Custom Controls for Improved Demand Response from Heat Pump Water Heaters

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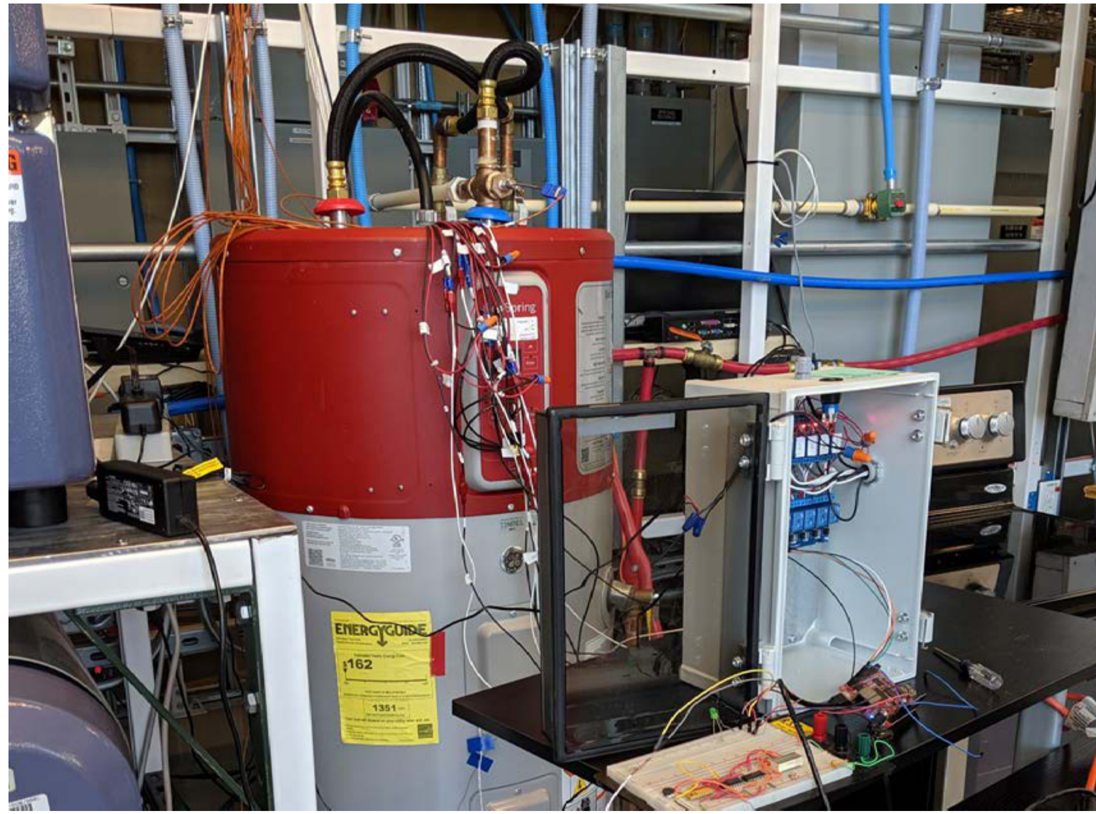
Overview

- Background on Grid Modernization Lab Consortium project
- NREL focused on electric water heaters
- Modified GE heat pump water heater (HPWH)
- “Standard” demand response (DR) controls
- Modified DR controls.



GMLC Project Overview

The work described in this presentation was part of a multi-year, multi-lab Grid Modernization Lab Consortium (GMLC) project, focused on developing standard modeling frameworks for various device fleets and grid services, representing these in a standard battery-equivalent format, and demonstrating the potential of these battery-equivalent device fleets to meet advanced grid service needs.

- NREL focused on residential electric water heaters
- Argonne National Lab focused on electric vehicles
- Oak Ridge National Lab focused on commercial refrigeration systems.

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

See full report (just published!!) for full details on all aspects of the project. Available at www.nrel.gov.

This presentation will focus on the experimental work related to residential HPWHs.

Laboratory Tests with Modified HPWH

In order to investigate demand response control of a HPWH, we modified a GE HPWH to allow for external control.

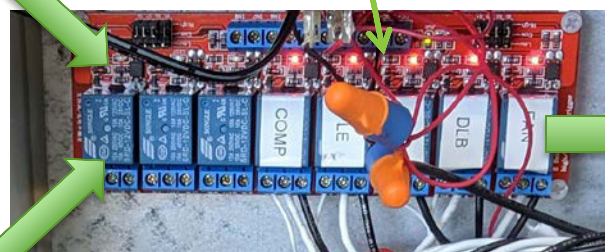
- This HPWH model supports CTA-2045 control, but we wanted more control (direct setpoint control) to increase or decrease the load.
- We also wanted to explore more complex controls that could be used for demand response, such as changes to the deadband, changes to the operating mode, and duty cycling.

→ The water heater was modified to allow control from an external single-board computer.

