yet to be developed. However, almost all commercial printers today are equipped with internet connectivity functionality and manufacturers must verify that this connectivity functions properly before sending the device to market. Therefore, it is not estimated to be prohibitively costly to perform the extra steps necessary to ascertain that the internet functionality is not interfering in a fundamental way that prohibits the device from entering and staying in sleep and shut-off modes.

Finally, our team recommends that the state of California implement a new labeling program to encourage manufacturers to set agreed-upon standards for consumer information purposes. Namely, we suggest that all ENERGY STAR qualified laser printer and MFD products should clearly state the ENERGY STAR-approved Typical Energy Consumption (TEC) value of the product (in Watts). In addition to TEC, we further suggest that the manufacturer provide the following metrics: 1) average energy usage of the product during active mode (in Watts), and average energy usage of the product in low power modes (in Watts).

Inkjet products should be labeled with their average power consumption in low power mode, which is the main metric currently used to calculate the ENERGY STAR Operational Mode coefficient. As our testing confirmed active mode energy usage to be very low for inkjet printers (<2W), we do not believe it would be beneficial to require active mode usage on labeling programs. These products spend the vast majority of their time in idle, sleep, or soft-off modes, and ENERGY STAR has correctly identified low power mode usage to be the key salient metric for consumers to make informed choices for selecting energy efficient inkjet products.

Providing vital energy usage information will facilitate fair comparison across device product lines and manufacturers to allow the consumer to make the best choice for their individual needs and interests. While some manufacturers already do include this information, it is currently not compulsory either through regulation or through an industry-led voluntary agreement. There are multiple ways that the product label on energy consumption may be provided. One method would be to design a sticker (similar to the current yellow Energy Guide that the federal government requires on currently regulated appliances). Another method would be to require the information to be written in an accessible, easy-to-understand manner in the product manual, both in printed and digital versions.

Costs to the manufacturer and downstream costs to the consumer to implement the labeling program would be mostly administrative in nature. Companies are already required to record

TEC and its component pieces for all laser printers and MFDS, which include average energy usage in active and low power modes. Inkjet testing for the OM test method similarly already records low power mode energy usage. Therefore, no additional test costs would be incurred in terms of engineering staff time, material costs, or testing equipment. Administrative costs associated with the labeling program would be primarily for marketing purposes, such as re-designing product manuals or designing new exterior labels to provide this additional information. Based on market data regarding administrative costs, we anticipate that the additional overhead costs would be less than 5% of the end product retail price.

Future Codes & Standards Recommendations

In summary, our recommendations for future codes and standards are twofold: 1) the Energy Commission is encouraged to collaborate with ENERGY STAR or design a separate testing mechanism to understand and record the effects of internet connectivity on device performance, in active, low power, and soft-off modes (i.e., connected to a power source); and 2) to design a labeling program for consumers to better compare typical energy consumption between products.

When designing a future test method for imaging devices incorporating internet connectivity, it will be important for the Energy Commission to be mindful of the fast-paced nature of the imaging product industry and require reviews of the product market every 2-3 years to ensure that the regulatory body is keeping pace with industry, while not stifling product innovation. The goal should be to sweep older, less efficient products out of the market, rather than to get ahead of industry and prevent them from introducing novel device features which may ultimately enhance energy savings and consumer comfort.

Finally, the Energy Commission may also want to consider how imaging devices may fit into future regulations and voluntary agreements around grid flexibility and demand response capability. Although the market for DR-capable appliances and load flexibility is still emerging, and currently restricted to large household appliances such as HVAC, dishwashers, and clothes washers/dryers, the goals of decarbonization in California require an aggressive approach to grid management. Indeed, early work from the CalFlexHub at the Lawrence Berkeley Laboratory envisions new ways to integrate home electronics to the grid, for example, through smart hubs. Full integration of small household electronics may require new thinking in the future that incorporate interoperability standards into small electronics, including printers. Although many current interoperability standards are led mainly by industry (i.e., CTA2045), the Energy Commission and CAISO will be responsible for ensuring communication with the grid provides safe, secure and effective connections for all customers.

