Laboratory and Field Evaluations of Grid-Interactive Water Heaters

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Outline

- Smart Neighborhood
  - Using model predictive control for home-level optimization of heat pump water heaters
- Virtual Battery
  - Estimating demand limiting capability of standard electric water heaters

Smart Neighborhood - Hoover Alabama Site

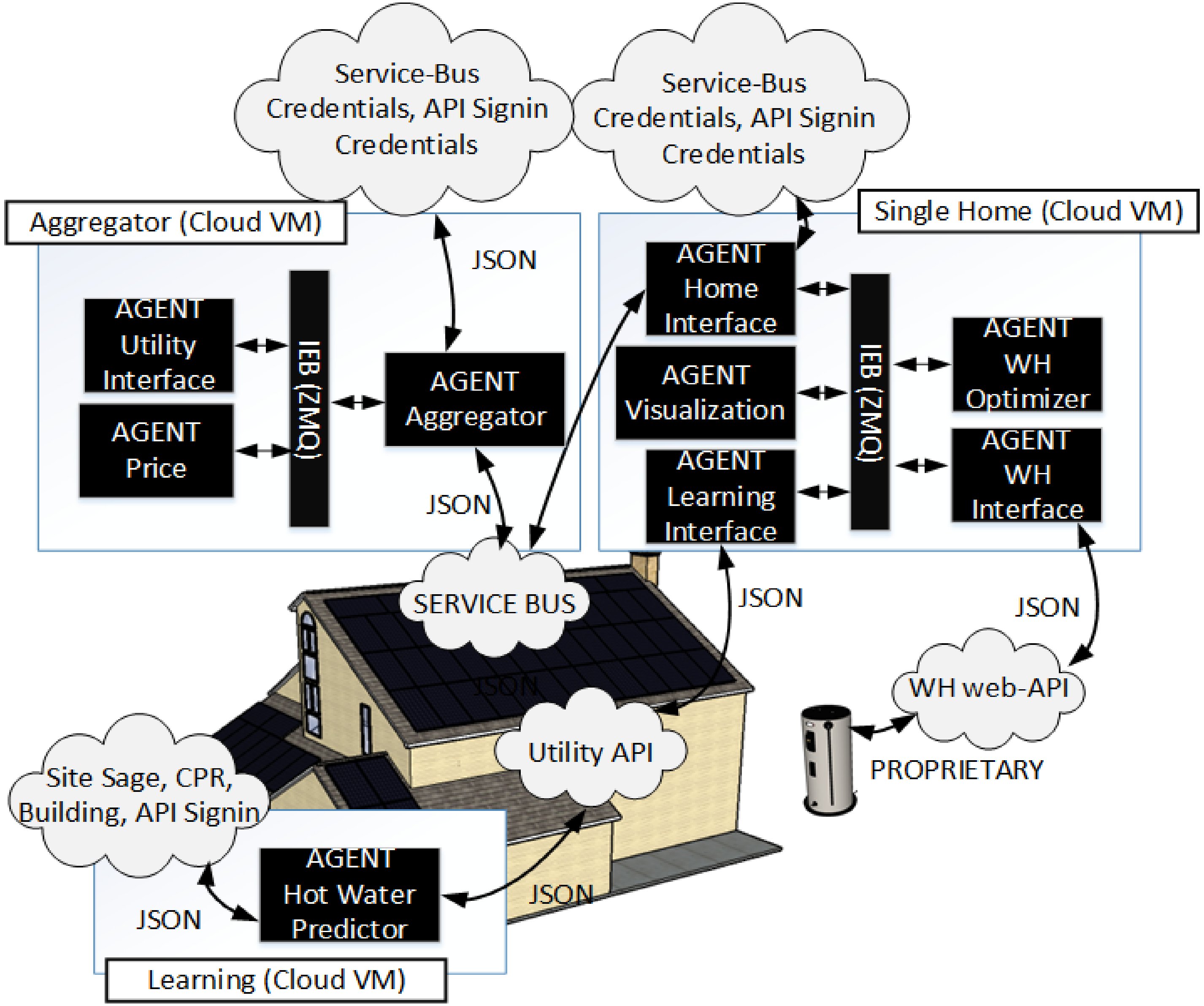
Distributed Energy Resources Community Microgrid

Reynolds Landing Neighborhood

Smart Neighborhood - Architecture

Cloud-Based Operation

- Integrate with vendor API
- Virtual machine for home-level agents
- Virtual machine for aggregator
- Virtual machine for learning agents



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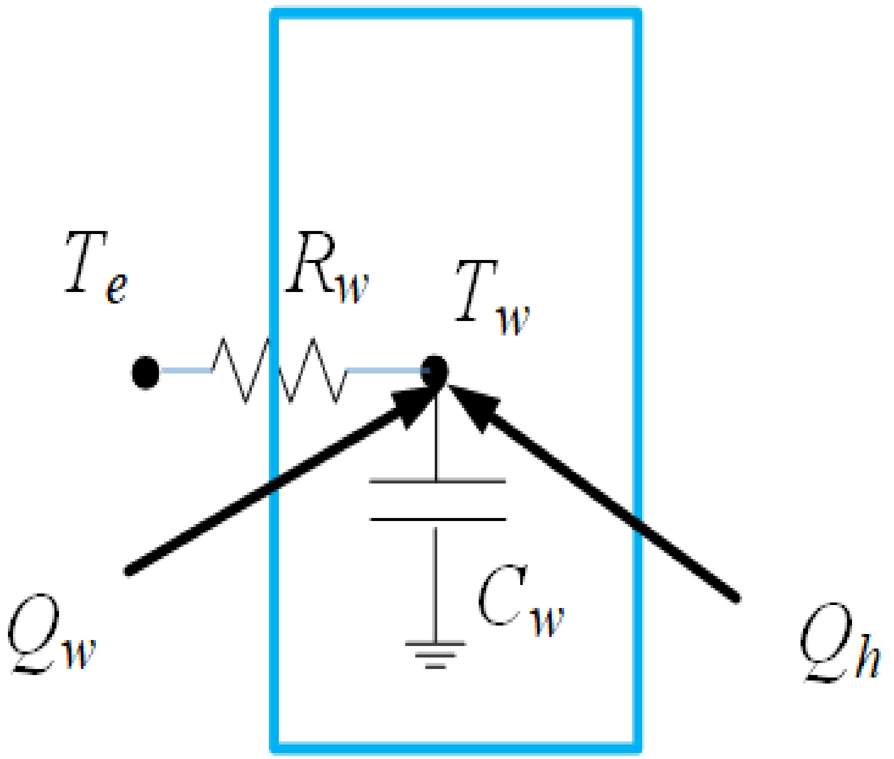
Smart Neighborhood - Water Heater Model

