Load Shifting with Heat Pump Water Heaters in the Southeast U.S.

Pacific Northwest National Laboratory
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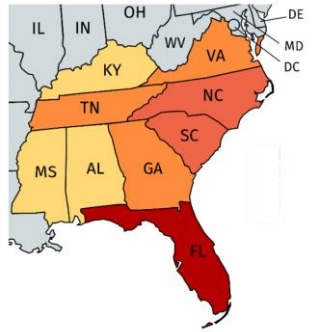
WBS # 1.4.1.19

Project Summary

Objective and Outcome:

- Assist Energy Solutions with heat pump water heater load shifting project in North Carolina
- Determine if load shifting results in a low-income community in North Carolina are similar to an average community in Florida



Team and Partners:

PNNL

Josh Butzbaugh, Travis Ashley, Cheryn Metzger

Partners

Energy Solutions
Florida Solar Energy Center
e-Radio

Stats:

Performance Period: FY21–FY24

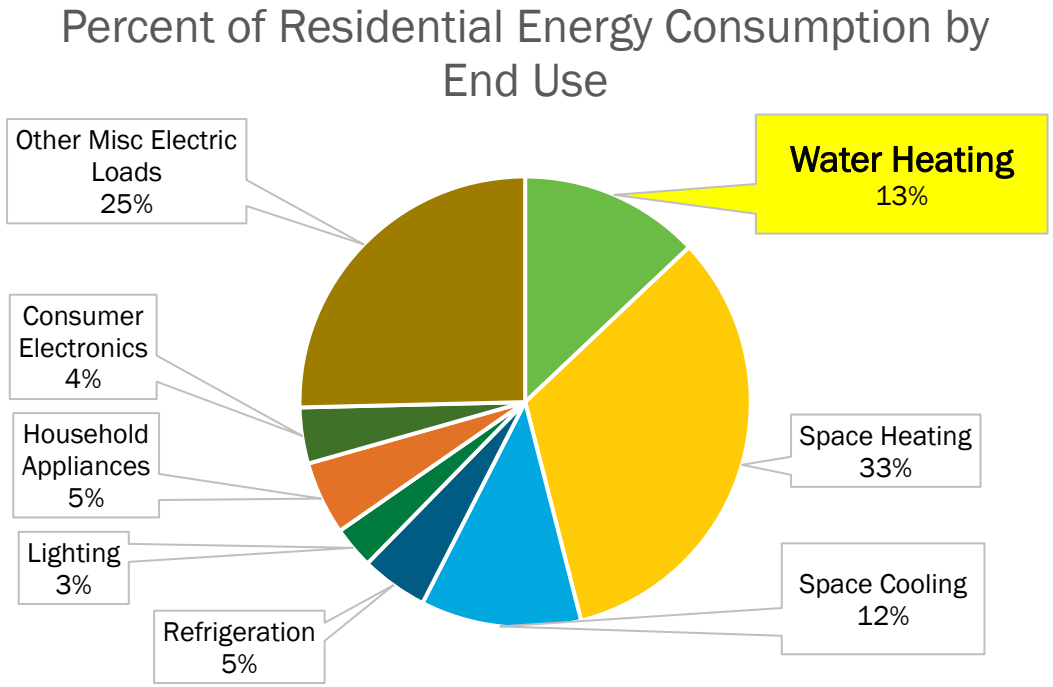
DOE FY23 Budget: $150k

Official Cost Share: $0k
Unofficial Cost Share: $400k from Energy Foundation

Milestone 1: Draft technical report on load shifting with HPWHs in North Carolina

Problem

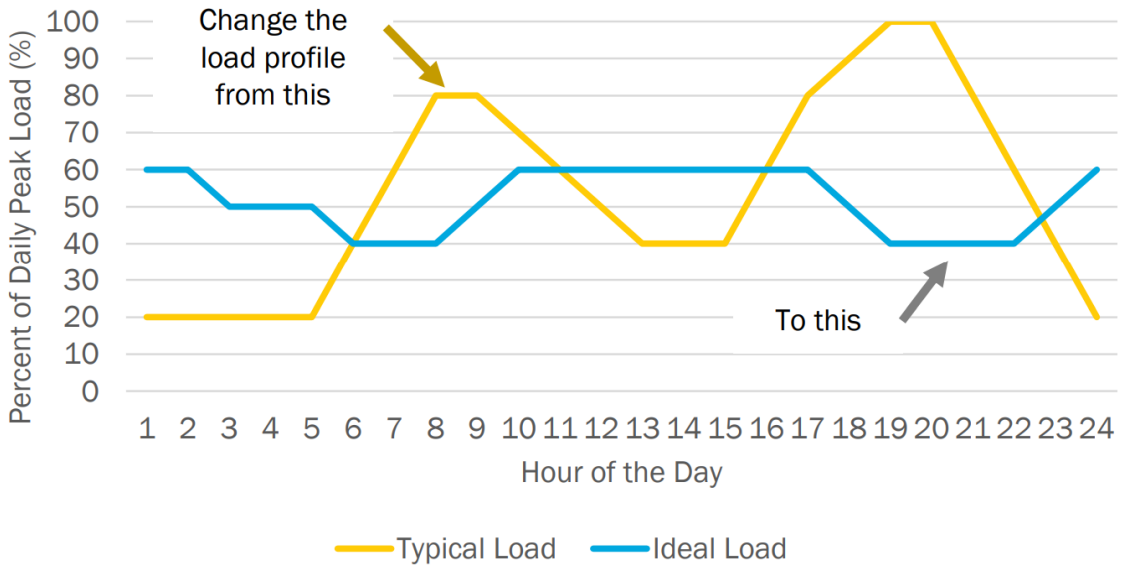
- **Water heating is the second largest energy end use in the U.S. residential sector**
- Underserved communities face a significant energy bill burden and are more likely to experience utility-implemented power outages
- **Heat pump water heaters (HPWHs) can save 60-70% of water heating energy** compared to electric resistance water heaters (ERWHs)



