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Permalink

<https://escholarship.org/uc/item/5zf742cx>

Journal

ASHRAE TRANSACTIONS 2025, VOL 131, PT 2, 131

ISSN

0001-2505

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Publication Date

2025-08-04

DOI

10.63044/s25fie02

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Energy Technologies Area
August 2025

10.63044/s25fie02



This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy,
Building Technologies Office, of the US Department of Energy
under Contract No. DE-AC02-05CH11231.

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Field Demonstration of Cost Minimizing Load Shifting Controls for 120V Heat Pump Water Heaters in Different Pricing Scenarios

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ABSTRACT

Recently released 120V heat pump water heaters (HPWHs) bring retrofit-ready products to the market, empowering consumers who wish to install these high-efficiency products but don't have easy access to 240V/30A electrical service. Adding new electric water heaters may exacerbate existing electric grid peak load challenges. Since HPWHs typically employ 50-80 gallon (189-303L) storage tanks they are a form of thermal energy storage (TES) which is already present, and can be leveraged without purchasing/installing additional TES products.

Load shifting controls, which intelligently adjust the state of charge of the available TES to avoid electricity consumption during peak times, for 120V HPWHs are critical for maintaining a stable electricity grid. Prior research has indicated that the most effective way to change consumer electricity consumption is to leverage utility programs implemented by third-party aggregator companies. Utilities have begun releasing time-varying electricity prices, and utility programs shifting loads in response to prices can maintain grid stability while reducing participant electricity bills. To increase adoption load shifting control strategies must 1) leverage currently available HPWH capabilities, 2) provide incentives to participants by reducing their electricity bills, and 3) be easily adapted to existing utility programs. LBNL's CalFlexHub and Stor4Build projects have developed cloud-based control algorithms that minimize occupant utility bills by creating customized load shifting signal schedules in response to a specific home's time-varying electricity price profile and typical electricity consumption patterns. The control algorithms are capable of using either CTA-2045 or manufacturer API communication protocols.

Field demonstrations deployed customized CTA-2045 signal schedules in 10 homes in response to 5 different electricity price profiles. Two electricity profiles represented summer and winter dynamic pricing scenarios, similar to the new or upcoming opt-in pricing programs offered by Pacific Gas and Electric Company and Southern California Edison. Three of the price profiles were 2024 time of use rate schedules offered by Californian utilities. The demonstrations showed that these techniques can shift 29-54% of the load away from peak periods, and reduce 120V HPWH electricity costs by 8-46% depending on the electricity price profile. Price profiles with high differences between the low and high price times show greater impacts. Simulations showed that adopting CTA-2045-B, with the Advanced Load Up feature, would increase the cost savings by 21 percentage points and the peak period consumption reduction by 31 percentage points.

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INTRODUCTION

Increased adoption of renewable power by utility companies is increasing grid stability challenges, such as the “duck curve” challenge in California (CAISO, 2013). The trend of transitioning from fossil power to intermittent renewables is coupled with increased adoption of electric vehicles and heat pumps, increasing predicted summer and winter peak by 79 and 91 GW respectively over 10 years (North American Electric Reliability Corporation, 2023). Utilities in the United States are responding to these challenges by deploying load shifting programs, encouraging their customers to consume electricity when renewables produce and provide services at other times of day (Alstone, et al., 2017) (Langevin, et al., 2024). These programs are typically combined with time of use prices, which feature different electricity prices at different times of day, thereby providing utility bill reductions as incentive to participate (Freier, Arnold, & Hesselback, 2019) (Gerke, et al., 2024).

