HPWH Demand Flexibility Study

Preliminary Results

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Sponsored by:

Agenda

1. Objective and Scope
2. Methodology
3. Preliminary Findings

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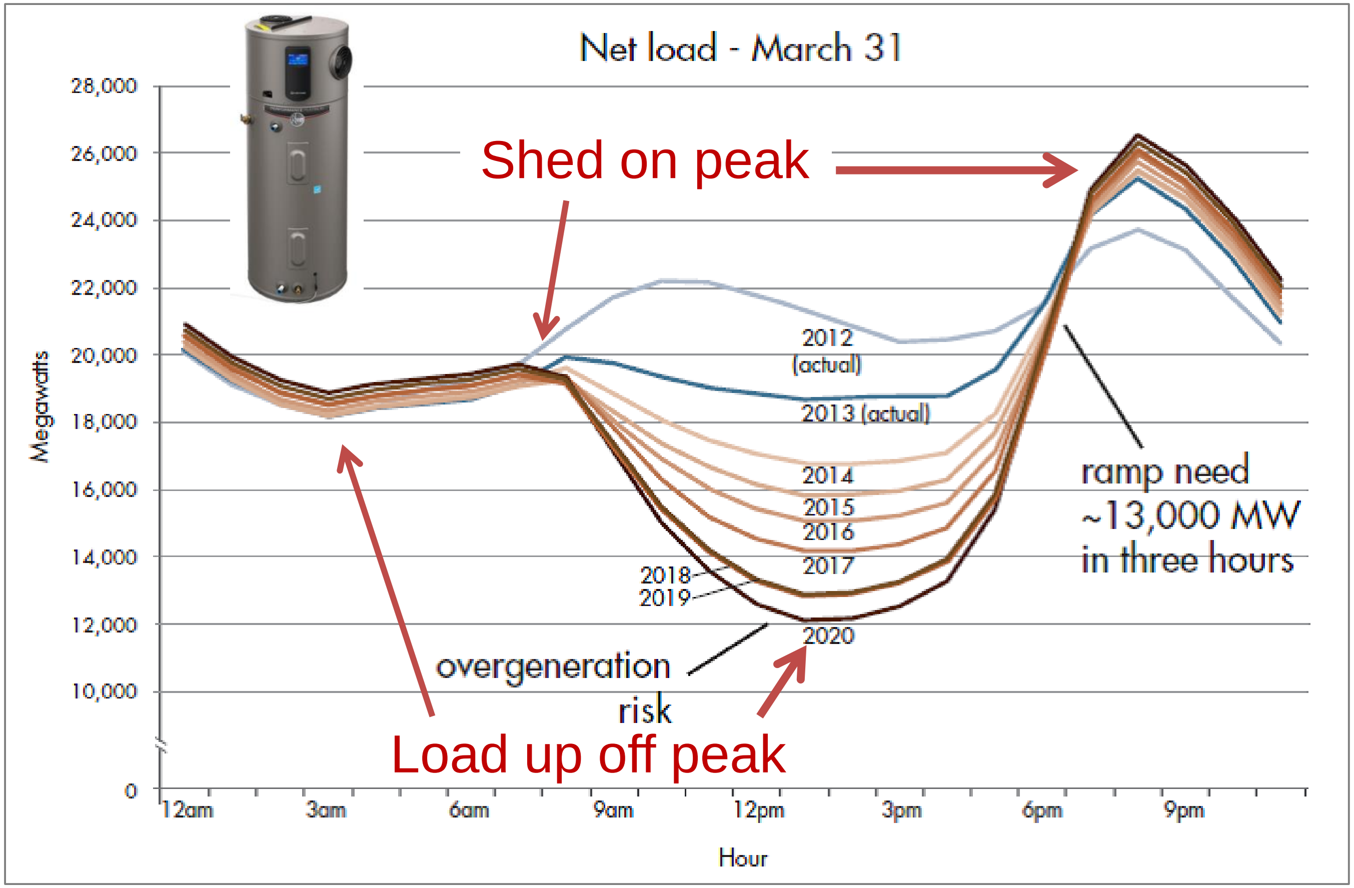
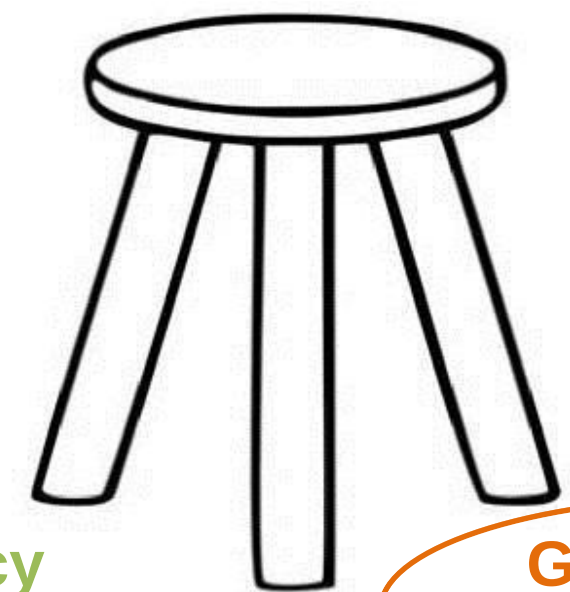
Study objective: Assess heat pump water heater demand flexibility potential in California



- How much can HPWH thermal storage reduce customer and grid costs?

Why does NRDC care? Fully valuing benefits of advanced electric water heating is key accelerate its adoption

Advanced Water Heating



Efficiency

Grid Services
(thermal storage+)

Emissions

Key questions

1. Myth or reality?
   - Evaluate common perception that “HPWH are not well suited to DR…”
2. Thermal storage
   - Evaluate HPWH thermal storage capacity and cost
3. Costs benefits
   - Customer bills
   - Utility/societal marginal costs
4. Energy efficiency
   - Storage efficiency penalty
   - Resistive element avoidance
5. GHG emissions benefits
   - GHG reductions from HPWH load shifting
6. Load coincidence
   - Grid peak
   - Solar / duck curve
7. Assurance of service
   - Ensure load shifting does not compromise customer hot water delivery

Study approach

2 parts:

1. **Simulation**
   - ❑ Ecotope HPWHsim simulation model

2. **Lab testing**
   - ❑ 4 HPWH models:
     - Rheem, 50 gallons
     - AO Smith, 66 gallons
     - Bradford White, 80 gallons
     - Sanden, 83 gallons
   - ❑ Calibrate Ecotope's model
   - ❑ Validate simulation results

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Price Signals: What to Optimize HPWH Operation for?