Source: 2023 Annual Energy Outlook, Table 4. Residential Sector Key Indicators and Consumption

Alignment and Impact

- The Building Technologies Office has a goal to decarbonize the building stock by 2050
- Residential electric loads fluctuate, and peak power is more expensive. These costs are passed onto customers.
- Thermal characteristics of storage water heaters provide an option to manage peak power requirements by shifting when water heaters operate
- When HPWH technology is combined with load shifting and time-of-use rates, there is **potential to greatly reduce energy bills**, which can have a **high impact for people living in underserved communities**



Photos Courtesy of NREL PICS Database

Approach – Use CTA-2045 (Branded EcoPort)

- In the recent past, utility provider demand response programs relied on ERWH technology and used direct load control scheme.
- The development of the CTA-2045 standard (branded EcoPort) for electric water heater load shifting has redefined load shifting control by using specific commands and allowing manufacturers to determine water heater responses to those commands.
  - Any number of stakeholders (including utilities) can pay for the hardware to turn an unconnected CTA-2045 enabled appliance into a connected appliance
  - Modular interface supports many types of communication (e.g. Wi-Fi, 4G LTE, FM, etc.)

Approach - Build on Lessons Learned from the NW

In FY18-21, PNNL conducted an electric water heater load shifting study in the Pacific Northwest in collaboration with the Bonneville Power Administration, Portland General Electric, and Northwest Energy Efficiency Alliance

- Studied use of the CTA-2045 standard (branded as EcoPort) using simple load shifting strategies for HPWHs and ERWHs
- Demonstrated grid-connected HPWHs as an effective resource to shift load
- Portland General Electric adopted some of the researched load shifting strategies into its program

The Pacific Northwest is a unique region for energy programs

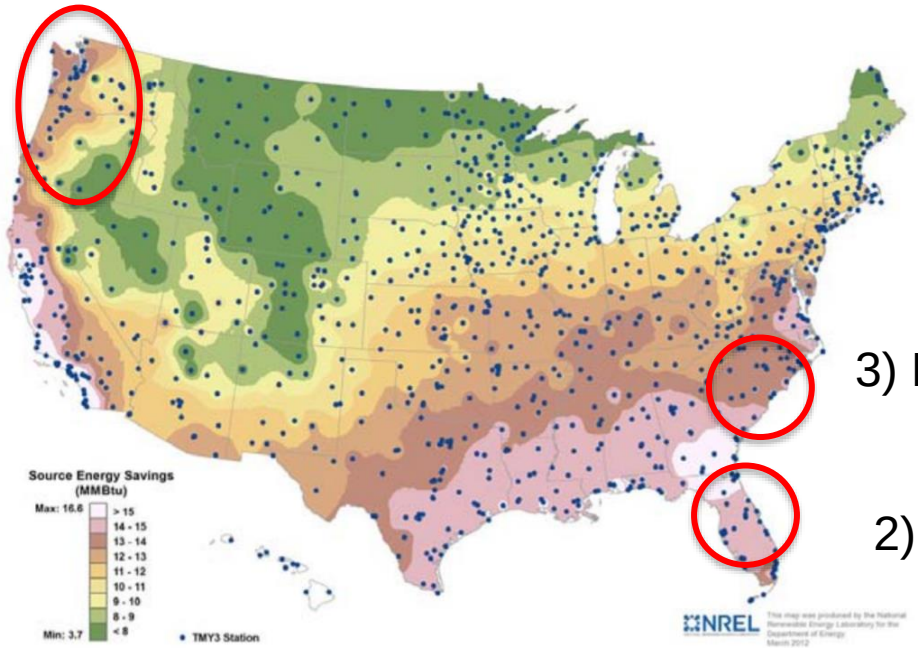
- Active and committed region to energy efficiency and demand response
- Extensive HPWH programs featuring instant rebates, tax credits, installer bonuses, and other tactics

Question became: *Can we repeat this success story in a region with high energy savings and load shifting potential?*

Approach - Target High Impact Area

- Southeast region is an ideal candidate for applying lessons learned from the Pacific Northwest
  - High number of residential electric water heaters in residential housing stock
  - Utility incentives for HPWHs are relatively sparse whereas utility demand response programs are more common
- In FY20-22, PNNL conducted a two-track HPWH load shifting study in Florida in partnership with the Florida Solar Energy Center (FSEC)
  - Field study of grid connected HPWHs in the Central Florida region
  - Lab testing of grid-connected HPWHs and a grid-connected ERWH in the FSEC lab

