ENERGY STAR Connected Thermostats

Stakeholder Working Meeting

March 23, 2018
# Attendees

<table>
<thead>
<tr>
<th>Attendee Name</th>
<th>Company/Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abigail Daken</td>
<td>EPA</td>
</tr>
<tr>
<td>Dan Baldewicz</td>
<td>ICF for EPA</td>
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<tr>
<td>John Clinger</td>
<td>ICF for EPA</td>
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<tr>
<td>Alan Meier</td>
<td>LBNL</td>
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<td>Leo Rainer</td>
<td>LBNL</td>
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<tr>
<td>Michael Blasnik</td>
<td>Nest Labs</td>
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<tr>
<td>Jing Li</td>
<td>Carrier</td>
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<td>Frank David</td>
<td>Carrier</td>
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<tr>
<td>Tai Tran</td>
<td>Carrier</td>
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<tr>
<td>Ray Rite</td>
<td>IRCO</td>
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<tr>
<td>Brian Rigg</td>
<td>JCI</td>
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<tr>
<td>Theresa Gillette</td>
<td>JCI</td>
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<tr>
<td>Shawn Hern</td>
<td>JCI</td>
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<tr>
<td>Diane Jakobs</td>
<td>Rheem</td>
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<tr>
<td>Carson Burrus</td>
<td>Rheem</td>
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<tr>
<td>Chris Puranen</td>
<td>Rheem</td>
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<tr>
<td>Ethan Rogers</td>
<td>ACEEE</td>
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<tr>
<td>Ulysses Grundler</td>
<td>EcoFactor</td>
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<tr>
<td>Brent Huchuk</td>
<td>ecobee</td>
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<tr>
<td>John Sartain</td>
<td>Emerson</td>
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<tr>
<td>Michael Siemann</td>
<td>WhiskerLabs</td>
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<td>Kurt Mease</td>
<td>Lux Products</td>
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<td>Steve Lazar</td>
<td>Lennox</td>
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<td>Nguyen Ho</td>
<td>Lennox</td>
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<td>David Bourbon</td>
<td>Mitsubishi Electric</td>
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<tr>
<td>Mike Lubliner</td>
<td>Washington State U</td>
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<td>Alex Bosenberg</td>
<td>NEMA</td>
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<td>Charles Kim</td>
<td>SCE</td>
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<td>Michael Fournier</td>
<td>Hydro Quebec</td>
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<tr>
<td>Ed Pike</td>
<td>Energy Solutions for CA IOUs</td>
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<tr>
<td>Ethan Goldman</td>
<td>VEIC</td>
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<tr>
<td>Rober Weber</td>
<td>BPA</td>
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<tr>
<td>Phillip Kelsven</td>
<td>BPA</td>
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Agenda

• Software Development

• Status updates

• Review of Resistance Heating Utilization (RHU) results
Software Development

• Meet Intellovations,
  – Eric Floehr, Founder
  – Craig Maloney, Developer

• New developer for the ENERGY STAR Connected Thermostat Software

• Upcoming Software Improvements
  – Error Handling
  – Speed/Efficiency Improvements
Software Release Framework

• **Bugfix Release**: repair minor issues (X,X,X+1): Software -> 1.1.3
  – No changes to certification data
  – Minimal stakeholder testing needed (Developer + Automated tests)

• **Feature Release**: add procedures/features (X,X + 1,X): Software -> 1.2.1
  – No changes to certification data
  – After Stakeholder testing, set as current software.

• **Major Release**: changes certification data/core calculations (X + 1, X, X): Software -> 2.0.0
  – Changes certification data, core thermostat calculations.
  – Should go live in conjunction with major specification changes, with specification development process and transition period between finalization and effective date (usually about 9 months).
  – Stakeholder involvement/metrics calls, testing, results discussion.
Software Discussion

- Can we revisit the requirement for using a particular sorting algorithm?
  - Causes a bunch of problems for some Partners
  - The goal in specifying a specific sorting algorithm was to enhance reproducibility
  - Can we use a sort that’s available in one of the other modules we use?
  - Maybe, let’s discuss offline
- Improvements to RHU meaningfulness tabled for later in call
Status Updates - Specification

