Model Based Building Chilled Water Loop
Delta-T Fault Diagnosis

Presented by:
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Outline

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• Energy Impact of Degrading Delta-T
• Cooling Coil Model
• Case Study Building Description
• Model Calibration
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Introduction

• Low chilled Water (CHW) delta-T is not only a waste of distribution pump power but the impact on the central plant even greater
• Many factors contribute to low CHW delta-T
• Avoidable causes and Non-avoidable causes
• CC engineers need to evaluate the chilled water loop delta-T performance and identify avoidable causes
Energy impact of degrading Delta-T

\[ Q \left( \frac{Btu}{h} \right) = 500 \text{ GPM} \Delta T \]
Cooling coil Model

- Effectiveness-NTU model (Braun, 1989)

\[ \dot{Q}_{\text{dry}} = \varepsilon_{\text{dry,a}} \dot{m}_a C_{pm} (T_{a,i} - T_{w,i}) \]

\[ \varepsilon_{\text{dry,a}} = \frac{1 - \exp(-Ntu_{\text{dry}} (1 - C^*))}{1 - C^* \exp(-Ntu_{\text{dry}} (1 - C^*))} \]

\[ C^* = \frac{\dot{m}_a C_{pm}}{\dot{m}_w C_{pw}} \]

\[ Ntu_{\text{dry}} = \frac{UA_{\text{dry}}}{\dot{m}_a C_{pm}} \]
Cooling coil Model (Cont.)

\[ \dot{Q}_{wet} = \varepsilon_{wet,a} \dot{m}_a (h_{a,i} - h_{s,w,i}) \]

\[ \varepsilon_{wet,a} = \frac{1 - \exp(-N_{tu_{wet}}(1 - m^*))}{1 - m^* \exp(-N_{tu_{wet}}(1 - m^*))} \]

\[ m^* = \frac{\dot{m}_a C_s}{\dot{m}_{w,i} C_{pw}} \]

\[ N_{tu_{wet}} = \frac{U A_{wet}}{\dot{m}_a} \]
Cooling coil Model (Cont.)

\[
f_{\text{dry}} = \frac{-1}{K} \ln \left[ \frac{(T_{dp} - T_{w,o}) + C^* (T_{a,i} - T_{dp})}{\left(1 - \frac{K}{Ntu_0}\right)(T_{a,i} - T_{w,o})} \right] \quad K = Ntu_{\text{dry}} \left(1 - C^*\right)
\]

(Braun, 1989)

\[
\varepsilon_{\text{wet}, a} = \frac{1 - \exp(-f_{\text{dry}} Ntu_{\text{wet}}(1 - m^*))}{1 - m^* \exp(-f_{\text{dry}} Ntu_{\text{wet}}(1 - m^*))} \quad \varepsilon_{\text{dry}, a} = \frac{1 - \exp(-f_{\text{dry}} Ntu_{\text{dry}}(1 - C^*))}{1 - C^* \exp(-f_{\text{dry}} Ntu_{\text{dry}}(1 - C^*))}
\]

\[
T_{w,x} = \frac{T_{w,i} + C^* \varepsilon_{\text{wet}, a} \left(h_{a,i} - h_{s,w,i}\right)}{C_{pm}} - \frac{C^* \varepsilon_{\text{wet}, a} \varepsilon_{\text{dry}, a} T_{a,i}}{\left(1 - C^* \varepsilon_{\text{wet}, a} \varepsilon_{\text{dry}, a}\right)}
\]

\[
T_{w,o} = C^* \varepsilon_{\text{dry}, a} T_{a,i} + (1 - C^* \varepsilon_{\text{dry}, a}) T_{w,x}
\]
Case study building

- 166,079 ft²
- Two 20 HP, 840GPM
- 201,670CFM
- OA 161,400CFM
Case study building chilled water loop delta-T

