Connected Heat Pump Water Heaters for Low-Income Homes in North Carolina

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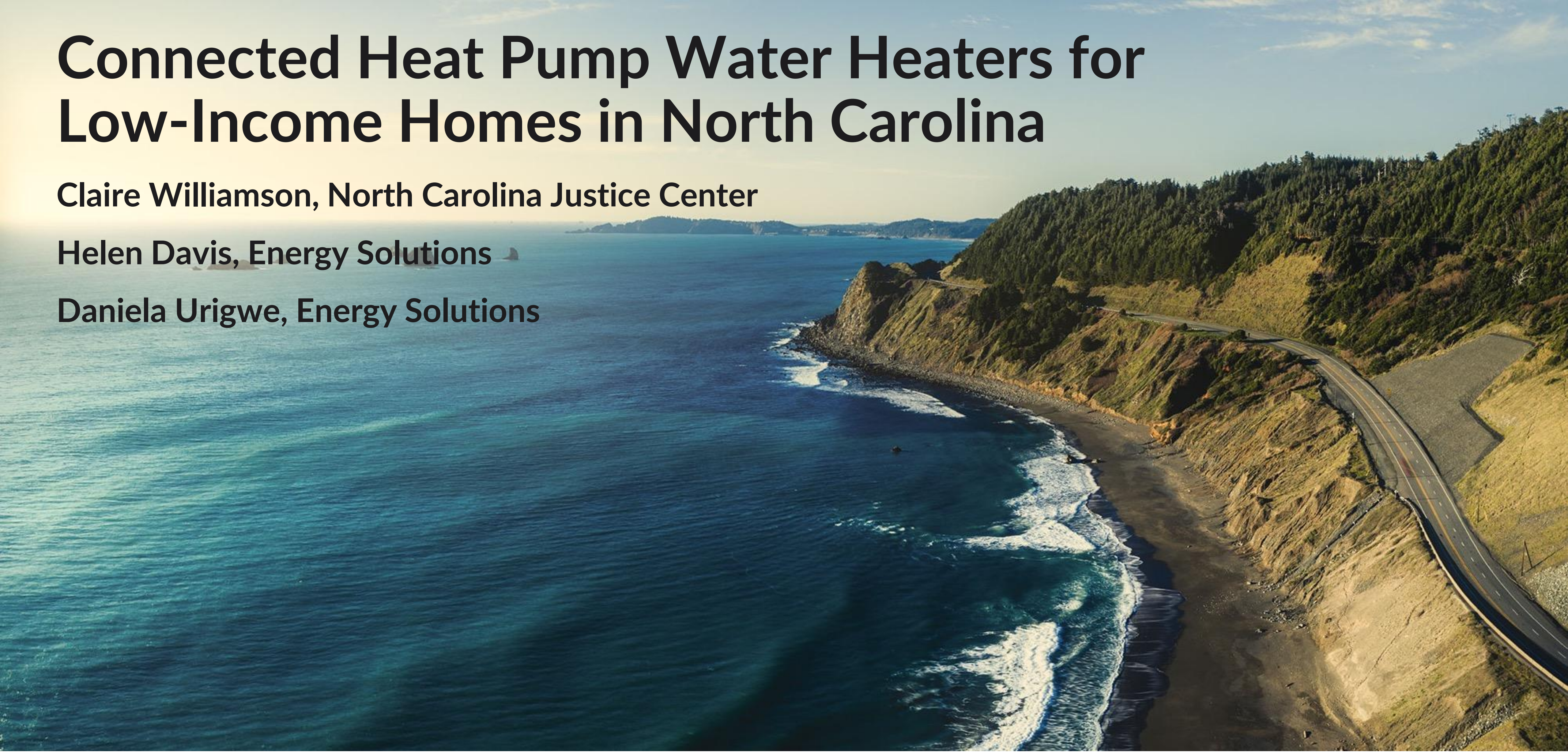


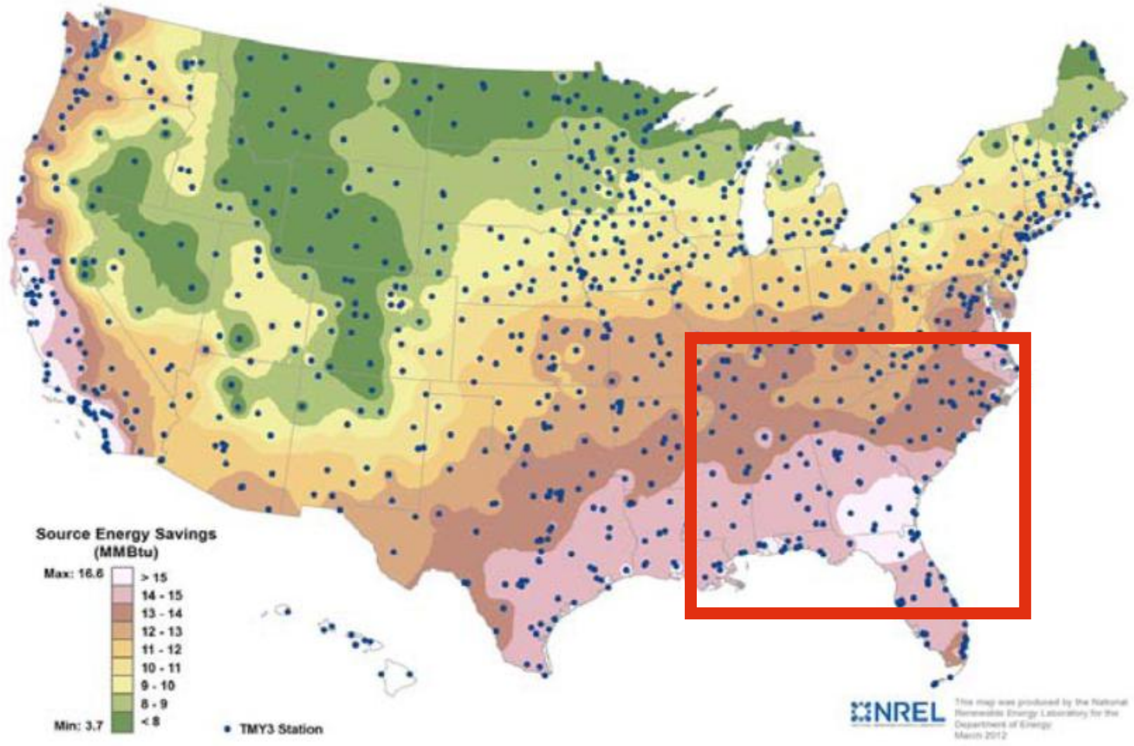
Energy Solutions

Project Motivation

Why the Southeast?