Single-Node Model

- Mixed integer linear programming
- Fast solution
- Computationally light
- Guaranteed global optimum



Smart Neighborhood - Objective Function

$$min\left(W_P\sum_{t=0}^{T}P_t^{WH}*\rho_t + W_{HP}\sum_{t=0}^{T}D_t^{HP} + W_{EL}\sum_{t=0}^{T}D_t^{EL} + W_{UP}\sum_{t=0}^{T}D_t^{UP} + W_{CYC}\sum_{t=0}^{T}D_t^{CYC}\right)$$

Cost

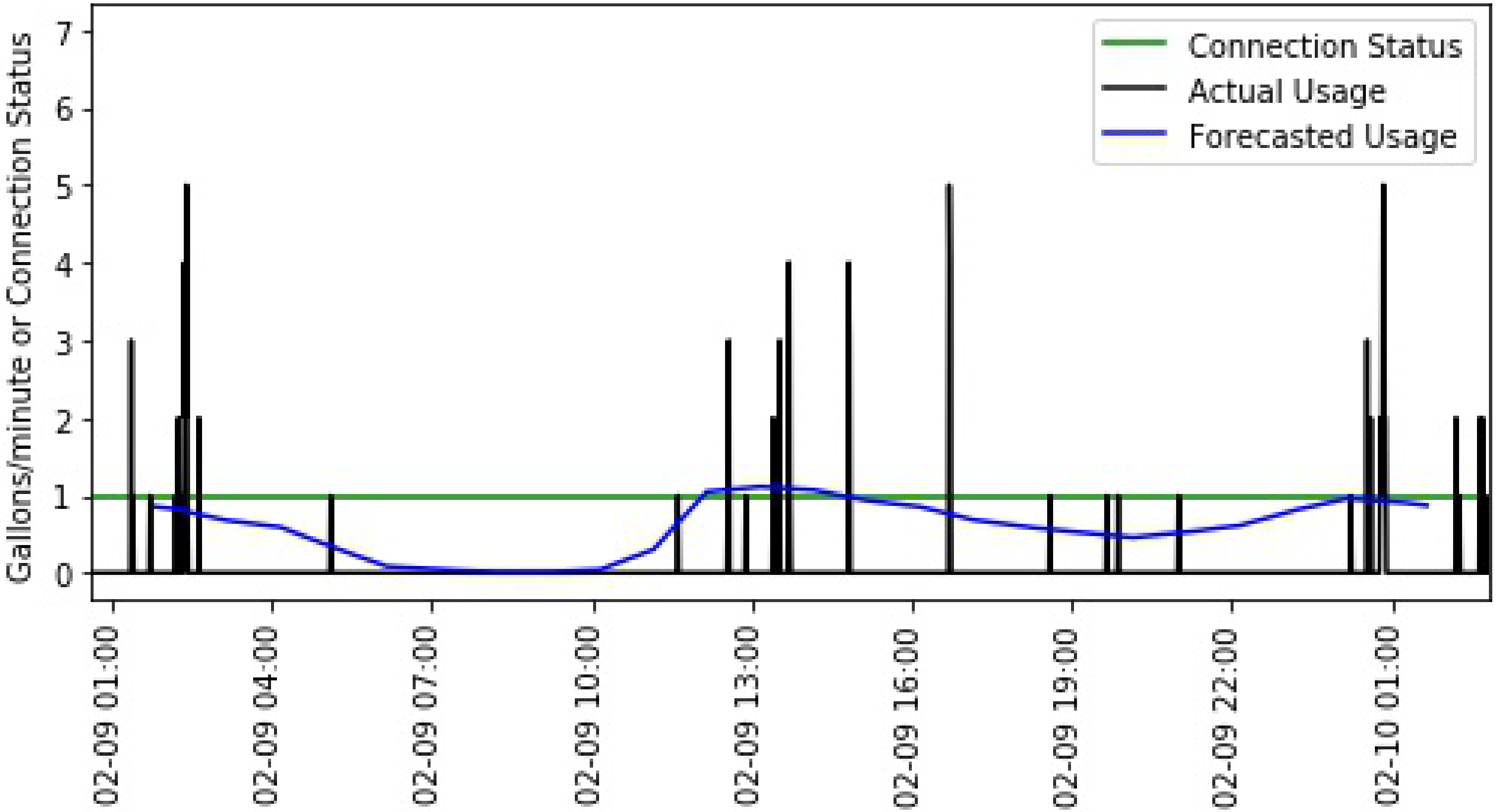
Target Minimum Temperature

Turn On Resistance Heating Temperature!

