Set point schedules and advanced control of HPWHs for load shifting and energy savings

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ACEEE 2015 Hot Water Forum

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Acknowledgements

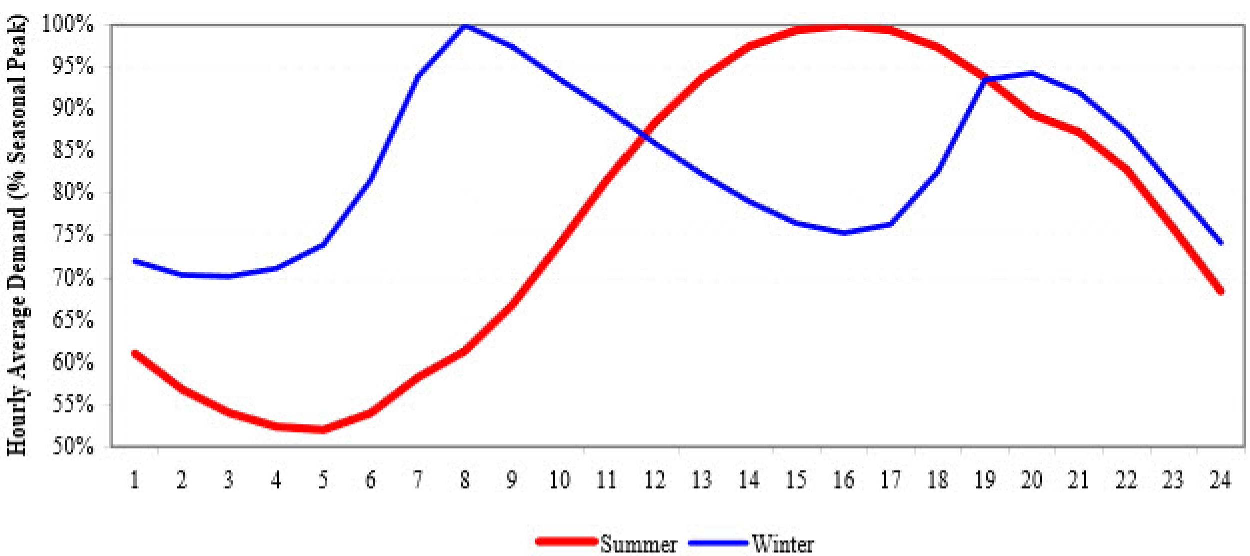
- **David Dinse**
  - **Tennessee Valley Authority**
- **DOE Building America**
- **Ben Larson**
  - **Ecotope**

Outline

- Background
- Load Shifting
  - Methodology
  - Results
  - Conclusions
- Advanced HPWH Control
  - Methodology
  - Results
  - Conclusions

Background

- Water Heating: ~20% of residential sector energy consumption
- Load shifting – transferring load during high demand periods to low demand periods.



Source: http://energymag.net/daily-energy-demand-curve/

  – Cheaper load generation
  – Curb need for more power plants to meet peak
  – Energy Conservation Standards for Residential Water Heaters
    - By 2015, Tanks > 55 gal. have required EF >= 2

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Load Shifting - Methodology

- 3 – distinct water draw profiles for HPWH
- 4 – Temperature set point schedules were investigated
- Compared to a baseline schedule (120°F - Hybrid)
- Peak Energy, Total Energy, and Hot Water Delivery Quality

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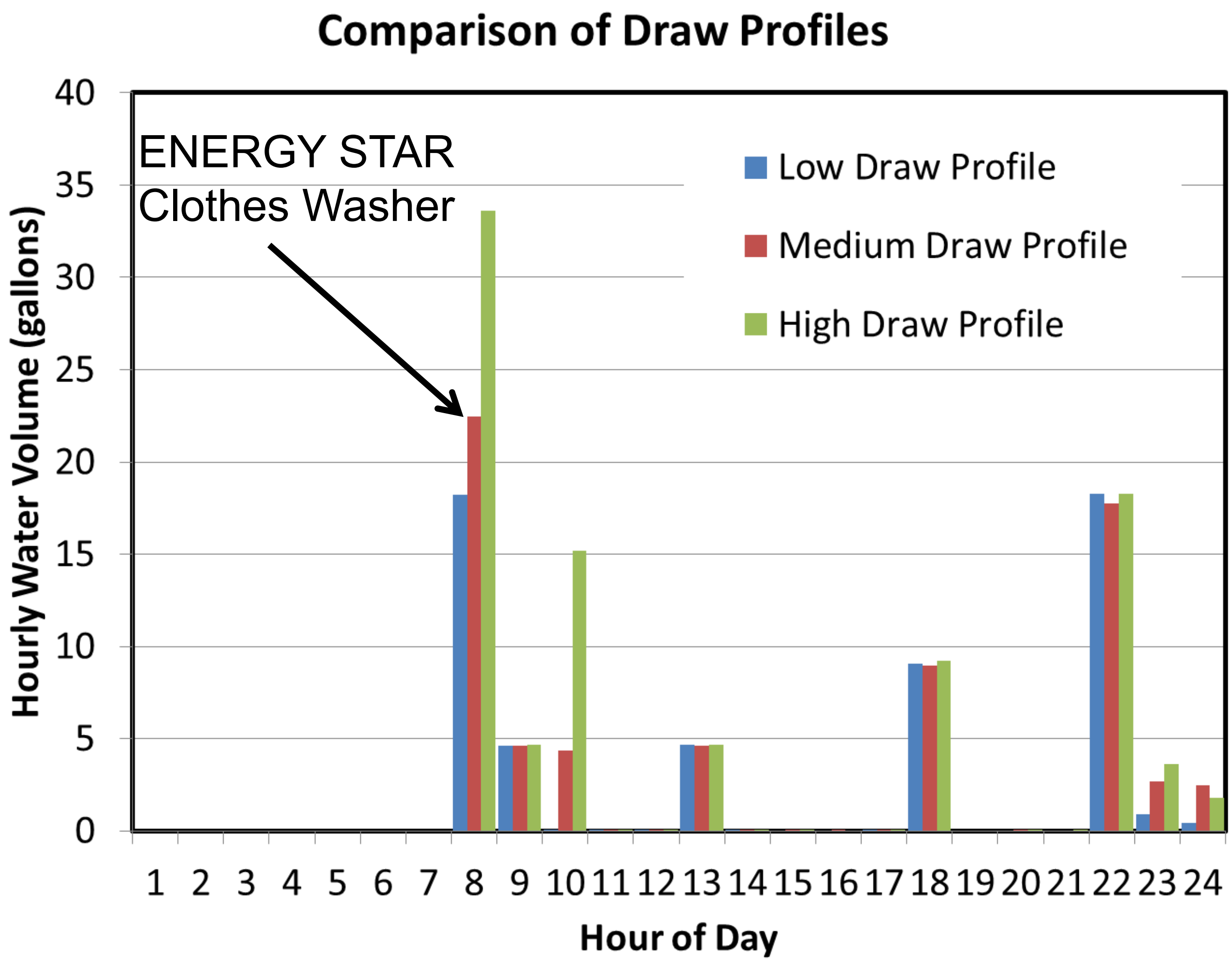
Load Shifting - Methodology