The Southeast is an ideal region to apply lessons learned from prior studies of connected water heaters.

- High penetration of residential electric water heaters
- High potential for energy savings through heat pump water heater (HPWH) market uptake
- Some utility demand response programs are available



Annual Source Energy Savings: HPWH vs. Electric WH in Unconditioned Space
Source: NREL Highlights: NREL Develops Heat Pump Water Heater Simulation Model, Kate Hudon 2012. Based on research performed by Jeff Maguire.

Project Motivation and Contributors

- 2017-2018: BPA, PGE, NEEA, and PNNL collaborated on a large-scale, connected HPWH study
- 2020-2022: PNNL partnered with the Florida Solar Energy Center on a Florida field study and lab testing of connected HPWHs

This study builds on prior work but focuses on low-income and hard-to-reach participants in high potential North Carolina.

Key Contributors

U.S. Department of Energy
Pacific Northwest National Lab (PNNL)
North Carolina Justice Center
Preserving Home

Project Funding and Contributors

- Project idea originated in conversations between Chris Granda, now at Energy Solutions, and Al Ripley, formerly with North Carolina Justice Center
- Funded by the Department of Energy with in-kind services and EcoPort communication modules provided by Pacific Northwest National Laboratory
- Preserving Home (previously Rebuilding Together of the Triangle) installed the HPWHs in eligible homes using state administered COVID recovery funding, providing a pool of potential participants. They also helped with last minute install needs.

Key Facts and Participants

About Energy Solutions

Our Mission: Create large-scale energy and environmental impacts by leveraging market-based solutions.

- For 25 years, our pioneering, market-driven solutions have delivered reliable, large-scale and cost-effective savings to our utility, government, and private sector clients across North America.
- We are a mission-led, employee-owned clean energy implementation firm whose team of smart, passionate people are committed to excellence and to building long-lasting, trusted relationships with our clients.

Project Goals

- **Save energy and money:** Document energy savings and opportunities for water heater load shifting to reduce energy costs for low-income customers
- **Shift load without compromising comfort:** Document operation of connected, load shifting HPWHs for the Southeast U.S. climate and for participant load profiles
- **Best practices for outreach:** Share lessons learned for implementing HPWH load shifting programs in low-income communities or with hard-to-reach customers

Key Project Facts

24 installations of 240-volt HPWHs with EcoPorts

Control via e-Radio cellular modules and CTA-2045 messages

$200 payment for study participation after completing surveys.

Installations in single family, low-income homes in North Carolina

1 year of control and monitoring

No mixing valves or changes to participant water heating mode

Participant Homes and Equipment

Home Ages	Between 1930 and 2010; most 1970s-era
Home Sizes	• Range: 640 to 2,535 sq. ft. • Average: 1,300 sq. ft.
Water Heater Location	• 11 in conditioned spaces • 9 in semi-conditioned space inside envelope • 4 in unconditioned space outside envelope
Prior Water Heater	• 12 gas WHs • 9 electric resistance WHs, 3 not reported
HPWH Size	• 23 50-gallon tanks • 1 80-gallon tank
HPWH Install Date	Between May 2021 and May 2023

Study Participants

- **All low-income**; about 80% are below 50% area median income
- **Most participant homes are comprised of seniors and adults.** Five homes also have children or teens.
- 1 to 6 people per home, **most commonly 1-2 occupants** per home
- Household occupancy changes common due to change in number of residents staying in home, health issues, etc.

Occupants	Number of Households
1	13
2	7
3	2
5	1
6	1

Occupant Category	Number of Households
Children (0-12 y.o.)	4
Teens (13-18 y.o.)	3
Adults (19-64 y.o.)	11
Seniors (65+ y.o.)	13

Participant Recruiting Highlights

Highlights

- Participants trust Preserving Home, so referral was successful
- Many participants had noticeable bill savings due to switch to HPWH