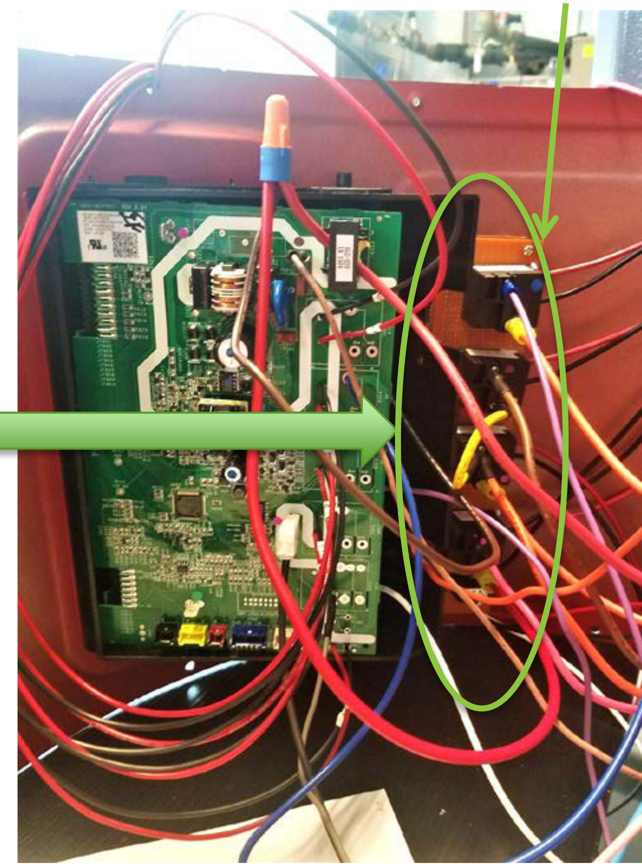
External Controller

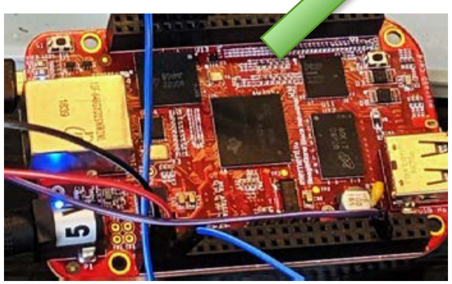
Original GE control board

Relays to switch between controllers



Relays for each heating source + fan



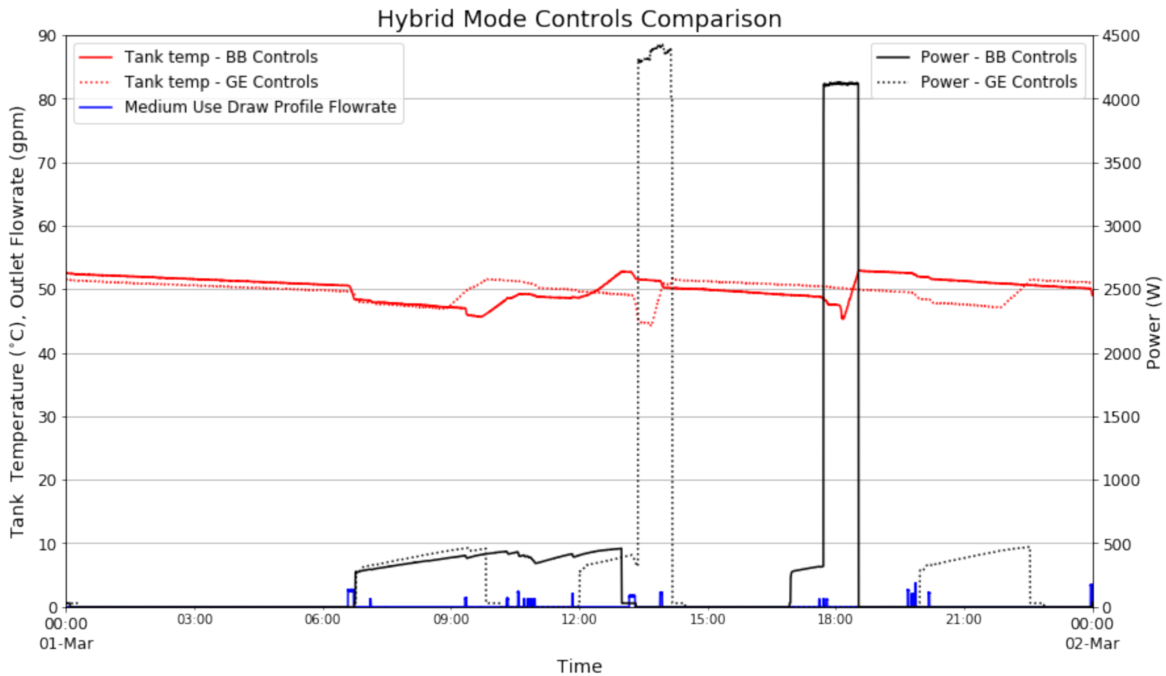


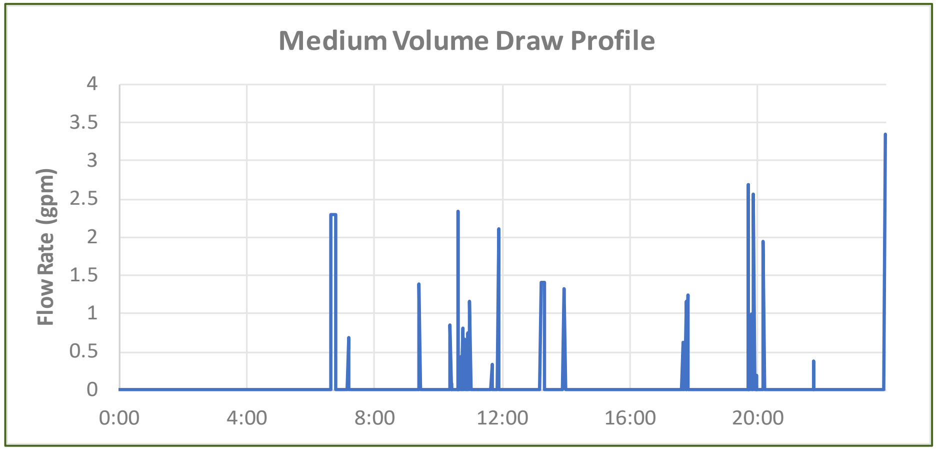
BeagleBone with custom controls

Reproducing Control Algorithms

- Started with GE control board and ran several tests with different draw profiles to tease out effective controls.
- The effective controls were implemented on the BeagleBone and tests were repeated.
- This process was repeated until the energy use from BB controls matched within 5% over 24-hour draw profile.

➢ Upper plot shows results from our "medium" usage draw profile (right). Despite some differences in timing, energy use for BB controller was 4% less than GE controller.