Manufacturers have recently begun selling novel heat pump water heaters (HPWHs) designed to reduce installed costs. These products work on 120 V circuits, instead of the traditional 240V requirements, reducing installation costs by ~\$800-15,000 (Khanolkar, Egolf, & Gabriel, 2023). To operate on a 120V circuit most of these products forgo the ~4 kW backup resistance elements employed in 240V HPWHs. One manufacturer produces two products, one designed for shared circuits with a 4,200 Btu/h (1,231 W) heating power heat pump and a second designed for dedicated 30A circuits with a larger 12,000 Btu/h (3,517 W) heating power heat pump (Rheem, 2022a, Rheem 2022b). A second major manufacturer offers a product with the traditional 4,200 Btu/h (1,231 W) heat pump and a 900 W backup resistance element (A.O. Smith, 2025). Since these products have less heating power than traditional HPWHs, which increases the risk of cold water events, they typically employ a combination of a) larger storage tanks, and b) elevated tank set temperatures with mixing valves outputting water at the user specified set temperature. Available products feature storage tanks ranging from 40–80 gallons (151-303 L), and manufacturers employ proprietary controls to increase the internal set temperature as needed to ensure hot water availability.

Adoption of 120V HPWHs drives increased electrical load, with the potential to add 29.7 GW of electric demand assuming full market adoption of the technology (Energy Information Administration, 2023). To avoid exacerbating existing peak demand challenges, controls shifting load away from peak periods are vital. Since HPWHs employ 40-80 gallon (151-303L) storage tanks and the communication capabilities needed for load shifting control, it’s possible to deploy controls that shift load away from peak periods without impacting hot water delivery performance. Further, it’s possible to shift load from times of peak demand to peak renewable production, avoiding both grid expansion and curtailment.

Deployment of controls which respond to time of use rates to reduce occupant electricity bills, customized to different sites based on their baseline electricity consumption patterns, has the potential to support utility programs helping to stabilize the grid. This research addresses that gap by testing a control approach designed to seamlessly integrate into utility programs. The control pre-computes customized load shifting signal schedules in response to both electricity price schedules and baseline electricity consumption (referred to as “price- and load-responsive control”). Customized signal schedules were deployed at 10 field sites throughout California with 120V HPWHs. The experiment was performed for 5 different electricity price schedules, 3 current time of use (TOU) schedules from Californian utilities and 2 schedules emulating typical price curves in dynamic pricing programs from LBNL’s CalFlexHub project. Specific research questions in this research included:

- How do the prior results from simulation studies transfer to in-field performance?
- How do differences in electricity price schedules impact the benefits of load shifting controls for 120V HPWHs?
- How can price- and load-responsive controls for HPWHs be seamlessly transitioned to utility programs?

METHODOLOGY

Field Sites

Sites were recruited from New Buildings Institute’s (NBI’s) prior field study monitoring the performance of 120V HPWHs (Khanolkar, Egolf, & Gabriel, 2023). That study featured installations at 32 field sites spread across California. Sites were typically in large metro areas such as (from North to South) Eureka, Sacramento, the San Francisco Bay Area, and Los Angeles providing operating conditions ranging from the marine, cool climate of northern coastal California to the hot, dry climate of the Central Valley. No sites were located in the cold mountain regions, in line with manufacturer recommendations that these products be installed in climates with typically warmer ambient air temperatures (Rheem, 2025a & b).

Of the 32 sites in NBI’s prior field study, 10 were recruited for participation in the load shifting study. To maintain site anonymity the specific locations of the sites were not specified; however, it is known that at least one site was located in the

territory of each Sacramento Municipal Utility district (SMUD, Sacramento), Pacific Gas and Electric Company (PG&E, northern California), and Southern California Edison Company (SCE, southern California).

To ensure access to quality data and enable detailed data analysis, all sites continued to use the monitoring equipment installed during the prior field study. These measurements included 1) the temperature of water entering and exiting the HPWH, 2) the flow rate of water through the HPWH, 3) the temperature and relative humidity of the ambient air, and 4) the electricity consumption of the HPWH. Each measurement had a 1 minute sampling frequency.