Residential Networking Equipment

Goals

Task 4.3 focuses on further evaluating the energy performance of current market products and identifying opportunities for energy savings while establishing performance benchmarks to guide future standards. The primary goals of this report include assessing the impact of expanded testing looking at energy use during both idle and active states across devices such as modems, wireless routers, integrated access devices (IADs), range extenders, and optical network terminals (ONTs). It aims to analyze minimum performance thresholds, settings, and attributes that contribute to improved energy efficiency, and evaluate the cost-effectiveness of incremental improvements for manufacturers and consumers. Additionally, the report considers the impacts of evolving technologies and increasing data demands, providing recommendations for updates to codes and standards (C&S) to ensure compatibility with emerging features and performance requirements.

Evaluated Energy Use

The testing methodology utilized voluntary standards, including the U.S. Voluntary Agreement (VA) and the EU Code of Conduct (CoC), supplemented by expanded protocols to evaluate energy consumption under both idle and active states. Results revealed significant increases in energy use during active states, particularly in modern devices with higher throughput capabilities. On average, modems exhibited a 52% increase in energy consumption at maximum tested data throughput, while wireless routers demonstrated a 56% rise. Integrated Access Devices (IADs) and range extenders showed even higher increases, with averages of 59% and 68%, respectively. In contrast, Optical Network Terminals (ONTs) displayed minimal differences between idle and active states, reflecting consistent energy performance across operating conditions.

To assess energy efficiency, metrics such as Mbps/Watt were applied. Proposed thresholds included 41 Mbps/Watt for modems, 20 Mbps/Watt for wireless routers, 9 Mbps/Watt for IADs, 20 Mbps/Watt for range extenders, and a wattage threshold of 1.5–2 W for ONTs. These thresholds aim to guide energy savings and inform future standards by establishing performance benchmarks that promote efficiency without compromising functionality.

While Mbps/Watt provides a straightforward metric for evaluating energy efficiency, it has notable limitations as a universal standard. The metric may oversimplify performance evaluations, failing to account for variations in functionalities, network configurations, and advanced features such as multiple input/output streams or mesh networking. These enhanced capabilities can lead to devices appearing less efficient despite providing superior performance.

Additionally, Mbps/Watt metrics must be defined at specific variables or targets, as the value increases exponentially with throughput. For example, a device may perform poorly at 5 Mbps throughput but meet efficiency targets at 500 Mbps, potentially undermining energy-saving objectives. To address these limitations, complementary metrics that incorporate device capabilities, usage scenarios, and performance variability should be developed. Such approaches would provide a more comprehensive assessment of energy efficiency and support the development of realistic and effective standards.

Range of Expected Energy Savings

To further assess the impact of removing high-consumption devices, a scenario was modeled based on enforcing performance thresholds for throughput-to-wattage metrics to the tested devices. Potential savings were found on average to be 64%, across the four throughput-driven subcategories comparing the worst-performing tested device to the lowest passing device and the best-performing tested device (Table B-1). The most improving category being the wireless range extenders due to having the widest range of performance values during testing.

Table B-1: RNE Tested Average Throughput Efficiency

RNE Subcategory	Minimum Tested Throughput	Minimum Passing Throughput	Best Tested Throughput
Modem	40.37 Mbps/Watt	42.83 Mbps/Watt	50.21 Mbps/Watt
Wireless Router	15.25 Mbps/Watt	22.49 Mbps/Watt	27.46 Mbps/Watt
Integrated Access Device	8.86 Mbps/Watt	9.03 Mbps/Watt	11.94 Mbps/Watt
Wireless Range Extender	9.71 Mbps/Watt	24.88 Mbps/Watt	25.55 Mbps/Watt

Using the collected test data, a basic user profile was developed to estimate energy impacts based on household data usage. A three-hour period of HD streaming (10 Mbps) and 4k streaming (20 Mbps), representative of typical usage patterns, was analyzed to assess energy consumption across device categories. The resulting energy use can be viewed in Table B-2.