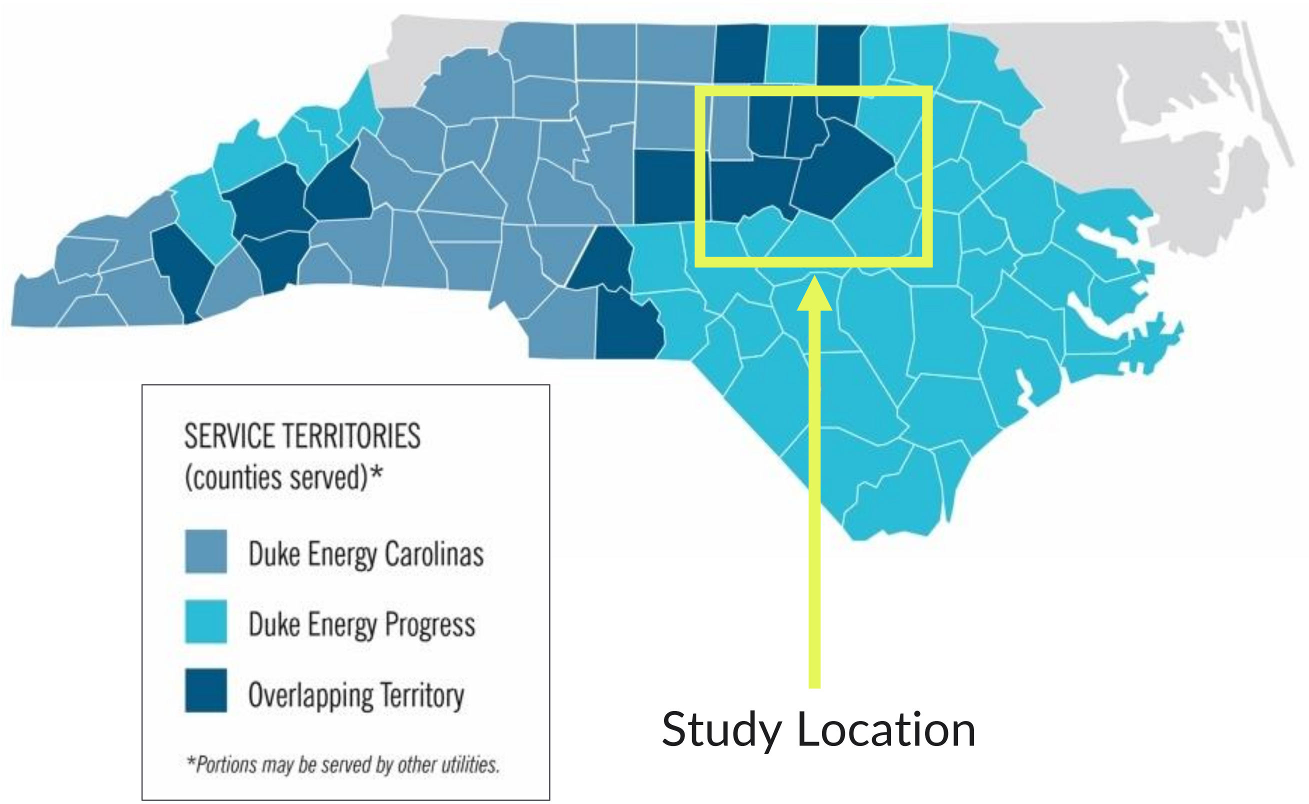
Challenges

- Some participants do not have email or Wi-Fi
- Some participants are unable to physically reach or see the HPWH user interface or communications module to troubleshoot
- Many participants did not trust online interactions; many were unwilling or unable to connect to manufacturer cloud

Load Shifting Design and Results

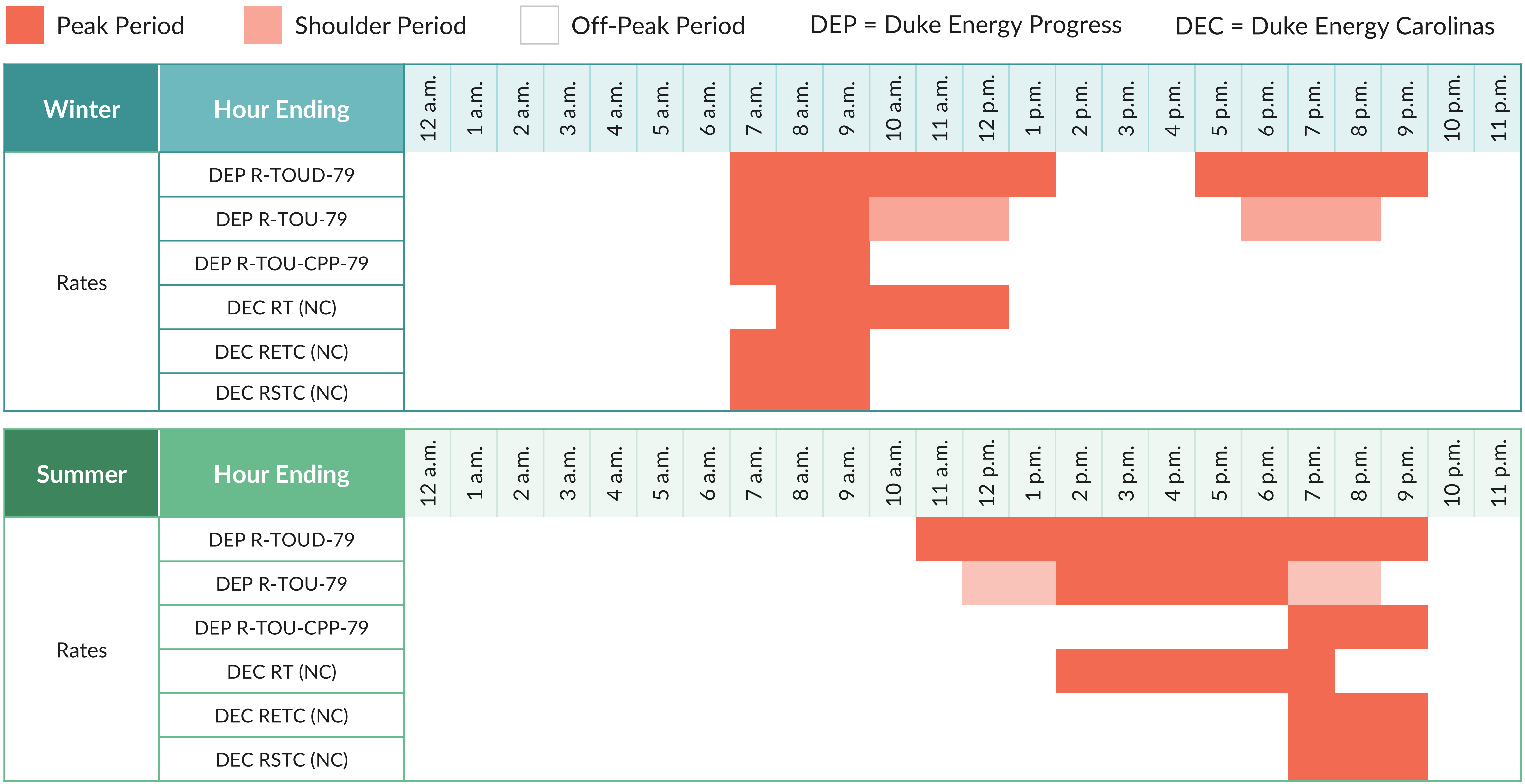
Utility Territories

Utility	Number of Households	Time of Use (TOU) Rate Available (at Time of Study Design)
Duke Energy Carolinas	7	**YES**
Duke Energy Progress	8	**YES**
Piedmont Electric Co-op	1	**YES**
Town of Apex	5	**YES**
Not Specified	3	N/A