The HPWHs were CTA-2045-A compliant, and communication modules were installed. CTA-2045-A enables the Shed (delay heating) and Load-Up (heat water to the set temperature) commands. CTA-2045-B, with which these HPWHs do not comply, adds an Advanced Load Up (ALU) command which increases the set temperature to increase stored energy.

Control Development

The load shifting controls for this research are based on development of price- and load-responsive controls in prior studies (Grant, Stuebs, Nordman, & Gehbauer, 2023). The development pathway 1) creates groups of HPWHs with similar baseline electricity consumption (indicating similar domestic hot water consumption), 2) compares the change in price over a coming time horizon to threshold price change values based on input parameters, 3) uses those comparisons to decide when to send CTA-2045-B Shed, Load-Up, and Advanced Load-Up (ALU) signals, and 4) customizes the parameters, changing the schedule of signals to send, for each group of HPWHs. The outcome is schedules of CTA-2045 signals that minimize the operating cost of each group, based on the observed baseline behavior, thus minimizing the fleet's operating costs.

The preliminary grouping method presented in (Grant, Stuebs, Nordman, & Gehbauer, 2023) identified HPWHs that consumed similar total amounts of electricity each day. This approach did not provide a representation of the time of day at which consumption occurs. In scenarios with time-varying prices timing is important. Updates to this approach create groups based on the root mean square error (RMSE) between profiles. Groups are identified by 1) calculating the RMSE between all combinations of two profiles, 2) identifying clusters of HPWHs that all have low RMSEs when compared to each other, and 3) selecting the HPWH pairing with RMSE's below a threshold. HPWH pairings with RMSE's above the threshold are then assigned to other groups. For this research, the RMSE threshold was identified by calculating the typical RMSE within individual data sets, representing typical day-to-day variation within a home. This created groups of HPWHs with load variation similar to what's likely to occur within a specific home.

The above-described process creates a load shifting signal schedule for each group with similar behavior for a specific electricity price schedule. The process was performed five times to enable field testing with five electricity price profiles.

The groups and load shifting schedules are generated using a dataset of 148 monitored domestic hot water consumption profiles (Kruis, Wilcox, Lutz, & Barnaby, 2017) and the resulting electric load curves using a simulation model that closely matches the performance of available products (Hoeschele, Haile, & Grant, 2022). This creates optimized load shifting signal schedules for realistic scenarios, but not direct insight into what schedule to apply to each specific water heater.

Since HPWHs do not measure domestic hot water consumption and adding that measurement would increase costs, it's important to leverage a toolchain that enables identification of the optimal strategy for new sites without access to hot water flow data. This research assigned field HPWHs to different groups, and the associated load shifting signal schedules, by identifying the group with electric load curves most similar to the baseline electricity consumption for each site. This was a two-step process. First, four weeks of baseline electricity consumption was used to calculate an average 24-hour electricity load curve. Second, calculating the RMSE comparing the baseline data to each HPWH identified the average RMSE between the field HPWH and each group. The group with the lowest average RMSE, indicating the least difference between the baseline profile and the profiles in the group, was selected as the most appropriate match.

Customization to 120V Products

120V HPWHs differ from traditional 240V products in two key ways. First, to ensure that the product can be powered with the 1,800 W available from a 120V/15A electrical circuit the manufacturers removed the ~4,000 W backup electric resistance elements. One manufacturer uses a 900 W resistance element, but most products don't include any backup power. Secondly, to reduce the risk of cold water events, manufacturers install a mixing valve on the outlet of the water heater and use an elevated set temperature for the storage tank. The mixing valve provides water at the user-specified set temperature, and the heat pump heats water to a higher temperature storing more energy in the tank.

The model and control algorithm were updated in three ways for 120V HPWHs. The backup resistance elements were removed from the model to emulate the majority of 120V products on the market. The water exiting the HPWH was modeled as having an external mixing valve set to 125 °F (51.7 °C) and an internal set temperature of 140 °F (60 °C). The utilized refrigerant in most HPWHs limits the maximum water temperature to 140 °F, matching the assumed internal set temperature. This means that the HPWHs will not be able to further increase the set temperature for load shifting purposes, precluding use of the CTA-2045 ALU command. Exclusion of ALU precluded increasing energy stored in the tank prior to shed events, an important strategy to avoid cold water events. In response, the maximum Shed period was reduced to three hours.