Table B-2: Energy Use Increase from Daily Video Streaming Across Device Categories

RNE Subcategory	Average Energy Use Increase with 3 hrs of HD Streaming (10 Mbps)	Average Energy Use Increase with 3 hrs of 4k Streaming (20 Mbps)
Modem	0.28 %	0.58 %
Wireless Router	1.19 %	1.83 %
Wireless Range Extender	1.39 %	2.39 %
Integrated Access Device	0.94 %	1.78 %

While these percentages may appear modest, compounding factors significantly amplify their impact. For instance, a typical network setup could utilize a modem, router, and range extender in tandem resulting in cumulative increases across all three devices. These calculations are based on current usage patterns but are expected to rise substantially with the adoption of higher-bandwidth technologies, such as 4K and 8K streaming, mesh networks, and increasing data demands.

Codes & Standards Impacts

Currently, residential networking equipment only has a few applicable voluntary performance agreements. First, the U.S. Voluntary Agreement for SNE establishes energy efficiency standards for small network equipment sold in the United States. It primarily focuses on idle state power consumption and assigns power allowances based on device type and features. The VA uses testing procedures derived from legacy ENERGY STAR standards, which emphasize idle state efficiency and compliance tiers. While the VA has been effective in promoting incremental improvements, its primary shortcoming lies in its lack of active-state testing, which fails to capture the higher energy demands of devices operating under real-world conditions, such as streaming or high-bandwidth usage.

The EU CoC for broadband equipment sets voluntary power consumption limits for both idle and active states. Unlike the VA, it incorporates limited active-mode testing, making it slightly more representative of real-world performance. However, its active-mode testing is restricted to low data rates, such as 10 Mbps, which do not reflect the higher throughputs demanded by modern devices. This limitation prevents the CoC from adequately characterizing the energy impact of devices operating at higher speeds or handling multiple simultaneous connections.

The ENERGY STAR program for SNE, which was sunsetted in 2021, focused primarily on idle state energy performance. It encouraged manufacturers to reduce standby power consumption but did not require assessments of active performance. Its primary limitation was the exclusion of active-mode testing, leaving a gap in evaluating energy efficiency under conditions where devices are heavily utilized. With ENERGY STAR no longer active for SNE, there is currently no federal standard addressing active-state energy consumption, creating a regulatory void.

Key Shortcomings Across Standards:

- **Idle-Only Focus:** Both the VA and ENERGY STAR standards emphasize idle performance, overlooking the substantial energy use during active states, which is becoming more relevant as data usage increases.
- **Limited Active Testing:** While the EU CoC incorporates some active-state testing, it is constrained to low throughput scenarios, failing to capture higher-speed energy demands.
- **Lack of Real-World Profiles:** Current standards do not reflect modern usage patterns, such as video streaming, online gaming, or mesh network configurations, which significantly impact energy use.
- **Technological Advancements Ignored:** Emerging features like mesh networking, multi-input/output streams, and smart-home integration are not addressed in existing frameworks, leaving gaps in evaluating newer technologies.

These shortcomings highlight the need for updated testing methodologies and standards that account for both idle and active states, support high-throughput scenarios, and incorporate allowances for advanced features. Addressing these gaps is critical to ensuring energy efficiency requirements remain aligned with modern device capabilities and usage trends.

Cost-Effectiveness Models

Expanding testing capabilities to include active-state evaluations and broader throughput conditions requires significant investments in equipment, testing time, and protocols. Equipment costs are estimated at $20,000–$30,000 per lab setup. This includes specialized tools such as network traffic generators, traffic analyzers, and automated test platforms to simulate and measure high data throughput scenarios accurately. These tools allow for more granular data collection, enabling comprehensive evaluations of performance under variable loads and active states.

Unlike VA testing, which primarily evaluates idle power consumption, expanded testing protocols simulate real-world usage, including sustained high-bandwidth activities like video streaming and multiple simultaneous connections. This expanded testing emphasizes load variability and dynamic scaling scenarios, which are largely absent from VA testing. By incorporating these elements, laboratories can better evaluate how devices handle peak loads and optimize energy usage during low-demand periods, providing a clearer picture of real-world efficiency. However, this does result in increased testing time, which can increase exponentially based on the granularity of tested data points. Resulting in more upfront costs to the manufacturer which may impact product pricing.