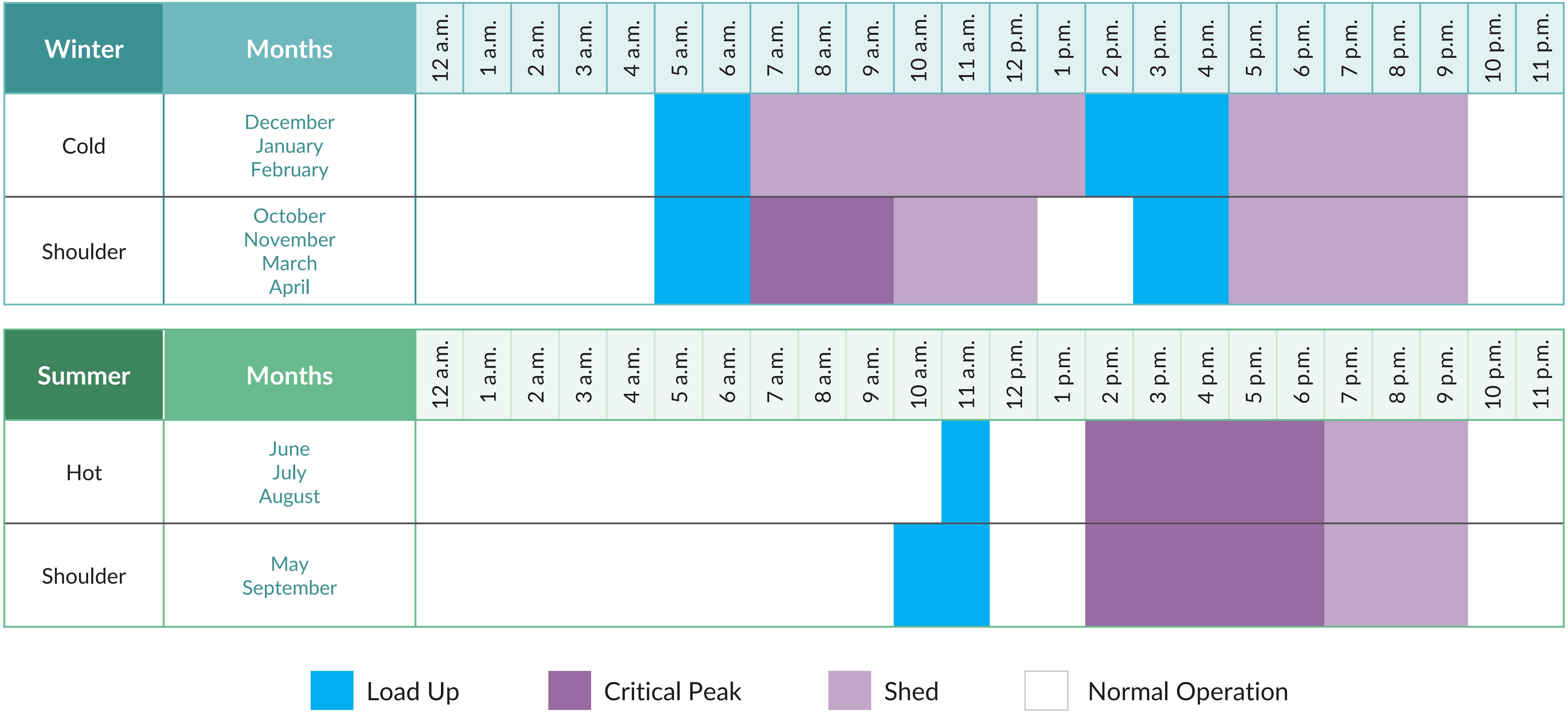


Source: Duke Energy

Duke Energy Time-of-Use Rate Periods (Early 2023)