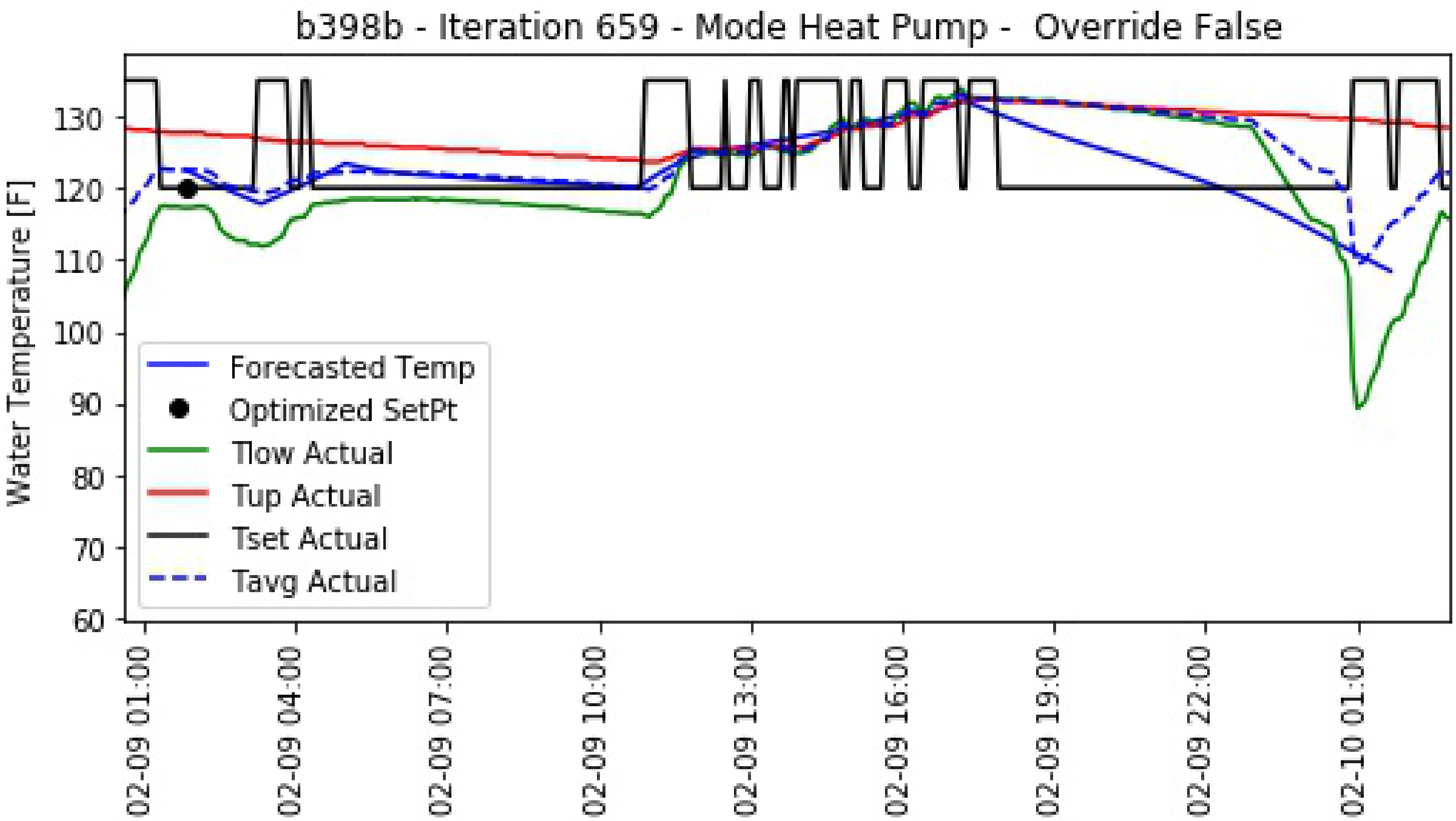
Maximum Temperature

Cycling Penalty

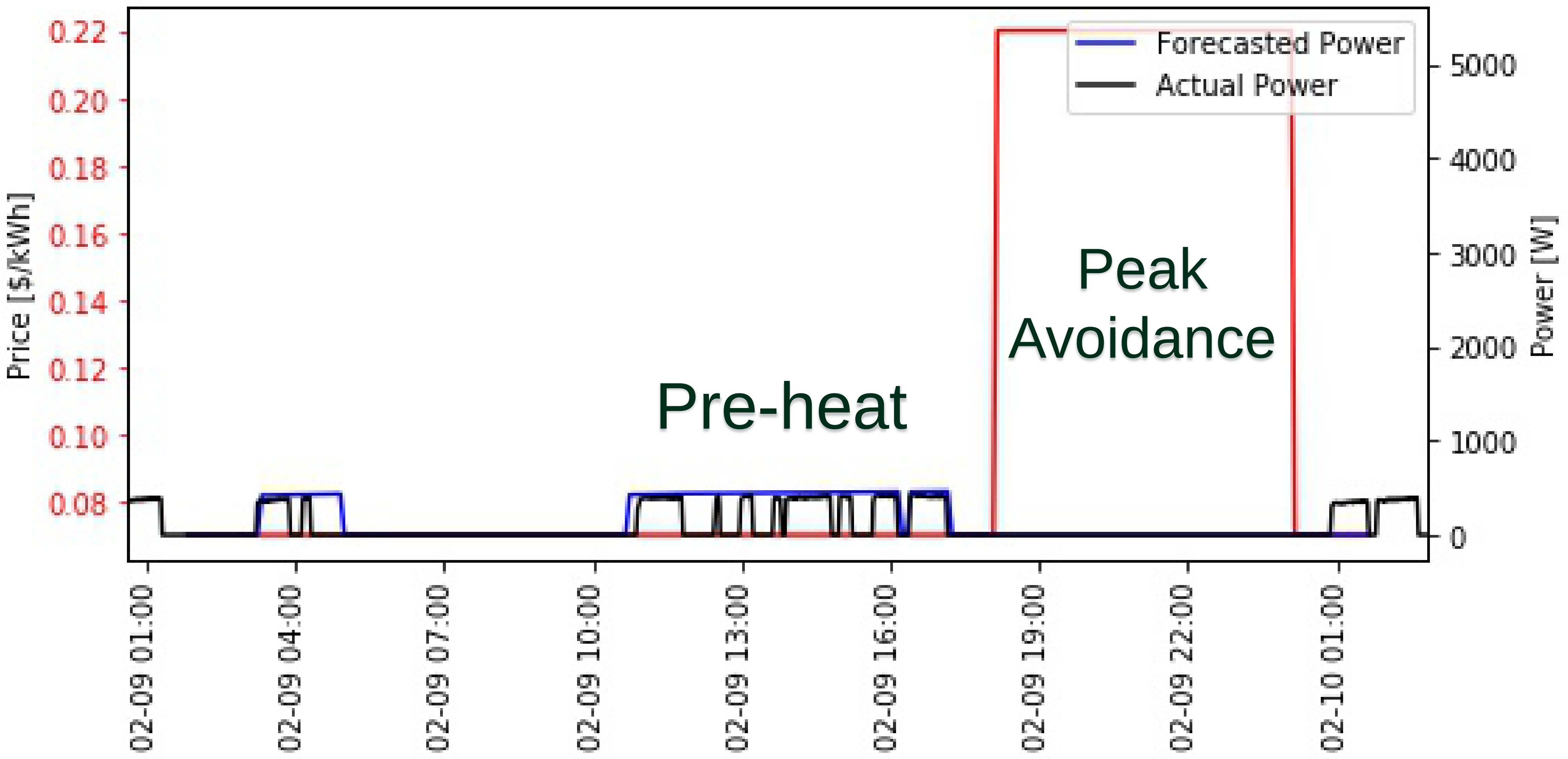
Smart Neighborhood - Example Set of Data



