The Northwest End-Use Load Research (EULR) Project

Graham B. Parker, CEM, CEA
David Clement

ABSTRACT

This article highlights the Northwest End-Use Load Research (EULR) project, an electrical end-use metering project being undertaken in residential and commercial buildings in the Northwest. Composed of two studies and funded by regional electric utilities and government agencies, the EULR project was initiated in 2017 and is managed by the Northwest Energy Efficiency Alliance (NEEA).

Designed to fill a widely recognized need for current electrical end-use data, the EULR project collects continuous energy consumption data, including key heating and cooling technologies and other major end uses, through the Home Energy Metering Study (HEMS) and the Commercial Energy Metering Study (CEMS). HEMS involves more than 400 residences and CEMS monitors more than 100 commercial buildings.

By filling a large gap in our understanding of contemporary energy end-use patterns, the EULR project will be useful to academic researchers, consultants, electric utilities, and energy-related government agencies for many years to come. Currently, the region's utilities and other organizations rely on 30-year-old data collected under the End-use Load and Conservation Program (ELCAP) to inform load forecasting, efficiency savings and conservation program planning. Since ELCAP, thanks to improved practices, codes and disruptive technologies, great strides have been made in equipment efficiency and building energy conservation. Additionally, greater attention has been paid to the region's winter and summer capacity constraint issues.

The insight gained through the EULR project will help achieve regional conservation and clean energy goals, and satisfy utility information needs. The collected data will provide:

- Greater understanding of the contribution of energy efficiency technologies to reduce peak demand
- Insight into the most effective ways to integrate renewable energy into the grid to increase reliability, especially as the deployment of distributed generation and new end-use technologies increases over time
- Prioritized data by end use to inform a range of utility functions including demand response, load forecasting, resource planning, distribution planning and program evaluation

HISTORY OF ENERGY METERING IN THE NORTHWEST

End-use Load and Conservation Program (ELCAP)

ELCAP was designed in the early 1980s to support the Bonneville Power Administration's (BPA's) load forecasting and conservation program planning functions (ELCAP 1984). ELCAP employed state-of-the-art end-use electrical and temperature monitoring equipment developed by Battelle-Pacific Northwest Laboratories in Richland, WA.* Including single-family, multifamily and manufactured homes, and commercial buildings across multiple sectors, ELCAP captured all electrical end uses in residential panels and as many end uses as feasible in commercial buildings, in addition to total-building electrical consumption.

The data were collected and downloaded over telephone landlines at 15-minute intervals and aggregated at an hourly basis from samples of residential and commercial buildings in the Northwest (Oregon, Washington, Idaho and Western Montana). The data collection included building audits, occupant interviews, indoor temperature and supplemental wood use monitoring, and, at selected sites, outside weather data collection from installed meteorological stations.

When launched in 1983, ELCAP was the largest electrical end-use data collection study in the country, with millions of hours of collected data. This data supported a variety of functions, including:

- Hourly and peak load forecasting

*Currently the Pacific Northwest National Laboratory (PNNL) (www.pnnl.gov).

- Short and long-term annual forecasting
- Assessment of the impacts of conservation measures and load management techniques
- Evaluation of BPA's conservation programs
- Assessment of the effects of the Northwest Power Planning Council* proposed energy efficiency building standards
- Evaluation of BPA standard heat loss analysis procedures
- Evaluation of the performance of various computerized mathematical heat loss models.

ELCAP was expanded many times to evaluate new residential single family and multifamily construction practices and commercial building retrofits. At the termination of ELCAP in 1992, approximately 400 residential buildings and 80 commercial buildings were metered.

Reports and data are archived on a site maintained by Northwest Power and Conservation Council (NWPCC) at https://elcap.nwcouncil.org/. The data continue to be used for evaluating technology energy savings and load impact by utilities, NWPCC, the Regional Technical Form, the U.S Department of Energy and other organizations throughout the country.

Residential Building Stock Assessment and Commercial Building Stock Assessment

NEEA launched the Residential Building Stock Assessment (RBSA) in 2011 to develop a characterization of the residential sector inclusive of the region's diverse climates, building practices and fuel choices. The characterization includes both the principal characteristics of the homes (e.g., size, insulation level and heating systems) and the principal characteristics of the occupants and their energy use patterns (e.g., lighting, appliances, electronics, heat pumps and gas furnaces/gas water heaters). Field surveys were conducted on more than 1,850 sites across the Northwest, including more than 1,400 single-family, multifamily and manufactured homes.

A subsidiary study of 100 single-family homes was conducted on a subset of RBSA homes. This study collected the end-use electricity usage

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*Currently the Northwest Power and Conservation Council (NWPCC) (www.nwcouncil.org).

of hard-wired and permanently plugged-in loads, as well as gas consumption of furnaces and gas water heaters. Designed to represent as many single-family houses across the Northwest as possible within project budget constraints, the study collected 15-minute interval electricity usage over the course of 2 years. The end-use data captured represented approximately 75% of the total household electricity load.

In 2017, a second RBSA was conducted to update the original characterization. The sample in this study includes 1,100 single-family homes, 523 low-rise multifamily units, and 411 manufactured homes. No end-use metering data was conducted in this study.
Specifically, the following data were collected from the second RBSA:

- Building configuration: foundation type, number of floors, room square footage, and conditioned area and volume
- Building envelope (shell): window characteristics, insulation types and thicknesses, and construction materials
- Air leakage: air leakage in cubic feet per minute at 50 pascals, as measured by a blower door test
- Heating, ventilating, and air conditioning (HVAC): equipment characteristics, nameplate information, location and TrueFlow® air handler flow testing and pressure measurements for electric central forced-air heating systems
- Domestic hot water: equipment characteristics, nameplate information, and flow rate measurements for showerheads and faucets
- Appliances: equipment characteristics (size and configuration) and nameplate information
- Electronics: equipment characteristics and nameplate information
- Lighting: type, style, wattage, quantity, control type and location.

