Detailed Laboratory Evaluation of Electric Demand Load Shifting Potential of Controlled Heat Pump Water Heaters

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Acknowledgements

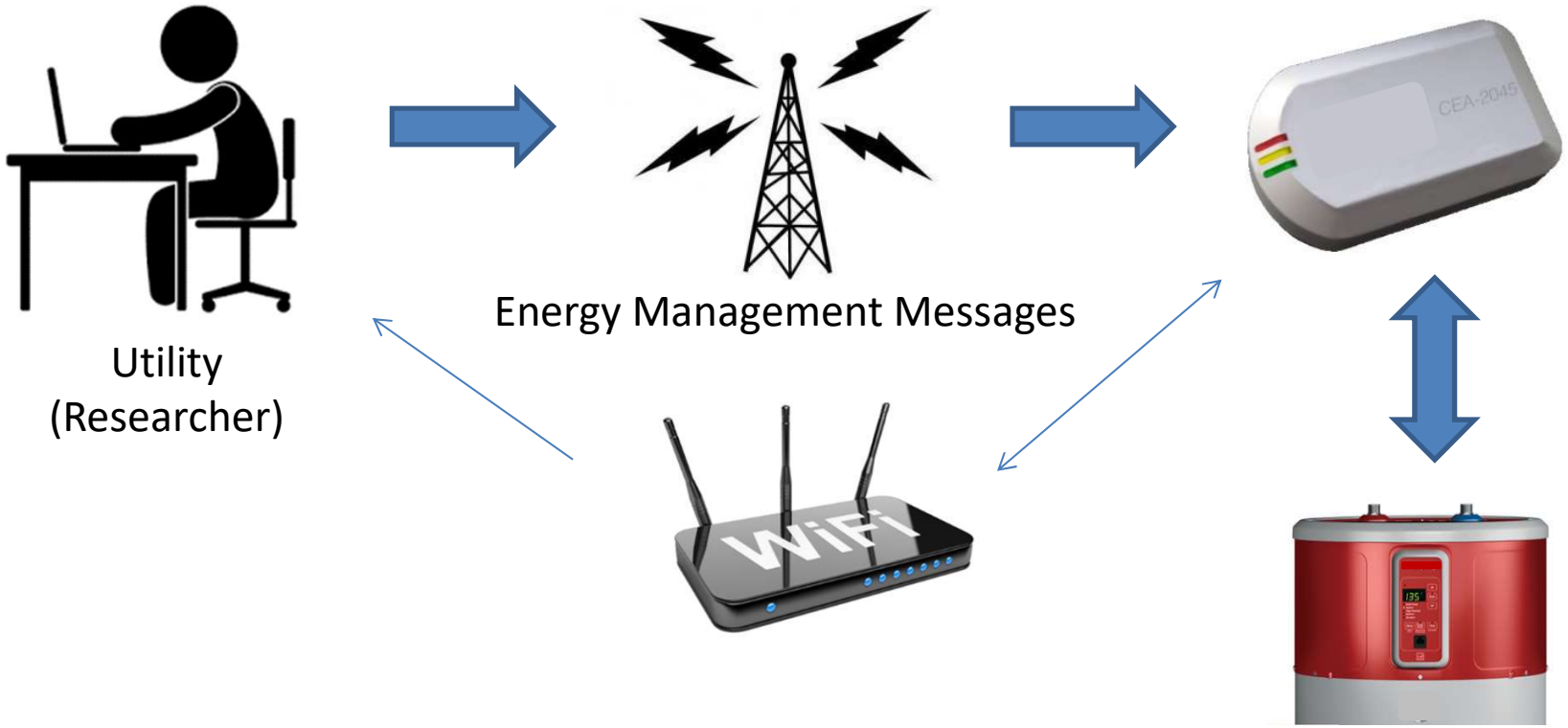
- **Marc LaFrance**
  - U.S. Department of Energy, Building Technologies Office
- **Cheryn Metzger**
  - Pacific Northwest National Laboratory

Introduction

- Evaluate the load shifting potential of grid-connected HPWH and HPWH relative to ERWH in Florida
- Lab experiments conducted using ANSI/CTA-2045-A (and-B)
- 4 heat pump water heaters (50 & 80 G), and 1 electric resistant
- Dec 2020 – June 2022, Central Florida

Manufacturer	CTA-2045	Tank Type	Capacity (Gallons)	Uniform Energy Factor
A.O. Smith	A	ER	50	0.93
Rheem	A	HP	50	3.55
A.O. Smith	A	HP	50	3.45
A.O. Smith	A	HP	80	3.45
GE	B	HP	50	Prototype

CTA-2045 Communication



Why is This Research Important?

ERWHs comprise >73% of water heaters in the Southeastern U.S.

- High saturation of ERWHs in SE U.S.
- Opportunity for increased HPWH market
- Big energy savings and demand reduction potential
- Most utility providers in this region do not offer HPWH incentives
- Same utility providers have load management programs
- Utilities value to promote grid-connected HPWHs with increased load shift potential

Experimental Design

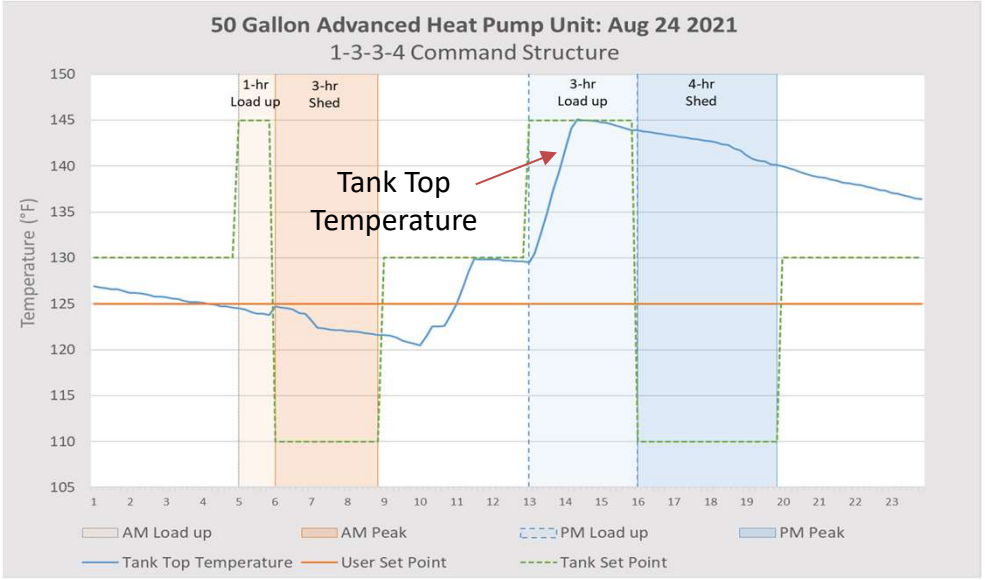
- Over 200 CTA-2045 command designs and seasonal baselines under:
  - 3 draw profiles (47, 57, & 69 GPD)
  - 2 heat pump settings (Hybrid and Economy)
- CTA-2045 messages used:
  - Load up: operate and raise the water temperature to its set point
  - Advanced load up (CTA-2045-B only): allows higher set point to provide greater shift
  - Shed load: avoid operation and use stored tank energy
  - Critical peak: aggressively avoid operation using stored tank energy
  - End shed: return to normal operation

Curtailment

- Message Scheme Example:
  - 1-3-3-4 = 1 hour AM load up, 3 hour AM curtail, 3 hour PM load up, 4 hour PM curtail
    Where load up immediately precedes curtailment, which start at 6AM and 4PM