Pricing Scenarios

To test the performance of these controls in different scenarios, the field tests deployed load shifting in response to five different electricity price schedules. The five different electricity price schedules were selected to represent various scenarios and evaluate the impact of electricity price structures on load shifting performance. The prices are shown in Figure 1.

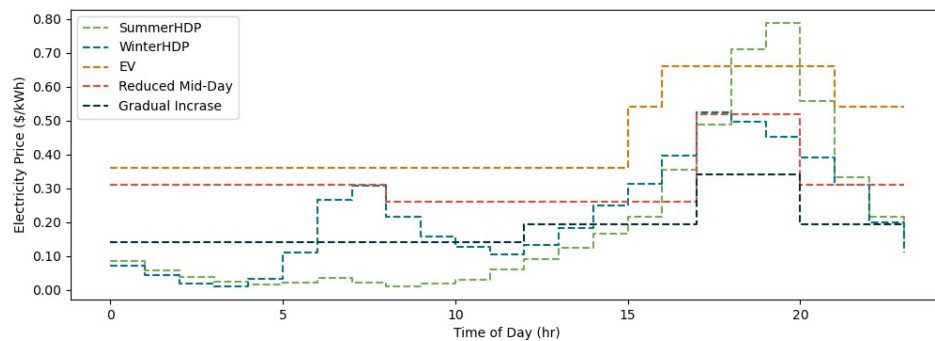


Figure 1: Electricity price schedules used in the study

Two of the price schedules were from Lawrence Berkeley National Laboratory’s CalFlexHub project (Piette, et al., 2022). CalFlexHub is helping prepare California for the 2024-2025 rollout of dynamic prices by developing, demonstrating, and commercializing controls that shift load in response to electricity prices. To support those goals CalFlexHub has released several Highly Dynamic Price (HDP) schedules denoted as “[Season]HDP” where [Season] is the name of a season. This research used the SummerHDP and WinterHDP price schedules as they are expected to be the times when load shifting is most beneficial. Shifting load away from times of peak demand is already common on hot summer days. California expects new periods of peak demand on cold winter mornings in the future. The SummerHDP profile represents a hot summer day, where cooling electricity demand stretches the capabilities of California’s electric grid, with prices as high as \$0.78/kWh during the 7-8 PM window. High solar power production and low electric demand for other services drive lower prices outside of the evening peak period, typically below \$0.10/kWh and as low as \$0.01/kWh from 8-9 AM. The WinterHDP also presents an evening peak price, though a little earlier at 5-6 PM and less expensive at \$0.53/kWh. Prices in the morning also increase, reflecting the morning heating peak, to a maximum of \$0.31/kWh from 7-8 AM. Prices during the mid-day period are not as low in WinterHDP as in SummerHDP, reflecting the reduced solar power production during that time of the year.

The other three electricity price profiles are utility TOU rate schedules in California from the summer of 2024. One rate schedule was selected for each PG&E, SCE, and SMUD – the three utilities participating in the study. The specific price schedules were selected to explore the impact of different price curve characteristics on performance. The selected prices were as follows. **EV**: As electric vehicles (EVs) become more common, rate plans structured for homes with EVs are becoming more common. This rate plan features a peak-period price of \$0.66/kWh, a mid-peak price of \$0.55/kWh, and an off-peak price of \$0.35/kWh. **Gradual Increase**: Typical TOU rates in California gradually increase throughout the day with a low off-peak price overnight, a slightly increased mid-peak price from mid-day to late afternoon, and a high price during the evening peak period. The price schedule used in this study features a maximum price of \$0.35/kWh during the peak, a mid-peak price of \$0.20/kWh, and an off-peak price of \$0.14/kWh. **Reduced Mid-Day**: This price profile was selected to evaluate how much the reduced price mid-day increased electricity consumption at times when California is commonly overproducing solar power. The profile featured a maximum price of \$0.63/kWh during the peak period, a mid-peak price of \$0.41/kWh overnight, and an off-peak price of \$0.36/kWh during the middle of the day.