The sample size chosen for the RBSA allows benchmarking of energy use within households at sufficient detail to assess the progress of changes in energy efficiency and home characteristics within the region. This study informs future energy planning efforts as well as energy efficiency utility programs by the region's utilities, the Energy Trust of Oregon (www.energytrust.org) and BPA (www.bpa.org).

NEEA also conducted the Commercial Building Stock Assessment (CBSA), a regional study of the energy use in commercial buildings, by collecting detailed information on building characteristics, installed equipment, and energy consumption for buildings throughout the Northwest. The CBSA is a key input into regional power planning such as the Northwest Power Plan, utility energy efficiency programs, codes and standards, and energy efficiency measures. Governments have also used this data to inform planning and policy discussions, such as energy use intensity (EUI) targets.

NEEA has conducted four CBSAs, the first of which took place in 2003, and the most current completed in May 2020. In the recent CBSA, site visits were completed on 932 commercial buildings across 12 building types. Data was collected through onsite assessments, building staff interviews, and utility submission of historical energy consumption data. Together, the RBSA and CBSA provide a rich data source for regional utility planners, and have yielded multiple analysis reports available at www.neea.org. For example, insight from the RBSA highlights the significant improvement in residential building and equipment efficiency in the decades since ELCAP ended, as shown in Figure 1. This figure shows how lighting technology and use has changed over the years in both peak load and time of peak use, which also provides clear evidence that current end-use data are needed.

Development of the EULR Project and HEMS/CEMS

Despite the helpful, contemporary data collected from the RBSA and CBSA, neither study provided electrical end-use data similar to the 30-year-old ELCAP study. This made it imperative for the region to undertake another comprehensive end-use load research project. Doing so would help regional planners understand current load profiles that may have altered the end-use performance landscape. Without this data, the load profiles of new appliances, such as game consoles, home office equipment and electric vehicles would remain unknown.

Without updated and continual end-use data, the region would be less able to address capacity and intermittent resource integration issues on an ongoing basis. It would not be able to provide the insight needed for more precise engineering and economic analysis to better inform future investments in energy efficiency and load forecasting for capacity planning.

The need for this data was first identified through work sponsored by the NWPCC's Regional Technical Forum (RTF) and the Northeast Energy Efficiency Partnerships (NEEP) Evaluation Measurement and Verification (EMV) Forum. Once identified, NEEP and NWPCC contracted with

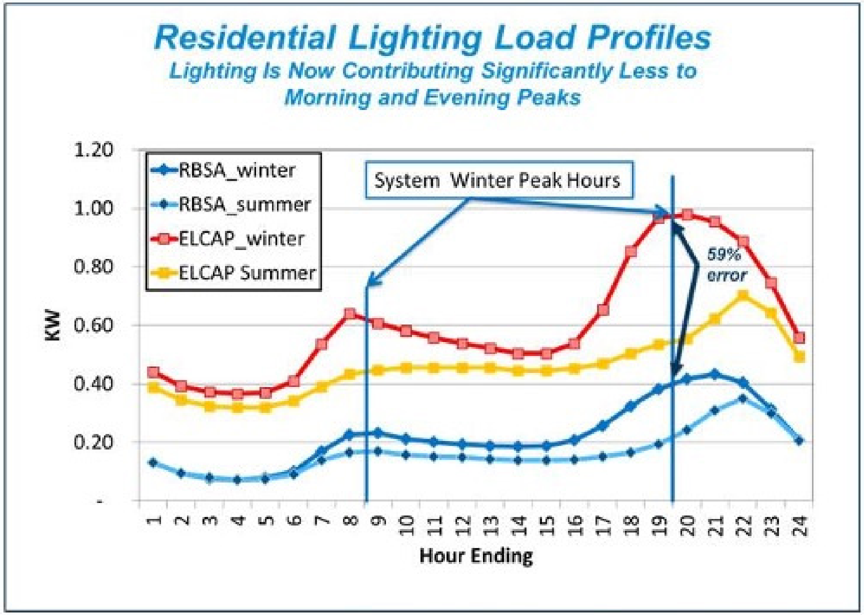

Figure 1. Illustration of the Change in Daily Lighting Load Homes in the 1980s to Homes in the RBSA. (Source: Northwest Power and Conservation Council, used with permission)

KEMA NV (Keuring van Elektrotechnische Materialen te Arnhem)* to search for and catalogue previous end-use load research studies.

In 2012, NWPCC tasked KEMA with building a business case for end-use metering. Three years later, regional stakeholders and NEEA's Board of Directors requested that NEEA begin work on developing an end-use load research project, and the EULR project was born. In late 2016, NEEA created a prospectus and began recruiting across the Northwest for partners to help fund the project and assist in its design.

To avoid the high upfront costs of a 1- or 2-year study large enough to produce statistically significant results, the sample was built gradually with costs spread over time. This approach also provided the opportunity to refine the research to better fit regional needs.