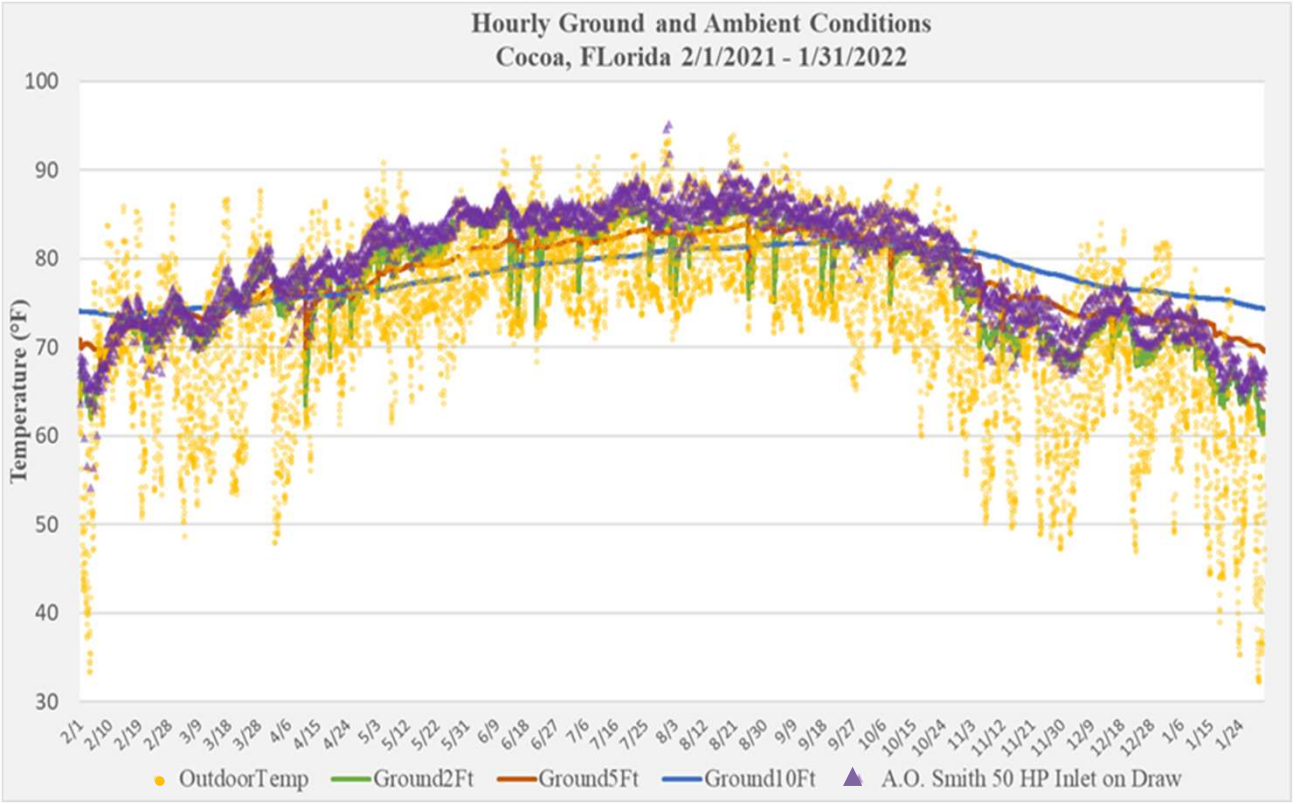
Experimental Design

- Evaluation of the Economy Mode dataset
- User set point 125°F
- Advanced load up allows tanks with mixing valves to shift the set point higher
- Prototype CTA 2045-B:
  - User SP: 125°F
  - Tank SP: 130°F
  - Tank SP during advanced load up: 145°F
  - Tank SP allowed to drop to 110°F during shed

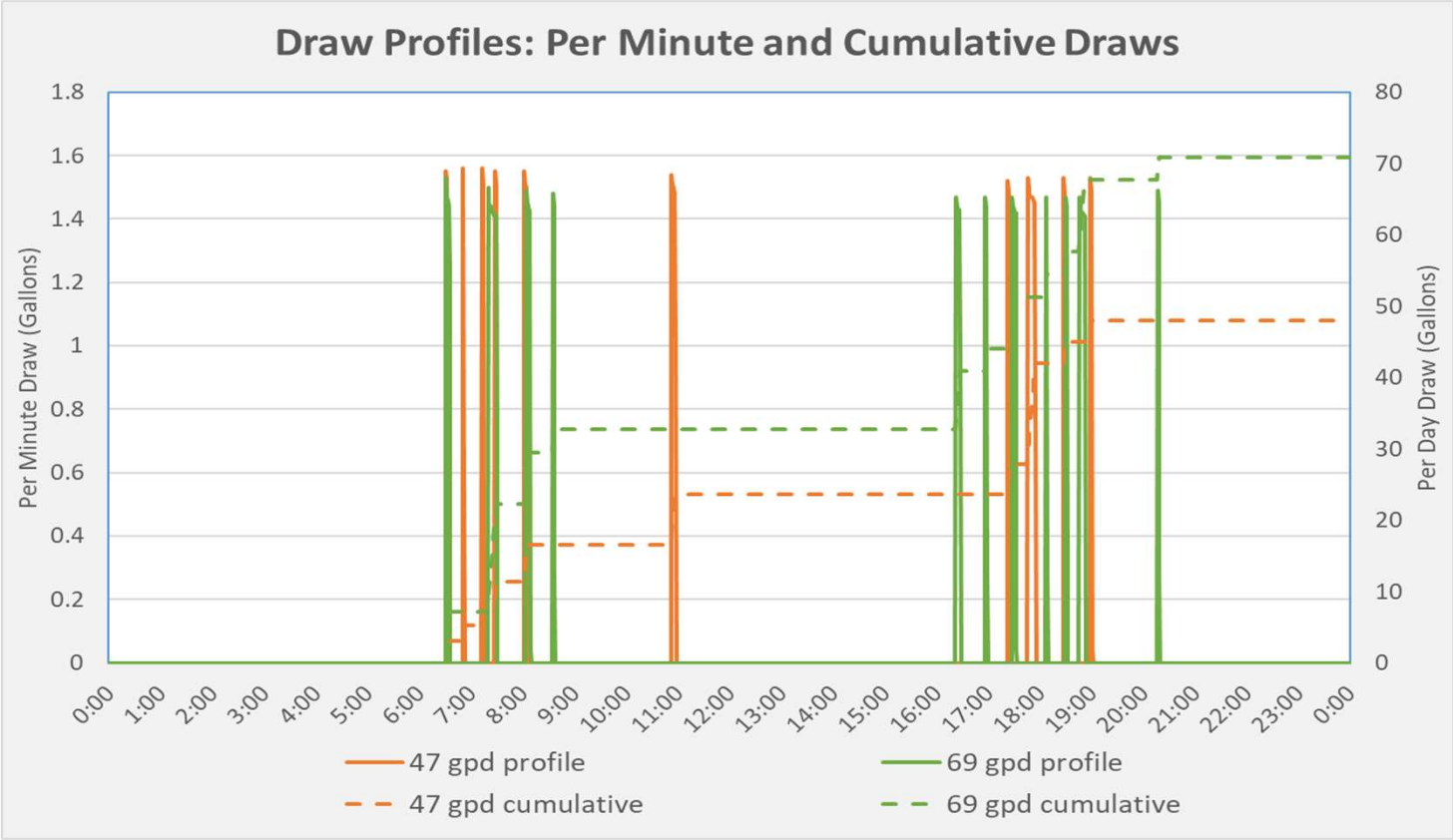


Central Florida Ground Temperatures

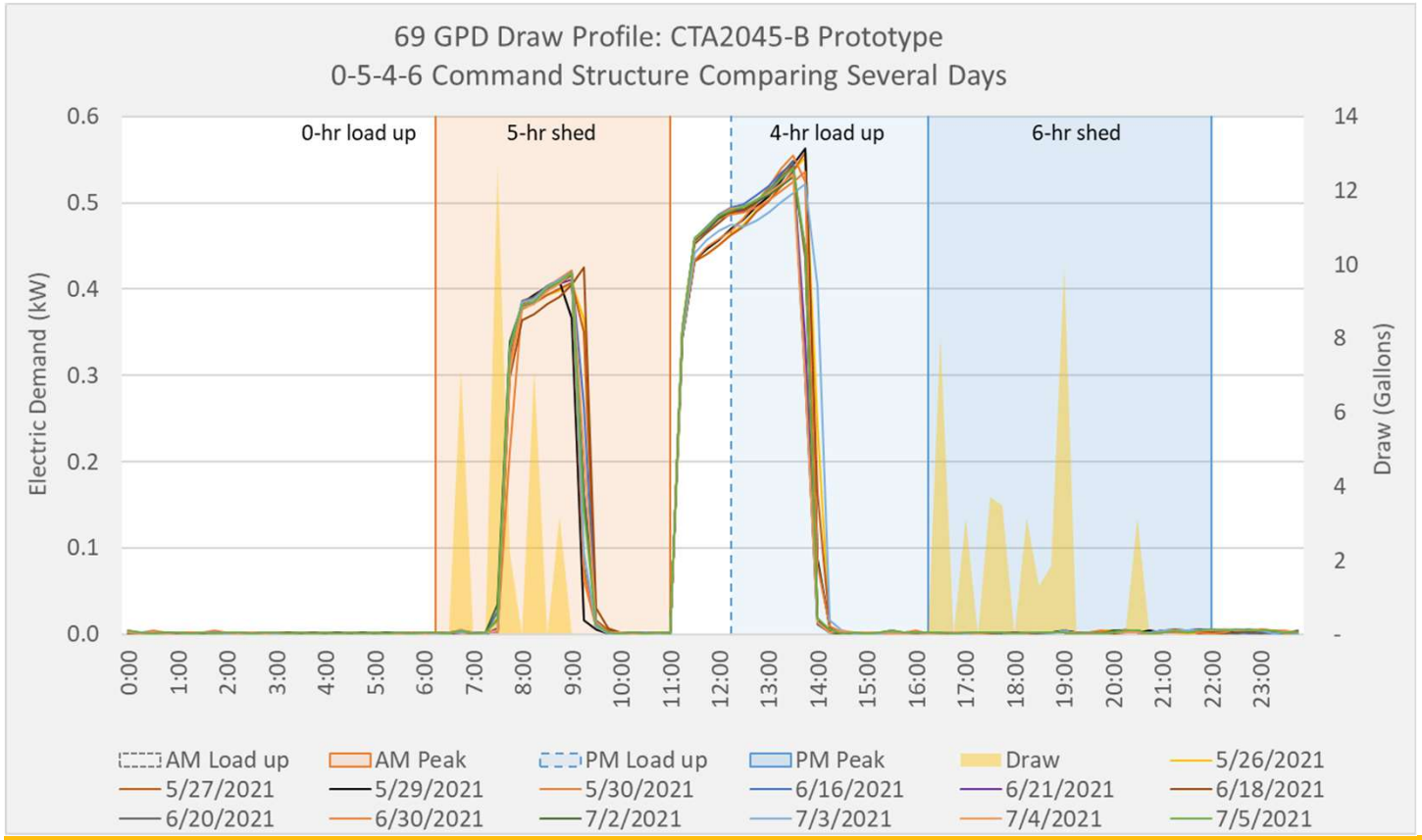
- Moderate inlet water temperatures:
- Low to mid 60s^{o}F in Jan-Feb
- Mid to high 80s^{o}F from Jun-Sept