RESULTS

CalFlexHub SummerHDP Field Test Results

Figure 2 presents the field results of testing load shifting control in the fleet of 10 HPWHs under the CalFlexHub SummerHDP price scenario. The test data is averaged across one week and the baseline data is averaged across a four week baseline period. The top plot shows the electricity price schedule, the middle plot shows the electric demand of the fleet, and the bottom plot shows the electricity cost of fleet operation. The red shaded periods indicate times when the price is above average, the blue lines show baseline operation (no load shifting control) while the green lines show electricity consumption during the testing week. The middle plot shows a distinct reduction in electricity consumption during the high price period, reducing total electricity consumption when the price was above average by 52%. Several HPWHs did activate their heat pumps at hour 22, when the price was still above average, as domestic hot water draws in those sites were large enough to require heating. The load shifting controls used the Load Up command to increase the electric demand during the low price hour 8-9 morning period; however, since the tanks were maintained close to the set temperature by the manufacturer’s controls, the increased electric demand and associated increase in energy stored in the tank were both marginal. The largest period of electricity consumption occurred overnight, after the HPWHs were released from Shed mode and recharged the tanks. Low overnight prices caused this shift to reduce the operating costs of the fleet by 46%.

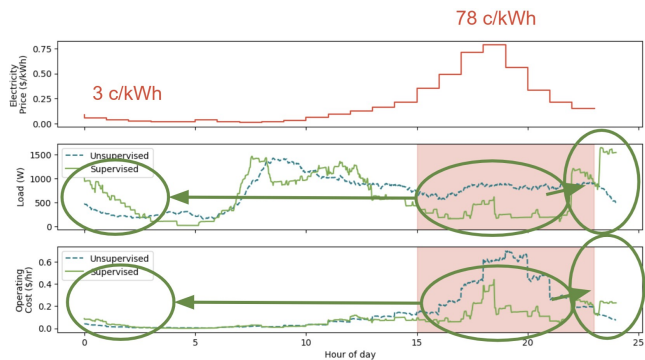


Figure 2: Load shifting field performance with the CalFlexHub SummerHDP prices

Reduced Mid-Day Field Test Results

Figure 3 presents field results showing the performance of 4 HPWHs with load shifting controls responding to the Reduced Mid-Day field test results. The controls responded to the sudden increase in prices at hour 16 by sending Load Up signals at hour 15 (before the increase), as evidenced by the increase in average demand from ~50 W in the baseline case to ~500 W in the load shifting case. This increase in load ensured the storage tanks were fully charged prior to the price increase, enabling a reduction in demand during the beginning of the high price period. Despite a spike in demand in the hour 18-19 window, the load shifting controls reduced the electricity high price electricity consumption by 29%. Moving that consumption to lower price times of day, primarily to the mid-day reduced price, results in 19% electricity cost savings.

One key observation in this test scenario is that there was not a period of snapback consumption after the end of the high-price period. The increased heat pump operation increasing storage in the tank, followed by the relatively short high price period, combined to leave storage tanks well charged at the end of the high price period. Because the tanks were still well charged, they did not all need to simultaneously activate their heat pumps to recharge the tanks.

Comparison of all Field Test Scenarios

Table 1 presents the reduction in operating costs and high price electricity consumption in all five testing scenarios. The CalFlexHub scenarios showed the highest operating cost reductions of 46% for SummerHDP and 30% for WinterHDP. They also showed high reductions in high price electricity consumption at 52% and 41%, exceeded only by the EV rate at 54%.