The EULR project was organized as both a residential study and a commercial study: the Home Energy Metering Study (HEMS) and the Commercial Energy Metering Study (CEMS). HEMS covers homes across Washington, Oregon, Idaho, and Western Montana, and prioritizes the loads that are most important to understanding residential energy characteristics. These include ductless heat pumps, ducted heat pumps, heat pump water heaters, central air conditioning, forced air furnaces and electric baseboard heaters.

CEMS focuses on key end uses within the office and retail sectors, with priority end uses including rooftop units, heat pumps, and electric resistance heating including terminal reheat and ventilation. In addition to the priority end uses for both CEMS and HEMS, additional end uses are metered opportunistically at the circuit panel.

To collect the data, circuit meters will be installed in homes and commercial buildings over the course of 4 years, after which all planned meters will have logged a full year's worth of data with some meters collecting data for 5 years. Data collection is designed to reflect greater weather, behavioral, and occupancy variability. This extended time period of data collection was seen as especially important for capturing the wide annual variation in weather-related impacts that have a large influence on winter peak electric demand and hydroelectric resource availability.

The EULR project links this metered data to additional information about site-specific building details and end-use details, including charac-

*KEMA is now DNV GL (www.dnvgl.com).

teristics data from the RBSA and CBSA. When analyzed together, this information can help explain not only how much energy is consumed, but the reasons energy is consumed.

HEMS/CEMS and EULR Project Funders

Many of the organizations that helped to scope the EULR project in 2016 and 2017 became project funders. Additional organizations joined as governance, operational plans and budgets were developed, and a few more organizations joined after the project began and meter installations were underway. With NEEA serving as the project manager, there are now 14 organizations playing a role, as shown in Table 1.

This special project is independently funded from NEEA's base funding with a projected budget of $12.5 million over 5 years. A funding share allocation mechanism was determined based on the size and customer base of each funder.

Project Organization and Governance

Two governing committees were formed. The Steering Committee oversees the project and has decision authority to advance project budgets, strategy and policy to NEEA's Board of Directors. The Steering Committee elected a chairperson and adopted a committee charter that gives each Steering Committee organization one representative and one vote.

A second committee, the Working Group, was designed to advise on technical issues and to act as a sounding board regarding project management issues. Each member of the Working Group is appointed by a Steering Committee member. Organizations may have one or two Work-

Table 1. Organizations involved in the Program

Project Funders	
Avista Utilities	Pacific Power
BPA	Portland General Electric
Clark Public Utilities	Puget Sound Energy
Energy Trust of Oregon	Seattle City Light
Eugene Water & Electric Board	Snohomish PUD
National Renewable Energy Laboratory	Tacoma Power
Project Advisors	
NWPCC	U.S. Department of Energy

ing Group members, at their own discretion. Both committees strive to achieve a consensus, with the Working Group often making recommendations to the Steering Committee on issues not within the Working Group's range of authority.

For electric utilities, academia, researchers and consultants, one of the most important Steering Committee decisions occurred in 2019. At the request of the U.S. Department of Energy's Building Technologies Office, and with a recommendation from the Working Group, the Steering Committee agreed to make 15-minute interval end-use load data publicly available, at no cost. The Steering Committee stated that this was the best way for the EULR project to advance energy efficiency across the nation. Fifteen-minute interval data from HEMS is presently available to the public free of charge on NEEA's website: https://neea.org/data/end-use-load-research/hems.

Contractors

In 2017, the Working Group created a subcommittee to develop a Request for Proposals (RFP) to administer HEMS. At the recommendation of the Working Group, the Steering Committee approved Evergreen Economics, Portland, Oregon as the HEMS contractor.

In 2018, the Working Group developed another RFP to administer CEMS. The Steering Committee approved the Working Group's recommendation of DNV GL as the CEMS contractor.

METERING, DATA COLLECTION AND DATA ARCHIVING

Home Energy Metering Study

The main objective of HEMS is to develop a robust characterization of continuous energy consumption of key heating and cooling measures to support utility planning of conservation programs and achievement of clean energy goals. To do so, beginning in 2018, the study began collecting whole-home and 1-minute interval data by electrical circuit from Northwest homes that have one or more of the following targeted equipment types:*

*The equipment deployed in HEMS allows capture and storage of 1-minute data to enable a more granular analysis of equipment electricity use patterns and fault detection (corrupted data). One-minute data are aggregated into 15-minute data for long-term public data archiving.

1. Ducted heat pumps
2. Ductless heat pumps
3. Heat pump water heaters
4. Electric forced-air furnaces
5. Central air conditioners
6. Electric baseboard heaters.

The HEMS contractor developed a comprehensive installation and data collection quality assurance plan** that includes documentation of processes and procedures for:

- Validating accuracy of meter installations
- Verifying circuit labeling for end uses and the metering of correct end uses
- Validating data quality
- Visual inspection of data
- Equipment installation and maintenance to ensure equipment efficacy
- Preventing and identifying meter data errors, lost data streams and equipment failures
- Data cleaning, storage and back-up
- Equipment repair and/or replacement and timeframes
- Addressing participant complaints, which includes the process for notifying the serving utility, identification of utility contacts, persons responsible for handling participant complaints, escalation procedures, and expected time to resolve participant complaints

The contractor used the existing 2016–17 RBSA study as the primary sample frame. This improved cost-effectiveness by utilizing detailed information about the homes and appliances of metering study participants, rather than recruiting homes for metering from the general population. Because the end-use equipment is known in each RSBA home, the contractor was able to efficiently recruit homes with one or more of the six target end uses.