1) Northwest
2018-2021



3) North Carolina
2023-2024

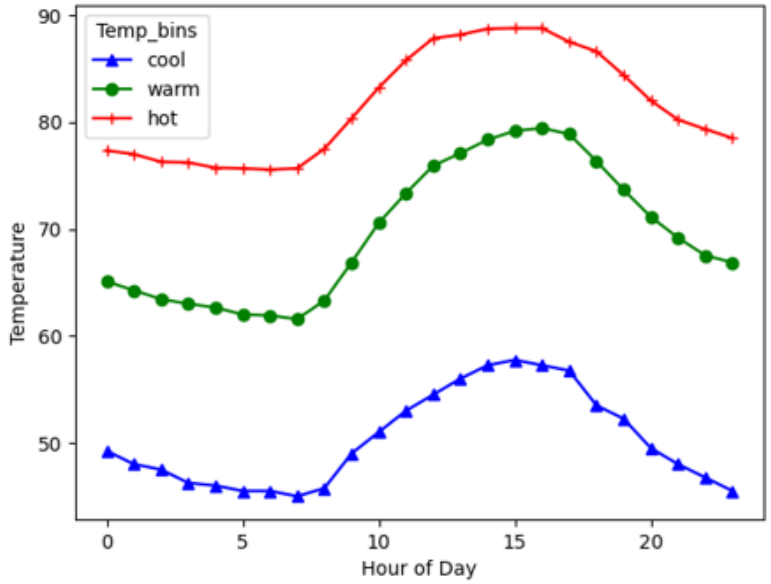
2) Florida
2020-2022

NREL Highlight: NREL Develops Heat Pump Water Heater Simulation Model, 2012. Based on research performed by Jeff Maguire.

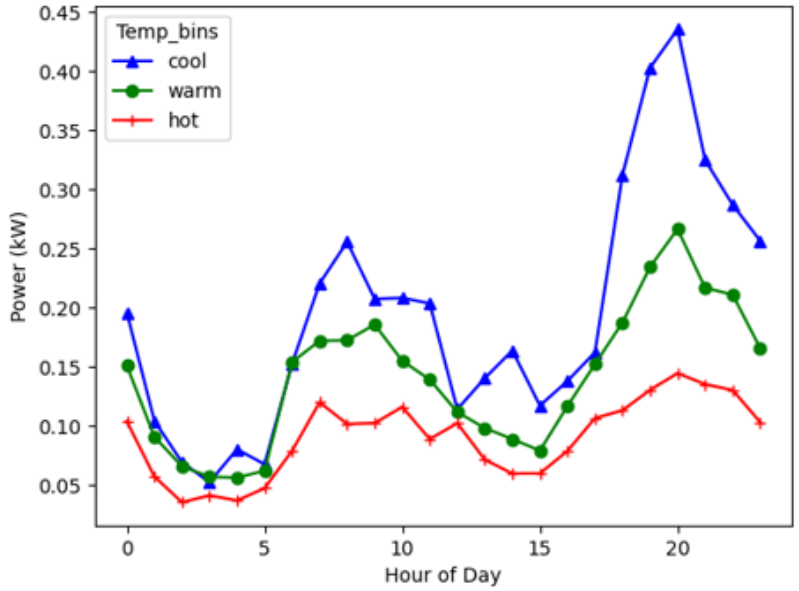
Approach – Establishing Baseline

- HPWH energy use is driven primarily by hot water consumption, surrounding air temperature, and inlet water temperature
- Correlation between air temperature and daily HPWH energy use in field study (0.86 R^2)
- To account for surrounding air temperature, three HPWH baselines were generated from the field data for the cool, warm, and hot air temperature bins
- Daily energy consumption and morning/evening load shifting was studied by strategy compared to temperature-binned baseline

Daily Air Temperature Profiles



Baseline Load Profiles



Daily avg temperature ranges by bin:

- Cool: < 59 °F
- Warm: 59 °F ≤ and < 78 °F
- Hot: 78 °F ≤

Approach –Load Shifting Strategy

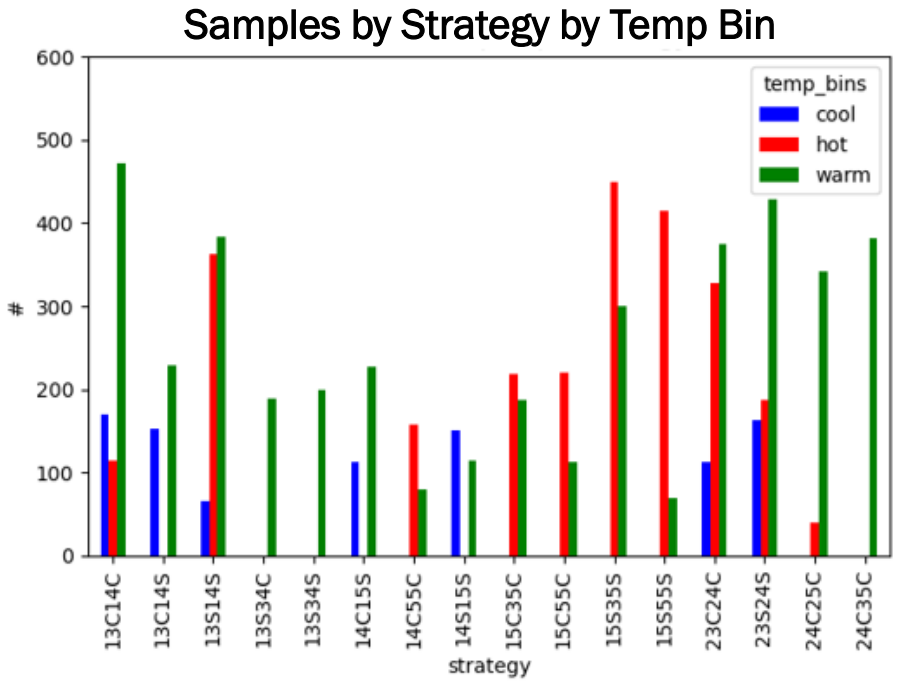
- **Load shifting strategy implementation**
  - Based on insight from utilities, peak demand periods were identified as 6–9 am and 4–8 pm
  - Morning curtailment always began at 6 am and evening curtailment at 4 pm
  - Load up periods always preceded the start of curtailment periods
- **A total of 16 strategies studied**
  - Used an abbreviation string of numbers and characters to denote the various load shifting strategies

Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

  - **CTA-2045 Curtailment types:** Shed = S, and Critical Peak = C



Progress

- Recruitment began in March 2020 in the Central Florida area
  - Recruited more than 45 occupied homes with HPWHs capable of EcoPort communications
  - Average of 3.2 occupants/home
  - 83% of participant HPWHs have 50 gallons of storage
  - 80% of HPWHs are installed in unconditioned garages
- EcoPort load shifting commands studied: load up, shed, and critical peak
- Load shifting strategies
  - 2 conventional strategies studied, repeated from PNW study: 1-3S-1-4S and 2-3S-2-4S
  - 14 new strategies investigated
- Experiments began in November 2020

Recruitment Flyer

Progress

Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

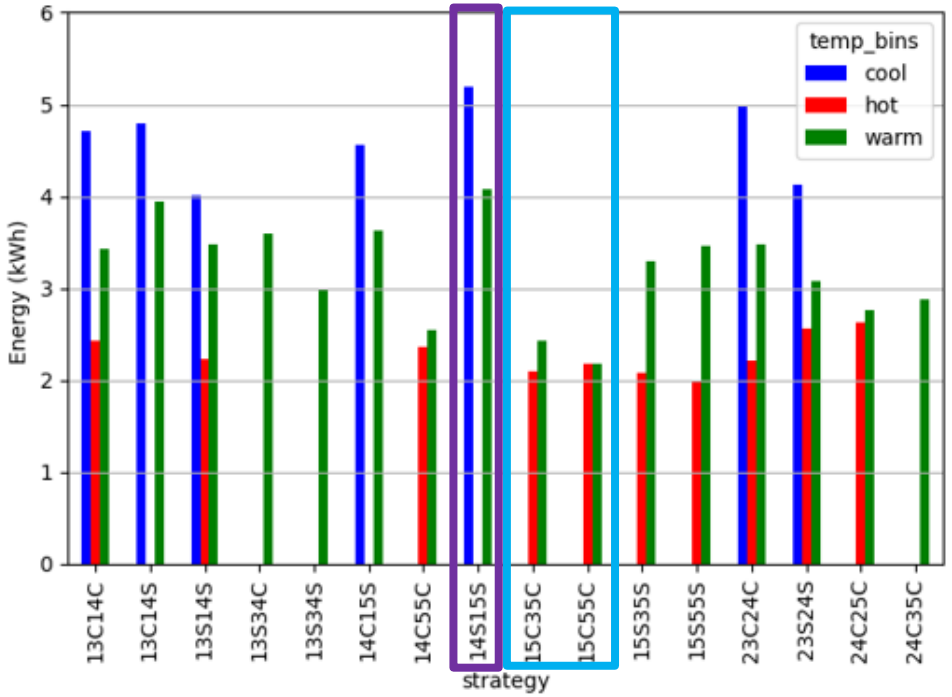
Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

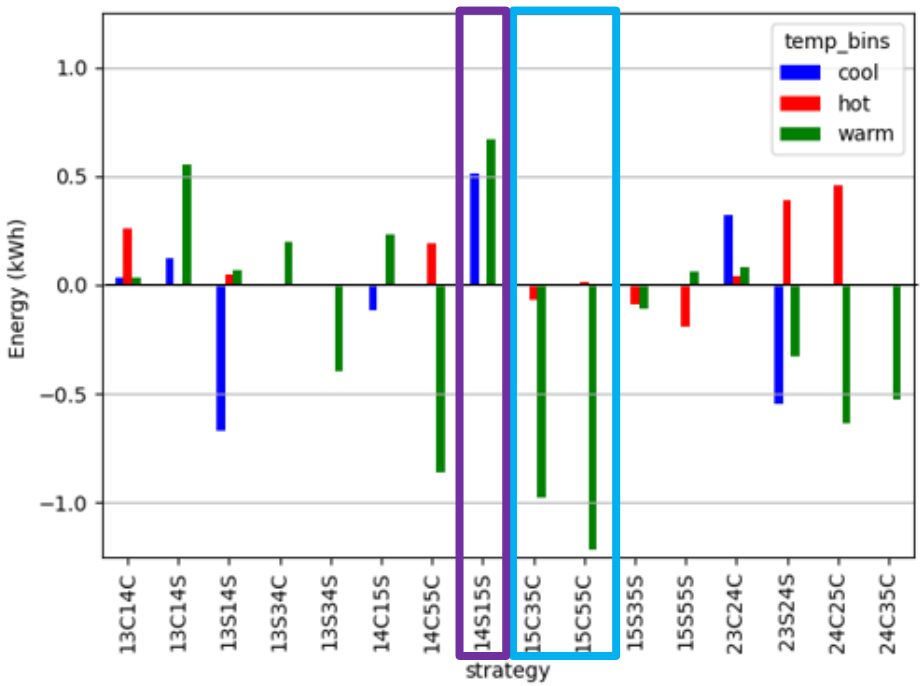
Results for Daily Energy Consumption

- Air temperature impact is clear across different strategy types.
- Strategy 1-4S-1-5S had the greatest energy consumption (Cool and Warm)
- Strategies 1-5C-3-5C and 1-5C-5-5C had lowest energy consumption (Warm), both had a longer afternoon load up duration and used Critical Peak curtailment commands

