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Energy Reporting: Device Demonstration, Communication Protocols, and Codes and Standards

California Energy Commission

Gavin Newsom, Governor

April 2019 | CEC-XXX-XXXX-XXX



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PREFACE

The California Energy Commission's 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, energy transmission and distribution and transportation.

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 solution, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission 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 Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission 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), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Energy Reporting: Device Demonstration, Communication Protocols, and Codes and Standards is the final report for the Unlocking Plug-Load Energy Savings through Energy Reporting project (Agreement Number EPC-15-026) conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to Energy Research and Development Division's EPIC Program.

All figures and tables are the work of the author(s) for this project unless otherwise cited or credited.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Energy reporting is the principle that all energy-using devices in buildings should be able to track their own energy use and report this to the local network. Energy reporting can provide building owners with easy access to highly granular energy use data. This report makes the case that energy reporting should become a free basic feature of all devices, and reports on a project intended to move us towards that goal.

The project collected a set of demonstration devices with energy reporting features, including products that were modified by the project team or the manufacturer, or are already available for sale. To show these devices operating live at meetings and conferences, the team created a management system that queries the energy reporting devices for their data, stores the data, and displays it in compelling visualizations.

The devices covered a wide range, including heating, ventilation, and air conditioning (thermostat and air purifier); lighting (individual bulb, task light, and auto-dimming overhead light); a vehicle charger; a water heater; electronics (notebook personal computer and universal serial bus charger); and three external meters (one integral with a dimming light switch). The demonstration uses a variety of communication protocols.

The report reviews existing communication protocols that support energy reporting and describes how to use them with a proposed reference data model for energy reporting. It also assesses ways that energy codes and standards processes can be leveraged to drive energy reporting technology into the market. Energy reporting could ultimately save California on the order of 2.5 terawatt-hours per year and about \$0.8 billion per year. Energy reporting is a highly practical technology with minimal (sometimes no) cost to consumers and manufacturers.

This report discusses creation of the energy reporting devices themselves, analysis and recommendations for data models and protocols for energy reporting, and energy codes and standards implications of energy reporting technology. While energy reporting does not directly save energy, it provides information for better decision-making to save energy in changing equipment operation, maintenance, and replacement.

Keywords: energy reporting, networks, energy, plug loads, buildings, codes and standards, devices.

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EXECUTIVE SUMMARY

Introduction

California has ambitious goals for efficiency increases, renewables production increases, and greenhouse gas emissions reduction. Meeting these goals will require addressing all end-use devices in buildings, having the best possible information for making decisions, using innovative control mechanisms to increase use of variable renewable sources, and making good use of low-cost technologies to provide these benefits.

Plug loads, which generally are considered to be devices plugged into common power outlets, consist primarily of electronics and miscellaneous devices. Plug loads account for an increasing portion of electricity consumption in both residential and commercial buildings. Recent surveys indicate that plug loads are responsible for at least 25 percent of building electricity use nationally, and even more in California. Although estimates of California plug-load electricity use differ, in part because definitions vary, the total certainly exceeds 50 TWh/year. The CEC forecasts that in the 10 years following 2014, the category of miscellaneous residential energy use will increase by about 50 percent, and that growth in plug loads will be more than 80 percent of the total growth in California electricity use.

Consumers and other building managers rarely have good information about which devices are using energy or how much they are using and when. In large buildings, they often do not even know what devices are present or where they are located within the building. This lack of knowledge impairs effective decision-making about changing device operating patterns, maintenance, and replacement. Methods available today to gather such data require the purchase, installation, and maintenance of new hardware at the end-use device or circuit level, and given the required expense and other complications, they are not widely used. The most common approach is dedicated external meter hardware at the device or circuit level. Non-intrusive load monitoring, which disaggregates individual devices from a central measurement with sophisticated software, has significant limitations on its capabilities, in addition to being costly.

For decades, building energy goals were principally limited to just reducing total annual use. However, with the need to integrate variable renewable energy sources, driven by state Renewable Portfolio Standards, it is also important to shift consumption in time.

This project originated with concern for the energy use of “plug loads”—principally electronic devices and miscellaneous devices. While the need for information and control capabilities is particularly stark for plug loads, and for electricity consumption, solutions should really be applicable to any energy-using device in buildings, and all forms of energy.

To meaningfully contribute to California’s energy-efficiency and climate change goals, mechanisms for providing granular data about device energy use need to have the following characteristics:

- Available at very low cost, and ideally, at no cost
- Widely distributed in products, and ideally, already in products when purchased

- Be applicable to all device types
- Capable of preserving customer privacy and security
- Minimally burdensome for device manufacturers
- Linked to an effective means for control to reduce or shift energy use

Research at Lawrence Berkeley National Laboratory (LBNL) in past years had articulated the concept of “energy reporting.” This is the principle that every end-use device can track its own energy use and report this along with related information to the local network. This allows data to be gathered at any time resolution desired. The project team also has identified dynamic electricity pricing as a control mechanism, which like energy reporting, is a technology which can apply to all end-use devices.

Once building managers can see where and how much energy is being used within the building, they can make better decisions about device operation, maintenance, and replacement. The time-varying price of electricity can then be used to directly drive device operation, or when combined with energy reporting data, lead to changes in control regimes.

Energy policy makers could use energy reporting data, anonymized for privacy, to observe actual device performance over time and geography, by model number. These data could then be used to inform test procedures, energy standards, and ensure that software updates to end-use devices do not undermine their efficiency. Utilities could also use these data to base rebates on actual individual device operation rather than on assumed average savings, thereby increasing the cost-effectiveness of and overall confidence in such programs.

In sum, the possibility of individual device energy reporting appears to be one of the many necessary technology and market advancements needed to reach state energy policy goals.

Project Purpose

The core purpose of the project was to move California substantially closer to a future in which energy reporting is a basic feature of most devices sold, so consumers and building operators can use that information to reduce building energy use. There are several barriers to this future, and this project was designed to substantially reduce several of them, covering awareness, technology, and policy.

The project’s goal was to create convincing evidence that energy reporting is a reality and could be readily incorporated into products and buildings, in the full range of electricity-using devices. The project sought to ensure that this evidence would be directly observable in the most straightforward and practical way possible, so that people interested in energy use could absorb the concept of energy reporting and embrace the idea that it should be a basic feature of all products. To that end, the project team developed a working system to demonstrate end-use devices that track and report energy use and a device that collects and displays the data.

For technology, the project sought to begin to identify a core set of communication protocols for energy reporting that would be suitable for every device to implement. These protocols should be harmonized so that data produced with them can be combined into a holistic view of

building energy use and performance, and include device characteristics data so that the energy use can be seen in its proper context.

For policy, the team sought to understand how best to use public sector capabilities, principally codes and standards, to move the technology into the market more quickly and with higher quality results.

Project Process

The project consisted of four major efforts: energy-reporting devices, communication protocols, a management system, and codes and standards.

The team planned to assemble a collection of at least three real end-use devices that would implement energy reporting technology, with the assumption that at least some would need to be created during the course of the project. Some devices would measure their energy input, while others would use operational state values and prior knowledge to estimate it. A set of tests of the devices were created to demonstrate the accuracy of the reported energy values.

For technology, the project team established an overall system architecture for energy reporting that would meet the goals listed above and evaluate communication protocol standards for how they support the capability. The team created a reference data model to use to harmonize data across protocols and be a guide for future standards technology development. The goal was for the work with technology standards organizations to advance existing and new communication protocols that are able to implement energy reporting in a way that was consistent with the project approach. Finally, the team produced guidance for product designers on how to use the protocols, and for energy standards organizations (e.g., ENERGY STAR®) on what to require in specifications.

The energy reporting devices could not function without a central device (a “management system”) to request and receive the data. Thus, the team built such a system for the purpose of demonstrating the energy reporting capability.

Finally, for codes and standards, the team assessed how energy reporting requirements could be folded into the California standards landscape, most notably appliance and building energy efficiency standards, Titles 20 and 24, respectively.

Project Results

The project plan consisted of four major efforts: energy-reporting devices, communication protocols, a management system, and codes and standards.

Energy-Reporting Devices

Although the original plan was to develop three devices, the collection eventually had twelve. These are listed in Table ES-1; photos of the devices are shown in Figure ES-1. For three of the devices, the research team engaged the manufacturer to modify the device. One the team directly modified. One was used from the manufacturer as is. The team built another based on control hardware from the manufacturer.

The devices served different purposes. Two devices report status that the management system converts into power and energy. Three are external meters. The RAD controller reports on the consumption of two devices: the task light it is integral to and an overhead lamp.

Table ES-1: Demonstration Device Information and Characteristics

Name	Device Type	Manufacturer	Physical Protocol	Application Protocol	Energy	Power	Measured/ Estimated
RAD	Controller and Task Light	Erik Page & Associates	Zigbee	Zigbee	X	X	Measured
RAD	Overhead Light	Philips	Zigbee	Zigbee	X	X	Estimated
Pirl	USB Charger	Pirl Technologies, Inc.	Bluetooth	Serial Text	X	X	Measured
Mila	Air Purifier	Mila USA	Wi-Fi	Serial Text	X	X	Estimated
MacBook	Notebook PC	Apple Inc.	Wi-Fi	REST API	X	X	Measured
Water Heater	Water Heater	A. O. Smith Corp.	CTA-2045 / Wi-Fi	REST API	X	X	Estimated
EVSE	Electric Vehicle Supply Equipment	Siemens AG	CTA-2045 / Wi-Fi	REST API	X	X	Measured
Thermostat	Thermostat	Venstar	Wi-Fi	REST API		Status	Estimated
Hue	Light Bulb	Philips	Zigbee/ Ethernet	REST API		Status	Estimated
Dimmer	Dimmer Switch	General Electric / Jasco	Zigbee	Zigbee	X		Measured
PowerBlade	External Meter	Lab11	Bluetooth	Custom	X	X	Measured
WeMo	External Meter	Belkin	Wi-Fi	REST API		X	Measured

The devices represented a variety of end uses and communications protocols used, and they covered both measured energy use and estimates.

When tested, the collection of devices generally performed well for accuracy, as assessed by comparing reported power use with that measured by laboratory-grade test equipment.

Devices with standard communication protocols were relatively easy to integrate.

Many of the devices have some networked control capability, but the team modified several of the devices to be able to receive a dynamic price signal as well.

Figure ES-1: Thumbnails of the Devices Used in the Study

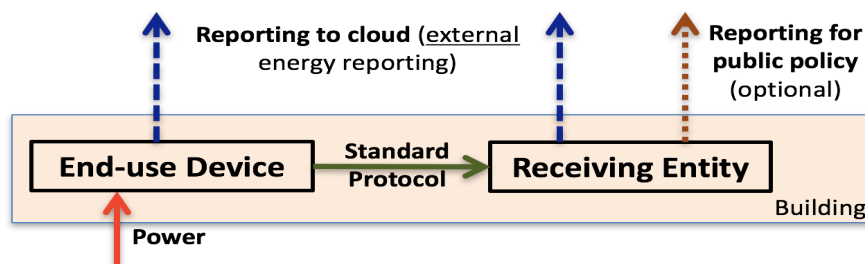


Source: Laura Wong

Communication Protocols

Figure ES-2 shows energy reporting's overall architecture. A key principle is that the default behavior should be limited to reporting the data to another entity within the building, and not to share it with an external entity. This is to address real privacy and security concerns. Reporting externally is allowed on an opt-in basis. While data may be conveyed with a variety of protocols, the team defined a reference data model for all such data to be translated into. The data model covers the energy and power data collected at intervals over time, as well as static data elements like brand, model, and location, which change rarely or never.

Figure ES-2: Overall System Architecture for Energy Reporting



Source: LBNL

The project team reviewed many protocols for how they implement or match the reference data model, to show how to use them in a consistent way. Standards development for energy reporting is an ongoing process that started years before this project and continues after, but the reference data model provides an excellent starting point. In most cases, the core focus of the standard is not energy reporting so the content does not reflect the focused attention to energy reporting issues that was applied in this project.

Management System

Creating a functional demonstration system of energy reporting devices required the creation of a central device—a “management system”—that queries the end-use devices for their energy reporting data, stores the data in a database, and displays it in several forms for viewing.

The management system developed for this project provides a time-series display of power levels over time, instantaneous power, and accumulated energy use. The demonstration system has already been shown at several conferences. The visualization system is compelling and flexible. The experience of integrating the devices confirmed the need for good interoperability standards in this area. The control elements were successfully integrated into several of the devices.

Codes and Standards

Many of the energy efficiency gains California has made in the last several decades have been accomplished, at least in part, with energy codes and standards. Analysis of the landscape of policy options to promote energy reporting adoption in products naturally focused on Title 20 and Title 24 for their focus on individual appliances and buildings, respectively. The project laid out a roadmap for moving requirements for energy reporting into future codes.

Technology/Knowledge Transfer

The project employed several methods to address market adoption. The first was to work towards necessary technology standards covering the topic in a sufficient and consistent way. Another was to bring the technology into voluntary programs like ENERGY STAR. A final method was to consider how energy codes and standards could compel incorporation of the technology into products and buildings. Active demonstrations of the technology working were conducted to help get the concept of energy reporting more widely recognized.

Intended users of the project results include standards organizations, manufacturers and the energy policy community, including those who operate voluntary programs and mandatory codes and standards. ENERGY STAR® is a key partner in promoting the technology.

The best near-term products to introduce energy reporting into are those that consume a lot of energy, those that have a lot of potential savings, and those that might shift load in response to time-of-use electricity rates. The ultimate intended market is all devices that communicate, which will be a larger fraction of sales every year.

There are a variety of ways that energy reporting and price responsiveness technology can find its way into California residential and commercial buildings. The first is for devices in the field

today to be retrofitted with a routine software update. Second is for manufacturers to update the firmware of products to include energy reporting with estimation. Third is for products to be designed with measurement hardware included along. The management system that receives the data could be a function added to a common device such as a Wi-Fi router or building energy management system.

Energy reporting could also be a highly valuable source of data for energy policy, to improve decision-making and program operation and efficiency. The technical advisory committee provided important guidance on project direction, and several members are highly involved in technology standards.

Benefits to California

If energy reporting became a basic feature of most devices and consumers used the information to control energy use and demand, the research team estimates a 5 percent reduction in plug-load energy use. Table ES-2 shows quantitative estimates of potential benefits to ratepayers after energy reporting is fully implemented. Benefits are presented in terms of electricity and cost savings, reduced electricity demand, and reductions in greenhouse gas (GHG) emissions. Estimates are based on the 2014 data on energy use of miscellaneous and electronic products provided by the California Energy Commission (Energy Commission). The Energy Commission data forecast a 50 percent growth in this energy consumption category in the residential sector over the subsequent 10 years; reducing that growth is a key motivation for implementing energy reporting.

Table ES-2. Savings in electricity, GHG emissions, and dollars from energy reporting

Sector	Electricity Savings (TWh/year)	Demand Reduction (GW)	GHG Emissions Reduction, CO₂ equiv. (Gigatonnes/year)	Retail Electricity Cost Savings (\$billion/year)
Residential	1.6	0.25	1.1	0.5
Commercial	1.0	0.12	0.7	0.3
All buildings	2.6	0.37	1.7	0.8

Notes: Columns may not add to the total for all buildings because of rounding. Data obtained from GFO-15-310, Attachment 12. Residential demand factor derived from prior ENERGY COMMISSION data. Commercial demand factor assumes flat load. TWh = terawatt-hours; GW = gigawatts.

Energy reporting savings derive from the insight end users gain from the energy reporting which identifies devices that are using an abnormally large amount of energy. Other benefits derive from the ability to have devices be price-responsive, to take advantage of time-of-use, critical peak, and potentially other new innovative dynamic tariffs. In California, energy savings could exceed 2.6 TWh/year in residential and commercial buildings, which corresponds to about \$0.8 billion/year in lower electric bills (after full deployment). To be conservative, this

only counts savings from electronics and miscellaneous devices. More savings should result from applying the technology to other plug load devices such as appliances. Ratepayers could save by not paying for energy that was being wasted. The technology could result in a demand reduction of more than 300 megawatts and a reduction in GHG emissions of more than 1.7 gigatonnes per year carbon dioxide CO₂ equivalent.

In addition to providing direct electricity savings, energy reporting collects valuable data for use by consumers, manufacturers, and policy makers. The Energy Commission could engage in follow-up projects to work with manufacturers to deploy more energy reporting products and verify their effective use in the field.

CHAPTER 1:

Overview

This report discusses the Lawrence Berkeley National Laboratory (LBNL) project Unlocking Plug-load Energy Savings through Energy Reporting. In this research, the research team developed and demonstrated the technology necessary to implement energy reporting in a wide range of devices (plug loads and others). This is in support of the California Energy Commission/Electric Program Investment Charge (EPIC) research to cost-effectively reduce energy use in buildings to meet several statewide energy policy goals. Those policy goals call for reducing greenhouse gas (GHG) emissions, reducing energy use in buildings through greater efficiency, reducing lighting energy use, increasing efficiency requirements in building codes and appliance standards, and moving the new buildings market to zero net energy (ZNE).

Building owners and managers rarely have good information about which devices are using how much energy, or when. In large buildings, they often do not even know what devices are present, or where they are located within the building. This lack of knowledge impairs effective decision-making about changing device operating patterns, maintenance, and replacement. Instead, there could be a future where every end-use device can track its own energy use and report it along with related information to the local network. To reference this idea, LBNL coined the term *energy reporting*. With this, building managers can see where and how much energy is being used within the building. This ability to monitor energy usage of any device and at any resolution could help save energy through enhanced device operation, maintenance, and replacement. Energy reporting data and mechanisms could also be used for device control.

Energy policy makers could use the data, anonymized for privacy, to observe actual device performance. These data could then be used to inform test procedures and energy standards, and ensure that software updates do not undermine device efficiency. Utilities also could use these data to base rebates on individual device operation rather than on assumed average savings, thereby increasing the cost-effectiveness of such programs.

Creating this future requires an overall architecture, the implementation of such an ability in products, development of technology for communicating the data, a system to receive the data, and relevant policy guidance to support the creation and use of such a technology.

Project Outline

This project was designed to bring a comprehensive approach to move us from a state in which very few devices are capable of energy reporting, and few people are aware of the concept, to a future state in which most products routinely report their energy use and most people understand the idea and use it. This process required efforts in four major areas. First, the team assembled a set of real end-use devices that report their energy. Second, communication protocols were assessed to determine how suitable they are for moving data from the end-use device to a central management system in the building. Third, management system software

was created to collect, store, and display the data. Fourth, energy codes and standards were evaluated to determine how they can increase the rate of adoption of energy reporting technology in devices and buildings.

One outcome of these tasks was the ability to bring the energy-reporting devices to meetings and conferences to show them operating, to provide compelling proof of the technologies. Another outcome was a guide for how to use select communication protocols for energy reporting, how others can be harmonized to a common data model, and content for the creation of new protocols or guidance on modifying protocols. The final major outcome was the development of a path forward on how best to utilize energy codes and standards for this purpose.

Report Organization

The remainder of the report is organized as follows. Chapter 2 describes the devices assembled to be part of our energy reporting demonstration, including their selection, operation, integration, and communications. Chapter 3 presents our reference data model for energy reporting, and assesses a variety of protocols for how they support its use and recommendations for implementation. Chapter 4 describes the proposed system architecture for energy reporting, the management system developed for the demonstration, and lessons learned for how to deploy such systems in the future. Chapter 5 reviews how energy codes and standards could be updated to encourage or require energy reporting technology, including potential barriers to doing so, the range of policy options available, and a recommended roadmap for implementation. Chapter 6 reviews project benefits, Chapter 7 describes technology transfer activities undertaken in the project, and Chapter 8 provides summary conclusions.

CHAPTER 2:

Energy Reporting Devices

Overview

This chapter will discuss the candidate hardware products for energy-reporting capability, the integration of energy-reporting hardware and software into at least three sample devices, a plan and method to test the prototype devices for accuracy, and test results.

The hardware products were combined with a management system (see Chapter 4) to create a compelling demonstration of a set of devices that report energy use, suitable for bringing to meetings and conferences to accompany reports on the project results. The products also were used to document the accuracy of the reported energy use with laboratory measurements of their actual power and energy use to compare with the reported values. The management system created by the research team also is used for both of these purposes, and uses the protocols and data model discussed and defined in Chapter 3. Chapter 4 assesses the protocols for how the data are communicated and integrated into the management system. This chapter covers how the devices operate internally and communicate the data out.

To show to a wide audience the full range of benefits that can be delivered by incorporating energy reporting capabilities, the research team built a portable, real-time demonstration kit that can be taken to various stakeholders—the California Energy Commission (Energy Commission), product manufacturers, standards organizations, and others. The tabletop demonstration kit consists of 12 end-use devices, a management system, and a user interface to visualize the results.

This chapter is organized as follows. It begins with a review of the criteria we used to select devices in our collection and our procedure for testing for accuracy. It then presents the devices we included in the collection; for each it covers how it acquires the data, how it communicates, and any test data. The chapter finishes with conclusions.

Device Selection Criteria

To identify devices that could effectively demonstrate the benefits of energy reporting, the team developed a set of desirable characteristics. These included the following:

- **Practicality of implementation.** The potential to incorporate energy reporting capabilities into devices with reasonable effort.
- **Energy saving potential.** Target devices with individual or collective substantial energy use in buildings.
- **Ease of demonstration.** Select portable components (e.g., size, weight, robustness) to streamline demonstrations.
- **Diversity.** Include a variety of end-use devices.

- **Complexity.** Minimize dependency on external services, such as Internet connectivity, water, etc.
- **Opportunity.** Probe the interest of private sector collaborators in developing prototypes.

The study considered a variety of device types, including electronics; lighting; appliances; heating, ventilation, and air conditioning (HVAC); and direct current (DC)-powered devices. It assumed that, although the long-run future and best option is to report from every end-use device directly, for an extended transition period, there will be a need for external meters that can report.

Testing Approach

The team developed a test procedure for each device, based on the following general outline. The specifics varied with the product type (e.g., modes and timing). The following terminology is used: “Report” refers to data communicated over the network from the end-use device, and “measurement” refers to energy and power meter readings. “Specified mode/level” includes major power states, as well as a selection of operating levels (e.g., for a light, several brightness levels between fully off and fully on) that were identified on a device-by-device basis.

Generic Device Test Procedure

To ensure consistency, the research team developed the following test procedure:

- A. Power the device directly from a suitable power meter.
- B. Integrate the device to be interrogated into the management system and establish communications.
- C. For each specified mode/level, execute the following steps:
 1. Set the product to the specified mode/level.
 2. Wait 10 seconds.
 3. Record the accumulated energy value from the power meter.
 4. Interrogate the device for its power level and cumulative energy use. Record the power level from the power meter.
 5. Repeat Step 3 twelve more times, at five-second intervals, for a total of 13 reports over 60 seconds.
 6. At the time of the thirteenth report, record the accumulated energy value from the power meter.
 7. Calculate the average of the 13 power values and the average power level indicated by the difference in the two cumulative energy reports. Also calculate the minimum, maximum, and standard deviation of the 13 power values.
 8. Report all of the measured and calculated values.

Discussion

The values of 5 seconds, 10 seconds, and 60 seconds (one minute) may need to be adjusted for particular devices. The power level may vary during the test period. This is not necessarily indicative of any kind of problem. For example, a computer might have background tasks that

begin or end during the period, or may dim the display, or have active modes, such as playing a video, that cause variable power draws.

Some devices have manufacturer-provided information, or standard test procedure results, that should also be part of the comparison/evaluation.

When analyzing the results, the most important comparison to make is the total energy used over the one-minute period versus that measured. Also of interest are variations in instantaneous power reported versus that measured.

For the test results below, the team used a Chroma 66201 power meter, which has a rated accuracy at 60 hertz AC power of 0.1 percent of reading plus 0.1 percent of range. For an example measurement in which the power level is 20 percent of the range (the meter has multiple ranges to choose from), the accuracy should be 0.6 percent. The Chroma was most recently calibrated in August 2018.

If the communications were not correctly implemented by the device, in most cases it would simply not work, or would result in erroneous data. Neither of these circumstances were found once the devices were properly integrated.

The thermostat is only reporting status, and as nothing is connected, this is not directly verifiable. All of the remaining devices (Mila, EVSE, MacBook, Water Heater, RAD, and Hue) have been tested for accuracy.

While we tested accuracy, the project had no specific goal for accuracy levels that devices should achieve. The intent is that future products report the accuracy level they are rated to achieve and then be able to test them with the procedure above to verify that they do achieve that accuracy.

Devices

This section reviews each device ultimately included in the demonstration setup. The original goal was to have at least three devices but the collection ended up with twelve. This section reviews the following:

- How the device was acquired/built
- The protocol used and integration challenges (device-specific)
- Energy tracking (including measured and estimated tracking)
- Power reporting
- Static data
- Accuracy
- Control capabilities

For three of the devices (RAD, Pirl, Mila), the research team engaged the manufacturer to modify the device. One of the devices (MacBook) the research team directly modified. One (EVSE) was used from the manufacturer as is. The team built another such device based on control hardware from the manufacturer (Water Heater).

Two devices report status that the management system converts into power and energy. Three are external meters. The RAD controller reports on the consumption of two devices: the task light it is integral to and an overhead lamp. Table 1 summarizes key data on each device.

Table 1: Demonstration Device Information and Characteristics

Name	Device Type	Manufacturer	Physical Protocol	Application Protocol	Energy	Power	Measured/Estimated
RAD	Controller and Task Light	Erik Page & Associates	Zigbee	Zigbee	X	X	Measured
RAD	Overhead Light	Philips	Zigbee	Zigbee	X	X	Estimated
Pirl	USB Charger	Pirl Technologies, Inc.	Bluetooth	Serial Text	X	X	Measured
Mila	Air Purifier	Mila USA	Wi-Fi	Serial Text	X	X	Estimated
MacBook	Notebook PC	Apple Inc.	Wi-Fi	REST API	X	X	Measured
Water Heater	Water Heater	A. O. Smith Corp.	CTA-2045 / Wi-Fi	REST API	X	X	Estimated
EVSE	EVSE	Siemens AG	CTA-2045 / Wi-Fi	REST API	X	X	Measured
Thermostat	Thermostat	Venstar	Wi-Fi	REST API		Status	Estimated
Hue	Light Bulb	Philips	Zigbee/Ethernet	REST API		Status	Estimated
Dimmer	Dimmer Switch	General Electric / Jasco	Zigbee	Zigbee	X		Measured
PowerBlade	External Meter	Lab11	Bluetooth	Custom	X	X	Measured
WeMo	External Meter	Belkin	Wi-Fi	REST API		X	Measured

It was clear that some devices would use Wi-Fi for communication and so would need an infrastructure device between these and the management system PC (just as a Wi-Fi access point does in a residential or commercial building). Early on, the team decided to include a Zigbee device (and eventually, two) and found the Intwine Connect gateway device that bridges these and more.

Mila

The Mila Air Purifier (Figure 1) is a household device, intended to cover a single room. It uses 3M HEPA filters certified to remove up to 99.97 percent of airborne particulates. The unit can track usage, and filters are pre-ordered for customers. It is presently only available in China but is expected to be introduced into the U.S. market; Mila is headquartered in California. As an air purifier manufacturer, health and the environment are a concern, so energy reporting was a natural fit. The Mila device already has communications, as Wi-Fi connectivity is central to some of its core capabilities. Mila was engaged to modify the device’s firmware. They did not modify the device hardware for the project, so the energy data are estimates based on spot measurements of the hardware at a dozen speed levels and idle.

Figure 1: Mila Company Logo and Air Purifier



Source: Mila, Laura Wong

The protocol used is simply serial text over the Wi-Fi link.

Measurements were made at LBNL of a sample unit at different fan speeds, as that is the primary driver of power consumption variation. The Wi-Fi connection is always active, and the display is always on (when the fan is off the logo is still displayed). Once a second, the Mila checks the fan speed, estimates the power draw from this, and accumulate this amount of energy use.

Figure 2 shows a graph of Mila power at different fan speeds, with a new (clean) filter and with one that is very dirty from lengthy operation in Shanghai. The dirty filter requires less power at the same nominal speed. The unit ends up operating more slowly with the dirty filter and so requires less power.

The Mila reports limited static data.

The Mila can be controlled from a phone app, and it also turns itself on and off as needed, as dictated by the air quality it measures. The manufacturer will add price-responsiveness to the Mila in a way similar to that of the RAD (below), with it reducing fan speed at times of high price.

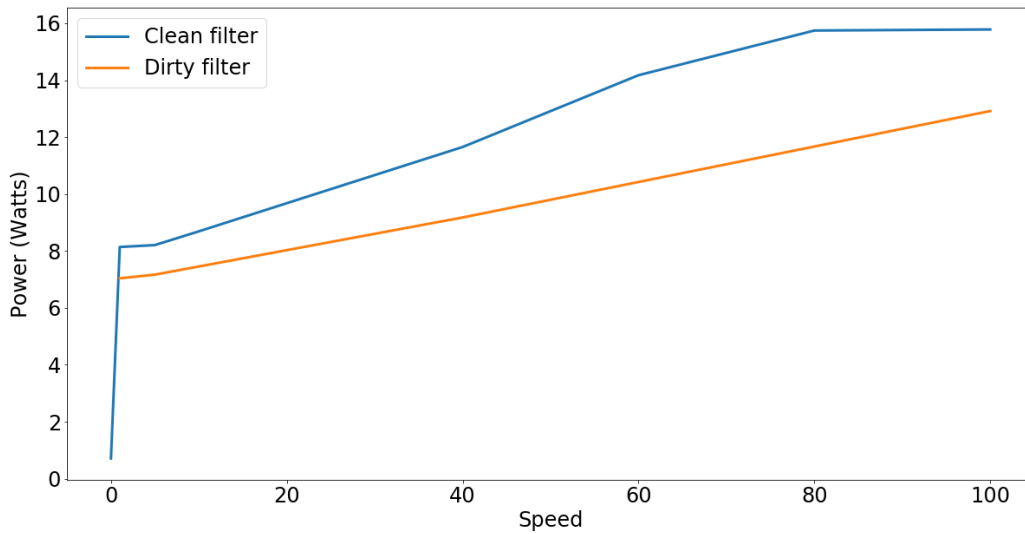
The modified Mila was not available for timely testing at LBNL and so power measurements were conducted by the manufacturer, Mila. Mila used a Huabang PZEM-021 power meter, which has a "Class 1.0" accuracy rating. This is 1% accuracy according to the manufacturer, and with a 20A rating, the absolute accuracy is not high. However, for our purposes, the issue is whether reports and measurements match each other, so any systematic inaccuracy in the meter doesn't affect that evaluation so long as it is consistent. Two filters were measured for their power at the same range of speeds as at LBNL: a very dirty filter and a completely clean one. The results

from these were then averaged and a quadratic formula fit to the data for an estimate of a modestly dirty filter.

$$Power = 8.79 + 0.0659x + 0.00130x^2$$

A dirty filter was measured at the same speeds as at LBNL. The Mila test was conducted with 230V AC power, in contrast to the 115V AC power for the research team test, and there are some differences in the system hardware. The power levels are much higher for the 230V test, over twice as high at the top speed. This is a combination of the hardware difference, higher voltage, and possibly meter inaccuracy. Again, for this purpose it is only the difference between measurements and reports that is of interest, not the absolute values.

Figure 2: Mila Power with a Clean (Blue) and a Dirty (Orange) Filter at Various Fan Speeds



Source: LBNL

This function was programmed into the Mila and the measurements for the dirty filter were compared, as shown in Table 2. There is some circularity in this approach in that the same motor and one of the two filters were used for both the initial assessment and for the accuracy evaluation. A dirty filter uses less power than a clean one in both the LBNL and manufacturer tests, so that the typical reporting value overstates the dirty filter measurement. A future product could track device on-time with a given filter and air quality to estimate how dirty a filter is and then adjust the value to get even closer. Over time the errors in the reported energy use should cancel out as half the time it will be underreporting when running with a clean filter.

Table 2: Mila Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
Idle	3.04	3.04	0	0
1	8.86	8.44	0.42	4.9
5	9.15	8.83	0.32	3.6
10	9.58	9.25	0.33	3.6
20	10.63	10.35	0.28	2.7
30	11.94	11.54	0.40	3.4
40	13.51	12.98	0.53	4.1
50	15.34	14.68	0.65	4.5
60	17.42	16.74	0.68	4.1
70	19.77	18.88	0.89	4.7
80	22.38	21.40	0.98	4.6
90	25.25	24.40	0.85	3.5
100	28.38	27.56	0.82	3.0

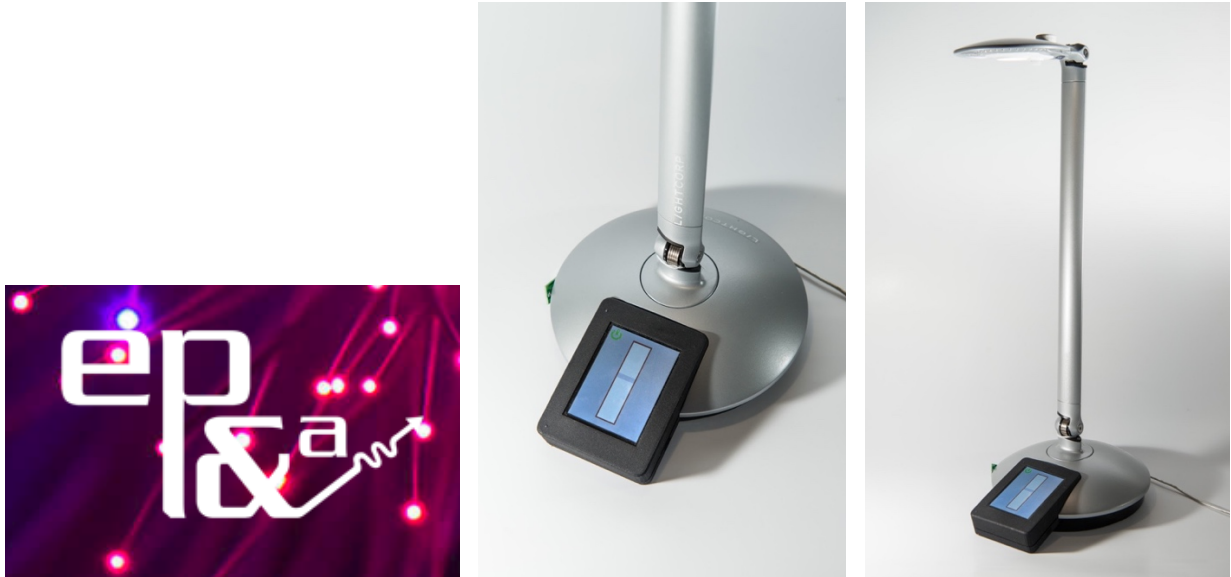
RAD

The RAD (“Readings at Desk”) Controller (Figure 3) is a device developed in the Bay Area, in part with another Energy Commission Electric Program Investment Charge (EPIC) project being conducted by LBNL on lighting control. The RAD is for use in office workstations. It:

- Measures the amount of light present at the work surface.
- Allows the user to define how much light they desire to have (using a small touch-screen display that shows the current and desired levels).
- Communicates to a wirelessly controllable overhead lighting fixture that illuminates the workstation such that measured light levels match requested light levels where possible.
- The RAD Controller is intended for use particularly when daylight is available to offset some or all artificial light. The unit the team had modified is integrated by the manufacturer into a task lamp, which provides convenient placement of the sensor (on top of the lamp), the display (in the lamp base), and powering (from the lamp). The RAD

communicates via Zigbee to the overhead light and to the wider network. For all of this work the team used standard Zigbee communications and encountered minimal difficulty in using it.

Figure 3: RAD Controller Company Logo and Photos of RAD Integrated into a Task Light



Source: Erik Page & Associates, Laura Wong

The Intwine Gateway bridged between the Zigbee and Wi-Fi protocols. With the assistance of the gateway manufacturer, the team created a system to pass the Zigbee commands across Wi-Fi encapsulated in Internet Protocol (IP) packets so the gateway is involved only in moving the data, not in its content.

The RAD already had communications for its basic functionality, but the team did have the manufacturer add hardware to measure power of the task lamp (including that used by the controller itself), as well as a temperature sensor.

The task lamp power is measured, but as the RAD has no hardware connection to the overhead light, its power is estimated. A typical light used with the RAD would be a 4' overhead lamp (light-emitting diode [LED] in a fluorescent tube form factor) so measurements of this type of lamp at various brightness levels was used in the estimation formula. For the demonstration, a Philips Hue Lamp (LED, but in the form factor of a traditional incandescent lamp) was used. Once every second, the RAD adds the current power level of each device to its accumulated energy value, to report out both when queried. They are two independent devices, even though both are being reported by one device.

¹ A lamp suitable for this is the Philips InstantFit LED T8 Lamp with EasySmart technology,

<http://www.usa.lighting.philips.com/products/product-highlights/instantfit/easysmart>

The RAD was also modified to take in a price signal, again directly with the Zigbee standard. When prices reach a relatively high level (\$0.20/kilowatt-hour [kWh]), it begins to reduce the target output level for the overhead light, dropping linearly until the price reaches \$1.00, at which point the light turns off entirely. The task lamp is not controlled by the RAD, and so is not price responsive.

The RAD also relays the temperature, again according to normal Zigbee standards.

The RAD communicates the following static information: manufacturer, brand, model, and its local Zigbee address.

Both of the devices in the RAD system were tested, and the results are shown in Table 3. The task lamp significantly underreports the AC power measured; it is actually reporting fairly accurately the DC power input that it measures. As more devices are powered by DC, including standard DC (e.g. USB or Ethernet), it may make sense to report this value, so long as the management system is clear on what is represented. The difference is the loss in the AC/DC external power converter. The overhead lamp reporting is quite accurate in general; one exception is 25 percent brightness, but even for that, the absolute difference is not large.

Table 3: RAD Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
Task lamp: min brightness	0.78	0.93	-0.15	-15.8
Task lamp: max brightness	6.50	7.38	-0.89	-12.1
Overhead lamp: min brightness	0.60	0.60	0.04	7.3
Overhead lamp: 25% brightness	0.95	0.85	0.1	11.8
Overhead lamp: 50% brightness	1.40	1.4	0.002	0.14
Overhead lamp: 75% brightness	1.97	2.00	-0.03	-1.45
Overhead lamp: 100% brightness	2.30	2.30	0.003	0.13

Pirl Charger

The Pirl charger (Figure 4) is a very-high-performance universal serial bus (USB) charger, with many protections for the charger itself and the device being charged. It is powered via a 7-18 volt (V) DC input that can be produced by an ordinary AC/DC wall adapter, a variety of batteries, a small solar panel, or by other means. Each port can deliver up to 2.7 amps (A)

(13.5 watts, W), and all four ports can operate simultaneously. In its original form it measures the total power being sent to the USB ports and displays it with LEDs. This device was of interest because it already had the measurement capability, so the energy information was presumably already of interest to some customers who buy the product. It also is a DC-powered device, showing how energy reporting applies to devices of any power type (and even to primarily non-electric devices).

Figure 4: Pirl Technologies Company Logo and Pirl Charger



Source: Pirl Technologies, Laura Wong

Unlike other devices in the study, the Pirl charger did not natively communicate. The research team engaged the manufacturer to modify the device by adding a standard Bluetooth communication card and modifying the device firmware to support communications. The additional hardware fit inside the existing product shell. The standard product has an aluminum case, which would block the Bluetooth signals. To avoid this, Pirl created custom 3D-printed covers in acrylic—one black and one clear (to be able to see the internal hardware).

The Pirl uses a simple ASCII text interface across Bluetooth with single-character commands and numeric values encoded in plain text (Bober 2018). Pirl provided Python code to read the data, making integration exceedingly easy.

The Pirl charger reports both the current power level (in watts) and accumulated energy (in watt-hours). For static data it reports the manufacturer name. The only control capability it implements is to change the brightness of the LED display, from “off” to one of three “on” levels.

For accuracy testing of the Pirl device, several test loads of convenient USB devices were used; specifically a USB fan and a mobile phone. Table 4 shows the test results. The Pirl reports the DC power input to it while the measurements were of AC input to a power adapter. To account for this, separate measurements were taken to determine the DC load that would induce the same amount of AC power to be consumed by the power adapter.

The manufacturer did its own estimates and reported that the upper bound of the error should be 4 percent above 15 W and 5 percent above 5–8 W (depending on input voltage); lower than this, the potential error rises sharply. This does not mean the device will be this far off; this is a maximum potential error.

The difference between these values and the estimates for the device is not clear. It is likely that the Pirl is reporting more accurately and that there is some other explanation.

Table 4: Pirl Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured AC Power (W)	DC Output from Adapter (W)	Absolute Difference (W)	Relative Difference (%)
No Load	0.24	0.39	0.36	0.12	34%
USB Fan	1.37	1.82	1.60	0.23	15%
USB Fan and Mobile Phone	9.72	11.26	10.02	0.30	3%

MacBook

The Apple device (Figure 5) is an unmodified (for hardware) notebook PC manufactured in 2012. For many years, Apple notebook PCs have had internal sensors for electricity, temperatures, and more. This commonly includes four voltage sensors and six current sensors, including monitoring of the DC input to the device. Usually the data are only used by Apple, but several companies have written software to access these data and other system status data to present to the interested user. Software for this purpose includes iStat (Bjango Pty 2016), and the Hardware Monitor application (Marcel Bresink Software-Systeme 2018).

Figure 5: Apple and Bresink Software Company Logos and the MacBook



Source: Marcel Bresink Software-Systeme, Laura Wong

The Hardware Monitor software is used to expose the power measured by the metering hardware in the MacBook. The LBNL team wrote additional software that queries this application once a second to obtain the instantaneous power usage and accumulates the energy use. The software also exposes a representational state transfer (REST) endpoint that responds to queries over the network. It conveys the power and energy data, as well as static data for the manufacturer, brand, and model. It cannot accumulate or report energy use while asleep or off, so that consumption is missed.

For static data it reports the manufacturer name, model, unique ID, MAC address, and local identity.

The MacBook Air has no additional control capabilities. Unfortunately all of the temperature sensors are internal, and so are above the ambient level shortly after the system has been operating. For this reason the MacBook does not report a temperature value.

