Development of an Online Expert Rule based Automated Fault Detection and Diagnostic (AFDD) tool for Air Handling Units: Beta Test Results

**ICEBO 2013, MONTREAL, CANADA**

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Agenda

• Why does industry need this work?
• Why HVAC?
• An automated solution.....
• AFDD techniques
• Early Results
Why does industry need this research work?

- Focus on production output in lieu of efficiency
- Difficult to track efficiency due to islands of information
- Competition from lower cost economies for investment

Energy Consumption remains relatively constant though production volume has decreased significantly.
Why Focus on HVAC Systems?

- Typically greater than 20% of an industrial site’s energy consumption
- HVAC systems get less efficient over time
- 20-30% energy savings are achievable by re-commissioning HVAC
How can AFDD help save HVAC Energy?
How can AFDD help save HVAC Energy?

Air Change Reduction
How can AFDD help save HVAC Energy?

- Inefficient control strategies
- Poor loop tuning
- Free cooling
- Incorporation of Deadbands

- Simultaneous heating & cooling
- Set point adjustments
- Manual operation
- Sub optimal performance of equipment
Why an automated tool?

20 to 1

Knowledge

Complexity
AFDD tool requirements
FDD Techniques

- FDD automates the process of detecting and diagnosing faults

FDD Methods
- Quantitative Model Based
  - Detailed Physical Models
  - Simplified Physical Models
- Qualitative Model Based
  - Rule Based
  - Qualitative Physics Based
- Process History Based
  - Statistical
  - Artificial Neural Networks
  - Other Pattern Recognition Techniques
  - Black Box
  - Gray Box

- A rule based FDD tool can be developed and implemented in industry relatively quickly utilising existing equipment
The Business Layer

Out of control checks:
- OutOfControl_supT_Hi
  - $T_{SUP}$
  - $T_{SUP,SP}$
  - High supply temp

- OutOfControl_supT_Lo
  - $T_{SUP}$
  - $T_{SUP,SP}$
  - Low supply temp

- OutOfControl_zonT_Lo
  - $T_{ZON}$
  - $T_{ZON,SP}$
  - Low zone temp

Temperature comparisons:
- $T_{SUP,PRE}$
- $T_{MIX}$

- Before fan supply temperature is higher than the mix temp:
  - Modes 2 - 4
  - $supT_{Hi, mixT}$

- Before fan supply temperature is lower than the mix temp:
  - Modes 1 & 2
  - $supT_{Lo, mixT}$

Component position checks:
- Heating valve is open when it should be closed:
  - Modes 2 - 4
  - $V_{HEA}$

- Heating valve is fully open for a number of consecutive hours:
  - Mode 1
  - $V_{HEA}$

- Cooling valve is open when it should be closed:
  - Modes 3 & 4
  - $V_{Coo}$
Design of Test Study – AHU Selection

- > 200 AHU’s available on 7 industrial and commercial sites
- AHU’s were selected with
  - Different component and sensor layouts
  - Varying levels of instrumentation

<table>
<thead>
<tr>
<th>Site</th>
<th>No. AHUs in pilot</th>
<th>Type</th>
<th>Type of zone(s) supplied</th>
<th>Operating hours per annum</th>
<th>BMS/Data logging Platform</th>
<th>Frequency of logged data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>Constant volume</td>
<td>Office &amp; canteen</td>
<td>8760</td>
<td>Trend</td>
<td>15 minutes</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Constant volume</td>
<td>Manufacturing Floor</td>
<td>8760</td>
<td>Tridium</td>
<td>15 minutes</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>Variable Volume</td>
<td>Manufacturing Floor</td>
<td>6240</td>
<td>Cylon</td>
<td>15 minutes</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Constant Volume</td>
<td>Commercial office space</td>
<td>6240</td>
<td>Cylon</td>
<td>7.5 minutes</td>
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<tr>
<td>5</td>
<td>3</td>
<td>Variable Volume</td>
<td>Commercial office space</td>
<td>6240</td>
<td>Schneider</td>
<td>15 minutes</td>
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<tr>
<td>6</td>
<td>2</td>
<td>Constant Volume</td>
<td>Manufacturing Floor</td>
<td>8760</td>
<td>Qlikview</td>
<td>15 minutes</td>
</tr>
</tbody>
</table>
Design of Test Study - Feedback
AFDD tool in Alpha testing