Comprehensive sampling and recruitment plans were developed by

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**The first law of ELCAP is: "You can always recover from bad analysis but never from bad data." This provided the inspiration to include a quality assurance plan in the EULR project.

the contractor and approved by the Working Group and Steering Committee prior to program launch. The sampling plan assured a representative allocation of homes for the target end uses and across the climate zones of the Northwest. The sampling plan recognized the significant challenge in recruiting homes with ductless heat pumps and heat pump water heaters, as there are relatively few homes in the region with that equipment installed.

Metering Equipment

Up to 20 circuits and the whole home are metered using current transformers (CTs) that are installed in the home's service panel and connected to the data logger. Additionally, the indoor temperature is measured in all homes, and the refrigerant/vapor line (surface) temperature is measured in homes equipped with heat pumps as a surrogate for the operating mode of the heat pump (e.g., when the unit is in defrost mode). Homes with supplemental heat (e.g., gas fireplaces) have a second indoor temperature set nearby the supplemental heat as a surrogate of when that supplemental heat is used. Exterior temperature is monitored for homes where there are no nearby weather stations to acquire exterior temperature data.

The metering configuration is shown in Figure 2. The pre-assembled metering package (labeled, "In the Box") is powered by a 110V dedicated circuit. It includes:

- An eGauge meter (https://www.egauge.net/) as the power metering device and data logger
- A wireless gateway that communicates with and collects data from the eGauge logger. This includes a cellular modem used to communicate with and transmit data to the cloud server.
- A Miratron (http://www.miratron.com/) receiver that accepts the temperature data from the Miratron remote temperature sensors, conditions the signal, and relays that signal to the eGauge logger.

Figure 3 shows an installation in a resident's garage including the temperature sensors and refrigerant line sensor.

Data collected from the cloud are distributed to various components in the system. Prior to archiving, the data undergo multiple rigorous quality assurance screens and testing. The data are then stored as raw

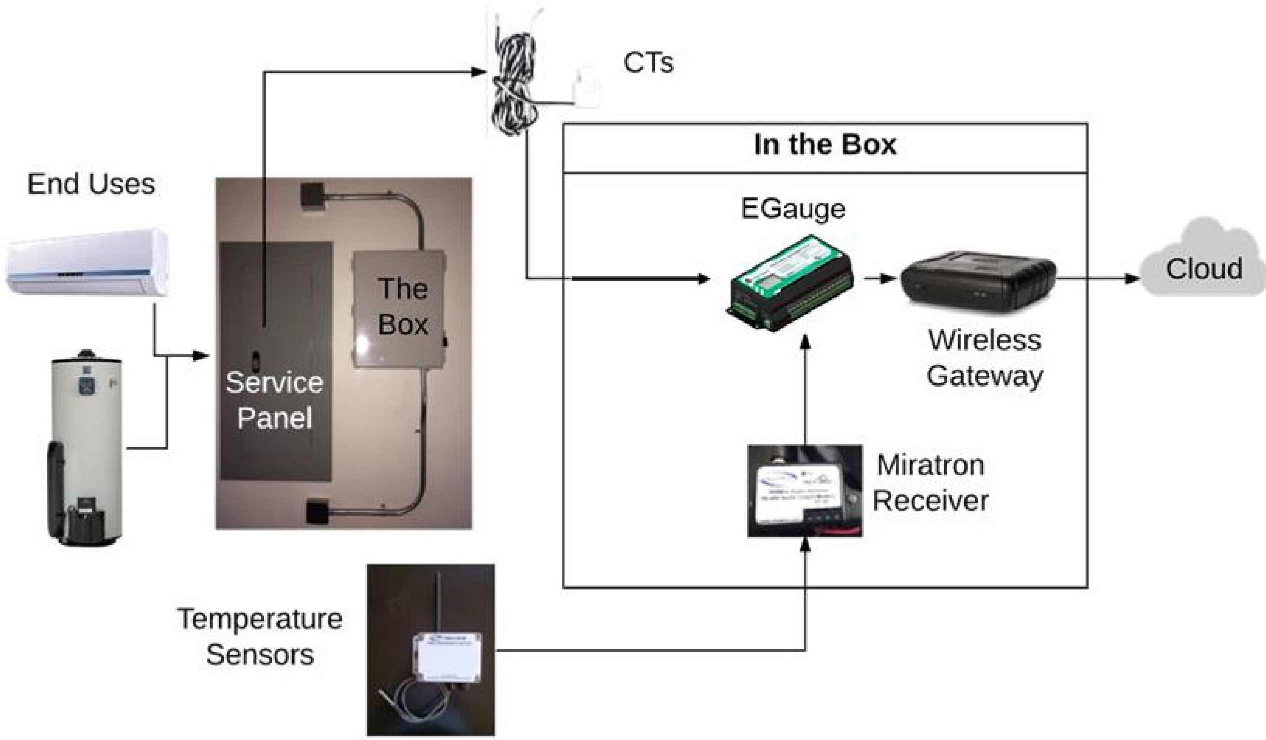


Figure 2. HEMS Metering Configuration
(Source: Evergreen Economics, used with permission)