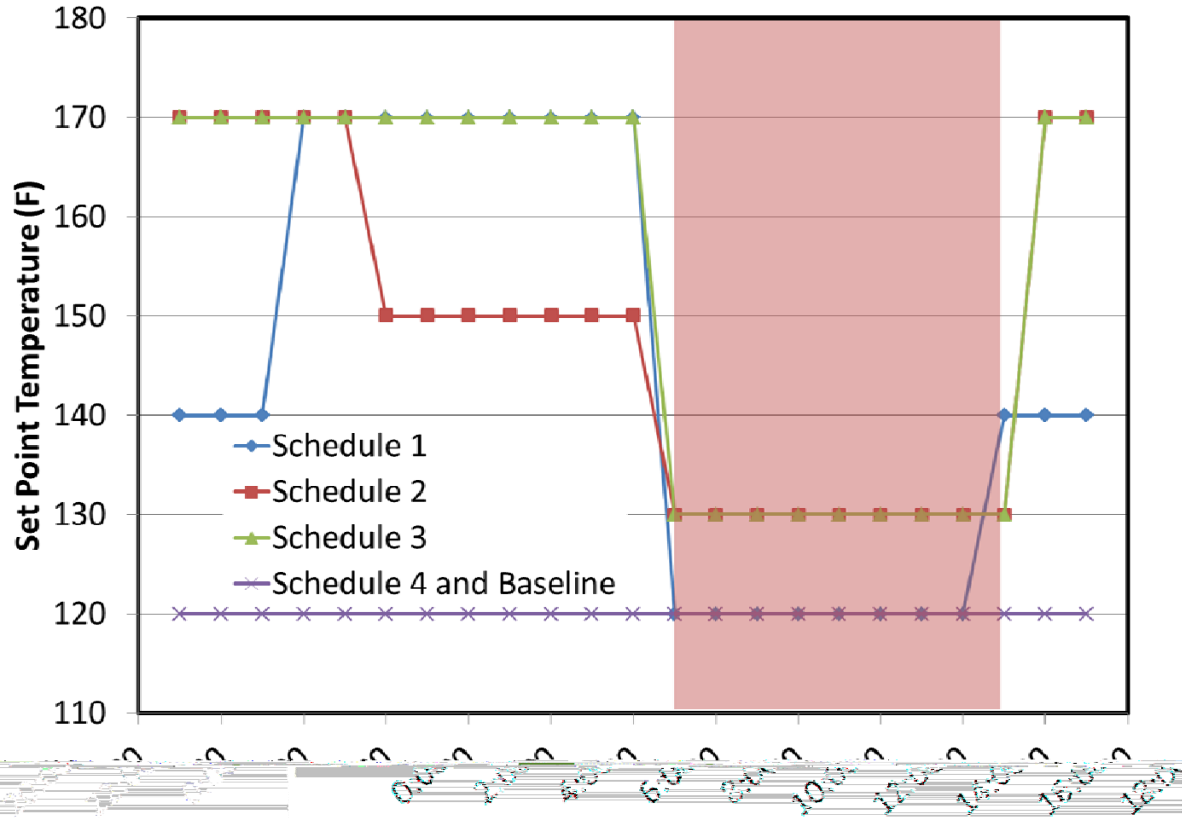


Draw Profile Name	Daily Volume (gal)
Low	57
Medium	69
High	91

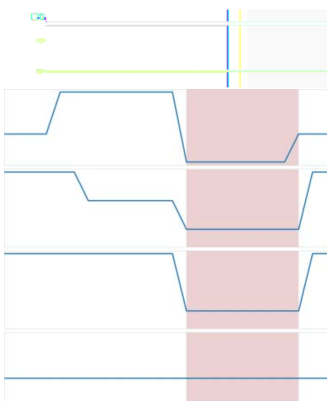
- Metrics: Peak load shifting, energy consumption, and ability to meet hot water demands

Load Shifting - Methodology

- Main goal - Minimize peak energy consumption (1-9 PM)



Load Shifting – Results



Energy Use During Peak Hours For Different Tank Set Point Schedules and Water Draw Profiles			
	Low Water Consumption (kWh)	Medium Water Consumption (kWh)	High Water Consumption (kWh)
Baseline	0.6	0.5	0.6
Schedule 1	0	0	0
Schedule 2	0	0	1.5
Schedule 3	0	0	0
Schedule 4	0.5	0.4	0.6

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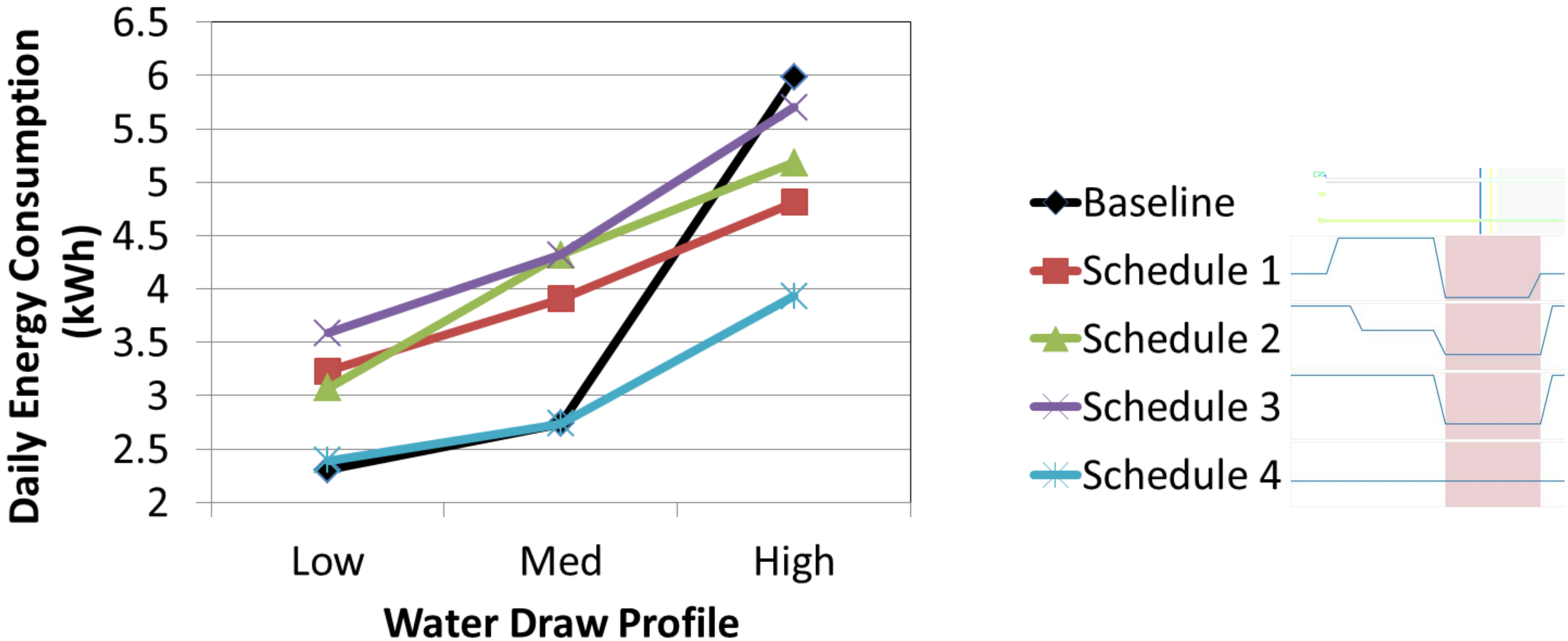
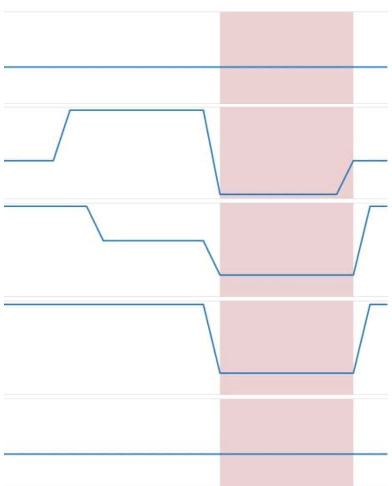
Load Shifting – Results



