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White Paper | COVID-19's Impact on Energy Use: The Northwest End Use Load Research Project

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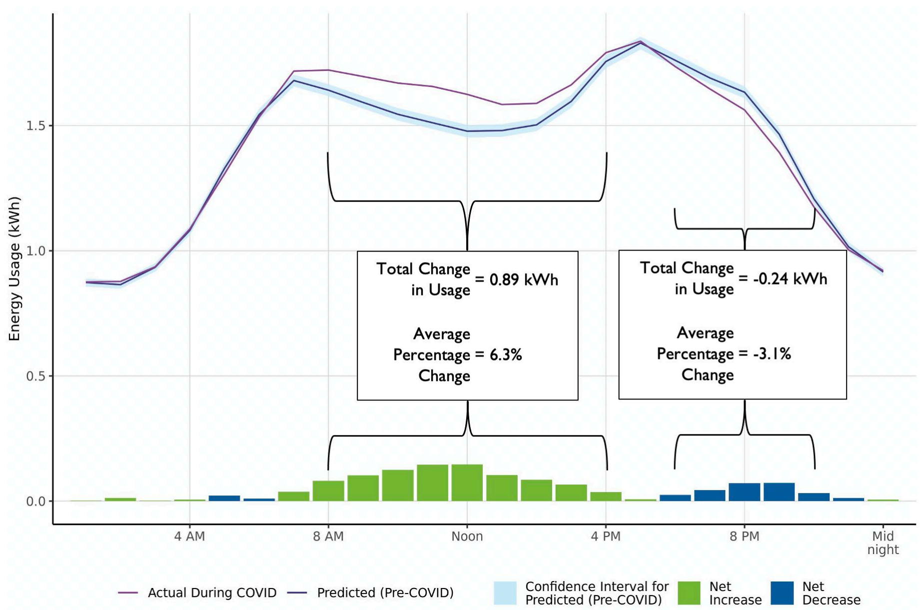
COVID-19's Impact on Energy Use: The Northwest End Use Load Research Project Executive Summary

When the COVID-19 pandemic struck in March of 2020, the Northwest End Use Load Research (EULR) project was already tracking energy use in over 200 homes and eight commercial buildings across the region. This coincidental timing gives the region an unprecedented window into the pandemic's direct impact on energy use in the Northwest.

Comprised of two studies—the residential Home Energy Metering Study (HEMS) and the Commercial Energy Metering Study (CEMS)—the EULR project is collecting continuous energy consumption data at the circuit level from residential and commercial buildings for up to five years. In March of 2020, NEEA suspended all new commercial installations and prevented new residential installations from restarting after their winter season hiatus due to COVID-19. Despite suspending installations, over 200 homes continued to anonymously report electricity demand by circuit.

Whole-Home Impacts of COVID-19



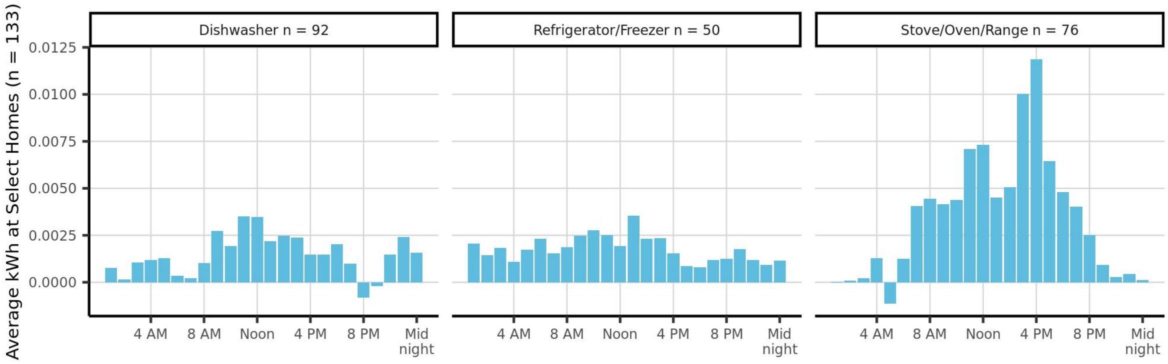
From March 2020 through January 2021, the EULR project measured the weather-normalized average total change in residential demand at 2.3%. Average load grew by 6.3% during the day and fell by 3.1% during the evenings, a pattern consistent with more people working and schooling from home.

COVID-19 Impacts Varied Through Time

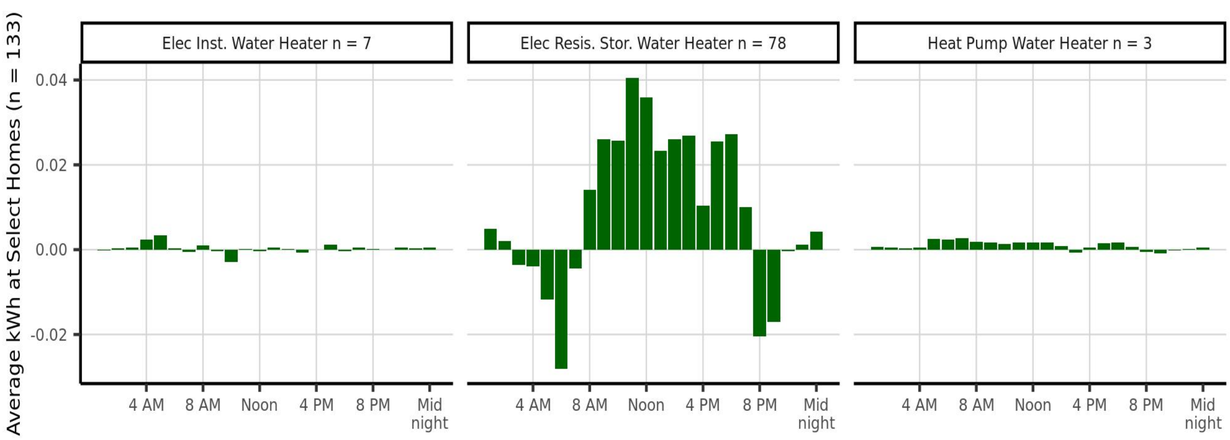
As the COVID-19 pandemic progressed, 15-minute interval EULR data showed that the degree of COVID-19 changes were not consistent over time. Four COVID-19 energy use phases were delineated using Google mobility data and the timing of stay-at-home orders. The phases in spring of 2020 and winter of 2020/2021, the worst of the pandemic, had the largest changes in demand. The summer/fall phase of 2020 (June through November) had nearly normal demand, as government restrictions eased and people spent more time outdoors and away from home.

