Grid-connected heat pump water heater benefits for low-income households

in the Southeastern United States

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ABSTRACT

Energy efficient heat pump water heaters (HPWHs) reduce water heating energy consumption compared to dominant baseline technologies. However, a HPWH's first-cost premium can put it out of reach for low-income households. Grid-connected controls can further increase HPWH value to households by enabling dispatchable energy storage and shifting electricity use to cheaper, off-peak periods. This paper presents the results of a study that explored the benefits of load shifting HPWHs for 24 low-income households in the Southeast U.S., aiming to support increased product deployment in this demographic.

The study used EcoPort modules to shift HPWH load for a study sample consisting primarily of low-income adults and seniors in North Carolina. Building on prior studies, the study's HPWH operating schedules were designed to maximize shifted energy and minimize participant electricity costs based on local time-of-use rates. The study documented load profiles of grid-connected HPWHs in a less-studied demographic group and explored how certain groups may have particularly flexible loads due to their unique usage profiles.

The results are relevant for HPWH product performance in the Southeast. The study quantified HPWH load shifting performance during North Carolina's hot summer, temperate shoulder, and occasionally sub-freezing winter seasons, including installations in conditioned, semi-conditioned, and unconditioned spaces. Finally, study results also demonstrate how controlled HPWHs can provide value to the regional grid by reducing seasonal peaks via demand response. Other lessons learned include HPWH acceptance for low-income and senior users and best practices for maintaining HPWH connectivity and reliability among users without prior product experience.

Project Background

In North Carolina, 73% of homes use electric resistance storage water heaters (ERWHs) making it the state with the third highest penetration of electric water heating and the state with the third largest fleet (3 million units) of these popular appliances (EIA 2020). Transitioning North Carolina's ERWHs to heat pump water heaters (HPWHs) could result in significant energy savings potential. North Carolina is also experiencing strong growth in annual peak electricity demand (Duke Energy 2024) and ranks fourth in the country in installed photovoltaic capacity. If North Carolina had 3 million HPWHs capable of load shifting, these appliances could flex to help reduce the system electric peak demand and to help accommodate the intermittent solar resource.

There has been little research targeting the potential to shift household water heating load in low-to-moderate-income (LMI) households. The relatively high upfront cost of HPWHs compared to ERWHs is a barrier for adoption in LMI households. To support increased product deployment in this demographic and within the Southeast U.S. where the potential for impact is high, this project investigates the benefits of load shifting HPWHs for 24 low-income households in North Carolina.

The project collected and analyzed short-interval electricity consumption data from 24 240-volt hybrid HPWHs equipped with EcoPort[1] universal communication modules (UCMs) from the summer of 2023 through the summer of 2024. These EcoPort-equipped HPWHs were installed by Rebuilding Together of the Triangle (RTT), the local affiliate of Rebuilding Together, a national nonprofit organization providing home repair and renovation services free of charge to those in need.

1 EcoPort is the brand name for technology that has been certified compliant with the ANSI/CTA-2045 technical specification.

Study participants had received the HPWHs over the preceding two years as part of RTT-provided retrofits, and the EcoPort UCMs were installed in subsequent site visits in mid-2023. For approximately one week each month during the study year, the project team allowed the HPWHs to operate without intervention to establish baseline, non-load shifting daily patterns of water heater electricity consumption. The rest of the time, the team sent demand response messaging to the water heaters, shifting electricity consumption from peak periods to off-peak periods during the day.

The project received U.S. Department of Energy and charitable foundation funding and significant in-kind support from the North Carolina Justice Center (NCJC), RTT, Orange County, NC, and the Pacific Northwest National Laboratory (PNNL).

Research Goals

The main goal of this research is to explore the energy saving and load shifting potential for HPWHs installed in LMI households in North Carolina. The study team also hopes to advance the body of knowledge about controlled HPWHs and their ability to generate benefits for the distribution grid. Specific topics addressed include:

- Quantification of the potential for peak demand reduction from HPWH in LMI households in the Southeast
- The impact of long load shifts on household hot water service
- Opportunities to make HPWH more available to LMI and senior households
- Analysis of HPWH load shifting electricity cost savings for North Carolina customers on time-of-use rates

Advisory Group

To make the results of this research as relevant as possible to energy efficiency and low-income community advocates in North Carolina, the study team recruited local and industry experts to an Advisory Group (AG). The AG reviewed the study's experimental design and study results, and they provide ongoing input on the project. Study participants were not recruited to the AG. A list of AG members is available in Appendix A.

Study Participants

To our knowledge, prior HPWH load shifting studies have not exclusively targeted LMI households. Low-income families often face a high energy cost burden. In North Carolina, households living at 50% of the Federal Poverty Level pay an average of 32.8% of their income for energy (Groundswell 2022). A primary motivation for the NCJC to partner with the study team was to demonstrate the potential economic benefits for LMI households in North Carolina of replacing less efficient water heaters with HPWHs.

Recruitment

The original experiment design included a participant sample of sixty households. This number was ultimately not attainable. Program partner RTT installed the EcoPort-equipped HPWHs free-of-charge along with other home repair services and appliances – only 35 HPWHs were able to be installed before the study period began.

RTT maintains very good relationships with its clients and provided the study team with a warm introduction to each study candidate household. Using materials approved by the PNNL Institutional Review Board, the study team then reached out to explain the study, the participant requirements, and compensation (participants received $100 at the beginning and end of the study). If a candidate household responded positively, the study team either emailed or mailed an informed consent document and a copy of the first of two surveys they would be required to complete. This process was labor intensive, as many of the participants did not have or regularly use email and required phone calls - sometimes repeat calls as voicemail was often not an option. A study team member and a local technician then visited each home to retrieve the signed consent form, help the participant complete the initial survey, and install an EcoPort UCM. Although all the HPWHs had EcoPorts, not all HPWHs came from the factory with the EcoPorts enabled, requiring additional on-site work to connect the EcoPorts in some cases.

Leveraging the existing relationship with RTT, and a labor-intensive delivery model designed to remove any cost or installation responsibility from the participants, the study team was able to recruit 24 out of 35 potential participants. An evolution of the participant sample is shown in Figure 1. The candidate households were not “early adopters” as has often been the case in prior residential HPWH load shifting studies.

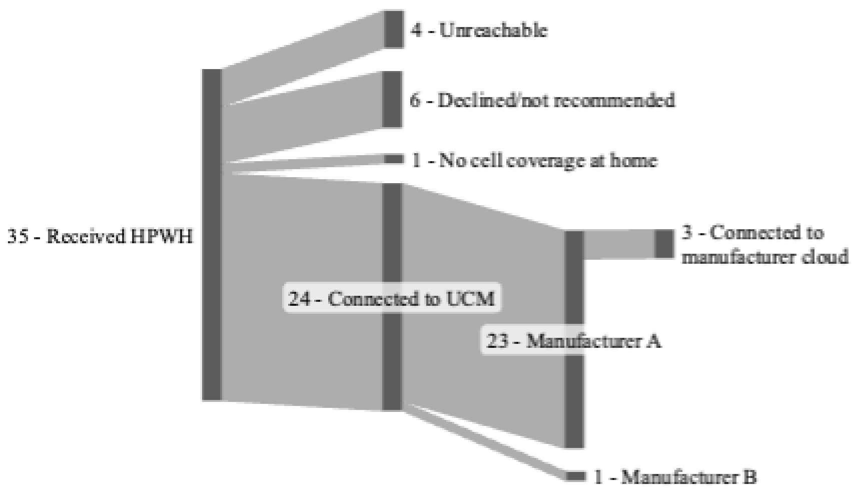

Figure 1. Evolution of the participant sample

The demographics of the study participants are shown in the following tables:

Table 1. Prior water heater fuel source

Fuel source	Units
Electricity	9
Natural Gas	12
Not Reported	3

Table 2. Customer electric utility

Utility	Households
Duke Energy Carolinas	7
Duke Energy Progress	8
Piedmont	1
Town of Apex	5
Not Reported	3

Table 3. Number of household occupants at the start of the study

Occupants	Households
1 person	13
2 people	7
3 people	2
5 people	1
6 people	1

Table 4. Types of occupants

Occupants include:	Households
Children (0-12 years old)	4
Teens (13-18 years old)	3
Adults (19-64 years old)	11
Seniors (65+ years old)	13

The predominant participants in this study include seniors that live in a household with at most 2 people. All participants reside in Chatham, Durham, Orange, or Wake counties in North Carolina. Participants own their homes and land, have resided there for at least two years, and state their intention to stay there for three years after receiving RTT services. RTT limits gross annual income for participants to a maximum of $58,000 per year for a household of two in Wake County and to lesser amounts for single-person households and households in other counties. The U.S. Census Bureau reports the median household income for Wake County in 2022 as $96,806 (Census Bureau 2022). About eighty percent of RTT clients have incomes below fifty percent of the area median income.

Despite North Carolina's high penetration of ERWH, about half the study households had gas storage water heaters prior to receiving an EcoPort-equipped HPWH. The majority of participants are Duke Energy customers, with a near even split of customers between the Duke Energy Progress and Duke Energy Carolinas service territories. The study included one 80-gallon water heater and twenty-three 50-gallon water heaters.

Energy Consumption Analysis

Pre-HPWH installation monitoring of participant water heating energy consumption was not within the scope of this project due to budget and logistical constraints. The study team was also not able to obtain historic electricity billing data from North Carolina utilities. Even if these data were available, RTT's home services are not limited to water heating; for example, they include home envelope improvements, HVAC, and other appliance retrofits. Due to the variety of retrofits participant households received and their broad impact on energy consumption, it is difficult to isolate the actual post-retrofit change in energy consumption solely due to the HPWH installation for participant households. Additionally, as mentioned above, participants had a mix of electric resistance and gas storage water heaters prior to receiving HPWHs, but for simplicity, this study did not assess the energy consumption or cost impact of switching from a gas storage water heater to a HPWH.

Pre-Retrofit Estimated Electricity Consumption

To estimate the energy savings from adopting HPWHs, the study team developed estimates of pre-retrofit water heating electricity consumption based on the U.S. Energy Information Administration's (EIA) 2020 Residential Energy Consumption Survey (RECS) regional and state-level results and the number of members in the study participants' households. Table 5 shows the estimated annual pre-retrofit energy consumption for participants before the HPWH installation, by number of occupants.

Table 5. Annual water heating electricity consumption by number of occupants in the South census division, adjusted for owner-occupied single-family homes[2]

Number of household members	Annual water heating energy consumption (kWh)
1	1,525
2	2,490
3	3,582
4	4,586
5	4,657
6 or more	5,945

Source: EIA 2020, Table CE4.9.

The study team also considered adjusting estimated water heating electricity consumption by income, but the RECS data indicated that annual average water heating electricity consumption did not vary significantly across the range of household incomes in the sample (EIA 2020, Table CE4.9).

Based on the RECS 2020 estimates and the actual occupancy of the study households, the estimated pre-retrofit total annual water heating electricity consumption for the 24 participant sample would have been approximately 46,460 kWh if all participants had previously had electric water heaters as represented in the RECS data. This estimate uses household occupancy as reported at the beginning of the study, but over the course of the study some participant households had new occupants move into the household, and these occupancy changes were not always reported to the study team. Therefore, this pre-retrofit energy use estimate may underrepresent the participant households' actual energy use based on occupancy.

Post-Retrofit Estimated Electricity Consumption

All HPWHs in the study were equipped with e-Radio cellular UCMs provided as an in-kind contribution from PNNL. All but one HPWH in the study also came equipped with manufacturer proprietary, Wi-Fi-based connectivity. The study team encouraged participants to use this feature and provided technical support but were only successful in connecting three HPWHs to Wi-Fi. Participants were either not interested, had reservations about connecting an appliance to their home networks, or did not have home Wi-Fi.

