EPRI
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Machine-Learning-Based Load Shaping for Residential Water Heating

SHIFTED ENERGY

Startup
Shifted Energy
Honolulu, HI

Host
Tucson Electric Power

TEP
Tucson Electric Power

Technology Solution

Electricity-based water heating technologies, including electric resistance water heaters (ERWH) and heat pump water heaters (HPWH), account for a significant fraction of building energy use and peak demand in some U.S. regions. While conventional load control methods have proven effective for lowering energy bills and shaving utility peaks by managing water heater operation, they have limitations that can reduce customer uptake and satisfaction. Connectivity and computing innovations could expand the benefits delivered by utility controls.

Shifted Energy's load control switches are IoT devices designed for interoperability across electric water heater technologies and products.

This pilot project was launched to test the active, intelligent load control solution developed by Shifted Energy for transforming electric water heaters into distributed energy resources that provide multiple grid support services without negatively impacting customers. The company's Grid Maestro platform integrates Internet-of-Things (IoT) control switches with machine learning to enhance load forecasting and optimize the dispatch of individual and aggregated water heating systems while avoiding cold-water events.

Project Overview

The project team featured Tucson Electric Power (TEP), a Fortis company, as the host utility working with subject-matter experts from EPRI and Shifted Energy to deploy and demonstrate IoT control switches as the hardware basis and communications hub for a virtual power plant built within Grid Maestro and comprised of a fleet of residential water heater units operated based on machine learning algorithms.

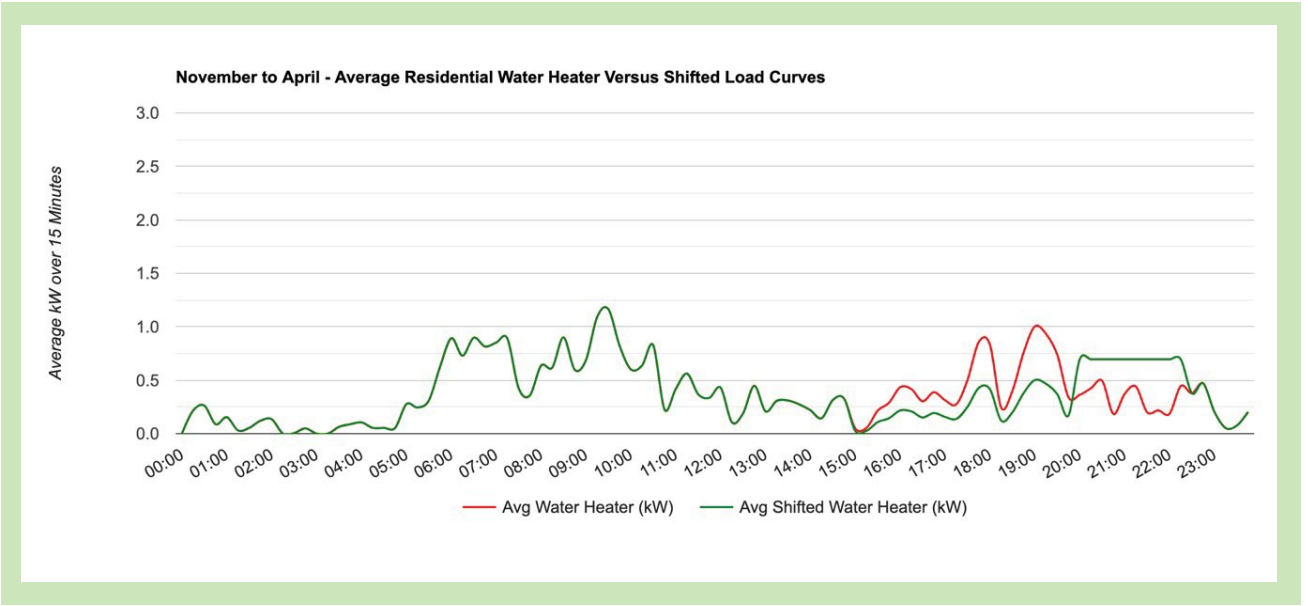
One key goal was to test the hypothesis that AI-based analytics and controls can provide better load forecasting and shaping than status quo approaches, including during shoulder months and peak demand periods. A second was to provide experience and learnings supporting development of a utility program offering in support of TEP's vision for co-optimized behind-the-meter demand-side management of water heating and other connected technologies.

TEP partnered with Scotia Group, a multi-family property manager in the Tucson area, with the long-term goal of recruiting and enrolling 500 residents to host the load control units. The primary target population for deployment of Shifted Energy's IoT-based (LTE CAT-M1) controllers was single-family homes with HPWHs previously purchased through TEP's energy

efficiency rebate program. In addition, multi-family residential buildings were targeted.

