Not Your Father's Water Heater Demand Response Program: Measuring Impacts from and Innovative Load Shifting Pilot

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If you could power your home with reliable, renewable energy every day, would you?

YES!!

- But I would want to make sure I was still had everything:
  - That I wanted
  - When I wanted it
  - …And didn’t really notice that my energy was clean

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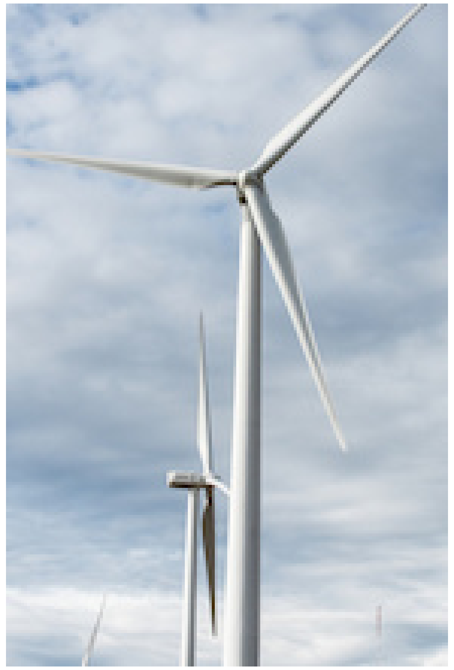
Opportunity

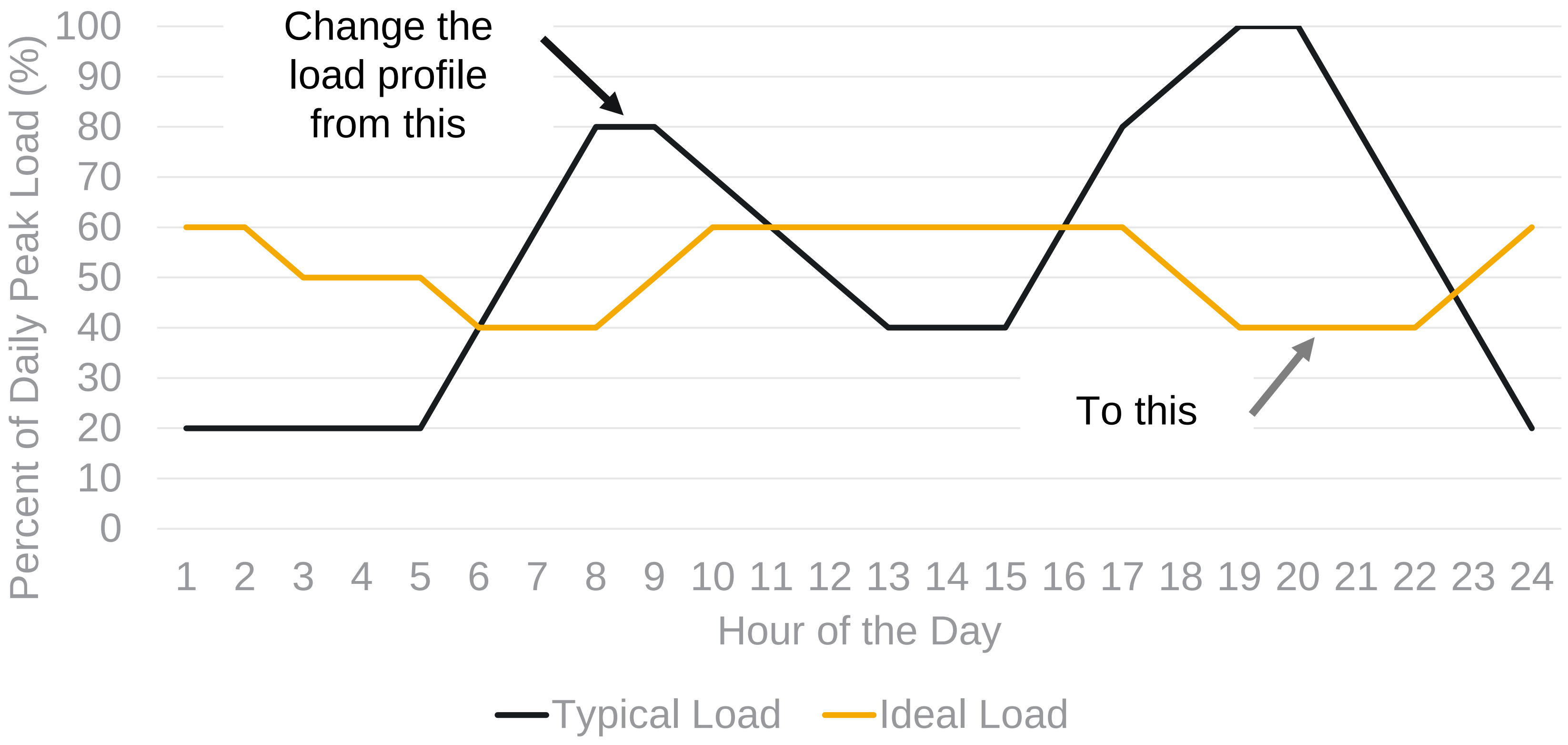
- Residential electric loads fluctuate, and peak power costs much more to utilities than baseload power
- Peak power demand can call for peaking power plants to serve load, or can lead to brown-outs due to peak capacity limitations
- Thermal characteristics of **water heaters** provide options to manage peak power requirements.
- HPWH load shifting performance remains unproven in key regions (e.g., SE) with the greatest energy efficiency and peak demand reduction potential.

IEPEC

Value Proposition

- Demonstrate **working towards** a 24x7 control paradigm for **shifting load to align with renewable generation** (e.g., morning load shifting toward mid-day when solar energy would be more prevalent);
- Quantify this value for utilities and consumers using both electric resistance and heat pump water heaters;
- Evaluate customer acceptance of this control paradigm.
- Peak management increases HPWH value to utilities creating an opportunity for energy savings





Photos Courtesy of NREL PICS Database

Team Members

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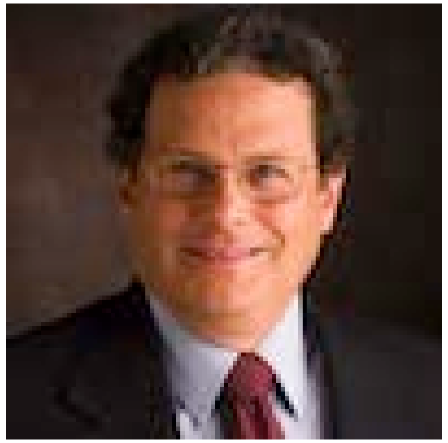

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Overview

- Water heating is the second largest energy use in U.S. residences
- Heat pump water heaters can save 60% of electric water heating energy
  - Only 70,000 shipments per year (1.5% mkt share of electric water heaters)
  - Market share has been flat since 2009 despite more than 180 models in the market
- Opportunity to demonstrate the viability of heat pump water heaters (HPWH) in providing load shifting
  - Pacific Northwest – active and committed region to studying energy efficiency and load shifting strategies to integrate into existing utility programs
  - Southeast and Mid-Atlantic – regions with high potential for energy efficiency and load shifting, need technology demonstration to justify launching new programs
  - Transfer lessons learned and best practices from PNW study to a field study based in the Southeast or Mid-Atlantic