Laboratory Draw Profiles: 47 and 69 GPD

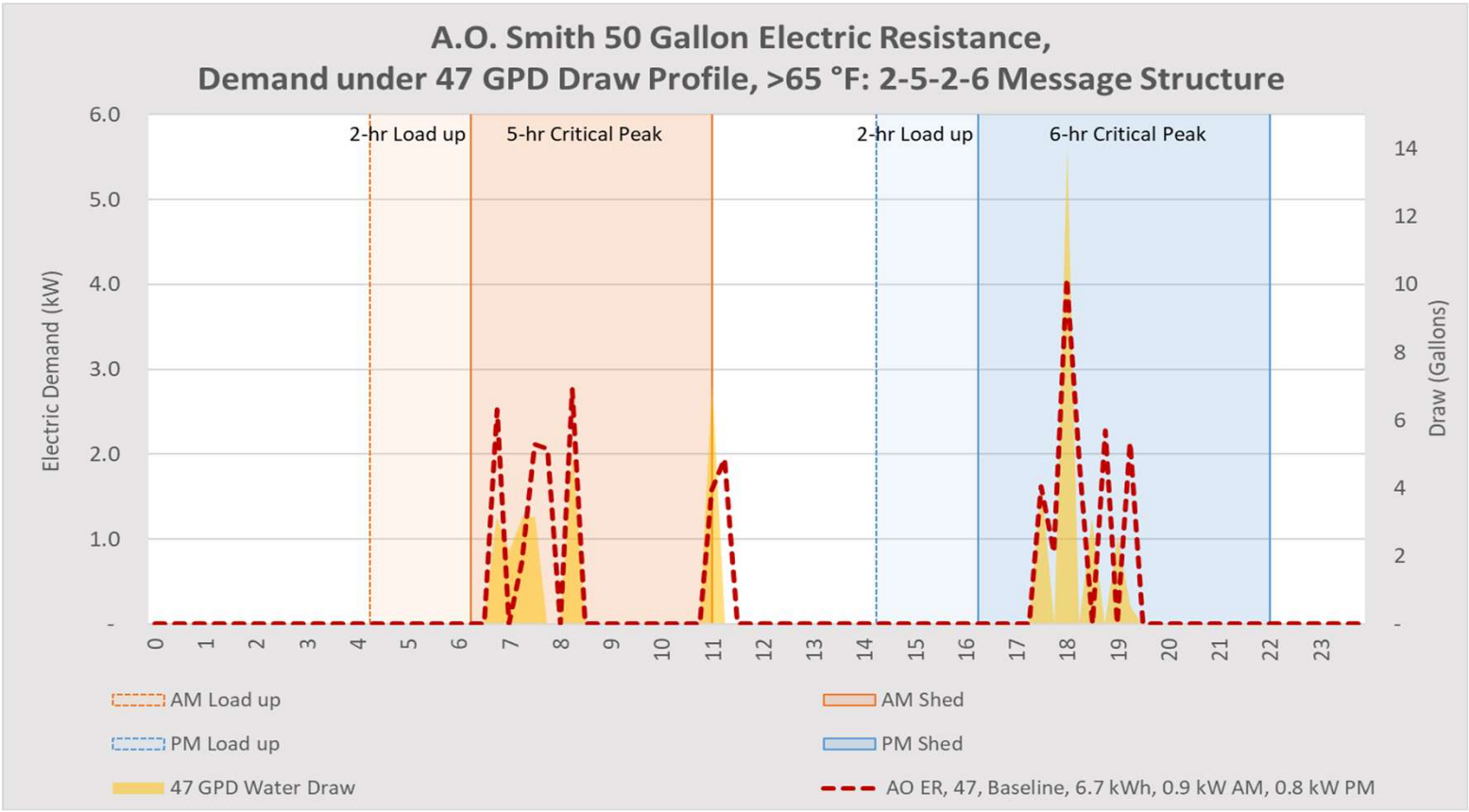


Repeatability of Testing



Example command structure demonstrating repeatability of test conducted on 13 days from end of May into early July

Results: Warm Weather, Electric Resistance Tank



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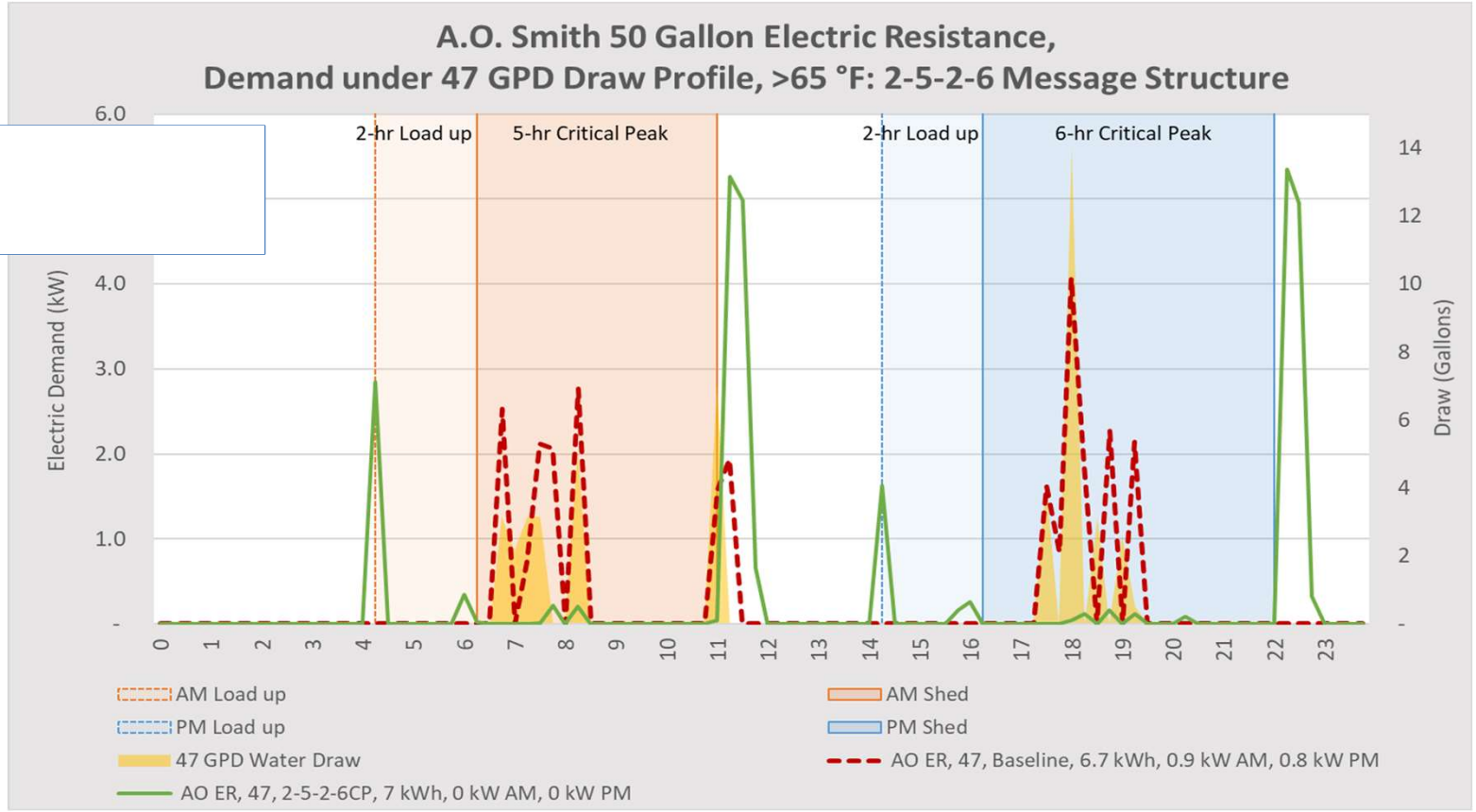
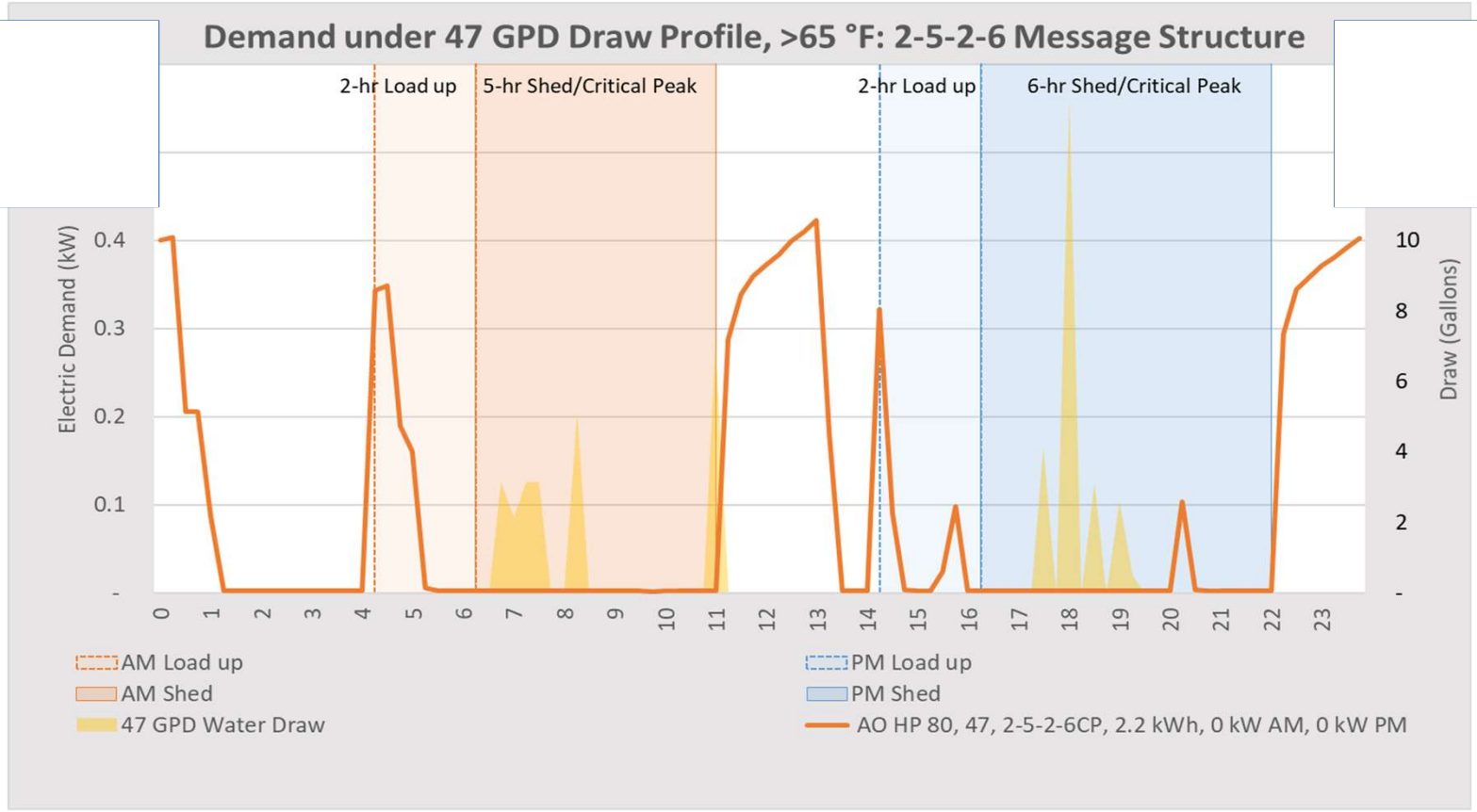