The HPWHs transmitted electricity consumption data to the UCM cloud in sub-5-minute intervals. Electricity consumption data reporting varies based on the equipment manufacturer. One HPWH manufacturer in the study estimates unit power consumption via installed telemetry, and this measured data is reported by the UCM. The other manufacturer monitors when HPWH components are switched on and off and uses static estimates for power drawn by the compressor and by the heating element(s), which are reported by the UCM. The study team used UCM-reported electricity consumption data for analysis, but in the latter case where pre-determined, static power estimates were reported via the UCM, an adjustment factor was applied to power draw values based on prior PNNL field studies that verified the power draw of this manufacturer's product.

The team was able to collect continuous electricity consumption data from all 24 HPWHs with relatively few data collection interruptions over the course of the study. Reported data were averaged by season, and annual, non-load shifting electricity consumption was estimated based on average consumption by season and season length.

[2] EIA's South census division includes Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

Aggregated total annual non-load shifting energy consumption for the 24 units was estimated to be approximately 24,450 kWh for an estimated 47% reduction in water heating electricity from the pre-retrofit estimate. The estimated average annual energy savings per household was approximately 920 kWh. Given the lack of measured pre-retrofit water heating energy consumption data, the variability of water use by household (including changes in household occupancy over the course of the study), and the small sample size, this estimate may not reflect the true savings seen by participants, but it gives a sense of the scale of energy savings experienced by study participants.

Other Factors Affecting Electricity Consumption

North Carolina is at the northern edge of the Southeast U.S., where water heaters are often installed in unconditioned spaces. Study participant HPWHs were installed in conditioned, semi-conditioned, and unconditioned spaces. HPWHs draw energy from the ambient air; therefore, their energy performance is more strongly affected by ambient air temperatures than ERWHs. HPWHs also require access to an adequate flow of ambient air as a heat source. If an HPWH is installed in a constrained space with inadequate airflow, normal operation will lower the temperature of the ambient air and decrease the HPWH's operating efficiency. Constrained spaces are commonly in conditioned spaces (like utility closets) but may be semi-conditioned or unconditioned. Due to the small size of the participant sample and lack of measured hot water consumption data we were not able to develop statistically significant estimates of the impacts of different ambient conditions on HPWH operation.

Load Shifting Design

In addition to energy savings, demand response-enabled HPWHs may also be able to reduce water heating energy costs for households that have access to time varying electricity rates (e.g., time-of use, or TOU rates) by shifting electricity consumption for water heating to times when electricity is cheaper. The study implemented a load shifting schedule for participant water heaters designed to take advantage of Duke Energy residential TOU rates that were newly introduced at the time of study design. The study team did not ask participants to enroll in a TOU rate since other loads in the home would not be shifted. Instead, the study analyzed water heating electricity consumption patterns during baseline (non-load shifting) and load-shifting periods to estimate the impact on electricity costs as if the customers were on a TOU rate.

Factors Considered in Experimental Design

UTILITY RATES

Duke Energy Progress (DEP) and Duke Energy Carolinas (DEC) TOU rates were used as a starting point for the experimental design with the goal to shift water heating electricity consumption to off-peak periods with cheaper electricity prices. The rates used were those available at the time of the study design in early 2023 and are no longer offered. Both DEP and DEC tariffs defined distinct peak, shoulder and off-peak periods for summer and winter. Figure 2 shows peak, shoulder, off-peak, and discount periods for DEP and DEC TOU rates used in the study's design by season, along with energy rates by time of use and demand charges. Other details, such as critical peak rates for certain rate schedules, fixed fees and eligibility criteria are omitted from the figure for simplicity. Electricity prices ranged from $0.27 per kWh on peak to $0.05 per kWh in discount periods, depending on the rate.

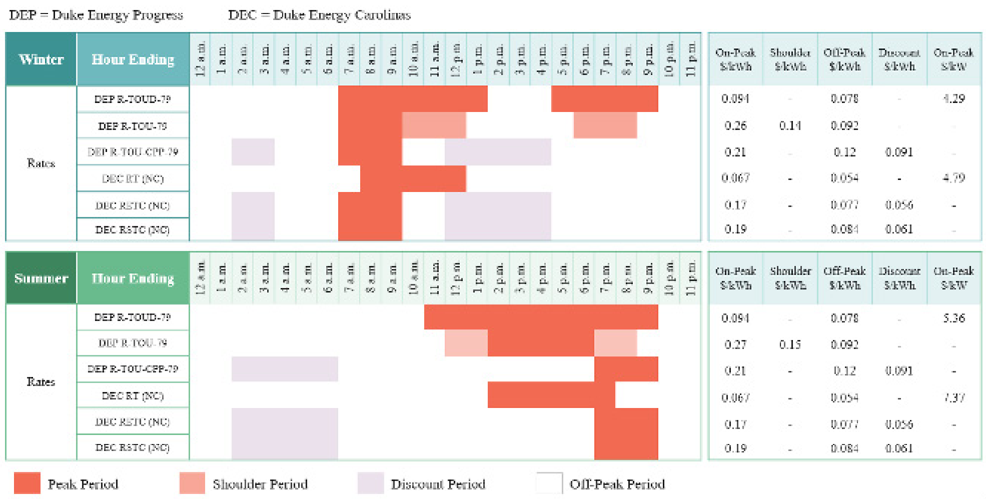

Figure 2. Duke Energy time-of-use rates (early 2023)

Although peak period timing differs across rates, at the time the study was designed the summer season peak period typically spanned 1 to 6 p.m. and/or 6 to 9 p.m. The winter season peak period included 6 to 9 a.m. for almost all rates examined, and one rate also included an evening peak period of 4 to 9 p.m. in the winter season. Based on the peak period schedule, the study scheduled daily load sheds for all participants between 1 and 9 p.m. in the summer season and between 6 a.m. and 12 p.m. and 4 p.m. and 9 p.m. in the winter season, which is a longer shifting time frame than most prior studies.

WEATHER AND SEASONS

In addition to the different on-peak, off-peak, and shoulder periods shown in Figure 2, DEP's former TOU rates defined a longer summer season (April to September) than did DEC's former TOU rates (May/June to September). To maximize the significance of the study results, the study team put all participants on a common load shifting schedule with a summer season of May to September and a winter season of October to April. This schedule captures much of the overlap between the DEC and DEP rate summer seasons and keeps April as a winter load shifting month because historic April temperatures in the region are more typical of cool season water heating operational patterns. Each month is assigned a season based on the utility TOU rates noted above – the summer load shifting schedule aims to shift load out of afternoon and evening peak windows, while the winter schedule shifts load out of the morning and evening peak windows. Additionally, summer and winter shifting were further segmented into hot and shoulder months (for summer) and cold and shoulder months (for winter). The load shifting plan draws on findings from prior PNNL HPWH load shifting studies that informed water heating pre-heating and load reduction period lengths, strategies for different weather conditions, and water heater demand management commands to optimize load shifting (Butzbaugh et al. 2022).

EXPERIMENTAL DESIGN

The above factors were synthesized to create the load shifting schedules used for this study. To establish a baseline (non-load shifting) load profile, the participants' HPWHs were allowed to run independently without demand management requests for approximately one week each month. Outside of these baseline data collection periods, the HPWHs were controlled to shape the participant's water heating load profile using the following requests: "Load Up" - increase energy use by heating water up to the user setpoint; "Shed" - avoid heating water unless there is a risk that the user will receive cold water, e.g., by reducing the water heater setpoint temperature; and "Critical Peak" - reduce demand more aggressively than shed, e.g., by reducing the water heater setpoint to a lower temperature than the Shed command. The CTA-2045 protocol describes how complying devices exchange information, but it does not specify what those devices do in response to demand management requests; exact response algorithms are proprietary and vary by HPWH brand. Other CTA-2045 requests were deemed unsuitable for the study and not used; for example, the "Advanced Load Up" command, which can result in water heating above the user setpoint for additional energy storage was not used because the participant households did not have water heater mixing valves to prevent scalding from over-heated water.

The study team compared HPWH electricity use during load shifting periods to usage during non-load shifting periods to document the energy shifted and potential cost savings to participants. Figure 3 summarizes the study's load shifting schedules, designed to minimize participant water heating costs based on Duke Energy TOU rates.

Figure 3 Study load shifting schedule

Due to the small participant sample size, to collect the greatest amount of comparable data all participants were kept on the same load shifting schedule regardless of household occupancy or water heater installation location.

The coldest months of the year in the study region are during the Winter-Cold load shifting schedule when the daily average temperature is in the mid-40's °F. Compared to the Winter-Shoulder schedule, Winter-Cold has a longer afternoon load up period to provide adequate time for the HPWH to recover and heat water given the low ambient temperatures. This schedule also employs "Shed" commands for load reduction, which do not allow tank temperatures to drift as low as "Critical Peak" commands do, to account for longer recovery times due to the low ambient temperatures.

The Winter-Shoulder schedule includes utility TOU winter months with warmer ambient temperatures compared to the Winter-Cold months. This allows the use of the more aggressive "Critical Peak" command in the morning shed to further decrease energy use, with a slightly shorter afternoon load up period than for the Winter-Cold schedule.

The Summer-Shoulder schedule includes utility TOU summer months with milder temperatures. This schedule features a longer load up period in the morning to account for milder temperatures than are expected during the Summer-Hot period. There is a long load shed window in the afternoon to minimize energy consumption – the

“Critical Peak” command is employed for the first five hours, followed by a “Shed” command in the evening. Some evening recovery may occur during the later Shed window if needed, but full recovery should not occur until the conclusion of the TOU peak window.

Finally, the Summer-Hot schedule includes utility TOU summer months with the hottest temperatures. This schedule matches the Summer-Shoulder schedule with the exception of a shorter morning load up period due to hot ambient temperatures.

Load Shifting Results

Study data collection will continue through late summer 2024, but results through June 2024 are described below. Figure 4 shows load shifting time windows as well as baseline (non-load shifting) and load shifting average daily demand profiles for all study schedules.

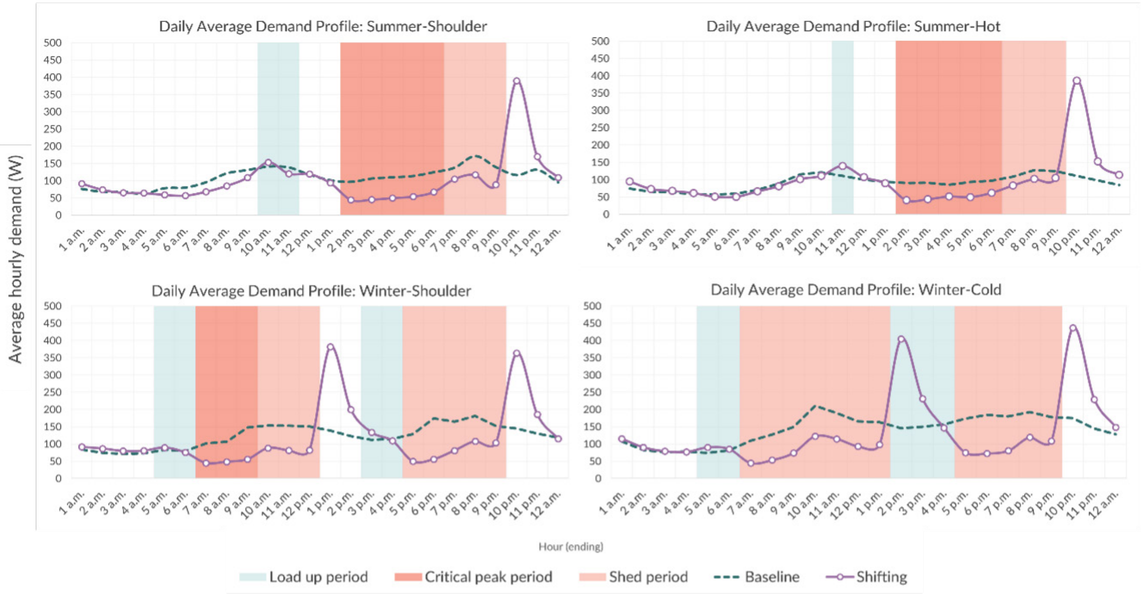

Figure 4. Baseline and load shifting average daily demand profiles for all study schedules

The demand profiles show that the participant water heaters responded to water heating demand management signals as expected, with minor load increases compared to the baseline, non-load shifting periods for load up periods, and load reductions compared to the baseline for critical peak and shed periods. Water heater load tended to recover at the end of the shed period, but average recovery load was in the range of the heat pump compressor power, rather than being dominated by electric resistance element operation. Due to the prevalence of low-occupancy households in the study, water heater energy usage for this population is generally low. Participant water heaters reliably shifted load out of peak periods while still providing participants with sufficient hot water to meet their daily needs.