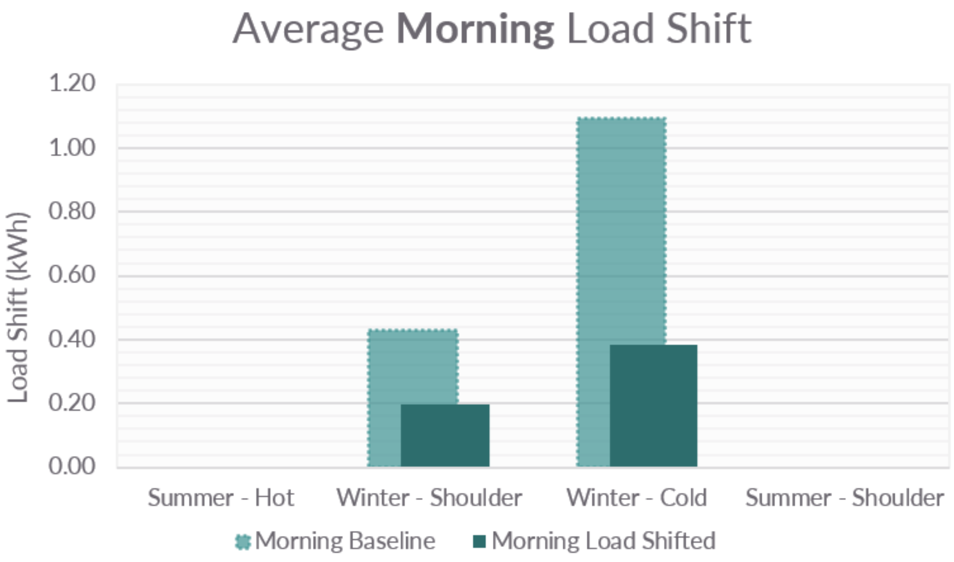


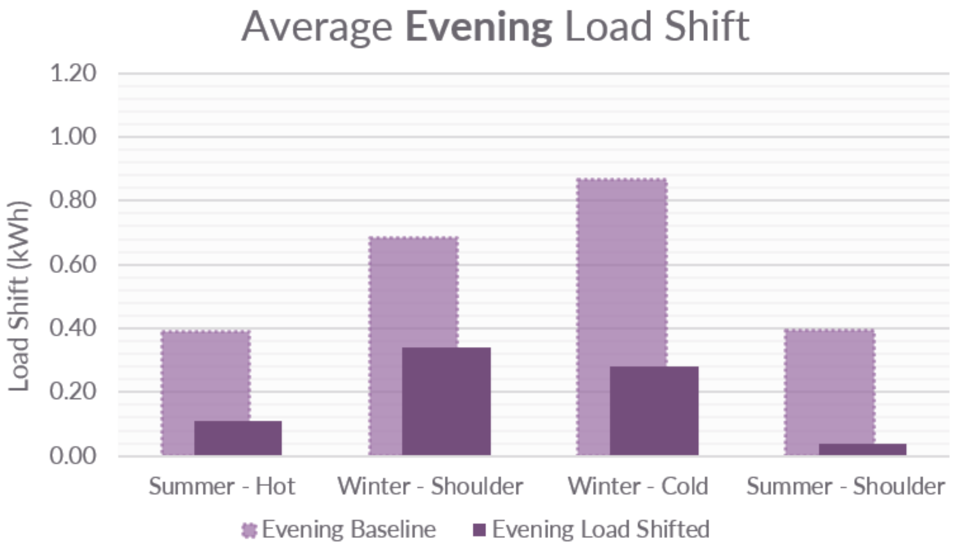
Seasonal Load Shifting Strategies



Results – Load Shifting by Season

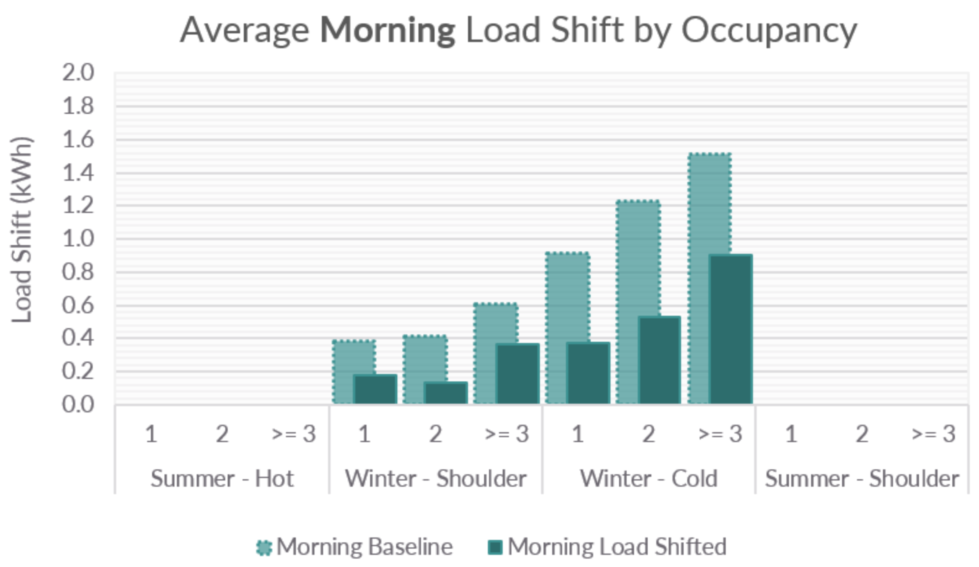
Shifting Schedule	Shed Periods	Average Daily Energy *Savings*	
		kWh	% of non-shifting baseline
Summer – Hot	Evening: 1 to 9 p.m.	0.10	4%
Winter – Shoulder	Morning: 6 a.m. to 12 p.m. Evening: 4 to 9 p.m.	0.11	4%
Winter – Cold	Morning: 6 a.m. to 1 p.m. Evening: 4 to 9 p.m.	0.20	6%
Summer – Shoulder	Evening: 1 to 9 p.m.	0.34	12%