Survey on operations of controls on production floor AHU 6, 7, 8, 9:
- Checked all C.M.W + L.T.H.W valves for signs of presence.
- All temperature sensors checked correctly calibrated and adjusted were required.
- Checked correct operation of fresh, recirc and reheat dampers.
- All associated field equipment (i.e. VSD’s, actuators, etc.) were good.

Finding running issue:

AHU 6 (a) Check, diffuser on level 3 are not operating.
(b) return motor faulty, reducing reducing air flow which is effecting operation of system’s damper’s and is causing area to overheating.
(c) Poor return damper balancing.

AHU 8 (a) Recirc damper not sealing correctly, air leaks.
(b) Cooling valve slightly passing, adding around valve to
Ay 8 valve.

AHU 9 (a) Recirc damper not sealing correctly, hairse damaged.
Alpha to Beta Testing

- Secure HTTPS communication
- Development of web based configuration tool
- Browser based GUI
AFDD tool in Beta testing

5.1C temperature rise across a closed heating coil and open cooling coil

April 2012  November 2012  February 2013  March 2013
AFDD tool in Beta testing

April 2012

November 2012

February 2013

March 2013
AFDD tool in Beta testing

Only a 0.6°C drop in temperature across a fully open cooling coil was identified as extremely unusual by the AFDD tool.

the Cooling Coil actuation valve was fully open for a long duration. This was deemed out of control by the AFDD tool and raised as a fault on the GUI.

April 2012  November 2012  February 2013  March 2013
AFDD tool in Beta testing

April 2012
November 2012
February 2013
March 2013
AFDD tool in Beta testing

A fully open cooling coil for an extended duration coupled with only a 2°C drop was raised as an issue by the AFDD tool.
### Requirements Versus Developments

<table>
<thead>
<tr>
<th>Rationale</th>
<th>Requirement(s)</th>
<th>Framework/Tool Developed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Access Layer Flexibility</td>
<td>Compatibility with any BMS type or age</td>
<td>A generic data access tool was developed</td>
</tr>
<tr>
<td>Business Layer Flexibility</td>
<td>Compatible with various combinations of sensors and components</td>
<td>Calculation of virtual values coupled with “rule libraries”</td>
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<td>Reliability</td>
<td>Low number of false positives/negatives</td>
<td>A error threshold applied to each rule based on rule makeup</td>
</tr>
<tr>
<td>Usability</td>
<td>User friendly graphical user interface (GUI)</td>
<td>A browser based GUI was developed</td>
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<td>Fault Priority</td>
<td>Quantification and prioritisation of the diagnosed faults</td>
<td>Each fault is prioritised in terms of cost and frequency of occurrence</td>
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<tr>
<td>Scalability</td>
<td>Rapid setup time per AHU</td>
<td>A web based site configuration tool was developed</td>
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<td>Low Cost</td>
<td>Ability to use existing measurements</td>
<td>First principal techniques and engineering computation utilised to calculate readings where none are present</td>
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Results

Faults: Passing heating coil, stuck damper actuator
Savings: €74,000

Faults: Passing coils, design issues
Savings: €26,000

Faults: Damaged dampers, high supply temperature, passing cooling coil
Savings: €53,000
Next Steps

• Develop OPC functionality to expand data capture capability
• Expand the business layer to incorporate humidity control AFDD
• Further develop the fault costing & prioritisation methodology
• Improve diagnostic and future prognostic capabilities
• Automate the link to planned maintenance systems
If we knew what it was we were doing, it would not be called research, would it?

Albert Einstein

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