Load Shifting – Results

- % of time tank water < 115°F



	Low Water Consumption (kWh)	Medium Water Consumption (kWh)	High Water Consumption (kWh)
Baseline	5%	9%	5%
Schedule 1	0%	0%	1%
Schedule 2	0%	5%	1%
Schedule 3	0%	0%	0%
Schedule 4	6%	9%	18%

Conclusions

- HPWH can be load shifted just as electric resistance water heaters.
- Load shifting HPWH consumes more overall energy except when the homeowner has large water draws (~>20 gal) and resistance heating is required to meet the demand.
- Load shifting with elevated tank temperatures improves hot water delivery quality.
- To maximize peak load shifting, energy savings, and hot water delivery quality, a HPWH set point profile should be tailored to a family's specific water use pattern.

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Advanced HPWH Control

- Maximize energy efficiency of HPWH by eliminating electric resistance use with advanced tank temperature set point control.
  - Forecast future water draws
  - Set point control algorithm
  - Input hot water draw data from real homes into HPWH computer models to simulate energy savings from advanced control
  - Spot checked modeled result with HPWH in Lab

Advanced HPWH Control – Methodology
Draw Forecasting

	Flow (gal)	# of Occurrences	Prob.
Friday,4:45,			
	0.0,	50	1
Friday,5:00,			
	0.0,	49	0.98
	3.5,	1	0.02
Friday,5:15,			
	8.5,	1	0.02
	8.4,	1	0.02
	9.5,	2	0.04
	3.8,	1	0.02
	1.9,	1	0.02
	1.8,	1	0.02
	0.0,	24	0.48
	8.9,	1	0.02
	8.1,	1	0.02
	8.0,	1	0.02
	9.1,	1	0.02
	7.7,	1	0.02
	2.5,	1	0.02
	1.3,	1	0.02
	4.4,	1	0.02
	3.1,	1	0.02
	0.8,	1	0.02
	2.6,	2	0.04
	5.2,	1	0.02
	1.5,	1	0.02
	4.8,	1	0.02
	0.6,	1	0.02
	4.1,	1	0.02
	2.2,	1	0.02
	1.7,	1	0.02

→

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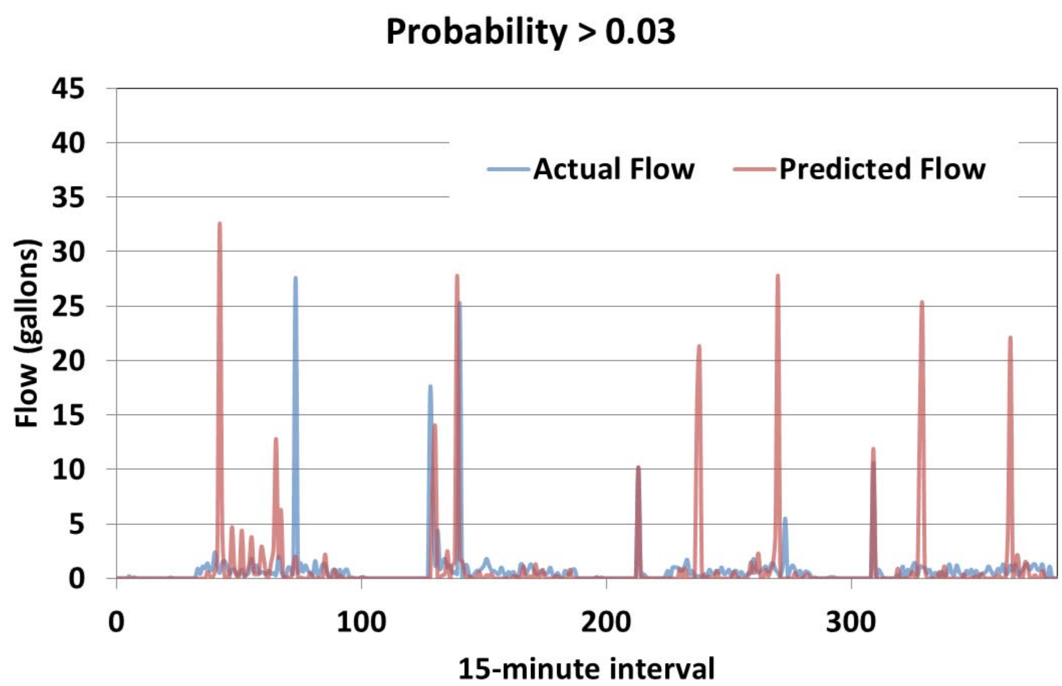
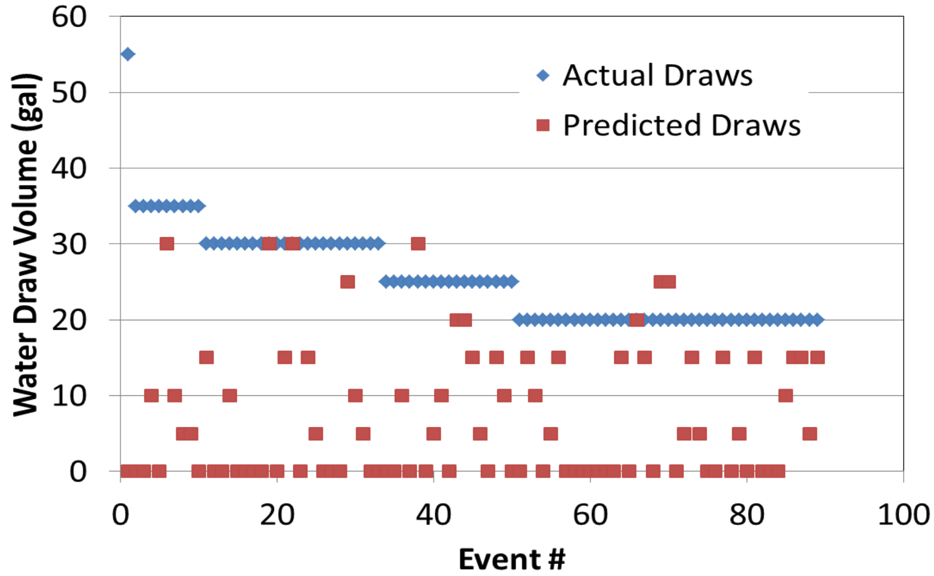
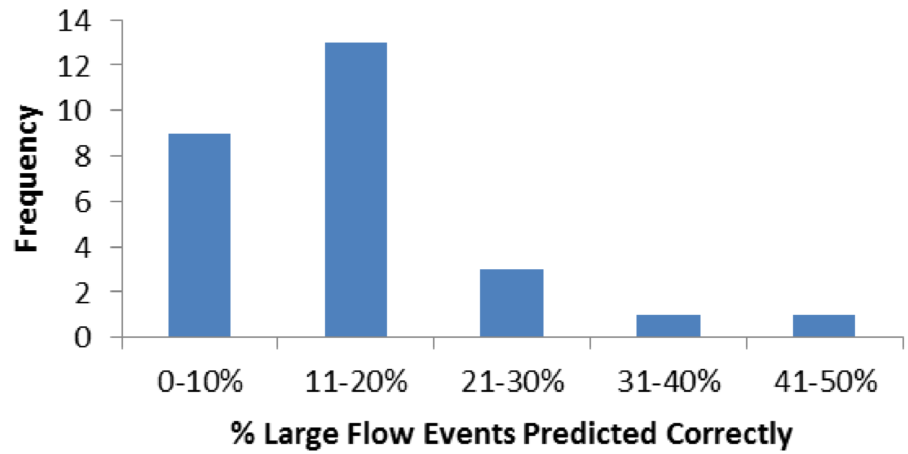