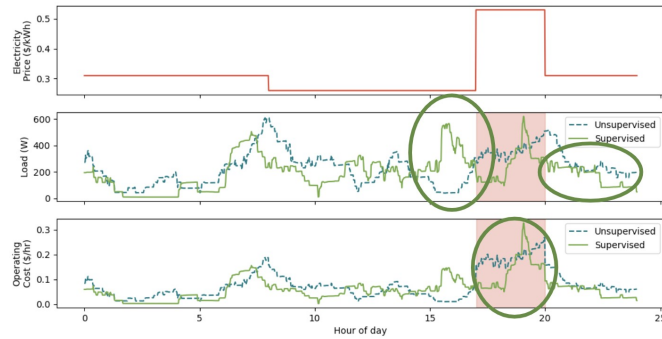


Figure 3: Load shifting field performance with the Reduced Mid-Day prices

Table 1: Key Performance Metrics in All Pricing Scenarios

Price Schedule	Operating Cost Reduction (%)	High Price Consumption Reduction (%)
CalFlexHub SummerHDP	46	52
CalFlexHub WinterHDP	30	41
EV	8	54
Reduced Mid-Day	19	29
Gradual Increase	18	21

Of the utility rate structures, Reduced Mid-Day showed the highest operating cost reduction at 19% followed by Gradual Increase at 18% and EV at 8%. EV showed the highest reduction in consumption during high price times at 54%, followed by Reduced Mid-Day at 29% and Gradual Increase at 21%. Aside from the reduction in high price consumption in the EV scenario, these impacts are all significantly lower than in the CalFlexHub pricing scenarios.

Impacts of Advanced Load Up

Since the tested 120V HPWHs do not enable the ALU command it's important to understand the potential performance impacts of that limitation. Simulations using LBNL's Flexi-HPWH and 148 monitored draw profiles (Grant, Stuebs, Nordman, & Gehbauer, 2023) with 80 gallon storage tanks evaluated the potential change in load shifting performance in one scenario. Figure 4 presents the sample impacts of enabling ALU. The left-hand figure shows the fleet response under CalFlexHub's SummerHDP without ALU, and the right-hand figure shows the fleet response with ALU. The top subplots show the electricity price curve, the middle plots show the electric power of the fleet of HPWHs, and the bottom plots show the HPWH fleet's operating cost. The red shaded periods indicate times of above average price, the blue dashed lines show the demand with standard manufacturer controls, and the green lines show the demand with load shifting control.

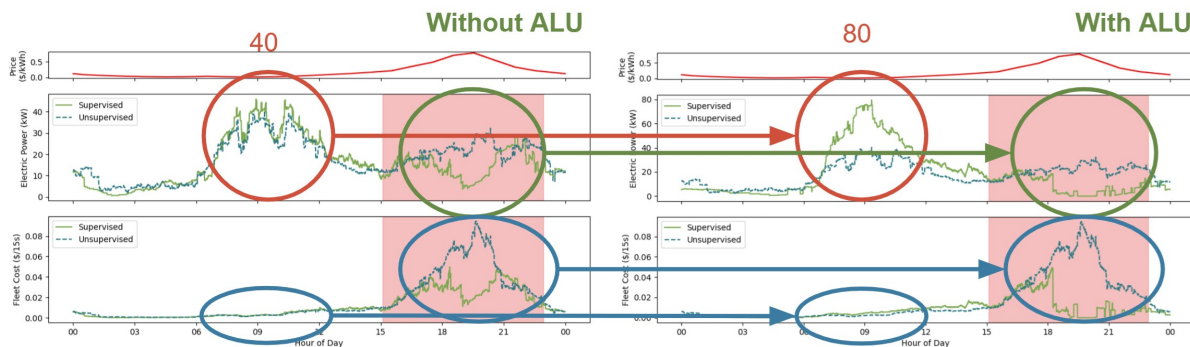


Figure 4: Comparison between load shifting performance with and without advanced load up