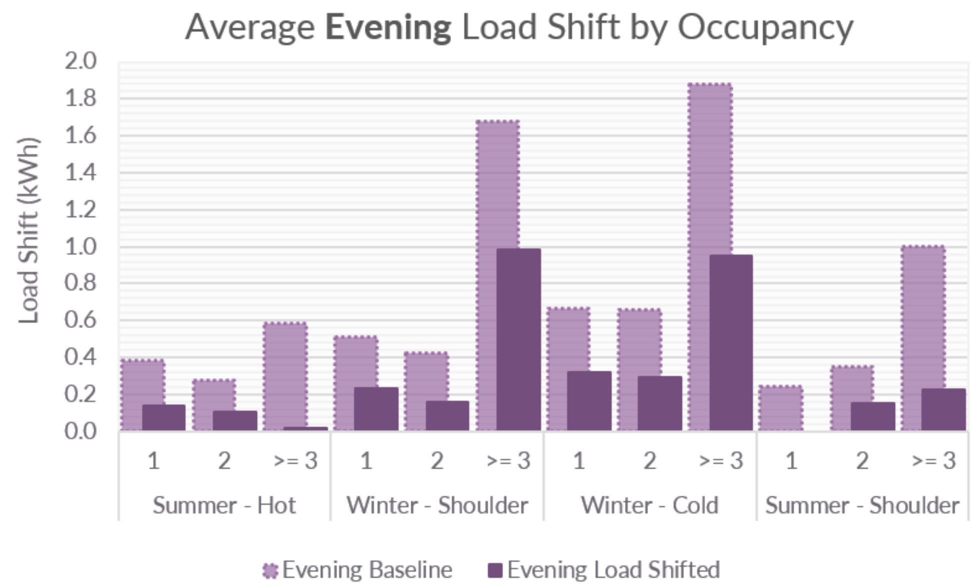




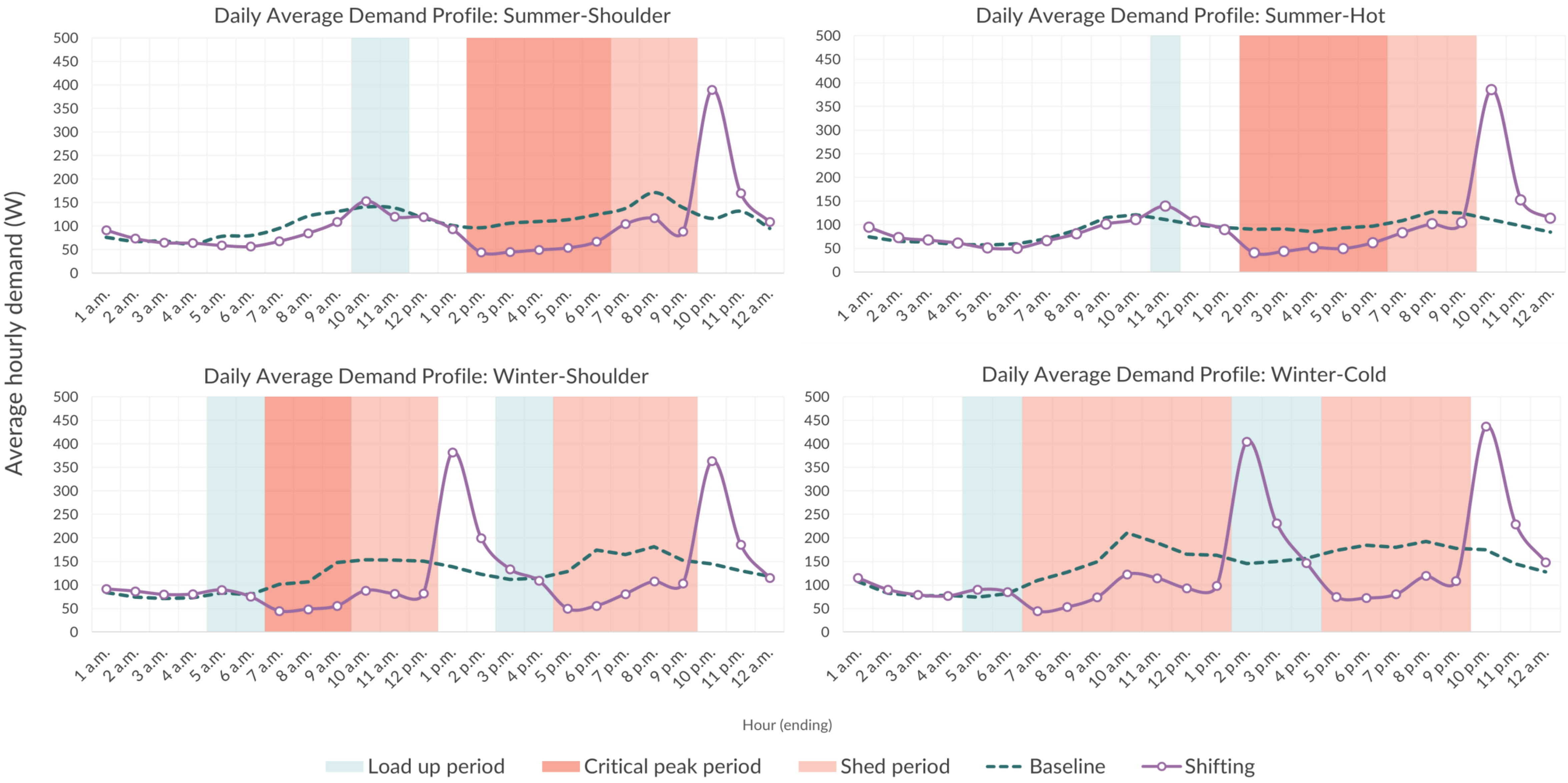
Results – Load Shifting by Occupancy

Shifting Schedule	Occupants	Count in Sample	Average Daily Energy *Savings*	
			kWh	% of non-shifting baseline
Summer – Hot	1	14	0.09	3.8%
Winter – Shoulder			0.02	0.8%
Winter – Cold			0.03	1.1%
Summer – Shoulder			0.24	9.2%
Summer – Hot	2	6	0.03	1.5%
Winter – Shoulder			-0.16	-6.5%
Winter – Cold			0.09	2.7%
Summer – Shoulder			0.19	7.7%
Summer – Hot	3 or More	4	0.26	9.7%
Winter – Shoulder			0.86	19.7%
Winter – Cold			0.98	18.6%
Summer – Shoulder			0.93	23.6%

