The R.E.D Carpet of Thermostat Optimization

Jesse Smith, Demand Side Analytics
Session 7D
November 3, 2022

IEPEC

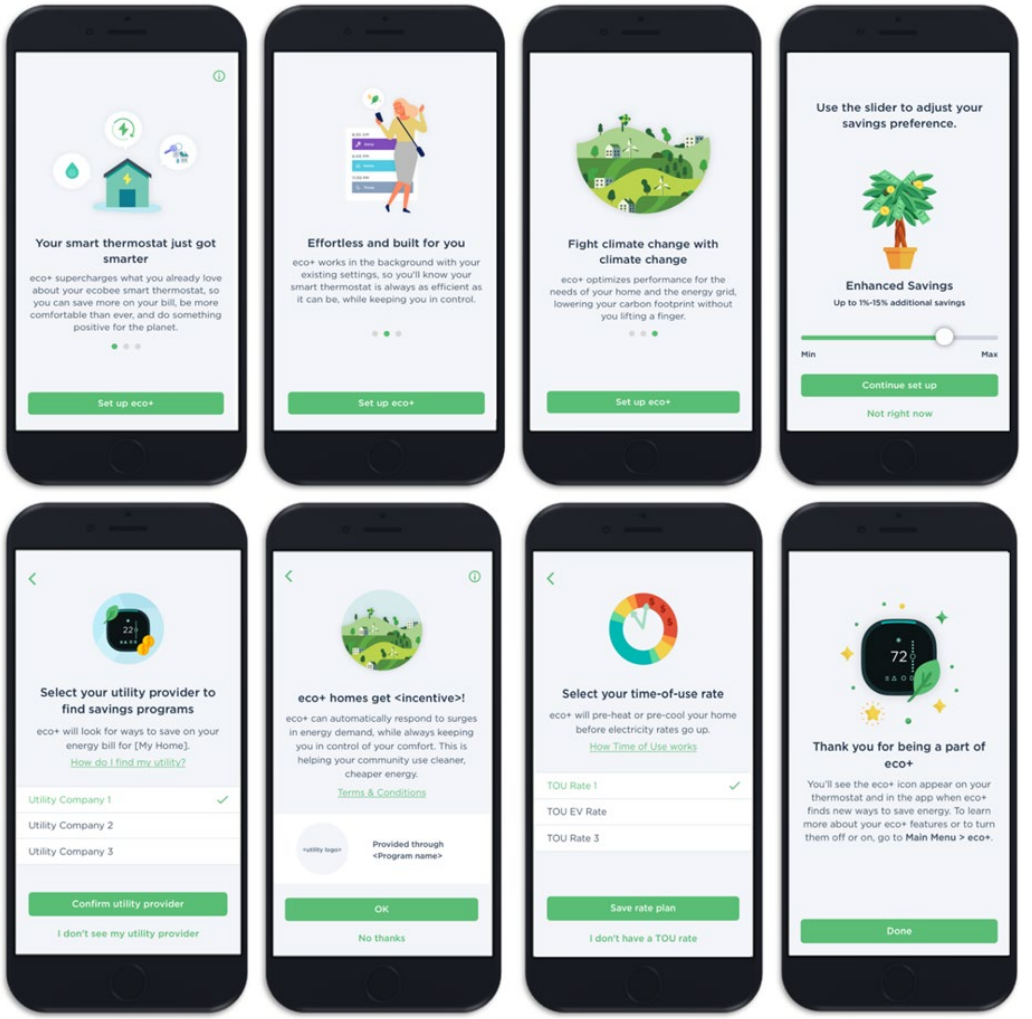
Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

ECO+ THERMOSTAT OPTIMIZATION PLATFORM OVERVIEW

Algorithm Types

- **Demand Response (DR)** – shifts cooling loads away from peak hours through customized pre-cooling and temporary temperature setbacks.
- **Time-of-Use Optimization (TOU)** – For ecobee owners with time-varying rates, shifts energy use from high price hours to lower price hours while maintaining the desired comfort levels.
- **Energy Efficiency (EE)** – Features help ecobee owners lower their overall heating and cooling energy consumption.
  - Enhanced Smart Home & Away
  - Schedule Assistant
  - Adjusting for Humidity