The Secret Sauce

CTA-2045

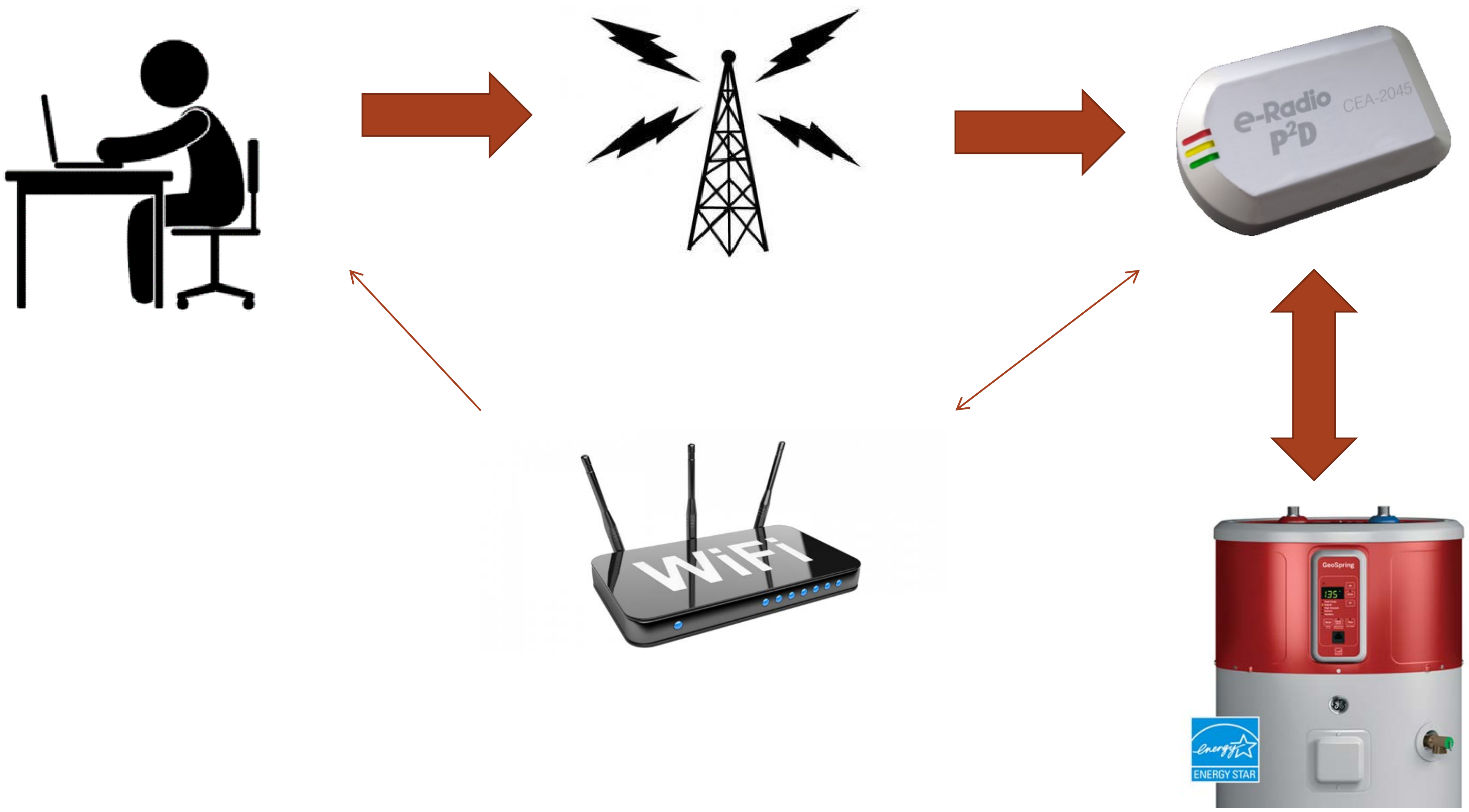
- Manufacturer only supplies standard port
- Others can pay additional costs to make devices “connected”
- Interface supports every type of communication method
  - Physical layer (e.g. Wi-Fi, 4G LTE, etc.)
  - Command layer (e.g. SEP, OpenADR, etc.)

Heat Pump Water Heaters

- HPWHs save an average of 60% of annual energy consumption
- 3-5 years payback for typical households
- Reduce peak loads
- Interactions with interior temperatures is minimal in most installations[1]
- NEEA Advanced WH spec
  - ✓ Noise issue solved, maximum decibel requirements
  - ✓ Cold-climate compressor cut-off temperature

[1]Widder et al. Interaction between HPWH or Other Internal Point Source Loads and a Central Heating System. NEEA/PNNL https://neea.org/img/uploads/interaction-between-heat-pump-water-heaters-and-heating-system.pdf

How It Really Works



Northwest Field Validation

- Project Scope
  - 145 HPWH (~40 sub-metered)
  - 86 Electric Resistance WH
  - 10 weeks of data per season
  - 2 load shifting events per day during peak hours
  - **Control group and event group flip-flop each week**

- Example Event Schedule for One Day

Date	Event Description	Duration	Start Time	End Time
Feb. 19th	Load Up	1 hr	5:00	5:58
Feb. 19th	Shed	3 hrs	6:00	9:02
Feb. 19th	Load Up	1 hr	16:00	16:58
Feb. 19th	Shed	3 hrs	17:00	20:02

Load Up Event = Force WH to turn on and reach set point

Shed Event = Force WH to turn off as long as customer still has hot water (exact definition of "hot water" is determined by manufacturer/algorithm)

Why Discuss This Methodology?

- There are not many established best practices when it comes to measuring demand response impacts
- There is no “right way” to measure impacts
- Our approach was to estimate impacts in several ways to see how they agree or disagree with one another
- If they come to same answer great, if not then judgement is required

Randomized Control Trial

- Treatment and control group switching week to week

- Challenge is to create groups that are balanced among numerous variables
  - Total kWh Per Day
  - Minutes > 1000 watts (resistance element usage)
  - Morning Use (between 5 a.m. and 9 p.m.)
  - Evening Use (between 5 a.m. and 9 p.m.)
  - Water Heater Brand (GE or AO Smith)
  - Location of Water Heater (e.g. basement, garage, etc.)

Balancing the Groups

- Using 6 variables create a k-means clustering model
- Clustering creates homogeneous groups based on data given
- Try different numbers of clusters
- When a final clustering model is selected, distribute the tanks in each group into two different groups

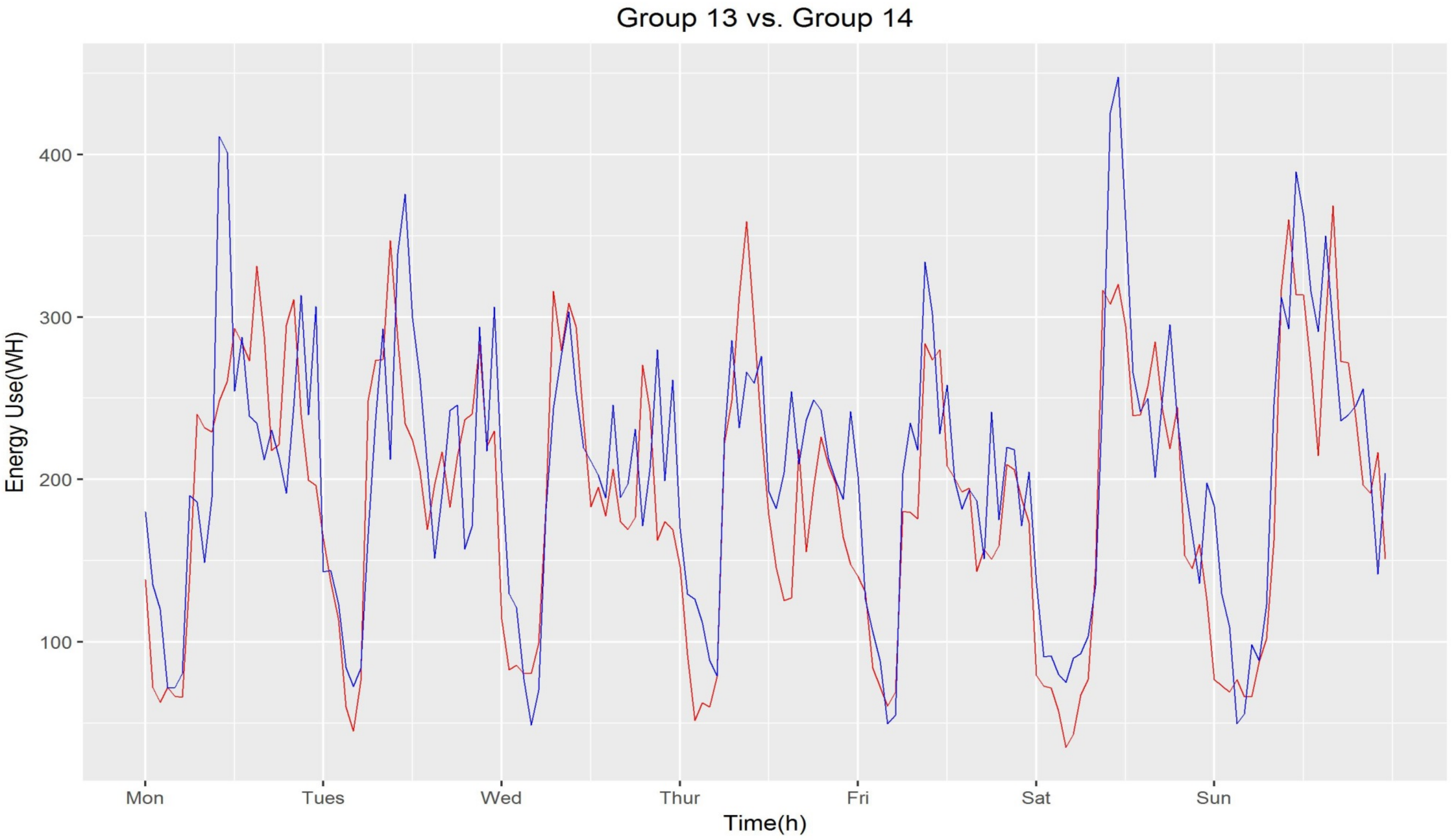
K-Means Cluster Analysis Results

Group	Statistic	Total Use (kWh)	Minutes > 1000 Watts	AM Use (W)	PM Use (W)
ERWH 1	Min	17	225	1224	709
	Mean	71	937	4465	6447
	Max	198	2638	11700	14633
ERWH 2	Min	18	237	1050	518
	Mean	74	976	4493	6568
	Max	214	2859	13659	12525
HPWH 13[1]	Min	6	0	353	251
	Mean	32	227	2371	2761
	Max	145	1715	10210	10260
HPWH 14	Min	4	0	252	475
	Mean	32	218	2170	2723
	Max	245	3429	11761	11843