Heating, Ventilation, and Air Conditioning (HVAC) Were Not the Drivers

Measuring changes in HVAC is a design priority for the EULR project, as HVAC is often the major driver of system peak electricity demand. However, the largest demand changes from COVID-19 were not from HVAC. In fact, the major proportion of the total change in residential electricity demand came from end uses including plug loads (electrical demand from products powered through an outlet), kitchen appliances, laundry, and water heaters.



With residents spending more time in the kitchen during the pandemic, average electricity demand for dishwashers, refrigerators/freezers and electric stoves increased across almost all hours. More cooking, cleaning and dishwashing created more demand for hot water, especially during mid-day hours. The effects of more dishwashing, cleaning, showering, and laundry combined to drive increased average kWh demand for hot water in all hours from 8:00 a.m. to 7:00 p.m. Average electricity demand for hot water increased more than the increase for all kitchen appliances combined.



Conclusion

The EULR project is helping to measure how the COVID-19 pandemic is affecting electricity demand. Initial findings show the magnitude of changes are not uniform across end uses or through time. And, while important questions remain—including those surrounding COVID-19's potential long-term impacts on energy end use—the EULR project is uniquely positioned to provide definitive answers with highly accurate metering for years to come.

COVID-19's Impact on Energy Use:
The Northwest End Use Load Research Project

When the COVID-19 pandemic struck, the Northwest End Use Load Research (EULR) project was already tracking energy use in homes and buildings across the Northwest. This coincidental timing gives the region an unprecedented window into the pandemic's direct impact on energy use across the region.

Even before the COVID-19 pandemic, the EULR project was providing needed insight into contemporary energy end use behavior in the Northwest. In fact, EULR was the first study of its kind since the 1991 End Use Load and Consumer Assessment Program (ELCAP), which was completed at a cost of over $50 million in today's dollars. At the time, ELCAP represented a giant leap in the nation's understanding of energy use and established a base of knowledge for energy efficiency by defining exactly how different types of residential and commercial customers were using electricity by end use. However, while ELCAP was the first regional end use load research project of its scale in the United States, it was also the last—until now.

The Need for New End Use Load Research

In the 30 years following ELCAP, utilities and energy efficiency organizations have conducted many end use load research studies. In specific terms, a 2016 whitepaper from the Northwest Energy Efficiency Alliance (NEEA) identified more than 40 studies in the previous decade alone.[1] Nearly all these studies, however, were small and limited in end uses, sample size, customer types, building types, time periods for metering, timeliness of data, rate designs, geographic locations and climate zones studied. These factors led to previous studies being insufficient for the purposes of the sponsoring Northwest organizations.

On average, the Northwest acquires more than $350 million of energy efficiency each year using data for planning that is sometimes as much as three decades old. This data does not factor in many of today's end uses, many of which were not yet invented or not commercially available at the time. For example, laptop computers, gaming consoles, ductless heat pumps, big screen televisions, heat pump water heaters and electric vehicles did not exist during the ELCAP research. A combination of utility energy efficiency programs, improved appliance efficiencies, new technologies and more efficient building codes are driving energy efficiency at such a pace that many of the region's econometric load forecasting models have struggled to accurately forecast electricity demand in recent years, which potentially indicates a structural break in energy consumption trends. Though utilities have hurried to develop combination econometric and end use forecasting models to better account for increased electric end use efficiencies and improve load forecasting accuracy, these new models still lack a critical input: accurate electric end use load data.

With NEEA as the umbrella organization, a group of Northwest utilities and other organizations banded together to create the Northwest End Use Load Research Project (EULR), a collaboration on end use load research at a regional level. These organizations eventually included Avista, the Bonneville Power Administration, Clark Public Utilities, Energy Trust of Oregon, Eugene Water & Electric Board, the Northwest Power & Conservation Council, National Renewable Energy Laboratory, PacifiCorp, Portland General Electric, Puget Sound Energy, Seattle City Light, Snohomish PUD, Tacoma Power, and the U.S. Department of Energy Building Technologies Office. With representation from each organization, a working group investigated each utility's internal data needs and prioritized them by end use for use in utility functions, including demand response, load forecasting, resource planning, distribution planning, transmission planning, financial planning, ratemaking and energy efficiency.