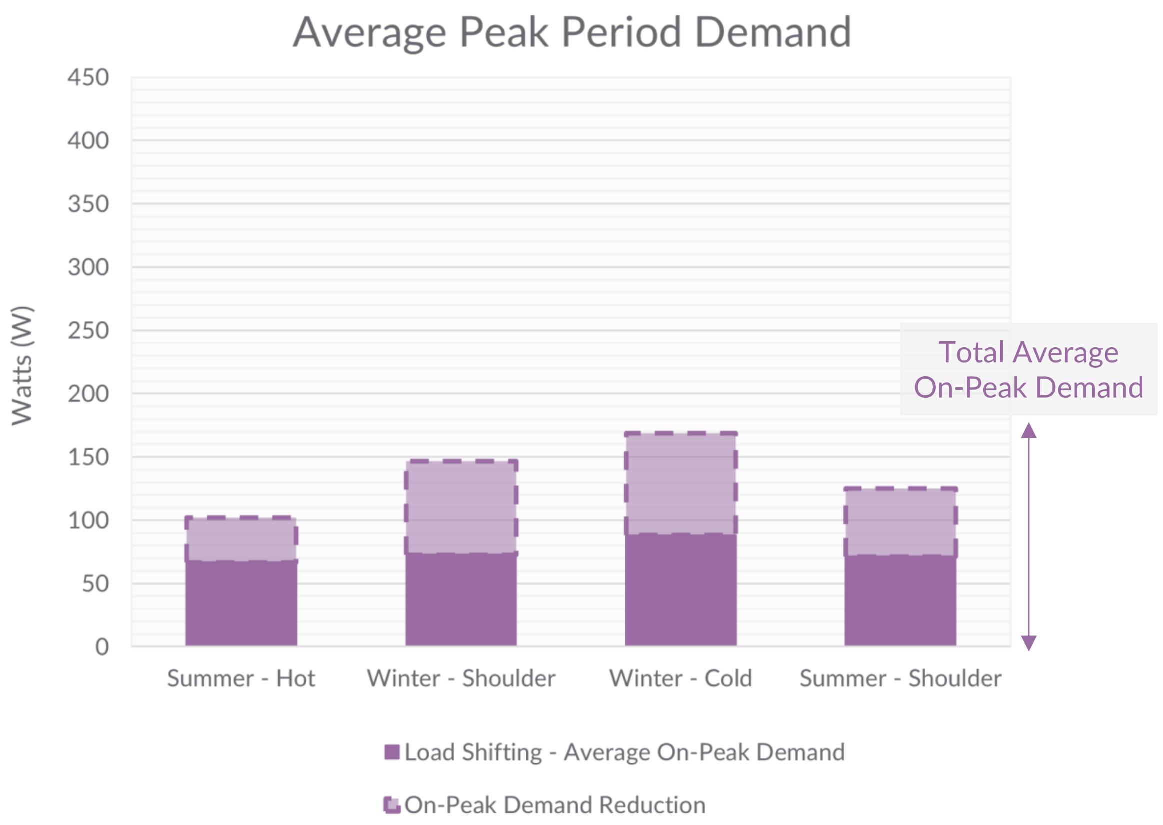




Results – Customer Demand Profiles by Season

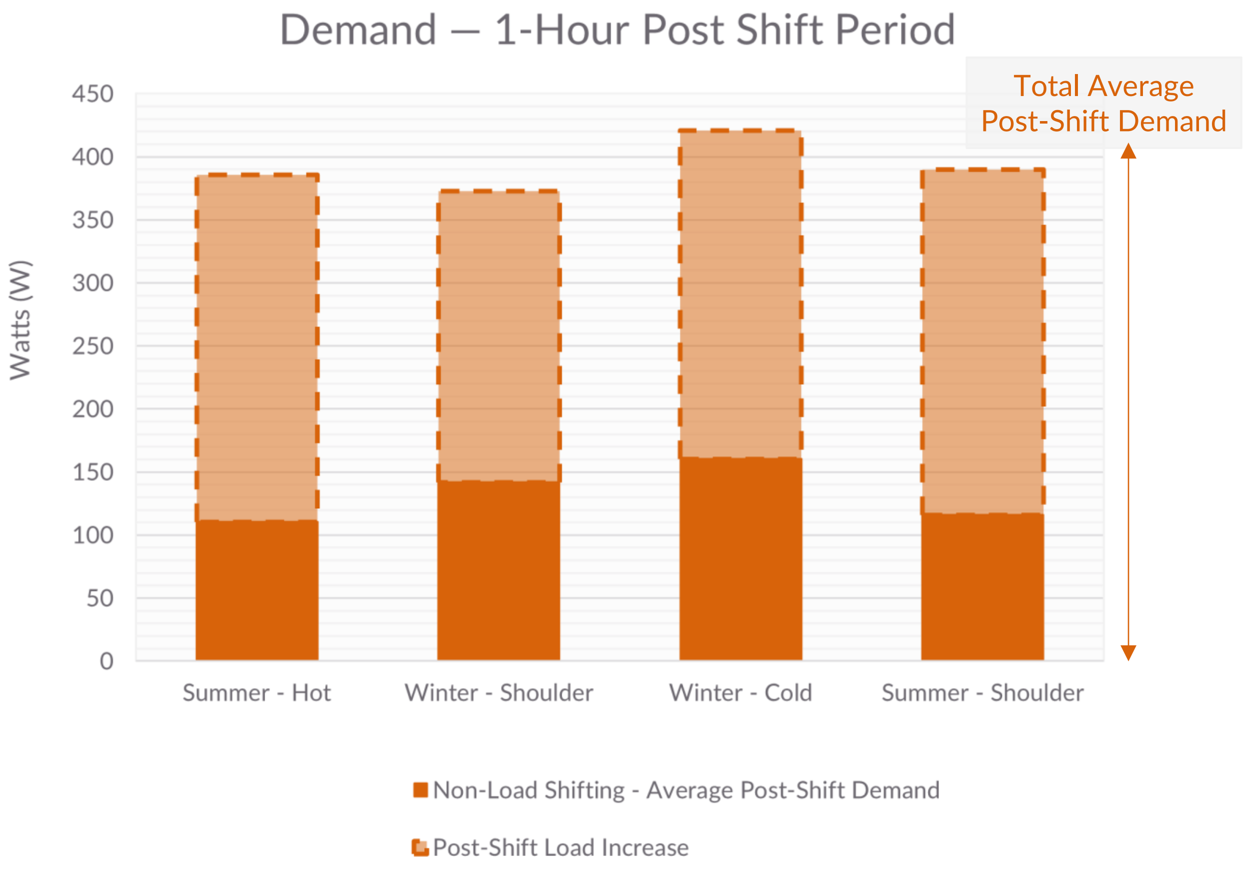


Results – On-Peak Demand and Electric Resistance Element Usage



Shifting Schedule	Hours of Load Shift Per Day	% of shift window hours with electric resistance use	
		Non-Load Shifting Baseline	Load Shifting
Summer – Hot	8	2.4%	1.7%
Winter – Shoulder	11	4.0%	1.6%
Winter – Cold	12	5.3%	2.1%
Summer – Shoulder	8	4.3%	1.7%

Results – Recovery Demand and Electric Resistance Element Usage

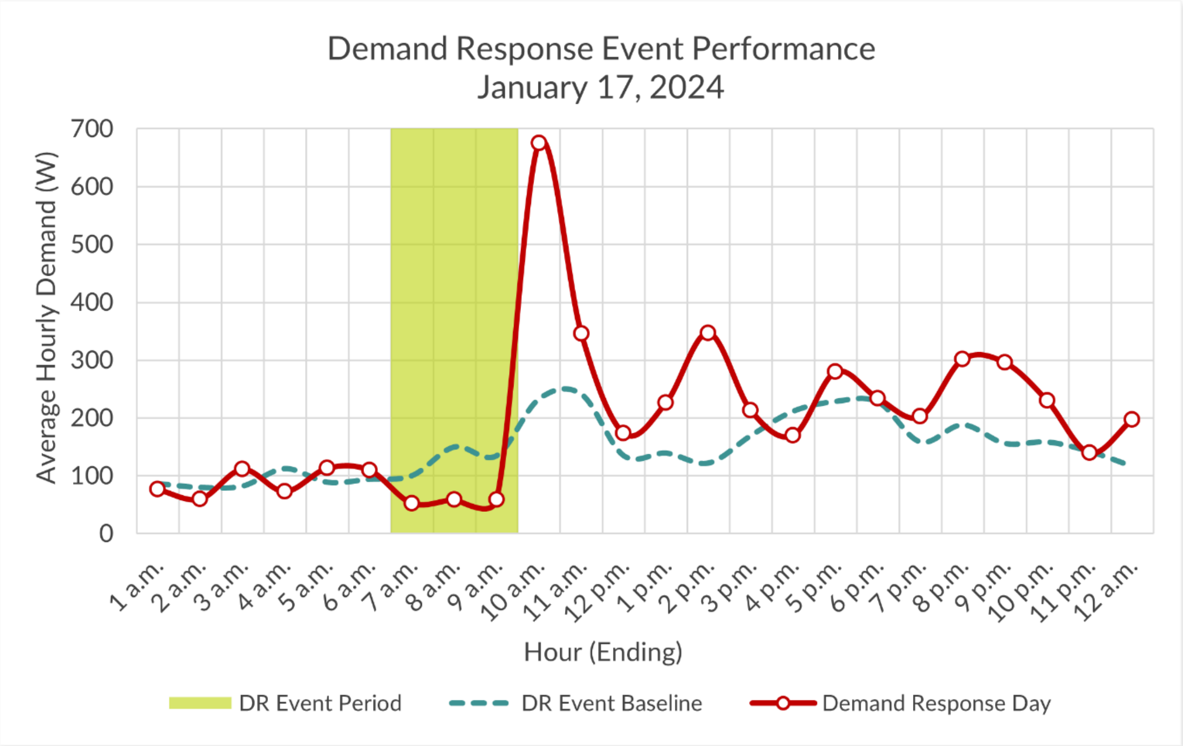


Shifting Schedule	% of post-shift window hours with electric resistance use	
	Non-Load Shifting Baseline	Load Shifting
Summer – Hot	3.4%	11.1%
Winter – Shoulder	4.1%	14.0%
Winter – Cold	4.3%	11.7%
Summer – Shoulder	4.3%	11.7%