Similar to the commercial imaging devices analysis, residential network equipment could also benefit from enhanced labeling requirements based on the expanded testing methodology to provide consumers with performance metrics based on standardized testing. These labels would provide consumers with clear and standardized information about energy performance under both idle and active conditions. Incorporating labeling costs, including design, implementation, and consumer education, should be factored into the overall cost-effectiveness model. Labels can serve as an important tool to drive consumer awareness and market transformation, encouraging the adoption of more energy-efficient products.

Future Codes & Standards Recommendations

The team's recommendations for future codes and standards emphasize the need for adaptability to keep pace with the rapid evolution of residential networking equipment (RNE). Given the short 2–3 year lifespan of these devices, any new standard must be flexible enough to address frequent technological advancements, such as higher data throughput, mesh networking, and smart home integration.

Through discussions with representatives from the Voluntary Agreement (VA), the team confirmed that the VA does not intend to evolve into a mandatory state requirement. As a result, any new code or standard for RNE will need to start fresh rather than build upon the existing VA framework. This approach allows for the creation of standards that better reflect modern usage patterns and emerging technologies without being constrained by the limitations of voluntary agreements.

The team recommends scalable frameworks that allow incremental updates as technologies evolve, reducing the need for frequent, resource-intensive revisions. Standards should also emphasize performance metrics that capture both idle and active states, along with dynamic load conditions, to provide a more accurate representation of real-world energy performance.

Enhanced labeling and reporting practices are strongly recommended to provide consumers with actionable information about device energy usage, encouraging informed purchasing decisions and pushing manufacturers to prioritize energy efficiency. Collaborative efforts with policymakers, manufacturers, and researchers are also advised to ensure the standards remain relevant and adaptable to future market trends.

Commercial Laboratory Equipment

Freezer

Goals

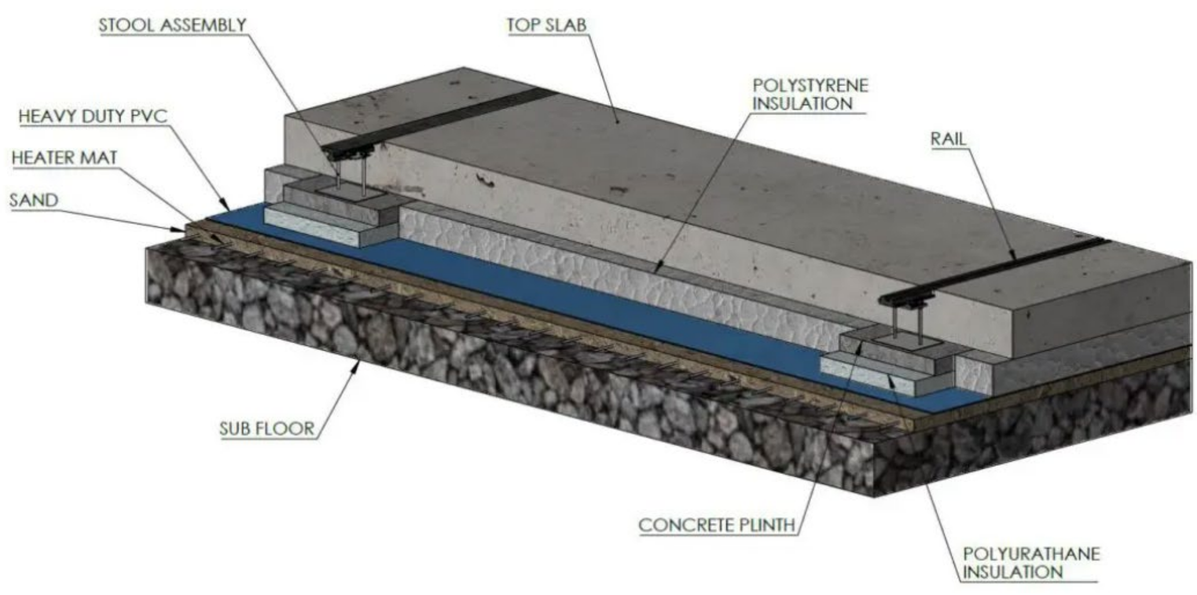
Based on the experimental reports from Tasks 4.1 and 4.2, the goals for freezers are to evaluate the energy consumption of laboratory freezers, propose a baseline minimum efficiency standard, and provide recommendations for improving efficiency. Additionally, develop a testing methodology for measuring these standards based on established experience.