Winter Morning Peak

In addition to daily load shifting, the study conducted a test peak demand response event, scheduled to coincide with North Carolina's annual winter morning electricity demand peak. The purpose of this event was to demonstrate how HPWH demand response can provide utility and regional grid benefits in addition to customer cost savings. Historical data show that peak demand in the region has typically occurred around 7:00 a.m. on a very cold winter weekday (Duke Energy 2020). Therefore, the test demand response event was conducted from 6:00 to 9:00 a.m. on January 17, 2024, a cold day with an event period temperature of approximately 20 °F. Figure 5 shows the results of this event.

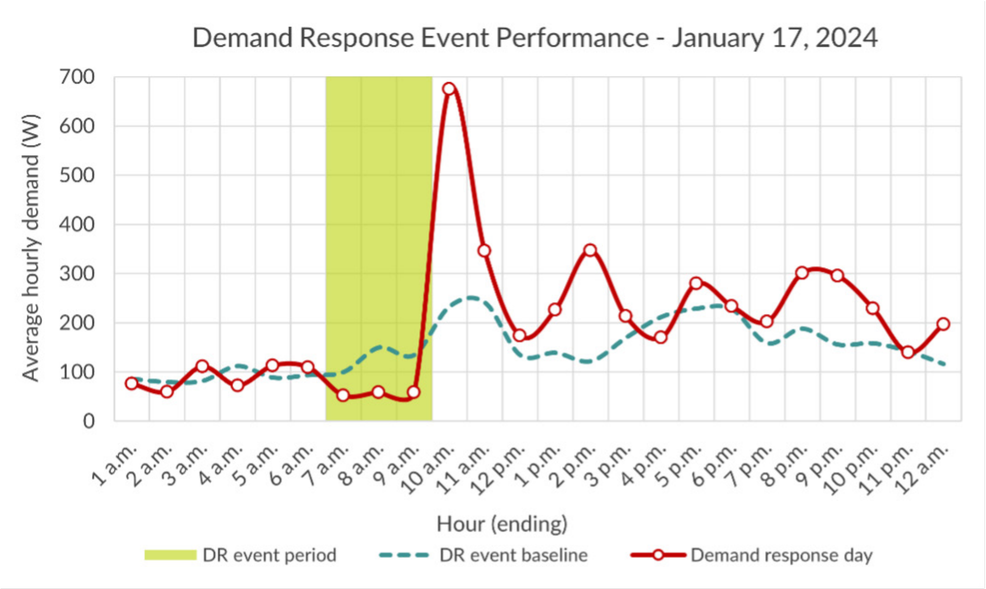

Figure 5. Results of peak day demand response event

The demand response event used a two-hour load up period followed by a three-hour critical peak period to demonstrate the ability of the HPWH to aggressively reduce load during the coldest conditions that often drive regional peak demand. This differs from the less aggressive "Shed" request used during daily load shifting in the Winter-Cold period. The HPWHs successfully minimized operation during this period, largely avoiding the use of heat pump compressors or electric resistance elements for the duration of the event. Compared to a DR event baseline of four similarly cold, non-load shifting days the same week, the participant HPWHs reduced demand by an average of 72 W per participant for the duration of the event. This suggests both that in the mornings during the DR event baseline period many HPWHs in the participant sample did not need to operate much to maintain setpoint temperature and that HPWH controls can be leveraged to effectively minimize electricity demand on command. The result of the annual peak test also suggests that, at least for residential customers like the study participants, implementing the Critical Peak load reduction request during the Winter-Cold period may not cause hot water run outs.

Energy and Customer Cost Impacts

The Duke Energy TOU rates described above include peak period windows of at least five hours. The experiment design therefore included load shifting windows of six to eight hours, which is longer than the load shifting windows used in prior studies. In October 2023, Duke Energy issued new TOU rates that differ from the rates used in this study. The new rates include different winter and summer season months, peak periods limited to 3 hours (6 to 9 a.m. in winter and 6 to 9 p.m. in summer), and new discount periods that offer lower rates overnight and on winter afternoons.[3] Therefore, under the new rates, controlled HPWHs should be able to more easily avoid peak periods and shift electricity consumption to discount periods to reduce household water heating costs.

Table 10 shows load shifting results in terms of energy saved and shifted.

Table 10. Load shifting results by schedule

Shifting schedule	Shed periods	Average daily energy savings (kWh, % of non-shifting baseline)		Average morning load shifted (kWh, % of non-shifting baseline)		Average evening load shifted (kWh, % of non-shifting baseline)	
Summer – Hot	Evening: 1-9 p.m.	0.10	4%			0.12	30%
Winter – Shoulder	Morning: 6 a.m.-12 p.m. Evening: 4-9 p.m.	0.11	4%	0.19	43%	0.35	50%
Winter – Cold	Morning: 6 a.m.-1 p.m. Evening: 4-9 p.m.	0.20	6%	0.38	35%	0.28	33%
Summer – Shoulder	Evening: 1-9 p.m.	0.34	12%			0.11	25%

Participants in the study were able to shift 35-43% of their baseline water heater electricity use in the morning period and 25-50% of water heating electricity use in the evening period. The effect of load shifting on overall electricity consumption was minor; daily electricity savings averaged 4-12% depending on season.

Household occupancy affected load shifting results. High occupancy households were able to shift more energy compared to lower occupancy households since they had higher baseline energy usage from which to shift load. Both low and high occupancy households were able to shift a similar percentage of their baseline, non-load shifting energy use. Table 11 shows results by occupancy.

Table 11. Load shifting results by schedule and occupancy

Shifting schedule	Occupants	Count in sample	Average daily energy savings (kWh, % of non-shifting baseline)		Average morning load shifted (kWh, % of non-shifting baseline)		Average evening load shifted (kWh, % of non-shifting baseline)	
Summer – Hot	1	14	0.09	3.8%			0.14	35%
Winter – Shoulder			0.02	0.8%	0.19	47%	0.25	47%
Winter – Cold			0.03	1.1%	0.38	41%	0.32	48%
Summer – Shoulder			0.24	9.2%			0.07	18%

[3] See Duke Energy Progress Time-of-Use webpage for more details: https://www.duke-energy.com/home/billing/time-of-use.

Shifting schedule	Occupants	Count in sample	Average daily energy savings (kWh, % of non-shifting baseline)		Average morning load shifted (kWh, % of non-shifting baseline)		Average evening load shifted (kWh, % of non-shifting baseline)	
Summer – Hot	2	6	0.03	1.5%			0.11	38%
Winter – Shoulder			-0.16	-6.5%	0.09	20%	0.20	41%
Winter – Cold			0.09	2.7%	0.53	43%	0.30	45%
Summer – Shoulder			0.19	7.7%			0.10	34%
Summer – Hot	>= 3	4	0.26	9.7%			0.06	11%
Winter – Shoulder			0.86	19.7%	0.35	62%	0.92	57%
Winter – Cold			0.98	18.6%	0.90	59%	0.95	51%
Summer – Shoulder			0.93	23.6%			0.28	30%

Based on energy consumption during non-load shifting days when the water heaters did not receive demand management signals, participant average annual non-load shifting HPWH energy consumption was estimated to be around 1,020 kWh. Participant water heating cost was estimated for both the non-load shifting case and the load shifting case, assuming that load shifting periods align with peak periods and using average costs of $0.26 per kWh on peak and $0.09 per kWh off peak (based on the former DEP R-TOU-79 rate, the simplest TOU rate reviewed). Using these on-peak and off-peak rates and extrapolating study results over the course of a year, the annual per participant water heating electricity cost would have been approximately $180 on the TOU rate without load shifting and $136 with load shifting, therefore, a participant on a TOU rate could save about $44 per year on water heating electricity costs by load shifting.

As noted, study participants were not actually moved to Duke Energy's former TOU rates and remained on the electricity tariffs they had selected before the study began. In terms of actual study participant impact, load shifting resulted in a minor overall reduction in electricity usage that would translate to an average cost decrease of about $7.50 annually per participant using Duke's non-TOU residential average rate of $0.12 per kWh.

Although load shifting while on TOU rates may reduce water heating electricity costs for controlled HPWHs, because TOU rates apply to all electricity usage on a meter they may increase the electricity costs of other home electric appliances like space heating and air conditioning if those loads cannot also be shifted off peak. Unlike HPWH, although electric space heating and cooling may be equipped with demand response technology, they do not usually have thermal storage. If the amount of electricity consumption that cannot be shifted is significant, moving to a TOU rate could increase customer bills overall.

Effect on Water Heater Operation

Because this study did not install participant water heaters, the study team did not control participants' water heating operation mode (e.g., heat pump, hybrid, or electric resistance mode) at the time of installation, nor did we ask participants to change the operation mode except in instances of troubleshooting. All participants generally operated their water heaters in a hybrid mode that prioritized the use of the heat pump compressor but allowed electric resistance elements to operate when needed to meet hot water demand. We reviewed the effect of the load shifting schedule on water heater component operation both during and immediately after load shifting windows, where electric resistance element operation is assumed at times when water heater power draw exceeds 500 W. Table 12 shows the average percentage of shift window hours with electric resistance element (ER) usage with and without load shifting, as well as the average shift window demand with and without load shifting. Although the incidence of on-peak ER element usage was low before load shifting, load shifting reduced the incidence of on-peak ER usage by 30-60% depending on the season, and it also reduced peak demand.

Table 12. Percentage of shift window hours with ER usage, for baseline (non-load shifting) and load-shifting cases, by season

Season	Daily shift hours	% of shift window hours with ER use, non-load shifting	% of shift window hours with ER use, load shifting	Avg. shift window (on-peak) demand (W), non-load shifting	Avg. shift window (on-peak) demand (W), load shifting	Avg. shift window (on-peak) demand reduction from shifting (W)
Summer - Hot	8	2.4%	1.7%	102.3	66.8	35.5
Summer - Shoulder	8	4.3%	1.7%	124.8	77.4	53.4
Winter - Cold	12	5.3%	2.1%	168.7	88.1	80.5
Winter - Shoulder	11	4.0%	1.6%	146.9	72.6	74.2

The water heater demand tended to recover in the one hour after the end of the shift window, as seen in Figure 4. This effect is quantified in Table 13, which shows an average demand increase of about 230-280 W in the hour immediately after load shifting, as well as a 2-3x increase in the incidence of ER element usage in that hour, compared to non-load shifting days. Even so, on average the post-shift demand is within the range of the heat pump compressor power.

Table 13. Percentage of 1-hour post-shift window hours with ER usage, for baseline (non-load shifting) and load-shifting cases, by season

Season	% of post-shift window hours with ER use, non-load shifting	% of post-shift window hours with ER use, load shifting	Avg. post-shift window demand (W), non-load shifting	Avg. post-shift window demand (W), load shifting	Avg. post-shift window demand increase from shifting (W)
Summer - Hot	3.4%	11.1%	110.5	385.8	275.3
Summer - Shoulder	4.1%	14.0%	116.1	389.9	273.8
Winter - Cold	4.3%	11.7%	160.2	420.7	260.4
Winter - Shoulder	4.3%	11.7%	142.0	372.8	230.9

Finally, we reviewed the per household effect of load shifting on water heater component usage, demonstrated in Table 14. As expected, before load shifting larger occupancy households (e.g., #13 and #31) relied on ER usage more frequently than smaller households due to higher hot water usage. For these households, load shifting reduced but did not eliminate on-peak usage of ER elements. Another household that experienced this effect was #29. This participant had a 50-gallon water heater sized for one occupant and reported one occupant at the beginning of the study, but at least 5 additional guests and occupants moved into the home over the course of the study, stretching the water heater to its capacity limits.

