Northwest Smart Thermostat Research Project

Presentation to MI EWR Collaborative

Lauren Gage and Jon Koliner

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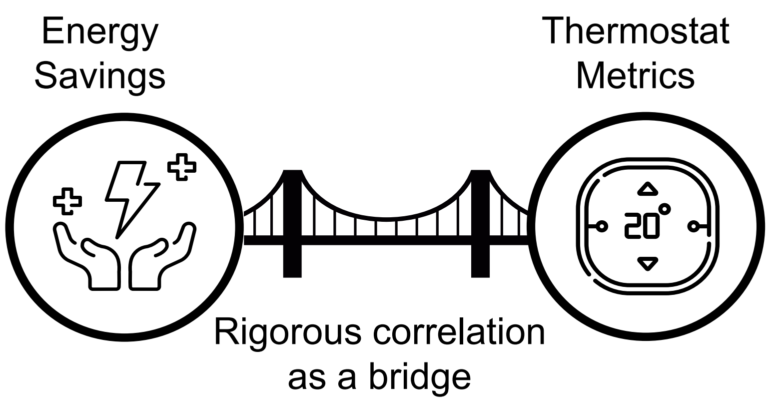
Design

Study Background

Commissioned Study: Regional study, co-funded by 10 regional utilities and organizations, managed and facilitated by NEEA.

Primary Study Objective: To develop a method to estimate energy savings for Smart Thermostats based on correlations with thermostat performance metrics.

Future Goal: Northwest utilities to quickly screen new products for inclusion in Qualified Products Lists and estimate energy savings from thermostat performance metrics without repeated one-off evaluations.



Team:

Apex Analytics
CLEAResult
Energy350
Empower Dataworks

https://neea.org/resources/northwest-smart-thermostat-research-study

Tamara Anderson: tanderson@neea.org

Key Steps in the Study

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Enroll Manufacturers and Opt-In Thermostat Users

Recruiting, legal agreements, requirements for opt-in, opt-in survey.

Collect Utility and Manufacturer Data

Manufacturers run Northwest Field Savings software and shared thermostat data for opt-ins. Utilities provide billing data for opt-ins.

Telemetry Analysis and Software Modification

Modify and test Northwest version of ENERGY STAR Thermostat Field Savings software.

Billing Analysis

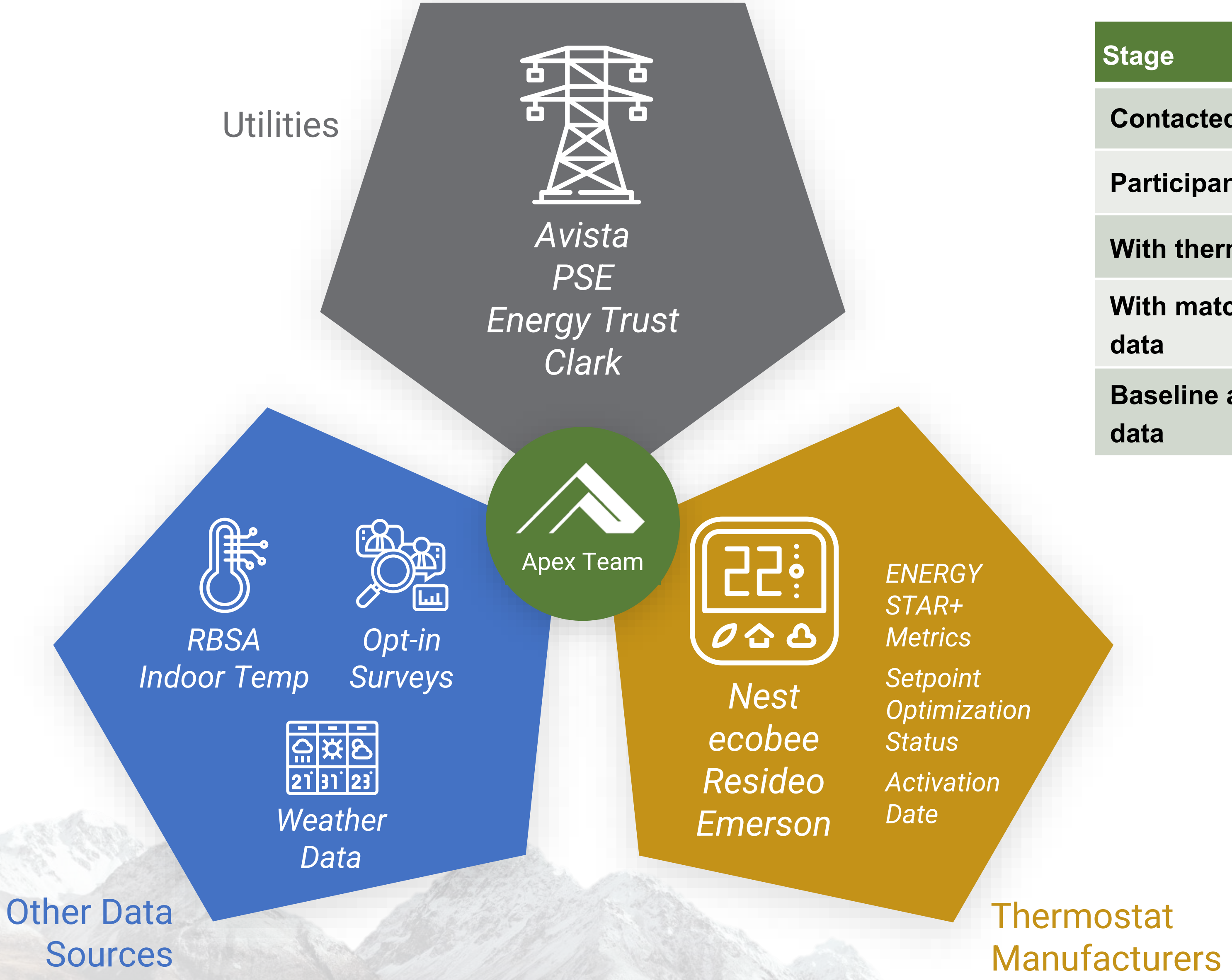
Pooled and site-level consumption analyses to determine energy savings.