Evaluated Energy Use

Data from 4.2 shows significant variations in energy consumption across different temperatures and refrigerants. For instance, large-capacity freezers such as the Kenmore 22442 and Frigidaire exhibit higher energy consumption at -4°C (25°F) and -20°C (-4°F), respectively. Laboratory freezers using the same refrigerant can still exhibit varying thermal efficiencies. A minimum efficiency standard can be established through a comparative analysis of energy consumption across various units.

Figure B-1 is about the composition of the laboratory freezer insulation layer.

Figure B-1: Composition of the Laboratory Freezer Insulation Layer



Range of Expected Energy Savings

Achieve significant reductions in energy consumption through improved refrigerant use and enhanced insulation performance.

Objective:

- Low GWP Refrigerants: As mentioned in Task 4.2, using low global warming potential (GWP) refrigerants like R290 and R600a can substantially improve the energy efficiency of freezers. For example, the Thermo Scientific freezer, which uses a R290/R170 refrigerant mix, exhibited better efficiency compared to models using R134a. By adopting these environmentally friendly refrigerants more widely, energy consumption is expected to decrease by 15%-25%.
- Enhanced Insulation: Optimizing insulation materials in freezers to reduce heat loss, especially under low-temperature conditions, can lead to a 10%-15% reduction in energy consumption. A well-insulated system reduces energy waste, particularly in low-temperature operations.

Codes & Standards Impacts

For freezers, the objective was to evaluate the effects of novel refrigerants and insulation technologies on manufacturing costs and market pricing, while establishing a baseline standard and proposing a testing methodology to inform the development of comprehensive standards.

Although the use of higher-efficiency refrigerants and advanced insulation materials may initially increase manufacturing costs, the long-term benefits—such as enhanced energy efficiency and reduced environmental impact—offer substantial savings to consumers. Compared to other refrigerants, R600 demonstrates superior energy efficiency; however, due to certain environmental hazards, it is commonly used in larger freezer units. Standardization of refrigerants for freezers across various sizes is recommended. As indicated in the experimental data from Task 4.2, the Energy Efficiency Index (EEI) ranges from a maximum of 2103.93 Wh/Cu to a minimum of 162.58 Wh/Cu. It is noteworthy that the unit with the highest energy efficiency was neither the largest nor the smallest by volume, suggesting considerable potential for improving energy efficiency. Due to limited evaluations of laboratory equipment, it is advisable to control freezer models with identical capacities during testing. Where feasible, testing should include scenarios in which refrigerants are interchangeable to accurately assess energy consumption efficiency.

Centrifuges

Goals

For centrifuges, the team looked to evaluate the energy consumption of centrifuges under varying speed and temperature conditions and propose recommendations for efficiency improvements. Additionally, establish a sleep mode based on standby energy consumption levels to ensure optimal energy efficiency during periods of inactivity.

Evaluated Energy Use

Testing in Task 4.2 indicates that models like the Eppendorf 5417R consume substantial energy at high operational speeds. Optimizing the fan system and refining standby modes are essential strategies for improving energy efficiency.