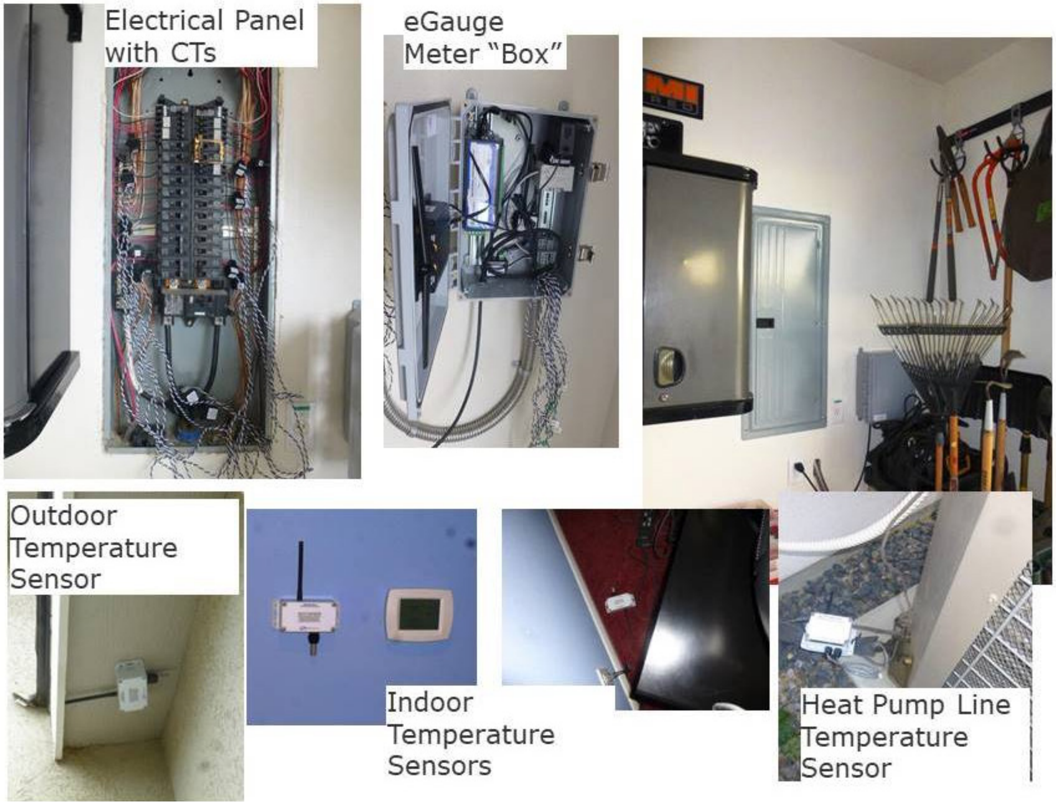


Figure 3. HEMS Metering Installation. (**Source: Graham Parker**)

15-minute data, processed and aggregated for analysis, and transferred to a final database for permanent public storage. The size of the database will vary over the course of the installations depending on the number of active sensor data streams, the duration of the project, and the target storage format.

Commercial Energy Metering Study

CEMS is designed to obtain whole-building consumption either through 15-minute interval or panel-level metering (current and voltage). The following end uses are prioritized:

- HVAC:
  - Rooftop units
  - Heat pumps
  - Electric resistance heating
- Additional identifiable end-use equipment on its own circuit:
  - Other HVAC (e.g., exhaust fans, terminal reheat, etc.)
  - Computer server rooms
  - Electric water heating
  - Refrigeration
  - Uninterruptable power supply/servers
  - Electric vehicle (EV) charging stations
  - Lighting and plug load
  - Indoor agriculture
  - Vertical transport
  - Solar and/or energy storage
- Temperature data (indoor and outdoor).

Metering Equipment

The metering suite is composed of several components which, depending on site-specific circumstances, will be installed for different functions and at different quantities. These site-specific circumstances include locations of building panels and unit disconnects, cellular reception, mounting options for metering equipment, and how the data logger will communicate locally with the cellular modem. The key components of the metering suite are:

- An eGauge energy meter that acts as the power metering device, data logger, and web server to provide user interface and push kilowatt data to the contractor's server. The eGauge energy meter requires Wi-Fi or cellular connection for server communications.

- Monnit wireless temperature sensors (www.monnit.com) configured to securely transmit their measurements via a wireless gateway. The primary location for temperature sensors is in the rooftop unit's supply plenum. If plenum access or wireless signal strength prohibits the primary placement in plenums, the contractors identify a location that improves deployment efficiency and measurement efficacy. Additionally, there will be one wireless temperature sensor deployed in every uniquely controlled indoor ambient zone being monitored.

- Monnit wireless gateway that communicates with and collects data from the wireless temperature sensors. It requires a Wi-Fi connection (via the cellular modem) to communicate with and transmit temperature data to the cloud server.

- Dry-contact KY or KYZ termination box and pulse transducer connected to the Wi-Fi router. This provides 15-minute interval whole-building load data without requiring work in an energized panel exceeding the electrical hazard risk threshold.

- Telemetry/communication devices connecting the eGauge meter and Monnit wireless gateway to the internet. The most common scenario will likely use a cellular modem and wireless router to broadcast a Wi-Fi signal through which the eGauge meter and Monnit gateway connect to the internet. The cellular modem provides a secure connection to the cloud server. The eGauge meters accept USB Wi-Fi devices that allow wireless communication and extend the Wi-Fi range of the central router.

- Voltage and current transformers fed through electrical conduits from the distribution or disconnect panel(s) to CEMS enclosures. The voltage wiring will be used to measure voltage and to power the eGauge meter, and possibly provide power to telemetry devices like the cellular modem and wireless router, depending on the installation scenario.

Figure 4 shows the metering equipment and HVAC return plenum temperature sensor installed.

The building sample was drawn from the CBSA, so the building characteristics are known. For metered buildings, the CBSA data will be updated with specific emphasis on type and size of the HVAC systems and other metered equipment. Additional information will be collected including building schedules, which often change, and HVAC set points. For sites that utilize energy management systems, the contractor will collect building schedules and set points for applicable HVAC equipment and conditioned zones.