The demand curve shows dramatic differences around both hours 9 and 20. The case without ALU responded to low

morning prices by sending Load Up commands, activating the heat pumps, and bringing the water to the set temperature. However, because the water in the tank was already close to the set temperature the increase in electricity consumption and stored energy were both marginal. In the case with ALU the demand during the low price time of day doubled, from 40 kW to 80 kW, performing twice as much heating and storing far more energy in the tank. The case without ALU showed a 29% decrease in consumption during the high price period; however, the stored energy was not adequate to fully coast through the high price period, and demand returned to normal before prices fell. The case with ALU reduced consumption when prices were high by 60%, maintaining low demand until prices returned to a minimum. The case without ALU was able to reduce operating costs by 32%. The improved performance enabled by ALU increased the operating cost reduction to 53%.

DISCUSSION

From Simulation to the Field

Prior work leveraged simulation to evaluate the potential of these controls, leaving uncertainty about how well their in-field performance (Grant, Stuebs, Nordman, & Gehbauer, 2023). The simulation study estimated that, for an electricity price schedule similar to the CalFlexHub schedules, the controls could reduce operating costs by 29% compared to 13% for CTA-2045-B signals that were not responsive to baseline loads. This study found the savings on CalFlexHub schedules to range from 30-46%, a significant improvement compared to the prior simulation results. The improvement in results is likely driven by the behavior of the occupants in the field sites. The draw profiles used in the simulation study features some sites with very high hot water consumption during the high price period, creating a situation where load shifting could avoid resistance element use and reduce but not eliminate high price consumption in several homes. Several sites in the field study consumed low volumes of hot water during high price times of day, facilitating eliminating high price electricity consumption.

One concern transferring to the field is the risk of increasing hot water runouts. This is especially true without ALU, as that limits the ability to increase stored energy prior to a shed period. No hot water runouts were identified in this research.

While this field study was performed in California, other studies have shown the potential of load shifting with HPWHs in other climates (Butzbaugh, 2023) (Urigwe, Granda, Davis, Butzbaugh, & Evren, 2024) (Hale, Leach, Cowiestoll, Lin, & Levie, 2022). These techniques should enhance load shifting performance in any location with time-varying electricity prices, or if utilities perform the control in response to their time-carrying wholesale, transmission, and distribution prices.

Impacts of Electricity Price Schedules

The CalFlexHub pricing scenarios showed the largest reduction in operating cost and second and third highest reduction in high price electricity consumption. This high performance was driven by the large dynamic range in the price profiles. The SummerHDP has a maximum price of \$0.78/kWh, a minimum price of \$0.01/kWh, and a typical overnight price of \$0.03/kWh. This difference made it feasible to reduce the paid electricity price by \$0.75-0.77 or 96-99%. WinterHDP showed the same trends, ranging from \$0.01/kWh to \$0.53/kWh and typical overnight prices of \$0.02/kWh. This price differential enabled load shifting controls to reduce the price of consumed electricity by \$0.51/kWh-\$0.52/kWh or 96-98%.

The utility rates didn't provide as dramatic of cost saving opportunities. The EV rate plan had the highest reduction between maximum and minimum prices at \$0.30/kWh but the lowest percentage reduction at 45% driven by the highest minimum price of \$0.36/kWh. Gradual Increase showed the lowest delta at \$0.20/kWh, but the highest percentage reduction at 56%. Reduced Mid-Day had a \$0.26/kWh reduction, or 50%. The lower delta in prices throughout the day provided lower economic value for shifting load; there was less opportunity for the controls to reduce utility bills by shifting load. Since the controls aim to minimize the cost of operating the fleet of HPWHs, they responded to the reduced economic value by shifting less load, providing less economic value for the HPWH owners and less grid-supportive load shifting operation.