Results – Electric Resistance Element Usage by Participant

		Summer - Hot		Summer - Shoulder		Winter - Cold		Winter - Shoulder	
		Percentage of Shift Window Hours with Electric Resistance Element Usage							
Participant	Occupants at start of study	Non-load shifting	Load shifting	Non-load shifting	Load shifting	Non-load shifting	Load shifting	Non-load shifting	Load shifting
13	6	31.3%	25.4%	45.0%	24.7%	31.3%	12.0%	31.5%	14.0%
31	5	7.8%	4.9%	29.5%	5.5%	38.5%	12.5%	29.4%	6.0%
29	1	21.9%	10.6%		13.8%	7.9%	0.4%	12.0%	5.1%
15	1					18.7%	11.9%	1.0%	3.0%
34	1		0.4%	10.7%		10.3%	0.3%	12.9%	0.1%
32	1		0.9%	9.8%	2.7%			2.4%	2.1%
25	2					4.4%	1.5%		
10	2	0.2%		0.5%	0.3%	3.2%	4.9%	1.7%	5.4%
19	2	0.7%	0.4%		0.6%	2.4%	3.2%	3.1%	2.9%
17	1	0.9%		1.6%	0.6%	4.4%	0.3%		
20	2	1.6%			0.3%	4.0%	0.8%	2.1%	0.2%
24	3	2.0%						1.0%	
16	1	2.5%		1.0%		0.4%	0.2%	0.7%	
30	3					0.8%	0.6%		
23	1					0.4%	1.1%		0.2%
28	1				0.6%	0.4%	0.6%	0.3%	0.3%
18	1	0.6%					0.6%		0.1%
26	1	0.2%				0.4%			
21	2				0.3%	0.4%	0.2%		0.2%
14	2								0.1%

Results – Winter Morning Peak Demand Response Event



Conducted test DR event from 6-9 a.m. on a cold winter day (20 °F) to simulate grid peak day load reduction

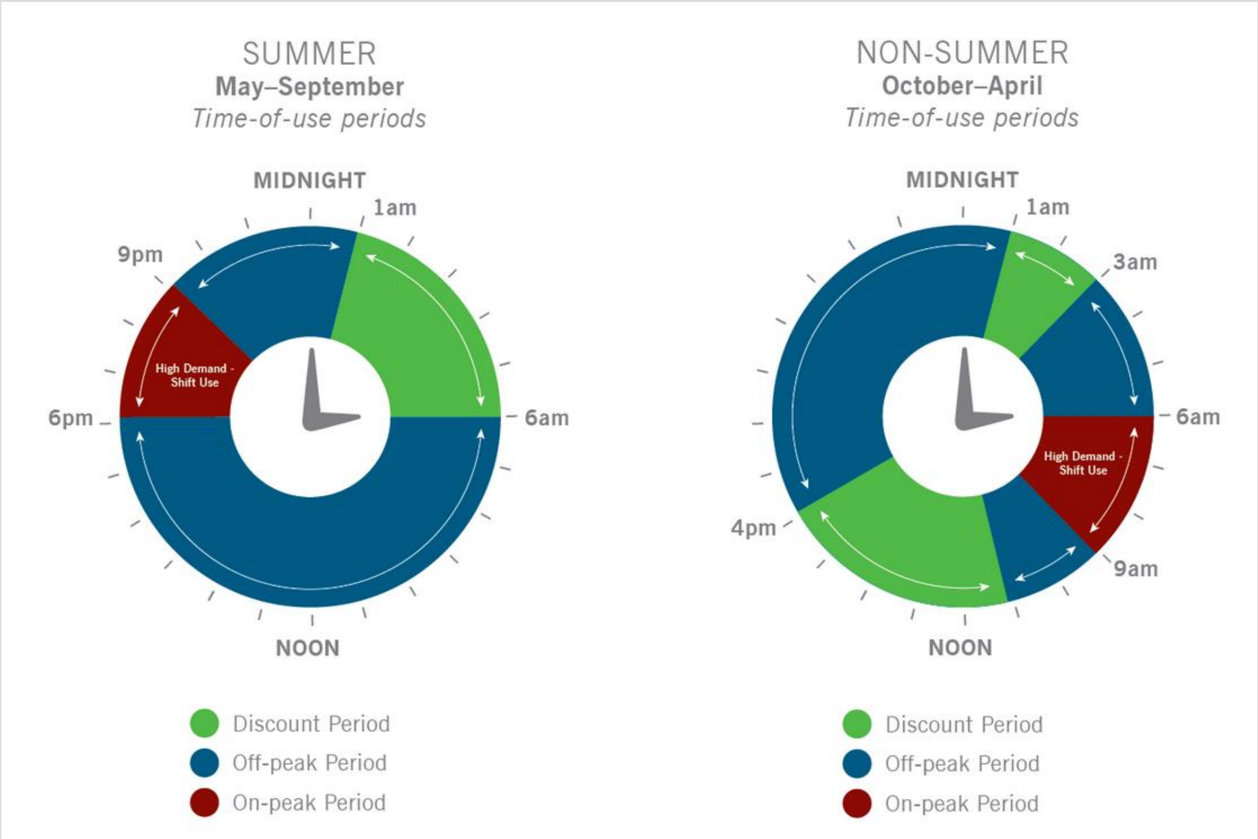
Water heaters minimized operation and avoided using compressors or electric resistance elements during the event.

Average load reduction was **72 W** per participant.

Controlled HPWHs can be a valuable grid asset and further contribute to annual peak load reduction, even for participants with low baseline energy use.

Regional Opportunities

- TOU rates used in study included 5+ hour peak periods, so load shifting periods were 6-8 hours
- Long load shifts were possible because of low occupancy and water usage for most participants
- More recent Duke Energy TOU rates have new season months, shorter peak periods, and low-price discount periods
- The shorter peak periods could make load shifting easier, and customers can save more by shifting operation to discount periods



Duke Energy Carolinas Residential Time-of-Use Rate, 2025
Source: Duke Energy, https://www.duke-energy.com/home/billing/time-of-use


Conclusions and Recommendations

Conclusions

- Controlled HPWHs can **reduce water heating electricity costs** for low-income households in the Southeast that have access to time-varying rates
- Demand responsive HPWH can **reduce load during grid peak periods** in the Southeast 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
- **Engaging low income and hard-to-reach households** can be successful when the programs are designed to respond to their needs

Recommendations

Customers

Educate low-income customers on how to lower costs on TOU rates

Set expectations for customers switching to HPWH

Upsize units to ensure hot water availability for variable occupancy or multi-generational homes

Programs

Reach out via trusted channels

Recognize the value of hard-to reach customers

Account for unique demographic impacts – e.g., seniors with low hot water use

Provide non-Internet-based enrollment and support options

Don't require home Wi-Fi, email or apps

Rates

Load shifting-favorable TOU rates (e.g., targeted peak periods and low off-peak costs) incentivize better participation

Customers without flexible loads may not benefit from time-varying rates – explore using connected product data to apply TOU rates only to flexible loads

Manufacturers and Installers

Low-income customers with product issues need support for both equipment *and* labor costs for warranty claims and reinstallations

Carefully consider HPWH install location within home to avoid performance issues and customer dissatisfaction

Thank you

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