It would be easy for Apple to include energy reporting capability by simply including it in some future system software update, since no new hardware is needed.

Table 5 and Figures 6–9 show the reported versus measured energy use of the MacBook in several different modes. The reports are significantly below the measured, but this is explained by the report being the DC input power to the device and the measured being the AC input to the power adapter. The percentage difference is in line with what we expect the power adapter might consume.

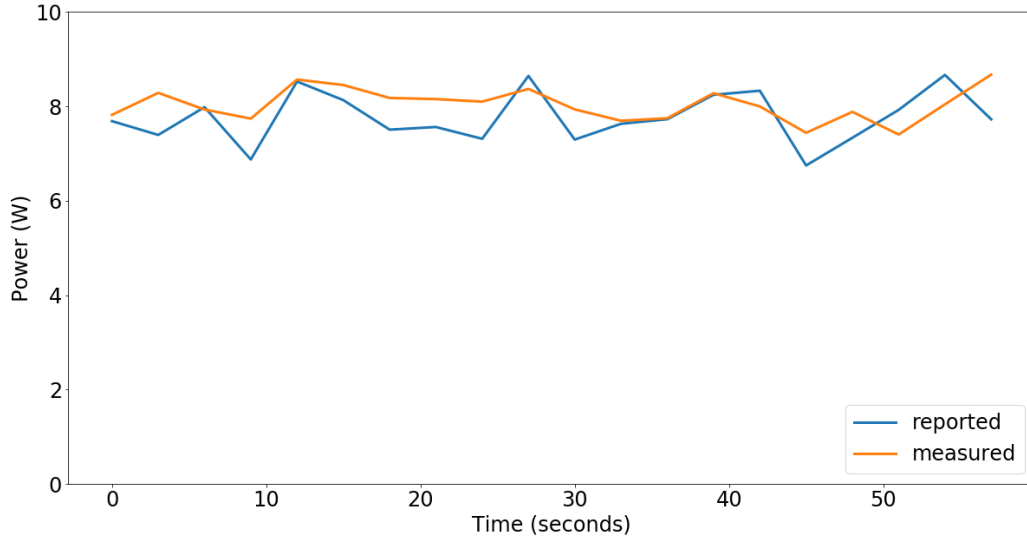
The figures show about 50 seconds of energy use. That the consumption is not constant is not surprising; computers are known to have such varying consumption. That the difference between the two values is not constant is more surprising; presently it is unclear why this would be the case, except that the measured value is of accumulated energy but the reported value is likely an instantaneous snapshot. All that said, the two shapes resemble each other, so there is clearly some correlation between the variations.

Table 5: MacBook Pro Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
Idle and minimum brightness	7.06	7.99	-0.93	-11.7
Idle and maximum brightness	10.3	11.7	-1.32	-11.4
Busy and minimum brightness	11.9	13.3	-1.42	-10.7
Busy and maximum brightness	15.5	17.1	-1.60	-9.3

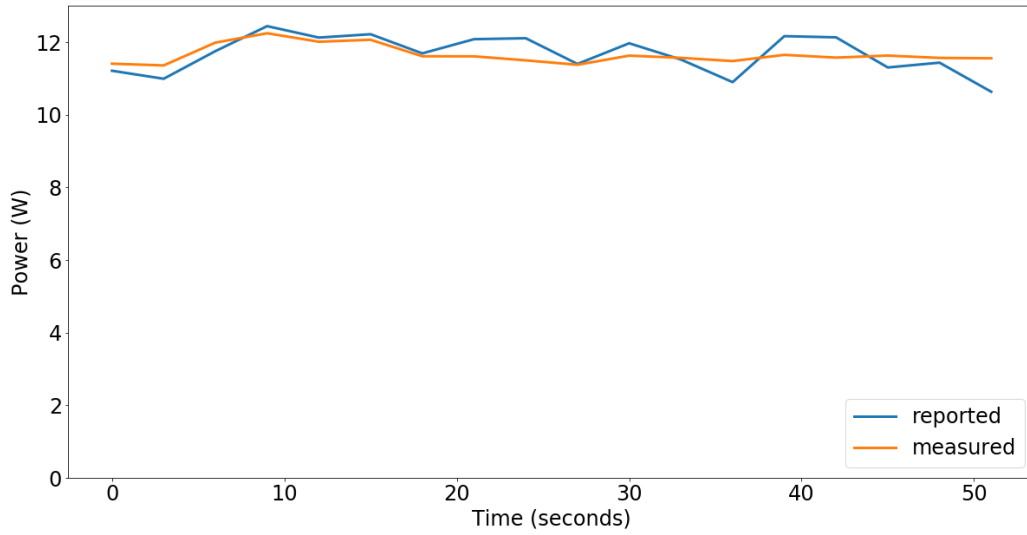
Note: Busy = running Microsoft Word, Terminal, and Safari, and playing a 1080p video with QuickTime.

Figure 6: MacBook Actual vs. Reported Power Consumption When Idle on Minimum Brightness



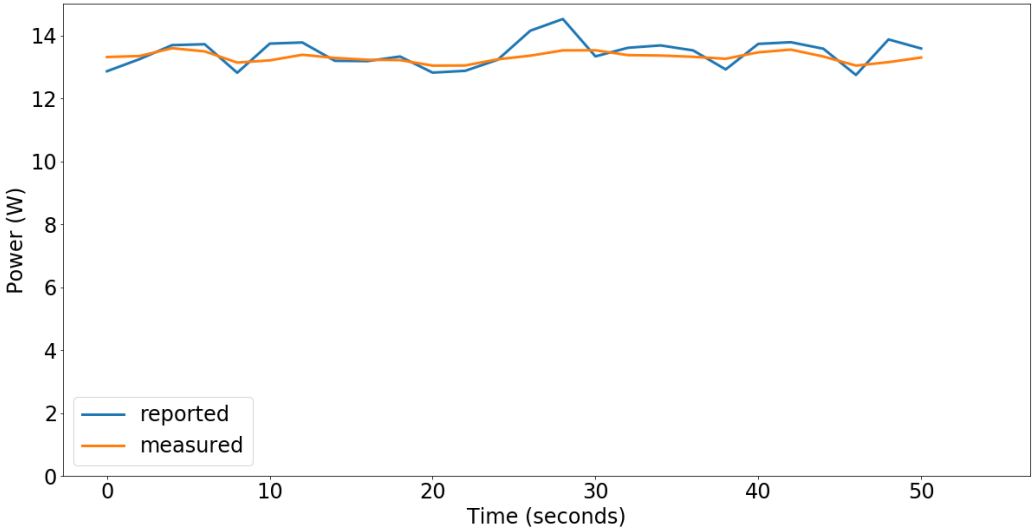
Source: LBNL

Figure 7: MacBook Actual vs. Reported Power Consumption When Idle on Maximum Brightness



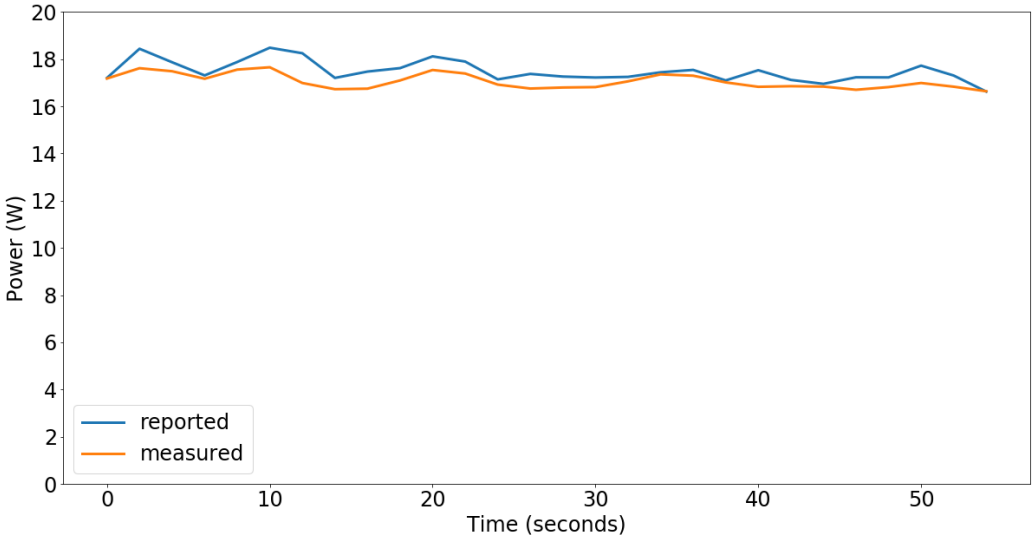
Source: LBNL

Figure 8: MacBook Actual vs. Reported Power Consumption When Busy on Minimum Brightness



Source: LBNL

Figure 9: MacBook Actual vs. Reported Power Consumption When Busy on Maximum Brightness



Source: LBNL

Water Heater

As part of demonstrating and promoting water heaters with technology based on the ANSI/CTA-205 standard (CTA 2018), the A. O. Smith company created “water heater simulators.” These are devices with real water heater controls and communications, but rather than switching on two elements that heat water (upper and lower, the way water heaters are typically constructed) they switch on two much smaller elements that heat aluminum plates suspended in air inside the “tank.” The actual temperature sensors are attached to these aluminum plates, and the controls operate exactly as they would if they were heating water in a regular tank. While the company made a dozen or so of these units, none were available for the team to acquire, so LBNL staff built a similar device (Figure 10), based on guidelines and advice from the company, and some experimentation.

Figure 10: A. O. Smith Company Logo, Photos of the LBNL Device, and the Commercial Product



Source: A.O. Smith, Laura Wong

The unit is about 23” tall and 13” in diameter. The “tank” was constructed from a ventilation duct. The CTA-2045 module is the soap-bar-shaped device on top. The LBNL unit has an indicator light for each element, to show when it is on. While an actual water heater consumes 230 V power, the controls only use one leg of that, and so uses 115 V power. As the element power just goes through relays, using the lower voltage is not a problem for that either. Initially the device used electric resistance heating elements rated at 100 W each, sandwiched between 6” x 3” aluminum plates of 3/16” to 1/4” thickness, serving as heat sinks. The thermostatic sensors for the upper and lower heating elements were fixed to the outside of the highly conductive aluminum heat sinks so that the water heater controls would turn the heating elements off when the heat sinks reached the controls setpoint (e.g., 120°F).

The 100 W heating elements resulted in quite short “on” cycles, typically under one minute, given the low mass of the heat sinks. These cycle-ons were much shorter than the cycle-off times (the length of time to dissipate enough heat to call for the element to turn back on) and

the cycle-on times of an actual water heater. In addition, the energy reporting data in the CTA-2045 module is only updated once a minute, which makes short cycles awkward.

To increase the length of the “on” cycles, the 100 W elements were replaced with 25 W elements, effectively slowing the heating of the aluminum sinks. The temperature setpoint of the water heater controls also changes the cycle times, with higher temperatures leading to shorter off-cycle behavior to maintain a higher average temperature. The lower-power heating elements also solved a dry-firing error that occurred upon startup of the model when the water heater controls were coupled with the higher-power elements. Because the higher-power elements resulted in very rapid heating of the elements and thermostats, the dry-fire error triggered shutdown of the unit, consistent with the water heater controls’ design to prevent heater operation when the water tank is empty.

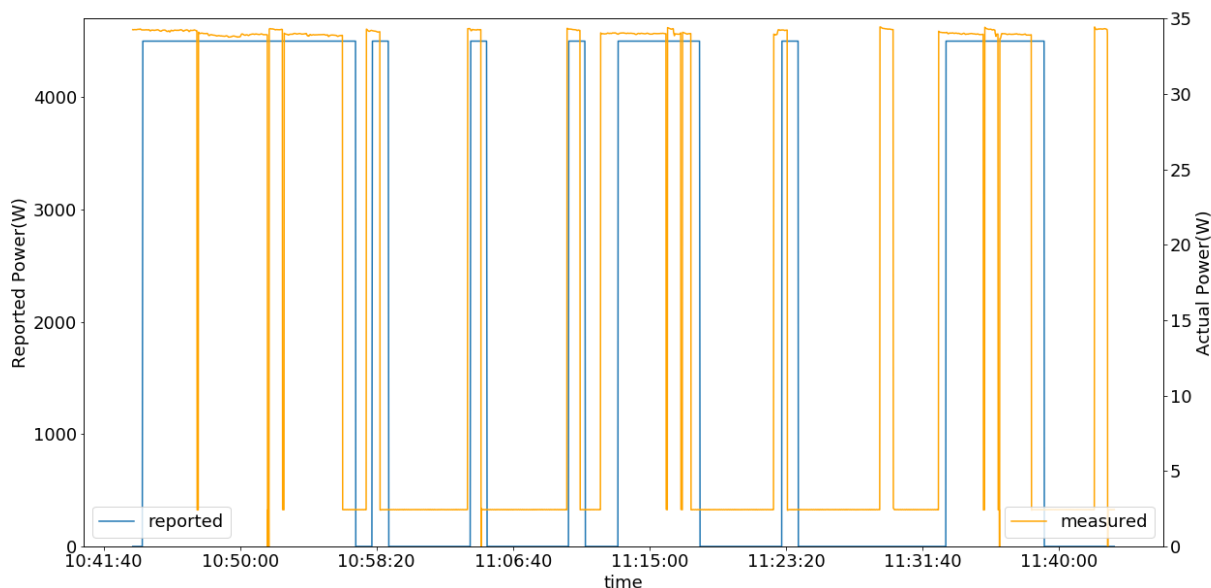
The controls used were from an A. O. Smith ProLine® XE Electronic Display Model water heater, which has a .95 Uniform Energy Factor, is grid management capable (through the CTA-2045 module), and has multiple operating modes. An Intwine CTA-2045 AC Universal Communication Module (UCM) was used for communications; this connects to the Intwine Gateway which exposes a REST endpoint (over Wi-Fi) for the communication. For static data, it reports only a device type of electric water heater (according to the CTA-2045 enumeration). Other static data reported are about the module itself. Integration was not difficult, as REST interfaces are easy to use.

The water heater estimates energy used based on its knowledge of how much power each element is supposed to be using. It does not include in the estimate the energy use of the controls themselves, which is about 2.4 W, typically. In addition, the estimate is only updated to the CTA-2045 module once a minute.

Figure 11 shows the data reported by the CTA-2045 module and the measured power. The data are scaled to have the peaks nearly match; the actual power is from the representative prototype, whereas the estimated power is on the level of an actual water heater. The heater operates by having only one element on at a time and assumes that both elements consume the same power level. The power data do show transitions between the two elements with the brief drops in power and slight differences between the two elements (one is slightly lower and more variable than the other). It appears that the water heater controls only periodically check to see if an element is on or not. For long cycles, and on average, this is fine, though for the short cycles, it can miss one entirely, as occurs twice in the figure. The reported data also lag the measures due to this periodicity. The reported data also do not include the power of the controls (just over 2 W, very low power, compared to the 4,500 W when an element is on).

The device does accept some grid control signals through the module.

Figure 11: Water Heater Power Data (Orange) and Reported Power Data (Blue)



Source: LBNL

EVSE

The technical term for an electric vehicle charger is electric vehicle supply equipment (EVSE). These vary in capability and complexity, but some models can communicate, primarily for grid coordination. The Siemens Level 2 charging station for residential and light commercial applications was determined to be suitable. The research team obtained one from the manufacturer (Figure 12).

Figure 12: Siemens Company Logo and EVSE



Source: Siemens, Laura Wong

The EVSE uses 230 V input power, which is unlikely to be available in places where LBNL would be demonstrating the energy reporting technology (an EVSE that uses only 115 V power is much less likely to have communication capability). For this reason the team constructed a power supply to convert regular 115 V power to 230 V and provide a 50 A, NEMA 6-50 2-Pole/3-Wire outlet matching the 50 A cord and plug that comes with the EVSE. The LBNL setup is only

capable of providing low power levels, e.g., less than 100 W, not the many kilowatts that the EVSE can normally provide, due to the size of the transformer we used. Part of the needed hardware is a “vehicle simulator” to take power from the EVSE; this has been done with an EVSE test device (from Clipper Creek) with added load in the form of light bulbs, to have power flow through the unit that can be measured and reported. The EVSE has a minimum power level of about 50 W for which it will report, so the bulbs need to draw more than that. Values below that level are suppressed and reported as zero, as a vehicle usually would never draw such a small amount. The EVSE can deliver up to 7.2 kW (notably almost 10 times the average power consumption of a California residence). Data comparing the measured and reported values are shown in Table 6. Graphs of the two values for each mode are nearly flat and so not included.

Table 6: EVSE Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Adjusted Measured	Absolute Difference (W)	Relative Difference (%)
No Load Plugged In	0	8.93	—	—	0
Plugged In No Charge Requested	0	10.63	0	0	0
80W Load	72.93	102.17	71.24	1.69	2.4
120W Load	94.29	135.60	93.17	1.12	1.2

Note: The Adjusted value subtracts the 10.63 baseline EVSE consumption as well as measured transformer losses at the different load conditions (31.8 W for the 120 W load, 20.3 W for the 80 W load). The Difference columns are relative to the Adjusted value.

“No Load Plugged In” is the state with the EVSE cord not connected to anything, and so include at least the processor, communications, indicators, and safety electronics.

“Plugged In No Charge” is the state with the EVSE plugged into the vehicle simulator when the device is not requesting any charge. This adds power for (less than 2 W) for the EVSE to confirm that the plug is connected (necessary before it will allow current to flow), to indicate this with the green 'halo' indicator light, and some power for the vehicle simulator.

“120W Load” is the state with the EVSE engaged in charging with 120 W of nominal load (two 60 W incandescent lamps connected in series to the probe sockets of the vehicle simulator). The Clipper Creek device consumes slightly more power in this mode, including for a resistor and indicator.

“80W Load” is similar except using two 40 W bulbs.

The EVSE reports only power delivered to the vehicle and does not include its own consumption or even wire losses in the cord. This is different from our purpose but not unreasonable. Thus, the Adjusted Measured value subtracts the 10.63 measurement with no load applied. In addition, our power measurements are upstream of the transformer and so include losses converting 115 V power to 230 V power. We took spot measurements and determined that for our 80 W and 120 W loads respectively, the transformer losses were 20.3 and 31.8 W. These

amounts were unexpectedly high and also help account for the large difference between the measured and reported values. The Adjusted Measured column in Table 6 subtracts these values from the measured. With these adjustments, the remaining difference between reported and measured is quite low, and the actual power delivered is likely even more accurate than that, as the Siemens device has revenue-grade hardware inside of it.

While the power at LBNL is anomalously high, the voltage out of the transformer is just over 211 V at 130 W of load, almost 10% below the nominal 230V power. This lower voltage likely accounts for the draw of the lamps being considerably lower than their nominal power rating.

The research team has connected to the EVSE via the CTA-2045 module (and from Intwine, but a DC-powered unit). It also uses the same REST API interface as the water heater module.

For static data, the module the team used reports some data about itself, but only a vendor-assigned device type for the EVSE. Other modules, including one from the manufacturer, report substantially more static data about the EVSE. The CTA-2045 module does provide for some control capabilities, but not price-based control. The Intwine CTA-2045 DC Universal Communication Module (UCM) receives these signals. The UCM connects to the Intwine Wi-Fi and exposes a REST endpoint to report power and energy.

The test measures the 115 V input power, and so includes the conversion losses from converting 115 V power to 230 V power; the meter used can take in up to 500 V. The project team estimates that the transformer adds about X W at no load and about XX percent of efficiency loss for load.

The EVSE measurements are optimized for the high-power levels of automobiles, so may be considerably less accurate at the low-power levels tested here, and may not account for the electricity use of the EVSE itself.

Thermostat

The Venstar Colortouch Model T7850 (Figure 13) is a thermostat designed for the residential market. It communicates over Wi-Fi but does not implement energy reporting. It can be queried over the network for its status (heating, cooling, or neither), and the management system uses the data to infer power levels and compute estimated energy use. A purpose of including this device in the demonstration was to show that many existing devices that do not implement energy reporting directly can still be brought into the energy reporting context.

The thermostat implements a REST API developed by Venstar that is then transmitted over a Wi-Fi link. It can be controlled over Wi-Fi by setting the setpoint and mode.

The Venstar reports no static data. Since the unit is not directly reporting energy or power, no accuracy measurement is applicable.

Figure 13: Venstar Company Logo and Thermostat

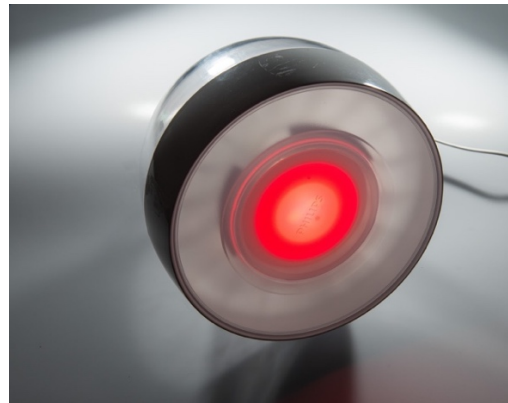


Source: Venstar

Hue

The Philips (now Signify) Hue light bulb (Figure 14) is similar to the Venstar thermostat only in that it reports status data (in this case, a brightness level).

Figure 14: Philips Company and Product Line Logos and the Product



Source: Philips (now Signify), Laura Wong

Communicating with a Hue bulb requires a Hue bridge. The bridge communicates with the bulbs via Zigbee, then relays data to the wider network over Ethernet (in this case, to the Intwine gateway via Ethernet). Communication from the bridge is via a REST API. Setting up the bulb requires a phone app, which also offers control capabilities. The Hue reports manufacturer, model, unique ID, local identity, device type (a different enumeration from ours), MAC address, and firmware version. Table 7 presents the accuracy evaluation.

Brightness varies on a scale from 0 to 100. The following equation is used to estimate energy (on_state is one for on and zero for off):

$$\text{Power (W)} = (0.000442 \times \text{brightness} - 0.00009 \times \text{brightness} + 1.89) * \text{on_state}$$

This formula is based on the measurements in Table 7, so the calculations are somewhat circular. To be more realistic, the above equation was determined based on three data points (the minimum, 50 percent, and 100 percent levels), determined a nonlinear regression that fit those three points, then used that for a greater number of points, as in the table.

Table 7: Hue Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
Off	—	0.43	—	—
Minimum brightness	1.90	1.89	0.01	0.32
20% brightness	2.06	2.07	-0.01	-0.24
30% brightness	2.27	2.29	-0.01	-0.53
40% brightness	2.58	2.59	-0.01	-0.43
50% brightness	2.95	2.99	-0.04	-1.39
60% brightness	3.42	3.48	-0.06	-1.64
80% brightness	4.66	4.71	-0.05	-1.14
100% brightness	6.23	6.30	-0.08	-1.20

Note: The Hue lamp color was set to white for the tests.

Dimmer Switch

This product—a dimmer switch suitable for lighting (Figure 15)—has both the GE and Jasco brand labels. In this case it appears that Jasco is the manufacturer and GE the brand. It can communicate with Zigbee and so be remotely controlled, and also implements energy reporting, using to the Metering (Smart Energy) cluster of the Home Automation Profile of Zigbee (the same cluster the RAD uses [NXP 2015]). The switch only reports energy, not power. The LBNL management system calculates average power for each period based on the energy value.

The switch of course is not an end-use device, but would be used to control non-communicating lamps. It operates like an external meter, but while an external meter is additional hardware to buy and install, the dimmer switch is hardware required for any such lamp application, though a non-communicating version could be used instead.

For safe and easy use, the dimmer switch was installed into a standard electrical box with a standard electrical outlet downstream of it so any 110 V AC device can be plugged into it.

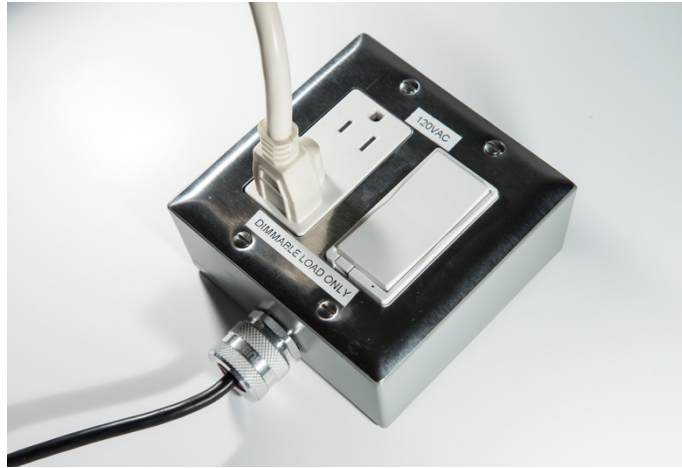
For static data, the switch reports manufacturer and its local identity (Zigbee address).

For control, the dimmer switch can be controlled manually or scheduled, and can control the on/off status and brightness of attached lighting (or another device, though only a few other devices are suitable for a dimming control).

For accuracy testing, three loads were used: a 9W LED bulb, a 50W incandescent bulb, and a 200W incandescent bulb. The dimmer switch does not report instantaneous power, but only accumulated energy use. The report rounds to the nearest tenth of a Wh (which for reference at \$0.10/kWh is one thousandth of a cent of electricity) and so at the low 9 W load only

increments this about every 35 seconds. At higher loads, it increments proportionally faster. To assess accuracy we took the difference between in energy between the first and last energy values when the report increased from one period do the next and compared it to the comparable accumulated energy value.

Figure 15: General Electric and Jasco Company Logos and the LBNL Device



Source: General Electric, JASCO, Laura Wong

As shown in Table 8, except for the 9 W load, the reports are quite accurate. In addition, it is quite likely that the measurement does not include the energy use of the switch itself, and a difference of about half a watt would make the absolute and relative differences smaller, particularly for the 9 W load. Thus, the dimmer switch performs very well.

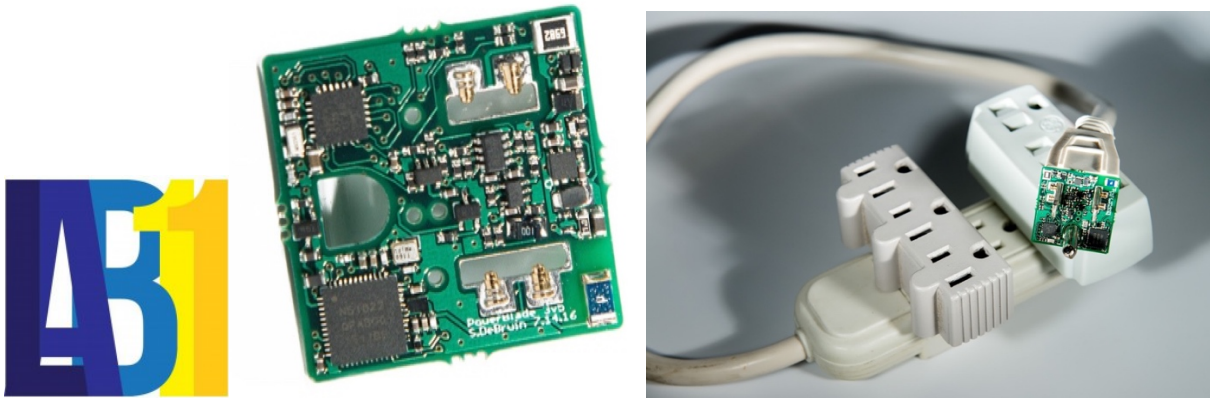
Table 8: Dimmer Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
Off	9.9	10.6	-0.75	-7.1
Minimum brightness	56.7	57.0	-0.28	-0.5%
20% brightness	216	216.8	-0.79	-0.3%

PowerBlade

The PowerBlade (Figure 16) is the smallest, lowest-cost, and lowest-power AC plug-load meter that measures real, reactive, and apparent power and power factor. It reports these data, along with cumulative energy consumption, over an industry-standard Bluetooth Low Energy (BLE) radio (DeBruin et al. 2015). It is produced by Lab11, which is a joint effort between the University of Michigan and University of California (UC) Berkeley. One of the key people in Lab11 also has a research appointment at LBNL.

Figure 16: Lab11 Logo and PowerBlade Photos



Source: Lab11, Laura Wong

The PowerBlade does not have knowledge of any static data of the device it is measuring, so it does not report any, and offers no control abilities. It also does not report on its own static data. For more information about the device see: <https://github.com/lab11/powerblade>.

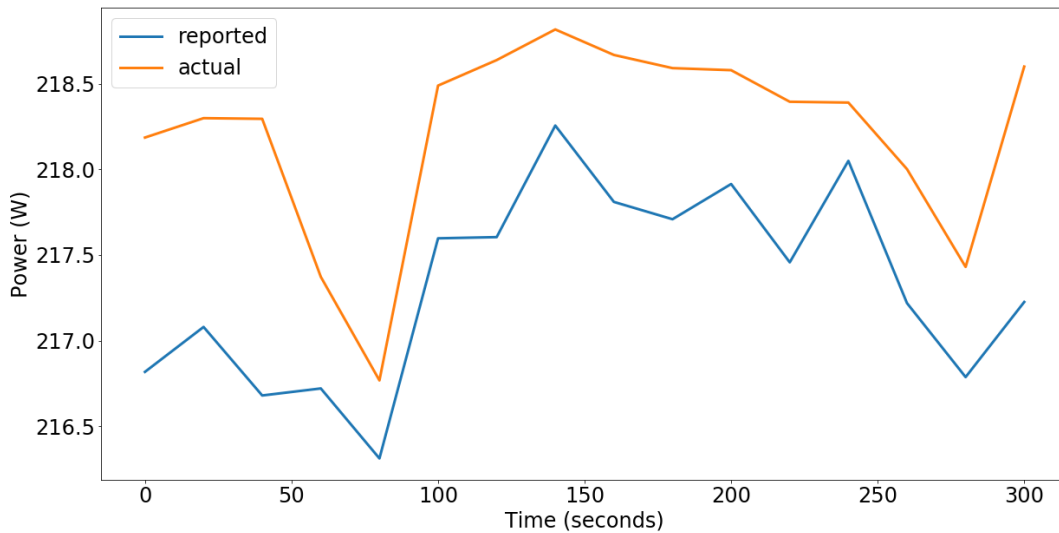
The PowerBlade was tested with light bulbs of various power, as shown in Table 9. Figure 17 shows time-series data for the 200 W nominal measurement. The y-axis does not have a zero origin, so this highly exaggerates the difference between the reported and measured values. The variation in the load power is reflected in the reported data. When examined at 1-second intervals, the PowerBlade data show a lot of noise in the data, as much as 3 W above and below the actual, but when averaged over longer periods (20 seconds in this case), most of that variation disappeared.

Table 9: PowerBlade Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
25 W LED bulb	25.5	25.6	0.05	0.2
60 W Inc. bulb	64.3	64.4	0.1	0.1
200 W Inc. bulb	217.3	218.2	0.9	0.4

Note: Inc. = incandescent

Figure 17: PowerBlade Power Data (Orange) and Reported Power Data (Blue)



Source: LBNL

Wemo

The Wemo Insight Wi-Fi Smart Plug (Figure 18) is installed between an electrical outlet and a device that is to be monitored and/or controlled. It uses Wi-Fi for communication, either to a dedicated phone application or (in this case) to software on LBNL's management system.

Figure 18: Belkin and Wemo Logos and LBNL's Device



Source: Belkin, Laura Wong

For static data it reports manufacturer, brand, model, unique ID, local identity, MAC address, and firmware version.

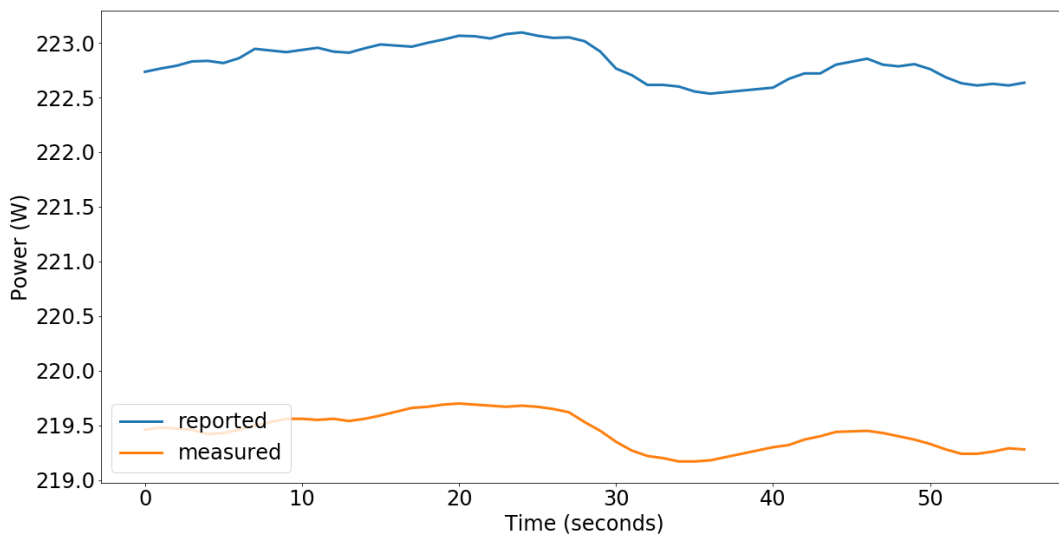
The Wemo was tested with light bulbs of various power, as shown in Table 10. Figure 19 shows time-series data for the 200 W load. The y-axis is not zero-origin. so that the difference is highly exaggerated. The difference between the two values is almost constant.

Table 10: Wemo Accuracy Evaluation

Mode/Level	Reported Power (W)	Measured Power (W)	Absolute Difference (W)	Relative Difference (%)
11 W LED bulb	10.2	11.8	1.7	14.1
50 W Inc. bulb	58.1	58.6	0.5	0.8
200 W Inc. bulb	222.8	219.5	3.4	1.5

Note: The voltage at LBNL is unusually high, leading to higher power values for incandescent bulbs.

Figure 19: Wemo Power Data (Orange) and Reported Power Data (Blue)



Source: LBNL

Intwine

The Intwine Gateway (Figure 20) is an infrastructure device for the LBNL demonstration setup. It connects Ethernet, Zigbee, and Wi-Fi; it is a Wi-Fi router. It also has cellular connectivity, which is not used during the demonstration (since reporting is all local) but is used for some device initialization. Additional software was installed in the gateway for passing Zigbee commands over Wi-Fi. While the gateway provides Bluetooth connectivity the management system obtains Bluetooth data directly from a dongle attached to the MacBook PC on which it operates.

Figure 20: Intwine Connect Logo and the Gateway



It would not be difficult to add energy reporting capability to the gateway itself, based on estimating power. The power of the gateway is fairly constant, but should vary modestly with the number of communication interfaces active.

Generic Issues

The LBNL experience with these devices raised several issues that could apply to a wide number of device types.

The first is an insight about the ability to report data that are outside the scope of energy reporting but are still useful for energy purposes. Ambient temperature and room occupancy are the premier examples of this. An increasing number of devices have such sensors for their own purposes, or just because they are so easy to include. Attaching the sensor to an end-use device is extremely convenient, as it avoids the need to buy, install, power, and maintain a dedicated sensor. The RAD controller added a temperature sensor for the demonstration at very low cost (the communication input for it on the processor board was already present and unused).

The second type of generic issue is tracking the energy used in low-power modes, such as for a PC in *sleep* or *off* modes. In this case, a software application is running, and this would not operate in either low-power mode. The software could observe the time the PC went to sleep or turned off, and the time it resumed operation, and note for each if it was powered from the mains or from the battery. This way it could estimate energy use during the low-power time. The battery state of charge also could be interrogated to further give evidence of whether it was mains-powered or on battery during the low-power time, or some combination.

Conclusions about the Devices

The LBNL selection of devices well-addressed the criteria for choosing them. Several of them are high energy-consuming devices: water heater, EVSE, and thermostat (for the heating and cooling equipment it controls). A few of the devices are large, but transportable, but many are quite small, easing their transport. The collection has a wide variety, including HVAC, lighting, appliances, vehicles, electronics, and external meters (the scope of work explicitly noted

covering the latter). Only one device studied (the Hue light) requires Internet connectivity to start operation, and none do for ongoing operation. Some devices performed two roles in that they report on their own energy use and also are measured by external meters. Finally, in three cases, private companies were contracted with to modify their own devices.

Standard application-layer protocols are very helpful in easing integration. For the devices, Zigbee was the most prominent in this regard. For IP communication, REST APIs are particularly easy to use, and would be even easier if the content were standardized. It would be possible to use the data elements directly with a REST API, though this would go against the goal to not create a new protocol. A REST API is a specific method of using the HyperText Transfer Protocol (HTTP) for exchanging structured data in a simple and reliable way. Because HTTP by default moves ordinary text data, has a simple structure, and is widely implemented, this is a convenient way to exchange data, and is straightforward to document and implement.

Perhaps the least successful part of the demonstration was communicating static data. This is ironic, as it is considerably easier to implement communications for static data than for dynamic data. Part of this problem was due to shortcomings in the protocols, in their lacking all the fields in the data model used. However, even when fields were available, devices often did not populate them with data.

The accuracy tests showed results that varied widely with each device. Most perform quite well. The goal was accuracy within 10 percent of the actual consumption, and in the cases where devices are outside of those bounds, it is clear how to bring them within this limit or the absolute differences are very low.

Overall, the tests on this study's collection of devices presents compelling evidence that energy reporting is feasible to include in products, not burdensome on manufacturers to do so, and provides data of sufficient accuracy to be useful for building owners.

CHAPTER 3: Energy Reporting Standards

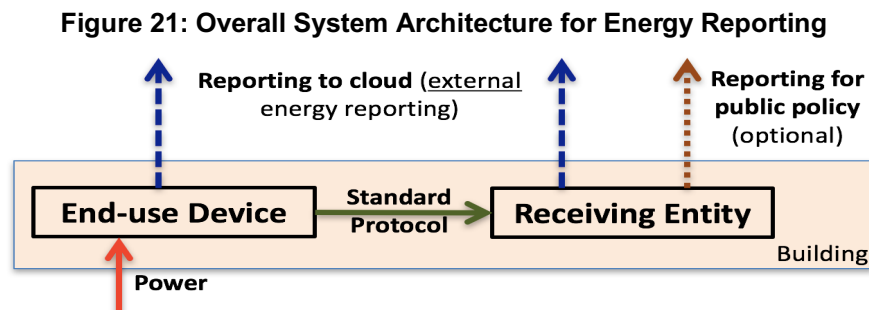
This goal of this portion of the project was to develop a draft protocol structure and data model for energy reporting, circulate the structure and model for review and comment among interested parties, and describe how the data model works with key communication protocols.

A key goal of the overall project on energy reporting is to make sense of the scattered landscape of relevant communication protocols. Compared to what is needed, most protocols are incomplete, ambiguous, and/or inconsistent. Working towards consistency and coherence is a long-term project; this project only began it. However, a core of clear, comprehensive, and consistent descriptions of how to create and use relevant protocols will spur the spread of energy reporting and help reinforce the goals of the technology. In addition, it is recommended that all implementers of management systems use the data model; this will make such systems more interoperable with each other, with other software, and be more consistent for people who use more than one such system.

This chapter is organized as follows. It begins with a review of the system architecture of Energy Reporting as advanced in this project, and how the project team assessed communication protocols. This is followed by an explanation of the role of data models in general and our reference data model in particular. Each of the elements in the energy reporting data model is discussed in detail. Then select important protocols are reviewed for how they support the energy reporting data model. The chapter finishes with conclusions.

Background

This section addresses the topic of how information moves from the reporting devices to a management system that collects the data, and how it is stored in the management system. Figure 21 shows the energy reporting's overall architecture.



Source: LBNL

Any system for communicating among devices or other entities needs to ensure that the data can be organized and understood both consistently and correctly. This requires standards or a locally determined internally consistent naming convention (essentially a local standard). This section focuses on the mechanisms by which data are represented and named. For any collection of devices, a consistent shared language is needed. For general interoperability,

the ideal is to have a single universal language, or standard. If that is not possible, there should be as few standards as possible, with clear correspondences, translations, and linkages among them.

Most of the data elements this project sought to address are within devices and can be divided into two groups: (1) data inherent in what the entity is (set at the time of product manufacture), or (2) data that are determined locally (set at the time of installation, or after).

Other areas of research inform standard data models. Key are user interface standards for energy-using devices (e.g., electronics power control and lighting). User interface standards comprise concepts that will be represented in device data models and used by humans in controls. For example, lighting controls may include “brightness levels” and terminology around color temperature of white light. It is helpful if concepts in user controls and data models correspond directly to each other, and it is preferable to adapt device technology to what works best for humans rather than the other way around. That is, concepts from user interfaces should be adopted by data models when feasible (Nordman 2017). Other research also addresses standard data models, e.g., recent work on data models needed for lighting (Brown et al. 2019). Finally, LBNL’s work on energy reporting, such as the Energy Reporting Framework (Nordman 2013), extends back to 2010.

Implementing a common data model will mean that device-level data can be brought into a unified platform, with standard names and fields. A consistent data model not only facilitates the analysis and interpretation of device-level data in the individual building, it also creates a consistent standard across the building sector for measurement and reporting.

A mechanism for reporting energy data exists within an overall system architecture that defines the relevant devices and their roles and capabilities. This structure and the data model used within it are not independent—they determine each other. Below are described some key aspects of the system. For example, one design principle underlying this architecture and the proposed data model is simplicity. Simplicity enables easier system implementation, makes it more likely that device manufacturers will incorporate the feature, more likely that users will use energy reporting, and more likely that devices and management systems will easily and automatically interoperate.

Another feature of this architecture is putting all the burden of tracking time-series data on the management system, not on the end-use device. This also makes coordination between the end-use device and the management system much simpler and easier.

An information model is an abstraction and representation of the entities in a managed environment, their attributes and operations, and the way that they relate to each other. It is independent of any specific repository, software usage, protocol, or platform (Westerinen et al. 2001). A data model is an implementation of the information model within a specific context or protocol. So, for example, a light with its attributes (e.g., color, brightness, power rating) can be encoded into an information model, but without specifics of the representation or encoding of these characteristics. A data model implementing this would include units of measurement for power, scales of brightness, and one or more mechanisms for specifying color.