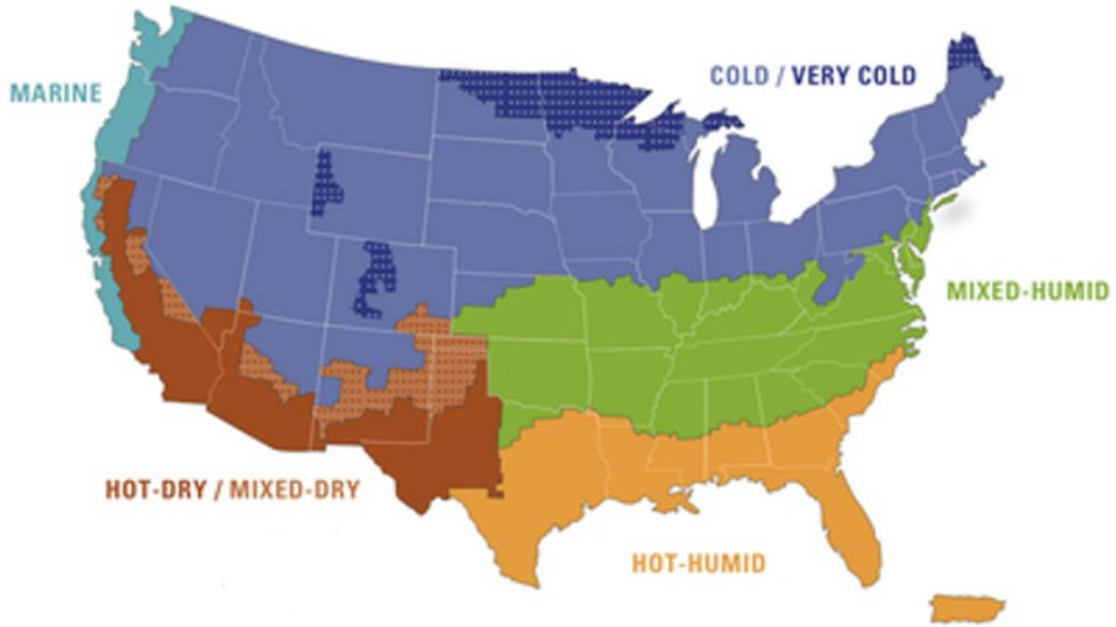
Configuration Screens



Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

EXPERIMENTAL DESIGN

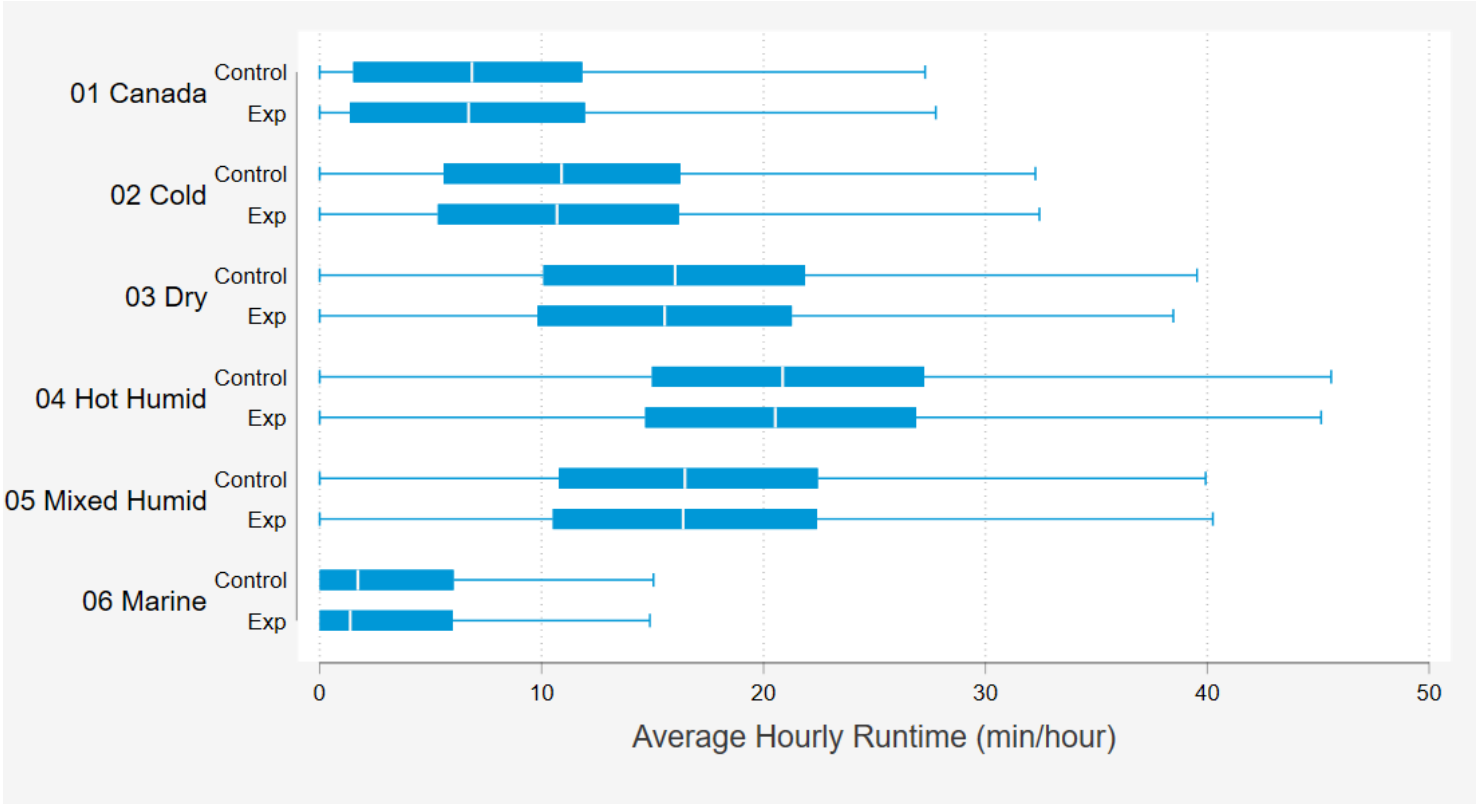
- Ecobee rolled out eco+ deliberately to facilitate measurement of impacts through a Randomized Encouragement Design (RED)
- Regions were analyzed separately for each of the three savings strategies



Thermostat Count by Region and Experimental Cell

Region	Experimental	Control	Buffer	Total
01 Canada	10,062	10,026	1,001	21,089
02 Cold/Very Cold	30,001	30,000	3,000	63,001
03 Hot-Dry/Mixed-Dry	5,579	5,570	557	11,706
04 Hot Humid	15,000	15,000	1,500	31,500
05 Mixed Humid	30,000	30,000	3,000	63,000
06 Marine	5,069	5,085	510	10,664
07 Canada TOU (Hydro One)	1,927	1,932	195	4,054
08 Cold TOU (Fort Collins)	140	139	13	292
09 Dry TOU (PG&E)	8,156	8,150	815	17,121
10 Dry TOU (SMUD)	2,800	2,800	280	5,880
11 Marine TOU (PG&E)	9,473	9,461	945	19,879
Total	**118,207**	**118,163**	**11,816**	**248,186**

PRE-TREATMENT EQUIVALENCE CHECKS - WAS THE RANDOMIZATION SOUND?



No statistically significant runtime differential in any of the regions during the pretreatment period.

Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

ANALYSIS OF AN R.E.D.

ITT impacts vs. LATE impacts

- Regression analysis of the RED produces estimates of the average impact of the eco+ *offer*.
  - These impacts are called the "ITT effect", or the Intent to Treat effect
- Not all users accept the offer. We assume all impacts come from devices that received the eco+ algorithms.
  - The eco+ effect on devices that received the algorithms is called the "LATE" or the Local Average Treatment Effect.
  - Converting the impacts requires division by the percent treated

$$LATE = \frac{ITT}{\%\ Treated} = \frac{50\ kWh}{0.6} = 83.33\ kWh$$

Which to consider?

- ITT matters for
  - Expected impact from deploying eco+ to XXX devices
  - Added utility benefit of an ecobee "out of the box"
- LATE matters for
  - What a *user* can expect from accepting eco+
  - What a utility can expect from eco+ DR participants

Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

ACCEPTANCE RATES (SUMMER 2019)

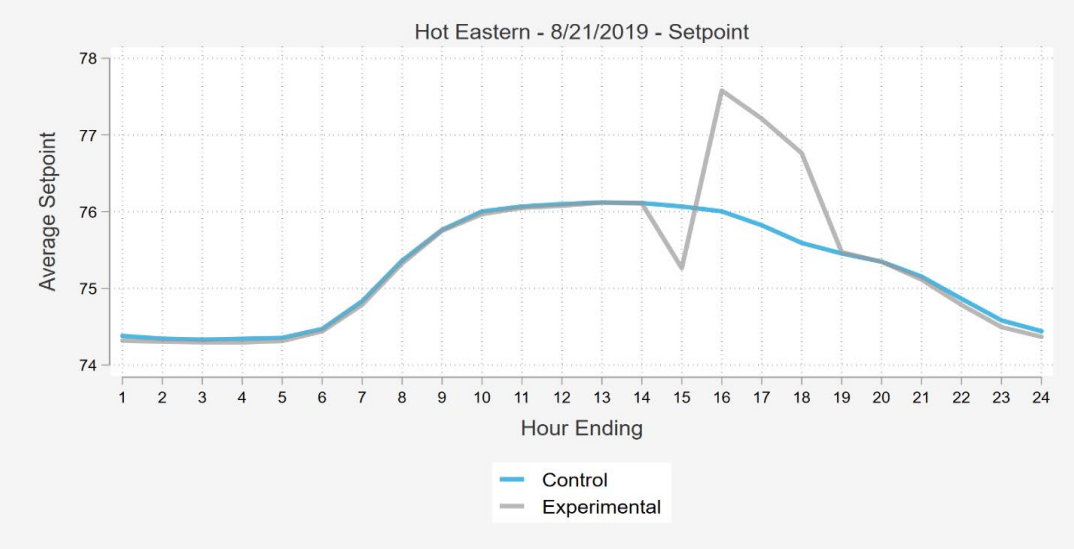
Stage	Stage Description	Device Count	Percentage
A	Randomized	118,207	N/A
B	Online	108,898	100.0%
C	Invited	104,080	95.6%
D	Has Features	81,303	74.7%
E	Terms Accepted	62,748	57.6%
F	Comfort Setting > 1	59,699	54.8%
G	Enabled Features	Varies by Strategy (~ 40%)	