Table 14. Percentage of shift window hours with ER usage, for baseline (non-load shifting) and load-shifting cases, by season and participant

		Summer - Hot		Summer - Shoulder		Winter - Cold		Winter - Shoulder	
Alias #	No. occupants at start of study	% of shift window hours with ER use, non-load shifting	% of shift window hours with ER use, load shifting	% of shift window hours with ER use, non-load shifting	% of shift window hours with ER use, load shifting	% of shift window hours with ER use, non-load shifting	% of shift window hours with ER use, load shifting	% of shift window hours with ER use, non-load shifting	% of shift window hours with ER use, load shifting
10	2	0.2%		0.5%	0.3%	3.2%	4.9%	1.7%	5.4%
11	1								
12	1								
13	6	31.3%	25.4%	45.0%	24.7%	31.3%	12.0%	31.5%	14.0%
14	2								0.1%
15	1					18.7%	11.9%	1.0%	3.0%
16	1	2.5%		1.0%		0.4%	0.2%	0.7%	
17	1	0.9%		1.6%	0.6%	4.4%	0.3%		
18	1	0.6%					0.6%		0.1%
19	2	0.7%	0.4%		0.6%	2.4%	3.2%	3.1%	2.9%
20	2	1.6%			0.3%	4.0%	0.8%	2.1%	0.2%
21	2				0.3%	0.4%	0.2%		0.2%
22	1								
23	1					0.4%	1.1%		0.2%
24	3	2.0%						1.0%	
25	2					4.4%	1.5%		
26	1	0.2%				0.4%			
27	1								
28	1				0.6%	0.4%	0.6%	0.3%	0.3%
29	1	21.9%	10.6%		13.8%	7.9%	0.4%	12.0%	5.1%
30	3					0.8%	0.6%		
31	5	7.8%	4.9%	29.5%	5.5%	38.5%	12.5%	29.4%	6.0%
32	1		0.9%	9.8%	2.7%			2.4%	2.1%
34	1		0.4%	10.7%		10.3%	0.3%	12.9%	0.1%

Other Participant Observations

As noted above, this study was unusual in that participants were all eligible to receive services for LMI households delivered by RTT. In addition to modest incomes most participant households consisted of one or two senior adults only. Participants were not "early adopters" and came to the study looking for affordable and dependable water heating, rather than the latest in energy efficient water heating technology. The study team received a few instances of negative participant feedback, including occasional comments about cold air, noise, and long water heating recovery times as participants became used to their new HPWH. However, the only enduring complaints were related to HPWH that malfunctioned in some way requiring replacement, unrelated to the study, or that were likely undersized due to changes in occupancy. There were no reports of lack of hot water due to load shifting. The participant surveys indicated that almost all participant households never or rarely ran out of hot water, ran out of hot water less frequently than with their prior non-HPWH water heater, that their water temperature was "just right" and that they would recommend a HPWH to family and friends.

For households that experienced issues, HPWH user experience may have been improved by increasing the size of the HPWH to better match household hot water consumption. Installers should also be aware that not every location in a home that can accommodate an electric resistance water heater is also appropriate for a HPWH, especially in tight homes or small spaces. Household occupancy fluctuated somewhat over the course of the study due to participant health challenges and new occupants moving in. In some cases, water heaters were undersized for this additional load, so we recommend upsizing units where feasible to ensure hot water availability for homes where occupancy fluctuates or for multi-generational homes with many occupants. We further recommend better educating customers to set expectations about both the energy saving benefits and limitations of HPWH technology (like slower recovery times).

We found that many of the participants in the study either did not have access to the internet or were not comfortable using the internet as a means of communication with the project. We recommend that all water heating demand response programs include non-internet-based enrollment and support options to make them more inclusive and accessible to more households. Furthermore, programs should not require home Wi-Fi or participant app connections, although these can be leveraged for households that have access to these features. Our experience was that demand response via cellular EcoPort modules was a reliable way to connect to HPWHs.

Finally, over the course of the study a couple HPWHs had issues that required troubleshooting, repair, or replacement. While HPWH warranties typically cover parts for ten years, we found that they cover labor costs for much shorter periods, typically one year if at all. Even if the manufacturer agrees to replace a HPWH unit, customers may find themselves responsible for unaffordable labor costs. Support for both equipment and labor costs for warranty claims and re-installations is especially important for low-income households. We recommend that programs work with HPWH manufacturers and installers to provide additional support for labor costs in HPWH warranty claims for the first several years of product life.

Conclusions and Recommendations

This study demonstrated that EcoPort-equipped controlled HPWHs can reduce water heating electricity costs for low-income households in the Southeast. Under TOU rates available when the study was designed, most of the utility customer savings come from reduced energy consumption thanks to the efficient HPWH technology, rather than from leveraging water heater controls to be able to take advantage of less expensive electricity.

This study also demonstrated that demand responsive HPWH can reduce load during grid peak periods without customer intervention and without causing cold water incidents. Seniors in low occupancy homes with low hot water usage may have greater flexibility to shift water heating times compared to other users. So, even though they offer a smaller magnitude of load reduction, they may offer greater reliability of load shed, making them a good target for inclusion in demand response programs.

The TOU rates considered in this study were difficult to take advantage of due to their long peak periods. TOU rates that are favorable to load shifting, with targeted peak periods and low off-peak costs, would incentivize better load shifting performance.

Finally, including LMI and hard-to-reach households, like the senior participants in this study, in HPWH load shifting programs is possible and can be successful when the programs are designed to respond to their needs and interests.

Appendix A. Advisory Group Membership

The Advisory Group includes the following individuals: SEEA - Maggie Kelley Riggins, Ashley McBride, Sydney Roberts; Rebuilding Together for the Triangle - Dan Sargent; NEEA - Geoff Wickes; NCJC - Claire Williamson; Advanced Energy - Jonathon Coulter; Clean Energy Fund - Jen Weiss, Michelle Myers; New Buildings Institute - Joe Wachunas; PNNL - Josh Butzbaugh, Sam Rosenberg, Fatih Evren; IBACOS - Ari Rapport; NORESCO - Ben Edwards; Sally Robertson (Freelance); and Energy Solutions - Chris Granda, Daniela Urigwe, Helen Davis, George Chapman.

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Additional Reports generated as part of this Study:

Summary of Participant Surveys

What is the Benefit of Time-of-Use Rates for Residential Customers?

Summary of Participant Surveys

North Carolina Heat Pump Water Heater Participant Demand Response Survey Results

September 11, 2024

INTRODUCTION

This project investigated the benefits of load shifting Heat Pump Water Heaters (HPWHs) for 24 low-income households in North Carolina. The goal of the project was to demonstrate that load shifting is feasible, and to support increased deployment of HPWHs to low-income households within the Southeast U.S. The Southeast has advantages for HPWH deployment because of the high share of electric resistance (instead of gas-fired) water heaters, allowing for an easier transition to HPWHs and because of higher ambient temperatures that are beneficial for HP operation.

The project collected and analyzed short-interval electricity consumption data from 24 240-volt hybrid HPWHs equipped with EcoPort universal communication modules (UCMs) from the summer of 2023 through the summer of 2024. These EcoPort-equipped HPWHs were installed by Rebuilding Together of the Triangle (RTT), the local affiliate of Rebuilding Together, a national non-profit providing home repair and renovation services free of charge to those in need. Study participants received the HPWHs over the preceding two years as part of RTT-provided retrofits, and the EcoPort UCMs were installed in subsequent site visits in mid-2023.

For approximately one week each month during the study year, the project team allowed the HPWHs to operate without intervention to establish baseline, non-load shifting daily patterns of water heater electricity consumption. The rest of the time, the team sent demand response signals to the water heaters, shifting electricity consumption from peak periods to off-peak periods during the day.

Surveys were distributed to the 24 participants at the beginning, middle, and end of the study – in May 2023, February 2024, and July 2024. The surveys and results are attached to this memo. Please note that as of this writing, participant #25 did not complete the first survey and participants #29 and #24 did not complete the final survey.

SUMMARY

Surveys were distributed to assess household and occupancy characteristics, the location of the water heater, and the satisfaction of the users with their HPWH.

Participants were asked about the number and age of home residents to determine the expected usage patterns for each home and to anticipate if we would expect to encounter issues shifting the water heating load. For example, if several people living in the home all work or go to school, there may be a hot water usage peak in the morning or evening. Questions related to the number of occupants were included in all three surveys to determine if there was a change in occupancy that could impact hot water usage and to be able to account for occupancy changes in the data analysis and reporting. With a larger sample, cross-tabulating occupancy changes with changes in satisfaction with the HPWH, or frequency of cold water events, could tell us whether increased occupancy is correlated with these issues.

The electric utility provider was asked on the second survey to confirm utility information shared by RTT and to determine if a time of use rate was available. Features of the homes such as number of appliances, bedrooms and bathrooms were collected so that we would be able to determine if the water heaters were sized appropriately if issues arose. The full results related to the occupancy and home characteristics are summarized in the attached tables.

Several questions were asked on the first and second surveys regarding the location of the water heater and if it is within the conditioned portion of the home, a semi-conditioned location such as a basement or garage, or an unconditioned space such as an exterior shed.

The third survey was shorter and simply asked a few final questions to fill in gaps and provide an opportunity to the participants to give comments on the project. It was notable that only one participant indicted that they attempted to change the settings on their HPWH. In conversations with participants throughout the study, it was indicated by more than one participant that they changed the setpoint temperature, so it is likely the participants interpreted this question to mean changes to the mode. We also asked whether they noticed changes in their electric bills, how quickly their hot water arrived, any changes in occupancy during the project, and the number of times that they experienced their hot water running out.

PARTICIPANT ISSUES

Two participants experienced operational issues with their HPWHs during the study as described below.

Participant #29 was already experiencing issues with their HPWH prior to the study and had been in touch with both the manufacturer and RTT to address the problem. In the Fall of 2023, #29 experienced a failure of the HPWH, including the failure of a thermistor sensor, a compressor malfunction, and a condensate line issue, and the unit was replaced.

Around January 2024 the occupancy of the home increased from 1 to 6 people, and the new, 50-gallon HPWH was not large enough to meet the needs of the household. Participant #29 continued to correspond with the manufacturer and ultimately ended up keeping the HPWH but operated it only in electric resistance mode. This conclusion came after multiple visits from technicians sent by the manufacturer who provided apparently incorrect information to the participant. This included saying that the HPWH should not be installed in a crawl space and would not work in its current location. Participant #29 tried placing the unit in a high demand mode, but still reported running out of hot water. Based on the data collected, the household regularly fully drained the hot water storage tank, which would result in cold water delivery from any type of water heater. It is unclear why or if the heat pump could truly meet load or not in that location. This participant was not happy with the performance of the unit, and unfortunately, we were unable to find an amenable solution.

During review of continuous electricity consumption data from participant #13, the research team noted that beginning in late November the water heater was only operating in electric resistance mode. The participant did not notice a loss of hot water but said that the water seemed to be hotter. The participant also noticed a $40 to $50 increase in their bill, which would be expected if the heat pump was not operating. Please note that participant #13 only noticed a change in the performance of their HPWH after the research team contacted them because of their unexpected usage data. The participant called the manufacturer who was willing to provide either a replacement HPWH or a replacement control board.

Like all participants, #13 had received the HPWH free of charge and was now quoted a labor charge of nearly $1,000 to install a replacement, but they could not afford that cost. As the research team worked with participant #13, RTT, and other parties to find a solution, the original HPWH, which was still in place, began using its heat pump again and operating as expected. The research team monitored the participant #13's HPWH for the remainder of the project (another six months) and, not observing anything out of the ordinary, left the HPWH in place. The manufacturer has a record of the unusual operation.

CONCLUSIONS

The small number of participants limited the statistical analyses we were able to perform on survey data. Furthermore, there were additional variables making the results even less uniform, such as the differences in the homes studied, installation dates of the water heaters, and water heating fuel used previously. The results of the surveys are included in the attached tables sorted by subject with open field responses in a separate table.

However, the project successfully implemented load shifting as detailed in the final report without the participants noticing a change in available hot water. Participants were able to save money by switching to a more efficient HPWH that continued to provide the same utility as their previous water heater but with a lower operating cost.