Advanced HPWH Control – Methodology
Draw Forecasting Accuracy



Baker Home

25-Home Study



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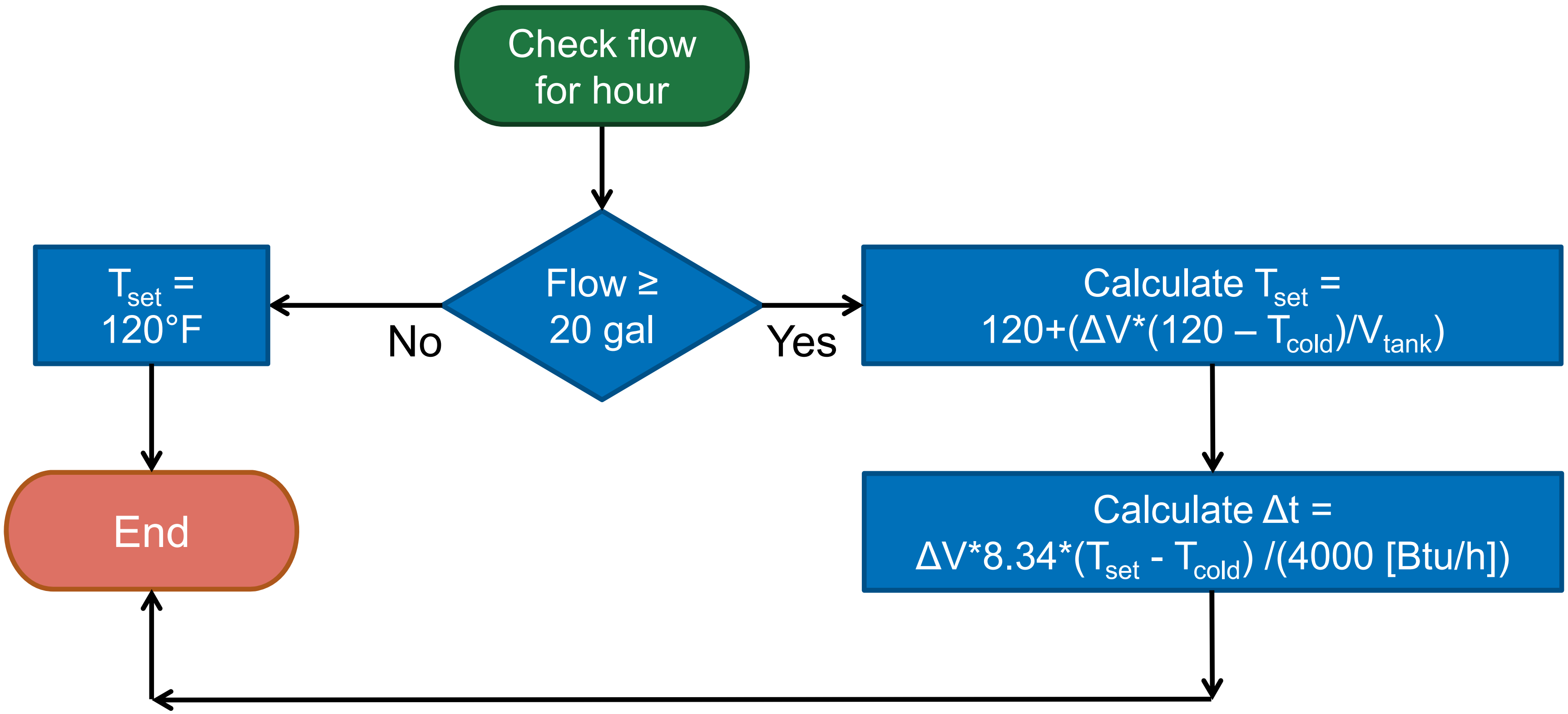
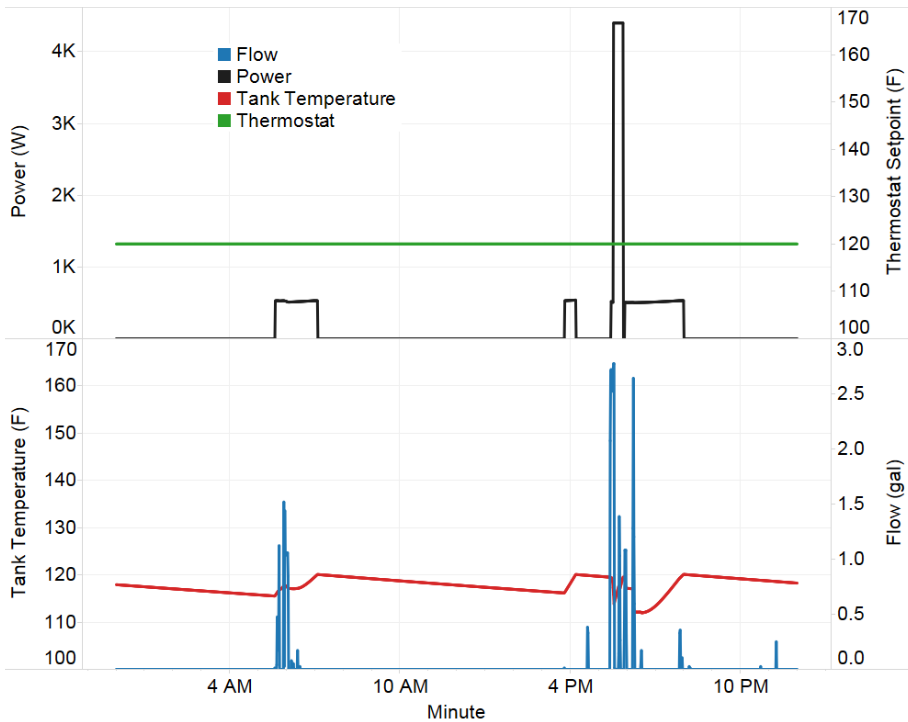
Advanced HPWH Control – Methodology Control Algorithm