This report describes how the underlying data models of various protocols that are relevant to energy reporting compare to the energy reporting data model (ERDM) data model used in this study. This model name and abbreviation are not necessarily intended to be the long-term name or abbreviation for it, but they are highly practical for this report. One thing to note is that even though information models and data models serve different purposes, it is not always possible to precisely define what information is needed. There is a gray area where an information model and data model overlap.

Definitions

A standard terminology is a prerequisite for a common language to describe entities in a building, methods for representing data in general, and syntactical conventions. The definitions below extend across all topic areas:

Energy reporting: The ability of an individual device to report on its own energy use and related data to the local network (Nordman 2013).

Data model: A mapping of the contents of an information model into a form that is specific to a particular type of data store or repository. A “data model” is basically the rendering of an information model according to a specific set of mechanisms for representing, organizing, storing, and handling data. A data model has three parts:

- A collection of data structures (e.g., lists, tables, relations)
- A collection of operations that can be applied to the structures (e.g., retrieval, update, summation)
- A collection of integrity rules that define the legal states (set of values) or changes of state (operations on values) (Westerinen et al. 2001)

Device: An energy-using entity that has an “atomic” relation to the building—it is attached or detached as a unit, such as a device with an electrical plug.

Component: An identifiable part of a device that cannot be operated separately from the device as a whole (e.g., an internal fan, data storage element, or product display).

Methodology

The project team first surveyed existing standards with the objectives of understanding what has already been developed and identifying research gaps that must be addressed before a complete data model could be described. Then, using this analysis, the team created a list of topics necessary to include in a standard data model for energy reporting. Finally, the team examined existing standards for how they addressed these topics for relevant information; analyzed them for consistency, coverage, and quality; and made recommendations for best practices and where further research is needed.

The core purposes of the investigation were to determine:

- Types of information to be represented, in general.
- Specific data elements to include.

- Names for those data elements.
- Data encoding (e.g., units, enumerations)

This report builds on an earlier LBNL report (Nordman and Cheung 2016). Several of the standards/data models in that study were dropped, some were retained, and new ones were added. This study also updated the draft model from the earlier report based on research and experience since that time and consultation with stakeholders.

Energy Reporting Data Models

The standards reviewed below are mainly application layer protocols and data model standards. Their purposes are diverse, ranging from dynamic building operation to energy program evaluation to scientific information exchange, and more. Due to this diversity, some of the standards have explicitly designed data models, while others only have ad-hoc defined elements that could potentially constitute a data model.

The general topics (collections of data elements) in Table 11 cover the range of information needed or useful in accomplishing energy reporting. Data are static if they rarely or never change, and dynamic if they are potentially different each time the device is queried. For example, the manufacturer name is static, and the location is also static for most devices, once placed, though it could change. The accumulated energy use will almost always change with each query.

Several items were added to the data model in the course of this research. First was to include data elements for accuracy of the energy reports. Also added to the model was the time of last change to the static data, as a way for a management to easily know when to requery all of the static data by querying this one data element. Only when that changes is there any point to requery the rest of the static data. For some devices the static data will never change (if it does not know potentially varying elements like location, or the device does not change location). It is helpful to have two ways to categorize the data elements; the specific topics can be grouped into larger, more general topics (the specific ones sometimes have just one data element each). See Table 11.

Table 11: Core Energy Reporting Topics

	General Topics	Specific Topics
Static	Identification	Unique Identification
		General Identification
	Local Data	Local Data
	Accuracy	Accuracy
Dynamic	Energy Reporting	Energy Reporting
	Other Data	Location
		Power State
		Static Power Data

Accuracy in measurement devices is commonly characterized as a percentage of the range of the measuring device plus a percentage of the actual value read. These two items were included (as fractions, not percents), plus the necessary size of the range. However, what many people will ultimately be interested in is the ultimate result for annual energy use, so a data element for that purpose was added. In addition, some devices may have accuracies that do not map well onto the range/reading characterization, so the annual integrated result is helpful (those that estimate power and energy may particularly benefit from this approach). For devices with range reading values, the annual value can be calculated.

The final data model, shown in Table 12, includes two items that are not actually part of energy reporting but are generally useful to know in a building: temperature and occupancy. Like energy reporting, these are not necessarily associated with the particular type of device that is reporting the information. Some devices may have internal reasons to know these values; others may not need them but provide them based on the fact that they are useful to know and adding them to the device may cost little or nothing. Aggregating these across a building or part of a building can be informative and contribute to saving energy, hence their inclusion here.

For control, some protocols that implement energy reporting allow for reporting the power state of the device, and some of these provide for setting it. Many other types of controls exist in protocols, but these are not directly tied to the ERDM. A key is that the ERDM model is independent of any particular details about the type of device or system that is reporting; most controls, such as a temperature setpoint or light brightness, are device-specific.

Another mechanism that is not device-specific is the current price of electricity. Some protocols can send the price; in this demonstration two devices were sent prices via Zigbee and one received a price via text over Wi-Fi. Price is not a property of the reporting device, but is similarly useful for general energy purposes in the way that temperature and occupancy are, so it is also included in the ERDM. A key point about all ERDM fields is that they are not related to the functionality of the device itself, but rather ones that apply to all devices.

Energy Reporting Data Model Element Review

This section discusses each element of the energy reporting data model (ERDM), and how to use and not use it.

Many data elements are text. Conventionally, text was just ASCII, but increasingly the Unicode standard is used to encode additional characters, particularly in other languages. The ERDM assumes that strings are ASCII. Unicode has several formats for encoding it into ASCII, such as UTF-8. Any Unicode data could then be translated between these.

Some protocols or databases have limits on the length of a particular string. Presumably these are long enough to cover the most important information for a data item.

Keyword/value pairs are used for data elements of varying or indeterminate format. These are to be a list delimited by an equals sign (“=”) between the keyword and value and a semicolon (“;”) between pairs.

Table 12: Detailed Energy Reporting Values (Black - Highest priority; Red - Medium; Blue - Lowest)

	Data Type	Comment
Static Data		
Identification		
Universally Unique Identity (UUID)	uuid	128 bits (16 bytes)
LocalIdentity	Text	list of "keyword=value;" e.g., IP address or MAC address, serial number
Manufacturer	Text	name of manufacturer, generally without suffix (e.g., Inc.)
Brand	Text	name of brand if different from manufacturer, otherwise empty
Model	Text	model number/name
IdentityGeneral	Text	list of "keyword=value;"
URL	Text	
DeviceType	Enumeration (0..92)	Universal Device Classification (Nordman and Cheung 2013)
Local Data		
LocalName	Text	locally determined name
LocalOtherInfo	Text	list of "keyword=value;"
LocationLocal	Text	list of "keyword=value;"
LastStaticDataChangeTime	Float or Text	Unix time or RFC 3339 time
Accuracy		
RangeMax	Float	Maximum power value in W
AccuracyRange	Float	Accuracy as fraction of range
AccuracyReading	Float	Accuracy as fraction of value
AccuracyTypical	Float	Accuracy as fraction of typical energy use
Dynamic Data		
Energy Reporting		
PowerLevel	Float	current electrical power in W
CumulativeEnergy	Float	accumulated energy use in Wh
Other Data		
TimeStamp	Float or Text	Unix time or RFC 3339 time
PowerState	Enumeration (0..5)	
Temperature	Float	Current temperature in Celsius
Occupancy	Text	list of "keyword=value;"
Electricity Price	Float	Index to typical price of electricity (typical=1)

Static Data Elements

UUID

A UUID is a “universally unique” identity, and is best defined in RFC 4122 (Leach et al. 2005). That said, using another method to generate a UUID is almost certain to work fine, since the key is for the item to be unique. How the UUID is generated does not need to be communicated or standard.

LocalIdentity

This data elements works best if the keywords used are as standardized as possible. Standard keywords proposed are:

- “IP” for an Internet Protocol address; conveyed in the standard text format of nnn.nnn.nnn.nnn for IPV4, with each of the four values in decimal and leading zeroes omitted, and hhhh:hhhh:hhhh:hhhh:hhhh:hhhh:hhhh:hhhh for IPV6 where each “h” is a hexadecimal digit.
- “MAC” for a MAC (Medium Access Control) address; in the standard format of hh:hh:hh:hh:hh:hh, where each “h” is a hexadecimal digit.
- “SN” for a Serial Number. This should be conveyed as closely as possible to what the manufacturer specifies in terms of punctuation, spacing, capitalization, etc., except that spaces should be replaced by underscores to avoid possible parsing errors.

This does not prevent other keywords from being used, and the standard set may expand over time. An example of this field could be:

```
SN=RTR45343;OWNER=Jackson
```

The data elements are not quoted, as spaces are to be translated to underscores when bringing data into the ERDM.

Manufacturer

This is the name of the manufacturer, as commonly recognized (that is, not a holding company if not widely known that way). It is recommended to omit the suffix (e.g., Inc., Corp., LLC, GMBH, etc.) as these are likely to be not known or reported inconsistently. For companies with widely known abbreviations (e.g., GE, IBM, or HP) there can be a question of whether the full name or abbreviation should be used. In the absence of a better guide, it is recommended to follow the lead of Wikipedia in deciding whether to use the name or the abbreviation. In most cases it should be the manufacturer itself setting the value, in which case it can be consistent across products.

Brand

Many products do not have a brand distinct from the manufacturer; in this case, this field is empty.

Model

A model number or name should be rendered as closely as possible to the manufacturer's usage, such as the use of dashes, capitalization, and spaces. Spaces should be replaced by underscore characters. In most cases the manufacturer itself should set the value, in which case it can be consistent across products. Some products have two model numbers with the second one more for internal use; in these cases the second one should go into the IdentityGeneral field.

IdentityGeneral

This field is a collection of additional keyword/value pairs to encode additional information about the device's identity in a general sense. This is information known about the device at the time of manufacture.

URL

Manufacturers should provide a URL to a web page of both human and machine-readable data about the product. Such a page should include a wide variety of information, with energy just a portion, but the energy data should include test procedure results, modal power levels, and information about compliance with energy standards, both mandatory and voluntary. The format of this page should be standardized for both parts.

DeviceType

Universal Device Classification (Nordman and Cheung 2014) is an enumerated list of just over 90 device types. This provides a simple standard mechanism to identify and categorize devices.

LocalName

The LocalName is created locally to provide context-specific identification, e.g., "Bathroom Light" or "Second Floor Printer." This is to be relayed or constructed from communicated data or manually entered into a management system.

LocalOtherInfo

Other types of information are highly local. An example might be a company equipment ID or date of last calibration. This is to be a set of keyword/value pairs.

LocationLocal

Location within a building is not a well-defined characteristic, ranging from a latitude/longitude value to a named room. As such, it is a list of keyword/value pairs. Over time, specific standard ways of describing local location should be identified with particular keywords.

LastStaticDataChangeTime

This field should start by being set to the time of product manufacture. Then it should only be updated when any of the static data elements change. For some devices, it will never change.

RangeMax

Accuracy of power values can be described one of two ways—or both can be used. The first is a combination of the maximum range of power values (RangeMax), the fraction of this range as it contributes to accuracy (AccuracyRange), and a fraction of the actual value (AccuracyReading). Accuracy of an individual power value can then be computed from these three values as:

$$\text{Accuracy} = (\text{RangeMax} * \text{AccuracyRange}) + (\text{Reading} * \text{AccuracyReading})$$

Where AccuracyRange and AccuracyReading are fractions and RangeMax is in W.

AccuracyRange

See RangeMax.

AccuracyReading

See RangeMax.

AccuracyTypical

The second characterization of accuracy is as a percent of typical annual energy use. This would typically be the sum effect of all the individual average power measurement accuracies that go into the total, so if a device consumes energy in a pattern markedly different from that which is typical, then it might have a different annual accuracy. An accuracy value can be accumulated over time as the sum of the individual power accuracies to reflect the accuracy of the accumulated energy value. This field could be static or dynamically updated by the device.

Dynamic Data Elements

PowerLevel

The power level is the instantaneous power being consumed by the device. Thus, the CumulativeEnergy field may not match the sum of power levels observed.

CumulativeEnergy

The total energy consumed by the device, usually since product manufacture. Occasional resets to zero are considered OK as they can be readily recognized by the management system.

TimeStamp

In general, the TimeStamp is not to be reported by end-use devices; rather it is recorded by a management system when a reading is registered. This avoids the need for end-use devices to have time-tracking synchronized with the management system. If a management system reports data externally to the building, or to another local management system, then TimeStamps would be included, as the data are not necessarily in real time as they are from end-use devices.

PowerState

PowerState in ERDM is a limited enumeration of possible power states. Some standards have much more detailed rendering of power states (e.g., EMAN) and others have only *on* and *off*. The ERDM enumeration includes Unknown, Off, Sleep, On, Ready, and Active. Electronics commonly use the set Off, Sleep, and On. Appliances are commonly Off, Ready, or Active.

Temperature

The temperature corresponding to the timestamp is recorded in Celsius. This is instantaneous, not an average over the interval in the way that power is.

Occupancy

There is no common standard for how to convey occupancy data, so this field provides for flexibility, with a set of keyword/value.

Individual Standards

This section reviews how to integrate several key standards for energy reporting with the ERDM.

CTA-2047

CTA-2047 (CTA 2014) is designed solely for energy reporting. It is only loosely associated with CTA-2045. It “provides an Information model that specifies the minimum requirements for consumer electronic and other networked devices to communicate Energy Usage Information (EUI) over a LAN.” (CTA 2014) It covers both measurement and estimation as sources of the data and covers several items outside the scope of the ERDM including run time and expected energy usage by mode.

CTA-2047 organizes the data elements into groups differently from the ERDM; this only affects presentation and does not affect their meaning.

CTA-2047 includes fields not addressed by the ERDM. These include: PowerValue (“Published power and/or energy value[s] [per industry or regulatory standard]”); EnergyStar (whether it meets an ENERGY STAR specification, and if so, what version of it); and StoredEUValue (“Human and machine-readable value[s] of EU stored for use in calculating EUI for each operating mode”). How precisely to apply these is not specified.

It also has a set of variables for externally defining time intervals over which the device should track energy. It also supports tracking the last time the device was turned on or off, though these are designed for external controls (e.g., a timer) that might not know the power consumption level of the attached device.

The standard identifies a sign convention in which positive values reflect power or energy used, and negative values are used for power or energy supplied.

Identification

CTA-2047 has a field for a “UID,” which is to be a “Human and machine-readable device unique identifier.” The UUID that the ERDM specifies fits this, when encoded into a human-readable form. Conventionally, UUIDs are written in text as hexadecimal, with the alphabetic values in lower case. Doing this would make such UUIDs both human and machine readable. Thus, the recommendation is to use a UUID for the UID field, and encode this as ASCII text.

CTA-2047 puts manufacturer, brand, and model all into one data field, along with version and serial number. Specifically:

“Human and machine-readable make (brand)/, model/model number, version of CTA-2047, Serial Number (inclusion of a Serial Number is optional)”

It is suggested that those who use CTA-2047 put a single space between each of these so that the spaces can be used to divide up the string. For translating these three fields from ERDM back to CTA-2047, any spaces should be replaced with the underscore character (“_”). Thus, when the data are encoded into CTA-2047, underscores should be used rather than spaces. Why the version number is listed here as well as separately is unknown.

With this, Manufacturer, Brand, and Model can be covered.

CTA-2047 has a field URI which is “Machine readable URI containing additional information on the device” which covers the URL. A URL is a particular type of URI. It is recommended to use a URL but the translation between CTA-2047 and ERDM is simply to copy the text.

CTA-2047 does not have fields corresponding to LocalIdentity, IdentityGeneral, or DeviceType.

Local Data

“Name” is the “Human readable descriptive name for the device, e.g., TV. A device may allow the name string to be modified, e.g., ‘TV’ may be changed to ‘Bedroom TV.’” This is identical to the ERDM format.

CTA-2047 does not have fields corresponding to LocalOtherInfo, LocationLocal, or LastStaticDataChangeTime.

Accuracy

CTA-2047 has a catch-all data element for accuracy, described as follows:

“EUI Accuracy (% accuracy of EUI that would be reported based on one of the following:

- a) StoredEUValue if used
- b) typical average operating conditions
- c) an applicable test standard when the device is in the ‘On mode’)

This does not map directly onto the method of characterizing accuracy in <https://openconnectivity.org/foundation/our-partners> data model so it cannot be numerically transferred.

Energy Reporting

CTA-2047 defines CurrentPower, which corresponds directly to the PowerLevel in ERDM, and TotalEnergy, which corresponds directly to CumulativeEnergy (though the latter also includes the cumulative time since the energy value was reset to zero). The standard discusses the issue that energy used in some low-power modes may not be reliably trackable if it does not have a clock that operates through all such periods and/or does not know exactly what mode it is in or if it is connected to mains power.

The standard also has optional facilities for reporting five-minute data for one hour, hourly data for 24 hours, and daily data for seven days.

Other Data

CTA-2047 uses only relative time, for tracking intervals; an advantage of this is that it is not necessary for the device to support the tracking of absolute time. Relative time is encoded in ASCII as DDDD:HH:MM:SS, e.g., “00:01:04:12,” or DDDD:HH:MM. Thus, while there is no value that corresponds to the ERDM TimeStamp, a management system will track absolute time so it can attach its own sense of time to data (including relative times) from CTA-2047 data.

CTA-2047 does not have fields corresponding to PowerState, Temperature, or Occupancy. In addition, CTA-2047 has several data elements not covered in the ERDM.

CTA-2045

CTA-2045 is more formally the Modular Communications Interface for Energy Management. It was created by merging two earlier standardization efforts—the Universal Smart Network Access Port (USNAP) and one from the Electric Power Research Institute (EPRI). Its primary purpose was to enable easier integration of distributed energy resources to implement demand response. However, it includes features for energy reporting. CTA-2045 defines an interface between an end-use device and a communications module attached to it. Those modules might then use one of many different protocols to communicate with the building as a whole (e.g., Wi-Fi, Zigbee, or Z-wave). Unfortunately, the standard does not describe how to pass semantic data over these links, so modules must be paired with the device on the other end, such as a proprietary gateway device or a cloud-based interface. These interfaces could be standardized, and if so, would presumably use the same semantics as the data on the other side of the module.

CTA-2045 also provides for passing through data packets of other protocols, including the Zigbee Smart Energy Profile (1.0 and 2.0), OpenADR (1.0 and 2.0), ECHONET, KNX, LonTalk, Sunspec, BACnet, and general IP packets. Some of these can be used for energy reporting, but if used, the fact that there is a CTA-2045 in the communication path is not relevant for data model purposes.

Figure 22 shows the two CTA-2045 modules used in our demonstration setup.

Figure 22: CTA-2045 Modules (AC and DC form factor)



Source: LBNL

Identification

CTA-2045 includes a 2-byte “Vendor ID” so the ID can be translated to a manufacturer name for Manufacturer (and vice versa). The list is maintained by “the standard development organization or users alliance.” It also includes 16-byte Model Number and Serial Number fields, corresponding to Model and the serial number keyword in LocalIdentity. If no serial number is available, then the field is to be all zeros, though the standard does not make clear if this is to be the number zero or the ASCII character zero.

CTA-2045 also includes a 2-byte Device Type which presently references a list of about 50 entries, which are only the devices that the writers anticipated were likely to be subject to demand response events.

Local Data

CTA-2045 does not support any of the local data fields of the ERDM.

Accuracy

CTA-2045 does not address accuracy.

Energy Reporting

CTA-2045 refers to energy reporting data with the term “commodity read” (since it can report on more than electricity). It can report an “instantaneous rate” and “cumulative amount” for electricity in watts and watt-hours. It can be reported whether the value is a measurement or an estimate.

Time is specified in “UTC seconds” (number “of seconds since 1/1/2000 00:00:00 UTC”), with time zone and daylight saving offsets specified.

Other Data

CTA-2045 provides for control via sending “relative price indicators” and episodic notifications such as “Critical Peak” and “Grid Emergency.” It also can send actual prices, with a variable number of digits after the decimal point, and a currency unit specified (according to an ISO coding).

CTA-2045 supports “GetPresentTemperature” to hundredths of a degree; temperatures can be specified in °C or °F. This is air temperature, for thermostats (water heaters are to report the tank temperature).

EMAN

The EMAN data model is probably the most complex and sophisticated one available, relevant to energy reporting, and one of only a few with energy reporting as a core focus. “EMAN” is the name of the working group that created several Internet Engineering Task Force (IETF) Request for Comments (RFCs 7326 and 7461; Parello 2014); it does not have official standing as a term but is a convenient name to use. In many cases, for field formats it references other IETF RFCs for definitions and usage.

EMAN has many features found in few (and in some cases no) other standards, such as detailed reporting of power characteristics, the ability to report on multiple power inlets and outlets of a device (power interfaces), and more. It includes mechanisms for describing power topology relationships among devices, and for summing (“aggregating”) the consumption of multiple devices. These additional features cover both static and dynamic data. EMAN is careful to define clear terminology.

EMAN does recognize that there is considerable diversity in the data available and used in this topic area, so it provides for several fields of keyword/value pairs.

EMAN provides for a range of ways to report data over intervals of time. These in general can be mapped to ERDM data and mapped back to EMAN, but in a single form.

EMAN explicitly notes the potential for using it for control via setting the power state of a device, and includes both a current state, a desired state, and a “reason” for the desired state. It also has a self-identified “importance” that a management system would presumably use in making control decisions.

EMAN has many fields for highly detailed reporting about power characteristics: voltage, current, frequency, reactive power, three-phase AC power details, and more.

Many features in EMAN do not map onto ERDM, so they would simply be not translated particularly those for power topology and detailed power characteristics.

EMAN is based on the MIB (Management Information Base) data that a device has. It describes how to use information defined elsewhere and possibly could be useful in the EMAN context, such as a temperature sensor.

Identification

EMAN specifies use of a UUID according to RFC 4122, so that this field can be brought into and out of the ERDM without modification.

EMAN has a “name” for human-readable information, which is suggested to possibly be IT identification (e.g., DNS name or MAC address) or anything else. An “alternatekey” is defined by the manufacturer, so presumably it could be a serial number or similar identification. EMAN

has a “role” field for “purpose” of the device, and a general “keywords” field for additional information. It also refers to other information that the device may already have and so can map into the EMAN scheme, including the MAC address, Internet Address, DNS name, and port numbers (this last one deriving from Ethernet port management). All of these fields map into the LocalIdentity and LocalName fields of ERDM but require careful parsing/mapping and likely custom interpretation,

EMAN does not have explicit fields for Manufacturer, Brand, Model, URL, or Device Type. Some of these are likely in other MIBs defined by the IETF.

Local Data

The LocalName, LocalOtherInfo, and LocationLocal fields of the ERDM are addressed above in Identification, as EMAN does not make the general/local distinction that ERDM makes. EMAN also does not address the LastStaticDataChangeTime.

Accuracy

EMAN specifies accuracy as a single value as a percent (in hundredths). This presumably is a percentage of the measurement, though the maximum power draw of the device can be reported. The source of the value (measurement or estimate) also can be reported.

Energy Reporting

The base unit for power is watts and for energy is kilowatt-hours. However, each can have an exponential range (in powers of 10) applied for particularly small or large measurements, and the measurement itself is a floating-point number, so there is no concern with losing significant digits for either.

Other Data

EMAN includes a complex system of power states that can be mapped to the simple ERDM list, but the reverse mapping will lose some of the detail of EMAN.

EMAN describes how to use information defined elsewhere in MIBs that could possibly be useful in the EMAN context, such as a temperature sensor (and perhaps occupancy if that is defined in a MIB).

Zigbee

Zigbee is one of the most commonly used protocols for digital communication. It was developed to provide low-power, wireless connectivity for a wide range of network applications concerned with monitoring and control. Its most current version, Zigbee 3.0, was developed so that different market-specific networks can merge and operate on the same network.

Zigbee applications use the concept of clusters to communicate attributes. Each cluster contains a set of related attributes along with commands to interact with those attributes. Each cluster corresponds to a specific piece of functionality for a device application.

Identification

The Basic Cluster in Zigbee contains some of the attributes that ERDM classifies as Identification attributes.

Zigbee specifies Manufacturer as ManufacturerName, while Model is defined as ModelIdentifier, both encoded as a character string. Manufacturer is a mandatory field, while the ModelIdentifier field is optional. It also has a DateCode attribute that specifies the date of manufacturing with additional characters available for specifying location and other details of where the device was manufactured. The DeviceType field as defined in the ERDM is specified in Zigbee as GenericDeviceType. In addition, there is a field called GenericDeviceClass, which specifies the particular application for which the Zigbee cluster is being used. Currently, both fields are used only in lighting applications. Other device types and device classes have not yet been included.

Zigbee lacks fields that correspond to the ERDM's IdentityGeneral, URL, UUID, LocalIdentity, and Brand.

Local Data

LocationLocal is specified in the Zigbee data model as PhysicalEnvironment, which describes the device's physical location within a building, with specific Zigbee codes for each particular location such as bedroom. It also has an attribute called LocationDescription that further describes the device's location within a room and is encoded as a character string. There is no Zigbee data item corresponding to LastStaticDataChangeTime.

Accuracy

Each measurement cluster in Zigbee has optional fields where the minimum (i16MinMeasuredValue) and maximum (i16MaxMeasuredValue) values that can be measured; these could be used to calculate the ERDM RangeMax field. As a result, AccuracyRange and AccuracyReading are not separately specified.

Energy Reporting

CumulativeEnergy is defined as CurrentSummationDelivered in the Simple Metering Cluster of Zigbee, while PowerLevel is not specified explicitly. There is a cluster called the Power Configuration Cluster that specifies the details of the attached power source but no details about the power consumption of the device itself.

Other Data

A time stamp is specified as utcTime in UTC standard format as a mandatory 32-bit attribute. Zigbee defines PowerState as the DeviceEnabled attribute; the data type is boolean so presumably it is limited to just *on* and *off*.

Temperature is specified in the Temperature Cluster of Zigbee. The measured temperature value is specified as i16MeasuredValue, and its tolerance is specified as i16Tolerance. Occupancy is specified as u8Occupancy in boolean format, where 1 is occupied and 0 is unoccupied. Some measurement clusters such as Temperature have a tolerance field that specify the accuracy for each reading.

Related Topics

As temperature and occupancy data have been included in the ERDM, the question of what to do with them arises. The data simply could be maintained in the system alongside the ER data. However, several other capabilities could be readily implemented, such as the following:

- Also querying dedicated temperature and occupancy sensors and other sources
- Aggregating the temperature and occupancy data across spaces such as rooms, HVAC zones, or lighting zones. This may involve combining data from multiple devices, which may have intermittent availability and varying quality.
- Estimating the data for spaces where the detailed data are not available
- Implementing a “Temperature Server” and “Occupancy Server” function that enables other devices in the building to query for these data by space type and to get the best information available

Standards Conclusions

A common data model for energy reporting is achievable. The ERDM is not the final word on this topic, but is a solid foundation to build from. Even from the limited set of models reviewed, there is clearly a lot of misalignment between them, which makes translation of many fields challenging. That said, the energy and power values are much more consistent across protocols, so the data most central to energy reporting can be converted reliably from one format to the next.

More experience with each protocol will likely result in particular ways to use them that are best for compatibility with ERDM, so this document will need to evolve. It is recommended that a standards committee facilitate a process for maintaining and updating this report, so there is a clear reference source for the most current information on this topic.

CTA-2047 and EMAN are the only data models designed specifically for energy reporting. EMAN is not likely to be reopened anytime soon, and adapting it to match the ERDM would be awkward. In contrast, CTA-2047 would be much easier to use as a platform for the ERDM in that it would be easy to reopen it and the distance between its current content and the ERDM is modest.

CHAPTER 4:

Energy Reporting Management System

The goals of this portion of the project were to create sample software that can gather, store, and present reported energy data; make it available for analysis; and show it working with this study's prototype hardware devices to provide both reporting and control.

This chapter is organized as follows. It first documents the strategy used to implement the system. It then reviews details of the how individual protocols and devices were integrated, as well as how the other parts of the system operate, including the database and graphical presentation. It concludes with needed future steps and insights gained from the development process.

Overview

Energy Reporting Technology Goals

Energy reporting is intended to be a low-cost feature, and in most cases, a no-cost one. There are some devices today that actively monitor and track their own energy use with dedicated hardware, and the cost of doing this is rapidly dropping. In addition, most devices can generate reasonably accurate values by estimates derived from internal operational information alone. This project focused on devices that already have a network connection for some other purpose; it seems likely that in the future virtually all energy-using devices will be networked.

Once devices are able to measure or estimate their energy usage, the end-use connected devices themselves can use these data in conjunction with other parameters like price of electricity, user configurable consumption bounds, and others to control their own consumption. However, most use of the data is gained from moving it to a central management system that stores the data, can extract and provide consumers with useful information using visualizations and analytics, and can enable control of the devices, as needed.

As part of this project, the research team acquired and assembled a set of connected devices that report their measured or estimated energy use (or that report some other parameter from which the power consumption can be estimated, to then accumulate energy use). The management system software receives the energy use data from all these devices, stores it, and then displays it for user consumption. The following sections describe the goals and the architecture of the management system, details of how each device communicates to the management system, and the instructions needed to set up the system.

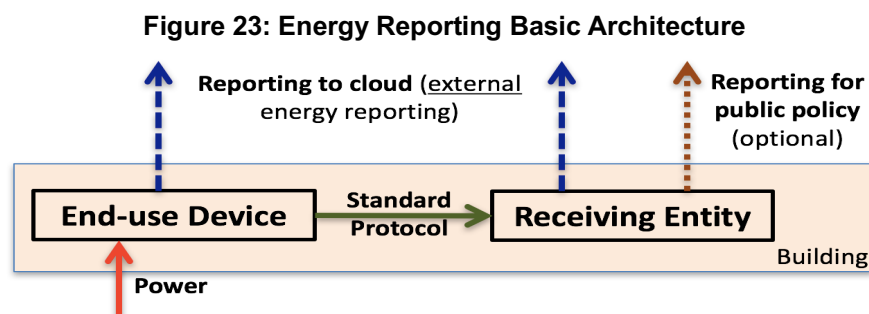
Project Demonstration Goals

The management system software created is intended to serve the demonstration, rather than form the basis of a future product distributed to others. The management system receives energy reporting information from diverse connected devices on the same network and

provides a compelling visualization of the data. The management system also can send control signals to a few of the devices. The price of electricity was selected as the control signal so devices could reduce service delivery during times of high price and take advantage of low prices by expanding services or storing energy.

Energy Reporting Architecture

The overall LBNL architecture for energy reporting (Figure 23) is organized around a central “management system” within each building that collects and processes data from many devices in the building (Nordman 2013). The management system decides when to ask for the data, and stores the data over time. This approach minimizes the burden on end-use devices in that they do not need to be configured for their energy reporting behavior and do not need to store time-series data. It also enables there to be more than one management system in a building. These might operate independently or in coordination, and can cover the same set of devices or different ones. Minimizing end-use device complexity makes it easier to introduce the energy reporting feature into devices and increases interoperability, as the interface between the management system and the end-use device is simpler.



Source: LBNL

Energy reporting data also can be conveyed outside the building to a product manufacturer or third party, or for public policy purposes. Many products sold today convey their operational status to the manufacturer’s infrastructure (usually “in the cloud”) and currently do or could easily include energy consumption a part of that communication. However, these uses are not considered part of the basic idea of energy reporting as defined here, and so are optional. While products can and will do such “external reporting,” it should not be considered essential or mandatory (or enabled by default), so that consumers are assured that their privacy and security are protected. This may be critical in getting public policy support for universal energy reporting capability. Alternatively, the term “local energy reporting” could refer to reporting that is only in-building.

The archetypal example of energy reporting is a device reporting its own energy information to a single management system (“self-reporting”), using a standard IP network. This case will likely cover most energy use and most devices.

Power strips, other external meters, Ethernet switches, and lighting control systems are examples of other ways to conduct energy reporting. In these cases a second reporting device

has knowledge of the energy use of the end-use device consuming power, which it then reports on behalf of that device (“other-reporting”). One such case is when the reporting device supplies power to the consuming device, and so can measure what is provided. Another case is when a reporting device has proprietary communications to the end-use device, but is able to relay the information to the management system over a standard protocol. A third case is when the reporting device has operational information about the end-use device and so is able to provide a reliable estimate (e.g., a thermostat for an HVAC system or a lighting control system that reports on many lights).

Energy reporting also includes the reporting of additional “static” data such as the device type, brand, model, etc. While such metadata are mostly static, there are exceptions; a product may change location within a building, or a device may have its hardware changed (e.g., a computer being outfitted with more memory). Using a standard data model is a key part of this architecture (Nordman and Cheung 2016).

The management system is a critical part of the energy reporting architecture because of its ability to collect and analyze the reported data. To do this, the management system needs a discovery mechanism for identifying devices on the network. There are many standard IP discovery protocols that exist and can be utilized for this purpose. When other technologies are used, such as Zigbee, then technology-specific discovery may be needed. Usually the management system will periodically scan the network for new devices, or may receive announcements from new devices. In some cases it may be necessary to manually alert the devices to each other’s identity, principally so that the management system knows how to reach each reporting device.

The management system is responsible for retrieving static data about each device and establishing a routine for querying each of them for energy and power data. Typically, the data will be collected on a fixed frequency for all devices, but can be customized to higher frequencies in cases where more granular data are useful. Similarly, the frequency of data collection also can be changed for particular periods of time of interest, such as when it is operating at higher power levels, or during periods of high energy cost. Since the management system bears the entire burden of deciding the schedule for obtaining data, and for storing it, the complexity imposed on each end-use device is minimized. An alternative would be for each end-use device to accumulate its own time-series data for a time and then upload it to the management system infrequently, but this adds complexity.

While energy reporting often includes instantaneous data on power, voltage, and current, the most useful data point is accumulated energy use—essentially a meter reading similar to one provided by a utility meter or car odometer. With the timestamp, this provides an ongoing picture of energy use over time. If one or a few data points are missing, the total value of the remaining points is still valid.

Once the data are collected, the management system can process and present them to the user numerically and graphically, aggregate them across devices and across time, or conduct various sorts of analyses. Likely ordinary additional functions would be to aggregate data over time,

location, and device type, and to provide summary statistics for easier user comprehension. Many additional analyses are also possible, including comparisons against external data (e.g., test procedure results) and cross comparisons among devices.

Management systems that collect energy reporting data will rarely if ever be a stand-alone device; rather, they will be a feature of some device or system already present in the building (to ensure it is not a source of notable additional energy use or hardware cost). In small buildings, a device like a network router that is always on (and has good network connectivity) is a good choice. In large buildings, a central management system (such as those for HVAC, lighting, or security) could incorporate energy reporting as an additional feature.

A key reference here is IEC 15067-2 (International Electrotechnical Commission, 2012) which defines an Energy Management Agent which covers the functionality described here. It also includes coordination with the utility grid, and describes price-based control as one of the methods for doing that. The 15067-2 architecture is then quite compatible with and supportive of the Energy Reporting architecture described here.

In large buildings, it may be desirable to have a hierarchy of such management systems to collect data from large numbers of devices by location or type and then relay aggregated data to a more central system. The EMAN mechanism from the IETF (Parello et al. 2014) particularly anticipates this usage.

A peculiarity of the energy reporting function is that it is not related to the core functionality of a normal end-use device (exceptions would be external meters for which reporting data may be a primary or secondary function). In this respect energy reporting is most similar to networking infrastructure technologies, such as device discovery or basic connectivity features such as the Dynamic Host Configuration Protocol (DHCP) for allocating IP addresses in a local network.

Control

An energy management system in a building generally acquires data from end-use devices and sends out requests or commands to devices to change their functional behavior. While energy reporting is defined here to cover only passive acquisition of data, there is no reason that the technology infrastructure has to be limited to that function. For most protocols that include the ability to report the power state of a device (e.g., on, off, or asleep), once devices are in communication for energy reporting data, it is trivial to add the capability to set a state (though whether a particular device supports this feature is another matter). That said, the security concerns around control may be significantly greater than for reporting.

While there are occasional good uses for energy reporting protocols as a control mechanism, it is expected that most control will be accomplished through other mechanisms— usually protocols specifically designed for device control.

Demonstration Management System

Overall Architecture

In the architecture discussed above, the management system is the only new entity, though it is likely that it will usually be a new function of an already existing device, rather than a new piece of hardware. In this implementation, the function is referred to as the “energy manager.”

This study’s original plan for the management system included the following features:

- **Open-source:** The software should be open-source and should avoid the use of proprietary components.
- **Multi-protocol/API:** It should be capable of communicating with a series of devices through a variety of mechanisms, using standard protocols as much as possible.
- **Extensible.** The system should be extensible, i.e., able to incorporate new devices and new protocols in the future.
- **Simple.** Overall, the system should have low complexity.
- **Local.** It should be capable of working on local communication networks, without an external Internet connection.

Other essential features include the following capabilities:

- **Display (with graphs).** It should display energy data easily and quickly, and aggregate data over time and across devices.
- **Easy integration.** It should easily integrate both metadata (mostly static) and time-series data from devices maintain reliability as the system is moved and manipulated.

For ease of implementation, an Apple notebook was selected as the platform on which to build the management system. This provided easy programming and a variety of flexible, quality tools and software subsystems. It was clear that at least one network infrastructure device would be needed to connect to other IP devices (over Ethernet and Wi-Fi), as well as other protocols such as Zigbee. The Intwine Connected Gateway was chosen, as it provided a variety of such connectivity features, a programming environment for protocol translation code, and a company founded by building energy researchers who share LBNL’s research interests. At the beginning of the project, it was not known what physical layer protocols would be used, so having a flexible device was helpful.

The Intwine gateway provided a variety of functions to the demonstration setup:

- **Local Network.** An Ethernet switch and Wi-Fi access point for good IP connectivity
- **Zigbee Coordinator.** A central entity for a local Zigbee network
- **REST Endpoint.** The gateway also exposes a REST endpoint for separate functions to control individual Zigbee devices.
- **Internet Access via Cellular.** The energy reporting architecture does not include external communication, but this feature was helpful in getting software updates for devices. It also was convenient to have a local network that did not need to be integrated into the LBNL network (the lab has security and other concerns for

such installations), and it provides easy access for when the demonstration is set up elsewhere.

Other elements of the system, other than the end-use devices themselves, were:

- The Bluetooth dongle (USB, on the MacBook) for connectivity to the PowerBlade device.
- The Philips Hue bridge device, to connect to the Hue light.
- External monitors, for easier viewing of reported data during demonstrations (two for the full demo).

Figure 24 shows the architecture as it is today. It may be adjusted as more devices are added. This figure also does not show the USB charger.

Figure 24: Demonstration Setup System Architecture



Source: LBNL

Protocols and Devices

In the long run, management systems for energy reporting will implement a defined set of protocols so that any device that supports one (or more) of those protocols can interoperate with the management system. Previous work by LBNL identified several dozen protocols that can be used for energy reporting, but it would be burdensome for management systems in general to have to support so many. A key question going forward is which set of features is reasonable to support and encourage; they may vary by building type. The following subsections outline the protocol structures that were implemented, which are indicative of the topic generally; for example, the initial division between IP and non-IP connectivity.

Internet Protocol Communication

Using the Internet Protocol has great advantage in enabling cost-effective, scalable, and flexible networking. Data transmitted with IP are relayed as flows between devices with the Transmission Control Protocol (TCP) or the User Datagram Protocol (UDP), but these convey nothing about the syntax or semantics of the data (though the inclusion of a port number indicates to the receiving device the format of the data, and hence the application to which the data should be sent). Thus, it is necessary to know what application layer protocol is used on top of TCP or UDP. Unfortunately, none of the implementations below is really ideal for this purpose. The two protocols used on top of IP are CTA-2045 and REST APIs.

CTA-2045

The standard CTA-2045 defines a standard interface between an end-use device and an external communications module. Unfortunately it does not define the interface between that module and the outside world. Modules are available for several communication technologies, including Wi-Fi, Zigbee, Z-Wave, and others. In the terminology of CTA-2045, the actual end-use device is a smart grid device (SGD) and the module is a universal communication module (UCM).

Two of the demonstration devices—the water heater and the vehicle charger—use CTA-2045. The modules (AC and DC) were from two different manufacturers: Skycentrics and Intwine Connect.

After setting them up and connecting them to the Internet through Wi-Fi, the Skycentrics modules act as a link between the Skycentrics cloud and the end-use device. The module sends the data (e.g., status, power, and energy consumption values) from the end-use device to the cloud by publishing on a Message Queuing Telemetry Transport (MQTT) message bus, to a particular topic. It also transfers price signals and GRID commands from the cloud interface back to the device via MQTT. The research team has been working with Skycentrics to modify their module to publish to a local MQTT broker instead of the cloud, but that work is still in progress. The specific device drivers can subscribe to these topics on the MQTT message bus (locally or on the cloud) and obtain the device consumption and state information.

The Intwine Connect modules have a similar setup and connection to Wi-Fi procedure, though they do not require Internet connectivity for the setup or in ordinary operation. Once connected, they expose a REST API that can be used to send/receive information. The

device drivers query the particular REST endpoints to obtain the power and energy consumption information.

REST API

A representational state transfer (REST) API is a method to use data transfer with the HTTP with standard text-based data encoding schemes such as HTML, XML, or JSON. This communication method was used for many of the devices in the demonstration setup. Some devices already had defined REST endpoints: the Philips Hue, Belkin Wemo, and Venstar. The research team developed a REST endpoint on the MacBook Air to publish its energy reporting. The Intwine Gateway exposes REST endpoints for all the Zigbee devices (the RAD controller with two separate lamps and the GE Smart Dimmer) with which it communicates. The CTA-2045 UCM modules manufactured by Intwine Connect also expose a REST API that is being used to obtain energy and power values; this is used for the water heater and EVSE.

To interface with REST APIs, the research team developed Python wrappers or used open-source libraries implemented for these products. The Python wrappers abstracted the process of sending REST API calls and extracting the necessary information such that the user only has to call a function `get_data()` with the URL and other necessary parameters and the function would return the power and energy values.

Non-Internet Protocol Communication

These methods use network layers other than the IP and typically link-layer protocols other than Ethernet or Wi-Fi.