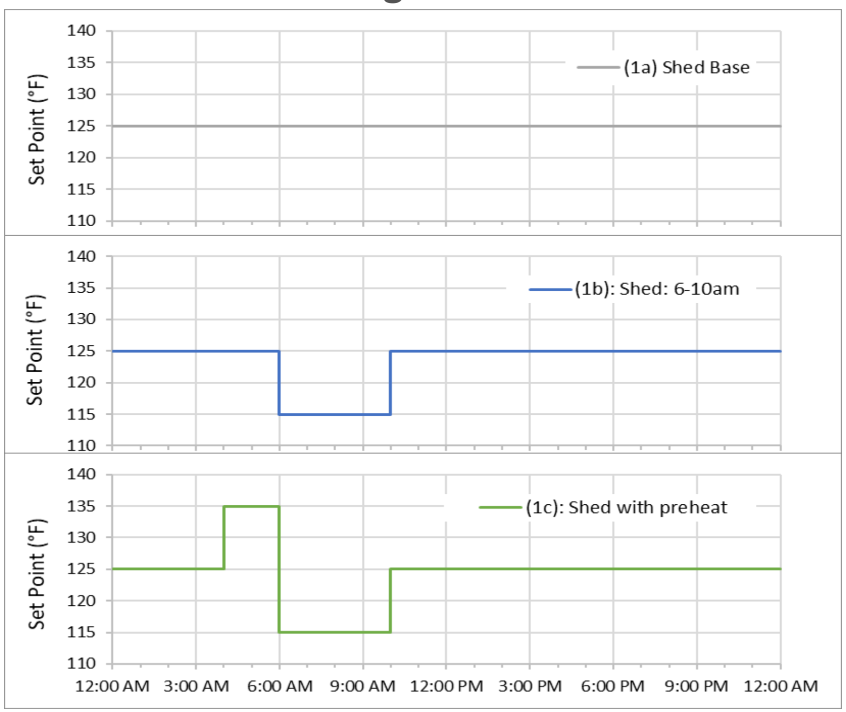


Basic Demand Response

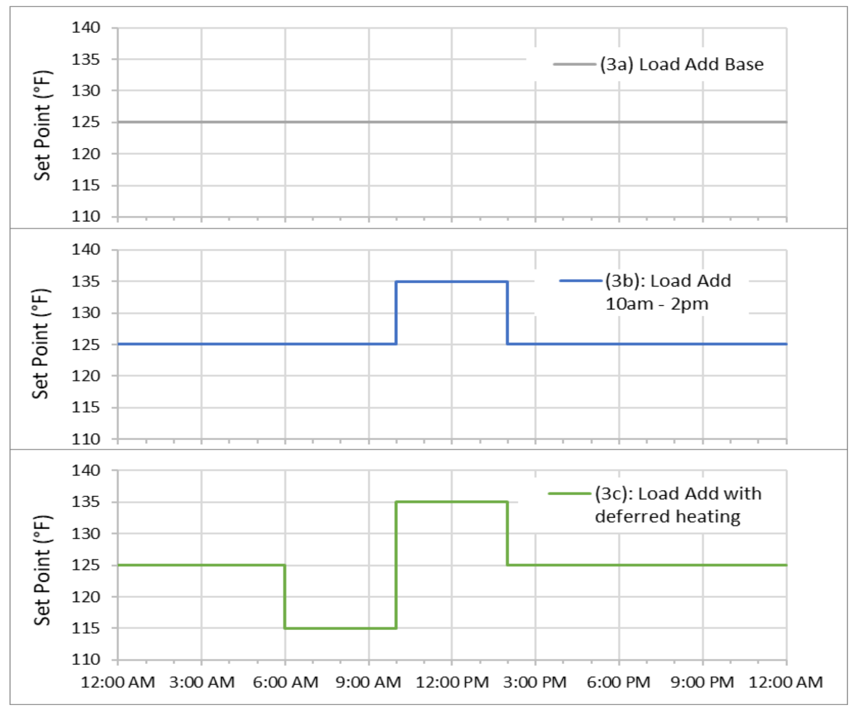
After we implemented the BeagleBone controls, we ran through a series of setpoint changes to illicit load add and load shed.

- Morning load shed, with and without preheating
- Afternoon load add, with and without deferred heating.