Range of Expected Energy Savings

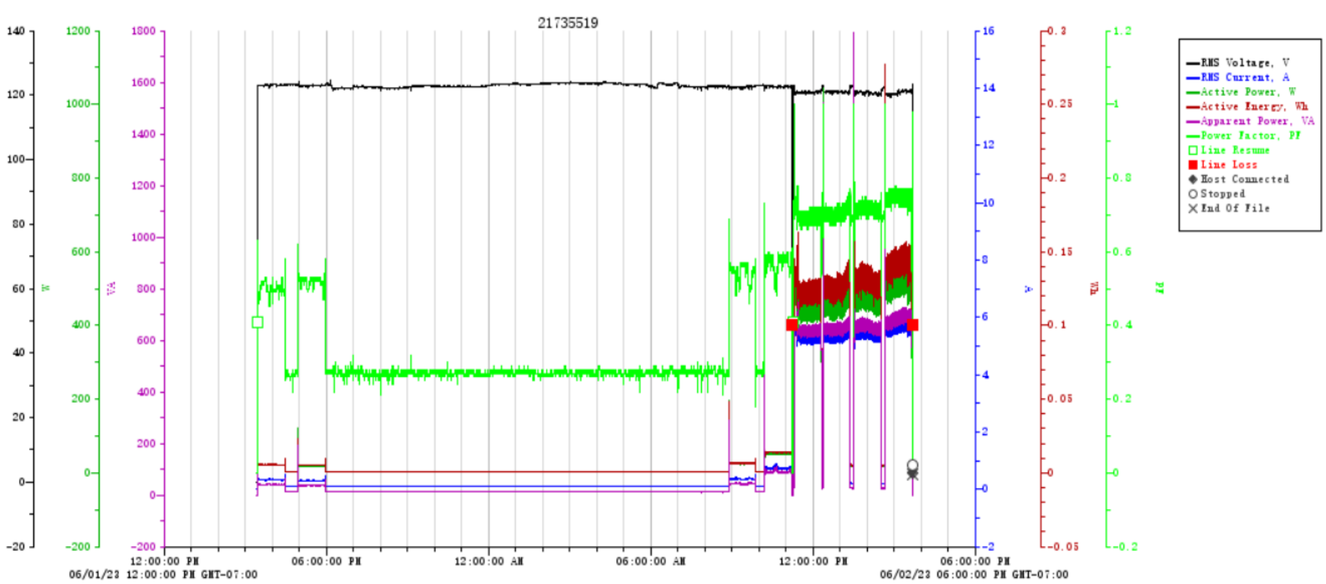
Achieve significant reductions in energy consumption during both operational and standby states by optimizing fan design and implementing smart standby functions.

Objective:

- Fan Design and Quantity: Task 4.2 suggests limiting the number of fans to no more than three and utilizing more efficient fan blade designs. This optimization can reduce the load on fan motors, improve cooling efficiency, and potentially lower energy consumption by 10%-20%.
- Smart Standby Mode: Introducing a smart standby mode where the centrifuge automatically enters a low-power state when not in use can reduce standby energy consumption by up to 60%, as highlighted in Task 4.2. Overall, this feature is expected to cut energy consumption during idle periods by 20%-30%.

Figure B-2 shows raw data for Centrifuge 5424 from June 01, 2023 11:11:41 to June 02, 2023 11:16:54. It includes 5424 for 37degree with 1000rpm, 2000rpm, 4000rpm, 8000rpm and 5417R from June 02, 2023 11:18:30 to June 02, 2023 15:39:45. It include 5417r for 37degree with 1000rpm, 2000 rpm, 4000rpm, 8000rpm.

Figure B-2: Data for Centrifuge 5424



Codes & Standards Impacts

For centrifuges, the objective is to evaluate the impact of fan optimization and intelligent standby modes on equipment costs and market adoption. Improve the cooling capacity, storage space, and standby energy consumption of the equipment.

Although initial manufacturing costs may increase due to new design requirements, the overall improvement in energy efficiency will reduce long-term operational costs. The new standard should encourage the broad adoption of intelligent standby modes to minimize energy waste from idle equipment. Future testing should prioritize centrifuges of identical capacity to validate operational performance. Additionally, standby modes should be optimized to minimize energy consumption while ensuring cell viability during dormancy.

Water Bath

Goals

The project team evaluated the energy consumption of water baths under different temperature and capacity conditions and looked to provide efficiency improvement recommendations based on existing data. Additionally, the team proposes suggestions for future testing.

Evaluated Energy Use

Data from Task 4.2 indicates that higher temperatures correlate with increased energy consumption. Significant reductions in energy use can be achieved by improving the heating system and insulation performance. For larger-capacity water baths, enhancing insulation is a key focus, while for smaller water baths, which are often ultrasonic, improving heating efficiency should be prioritized.

Range of Expected Energy Savings

Achieve significant reductions in water bath energy consumption by improving heating efficiency and insulation performance.