Zigbee

The demonstration devices in this study that use Zigbee are the RAD controller (two devices: the overhead lamp and the task lamp) and the GE/JASCO Smart Dimmer switch.

For these, the Intwine Gateway's capabilities translated between Zigbee messages and IP packets. The management system sends IP packets as a particular command and parameters through the Intwine Gateway's REST endpoint (as with all uses of REST, over HTTP on an IP connection) for a particular Zigbee device. The Intwine Gateway receives this request and sends the corresponding Zigbee message to the device. For the reverse communication, the device sends a Zigbee message to the gateway, extracts the data, and sends it as the response (in a JSON format) to the REST request made by the management system. This translation does not change the content or meaning of the message, it simply changes the format of the message.

The Zigbee standard is actually a set of components called Cluster Libraries, and any given device implements only one or more of those components. The cluster libraries used for energy reporting were Metering (Smart Energy) cluster (0x0702) and Electrical Measurement cluster (0x0b04).

Bluetooth

The study included two Bluetooth devices. First is the PowerBlade prototype device (Lab11 2018). The communication method between the management system and the PowerBlade was

originally created to communicate between a phone application and the device. The management system simply used the same mechanism, which is using a BLE radio to listen to the advertisements being published by the PowerBlade and extracting information from these advertisements. The second device is the Pirl USB Charger, which sends ASCII text over the BLE link.

Management System Components

The management system has three components: (1) a set of drivers for each end-use device, (2) a database for storing the data, and (3) a visualization system for displaying the results.

Drivers

The energy management system communicates to each device using drivers (also called *translators* or *interfaces*). The driver collects information such as state or other parameters from the device and uses them to estimate or report energy use. The energy and power data collected is saved to a local database (described in the next section). Each of the connected devices currently in the portfolio has a different mechanism to communicate, and each driver is developed to cater to its specific protocol or data model. All drivers except for one (the driver for the PowerBlade) were developed in the Python programming language. The following sections describe the details of each driver.

Venstar Thermostat

The Venstar Thermostat (ColorTouch T7850) uses Wi-Fi as link-layer protocol and is connected to the Intwine Wi-Fi network. The thermostat has a local REST endpoint that can be accessed; this is a default feature of the product as sold. The REST API documentation is public.

GET http://<IP address of the thermostat>/query/info

reports the state of the HVAC system. The Venstar does not implement energy reporting, but the status information can be used to estimate consumption of an attached HVAC system through calculations in the management system (in this driver). State=0 indicates that the HVAC system is idle, State=1 indicates that the system is heating, and State=2 indicates that it is cooling. As there was no real HVAC equipment connected to the thermostat, the management system used a heating load power level of 2,500 W and a cooling load of 3,500 W. It polled the state every second, so that on a time basis was able to get a highly accurate view of the system status. The energy was accumulated by summing these power values (from the status reported every second) and both power and energy were stored in the database on an ongoing basis.

The Venstar thermostat does not report any static information.

Philips Hue

The Hue lamp (Table Lamp model 71996/61/PU) was connected to the Hue bridge over Zigbee, the Hue bridge was connected to the Intwine Gateway via Ethernet, and the energy manager was connected to the Intwine Gateway over Wi-Fi. To obtain values from the Hue, it was necessary to first create a USER on the Hue Developer Program (Philips 2018) and provided access to that user on the Hue Bridge. Using this authorized username, the qhue function (Qhue 2018), which

is a Python wrapper over the Philips Hue API, was used to connect to the Hue Bridge (using its IP address). Once the connection was established, it was possible to obtain the light state and light brightness of the Hue lamp attached to the bridge. By measuring the power consumption at different brightness levels (using a Chroma Power Meter, model 66200), the following linear equations were derived to estimate the power consumption:

```
If state == 'on':  
    power = 1.7 + (brightness * 6.2/255) W  
else:  
    power = 1.7 + 0.41 W
```

The state was polled every second and the power was calculated every second. The energy was computed as a sum of these power values reported every second, and both were continuously pushed to the database.

Static information about the Hue lamp can be obtained by querying different REST endpoints exposed by the device itself.

Belkin Wemo Plug

Similar to the Philips Hue, a Python library called `pywemo` (McCracken 2018) was used to discover the Wemo device (using its IP address) and then connect to it. The Wemo and the energy manager must be on the same network; in this case, both were connected to the Intwine Gateway's Wi-Fi network. Once connected, the current power of the device (the actual power reported in kilowatts) was queried, and this query was repeated every second. The energy was computed as a sum of these power values reported every second, and both were continuously pushed to the database.

This same Python library, `pywemo`, can be used to obtain static information about the Wemo plug.

PowerBlade

When a device is plugged in through the PowerBlade, the PowerBlade advertises the consumption information as BLE (Bluetooth Low Energy) packets every second. These are simply broadcast, not directed to any particular device. The energy manager has BLE capability (which was made possible through use of a BLE dongle) and reads these packets using a script developed by researchers at the University of California (UC) Berkeley (Lab11 2018). This script reports both the actual power and the accumulated energy consumption since the beginning of use. The script was modified to add the capability of pushing both the real power and energy values to the local database. Following is an example of the information from a PowerBlade advertisement:

```
PowerBlade  
Local calibrated unit  
Sequence Number: 59  
RMS Voltage: 124.35 V
```

Real Power: 101.89 W
Apparent Power: 106.44 VA
Cumulative Energy Use: 1.18 Wh
Power Factor: 0.96
Flags: 66
Raw voltage: 209.00
Volt scale: 0.59
Pscale: 16665.00

The PowerBlade does not report any static information.

MacBook Air

For the MacBook, the research team developed a driver on both ends of the link. On the device side, current and voltage were measured and extracted using Marcel Bresink's hardware monitor software for Mac (Bresink, no date). That software presents the information on screen, but it is not designed for external communication. The LBNL software parsed its output to obtain the power consumption of the MacBook. A REST API was developed on the MacBook to return this power consumption value whenever queried (assuming that the energy manager is on the same network, and in this case both were connected to Intwine Gateway's Wi-Fi network):

GET http://<ip_address_of_mac>:5000/get_data

This returned a JSON file containing a single power consumption value in watts at that instant when the request was made.

On the energy manager, the driver polled the above endpoint every second and obtained power values that were added to obtain energy values as well. Both of these were pushed to the database every second.

The MacBook currently does not communicate any static data.

GE Smart Dimmer

The GE Smart Dimmer communicates via Zigbee and uses the Intwine Gateway as a Zigbee Coordinator. The dimmer implements the Metering (Smart Energy) cluster of the Zigbee Cluster Library. A function was created on the Intwine Gateway that can be called by the energy manager at periodic intervals to obtain the "CurrentSummationDelivered" or the energy consumed attribute.

The driver on the management system queried the Smart Dimmer via the gateway to obtain the Energy consumed value

GET https://<ip of intwine gateway>/edgebus/v1/devices/smart_dimmer/get_energy

where *smart_dimmer* is the object created on the gateway to communicate with the device and *get_energy* is the REST endpoint of the function that polls the metering cluster and outputs the energy consumption value. As the Smart Dimmer only reports the energy, the power was derived using:

$$power = (energy - prev_energy) / (time_now - prev_time) * 3600$$

Both of these, the actual energy and derived power, were pushed to the database every second.

By querying the Zigbee Device Object (which is a specific class every Zigbee device must implement), it was possible to obtain static information about the Smart Dimmer.

RAD Controller

The RAD controller communicates via Zigbee using the Intwine Gateway as a Zigbee Coordinator. The RAD implements the Metering (Smart Energy) cluster and the Electrical Measurement cluster of the Zigbee Cluster Library for both the overhead lamp and the task lamp. Thus, the energy manager polls these clusters at periodic intervals via the Intwine Gateway.

Table 13 shows the agents that were created on the Intwine Gateway, the Zigbee clusters used, and attributes associated with it. All these values were exposed as REST endpoints by the Intwine Gateway.

Table 13: Intwine Gateway Agent Name, Device It Refers to, Clusters, and Attributes

Agent Name	Device	Zigbee Cluster Library	Attribute	Value
rad1	Overhead Lamp	Metering (Smart Energy)	CurrentSummationDelivered	Cumulative Energy (kWh)
rad1	Overhead Lamp	Electrical Measurement	ActivePower	Active power (W)
rad2	Task Lamp	Metering (Smart Energy)	CurrentSummationDelivered	Cumulative Energy (kWh)
rad2	Task Lamp	Electrical Measurement	DCPower	DC power (W)

The driver side on the energy manager polled the following endpoints to obtain the necessary values:

GET https://<ip of intwine gateway>/edgebus/v1/devices/rad1/get_energy (Overhead lamp)

GET https://<ip of intwine gateway>/edgebus/v1/devices/rad1/get_active_power (Overhead lamp)

GET https://<ip of intwine gateway>/edgebus/v1/devices/rad2/get_energy (Task lamp)

GET https://<ip of intwine gateway>/edgebus/v1/devices/rad2/get_dc_power (Task lamp)

The RAD reported both power and energy values for both the overhead and task lamp (the values for the overhead lamp were estimates and for the task lamp were measured). The URLs were polled every second and all the reported values were pushed to the database.

By querying the Zigbee Device Object (which is a specific class every Zigbee device must implement), it was possible to obtain static information about the Smart Dimmer.

A. O. Smith Water Heater

The A. O. Smith Water Heater supports network communication through a CTA-2045 module. The Intwine Connect's CTA-2045 UCM for AC appliances (Intwine 2018a) was used for the module. After connecting the UCM to the Wi-Fi, the module exposes a REST API:

```
GET http://<ip of the UCM>/commodity.cgi
```

that can be queried (Intwine 2018b). While Intwine provided both the UCM module and the gateway, in this case there was no functionality that the gateway provided to the UCM other than generic Wi-Fi connectivity. The driver that was developed polled the API every second and obtained the power and the cumulative energy value, since being plugged in, and pushed these values to the database.

Static information about the Water Heater can be obtained by querying different REST endpoints exposed by the Intwine Connect manufactured CTA-2045 module.

Database

The open-source InfluxDB (Influxdata 2018a) database software was used by the management system to store the energy consumption and power values sent from different device drivers. InfluxDB is a time-series database whose performance has been optimized for managing time-series data. It provides a graphical user interface called Chronograf, which can be used for real time visualizations. In the management system, there is one instance of the database for each device.

The management system also used the SQLite3 (SQLite n.d.) database, which is a relational database, to store the static information obtained from the devices.

Visualization

The last component of the energy manager is the mechanism used to provide graphical presentation of the energy reporting data. A software system called Chronograf (Influxdata 2018b) enabled us to query the power or energy values in each of the Influxdb databases, and the management system used the built-in visualization options to plot the query results.

A scaling factor field was used to allow both large and small loads to be plotted legibly on the same chart. The power of all the devices was divided by a scaling factor before plotting to create a meaningful chart. For example, the scaling factor of the Hue lamp is 1, whereas it is 100 for Thermostat, so scaling was necessary.

As devices were added to the demonstration setup, at one point it became clear that the screen was becoming too crowded, so two separate Chronograf dashboards were created to accommodate the 12 devices that are reporting energy; each dashboard was displayed on a separate external monitor (although the screen of the energy manager could be used for one).

- Dashboard1: Hue lamp, Water Heater, Wemo (measuring the Water Heater), RAD Overhead lamp, and RAD Task lamp)

- Dashboard2: Thermostat, Smart Dimmer (measuring a 72 W incandescent bulb), MacBook Air, and PowerBlade (measuring a monitor displaying one of the dashboards)

Each dashboard had the following charts (Figure 25):

- A time-series display of the average power (scaled) for all the devices in that dashboard. The queries shown above were used to retrieve the power consumption data.
- Each device had a gauge chart that displayed the power consumption (actual, not scaled).

Each device also had a number that showed the cumulative energy consumption.

Figure 25: A Snapshot of the Energy Manager Dashboard Reporting Power and Cumulative Energy Consumption for Five Devices



Source: LBNL

Demonstration Operation

The demonstration hardware is operated as follows.

Demonstration Setup Procedure: Hardware and Software

1. Plug in the Intwine Gateway and wait for a few minutes until it has completed its startup procedure.

2. Plug in the reporting devices, with additional devices for the Smart Dimmer (e.g., an incandescent bulb would work—the tests used a 72 W bulb), the PowerBlade, and the Wemo.
3. Start the web app that exposes the REST API on the MacBook Air.
4. Start up the energy management system (a MacBook Pro).
5. Ensure that the devices are connected to the Intwine Gateway's Wi-Fi.
 - a. Use the Wemo app to set up the Wemo.
 - b. Use the Hue app to set up the Hue lamp.
 - c. Use the Summon app to ensure that the PowerBlade is up and running.
 - d. Verify that all devices (Venstar thermostat, Hue bridge, Wemo, MacBook Air, energy management system (a MacBook Pro), and the Water heater via the CTA-2045 Module) are connected to the Intwine Gateway; check the “LAN clients” list on the gateway's admin page.
6. Once all the devices have completed the startup procedures, run the startup script. It:
 - a. Launches influxdb (database).
 - b. Launches Chronograf (real-time visualization based on time series data from influxdb).
 - c. Launches the device driver for each device. Each driver establishes a connection to its respective device, requests static data (if available) and starts requesting dynamic data (power/energy values, or device state), and pushes the power and energy values to the database.
 - d. Launches Chronograf. The Chronograf dashboards pull data from the database in real time and display it.
7. The system operates indefinitely until interrupted.

Device Dynamic Operation

Most devices have a nearly static power consumption during the demonstration. However, some of the devices can be communicated with to change their state of operation:

- MacBook Air: Running some heavy processes or playing some videos on the MacBook can cause significant changes in power consumption.
- Water Heater: The water heater has two plates to be heated, and once a setpoint is set, it turns on the top and bottom plates (one at a time) to achieve this setpoint. This turning on/off heating cycles cause changes in the power consumption.
- RAD: The RAD controller has an on-screen slider that allows a user to control the level of the overhead lamp. Therefore, changing this setting would cause the power consumption of the overhead lamp to change.
- Smart Dimmer: In this demo, a 72 W incandescent bulb was plugged into the Smart Dimmer, which has a dimmable switch. The light level of the lamp can be changed based on the duration of the switch being pressed, and on which side of the switch is being pressed. The top part of the switch increases the intensity, and the bottom decreases the intensity. Single clicks on either of these sides will cause the bulb to turn on or off. All these actions cause changes in the energy consumption.

- Thermostat: In principle, the thermostat should cycle on and off on its own, but as it was not actually controlling a heating or cooling system, it generally was in a static state of operation during the demonstration. However, the setpoint could be changed during the demo, either manually or over the network.

Controlling Device Operation

Some devices in this study's portfolio allowed the energy manager to change its operation. Even though comprehensive controls were not integrated into the energy manager, these devices could be controlled in the following ways:

- RAD Controller: A price of electricity could be sent to the RAD controller, based on which, it would change the light level of the overhead lamp.
- CTA-2045 Devices (Water Heater and potentially the EVSE): The standard specifies that the devices must change their operation state based on grid signals and prices that are sent to it via the CTA-2045 module.
- Venstar Thermostat: The device allows the heating and cooling setpoints to be changed by sending a REST POST request to its API.
- Wemo: The pywemo Python library allows the energy manager to turn the Wemo plug on and off.
- Hue Lamp: The Hue lamp allows the energy manager to change the brightness, state, and color by sending a PUT request to its REST endpoint.
- Mila Air Purifier: It accepts a price signal over serial text and changes the fan speed in response.

Findings

In the course of this project, a variety of insights became apparent that are useful in the future creation and deployment of energy reporting technology. These are presented as follows.

Integration Challenges

Some devices have operational peculiarities that affected the energy reporting data, operation of the demonstration, or its interpretation. For example, the water heater has a limit on the number of cycles per day that it is allowed to run, to prevent a unit from excessively wearing out the relays with high cycle counts per day. This did not apply to this study, since the unit was not even turned on most days. The cycle limit is 24 complete on/off cycles per day, or 12 in a single hour. For demonstration purposes, short cycles were appealing, in that they more readily visually showed the cycling behavior to an observer; the actual cycle times of a water heater are quite long. The LBNL implementation used heater modules that enabled us to select their power level and aluminum plates that enabled us to select their dimensions. Higher power levels reduce the cycle-on time, and more massive plates increase the cycle-on and cycle-off times. The first implementation had 100 W heaters for each relay, but those resulted in very short (e.g., 10-20 second) *on* times; the *off* times were many minutes, though less than 10.

Through experimentation, the research team determined what hardware would result in times suitable for the demonstration.

Unrelated, but also for the water heater, there can be a time difference between when energy is consumed and when reporting of it is received. This occurs because the polling rate of the energy manager is faster than the rate at which the devices update their power and energy consumption values. In this study, the water heater pushed power and energy consumption values to the CTA-2045 module at a rate slower than that which the energy manager polled the CTA-2045 module. The energy manager polled the CTA-2045 module every second, whereas the water heater updated the power and energy values in the module only about every 30 seconds. Due to this, the same value was read for 30 seconds, until a new value was pushed.

Device Discovery

For many network technologies, a first step is to enable devices that might usefully communicate with each other to “discover” each other on the network. Ideally a management system will automatically find new devices shortly after they arrive on the network, without any action by the user. This can occur if the device advertises its presence, or if the management system periodically scans for new devices. The details of device discovery depend on the particular mechanism used. Good discovery protocols are highly valuable when people are trying to make products work. For energy reporting the need is even greater, since people are not highly motivated to do extra work for a nonprimary function.

Implications for Future Products

One expected issue that was encountered was that combinations of power levels and time intervals can easily result in very small values of incremental energy. This can make successive time periods show the same accumulated energy value, or even if they increment, the increments can vary even with a constant power flow. For example, consider a device in a low-power mode that consumes 2 W. It will take more than 20 days for it to accumulate 1 kWh of consumption. Each watt-hour of accumulated energy will take 30 minutes, and each milliwatt-hour (mWh) will take almost 2 seconds (1.8 seconds). Thus, for readings 1 second apart, many will have no increment in the energy value if denominated in mWh. That said, it seems unnecessary to query such a small load so often, but it does seem prudent to report accumulated energy in no less resolution than 1 mWh. For power, a tenth of a watt seems like the minimum acceptable granularity for reporting. Neither of these values address the accuracy of the values; that is a separate concern.

Some of the devices studied accumulate energy use from the beginning of their operation, while others start from zero with each power-on cycle. This is an issue of the device having non-volatile random access memory (NVRAM) that it can use for this purpose and frequently update. If a management system sees a device reporting a lower accumulated energy use than a previous period, it can reasonably infer that the meter value reset.

The Zigbee devices used in this study almost always implemented the same clusters (from the Zigbee Cluster Library) for reporting energy (metering cluster) and power (electrical

measurement cluster). Not all devices report both. This makes it easy for a management system to obtain energy reporting data for Zigbee devices.

The CTA-2045 standard addresses communication between the end-use device and the module, but it does not specify a data model or protocol for the communication from the module out. Thus, manufacturers of CTA-2045 modules can have their own data standard and protocols for the external interface. Skycentrics modules send data via MQTT, whereas Intwine Connect modules expose REST endpoints to send data, with different data models.

Devices that expose a REST interface should use the data elements from the standard data model, as there is no other such standard for it in wide use.

Privacy and Security Considerations

Energy reporting potentially can be used to undermine user privacy and security. Someone who is not supposed to have the data can identify which devices someone owns and their living patterns (as evidenced by how they use energy). Policy makers must ensure that users fully understand the implications of decisions, and they should have to actively opt-in to sharing data with third parties if any risk could be involved. External reporting on an anonymous basis could be very useful for public policy development without undermining user autonomy or putting users at risk; a standard and trusted mechanism for this needs to be developed. While products that report data directly to an outside organization (e.g., manufacturer or service provider) may be sold, such direct external reporting should not be part of any energy reporting policy requirements; it should be made clear that policies only encourage or require local reporting, for the benefit of the building owner. External reporting should be optional, up to the individual user's discretion.

For security, it would help to have only the reporting function enabled by default, with the requirement that any device control mechanism be actively enabled before functioning. This would also apply to any control signals from outside the building that might get passed through to the management system.

A key question is to what degree a reporting device can determine if a management system request is from a device on the same local network or from the outside. The local network is the boundary between a customer's devices and the wider Internet; a modem is generally the demarcation point. A local network may have multiple "subnets" of varying technologies, such as Ethernet or Wi-Fi. A hacker could compromise a local device and then use it to gather energy reporting data and relay it to the outside, so limiting reporting to local devices is not a guarantee of security but it greatly helps. Basic security measures such as having passwords on Wi-Fi access points is also needed, to keep passersby from easily joining a local network, and energy reporting devices should cease reporting when on a non-password-protected network.

A networked device can determine if another device is on the same subnet, and in these cases be assured that the device is local. However, not being on the subnet does not mean the other device is non-local. A typical residence might have only two subnets—Ethernet and Wi-Fi—but larger networks can have many dozens.

Two mechanisms might be of help. One is that many buildings have a network address translation (NAT) service at their demarcation point with the wider Internet. This service enables multiple devices in a local area network (LAN) to share a single IP address. This function might provide signatures for addressing that can help determine if a device is local or not. Similarly, device discovery protocols might also help determine device locality. Another approach is to organize energy reporting (or discovery) by subnet, and have special devices to relay data between them. Finally, firewalls at the network boundary could be set to block energy reporting data so that it would not inadvertently “leak” out of the building. This topic area needs attention by network security professionals.

In general, non-IP networks are always local to the building, so any device on the non-IP portion of the network does not raise the security concern cited above. However, the gateway device between them and the IP network needs to be cognizant of the device locality question.

An additional possible function of energy reporting is to enable data sharing for energy research in general including public policy purposes. For example, annual consumption for a specific brand and model of an appliance could be tracked across time for thousands of units to see how actual usage matches laboratory test procedures and to assess any degradation of performance over time. Many such uses of the rich data can be imagined. For the vast majority, it is not necessary to know the specific owner and address of the device; data could be anonymized to reference only a zip code, for example. In addition, some purposes don’t need the time granularity that a building owner might collect so that data could be aggregated in time. A trusted third party that would ensure anonymity would be helpful to have that could receive the data and do necessary processing before sharing with others; Consumers Union, for example, is a widely trusted organization in such matters.

Possible Additional Functions of Management Systems

The core utility of energy reporting is to provide information to building managers that they can use to save energy. Beyond the basic purpose of energy reporting, the data could be used for many other purposes, for the building owners and occupants, and for public purposes. Many useful IT technologies have been applied to usages not anticipated before their deployment, and/or unrelated to their original purpose. It is quite likely that energy reporting will follow this pattern. Each of these cases describes functionality or benefits that are not, or are not necessarily, related to the device’s primary function. This makes energy reporting different from most network interactions, and applicable to any type of device.

Billing

A common problem in improving building energy efficiency is that the party that makes a decision determining future energy use is not the one that pays for the energy it requires. This is most common in rental contexts (residential or commercial) which have a mixture of devices bought by the owner and by the tenants. Building owners could use energy reporting data to bill their tenants for energy they use based on time of use, type of device, or both (and if the tenant pays the bill, the reverse could be done). Third parties that own and/or manage specific energy-using equipment, such as a vending machine or set-top box, could pay for the electricity their

devices use to have the proper incentive to be efficient. Such financial arrangements would not be an electric utility relationship so that the accuracy requirements for revenue utility meters should not apply; the accuracy need only be agreeable to both parties.

Inventory

Energy reporting systems will automatically inventory devices in a building. Today, conducting inventories is usually an expensive manual process, done periodically by companies and government agencies. With energy reporting, inventories can be done at very low cost as often as is useful. Obviously, devices that do not implement energy reporting (principally because they do not communicate) will not appear in such inventories, but a partial list is better than none, and the device participation rate will expand over time. Energy reporting protocols could be used to report the location of a device within a building (though how a device determines its location is outside the scope of energy reporting). Energy reporting could also be used to identify unexpected usage during times when the location is unoccupied. It could also help in acquiring usage patterns to inform better equipment scheduling (e.g., based on occupancy data or equipment use) or aid in tracking equipment maintenance (e.g., filter and battery changes).

Operation and Maintenance

Devices that implement energy reporting could self-identify potential or definite maintenance issues or failures, as could management systems that receive the data. For example, a refrigerator that suddenly requires more energy per day to maintain its normal setpoint may have a compressor or gasket malfunction. This could be identified by observation of a significant and ongoing change in consumption patterns, or by observing that the device is using significantly more than test procedure results indicate it should. The concern could be flagged to building operators, or (on an opt-in basis) to manufacturers and/or public policy organizations.

Embedded Sensing

Other types of data that are unrelated to or abstracted from device functionality could be relayed with energy reporting protocols. For example, buildings may find it useful or important to know the ambient temperature around a device, and this could be a free or inexpensive way to get additional sources for temperature data. Ambient light and sound levels could be similarly reported, as could the device's assessment of occupancy of the surrounding space.

Components, Batteries, and Aggregations

While the starting point for energy reporting is on the entire individual device, in some cases it can be valuable to obtain data on components, for example, on a fan, motor, memory unit, or display. At least one protocol (EMAN) provides a standard mechanism for defining structures of nested components and ways to report on their energy status. An internal battery is just another component, albeit one that can produce energy in addition to consuming it. The reporting for the product as a whole represents its connection to external electrical systems, and would not be affected by power flows into or out of the battery. Devices or management systems that do not address components are not burdened by this additional complexity.

An aggregation is a summation of a collection of entities being reported on. These could be all the devices in a building location, all the devices on an electrical circuit, or all the devices of a certain type. In addition, an aggregation could sum across components, e.g., all fans inside of products in a building. An aggregation just needs a list (of unique identifiers) of the entities it covers.

Conclusions and Recommendations

The experience with creating a management system for the demonstration showed that doing so is highly practical and straightforward. Most of the effort required went to the integration of specific end-use devices; this can be mostly eliminated by using products that implement good technology standards for energy reporting.

It would be helpful to explicitly outline definitions of basic functionality for management systems that could be used as a guide by creators of management systems and referenced by programs such as ENERGY STAR.

CHAPTER 5:

Energy Reporting Codes and Standards

Introduction

LBNL subcontracted Energy Solutions to investigate policy options to enable adoption of energy reporting into building codes and appliance standards. This Policy Roadmap lays out a pathway for accelerating the adoption and deployment of energy reporting technology in devices and buildings through codes and standards. In this report, “energy reporting” is defined as the ability of an energy-using device that is associated with a building (e.g., HVAC and water heating equipment, appliances, plug loads) to collect information on its own energy use and report that information to network within the building. Although device-level monitoring and reporting is the primary focus of the research initiative, there are other mechanisms to collect energy use data such as circuit-level monitoring, submeters, and whole-building meters. When these other mechanisms are discussed in this report, it will be explicitly stated, such as “building-level energy reporting.” “Energy monitoring” will also be used to refer to external metering of energy use.

Section 2 of this Policy Roadmap provides a background on energy reporting and identifies where energy reporting has been adopted as a policy. Section 3 discusses barriers to establishing and implementing energy reporting policies. Section 4 describes the existing and future policy options for devices and buildings. Section 5 describes the short-, medium-, and long-term activities that could help encourage energy reporting to become more prevalent in the market.

Background

Energy codes and appliance and equipment standards serve as one of the nation’s most effective policies to improve energy efficiency, reduce greenhouse gas (GHG) emissions, and save consumers money. Appliance standards typically consist of mandatory minimum energy efficiency performance requirements, based on prescribed test procedures, that a given product must meet to be sold in the United States (in the case of federal standards) or a given state (for state-level standards). Appliance standards are highly cost-effective and result in significant energy savings while spurring technological innovation. Cost-effectiveness typically means that the increase in cost for a more energy efficient product is less than the cost of energy saved by the typical consumer over the lifetime of the product.

California adopted the first appliance efficiency standards in the 1970s, and other states quickly followed suit. This set the stage for the first national appliance standards prescribed in the mid-1980s implemented by the U.S. Department of Energy (DOE). Several subsequent legislative amendments have required DOE to amend these standards and have also expanded the list of products subject to regulation. The DOE now covers more than 60 products with appliance standards, representing about 90 percent of home energy use, 60 percent of

commercial building energy use, and 30 percent of industrial energy use (DOE, 2017b). Currently, 11 states plus the District of Columbia have existing state-level appliance efficiency standards, and California is a significant player by continuing to develop new efficiency standards for other products and technologies that are not covered by DOE's program through the California Appliance Efficiency Standards (Title 20). However, both state and federal appliance standards typically prescribe requirements based on performance, or how much energy is consumed by the product assuming a specific duty cycle and annualized (if possible). Therefore, energy consumption is often reported as an annual energy use metric of expected and it is not common for consumers to have a real-time understanding of their devices' actual energy consumption.

Like appliance standards, building energy codes provide guidelines for energy performance that must be achieved in new and altered buildings. Current United States federal law requires states that have building energy codes to compare the statewide code to model national energy codes whenever the DOE determines that the new edition is more energy-efficient than the previous one. States that have building energy codes must maintain their codes so they result in energy performance that is equal to or better than that achieved through the latest edition of the national model codes, ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) Standard 90.1: Energy Standards for Buildings Except Low-Rise Residential Buildings (ASHRAE, 2016) for nonresidential buildings or the International Energy Conservation Code (IECC) for residential buildings (International Code Council, 2017). Most states adopt the national model codes, but California has crafted its own code—the California Building Energy Efficiency Standards (Title 24, Part 6)—which the Energy Commission updates every three years. California's standards have exceeded the stringency of ASHRAE 90.1 and IECC (DOE, 2016). The implementation of building energy codes nationwide is estimated to have saved four quads of energy since 1992 (DOE, 2016).

In the United States, the built environment represents about 40 percent of energy use and 38 percent of GHG emissions (EIA, 2017). In both commercial and residential buildings, heating, ventilation, and cooling (HVAC) and lighting represent more than 50 percent of total building energy use (EIA, 2012). Plug loads represent about 11 percent of total energy consumption in residential buildings and about 20 percent of total energy consumption in commercial buildings and are steadily becoming a larger proportion of energy end use in the built environment (EIA, 2016). Plug loads include a variety of devices found in both commercial and residential buildings and can be defined as a product powered by means of an ordinary alternating current plug, such as computer monitors, phone chargers, and other smaller devices (Nordman & Sanchez, 2006). Although plug loads represent a growing energy load in buildings, more granular information about plug load energy use remains largely unknown and unmeasured. Energy reporting is an important tool to capture such data and apply it to achieve reductions in device and building energy use.

The goal of this chapter is to identify current and potential energy reporting policies and outline a path forward for adopting such policies in appliance standards and building codes, leveraging the demonstrations. The following section discusses energy reporting technology as

a provider of feedback that leads to reduced energy consumption. Estimations of the savings that have been attributed to previous and existing efficiency programs will be discussed, as will the impact of consumer behavior on those efficiency goals.

Barriers to Code Adoption and Potential Solutions

When evaluating the ability of a proposed code change, or measure, to be adopted into code, a variety of factors are considered. Matters of cost implications, policy alignment, and technology availability are all analyzed with consumers, manufacturers, and other stakeholders in mind. Particularly, in California, measures must realize energy savings to keep pace with ambitious statewide climate goals. All measures must meet the following minimum requirements to be successfully adopted into code:

- Measures must result in energy savings.
- Measures must be technically feasible.
- Measures must be market-ready, which means products or design strategies should be readily available and well-understood by designers, builders, and manufacturers.
- Measures must be cost-effective in most applications. They must show reliable and persistent energy cost savings.
- Measures should have a clear mechanism for compliance and enforcement.
- Measures must align with overarching policy goals.

Barriers to code adoption occur when a technology or energy-saving feature is not able to meet one or more of the considerations described above. Although energy reporting requirements have been adopted in national model energy codes (such as ASHRAE Standard 90.1) as well as voluntary appliance standards (such as ENERGY STAR[®]), device-level energy reporting for mandatory measures does not yet exist. Building-level end-use energy reporting also has not been adopted in California's energy code, and a standardized approach to energy reporting across devices and networks has not been adopted by the industry. Table 14 lists the specific, potential roadblocks to energy reporting policy are listed by order of importance.

Further discussion on each of these topics, as well as potential solutions, are presented with the goal of identifying and resolving roadblocks and facilitating mandatory energy reporting code adoption.

Energy Savings

Unlike many traditional efficiency measures, no direct energy savings can be achieved from mandating energy reporting. Overcoming the ambiguity of quantifiable and attributable savings associated with programmatic energy reporting efforts is noted in the literature as one of the most crucial factors in advancing the adoption of energy reporting policy. California can still make significant strides towards standardizing energy reporting through non-programmatic approaches that circumvent this potential roadblock. The Warren-Alquist Act (which

established the statewide authority of the Energy Commission to make California energy policy) established that new or updated energy efficiency standards and regulatory requirements must be proven to create “energy savings” that are “economically and technically feasible” (State of California, 2018). This is in keeping with provisions related to the creation of standards pursuant to the Energy Policy and Conservation Act of 1975 (EPCA),² which also clearly defines when and how standards can be created. However, it is possible to enact standards without clear proof of direct energy savings.

Table 14: Main barriers to adoption of energy reporting policy

Barrier	Appliances	Buildings
Energy Savings	X	X
Incremental Cost and Demonstration of Cost Effectiveness	X	X
Consumer Privacy	X	
Standardization in Data Models and Communications Protocols	X	X
Changes in Energy Reporting Technology	X	X
Compliance and Enforcement		X

In fact, the Warren-Alquist Act specifically articulates labeling as a potential energy saving measure, as the Energy Commission “may prescribe other cost-effective measures, including incentive programs, fleet averaging, energy and water consumption labeling not preempted by federal labeling law” (State of California 2018). The Energy Commission has demonstrated its willingness to use this authority by requiring labeling or testing that will indirectly result in energy savings, exemplifying an application of the Warren-Alquist Act. For example, in a recent Title 20 rulemaking for air filters, the Energy Commission enacted a regulation that mandated labeling (State of California, n.d. a) to achieve savings but did not create an associated efficiency standard (State of California, n.d. b). The Energy Commission has also enacted “Test & List” requirements for several products (namely, whole house fans, evaporative coolers, residential exhaust fans, and heat pump water chilling packages) (State of California, n.d. c) without simultaneously establishing efficiency standards for those products. Additionally, Joint Appendix 8 (JA8) of California’s Title 24, Part 6 also mandates labeling for single light-emitting diode (LED) luminaires and LED systems with no associated efficiency standard (California Energy Commission, 2013). As low-cost efficiency measures focused on implementing requirements (such as energy reporting devices) that result in non-technically derived savings (such as behavior changes that lower energy use) become more prevalent, a commonly used

² Among other requirements, EPCA states that a product must consume at least 150 kWh yearly for the U.S. Secretary of Energy to be authorized to establish an energy conservation standard for it.

methodology to calculate energy savings must evolve to encompass such practices. Additionally, this methodology should be standardized domestically to ensure fair efficacy in the reporting of standard compliance nationwide.

Though the energy savings directly attributable to energy reporting implemented in products are not fully understood, the Energy Commission can make important strides to further the proliferation of technologies that enable energy reporting. The Energy Commission's demonstrated support for labeling could easily be applied to energy reporting-enabled devices and may represent a prime opportunity to engage with industry. Similarly, requirements for manufacturers to test and report device data to the Energy Commission suggests that new standards can eventually be developed using a foundation of other indirect actions. Such reporting requirements could present an opportunity for California to gather information about energy reporting-enabled devices in the short term in service of longer-term goals.

Incremental Costs and Demonstration of Cost Effectiveness

While manufacturers could incur some incremental costs related to developing or updating software code, energy reporting will not require customers to purchase additional hardware, resulting in zero incremental costs to the customer. Energy reporting data will be received by an existing piece of hardware that already provides another service to the customer, such as a Wi-Fi router providing Internet access.

The Energy Commission requires a cost-effectiveness study be completed for proposed code changes to Title 20 or Title 24, Part 6. For measures or code changes to be formally adopted, they must demonstrate cost-effectiveness. Most measures demonstrate cost-effectiveness by balancing incremental costs (construction, hardware, software, installation, maintenance) with energy cost savings. Since energy reporting has no direct savings, measures will only be cost-effective if they also have no incremental costs to the customer. The Energy Commission might entertain factoring the indirect energy cost savings into a measure cost-effectiveness analysis if there were strong evidence that the specific energy reporting measure inspired changes in behavior that reduced energy use.

Even for measures that have zero incremental cost, demonstrating cost impacts likely will be a barrier to adoption for both Title 20 (appliance standards) and Title 24, Part 6 (building codes). It will be necessary to provide evidence of any difference in costs between current code or standard-level building technology and the technology that is capable of energy reporting; specifically, potential software and hardware costs (if any) will need to be explored and justified. Without well-informed cost data, the Energy Commission is not likely to adopt these regulations. In such scenarios, stakeholder pushback is likely and can delay or prevent new standards from being adopted.

There are several policy pathways where cost-effectiveness plays a less central role in the rulemaking process. States outside of California, such as Washington, have their own rulemaking process and have already passed building-level energy reporting standards that rely on other means of collecting energy use data apart from device-level monitoring and reporting. These requirements have lower thresholds for proving cost-effectiveness, and a higher reliance

on engineering or expert judgement. Within California, local cities also have jurisdiction to pass their own regulations that go beyond Title 24, Part 6 as long as they do not weaken the overall energy performance of buildings. Passing such local “reach codes” could be an effective method to integrate prescriptive energy reporting to energy codes prior to adoption at the state level.

There are solutions, working within Title 24 and Title 20, to demonstrate cost-effectiveness and circumvent the need for this analysis. Conducting case studies and collecting field data around actual energy reporting costs could support an argument that there are no incremental costs for energy reporting, and that existing code requirements already include the hardware and software needed to comply with controls requirements including reporting energy use data collected from meters or circuit-level monitoring.

The second solution to adopt measures facing scrutiny around cost-effectiveness is to introduce them into the California code as an optional measure. Measures that are not mandatory for all buildings—but instead are a performance option, a trade-off to a mandatory or prescriptive requirement, or a voluntary measure in the California Green Building Standards (CALGreen or Title 24, Part 11)—are not required to demonstrate cost-effectiveness. Often, a measure is first introduced into the building code as optional then made mandatory in future cycles once it becomes standard industry practice and has demonstrated cost-effectiveness in the field.

Consumer Privacy

In this report, energy reporting is defined as data that are kept within a local network, resulting in fewer privacy concerns than if data were transmitted over the Internet to known locations outside of the building or including the cloud. Privacy concerns could be remedied if energy reporting functions are enabled by default, as discussed in other sections of this report. However, consumer privacy is still a potential barrier since energy reporting requires an Internet connection, which has the potential to undermine user privacy and security. For example, many stakeholders expressed privacy concerns when the Energy Commission considered requirements for connected devices in past rulemakings. During the introduction of demand response-enabled thermostats during the 2008 and 2013 code cycles, stakeholders noted that data confidentiality was an implementation concern. While this proposal suggests that energy reporting-enabled devices will only display data to people within buildings and will not be available to third parties, privacy fears may still be prevalent among consumers. This is further complicated because Internet attacks on data are widespread and challenging to track or halt. Policy avenues as well as industry coalitions must work together to protect consumers, especially considering that energy reporting has the potential to facilitate demand response price-responses. Voluntary manufacturer agreements may spur technological advancement to protect data using software within the device. Similarly, labeling schemes could be utilized at the state or federal level to educate consumers about data risks.

Ultimately, manufacturers and policy makers must work together to break down barriers to the widespread implementation of energy reporting devices. While state policy can help address concerns of the public, manufacturers ultimately must create and standardize the hardware

and software energy reporting-enabled devices require to ensure ease-of-use and security risks are mitigated. Barriers will most likely require a combination of voluntary agreements and mandatory policy (discussed in subsequent sections) to be overcome.

Standardization in Data Models and Communication Protocols

As energy reporting-enabled devices proliferate in the market in various product categories, it will be important for each device to communicate information in a standardized way to the customer's central aggregating device, such as a smart tablet or an energy management and control system (EMCS). Currently, manufacturers of smart or connected devices use a variety of communications protocols, most of which can convey energy reporting data. These include Zigbee, Z-wave, BACnet, Ethernet, Wi-Fi, Bluetooth, CTA-2047, CTA-2045, EMAN, OpenADR, and REST APIs. These communications protocols differ widely depending on whether they are physical layer-only, physical layer and application layer, data link only, or application. Consequently, these various protocols are generally not compatible with each other, and developing new requirements for energy reporting would be easier to do if a limited number of protocols were accepted and used in code requirements. A limited number of protocols would reduce barriers for several reasons:

1. **Ease of referencing related standards:** If a limited number of protocols were used, it would be easier to reference other standards that set the requirements for cybersecurity and electrical safety. With the current scenario of numerous protocols, setting new requirements for energy reporting for devices in particular could face security and safety challenges.
2. **Communication improvements between multiple devices:** It would be cumbersome to integrate information from all devices in a building if they individually are designed to use different communication protocols.
3. **Features and data unable to be translated:** Through testing, it has been found that not all communication protocols are able to pass the same energy reporting information.

To be able to present granular data on energy reporting across multiple devices, it is important to establish a uniform minimum set of parameters that must be reported from every device. Establishing these data sets, also called the data model, is an important step to rectifying this lack of standardization. Consistent parameters will enable comparability across systems, cooperation with other software, and data validation. In addition to work described in Chapter 3, a manufacturer-centric foundation exists for such standardization, as noted by the Association of Home Appliance Manufacturers (AHAM), which is working to establish such standardization across governmental and association lines for smart connected devices through AHAM Standard SA-1-2014 (McGuire, 2016). Though it does not include energy reporting at this time, this industry effort would be a good forum to use to engage with stakeholders to propose uniform energy reporting requirements. A long-term strategy tracking

the progress of and participating in the development AHAM Standard SA-1 would complement parallel standardization efforts.

When making decisions about which communications protocols to reference in appliance standards or building codes, policy makers should aim to enable sufficient standardization, so devices are interoperable and data reported from devices can be compiled and aggregated seamlessly, while also providing sufficient flexibility to allow technology to continue to evolve and mature. Since communications protocols that could be used for energy reporting are still under development, this report does not recommend which protocols the appliances standards might reference to ensure devices are capable of energy reporting—or that building codes might reference to ensure building control systems can receive data from various energy end loads, including devices.