Choosing the Study Methodology

Due to high cost, a single study with a large, statistically significant sample with comprehensive metering of end uses was infeasible. Instead, a selective, ongoing effort that spreads the costs over time was seen as more workable and would provide a built-in opportunity to refine the research to better fit regional needs. The working group decided that meters should be in place for as long as practical to capture more weather-related, behavioral and occupancy variability, and that, wherever possible, the research would leverage the work already being done via the alliance's Residential Building Stock and Commercial Building Stock Assessments (RBSA and CBSA). The additional information from these assessments would help explain not just how much energy is being consumed, but also why it's being consumed.

The working group then developed a strategy to implement an ongoing collection process, as opposed a large one-time snapshot study. The strategy includes:

- Conducting continuous residential metering at the circuit level, sampling approximately 75–100 new residences each year for five years for the identified priority end uses of heating, ventilation, air conditioning (HVAC) and water heating. Known as the Home Energy Metering Study (HEMS), the residential portion of this study will sample approximately 400 homes to obtain a high confidence level.
- Conducting continuous commercial metering for identified priority end uses, sampling approximately 20–25 new retail and office buildings each year for five years. Known as the Commercial Energy Metering Study (CEMS), the commercial portion of this study will sample approximately 100 commercial buildings.

The working group designed the sampling so that both HEMS and CEMS focus on HVAC end uses as priorities, with metering quotas by end use established based upon their prevalence within the sample population. As many other end uses as possible would also be metered at the circuit panel. These include refrigerators, ranges, washers, dryers, pool pumps, solar panels and EV chargers for HEMS, and computer server rooms, refrigeration, terminal reheating and lighting for CEMS. As HEMS and CEMS are conducted continuously with present-day metering technology, they are expected cost approximately $2.5 million per year over five years, including the research management and data library functions.

In 2017, the working group issued a request for proposals to implement the HEMS project, and selected Evergreen Economics as the contractor. In 2018, the working group issued a request for proposals to implement CEMS, and selected DNV as the contractor.

Launching the Studies

In 2018, HEMS began recruitment and installations of metering equipment the second half of the year. The metering focused on ducted heat pumps, ductless heat pumps, heat pump water heaters, electric forced air furnaces, central air conditioners and electric baseboard heaters. By the end of 2019, the project was continuously metering end uses at one-minute intervals in more than 200 homes across Oregon, Washington, Idaho and Montana.

CEMS focused on office and retail buildings with rooftop units, heat pumps and electric resistance heating as priorities. Commercial installations began in early 2020, with a total of eight commercial buildings completed by February of that year.

The Completely Unexpected

Originally, the majority of metering equipment installations were to occur in 2020. Instead, due to COVID-19, the fewest installations happened in 2020. At the beginning of the pandemic, the Northwest experienced some of the first cases of COVID-19 in the United States. In early March 2020, NEEA reached the decision to suspend all commercial installations and to prevent residential installations from restarting after their winter season hiatus. Oregon and Washington stay-at-home orders arrived on March 23, 2020, lending support to NEEA's decision to suspend all installations.

As installers could no longer enter homes and businesses to install metering equipment, the COVID-19 pandemic introduced a major challenge to project completion. Despite the swirling uncertainty, the project funders' commitment never wavered.

COVID-19 Drives Changes in Residential Electricity Use

With more than 200 homes continuously monitored minute-by-minute, HEMS presented a unique opportunity to understand COVID-19's impact on residential electricity use. While most utilities were using whole-home demand to try to understand how COVID-19 was affecting electric end use demand, EULR was tracking and measuring actual pandemic-driven changes in individual electric end uses as they occurred in real time across the four Northwest states—Idaho, Montana, Oregon and Washington.

Across the country, significant changes to total electric demand have been reported, with the commercial sector hit especially hard by the pandemic. Most public reports of changes in electricity demand have focused on total electric demand, combining residential, commercial and industrial usage. These customer classes were affected differently, but in aggregate, utilities have seen their total load fall within a range of 5–13%. As parts of the U.S. began reporting changes to residential demand associated with COVID-19, EULR data demonstrated the Northwest had less change in residential loads than what was reported elsewhere.

Though this regional difference in electric demand isn't surprising considering all the factors at play (including winter and summer peaking loads, variations in seasonal weather, differences in common heating and cooling equipment, and varying rate structures and home construction methods), the EULR data provides further contextual insight into the pandemic's impact on residential energy use.

While the U.S. Bureau of Economic Research (U.S. BER) reported an increase of 10% to nationwide residential demand during April–June 2020, Pecan Street, a load research project in a large Austin, Texas housing development, reported residential load increases of 20% in March and 17% in April 2020. The data from these studies differ from those measured by EULR in two important ways:

- First, the Pecan Street data measured different time periods. As the HEMS interval data was continuously reported, it was observed that the degree of change in the same Northwest residential loads varied across the months being measured.
- Second, it was unreported if the Pecan Street project used any weather-normalization method on its data. The weather normalization method used by the U.S. BER was different than the weather-normalization method used by Evergreen Economics in EULR.

This leaves open the possibility that at least a portion of the U.S. BER-measured changes are due to differences in weather normalization methodologies, or in Pecan Street's case, simply that materially different weather conditions existed when comparing March/April 2020 to March/April 2019. The EULR project, on the other hand, measured Northwest residential load over a much longer timeframe (from March 2020 through February 2021), compared it to a 2019 load over the same period, and adjusted for weather differences. This led to a much smaller measured total household increase of 2.3%.