Price Signal	Objective
Utility marginal costs (PG&E 2024), including energy, emissions, capacity, T&D, no retail rate adder.	Grid energy/societal cost perspective
Residential TOU rate: hypothetical "Flexible water heating" rate, developed by NRDC based on PG&E 2024 marginal costs	Consumer bills
TDV + NEM2: CEC's 30-yr present value projection of grid energy costs + Net Energy Metering (NEM2)	CA 2019 building code

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Hourly Marginal Costs (PG&E 2024) – Annual Average

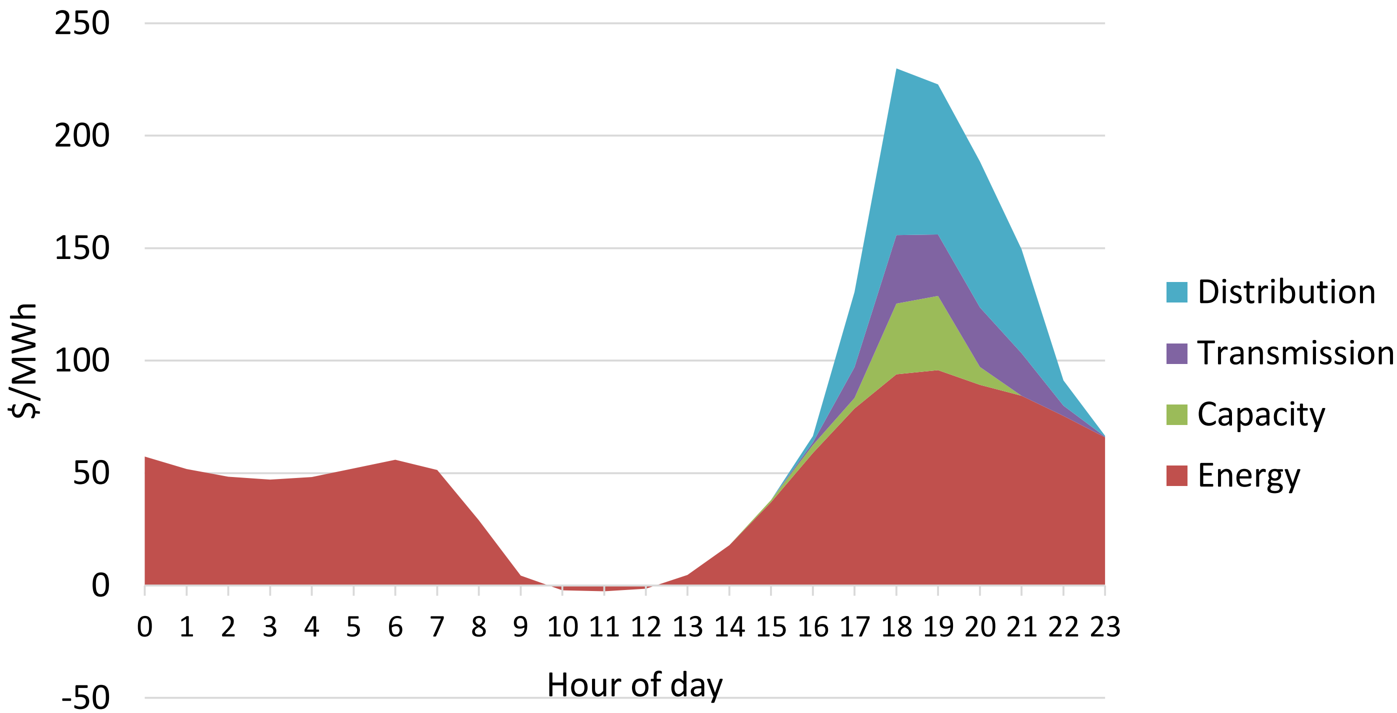

Chart shows annual average of hourly values for simplicity.
Price schedule has 8760 hourly values for entire year.

Hourly Marginal Costs (PG&E 2024) – Monthly Average

Average of CZ3 ($/kWh)	Hour of Day																							
Month	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.05	0.04	0.04	0.04	0.05	0.06	0.06	0.06	0.05	0.01	0.01	0.01	0.00	0.01	0.02	0.05	0.09	0.12	0.15	0.15	0.15	0.11	0.07	0.05
2	0.05	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0.03	0.05	0.07	0.10	0.13	0.13	0.12	0.09	0.07	0.06
3	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.03	0.00	-0.01	-0.01	-0.01	-0.01	0.00	0.02	0.04	0.07	0.11	0.12	0.12	0.10	0.08	0.06
4	0.05	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.00	-0.02	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	0.00	0.04	0.07	0.10	0.11	0.11	0.08	0.06
5	0.05	0.04	0.03	0.03	0.03	0.03	0.04	0.02	0.00	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01	0.00	0.03	0.06	0.08	0.10	0.10	0.10	0.08	0.06
6	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.02	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.02	0.04	0.06	0.09	0.13	0.14	0.13	0.09	0.07
7	0.07	0.06	0.06	0.06	0.05	0.05	0.06	0.04	0.03	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.07	0.09	0.16	0.18	0.20	0.17	0.11	0.08
8	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.02	0.01	0.02	0.02	0.03	0.05	0.06	0.08	0.14	0.30	0.32	0.28	0.21	0.11	0.08
9	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.03	0.00	-0.01	-0.01	0.00	0.00	0.02	0.05	0.12	0.51	1.04	0.85	0.56	0.40	0.17	0.08
10	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.01	-0.01	0.00	0.00	0.00	0.02	0.04	0.07	0.13	0.34	0.27	0.19	0.15	0.10	0.07
11	0.06	0.06	0.05	0.05	0.06	0.06	0.07	0.06	0.03	0.01	0.00	0.00	0.00	0.01	0.03	0.06	0.08	0.11	0.13	0.12	0.12	0.10	0.08	0.07
12	0.06	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.05	0.02	0.01	0.01	0.01	0.02	0.04	0.07	0.09	0.13	0.15	0.15	0.14	0.11	0.07	0.06

1. Chart shows monthly average of hourly values, $/kWh. Simulation uses hourly price schedule (8760 hours/year).
2. Calculation of total hourly marginal cost based on PG&E's 2024 variable marginal costs. Includes energy, capacity, transmission, and distribution.