[1] Groups 13 and 14 were arbitrary group numbers chosen to decipher between the different HPWH groups

This is What Balanced Groups Look Like

- Group 13
- Group 14

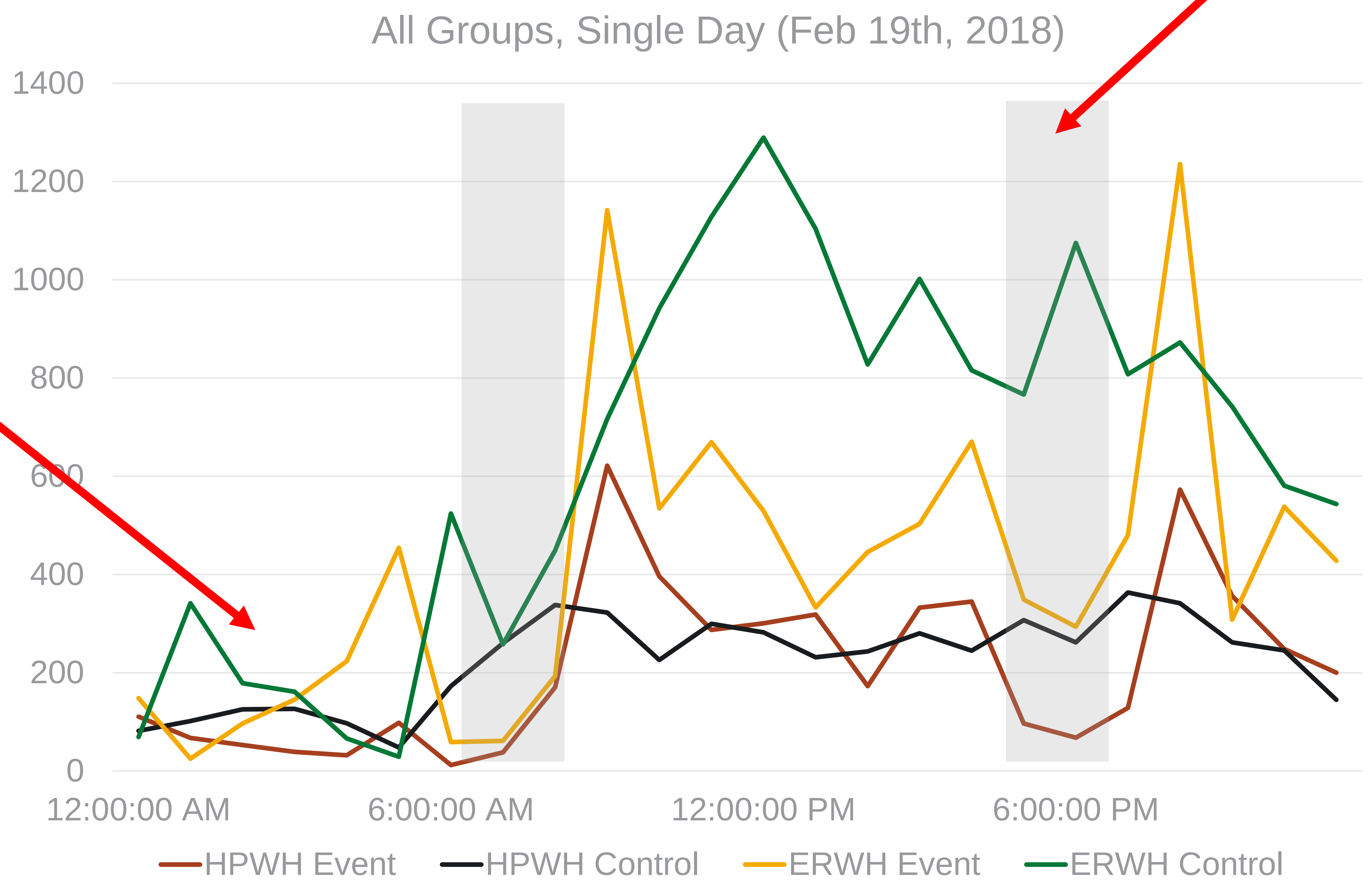


General Trends

Results: Single Day Example

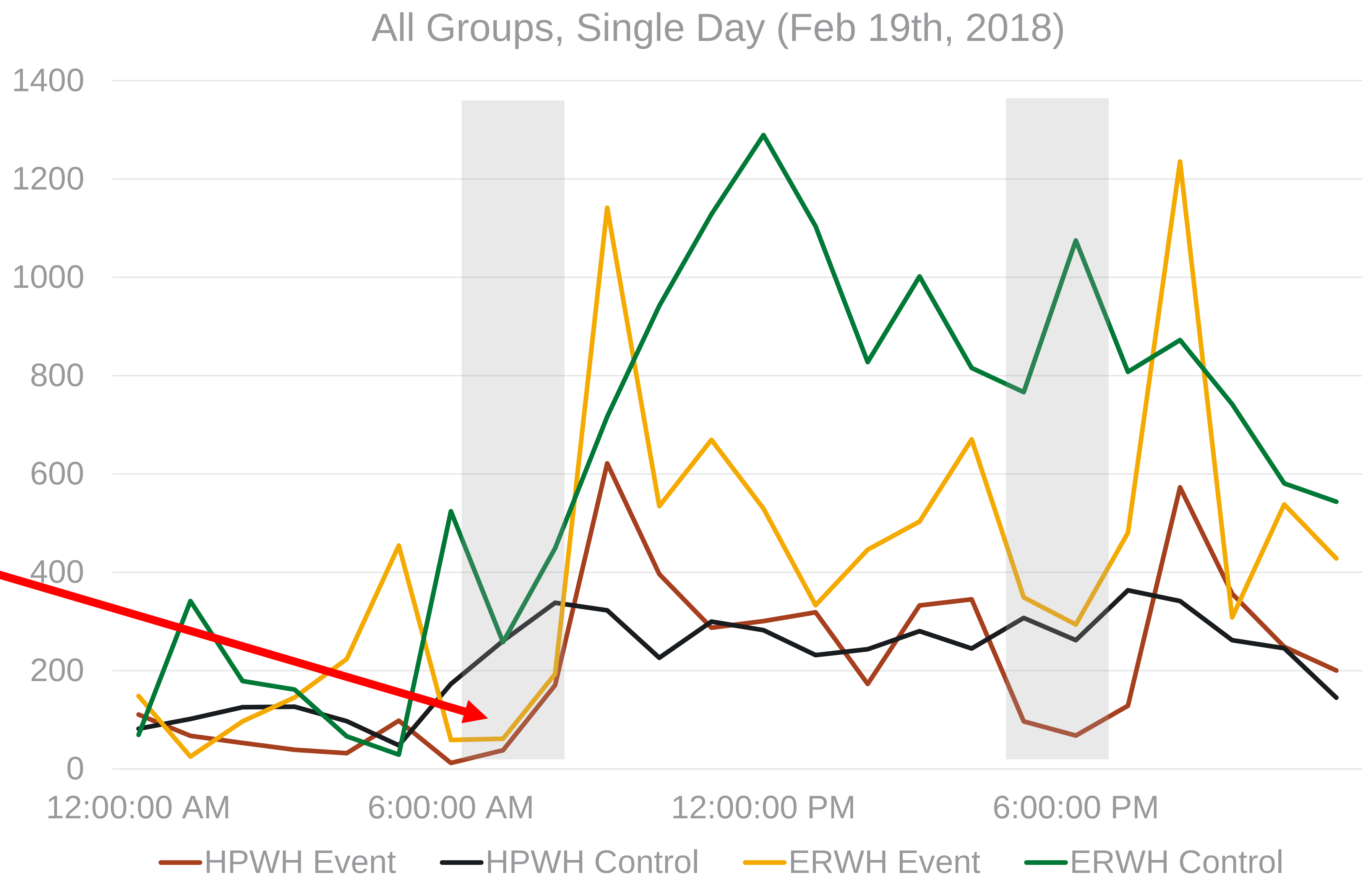
Grey bars = shed events

Low energy use by all groups at night

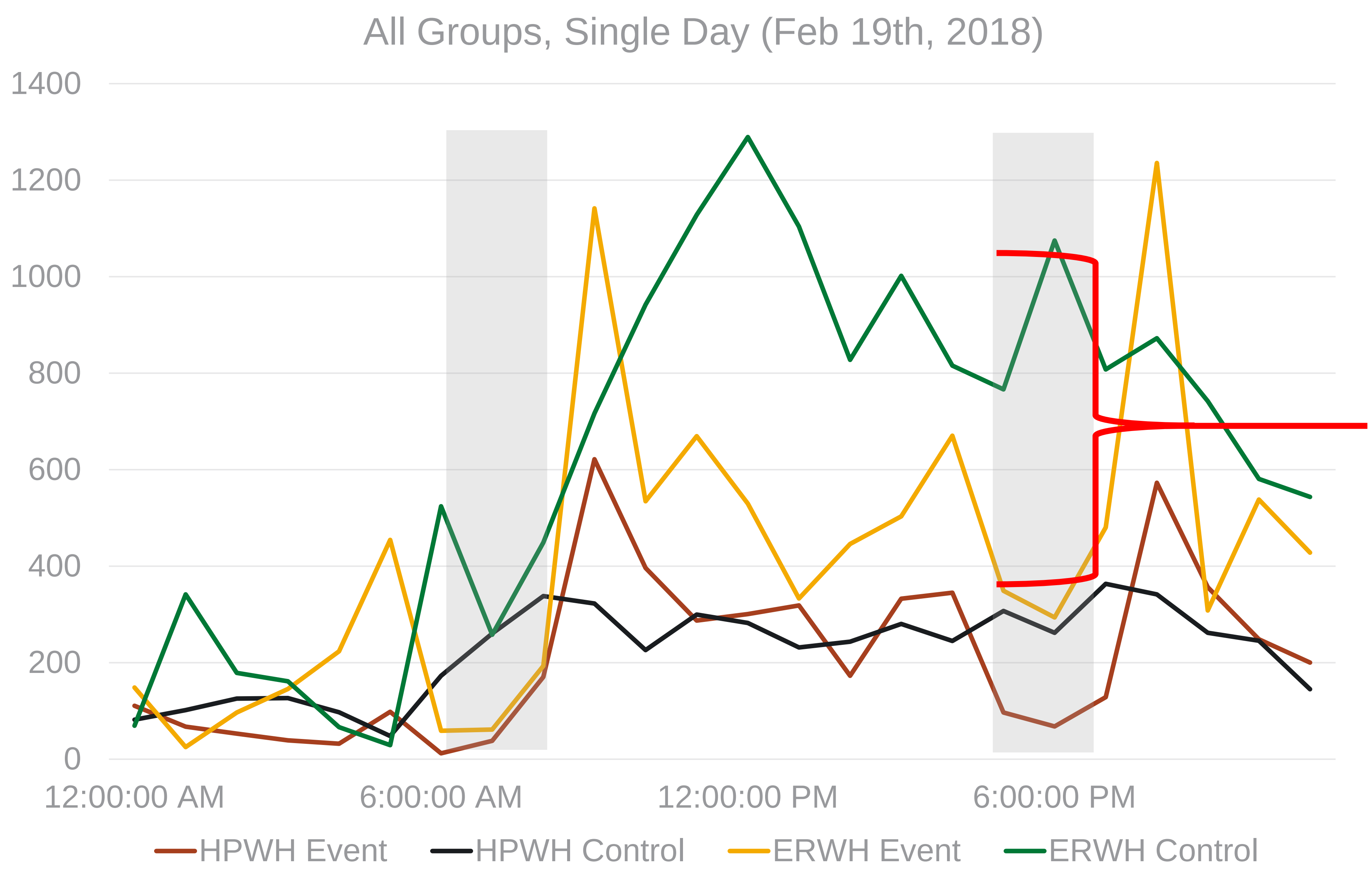


Single Day Example

Event groups use less energy during shed event

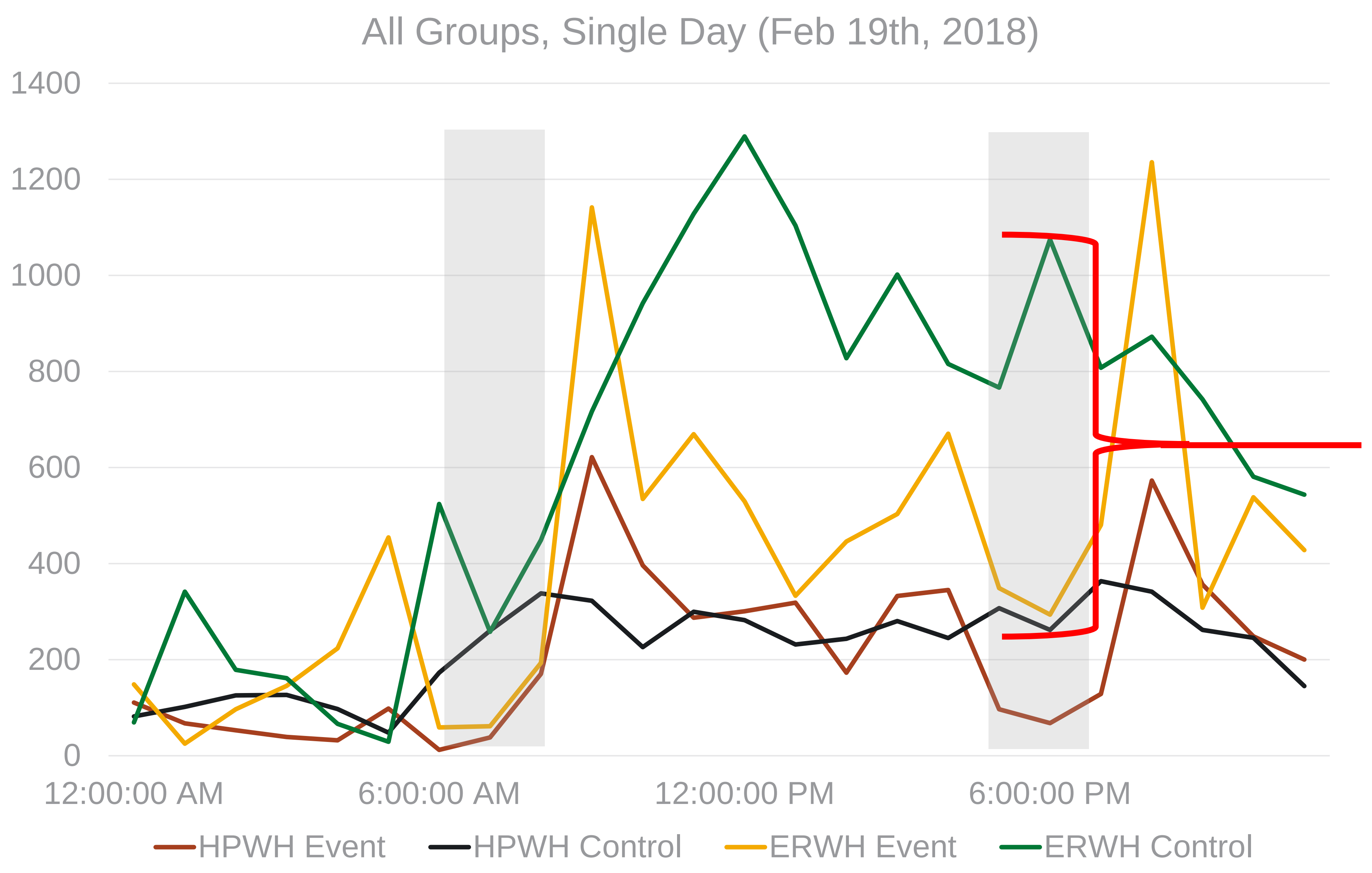


Single Day Example



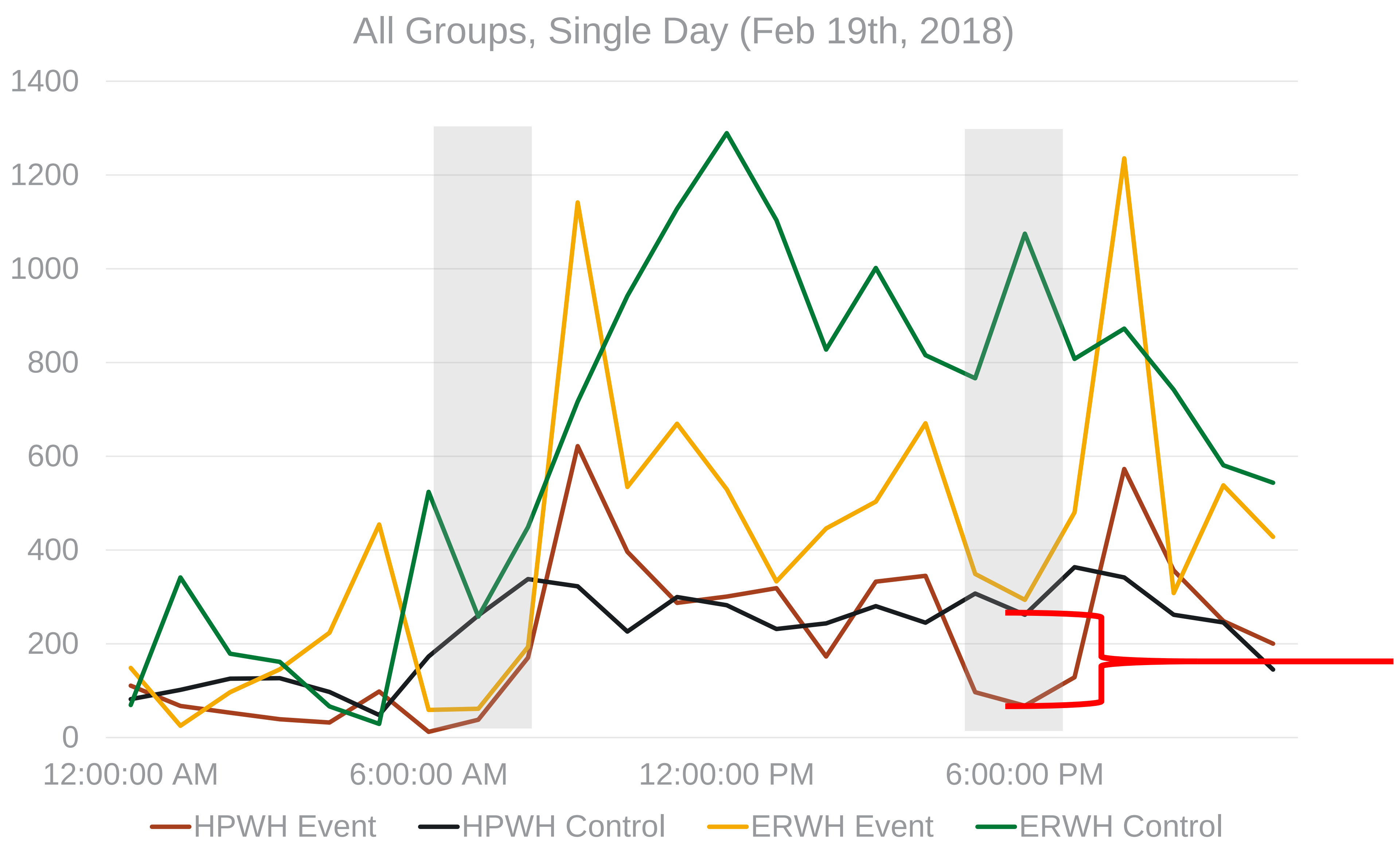
Large peak reduction with connected ERWH

Single Day Example



Larg**er** peak reduction when switching to (“dumb”) HPWH

Single Day Example



Even greater peak load reduction with *connected* HPWH

Average Peak kW Reduction During Shed Events Per Water Heater

- Many ways to determine the average kW reduction
  - Baseline 1: Event Group vs. Control Group
  - Baseline 2: Prior- Week Baseline
