Impacts of the OPA HVAC Installation Optimization Training Program on Realized Energy Efficiency of Retrofit AC Systems

Michael Sullivan, Nexant, Inc., San Francisco, CA
Jesse Smith, Nexant Inc., Philadelphia, PA
Kausar Ashraf IESO, Ontario, Canada
Phil Bosco, IESO, Ontario, Canada

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Introduction

Problem
- more than 25% of retrofit energy savings lost to installation practices

Solution
- Training for sales and installation contractors
  - Fundamentals of duct design and sealing
  - Calculation of correct size of system (in AC Tons)
  - Correct evaporator coil matched with condensing unit
  - Correct air flow over the evaporator coil
  - Correct refrigerant charge
  - Complete commissioning
HVAC Installation Optimization

- Training course required of all contractors claiming incentives under OPA
- 16,000 contractors trained in the spring of 2013 and 2014
- 40 hours of classroom training
- Most were refrigeration mechanics so the course was a refresher – i.e., nothing new but a serious reminder of best practices
Evaluation Methodology

- RCT impossible to implement
  - Program was underway when evaluation was started
  - Sales and installation technicians voluntarily selected dates and times of training

- Key question was:
  - Not whether training improved awareness of best practices (they were trained technicians)
  - But whether training in best practices improved energy efficiency of installations
Approach

Compare field energy efficiency ratios (EER) for units installed before and after training.

1. All locations receiving HAC Incentives (2011 through 2013) identified
2. 100 installers who had installed at least 10 air conditioning systems before and after exposure to the 2013 training were selected at random
3. Owners of buildings with AC units installed by each trainee were recruited in random order – one system before the installer was trained and one after
4. Engineers visited the cooperating sites collecting static field measurements and installing data loggers measuring current and temperature data needed to calculate the EER of the installed units
5. Loggers recovered after 3-5 weeks during the summer season.
6. Data were cleaned
Field Measuring EER

- Simple in principal, difficult in practice
- **cooling energy**
- **power consumption**
- Requires solid measurements of numerous inputs varying over time

Cooling Energy

\[
\text{Cooling Energy} \left[ \frac{\text{Btu}}{\text{hr}} \right] = 4.5 \times \text{CFM} \times \Delta h
\]

\[
\Delta h = h_{\text{return}} - h_{\text{supply}}
\]

\[
h = \text{Enthalpy} = S H_{\text{air}} \times DBT_{c} + (S H_{\text{vapor}} \times DBT_{c} + h_{\text{wv}}) \times \frac{\text{Ratio} \times AVP \times RH}{100}
\]

\[
\frac{BP - AVP \times RH}{100}
\]

Power Consumption

\[
\text{Power Consumption} = \left[ V_{\text{AHU}} \times I_{\text{AHU}} \times \text{Power Factor}_{\text{AHU}} \right] + \left[ V_{\text{AC}} \times I_{\text{AC}} \times \text{Power Factor}_{\text{AC}} \right]
\]
## Resulting measurements

<table>
<thead>
<tr>
<th>Filter</th>
<th>Number of Participants Removed</th>
<th>Remaining Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial target</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>Unable to install equipment</td>
<td>19</td>
<td>181</td>
</tr>
<tr>
<td>Logger failure in field</td>
<td>13</td>
<td>168</td>
</tr>
<tr>
<td>Logger provided questionable data</td>
<td>3</td>
<td>165</td>
</tr>
<tr>
<td>Data filters</td>
<td>55</td>
<td>110 (55 pre-training and 55 post-training)</td>
</tr>
</tbody>
</table>
Results

IEER varies over time within subjects
Results

- Average EER of installed units is somewhat higher than expected

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of Homes</th>
<th>Average Ratio</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Training</td>
<td>55</td>
<td>0.8131</td>
<td>0.2619</td>
</tr>
<tr>
<td>After Training</td>
<td>55</td>
<td>0.7814</td>
<td>0.2566</td>
</tr>
<tr>
<td>Difference (After – Before)</td>
<td>-0.0317</td>
<td>0.2593</td>
<td></td>
</tr>
</tbody>
</table>

- Training doesn’t improve EER

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>T-statistic</th>
<th>P-value</th>
<th>95% CL Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pooled</td>
<td>-0.0317</td>
<td>-0.64</td>
<td>0.5224</td>
<td>-0.1297</td>
</tr>
</tbody>
</table>
Results

LFER model doesn’t detect a change in EER either

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>95% Confidence Limits</th>
<th>Z-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-10.2749</td>
<td>3.3497</td>
<td>-16.8401</td>
<td>-3.07</td>
<td>0.0022</td>
</tr>
<tr>
<td>AC Tonnage</td>
<td>-2.5687</td>
<td>0.3732</td>
<td>-3.3002</td>
<td>-6.88</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>AHU Fan Wattage</td>
<td>-0.0068</td>
<td>0.0010</td>
<td>-0.0087</td>
<td>-6.91</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Supply RH</td>
<td>-0.1632</td>
<td>0.0276</td>
<td>-0.2173</td>
<td>-5.91</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Return RH</td>
<td>0.2866</td>
<td>0.0263</td>
<td>0.2350</td>
<td>10.89</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Outdoor Temp (F)</td>
<td>-0.0736</td>
<td>0.0099</td>
<td>-0.0930</td>
<td>-7.43</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>CFM</td>
<td>0.0102</td>
<td>0.0010</td>
<td>0.0081</td>
<td>9.77</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Rated EER</td>
<td>0.7463</td>
<td>0.2719</td>
<td>0.2134</td>
<td>2.74</td>
<td>0.0061</td>
</tr>
<tr>
<td>Treatment</td>
<td>0.0228</td>
<td>0.2610</td>
<td>-0.4889</td>
<td>-0.09</td>
<td>0.9305</td>
</tr>
<tr>
<td>Delta T (F)</td>
<td>0.9208</td>
<td>0.0727</td>
<td>0.7782</td>
<td>12.66</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
Conclusions and Recommendations

Conclusions

1. Realized EER somewhat higher than expected based on priors – closer to 80% than 70-75% reported in literature
2. No improvement in realized EER resulted from installation optimization training

Recommendations

1. Further investigation of installations to refine our understanding of the problem – suspect ducts
2. If appropriate, provide additional incentives to support duct maintenance and repair
3. Require proof of compliance with best installation practices as a condition of performance payments