Daily Energy Consumption



Daily Energy Consumption vs HPWH Baseline



Progress

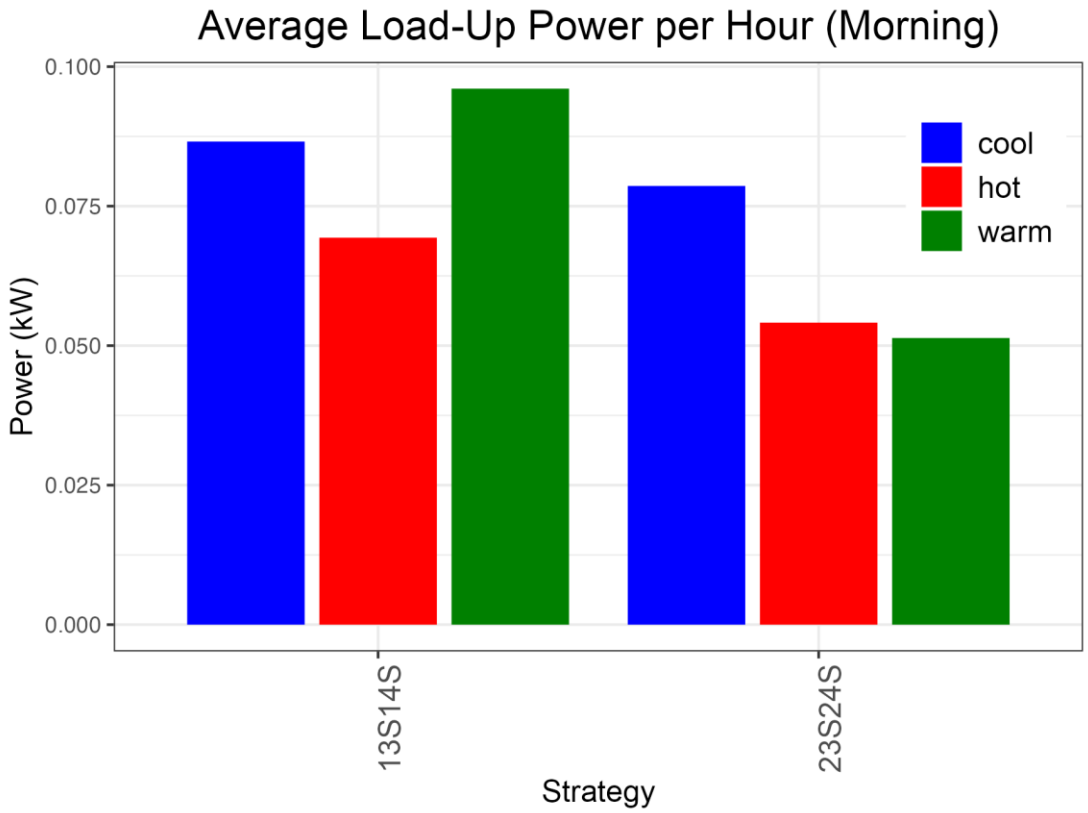
Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

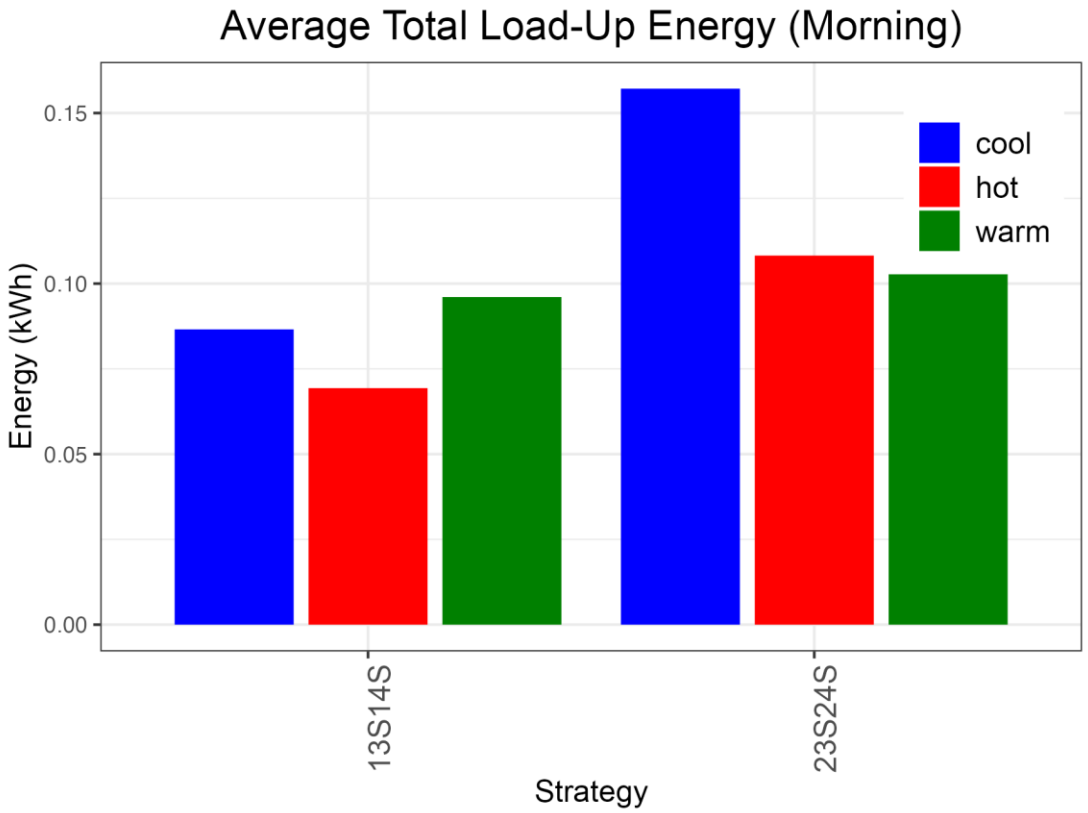
Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