The increased cost savings from price schedules with higher deltas becomes especially important when considering the economics of load shifting. Communication currently requires purchasing a ~\$150 CTA-2045 module and supporting homeowners through the installation process. Since higher price deltas provide more savings, they increase the benefit/cost ratio and economic appeal of installing the hardware. Price schedules with high deltas, or free communication methods like OpenADR via wireless networks, can improve the economics of load shifting (OpenADR Alliance, 2024). Californian utility programs like PG&E's WatterSaver and Southern California Edison's SmartShift use CTA-2045 modules because for savings with their wholesale prices, but the savings for a homeowner with typical prices are not likely to be worthwhile.

Benefits of Advanced Load Up

The ALU command increases the set temperature of the HPWH while performing the load up operation, storing additional energy in the tank. This command increases both the ability of the HPWH to consume low price electricity, and the ability to consumed stored energy during high price periods thus avoiding high price electricity consumption. In the simulated case enabling the ALU command could increase the energy cost savings from 32% to 53%, improving the cost savings by 21 percentage points. It also increased the reduction in high price electricity consumption from 29% to 60%, 31 percentage points, providing significantly more load shifting service to the utility.

The ALU feature also reduces the risk of cold water events occurring during high price periods. Load shifting tends to use the Shed command during to avoid high price electricity consumption, which delays water heating cycles and increases the risk of cold water events. Using the ALU command increases the energy stored in the tank, improving access to hot water during high price periods compared both to load shifting without ALU and to baseline scenarios with no load shifting control.

Deployability

Current utility programs feature implementers sending schedules of CTA-2045-B signals to fleets of HPWHs. Targeting those programs, this research created tools that utilities can use to refine their CTA-2045 schedules and improve the impacts. Since this approach leverages signal schedules customized to different groups of HPWHs with similar behavior, the deployment challenge is identifying the correct signal schedule to use for a participating HPWH.

The controls are pre-computed signal schedules for groups of HPWHs with similar behavior customized to an electricity price schedule. When identifying the signal schedule for a new HPWH, the utility needs to identify the group with the most similar baseline electricity consumption to send signals on the corresponding schedule. The identified methodology leverages four weeks of baseline data, gathered through CTA-2045-B communications, to identify a typical load curve for the HPWH in the field. That typical load curve is then compared to the load curve of every HPWH in the database used to generate the price- and load-responsive CTA-2045-B signal schedules by calculating the RMSE. This enables identifying the average RMSE comparing the typical load curve to each group, and identifying the group with the lowest RMSE enables selecting the signal schedule that will perform best for the new HPWH. This proposed toolchain supports utility adoption of advanced HPWH load shifting controls by enabling them to run a simple analysis script to identify the best signal schedule.

The Department of energy's Stor4Build consortium is currently funding tools supporting deployment of these techniques at scale. Specific actions to facilitate deployment include seeking input on user needs from Californian utility load shifting programs, developing a user-friendly tool to enable utility programs to perform the analysis with minimal coding skills, and connecting the toolchain to California's MIDAS price server for analysis with current time of use rates.

CONCLUSION

Utilities are responding to increased deployment of intermittent renewables and building electric loads by offering load shifting programs. These programs are typically coupled with time-varying electricity prices providing the ability to shift load in ways that simultaneously support grid stability and reduce participant utility bills. Achieving the best load shifting impacts requires designing load shifting strategies around both the electricity price and baseline load. Field demonstrations showed the impacts of shifting load in 10 120V heat pump water heaters in response to five different electricity price schedules. Cost savings ranged from 8-46% and high price electricity consumption reductions ranged from 21-54%, with the difference driven primarily by the difference between the maximum price and adjacent prices. Adoption/deployment of CTA-2045-B and Advanced Load Up significantly improves load shifting impacts. The load shifting control generation toolchain is designed for integration into existing utility load shifting programs.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. Additional support was provided by the California Energy Commission (CEC) under the Electric Program Investment Charge program. We are grateful to the CEC's Matt Fung and Kadir Bedir for their support of this program.

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