– Calculate required set point temperature and pre-heat duration for draws ≥ 20 gallon

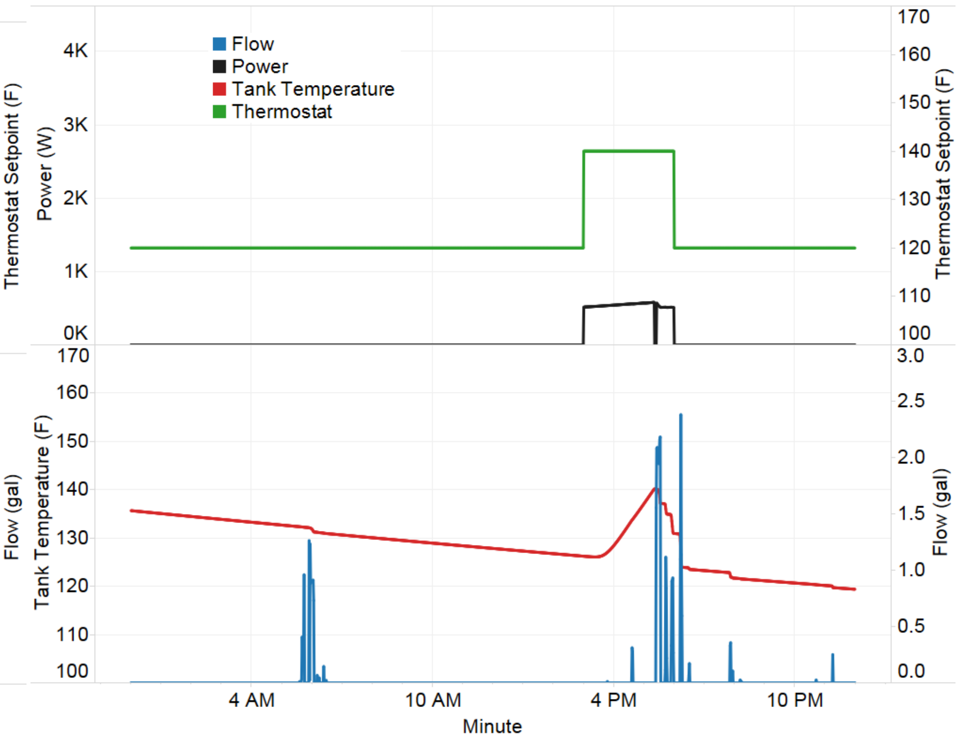


Advanced HPWH Control - Results

- Initial modeling results – real house water draws



T_{set} = 120°F, Hybrid Mode



Advanced Control
HP only during elevated T_{set}

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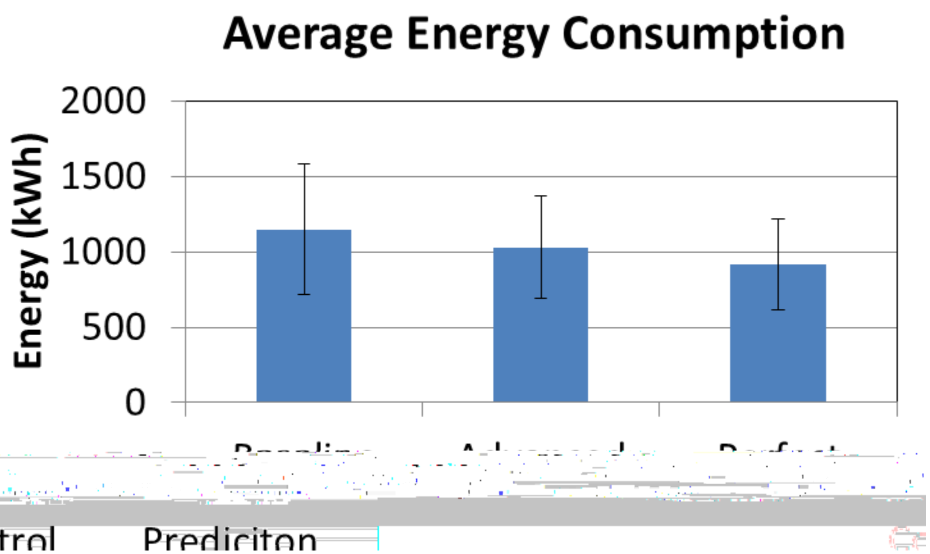
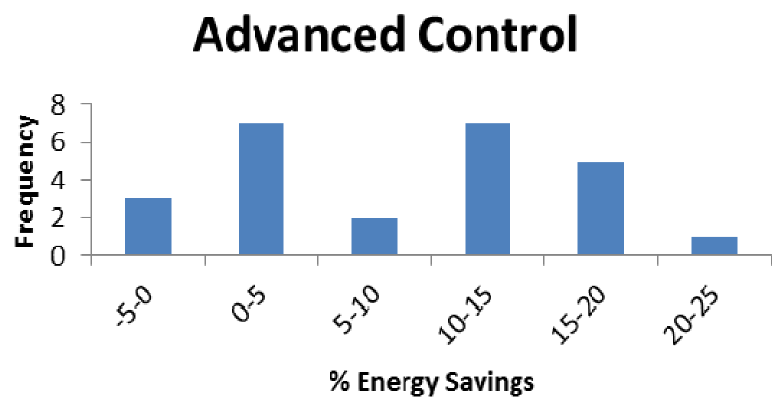
Advanced HPWH Control - Results