The contractor will additionally note space type and distinct internal loads (e.g., server room, locker room, kitchen) for each HVAC unit. They will also take photographs of all HVAC equipment to record existing conditions and surroundings.

Analysis and Preliminary Results

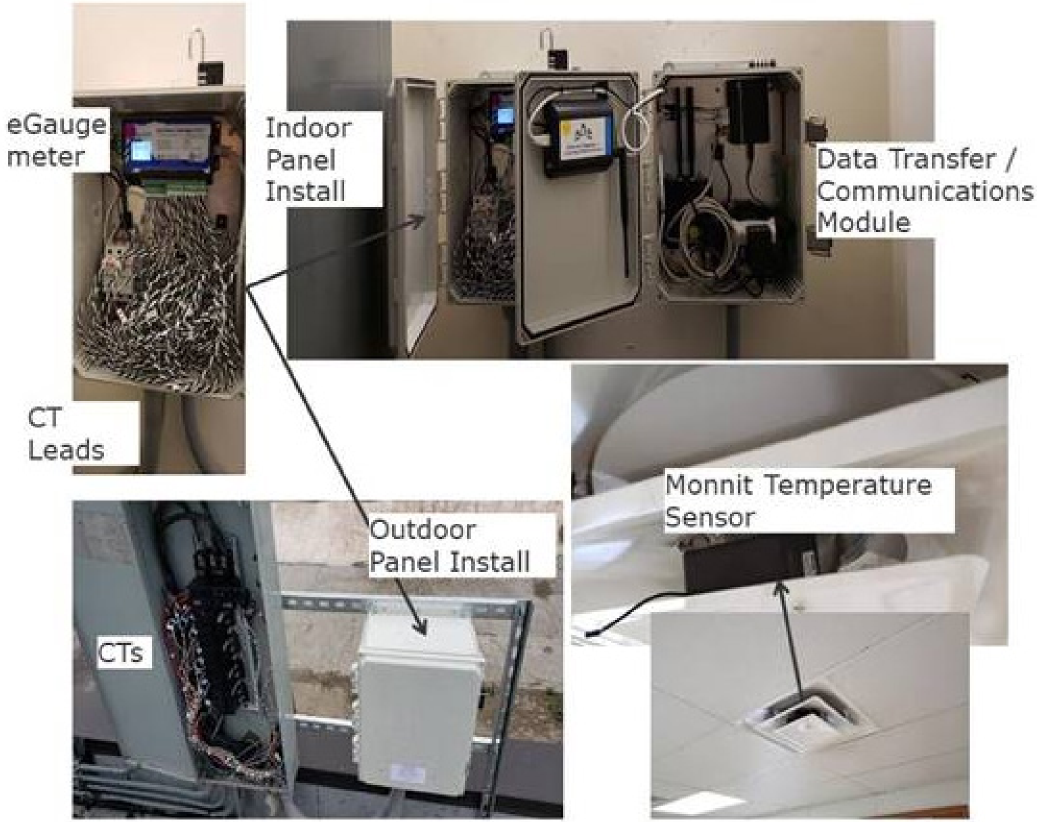
Analyses of the HEMS data will be conducted annually to utilize the augmented data and to investigate new lines of inquiry. The specific analysis plan is currently in the process of finalization.

In response to the stay-at-home orders and public health and safety concerns of COVID-19, installation of new metering equipment in both the HEMS and CEMS was suspended in the spring of 2020. Although no new meters have been installed since that time, data collection continued from the approximately 200 homes, with metered data for over 300 of the target end uses. These data provide a unique opportunity to understand the impacts that the COVID-19 pandemic has had from a residential energy usage and load shape perspective. Thus, the analysis plan will be designed to utilize the data collected during the pandemic to gain actionable insights into the impact of COVID-19 on household energy usage overall and for each targeted end use.

To better understand the changes in home energy use brought by COVID-19, the contractor surveyed HEMS participants from October to December 2020. Figure 5 shows the changes brought by increased work-from-home frequency among the 113 responses.

Figure 6 further demonstrates the value of the HEMS data in understanding the energy-use effects of COVID-19. This figure shows a whole-house load profile by metered end-uses (not weather-normalized) from April 1, 2019 (pre-COVID-19), to April 1, 2020 (during

Figure 4.
CEMS Metering Suite
(Source: DNV GL, used with permission)