The warm introduction from RTT and gift cards seem to motivate participants to join the study. Reaching this population was challenging as participants generally did not use email regularly – so many phone calls were needed. On the final survey all participants indicated that they did not change the settings on the water heater, with some specifying the settings were too complicated. Within the survey we received several questions that the team responded to, and we assisted the participants with proper maintenance of the HPWH.

Many of the questions within the survey may have brought the participants attention to potential issues that they otherwise would not have noticed. As an example, most people said they noticed the cold air and noise from the water heater (16 and 14 of 24 respectively). It is possible if the questions were not asked and participants were simply asked to state any issues they experienced, cold air and noise would not have been mentioned by as many participants. For future studies, we would consider asking less specific questions and developing simpler surveys.

Correlation was not noted between dissatisfied participants and those whose water heaters appeared to be in a space with less airflow. Also, participants did not appear to notice a difference in hot water delivery or costs during the winter months when HPWHs located in colder areas used electric resistance mode. There were participants who noted their electric bills increased when they received the HPWH and when the study began; however, it is unlikely those increases were due to the study, since data analysis showed a slight decrease in HPWH electricity use due to load shifting. Participants that switched from a gas to an electric water heater were expected to see an increase in their electric bill due to that change.

With a few exceptions, participants generally liked the HPWH. All the participants who responded indicated that the temperature of the hot water was just right on the first survey and only one participant changed the response to indicate the water was not hot enough on the second survey. 18 of 24 participants said they would recommend a heat pump water heater like your current water heater to friends and family and that they run out of hot water less frequently than with their previous water heater.

Attachments:

Copies of the surveys sent

Results tables

North Caroline Heat Pump Water Heater Study
Study Questionnaire #1

Address: ____

Where is your water heater located?
Inside your house (check one)
_____ Basement
_____ Closet
_____ Other (where?) __________

Outside your house (check one)
_____ Garage
_____ Outdoor closet or shed
_____ Crawlspace under your house
_____ Other (where?)________________

If your water heater is inside your house, is it in a heated area (circle one)? Yes No

Do you share your water heater with another home (circle one)? Yes No

Please tell us how you feel about your new water heater on a scale of 1 – 5, where 5 is "I really like it" and 1 is "I really don't like it" (circle one)? 1 2 3 4 5

Is your hot water temperature (circle one): Not hot enough Just right Too hot

Do you ever run out of hot water (circle one)? Yes No

If "Yes", do you run out of hot water (check one)
_____ Every day
_____ A couple times each week
_____ Infrequently, maybe once a month
_____ It's only happened once or twice

Compared to your old water heater, have you noticed a difference

In the temperature of your hot water? My water now hotter the same cooler

In the amount of hot water available? The amount of hot water is the same less more

Compared to your old water heater, Please tell us how you feel about your new water heater on a scale of 1 – 5, where 1 is "I liked my old water heart much better" and 5 is "I like my new water heater much better" (circle one)

1 2 3 4 5

Is there anything about your new water heater that we should know to help improve the products in the future?

Is there anything unusual about your household's hot water usage?

What type of house do you live in?
_____ Single-family detached
_____ Single-family attached (condo, duplex)
_____ Apartment in a multi-family building

How many bedrooms are in your home? ________________

How many people live in the home by age group (for at least 4 days per week)?
_____ Children (0-12)
_____ Teenagers (13-18)
_____ Adults (19-64)
_____ Seniors (65+)

How many people work or attend school outside the home?
_____ Children (0-12)
_____ Teenagers (13-18)
_____ Adults (19-64)
_____ Seniors (65+)

How many of the following hot water fixtures and appliances do you have (check all the apply)?
_____ Shower(s)
_____ Bathtubs(s)
_____ Clothes washer(s)
_____ Dishwasher(s)
_____ Other (what is it?) _____

Do you have any questions about your new water heater, or about this study? Please ask the technician, or write your question here, call ((919) 326-6897, or email NCWaterHeater@energysolution.com and we will get back to you as soon as possible.

Thank You!

North Carolina Water Heater Survey

Thank you for participating in the North Carolina Water Heater Study! Please answer the enclosed questions to the best of your ability. If you complete and return both this survey and the final survey we will send you this summer, we will send you a $100 payment!

If you have any questions about this survey or do not feel comfortable answering any of the questions, please contact us anytime at NCWaterHeater@energy-solution.com or (919) 326-6897. If we have your email on file, you should have also received this survey through your email. You only need to complete the survey once—either mail back the enclosed paper version or submit the online survey through the email link.

We use your contact information to match your survey with our record and will keep all your information confidential.

Hints for keeping your heat pump water heater working well and saving you money!

Your water heater pulls heat from the air and needs good air flow to function properly. Please don't put anything on top of your water heater to avoid blocking the air intake and make sure that the exhaust vents on the side of the top of the tank are not blocked.

Clean the air filter on the top of the air intake every 3-6 months.

Energy Solutions

Questions? *call* (919) 326-6897 *or email* NCWaterHeater@energy-solution.com

1. Name: ____________________

2. Address: ____________________

3. Email (*optional*): ____________________

4. How many bedrooms are in your home? ________

5. How many showers or bathtubs are in your home? ________

6. How many people live in your home? ________

7. Where is your water heater located? *Please check one:*

   ☐ Inside in a heated area
   Examples: a heated basement, a cooled attic, an indoor utility room, an indoor closet

   ☐ Outside the heated area of your home
   Examples: an outdoor, detached shed or enclosure or a detached garage with no heat or air conditioning

   ☐ In-between – not as cold as outside, not as warm as inside
   Examples: an unheated basement, a crawl space, an attached garage, a shed or closet that is part of your home but can only be accessed by an outside door

8. How do you heat your home? *Please check all that apply:*

   ☐ Natural gas
   ☐ Electricity
   ☐ Fuel oil
   ☐ Propane
   ☐ Not sure
   ☐ Other: ____________________

9. How do you stay cool in the summer? *Please check all that apply:*

   ☐ Central air conditioner
   ☐ Window air conditioner
   ☐ Fans
   ☐ I do not use cooling
   ☐ Other: ____________________

10. Who is your electric utility provider? *Please check one:*

   ☐ Duke Energy Progress
   ☐ Duke Energy Carolinas
   ☐ Duke, but not sure which one
   ☐ Piedmont
   ☐ Town of Apex
   ☐ Other: ____________________

11. Since getting your new water heater, how frequently do you run out of hot water?

   ☐ Never
   ☐ A couple times a year
   ☐ About once a month
   ☐ About once a week
   ☐ Every day
   ☐ Other: ____________________

OVER

12. Do you run out of hot water more or less frequently with your new water heater than your old one?
    - ☐ More frequently
    - ☐ Less frequently

13. Have you noticed increased cold air near your new water heater?
    - ☐ Yes
    - ☐ No

14. If you answered "Yes" to question #13, please choose the statement that best describes your feelings:
    - ☐ I like the cold air.
    - ☐ The cold air doesn't bother me.
    - ☐ I don't like the cold air, but it's not a big problem.
    - ☐ I wish my water heater didn't make cold air.

15. Have you noticed any noise coming from your new water heater?
    - ☐ Yes
    - ☐ No

16. If you answered "Yes" to question #15, please choose the statement that best describes your feelings:
    - ☐ The noise doesn't bother me.
    - ☐ I don't like the noise, but it's not a big problem.
    - ☐ I wish my water heater didn't make noise.

17. How is the temperature of your hot water?
    - ☐ Too hot
    - ☐ Not hot enough
    - ☐ Just right
    - ☐ Not sure

18. Would you recommend a heat pump water heater like your current water heater to friends and family?
    - ☐ Yes
    - ☐ No

19. Is there anything else about your heat pump water heater that you would like us to know?

THANK YOU!

North Carolina Heat Pump Water Heater Project

Final Questionnaire

We appreciate your continued participation in the North Carolina Heat Pump Water Heater Project. We appreciate your continued participation in the North Carolina Heat Pump Water Heater Project. Please answer the enclosed questions to the best of your ability. If you complete and have completed previous surveys, once we have received the communications module, we will mail you a final $100 payment

If you have any questions about this survey or do not feel comfortable answering any of the questions, please contact us anytime at NCWaterHeater@energy-solution.com or (919) 326-6897. If we have your email on file, you should have also received this survey through your email. You only need to complete the survey once—either mail back the enclosed paper version or submit the online survey through the email link.

We use your contact information to match your survey with our records and will keep all your information confidential.

Energy Solutions

Questions? *call* (919) 326-6897 *or email* NCWaterHeater@energy-solution.com

Please confirm your address:

1. Street Address____

   City____________________State______ Zip Code ________

2. Would you like your final Visa gift card for $100 to be mailed to this address or a different address?
   - ☐ The address above
   - ☐ A new address: ________________________________

Please answer the following questions to the best of your ability

3. During the study, did you change the settings on your water heater? If so, what setting did you change and why?
   - ☐ Yes, because____________________________________
   - ☐ No

   If you answered yes, which settings did you change, and approximately when did you change them? ________________________________

4. Did you have days in which you ran out of hot water over the past year? If so, how many?
   - ☐ None
   - ☐ 1-2
   - ☐ 3-5
   - ☐ 6-10
   - ☐ 11 or more
   - ☐ Other (or comment box) ________________________

5. Have you noticed a difference in the time it takes for hot water to arrive when it is turned on? (check all that apply)
   - ☐ Hot water arrives faster
   - ☐ Hot water takes longer to arrive
   - ☐ No change in the time for hot water to arrive
   - ☐ Other (or comment box) ________________________

6. Did the number of people living in your home change over the past year? If so, please explain. ____

OVER

7. Did you notice a change in your electric bill after you received the heat pump water heater? (check one)
   - ☐ My electric bill went up
   - ☐ My electric bill stayed the same
   - ☐ My electric bill went down
   - ☐ Other ________________________________

8. Did you notice a change in your electric bill after this study began in June 2023? (check one)
   - ☐ My electric bill went up
   - ☐ My electric bill went down
   - ☐ There was no change
   - ☐ Other ________________________________

9. Now that the study is complete, we need to disconnect the communication module from your water heater. Would you like us to visit your home August 5-9 to disconnect and remove the communications module or would you prefer to receive a shipping label so that you can do it yourself? Instructions are attached for removal.
   - ☐ Please send me a shipping label
   - ☐ Please come to my home to remove the communications module

10. Our team took photos of your heat pump water heater and then communications module when your water heater was installed and we keep them in a secure file. These photos do not include any of the people living in your home or other information that would allow anyone to tell who you are or where you live. The study team would like to use some of the photos in publications to discuss installation lessons learned and best practices. Do you provide consent for the research team to use photos of your water heater?
    - ☐ Yes, it is OK to use photos of my water heater
    - ☐ No, do not include photos of my water heater in your report

11. Please provide any comments on the administration of the study such as details on if communication was effective, if your questions were answered, if you felt the compensation was fair, etc.

____

____

____

____

THANK YOU!