Correlate Metrics and Savings

Correlation of energy savings with thermostat performance metrics.

Throughout, we coordinated with advisory team members, manufacturers and ENERGY STAR.

Data Collection



Stage	Total	Ecobee	Emerson	Nest	Resideo
Contacted/Emailed	50,072				
Participants in study	3,943	1,641	587	1,177	538
With thermostat data	3,367	1,641	95	1,106	525
With match to billing data	1,452	247	61	747	397
Baseline and reporting data	1,166	194	58	576	338

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Key Findings

Key Findings

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Smart thermostat installation resulted in statistically significant energy savings.

Major home and life changes occurring in a similar timeframe to thermostat installation impact energy savings substantially.
(EVs, renovations, occupancy, HVAC upgrades)

Energy savings were not strongly correlated with any performance metrics.

- Lack of correlation persisted across performance metrics, including new metrics with regional baselines and was not dependent on thermostat models.
- Therefore, the study team could not establish a method to estimate energy savings from performance metrics.

Primary Study Goal

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Smart Thermostat Installation Resulted in Statistically Significant Energy Savings

Thermostats Save Energy: Pooled Analysis

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Using pooled analysis, study found energy savings of approximately 5% for gas furnaces and heat pumps with electric backup.

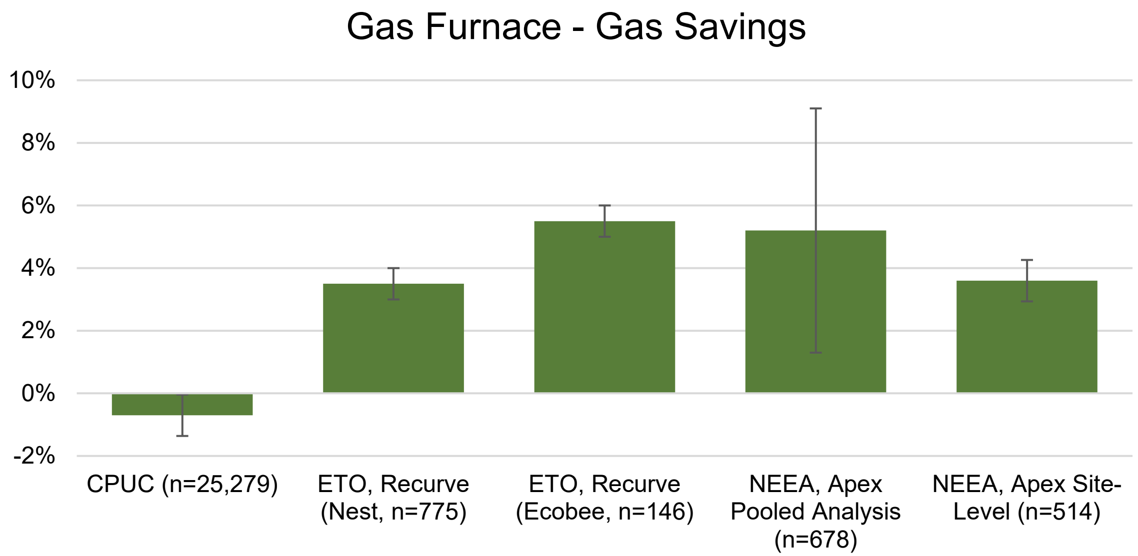
Pooled analysis:

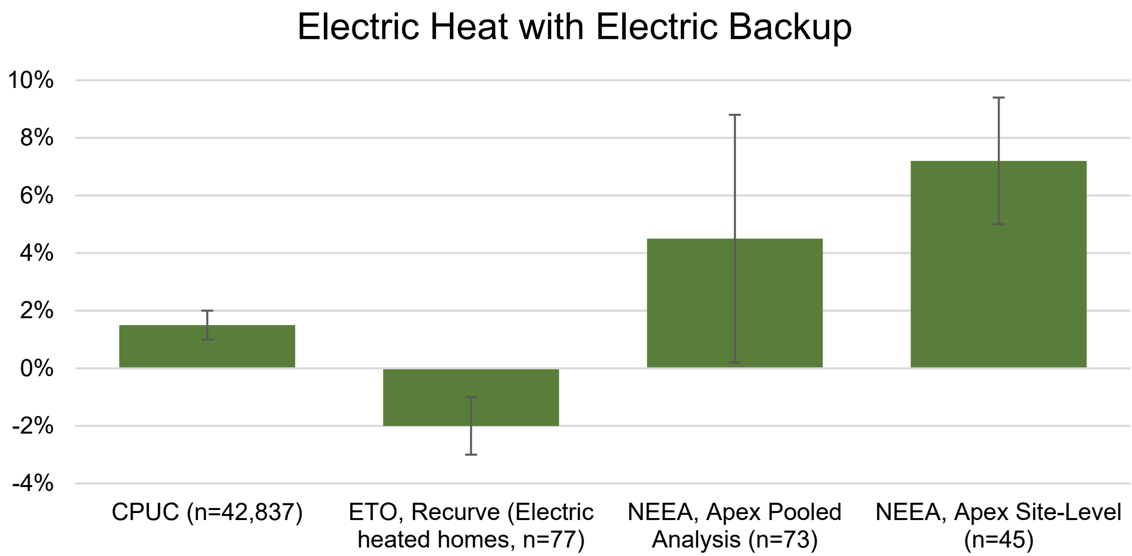
- Controlled for setpoint optimization (eco+, Connected Savings)
- No significant fan savings for gas furnaces

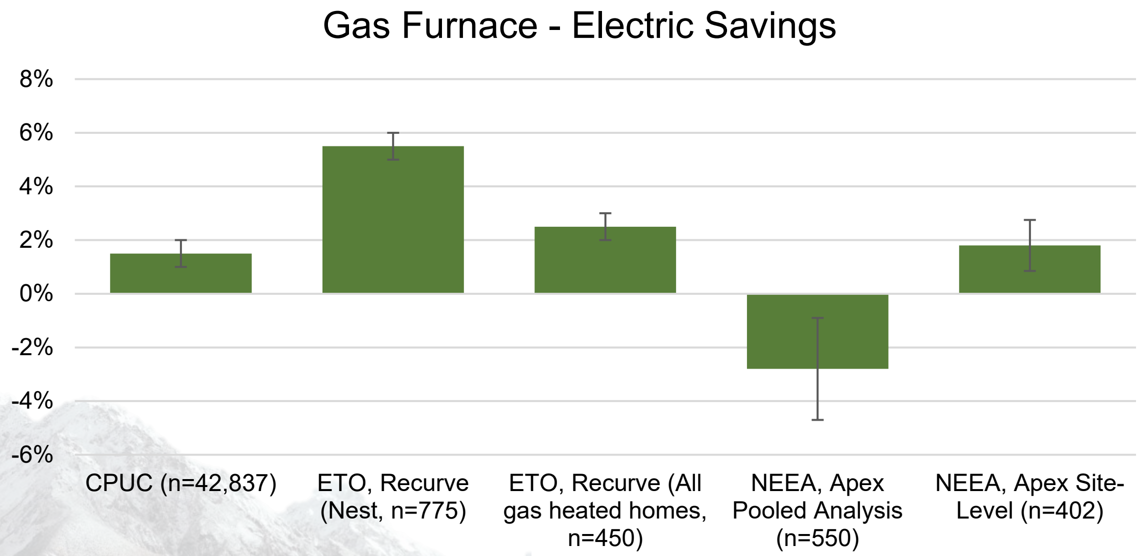
Heating System Type	Fuel	n	Post-installation			Additional Estimated Savings during Optimization*
			Average Savings	Std Error of Avg Savings	Percent Savings	
Gas Furnace or Boiler	Electricity	550	-220 kWh	110 kWh	-2.4%	2.8%*
	Gas	678	43 therms	20 therms	5%	6.3%*
Heat Pump with Electric Backup	Electricity	73	670 kWh	402 kWh	4.5%	1.9%*
	Gas	*23*	*-34 therms*	*54 therms*	*-5.1%*	*-28.8%*
Electric Furnace or Boiler	*Electricity*	*25*	*760 kWh*	*789 kWh*	*5%*	*-2.3%*
Heat Pump with non-Electric Backup	*Electricity*	*5*	*1477 kWh*	*1257 kWh*	*10%*	*NA*

Thermostats Save Energy: Comparison to Other Studies

Study found similar energy savings results to other regional studies.







Billing Analysis Discussion

- **Finding:**
  - Smart thermostat installation results in comparable primary fuel use reduction to other regional studies.
- **Caveats:**
  - Study’s primary goal was correlation of thermostat metrics; sampling was based on this.
  - Therefore, billing analysis was a convenience sample and therefore is potentially biased (i.e., not a definitive analysis of thermostat energy savings in the NW)
- **Other Findings** (under those caveats):
  - Optimization appears to contribute to additional savings of similar magnitude to installation (2-6%)
  - Onboard occupancy sensing feature may explain all of the remaining observed savings but due to caveats and reduced cell sizes, this result is not definitive