- 25-home study





	Advanced Control Savings	Perfect Prediction Savings
Average	8.9%	18.5%
Standard Deviation	7.4%	8.2%
Minimum	-0.8%	3.9%
Maximum	24.4%	39.5%

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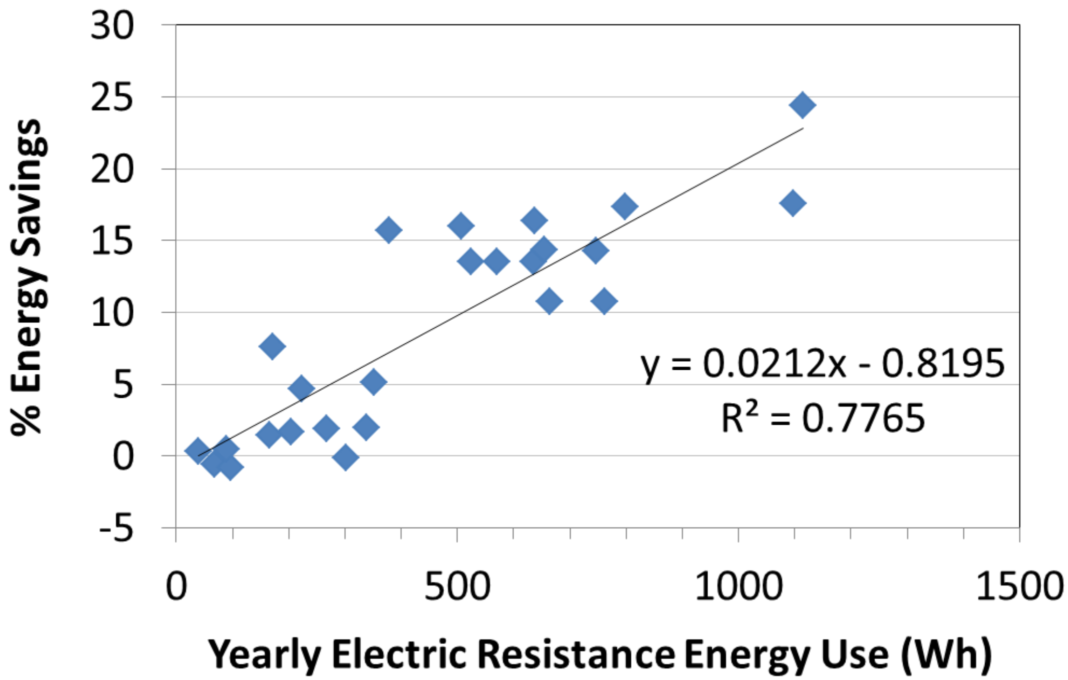
Advanced HPWH Control - Results



Linear relationship between ACA savings and homeowners past strip heat use, i.e. high water draws.

Advanced HPWH Control - Results

Spot check models using real HPWHs.

	Appliance Lab			Model
Day	**Baseline Energy (kWh)**	**Learning Energy (kWh)**	**% Savings**	**% Savings**
1	5.1	2.1	59%	51%
2	5.6	3.4	39%	34%
3	5.4	2.1	61%	49%
4	4.7	2.4	49%	35%
5	2.3	3.1	-35%	-29%

Conclusions

- Advanced Control Algorithm yields on average 9% yearly energy savings over baseline HPWH.
- If forecasting future water draws is improved energy savings will increase.
- Method will not work on homes with very irregular water draw patterns.
- Method will save more energy in homes that have many large water draw events.

Thank You.

- Questions?

- For more info:
  - Load Shifting
    - Boudreaux, P.,J. Munk, R. Jackson, A. Gehl, D. Dinse, C. Lyne. Effect of Setup Thermostat Schedule on Heat Pump Water Heater Energy Consumption, Coefficient of Performance and Peak Load. *Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA.
  - Advanced Control Algorithm
    - Boudreaux, P.,J. Munk, R. Jackson, A. Gehl. A. Parkison, and J. Nutaro. *Improving Heat Pump Water Heater Efficiency by Avoiding Electric Resistance Heater Use.* Report ORNL/TM-2014/483. Oak Ridge, TN: Oak Ridge National Laboratory.