Smart Neighborhood - Example Set of Data



Smart Neighborhood - Example Set of Data



Smart Neighborhood – Conclusions and Future Work

- Challenging to work with equipment APIs (sensing overrides, achieving desired response with API inputs)
- Initial results aimed at load shaping are very encouraging

- Improve cycling behavior of MPC implementation
- Implement learning algorithm for hot water use
- Evaluate benefits to customer, utility, and society

Virtual Battery

- Objectives
  - Can building loads be used like batteries to provide demand-side power balancing?
  - Quantify typical power flexibility of building loads
    - Residential and Commercial HVAC
    - Residential Water Heaters
    - Commercial Refrigeration
  - How can the loads be controlled?

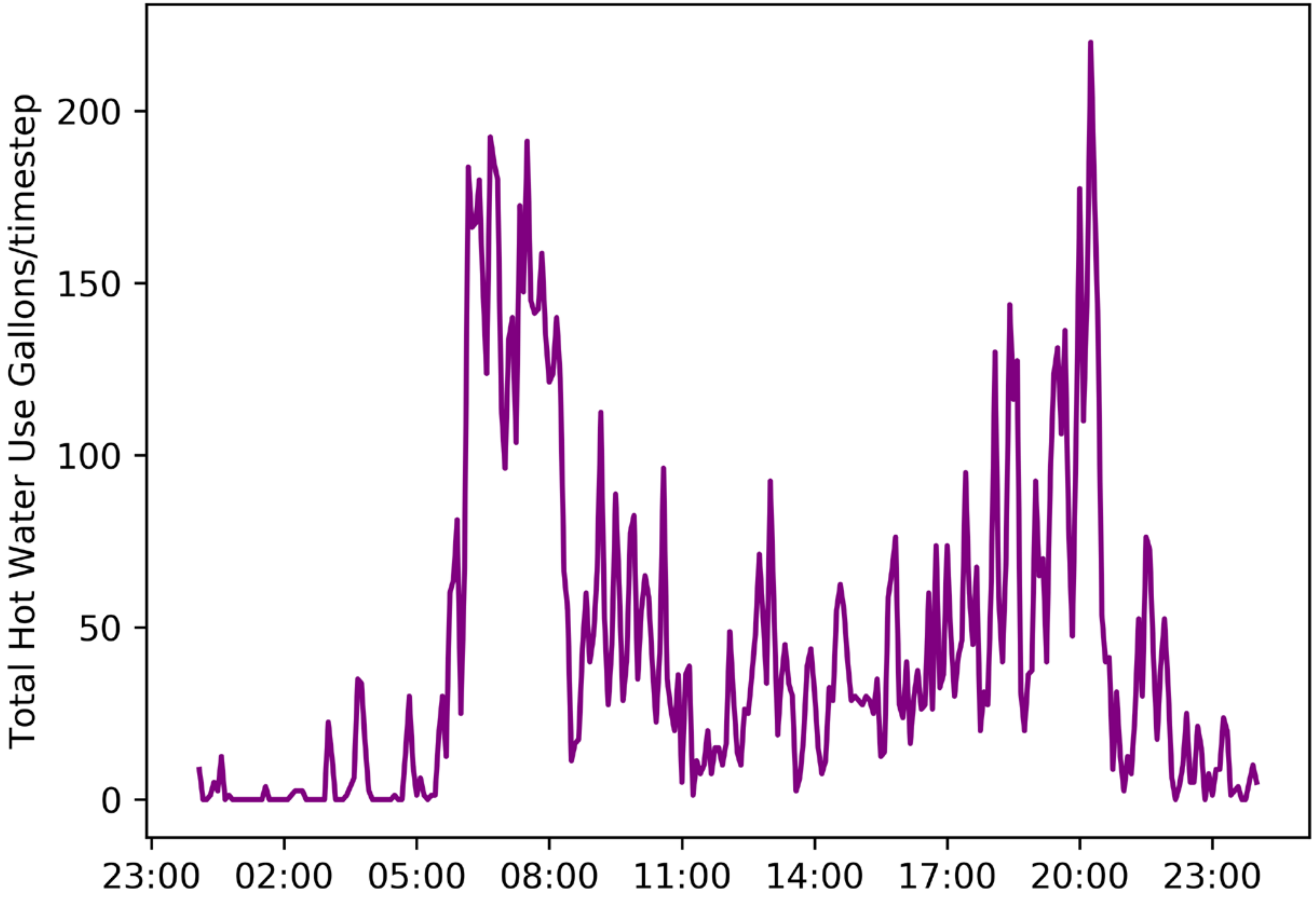
Virtual Battery – Load Leveling/Peak Limiting

- Evaluate the load leveling/peak limiting potential of electric resistance water heaters
  - 2-node model
  - Use measured hot water usage from Smart Neighborhood
  - Evaluate two control algorithms
    - Priority-Based Control
    - Model Predictive Control