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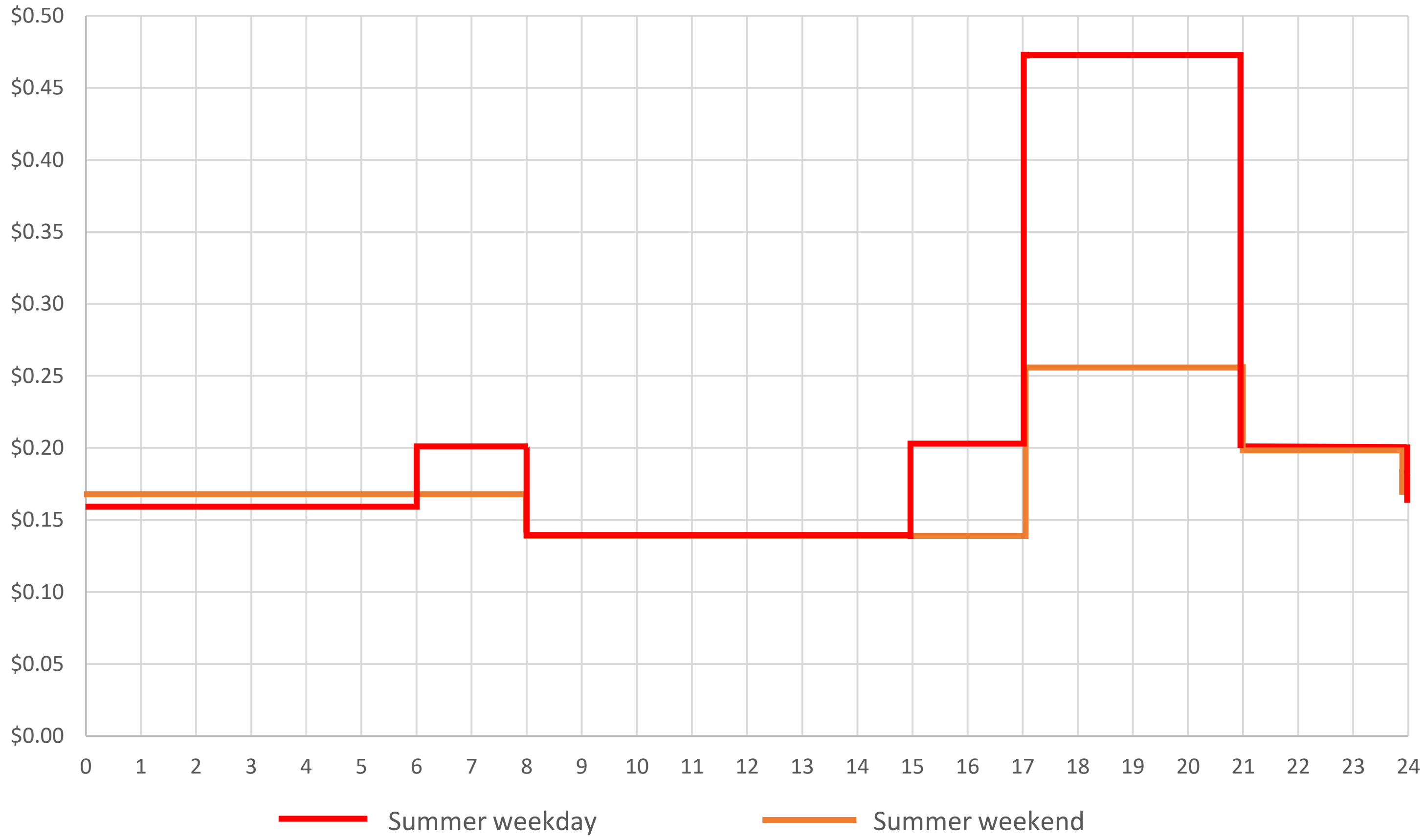
Residential Time of Use: Hypothetical NRDC “Flexible Water Heating” Rate

Reflective of PG&E 2024 marginal costs. 3x peak/off-peak price differential. Morning partial-peak to reflect morning energy marginal cost mini-peak.



Control Strategies: How to optimize HPWH operation for price schedules

3 levels of "smartness", to evaluate their relative effectiveness:

1) **Simplest: On/off timer**
   - Can be installed by user/electrician/plumber, available with current technology.
   - Response only to a known, fixed price TOU price schedule

2) **Smarter: Load-up / shed**
   - Load up to 135F/145F/155F during price trough, shed on peak, 125F rest of the time
   - Site or cloud controls
   - Fixed price TOU price schedule

3) **Smartest: Advanced price optimization, grid-connected**

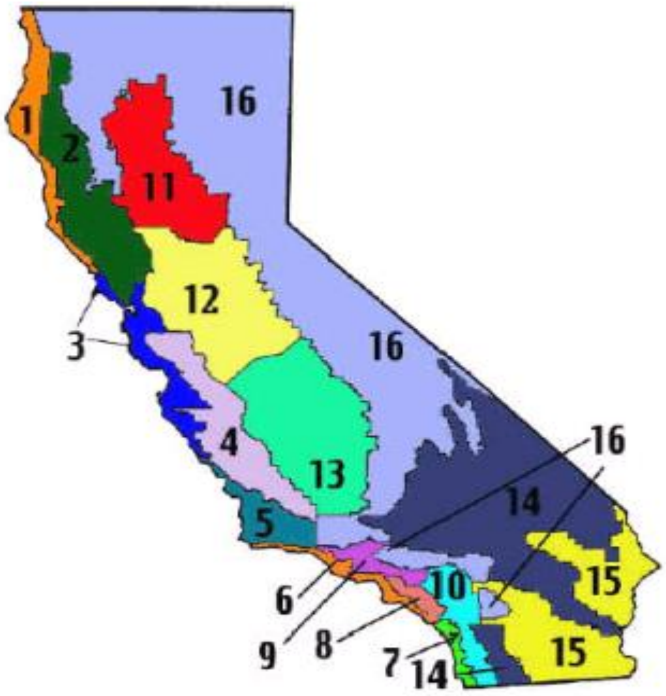
   Hourly optimization based on look-ahead price signal received via outside communication.
   - Grid connectivity and new control functions needed
   - Responds to any price schedule: dynamic or TOU

Simulation Runs

Optimization parameters:

Input values	**# of values**
Price signals: Utility marginal costs, TOU, TDV-NEM2	3
Units: Hybrid HPWH (50, 65, 80-gal), HP-only (50, 80-gal, Sanden Gen3-80), ERWH (50, 65, 80-gal)	11
Max water temp: 125, 135, 145, 155	4
Climate zones: all 16 CA climate zones	16
Draw patterns: 1-5 bedrooms (from CEC compliance tool CBECC-Res)	5
Control strategies: On/Off Timer, Load-up/Shed, Advanced	3
Total Scenarios	**31,680**

California climate zones:



How to assess if a simulation scenario is successful?