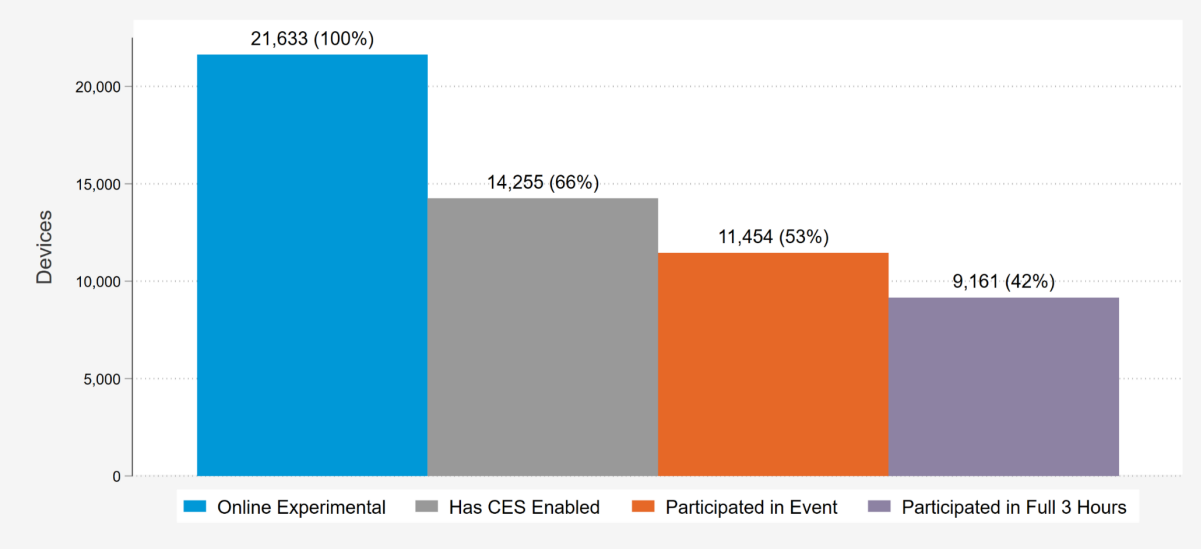
The eco+ opt-in procedure has evolved since the 2019 rollout to more of a default with opt-out experience

DEMAND RESPONSE

DR FEATURE OVERVIEW

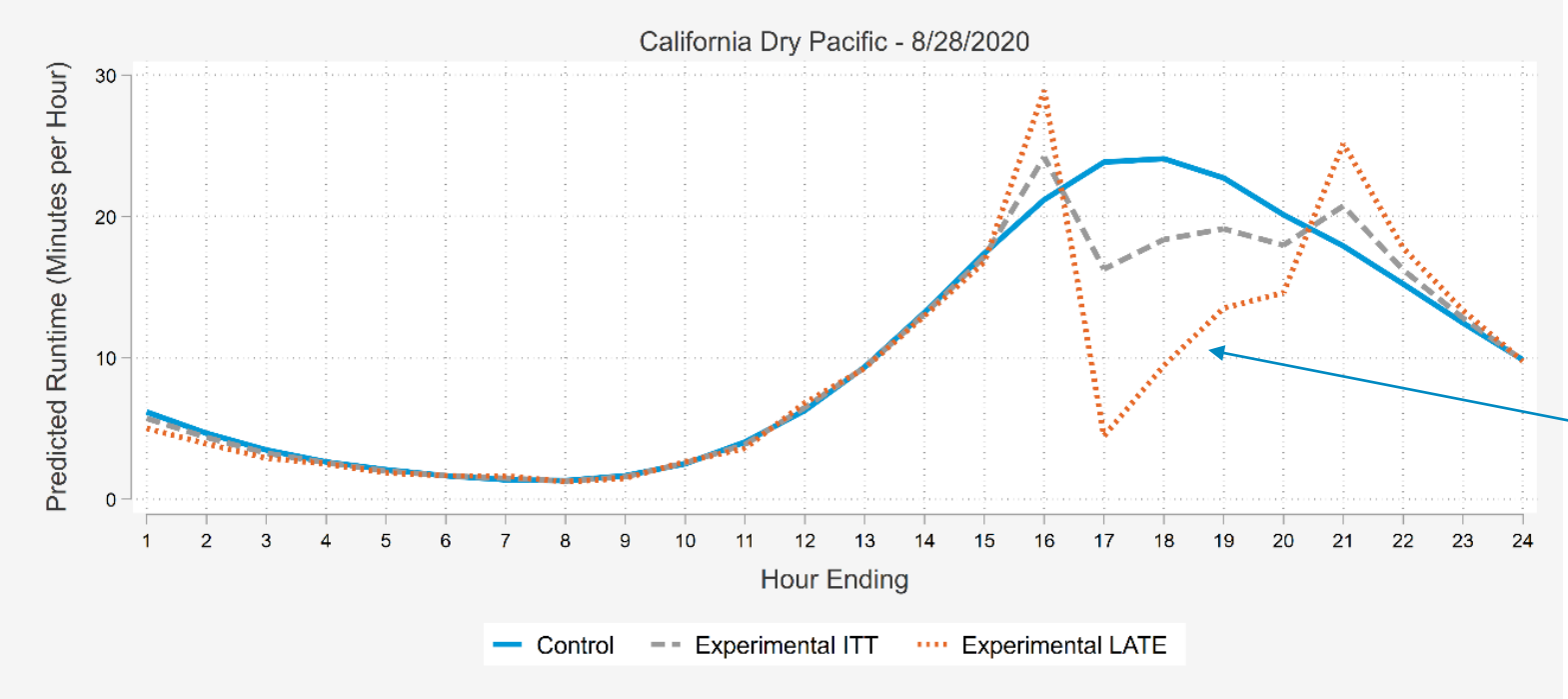
- Demand response is the algorithm that adjusts thermostat set points to shift cooling load to off-peak hours
- Events range from 2 to 4 hours and typically included an hour of pre-cooling prior to the event start time
- Conversion from ITT to LATE (11,454 / 21,633 = 0.5295)





Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

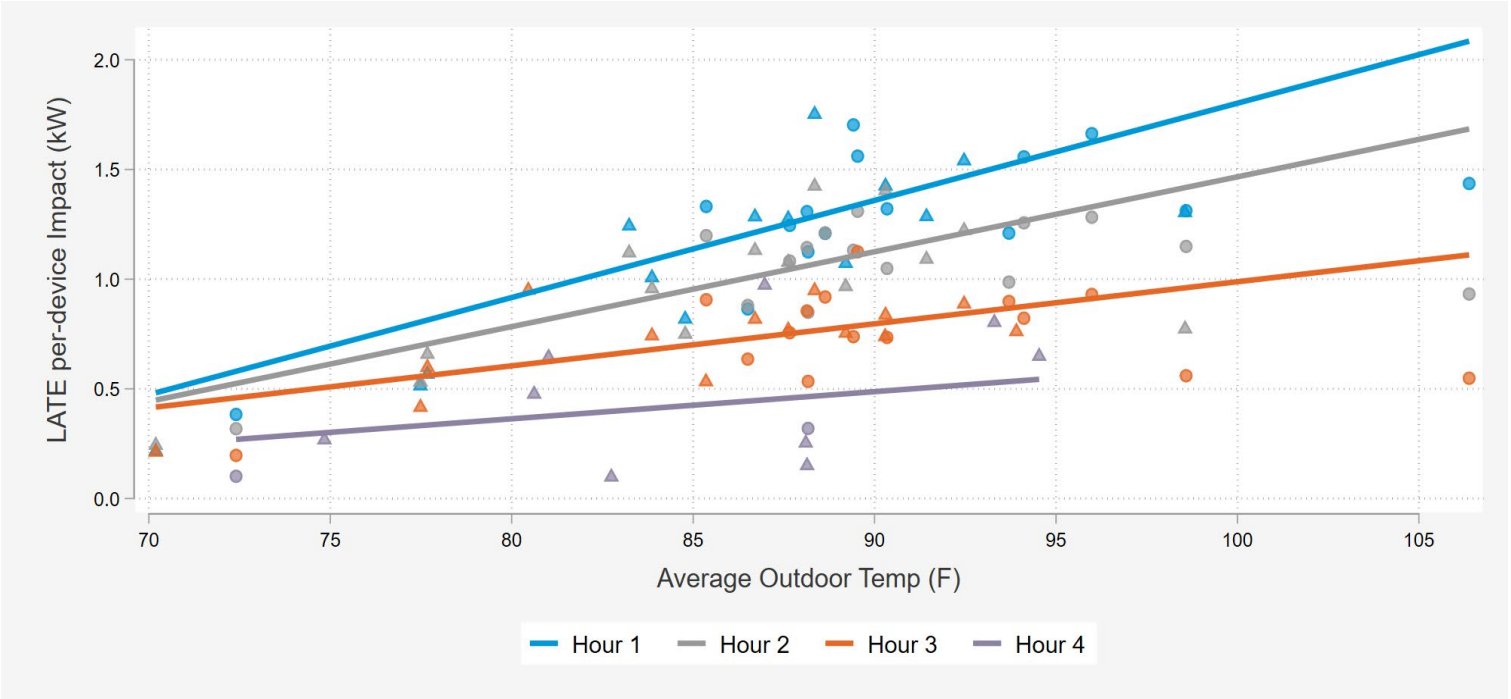
EXAMPLE EVENT RUNTIME – CALIFORNIA 2020



LATE impacts are the difference between the orange and blue lines

Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

TIME-TEMPERATURE RELATIONSHIP: SUMMER 2019 AND 2020

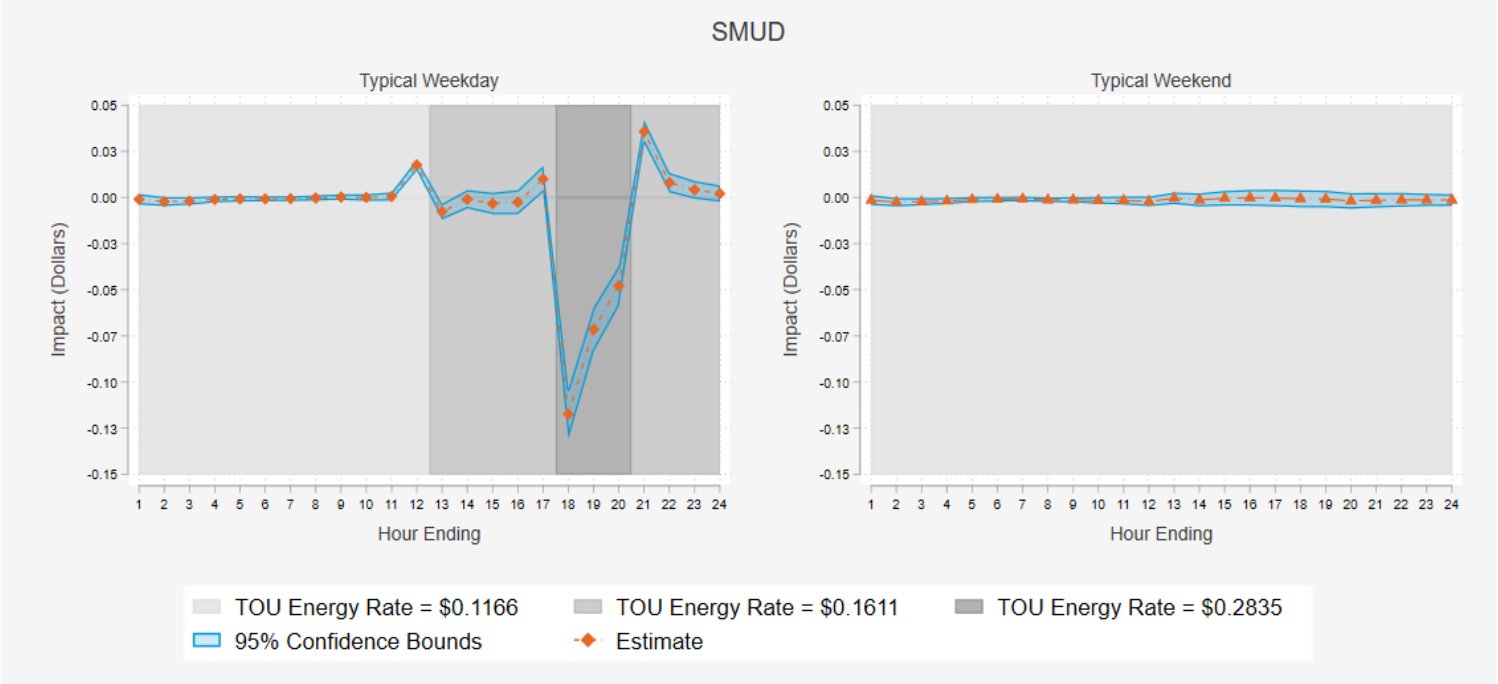


- Hour of the event is a stronger predictor than hour of the day.
- Load impacts are highest during the first event hour and fade in subsequent hours.
- Load impacts are positively correlated with outdoor air temperature.