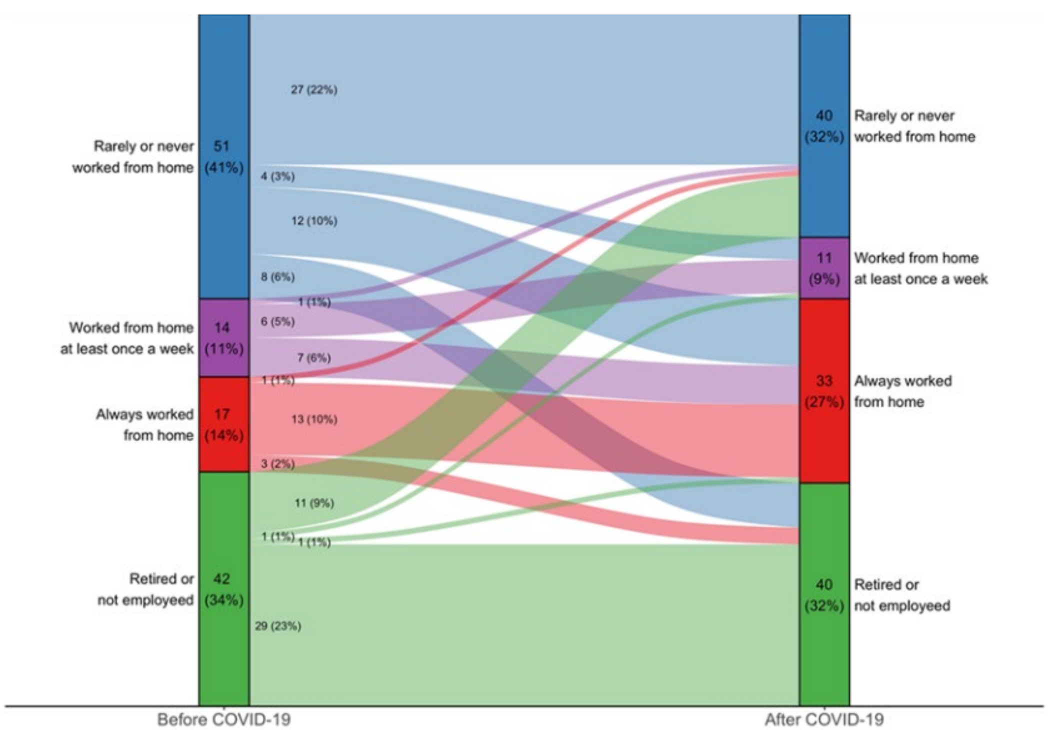
How Does COVID-19 Cause Changes in Electricity Consumption?

While data from metering end uses in homes helps explain which end use loads were changing the most, the EULR project sought to understand the reasons behind the changes. Using a survey of HEMS participants in the fall and winter of 2020–2021, the EULR project gathered important data to understand behavioral changes in electric end use equipment made by the residents. The survey had been conducted annually prior to COVID-19, with the following question topics added in 2020 to uncover the pandemic's impacts:

- Changes in occupancy
- The timing of changes in occupancy
- The reasons for changes in occupancy
- Changes in employment status
- Working at home
- Frequency of working at home
- Schooling at home

Figure 1 shows the patterns of working-from-home behavioral change before and during COVID-19.

Figure 1
Working from Home: Pre-COVID-19 and After COVID-19 Began



Source: Evergreen Economics.

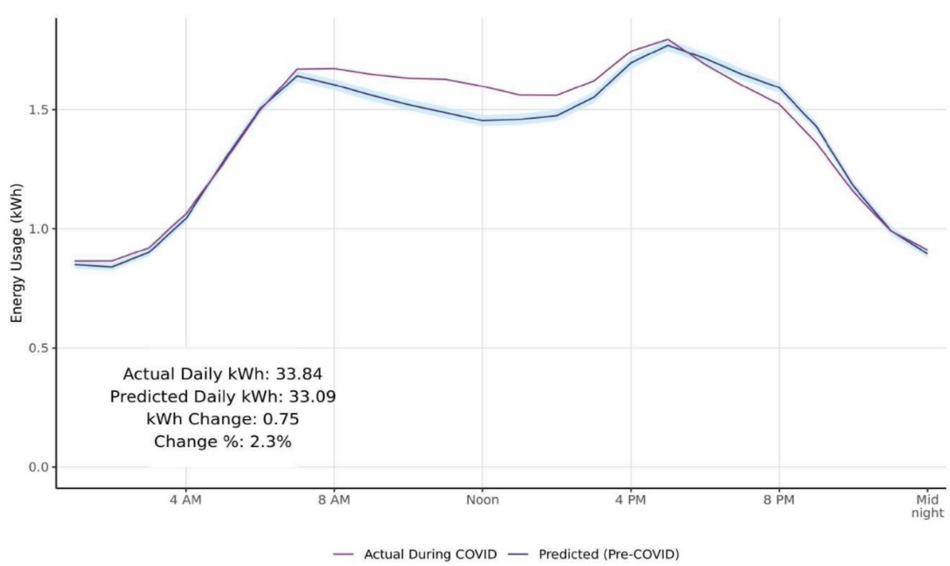
Study participants representing more than 100 homes responded to the survey questions about working from home. As shown in Figure 1, the number of homes with residents who rarely or never worked from home dropped from 51 to 40, or a decrease of 22%. The homes with people that always work from home since the beginning of the pandemic grew from 14 to 33, an increase of 135%. The number of people retired or not employed remained stable and roughly consistent with the general population, as documented in the "Annual Social and Economic Supplement to the Current Population Survey."[2]

Whole-Home Impacts of COVID-19

Using 15-minute interval data for the following comparisons, the metered overall 2.3% change in whole-home load varied throughout the day. As shown in Figure 2 below, the dark blue prediction line represents the 2019 load adjusted to match the same weather conditions experienced during the pandemic. The red line shows the actual load during the pandemic. The higher level of actual load than predicted load occurs in the middle of the day, consistent with more people at home than before the pandemic. At mid-day, residential load is 6% higher, a difference narrowed and reversed as the afternoon and evening progressed, when the load averaged 3.1% lower than expected.