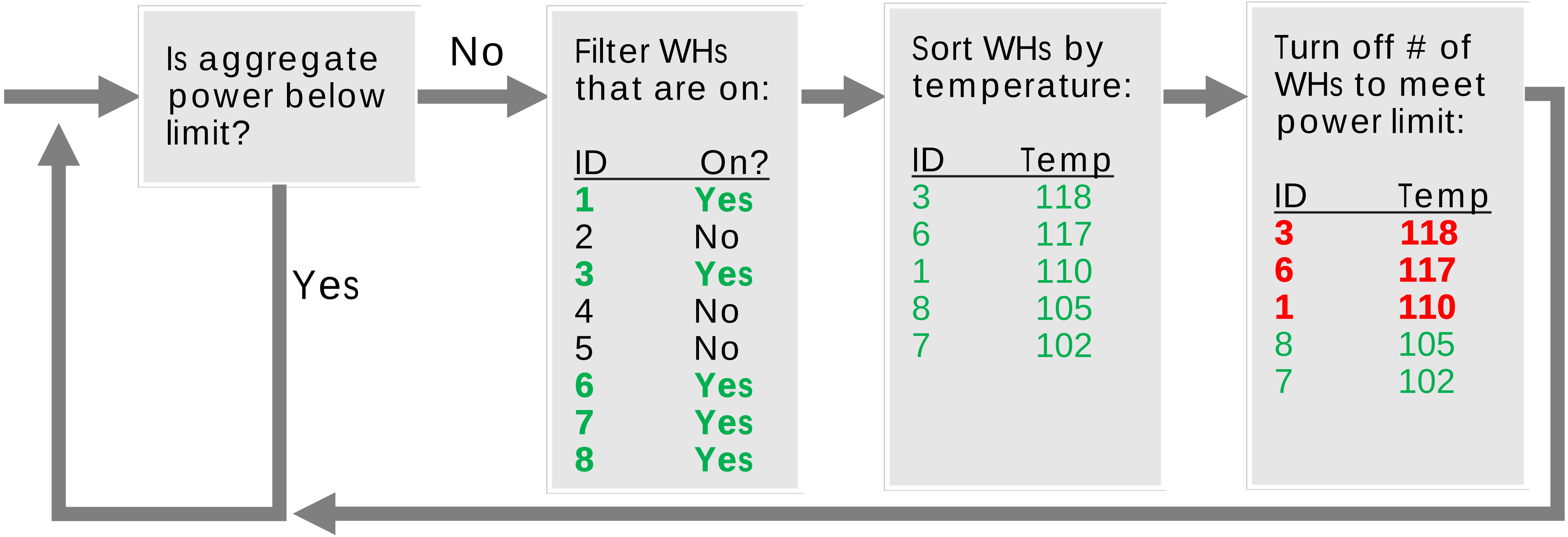
Virtual Battery – Aggregate Hot Water Use

50 homes

Avg hot water use 51 gal/day for 1/16/2019



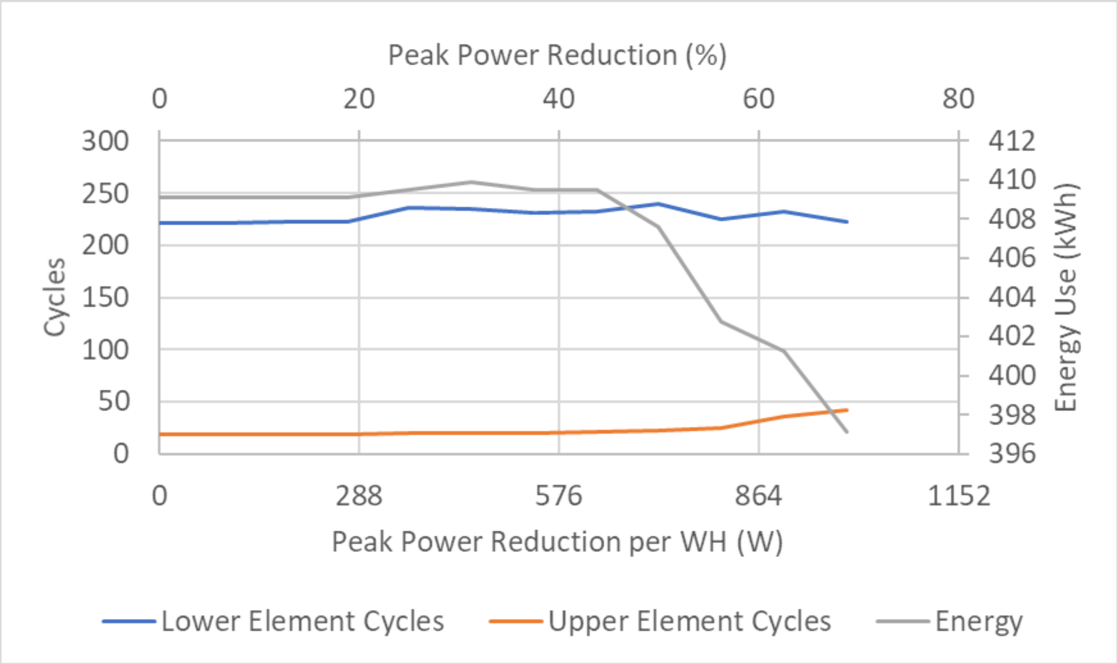
Virtual Battery – Priority-Based Control