Morning Load Shed

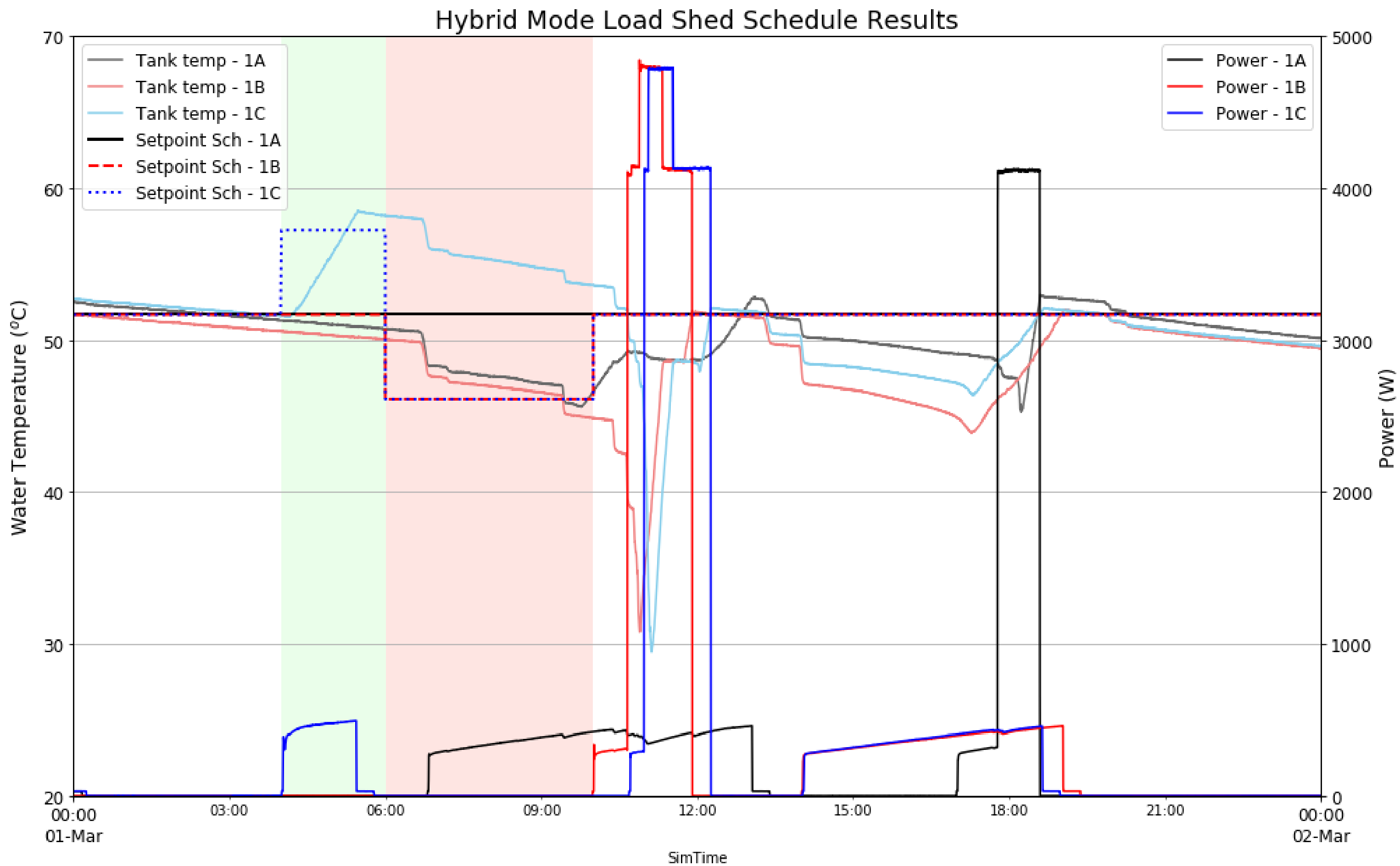


Afternoon Load Add



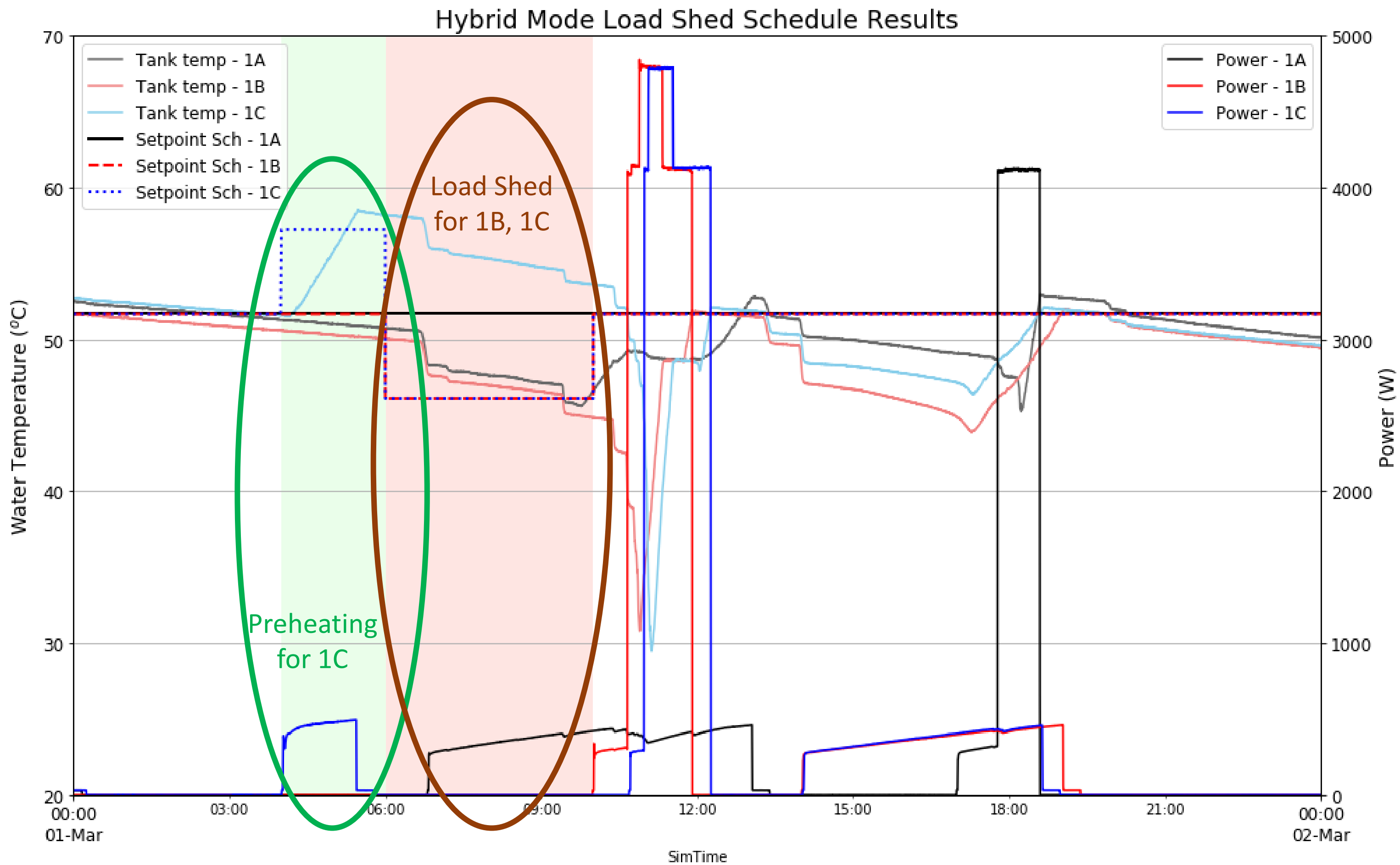
** These tests were designed and implemented before ENERGY STAR® released draft requirements and test procedures around Connected Residential Water Heaters.*

Basic Demand Response – Load Shed



Mode	Schedule	Total Energy (kWh)	Energy during DR period (kWh)	Min outlet water temp (°C)
Hybrid	1a (fixed setpoint)	5.96	1.12	47
	1b - Load Shed	7.48	0	36.2
	1c - Load Shed w/ preheat	8.05	0	48.4