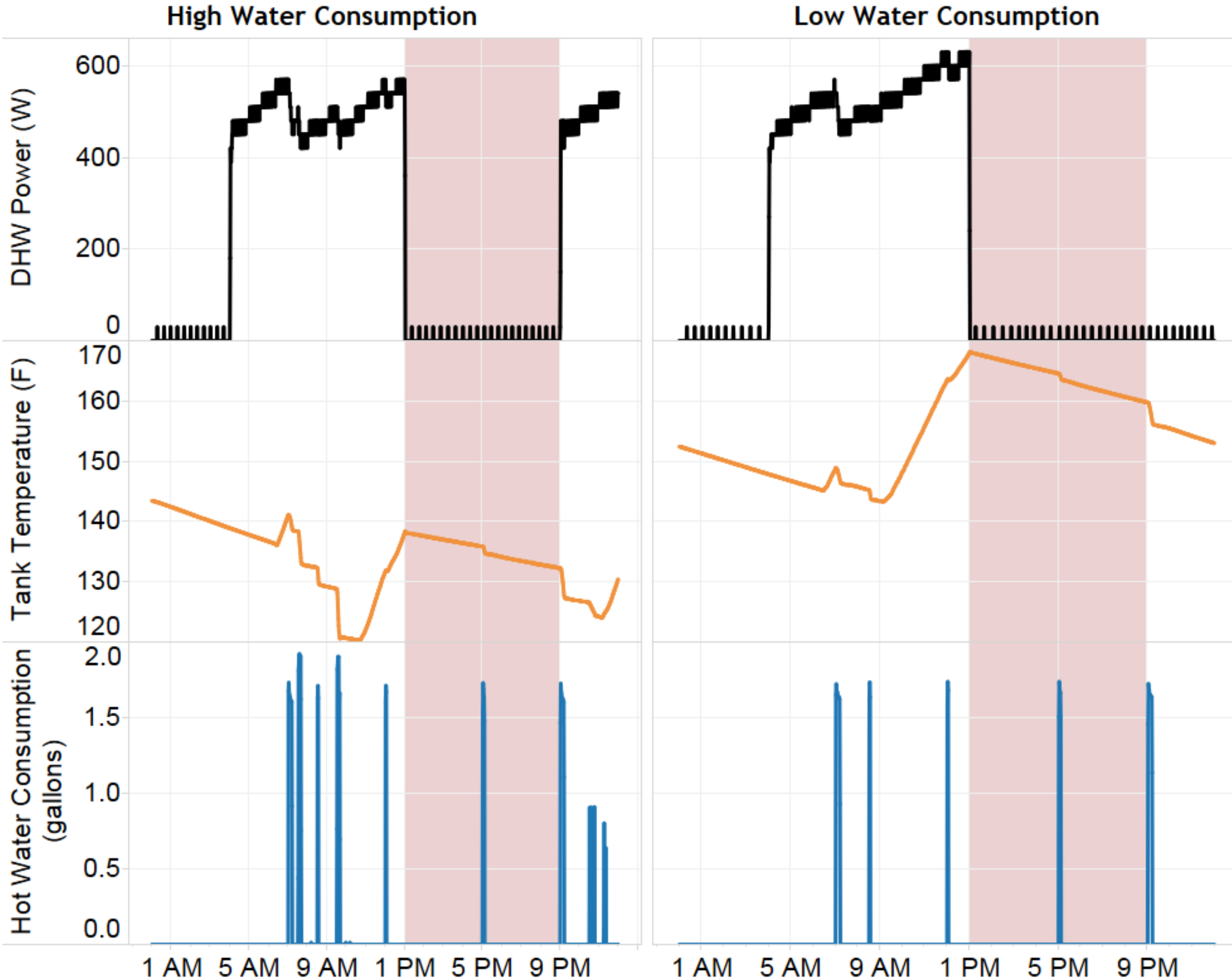
Extra Slides in case of questions

Results – Baseline

	Low Water Draw Profile (kWh)	Medium Water Draw Profile (kWh)	High Water Draw Profile (kWh)
Conventional WH	8.5	N/A	13.2
Baseline HPWH	2.3	2.7	6.0
Baseline HPWH Peak Energy	0.6	0.5	0.6

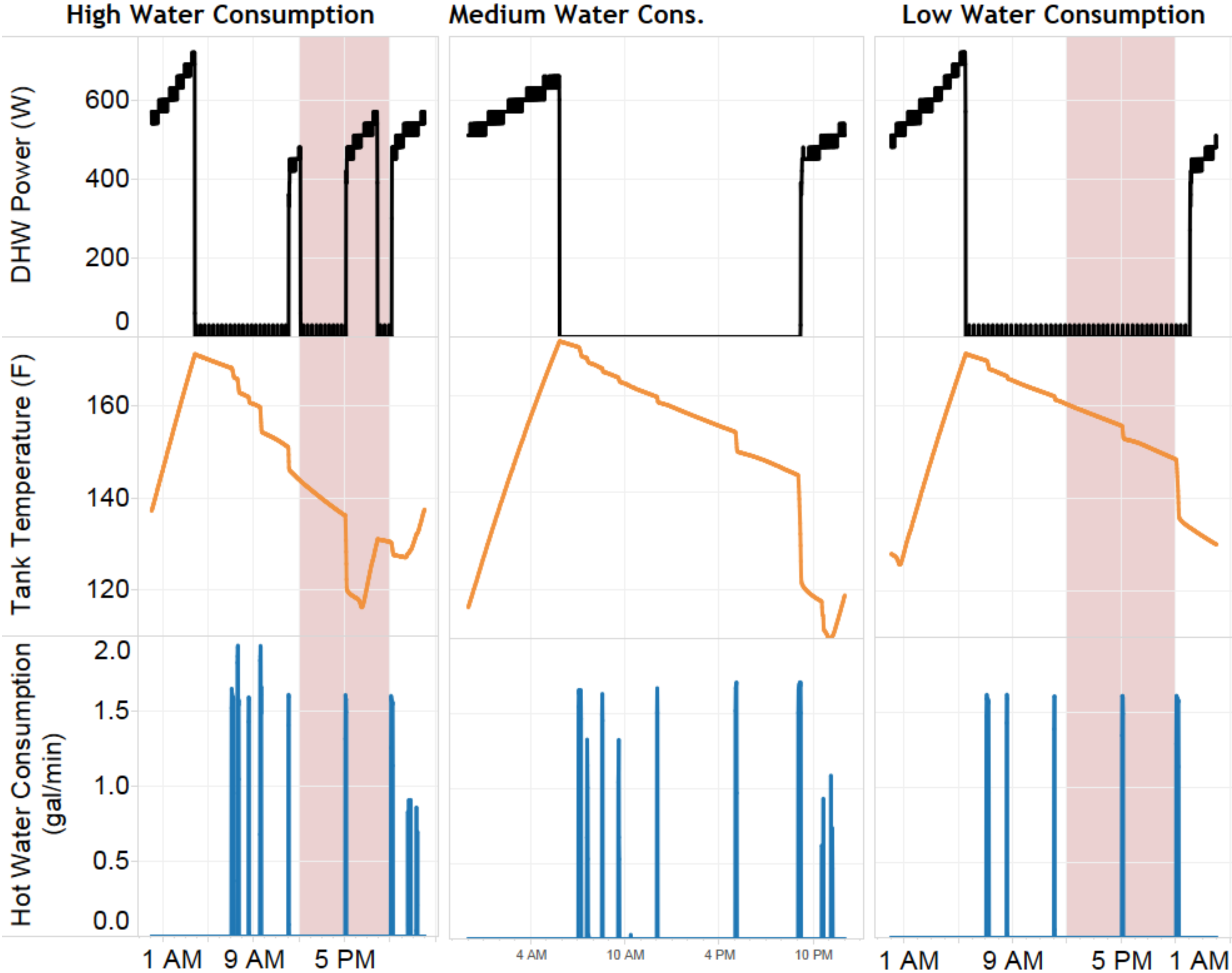
	Low	Medium	High
% time below 117°F	4%	21%	13%
Water Heater COP	2.8	3.0	1.9