Simulation scenario successful if:

1. Controls do not compromise customer hot water delivery
   - ❑ (# gallons delivered < 105F) < 0.3% *

AND

2. Costs no higher than uncontrolled case
   - ❑ Price arbitrage gains > cost of increased energy use

* Hiller C., ASHRAE 1998, DHW sizing guideline: 12 runouts / year. Corresponds to 0.3% missed gallons

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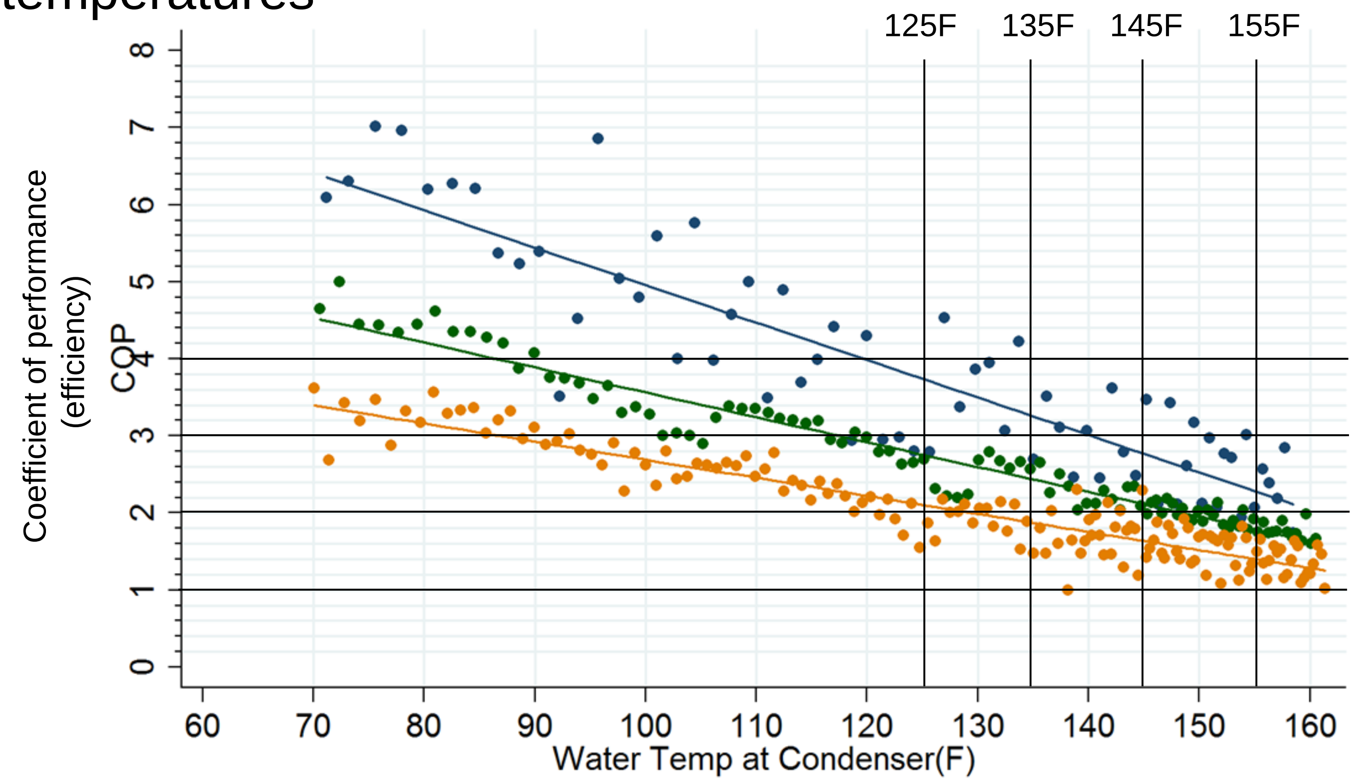
Compressor efficiency decreases and thermal losses increase at higher set points

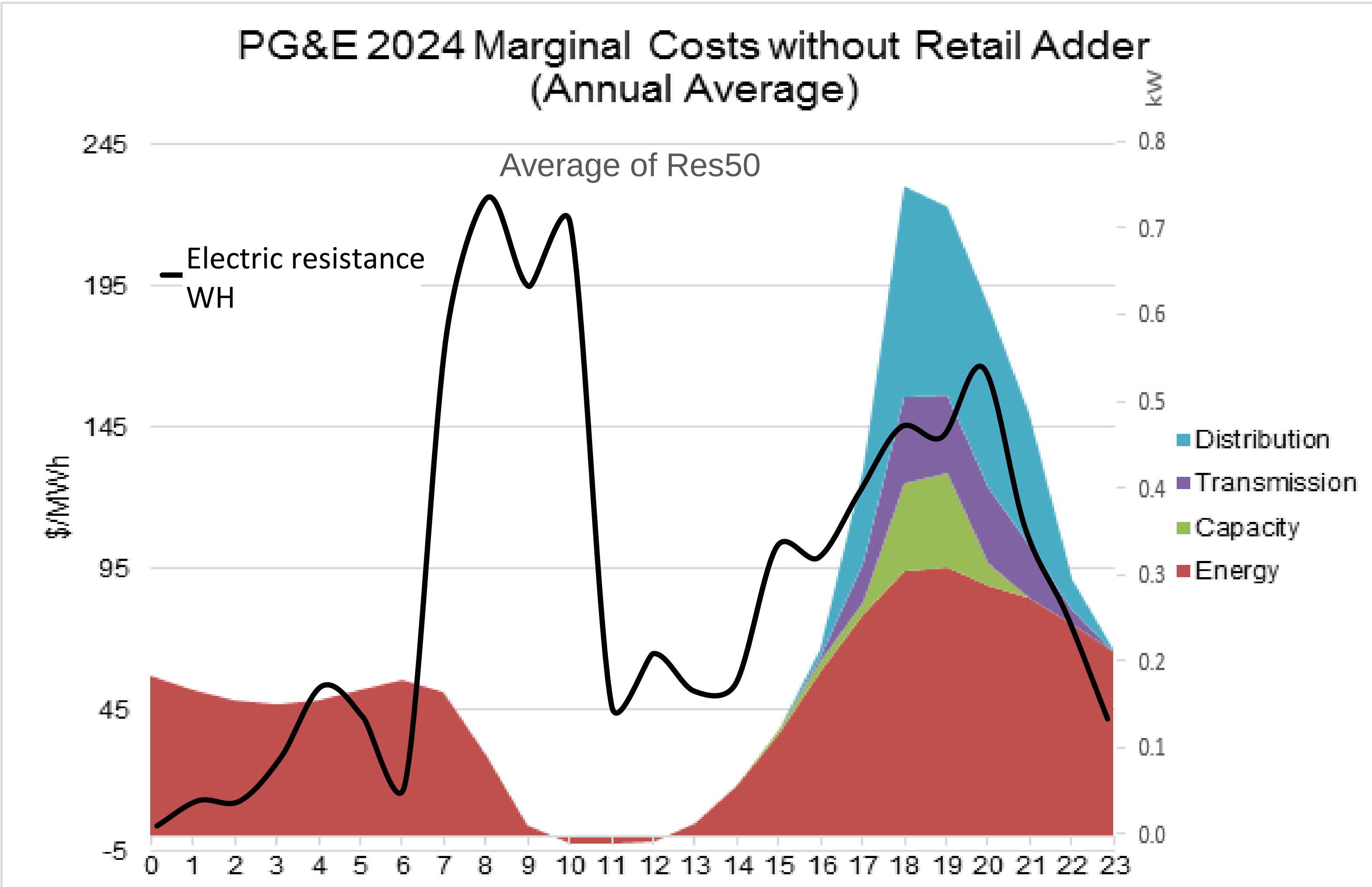
- Lab testing measured compressor efficiency at higher water temperatures