Basic Demand Response – Load Shed



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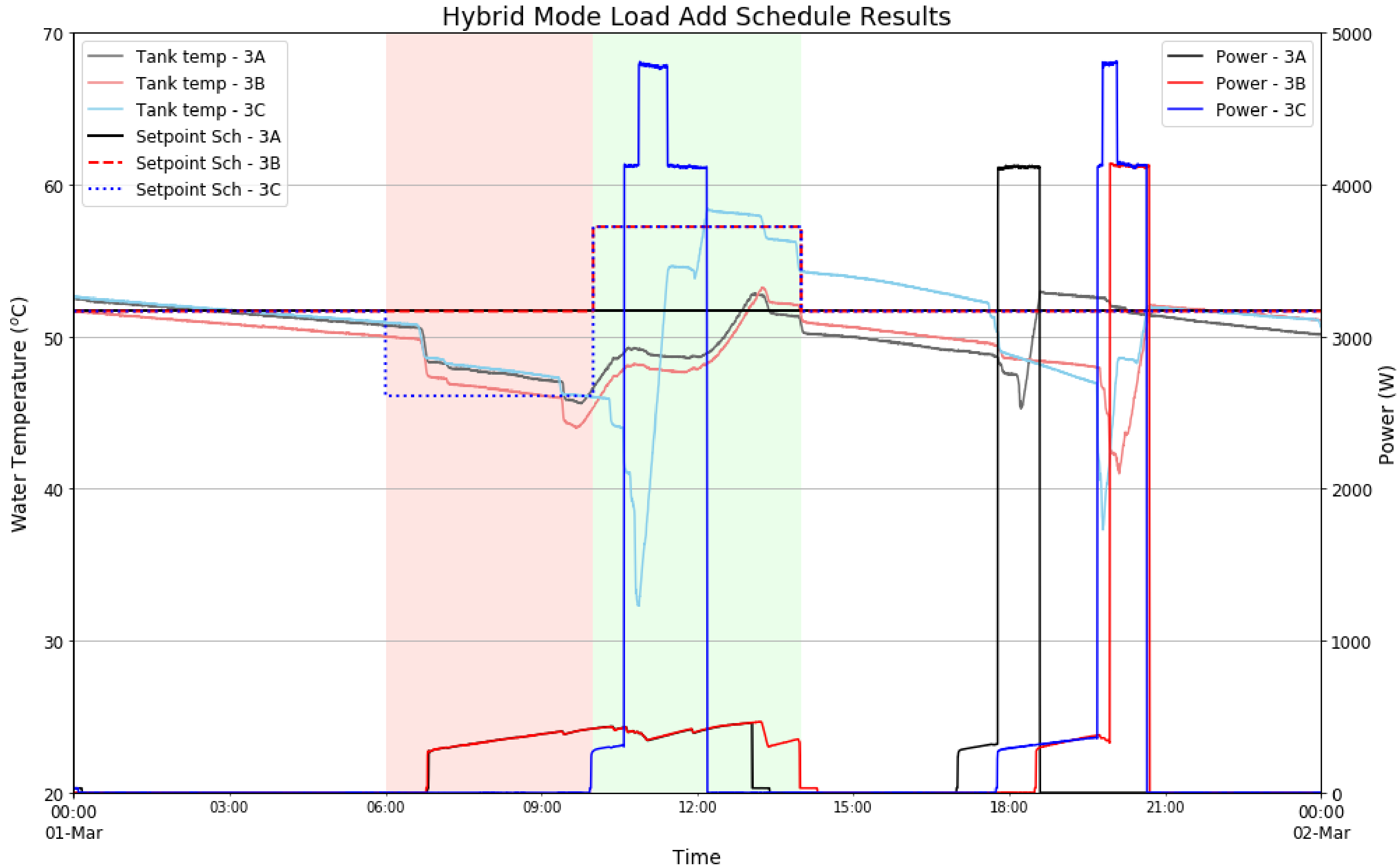
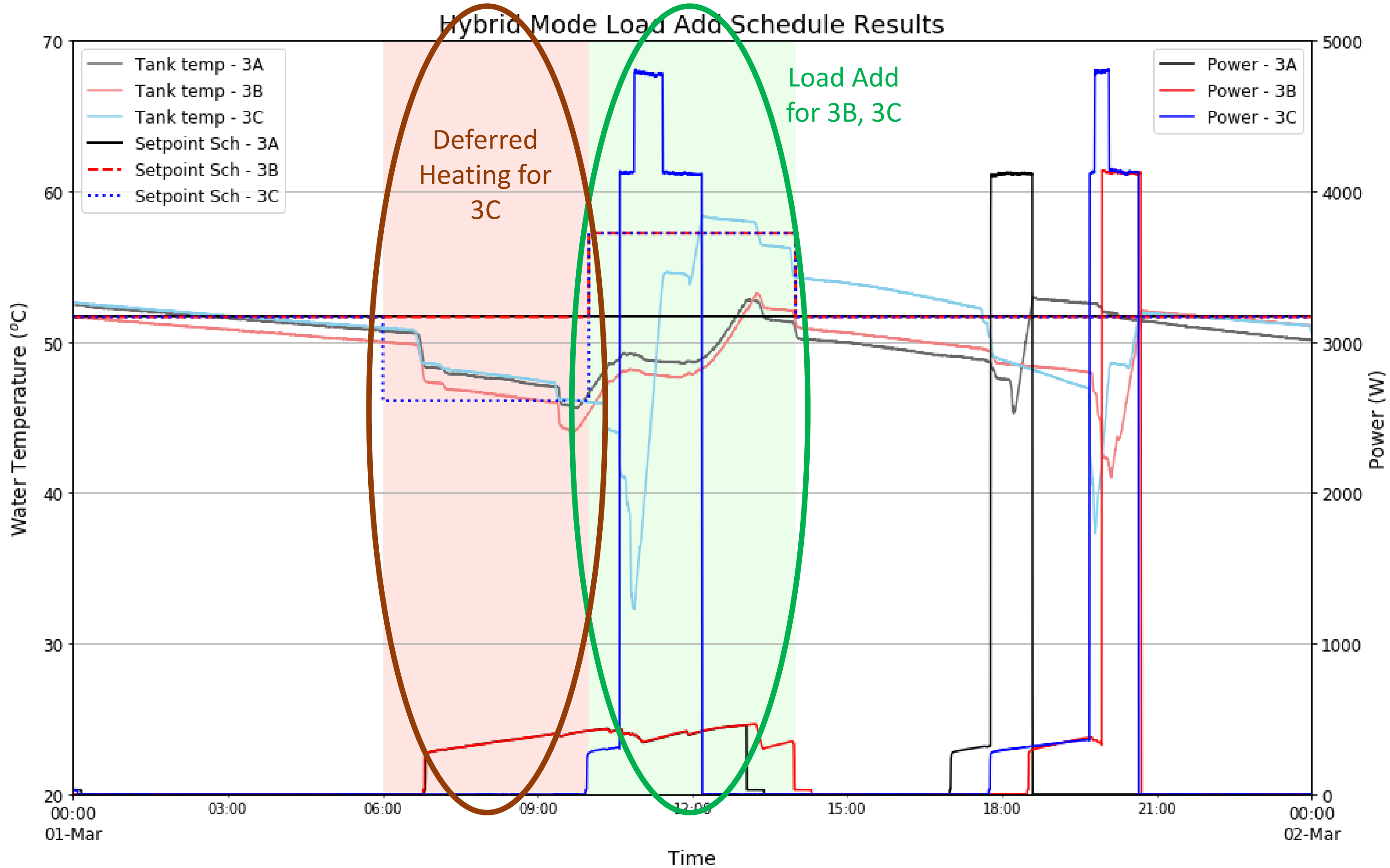
Basic Demand Response – Load Add