Results: Warm Weather, Heat Pumps



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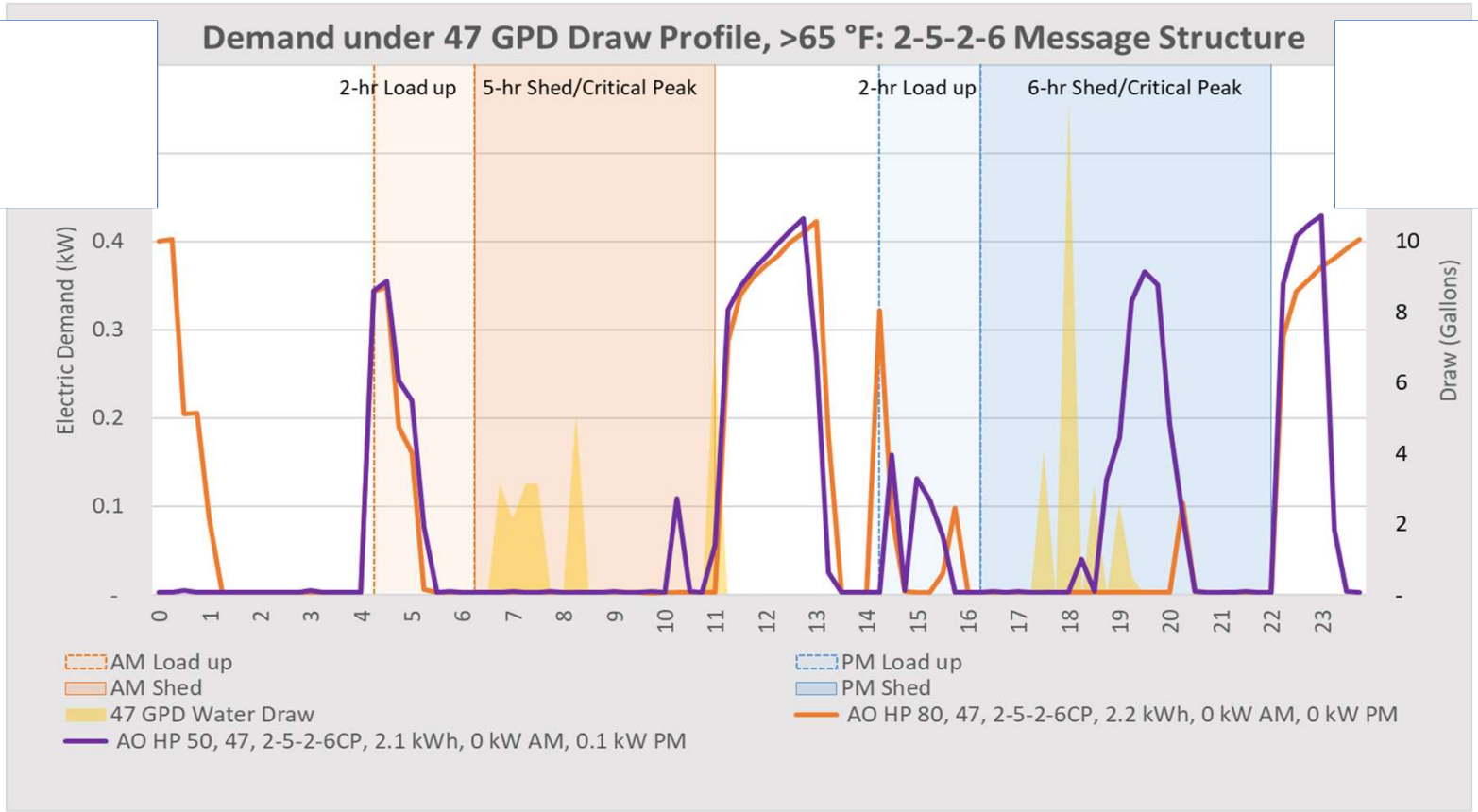

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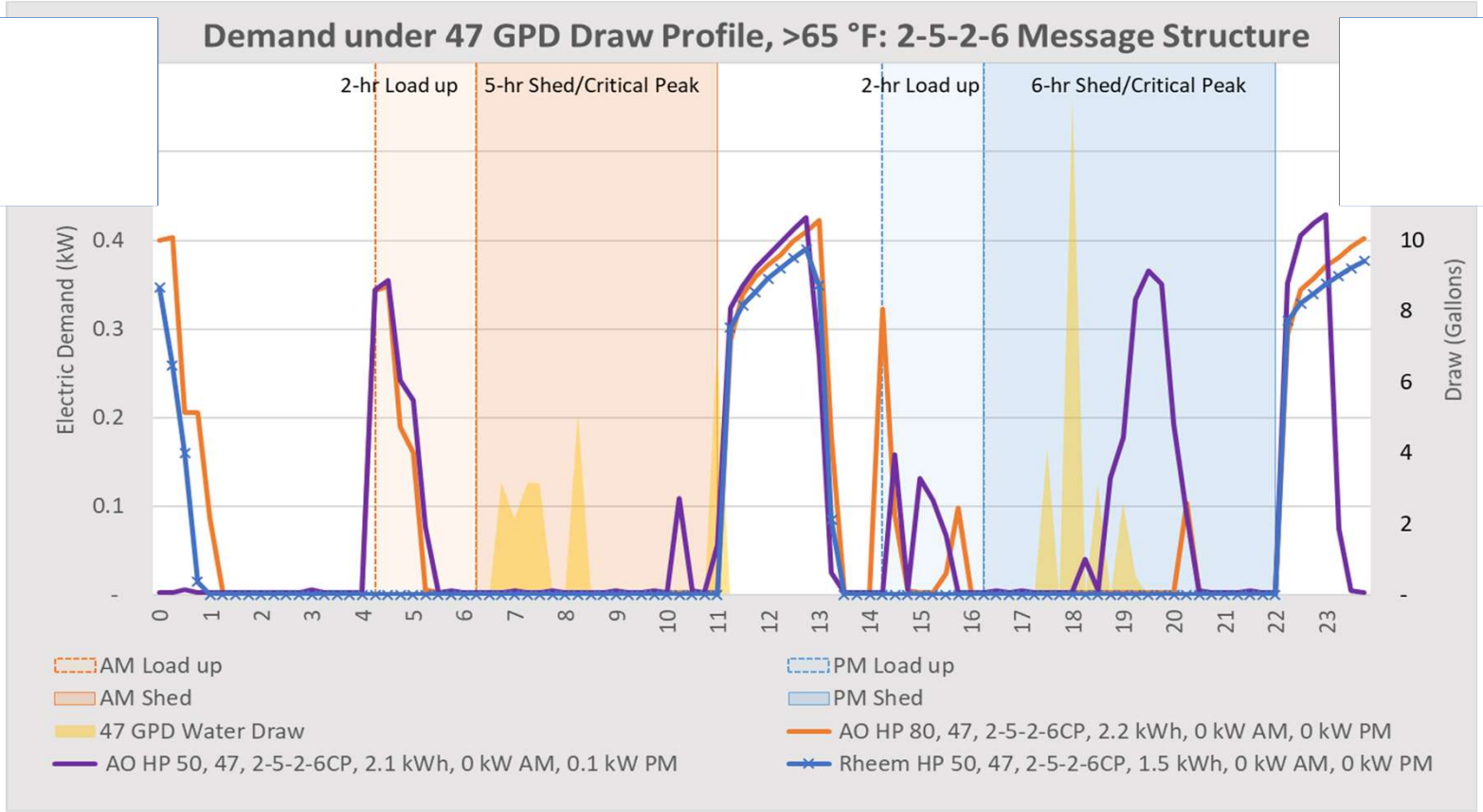