TIME OF USE

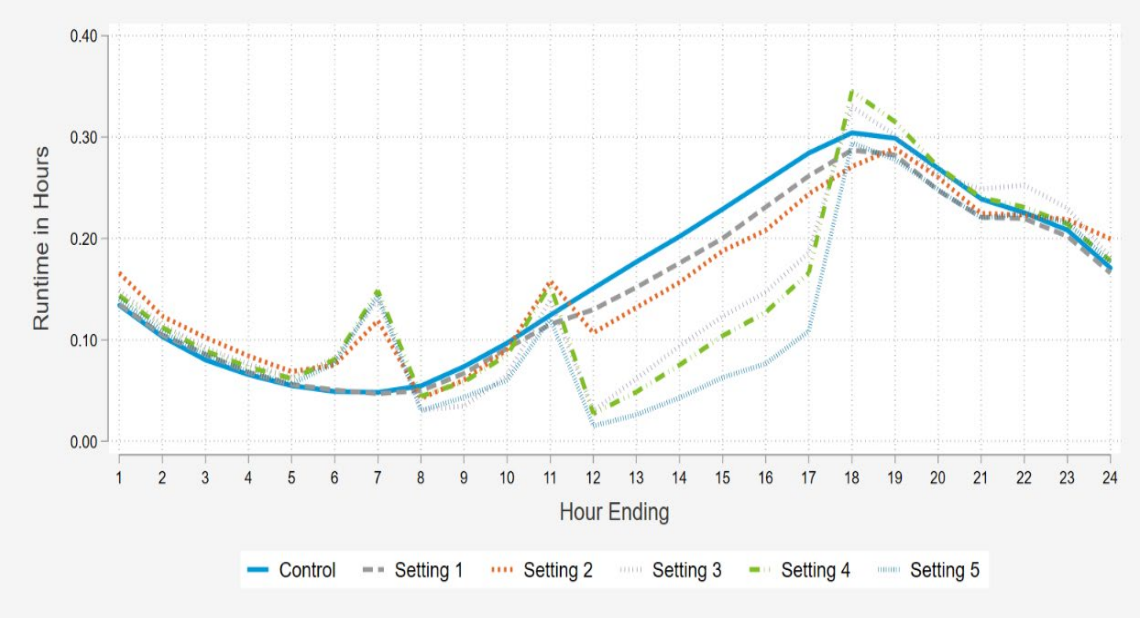
TOU FEATURE OVERVIEW

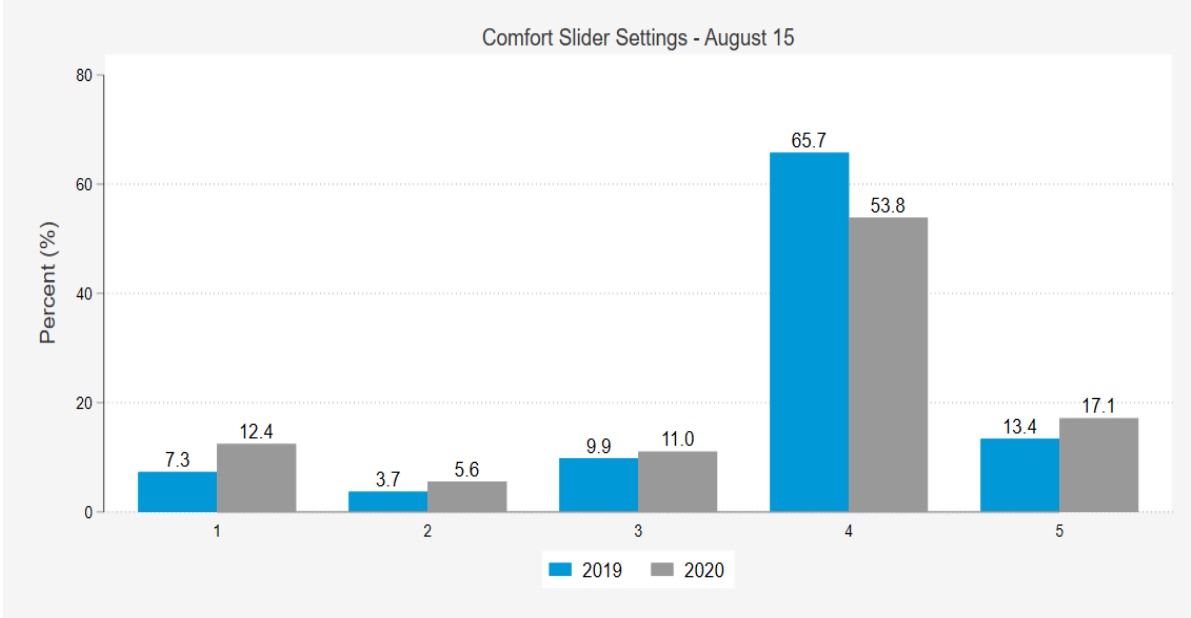
- The TOU feature modifies AC usage in response to the price signals in the participant's tariff
  - ➢ Pre-cooling during the hour before a price increase
  - ➢ Temperature setback during high price hours
- Customers receive bill savings from moving cooling load to periods when electricity is less expensive and from periods where it is more expensive



Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

TOU FEATURE OVERVIEW





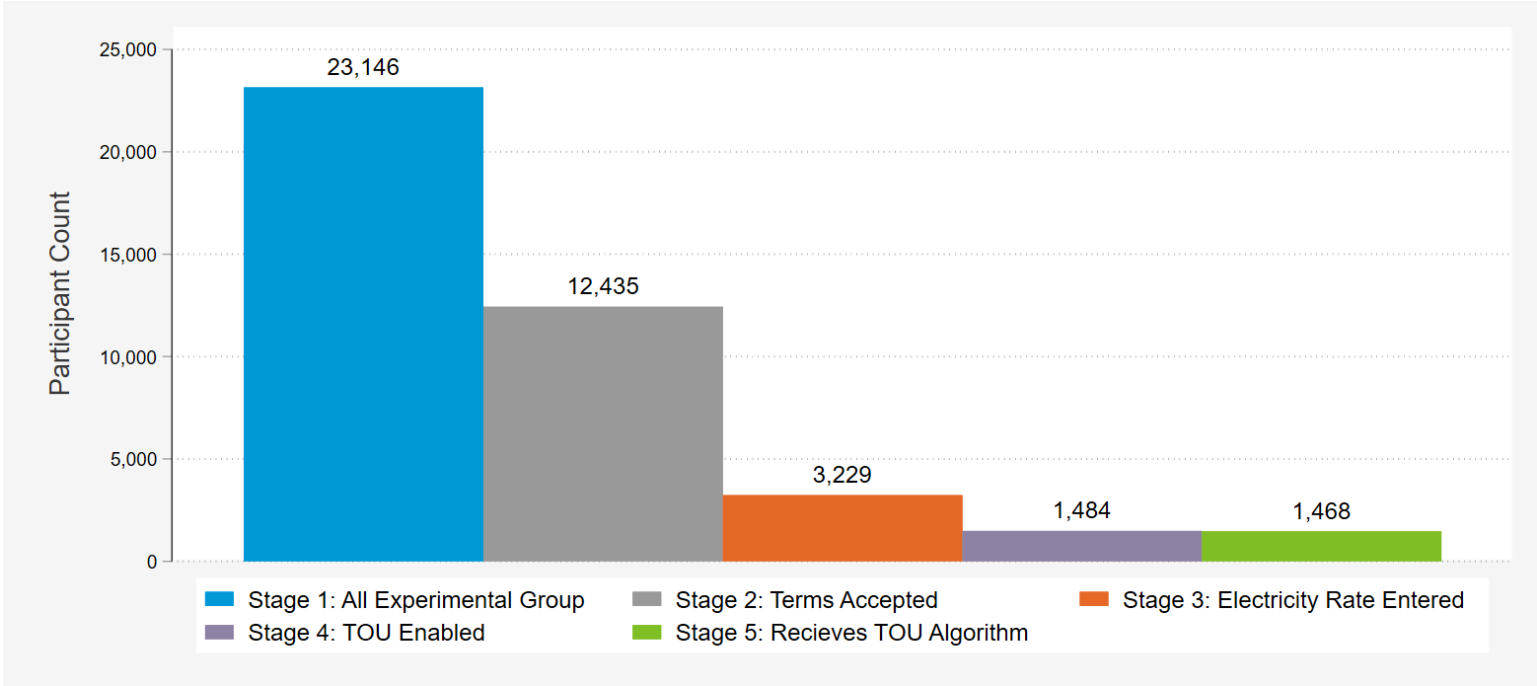
- The eco+ "slider" allows users to customize their savings and comfort preference
- Ontario summer 2019 load shapes show how the slider settings translate to AC runtime profiles
- Over time users tended to move away from the default slider level of 4

TOU ACCEPTANCE RATES MADE THE ITT ANALYSIS UNDERPOWERED

Challenges

- Not every household faces a time-varying rate, even in the target cells
- How well do customers know their tariff?
  - ➢ Opt-in versus default
- Summer 2020 focus on minimizing attrition from stage 3 to stage 4