Air Temperature: Blue – 95F, Green – 67.5F, Gold – 50F

➢ Trade-off between thermal storage and energy efficiency

Sample results
CZ12, 3 bedrooms, 50G ERWH, 66G HPWH



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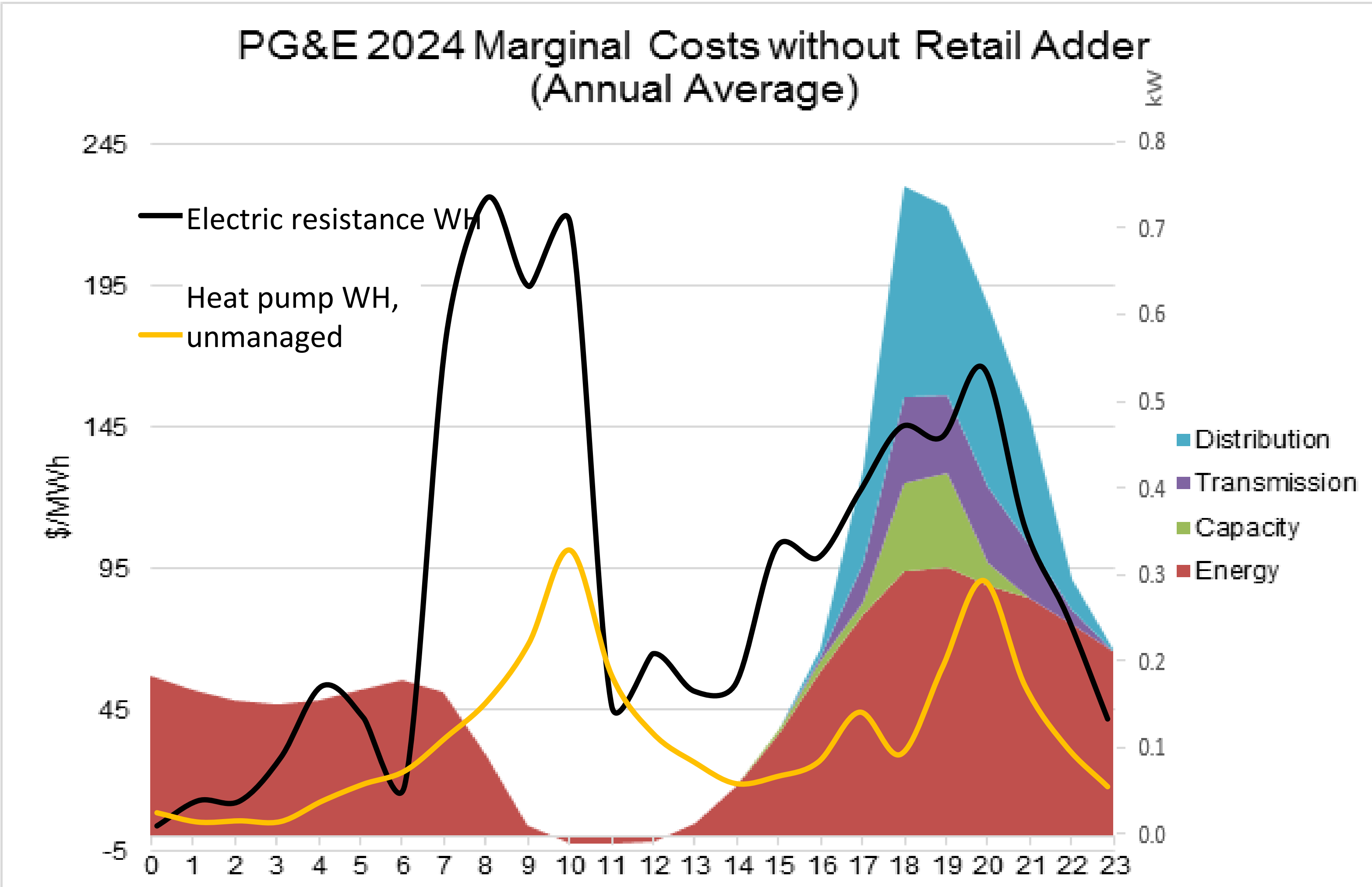