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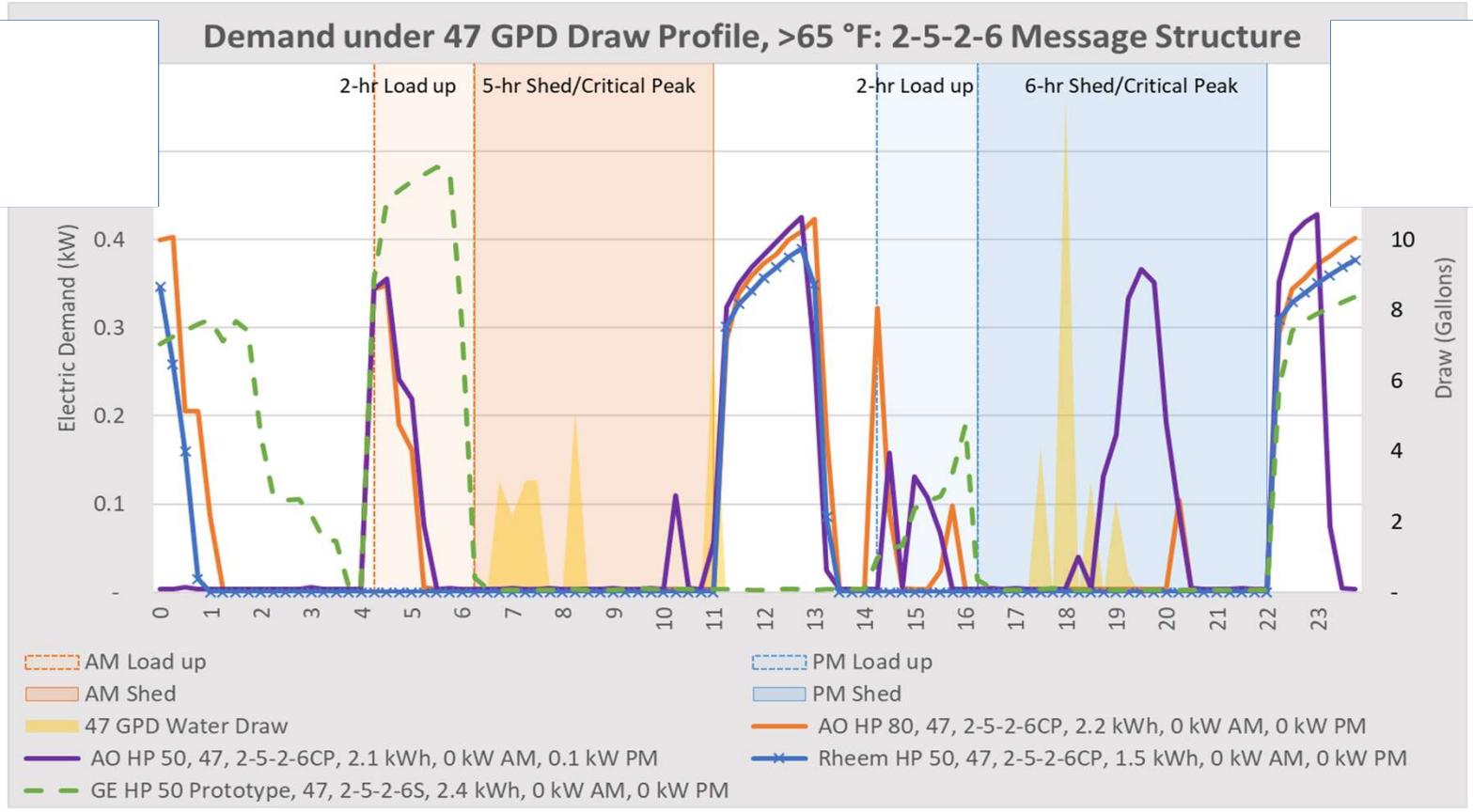
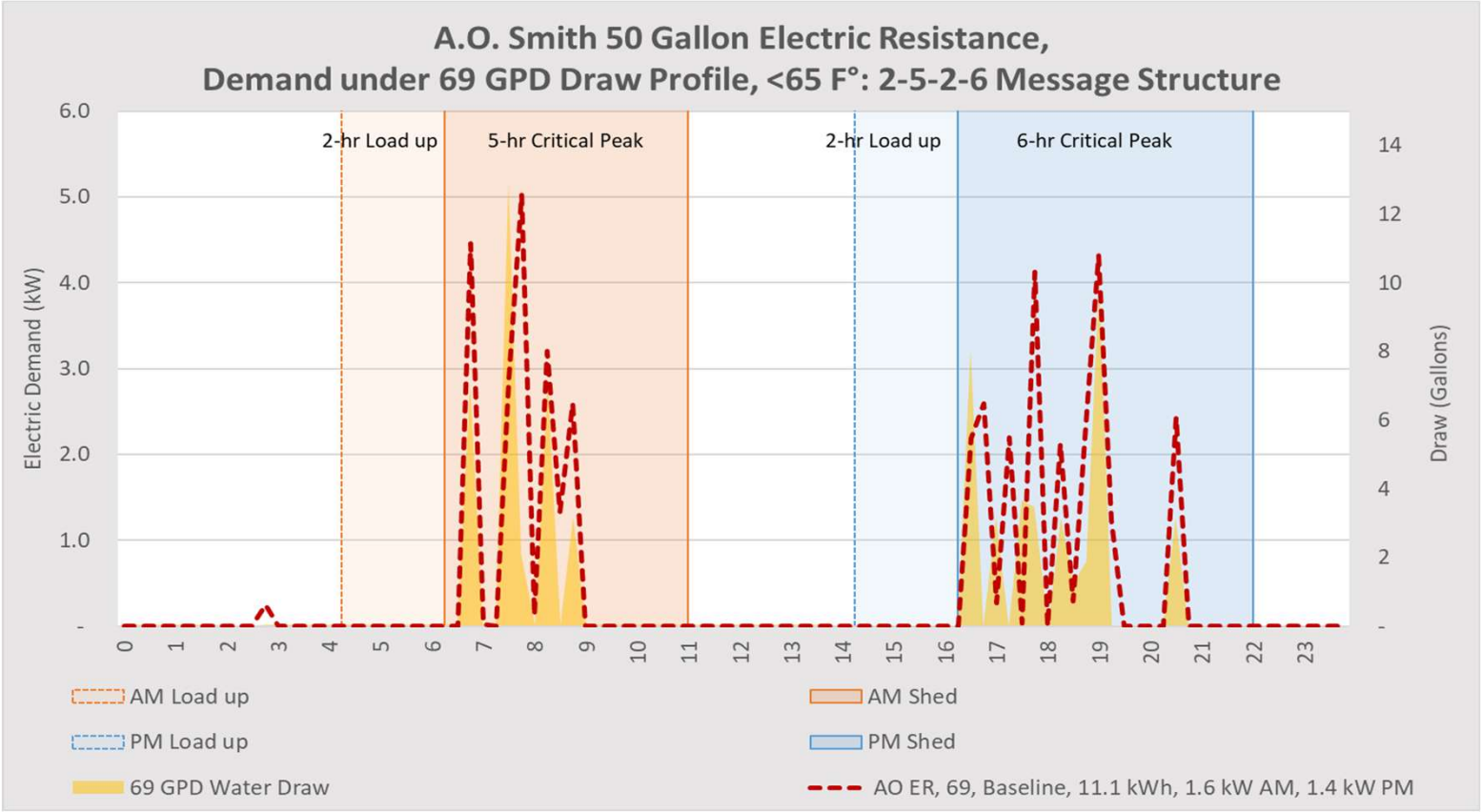