Results for Morning Load-up

- For the Cool temperature bin, the two-hour load up (e.g., 2-3S-2-4S) provides almost twice the thermal storage benefit compared to the one-hour load up (e.g., 1-3S-1-4S)
- For the Hot and Warm temperature bins, the second hour of load up has diminishing returns





Progress

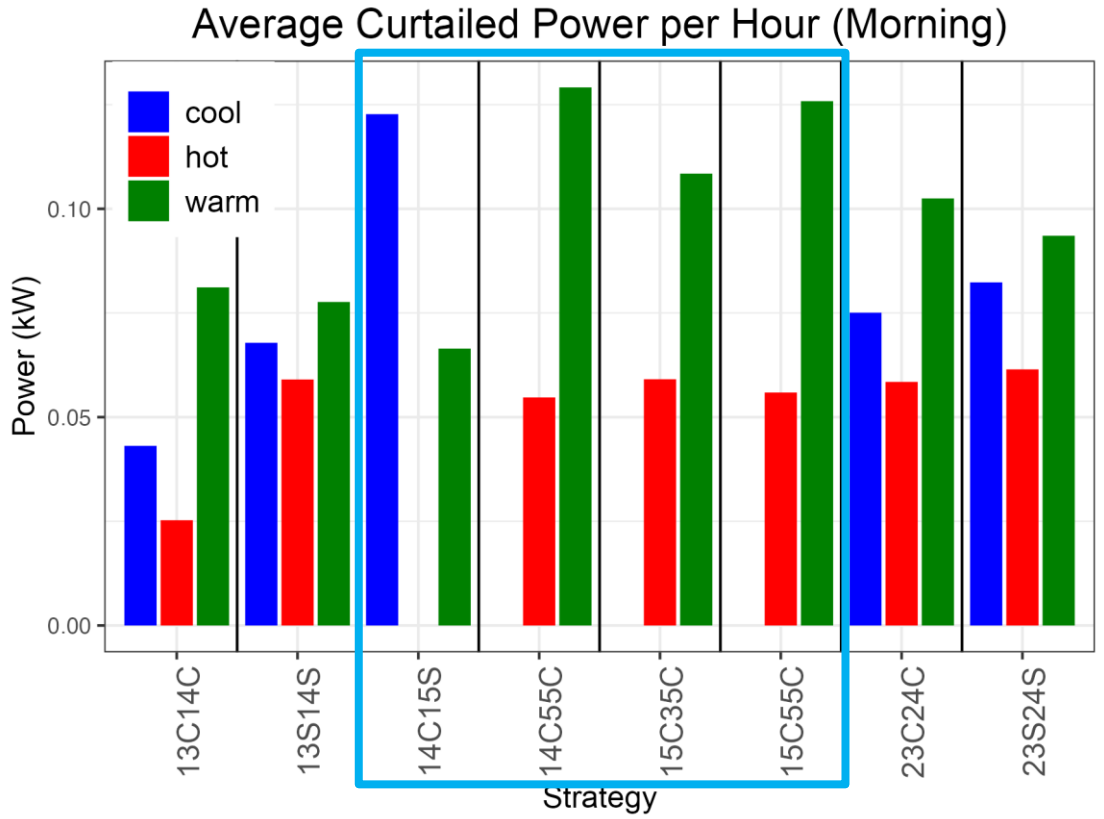
Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

Results for Morning Curtailment

- Critical Peak command over a four- or five-hour duration (e.g., 1-4C-1-5S, 1-4C-5-5C, 1-5C-3-5C, and 1-5C-5-5C) provided the largest curtailment, both in terms of hourly average power and total curtailed energy
- Average curtailed power per hour was relatively consistent in the Hot temperature bin across duration and commands



Progress

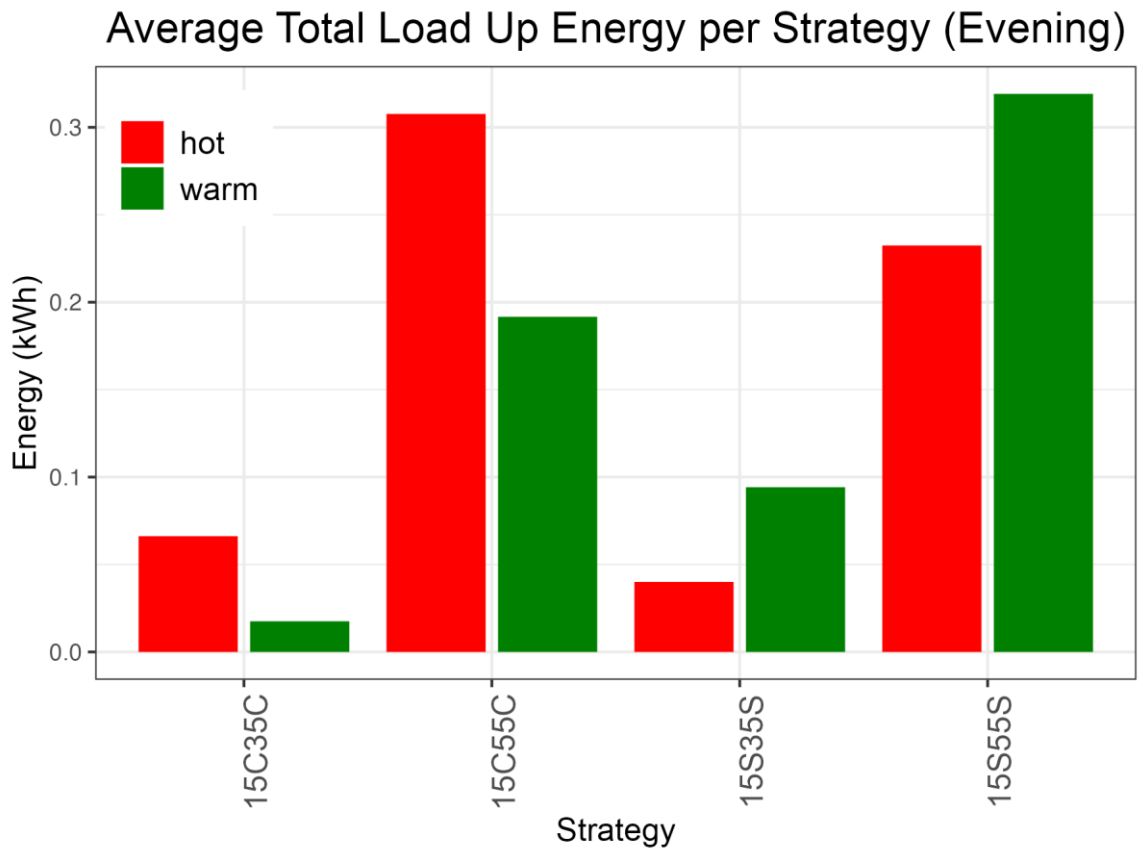
Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