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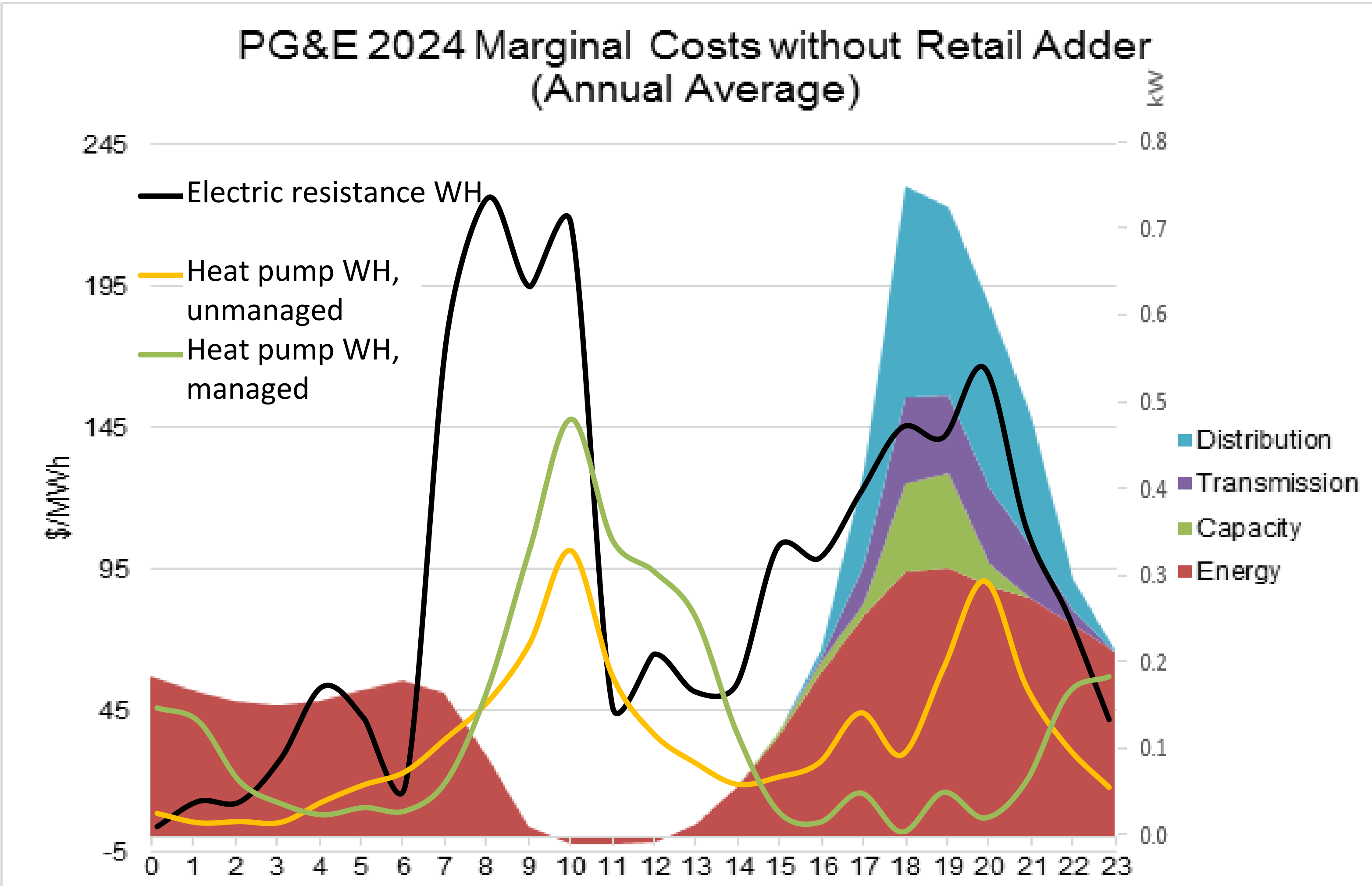