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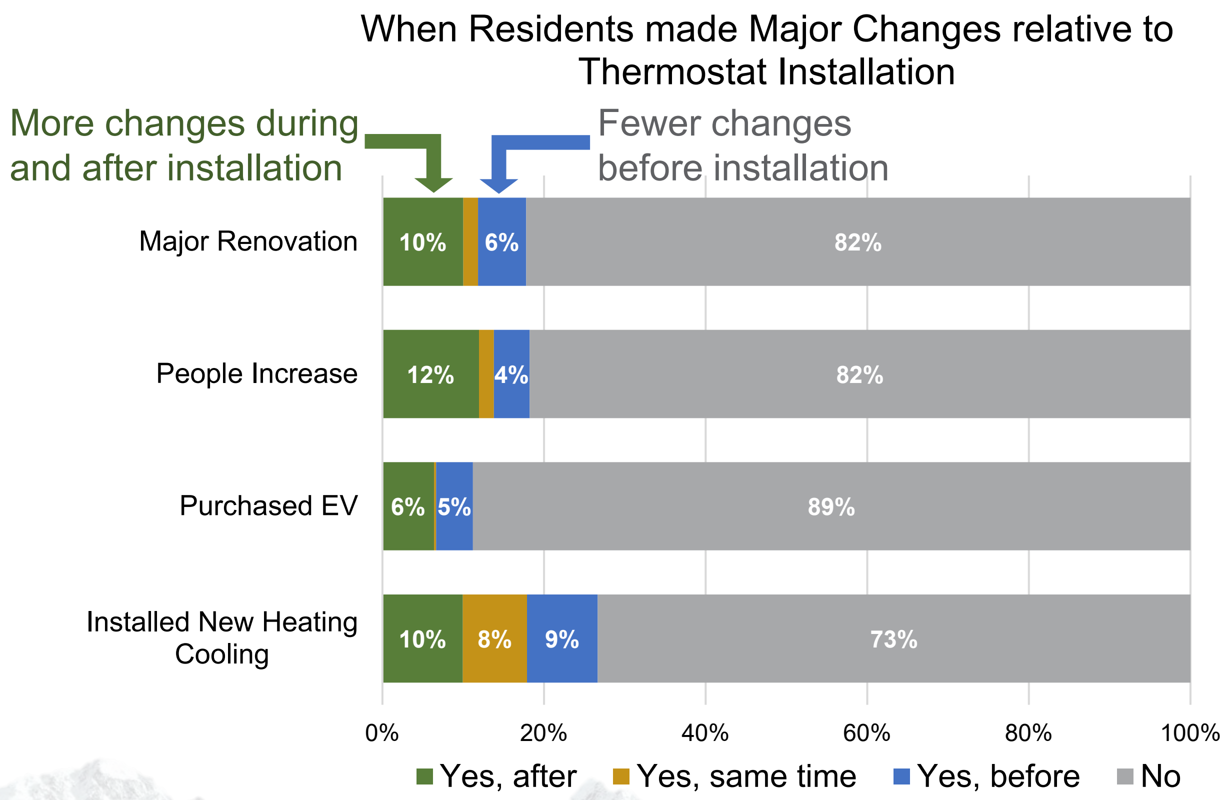
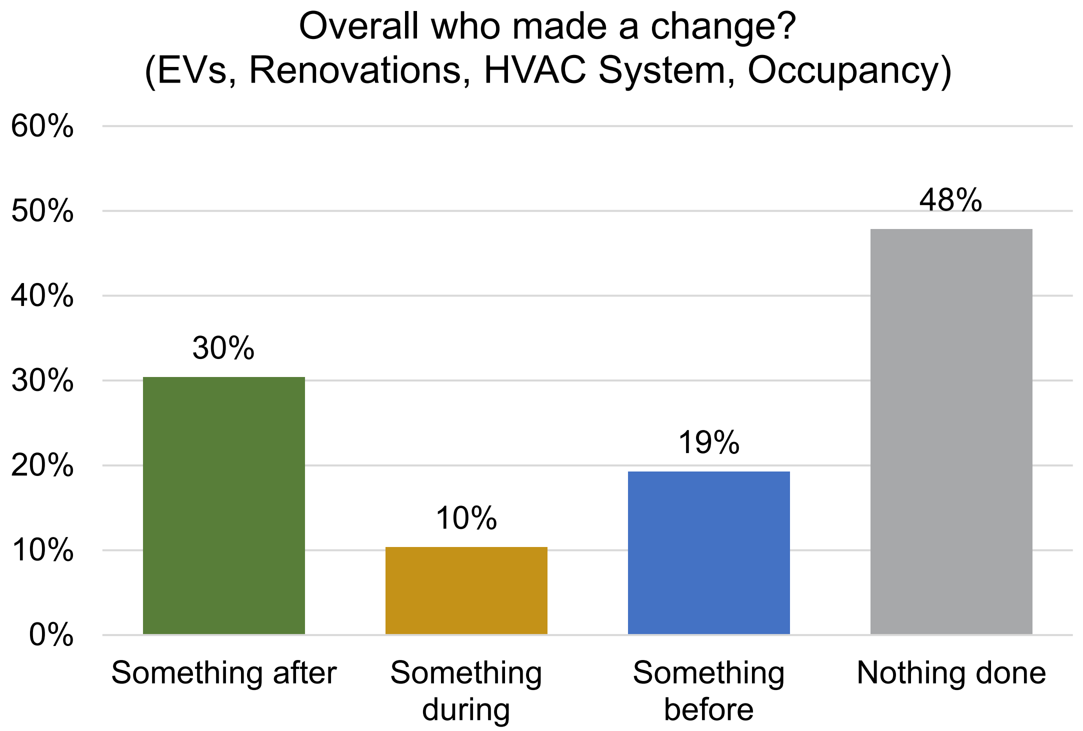
Major Home and Life Changes Impact Energy Savings Substantially

Major changes impact energy savings: Installation Timing

People tend to install thermostats before other major energy-changing behaviors (e.g., purchasing EVs, home renovations, occupancy changes, HVAC upgrades).