While the graph represents the daily average of over 100 homes, some of the metered homes exhibited very different patterns than the one pictured. However, the predominant pattern is represented in the graph, with a high degree of precision as shown by the narrowness of the 95% precision light blue band around the dark blue prediction line.

Figure 2
Weather-Normalized Change in Northwest Residential Electricity Use



Source: Evergreen Economics.

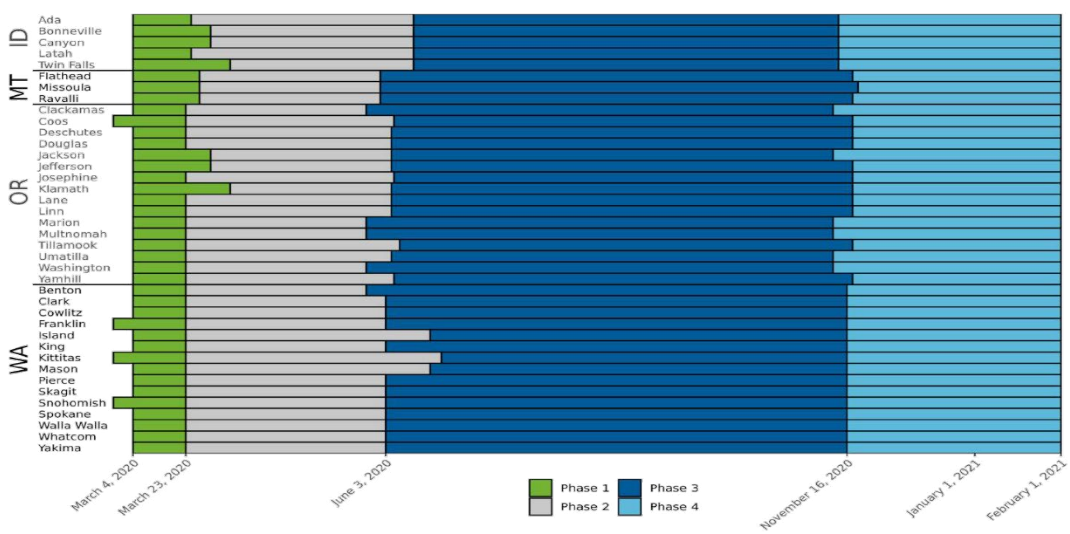
COVID-19 Impacts Varied Through Time

To account for non-uniform changes in electricity end use demand, the figures below split the time period of March 2020 to February 2021 into the phases of state governmental restrictions. As shown in Figure 3, the identified phases are:

Phase 1: Start of the Pandemic (green)
Phase 2: Shelter in Place (gray)
Phase 3: Summer/Fall Re-opening (dark blue)
Phase 4: Late Fall/Winter Surge (light blue)

Note that Figure 3 shows that the phases occasionally differed across counties even within the same state.

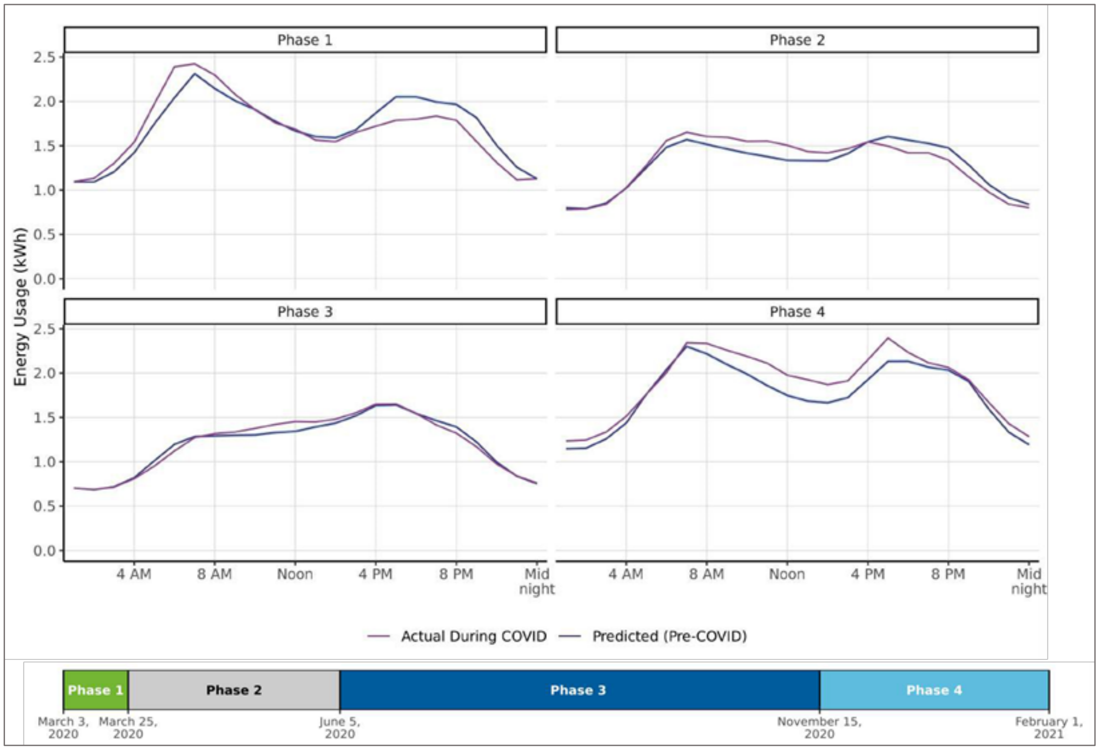
Figure 3
Four Pandemic Phases by County



Source: Evergreen Economics.