  - Baseline 3: Full Season Baseline

	ERWH (Baseline)	Connected ERWH	HPWH	Connected HPWH	% WH Load Reduced Compared to Baseline
Winter Morning	616	374	310	533	87%
Winter Evening	668	321	437	602	90%
Summer Evening	474	347	365	448	95%

What About the Consumer?

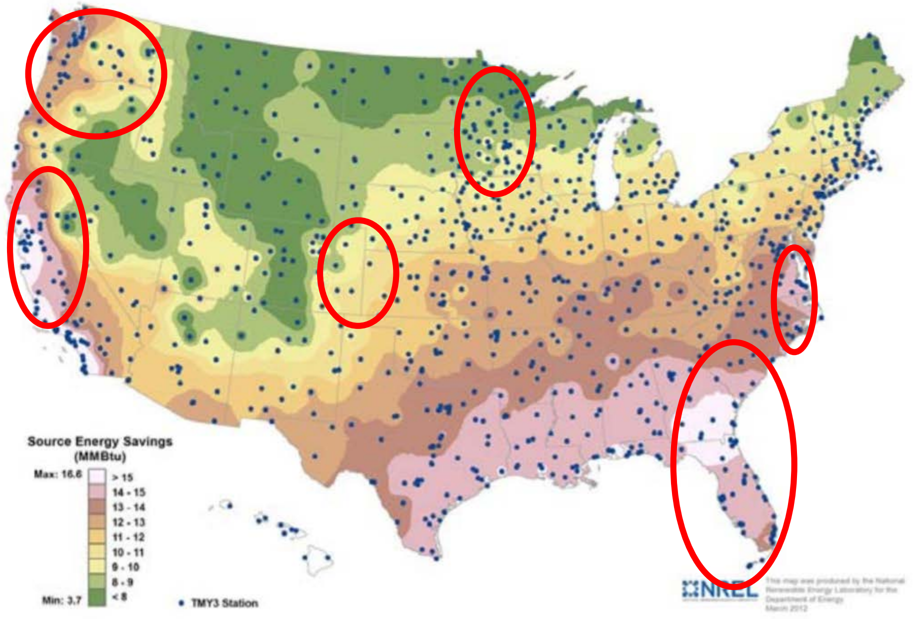
- Opt-Outs allowed two ways:
  - Button on the water heater (likely from immediate displeasure)
  - Through the web portal (likely due to a planned extra full household)

- 1634 opt-out hours during the winter season
- Out of 40,000 opportunities to opt-out (145 customers, about 28 event-hours per week)
- Results in 4% opt-outs (relatively low!)

- Most customers seem largely unaffected by the demand response program

What's Next?

- FY20: Load Shifting with Heat Pump Water Heaters
  - Field Validation in the Northwest
    - ✓ Artificial Intelligence learning occupant behavior to push load shift even more where possible.
    - ✓ Support for transferring knowledge to other regions
  - Field Validation in the Southeast
    - ✓ Recruiting, installing connection devices, collecting data



- FY20: Load Shifting With Ductless Mini-Splits
  - Taking advantage of CTA-2045 enabled devices that are already in the field
  - First field validation study of HVAC/heat pump load management using CTA-2045

Published (Or Nearly Published) Reports

- BPA (Bonneville Power Administration). 2018. *CTA-2045 Water Heater Demonstration Report Including A Business Case for CTA-2045 Market Transformation.* https://www.bpa.gov/EE/Technology/demand-response/Documents/Demand%20Response%20-%20FINAL%20REPORT%20110918.pdf
- Metzger, CE, Ashley T, Bender, S, Morris, S, Kelsven P, Urbatsch E, Kelly N, Eustis, C. 2018. *Large Scale Demand Response with Heat Pump Water Heaters.* ACEEE (American Council for an Energy Efficient Economy). http://iframes.aceee.org/confpanel.cfm?&ConferencePanelID=291
- 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.