Results: Cool Weather, Electric Resistance Tank



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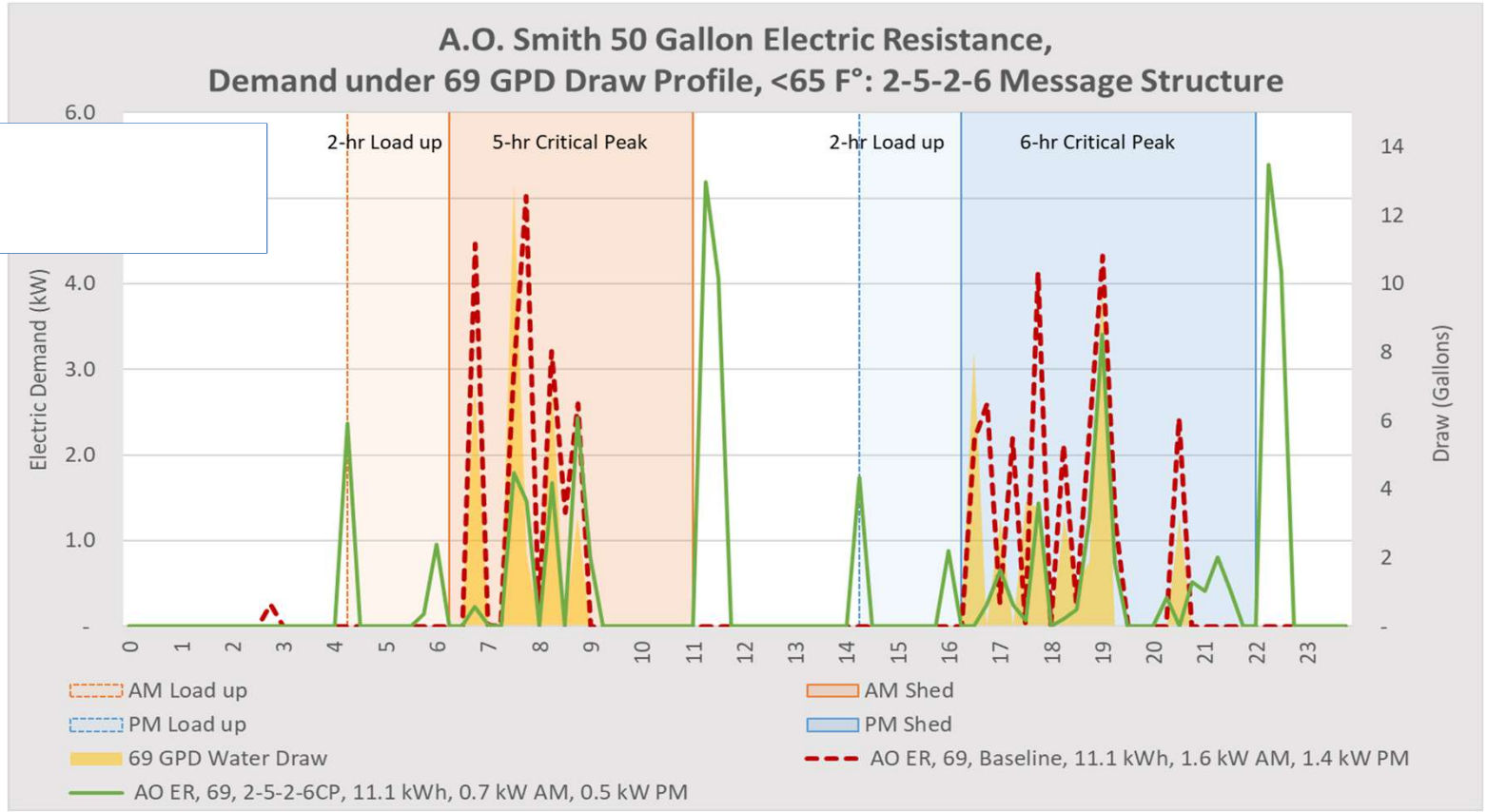

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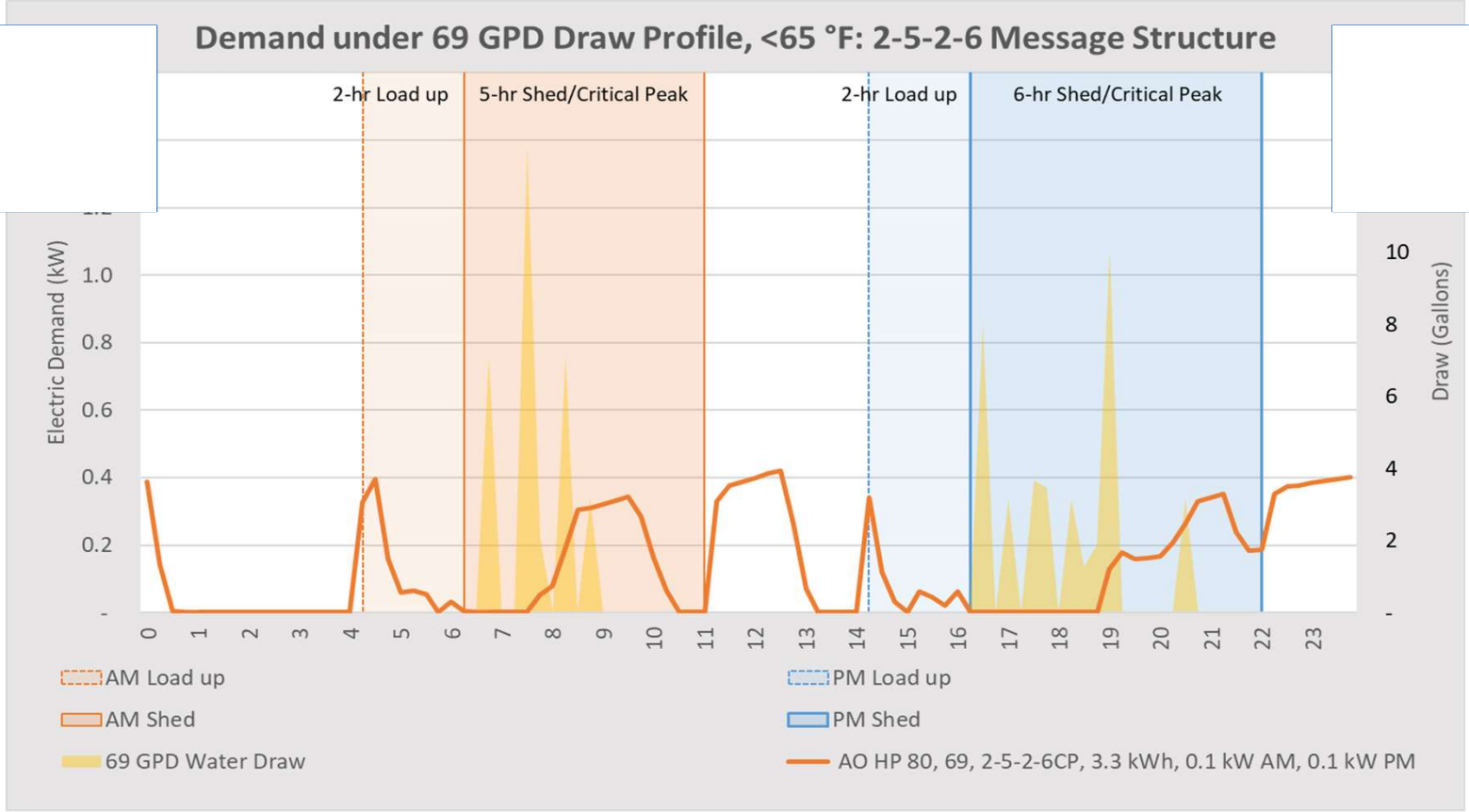

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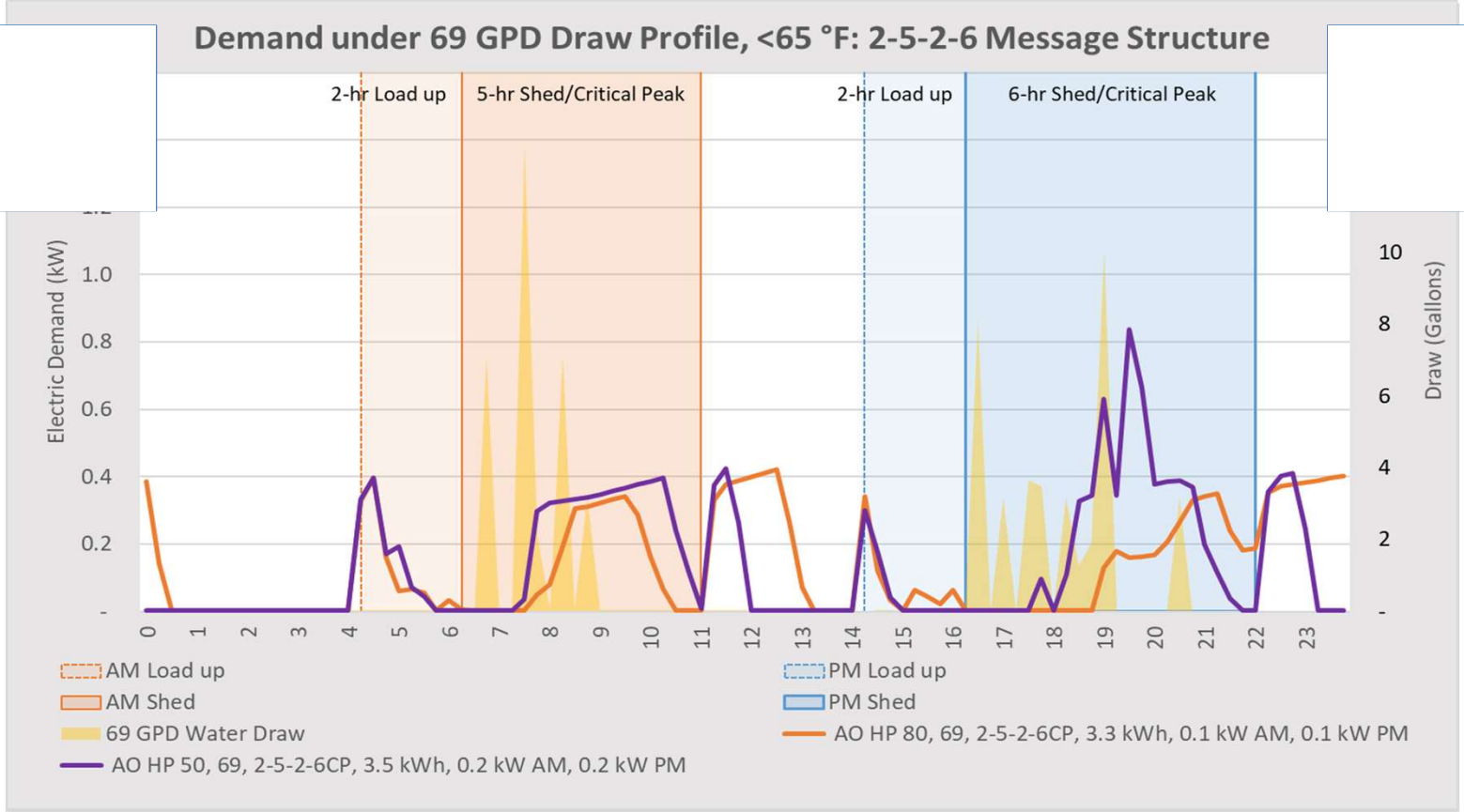