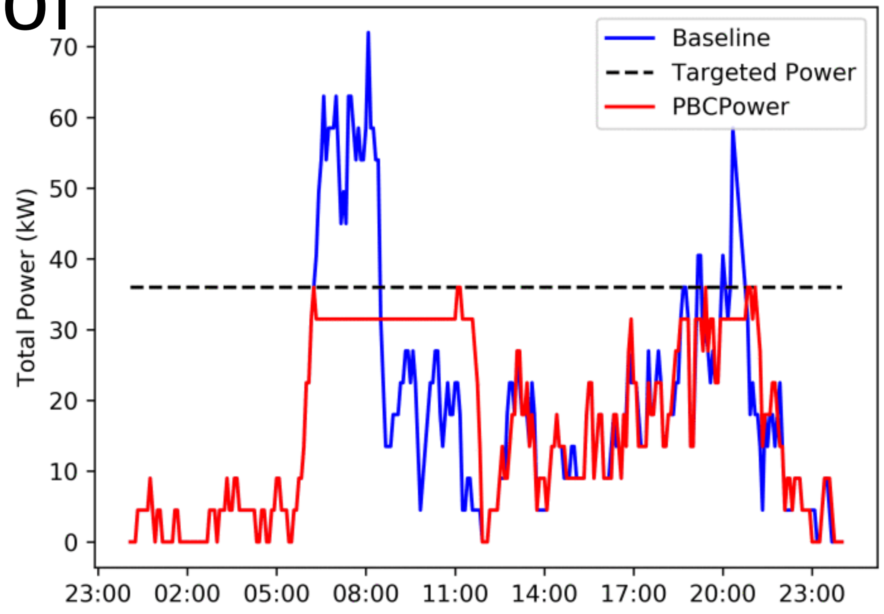
Note: Only lower element is controlled with PBC

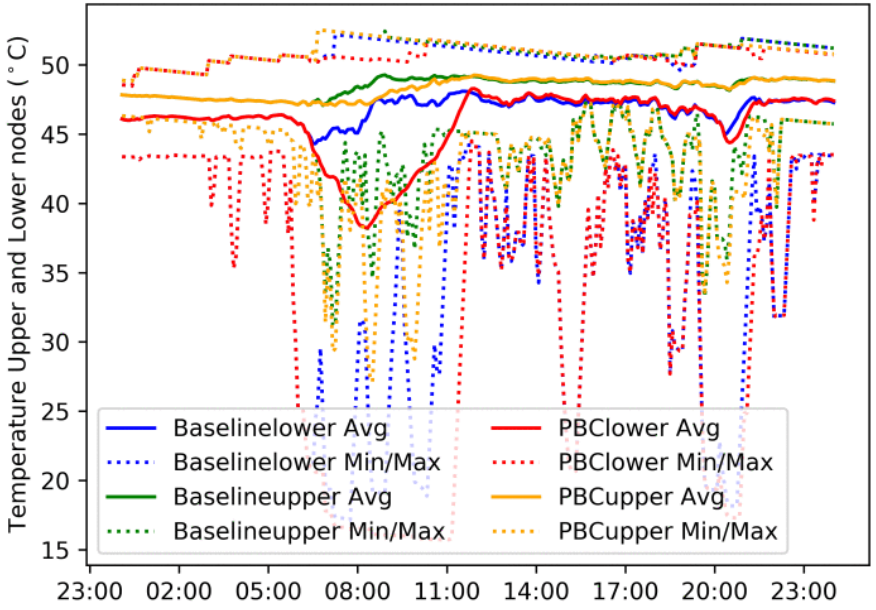
Virtual Battery – Priority-Based Control

- 40%-50% peak power reduction with negligible effect on upper tank temperatures



~600 W per WH peak power reduction potential





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Virtual Battery – Model Predictive Control

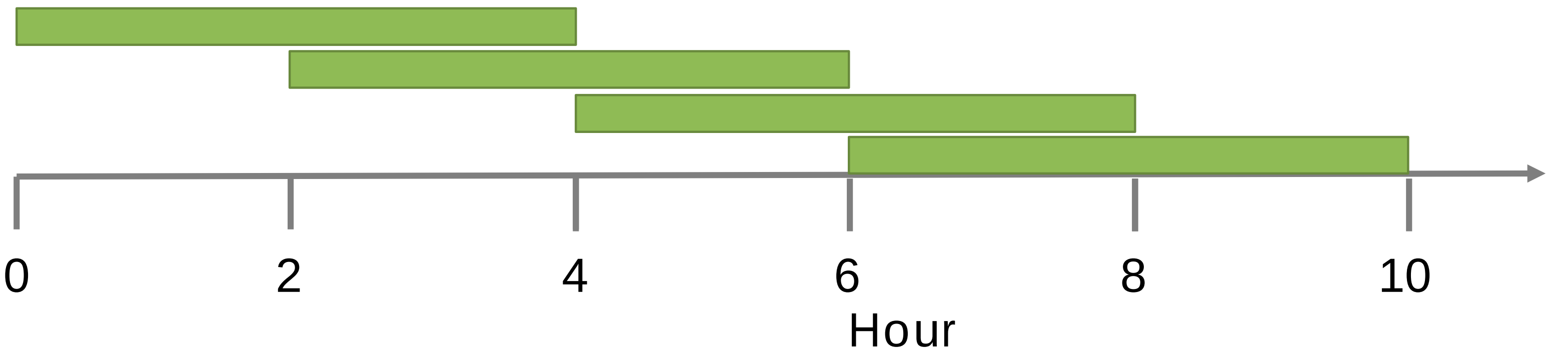
$$min\left(W_P\sum_{t=0}^{T}\sum_{wh=1}^{wh}P_t^{WH} + W_{MIN}\sum_{t=0}^{T}\sum_{wh=1}^{wh}D_t^{MIN} + W_{MAX}\sum_{t=0}^{T}\sum_{wh=1}^{wh}D_t^{MAX} + W_{UP}\sum_{t=0}^{T}\sum_{wh=1}^{wh}D_t^{UP}\right)$$