Mode	Schedule	Total Energy (kWh)	Energy during DR period (kWh)	Min outlet water temp (°C)
Hybrid	3a (fixed setpoint)	5.96	1.27	47
	3b - Load Add	6.32	1.59	44.3
	3c - Load Add w/ deferred heat	11.82	7.11	36

Basic Demand Response – Load Add



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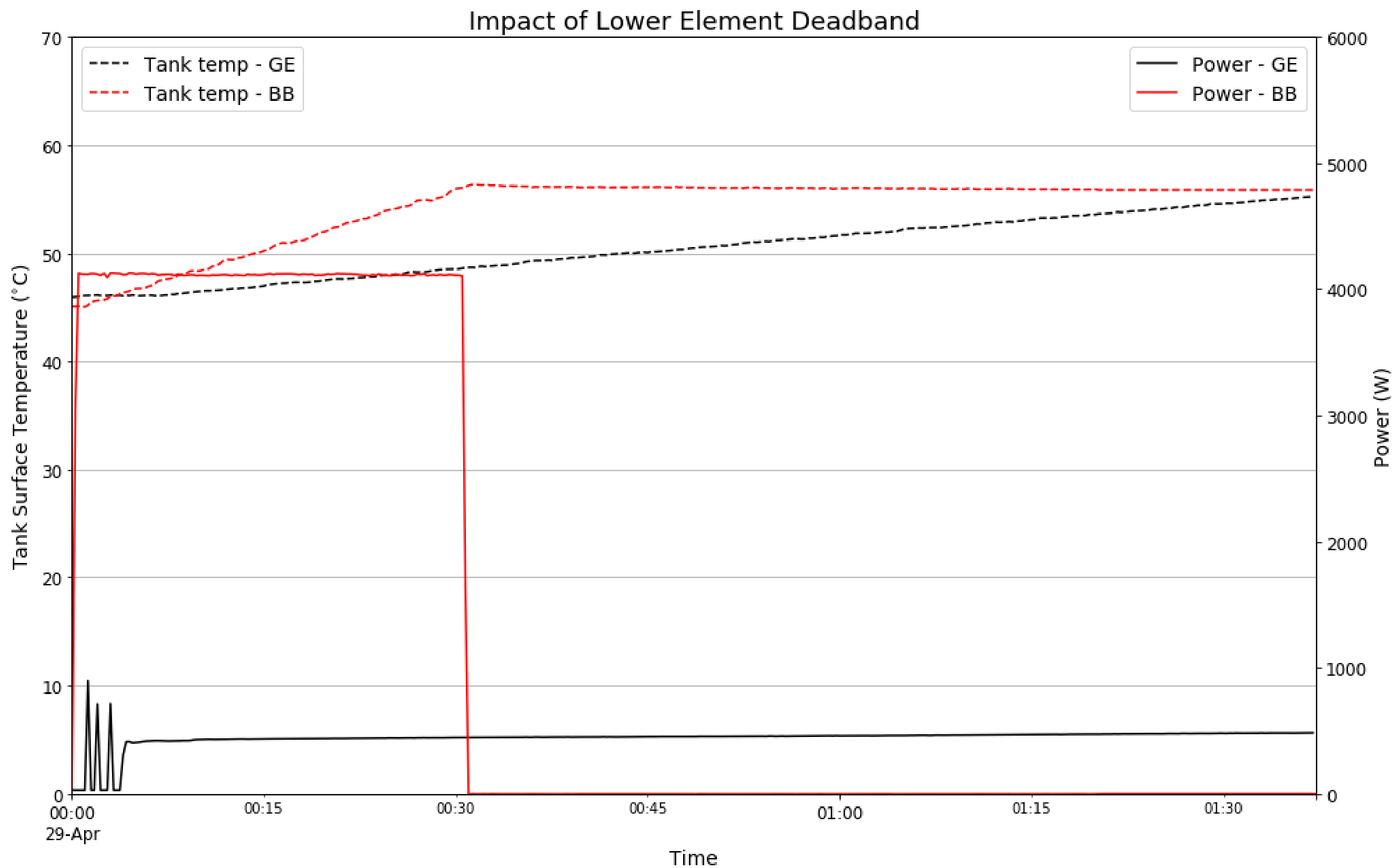
Advanced Demand Response

Based on results from the Basic Demand Response tests, the following changes were implemented to illicit more load shifting and deliver better comfort.