Changes in Energy Reporting Technology

Many typical policy avenues cannot keep up with the quickly evolving market surrounding energy reporting devices, so any policy created could become obsolete by the time it is in effect. To meet this challenge, measures must be flexible enough to accommodate the evolving market through two potential solutions. First, energy reporting devices could be regulated by grouping them by product category, to ensure that similar devices have the necessary software and existing hardware to enable energy reporting. Such a standard would simply define that energy reporting must be an available feature for all devices in the category, and not define the hardware or software mechanisms. Second, devices in general could be regulated as a group under building codes that are typically updated every three years, which is a shorter timeline than appliance standard updates. For example, the building code could add a code-compliance trade-off that would allow appliances with energy reporting capabilities to be installed to help meet code requirements.

Compliance and Enforcement

New requirements in building energy codes and appliance standards must be crafted such that they can facilitate compliance and that code officials have a way to enforce compliance. In California, the Energy Commission promotes and enforces compliance with energy standards and is authorized to adopt regulations designed to increase compliance.

At the device level, compliance and enforcement of energy reporting are relatively straightforward because a test standard or protocol can determine whether a device can meet the requirements. LBNL created a test protocol to test the energy reporting functionality of a device. This test protocol would need to be certified by a body, such as the Air-Conditioning, Heating, & Refrigeration Institute (AHRI) or ENERGY STAR, and then be adopted by the governing body, such as the Energy Commission. Testing agencies and companies can then determine if the device complies with the energy reporting requirements.

Compliance and enforcement of energy reporting requirements in building codes is more complicated. Unlike test standards that can definitively state whether a device or system is

code-compliant, requirements in a building energy code must comply in the field after being installed. Verification for most requirements also happens in the field when a code official determines that the building component as installed meets the requirement. Device-level energy reporting requirements cannot be enforced by building energy codes because most devices are purchased and installed after the building code compliance process is complete. In the short term, it is more practical to establishing energy monitoring, recording, and reporting requirements for devices like HVAC equipment, water heating equipment, and luminaires that are installed before building code compliance is completed. For example, it could be required that the energy use of major end uses such as HVAC and lighting be monitored and recorded separately and reported to the energy management control system (EMCS) and then could be verified by a code official. Such requirements already exist in the national model energy codes.

One potential pathway to regulate devices that are installed after occupancy through the building code is to establish controls requirements for the EMCS that control all energy loads within the building so the EMCS is capable of controlling devices that may be installed in the future.

Policy Options

The potential savings that can be achieved through energy reporting are well known, yet policies mandating this type of capability are scarce. Many missed opportunities to create valuable, effective energy reporting policy stem from a lack of understanding of the importance of consumer behavior in the success of energy reporting programs among policy makers (Energy and Environmental Economics, Inc., 2011). Additionally, important questions regarding energy reporting's relationship to privacy, data collection and dissemination methods, and security must be resolved uniformly. This section will detail the existing policy options to implement device-centered energy reporting programs and detail pitfalls in potential policies, and recommend the best policies to implement at the state and federal levels to further device energy reporting strategies.

Current Drivers: Existing Appliance Energy Reporting Policy

California continues to be a leader in implementing state laws and voluntary programs that further the usage of advanced metering and consumer consumption data for energy-saving purposes. Two laws, California Senate Bills (SB) 488 (approved October 11, 2009) and 1476 (approved September 29, 2010), ensure that utilities in the state have a vested interest in energy reporting programs and take steps to protect consumer data. A third law, California Senate Bill 350 (approved October 7, 2015), codifies strict efficiency and renewable grid-integration standards, which could further influence the proliferation of energy reporting programs.

The first of the three bills passed, SB 488, requires that publicly owned electric utilities have a “comparative electricity usage disclosure program[s]” (California Senate Bill 488 - Chapter 352, 2009) for the purposes of reporting the energy used by a residential customer relative to similar residences in the surrounding area (Consortium for Energy Efficiency, n.d.). SB 488 allows the Energy Commission to evaluate potential energy savings from any electrical corporation (utility). The second bill, SB 1476, introduces third-party entities into the process of

data dissemination, and requires that customers can receive third-party-generated energy usage data by the end of 2011 (Energy and Environmental Economics, Inc., 2011), and protects consumers from improper usage of the electric consumption data or their associated personal information (California Senate Bill 1476 - Chapter 497, 2010). The third bill, SB 350, sets renewable energy and efficiency standards by requiring the state to utilize energy efficiency and demand response techniques to double statewide efficiency savings by January 1, 2030 (California Senate Bill 350 - Chapter 547, 2015). While SB 1476 and SB 488 clearly target energy reporting programs, SB 350 may also aid in the proliferation of such programs as a mechanism to meet the state's statutory goals.

In addition to these legislative acts that mandate utility support of energy reporting programs, California also funds Flex Alert, a voluntary consumer-focused energy conservation alert program focused on saving energy in times of high demand but low supply, mainly through device-based energy saving suggestions (California Independent System Operator, 2017). Specifically, the program's three most common suggestions for saving energy are consistently thermostat adjustment, turning off lights, and utilizing devices during off-peak periods (Summit Blue Consulting LLC, 2008). While the program is not directly attributable to utility activities, state support has allowed the program to produce large savings through suggesting small behavioral changes (Summit Blue Consulting LLC, 2008), proving the power of behavior-gear energy reporting. The implementation of mandatory energy reporting at the building and device level has the potential to further support such efforts.

Federally, the U.S. Environmental Protection Agency (EPA) and DOE manage ENERGY STAR, a highly successful national voluntary program that certifies efficient and smart devices to reduce energy usage and GHG emissions while saving customers money. Currently, ENERGY STAR is the only nationwide program that specifically targets and supports the usage of energy reporting mechanisms in devices by improving consumer knowledge through labeling.

Beginning with a provision in the agreement between manufacturers and energy efficiency organizations finalized in July 2010 and subsequently incorporated into EPCA, ENERGY STAR includes requirements for certain products that have connected functionality. For a product to have connected functionality, it must include (among other features): a mechanism for bi-directional data transfers, communications hardware, remote management capabilities, demand response capabilities, and energy consumption reporting. Energy consumption reporting requires that "the product shall be capable of transmitting energy consumption data via a communication link to energy management systems and other consumer authorized devices, services, or applications" (US Environmental Protection Agency and US Department of Energy, 2018).

Currently, eight ENERGY STAR product categories contain products with criteria for connected functionality, and these categories total hundreds of individual models. Smart thermostats are the only product *required* to have connected functionality to receive ENERGY STAR certification, while all other product categories listed below include connected functionality as an option. Product categories include the following:

- Smart Thermostats³
- Clothes Dryers
- Clothes Washers
- Refrigerators
- Freezers
- Room Air Conditioners
- Light Bulbs
- Light Fixtures

These products provide a basis for mandatory energy reporting in state codes and prove that such functionality currently exists in the marketplace.

Current Drivers: Existing Building Energy Reporting Policy

California has set ambitious goals for achieving zero net energy (ZNE) buildings—by 2020 for new residential buildings, and by 2030 for new nonresidential buildings, as well as half of the existing commercial building stock. Because plug loads account for a significant portion of energy use in both residential and nonresidential building types, policy makers have been considering how to address energy use from plug loads through building codes. Energy reporting requirements that enable buildings to report energy use data to building managers and occupants can help achieve this goal because if people know how they are using energy they can modify their behavior to realize energy and energy cost savings.

Following the logic that knowledge about energy use can motivate change, the state of California has a statute in place—Assembly Bill (AB) 802—that requires large buildings to disclose energy use information on an annual basis. AB 802 mandated the Energy Commission to “create a benchmarking and disclosure program through which building owners of commercial and multifamily buildings above 50,000 square feet gross floor area will better understand their energy consumption through standardized energy use metrics” (California Assembly Bill 802 - Chapter 590, 2015). As a result of this bill, as of June 1, 2018, building owners are now required to report building characteristic information using ENERGY STAR Portfolio Manager on an annual basis. Starting in 2019, AB 802 will expand to require multifamily buildings (larger than 50,000 square feet) with 17 or more residential utility accounts to report their energy use data. AB 802 does not set mandatory energy reporting standards for all building types in California. Rather, the policy has focused on major building end uses and energy benchmarking for large commercial, and multifamily building types. Some local jurisdictions including San Francisco, Berkeley, and Los Angeles, have benchmarking requirements that are more stringent than the statewide requirements. See Table 15 for a summary of local and statewide benchmarking requirements.

Data collected in compliance with disclosure requirements serves as a benchmark to monitor each building’s energy performance over time and to compare the energy performance of similar buildings to identify opportunities for efficiency improvements. Most benchmarking

³ ENERGY STAR defines a smart thermostat as a Wi-Fi enabled device that automatically adjusts heating and cooling temperature settings.

policies only require the disclosure of whole-building energy use information reported annually, which is not sufficiently granular for utilities and consumers to understand energy use and prevents a more targeted effort for energy performance improvements. If buildings were capable of recording and reporting energy consumption of major end uses and devices, the data reported in compliance with benchmarking requirements would be more useful to building managers as they strive to maintain the energy performance of buildings over time. The data would also be more useful for jurisdictions, utilities, or third parties that aim to design programs to support energy improvements in existing buildings.

Table 15: Existing energy benchmarking and disclosure ordinances and statutes

Standard, Policy, or Mechanism	Measure Name	Type of Requirement (building-level, circuit-level, or device-level)	Measure Description
Local Ordinances	San Francisco	Building	Publicly and privately owned nonresidential buildings $\geq 10,000$ ft ² must: 1. Benchmark building energy use using the ENERGY STAR Portfolio Manager and report results to the San Francisco Department of Environment and tenants on an annual basis. The annual report must present: Contact information and ft ² , energy use intensity (EUI), 1–100 Performance Rating provided by Portfolio Manager, where applicable, and GHG emissions from energy usage. 2. Perform and audit once every five years. Requires ASHRAE Audit Level II or higher for buildings $\geq 50,000$ ft ² and ASHRAE Audit Level I or higher for buildings 10,000–49,999 ft ² .
Local Ordinances	City of Berkeley Building Energy Savings Ordinance (BESO)	Building	The BESO includes benchmarking and audit requirements for all buildings >600 ft ² with effective dates and frequency of reporting varying by building type and size: 1. Nonresidential buildings $\geq 25,000$ ft ² must report energy use to the City of Berkeley Director of Planning and Community Development through the ENERGY STAR Portfolio Manager annually and submit an energy assessment every five years. 2. Nonresidential buildings $<25,000$ ft ² must submit energy assessment every 10 years and at the time of sale. 3. Small residential (1–4 dwelling units) must complete an energy assessment at the time of sale.
Local Ordinances	City of Los Angeles Existing Buildings Energy and Water Efficiency Program (EBEWE Program)	Building	Owners of certain types of buildings are required to disclose their building's energy and water consumption using ENERGY STAR Portfolio Manager to the City of Los Angeles Department of Building and Safety. Applies to: 1. City-owned buildings $\geq 7,500$ ft ² . 2. Owned by local agency of the state $\geq 20,000$ ft ² . 3. Privately owned buildings $\geq 20,000$ ft ² and city-owned buildings $\geq 15,000$ ft ² must submit initial audit and retro-commissioning reports every five years.

State Statutes	Building Energy Benchmarking Program (AB 802)	Building	Owners of buildings $\geq 50,000$ ft ² with must report annual energy use to the California Energy Commission through the ENERGY STAR Portfolio Manager. This requires utilities to provide building owners with building-level energy-use data.
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Finally, as discussed in the previous section, California’s electricity disclosure laws for utilities (SB 488 and SB 1476) and supporting framework, such as Flex Alert and other energy disclosure programs, help set the foundation for energy reporting requirements in general.

For buildings, these bills underscore the need for advanced building-level energy monitoring and reporting so that accurate energy use data are readily available to support voluntary programs and state-wide energy goals.

Voluntary Policy Opportunities for Devices

Voluntary policies for devices may be an effective strategy to integrate energy reporting capabilities into hardware. Use of the market to transform the existing device stock ahead of mandatory regulations will allow manufacturers more time to innovate and refine energy reporting technology and communications protocols. Strategies to influence the market in the direction of energy reporting-enabled devices, including the following:

- Expansion of ENERGY STAR products meeting the connected guidelines
- Appliance upgrade rebates (supported by states or the federal government)
- Coordinated international trade agreements to drive device demand
- Negotiated manufacturer pacts

The expansion of individual products currently classified as having connected functionality in the ENERGY STAR database could lead to a nationwide effort to move devices towards enveloping more energy reporting components. The United States has a recent history of championing efficient devices through structured rebate programs meant to dramatically alter the existing device stock. One example of such a program to date is the State Energy Efficient Appliance Rebate Program (SEEARP), which was in operation from 2009–2012 and provided \$300 million to be shared among individual states and protectorates to aid consumers in making long-term energy investments (DOE, n.d.). Appliances qualified for rebates based on federal criteria (and in some cases, additional state criteria), mainly based on meeting or exceeding ENERGY STAR specifications for qualifying product categories. This program type proved highly successful, saving 161 million gallons of water and 35 billion British thermal units (BTUs) per year in the state of Washington alone (DOE, 2013). Should a similar program be implemented in the future, devices with connected, energy reporting functionality could carry the potential of larger incentives on the state or federal level to increase their attractiveness.

Manufacturer-centered negotiations also carry multiple benefits for the enactment of more energy reporting policy, particularly regarding devices. Manufacturers tend to be receptive to

voluntary agreements regarding appliance standards because they lend market clarity and alignment and avoid a patchwork of state appliance standards (Environmental and Energy Study Institute, 2017). From the standpoint of the evolution of policy, voluntary agreements are often a crucial stepping stone to eventual mandatory policy. Many countries that encourage manufacturer negotiations for products often complete transitions to prescriptive standards (World Energy Council, 2008), such as the eventual evolution of ENERGY STAR specifications into DOE regulations. Similarly, states can also drive change by facilitating voluntary manufacturer agreements for a state or group of states, leading to an economy of scale (Environmental and Energy Study Institute, 2017). Manufacturer agreements may encourage innovation that could spur the inclusion of energy reporting capabilities in newly marketed devices.

International trade agreements also can have a profound impact on furthering energy reporting capability in devices, as well as energy efficiency goals in general. While the underlying premise of agreements is mandatory in nature, countries enter into such agreements voluntarily. This “harmonization” of complex trade systems could be leveraged to integrate wide-scale device energy reporting programs, and has been noted as a necessary tool to achieve the ambitious world carbon reductions envisioned by the Paris Agreement (Yada et al. 2017).

While continued ENERGY STAR labeling and the integration of new products into voluntary standards may help aid the proliferation of energy reporting-enabled devices, it should be noted that innovation is often spurred by a combination of voluntary and mandatory tactics. Increased labeling and participation in voluntary programs both have the potential to shift the market to a stagnant state where there is little incentive left to innovate (World Energy Council, 2008). It is mandatory initiatives that “phase-out” less efficient devices (which most likely are not connected or have energy reporting capability), forcing a shift in stock traits (World Energy Council, 2008).

Voluntary Policy Opportunities for Buildings

The primary opportunities for voluntary building codes include introduction of optional design pathways to Title 24, Part 6 and development of requirements for model reach codes. The Energy Commission must demonstrate that proposed changes to mandatory and prescriptive building requirements in Title 24, Part 6 are cost-effective. In some cases, the code provides alternative pathways that a designer can voluntarily follow to comply with a mandatory or prescriptive requirement. For example, the 2019 Title 24, Part 6 standards offer an option for designers to install demand responsive thermostats and a home automation system that is capable of responding to demand response events and controlling appliances and lighting *instead* of pursuing the mandatory solar-ready requirements (Exception 6 to Section 110.10(b)1A). Similarly, the primary prescriptive pathway for single-family homes calls for the use of a gas instantaneous water heater, but designers have the option of installing a heat pump water heater in conjunction with other defined efficiency measures instead (Section 150.1(c)8A).

It may be possible to introduce a voluntary energy reporting requirement that relies on data collected from devices or some other monitoring technique (e.g., circuit-level monitoring) into Title 24, Part 6 using this pathway of designer alternatives. While this approach allows for new measures to be introduced to the building code gradually, the Energy Commission aims to adopt mandatory and prescriptive requirements without alternative pathways to avoid complex code language and resulting challenges with compliance and enforcement. Alternative approaches are often only considered if there are legitimate reasons why some designers might not be able to comply with the primary requirement due to technical, cost, or other practical reasons and a workaround is necessary to ensure all buildings have a pathway to compliance.

Energy reporting could also be introduced into Title 24, Part 6 as a voluntary performance option. Under this approach, the Energy Commission could update the compliance software used to model residential and nonresidential buildings so designers that implement an energy reporting strategy in their buildings receive credit for doing so when they calculate the energy performance of their building. Pursuing a performance option could result in a small credit being offered for several years until there is sufficient data that can be used to update the credit so it more closely matches the realized energy savings.

Outside of Title 24, Part 6, there could be opportunities to introduce energy reporting requirements in model reach codes such as ASHRAE Standard 189.1: Standard for High-Performance Green Buildings Except Low-Rise Residential Buildings, or CALGreen. These model reach codes are written in code-enforceable language and can be adopted in their entirety or with amendments. The U.S. Army Corps of Engineers has already adopted ASHRAE Standard 189.1. Language in model reach codes can also serve as a starting point for local jurisdictions that aspire to adopt local reach ordinances but need to tailor the requirements to account for local needs. Adopting language into a model reach code can be a good way to test out new or innovative codes to see if they gain traction among builders or jurisdictions. Some, but certainly not all, requirements that have been in model reach codes for one or more code cycle are considered for adoption into mandatory building codes. However, inserting an energy reporting requirement into a model reach code for several code cycles would not necessarily help overcome the hurdle of demonstrating cost-effectiveness that must be achieved before the Energy Commission would consider adopting the measure into Title 24, Part 6 as a mandatory or prescriptive requirement.

There is an option to work with local jurisdictions to craft energy reporting reach codes that would be mandatory only within that jurisdiction. Since local ordinances are mandatory within a jurisdiction, local reach codes are discussed in the In the last decade, many states have shifted towards implementing ambitious energy-saving and efficiency-increasing initiatives, which could be leveraged and combined with voluntary tactics to increase the propagation of devices with energy reporting capability built in. State-level energy efficiency research standards (EERS) currently exist in 26 states, with seven states (including California) mandating that EERS implemented by utility entities must be cost-effective . As previously noted, because behavior-based energy reporting strategies are often implemented for a low cost, these programs stand to become a crucial piece of reaching these state targets. Similarly, many states

also implement mandatory device energy efficiency standards (for devices not preempted by federal law), which could be leveraged to include provisions for mandatory device-level energy reporting capabilities. As noted by the Appliance Standards Awareness Project (ASAP), states are often the first to implement cutting-edge appliance standards, influencing the federal government to follow suit .

Through voluntary federal standards and mandatory state standards, minimum efficiency performance standards (MEPS) often emerge. While most device efficiency standards in the United States are in the form of MEPS , there are no standards mandating the incorporation of energy reporting software into efficient devices. While this feasibly could be integrated into national MEPS, in order to stem anticipated market lags achieving a product base and qualified technicians to serve efficient devices with new features , voluntary standards could be a vital first step. Concurrently, the literature also identifies protocols for the testing and measurement of devices as critical elements for improving energy efficiency . Such protocols will be equally vital to ensure that energy reporting data are measured and delivered uniformly to customers.

Mandatory Policy Opportunities for Buildings section of this report.

Although evaluating voluntary building rating systems is outside of the scope of this report, adopting energy reporting requirements into voluntary building rating systems would be a helpful step in pursuing energy reporting requirements in building codes. Doing so could help increase the prevalence of energy reporting in buildings, allowing industry to address outstanding technical barriers and improve market readiness. The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program is a voluntary building performance rating program that rates the performance of buildings designed to perform above the minimum code. It provides credit for advanced energy metering that includes requirements for energy reporting of all fuel sources at the end-use level, and includes requirements for data recording, storage, and accessibility.

Mandatory Policy Opportunities for Devices

In the last decade, many states have shifted towards implementing ambitious energy-saving and efficiency-increasing initiatives, which could be leveraged and combined with voluntary tactics to increase the propagation of devices with energy reporting capability built in. State-level energy efficiency research standards (EERS) currently exist in 26 states, with seven states (including California) mandating that EERS implemented by utility entities must be cost-effective (American Council for an Energy Efficient Economy, 2017). As previously noted, because behavior-based energy reporting strategies are often implemented for a low cost, these programs stand to become a crucial piece of reaching these state targets. Similarly, many states also implement mandatory device energy efficiency standards (for devices not preempted by federal law), which could be leveraged to include provisions for mandatory device-level energy reporting capabilities. As noted by the Appliance Standards Awareness Project (ASAP), states are often the first to implement cutting-edge appliance standards, influencing the federal government to follow suit (Appliance Standards Awareness Program, 2017).

Through voluntary federal standards and mandatory state standards, minimum efficiency performance standards (MEPS) often emerge. While most device efficiency standards in the United States are in the form of MEPS (Weil & McMahon, 2001), there are no standards mandating the incorporation of energy reporting software into efficient devices. While this feasibly could be integrated into national MEPS, in order to stem anticipated market lags achieving a product base and qualified technicians to serve efficient devices with new features (Weil & McMahon, 2001), voluntary standards could be a vital first step. Concurrently, the literature also identifies protocols for the testing and measurement of devices as critical elements for improving energy efficiency (International Energy Administration, 2011). Such protocols will be equally vital to ensure that energy reporting data are measured and delivered uniformly to customers.

Mandatory Policy Opportunities for Buildings

The primary policy opportunities for mandatory building codes are adopting energy reporting requirements in model building energy codes, state building codes, and local building codes. National model energy codes, such as ASHRAE Standard 90.1 and the 2018 International Energy Conservation Code (International Code Council, 2017), are model mandatory energy codes that many states adopt as their statewide building codes. Including energy reporting requirements in national model energy codes will lead to mandatory statewide requirements as states adopt the model code. Adopting energy reporting requirements into model codes also can influence states that have their own energy code, like California, which often aims to adopt requirements that meet or exceed ASHRAE Standard 90.1 and IECC in terms of energy efficiency performance. ASHRAE Standard 90.1 already includes requirements that certain major energy end uses report their energy use. See Table 15 for a summary of the requirements in ASHRAE Standard 90.1.

As mentioned, most states adopt model building energy codes as their energy code. However, California develops its own energy code. There is an opportunity to work directly with the Energy Commission to adopt mandatory or prescriptive requirement into Title 24, Part 6.

Local jurisdictions can adopt more stringent building codes (reach codes) than are required statewide. Reach codes can serve as examples that can lead to changes to state building codes and national model codes. The measure may be cost-effective at the local level because of favorable utility rates, rate structures, or other economic parameters that are local to the region. Local jurisdictions sometimes have more aggressive energy and climate goals than state or nationwide goals, which motivate more aggressive interventions on a local level. Other barriers, such as manufacturers' ability to meet demand if a statewide standard is adopted and concerns about applicability across climate zones and building types may not be applicable. Many states, including California, allow local jurisdictions to adopt local building code ordinances that are at least as stringent as the statewide building code. Thirteen local jurisdictions in California have adopted ordinances that are more stringent than 2016 Title 24, Part 6. Additionally, once measures are proven in the field, it is easier to push them for adoption into state and national codes. An excellent example is the air leakage testing measure, which was first introduced in the Seattle energy code, then adopted by the Washington State Energy Code, and now is part of ASHRAE Standard 90.1-2016.

Cities across the United States, such as Boston, New York City, Chicago, and others, already require annual whole-building energy reporting. Specifically, New York City also requires standardized protocols when submitting data (New York City Mayor's Office of Sustainability, 2019). Some of these programs serve as a benchmarking tool, though requiring end-use energy reporting at the building level would be an appropriate next step, if it is not already part of the policy or energy code.

Activities

Considering the background and policy landscape for energy reporting in California, there are short-term, medium-term, and long-term activities that can advance adoption of energy reporting requirements in building energy codes and appliance standards. Title 24, Part 6—as well as national model energy codes, such as ASHRAE Standard 90.1 and the IECC—operate on a three-year cycle. Amendments to California's building and appliance standards are subject to lengthy and public engagement processes throughout each adoption cycle. As such, advocacy activities for building energy codes are time-bound and more time sensitive than activities related to appliance standards, such as Title 20 for California, which operate on a continuous, rolling cycle. The following chronological approach to activities lays out a roadmap for implementing energy reporting requirements in building energy codes and appliance standards.

Short-Term (0–1 year)

Appliance Standards

For appliance standards, the short-term step is to better understand the implementation, barriers to adoption, and savings potential for energy reporting currently in products, specifically through data collection efforts leveraging ENERGY STAR. ENERGY STAR includes criteria for energy consumption reporting for certain product categories with connected product criteria. For a product to have connected functionality, it must include (among other features) the following:

- A mechanism for bidirectional data transfers, communications hardware
- Remote management capabilities
- Demand response capabilities
- Energy consumption reporting⁴

Two products are being considered by the EPA where connected functionality may be required: uninterruptible power supplies and residential water heaters. As mentioned previously, there

⁴ Energy consumption reporting requires that “the product shall be capable of transmitting energy consumption data via a communication link to energy management systems and other consumer authorized devices, services, or applications.”

are seven other product categories where connected functionality is optional, listed in the Options section of this report.

Further understanding of these products and implementation of energy reporting will also necessitate outreach to manufacturers, EPA, and consumers of products where energy reporting is currently available.

Building Codes

Short-term activities, over a one-year timespan, must focus on identifying and prioritizing specific energy reporting measures, also known as *high priority measures*. As part of this project, several existing and potential measures related to energy reporting were identified and are described below. These measures must be vetted and prioritized in terms of their applicability into various energy codes. Table 16 shows a list of measures that are already required in ASHRAE Standard 90.1; Title 24, Part 6; or in local ordinances and California state laws. Table 17 shows a list of measure ideas for Title 24, Part 6; ASHRAE Standard 90.1; the IECC; and California state law.

Table 16: Existing building energy reporting requirements in national and local energy codes and standards

Standard, Policy, or Mechanism	Measure Name	Type of Requirement (building-level, circuit-level, or device-level)	Measure Description
Title 24, Part 6	Separation of Electric Circuits for Electrical Energy Monitoring	Circuit	Requires electrical circuits in certain buildings to be designed so similar load types (e.g., all lighting, water heating, HVAC, plug loads) are on same circuits.
Title 24, Part 6	Service Electrical Metering	Building	All meters must have capability to meter instantaneous kW demand and track kWh use for a user-defined period. Meters for buildings where electrical service is rated at more than 250 kilovolt-amperes (kVA) must be capable of tracking historical peak demand and meters for buildings where service is rated at more than 1,000 kVa and must track kWh per rate period.
Title 24, Part 6	Energy Management Control System (EMCS)	Building	EMCS systems are never required, but they are defined in the standards and designers are allowed to use EMCS to comply with lighting and HVAC controls requirements in Title 24. If an EMCS is installed, acceptance tests must be conducted to ensure it is commissioned properly.
ASHRAE 90.1	Direct Digital Control (DDC)	Building	DDC systems are required in certain building types. DDC systems are mostly controlled by an EMCS, which also provides the ability to perform energy monitoring, recording, and reporting.

Standard, Policy, or Mechanism	Measure Name	Type of Requirement (building-level, circuit-level, or device-level)	Measure Description
ASHRAE 90.1	Chiller Monitoring Requirements	Circuit	Some electric-motor-driven chilled water plants (capacity thresholds that vary by climate zone) must have measuring devices that measure electric energy use and efficiency of the plant. Energy use and efficiency shall be trended every 15 minutes and graphically displayed and include hourly, daily, monthly, and annual data. The system shall maintain all data collected for a minimum of 36 months.
ASHRAE 90.1	Energy Monitoring	Circuit	Measurement devices are required to be installed in new buildings larger than 25,000 sf to monitor the electrical energy use for each of the following separately: total electrical energy, HVAC systems, interior lighting, exterior lighting, receptacle circuits.
ASHRAE 90.1	Energy Recording and Reporting	Circuit	Electrical energy use for loads required to be monitored are required to be recorded a minimum of every 15 minutes and reported at least hourly, daily, monthly, and annually.
ASHRAE 90.1	Fossil fuel site use monitoring and reporting (submetering)	Building	Measurement devices are required to be installed to monitor the energy use of the following types of energy: Natural gas, fuel oil, propane, steam, chilled water, and hot water. Buildings smaller than 25,000 sf are exempted. The energy use of each building on the building site is required to be recorded at a minimum of every 60 minutes and reported at least hourly, daily, monthly, and annually.
ASHRAE 189.1	Energy Consumption Management	Circuit	Requirements to monitor fuel use (electricity, natural gas, others), collect data on hourly basis, and store data for 36 months. Submetering of HVAC, lighting, plug, and process loads is required for buildings meeting certain thresholds.
ASHRAE 189.1	ENERGY STAR Equipment	Device	ENERGY STAR-rated equipment is required for specific products, heating and cooling equipment, water heaters, electronics, office equipment, lighting, commercial food service, and other products.
ASHRAE 189.1	Track and Assess Energy Consumption	Building	Requirements for documenting, benchmarking, and assessing energy performance on a periodic basis using energy reporting are in Section 7.3.3.

Table 17: High-priority energy reporting measure ideas for building energy codes and standards

Standard, Policy, or Mechanism	Measure Name	Type of Requirement (building-level, circuit-level, or device-level)	Measure Description
Title 24, Part 6	Circuit-level Energy Reporting	Circuit	Require circuit-level energy monitoring and reporting to align with the ASHRAE 90.1 requirement.
Title 24, Part 6; ASHRAE 90.1; IECC	Energy Reporting User Interface for Nonresidential Buildings	Building	Many building owners and building industry professionals have specified energy displays to be mounted in office lobbies. In most cases, these displays show real-time data of energy and water consumption and use. These displays are generally informational only and do not provide control of the underlying building systems. This is different from conventional Building Management Systems or Energy Management Control System (EMCS) that offer control of the underlying building systems. Although energy displays in lobbies have been relatively popular in sustainability-oriented buildings, the current shift in the industry is towards providing larger picture buildings analytics and continuous commissioning, of which energy displays may play a part. These displays can inspire behavioral changes that lead to energy savings.
Title 24, Part 6; ASHRAE 90.1; IECC	Update Metering and Submetering Requirements for Multifamily Buildings	Circuit	This measure would review the existing requirements for metering and submetering multifamily buildings and would recommend revisions, as appropriate, to help building owners and occupants understand energy use in the building which could help inspire continuous improvement.
Title 24, Part 6 ASHRAE 90.1 IECC	Encourage use of connected equipment and devices	Device	Explore opportunities to update the building code to give builders credit for using connected devices. This would likely be as a trade-off to mandatory requirements or as part of an alternative prescriptive option.
Title 24, Part 6	Energy Reporting Requirements for Controlled Receptacles	Circuit	Consider updating existing requirement for controlled receptacles so the receptacles report out energy use in on/off/standby mode function to building owners. If connected devices capable of energy reporting are installed, a credit could be provided in the performance path.

Standard, Policy, or Mechanism	Measure Name	Type of Requirement (building-level, circuit-level, or device-level)	Measure Description
Title 24, Part 6	Update EMCS requirements to require energy reporting	Building	EMCS are never required, but they are defined in the standards and designers are allowed to use EMCS systems to comply with Title 24 lighting and HVAC controls requirements. If an EMCS is installed, an acceptance test must be conducted to ensure it is commissioned properly. Consider updates to require energy reporting of major building end uses through EMCS.
State Statutes	Update AB 802 (Energy Benchmarking and Disclosure) to include more building types	Building	Consider expansion to AB 802 to more building types. Currently, it is required in 2018 for commercial buildings with more than 50,000 sf of gross floor area and no residential buildings. Starting in 2019, buildings with 17 or more residential utility accounts (multifamily buildings) will be required to meet AB 802.
Title 24, Part 6	Chiller Monitoring Requirements	Circuit	Consider adopting the chiller monitoring requirements in ASHRAE 90.1 into Title 24.

The next step would be to evaluate these measure ideas in greater detail and begin the process of submitting ideas, as appropriate, to the various policy avenues.

Medium-Term (1-3 years)

Appliance Standards

With an understanding of how the technology is being implemented and using data from ENERGY STAR, more thorough energy modeling would need to be conducted in the medium-term to confirm potential energy savings and help identify specific products or group of products that the Energy Commission would consider applying an energy reporting requirement to in Title 20. Also, a more thorough technical feasibility study is needed to ensure no manufacturers would be adversely impacted. The Energy Commission’s open docket on Low-Power Mode Roadmap (Docket: 17-AAER-12) could be a good opportunity to propose energy reporting requirements.

Provided alongside this policy roadmap is a proposal to include energy reporting requirements for Title 20 appliance standards. The proposal requires separate energy monitoring, recording, and reporting of devices with a range of options for scope of coverage. The proposal was developed using the Energy Commission template and includes all the information needed by the Energy Commission to adopt the requirement. As the proposal moves through the code development process, the Energy Commission and other stakeholders will have the opportunity

to ask questions and comment on it. These comments are likely to be around the topic of incremental cost and cost-effectiveness of the new requirements.

Additional medium-term activities also include: expanding the ENERGY STAR provisions to new product categories and further refining the voluntary requirements currently in place, and studying installments of equipment with energy reporting technology to better understand consumer behavior.

Building Codes

Medium-term activities represent a continuation and natural succession of short-term activities. High-priority energy reporting measure ideas that would have been identified previously will be developed into measure proposals for various energy codes, standards, and state laws. These measure proposals will be followed through the code development process and may include navigation of public review and rulemaking processes.

As with the appliance standards, provided alongside this policy roadmap is a measure proposal for Title 24, Part 6, based on major end-use energy reporting requirements in ASHRAE Standard 90.1. The proposal requires separate energy monitoring, recording, and reporting of major end-uses, including HVAC, interior lighting, exterior lighting, and plug and process loads when EMCS are installed in a building. The proposal also has been developed using the Energy Commission template and includes all the information needed by the Energy Commission to adopt the requirement. As the proposal moves through the code development process, the Energy Commission and stakeholder comments are likely to be around the topic of incremental cost and cost-effectiveness of the new requirements.

In the next two to three years, outreach should be conducted to solicit feedback from industry partners, device manufacturers, and organizations representing industry, such as the National Electrical Manufacturers Association (NEMA). The measure proposal may be modified and bolstered through the support of these industry partners. Finally, the measure proposal will go through the Title 24 rulemaking process, including at least two rounds of public review. During this stage, the proposal authors will be required to review language iterations released by the Energy Commission and ensure that the requirements and their intent remain intact and are successfully adopted.

This proposed change for the 2022 code cycle will leverage existing controls requirements in Title 24, Part 6 to create a foundational requirement that energy end uses must monitor their own energy use and convey that information to a central location within the building. Although this requirement does not go as far as requiring device-level energy monitoring and reporting, it will lay the groundwork for a device-level requirement to be considered in the future. Given the burden of proof that is required to successfully advocate for a code change, it is not realistic to get all the way to a device-level reporting requirement in one code cycle. If the proposed change to the EMCS requirements are adopted for the 2022 code cycle, it may be possible to pursue device-level reporting requirements for some end uses in the 2025 cycle.

Long-Term (4–10 years)

Appliance Standards

A long-term goal would be to include energy reporting requirements in every energy efficiency standard. Adoption of requirements (and more evidence of energy savings as a result) in Title 20 could set the stage for adoption at the federal level. This has been done with a number of products through National Appliance Energy Conservation Act (NAECA) of 1987, Energy Policy Act (EPA) of 2005 and Energy Independence and Security Act (EISA) of 2007. Though DOE is likely constrained by EPCA on regulating such as design standard, one longer term approach could be inclusion of energy reporting provisions in an energy bill for products covered by DOE's Appliance Standards Program that, if passed and signed into law, would eventually update EPCA.

Building Codes

Once measures are successfully adopted into a building energy code, they are implemented in buildings and provides an opportunity to receive feedback and gather field data related to compliance, ease of implementation, and other impacts on cost and constructability. It is important to monitor the impact of new requirements in the code and make adjustments, as needed, in the next code cycle. Sometimes, new requirements are introduced as optional (not mandatory) and depending on their success in the field, have the potential to become mandatory in the next code cycle. The energy code, in general, also requires maintenance to keep it aligned with industry standards (for example, by updating references to test standards) and best practices. Requirements introduced in one code cycle can also be strengthened in the next few cycles as the market gains knowledge of the requirement and it becomes common practice.

Energy reporting technology is changing rapidly. It is important to track the changes in technology and how they relate to the energy reporting requirements in the code. Newer, simpler implementations that may be less costly can open the door to strengthening the requirements. Other concerns, such as those of privacy, may also be alleviated by improvements in security in the future. These changes could make energy reporting for buildings more agreeable to building owners. Advances in communication protocols, data standards, and device capabilities also could require adjustments to existing code language.

The Title 24, Part 6 measure proposal, submitted alongside this report, does not place energy reporting as a mandatory measure for all buildings in California. In subsequent code cycles, as energy reporting becomes common practice, additional submetering, recording, and reporting requirements could be placed. Based on energy savings data collected from buildings that include energy reporting systems, and new cost information from EMCS and device manufacturers, the energy reporting requirements could be expanded. Some of the other measure ideas that are presented in Table 17 also could be proposed. This is a continuous, iterative process where short-term and medium-term activities would be repeated.

Summary

This report identified policy avenues for energy reporting requirements for connected devices and described the steps to implement energy reporting into energy efficiency standards in California and nationwide. As the demand for connected devices increases, codes and standards (voluntary and mandatory) can promote the use and development of energy reporting, resulting in more accurate energy data that will inform future energy efficiency policies.

CHAPTER 6:

Project Benefits

Details

Energy reporting renders the energy use of plug load devices visible and controllable. California ratepayers will benefit from significant energy and cost savings once it is widely deployed. Standardization of key communication features will support broad adoption and create a friendly environment for further technological innovation. Use of a price signal to indirectly control devices can obtain load-shifting and peak-trimming benefits to save money and help with renewables integration. Energy reporting technology will enable these benefits without increasing the manufacturing cost of products. This section reviews the various benefits expected to be spawned by this project. It first reviews the quantitative estimates and then assesses qualitative aspects.

Quantitative Estimates, Timeframe, and Assumptions

Most plug-load energy use occurs in residential and commercial buildings. The Energy Commission estimates⁵ that miscellaneous energy use (including lighting), televisions, and pools—the closest surrogates for plug loads—account for over 40 percent of total residential electricity use, or 32 TWh/year. In commercial buildings, the California Commercial End-Use Survey concluded that miscellaneous and office equipment is responsible for about 24 percent of California’s total electricity use, or 20 TWh/year. Because definitions of plug loads differ, the percentages are approximate. Nationally, the category labeled “other” energy use in all buildings is responsible for about 25 percent of (primary) energy use in buildings. Plug loads consume more than 50 TWh/year in California buildings, and there is considerable evidence that the energy used by plug loads is increasing.

Savings attained by energy reporting will be achieved primarily as devices are replaced through turnover. Plug-load devices, particularly electronics, are replaced more rapidly than other energy-using devices. It is, however, impossible to project precisely when specific types of devices will be replaced and how much savings will be achieved by the collection of data and the control mechanism. Given an incremental cost of zero, however, even a low penetration of the technology will be highly cost effective. The most useful way to consider savings from energy reporting is to assess the savings if all electric plug-load devices had an energy-reporting capability and then estimate the percentage of all devices that incorporate energy reporting at any future time. Because devices that use more energy are a higher priority for energy reporting, they should be expected to obtain it more quickly. For technology savings, a conservative estimate is that the availability of energy reporting data to building owners and

⁵ Data from GFO-15-310, Attachment 12. These reflect only consumption in investor-owned utility areas and so underestimate the total consumption of plug loads in California.

occupants will lead to a 5 percent reduction in plug load electricity use. To be conservative, this estimate only includes savings from electronics and miscellaneous devices. The Energy Commission also includes appliances in the plug load category, and energy reporting should help to achieve additional savings from appliances as well.

Table 18 shows quantitative estimates of potential benefits to ratepayers after energy reporting is fully implemented. Benefits are presented in terms of electricity savings, reduced electricity demand, and reductions in GHG emissions. Estimates are based on the 2014 data on the energy use of miscellaneous and electronic products provided by the Energy Commission. It is notable that the Energy Commission data forecast a 50 percent growth in this energy consumption category in the residential sector over the subsequent 10 years; reducing that growth is a key motivation for implementing energy reporting.

Table 18. Savings in electricity, GHG emissions, and dollars from energy reporting

Sector	Electricity Savings (TWh/year)	Demand Reduction (GW)	GHG Emissions Reduction, CO₂ equiv. (Gigatonnes/year)	Retail Electricity Cost Savings (\$billion/year)
Residential	1.6	0.25	1.1	0.5
Commercial	1.0	0.12	0.7	0.3
All Buildings	2.6	0.37	1.7	0.8

Notes: Columns may not add to the total for all buildings because of rounding. Data obtained from GFO-15-310, Attachment 12. Residential demand factor derived from prior Energy Commission data. Commercial demand factor assumes flat load.

The direct effect of energy reporting on peak demand will be small but still significant—about 0.37 GW. In the residential sector, for example, the Energy Commission estimates that uses in the miscellaneous category (plus lighting) are responsible for only 24 percent of peak demand, a smaller share than its portion of energy use. However, the ability of energy reporting to produce highly targeted time-series data can enable control to target savings during times of peak demand. And most critically, the ability to send time-varying prices to individual devices will enable considerably more peak reduction. There will be some additional air conditioning benefits in both the residential and commercial sectors because reduced plug loads generate less heat for air conditioners to remove.

The energy values at the basis of these estimates are from the Energy Commission. The percentage of savings is a matter of professional judgment, and intended to provide an indication of the order of magnitude of the savings; precision is not possible here, nor necessary for concluding that the technologies are highly merited.