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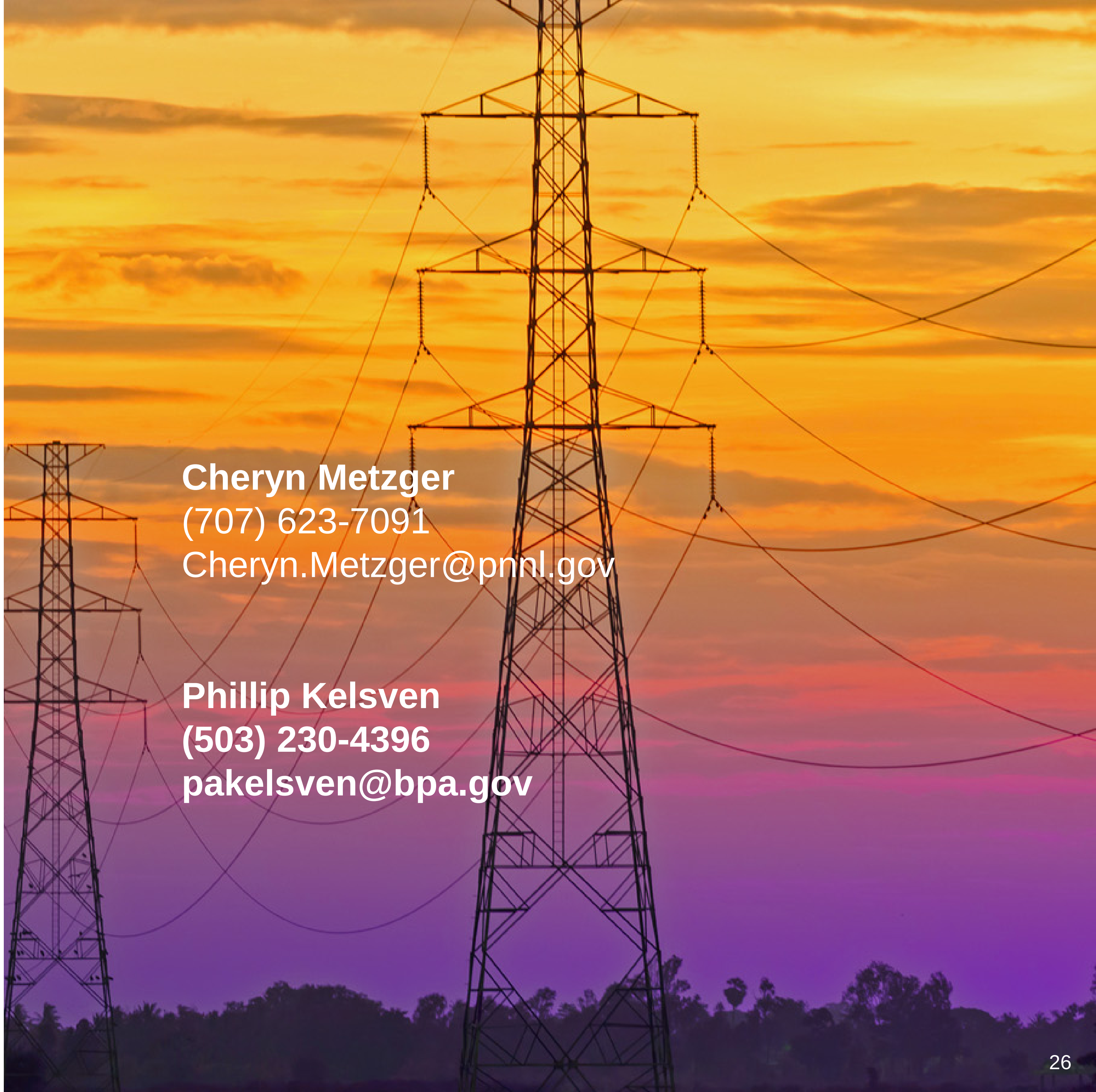
Thank you



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Full Season Results

- Average Hourly Peak (Watts) during Shed Events Per Water Heater

	ERWH (Baseline)	Connected ERWH	HPWH	Connected HPWH
Winter Morning	616	242	306	83
Winter Evening	668	348	232	66
Summer Evening	474	127	109	26

- Average Peak Reduction from Baseline (Watts Reduced) during Shed Events Per Water Heater

	ERWH (Baseline)	Connected ERWH	HPWH	Connected HPWH	%Reduced Compared to Baseline
Winter Morning	616	374	310	533	87%
Winter Evening	668	321	437	602	90%
Summer Evening	474	347	365	448	95%

Total Energy Shifted

Approximate Energy Shifted During Peak Afternoon Hours (Average of Baselines, Rounded to the Nearest 50 W, Multiplied by the Average Number of Hours Per Event For That Season)

Season	HPWH Energy Shifted Per Event (Wh)	Average Event Length (Hours)	ERWH Energy Shifted Per Event (Wh)	Average Event Length (Hours)
Winter	300	2	600	2
Spring	250	2	1050	2
Summer	350	4	1300	4

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Reduced Risk for Utilities, Reduced Cost to Consumers

Winter Peak Load Reduction	ER BL (W/Hour of DR Event)	ER BL – ER with DR (W/Hour of DR Event)	ER BL – HPWH Control (W/Hour of DR Event)	ER BL – HPWH with DR (W/Hour of DR Event)	% Savings for Switching to HPWH with DR (W)
Morning Peak	616	374	310	533	87%
Evening Peak	668	321	437	602	90%

~90% of evening peak load power can be reduced by switching from uncontrolled ERWHs to Connected HPWHs

Acronyms: ER = electric resistance, BL= Baseline, W = watt, DR = demand response, CI = confidence interval, ERWH = electric resistance water heater, HPWH = heat pump water heater

Reduced Risk for Utilities, Reduced Cost to Consumers

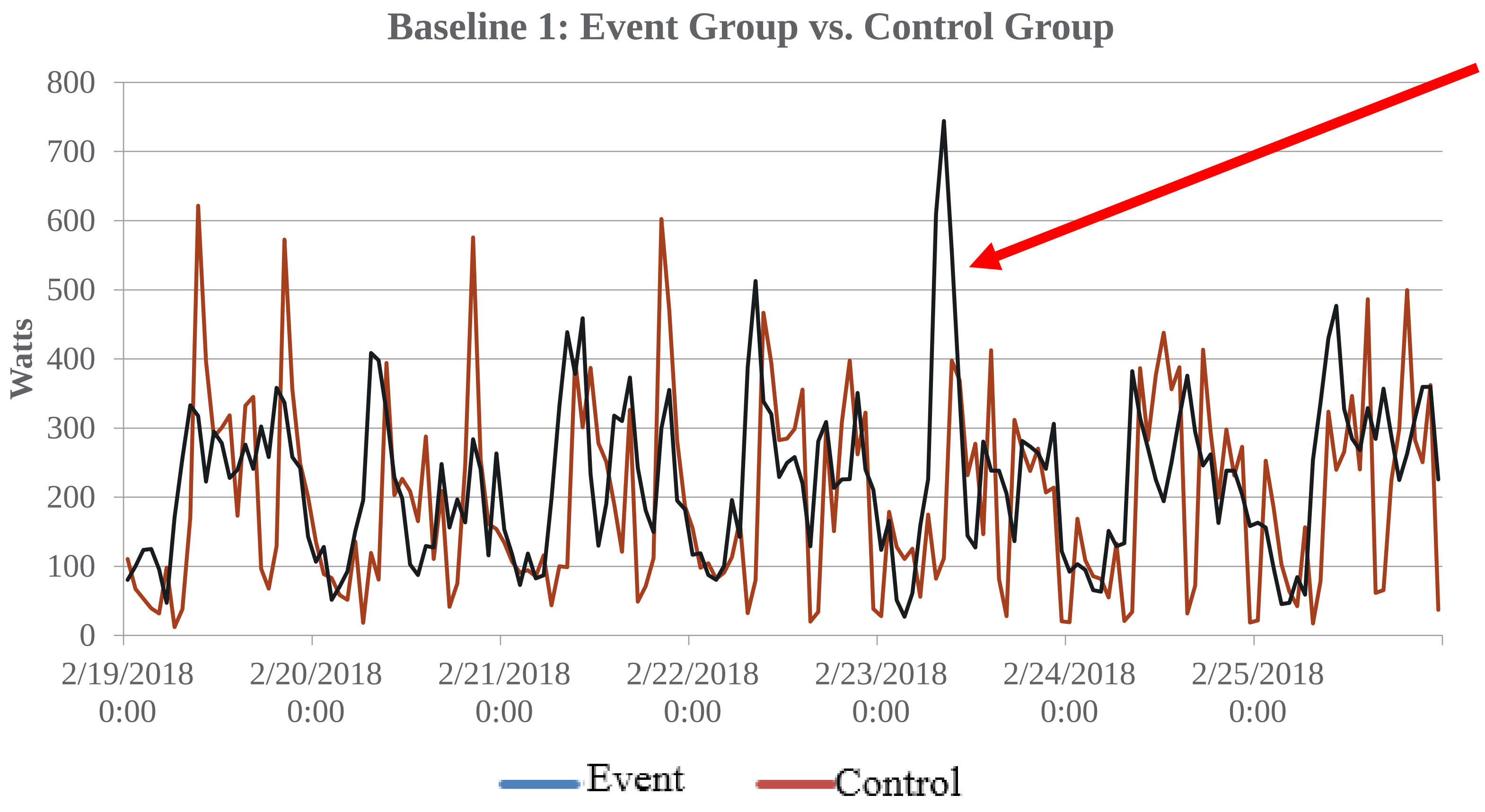
Winter Peak Load Reduction	ER BL (W/Hour of DR Event)	ER BL – ER with DR (W/Hour of DR Event)	ER BL – HPWH Control (W/Hour of DR Event)	ER BL – HPWH with DR (W/Hour of DR Event)	% Savings for Switching to HPWH with DR (W)
Morning Peak	616	374	310	533	87%
95% CI for Morning Peak	85	79	83	84	N/A
Evening Peak	668	321	437	602	90%
95% CI for Evening Peak	57	77	65	58	N/A