In each of the phases, differences can be observed in the actual and predicted load shapes. The phase with the least COVID-19 related difference is Phase 3: Summer/Fall Re-opening. The largest differences are seen between Phase 1 and Phase 4. In these phases, government restrictions increased as infection rates rose, leading to less mobility and larger changes in behavior, including more cooking at home. The more government restrictions by phase, the higher the actual residential peak demand became in comparison to the predicted peak demand.

Figure 4
Phases of COVID-19 Impacts on the Northwest

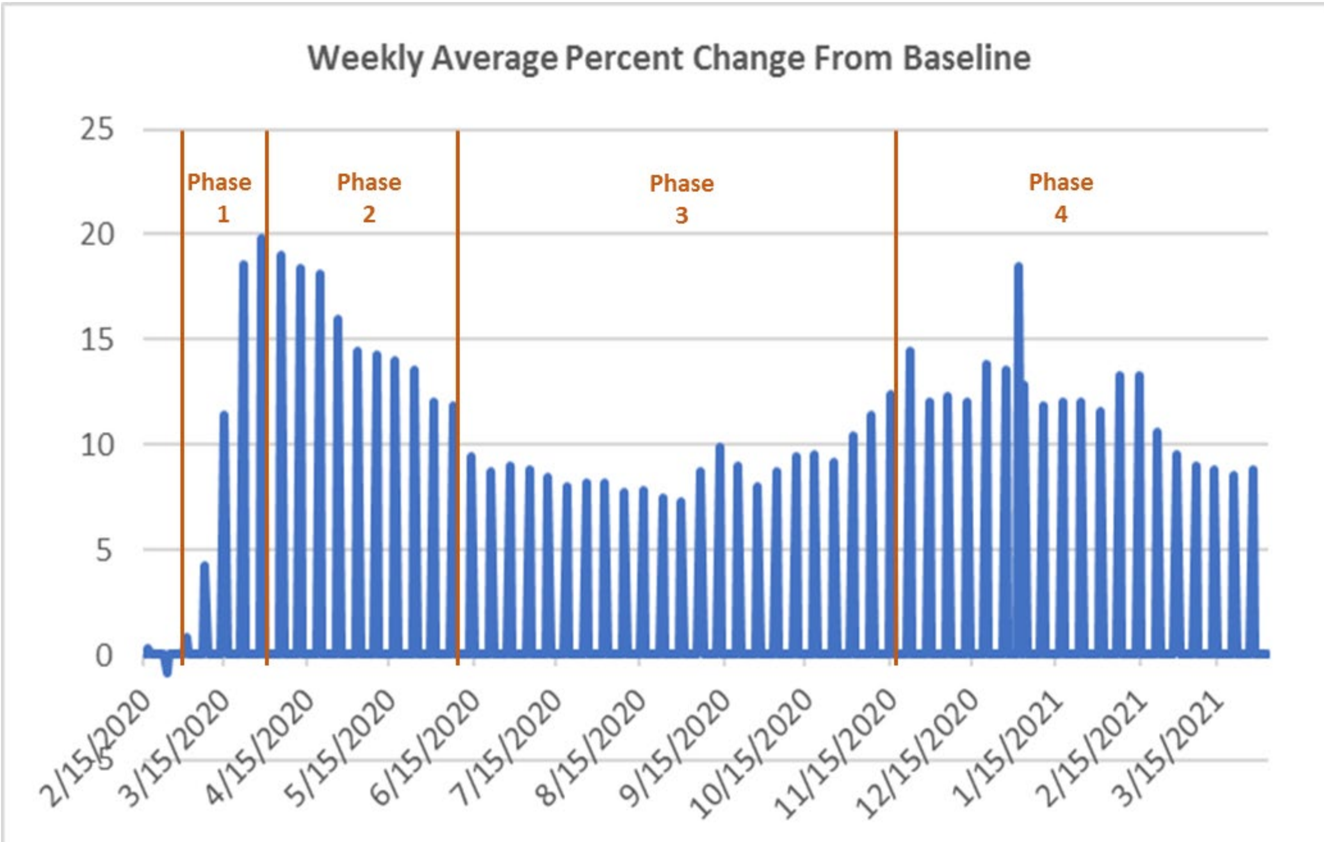


Source: Evergreen Economics.

Evergreen Economics used Google Mobility Data[3] and the timing of stay-at-home orders to help identify the phases in electricity consumption. The Google Mobility Data is collected primarily through anonymously tracking phones using the Google Maps app. Using this data, Figure 5 demonstrates the weekly average mobility to residences in Washington state, along with the identified phases as compared to the baseline median value from the five-week period of January 3 through February 6, 2020.

Figure 5 demonstrates that while residential mobility varies throughout the pandemic, it generally aligns with the COVID-19 phases identified by Evergreen Economics. For example, as would be expected in Phase 3: Summer/Fall Re-opening, summer trips to residences decline significantly when people spend more time away from home and travel less frequently to residences. Alternatively, greater travel to residences suggests that when people leave home, it is for shorter duration trips that end back at home. The largest short-term spikes in travel to residences occurred during holiday periods. As measured by Google, travel to workplace, public transit, retail and grocery destinations all fell by more than 50% from the baseline during the last week of March and first week of April 2020. The fourth phase saw a surge in COVID-19 infections, which coincided with more trips to residences as opposed to other destinations. While other destinations saw greatly reduced travel, travel to parks saw a weekly average increase of 68%.