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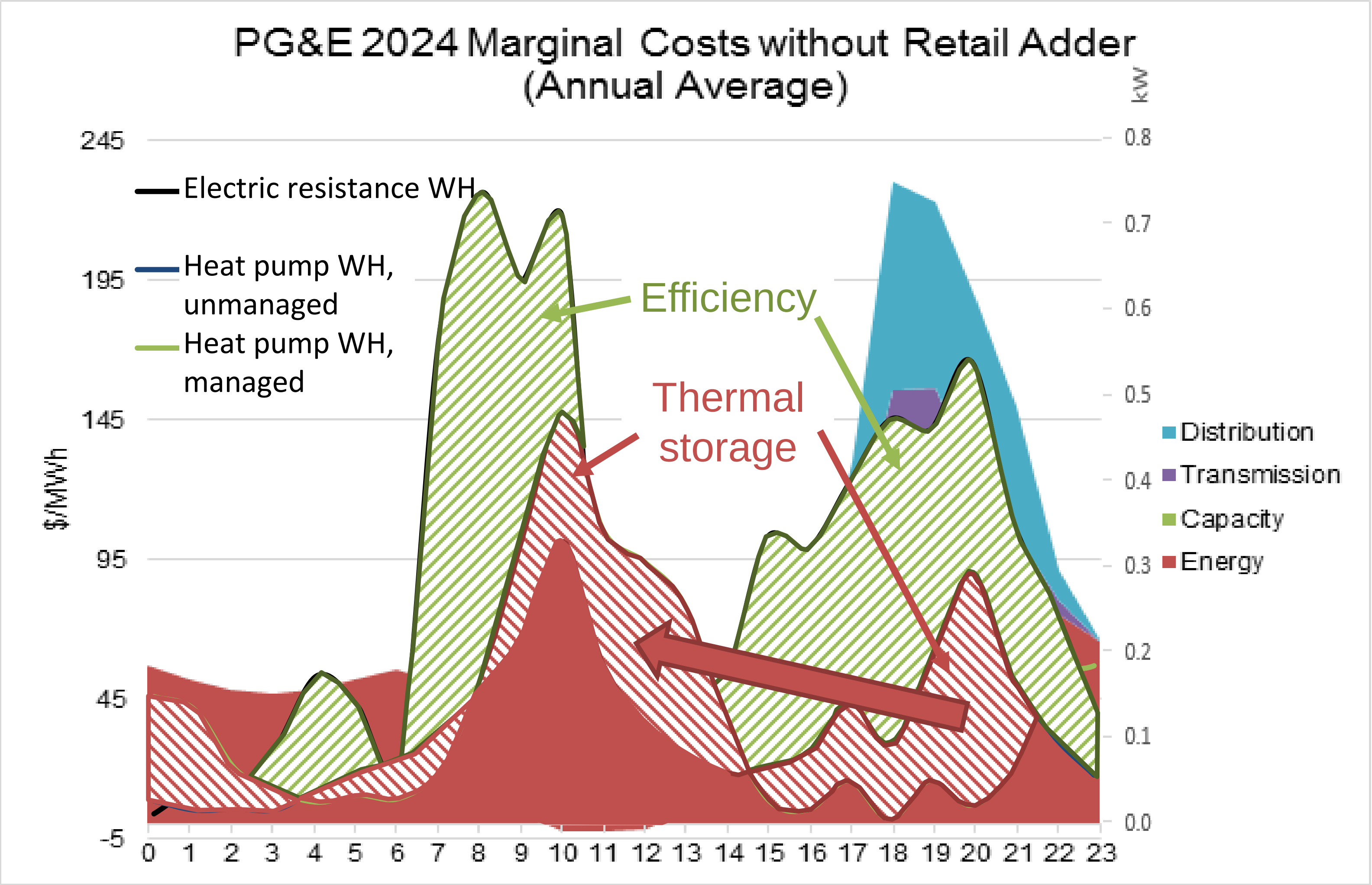
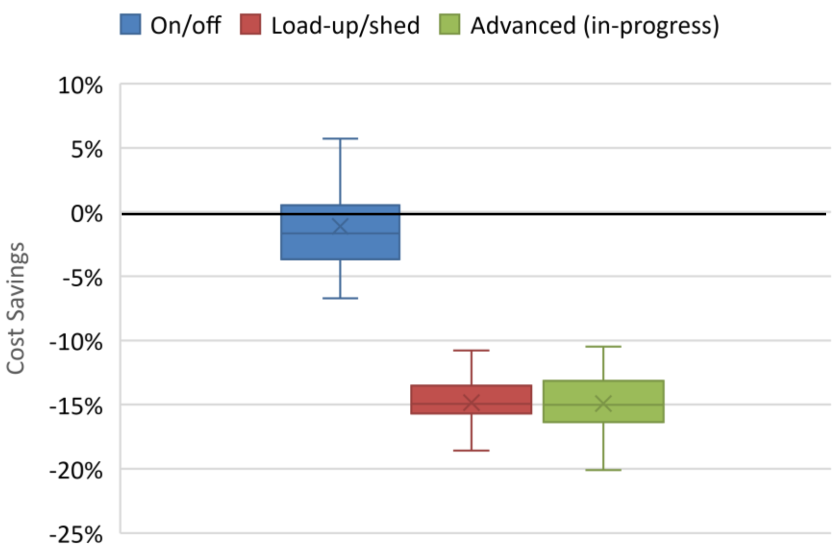
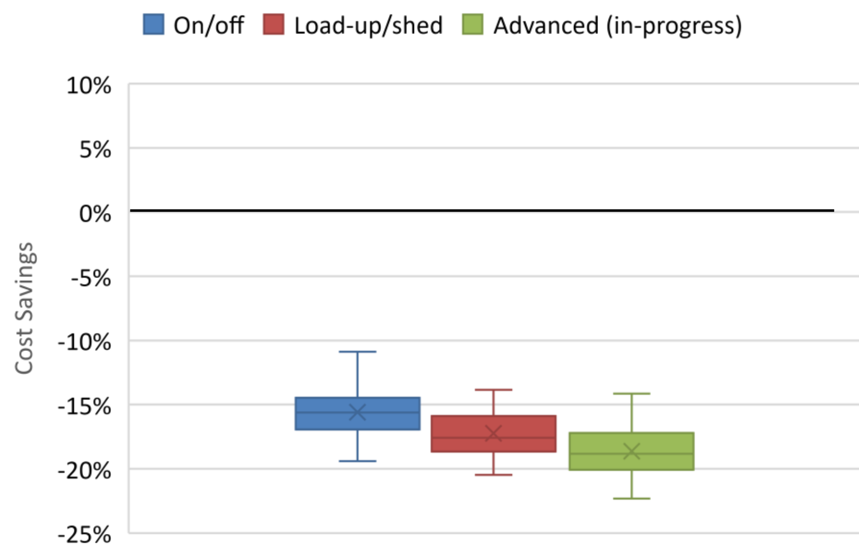