~90% of evening peak load power can be reduced by switching from uncontrolled ERWHs to Connected HPWHs

Acronyms: ER = electric resistance, BL= Baseline, W = watt, DR = demand response, CI = confidence interval, ERWH = electric resistance water heater, HPWH = heat pump water heater

Average kW Reduction During Shed Events (For each water heater type)

- Many ways to determine the average kW reduction
  - Baseline 1: Event Group vs. Control Group



Unpredictable behavior is expected in this baseline

  - Baseline 2: Prior- Week Baseline
  - Baseline 3: Full Season Baseline

Average kW Reduction During Shed Events (For each water heater type)

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- Many ways to determine the average kW reduction
  - Baseline 1: Event Group vs. Control Group
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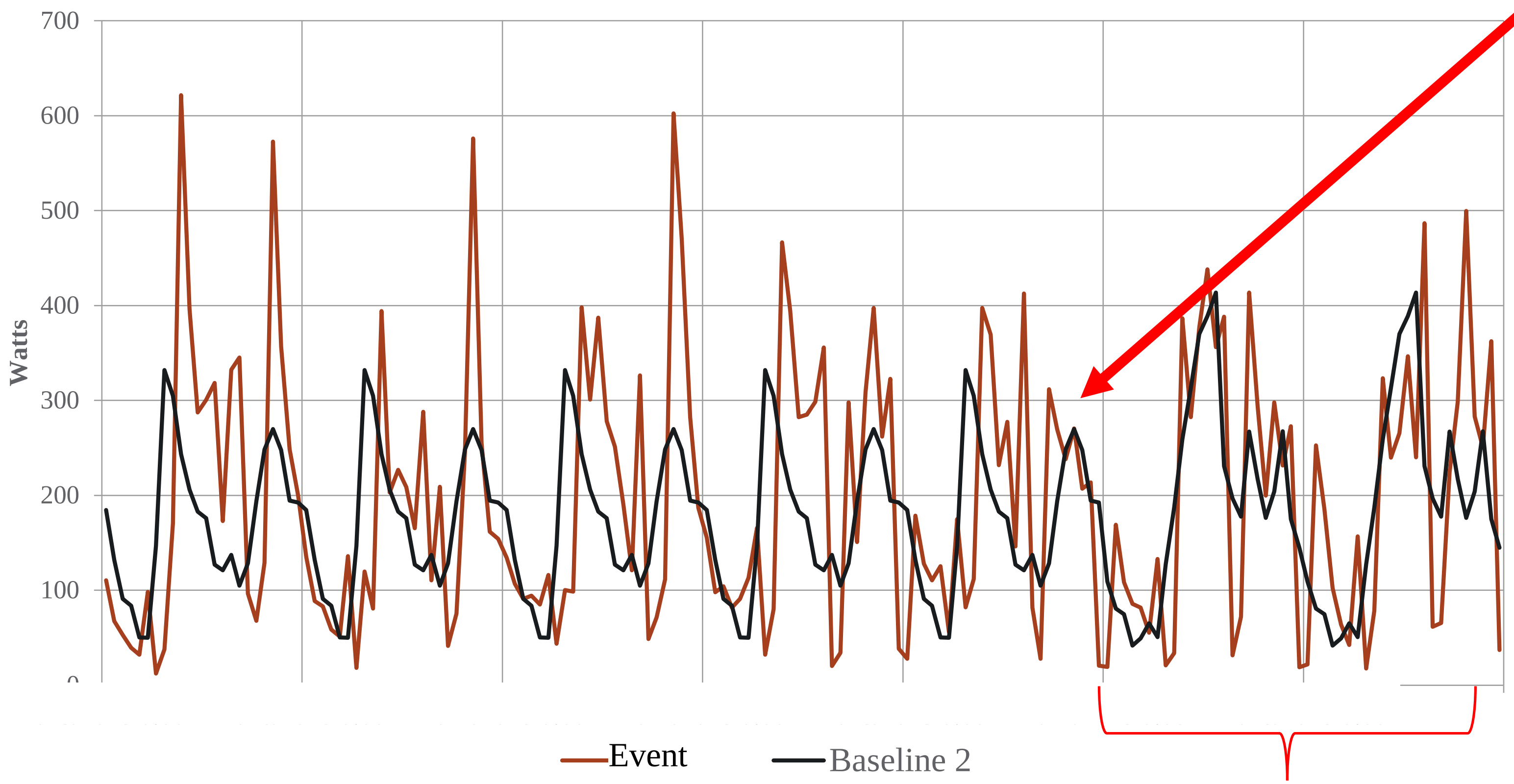
Baseline 2: Prior-Week Baseline



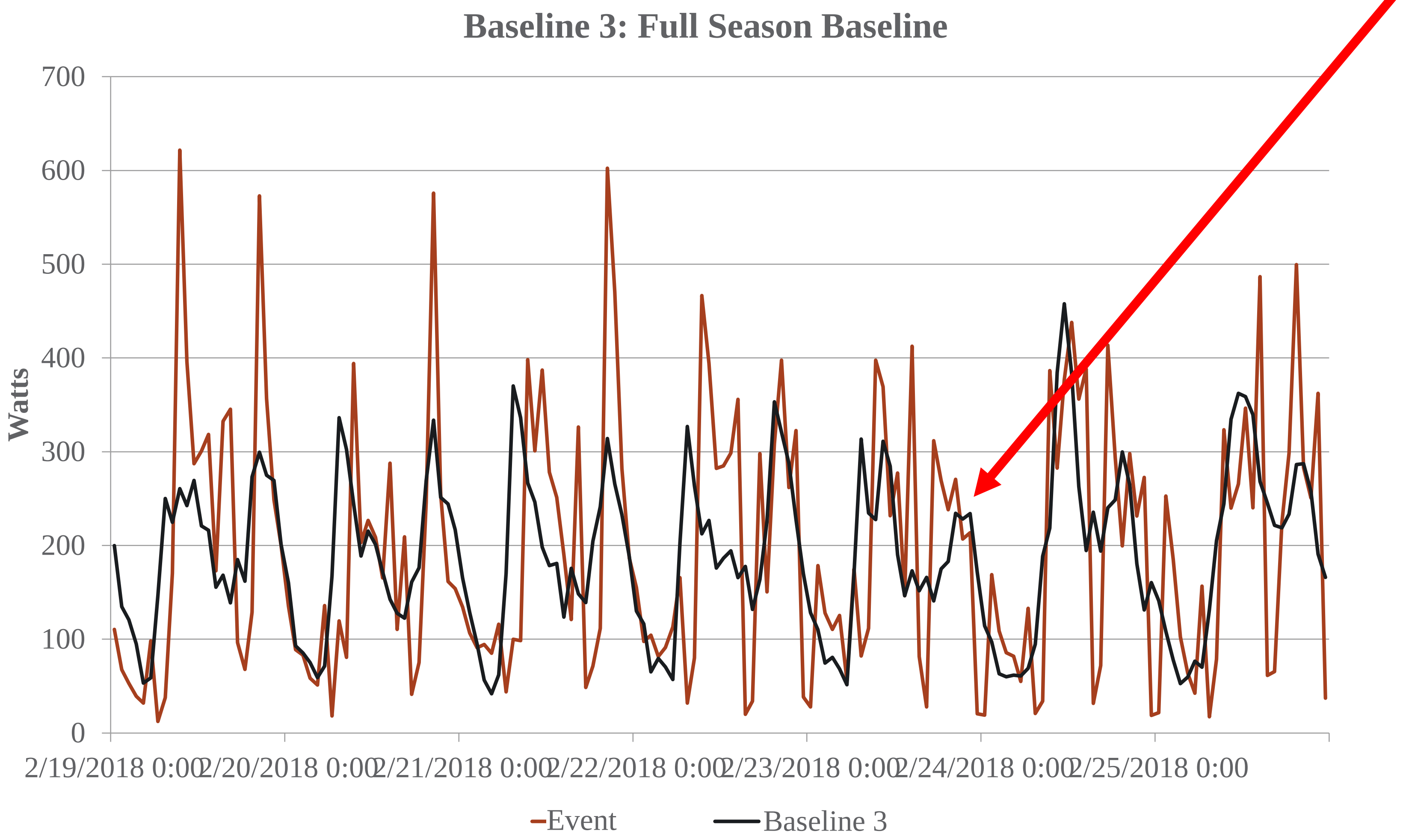
Unpredictable behavior is averaged out in this baseline

