Development of an Energy Impact Model for RTU Economizer Faults

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July 15, 2014
Why Economizer FDD is Important

- **Economizer faults are common in the field**
  - 215 RTUs studied, 62% had failed economizers (Jacobs 2003)
  - 503 RTUs studied, 64% had economizers needing service (Cowan 2004)

- **Some common problems**
  - stuck dampers
  - dampers not fully modulating
  - outdoor-air temperature (or enthalpy) sensor out of calibration
  - improper change-over set point

- **Faults may cause 10% to 30% more annual energy** (Katipamula 2011)

- **California Title 24 economizer requirements**
  - newly installed 4.5 ton or greater RTUs must have economizer
  - must have economizer FDD system
Determining Fault Impacts is also Important

Fault impacts required for optimal service recommendation

- significant impact on energy usage
- service and maintenance is expensive

Need methodology to assess the severity of economizer faults

- *Economic performance degradation index (EPDI)* (Li 2009)
- Virtual sensors for AFDD (Li 2009, Kim 2013)
Economizer faults impact system in several ways

- cooling capacity
- ventilation load
- cycle efficiency
- sensible heat ratio

These contribute to

- longer run-times
- more energy
- discomfort
Economizer modulates damper to control ventilation

- During warm outdoor-air conditions, only the minimum ventilation requirement should be provided.
- When the damper is stuck open, a larger fraction of outdoor-air is brought into the RTU.
- This causes the mixed-air enthalpy to increase.
Economizer modulates damper to control ventilation

- During warm outdoor-air conditions, only the minimum ventilation requirement should be provided.
- When the damper is stuck open, a larger fraction of outdoor-air is brought into the RTU.
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Cycle impacts include

- higher evaporation temperature
- minimal impact on condensing temperature
- reduced pressure ratio
Determining Energy Impact of Fault

Use virtual sensors to estimate energy required to meet a cooling load

\[ W_{\text{elec}} = \dot{W}_{\text{comp}} \Delta t_{\text{load}} \]
\[ = \frac{\dot{Q}_{\text{cool}}}{\text{COP}} \Delta t_{\text{load}} \]

where \( \Delta t_{\text{load}} \) is the run-time required to meet the total cooling load.

Determine the relative impact on energy using models of normal performance

\[ r_{\text{elec}} = \frac{W_{\text{elec,actual}}}{W_{\text{elec,normal}}} \]
\[ = \frac{\left( \frac{\dot{Q}_{\text{cool}} \Delta t_{\text{load}}}{\text{COP}} \right)_{\text{actual}}}{\left( \frac{\dot{Q}_{\text{cool}} \Delta t_{\text{load}}}{\text{COP}} \right)_{\text{normal}}} \]
\[ = \frac{r_{\text{cool}}}{r_{\text{COP}}} r_{\text{run}} \]
Run-time can be determined from the total cooling load and equipment capacity

\[
\Delta t_{\text{load}} = \frac{Q_{\text{load}}}{\dot{Q}_{\text{cool}}} = \frac{Q_{\text{space}} + Q_{\text{vent}}}{\dot{Q}_{\text{cool}}}
\]

The relative increase in run-time caused by the fault can be defined as

\[
r_{\text{run}} = \frac{\left(\frac{Q_{\text{load}}}{\dot{Q}_{\text{cool}}}\right)_{\text{actual}}}{\left(\frac{Q_{\text{load}}}{\dot{Q}_{\text{cool}}}\right)_{\text{normal}}} = \frac{(1 - x_{\text{vent,norm}}) r_{\text{space}} + x_{\text{vent,norm}} r_{\text{vent}}}{r_{\text{SHR}} r_{\text{cool}}}
\]
Use virtual sensors to “measure” actual performance and normal models to estimate fault-free performance.

\[
\begin{align*}
    r_{\text{cool}} &= \frac{\dot{Q}_{\text{cool,actual}}}{\dot{Q}_{\text{cool,virtual}}} \\
    r_{\text{COP}} &= \frac{\text{COP}_{\text{actual}}}{\text{COP}_{\text{virtual}}} \\
    r_{\text{SHR}} &= \frac{\text{SHR}_{\text{actual}}}{\text{SHR}_{\text{virtual}}} \\
    r_{\text{vent}} &= \frac{\dot{Q}_{\text{vent,actual}}}{\dot{Q}_{\text{vent,virtual}}}
\end{align*}
\]
Laboratory Testing and Analysis

4-ton RTU installed in psychrometric chambers

- integrated economizer with control overridden
- scroll compressor
- TXV installed
- R410A

<table>
<thead>
<tr>
<th>Condition</th>
<th>$T_{oa}$ [°C]</th>
<th>$\phi_{oa}$ [%]</th>
<th>$T_{ra}$ [°C]</th>
<th>$\phi_{ra}$ [%]</th>
<th>Damper Position [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition A</td>
<td>31.50</td>
<td>0.40</td>
<td>26.00</td>
<td>0.50</td>
<td>10, 30, 50, 70</td>
</tr>
<tr>
<td>Condition B</td>
<td>31.50</td>
<td>0.50</td>
<td>26.00</td>
<td>0.50</td>
<td>20, 40, 60, 80</td>
</tr>
<tr>
<td>Condition C</td>
<td>37.78</td>
<td>0.50</td>
<td>26.00</td>
<td>0.50</td>
<td>0, 33, 50, 67, 100</td>
</tr>
</tbody>
</table>
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Capacity and Efficiency Impacts

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What’s the Problem?

- With damper stuck open,
  - more capacity
  - greater efficiency
- These improvements are negated by
  - much greater ventilation load
  - much longer run-time
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Energy Impacts

$r_{elec}$ [-]

$OAF$ [-]

$T_{oa} = 31.50 ^\circ C$, $\phi_{oa} = 40\%$

$T_{oa} = 31.50 ^\circ C$, $\phi_{oa} = 50\%$

$T_{oa} = 37.78 ^\circ C$, $\phi_{oa} = 50\%$
Conclusions

- Methodology to estimate stuck damper fault impacts has been proposed
- Outputs can use virtual sensors from AFDD and be used in EPDI
- Future Work
  - Identify minimum sensor requirement
  - Evaluate multiple fault scenarios
  - Propose criteria for optimal service scheduling