North Carolina Heat Pump Water Heater Participant Demand Response Survey Results
Location of Water Heater

	1st Survey	1st Survey	1st Survey	1st Survey	1st Survey	2nd survey	2nd survey	
Participant	**Where is your water heater located?**	**Other, Where?**	**Outside your house**	**Other, Where?**	**If your water heater is inside your house, is it in a heated area?**	**Where is your water heater located?**	**conditioned, unconditioned, semiconditioned inside envelope, semiconditioned outside envelope**	**Conditioned/Unconditioned from photos**
ESOh010	Basement					In-between	semiconditioned inside envelope	Conditioned
ESOh011	Closet				Yes	Inside in a heated area	conditioned	Conditioned
ESOh012	Basement				Yes	Inside in a heated area	conditioned	Conditioned
ESOh013	Basement				No	In-between	semiconditioned inside envelope	Unconditioned
ESOh014		laundry room				Inside in a heated area	conditioned	Conditioned
ESOh015			Outdoor closet or shed			Outside the heated area of your home	semiconditioned outside envelope	Unconditioned
ESOh016	Other	wash room			Yes	Inside in a heated area	conditioned	Conditioned
ESOh017	Other	laundry room	Other	Con phuch	No	In-between	semiconditioned inside envelope	Unconditioned
ESOh018	Basement				No	Inside in a heated area	semiconditioned inside envelope	Conditioned
ESOh019	Closet				Yes	Inside in a heated area	conditioned	Conditioned
ESOh020	Basement				No	Inside in a heated area	semiconditioned inside envelope	Unconditioned
ESOh021	Other		Garage			In-between	semiconditioned outside envelope	Conditioned
ESOh022	Other	storage closet			Yes	Inside in a heated area	conditioned	Conditioned
ESOh023	Closet				Yes	Inside in a heated area	conditioned	Conditioned
ESOh024	Other	next to laundry/hallway			Yes	Inside in a heated area	conditioned	Conditioned
ESOh025						In-between	semiconditioned outside envelope	Unconditioned
ESOh026	Basement					Inside in a heated area	semiconditioned inside envelope	Unconditioned
ESOh027			Garage			In-between	semiconditioned outside envelope	Unconditioned
ESOh028	Other				Yes	Inside in a heated area	conditioned	Conditioned
ESOh029			Crawlspace under your house		No	In-between	semiconditioned inside envelope	Conditioned
ESOh030	Basement		Crawlspace under your house		Yes	In-between	conditioned	Conditioned
ESOh031		laundry room			No	In-between	semiconditioned inside envelope	Conditioned
ESOh032		laundry room			Yes	Inside in a heated area	conditioned	Conditioned
ESOh034	Basement		Crawlspace under your house			Outside the heated area of your home	semiconditioned inside envelope	Conditioned

Participant	How many bedrooms are in your home?	How many showers or bathtubs are in your home?	Survey 2 people in home	Survey 1 people in home	If the number of people living in your home changed over the past year, please explain the change (did it go up or down, and by how many?). If it stayed the same, answer "same".	How many Children (-12) live in the home by age group (for at least 4 days per week)?	How many Children (-12) work or attend school outside the home?	How many Teenagers (13-18) live in the home by age group (for at least 4 days per week)?	How many Teenagers (13-18) work or attend school outside the home?	How many Adults (19-64) live in the home by age group (for at least 4 days per week)?	How many Adults (19-64) work or attend school outside the home?	How many Seniors (65+) live in the home by age group (for at least 4 days per week)?	How many Seniors (65+) work or attend school outside the home?	How do you heat your home?	How do you stay cool in the summer?	Who is your electric utility provider?	Electric utility from RTT	How many of the following hot water fixtures and appliances do you have (check all the apply)?	Did you notice a change in your electric bill after you received the heat pump water heater?	Did you notice a change in your electric bill after this study began in June 2023?	Size of Replaced Heater from RTT	Fuel of Replaced Heater from RTT
ESOh10	5	3	4	3	Went up by 1 since Christmas then back down by 1 since middle of June.					1	1	1		Electricity;	Central air conditioner;	Duke, but not sure which one	DEP	Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	Didn't notice	Didn't notice	40 gallon	Natural Gas
ESOh11	3	1	1	1	SAME							1		Natural gas;	Central air conditioner;	Duke, but not sure which one	DEC	Shower(s); Clothes washer(s)	My electric bill went up.	My electric bill went up.	50 gallon	Natural Gas
ESOh12	3	2	1	1	no							1		Natural gas;	Central air conditioner;	Duke Energy Progress	DEC	Shower(s); Bathtub(s); Clothes washer(s)	My electric bill went down.	there was no change	50 gallon	Natural Gas
ESOh13	3	1	4	9	no	1	1	2	2	1		2		Natural gas; Other: wood boiler	Central air conditioner; Fans	Duke Energy Progress		Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	My electric bill went up.	My electric bill went up.		
ESOh14	3	1	2	2	1 additional person for the past 2 months					2				Electricity;	Central air conditioner;	Duke Energy Carolinas	DEC	Shower(s); Bathtub(s); Clothes washer(s)	My electric bill stayed the same.	My electric bill went down.	50 gallon	Electric
ESOh15	3	1	2	1	NA							1		Electricity;	Central air conditioner;	Duke Energy Progress	DEC	Shower(s); Bathtub(s); Clothes washer(s)	My electric bill went down.	there was no change	40 gallon	Electric
ESOh16	3	1	2	1	Same							1	1	Electricity;	Central air conditioner;	Duke, but not sure which one	Piedmont	Shower(s); Bathtub(s); Clothes washer(s)	My electric bill went down.	My electric bill went down.	40 gallon	Natural Gas
ESOh17	2	1	1	1								1	1	Electricity;	Central air conditioner;	Duke Energy Progress		Shower(s); Clothes washer(s)	My electric bill went up.	My electric bill went up.		
ESOh18	4		1	1	no							1	1	Natural gas;	Central air conditioner;	Duke Energy Progress	DEC	Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	My electric bill went up.	My electric bill went down.	40 gallon	Natural Gas
ESOh19	2 to 3	2	2	2	NO					1		1	1	Electricity;	Central air conditioner;	Duke Energy Carolinas	DEC	Shower(s); Bathtub(s); Clothes washer(s)	My electric bill stayed the same.	My electric bill stayed the same.	40 gallon	Natural Gas
ESOh20	3	1	2	4	Same					2	2			Electricity;	Central air conditioner;	Duke Energy Progress	DEP	Shower(s); Bathtub(s)	My electric bill went down.	My electric bill went down.	50 gallon	Electric
ESOh21	3	2	2	3	Same			1	1	1				Electricity;	Central air conditioner;Fans;	Duke Energy Progress	DEP	Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	My electric bill stayed the same.	My electric bill stayed the same.	50 gallon	Electric
ESOh22	3	2	1	1	no, the number of people in my household changed					1				Natural Gas	Central air conditioner;	Town of Apex	Town of Apex	Shower(s); Bathtub(s); Clothes washer(s)	My electric bill went down.	there was no change	40 gallon	Natural Gas
ESOh23	3	2	1	1	Same							1		Electricity;	Central air conditioner; fans	Duke Energy Progress	DEP	Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	My electric bill stayed the same.	My electric bill stayed the same.	50 gallon	Electric
ESOh24	3	1	3	6		2	2			1	1			Natural gas;	Central air conditioner;	Duke, but not sure which one	DEP	Shower(s); Bathtub(s); Clothes washer(s)			40 gallon	Natural Gas
ESOh25	3	2	2 (sometimes)		no									Natural Gas	Central air conditioner;	Duke Energy Progress	DEP		other: somewhat	other: somewhat	50 gallon	Natural Gas
ESOh26	2	1	2	1	no							1	1	Natural gas	Window air conditioner;	Town of Apex	Town of Apex	Shower(s)	My electric bill went down.	My electric bill went down.	40 gallon	Electric
ESOh27	4	3	1	1						1				Natural gas;Electricity;	Central air conditioner;	Town of Apex	Town of Apex	Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	My electric bill went up. (about $20)	My electric bill stayed the same.	50 gallon	Natural Gas
ESOh28	3	1/1.5	1	1	same							1		Electricity;	Central air conditioner;	Duke Energy Carolinas	DEC		Duke Energy went up on its rates. not this.	all utility went up on its ratings not this. same	50 gallon	Electric
ESOh29	3	1.5	1	1								1		Electricity;	Central air conditioner;	Town of Apex	Town of Apex				40 gallon	Natural Gas
ESOh30	2	1	3	2	Same	1	1							Electricity;	Central air conditioner;	Town of Apex	Town of Apex	Shower(s); Clothes washer(s)	My electric bill went down.	My electric bill went down.	40 gallon	Electric
ESOh31	3 to 4	2	5	8	Same	2	2	1	1	2				Natural gas;	Central air conditioner;	Duke Energy Progress	DEP	Shower(s); Dishwasher(s)	My electric bill went down.	My electric bill stayed the same.	50 gallon	Electric
ESOh32	3	1	1	2	Just 2					1		1		Electricity;	Central air conditioner;	Duke Energy Progress		1 shower, 1 clothes washer	My electric bill went down.	My electric bill went down.		
ESOh34	2	2	2	2	no					1	1			Electricity;	Central air conditioner;	Duke Energy Progress	DEP	Shower(s); Bathtub(s); Clothes washer(s); Dishwasher(s)	My electric bill stayed the same.	there was no change	50 gallon	Natural Gas

	2nd Survey	2nd Survey	2nd Survey	1st Survey	1st Survey	1st Survey	2nd Survey	2nd Survey	2nd Survey	2nd Survey	2nd Survey	1st Survey	1st Survey	1st Survey	1st Survey	3rd Survey	3rd Survey	3rd Survey	3rd Survey
Participant	**Since getting your new water heater, how frequently do you run out of hot water?**	**How is the temperature of your hot water?**	**Do you run out of hot water more or less frequently with your new water heater than your old one?**	**Compared to your old water heater, have you noticed a difference in the temperature of your hot water?**	**Compared to your old water heater, have you noticed a difference in the amount of hot water available?**	**Compared to your old water heater, Please tell us how you feel about your new water heater on a scale of 1-5, where 1 is "I liked my old water heater much better: and 5 is "I like my new water heater much better"**	**Have you noticed increased cold air near your new water heater?**	**If you answered "Yes" to question #13, please choose the statement that best describes your feelings:**	**Have you noticed any noise coming from your new water heater?**	**If you answered "Yes" to question #15, please choose the statement that best describes your feelings:**	**Would you recommend a heat pump water heater like your current water heater to friends and family?**	**Please tell us how you feel about your new water heater on a scale of 1-5, where 5 is "I really like it" and 1 is "I really don't like it"**	**Is your hot water temperature:**	**Do you ever run out of hot water?**	**If "Yes", do you run out of hot water**	**During the study, did you change the settings on your water heater? If so, what setting did you change and why?**	**If you answered "yes" to Question 3, tell us what you changed and why.**	**Did you have days in which you ran out of hot water over the past year? If so, how many?**	**Have you noticed a difference in the time it takes for hot water to arrive when it is turned on? (check all that apply)**
ESOh010	Other: 1 time when I take a shower so I won't :)	Just right	Less frequently	the same	more	5	No		No		Yes	5	Just right		Very rarely, when have company	no		0-2	Hot water arrives faster.
ESOh011	Never	Just right		the same	the same	5	Yes	Have	Yes	I don't like the noise, but it's not a big problem.	Yes	5	Just right	No		no		none	No change in the time for hot water to arrive.
ESOh012	Never	Just right	Less frequently	the same	more	5	Yes	I don't like the cold air, but it's not a big problem.	No	The noise doesn't bother me.	Yes	5	Just right	No		no		none	No change in the time for hot water to arrive.;
ESOh013	Every day	Just right	More frequently	the same	more	5	No		No		No	5	Just right	No		no		11 or more	Hot water takes longer to arrive.
ESOh014	Never	Just right	Less frequently	the same	the same	3	Yes	I don't like the cold air, but it's not a big	Yes	The noise doesn't bother me.	Yes	4	Just right	No		no		none	Hot water takes longer to arrive
ESOh015	Never	Just right	Less frequently	the same	the same	5	No		No		Yes	5		No		no		none	No change in the time for hot water to arrive.;
ESOh016	Never	Just right	Less frequently	the same	the same	5	Yes	I don't like the cold air, but it's not a big problem.	Yes	I don't like the noise, but it's not a big problem.	Yes	5	Just right	No		no		none	No change in the time for hot water to arrive.;
ESOh017	Never	Just right	Less frequently	the same	the same	4	Yes	I don't like the cold air, but it's not a big	Yes	The noise doesn't bother me.	Yes	4	Just right	No		no		none	Hot water takes longer to arrive.;
ESOh018	Never	Just right	Less frequently	the same	the same	4	No		Yes	I don't like the noise, but it's not a big problem.	Yes		Just right	No		no		none	Hot water arrives faster.
ESOh019	A couple times a year;	Just right	More frequently	the same	more	5	Yes	I don't like the cold air, but it's not a big	Yes	I wish my water heater didn't make noise.	Yes	4	Just right	Yes	A couple times each	no		3-5	Hot water takes longer to arrive.;
ESOh020	Never	Just right	Less frequently	cooler	the same	4	No		No		Yes	5	Just right	Yes	It's only happened once or twice	no	I could not figure out how to do	none	No change in the time for hot water to arrive.
ESOh021	Never	Just right	Less frequently	hotter	more	5	Yes	The cold air doesn't bother me.	Yes	I don't like the noise, but it's not a big problem.	Yes	4	Just right	No	Infrequently, maybe once a month	no		0-2	Hot water takes longer to arrive.
ESOh022	Never	Not hot enough	Less frequently	cooler	the same	5	Yes	I like the cold air; the cold air doesn't bother me	Yes	The noise doesn't bother me.	Not sure		Just right	No		no		none	No change in the time for hot water to arrive.
ESOh023	Other: Only when guests stay over, using the shower more, dishwasher, and laundry around the same time.	Just right	Less frequently	the same	more	3	Yes	I wish my water heater didn't make cold air.	Yes	I wish my water heater didn't make noise.	No	4	Just right	No		no		0-2	No change in the time for hot water to arrive.
ESOh024	About once a month	Just right	More frequently	the same	the same	3	Yes	The cold air doesn't bother me.	No		No	4	Just right	No					
ESOh025	Other: takes longer to heat	Just right - when it gets to faucets (?) takes too long	More frequently				Yes	- none of the above	Yes		No					no		none, just slow to get hot	No change in the time for hot water to arrive.;
ESOh026	Never	Just right	Less frequently	hotter	more	5	No		No		Yes	5	Just right	No		no		none	Hot water arrives faster.
ESOh027	Never	Just right	Less frequently	the same	more	5	Yes	The cold air doesn't bother me.	Yes	The noise doesn't bother me.	Yes	5	Just right	No		yes	Temperature to 110. I do not use very hot water, and reducing temperatur	none	Hot water arrives faster.
ESOh028	Never	Just right	Less frequently	the same	the same	2	Yes	I don't like the cold air, but it's not a big problem.	No		Yes	1	Just right	No		no		none	No change in the time for hot water to arrive.
ESOh029	Other: all of the time, not happy	Just right	More frequently	the same	less	3	Yes	I wish my water heater didn't make cold air.	Yes	I wish my water heater didn't make noise.	No	4	Just right	Yes	It's only happened once or twice				