Not considered in the above quantification is that energy reporting will apply equally well to non-plug-load devices as to plug loads. Because those other devices (even ones that are

primarily non-electric) consume many times the plug-load total, the long-run savings for all applications are much greater than indicated.

Cost/Benefit Ratios

The expected benefits and costs of the project are summarized in Table 19, with the ultimate savings applied throughout a 10-year period.

Table 19. Benefit/cost ratios from the perspective of the Energy Commission and of consumers

	CEC/EPIC Perspective	Consumer Perspective
Benefit	\$8 billion	\$19 billion
Cost	\$2 million	\$0
Benefit/Cost Ratio	~4,000	∞

Market Segments

The comprehensive energy reporting plug-loads strategy affects primarily the residential and commercial buildings sectors. The savings will occur gradually as legacy equipment is retired. Many plug-load devices have relatively short lifetimes (less than 10 years) so that a significant fraction of the potential energy savings can be attained soon after the strategies are implemented. Of course some legacy products will remain, but, ultimately, the entire stock of plug-load devices will be affected.

Other Benefits

The energy reporting technology can, in some cases, be used to provide consumers with new features and services. For example, standardization of communication protocols creates a friendly environment for further technological innovation, such as fault detection, security, and safety. Energy reporting also enhances safety by identifying anomalous energy usage patterns. The popularity of these additional capabilities and features may become the motivating reason consumers choose certain products.

Relation to State Policy Goals

The State of California has many policy goals to which energy reporting contributes. For example, Public Utilities Code § 8360 has the following goals (this a subset and paraphrased) to which this project contributes with energy reporting and price control:

- Increased use of digital information and control technology
- Dynamic optimization of grid operations and resources, with attention to cyber security.
- Deployment and integration of cost-effective distributed resources and generation, including renewable resources.

- Development and incorporation of cost-effective demand response, demand-side resources, and energy-efficient resources.
- Deployment of cost-effective smart technologies, including real time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices for metering and communications.
- Integration of cost-effective smart appliances and consumer devices.
- Deployment and integration of cost-effective advanced electricity storage and peakshaving technologies.
- Provide consumers with timely information and control options.
- Develop standards for communication and interoperability of appliances and equipment.
- Reducing barriers to adoption of smart grid technologies.

The Public Utilities Code § 740.1(e) specifies that projects should have objectives that include efficiency, shifting electric system load, and reducing operating costs. Energy reporting and price responsiveness contribute to these.

The California Public Utilities Commission (CPUC) has several proceedings and goals related to this project. Among those that this contributes to are demand response, residential ZNE buildings, energy efficiency, net energy metering, and smart grid (including demand-side technologies). More broadly, the concept of device self-reporting can be extended to other, related types of resources, such as water; the CPUC has a proceeding on the water-energy nexus. This project will enable building owners to understand what devices are using energy at what time and so be able to identify when to replace products, perform maintenance, or change operation—all of which save energy. That is, it is an enabling technology for saving energy and attaining ZNE goals.

Relation to Energy Commission Long-term Plans

It is important to recognize that this project would not be possible at all without significant prior investment by the Energy Commission in research in the areas of electronics and networks.

Summary

This project could eventually produce, conservatively, a 5 percent reduction in plug-load energy use. This reduction will derive from the insight end users gain from the energy reporting which identifies devices that are using an abnormally large amount of energy. Other benefits will derive from the ability to have devices be price-responsive, to take advantage of time-of-use, critical peak, and potentially other new innovative dynamic tariffs. In California, energy savings will exceed 2.6 TWh/year in residential and commercial buildings, which corresponds to about \$0.8 billion/year in lower electric bills (after full deployment). To be conservative, this only

counts savings from electronics and miscellaneous devices. More savings should result from applying the technology to other plug load devices such as appliances. Ratepayers will save by not paying for energy that was being wasted. The technology will result in a demand reduction of more than 300 megawatts and a reduction in GHG emissions of more than 1.7 gigatonnes per year CO₂ equivalent.

In addition to providing direct electricity savings, energy reporting collects valuable data for use by consumers, manufacturers, and policy makers.

CHAPTER 7:

Technology Transfer

Background and Introduction

In this research, LBNL developed and demonstrated the technology necessary to implement energy reporting in a wide range of plug load devices. The goal of this portion of the research was to make the knowledge gained, experimental results, and lessons learned available to the public and key decision makers. This chapter summarizes work done by LBNL to carry out the Technology/Knowledge Transfer Plan. It provides an overview and describes the technology transfer activities conducted to disseminate energy reporting strategies, especially among key stakeholders.

Outreach Activities

As part of the Technology/Knowledge Transfer Plan developed for this project, Table 20 identifies key stakeholders and target messages and information needs to help bring energy reporting into common use. (Note that these needs significantly overlap with each other so a distinct activity is not needed for each category below.) The project team sought to reach all of these key stakeholders in the activities described below.

The outreach described here falls into two categories: (1) targeted outreach and (2) general outreach. Targeted outreach applies to technology standards, California regulations, and ENERGY STAR. General outreach applies to users and manufacturers, building designers and contractors, and manufacturers. Outreach efforts are described in more detail below.

Table 20: Energy Reporting Messages and Information Needs by Audience Type

Audience	Target Message/Information Needs
Users and manufacturers	Inform users and manufacturers of the powerful capabilities, intricacies, and benefits of a highly functioning energy reporting system.
Residential builders, contractors, developers; architects and engineers	Disseminate research results.

Device manufacturers	<p>Show a clear, simple path for how manufacturers can incorporate energy reporting capability into their products and how it can be used by their customers.</p> <ol style="list-style-type: none"> 1. Conduct bench-top demonstrations of the management system, energy reporting protocols, and hardware prototype plug load devices. 2. Disseminate open source software that implements a reference management system. 3. Disseminate research results and guidance documents to inform how to utilize and deploy energy-reporting capability.
Technology standards organizations	Develop an energy reporting protocol structure and data model for adoption into standards and guidelines.
California Title 20 and Title 24, California Energy Commission, Efficiency Division	<p>Identify and prioritize policy changes to:</p> <ol style="list-style-type: none"> 1. Accelerate the adoption of energy reporting technology in devices and buildings. 2. Develop a roadmap to use energy reporting to advance energy efficiency in California.
EPA ENERGY STAR	Present relevant research results for adoption into ENERGY STAR standards.

General Outreach

The core of the general outreach effort is the demonstration setup, which by its existence proves that energy reporting is possible, immediately feasible for manufacturers to include in products, and readily usable by building owners and operators. Further, the demonstration generally piques the interest of the audience, and engages them in the critical need for energy reporting. The setup covers the following characteristics and capabilities:

- **Wide range of products.** The devices in the collection include HVAC, lighting, electronics, water heating, and power distribution, as well as external energy meters. Energy reporting is possible for any device with communications capability.
- **Variety of protocols.** The demonstration setup used multiple physical layers (Wi-Fi, Ethernet, Bluetooth, and Zigbee) as well as multiple application layers for Internet Protocol communication.
- **Both measurement and estimation.** Four of the products as well as all three external meters use measurement; the remaining use estimation. Estimation is a truly no-new-hardware solution; when incorporated early in the design process, measurement can be minimally difficult, as some power conversion circuits already include the capability.
- **Ease of implementation.** When initially designed into products, the incremental burden of energy reporting can be small. Subsequent products can leverage most of the design and programming effort of the original design.

- **Querying flexibility.** The management system queried all of the devices at time intervals of one second. One device updated the reporting data only once each minute, but was able to respond to queries seconds apart. For most products and in most buildings, the interval of querying will likely be much longer, e.g., hourly or daily, but it is reassuring to know that much higher frequencies are attainable for those circumstances where it is useful. In addition, the architecture allows the management system to change the periodicity at any time and the reporting device can respond automatically.
- **Reasonable accuracy.** A dedicated external meter will normally be able to provide the highest accuracy possible, but for energy reporting purposes, the highest accuracies are generally not needed.

The demonstration setup includes 12 devices that report energy use, including three external meters. It also includes a PC that runs the management system software, a gateway device that provides multi-protocol connectivity, and two PC monitors for displaying the data graphically.

The full demonstration setup was taken to the ACEEE Summer Study on Energy Efficiency in Buildings, held most recently August 12–17, 2018, at the Asilomar Conference Center in Pacific Grove, California (see Figure 26). It was shown on two separate days for both of the afternoon poster sessions. The entire conference had about 900 attendees, and all were invited to the poster sessions.

Figure 26. The First Showing of the Demonstration Setup



Source: LBNL

Half of the setup was brought to Carbon Smart Building Day on September 11, 2018, in San Francisco, California. The demonstration was organized to be part of the Global Climate Action set of meetings. Finally, the full setup was brought to the Energy Commission, for a demonstration in the main building lobby, on April 10, 2019. LBNL intends to continue to seek out opportunities to show the demonstration setup after the project performance period ending April 2018 (though finding resources to support this effort may be challenging). At this

time it has only been transported by car. Transporting by air (e.g., to an out-of-state location) would require cases to be built for shipping the many devices.

Three posters were created for the EPIC Symposiums of 2018 and 2019, and for the 2018 ACEEE Summer Study, as shown in figures 26 through 28 in the Project Materials section below.

In November of 2016, Bruce Nordman presented the energy reporting concept (see Figure 30) and project to a meeting of the Electronic Devices and Networks Annex (EDNA),⁶ a project of IEA-4E which focuses on Energy Efficient End-use Equipment, which is itself a project of the International Energy Agency (IEA). EDNA focuses on “network connected devices.”

A paper was presented at the 2017 Conference on Energy Efficient Domestic Appliances and Lighting on “Energy Reporting: Technology, Development, and Applications” (Nordman and Khandekar 2017).

Electronic Outreach

Project results are available at the project website, ereporting.lbl.gov.

LBNL produced a 2.5-minute video on the project (see Figure 31), which is posted online at <https://www.youtube.com/watch?v=-viLz3dXPTw>. Production was not funded by the Energy Commission.

A collection of high-quality digital photos of each of the reporting devices was provided to the Energy Commission (Figure 32).

Technology Standards

A key audience for this outreach is technology standards organizations. A goal of this project is to have new standards be created that are consistent with the data model, and existing ones harmonized over time as they are updated. There had been relatively few opportunities to do so until early 2019. The possibly most important organization that LBNL sought to interact with is the Open Connectivity Foundation (OCF), which was created in early 2016. OCF has many large technology companies as members, many based in California. Beginning in March of 2016, LBNL sought to join OCF, but LBNL concerns about intellectual property obligations interfered. Finally in February 2019, OCF created a committee that invited liaison members of other standards organizations, and LBNL became eligible to participate through this mechanism. The specific committee is for “One Data Model;” as the project is oriented to a standard data for energy reporting data, it is hard to imagine a more relevant committee. This activity will extend long past this project, but LBNL began working on energy reporting a decade ago, long before this project.

In a similar vein, the existing standard most relevant to this project is CTA-2047-A on “CE Energy Usage Information (CE-EUI)” where CE stands for Consumer Electronics (this organization was previously known as the Consumer Electronics Association but has been renamed Consumer Technology Association). LBNL was involved in creating the initial version

⁶ Note: This meeting was outside of California and LBNL’s participation did not come out of Energy Commission funds.

of CTA-2047-A several years ago, before this project. In February 2019, CTA-2047-A came up for reconsideration and LBNL proposed to reopen it for revision. This could move forward in 2019. LBNL will propose the energy reporting data model.

The last major standards development is [iot.schema](http://iot.schema.org), a project of schema.org. The organization schema.org was founded by Google, Microsoft, Yahoo, and Yandex to establish essential data models. LBNL presented the energy reporting data model to [iot.schema](http://iot.schema.org), but they are at an early stage of development of their work overall.

Energy Codes and Standards

The work on energy codes and standards, which was conducted by Energy Solutions of Oakland, California, produced a general roadmap for integrating energy reporting into buildings and products. Energy Solutions developed two proposed measures—one appliance standards approach and one building codes approach—that address specific near-term opportunities for California Title 20 and Title 24. As part of this effort, Energy Solutions consulted with relevant staff of the Energy Commission’s Efficiency Division.

Measure proposals are typically distributed widely in California to staff at the Energy Commission, California Public Utilities Commission, utilities (investor-owned utilities and other utilities), advocates, manufacturers, and others.

LBNL will seek to align approaches taken in state energy codes and standards with those taken in ENERGY STAR test procedures and specifications.

Partner Activities

For this project, LBNL identified several key information distribution channels for information about energy reporting that will effectively leverage project partners.

Technical Advisory Committee (TAC)

The TAC is composed of representatives from manufacturers, technical experts, EPA ENERGY STAR, and the Energy Commission. LBNL periodically reached out to the TAC and its members for advice on technology/knowledge transfer strategies and to encourage them to be early adopters of the study findings. The TAC had an initial meeting in October 2017 to review project plans, results, questions, and documentation, and had a subsequent meeting in April 2019.

Energy Solutions

Energy Solutions is identifying energy efficiency policy instruments that could be modified in light of the energy-reporting technology and discovering ways to achieve those modifications. They will recommend specific changes to energy codes and standards to encourage or require including energy-reporting capability both in end-use devices and in central management systems. Additionally, they are researching ways that data collected via energy reporting could be leveraged to further develop energy policy research.

Figure 28. 2019 EPIC Symposium Poster

Making Consumption Visible with 'Energy Reporting'

Bruce Nordman, Aditya Khandekar, Marco Pritoni, Anand Prakash

Problem Statement

How do you know what devices in a building use how much energy? And when?

Building owners typically have little information about this. External metering is expensive and cumbersome – and so rarely used.

Detailed data on device energy use could enable better decisions. To be widespread, the capability needs to be extremely simple to obtain and low cost (ideally free).

The **Energy Reporting** concept can solve this.

Imagine a future ... with Energy Reporting

All devices in buildings track their own energy use and report this and other information to the local network ... for free!

We could use this data to better ...

- Operate equipment (including with Time-Of-Use rates)
- Know when maintenance is needed
- Inform replacement decisions
- Justify utility rebates
- And more

Many communication protocols can be reversed to send prices as effective control signals to aid renewables integration

This EPIC LBNL project aims to move us to a world in which Energy Reporting is a **basic feature** of all end-use devices used.

Project Results – How California Benefits

When this technology is fully deployed, savings will likely be on the order of (and could be more):

- \$800 million/year in savings to California ratepayers
- 2.7 TWh/year savings for all California buildings
- .75 GW of demand reduction statewide
- 1.7 GT/year reduction in CO₂
- Includes language for Title 20 and Title 24 energy codes and standards – a core component of the project

Demonstration – Communications

Demonstration – Management System

Our management system collects reported data and stores it in a local database. A 'dashboard' shows energy use over time, instantaneous power, and accumulated energy.

Data can be graphed, aggregated, or analyzed as user needs.

The figure shows a sample management system display.

The management system also sends electricity prices.

Making this a Reality

In this project we are helping to make Energy Reporting a reality by demonstrating its feasibility and practicality, addressing technology gaps in communications protocols, and considering the role of energy codes and standards.

Energy Reporting will bring safe, affordable, and equitable technology to saving energy in all end uses. This can be a critical part of California's solutions to reduce energy use and greenhouse gas emissions in new and existing buildings. Control with prices will provide better grid integration and reliability. Much better data will result in better energy decisions by consumers and policymakers.

System Architecture

- Most devices will estimate energy use
- Use network connection already present
- Basic capability only within building – for privacy, security
- Also provide other info – e.g. brand, model, etc.
- Data "pulled" from end-use device
- Receiving entity is a "management system" within a building that collects, stores, and presents Energy Reporting data

Demonstration – Devices

We have assembled a collection of **real devices** that do Energy Reporting

- Some are for sale today
- Some we modified
- Some we had the manufacturer modify
- Some are external meters

We also created a 'management system' to collect and display the data.

The devices use different physical layer communication protocols

- Bluetooth, Zigbee, Ethernet, Wi-Fi
- And diverse application layer communication protocols
- CTA-2045, Zigbee, REST APIs, and serial/text

Seven devices report measured consumption; the rest estimate it. Some take in prices or other control signals.

Bruce Nordman
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Source: LBNL

Figure 29. 2018 ACEEE Summer Study Poster

Energy Reporting

Bruce Nordman, Aditya Khandekar, Marco Pritoni, Anand Prakash, Callie Clark, Jordan Shackelford

Why Energy Reporting?

- People rarely know how much energy is used by end-use devices, individually or collectively
- Current solutions are either expensive, cumbersome, non-interoperable or a combination of those, so rarely used.

Solution

- Enable devices to track / report their own energy use
- Do this at no incremental cost*
- Disperse the technology to all energy-using devices

Goal: Move to a world in which Energy Reporting is a basic feature of all end-use devices

Demonstration

We have assembled a collection of **real devices** that can do Energy Reporting for demonstrations at meetings and conferences.

- The devices use different communication protocols: Bluetooth, Zigbee, Ethernet, WiFi
- They report actual consumption if available or estimate the consumption
- The data is collected by an energy manager, stored in a timeseries database (InfluxDB) which can be visualized according to user requirements
- Current list of devices: Notebook PC, Philips Hue lamp, AO Smith Water Heater, a Task lamp that can control an overhead fixture, Venstar Thermostat, Belkin Wemo, Powerblade, GE Smart Dimmer

This is our project logo. Power (the power symbol) is transformed into digital information about the power (the squares that are filled-in or not) and then communicated (the line and arrow). Because this is to save energy the data are green.

System Architecture

- Most devices will estimate energy use
- Use network connection already present
- Basic capability only within building - for privacy, security
- Also provide other info – e.g. brand, model, etc.
- Data "pulled" from end-use device
- Receiving entity is a "management system" within a building that collects, stores, and presents Energy Reporting data

Proposed Reference Data Model

Item	Data Type	Comment
ItemType	enumeration	One of 'Sensor', 'Enumeration', 'Text', 'Float', 'List'
Units	Text	ISO 8601 or IEEE 841
Identification_Unique	Text	128 bit (128 bytes)
LocationKey	Text	List of "Sensor-Device"
Identification_General	Text	List of "Sensor-Device"
EntsManufacturer	Text	Name of Manufacturer, generally without suffix (e.g. Inc.)
EntsBrand	Text	Name of Brand if different from manufacturer, otherwise empty
EntsModel	Text	Model number/name
EntsIdentification	Text	List of "Sensor-Device"
EntsURL	Text	List of "Sensor-Device"
Classification	Enumeration (0..99)	Universal Device Classification, B. Nordman and H.Y. Chung, 2013.
LastDate	Text	Locally-accumulated report
LocationKey	Text	List of "Sensor-Device"
LocationInfo	Text	List of "Sensor-Device"
Coordinate	Text	List of "Sensor-Device"
PowerState	Enumeration (0..5)	
Timestamp	Float or text	Unix time or RFC 3339 time
Transparency	Float	current electrical power in W
Energy Reporting	Float	accumulated energy use in Wh
CumulativeEnergy	Float	

Energy Codes and Standards

- How policy could encourage or require
 - Deployments of Energy Reporting
 - More interoperable Energy Reporting
- How Energy Reporting data could be used in policy
 - How it should be used in policy
 - Strategy for moving forward

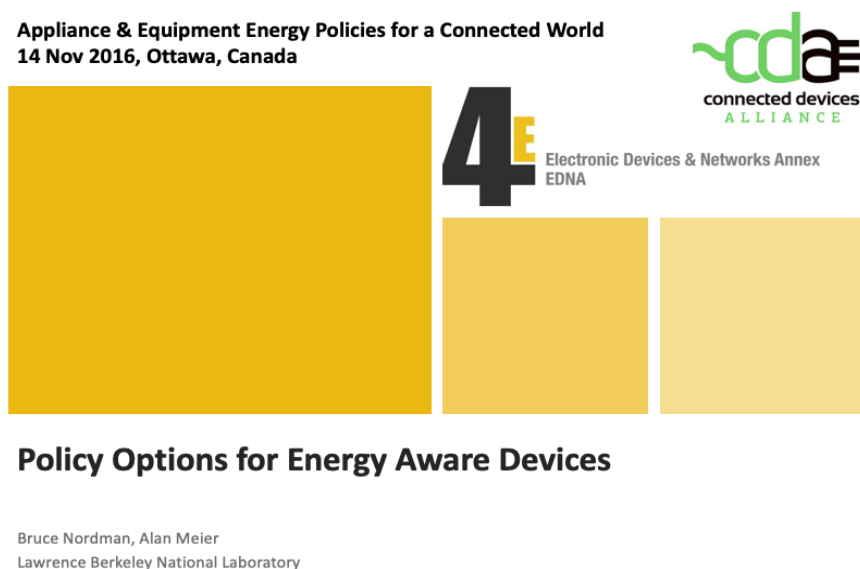
Applications – Energy Saving Opportunities

- Device operation / maintenance**
 - Inform decisions about equipment replacement, repair, operation, etc.
- Building operation**
 - Better control of energy use for local or grid concerns
- Billing**
 - Ability to bill tenants or vendors for energy use of end-use devices
- Monitoring and verification**
 - Compare actual energy use to that estimated in design
- Asset management**
 - Track the presence, location, and identity of devices

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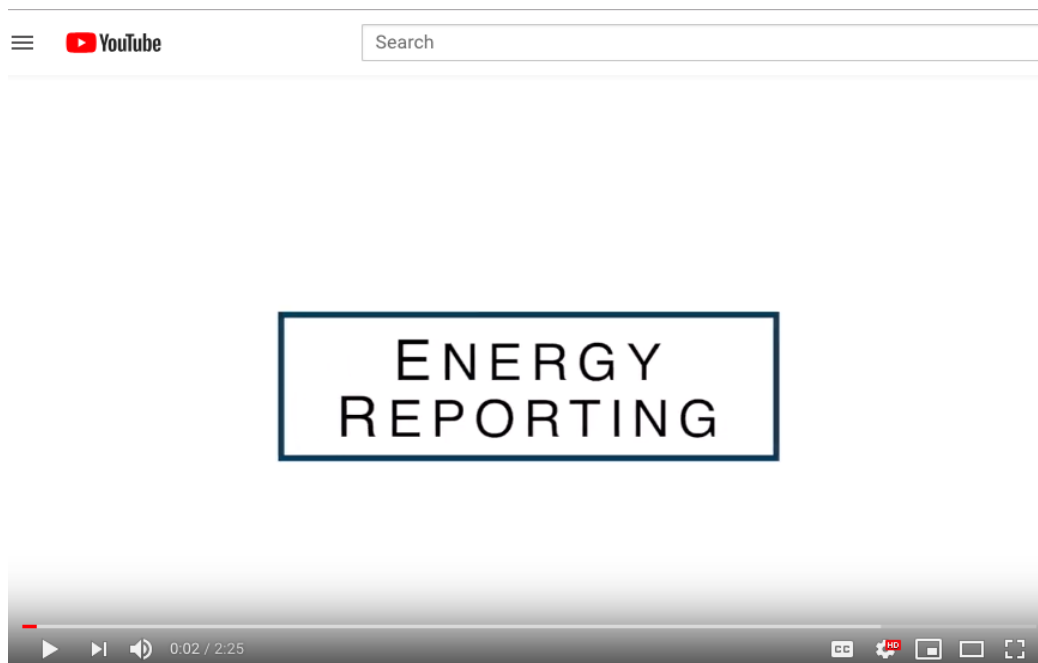
Source: LBNL

Figure 30. Presentation to IEA-4E EDNA Meeting, Ottawa, Canada, November 2016



Source: LBNL

Figure 31. Introduction to Energy Reporting Video



Source: LBNL

Video link: <https://www.youtube.com/watch?v=-vLz3dXPTw>

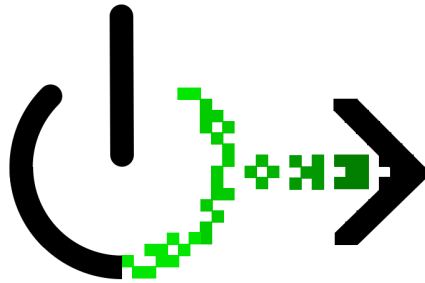
Figure 32. Thumbnails of high-quality digital photos of the devices used



Source: Laura Wong

Figure 33 shows the symbol developed for this project for energy reporting. The symbol is to convey *power* (with the power symbol), digitalization (with the pixelation), communication (with the arrow), and greenness/energy saving (with the green color).

Figure 33: Energy Reporting Symbol



Source: LBNL

CHAPTER 8:

Conclusions

This project has significantly advanced the technology of energy reporting in several domains: hardware prototypes, technology standardization, and energy codes and standards. More work remains, but this is a solid foundation on which to build. This section reviews the major task areas of the report for their conclusions and next steps.

Devices

The collection of real devices that do energy reporting well-addressed the criteria for choosing them, and so covered a wide variety of product characteristics. The collection includes twelve devices. Several are high-energy-consuming devices: water heater, EVSE, and thermostat (for the heating and cooling equipment it controls), for which the energy reporting feature is particularly valuable. The collection encompasses a wide variety, including HVAC, lighting, appliances, vehicles, electronics, and external monitors, showing its broad applicability. In three cases, private companies were contracted with to modify their devices.

Standard application-layer protocols are very helpful in simplifying integration; ultimately they can eliminate any active integration effort and the technology will “just work.” For the devices studied here, Zigbee was the most prominent in this regard. For other communication, REST APIs are particularly easy to use and would be even easier if the content were standardized. It would be possible to use the data elements of this study directly with a REST API, though this could be seen as undermining the project goal of not creating a new protocol.

Perhaps the least successful part of the demonstration is communicating static data, which is ironic, as it is considerably easier to implement the static data than the dynamic data. Part of this is due to shortcomings in the protocols, as they did not include all the fields in the data model developed for the project.

The accuracy tests showed results that varied widely with each device. Some performed quite well. Others were much less accurate, though in most cases it is clear why and how to fix it. The goal was accuracy within 10 percent of the actual consumption, and in the cases that were outside of those bounds, it is clear how to bring them within this limit.

Overall, the results of this study are compelling evidence that energy reporting is feasible to include in products, is not burdensome on manufacturers to do so, and provides data of sufficient accuracy to be useful for building owners.

To help disseminate these results among researchers and product developers, it would be helpful if the demonstration setup could be brought to meetings and conferences after the conclusion of this project, and even have additional products added to it.

Protocols

A common data model for energy reporting is achievable. The ERDM is not the final word on this topic, but a solid foundation to build from. Even from the limited set of models reviewed above, there is clearly a lot of misalignment between them, making translation of many fields challenging. That said, the energy and power values are much more consistent across protocols, so the data most central to energy reporting can be reliably converted from one format to the next.

More experience with each protocol will likely result in particular ways to use them that are best for compatibility with ERDM, so the content in this document will need to evolve. This suggests an ongoing effort and repository of the information, which is the type of activity usually conducted by a technology standards organization. Thus, having the document maintained by a standards committee would provide a source for the most current information on the topic and a clear process for updating it.

There is considerable standards development work that needs to be done for existing protocols, such as adding missing fields to protocols (particularly for static data) and clarifying and harmonizing the intended meaning and application of individual data fields. New protocols can be constructed, to be consistent with this study's data model from the start and to cover all core fields.

Management System

The experience with creating a management system for the demonstration showed that doing so is highly practical and straightforward. Most of the effort required went to the integration of specific end-use devices; mostly, this can be eliminated by manufacturers using only a few high-quality technology standards for energy reporting in their products.

It would be helpful to explicitly outline a definitions of basic functionality for management systems which could be used as a guide by creators of management systems and referenced by programs such as ENERGY STAR.

It was not the intention of this project that the management system developed be the direct basis for systems widely deployed in buildings. A compelling model is web browser software, which is available from private companies and nonprofit organizations. It is anticipated that some such software will be free and others be sold by companies, either as stand-alone systems or integrated into larger software products. This is the area of energy reporting least in need of further investment by the public sector.

Policy

This report identified policy avenues for energy reporting requirements for connected devices and described the steps to implement energy reporting into energy efficiency standards in California and nationwide. As the demand for connected devices increases, codes and standards (voluntary and mandatory) can promote its development and use, resulting in more accurate energy data that will inform future energy efficiency policies. This report and two

attached CASE study documents (Appendix A and Appendix B) outline both recommended near-term actions and provide a roadmap for future activities.

How policy can be moved, and how fast, depends on the trajectory of the technology and its incorporation into products. This will need to be periodically assessed and considered to shape future policy efforts.

An open question is in what cases might it be merited to impose accuracy requirements. This may be unnecessary, as manufacturers might fear that selling products with poor reported accuracy would reflect badly on products, and so in general ensure that their products have reasonably high accuracy. There may be specific applications, e.g., products that obtain utility rebates, where accuracy requirements are established.

Benefits to California

This project is expected to eventually produce for California, conservatively, a 2.6 TWh reduction in electricity energy use, along with 0.37 GW of demand reduction, 1.7 gigatonnes/year of GHG emissions reduction (CO₂ equivalent), and 0.8 \$billion/year of ratepayer savings. Estimates are based on Energy Commission data.

The energy reporting savings will derive from the insight end users gain from the energy reporting which identifies devices that are using an abnormally large amount of energy. Other benefits will derive from the ability to have devices be price-responsive, to take advantage of time-of-use, critical peak, and potentially other new innovative dynamic tariffs. In addition to providing direct electricity savings, energy reporting collects valuable data for use by consumers, manufacturers, and policy makers.

Tech Transfer

The project team engaged in a variety of technology transfer activities, mostly towards the end of the project period, as that was when the demonstration setup was available for showing and other results were available. Outreach was both conventional and electronic, and covered the demonstration setup, posters, a conference paper, and a video. The demonstration setup has brought to two conferences and to the Energy Commission. A continuing LBNL activity is to bring the standard data model to technology standards committees. The two CASE reports will be distributed to the community of people who write and shape future appliance and building standards. The project leveraged the Technical Advisory Committee, Energy Solutions (the subcontractor), and several partner organizations, such as ENERGY STAR and *Home Energy* magazine.

There are a variety of ways that energy reporting and price responsiveness technology can find its way into California residential and commercial buildings. The first is for devices in the field today to be retrofitted with a routine software update. Second is for manufacturers to update the firmware of products to include energy reporting with estimation. Third is for products to be designed with measurement hardware included along. The management system that receives

the data could be a function added to a common device such as a Wi-Fi router or building energy management system.

GLOSSARY

Term	Definition
AC	Alternating Current
ACEEE	American Council for an Energy Efficient Economy. A nonprofit research and advocacy organization focusing on energy end-use efficiency.
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
BLE	Bluetooth Low Energy
CEC	California Energy Commission. A state agency responsible for many aspects of energy use and production in California.
CO ₂	Carbon Dioxide
CTA	Consumer Technology Association. A trade association for electronics and other companies that also includes a technology standards development activity.
CTA-2045	Modular Communications Interface for Energy Management
CTA-2047	CE Energy Usage Information (CEEUI)
DC	Direct Current
DOE	U.S. Department of Energy
EDNA	Electronic Devices and Networks Annex. A project of the International Energy Agency's project IEA-4E which focuses on Energy Efficient End-use Equipment.
EMAN	Energy Management
Energy Reporting	Energy reporting is the capability of an end-use device to track its own energy use and report this data to the local network.
Energy Solutions	A consulting company located in Oakland, California, that specializes in topics related to energy use and efficiency.
ENERGY STAR®	A voluntary program of the United States Environmental Protection Agency and United States Department of Energy that primarily labels products that have lower energy use and climate pollution than the market as a whole.
EPA	U.S. Environmental Protection Agency

EPIC (Electric Program Investment Charge)	The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.
EPRI	Electric Power Research Institute
ER	Energy Reporting
ERDM	Energy Reporting Data Model
ETCC	Emerging Technologies Coordinating Council. The major California investor-owned utilities created the ETCC to facilitate collaborations on emerging technologies projects.
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse Gas
GW	Gigawatt
HEPA	High Efficiency Particulate Air
<i>Home Energy Magazine</i>	A nonprofit magazine based in Berkeley, California, that focuses on practical issues in reducing energy use in residences.
HVAC	Heating, Ventilating and Air Conditioning
IETF	Internet Engineering Task Force
IP	Internet Protocol
kWh	kilowatt-hour
LBL	Lawrence Berkeley National Laboratory. A research laboratory in Berkeley, California, that is operated by the University of California for the United States Department of Energy.
LED	Light-Emitting Diode
MAC	Medium Access Control
MIB	Management Information Base
MQTT	Message Queuing Telemetry Transport
OCF	Open Connectivity Foundation. A nonprofit standards development organization that strives to create greater interoperability of network-connected devices.
OpenADR	Open Automated Demand Response

RAD	Readings at Desk
REST	Representational State Transfer
RFC	Request for Comments
schema.org	An activity sponsored by major technology companies for the purpose of standardizing data models for common information technology activities.
Smart grid	Smart grid is the thoughtful integration of intelligent technologies and innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities.
TAC	Technical Advisory Committee
TWh	Terawatt-hour
UCM	Universal Communication Module
URL	Universal Resource Locator
USB	Universal Serial Bus
USNAP	Universal Smart Network Access Port
UUID	Universally Unique Identifier
Zigbee	A building control communications protocol
ZNE	zero net energy

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APPENDIX A:
Appliances CASE Report



Energy Research and Development Division
LBNL EPC-15-026, Unlocking Plug-Load Energy Savings
through Energy Reporting
Task B: Assist in Developing Codes and Standards

Energy Reporting Codes and Standards Report: Measure Proposal for Appliance Standards

Prepared for: California Energy Commission

Prepared by: Energy Solutions

California Energy Commission

Edmund G. Brown Jr., Governor

April 2019



**Proposal for Title 20 Energy Reporting Requirement
2019 Appliance Efficiency Standards**

[Lawrence Berkeley National Laboratory (LBNL), 2019]

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Purpose

This report proposes changes to the California Energy Commission’s Title 20 Code of Regulations, §§ 1601-1608. This report specifically introduces a cross-cutting energy reporting requirement for network-connected devices. Several prescriptive policy options are introduced, encompassing various device categories with a range of scope. The goal of implementing such code language is to harness data to inform consumers of their disaggregated energy usage and facilitate energy savings through indirect means, such as the collection of time-of-use or other data to inform future demand response efforts.

Product/Technology Description

Devices with the potential to measure or estimate and track their own energy usage and communicate such data to a local network and/or consumer are considered to have “energy reporting” potential.⁷ These products use an Internet connection as the vehicle to report energy usage data and are thus referred to as “connected.” This report will discuss the implementation of a new prescriptive, minimal incremental cost requirement for network-connected devices to have the ability to “report-out” energy consumed during use. Proposed code language changes will not offer updated efficacy requirements, and thus will not produce direct energy savings. However, these devices have the potential to spur indirect energy savings through a variety of avenues (Nordman & Aditya, *Energy Reporting: Technology, Development, and Applications*, 2017), including the following:

- Energy accounting to enable users to clearly see shifts in device-specific energy usage, which could facilitate the expedited replacement of inefficient or failing equipment
- Facilitating more accurate billing of tenants or vendors
- Enabling better building operation by controlling energy use for grid optimization
- Monitoring and verification of actual energy use compared to estimations
- Managing and tracking the presence, location, and identity of connected devices
- Enabling consumers to understand the amount of energy consumed and associated costs by various plug loads, therefore distributing information that could lead to a change in usage behavior
- Enabling direct control over spaces to save additional energy. For example, energy reporting data could yield valuable information regarding the occupancy of rooms, allowing more precise control of services such as HVAC and lighting.

Energy-reporting-enabled products (such as water heaters and vehicle chargers) currently exist in the device market, as do increasing quantities of plug-loads. California does have existing horizontal standards that set a precedent for the integration of such technology into code, including for battery chargers and external power supplies. However, this combination of the high proliferation of plug loads with the increasing market share of potential energy-reporting enabled devices has yet to be addressed in broad energy policies in California, producing

⁷ Energy reporting capabilities are also termed as “energy aware” devices, as defined by the International Energy Agency report, *Energy Aware Devices: Study of Policy Opportunities* by Bruce Nordman and Alan Meier. <https://www.iea-4e.org/document/395/energy-aware-devices-study-of-policy-opportunities>

challenges for the implementation of potential demand response grid management solutions or behavioral energy management programs.

Three alternatives currently exist to device-specific reporting of energy usage over an Internet-enabled network, and all have limitations. First, although monthly energy bills sometimes give the aggregate total amount of energy consumed in a home compared to previous months, these totals do not allow consumers to see how much energy individual devices are using. Instead, consumers must guess and/or make calculations to estimate such totals. Second, although metering devices currently exist and can be plugged into an outlet along with a device to give a readout of the energy used, such equipment often does not aggregate results for easy viewing, and if not Internet-enabled, they require physical viewing of each outlet at regular time intervals. Due to the fact that these devices are cumbersome and expensive, they are rarely used in practice. Requiring devices already capable of connecting to the Internet to be equipped with energy reporting software will reduce or eliminate any additional costs to the customer as a result of energy reporting. Customers would use a centralized device for visually representing energy consumption. Third, load monitoring allows users to discern individual device energy usage quantities, either by intrusive or non-intrusive means (termed ILM or NILM, respectively). However, while this technique can yield disaggregated data, equipment costs (especially in the case of intrusive load monitoring systems) can be prohibitive, and non-intrusive methodology is often less accurate than the more expensive intrusive alternatives (Aladesanmi & Folly, 2015) (Mathur, 2015). For example, a \$249 NILM device currently on the market, Smappee®, enables an 80 percent accurate view of disaggregated appliance usage via a box connected to the consumer's breaker panel, which transmits data over Wi-Fi. However, this technology is unable to differentiate smaller plug loads, which are masked by power-draws from larger appliances (Brown, 2014). In this and other instances of NILM technology, smaller plug loads are not readily visible, and it is nearly impossible to obtain metadata or exert control over connected devices.

Overview

Table 1 provides an overview of the key aspects contained in this measure proposal.

Table 1: Summary of Proposal

Topic	Description
Description of Standards Proposal/Framework of Roadmap	<p>Connected devices are defined as devices that are network-connected and able to transmit data, including energy usage data, over a communications network. Energy reporting is the ability of a connected device to track its own energy usage and to convey that energy usage to the consumer via a central device in the same building. This proposal offers five potential prescriptive code improvement options for existing network connected devices to report-out energy consumed. Scopes of coverage include the following:</p> <ul style="list-style-type: none"> • Option 1: All “connected devices” currently covered in §1605.3 of the California Code of Regulations, Title 20, Division 2, Article 4, Appliance Efficiency Regulations. • Option 2: A specific list of “connected devices” that are not currently covered in §1605.3, §1605.2, or §1605.1. • Option 3: Both Option 1 and Option 2. • Option 4: All “connected, electrical devices” excluding those in §1605.1 and §1605.2. • Option 5: All “connected, electrical devices” including and those in §1605.1 and §1605.2. <p>Compliance will be measured using binary methodology to validate whether a device has the ability to report-out its energy usage.</p>
Technical Feasibility	<p>ENERGY STAR currently specifies eight product categories as having “connected functionality,” and all products would be in compliance with any of the proposed prescriptive options introduced into California’s Title 20 code language.</p>
Energy Savings and Demand Reduction	<p>Refrigerators, electric clothes dryers, televisions, soundbars, and game consoles were studied to estimate the energy usage and associated potential energy savings in California. The current energy use of the network connected installed base for these devices totals approximately 3,000 gigawatt-hours (GWh) yearly. Savings totals for the current and projected saturation of these devices are also estimated.</p>
Environmental Impacts and Benefits	<p>None of the proposed measure options are expected to produce negative environmental externalities but will likely result in energy savings, leading to less energy demand, subsequent greenhouse gas emission reductions and related data availability.</p>
Economic Analysis	<p>Mandatory energy reporting for Internet-enabled devices would be a minimal- cost solution and will not negatively impact any community or economic sector, and in turn, will allow all home and business owners to save money by curbing energy use in response to information availability.</p>

Consumer Acceptance	Consumer response to proposed changes is expected to be positive, with minimal pushback, since only a basic knowledge of Internet connectivity is required to interact with a device interface and will improve a user's ability to understand his or her energy usage. Additionally, connected devices already fall under ENERGY STAR's labeling avenue to meet the program's efficiency standards, which consumers already recognize, so no additional label is required.
Other Regulatory Considerations	If a regulatory option is to include federally regulated products, the issue of preemption must be considered. However, at this time no immediate preemption concerns were identified.

Methodology

Current Standards

In the State of California, no voluntary or mandatory standards exist which require network-connected devices to report-out energy usage. Only voluntary federal standards are currently in existence and are administered jointly by the U.S. Department of Energy and U.S Environmental Protection Agency ENERGY STAR program. There is also no voluntary or mandatory industry protocol standardizing energy reporting features in devices.

Proposed Measure

This proposal would create a new section in the California Code of Regulations, Title 20, Division 2, Article 4, Appliance Efficiency Regulations: “§1610 Energy Reporting,” and provides five options for potential code improvements with a range of scopes of coverage and several accompanying definitions for §1602 (discussed below in the *Proposed Standards and Recommendations* section of this report). Title 20 §1610 code change options are summarized below, generally increasing in scope:

Option 1: “Connected devices” currently covered in §1605.3 (see Group A in Error! Not a valid bookmark self-reference. below).

This option would enact an energy reporting requirement for all products currently covered by California efficiency standards that also have the classification as a “connected device” according to the new associated definition. This option would not designate an energy reporting requirement for a federally preempted device or devices that are not covered by California efficiency standards. Definitions in §1602 would need to be updated to include a new definition for connected devices.

Option 2: A specific product list of “connected devices” that are not currently covered in §1605.3, §1605.2, or §1605.1 efficiency standards” (see Group B in Error! Not a valid bookmark self-reference. below).

This option would enact an energy reporting requirement for all products currently covered by California efficiency standards that also have the classification as a “connected device”

according to the new associated definition. This option would also designate an energy reporting requirement for other specified devices that are not currently covered by California efficiency standards in §1605.3 and §1605.2 or federal standards in §1605.1. Some examples of these connected devices include smart speakers and game consoles. Definitions would need be updated in §1602 to include a new definition for connected devices, as well as these new products.

Option 3: Combination of Group A and B in Error! Not a valid bookmark self-reference. below.

See associated descriptions above.