- Certifications
  - 23 products
  - 7 brands
  - Several other potential partners

- Utility program reliance on ENERGY STAR continues to grow – now including utilities serving about 16 million households

- Renewed request to consider line voltage thermostats
  - Adding would require some work developing appropriate requirements
  - Not sure when EPA will be able to move on this
Status Updates - Metric

• Regional Baselines
  – LBNL continues to work on this
  – Interim results in 2018 to discuss on a later metrics call
  – Intended completion 2019

• Including installations controlling staged and variable capacity equipment
  – Open data call, currently have two data sets submitted
  – Considering ways to move forward this summer even without additional data
Resistance Heat Utilization

- Data from software output
  - Calculates minutes of resistance heat as percentage of total heating run time of any kind for each day of the year
  - Bins data by average outdoor temperature during that day
  - Results available regionally and nationally (unweighted sum)
- Four data sets submitted, but one doesn’t make sense
  - Data input problem? Working with stakeholder to fix.
- Expected results (if any):
  - Use of resistance heat at very low outdoor temps equipment dependent, not control dependent
  - Use of resistance heat rare at higher ambient for all solutions
  - Most likely to see differentiation in use at intermediate temperatures
RHU Calculation Details

For heat pump systems only, calculate RHU in 12 (daily average) outdoor temperature bins (0≤T<5°F, 5≤T<10°F,…, 55≤T≤60°F). For example RHU_{0-5F} is calculated as follows:

\[
RHU_{0-5F} = \frac{(t_{\text{emer}g_{0-5F}} + t_{\text{aux}_{0-5F}})}{(t_{\text{emer}g_{0-5F}} + t_{\text{comp}_{0-5F}})}
\]

where,

\( t_{\text{emer}g_{0-5F}} \) = total emergency resistance heating run time in the interval data file that occurs on core heating days where 0°F ≤ average daily outdoor temperature < 5°F.

\( t_{\text{aux}_{0-5F}} \) = total annual auxiliary resistance heating run time in the interval data file that occurs on core heating days where 0°F ≤ average daily outdoor temperature < 5°F.

\( t_{\text{comp}_{0-5F}} \) = total compressor heating run time in the interval data file that occurs on core heating days where 0°F ≤ average daily outdoor temperature < 5°F.

Note: highest value is 1.00 (resistance heat in use for all heating minutes), lowest is 0.00 (no resistance heat use in any heating hour); lower is better.
RHU Discussion

• On emergency heat: if the compressor has a cut-out at some temperature, does it count as emergency heat?
  – Yes
  – If the cutout is 30F or whatever, service providers would be penalized for that?
• Note that two units, both using resistance heat all minutes of the day, but one using the compressor also: both would score RHU 1, but the one using the compressor also would have effectively higher efficiency. Not captured in RHU.
• Sizing would effect this, but it also effects RHU otherwise
• Can we distinguish when the compressor is locked out by temperature vs. actually not working?
• In some thermostats, “emergency heat” is used only when the compressor is broken, and must be set deliberately by a user.
RHU Discussion

• Compressor lockout T and temperature when aux heat comes on set by installer and would not be changed by the CT service provider, generally (need permission)
• But CT vendors can set a default, which may affect where installations end up
• The lockouts are a critical issue for energy efficiency programs – installers often don’t set them where programs recommend
  – Is there a way for us to use the spec to make it easier to verify that the setting is where programs expect it to be?
  – At the installation (for an inspector) or via CT service provider data reporting? Both valuable.
  – Do vendors have the ability to *read* these values? Yes.
RHU Discussion

- Electric resistance heating can also be staged. Do we take that into account?
  - Not at the moment.
  - Which systems tend to have this? You typically need a thermostat intended to control a multistage compressor to use this, but do not need to have a multistage compressor
  - Under the control of the installer – how common? Little data but we think could be rare
  - Table; include in discussion of multistage/variable capacity systems
Specific questions we hoped to answer

• Are there differences between products in their resistance heating (Aux/Emergency) use results?
  – Are these differences statistically significant?
  – What would the energy impact of the differences be?