Results for Evening Load-up

- Longer evening load up duration appeared to add beneficial storage due to capturing rebound from morning curtailment, especially when paired with longer morning curtailment
- For example, 1-5C-5-5C and 1-5S-5-5S load-up over three times as much energy as 1-5C-3-5C and 1-5S-3-5S



Progress

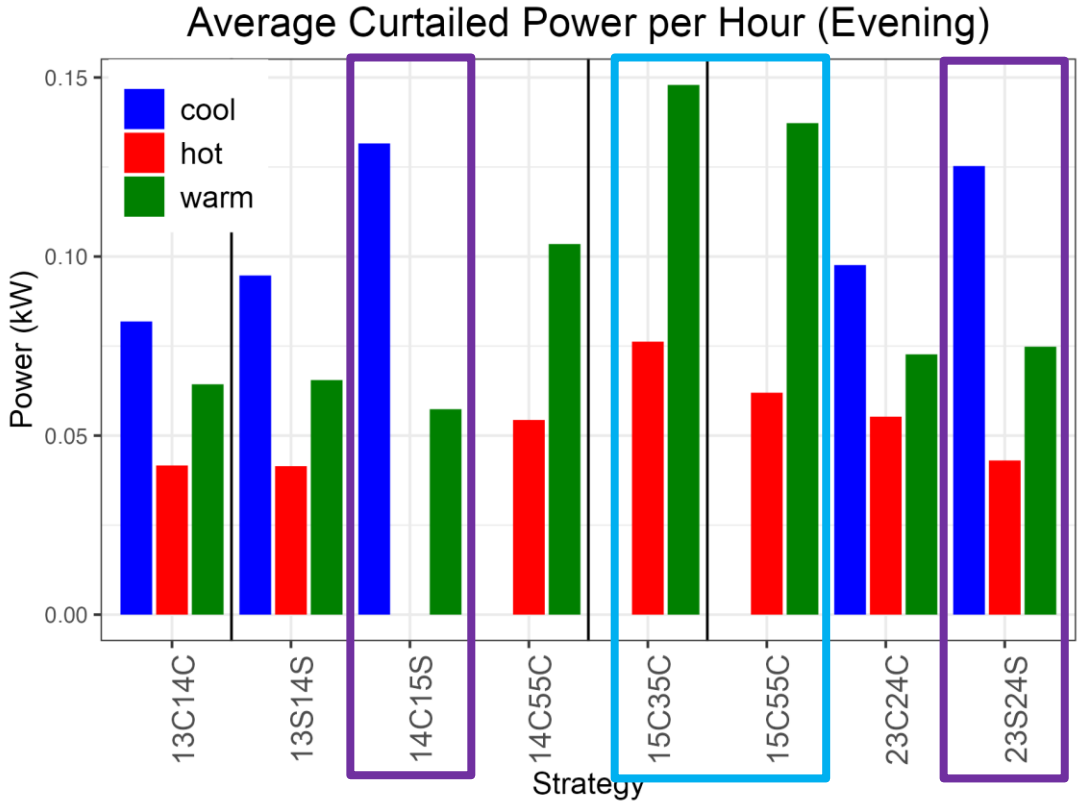
Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

Results for Evening Curtailment

- For the Warm temperature bin, the Critical Peak command over a five-hour duration (e.g., 1-5C-3-5C and 1-5C-5-5C) provided the largest curtailment
- For the Cold temperature bin, the Shed command over a four- or five-hour duration (e.g., 2-3S-2-4S and 1-4C-1-5S) provided the largest curtailment