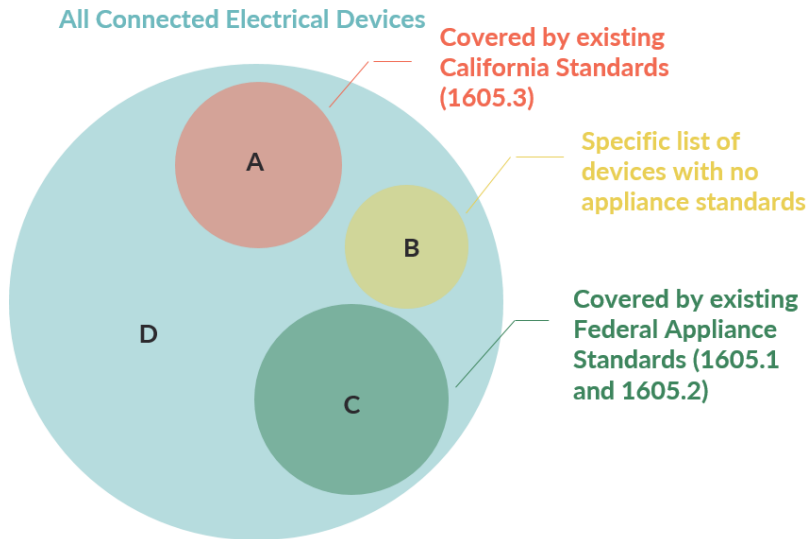
Option 4: All “connected, electrical devices” excluding those in §1605.1 and §1605.2 (see Group A, B, and D in Error! Not a valid bookmark self-reference. below).

This option would enact an energy reporting requirement for all products currently covered by California efficiency standards that also have the classification as a “connected device.” This option would also designate an energy reporting requirement for all other “connected electrical devices” (as designated by the new associated definition), excluding products in §1605.1 and §1605.2. This would also add a new definition for both “connected devices” and “electrical devices” in §1602.

Option 5: All “connected, electrical devices” including those in §1605.1 and §1605.2 (see Group A, B, C, and D in Error! Not a valid bookmark self-reference. below).

This option would enact an energy reporting requirement for all products currently covered by California efficiency standards that also have the classification as a “connected device.” This option would designate an energy reporting requirement for all “connected electrical devices” (as designated by the new associated definition) including products in §1605.1 and §1605.2, which are covered by federal standards. This would also add a new definition for both “connected devices” and “electrical devices” in §1602.

Figure 1: Potential Scope of Coverage



Source: Energy Solutions

Proposed Standards and Recommendations

Proposed Definitions

Connected device: “A device that is network-connected via a hardware component, and thereby able to transmit energy usage data over a network.”

Energy reporting: “The ability of a connected device to continuously track its own energy usage and to convey that energy usage to the consumer in the same building 8).”

Electrical device: “Equipment that requires and utilizes electricity obtained via an alternating or direct current electrical outlet to function.”

Proposed Test Procedure and Reporting Requirement

Lawrence Berkeley National Laboratory (LBNL) has formulated a connected device test procedure which can be applied to a variety of end-use devices. It should be noted that some aspects of the test procedure (such as modes and timing) vary by product. The general procedure is below (Nordman, Prakash, Pritoni, & Khandekar, Energy Reporting: Task 4 - Management System Report, 2018, p. 11):

- i. Power the device directly from a suitable power meter.*
- ii. Integrate the device to be interrogated into management system and establish communications.*
- iii. For each specified mode/level, execute the following steps:*

- a. *Set the product to the specified mode/level.*
- b. *Wait ten seconds.*
- c. *Record the accumulated energy value from the power meter.*
- d. *Interrogate the device for its power level and cumulative energy use. Record the power level from the power meter.*
- e. *Repeat step b twelve more times, at five-second intervals, for a total of 13 reports over 60 seconds.*
- f. *At the time of the 13th report, record the accumulated energy value from the power meter.*
- g. *Calculate the average of the 13 power values and the average power level indicated by the difference in the two cumulative energy reports. Also calculate the minimum, maximum, and standard deviation of the 13 power values.*

Report all of the measured and calculated values.

Proposed Standard Metrics

No amendments to efficiency metrics will be made due to any prescriptive code changes proposed in this report. Compliance with the new standard will be measured using binary methodology simply validating whether a device has the capability to report-out its energy usage. See the test procedure for more information. Additionally, devices should be able to statically report identification information during the first use to establish IP address, location, manufacturer, and other information that may be helpful to classify data. For prescriptive code options enveloping federal products, further research should be conducted to determine possible preemption issues. Similarly, while at this time we don't anticipate imposing specific accuracy requirements on connected device outputs (other than mandating that a device simply report its accuracy), preemption concerns should be further researched.

Analysis of Proposal

Scope/Framework

This proposal aims to integrate energy reporting requirements into existing prescriptive codes for connected devices. Internet-enabled devices are specifically proposed to be integrated into California's Title 20 code language in all options outlined above because no additional hardware is required to implement an energy reporting requirement for products with this existing classification. Only additional software is required for devices with the existing ability to connect to the Internet.

Product Opportunities

While no efficiency upgrades are proposed for specific products, this cross-cutting proposal will be an important first step to achieving indirect energy savings statewide for no additional incremental cost for manufacturers.

Technical Feasibility

ENERGY STAR currently specifies eight product categories as having “connected functionality,” meaning that these products are able to connect to the Internet to report their energy usage. ENERGY STAR includes criteria for energy consumption reporting for certain product categories with connected product criteria. For a product to have connected functionality, it must include (among other features):

- A mechanism for bi-directional data transfers, communications hardware,
- Remote management capabilities,
- Demand response capabilities, and
- Energy consumption reporting.⁹

All such products would be in compliance with any prescriptive option introduced into California’s Title 20 code language.

Statewide Energy Savings

Refrigerators, electric clothes dryers, televisions, soundbars, and gaming consoles were studied to estimate the energy usage and associated potential energy savings in California. The current installed base and a forecast of the network-connected installed base after full stock turnover are estimated in Table 2.¹⁰

Table 2: Current Overall and Network Connected Portion of Installed Base in California

Product	Total Installed Base (millions)	Network Connected Installed Base (millions)
Game Consoles	5.1	5.1
Televisions	13.7	7.4
Soundbars	2.3	0.5
Refrigerators	14.2	1.2
Clothes Dryers ^a	3.2	0.5

^a Only electric clothes dryers represented.

The market for smart (i.e., network-connected) devices is expected to grow over the coming decade. In fact, more than half of consumers are expected to buy at least one connected device in the coming year (GutCheck, 2018). Similarly, companies are also embracing connected

⁹ Energy consumption reporting requires that “the product shall be capable of transmitting energy consumption data via a communication link to energy management systems and other consumer authorized devices, services, or applications.”

¹⁰ The network-connected installed base is calculated using the percent of 2019 sales that are network-connected. To the extent that the percent of the installed base that is network-connected will increase, this is a conservative estimate of what the network connected installed base will be after stock turnover.

technology, with LG recently releasing all 2018 dishwasher models with included Wi-Fi connectivity capability (LG, 2018). However, it is important to note that while network connectivity is an important precursor to enabling energy reporting, the proliferation of Wi-Fi enabled devices does not directly translate to an increase in energy reporting. Not all network-enabled devices have the ability to report energy, meaning that the market adoption of energy reporting will likely be much lower than the adoption of ‘smart’ appliances. Because the market adoption of energy-reporting enabled appliances is assumed to be low, the annual energy consumption of network connected installed base in California is assumed to be a proxy for the energy usage of appliances that can report their energy usage in a case where a standard is implemented.

The energy usage of the network-connected portion of the installed base was calculated and further transformed to determine the hypothetical total amount of energy saved should an energy reporting mandate lead to a reduction in energy usage. While a prescriptive energy reporting requirement will not directly result in energy savings, the literature suggests varied savings potential. One study suggests that device-level, indirect energy savings due to feedback derived from energy reporting could be as high as 12 percent (King, 2018), while Erhardt-Martinez et al. stipulates that only 0.4-6 percent of residential electric consumption could be achieved if using a feedback program (Erhardt-Martinez, et al., 2010). Since indirect savings totals will rely on the type of behavior program implemented, a range of potential savings totals within the literature-derived range are given in Table 3.

Table 3: Consumption of Network Connected Devices and Associated Potential Savings

Product	Annual Energy Consumption of Network Connected Installed Base in California (GWh/year)	Energy Reduction from a 2% Energy Savings due to Energy Reporting (GWh/year)	Energy Reduction from a 5% Energy Savings due to Energy Reporting (GWh/year)	Energy Reduction from a 10% Energy Savings due to Energy Reporting (GWh/year)
Game Consoles	400	8	20	40
Televisions	1,500	30	75	150
Soundbars	31	1	2	3
Refrigerators*	670	14	34	67
Clothes Dryers*	390	8	20	39
TOTAL	3,000	60	150	300

* Signifies that a product is federally preempted.

For each product analyzed, hypothetical changes to the percent of energy-reporting network-connected devices in the installed base in California were assumed to forecast potential

increases in savings as the market evolves. While the smart kitchen appliance market is expected to grow annually at a compound rate of by 23.4 percent until the year 2025 (Appliance Design, 2017), other device categories (such as electronics) may not grow at the same rate. While the expected increase in energy-reporting devices is unknown, it can be reasonably assumed that their growth rate will be significantly less. Specifically, each connected device studied was assumed to experience an arbitrary 10 percent increase compared to current values by the year 2023. Results are reported in Table 4. Market research must be performed to refine this assumption.

Table 4: Potential Future Savings Attributed to Energy Reporting

Product	Annual Energy Consumption of Network Connected Installed Base in California (GWh/yr)	Energy Reduction from a 2% Energy Savings due to Energy Reporting (GWh/yr)	Energy Reduction from a 5% Energy Savings due to Energy Reporting (GWh/yr)	Energy Reduction from a 10% Energy Savings due to Energy Reporting (GWh/yr)
Game Consoles [×]	400	8	20	40
Televisions	1,800	35	90	180
Soundbars	46	1	2	5
Refrigerators*	1,500	30	74	150
Clothes Dryers*	620	12	31	62
TOTAL	4,300	86	220	430

** Signifies that a product is federally preempted.*

[×] Game consoles are already assumed to have 100% connectivity, so no additional savings will be achieved.

Cost-effectiveness

Collecting and storing energy reporting data will occur on an existing IP-connected device, such as a network router or energy management system. These existing systems already receive data, such as timestamp, power state, location, etc., and could communicate with other devices if a standard protocol is used, so additional software modifications and costs are estimated to be

minimal. Energy reporting is intended to be offered as an additional feature of the central device rather than a stand-alone service offering, which would avoid any additional hardware costs to the customer as well (Nordman & Aditya, Energy Reporting: Technology, Development, and Applications, 2017). In the most conservative scenario of 2 percent savings for the five products analyzed, break-even cost-effectiveness analysis suggests that the incremental cost of adding the energy reporting functionality to a device would have to exceed on average \$15 per unit for the measure to not be cost-effective i.e., have a benefit-cost ratio of less than 1.0. See Appendix A for more details regarding these assumptions and calculations.

Environmental Impacts/Benefits

This proposal will have no quantifiable negative environmental impacts on the State of California. The implementation of energy reporting software in devices with existing hardware will not produce any additional impacts associated with material extraction, manufacture, packaging, or shipping of the product. Manufacturers need not implement additional hardware improvements to display energy usage, as software coupled with existing Internet-enabled hardware will enable information to be transferred to a receiving device. While there are no direct energy savings from this proposal, indirect savings will most likely result as the effect of behavioral changes implemented via potential utility programs. Such savings will result in less electricity demand, thereby improving air and water quality.

Impact on California's Economy

“Energy reporting...will provide building owners with valuable information to make decisions on purchase, maintenance, replacement, operation, and more, and can in some cases directly inform or drive building operation” (Nordman, Prakash, Pritoni, & Khandekar, Energy Reporting: Task 4 - Management System Report, 2018, p. 9). Such advantages will not negatively impact any community or economic sector, and in turn, will allow all home and business owners to save money by curbing energy use in response to information availability. Additionally, since prescriptive requirements are only meant to affect devices with Internet connectivity, no devices will be phased-out due to this measure, preserving manufacturing channels.

Consumer Utility/Acceptance

As noted in the literature, consumer behavior has the potential to be affected by energy reporting, as this will enable consumers to be aware of the disaggregated energy usage of their devices. It has been proven that this knowledge impacting customer behavior is an emerging factor known to influence appliance (and general) energy savings cost-effectively (Allcott, 2011), and that most cumulative appliance energy savings can be attributed to such changes in consumer behavior (Ehrhardt-Martinez, et al., 2010).

No additional education or training would be required for savvy consumers to interact with energy reporting technology; all that is required is a basic knowledge of Internet connectivity and interaction with an application interface. Additionally, because ENERGY STAR already supplies a labeling avenue for connected devices that meet the programs efficiency standards, no additional label is required to alert consumers to the energy reporting capability when they

purchase such a device. No existing recycling programs or toxic substance warnings (if applicable) would need to be amended for this prescriptive software requirement. There is the potential to include an opt-in rebate system to facilitate the privacy-protected exchange of data, but the structure of such a program would need to be researched further before implementation.

Other Regulatory Considerations

If a regulatory option is to include federally regulated products, the issue of preemption must be considered. The Warren-Alquist Act does mandate that new or updated energy efficiency standards and regulatory requirements must be proven to create “energy savings” that are “economically and technically feasible” (State of California, 2018). This is in keeping with provisions related to the creation of standards pursuant to the Energy Policy and Conservation Act (EPCA),¹¹ which also clearly defines when and how standards and test procedures can be created when energy efficiency requirements are changed.

EPCA defines the “measure of energy consumption” as a “means [of] energy use, energy efficiency, estimated annual operating cost, or other measure of energy consumption.” Similarly, EPCA language supersedes state regulations such that no state regulations can “[require] testing or the use of any measure of energy consumption, water use, or energy descriptor in any manner other than that provided under section 323; or ... [require] disclosure of information with respect to the energy use, energy efficiency, or water use of any covered product other than information required under section 324” (Office of the Legislative Counsel for the United States House of Representatives, 2014).

While this federal language spans topics beyond efficiency, it is reasonable that preemption may not apply to any code options presented above. The proposed requirements only stipulate that a *capability* to report energy be present in a given device, and do not mandate that resulting information be disseminated, that the device be tested to verify how well they capture energy use, that efficiency levels be verified, or that reported values be used in a pre-determined way. The proposed test procedure and mandate simply require that the presence of the energy reporting capability be verified in a binary fashion. Mandating that energy reporting software be present in a device will require testing to verify its presence, but no further testing is required. The code options presented above also comply with the second part of the above EPCA provision, in that no new information regarding the device’s energy efficiency is required to be disclosed.

An important caveat to these conclusions about federal preemption surrounds devices which may be regulated by a non-efficiency-centered agency (such as the Food and Drug Administration or Federal Communications Commission). Devices which fall under preemption protections from these and other similar agencies may have the technical ability to connect to a network (therefore meeting the pre-requisite for energy reporting capability) but may not be authorized to report energy use. Preemption of laws attempting to override the design

¹¹ Among other requirements, EPCA states that a product must consume at least 150 kWh yearly for the Secretary of Energy to be authorized to establish an energy conservation standard for it.

requirements of these devices tend to be strict. As such, the state should not attempt to regulate such devices.

Conclusion

As network-connected devices continue to become more prevalent, a prescriptive requirement mandating that such products can report energy use to consumers will be crucial to reaching California's ambitious energy saving goals. Initial research indicates that instituting such code language in Title 20 is technologically and economically viable, while producing a minimal burden on manufacturers, and is a crucial first step to achieving possible indirect savings from energy reporting that are noted by various literature studies.

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Appendix A: Energy Savings Calculations and Assumptions

Variables

Installed Base in California (in millions) = Device count in residential buildings, as indicated by the RASS Database

Percent Network Connected (N.C.) = The percent of the Installed Base in California that is assumed to be network connected

Unit Energy Consumption (kWh/yr) = Yearly consumption of the given device under predetermined usage conditions (defined below per device)

Annual Energy Consumption of Installed Base in California (GWh/yr) = Installed Base in California \times Unit Energy Consumption

Annual Energy Consumption of N.C. Installed Base in California (GWh/yr) = Annual Energy Consumption of Installed Base in California \times Percent N.C.

Number of Households in California = 14,176,670 (as of 2018)¹²

Cost of Electricity = \$.18 per kWh 2019 statewide average, assuming 50% residential and 50% commercial sector¹³

Design life = The estimated number of years before the product is no longer usable

Calculation Steps

Game Consoles (G.C.)

Installed Base in California = Percent Homes with One or Multiple G.C. \times Number of Homes

Installed Base in California = 36%¹⁴ \times 14,176,670

Installed Base in California = 5,103,601 \approx 5.1 million

Design Life = 6 years¹⁵

Percent Network Connected = 100%¹⁶

Unit Energy Consumption (combining active, standby, OFF modes) = 79 kWh/yr¹⁷

Annual Energy Consumption of Installed Base in California = 79 kWh/yr \times 5.1 million

Annual Energy Consumption of Installed Base in California = 402.9 GWh/yr

Annual Energy Consumption of N.C. Installed Base in California = 402.9 GWh/yr \times 100%

Annual Energy Consumption of N.C. Installed Base in California = **402.9 GWh/yr**

Refrigerators

¹² According to the United States Census Bureau (quantity utilized throughout).

¹³ California Energy Commission. Adopted California Energy Commission Demand Forecast Report 2018-2030. Mid-Case Final Demand Forecast. Form 2.3. Updated January 22, 2018.
http://www.energy.ca.gov/2017_energypolicy/documents/2018-02-21_business_meeting/2018-02-21_middemandcase_forecst.php

¹⁴ Table 10-1, Energy Consumption of Consumer Electronics in U.S. Homes in 2017. Nationwide percent penetration assumed representative for California. Only the primary G.C. was counted in this analysis, as it is assumed that usage is greatest for the primary device.

¹⁵ Pg. 18. Analysis of Standards Proposal for Game Consoles.

¹⁶ Number derived from the percent of models sold that have “connected” or “smart” functionality available for purchase online (stores analyzed: Best Buy)

¹⁷ Table 10-5, Energy Consumption of Consumer Electronics in U.S. Homes in 2017

Installed Base in California = Percent of Homes with One or Multiple Refrigerators × Number of Homes

Installed Base in California = 100%¹⁸ × 14,176,670

Installed Base in California = 14,176,670 ≈ 14.2 million

Design Life: 15.6 years¹⁹

Percent Network Connected = 8.4%²⁰

Unit Energy Consumption = 565 kWh/yr²¹

Annual Energy Consumption of Installed Base in California = 565 kWh/yr × 14.2 million

Annual Energy Consumption of Installed Base in California = 8,023 GWh/yr

Annual Energy Consumption of N.C. Installed Base in California = 8,023 GWh/yr × 8.4%

Annual Energy Consumption of N.C. Installed Base in California = **673.9 GWh/yr**

Electric Clothes Dryers

Installed Base in California = Single Family + Multifamily Homes with Electric Clothes Dryer

Installed Base in California = 3,171,23122 ≈ 3.2 million

Design Life = 15.94 years²³

Percent Network Connected = 16.3%²⁴

Unit Energy Consumption (Single Family Home) = 747 kWh/yr²⁵

Unit Energy Consumption (Multifamily Home) = 733 kWh/yr²⁶

Unit Energy Consumption (Average) = 740 kWh/yr

Annual Energy Consumption of Installed Base in California = 740 kWh/yr × 3.2 million

Annual Energy Consumption of Installed Base in California = 2,368 GWh/yr

Annual Energy Consumption of N.C. Installed Base in California = 2,368 GWh/yr × 16.3%

Annual Energy Consumption of N.C. Installed Base in California = **386.5 GWh/yr**

Televisions

18 2009 California Statewide Residential Appliance Saturation Study. Groups which gave survey data resulting in less than 1 percent of the final sample size were not included in this analysis.

19 Technical Support Document: Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers

20 Smart Home Appliances Market Report

21 Table 15, Plug Loads and Lighting Modelling CASE Report. Number is the estimated usage for a primary refrigerator in a three-bedroom home and is assumed representative statewide.

22 2009 California Statewide Residential Appliance Saturation Study

23 Table 8.1.1., Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment. Residential Clothes Dryers and Room Air Conditioners

24 Smart Home Appliances Market Report

25 Table 30, Plug Loads and Lighting Modelling CASE Report. Number is the estimated usage for an electric dryer in a three-bedroom home and is assumed representative statewide.

26 Table 30, Plug Loads and Lighting Modelling CASE Report. Number is the estimated usage for an electric dryer in a three-bedroom home and is assumed representative statewide.

Installed Base in California = Percent Homes with One or Multiple TVs × Number of Homes

Installed Base in California = 96.5%²⁷ × 14,176,670

Installed Base in California = 13,680,486 ≈ 13.7 million

Design Life = 10 years²⁸

Percent Network Connected = 54%²⁹

Unit Energy Consumption (combining active and OFF modes) = 202 kWh/yr³⁰

Annual Energy Consumption of Installed Base in California = 202 kWh/yr × 13.7 million

Annual Energy Consumption of Installed Base in California = 2,767.4 GWh/yr

Annual Energy Consumption of N.C. Installed Base in California = 2,767.4 GWh/yr × 54%

Annual Energy Consumption of N.C. Installed Base in California = **1,494.4 GWh/yr**

Soundbars

Installed Base in California = Percent Homes with One or Multiple Soundbars × Number of Homes

Installed Base in California = 16%³¹ × 14,176,670

Installed Base in California = 2,268,267 ≈ 2.3 million

Percent Network Connected = 21%³²

Design Life = 5.4 years³³

Unit Energy Consumption = 65 kWh/yr³⁴

Annual Energy Consumption of Installed Base in California = 65 kWh/yr × 2.3 million

Annual Energy Consumption of Installed Base in California = **149.5 GWh/yr**

Annual Energy Consumption of N.C. Installed Base in California = 149.5 GWh/yr × 21%

Annual Energy Consumption of N.C. Installed Base in California = **31.4 GWh/yr**

27 Table 7-1, Energy Consumption of Consumer Electronics in U.S. Homes in 2017. Nationwide percent penetration assumed representative for California. Only the primary TV was counted in this analysis, as it is assumed that usage is greatest for the primary device.

28 Pg. 15, Analysis of Standards Options for Televisions. Pacific Gas & Electric Company.

29 Number derived from the percent of models sold that have “connected” or “smart” functionality available for purchase online (stores analyzed: Best Buy, Sears)

30 Table 7-9, Energy Consumption of Consumer Electronics in U.S. Homes in 2017. Only the primary TV was counted in this analysis, as it is assumed that usage is greatest for the primary device.

31 Table 8-1, Energy Consumption of Consumer Electronics in U.S. Homes in 2017. Nationwide percent penetration assumed representative for California. Only the primary soundbar was counted in this analysis, as it is assumed that usage is greatest for the primary device.

32 Number derived from the percent of models sold that have “connected” or “smart” functionality available for purchase online (stores analyzed: Best Buy)

33 States Go First: How States Can Save Consumers Money, Reduce Energy and Water Waste, and Protect the Environment with New Appliance Standards

34 Table 8-8, *Energy Consumption of Consumer Electronics in U.S. Homes in 2017*. Only the primary soundbar was counted in this analysis, as it is assumed that usage is greatest for the primary device.

APPENDIX B:
Building CASE Report

Energy Research and Development Division

LBNL EPC-15-026, Unlocking Plug-Load Energy Savings
through Energy Reporting

Task B: Assist in Developing Codes and Standards

Building Energy Efficiency Measure Proposal to the California Energy Commission

**For the 2022 Update to the Title 24, Part 6
Building Energy Efficiency Standards**

Energy Reporting for Major End Uses in Nonresidential Buildings

Prepared for: California Energy Commission

Prepared by: Rahul Athalye, Chris Uraine, Brett Webster,
Rebecca Avilés and Heidi Werner, Energy Solutions

California Energy Commission

Gavin Newsom, Governor

March 2019



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Document Information

Category: Codes and Standards

Keywords: Statewide Codes and Standards, Title 24 Part 6, 2022, energy, efficiency, electrical energy monitoring, energy reporting, energy recording, energy management, energy management control system (EMCS), direct digital control (DDC), demand response control.

EXECUTIVE SUMMARY

Lawrence Berkeley National Laboratory (LBNL), under funding from the California Energy Commission’s (Energy Commission) Energy Program Investment Charge (EPIC) Program and further support from the U.S. Environmental Protection Agency (EPA), has been working on a project entitled “Unlocking Plug-load Energy Savings through Energy Reporting.” As part of this effort, LBNL subcontracted Energy Solutions to investigate policy options to enable adoption of energy reporting into codes and standards. This building energy efficiency measure proposal is exploratory in nature and not intended for formal, public submission to the Energy Commission docket. The structure and information provided in this report is based on the Energy Commission template for proposal submissions, and it has been modified for the purpose of this exercise.³⁵

This proposal presents recommendations to support the Energy Commission in updating the California Building Energy Efficiency Standards (Title 24, Part 6) to improve the energy efficiency of California’s buildings and meet the State’s ambitious energy and carbon reduction targets. This report and the code change proposal presented herein provides technical and cost-effectiveness information required for successful adoption of new regulations through the rulemaking process.

Scope of Code Change Proposal

The proposal adds requirements for the monitoring, recording, and reporting of electrical end-uses within the building, including HVAC, interior lighting, exterior lighting, and plug and process loads. Table 1 provides an overview of the scope of the proposed changes, including the type and location of code change, standard documents affected by the code change, and whether modifications to compliance software and forms are needed.

Table 2: Scope of code change proposal

Standards Requirements	Compliance Option	Appendix	Modeling Algorithms	Simulation Engine	Compliance Documents
Mandatory	N/A	Nonresidential Compliance Manual Chapters 2, 4, 5, 7, 10, 13, and Appendix D	N/A	N/A	NRCI-LTI-02-E NRCI-LTO-02-E NRCA-MCH-18-A

Measure Description

This measure proposes energy reporting requirements for Energy Management Control Systems (EMCS). EMCS use is widespread. They are capable of supporting energy reporting, but not

³⁵ The Building Energy Efficiency Measure Proposal Template is available on the Energy Commission’s website: <https://www.energy.ca.gov/title24/participation.html>.

currently required to capture this information. This measure leverages EMCS capabilities by updating its definition to require energy reporting for major end-uses. The proposed measure also provides a standardized approach for energy reporting which will provide clarity to both users and manufacturers.

Market Analysis and Regulatory Impact Assessment

The California energy management system marketplace consists of numerous well-established providers, each contributing a unique component to the overall product and system. The technology to support energy reporting within an EMCS is readily available from multiple established companies, with smaller firms growing in their market share over the past decade (while also offering overlapping services and features such as software and building automation).

Statewide Energy Impacts

The proposal requires energy reporting of major end-uses in the building. Energy reporting by itself does not result in energy savings. However, actions taken as a result of analyzing energy consumption will result in energy savings. There have been several studies, described in Section 4.0, that document energy savings resulting from energy reporting through continuous commissioning of buildings, behavior change, and improved demand response.

Cost-effectiveness

Title 24, Part 6 does not require buildings to install an EMCS, rather it allows designers to use an EMCS to fulfill the building controls requirements for lighting, HVAC and DR systems. The proposed code change modifies only the minimum functional requirements of an EMCS. In addition, most EMCS platforms today are already equipped with energy reporting capabilities and would require no additional cost as a result of this measure. Therefore, the proposed change does not add a cost burden to the installation of an EMCS, and therefore, no additional incremental cost is incurred. While the incremental cost is zero, there may be indirect savings from energy reporting. Thus, the measure is considered to be cost-effective. Further details on cost-effectiveness are presented in Section 5.0.

1. Introduction

Lawrence Berkeley National Laboratory (LBNL), under funding from the California Energy Commission's (Energy Commission) Energy Program Investment Charge (EPIC) Program and further support from the U.S. Environmental Protection Agency (EPA), has been working on a project entitled "Unlocking Plug-load Energy Savings through Energy Reporting." As part of this effort, LBNL subcontracted Energy Solutions to investigate policy options to enable adoption of Energy Reporting into codes and standards. This building energy efficiency measure proposal is exploratory in nature and not intended to be a final submission to the Energy Commission docket. The structure and information provided in this report is based on the Energy Commission's template for proposal submissions, and it has been modified for this proposal.

This proposal presents recommendations to support the Energy Commission in updating the California Building Energy Efficiency Standards (Title 24, Part 6) to improve the energy efficiency of California's buildings and meet the state's ambitious energy and carbon reduction targets. This report and the code change proposal presented herein provides technical and cost-effectiveness information required for successful adoption of new regulations through the rulemaking process.

Section 2 of this report describes the history of the measure, whether it has been implemented in other codes and standards, how the measure aligns with the state's zero net energy (ZNE) goals, and how the proposed code change would be enforced and the expected compliance rates.

Section 3 presents the market analysis, including a review of the current market structure, a discussion of product availability, and the useful life and persistence of the proposed measure. This section offers an overview of how the proposed standard will impact various stakeholders including builders, building designers, building occupants, equipment retailers (including manufacturers and distributors), energy consultants, and building inspectors. Finally, this section presents estimates of how the proposed change will impact statewide employment.

Section 4 describes the methodology and approach used to estimate energy, demand, costs, and environmental impacts. Section 5 describes the methodology for performing the lifecycle cost and cost-effectiveness analyses and provides the results of those analyses. Section 6 extends the per unit savings across the state to determine first year statewide energy, cost, and greenhouse gas (GHG) savings, as well as other impacts.

Section 7 provides specific recommendations for language for the Standards, Appendices, Alternate Calculation Manual (ACM) Reference Manual and compliance documents.

2. Measure Description

2.1 Measure Overview

The intent of the proposed code change is to make electrical energy use information from major end-uses in nonresidential buildings readily available to the building manager. This will be achieved by adding a requirement that if an Energy Management Control System (EMCS) is installed it must have the capability to record and report the electrical energy use of each major energy-use system that it controls. The proposed code change specifies which loads must be monitored separately, how frequently data must be recorded, how frequently data must be reported to the building manager, how long data must be stored, and how information must be displayed. The proposed change also requires the following related changes:

- If there are tenant spaces, that electrical energy use data be made available to tenants of each tenant space.
- All demand responsive (DR) controls in the building, including DR controls that are integrated with devices such as water heaters, appliances, or other DR-capable devices, must be capable of monitoring their own electrical energy use and when the building has an EMCS, reporting that information to the EMCS.

The proposed code change aligns with existing requirements in ASHRAE Standard 90.1-2016. In addition to the substantive changes described above, this report recommends that all existing requirements related to the EMCS be consolidated into one section of Title 24, Part 6. Currently EMCS requirements are located in three sections of the code. Consolidating the requirements simplifies the code language, makes it easier for users to understand the requirement, and could lead to improved compliance. The recommendations to consolidate the EMCS requirements are consistent with recommendations that the Statewide Utility Codes and Standards Team included in the Demand Response Cleanup Codes and Standards Enhancement Report that was submitted to the Energy Commission for consideration during the 2019 code cycle (Statewide Utility Codes and Standards Team, 2018).

2.2 Measure History

California has set ambitious goals for achieving zero net energy (ZNE) buildings for new nonresidential buildings by 2030. As the Energy Commission considers code change proposals that will allow the state to meet its ZNE goals for nonresidential buildings, measures that enable building managers and occupants to make informed decisions about energy use should be prioritized. Energy reporting strategies like the ones described in this report are being recognized for their ability to provide detailed and reliable energy consumption information.

While no direct energy savings can be attributed to energy reporting, granular energy consumption data drive an understating of consumption patterns to determine whether systems are functioning as intended and for building managers to optimize energy consumption (Abrahamse, Steg, Vlek, & Rothengatter, 2005). Interventions aimed at reducing energy can be made more effective if detailed energy use data is available for analysis. Disaggregated energy consumption data has the potential to inform and empower building

actors with granular information on the performance of their space (Froehlich, et al. 2011). Savings realized by metering and reporting programs have ranged from 1% to 20% depending on the application of the metering and reporting systems (Plourde, 2011). Highest energy savings are achieved through ongoing commissioning (e.g., ongoing identification of operations and maintenance improvements) (Plourde, 2011).

The ASHRAE Standard 90.1 committee recognized the value of energy monitoring and reporting requirements when they approved requirements for the 2013 edition of the Standard. The requirements are mandatory and appear in the Power (Section 8.4.3) and Other Equipment (Section 10.4.5) sections. For the 2016 edition, requirements were added for Chilled-Water Plant Monitoring (Section 6.4.11). ASHRAE Standard 90.1 follows the American National Standards Institute (ANSI) process that includes public reviews of proposed changes to the Standard. There was significant industry support for the energy reporting requirements. The requirements are only applicable to buildings larger than 25,000 ft², ensuring that an EMCS will almost always be present. The requirements have stayed in place in the 2016 edition and will almost certainly be in place in the 2019 edition of the Standard.

The proposed requirements presented in this report aim to harmonize the Title 24, Part 6 requirements with the electrical energy monitoring requirements in Section 8.4.3 of ASHRAE 90.1-2016. This harmonization includes recommending (in Section 7 Proposed Revisions to Code Language) the specific reporting and recording frequencies for energy reporting. Because the proposed change to Title 24, Part 6 have already been vetted through the Standard 90.1 process and have been in the national model code for two full code cycles, we do not anticipate significant concerns with adding reporting requirements to Title 24, Part 6.

At a national level, DOE is required by statute to review each new edition of Standard 90.1 and conduct an analysis to quantify the expected energy savings relative to the previous version (42 U.S.C. 6833). In February 2018, DOE completed their analysis and public comment process to determine that the 2016 version of Standard 90.1 would improve overall energy efficiency in buildings (U.S. Department of Energy, 2018). Following an affirmative determination from DOE, states with their own building code shall “not later than 2 years after the date of the publication of such determination, certify that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency in accordance with the revised standard for which such determination was made. Such certification shall include a demonstration that the provisions of such State's commercial building code regarding energy efficiency meet or exceed such revised standard” (U.S. Department of Energy).

This DOE determination means that California nonresidential building code must result in energy performance that is equal to or better than the energy performance achieved through the current edition of Standard 90.1. Energy performance is evaluated on the code as a whole – not on a measure-by-measure basis. California legally does not have to adopt any one measure in Standard 90.1 as long as the aggregate of all measures in Title 24, Part 6 result in the same or better energy performance as the aggregate of all measures in Standard 90.1.

Adopting new Standard 90.1 requirements into California's building code is a best practice for energy policy and happens regularly with some language modification. For instance, language in Standard 90.1, which is intended for a national audience, is regularly reviewed for applicability and cost-effectiveness in California's climate zones (Statewide CASE Team, 2017). Requirements that are not suitable for specific areas are modified.

Adding Standard 90.1-2016 energy reporting requirements into California's Building Energy Efficiency Standards would help California meet and exceed ASHRAE's code and align the state with national trends.

The proposed code change builds upon existing requirements in the 2019 Title 24, Part 6 Standards including existing EMCS functional requirements and clear language that an EMCS can be used to comply with mandatory lighting, mechanical, and DR control requirements. Although Title 24, Part 6 does not require an EMCS, they are common in nonresidential buildings, especially those with multi-zone systems.

An EMCS is almost always used when the building has direct digital control (DDC), and since section 120.2(j) of Title 24, Part 6 requires DDC in most nonresidential buildings an EMCS is present in most newly constructed nonresidential buildings. The EMCS is often used to comply with the control requirements in Title 24, Part 6.

Currently, when an EMCS is installed, it must be capable of monitoring energy loads, adjusting operations to optimize energy usage, and respond to DR signals. The requirements being proposed here update the EMCS definition to add a requirement that the EMCS also be capable of recording and reporting electrical energy use to the building operator through the EMCS. An EMCS would collect electrical energy use data from all major energy-using systems it monitors, which may include HVAC, water heating, interior and exterior lighting, controlled receptacles, DR controls, and smart devices.

Preliminary investigations have shown that most EMCS products from a variety of manufacturers have energy reporting capabilities though there is no standardized approach to energy reporting. This proposal leverages existing capabilities while also providing standardization of how energy consumption is reported. Requiring reporting of end-use consumption to the building owner or facility operator does not in itself generate energy savings, however, several research studies have shown that providing this information leads to savings in most cases. Because it is standard practice for an EMCS to have energy reporting capabilities, the code changes proposed in this measure do not have additional cost, and therefore, are deemed to be cost-effective.

2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each Title 24, Part 6 document will be modified by the proposed change. See Section 7 Proposed Revisions to Code Language of this report for detailed proposed revisions to code language.

The proposed new Section 110.13, to centralize and consolidate EMCS requirements, will greatly clarify the code language. Current code language that discusses when an EMCS can be used to comply with control requirements could be clearer. In the 2019 code cycle the Statewide Utility Codes and Standards Team advocated for additional cleanup of this language (Statewide Utility Codes and Standards Team, 2018). Should the Energy Commission modify the EMCS definition they should also pursue these recommendations.

2.3.1 Standards Change Summary

This proposal would modify the following sections of the Building Energy Efficiency Standards as shown below. See Section 7 Proposed Revisions to Code Language of this report for the detailed proposed revisions to the standards language.

- Section 100.1 - Definitions and Rules of Construction: Modify the definition of EMCS to state that they be capable of receiving energy use data and recording and reporting it.
- Section 110.12(a) - Mandatory Requirements for Demand Management: Add a requirement that all DR controls in the building, including DR devices, be capable of monitoring and reporting their own energy use and that if the building has an EMCS the information be transmitted to the EMCS.
- Section 110.13 - Requirements for Energy Management Control Systems: Create a new section of the standards and consolidate all requirements that pertain to the EMCS into this section. Adds requirements that if an EMCS is installed it be capable of monitoring energy loads that it controls and reporting on electrical energy use. Move requirements that were previously in Sections 120.2(a), 130.0(e) and 150.0(k) into new section.
- Section 120.2(a) - Required Controls for Space-conditioning Systems: Move requirements that identify when an EMCS can be used to comply with thermostatic controls requirements from Section 120.2(q) to Section 110.13(b).
- Section 120.5(a) - Required Nonresidential Mechanical System Acceptance: update reference to EMCS functional requirements from “Part 6” to “Section 110.13(a)”.
- Section 130.0(e) - Lighting Systems and Equipment-General: Move requirements that identify when an EMCS can be used to comply with nonresidential lighting controls requirements from Section 130.0(e) to Section 110.13(b).
- Section 150.0(k) - Mandatory Features and Devices: Move requirements that identify when an EMCS can be used to comply with residential indoor and outdoor lighting controls requirements from Section 150.0(k)2G and 150.0(k)3B, respectively, to Section 110.13(b).

2.3.2 Reference Appendices Change Summary

Currently, acceptance testing requirements for the various functions of an EMCS are described in numerous locations of the Title 24, Part 6 Reference Appendices including Nonresidential Appendices (NA) sections 7.5.10, 7.6.3, and 7.7.2. The proposed code change adds an acceptance test to verify the energy reporting capabilities of the EMCS, to provide assurance that the EMCS is set up and programmed correctly, and that energy use data collected in compliance with the energy reporting requirements is accurate. Additionally, the proposed code change recommends that the Energy Commission consider consolidating all tests that pertain

to the functionality of the EMCS into one location in the Nonresidential Appendices. Proposed language on this consolidation is found in Section 0 of this report.

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

The proposed code change will not modify the ACM Reference Manuals.

2.3.4 Compliance Manual Change Summary

The proposed code change will modify the following section of the Nonresidential Title 24, Part 6 Compliance Manual:

- Chapter 2 Compliance and Enforcement
- Chapter 4 Mechanical Systems
- Chapter 5 Nonresidential Indoor Lighting
- Chapter 7 Sign Lighting
- Chapter 10 Covered Processes
- Appendix D - Demand Response Controls

2.3.5 Compliance Forms Change Summary

The proposed code change will modify the following compliance forms listed below:

- **NRCI-LTI-02-E** – Energy Management Control System or Lighting Control System
- **NRCI-LTO-02-E** – Energy Management Control System or Lighting Control System
- **NRCA-MCH-18-A** – Energy Management Control System Acceptance

2.4 Regulatory Context

2.4.1 Existing Requirement in Title 24, Part 6

The 2019 Title 24, Part 6 standards do not include requirements for energy reporting, however there are several existing requirements that this proposal builds upon. Namely, requirements for EMCS, demand responsive controls, the design of electric circuits, and service electrical metering. These requirements are summarized in Table 2. EMCS requirements were added to Title 24, Part 6 for the 2008 code cycle. Since then, technology has matured and become well known within the building industry. The proposed update requires energy reporting of all major electrical end-uses, something that most EMCSs are capable of today.

Table 2: Existing requirements in Title 24, Part 6 relevant to proposed code change

Building Code and Section Number	Measure Name	Measure Description
Title 24, Part 6 Section 130.5(b)	Separation of Electric Circuits for Electrical Energy Monitoring	Requires electrical circuits in certain buildings to be designed so similar load types (e.g., all lighting, water heating, HVAC, plug loads) are on the same circuits.
Title 24, Part 6 Section 130.5(a)	Service Electrical Metering	All meters must have capability to meter instantaneous kW demand and track kWh use for a user-defined period. Meters for buildings where electrical services is rated at more than 250 kVA must be capable of tracking historical peak demand and meters for buildings where service is rated at more than 1000kVa must track kWh per rate period.
Title 24, Part 6 Sections 100.1(b), 110.2(c), 120.2(a), 130.0(e)	Energy Management Control System (EMCS)	An EMCS is never required, but it is defined in the Standards and designers are allowed to use an EMCS to comply with lighting and HVAC controls requirements in Title 24. If an EMCS is installed, acceptance tests must be conducted to ensure it is commissioned properly.
Title 24, Part 6 Section 110.12, Joint Appendix 5	Demand Responsive Controls	Title 24, Part 6 requires demand responsive controls for HVAC systems in all nonresidential buildings (via smart thermostats or controls for DDC systems) and lighting in buildings over 10,000 ft ² . The demand responsive controls must meet several functional requirements.

2.4.2 Relationship to Requirements in Other Parts of Title 24

There are no requirements in other parts of Title 24 that are relevant to the proposed code changes.