Objectives:

- Heating Efficiency: According to the recommendations in Task 4.2, the energy required for heating should be calculated using the formula $Q=m \cdot c \cdot \Delta T$, ensuring that heating efficiency reaches at least 80%. Reducing frequent heating cycles and optimizing heating intervals is projected to decrease energy consumption by 15%-20%. Data from small water baths such as DK SONIC, Emerson CPX1800H, and Kendal Commercial Grade indicates that the Kendal Commercial Grade unit demonstrates superior heating efficiency, revealing substantial potential for further improvements in this area.
- Insulation Performance: Task 4.2 highlights the importance of enhancing insulation design to minimize heat loss, especially during prolonged high-temperature operation. Improved insulation can reduce energy consumption by 10%-15%. The Fisher Scientific Isotemp Dual Digital Water Bath, a 15L ultrasonic-capable unit, has been shown to have higher total consumption and lower thermal efficiency during repeated heating cycles compared to other smaller water baths. When maintaining a stable temperature of 37°C (99°F) for extended periods, ensuring minimal energy consumption is critical.

Codes & Standards Impacts

The project team identified the impacts of developing a new standard mandating more efficient heating systems and improved insulation for water baths to minimize energy waste, alongside providing detailed recommendations for the standard’s specifications.

While implementing a more efficient system may initially raise manufacturing costs, the energy savings over time are expected to compensate for the investment within 2-3 years. The standard should require that water baths maintain consistent temperatures, reduce unnecessary heating cycles, and ensure that large water baths do not exceed 1W of power consumption when insulated. Future testing should involve a wide range of large water baths of various capacities to assess and compare their insulation materials and energy consumption.

Incubator

Goals

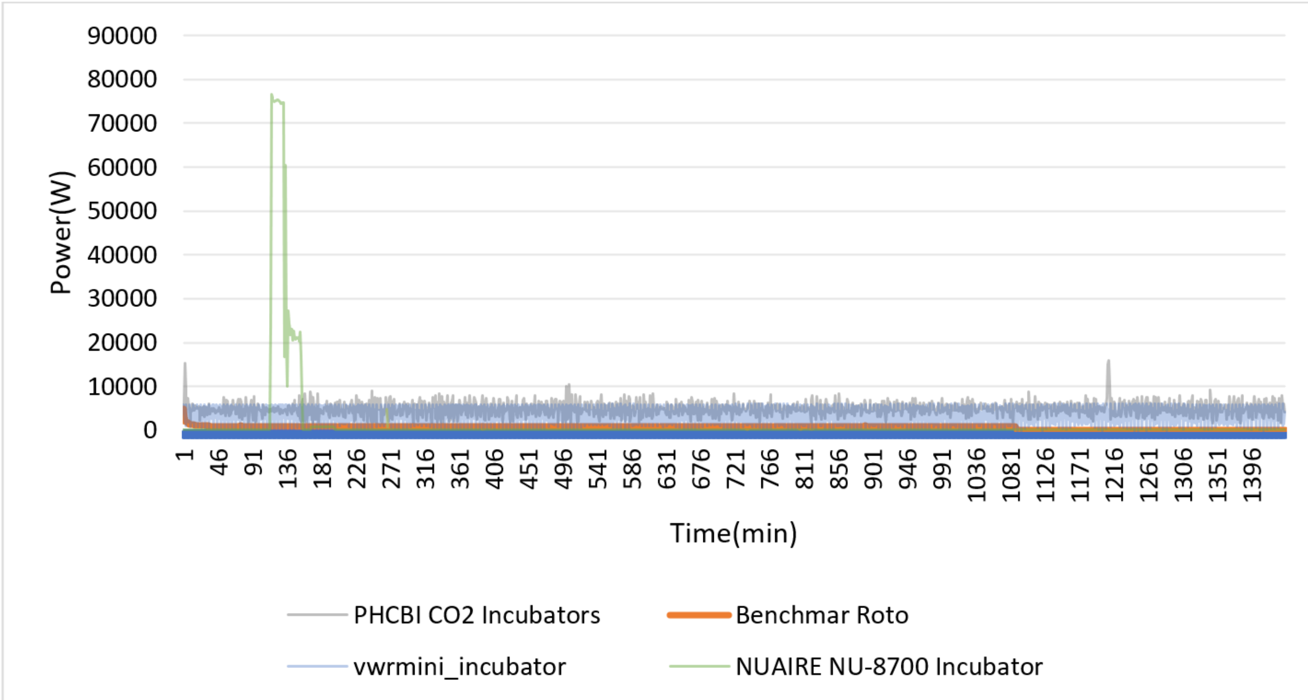
Evaluate the energy consumption of incubators under different temperature conditions and propose recommendations to improve energy efficiency. Additionally, the team identified the optimal relationship between incubator volume and thermal cycling based on existing data to reduce energy waste. Since thermal cycling is manufacturer-controlled, recommendations should focus on design improvements that optimize thermal retention and minimize the frequency of heat cycles to achieve significant energy savings.