Results – Schedule 1



	Low	Medium	High
Daily Energy (kWh)	3.2	3.9	4.8
Peak Energy (kWh)	0	0	0

Results – Schedule 2



	Low	Medium	High
Daily Energy (kWh)	3.1	4.3	5.2
Peak Energy (kWh)	0	0	1.5

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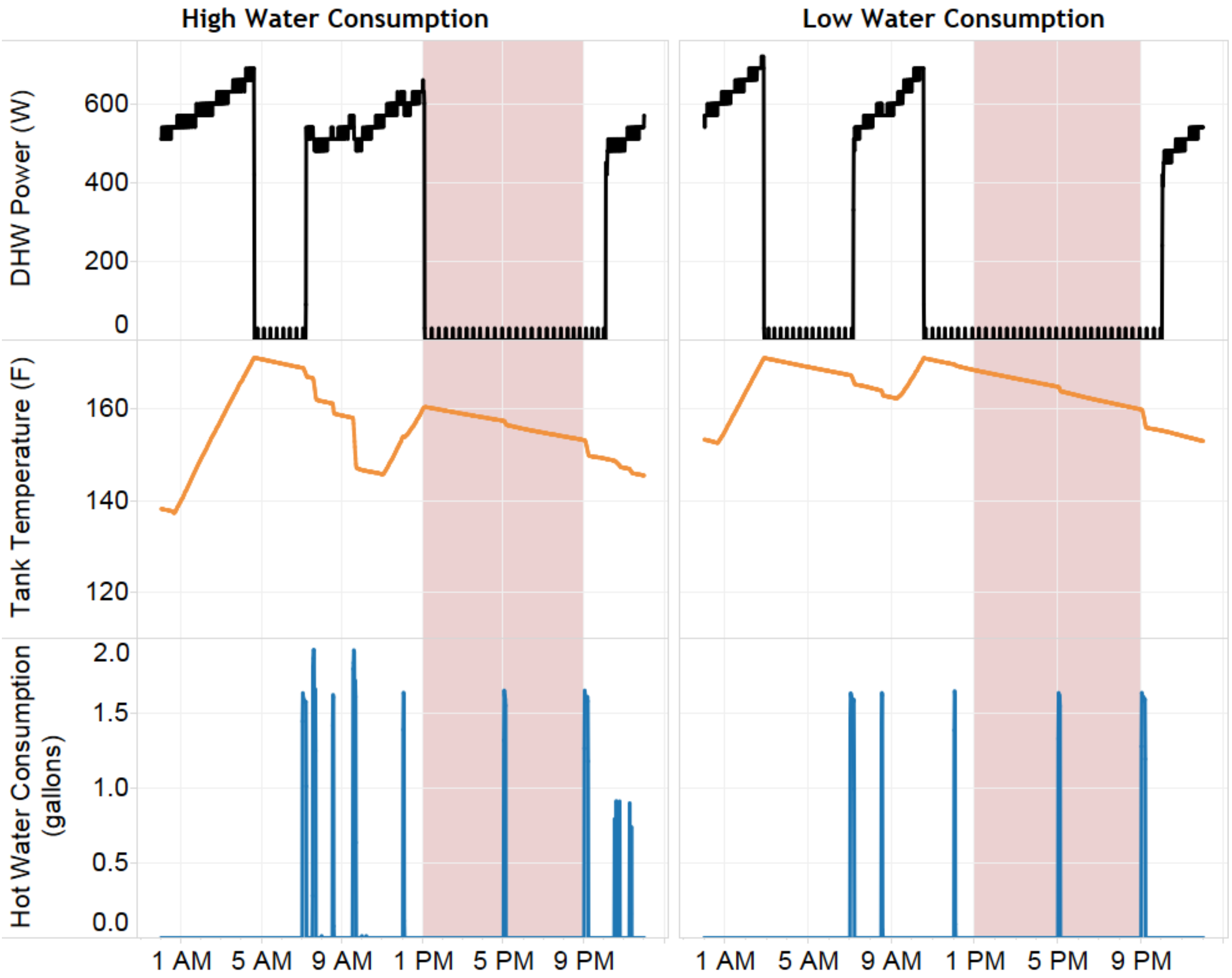
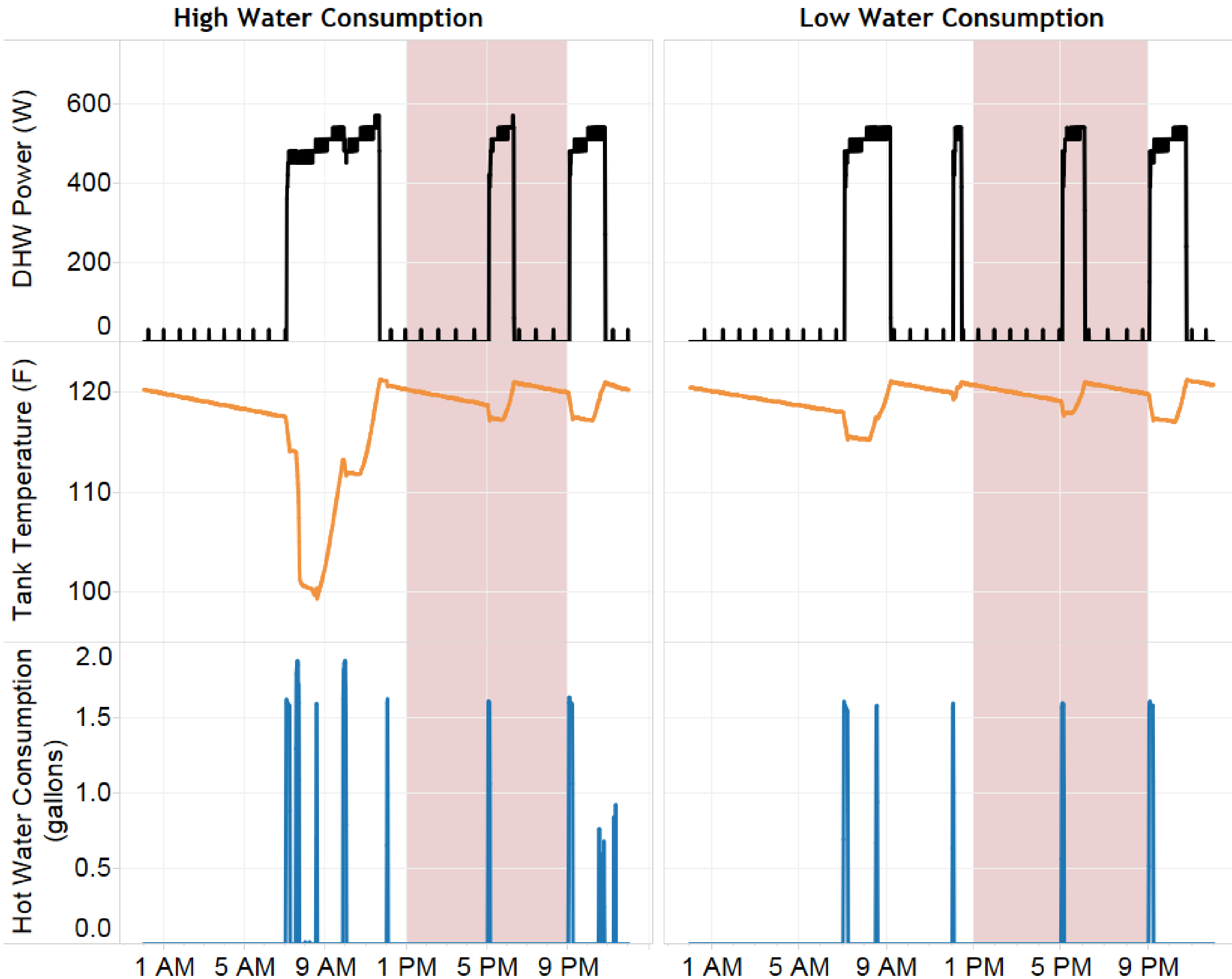
Results – Schedule 3



	Low	Medium	High
Daily Energy (kWh)	3.6	4.3	5.7
Peak Energy (kWh)	0	0	0

Results – Schedule 4



	Low	Medium	High
Daily Energy (kWh)	2.4	2.7	3.9
Peak Energy (kWh)	0.5	0.4	0.6