• Will products that perform better in some conditions show equivalent superior performance at other conditions?
  – RHU optimization at different Temp. bins for different products
  – Differentiation at moderate temperatures?

• Are there temperature bins where all products are effectively equal, when outdoor temperature is the primary driver of Aux/Emergency usage (Cold/Very Cold Temperatures)?
### Primarily found in Mixed Humid and Hot Humid climates

<table>
<thead>
<tr>
<th>Climate</th>
<th>Birch</th>
<th>Maple</th>
<th>Oak</th>
<th>Spruce</th>
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<tbody>
<tr>
<td>Hot Humid</td>
<td>127</td>
<td>138</td>
<td>217</td>
<td>462</td>
</tr>
<tr>
<td>Marine</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>88</td>
<td>117</td>
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<tr>
<td>Mixed Humid</td>
<td>184</td>
<td>893</td>
<td>273</td>
<td>535</td>
</tr>
<tr>
<td>Very Cold – Cold</td>
<td>&lt; 10</td>
<td>70</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Mixed Dry – Hot Dry</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>129</td>
</tr>
</tbody>
</table>

- Expected result
- Obviously affects which temperature bins have more data
  - Hot Humid never has days in the low temperature bins
# Statistical Significance Results: All Climate Zones (N >= 10)

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>NA: Not Measured</th>
<th>** P &lt; 0.05</th>
<th>* 0.05 &lt;= P &lt;= 0.10</th>
<th>NS 1: 0.10 &lt; P &lt;= 0.25</th>
<th>NS 2: P &gt; 0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>** p (α = 0.05)**</td>
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<tr>
<td>** p (α = 0.05)**</td>
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<td>** p (α = 0.05)**</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ABS(Maple-Birch)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ABS(Oak-Birch)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABS(Oak-Maple)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notes</td>
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<tr>
<td>Count: NA's</td>
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<tr>
<td>Count: **</td>
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<tr>
<td>Count: * and **</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>** rhu_00F_to_05F**</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Exclude T Bin</td>
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<tr>
<td>** rhu_05F_to_10F**</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Exclude T Bin</td>
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<tr>
<td>** rhu_10F_to_15F**</td>
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<td>NA</td>
<td>NS 2</td>
<td>Exclude T Bin</td>
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<tr>
<td>** rhu_15F_to_20F**</td>
<td>NA</td>
<td>NA</td>
<td>NS 2</td>
<td>Exclude T Bin</td>
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<tr>
<td>** rhu_20F_to_25F**</td>
<td>NS 1</td>
<td>NS 2</td>
<td>NS 2</td>
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<tr>
<td>** rhu_25F_to_30F**</td>
<td>NS 2</td>
<td>NS 2</td>
<td>**</td>
<td></td>
<td>- 1</td>
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<tr>
<td>** rhu_30F_to_35F**</td>
<td>NS 2</td>
<td>NS 1</td>
<td>*</td>
<td></td>
<td>-</td>
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<tr>
<td>** rhu_35F_to_40F**</td>
<td>NS 2</td>
<td>NS 1</td>
<td>*</td>
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<td>-</td>
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<td>** rhu_40F_to_45F**</td>
<td>NS 1</td>
<td>NS 2</td>
<td>**</td>
<td></td>
<td>- 1</td>
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<tr>
<td>** rhu_45F_to_50F**</td>
<td>**</td>
<td>NS 2</td>
<td>**</td>
<td></td>
<td>- 2</td>
</tr>
<tr>
<td>** rhu_50F_to_55F**</td>
<td>NS 2</td>
<td>NS 1</td>
<td>*</td>
<td></td>
<td>-</td>
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<tr>
<td>** rhu_55F_to_60F**</td>
<td>NS 2</td>
<td>*</td>
<td>**</td>
<td></td>
<td>- 1</td>
</tr>
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</table>
### N, Effect Sizes, Standard Error of Effect (seNet)