The project scope also included delivery, installation, and commissioning of up to 525 controllers as CTA-2045 demonstration units, followed by machine learning training then intelligent management across several load shifting events and experiments. Project tasks spanned the following areas of interest:

- **Grid services and benefits:** quantify baseline water heater load shapes for single- and multi-family homes and water heater types (ERWH, HPWH); quantify overall water heater load (kW) and energy usage (kWh) and available reductions from shifting to off-peak time periods; evaluate potential grid benefits from shifting load from early morning and peak early evening hours to match solar production curves, accounting for seasonal variability; and evaluate cost-effectiveness and maximum potential benefits.
- **Consumer perceptions and impacts:** quantify potential customer benefits provided by combining water heater controls with TEP's time-of-use and demand rates; evaluate customer response to utility control of water heater operation; evaluate potential ancillary benefits for customers (maintenance and leak alerts, remote shut-off control, marginal energy savings, etc.) and the utility (frequency regulation, non-wires alternatives); and evaluate the opportunity to aggregate water heating load for grid services while maintaining customer satisfaction.
- **Machine learning for aggregated demand-side management:** evaluate forecasts of baseline consumption vs. actual consumption for aggregated groups and entire fleet; evaluate forecasts of load shift capacity and energy impacts vs. actual capacity and impacts; evaluate load shape elasticity with dynamic optimization and capacity tradeoffs of optimal load shape vs. maximum load shift; and extrapolate potential impacts and benefits, by month and season, for a full-scale water heater control program.



Control optimization based on machine learning algorithms can reduce utility peaks by shifting water heating loads to align with solar energy production—and to later in the evening when overall demand drops.

Results & Learnings

Reaching customers was challenging during the pandemic, as planned in-person interactions between property managers and tenants shifted to electronic outreach. Customers proved eager to participate in the load control demonstration, but the compressed pilot project schedule and laborious enrollment paperwork posed additional challenges. Controller installs in multi-family buildings averaged about three units per hour, while the process for single-family homes, though more time-consuming, was streamlined by use of the CTA-2045 standard.

Across the pool of participating water heaters, baseline per-tank total daily consumption was 4.0 kWh, compared to the U.S. average of 12.66 kWh. Per-tank peak loads averaged 0.15 kW in the morning and 0.33 kW in the evening. Intra-peak water heater load profiles varied significantly by customer, highlighting the value of Shifted Energy's solution in tailoring individual event dispatch profiles to match unique usage patterns.

TEP's overall load curve shows distinct seasonality, with a single peak during the summer and two peaks during the winter. Based on actual and simulated dispatch profiles generated in this pilot project, Shifted Energy's machine learning algorithm demonstrated the capability to shave the various seasonal peaks and also to project potential load shift capabilities at other times.

Shifting to align water heating loads with mid-day solar production (10 am - 2 pm) increased the baseline load by 5.5 kW for an aggregation of 86 heaters,

corresponding to 0.06 kW per tank. This boosted per-tank total daily consumption by 0.25 kWh. On the other hand, results suggest the potential for automated load control to deliver customer energy efficiency savings of ~7%. However, the economic gain for low-usage heaters like those involved in this study may not be worth the added wear and tear on load control components and the related reduction in lifespan.

Utility-led technology implementation, facilitated by Scotia Group, enabled direct communication and relationship development with customers and property managers. Learnings by TEP during customer enrollment will be applied to guide future program rollouts, including for multi-family buildings and under-served populations where tenant-landlord relationships may pose barriers. Property managers benefited from the project not only by helping their residents but also from the monitoring capabilities provided by Shifted Energy's controller, including detection of leaks and faulty heating elements.

Implications & Next Steps

This pilot project demonstrated the potential of Shifted Energy's solution for IoT-enabled, machine-learning-based load control of aggregated customer systems as virtual power plants. It also has laid the foundation for continued collaboration with TEP in deploying additional water heater control switches and conducting a more rigorous programmatic evaluation, enrolling sufficient customers to set up three aggregated groups for learning, optimized dispatch, evaluation, and continuous improvement.

Pending results, TEP will consider similar programs in support of the utility's larger vision of harnessing the demand-side flexibility provided by connected water heating and pool pump controls, rate-optimized thermostats, and both electricity storage by batteries and thermal energy storage by heating, ventilation, and cooling systems.

TESTIMONIAL: Shifted Energy

The opportunity to collaborate with EPRI and TEP in proving the benefits of machine learning applied to aggregated load shifting has improved Shifted Energy's product while also providing insights for developing even smarter algorithms to deliver greater value to our utility partners.

TESTIMONIAL: Tucson Electric Power

Having not built many customer programs from scratch, TEP has benefited from the support provided by EPRI and Shifted Energy, instilling confidence in our team from the very beginning of this project and as the rollout of our connected water heating program continues.

TESTIMONIAL: EPRI

As decarbonization proceeds, the need to manage electric loads will grow. Because the inherent thermal energy storage capacity of electric water heaters makes them an ideal controllable load, EPRI looks forward to continued analysis of the data streaming from this project to inform stakeholders on the benefits of AI-based technology for aggregated load management.

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3002023035

March 2022

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