	2nd Survey	2nd Survey	2nd Survey	1st Survey	1st Survey	1st Survey	2nd Survey	2nd Survey	2nd Survey	2nd Survey	2nd Survey	1st Survey	1st Survey	1st Survey	1st Survey	3rd Survey	3rd Survey	3rd Survey	3rd Survey
Participant	**Since getting your new water heater, how frequently do you run out of hot water?**	**How is the temperature of your hot water?**	**Do you run out of hot water more or less frequently with your new water heater than your old one?**	**Compared to your old water heater, have you noticed a difference in the temperature of your hot water?**	**Compared to your old water heater, have you noticed a difference in the amount of hot water available?**	**Compared to your old water heater, Please tell us how you feel about your new water heater on a scale of 1-5, where 1 is "I liked my old water heater much better: and 5 is "I like my new water heater much better"**	**Have you noticed increased cold air near your new water heater?**	**If you answered “Yes” to question #13, please choose the statement that best describes your feelings:**	**Have you noticed any noise coming from your new water heater?**	**If you answered “Yes” to question #15, please choose the statement that best describes your feelings:**	**Would you recommend a heat pump water heater like your current water heater to friends and family?**	**Please tell us how you feel about your new water heater on a scale of 1-5, where 5 is "I really like it" and 1 is "I really don't like it"**	**Is your hot water temperature:**	**Do you ever run out of hot water?**	**If "Yes", do you run out of hot water**	**During the study, did you change the settings on your water heater? If so, what setting did you change and why?**	**If you answered "yes" to Question 3, tell us what you changed and why.**	**Did you have days in which you ran out of hot water over the past year? If so, how many?**	**Have you noticed a difference in the time it takes for hot water to arrive when it is turned on? (check all that apply)**
ESOh030	Never	Just right	Less frequently	the same	more	4	No		No		Yes	4	Just right	No		no		none	Hot water arrives faster.
ESOh031	About once a month	Just right	Less frequently	the same	less	3	Yes	I don’t like the cold air, but it’s not a big problem.	Yes	The noise doesn’t bother me.	Yes	3	Just right	Yes	A couple times each week	no		3-5	No change in the time for hot water to arrive.
ESOh032	Never	Just right	Less frequently	hotter	the same	5	Yes	I don’t like the cold air, but it’s not a big	Yes	The noise doesn’t bother me.	Yes	5	Just right	No		no		none	Hot water arrives faster.
ESOh034	Never	Not hot enough	Less frequently	the same	the same	3	No		No		Yes	5	Just right	No		no		none	No change in the time for hot water to arrive.

What is the Benefit of Time-of-Use Rates for Residential Customers?

Chris Granda, Energy Solutions

Energy Solutions

Introduction

Electric heat pump water heaters (HPWH) offer customers attractive energy savings compared to conventional electric resistance water heaters. “Smart” HPWH with demand response or load-shifting capability can allow customers also to take advantage of time-of-use (TOU) electricity rates. Field research has shown that smart HPWH can shift most or all electricity consumption for residential water heating away from peak demand periods. Unfortunately, customers who purchase smart HPWH and choose a TOU rate may not experience significant savings on their electricity bills. Total savings depends upon the design of the TOU rate, and the electricity consumption of other major appliances in the home.

The following analysis is based on TOU residential electricity rates offered by Duke Energy Progress (DEP) in North Carolina and by Pacific Gas & Electric in California in 2024. This initial analysis uses several assumptions about HPWH electricity consumption and load shifting capability which are detailed below.

Energy Savings

Water heating is usually the second largest energy end use in U.S. homes after space heating. The current U.S. stock of residential water heaters is largely split between natural gas-fired and electric resistance technology with, one fuel type may dominate in different states. For example, 75% of homes in North Carolina have electric resistance water heaters while 78% of homes in California have gas-fired water heaters.[1]

Field monitoring[2] suggests that heat pump water heaters reduce electricity consumption for residential water heating by 45% to 66%, compared to a conventional electric resistance storage water heater. The actual electricity consumption of a HPWH depends on many factors, including whether it is installed in conditioned (e.g., closet, utility room), semi-conditioned (e.g., garage or unfinished basement) or unconditioned space (e.g., outdoor shed). HPWH are usually an easy replacement for electric resistance water heaters because they use the same 240 V circuit and only require the addition of a drain for condensate from the heat exchanger.

The recent DOE final rule on energy conservation standards for consumer water heaters requires that the most common sizes of electric storage water heaters made after May of 2029 be HPWHs. In the years that follow, as electric resistance water heaters reach end-of-life and are replaced, the national stock of electric storage water heaters will transition to be about 61% HPWH.[3] States with large numbers of electric resistance water heaters[4] should see significant reductions in residential water heating electricity consumption as the national fleet of HPWH grows. Utilities serving these states also should see reductions in residential sector peak electricity demand due to reduced electricity used for water heating.

1 Energy Information Administration Residential Energy Consumption Survey 2020. State Water Heating Table.

2 Estimate based on North Carolina HPWH project and similar field studies performed by PNNL and others.

3 DOE estimate Federal Register vol. 89, No. 88 page 37898

4 EIA RECS 2020. Florida, Texas, North Carolina, Georgia, Pennsylvania, New York and Virginia all have over 2 mil electric resistance water heaters each

For example, 3 million homes in North Carolina heat water with electricity, almost all currently use electric resistance storage water heaters. On average, these homes consume 2,895 kilowatt hours (kWh) annually to heat potable water, [5] accounting for 23% of their total average annual electricity consumption. Participants in the North Carolina HPWH Project experienced a 43% reduction in electricity consumed to heat water after receiving a HPWH. By 2043, following the 2029 compliance date for the federal standard and allowing enough time for most of the current stock of electric resistance water heaters to be replaced, there should be over 2 million HPWH in North Carolina. After full market adoption, HPWH will save North Carolinians over 3 terawatt hours of electricity annually.

Demand Savings

A residential electric resistance water heater is typically rated at 3,000 to 5,500 watts of input power, which makes it one of the household appliances with the highest electricity demand. Most electric resistance storage water heaters automatically turn on whenever the temperature of the water in the tank drops below a set point. Because residential uses of hot water (showering, dishwashing, laundry) happen around the same times of day in many homes, the combined effect of millions of electric resistance water heaters switching on around the same time is an important driver of the residential daily electricity demand peak. For this reason, utilities have been targeting electric resistance storage water heaters with demand response programs for many years.

HPWH compressors are rated at 500 to 800 W but most HPWH also have 4,500 W electric heating elements like electric resistance water heaters. The heat pump provides most of the water heating, but the electric resistance elements may turn on when hot water usage is high. Compared to electric resistance water heaters, this means that HPWH significantly reduce average water heating electricity consumption but may or may not reduce peak electricity demand. The North Carolina HPWH project and other similar field studies[6] have shown that demand response capable "smart" HPWH can efficiently meet residential hot water needs while completely avoiding electricity consumption during peak demand periods.

Analysis

Electricity rates for commercial or industrial customers often include both energy charges, in terms of kilowatt hours consumed during a billing period, and demand charges based on the peak consumption during the billing period. This separation reflects the costs of both generating electricity and providing sufficient capacity to meet demand at a given time and location. Older residential electricity meters do not measure demand, and traditional residential electricity rates are a fixed cost per kilowatt hour. Fixed residential rates do not provide an incentive to customers to track or control their electricity demand.

Modern residential metering allows time-of-use (TOU) electricity rates that vary during the day with a higher per-kWh charge during peak demand periods and lower charges during shoulder and off-peak times. The purpose of

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5 EIA RECS 2020 Table CE4.6.EL.ST

6 Fenaughty, Karen; Josh Butzbaugh; Travis Ashley. Factors Influencing Grid-Connected Heat Pump Water Heater Performance in the Southeast U.S. Proceedings of the 2024 ACEEE Summer Study

Metzger, CE, Kelsven P, Ashley T, Bender, S, Kelly N, Eustis, C. 2019. Not Your Father's Water Heater Demand Response Program: Measuring Impacts from an Innovative Load Shifting Pilot. International Energy Program Evaluation Conference. August 2019.

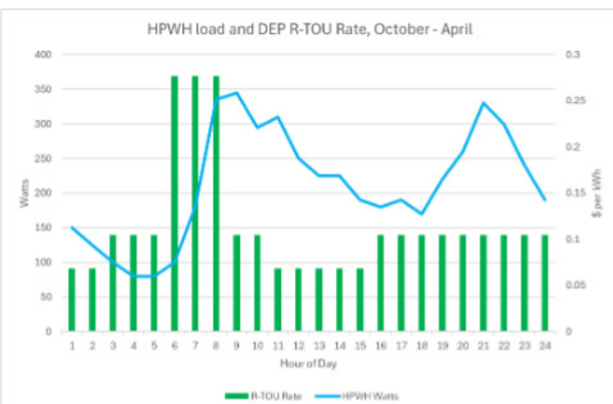
TOU rates is to motivate customers to reduce their electricity consumption during peak period by giving them the opportunity to save on their electricity bills. In most parts of the U.S., a HPWH will save electricity customers more than enough on their bills over the expected life of the HPWH to pay back the incremental cost compared to an electric resistance water heater. Our analysis explores whether “smart” HPWH with demand response technology could use TOU rates to provide attractive electricity demand savings as well. We looked at the impact on customers who are on conventional fixed rates with the option of choosing a TOU rate in North Carolina and at customers who are already on default TOU rates in California.