Progress

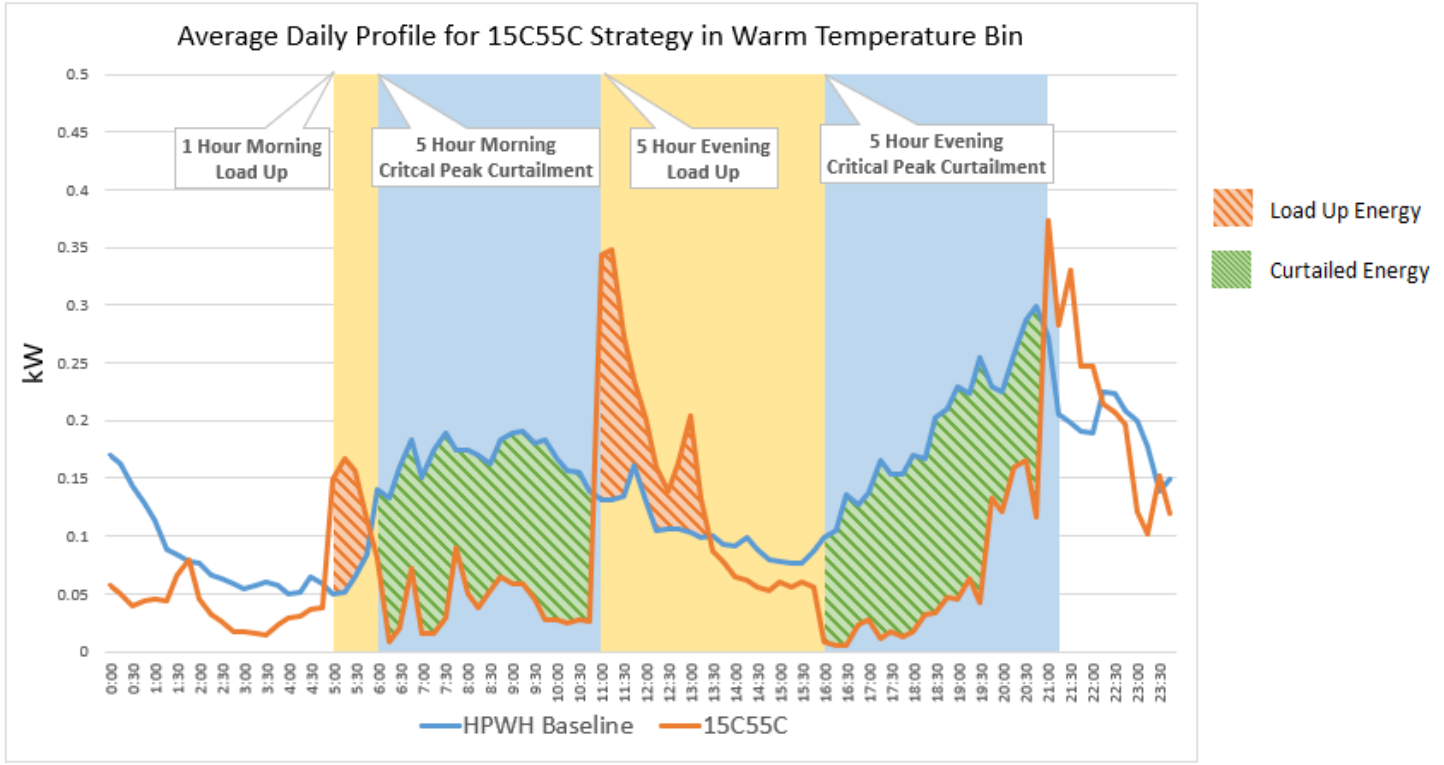
Example: 1-3S-1-4S = 1 hr AM Load Up, 3 hr AM Shed, 1 hr PM Load Up, 4 hr PM Shed

Morning & Evening Load Up Duration

Morning & Evening Curtailment Duration and Type

Results – Identifying Optimal Strategies

- Majority of days in Central Florida fall into the Warm temperature bin
- For the Warm bin, 1-5C-5-5C and 1-5C-3-5C had the lowest energy consumption and were also the most effective at curtailing load in the morning and evening peak periods compared to the HPWH baseline
  - Curtail 76% of power per hour (~0.13 kW/hour) in morning and evening compared to the HPWH baseline
  - Compared to the estimated ERWH baseline, curtail 1.6 kWh in morning and 1.75 kWh in evening over peak period



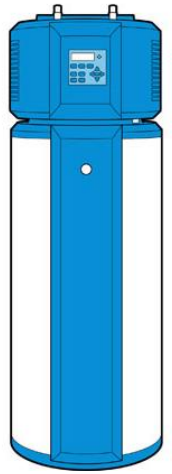
Progress

Conclusions from Florida HPWH Load Shifting Study

- HPWHs provide inherent peak load reduction compared to ERWHs due to improved energy efficiency, and can effectively shift load through grid-connected functionality, providing additional peak load reduction
- Grid connectivity by itself can result in HPWH peak power reduction up to 76% per hour of curtailment
- Peak energy reduction over the duration of a curtailment event can be as much as 0.74 kWh per event compared to the HPWH baseline and 1.75 kWh per event compared to the estimated ERWH baseline
- For the Florida homes best suited for grid-connected HPWHs, **energy reductions of 4.9 GWh during the morning peak period and 5.4 GWh during the evening peak period are achievable** when replacing ERWHs with grid-connected HPWHs enrolled in load shifting programs








Progress and Future Work – Underserved Communities

PNNL and its partner Energy Solutions are moving the HPWH load shifting study to an underserved community in North Carolina

- Set up a contract with Energy Solutions
- The Energy Solutions team has undergone PNNL's IRB training
- Submitted the study application, informed consent, and initial recruitment materials to PNNL's IRB. Collaborating with IRB to update materials and receive study approval.
- Energy Solutions received a list of ~40 potential study participants with CTA-2045 enabled HPWHs from Rebuilding Together for the Triangle (RTT) for recruitment
- Currently developing a study plan for load shifting strategies and baseline data collection
  - Analysis if participants were on time-of-use rates
  - Sharing results with DOE's Connected Communities partners: Duke Energy, Ibacos

Thank You

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WBS # 1.4.1.19

REFERENCE SLIDES

Team

Josh Butzbaugh, PI

Travis Ashley, Analysis

Cheryn Metzger, PM

Energy Solutions

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Creating Energy Independence

e-Radio

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	$530,875				$245,016							
Spent budget	$445,220				$103,171							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Compile results of the SE field study				◆								
Current/Future Work												
Draft technical report on load shifting for HPWH in North Carolina					■	■		◆				