Figure 5
Trips to Residences in Washington State Align with COVID-19 Phases



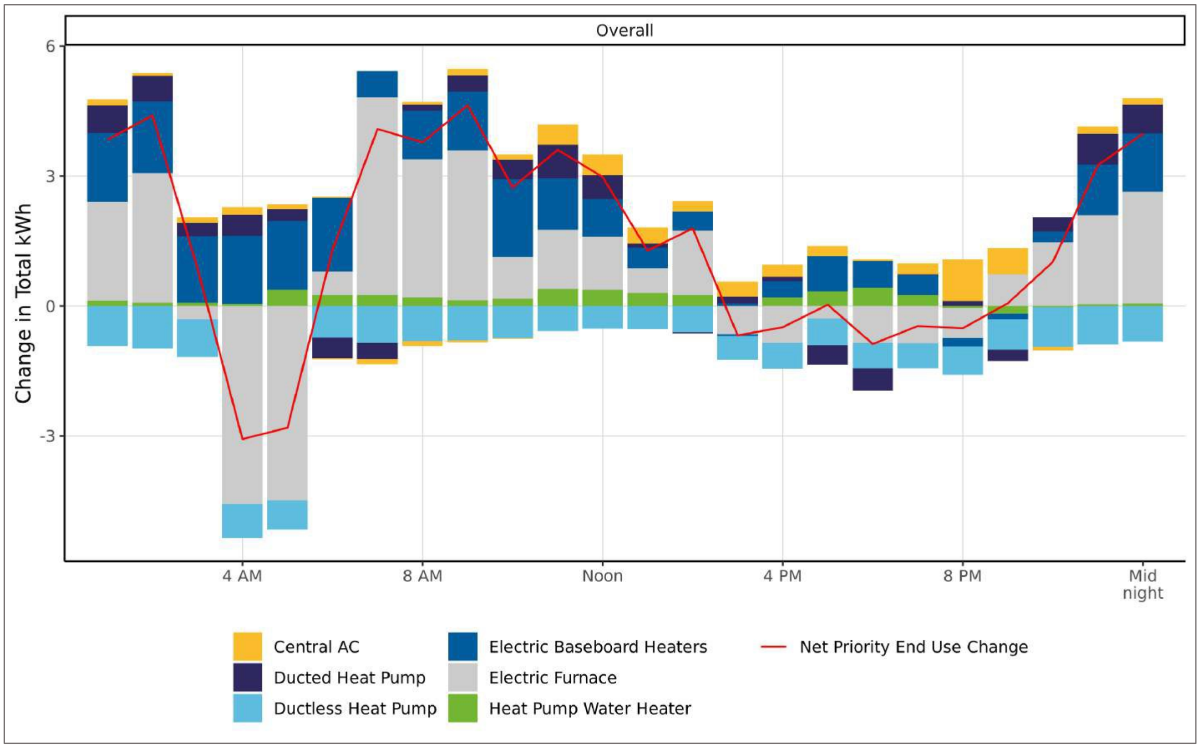
Source: Google COVID-19 Community Mobility Reports and NEEA.

COVID-19 Impacts to Heating, Ventilation, and Air Conditioning (HVAC) Were Minor

As a major contributor to residential demand and a frequent swing factor driving system peak demand during weather events, HVAC is of particular interest for utilities. For HVAC contributions to the changes in household load (Figure 6 below), many observed changes were easily explained by the increase in residents working from home. Electric baseboard heaters (more common in multifamily housing, mobile homes and older homes) were used more, especially in the early morning hours of 4–6 a.m. Electric furnaces (more common in older, single-family homes) were used less in the 4–6 a.m. hours, but used more later in the day, 7 a.m.–2 p.m. This indicates a shift in electric furnace heating load from early morning to late morning.

While central air-conditioning, ducted heat pumps and heat pump water heaters all saw increased use after COVID-19 began, not all HVAC changes are as straightforward. For example, while some ductless heat pumps averaged a modest 3% gain in electricity use during the pandemic, other ductless heat pumps were consistently used less throughout the day and evening. A possible explanation is that with more people at home, the likelihood of heating and cooling the entire home increases. Therefore, ductless heat pumps, as secondary heating sources, may have been turned off if the resident engaged their whole-home heating or cooling options, instead of just heating or cooling the room with a ductless heat pump.