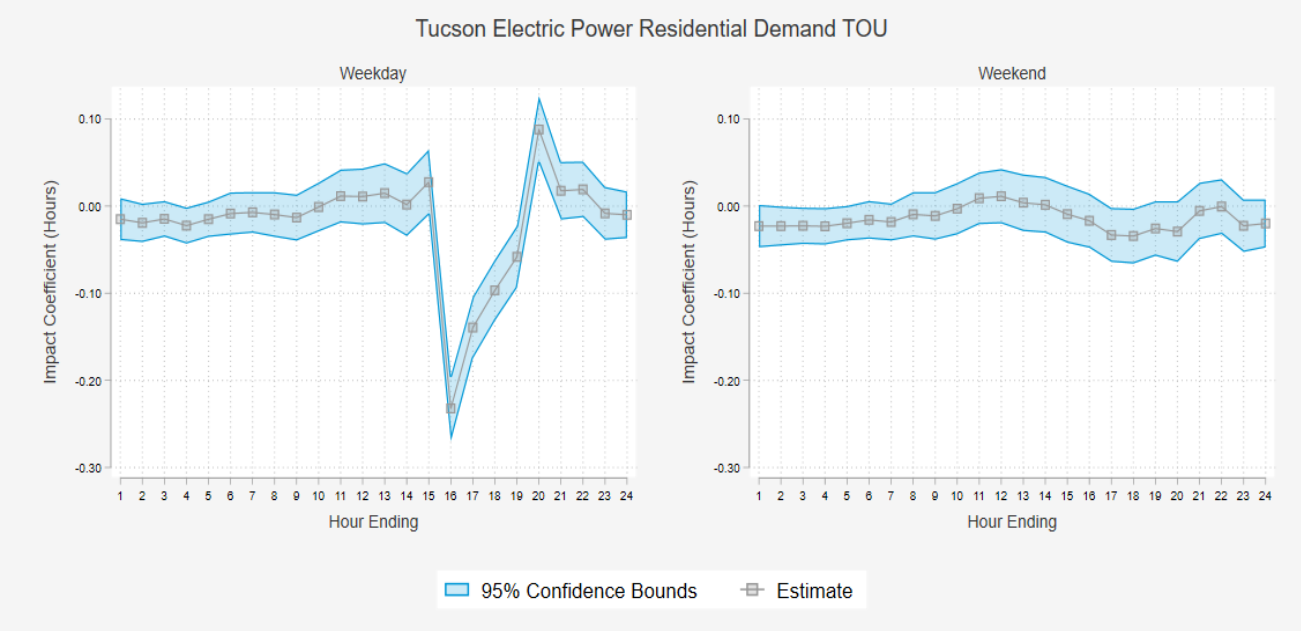
Participation Waterfall – Summer 2019



Instead of using the RED, we used a matched control group approach for the TOU analysis

Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

METHODS: DIFFERENCE-IN-DIFFERENCES PANEL REGRESSION



$$Runtime_{t,d,h} = \beta_0 + \beta_1 * Post + \beta_2 * CDH60 + \beta_3 * Relative\ Humidity + \beta_t * Treatpost$$

- **$Runtime_{t,d,h}$**: The hourly runtime for thermostat t, on a weekend vs. weekday, in hour h. Ranges from 0 to 1, where zero is no cooling runtime and 1 means the air conditioner operated for all 60 minutes of the hour.
- **β_0**: The average of the thermostat-level fixed effects. Comparable to the model intercept in ordinary least squares regression.
- **Post**: Indicator equal to 1 on or after the first eco+ invitation for a study region. Zero otherwise. The β_1 coefficient captures differences in pre and post-period for the control group.
- **CDH60**: Cooling degree hours, base 60 degrees (F). Equal to the maximum of outdoor temperature minus 60, and zero.
- **Relative Humidity**: Relative outdoor humidity for thermostat t, on date d, in hour h. Ecobee stores RH values on a scale from 0 to 100.
- **Treatpost**: Equal to 1 for the experimental group in the post-period. Zero otherwise. The coefficient β_t is our parameter of interest.

PACIFICORP RESIDENTIAL EV-TOU IMPACTS

Performance Metrics

- Bill savings of 51 cents per weekday
  - 14.7% reduction in cooling usage
  - 23.3% reduction in cooling cost
- Average demand savings of 0.43 kW over the five-hour peak window
- Average energy savings of 2.5 kWh per day
  - Almost all customers who enabled the TOU feature also enabled the EE features
  - Hard to isolate the impact of a single feature

Average Hourly Impact – Summer 2020 Weekdays

Hour Ending	Ref Run Time (Hours)	Treat Run Time (Hours)	Treat Effect (Hours)	Energy Impact (kWh)	Percent Energy Impact	Rate	Bill Impact
1	0.18	0.18	-0.01	-0.02	-3%	$0.07	$0.00
2	0.14	0.13	-0.01	-0.02	-6%	$0.07	$0.00
3	0.11	0.10	-0.01	-0.04	-12%	$0.07	$0.00
4	0.09	0.08	-0.01	-0.04	-13%	$0.07	$0.00
5	0.07	0.06	-0.01	-0.04	-19%	$0.07	$0.00
6	0.06	0.05	-0.01	-0.04	-21%	$0.07	$0.00
7	0.05	0.05	0.00	-0.01	-9%	$0.07	$0.00
8	0.05	0.05	-0.01	-0.02	-11%	$0.07	$0.00
9	0.08	0.07	-0.01	-0.03	-13%	$0.07	$0.00
10	0.12	0.10	-0.02	-0.05	-13%	$0.07	$0.00
11	0.15	0.14	-0.01	-0.05	-10%	$0.07	$0.00
12	0.19	0.17	-0.02	-0.06	-10%	$0.07	$0.00
13	0.24	0.21	-0.03	-0.10	-13%	$0.07	-$0.01
14	0.29	0.27	-0.02	-0.05	-6%	$0.07	$0.00
15	0.34	0.34	0.00	0.01	1%	$0.07	$0.00
16	0.38	0.17	-0.21	-0.65	-55%	$0.22	-$0.15
17	0.41	0.24	-0.16	-0.51	-40%	$0.22	-$0.11
18	0.43	0.30	-0.12	-0.39	-29%	$0.22	-$0.09
19	0.43	0.33	-0.11	-0.33	-24%	$0.22	-$0.07
20	0.41	0.33	-0.09	-0.28	-21%	$0.22	-$0.06
21	0.39	0.44	0.05	0.17	14%	$0.07	$0.01
22	0.36	0.38	0.02	0.05	5%	$0.07	$0.00
23	0.32	0.31	-0.01	-0.04	-4%	$0.07	$0.00
24	0.26	0.25	-0.01	-0.03	-3%	$0.07	$0.00
Total	**5.55**	**4.73**	**-0.82**	**-2.56**	**15%**		**-$0.51**

OVERALL TIME-OF-USE RESULTS

Rate	Climate Region	Peak Duration (hours)	Price Ratio	Average kW Savings During Peak Period	On-Peak Percent Savings	Overall Percent Energy Savings	Percent Savings on Cooling Energy	Daily Bill Savings
Hydro One Res TOU	Canada	6	2.0	0.18	36%	3.4%	8%	$0.09
FPL RTR-1	Hot Humid	9	5.8	0.22	13%	5.0%	10%	$0.39
PG&E EV-A	Mixed Dry	6	3.7	0.18	28%	8.8%	19%	$0.50
PG&E EV-A	Marine	6	3.7	0.10	20%	4.0%	11%	$0.23
SMUD Res TOD (2019)	Hot Dry	3	2.4	0.25	23%	3.5%	8%	$0.19
SMUD Res TOD (2020)	Hot Dry	3	2.4	0.28	21%	3.1%	7%	$0.18
Duke Energy RT	Mixed Humid	6	1.2	0.25	20%	7.7%	9%	$0.11
PacifiCorp EV-TOU	Cold	5	3.3	0.43	33%	14.7%	23%	$0.51
Tucson Electric Power Demand TOU	Dry	4	1.7	0.46	25%	6.2%	9%	$0.17