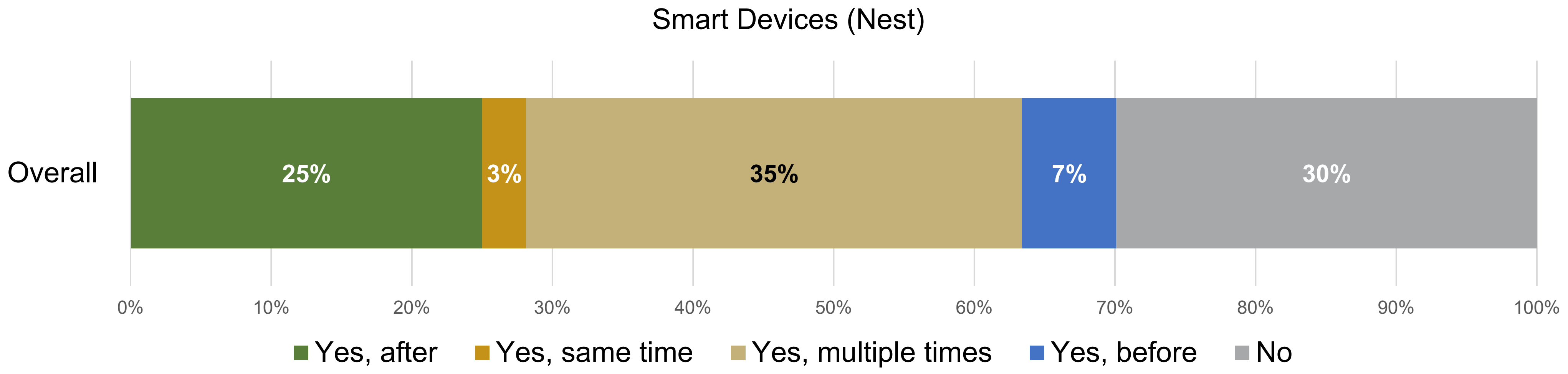




Sums to >100% due to multiple choices allowed

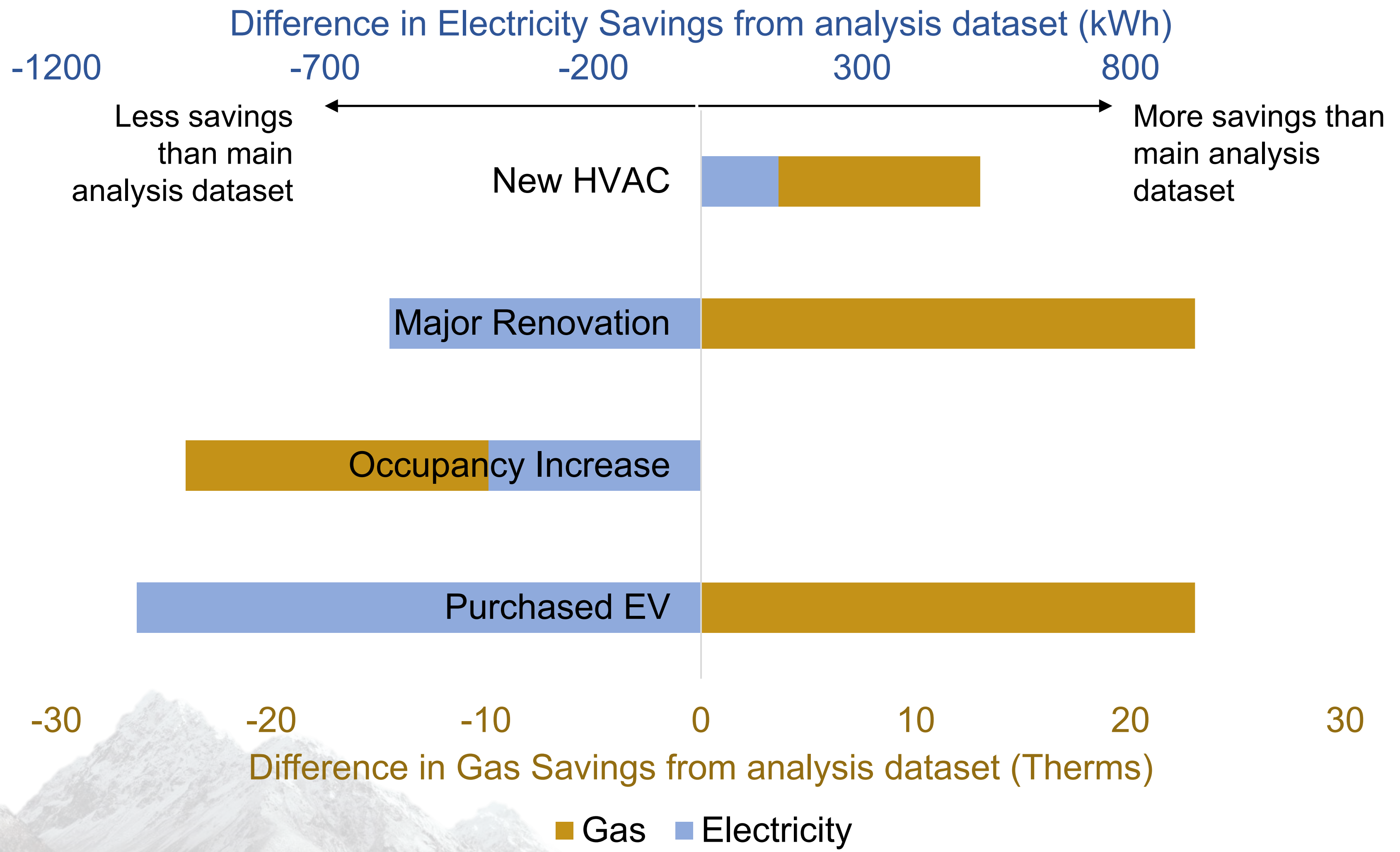
Major changes impact energy savings: Installation Timing Bonus Slide