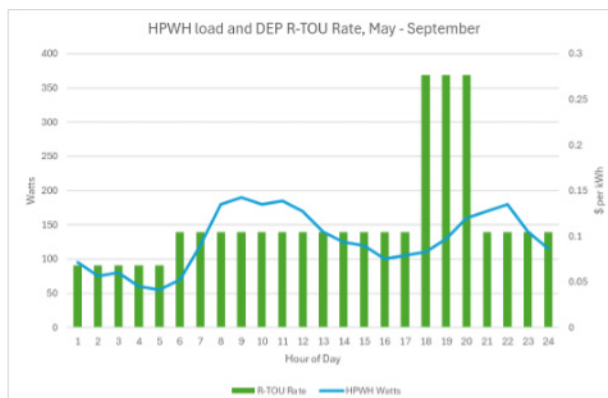
Case Study: North Carolina HPWH Project

From 2021 to 2024 Energy Solutions worked with the North Carolina Justice Center and Rebuilding Together of the Triangle (RTT) to replace either electric resistance or natural gas storage water heaters with smart HPWH in the homes of 24 low-income, residential electricity in North Carolina. Energy Solutions remotely monitored the energy consumption of the smart HPWH and ran daily load-shifting schedules to assess the HPWH demand response potential of participant households.

Participants in the Project were served by Duke Energy Progress (DEP), Duke Energy Carolinas (DEC), and several small municipal utilities. DEP Duke Energy Corporation serves 3.7 million customers in North Carolina and DEP offers residential customers a fixed residential rate (RES) with different fixed price-per-kWh in the summer and winter and a residential TOU rate (R-TOU) that charges a different price-per-kWh at different times of day for on-peak, shoulder, and off-peak periods.[7] DEP’s RES and R-TOU rates are included in Attachments 1 & 2.

Figures 1 & 2: DEP TOU rate and uncontrolled HPWH electricity demand profile





Figures 1 & 2 overlay DEP’s R-TOU price per kWh by hour of day (green bars) with the electricity demand curve for an uncontrolled HPWH.[8] Figure 1 shows that peak electricity demand for an uncontrolled HPWH in winter falls during the expensive weekday morning peak period for DEP’s R-TOU rate. This is also the usual time of

7 DEP also offers two other residential TOU rates – one includes a demand charge and the other includes “critical peak pricing.” These rates are outside of the scope of this analysis.

8 Hunt, Walter, Mayhorn, Ashley, and Metzger. “Factors Influencing Electrical Load Shape of Heat Pump Water Heaters” ASHRAE Journal. February 2021

North Carolina's annual electricity demand peak. Figure 2 shows that in the summer HPWH evening electricity consumption somewhat overlaps with the weekday evening peak period. Over 12 months, Energy Solutions was able to remotely signal the 24 HPWHs to shift energy use times and demonstrate that most electricity demand could be shifted to off-peak periods without causing the participants to run out of hot water, including during the annual system peak.

The load-shifting capability of smart HPWH is beneficial for the North Carolina grid, but would DEP customers with smart HPWH also see benefits from shifting to the R-TOU rate? The North Carolina HPWH Project was not able to obtain participant electricity billing data from DEP and did not encourage participant to sign up for the TOU rates during the project. The following analysis estimates what the impact on total participant electricity bills would have been if participants had changed from DEP's RES fixed residential rate to DEP's R-TOU rate.

U.S. Department of Energy data[9] estimates that the average home in North Carolina uses 12,498 kWh of electricity per year and that the three appliances that use the most electricity - water heaters, air conditioners, and heaters[10] - are responsible for 66% of that total. Table 1 compares the estimated electricity costs based on U.S. DOE estimates of electricity consumption for electric water heating, air conditioning, and space heating in North Carolina under three different scenarios.

Table 1: Estimated annual appliance electricity costs in North Carolina

Scenario Analyses	Scenario 1 RES Electric Resistance ESWH	Scenario 2 RES HPWH	Scenario 3 R-TOU HPWH 100% off-peak load shifting	Scenario 4 R-TOU HPWH 100% off-peak AC and heat 50% off-peak load shifting
Electric water heating	$336	$171	$145	$145
Electric air conditioning	$287	$287	$315	$282
Electric space heating	$332	$332	$331	$299
All three appliances*	$955	$790	$791	$726

**Variable energy costs only. Does not include fixed bill charges.*

Estimates of electricity charges under the two different rates were developed using load shapes for residential electric heating and cooling for the Southeast region available from the Electric Power Research Institute.[11]

Scenario 1 presents a pre-program baseline scenario representing the annual electricity charges for electric resistance water heating, and electric air conditioning and space heating for a typical North Carolina residential electric customer. Scenario 2 estimates annual electricity charges after swapping out the electric resistance storage water heater for a HPWH with savings like those achieved in the North Carolina HPWH project. Comparing

9 US EIA, Residential Energy Consumption Survey 2020 state data table

10 A majority of North Carolinians heat their homes with electricity, and a majority of those use electric resistance while the balance use heat pumps.

11 EPRI Load Shape Library 8.0 https://loadshape.epri.com/enduse

Scenario 1 and 2 shows that without demand response the HPWH saves the typical North Carolina household $165 per year. The incremental cost of purchasing and installing a HPWH compared to an electric resistance storage water heater is about $2,000 in North Carolina. With an expected life of thirteen years, a HPWH installed in a home DEP's service territory should payback the higher upfront cost in electricity savings.[12]

Scenario 3 presents the smart HPWH scenario and includes the effect of also switching to the R-TOU rate. Energy Solutions found that load-shifting had negligible impact on total HPWH electricity consumption compared to HPWH without load shifting. In Scenario 2, Energy Solutions estimated that the typical North Carolina household electricity bill would be a dollar per year higher with a smart HPWH and the R-TOU rate than it would be with a HPWH on the fixed RES rate, in other words, negligible net benefit to the customer.

To understand this result, it is important to remember that residential electricity rates apply to all electricity consumed on a specific meter, whether the appliances that consume the electricity are capable of load-shifting or not. Scenario 3 assumes that all electricity consumption for water heating was shifted off-peak but that there was no load-shifting for either air conditioning or electric space heating. Under this scenario the savings from shifting water heating electricity off-peak are countered by increased costs for air conditioning, which also consumes electricity on-peak and on-peak electricity costs more under R-TOU than RES.

In 2024, a smart HPWH cost somewhere between $75 and $150 more than a HPWH without demand response capability to purchase at retail. For HPWH, the meaning of "smart" and its associated costs are still evolving but manufacturer estimates of the technical incremental cost at scale of installing an EcoPort[13] (to enable demand response communications) in HPWH at the factory are usually around $25 each. To make HPWH with EcoPorts fully demand response capable, they also need a universal communications module that currently costs $75 to $150 but may be cheaper if produced at scale. Customer might be able to achieve most of the demand response capability at a lower price if they can find a HPWH that does not have an EcoPort but allows TOU rate schedules to be programmed in by the user. This programming can be a non-trivial exercise for customers given the complexity of R-TOU rates and the possibility that it could change multiple times over the life of the HPWH. Whatever the incremental cost of enabling demand response for HPWH, customers are unlikely to recover it at a savings of $1 per year.

DEP customers also could invest in a smart thermostat to shift air-conditioning and electric space heating electricity load. A full analysis of the incremental costs and load shifting capability for smart thermostats in North Carolina is beyond the scope of this paper. However, because residential electric heating and cooling rarely includes thermal storage capacity, smart thermostats are not able to shift as much electrical load as a smart HPWH. Shifting space heating and cooling loads without thermal storage also means that interior temperatures may regularly stray outside of normal ranges and cause thermal comfort issues, limiting the duration of a load shift. Scenario 4 in Table 1 estimates the savings under R-TOU if customers shifted 50% of both cooling and heating electricity consumption off peak periods. In this final scenario, demand response for smart HPWH and a smart thermostat to control air conditioning and space heating under R-TOU would save a typical customer an additional $64 per year. In summary, a HPWH is an attractive option for DEP customers with electric resistance storage water heaters. Adding demand response capability with a smart HPWH and adopting DEP's R-TOU rate would offer little additional benefit without also shifting or reducing HVAC loads during peak times.

12 Customers may also be able to take advantage of federal tax credits for HPWH and DEP incentives.

13 "EcoPort" is the brand name of ANSI/CTA – 2045 receptacles that accept Universal Communications Modules for demand response signalling.

Case Study: California WatterSaver Program

In 2022, Pacific Gas & Electric Company (PG&E) engaged a contract team lead by Association for Energy Affordability (AEA) and including Energy Solutions, to design and operate the "WatterSaver" electric storage water heater load shifting program. WatterSaver is open to PG&E residential customers with electric resistance storage water heaters or HPWH and has the goal of evaluating smart electric storage water heaters (ESWH) as a demand response resource in northern California. As in the NC HPWH Project, WatterSaver is successful at shifting electric water heater load out of peak periods. The impacts of the load shifting on electricity bills for 204 WatterSaver participants are shown in Table 2.[14]

Table 2: Impacts of WatterSaver Program on Participant Electricity Bills

Utility/Tariff	Avg Annual Electricity Bill	Savings Advanced Load Up		Savings Basic Load Up (< 140°F)		Savings Basic Load Up (≥ 140°F)	
PG&E TOU-C	$ 2,000	$ 7	-0.4%	$ 12	-0.6%	$ 43	-2.1%
SCE TOU-D-4-9	$ 1,600	$ 32	-2%	$ 21	-1.3%	$ 55	-3.4%

Source: Amélie Besson,[15] Programs Manager, AEA

PG&E = Pacific Gas & Electric Company

SCE = Southern California Edison

TMV = thermostatic mixing valve

Like the North Carolina HPWH project, WatterSaver is able to successfully shift water heating electricity consumption off of peak demand periods for participants. Table 2 shows the results for three different ESWH demand response scenarios. The last row of Table 2 shows the estimated impacts on WatterSaver participants' electricity bills under PG&E's default domestic customer TOU rate. However, for PG&E and SCE the default residential electricity is a TOU rate and WatterSaver participants are required to be on a TOU rate to participate in the program. Therefore, there is no impact from the TOU rate increasing the cost of electricity for other electric appliances in the home as there was in North Carolina.

While the North Carolina HPWH project found little impact on HPWH energy consumption from of load-shifting, some WatterSaver participants see slightly increased electricity consumption and bills. This appears to be due to the difference in demand response strategies pursued in the two programs. The WatterSaver program continues to fine tune load-shifting parameters to address energy use increases and to fine tune load-shifting strategies to optimize costs based on California TOU rates.

14 Presented at the American Council for an Energy Efficient Economy at the 2024 Hot Water Forum, March 2024

15 Besson, Amelie et.al., "Thermal Storage Load Shifting Lessons learned from PG&E WatterSaver Program" Proceedings of the ACEEE 2024 Hot Water Forum

Conclusions

The purpose of a residential TOU rate is to give residential electric customers a compelling financial incentive to shift their electricity load. Both the North Carolina and California studies discussed above found that the TOU rates considered were unlikely to achieve this goal by themselves. The incentives offered are too small and can be outweighed by other choices available to the customer, or by changes to tariffs or demand response programs.

From a residential energy program design perspective, incentives administered through rates start with inherent limitations. For example, financial incentives for residential energy efficiency measures work best when they are available upfront when customers are making purchasing decisions about the targeted technology. TOU rates provide incentives after a purchase over time as a series of reductions on electricity bills. This means that the TOU rate incentive does not defray the incremental cost of demand- response capable appliances, and the incentive is diluted by being split up over a series of utility bills.

Finally, if customers are being asked to invest in demand response capable appliances, with the promise of being reimbursed through energy savings over time, they are being asked to assume the performance risk for demand response technology. This kind of performance risk is also a barrier to energy efficiency programs that promote new technologies. Performance risk is one reason that HPWH sales remain in the low single-digits of all electric storage water heater sales despite the fact that heat pumps (as refrigerators and air conditioners) are a familiar technology and the energy savings is large enough to be observable in electricity bills. The benefits from TOU rates are dependent the design of the tariff and whether the customer's demand response technology is able to take advantage of it, something the customer has no experience with and may not understand.

Appendix 1:

Duke Energy Progress RES Rate Schedule

Date: 9/1/2024

NCUC Docket No. E-2, Sub 1300

Appendix 2:

Duke Energy Progress R-TOU Rate Schedule

Date: 9/1/2024

NCUC Docket No. E-2, Sub 1300

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