2.4.3 Relationship to Federal, State, and Local Laws

There are no current federal energy reporting laws for buildings, but several state laws do require some form of energy reporting and benchmarking.

California Assembly Bill (AB) 802, which was chaptered in 2015, required the Energy Commission to “create a benchmarking and disclosure program through which building owners of commercial and multifamily buildings above 50,000 ft² gross floor area will better understand their energy consumption through standardized energy use metrics” (California Assembly Bill 802 - Chapter 590, 2015). As a result of this bill, starting in June 1, 2018, building owners are required to report building characteristic information using ENERGY STAR Portfolio Manager on an annual basis. Starting in 2019, AB 802 will expand to require multifamily buildings (larger than 50,000 ft²) with 17 or more residential utility accounts to report their energy use data. Some local jurisdictions including San Francisco, Berkeley, and Los Angeles, have benchmarking requirements that are more stringent than the statewide requirements. See Table 4 for a summary of local and statewide benchmarking requirements.

Data collected in compliance with disclosure requirements serves as a benchmark to monitor each building’s energy performance over time and to compare the energy performance of similar buildings to identify opportunities for efficiency improvements. Most benchmarking policies require the disclosure of whole-building energy use information reported annually, which is not sufficiently granular for utilities and consumers to understand energy use and prevents a more targeted effort for energy performance improvements. If buildings were capable of recording and reporting energy consumption of major end-uses and devices, as this code change proposes, the data reported in compliance with benchmarking requirements could be more useful to building managers as they strive to maintain the energy performance of buildings over time. The data would also be more useful for jurisdictions, utilities, or third parties that aim to design programs to support energy improvements in existing buildings.

Table 3: State and local policies relevant to proposed code change

Type of Policy	Name	Description
State Statutes	Building Energy Benchmarking Program (AB 802)	Owners of buildings $\geq 50,000$ ft ² must report annual energy use to the California Energy Commission through Energy Star Portfolio Manager. Requires utilities to provide building owners with building-level energy-use data.
Local Ordinances	San Francisco Benchmarking Policy	Publicly- and privately-owned nonresidential buildings $\geq 10,000$ ft ² must: 1. Benchmark building energy use using Energy Star Portfolio manager and report results to the San Francisco Department of Environment and tenants on an annual basis. The annual report must present: Contact information and square footage, EUI, 1-100 Performance Rating provided by Portfolio Manager, where applicable Greenhouse gas emissions from energy usage. 2. Perform and audit once every 5 years. Requires ASHRAE Audit Level II or higher for buildings $\geq 50,000$ ft ² and ASHRAE Audit Level I or higher for buildings 10,000 - 49,999 ft ² .
Local Ordinances	City of Berkeley Building Energy Savings Ordinance (BESO)	The BESO includes benchmarking and audit requirements for all buildings >600 ft ² with effective dates and frequency of reporting varying by building type and size: 1. Nonresidential buildings $\geq 25,000$ ft ² must report energy use to the City of Berkeley Director of Planning and Community Development through Energy Star Portfolio manager annually and submit energy assessment every 5 years. 2. Nonresidential buildings $<25,000$ ft ² must submit energy assessment every 10 years and at time of sale. 3. Small residential (1-4 dwelling units) must complete energy assessment at time of sale.
Local Ordinances	City of Los Angeles Existing Buildings Energy and Water Efficiency Program (EBEWE Program)	Owners of certain types of buildings are required to disclose their building's energy and water consumption using ENERGY STAR Portfolio Manager to the City of Los Angeles Department of Building and Safety. Applies to: 1. City-owned buildings $\geq 7,500$ ft ² 2. Privately owned or owned by local agency of the state $\geq 20,000$ ft ² . 3. Privately owned buildings $\geq 20,000$ ft ² and city-owned buildings $\geq 15,000$ ft ² must submit initial audit and retro-commissioning reports every 5 years.

2.4.4 Relationship to Industry Standards and Model Energy Codes

Energy reporting of major electrical end-uses at the building level has been part of ASHRAE Standard 90.1 since the 2013 edition. The requirement within Standard 90.1 states that major building end-uses, including HVAC, interior lighting, exterior lighting, and receptacle circuits, shall be separately monitored, and the energy consumption be recorded at 15-minute intervals and reported on an hourly, daily, monthly, and annual basis. The requirement only applies to buildings larger than 25,000 ft², effectively ruling out small buildings with simple systems that may not employ an EMCS. The proposed measure leverages and aligns with the energy

reporting requirements in ASHRAE Standard 90.1 (ASHRAE, 2016) and ASHRAE Standard 189.1 (ASHRAE, 2018).

shows existing requirements in ASHRAE Standards 90.1 and Standard 189.1 that are relevant to the propose code change.

Table 4: Requirements in model energy codes relevant to proposed code change

Building Code and Section Number	Measure Name	Measure Description
ASHRAE 90.1 Section 6.4.3.10	Direct Digital Control (DDC)	DDC systems are required in certain building types. DDC systems are mostly controlled by EMCS, which then also provides the ability to perform energy monitoring, recording, and reporting.
ASHRAE 90.1 Section 6.4.3.11 and 6.4.3.12	Chiller Monitoring Requirements	Some electric-motor-driven chilled water plants (capacity thresholds that vary by climate zone) must have measuring devices that measure electric energy use and efficiency of the plant. Energy use and efficiency shall be trended every 15 minutes and graphically displaced and include hourly, daily, monthly, and annual data. The system shall maintain all data collected for a minimum of 36 months.
ASHRAE 90.1 Section 8.4.3.1	Energy Monitoring	Measurement devices are required to be installed in new buildings larger than 25,000 ft ² to monitor the electrical energy use for each of the following separately: total electrical energy, HVAC systems, interior lighting, exterior lighting, receptacle circuits.
ASHRAE 90.1 Section 8.4.3.2	Energy Recording and Reporting	Electrical energy use for loads required to be monitored are required to be recorded a minimum of every 15 minutes and reported at least hourly, daily, monthly, and annually.
ASHRAE 90.1 Section 10.4.5	Fossil fuel site use monitoring and reporting (submetering)	Measurement devices are required to be installed to monitor the energy use of the following types of energy: Natural gas, fuel oil, propane, steam, chilled water, hot water. Buildings smaller than 25,000 ft ² are exempted. The energy use of each building on the building site is required to be recorded at a minimum of every 60 minutes and reported at least hourly, daily, monthly, and annually.
ASHRAE 189.1 Section 7.3.3	Energy Consumption Management	Requirements to monitor fuel use (electricity, natural gas, others), collect data on hourly basis, store data for 36 months. Sub-metering of HVAC, lighting, plug, and process loads is required for buildings meeting certain thresholds.
ASHRAE 189.1 Section 7.4.7.3	ENERGY STAR Equipment	Energy Star-rated equipment is required for specific appliances, heating and cooling equipment, water heaters, electronics, office equipment, lighting, commercial food service, and other products.
ASHRAE 189.1 Section 10.3.2.1.3.2	Track and Assess Energy Consumption	Requirements for documenting, benchmarking, and assessing energy performance on a periodic basis using energy reporting in section 7.3.3.

2.5 Compliance and Enforcement

Compliance with and enforcement of the proposed energy reporting requirements is feasible without major restructuring of the compliance process or additional Energy Commission staff support. For this report, a complete assessment of potential compliance barriers on market actors has not been completed, though it is expected that this proposal shall be updated as it moves through the code development process. An assessment of market actors and potential barriers will be conducted through stakeholder interviews as well as public hearings. Some of the market actors affected by the energy reporting requirements are: building designers; EMCS manufacturers and distributors; field technicians; plans examiners; field inspectors; building owners; and facility managers and operators. As part of this code change, existing compliance forms will need to be updated to properly capture new specifications for each of the four main compliance process phases: design phase, permit application phase, construction phase and the inspection phase. Section 0 lists the necessary forms that will need updating. In addition, new acceptance tests are required to test the energy reporting functionality of the EMCS. For the energy reporting measure, EMCS requirements in the building energy code must comply in the field after being installed. Currently, code officials and building technicians must already verify the numerous EMCS requirements through existing compliance certifications.

On a larger, more long-term scale, energy reporting could contribute to the whole building compliance process. By adding energy reporting of major end-uses to the EMCS requirements, building inspectors could leverage this energy data to check major building components and revise their existing in-field commissioning checks - ultimately making this more of a digital process, rather than lengthy field assessments. The opportunity to leverage EMCS data for building compliance and enforcement checks is worth further exploration with the Energy Commission.

3. Market Analysis

A market analysis was completed with the goal of identifying current technology availability, current product availability, and market trends. The analysis considered how the proposed standard may impact the market in general and individual market players. Information about the incremental cost of complying with the proposed measure was collected. Estimates of market size and measure applicability were identified through research and outreach with the Energy Commission. Key industry stakeholders were not contacted for this report, though it is expected that they would be contacted as this measure moves forward. In a standard measure proposal to the Energy Commission, a wide range of industry players are contacted and invited to participate in stakeholder meetings to weigh in on the proposed code changes. Information on these key stakeholders is provided in the following sections.

3.1 Market Structure

The California energy management system marketplace consists of numerous well-established providers, each contributing a unique component to the overall product and system. These contributing providers include: manufacturers/providers; analytics vendors; and software vendors. Energy reporting is a feature of an EMCS that has existed on the market for decades.

The principal EMCS manufacturers and suppliers are international in scale, with diversified market consumers (residential, nonresidential, industrial, and utility-scale). Such manufacturers include large companies such as Schneider Electric, Johnson Controls, Honeywell, and Siemens. Several of these firms are multibillion-dollar businesses that have specialized in high-end building and HVAC equipment. In 2014, Schneider Electric alone reported billions in energy management sales serving North America, Western Europe, Asia Pacific, and 'Other' global markets. Between these four companies, EMCS systems (on the market and available for purchase) come with the ability to record and store energy reporting data (as well as other subsystem information). More advanced EMCS systems also offer software and built-in displays that automatically aggregate and display this information. The technology to support energy reporting within an EMCS is readily available from multiple established partners, with smaller firms growing in their market share over the past decade (while also offering overlapping services and features such as software and building automation).

According to the 2012 Commercial Building Energy Consumption Survey (CBECS), commercial buildings spend \$1.44 per square foot per year on electricity (U.S. Energy Information Administration, 2012). New providers are rapidly entering the space to offer insights and strategies to better manage this significant energy spend. The following sections detail this landscape.

3.2 Technical Feasibility, Market Availability and Current Practices

3.2.1 Current Market Availability

In the 1980s and 1990s, effective energy monitoring was quite expensive. It required equipment (sensors, wiring, dataloggers), installation, and testing for each specific monitoring point of interest. The required equipment for monitoring/reporting is nowadays contained and present at a site and/or building in the form of an EMCS. An EMCS can collect the same information that earlier data acquisition systems would detect (Heinemeier, 1993). By relying less on complex and expensive data acquisition systems, building energy management systems have become more available and affordable over the past decades. EMCS-based monitoring and energy reporting offers an incredible amount of computing capabilities and power. EMCS can collect raw data and carry out sophisticated data and systems analysis for the user. Although most EMCS products have the capability to implement energy reporting strategies, not all products come pre-programmed with the functionality and not all building managers enable the feature or are trained to utilize this functionality. Ensuring the EMCS is set up and programmed would enhance its ability to provide accurate information through its energy reporting features. EMCS platforms are working to make this commissioning simpler and more straightforward. An acceptance test to verify the EMCS is set up and programmed correctly to comply with the proposed energy reporting requirements is needed and proposed language is included in Section 0 of this report.

Over the past three decades EMCS technology has evolved from pneumatic, and mechanical devices to direct digital controls (DDC) or computer-based controllers and systems (Hatley, Meador, Katipamula, & Brambley, 2005). In 2018, Greentech Media mapped the various providers of the building energy landscape. EMCS devices are difficult to generalize based on the many model characteristics and installed functions. Yet, as captured in **Error! Reference source not found.**, the providers in this space are numerous - many specializing in certain system controls and analysis. The options for EMCS technology are expanding and readily available.

Figure 1: Energy Management Platform Providers

Selected Energy Management Platform Providers Within the Building Energy Landscape



Source: [Greentech Research](#)

3.2.2 Current Buildings Utilizing EMCS

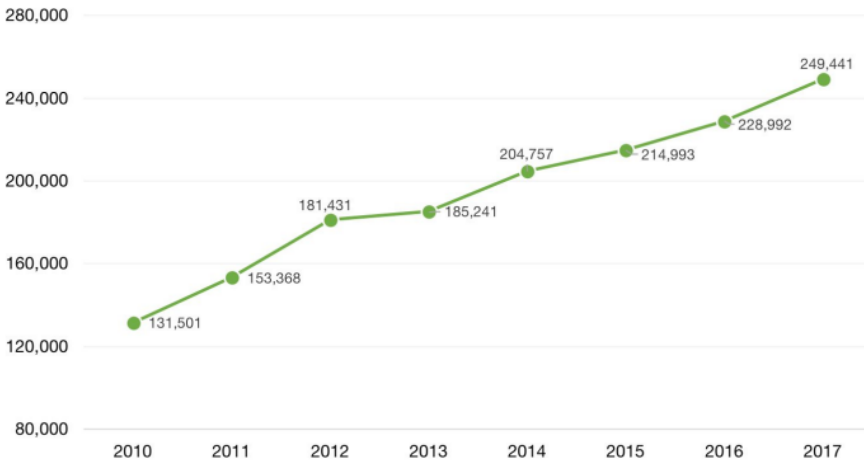
An EMCS may capture and record energy loads through a variety of strategies and control configurations. The proposed code changes in this report do not dictate specific configurations and allow for flexibility in how systems are designed.

An increasing number of companies and buildings are using EMCS for more effective resource management. In a 2015 Ecova study, nearly 200 multi-site companies across industries were surveyed on how they selected, managed, and maintained EMCS systems. A majority of companies, 82 percent, have EMCS installed at some or all of their facilities, and 68 percent have EMCS installed at over half of their facilities (Ecova, 2015 b). An earlier 2013 Ecova study shows the proliferation of this technology, where in 2013 only 45% of companies had EMCS installed at their facilities (Ecova, 2015 a). More and more companies reported using EMCS due to limitations on human resources and internal energy expertise.

A 2019 research effort by Greentech Media further uncovered the extent of commercial buildings that are benchmarking their energy data in Energy Star Portfolio Manager (Aamidor, 2019). Approximately 50 percent of commercial floorspace (249,441 buildings in 2017) had been benchmarked in Energy Star (Aamidor, 2019). To complete this type of benchmarking, building owners need access to their utility bill data. This high, voluntary, participation rate in energy benchmarking supports the claim that energy reporting is an in-demand and useful building feature. The Energy Star Portfolio Manager data alone may also underrepresent installed energy management systems if building owners use other and multiple vendors for their energy management solutions. Within commercial spaces, offices, retail, medical and lodging had the greatest share of Energy Star benchmarking participants. These commercial spaces are a prime target for energy reporting requirements and align with the proposed measure outlined in this proposal.

Figure 2: Annual Buildings Participating in ENERGY STAR's Data Benchmark

Annual Buildings Participating in Energy Star's Data Benchmark



Source: [Green Tech Research](#)

3.2.3 Current Energy Monitoring Strategies and Solutions

Energy management control systems have evolved in complexity over time. Their overarching goal is to provide feedback to building personnel in building commissioning, operation, and maintenance. It is important that today's products have the ability to work with different existing systems on an open network. In fact, participants of the 2015 Ecova study named integration with current assets as the primary purchasing criterion for EMCS.

In California, a current building practice given existing Title 24, Part 6 standards is that many EMCS are installed as lighting controls (as opposed to a formal lighting control system) to comply with control requirements. An installed EMCS in California requires an installation certification to be recognized as compliant. In the 2019 Title 24, Part 6 standards, EMCS are required to be able to communicate with and respond to demand response signals. This is a recent example of the expanding requirements for EMCS technology. Similarly, with the proposal to specify energy reporting as a capability of an installed EMCS, we would increase the installed functionality of these devices.

Outside of California, on day-to-day EMCS operation strategies, 56 percent of building owners collect 15-minute interval meter data (Ecova, 2015b). This interval meter data are 96 percent electric data. Interval data, paired with direct feedback, a feature in many EMCS devices, gives occupants the greatest visibility into their building systems.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

The proposed code change modifies existing standards, though it does not add cost for the builder.

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes is within the normal practices of building designers. The building industry, including building designers and energy consultants, should plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. This proposed energy reporting measure aims to provide building designers and energy consultants a greater understanding of building energy consumption. Often, buildings are designed to be high performing and energy efficient, but system faults or occupant behavior create a less-efficient reality. Access to energy reporting data will aid detection of problems and offer feedback to building designers and energy consultants.

3.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Department of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have any impact on the safety or health occupants or those involved with the construction, commissioning, and ongoing maintenance of the building.

3.3.4 Impact on Building Owners and Occupants (including homeowners and potential first-time homeowners)

The proposed code change modifies existing standards with the intent of increasing greater adoption and compliance with energy management standards that could benefit occupants by reducing energy bills. In Section 4 of this proposal, an explanation of how energy reporting leads to energy savings is outlined. Building owners and occupants will benefit from greater transparency of their main building components energy consumption, detection of faults, and measurement and verification.

3.3.5 Impact on Building Component Retailers (including manufacturers and distributors)

The proposed regulations will modify existing standards, the intent is to grant building owners and occupants greater access to their energy data. Energy management systems manufacturers and service providers will want to continue to align all future products with energy reporting capabilities and best practices.

3.3.6 Impact on Building Inspectors

The proposed regulations will modify existing standards, there are no anticipated impacts on building inspectors.

3.3.7 Impact on Statewide Employment

Findings from the 2017 DOE U.S. Energy and Employment Report (USEER) show that California has more than 301 thousand jobs in Energy Efficiency (13.8 percent of all energy efficiency jobs

nationwide) (U.S. Department of Energy, 2017). This is more than any other energy sector, with electric power generation employing the second largest number of workers, with more than 203 thousand jobs. Energy efficiency jobs in California and nationwide are increasing - with 133 thousand more jobs in 2016 than the previous study.

These proposed changes would modify existing standards and support the growth of this industry by maintaining the importance of energy reporting and energy efficiency within our buildings. The code changes are anticipated to support the growth trend in the energy efficiency sector statewide.

3.4 Economic Impacts

3.4.1 Creation or Elimination of Jobs

The proposed regulations will not impact the number of jobs created/eliminated over a multi-year period within California.

3.4.2 Creation or Elimination of Businesses within California

The proposed regulations will not impact the creation or elimination of businesses within California.

3.4.3 Competitive Advantages or Disadvantages for Businesses within California

The proposed regulations do not create a competitive advantage or disadvantage for California businesses.

3.4.4 Increase or Decrease of Investments in the State of California

The proposed regulations do not impact investments in the State of California as compared to existing standards requirements.

3.4.5 Effects on Innovation in Products, Materials, or Processes

The proposal is expected to accelerate the continued development of energy management technology, particularly integrated energy reporting systems. The proposal is expected to continue to drive down overall costs of energy reporting equipment. No other impacts on innovation in products, materials or processes are expected.

3.4.6 Effects on the State General Fund, State Special Funds and Local Governments

3.5.6.1 Cost of Enforcement

Cost to the State

The proposed regulations present no new cost impacts to the State.

Cost to Local Governments

The benefits from energy reporting could support local government climate action planning, development of local reach codes, and the implementation of energy performance benchmarking ordinances. Proper use of building energy reporting could also decrease the time necessary to verify major building component operations, code compliance, and energy use. The cost to local governments from this proposed regulation, training or otherwise, is expected to be unchanged or decrease.

3.5.6.2 Impacts on Specific Persons

No additional impacts on specific persons are anticipated.

4. Energy Savings

4.1 Key Assumptions for Energy Savings Analysis

Energy reporting will not directly result in energy savings. However, ensuring that EMCS systems are using this capability and standardizing the format and frequency of reporting provides a key enabling feature that can unlock several pathways to increased energy savings. These pathways include:

- **Continuous commissioning.** Continuous commissioning is an ongoing process that aims to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings (Haasl et al. 2004). A fundamental component of continuous commissioning is the ability to monitor and report the energy use of various building subsystems. This reported data can be used to verify and ensure the persistence of operational energy use targets achieved during commissioning, which could otherwise degrade over time.
- **Demand response.** Automated demand response (ADR) programs commonly operate under the rule-of-thumb that buildings must shed a minimum of five percent of total building electricity load during a DR event. This is mostly to ensure that the load shed is not confused with normal fluctuations in building energy use. Energy reporting from building subsystems could effectively act as a sub meter on individual building systems (e.g., HVAC, lighting, plug loads). This would allow DR baselines and load shed events to be visible for individual sub-systems as well as the entire building, thereby allowing for more reliable monitoring of smaller building load reductions. In aggregate, this could result in more DR participation both through an increase in event participation from those facilities that are already enrolled in DR programs, and from expanded enrollment.
- **Behavior change.** There have been a multitude of studies examining and verifying the important role of occupant behavior in building energy consumption (Dietz et al. 2009; Francisco et al. 2018; Wolfe et al. 2014). Providing feedback to occupants about energy use has been identified as one of the core strategies for motivating behavior change. While this is mostly applicable in residential settings where occupants have more control over building energy systems, there is evidence that real time graphical displays of energy use can motivate an increase in energy efficient behaviors from commercial building occupants (Wolfe et al. 2014).

4.2 Energy Savings Methodology

Realizing energy savings from energy reporting through the pathways described above depends on additional steps and actions by buildings managers, occupants, and utilities. Given the inherent uncertainty of when and how these steps are carried out, specific energy savings estimates were not calculated for this report. Rather, a discussion of how such pathways could be calculated, and rough estimates of energy savings and demand reductions are presented below for each energy saving pathway.

4.2.1 Monitoring-based Commissioning

According to Section 120.8 of the 2019 Title 24, Part 6 Standards, building commissioning is “systematic quality assurance process that spans the entire design and construction process, including verifying and documenting that building systems and components are planned,

designed, installed, tested, operated and maintained to meet the owner’s project requirements”(California Energy Commission 2018). Monitoring-based commissioning (MBCx) differs from the commissioning process required by Section 120.8 primarily by the fact that it is an ongoing process, rather than a one-time procedure carried out during design, construction, and occupancy. The goal is to provide continuous building performance improvement through data monitoring, analysis, and corresponding adjustments. Monitoring and reporting of building energy subsystems is a key enabling technology for monitoring-based commissioning, though it is not sufficient on its own. An additional network of sensors is needed to monitor a given system’s performance and report data back to the EMCS. These sensors will measure things like occupancy, outdoor air temperature, air handler supply, return and mixed-air temperatures, chilled water supply and return temperatures. **Error! Not a valid bookmark self-reference.** outlines the three phases of setting up a monitoring-based commissioning system in a building. The role that energy reporting plays in this process is to:

1. Establish energy consumption baselines after a building is commissioned (new construction) or retro-commissioned (existing building).
2. Track whole building and subsystem energy use and use data to report anomalies when values fall outside of expected ranges.
3. Verify savings once adjustments have been made.

Table 5: The phases of monitoring-based commissioning

MBCx planning phase		
1.1	Collect building documentation and create/update current facility requirements (CFR)	Collect building
1.2	Define high priority systems for performance monitoring	Define high-prio
1.3	Create a Monitoring Action Plan (MAP)	Create a Monit
1.4	Specify or enhance an Energy Management and Control System (EMCS)	Specify or enha
1.5	Create Training Plan	Create a Traini
EMCS Configuration Phase		
2.1	Define data configuration requirements	Define data con
2.2	Calibrate critical sensors	Calibrate critica
2.3	Perform EMCS data quality checks	Perform EMCS
2.4	Create an EMCS user interface	Create an EMC
2.5	Configure the fault detection and diagnostics (FDD)	Configure the fa
2.6	Configure energy savings and anomaly tracking	Configure ener
MBCx Implementation Phase		
3.1	Identify issues and opportunities using EMCS and Monitoring Action Plan	Identify issues

3.2	Investigate root cause for prioritized issues	Investigate root
3.3	Identify and implement corrective actions, and update facility documentation	Identify and imp
3.4	Verify performance improvement	Verify performa
3.5	Implement reporting, documentation, and training	Implement repo

Source: Adapted from (Harris et al. 2018)

As shown in Table 5, fault detection and diagnosis (FDD) is a part of the monitoring-based commissioning process, but energy reporting could be used to support FDD separately as well. That is, subsystem monitoring could be used to alert building operators when energy consumption of individual systems fall outside of normal ranges. Operators could then use software or manual diagnostics to help correct the problem, faster than they would have during normal building tune-ups. This would likely yield smaller savings than continuous MBCx, but could also require a less complex system. From the literature, energy savings estimates for ongoing commissioning range from 15-45 percent, however, as with all savings estimates, the baseline case matters (Plourde 2011). In the context of the currently proposed measure, the baseline would be buildings that currently have EMCS installed, but are not using it to monitor, report, and store data on energy use from building subsystems. Subsequently, it would require a survey of facility managers or chief engineers to determine the likelihood that they would pursue a monitoring-based commissioning system if their EMCS systems were required to collect data from building subsystems.

4.2.2 Demand Response

In addition to EMCS capability for fine tuning efficient building operations, these systems allow for much higher levels of precision and control for participation in DR programs. By measuring the level of energy services being provided in a building (e.g., lumens, temperature to a zone, ventilation airflow) in combination with the energy consumption of these systems, EMCS can fine tune a desired response both in terms of energy reduction and change in the level of the energy service provided during a DR event. In this way, EMCS have been shown to increase the demand responsiveness of buildings (Piette, Kiliccote, and Ghatikar 2008).

By mandating and standardizing the monitoring and reporting of EMCS, the proposed code change can help increase the visibility of DR event participation. This is especially true for DR program administrators and evaluators who may be aggregating data across many buildings. Reporting consumption data by building subsystem in standardized intervals will allow these groups to aggregate data easily and verify event participation on a more granular level than with whole building meter data. In an interview with the Statewide Utility ADR implementation team it was stated that: “[energy reporting] would help to reduce time spent reviewing measures, commissioning, on-site load shed test analysis, and performance analysis for all customers.” In turn, DR program administration costs could be reduced, and administrators could have more time to recruit additional participants. To the extent that additional recruitment efforts were able to increase DR program enrollment, a decrease in TDV energy use could be expected. Furthermore, subsystem monitoring could allow for smaller load sheds

during DR events, as these events would be more visible than if only whole building meter data was tracked. To the extent that current customers opted in to more DR events, TDV energy use would also decrease.

To estimate the additional TDV energy savings from an increase in DR participation, a survey of DR program implementers could help to estimate the percentage increase in customer enrollment and participation due to the proposed measure reporting requirements. These estimates would serve as foundational assumptions to estimate additional TDV energy savings that could result from the proposed code change.

4.2.3 Behavior Change

Giving occupants information about their energy consumption can influence energy-saving behavior (Abrahamse, Steg, Vlek, & Rothengatter, 2005), but ultimately the consumer must choose to act upon the feedback they are given (Foster & Mazur-Stommen, 2012). So, while energy reporting alone cannot generate direct energy savings, there is a wealth of research that posits energy feedback can enable commercial building operators and facility managers to:

- track and adjust energy consumption;
- identify and respond to broken equipment (detect faults);
- identify and eliminate wasteful practices;
- more properly estimate and understand the impact of energy conservation actions; and
- streamline operations for long-term performance

Feedback format and frequency have been shown to contribute to the success and/or degree of energy savings (Ehrhardt-Martinez, et al., 2010). Characteristics of successful feedback that leads to energy savings include: frequent feedback, the useful and graphical representation of data, the pairing of energy feedback with suggested actions, and goal setting (comparing your data against your goal) (Ehrhardt-Martinez, et al., 2010). With varying subsets of these features in current energy reporting systems, Ehrhardt-Martinez estimates that energy reporting-based feedback programs could result in 4-12 percent energy savings of typical energy usage, but also notes that achieved savings could be even higher.

The behavioral science behind energy conservation and human decision-making is a growing topic of research, but most studies have occurred in the residential sector where occupants have more control over the building's end uses. That said, nonresidential occupants still have control over end uses such as lighting and plug loads, so there is good reason to believe the effects of behavioral research in the residential sector apply in the commercial sector as well, but perhaps to a lesser degree. There is evidence that energy conservation can occur just by letting occupants know that they are being monitored (the so-called 'Hawthorne Effect'), and there is also research that suggests information displays can be effective (Schwartz et al. 2013; Francisco et al. 2018). Energy reporting could support both of these pathways toward behavior-led energy savings.

5. Lifecycle Cost and Cost-Effectiveness

The proposed code change adds recording and reporting requirements to an EMCS. The market analysis in Section 3 of this report showed that most EMCS platforms today are already equipped with this capability. In addition, Title 24, Part 6 does not require buildings to install an EMCS, rather it allows designers to use an EMCS to fulfill the building controls requirements for lighting, HVAC and DR systems. The proposed code change would modify only the minimum functional requirements of an EMCS. Thus, the proposed change does not add a cost burden to the installation of an EMCS, and therefore, no additional incremental cost is incurred. In addition, while there are no direct savings from energy reporting at the end-use level, research summarized in Section 4 of this report shows that indirect energy savings are produced through monitoring-based commissioning, improved and increased demand response, and through behavior change. Thus, the incremental cost for this measure is zero but the energy savings in most scenarios are non-zero. Therefore, a cost-effectiveness analysis is not required and has not been provided. However, information about the costs and energy cost savings associated with this measure has been provided below.

5.1 Energy Cost Savings Results

This proposed measure modifies existing requirements and is not a mandatory measure. An energy cost savings analysis is therefore not required.

5.2 Incremental First Cost

The authors conducted preliminary market research and reviewed current available information for EMCS systems to gauge the market penetration of EMCS systems that have energy reporting features. The findings are preliminary and warrant further exploration, most firms and manufacturers provide limited detail on sales and revenue data.

The energy management market is complex with vast solutions, many of them overlapping. In a 2005 report by the Pacific Northwest National Laboratory (PNNL) on desired EMCS features, it was noted that tracking major end-use energy was not necessarily done through an EMCS, but through more expensive standalone systems (Hatley, Meador, Katipamula, & Brambley, 2005). While the EMCS products and practices have shifted since 2005, it is significant to highlight that energy reporting through an EMCS could be less expensive than standalone systems. Leveraging the EMCS for the task of energy reporting could be a cost *saving* feature, especially for historical installations that still make use of expensive, wired sensors and controllers (Hatley, Meador, Katipamula, & Brambley, 2005). These sensors could be retired and replaced with wireless controls that are less expensive to maintain and install. Greater research on this possible savings trade-off needs to be gathered.

Reviews of current EMCS offerings do not reveal any additional costs for energy reporting functionality. In comparison, the ability for an EMCS system to automatically manage and respond to energy reporting data is more advanced and not as readily provided as a default feature. These features, as well as the expertise of a skilled technician or engineer could result

in EMCS costs – yet energy reporting itself is a clear product specification and not a source of increased costs.

5.3 Lifetime Incremental Maintenance Costs

Incremental maintenance cost is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the period of analysis. For the proposed code change, incremental maintenance costs are likely to be zero because the added feature of energy reporting is part of the EMCS. The maintenance of the energy reporting feature would be part of maintaining the proper functioning of the EMCS, and therefore would not add new costs.

6. First Year Statewide Impacts

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

Statewide savings were not calculated for this report since this measure does not directly result in energy savings.

6.2 Statewide Greenhouse Gas Emissions Reductions

Avoided greenhouse gas (GHG) emissions were not calculated because no direct energy savings will result from the proposed measure. To the extent that the proposed code change unlocks energy saving and demand response pathways described in Section 4, GHG savings would also result.

6.3 Statewide Water Use Impacts

The proposed code change will not result in water savings or increased water usage

6.4 Statewide Material Impacts

The proposed code change will not result in statewide material impacts.

6.5 Other Non-Energy Impacts

To the extent that the proposed measure leads to the changes described in Section 4, there are a variety of non-energy benefits that would also result:

1. **Ease of building operation.** Utilizing the energy monitoring and reporting, building operators will be able to more easily see how the building and its various components (HVAC system, lighting and lighting controls, and plug loads) are functioning over a period of time. This will enable building operators to identify faults and non-optimal performance. When retrofits or tune-up measures are implemented, the energy reporting capability will allow comparison of the energy consumption before and after the measure was implemented, driving down measurement and verification costs, as well simplifying the process for the building operator.
2. **Data availability and simulation calibration.** Standardizing the monitoring and recording of energy use of building subsystems will more easily facilitate data collection efforts and comparisons across buildings throughout the state. Additionally, this data can be used to facilitate calibrated building energy simulations and compare end-use energy consumption in simulation versus what was measured. This process can help improve simulation models and ultimately lead to more accurate energy information during building design. The data could also be useful in identifying measures, and for establishing future energy codes and state policies.
3. **Decreased administrative burden for demand response program implementers.** As discussed in Section 4, reporting subsystem energy use can allow DR program implementers to more easily verify customer performance and load shed testing. This can lower administrative costs for these programs.

7. Proposed Revisions to Code Language

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the code documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions). Struck text highlighted in teal has been moved from the section where the struck text appears to section 110.13(b) or NA7.19 with no changes to the code language. Underlined text highlighted in turquoise has been moved into section 110.13(b) or NA7.19 from another section with no changes to the code language.

7.1 Standards

SECTION 100.1 - DEFINITIONS AND RULES OF CONSTRUCTION

ENERGY MANAGEMENT CONTROL SYSTEM (EMCS) is an automated control system that regulates the energy consumption of a building by controlling the operation of energy consuming systems, and is capable of monitoring loads, ~~and~~ adjusting operations in order to optimize energy usage and respond to demand response signals, and recording and reporting electrical energy use for various end-uses within the building.

SECTION 110.12 - MANDATORY REQUIREMENTS FOR DEMAND MANAGEMENT

Buildings, other than healthcare facilities, shall comply with the applicable demand responsive control requirements of Sections 110.12(a) through 110.12(d).

(a) Demand responsive controls.

1. All demand responsive controls within the building, including devices that can respond to a demand response signal, must be capable of monitoring and reporting their energy consumption every 15 minutes. When a building has an EMCS, the demand responsive controls shall report their consumption to the EMCS.

SECTION 110.13 - MANDATORY REQUIREMENTS FOR ENERGY MANAGEMENT CONTROL SYSTEMS

Buildings, other than healthcare facilities, shall comply with the applicable requirements of Sections 110.13(a) through 110.13(b).

- (a) Energy Recording and Reporting. Energy Management Control Systems (EMCS) that are used to comply with controls requirements specified in Section 110.13(b) shall meet the following functional requirements for recording and reporting electrical energy use:
 1. The EMCS shall record all electrical energy use for all loads it is monitoring and shall monitor and record the electrical energy use for each of the following loads separately:
 - A. Total electrical energy
 - B. HVAC systems
 - C. Interior lighting
 - D. Exterior lighting

E.Receptacle circuits

2. EMCS must display electrical energy use from each major end-use separately.
3. Electrical energy use shall be recorded at a minimum of every 15 minutes.
4. Electrical energy use shall be reported at least hourly, daily, monthly, and annually.
5. EMCS shall be capable of maintaining all data collected for a minimum of 36 months.
6. EMCS shall be capable of transmitting electrical energy use data to the direct digital controls, when such controls exist in the building.
7. The data for each tenant space shall be made available to that tenant.

(b) Using EMCS to Comply with Controls Requirements.

1. **Use of an EMCS to Meet HVAC Control Requirements.** An EMCS may be installed to comply with the requirements of one or more thermostatic controls if it complies with all applicable requirements for each thermostatic control.
2. **Use of an EMCS to Comply with Lighting Control Requirements.**
 - i. For nonresidential, high-rise residential, and hotel/motel buildings, an EMCS may be installed to comply with the requirements of one or more lighting controls if it meets the following minimum requirements:
 1. Provides all applicable functionality for each specific lighting control or system for which it is installed in accordance with Sections 110.9, 130.1 and 130.2; and
 2. Complies with all applicable Lighting Control Installation Requirements in accordance with Section 130.4 for each specific lighting control or system for which it is installed; and
 3. Complies with all applicable application requirements for each specific lighting control or system for which it is installed, in accordance with Part 6.
 - ii. For low-rise residential buildings:
 1. Interior Lighting. An Energy Management Control System (EMCS) may be used to comply with control requirements in Section 150.0(k) if at a minimum it provides the functionality of the specified controls in accordance with Section 110.9, meets the installation certificate requirements in Section 130.4, meets the EMCS requirements in Section 130.0(e), and complies with all other applicable requirements in Section 150.0(k)2.
 2. Outdoor lighting. An energy management control system that provides the specified lighting control functionality and complies with all requirements applicable to the specified controls may be used to meet these requirements.

SECTION 120.2 - MANDATORY REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

- (a) Thermostatic Controls for Each Zone.** The supply of heating and cooling energy to each space-conditioning zone or dwelling unit shall be controlled by an individual thermostatic controls that responds to temperature within the zone and that meet the applicable requirements of Section 120.2(b). An Energy Management Control System (EMCS) may be installed to comply with the requirements of one or more thermostatic controls if it complies with all applicable requirements for each thermostatic control.

SECTION 120.5 - REQUIRED NONRESIDENTIAL MECHANICAL SYSTEM ACCEPTANCE

- (a) 17. When an Energy Management Control System is installed, it shall functionally meet all of the applicable requirements of ~~Part 6~~ Section 110.13(a).

SECTION 130.0 - LIGHTING SYSTEMS AND EQUIPMENT, AND ELECTRICAL POWER DISTRIBUTION SYSTEMS—GENERAL

~~(e) Energy Management Control System (EMCS). An EMCS may be installed to comply with the requirements of one or more lighting controls if it meets the following minimum requirements:~~

- ~~1. Provides all applicable functionality for each specific lighting control or system for which it is installed in accordance with Sections 110.9, 130.1 and 130.2; and~~
- ~~2. Complies with all applicable Lighting Control Installation Requirements in accordance with Section 130.4 for each specific lighting control or system for which it is installed; and~~
- ~~3. Complies with all applicable application requirements for each specific lighting control or system for which it is installed, in accordance with Part 6;~~

SECTION 150.0 - MANDATORY FEATURES AND DEVICES

(k) Residential Lighting

2. Interior Lighting Switching Devices and Controls.

- G. ~~An Energy Management Control System (EMCS) may be used to comply with control requirements in Section 150.0(k) if at a minimum it provides the functionality of the specified controls in accordance with Section 110.9; meets the installation certificate requirements in Section 130.4, meets the EMCS requirements in Section 130.0(e), and complies with all other applicable requirements in Section 150.0(k)2.~~

3. Residential Outdoor Lighting.

- A. For single-family residential buildings, outdoor lighting permanently mounted to a residential building, or to other buildings on the same lot, shall meet the requirement in item i and the requirements in either item ii or item iii:
- i. Controlled by a manual ON and OFF switch that permits the automatic actions of items ii or iii below; and
 - ii. Controlled by a photocell and either a motion sensor or an automatic time switch control; or
 - iii. Controlled by an astronomical time clock control.
- B. Controls that override to ON shall not be allowed unless the override automatically returns the automatic control to its normal operation within 6 hours. ~~An energy management control system that provides the specified lighting control functionality and complies with all requirements applicable to the specified controls may be used to meet these requirements.~~

7.2 Reference Appendices

NA7.5.10 Automatic Demand Shed Control Acceptance

NA7.5.10.1 Construction Inspection

Prior to Acceptance Testing, verify and document the following:

~~(a) That the EMCS interface enables activation of the central demand shed controls.~~

NA7.6.3 Demand Responsive Controls Acceptance Tests

NA7.6.3.1 Construction Inspection

Prior to Functional Testing, verify and document the following:

(a) That the demand response control is capable of receiving a demand response signal directly or indirectly through another device and that it complies with the requirements in Section 130.1(e).

(b) If the demand response signal is received from another device (such as an EMCS), that system must be capable of receiving a demand response signal from a utility meter or other external source.

NA7.7.2 Energy Management Control System (EMCS) Installed in Accordance with Section 130.1(f)

NA7.7.2.1 Installation Requirements

~~(a) The EMCS shall be separately tested for each respective lighting control system for which it is installed to function as.~~

~~(b) List and verify functional compliance with all applicable requirements in accordance with Sections 130.1 through 130.5.~~

~~(c) If applicable, list and verify functional compliance with all applicable requirements for all applications for which the EMCS is installed to function as, in accordance with Section 140.6.~~

~~(d) If applicable, list and verify functional compliance with all applicable requirements for all applications for which the EMCS is installed to function as, in accordance with Section 140.7.~~

~~(e) If applicable, list and verify functional compliance with all applicable requirements for all applications for which the EMCS is installed to function as, in accordance with Section 150(k).~~

NA7.19 Energy Management Control System (EMCS) Acceptance

NA7.19.1 Installation Requirements

(a) Verify and document that the EMCS interface enables activation of the central demand shed controls and that it complies with the requirements in Section 110.12.

(b) Verify the EMCS complies with all energy recording and reporting requirements in accordance with Section 110.13.

(c) The EMCS shall be separately tested for each respective lighting control system for which it is installed to function as.

(d) List and verify functional compliance with all applicable requirements in accordance with Sections 130.1 through 130.5.

- (e) If applicable, list and verify functional compliance with all applicable requirements for all applications for which the EMCS is installed to function as, in accordance with Section 140.6.
- (f) If applicable, list and verify functional compliance with all applicable requirements for all applications for which the EMCS is installed to function as, in accordance with Section 140.7.
- (g) If applicable, list and verify functional compliance with all applicable requirements for all applications for which the EMCS is installed to function as, in accordance with Section 150(k).

7.3 ACM Reference Manual

There are no proposed changes to the ACM Reference Manual.

7.4 Compliance Manuals

Chapters 2, 4, 5, 7, 10, and 13, and Appendix D of the Nonresidential Compliance Manual will need to be revised.

7.5 Compliance Forms

Forms NRCI-LTI-02-E, NRCI-LTO-02-E, and NRCA-MCH-18-A will need to be revised. No new forms will need to be created.

8. References

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