<table>
<thead>
<tr>
<th>Item</th>
<th>Row Labels</th>
<th>rhu_20F to_25F</th>
<th>rhu_25F to_30F</th>
<th>rhu_30F to_35F</th>
<th>rhu_35F to_40F</th>
<th>rhu_40F to_45F</th>
<th>rhu_45F to_50F</th>
<th>rhu_50F to_55F</th>
<th>rhu_55F to_60F</th>
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<tbody>
<tr>
<td>Birch</td>
<td>N (nearest 10)</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Maple</td>
<td>N (nearest 10)</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
<td>140</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Oak</td>
<td>N (nearest 10)</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

- **ABS(Maple-Birch)**
  - Effect: 0.07
  - Se Net: 0.06
- **ABS(Oak-Birch)**
  - Effect: 0.07
  - Se Net: 0.06
- **ABS(Oak-Maple)**
  - Effect: 0.00
  - Se Net: 0.05

### Notes:
- N reaches low counts in colder bins. More data -> Less Error
- Effect sizes often ≥ 0.05 RHU (bold in table).
Results Summary

- Relatively little data at very cold outdoor temps – heat pumps not typically installed in those climates.
  - Did not spend time looking at bins with less than 10 thermostat-days in the bin total for that product.
- Most installations in Hot-Humid and Mixed-Humid climates, as expected
- Significant variation within each temperature bin, as expected based on differences in controlled equipment
- Little statistically significant differentiation, and not all where we expected to see it
RHU Discussion

• The whole analysis is underpowered
• Wider temperature bins? Oversample heat pumps?
• Did not do a linear regression (RHU vs. Tout) b/c expected to be non-linear
• Not a normal distribution – should be use something other than T-test? Non-parametric analysis might help – need a statistician who knows more. May need more data.
• Can we sum subsequent resubmissions to increase our data?
• Increase sample size, oversample heat pumps, etc… More work for vendors – but if the software is faster, it might make up for it!
• Back of the envelope estimate of how much energy we are talking about: not uncommon to have 800 hours of heating run time, so 5% of that is 40 hours. If it’s a 20kW backup is common (in the mid-atlantic), that would be 800 kWh/year. Actually, might be half, b/c the compressor would’ve needed some energy to deliver that heat. Even if it’s 10 kW back up and we assume the compressor would have used half the energy, it would be 200 kWh/year.
• CONSENSUS: there appears to be enough energy in play here to matter: several hundred kWh/year
**RHU Discussion**

- Larger sample size vs. oversampling heat pumps in Marine and Very Cold – Cold?
  - Total number of runs would be larger for larger sample size than to add additional sample with all heat pumps that would be used just for heat pump calculations.
  - How will this work for vendors with smaller deployed base?

- Would hourly data have less noise?
  - Instead of average outdoor temp, could bin by degree days based on hourly temperatures
  - Thermal inertia makes

- Fewer temperature bins?
  - 10 degree bins where we expect differentiation, also large bins under 20 or over 50
  - Will autocorrelation in each home mean that wider bins don't give more power?
  - Temperature variations inside the bin will tend to increase variation; introduces distortion if different vendors have a different distribution with the bin.

- Can we output the weather data being used when we output thermostat data?
True that RHU is not linear with outdoor temperature.
RHU Future Considerations

• More Data -> More Climate Zones + Higher Signal to Noise Ratio
  – Mixed Humid #1 Zone for RHU, other zones greatly under-represented (equipment preferences by region).
  – Sampling randomly from populations in climate zones makes this issue even more pronounced.
  – Possible Datacall: Send all available equipment type 1 into tool, to maximize RHU calculation accuracy.
  – Would the data be cleaner if we use hourly temperature bins and run times instead?

• Data Reminder:
  – Auxiliary Heating is resistance heat when Compressor is operational.
  – Emergency Heating is resistance heat when Compressor is offline/non-operational.
Statistical Significance Calculations

- Comparing mean ($\bar{X}$) and standard error (se) of Item A and Item B

- Effect: $X_{EFF} = \text{abs}(\bar{X}_A - \bar{X}_B)$

- SE of the Effect: $se_{EFF} = \sqrt{se_A^2 + se_B^2}$

- Z-score: $z = \frac{X_{EFF}}{se_{EFF}}$

- P-value: $p(\alpha = 0.05) = \exp(-0.717 \times z - 0.416 \times z^2)$