People tend to install Nest thermostats before installing other smart devices



Major changes impact energy savings: Gas Furnace Site-Level Savings

Energy impacts of major changes are comparable to or larger than thermostat energy savings.



Major changes impact energy savings: Billing Analysis Considerations

Important to control for these major life changes to establish accurate energy savings for smart thermostats.

- Other energy use changes are large compared to thermostat installation and relatively prevalent
- Time asymmetry means both quasi-experimental and future comparison groups may bias towards reporting low savings

Surveys or other method should be used to detect major energy use changes.

Energy Savings are Uncorrelated with Performance Metrics

Performance metrics

Study modified the ENERGY STAR® software to calculate new metrics.

Calculated metrics included:

- All ENERGY STAR metrics
- Runtime difference from regional baseline
- Temperature gradients with and without HVAC
- Excess resistance score
- Additional resistance heat metrics for heat pumps
- Runtime to indoor-outdoor temperature difference model

Energy savings were not strongly correlated with any performance metrics

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- Study tested whether we could predict adjusted site-level savings using thermostat metrics.
- Study did not find strong correlation of any of these metrics with energy savings, across performance metrics and with inclusion of additional site level information.

Due to lack of strong correlation, the study team could not establish a method to estimate energy savings from performance metrics.

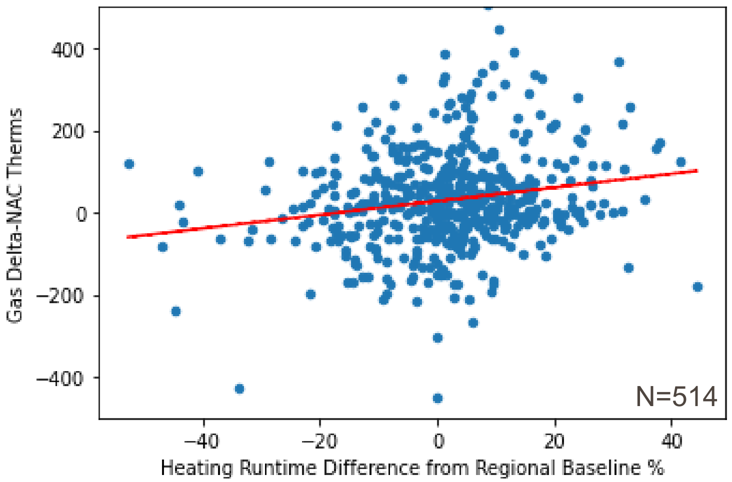
Primary variables *(Used in all tested models)*	**Secondary variables *(Used in some tested models)***
Runtime difference from comfort baseline Runtime difference from regional baseline For heating and cooling	HVAC and no-HVAC temperature gradients Integral of sigmoid resistance function Excess resistance score DNRU reduction

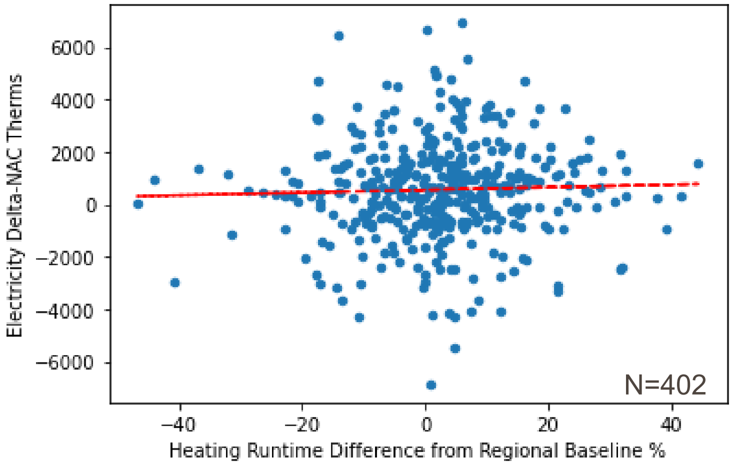
Thermostat Metrics and Billing Analysis Correlation