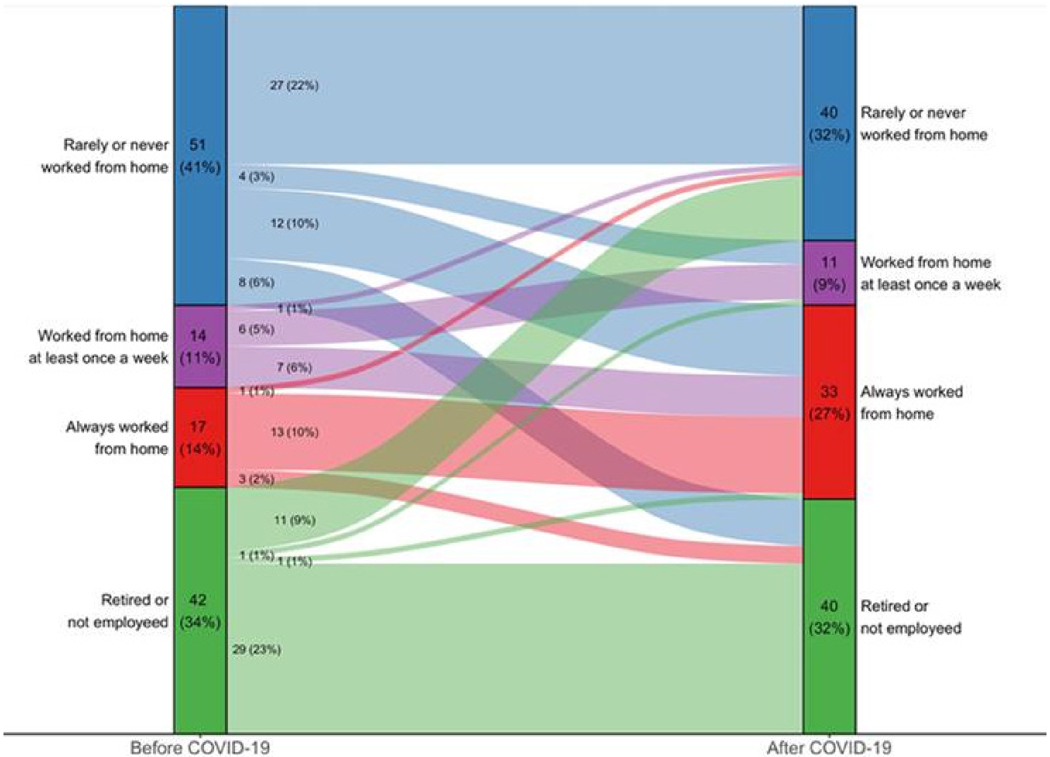


Figure 5. Change in Work-from-Home Frequency Before and During Covid-19 (Source: Evergreen Economics, used with permission)

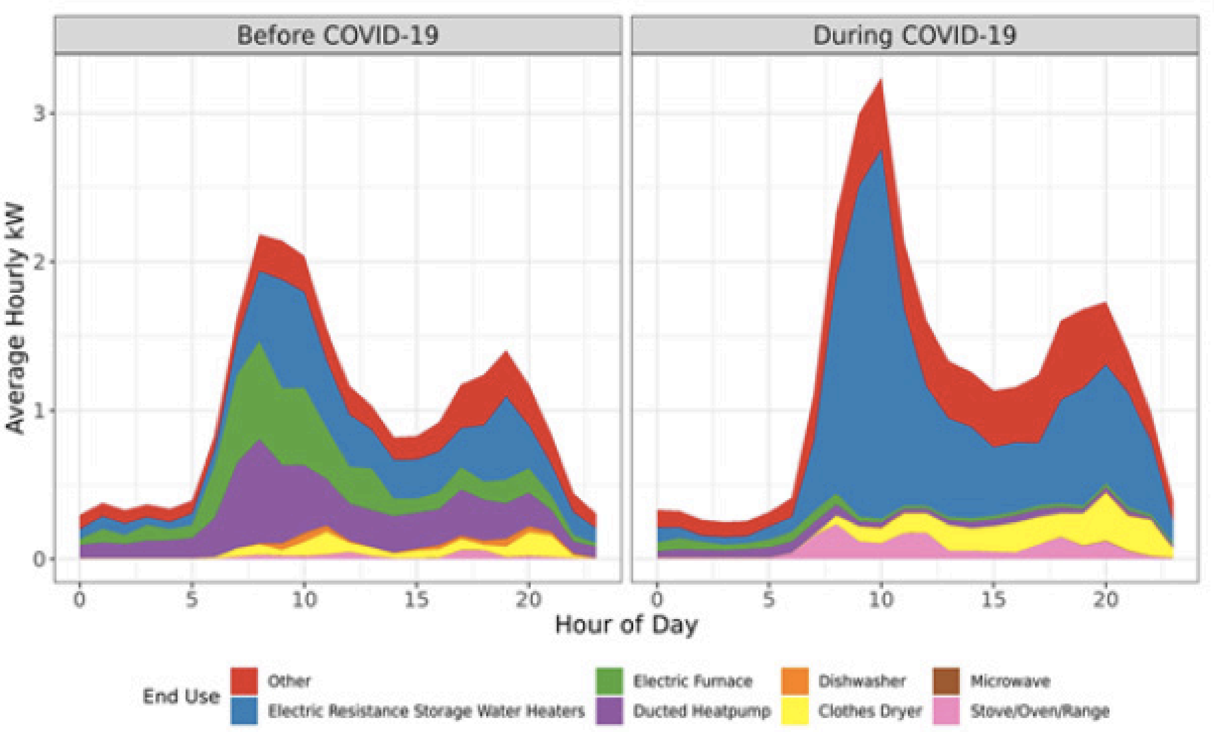


Figure 6. Whole Home Load Profile by End Use Before and During Covid-19 (Source: Evergreen Economics, used with permission)

COVID-19). The data demonstrate water heating and space heating (heat pump) as driving the majority of the load increase. Other end uses have increased as well, including a clothes dryer, cooking appliance, and non-dedicated circuits (e.g., lighting and plug loads). There is also a noticeable shift in the time of day of peak usage for major end uses (e.g., water heater, dryer, stove/range), which is likely attributed to more cooking and cleaning at home, people working from home, and children educated from home.

Another example of the impact of COVID-19 is shown in Figure 7. In this figure, the average use of a single burner on the range is shown in April 2019 (pre-COVID-19) and April 2020 (during COVID-19). The data for this home show a total average daily kW increase in 2020, most significantly during the weekday, and a noticeable shift in the time of day the burner was used during the weekday.