Weekend days

  - Baseline 3: Full Season Baseline

Average kW Reduction During Shed Events (For each water heater type)

- Many ways to determine the average kW reduction
  - Baseline 1: Event Group vs. Control Group
  - Baseline 2: Prior- Week Baseline
  - Baseline 3: Full Season Baseline



Baseline 3 trends toward a typical hot water load profile

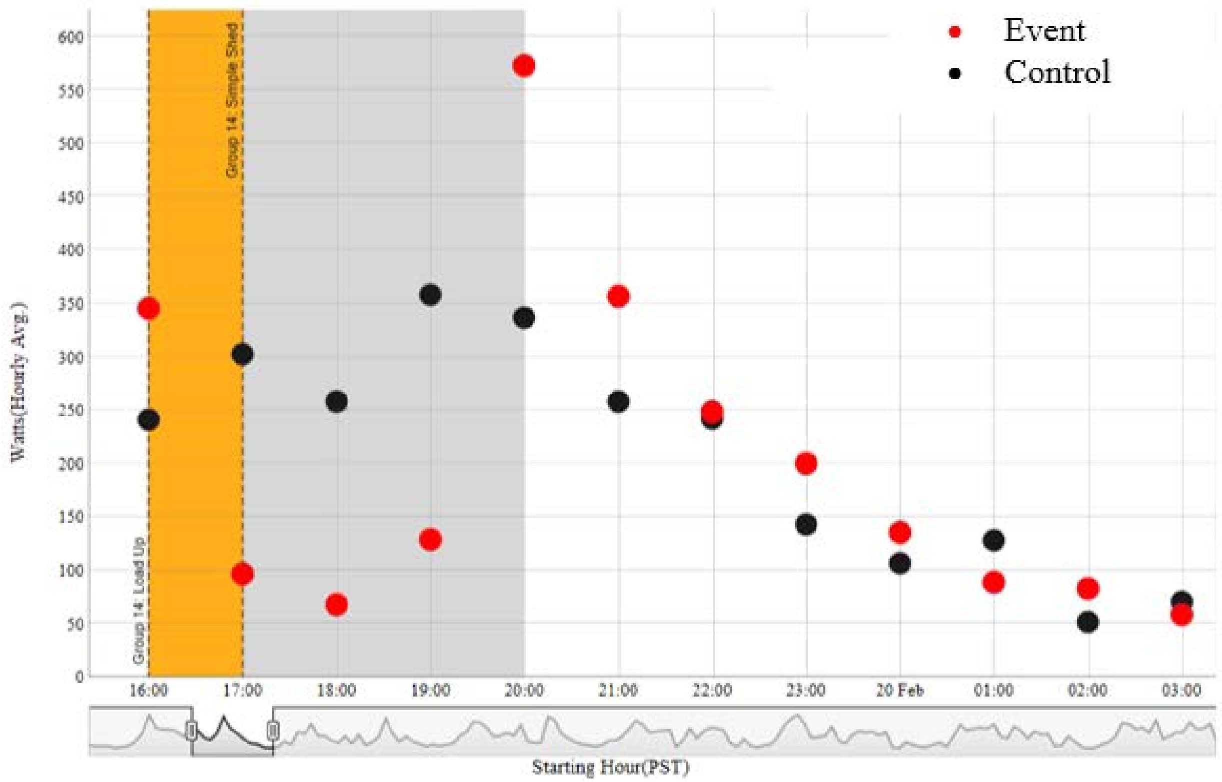
kW Reduction Using All Shed Events

	Heat Pump Water Heaters (n=145)			Electric Resistance (n=86)		
Baseline #	Base 1	Base 2	Base 3	Base 1	Base 2	Base 3
Average Impact from 10pm to 5am	84	95	84	133	146	194
Std. Dev.[1] from 10pm to 5am	34	25	N/A[2]	81	59	N/A
Average Impact from 6am to 10am	201	196	232	337	318	444
Std. Dev. from 6am to 10am	45	45	N/A	67	121	N/A
Average Impact from 11am to 4pm	170	148	N/A[3]	322	329	N/A
Std. Dev. from 11am to 4pm	47	29	N/A	114	133	N/A
Average Impact from 5pm to 9pm	142	161	167	328	312	316
Std. Dev. from 5pm to 9pm	47	46	N/A	85	99	N/A

1. Standard deviation provides information about the variation of the average impact between the 10 weeks studied in the season
2.Only the last week of the season is part of this event group
3. No events occurred during this time for the week of March 26th

Recovery Time/Energy: HPWH

- Challenges
  - Unknown recovery energy associated with draws during shed period
  - Unknown recovery energy associated with draws during recovery period



Orange Region Represents the Load Up Period, Grey Region Represents the Shed Period

Recovery Time/Energy: ERWH

- Challenges
  - Unknown recovery energy associated with draws during shed period
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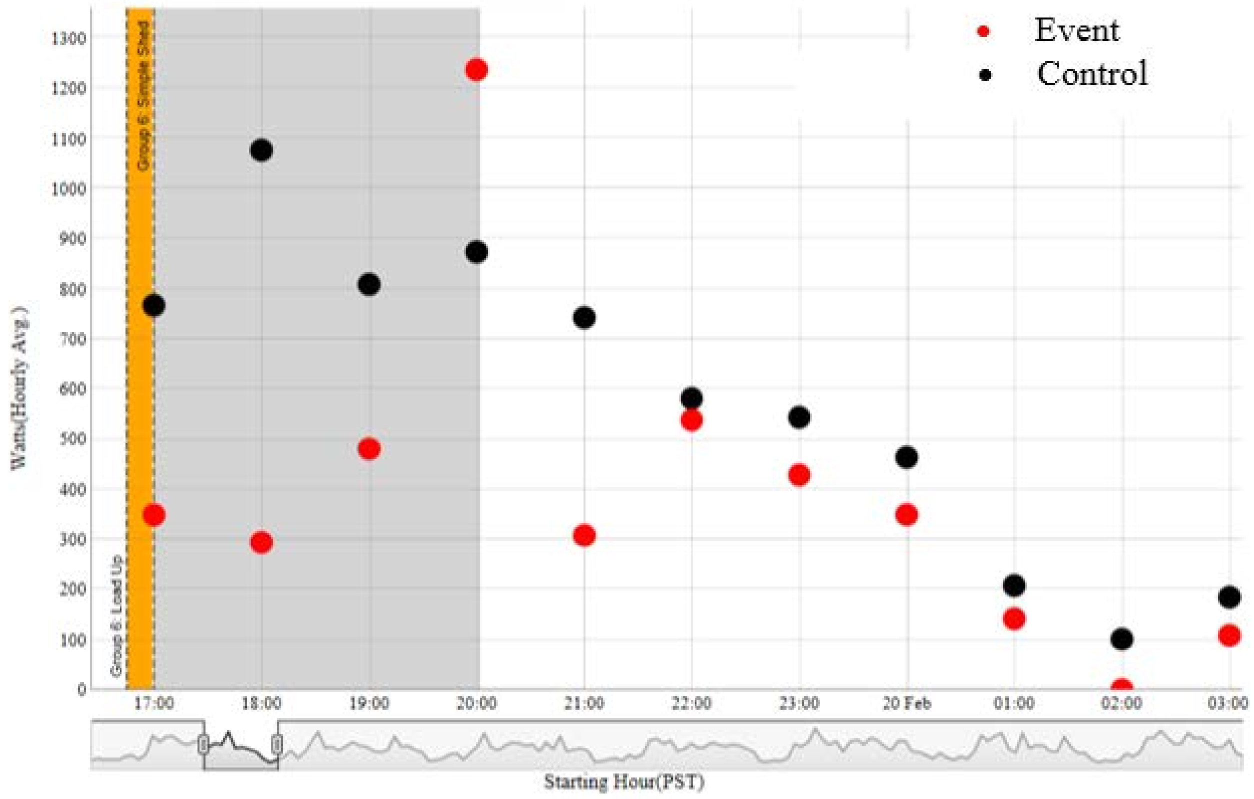

Orange Region Represents the Load Up Period, Grey Region Represents the Shed Period