For **gas furnaces**, raw correlation between thermostat metrics and savings is very weak for gas and insignificant for electricity

Out of Sample Bias Error for Savings (95% confidence interval):
+/-65% (gas), **+/-600%** (electricity)

Leave-One-Out by manufacturer: **+/-80%** (gas)





Thermostat Metrics and Billing Analysis Correlation

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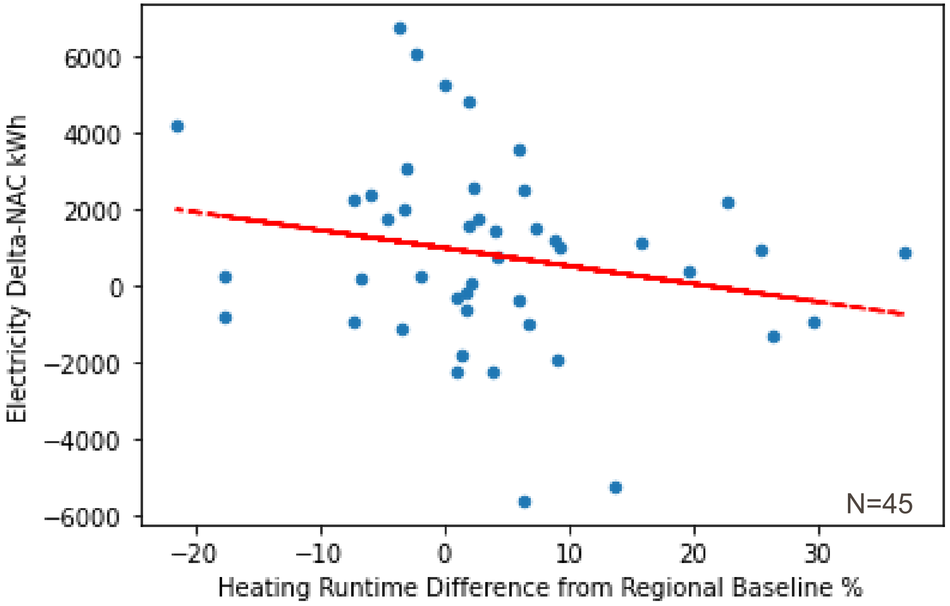
Raw correlation between thermostat metrics and savings is insignificant for **heat pumps**

Out of Sample Bias Error for Savings (95% confidence interval): **+/-105%** (electricity)



Possible Reasons for Lack of Correlation

Thermostat Metrics Don’t have Site-Specific Baseline

- Ideal method would use runtime and indoor temperature for both pre- and post-installation periods by site and correlate to energy usage changes.
- Thermostat telemetry metrics have only post-installation data.
- Neither baseline (regional baseline and ENERGY STAR site-specific baseline) correlated with site-specific savings.
- Key issue: it’s apples to oranges: we’re comparing people’s energy use to post-installation thermostat metrics vs artificial baseline (i.e., regional average or site-specific comfort temperature).

Thermostat metrics are noisy

- Hourly-level telemetry data has a low signal-to-noise ratio.

Future Research Considerations: Correlations

Performance Metrics Opportunities

- There is potential to use some of the additional metrics related to building shell and HVAC performance for behavioral messaging or HVAC diagnostics by EE programs.

Future Design Considerations

- Metrics generated from thermostat data alone are not a recommended avenue for determining overall or make/model specific energy savings.
  - Although study sample was smaller than originally hoped, NEEA advisory team agreed that the results were sufficiently reliable and that a larger sample would be very unlikely to change the outcome.
- If organizations want to correlate thermostat metrics and energy savings in the future, entities will need legal and technical infrastructure with each thermostat manufacturer. Future designs could gain customer and manufacturer agreements on program front-end.

Manufacturer Feedback

- Generally, manufacturers (and ENERGY STAR) accepted the results, although one manufacturer stressed that the pooled analysis results come from a convenience sample.
- Multiple manufacturers expressed a desire to understand how this impacts Qualified Product Lists, and want to come to an expeditious solution.

Thank you!

For more information, contact:

Lauren Gage (laureng@apexanalyticsllc.com)

Jon Koliner (jonk@apexanalyticsllc.com)

Appendix

Metric: Excess Resistance Score

Use model coefficients from the Delta-T runtime regression β_comp, β_res that capture relative magnitude of compressor and resistance output rates. Define thermal output variables based on run-time data and the fitted model parameters.

$$Res_{d,h}^{output} = \beta_{res} \cdot \left(RT_{d,h}^{aux} + RT_{d,h}^{emer}\right)$$

$$Comp_{d,h}^{output} = \beta_{comp} \cdot \left(1 - \rho \cdot \left(47 - T_{d,h}^{out}\right)\right) \cdot \left(RT_{d,h}^{comp} + RT_{d,h}^{aux}\right)$$

$$Comp_{d,h}^{available} = \beta_{comp} \cdot \left(1 - \rho \cdot \left(47 - T_{d,h}^{out}\right)\right) \cdot \left(60 - RT_{d,h}^{comp} - RT_{d,h}^{aux}\right)$$