Power Exceeding Power Limit

Target Minimum Temperature

Maximum Temperature

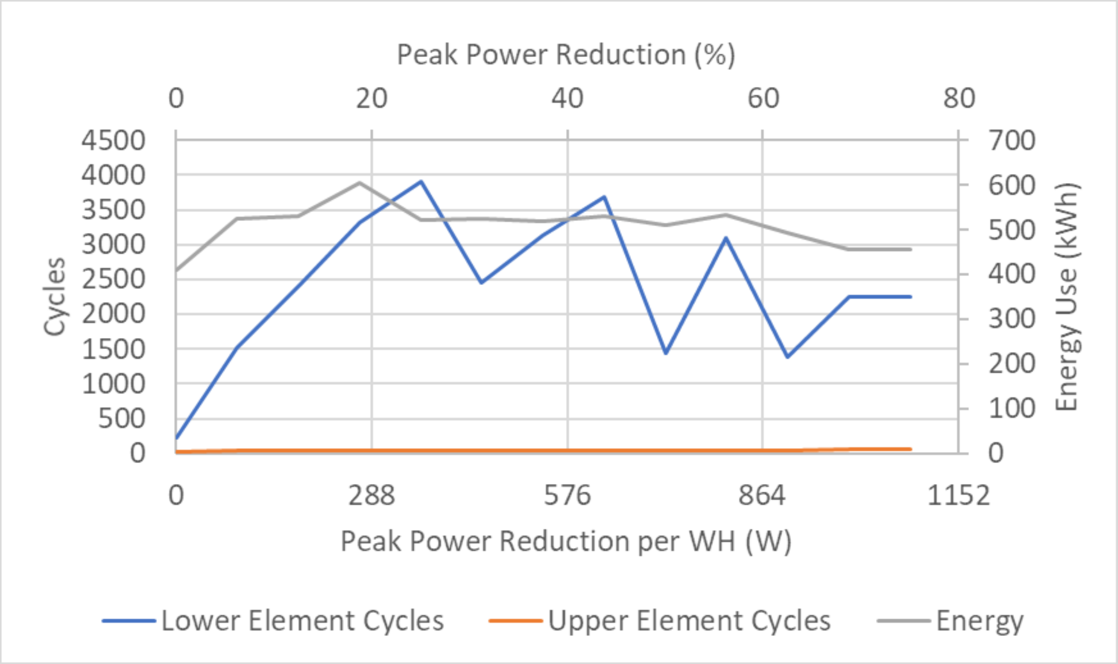
Deviation from Set Point

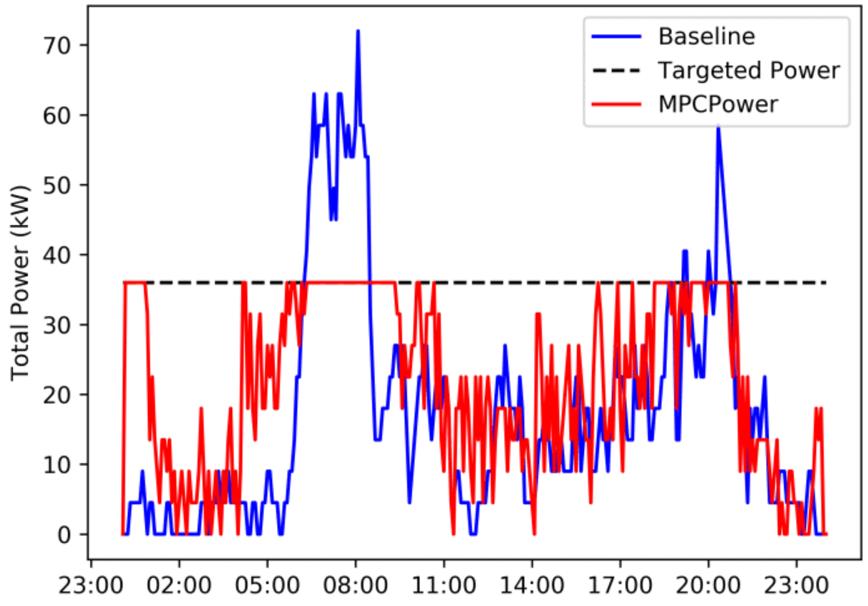


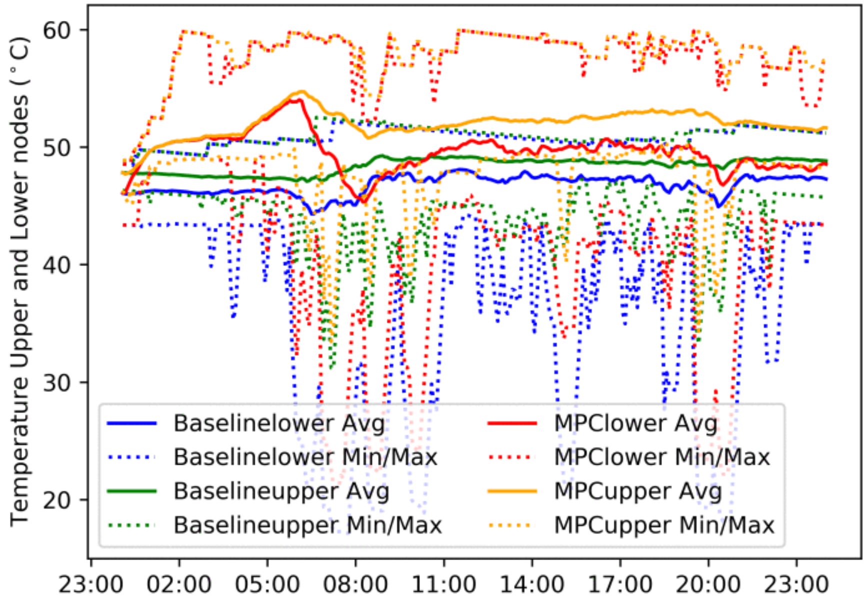
Forecast period = 4 h
Forecast interval = 2 h

Virtual Battery – Model Predictive Control

- 50+% load reduction with better temperature control than PBC
- Higher energy use
- No cycling penalty in objective function, results in too many cycles