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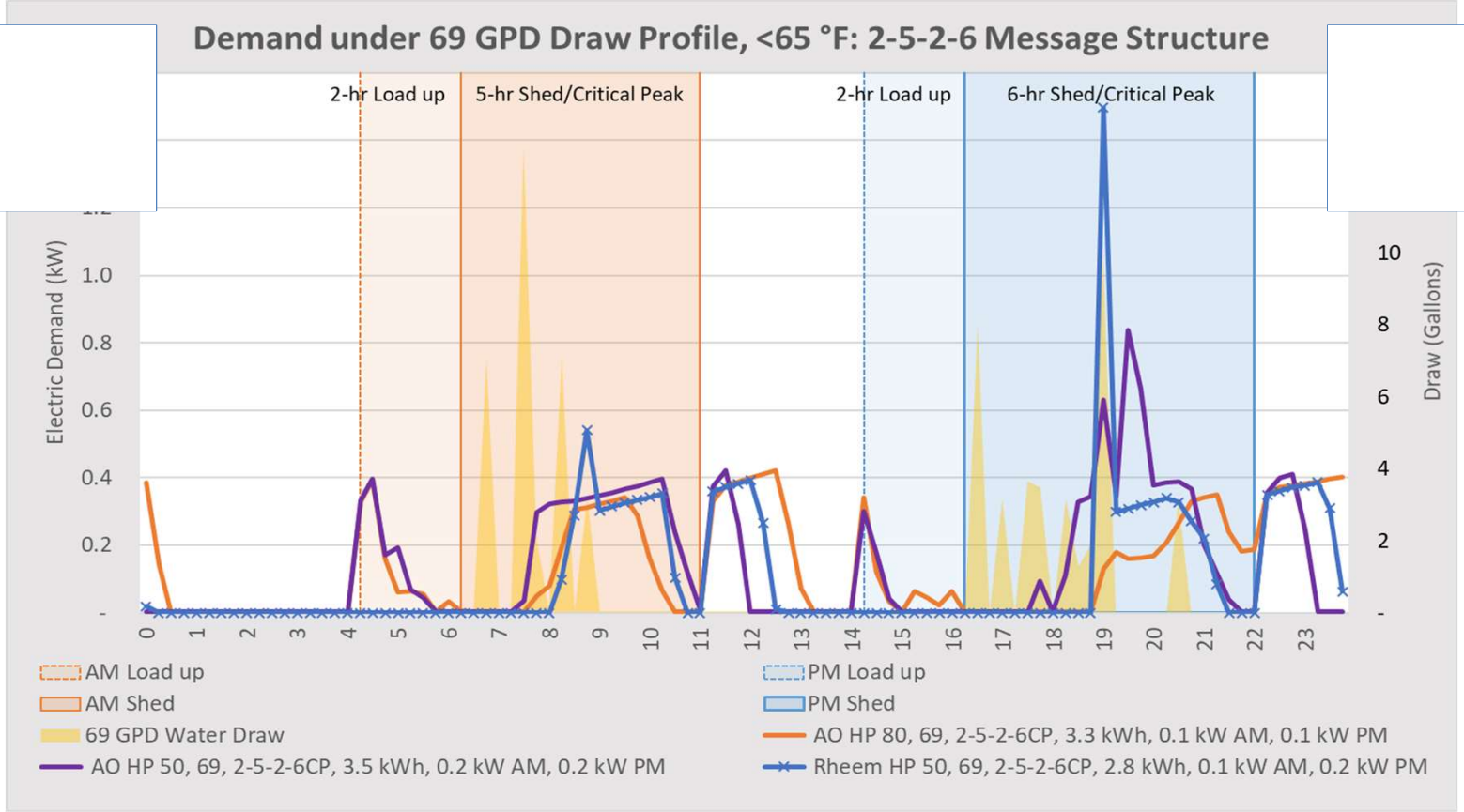