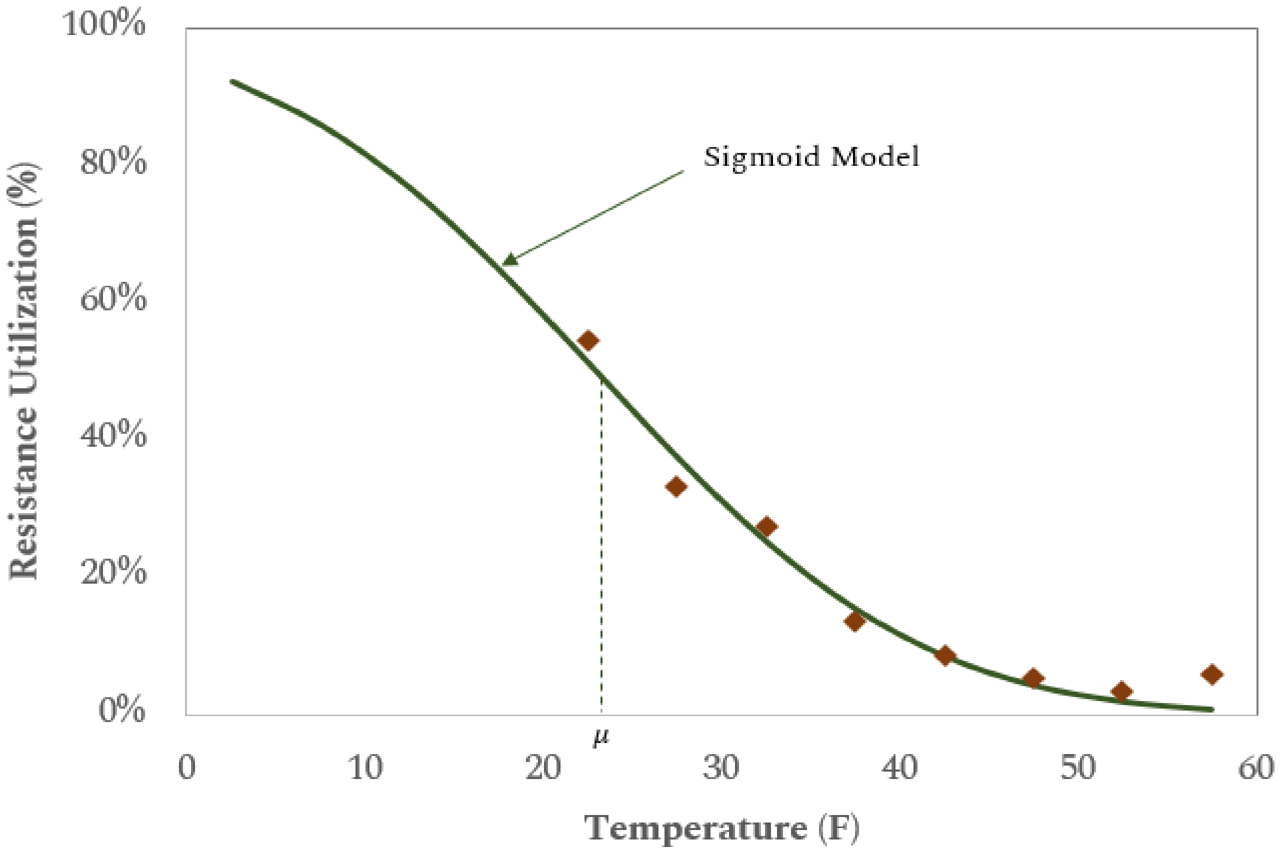
$$Res_{d,h}^{excess,2} = \text{minimum}\left(Res_{d,h}^{output} + Res_{d,h-1}^{output},\ \ Comp_{d,h}^{available} + Comp_{d,h-1}^{available}\right)/2$$

$$Res^{excess,2} = \frac{\sum_{d,h} Res_{d,h}^{excess,2}}{\sum_{d,h}\left(Res_{d,h}^{output} + Comp_{d,h}^{output}\right)}$$

Metric: Sigmoid Model

- Fit a sigmoid model to binned resistance utilization

$$RU_{bin} = \frac{1}{2} \times \left(1 - \mathrm{erf}\left(\frac{TBM_{bin} - \mu}{\sigma \times \sqrt{2}}\right)\right)$$



Correlation Detail: Gas Furnaces

Model	fuel	Intercept	Intercept_stderr	Coefficient	Std. Error	Adj. R-squared	xv_cvrmse_mean	xv_cvrmse_std	xv_nmbe_mean	xv_nmbe_std
DNAC ~ percent_savings_estar_heating	Electricity	485	294	12.63	25.48	-0.003	300%	60%	4%	26%
DNAC ~ percent_savings_regional_heating	Electricity	615	116	7.13	8.77	-0.001	351%	94%	21%	28%
DNAC ~ percent_savings_estar_heating	Gas	-7	17	1.91	1.47	0.002	441%	1743%	-51%	231%
DNAC ~ percent_savings_regional_heating	Gas	13	6	1.63	0.46	0.036	2037%	2644%	131%	325%