Further analysis is planned to quantify the regional impact on home energy use during each phase of COVID-19. This analysis, combined with analysis on the CEMS sample once completed, will provide a more comprehensive and robust characterization of the energy impacts of COVID-19.

CONCLUSION

Data from the EULR project will be useful to academic researchers, consultants, electric utilities, and energy-related government agencies for many years to come. Using HEMS data on the more than 200 residences continuously collected to date, research is planned or has already begun on the distribution system impacts of distributed energy resources, electric transmission planning, end use and building modeling, and to characterize electric heat pump control logic, especially as it pertains to electric resistance back-up mode during cold weather.

While COVID-19 has suspended the recruitment of HEMS homes and CEMS buildings until mid-to-late 2021, the data currently being collected will be instrumental in understanding the short- and long-term impacts of COVID-19 on energy use consumption patterns. The EULR project provides the opportunity to track and measure long-term changes in end-use energy consumption patterns with metered

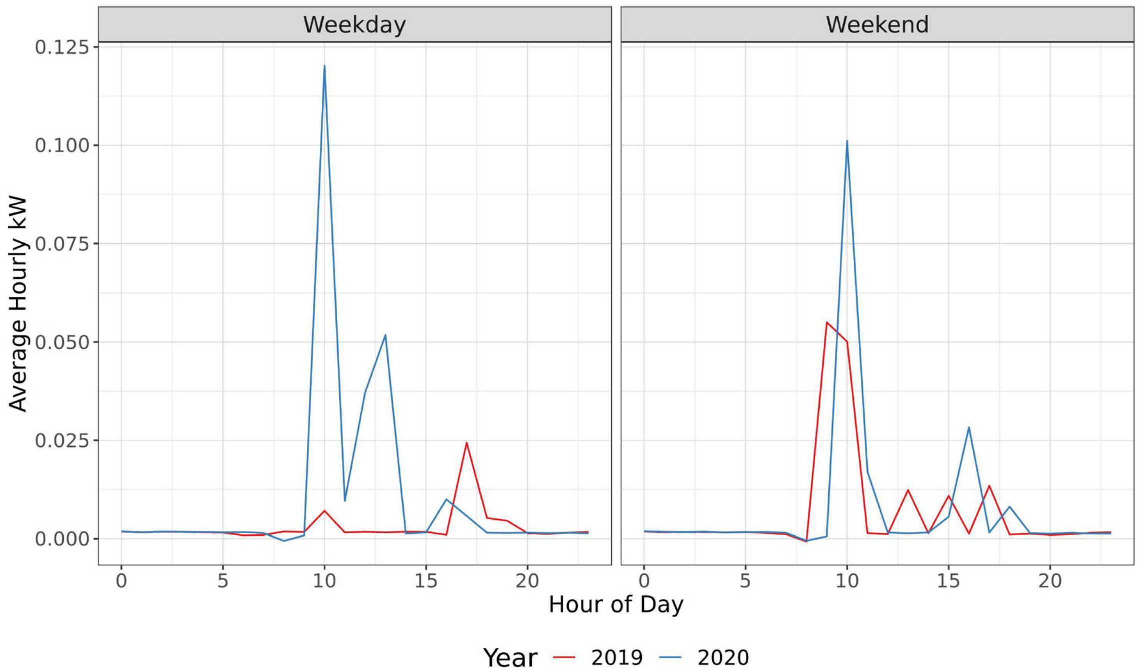


Figure 7. Home Range Burner Average Hourly Load: Weekday and Weekend, Before and During Covid-19. (Source: Evergreen Economics, used with permission)

data from across the Northwest before, during and after the COVID-19 pandemic.

In the meantime, 15-minute interval data from HEMS can be downloaded free of charge on NEEA's website: https://neea.org/data/end-use-load-research/hems.

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AUTHOR BIOGRAPHIES

Graham Parker CEM, CEA, is the President of Graham Parker & Associates, LLC. Mr. Parker is a retired former Emeritus staff at the Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL). In his nearly 46 years at PNNL, he focused on the design, conduct and analysis of the evaluations of the performance of buildings and equipment. He has worked with domestic and international clients to develop and promulgate energy policies, improve building energy and water efficiency and deploy new and emerging technologies.

Mr. Parker is a Chemical Engineer graduate of Oregon State University. He is a Fellow in the Association of Energy Engineers (AEE) and a member of the AEE Hall of Fame. He is a Certified Energy Manager and Certified Energy Auditor. He is a member of the Working Group for the Northwest End-Use Load Research Project and serves on the Northwest Power and Conservation Council's Regional Technical Forum. He is the 2005 recipient of the Presidential Award for Leadership in Federal Energy Management and the 2017 recipient of the Tom Eckman Lifetime Achievement Award for Energy Efficiency.

David Clement is a Senior Program Manager with the Northwest Energy Efficiency Alliance (NEEA). He leads the Northwest End Use Load Research project, consisting of the Home Energy Metering Study (HEMS) and the Commercial Energy Metering Study (CEMS). In prior positions, David was Director of Resource Planning, Forecasting, and

Analysis for Seattle City Light, where he led five integrated resource plans (IRPs). He also was Director of the Electric Transmission and Western Energy Services at Cambridge Energy Research Associates, where he consulted on regulatory policy, regional transmission organization market design, resource planning, renewables development, and institutional investments. At PacifiCorp, he managed Corporate Strategic Planning, and worked in the Economic Development and Load Forecasting Departments. His thesis for a Masters in Agricultural and Resource Economics was selected for presentation at a National Academy of Sciences Annual Meeting.

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