Evaluated Energy Use

Data from Task 4.2 indicates significant differences in energy consumption among various incubator models operating at the same temperature. Energy use can be greatly reduced by enhancing insulation systems and optimizing temperature control mechanisms. Small incubators, despite their unique functionalities, show poor thermal efficiency when used solely for insulation purposes. Observation of their insulation layers reveals that incubators with lower thermal efficiency often have simpler, less effective insulation. In contrast, larger incubators demonstrate varied thermal efficiency due to differences in heat cycling. For instance, when maintaining a temperature of 37°C (99°F), the NUAIRE NU-8700 Incubator consumes nearly half the energy compared to the PHCBI CO2 Incubator, while maintaining an internal temperature range of 36.9-37°C (99°F). Therefore, studying temperature distribution and heat cycling efficiency is essential for improving overall energy performance.

Figure B-3 shows data for incubator 37-degree states for 24 hours. (Note, the hatch opening part has been deleted from the data).

Figure B-3: Data for Incubator 37-degree States for 24 hours



Range of Expected Energy Savings

The project team evaluated ways to significantly reduce energy consumption in incubators through improved temperature control and enhanced insulation performance.

- Temperature Control and Heating Intervals: Task 4.2 suggests that incubators should automatically reheat only when temperature deviation exceeds ±0.2°C to minimize frequent heating cycles. Implementing this measure can maintain temperature stability while reducing energy consumption by at least 10%-20%.
- Enhanced Insulation Materials: According to Task 4.2, high-end incubators that utilize advanced insulation materials can limit temperature fluctuations to within 0.5°C even after the heating system is turned off. This enhancement can lower energy consumption by 15%-25% during prolonged operation.

Codes & Standards Impacts

The new standard should mandate improvements in temperature control and insulation performance for incubators to enhance energy efficiency. Future testing should compare different models of similar capacities, with a tiered approach for different capacity ranges to account for cost considerations.

Small incubators often lack insulation requirements, leading some manufacturers to prioritize cost savings over insulation performance. To address this, a minimum insulation standard should be introduced for small incubators. For large incubators, regulating the frequency of heat cycles is essential to reduce unnecessary energy consumption.

Autoclave

Goals

Due to the complexity of internal components within autoclaves, it can be challenging to determine which specific part is operating at any given time. However, general recommendations can still be made based on the overall operational cycle.

Evaluated Energy Use

Data from Task 4.2 shows that autoclaves have high energy consumption during the heating phase, with power usage exceeding 1200W. Among the models studied, only the Consolidated_hinged_autoclave is a storage-type autoclave, while the other four are bench-top autoclaves. These models operate in both "unwrapper state" and "handplace state," allowing for an evaluation based on the overall performance of their complete operational cycles.

Range of Expected Energy Savings

The project team evaluated ways to significantly reduce energy consumption in autoclaves through the following ways:

- Peak Power Reduction: It is recommended to optimize heating elements to limit power consumption during the heating phase, reducing energy use by 10%-20%.
- Cycle Efficiency Improvement: Shortening the duration of high-power phases during sterilization cycles can further reduce energy consumption by 15%-25% without compromising sterilization effectiveness.
- Equipment Recyclability: Some older machines have shown safety issues, such as pressure problems after completing a full cycle. Manufacturers should prioritize the timely recycling of outdated machines to prevent potential safety incidents.

Codes & Standards Impacts

Given the complexity of autoclaves, evaluations should focus on the entire operational cycle. A standardized, tiered assessment system should be established to compare and rank different models based on their volume and overall performance.