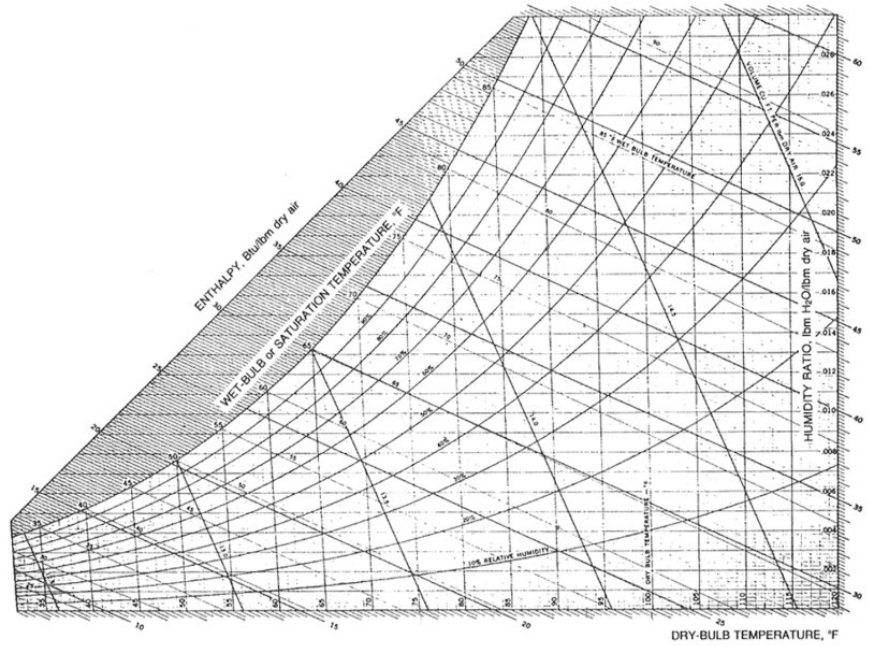
Similar results during pre-pandemic and during COVID

Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

ENERGY EFFICIENCY

ENERGY EFFICIENCY FEATURE OVERVIEW

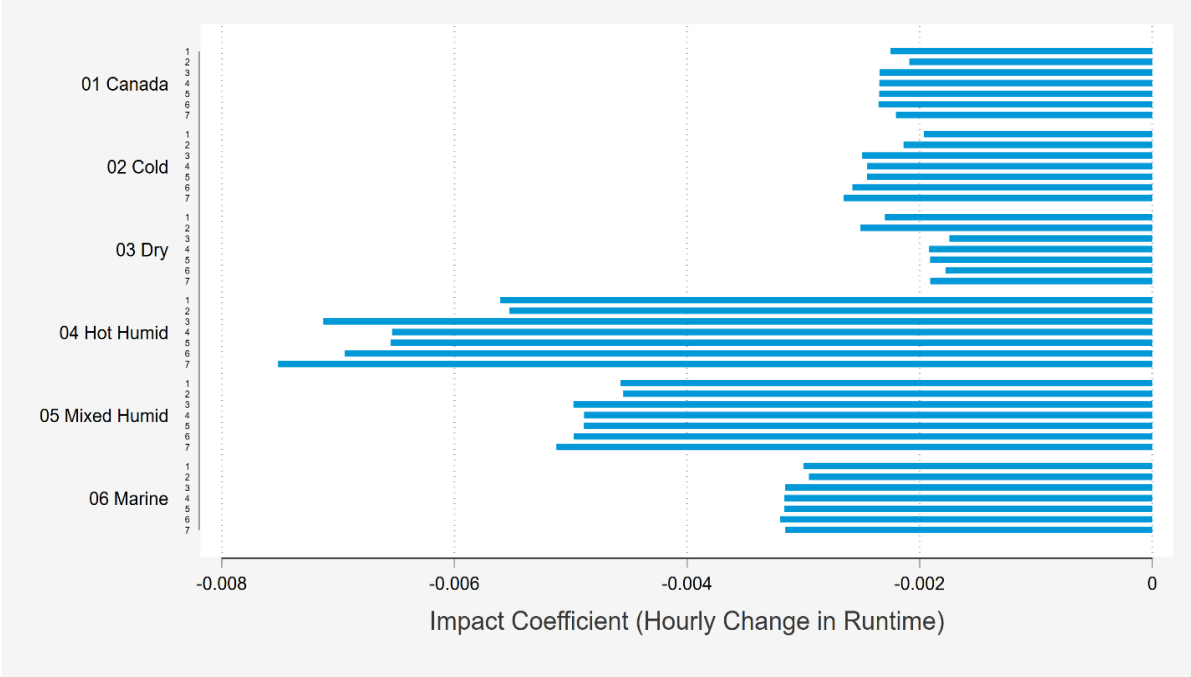
- Suite of features designed to reduce overall heating and cooling consumption
  - **Enhanced Smart Home & Away** – builds on the existing Smart Home & Away feature available to all ecobee users.
  - **Schedule Assistant** – when thermostat schedules are not matched up with users' occupancy patterns, Schedule Assistant recommends a new schedule.
  - **Adjusting for Humidity**– detects fluctuations in indoor humidity to ensure homes feel like the temperature they have set on their thermostat.
- The RED framework is designed to estimate the effect of eco+ as a bundle.



EE MODEL SELECTION

- DR event days are excluded from the EE analysis.
- EE impacts were consistent across candidate model specifications
  - Model 7 was used for reporting
- Instrumental variable regression is an alternative analysis approach for this type of R.E.D.
  - The eco+ offer is as an instrumental variable for treatment delivered
  - IV regression returns nearly identical results to the primary ITT method

Model	DID Variables	Explanatory Variables
1	post, treatpost	
2	post, treatpost	Date
3	post, treatpost	CDH60
4	post, treatpost	CDH60, Hour
5	post, treatpost	CDH60, Hour, DOW
6	post, treatpost	CDH60, Hour, DOW, CDHLast24
7	post, treatpost	CDH60, Hour, DOW, CDHLast24, RH



Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

ENERGY EFFICIENCY KWH IMPACTS (LATE)

Summer 2019

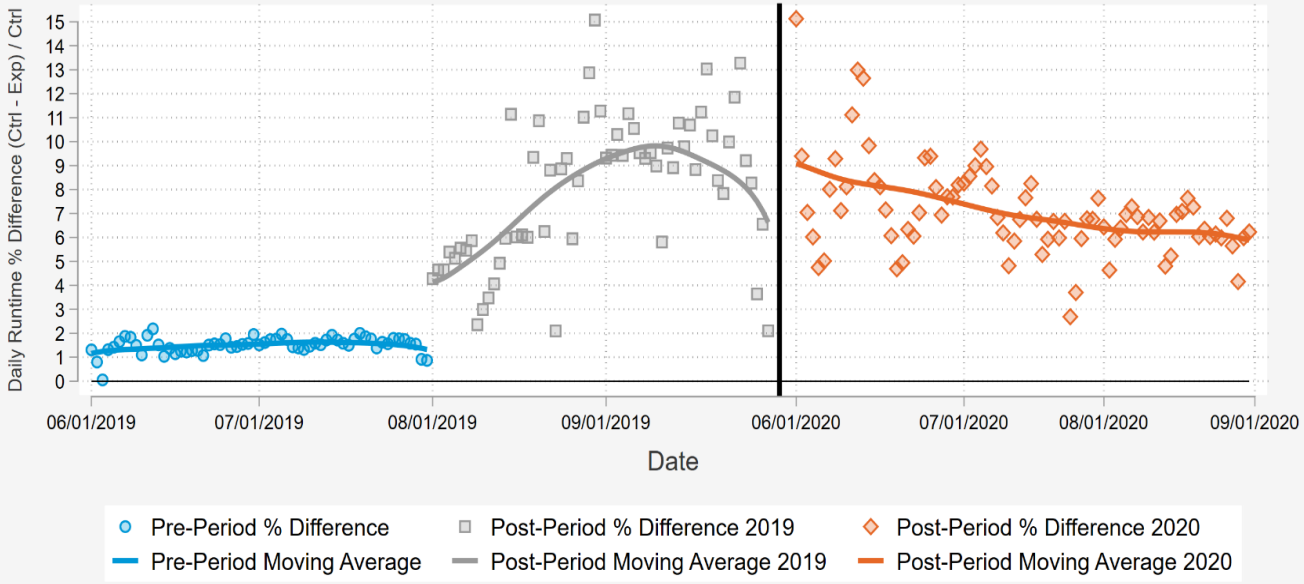
Region	August Per-Device kWh	September Per-Device kWh	Total kWh
01 Canada	19.0 ± 10.5	5.0 ± 11.8	23.9 ± 15.8
02 Cold/Very Cold	22.2 ± 7.3	16.8 ± 6.5	38.9 ± 9.8
03 Hot-Dry/Mixed-Dry	17.5 ± 16.2	10.9 ± 17.3	28.5 ± 23.7
04 Hot Humid	56.3 ± 13.7	59.5 ± 11.6	115.9 ± 18.0
05 Mixed Humid	33.9 ± 7.1	33.3 ± 6.7	67.2 ± 9.8
06 Marine	26.6 ± 14.6	15.0 ± 10.4	41.6 ± 17.9