CHW Delta-T Vs. Load

CHW Delta-T Vs. OAT

# Case study building—AHUs

<table>
<thead>
<tr>
<th>Unit</th>
<th>Service</th>
<th>Ent. Air LVG. Air</th>
<th>Design Area SQFT</th>
<th>Min Outside Air cfm</th>
<th>Max Outside Air cfm</th>
<th>ENT. Air D.B W.B</th>
<th>LVG. Air D.B W.B</th>
<th>FIN /IN</th>
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</thead>
<tbody>
<tr>
<td>AHU L1</td>
<td>LABS</td>
<td>44,500</td>
<td>44,500</td>
<td>44,500</td>
<td>90</td>
<td>96</td>
<td>76</td>
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<td>LABS</td>
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<td>45,000</td>
<td>45,000</td>
<td>90</td>
<td>96</td>
<td>76</td>
<td>50.9</td>
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<tr>
<td>AHU L3</td>
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<td>45,000</td>
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<td>96</td>
<td>76</td>
<td>50.7</td>
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<td>AHU L4</td>
<td>ANIMAL ROOM</td>
<td>11,760</td>
<td>11,760</td>
<td>11,760</td>
<td>29.4</td>
<td>96</td>
<td>76</td>
<td>50.4</td>
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<tr>
<td>AHU LS</td>
<td>SEMINAR</td>
<td>4,500</td>
<td>1,310</td>
<td>4,500</td>
<td>11.5</td>
<td>83.8</td>
<td>69</td>
<td>50.7</td>
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<tr>
<td>AHU LB</td>
<td>BOOKSTORE</td>
<td>4,650</td>
<td>460</td>
<td>4,650</td>
<td>11.5</td>
<td>79.8</td>
<td>63.8</td>
<td>50.8</td>
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<tr>
<td>AHU LC</td>
<td>CORYSTORE</td>
<td>4,300</td>
<td>430</td>
<td>4,300</td>
<td>11.5</td>
<td>79.8</td>
<td>63.8</td>
<td>50.7</td>
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<tr>
<td>AHU LD</td>
<td>DINING</td>
<td>14,160</td>
<td>7,840</td>
<td>14,160</td>
<td>29.4</td>
<td>89.4</td>
<td>71.5</td>
<td>50.5</td>
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<tr>
<td>AHU LO</td>
<td>OFFICES</td>
<td>19,000</td>
<td>5,600</td>
<td>19,000</td>
<td>42.8</td>
<td>83.3</td>
<td>66.8</td>
<td>51.8</td>
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<td>AHU SG</td>
<td>SWITCHGEAR</td>
<td>8,800</td>
<td>0</td>
<td>8,800</td>
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<td>90</td>
<td>72</td>
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Case study building—AHUs (Cont.)

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<th>No</th>
<th>Parameters</th>
<th>AHU L2</th>
<th>AHU O</th>
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<tr>
<td>1</td>
<td>Width (inch)</td>
<td>130</td>
<td>102</td>
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<tr>
<td>2</td>
<td>Height (inch)</td>
<td>90</td>
<td>55</td>
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<tr>
<td>3</td>
<td>Number of rows</td>
<td>8</td>
<td>6</td>
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<tr>
<td>4</td>
<td>Tube outside diameter (inch)</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>5</td>
<td>Tube inside diameter (inch)</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>6</td>
<td>Tube material</td>
<td>copper</td>
<td>copper</td>
</tr>
<tr>
<td>7</td>
<td>Fin/Inch</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>Fin thickness (inch)</td>
<td>0.008</td>
<td>0.008</td>
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<tr>
<td>9</td>
<td>Fin material</td>
<td>Aluminum</td>
<td>Aluminum</td>
</tr>
<tr>
<td>10</td>
<td>Tubes center to center distance (perpendicular to air flow) (inch)</td>
<td>1.25</td>
<td>1.25</td>
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<tr>
<td>11</td>
<td>Tube Spacing (Parallel to air flow) (inch)</td>
<td>1</td>
<td>1.25</td>
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Model Calibration

AHU L2 chilled water delta-T (Model Vs. Trending)

CV(RMSE) error is 2.9%
Model Calibration (Cont.)

<table>
<thead>
<tr>
<th>AHU O</th>
<th>Air Side</th>
<th>Waterside</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After coil</td>
</tr>
<tr>
<td>No</td>
<td>CFM</td>
<td>T (°F)</td>
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<tr>
<td>1</td>
<td>6,450</td>
<td>74.9</td>
</tr>
<tr>
<td>2</td>
<td>6,450</td>
<td>97.1</td>
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<tr>
<td>3</td>
<td>6,450</td>
<td>97.9</td>
</tr>
<tr>
<td>Design</td>
<td>19,000</td>
<td>83.3</td>
</tr>
</tbody>
</table>

AHU O Model:

CV(RMSE) is 6%
Fault Diagnosis

CD set point 55 °F
Fault Diagnosis (Cont.)

CHW valve 100% open
Fault Diagnosis (Cont.)

CD set point 50 °F

Outside Air Temp (°C)

CHW Loop Delta-T (°F)

OfficeAHUAverageCFM
OfficeAHUMaxCFM
LabAHUMinCFM

Outside Air Temp (°F)

CHW Loop Delta-T (°C)

-17.8 -12.2 -6.7 -1.1 4.4 10.0 15.6 21.1 26.7 32.2 37.8 43.3

0 5 10 15 20 25

0 1 02 03 04 05 06 07 08 09 0 1 0 0 1 1 0
Fault Diagnosis (Cont.)

CD set point 50 °F; Office AHU w/o Economizer
Summary

• Based on simulation results, there is a good potential to improve the case study building’s chilled water delta-T.
• The lower discharge air temperature set point is the main avoidable cause of low chilled water delta-T for the case study building.
• Economizer contributes to low chilled water delta-T during cool season.
• The chilled water laminar flow in the cooling coil is not a major cause for cooling coil lower delta-T.
Summary (Cont.)

- A few of the chilled water valves may be leaking by or the coil control valves may not precisely modulate the chilled water flow, although the chilled water valves are overall under fairly good controlling.
Thanks