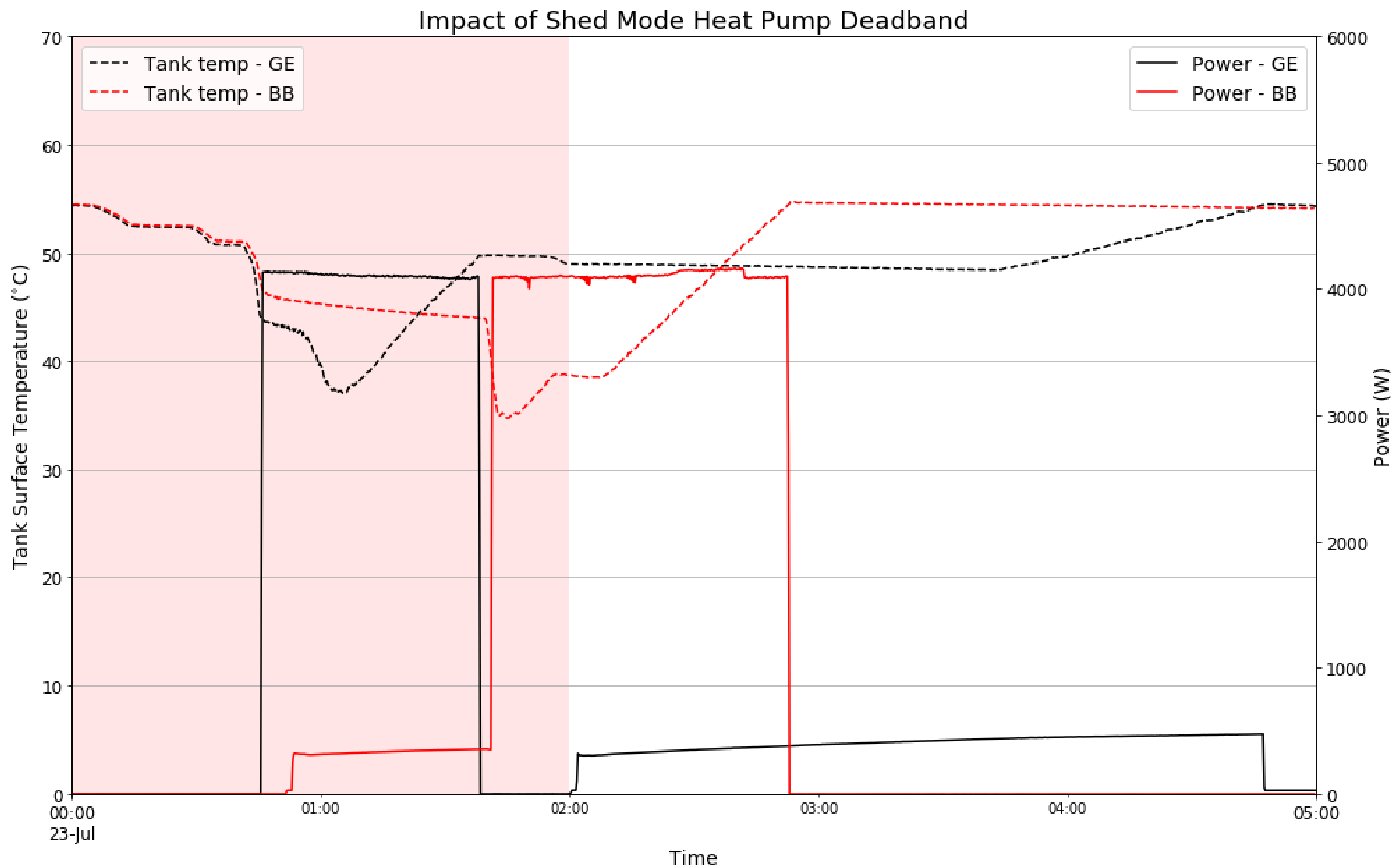
1. **Lower Element Deadband:** Add deadband for lower element in hybrid mode that will turn on lower element if tank temperature is significantly below setpoint. This will help speed up recovery, especially following shed events.
2. **Reduced Heat Pump Deadband for Shed Event:** Reduce deadband for heat pump during shed event to 1°C. This will ensure that the heat pump comes on more quickly to avoid use of electric elements, especially following shed events.
3. **Superboost:** Create "superboost" mode for hybrid mode load add events that combines use of the heat pump and lower element, reduces the deadband to 1°C, and increases the setpoint to 71°C (160°F). If the tank temperature drops below the deadband temperature, the heat pump and lower element will turn on together.
4. **Duty Cycle:** Duty cycle control defined by % on-time and duration of each on period. Hybrid mode duty cycle only applies to the heat pump and keeps fan on the entire time.

Advanced DR: Lower Element Deadband



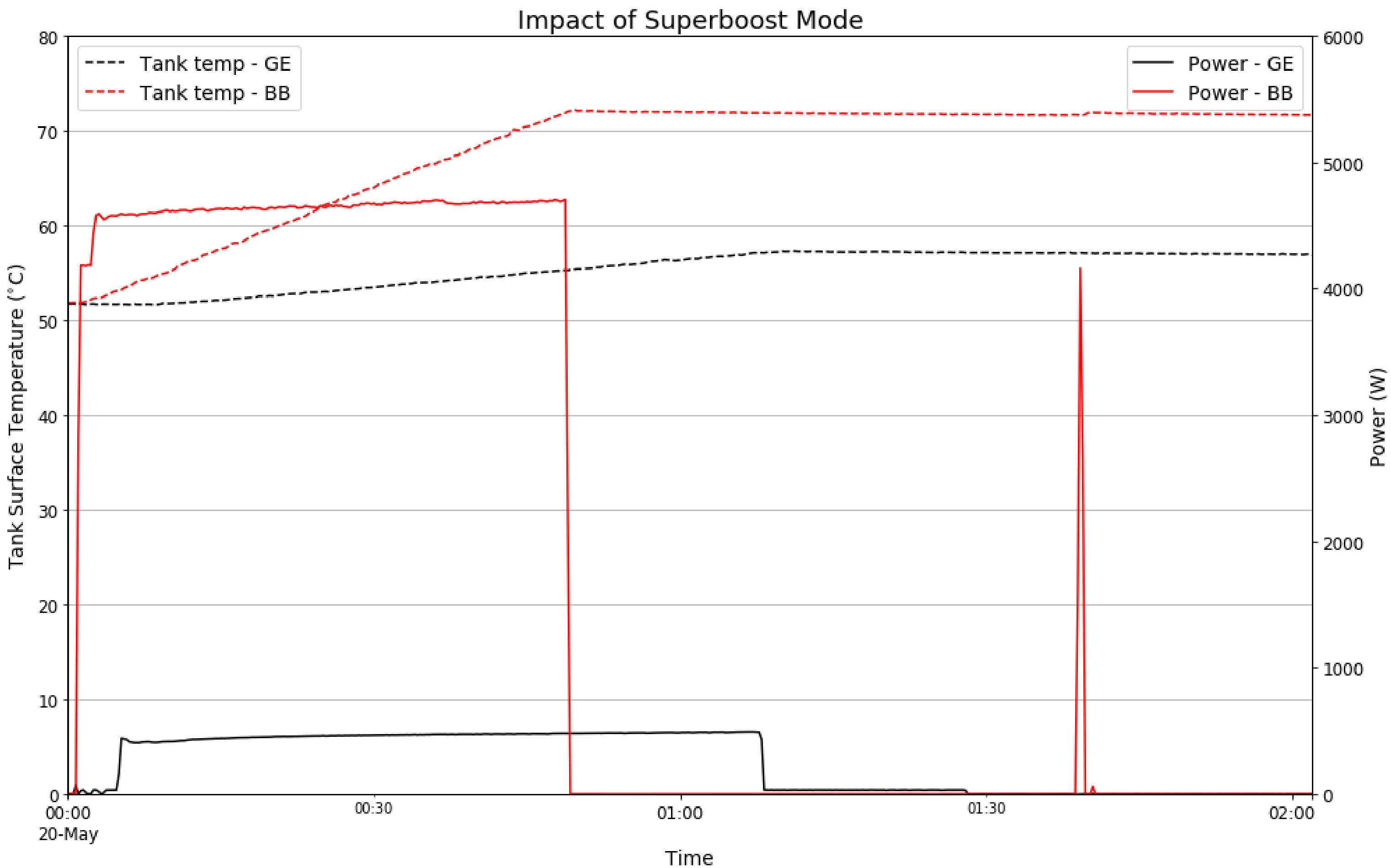
Mode	Control	Test Case	Total Energy (kWh)	Recovery time (min)
Hybrid	Element Deadband	GE Controls	0.72	90+
Hybrid	Element Deadband	Custom Controls	2.09	30