Findings: Cost Savings by Control Strategies

R134a Hybrid

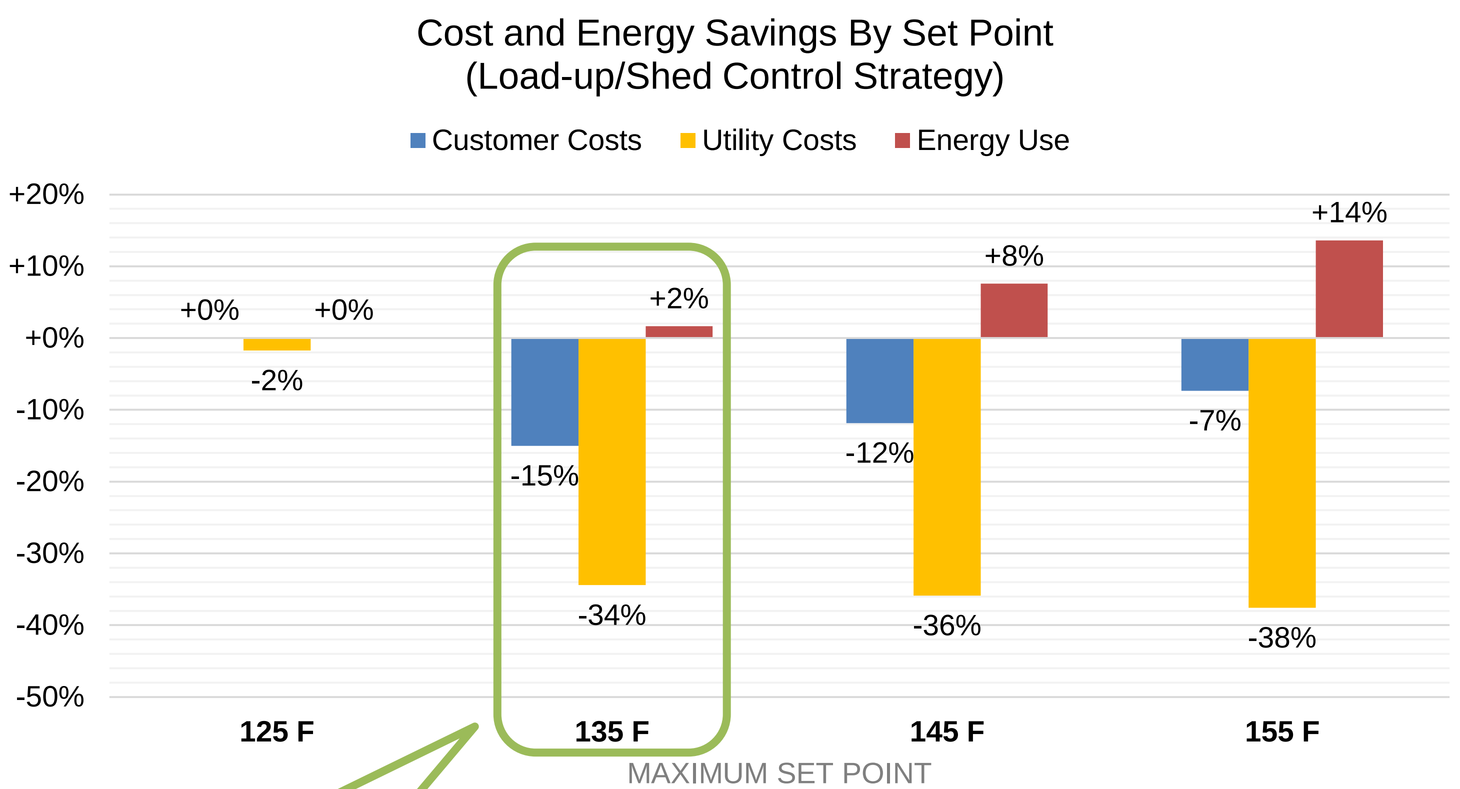


CO_2 Heat Pump



- On/off strategy yields limited savings with R134a hybrid technology, and causes significant runouts
- Advanced strategy is work-in-progress

Findings: Optimal Control Temperature



Optimal temperature for cost / efficiency

Findings: HPWH thermal storage

Modest storage capacity per HPWH, but significant in aggregate:

- Effective storage capacity: Roughly 0.3 to 0.6 kWh per evening per HPHW
- "If all water heaters in CA were managed…" it would provide 1 to 2 GW storage capacity
- Limited by peak-coincidence, efficiency penalty, and run-outs
- Varies by household size, climate zone, season.

Roughly half the cost per kWh of stored energy vs. battery storage:

- $80-$600 / kWh for HPWH thermal storage
- Compared to $400-$800 / kWh for battery storage

Sources and assumptions:

- HPWH storage: $50-$200 for mixing valve and control module
- Home batteries: $400-$800/kWh (Business Insider, "10 home batteries that rival Tesla's Powerwall 2", May 18, 2017)

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Findings: operational costs savings

Operational savings depend on what controls optimize for:

	Customer bill savings	Utility marginal cost savings
Optimizing for customer costs (TOU)	-15% to -20%	-35%
Optimizing for grid marginal costs	0% to +5%	-60%

- Optimizing for customer bills yields significant cost savings for both customers and grid/society
- Optimizing for grid marginal costs can **potentially increase customer bills**.
  - Would requires different mechanism to compensate customers, e.g. free or discounted water heater, annual cash payment, etc…

Outcomes scorecard

	ERWH Unmanaged	ERWH Managed	HPWH Unmanaged	HPWH Managed
Peak coincidence (5pm-9pm)	20%	0%	15%	1%
Solar coincidence (8am-5pm)	50%	80%	55%	65%
Effective storage capacity / evening	-	1-2 kWh	-	0.3-0.6 kWh
Energy use (kWh/y)	2,570	2,640 (+3%)	1,030 (-60%)	1,040 (-60%/+1%)
Resistive kWh	100%	100%	16%	14%
Consumer bills	$500	$380 (-25%)	$180 (-65%)	$150 (-70%/-16%)
Utility marginal costs	$180	$80 (-55%)	$57 (-70%)	$37 (-80%/-35%)

3-bedroom house, CZ12, ERWH 50-gallon + 30F thermal storage / HPWH 65-gallon +10F

* Pending further control optimizations

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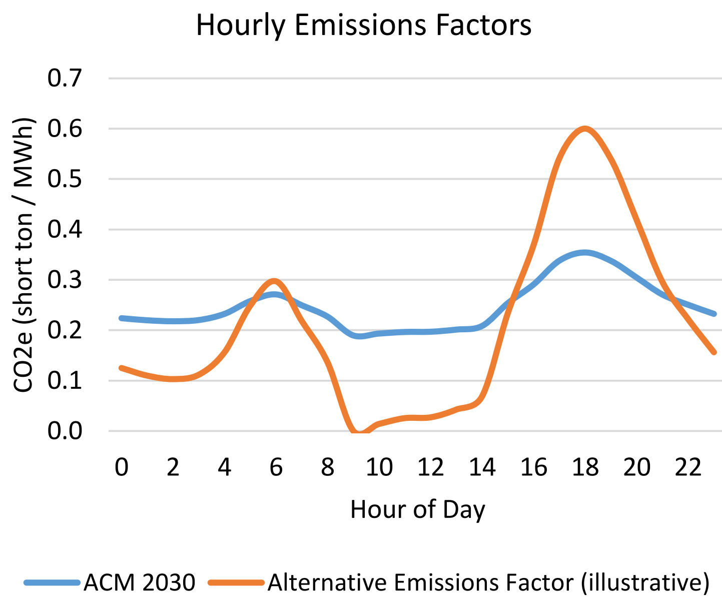
How about GHG reductions?

	ERWH Unmanaged	ERWH Managed	HPWH Unmanaged	HPWH Managed
CO2e (kg)	700	650 (-7%)	270 (-60%)	265 (-61%/-2%)

Wait, why such low GHG reductions from load management?

- ➢ GHG bean counting issue:
  - o CPUC ACM emissions factors have low peak/off-peak differentiation
  - o Uses RPS as both floor and ceiling
  - o Not appropriate to value load shifting
- Highly differentiated emissions factors could yield > 50% GHG reductions!



* Avoided Cost Model: http://www.cpuc.ca.gov/General.aspx?id=5267

* RPS: Renewable Portfolio Standard

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Key Takeaways

1. Significant potential for cost-effective HPWH load shifting
   – 130-140F sweet spot ("sweet range")
   – 15-20% customer savings potential
   – 30-60% utility savings potential

2. Requires:
   1. Smart control technology
   2. Load flexibility programs
   3. TOU rates: cost-reflective and sufficiently differentiated OR alternative customer compensation mechanism
   4. Incentive programs and supportive regulatory environment (e.g. building code)
   5. Appropriate GHG accounting methodology for load shifting

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Thanks!

Questions?

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