Summer 2020

Region	June Per-Device kWh	July Per-Device kWh	August Per-Device kWh	Total kWh
01 Canada	13.2 ± 10.4	29.9 ± 15.1	16.1 ± 12.7	59.2 ± 22.3
02 Cold/Very Cold	16.1 ± 6.3	28.8 ± 8.7	19.8 ± 7.7	64.8 ± 13.2
03 Hot-Dry/Mixed-Dry	21.7 ± 9.8	36.3 ± 11.7	39.0 ± 12.9	96.9 ± 20.0
04 Hot Humid	41.4 ± 14.2	38.4 ± 15.8	31.2 ± 16.2	111.0 ± 26.7
05 Mixed Humid	21.5 ± 7.6	31.3 ± 9.3	21.4 ± 8.5	74.2 ± 14.7
06 Marine	16.0 ± 7.5	16.9 ± 8.6	22.4 ± 11.2	55.3 ± 16.0

ENERGY EFFICIENCY PERCENT IMPACTS (LATE)

- Effect appears when treatment began and held up over two summers
- All measurement is done on an ITT basis
- LATE impacts a function of the definition of "treated"
  - A conservative definition of treated means a low acceptance rate and higher LATE impacts
  - A looser definition of treated means a higher acceptance rate and lower LATE impacts



Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

A WORD OF CAUTION ABOUT PERCENT IMPACTS..

- This study found the largest energy savings in regions with the warmest weather and largest air conditioning consumption.
- However, hotter regions showed the smallest *percent* impacts.

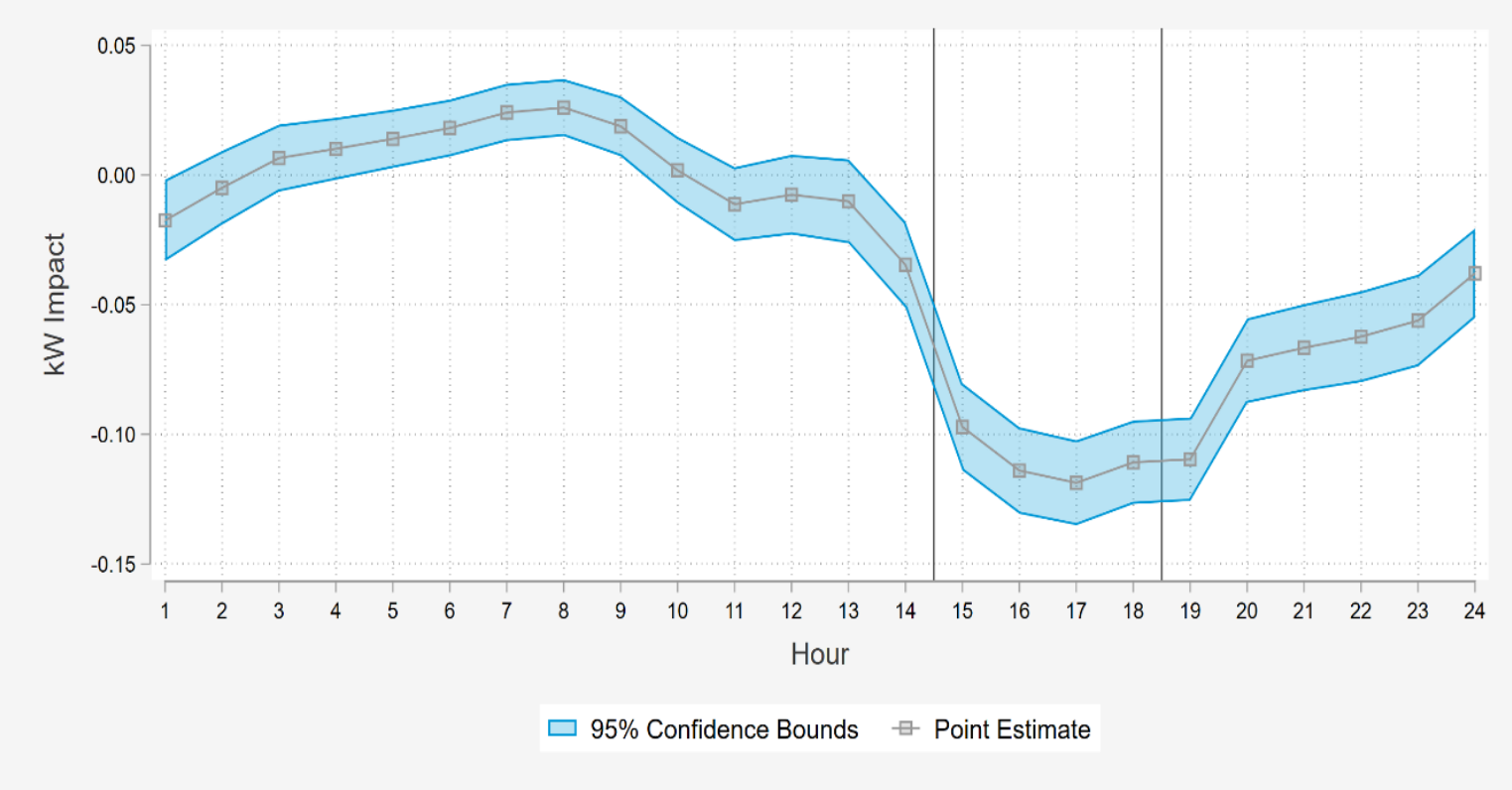
Region	June Percent Savings	July Percent Savings	August Percent Savings
01 Canada	4.8%	6.0%	4.5%
02 Cold	3.8%	4.2%	3.6%
03 Dry	4.8%	6.1%	5.7%
04 Hot Humid	4.6%	3.5%	2.8%
05 Mixed Humid	3.9%	3.8%	3.2%
06 Marine	12.1%	10.4%	8.7%

- AC runtime as an approximately linear function of the temperature differential between outdoor temperature and setpoint (Delta T).
- Raising the setpoint by one degree reduces the differential by one degree and creates the corresponding reduction in runtime.
- In extreme conditions, the vast majority of cooling energy is still required.

Outdoor Temp (F)	Original Setpoint (F)	Original Delta T	New Setpoint (F)	New Delta T	Percent Change
100	70	30	71	29	3.33%
80	70	10	71	9	10%

TIME-DIFFERENTIATED IMPACTS

Mixed Humid Hourly kW Impacts from EE



Takeaways

- 0.05 to 0.1 kW of peak demand reduction from the EE algorithm
  - Useful data point for TRM development
- This actually works against DR slightly
  - EE features lower the DR baseline
  - Non-issue if the "credit" is given for peak demand reductions from E

Demand Side Analytics
DATA DRIVEN RESEARCH AND INSIGHTS

QUESTIONS?

Jesse Smith
Partner & Principal Consultant
Demand Side Analytics, LLC
jsmith@demandsideanalytics.com
770.401.9018