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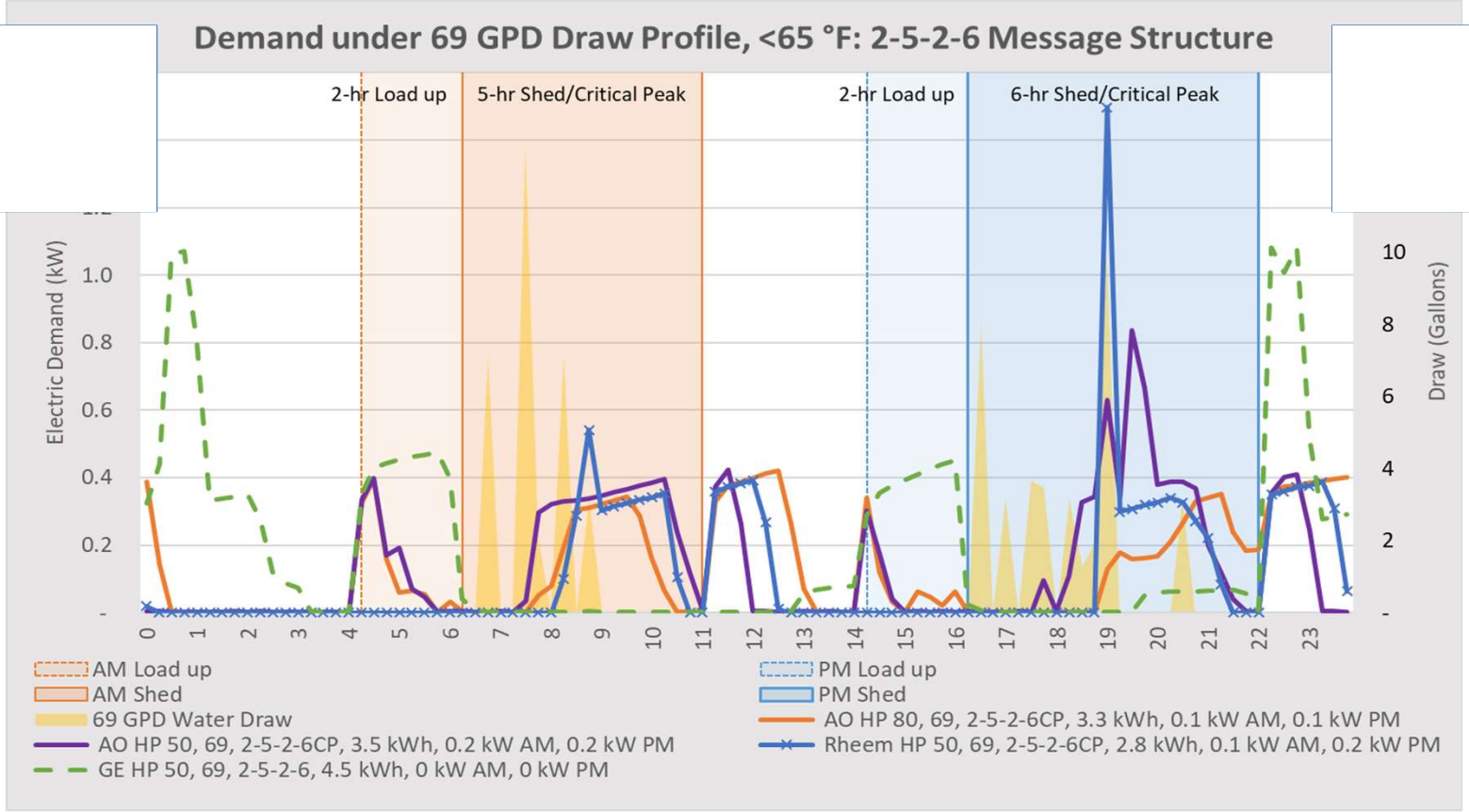
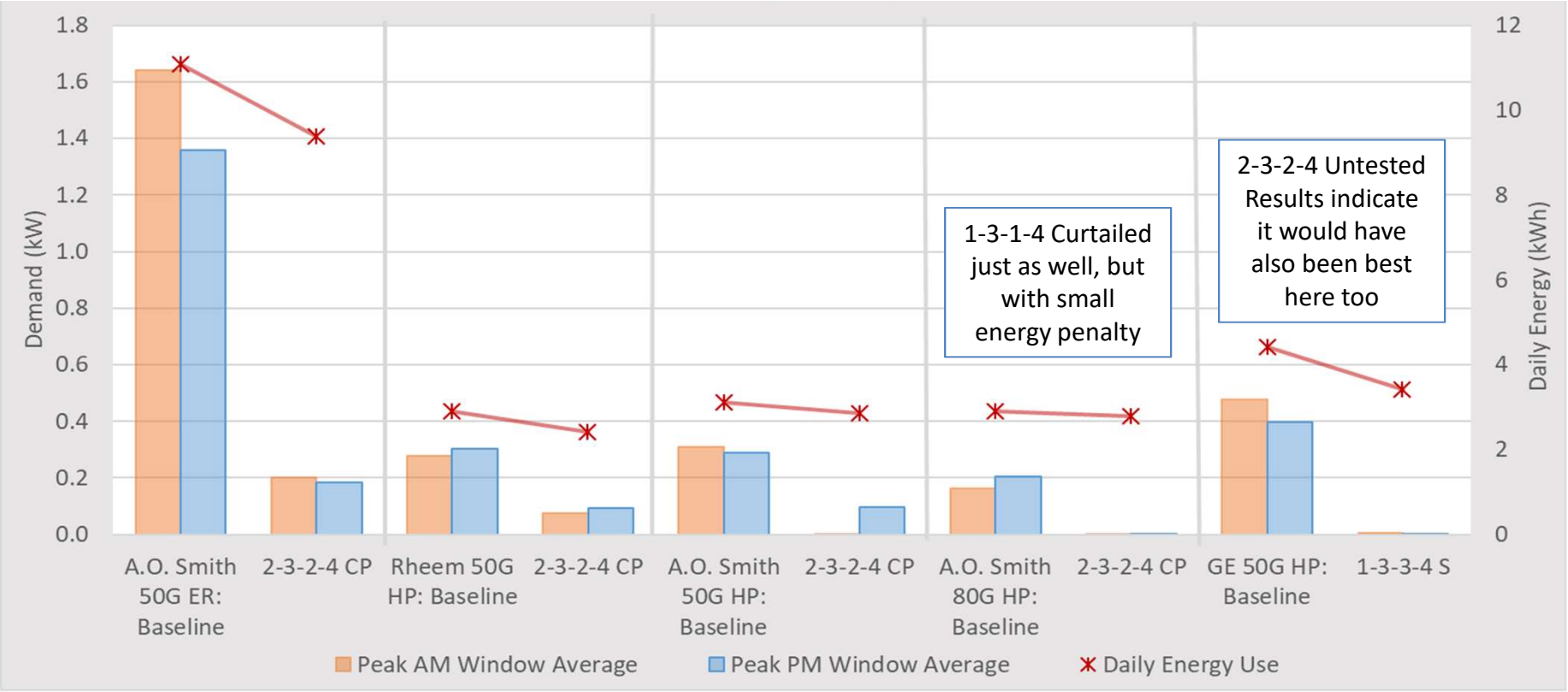
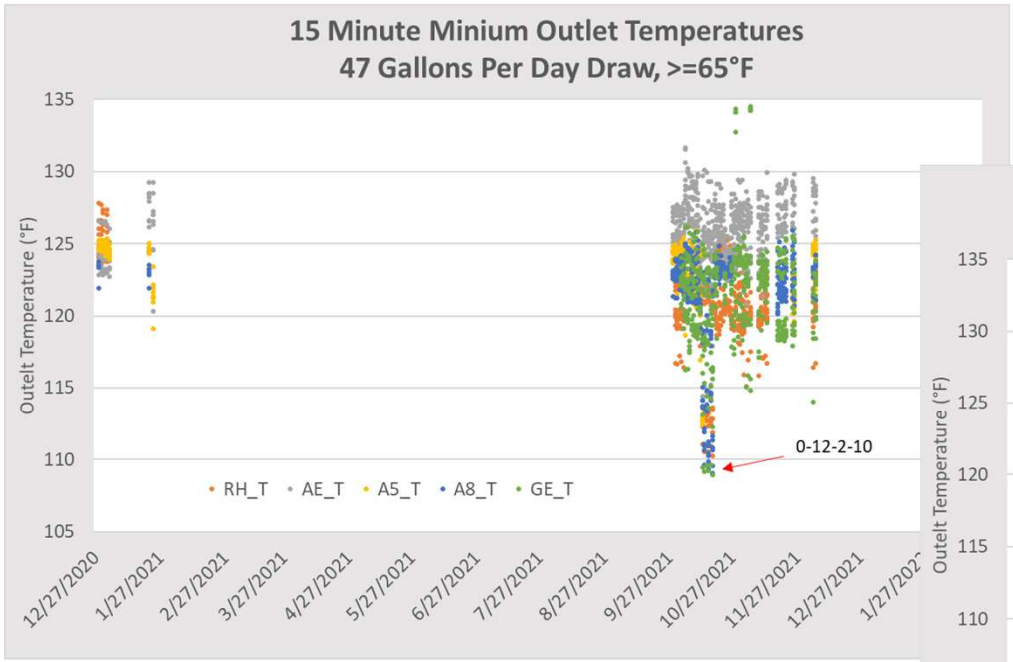
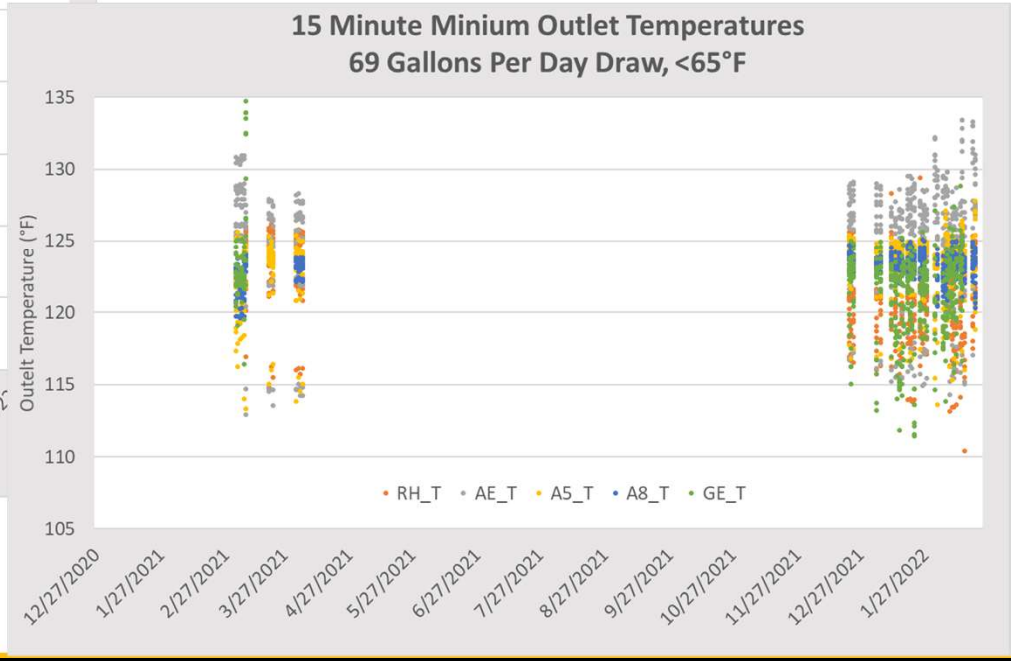


Best Colder Weather Strategies



Minimum Outlet Temperatures





Conclusions

- HPWHs energy savings of 66-77% compared to ER tank
- Connected ERWH
  - Winter: Unable to perfectly curtail load, but did provide energy use reduction in winter (1.69 kWh, 15%)
  - Summer: Some tests show perfect peak load shed but with energy penalty
- Peak demand reductions for connected HPWH vs. unconnected ER tank
  - Up to 1.64 kW (99%) in cold weather (69 GPD draw) (am)
  - Up to 1.04 kW (100%) in warm weather (47 GPD draw) (pm)
- Peak demand was reduced by up to 0.31 kW (>99%) more for connected compared to unconnected CTA-2045-A HPWH units
- Most strategies provided complete shed during warm weather tests

Conclusions

- 2-hour load up important for colder weather shed
- 80 Gallon and the Advanced Load Up units completely shed load during the cold weather tests (69 GPD draw)
  - 1.64 kW (am) and 1.36 kW (pm) over unconnected ER
  - 0.16 kW (am) and 0.21 kW (pm) over unconnected A.O. Smith 80 G
  - 0.48 kW (am) and 0.40 kW (pm) over unconnected GE Prototype 50G
- All connected units demonstrated increased demand following curtailment
- Delivered temperatures during curtailment chiefly >115 °F
  - Always >110 °F (prototype excluded)
- Peak demand reductions from connected water heaters are potentially large for an electric utility in the future with many thousands of such water heaters operating under control

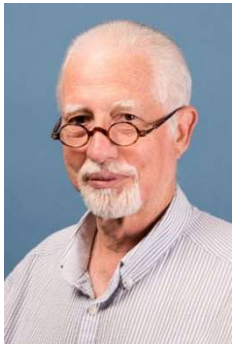
Caveats

- Laboratory Tests: Results are indicative, not predictive, as laboratory tests are necessarily deterministic for repeatability
- Not all test structures were tested on all units within a given temperature range
- Findings may be impacted by different operation mode settings and different draw patterns
- Geography: Warm temperatures in Central Florida
  - Daily average outdoor temperatures (43-85°F) and inlet temperatures (low 60°Fs to high 80°Fs) are relatively mild compared to many other locations

Future Research

- Evaluation of tests using hybrid mode
- Field component on ~50 Central Florida homes
  - Three monitored field sites
  - Influence of occupancy and unit location (conditioned vs. unconditioned)
- Laboratory testing of additional manufactures and Version 2 of prototype with advanced load up

Questions?

Karen Fenaughty, Danny Parker, Carlos Colon, and Robin Vieira

FSEC Energy Research Center, University of Central Florida

With special thanks to: Safvat Kalagchy and Nicholas Bonilla


Josh Butzbaugh and Ebony Mayhorn, Ph.D.
Pacific Northwest National Laboratory