Advanced DR: Shed Mode Heat Pump Deadband



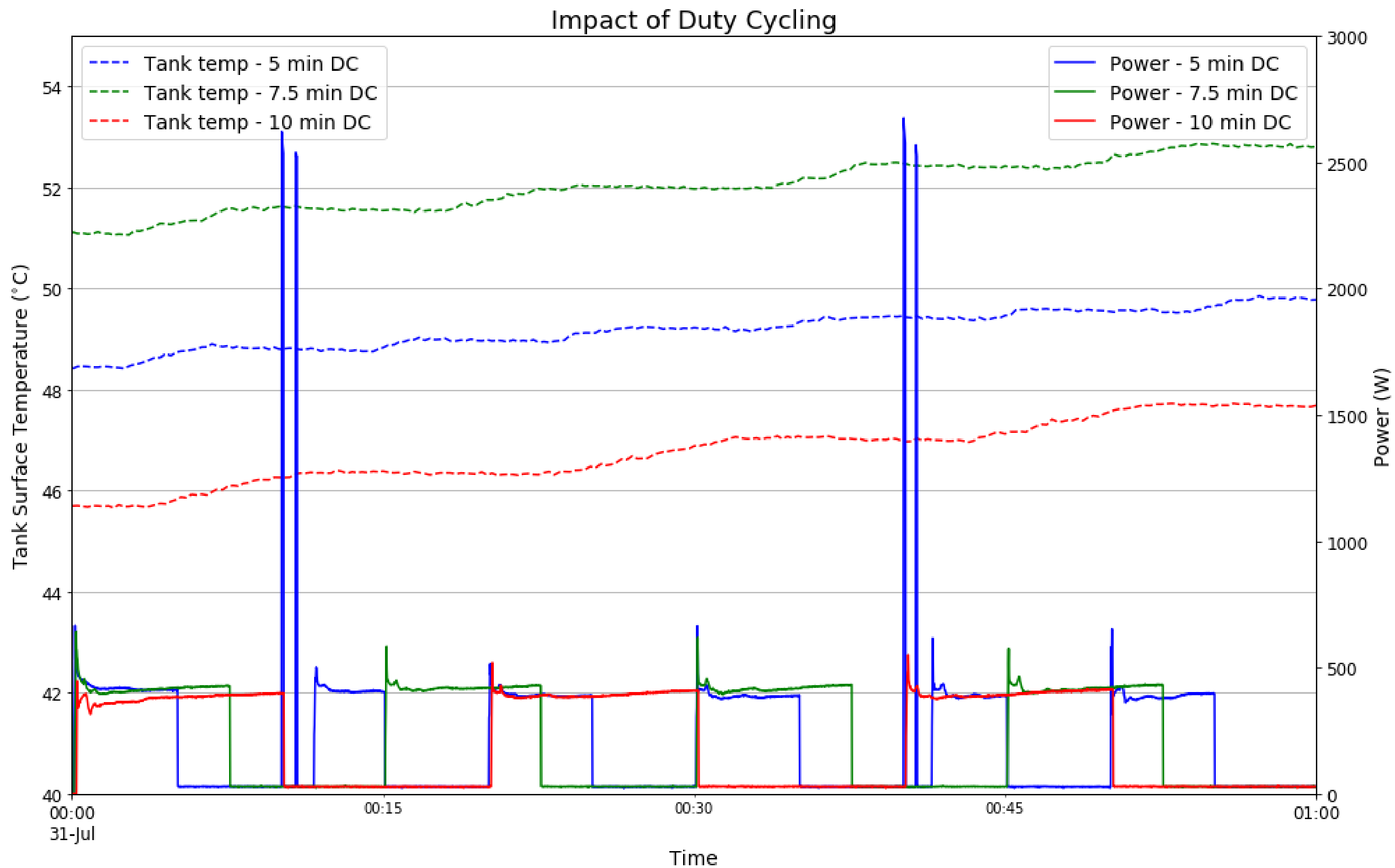
Mode	Control	Test Case	Total Energy (kWh)	DR period (kWh)	Recovery time (min)
Hybrid	Load Shed Event	GE Controls	4.73	3.60	167
Hybrid	Load Shed Event	Custom Controls	5.16	1.54	53

Advanced DR: Superboost Mode



Mode	Control	Test Case	Total Energy (kWh)
Hybrid	Load Add	GE Controls	0.5
Hybrid	Superboost Load Add	Custom Controls	3.74

Advanced DR: Duty Cycling



Mode	Control	Test Case	Total Energy (kWh)	ΔT (°C)
Heat Pump	Duty Cycle	50%, 5 min on	0.21	1.44
Heat Pump	Duty Cycle	50%, 7.5 min on	0.22	1.81
Heat Pump	Duty Cycle	50%, 10 min on	0.21	2.07

Conclusions

This project attempted to explore different ways of implementing demand response with a heat pump water heater.

- While not intended to be comprehensive, the control modifications improve both the ability to respond to DR events and ability to recover relative to the basic DR tests.
- The results from these experiments were implemented in simulation, which could be used to explore other control changes that may be more effective at shedding or increasing load for a short period of time.
- Some of the controls explored could have negative impact on longevity of the HPWH, such as using duty cycling of the compressor.
- Increasing the tank set point should be done in tandem with installation of a mixing valve.
- We encourage manufacturers to think creatively about how they implement controls for demand response.

Thank You!

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