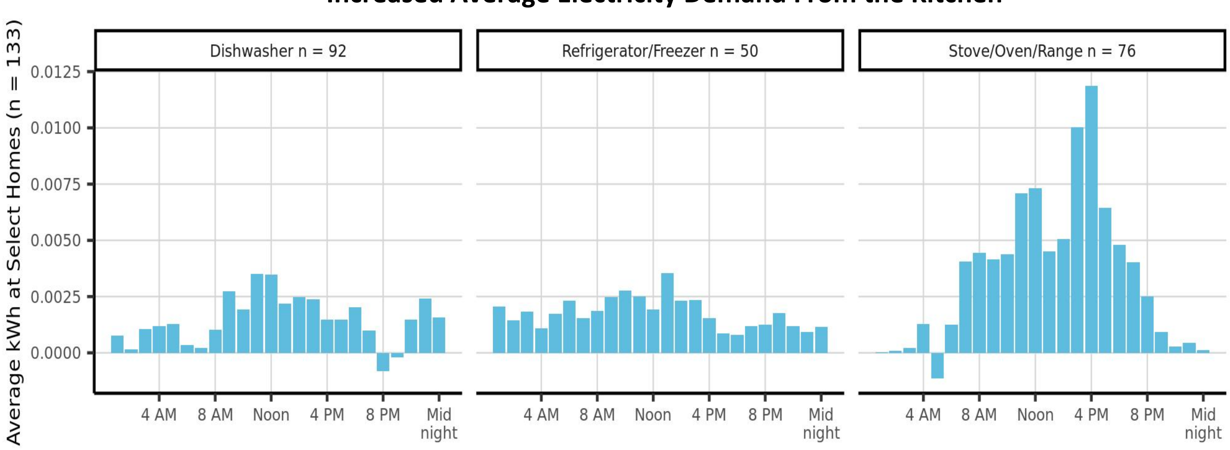
Figure 6
Changes in Total kWh by Priority End Use



Source: Evergreen Economics.

With residents cooking more at home, the kitchen became an important driver of increased residential demand during the pandemic. As shown in Figure 8, average kWh electricity demand from the refrigerator, range and dishwasher increased across almost all hours.

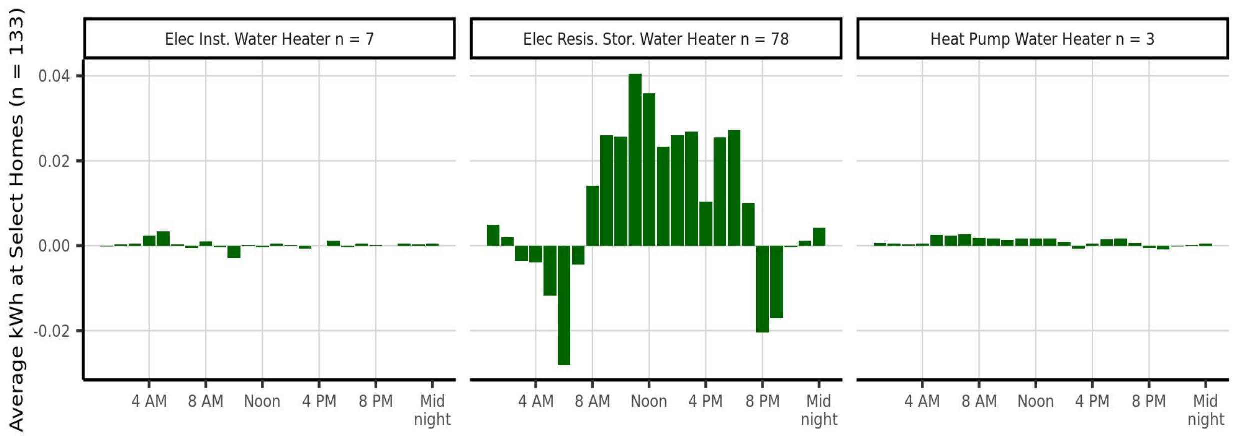
Figure 7
Increased Average Electricity Demand From the Kitchen



Source: Evergreen Economics.

As shown in Figure 8 below, more cooking, cleaning and dishwashing created more demand for hot water, especially during mid-day hours. More people showered at home instead of at school or at a gym, and they also tended to do more laundry during the day instead of evenings and weekends.

Figure 8
COVID-19 Drives Increases in Electricity Demand for Hot Water



Source: Evergreen Economics.

HVAC and Appliances Not the Largest Factors in Increased Demand

While electric resistance water heaters were important to increased demand, on average, the largest change in residential demand from beginning of the pandemic in March to January 2021 came from electric end uses identified as "additional load." Additional load is a combination of plug load and lighting, making up over half the total increase in residential load from COVID-19. Plug load includes end uses such as computers, printers, televisions, stereos, portable heaters, portable air conditioners, and portable lighting. In order of the scale of impacts, additional load was followed by water heating, kitchen, and laundry. Little or no change in combined HVAC loads attributable to COVID-19 could be detected. The average, weather-normalized changes in the hourly HVAC loads combined ranged between zero and minus three one-hundredths of a kWh through the eleven-month time period.

Conclusion

The Northwest End Use Load Research Project (EULR) is metering end use data continuously at one-minute intervals for residences and at 15-minute intervals for commercial buildings. The five-year project is capturing the impacts of changes in home occupancy patterns, home appliances, weather impacts, electric vehicles, building codes, and perhaps most importantly for the near future, the COVID-19 pandemic. More than 200 residences are continuously reporting data that has captured energy use load shapes before and during COVID-19, and another 200 installations are planned. EULR has made 15-minute data freely accessible on NEEA's website: neea.org/EULRdata.

Initial data shows that Northwest residential loads have increased during COVID-19, but not at the same magnitude as other parts of the country. And while important questions remain—including those surrounding COVID-19's potential long-term impacts on energy end use—the EULR project is uniquely positioned to provide definitive answers with highly accurate metering for years to come.

Endnotes

[1] James, Aaron, and Clement, David, "Regional End Use Load Research: Current Landscape," NEEA Whitepaper, Conduit: End Use Load Research Update, 2016. https://conduitnw.org/Pages/File.aspx?rid=3361

[2] "Annual Social and Economic Supplement to the Current Population Survey," U.S. Bureau of Census, 2019.

[3] Google LLC "Google COVID-19 Community Mobility Reports." https://www.google.com/covid19/mobility