~700 W per WH peak power reduction

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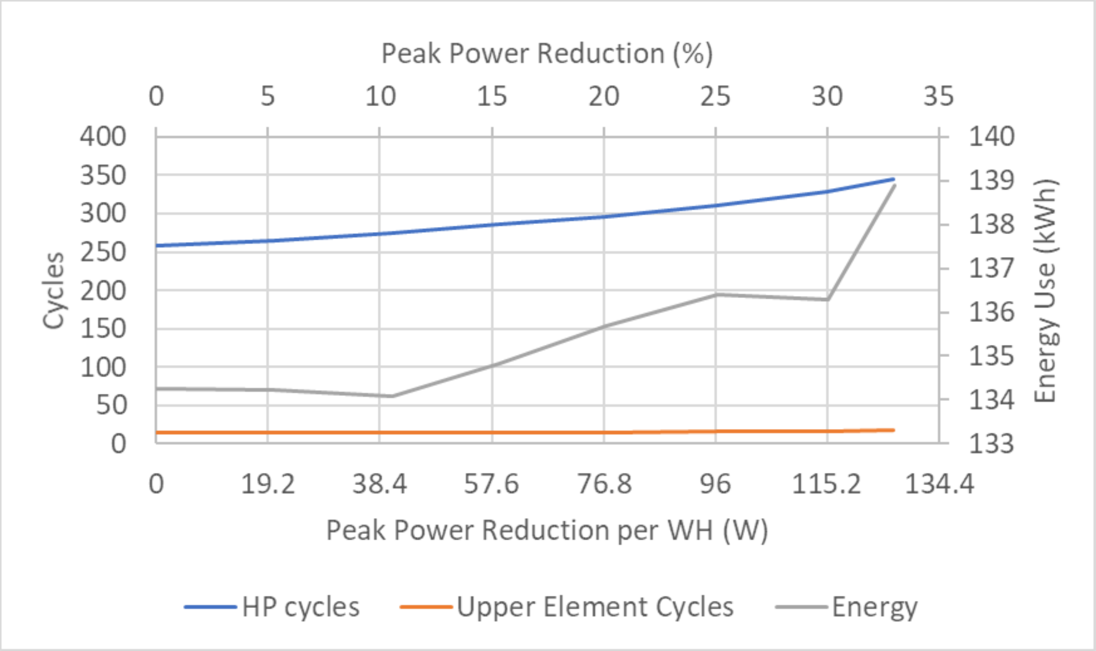
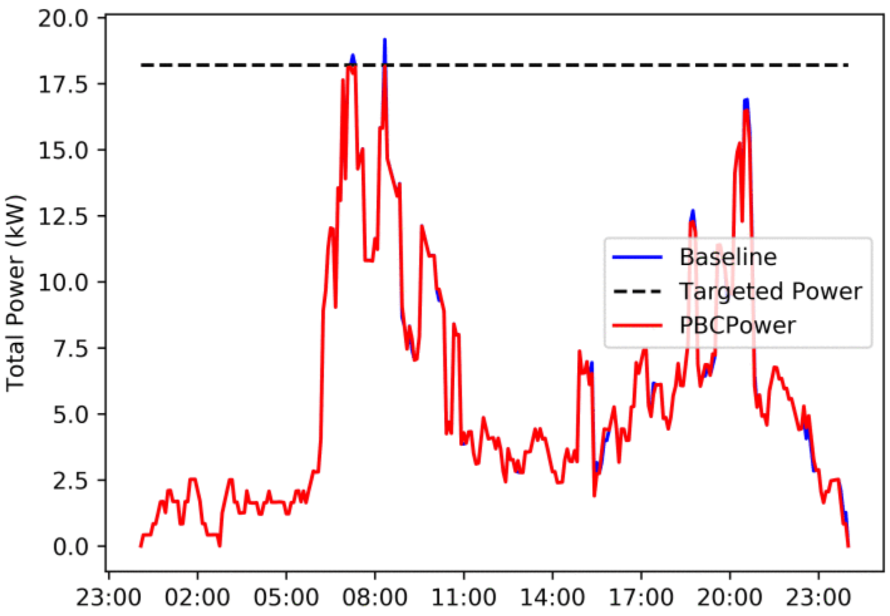
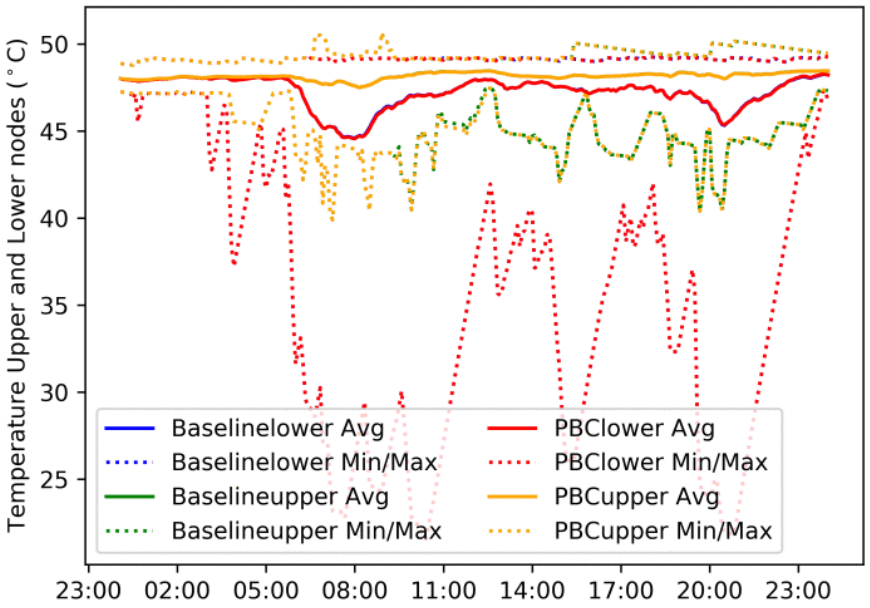
Virtual Battery – PBC + HPWH

- 30% peak power reduction with negligible effect on upper tank temperature







~115 W per WH peak power reduction potential

Virtual Battery – Water Heating

- Relatively diverse/asynchronous operation of water heaters allows for large flexibility and potential to use simple control strategies
- For aggregate control of water heaters, simple control strategies like priority-based control are likely sufficient
- This was just one example, load following or shaping is also feasible