MAXIMIZING HYDRONIC SYSTEM DESIGN – PART II

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TODAY’S TOPICS

• A Brief review of the highlights or “Take a Ways” from Part I
• With todays BMS’s, who’s responsible for controlling the boiler operation?
• Boiler mass and system mass considerations and including sizing suggestions
• Some highlights on venting of condensing boilers
• Condensing boilers and condensate neutralization
• Insights on fan coil sizing for both high and low temperatures
• A look at some of the non-traditional heating systems employing condensing boilers
• Condensing boilers with dual returns; some application insights
• The hybrid system application from an engineers perspective
• Summary
• Q&A
PART 1

A few things to remember!
CONDENSING TECHNOLOGY
CONDENSING BOILER TYPES

- **Firetube [SS]**
  - High Mass

- **Modified Firetube [SS]**
  - High Mass

- **Cast Aluminum**
  - Low/Mid Mass

- **Cast iron w/ add-on HX**
  - Low Mass

- **Copper fin w/add-on HX**
  - Low Mass
HIGH MASS BOILER

- Robust design & construction
- Large water Volume
- >50 gallons per MMBTU
- Thermal storage for system reduces cycling
- Handles variable flow pumping
- Low waterside pressure drop
THE SCIENCE BEHIND
CONDENSING

Boiler Efficiency Improves Dramatically with Condensing

Counter-flow Heat Exchanger

Cold water return/inlet temperature introduced near the coldest flue gases

Effective Heating Surface to promote condensing
BURNER WITH CONSISTENT FUEL/AIR RATIO CONTROL
VARIABLE FLOW PRIMARY SYSTEM
HIGH & MEDIUM MASS BOILERS

Condensing

Noncondensing
PRIMARY-SECONDARY PUMPING
LOW MASS BOILERS

Cast Aluminum

Copper Fin w/ Hx
SYSTEM CONTROL
• Hot Water Supply Temperature Reset
• Pump Control
  – Delta T
  – Delta P
  – Critical Zone Reset
SYSTEM DESIGN & APPLICATIONS – SYSTEM CONTROL STRATEGIES ΔT PUMP CONTROL
• Hot Water Reset
  – Load is proportional to the outside air temperature
  – Water temperature can be decreased to meet load
SYSTEM DESIGN & APPLICATIONS – SYSTEM CONTROL STRATEGIES ΔP PUMP CONTROL
### System Design & Applications – System Control Strategies ΔT Pump Control

- Newer method with pump microprocessors
  - Built-in VFDs or EC motors
- Methodology:
  - Uses supply & return temperature sensors in system piping
  - Flow rate varies to match required heat output
  - HWR is constant resulting in lower temperatures
- Results:
  - More time in condensing mode
  - Decreased boiler cycling
  - Increased system efficiency
- Uses:
  - Primary boiler pumps
SYSTEM DESIGN & APPLICATIONS – SYSTEM CONTROL STRATEGIES
CRITICAL ZONE RESET

• Use of DDC system to monitor valve positions
• Requires sequence to be programmed
• Increased complexity & cost
• Methodology:
  – Keep one control valve fully open
  – Trim & respond setpoint
• Results:
  – Higher energy savings due to response directly from the load
• Uses:
  – Variable primary flow
  – Primary secondary
WHO CONTROLS THE HOT WATER SYSTEM & BOILER STAGING?
WHO CONTROLS THE HOT WATER SYSTEM & BOILER STAGING?

- **Boiler Manufacturer:**
  - More flexibility
  - Better understanding of safeties
  - Factory tested
  - Reduced commissioning

- **Temperature Controls Contractor**
  - Simpler algorithms with pre-configured solutions
  - Would prefer to control the system

- **Compromise**
  - Boiler manufacturer to control staging
  - Provide interface to BAS
  - Control Contractor enables/disables or adjusts set points
BOILER SEQUENCING
BASED ON LOAD
• Low return water temperatures
• Consistent excess air levels
• Lower pumping Rates
• Multiple boilers firing at optimum rate
CONSIDERATIONS FOR CONDENSING BOILERS – BUFFER TANKS

- New boiler technology vs. old boiler technology
- Water mass
  - Low mass
  - High mass
- Reasons for buffer tanks
  - Stores excess energy
  - Prevent boiler cycling
  - Better temperature control
  - Increased system efficiency
- May not be required based on system mass
CONSIDERATIONS FOR CONDENSING BOILERS – BUFFER TANKS

Tank Sizing Calculations

- Minimum Boiler Cycle Time
- Minimum Boiler Output
- Minimum System Load
- Temperature Differential in Tank

\[
\text{TOTAL BUFFER TANK SIZE (GALLONS)} = \left( \frac{\text{MANUFACTURER’S RECOMMENDED MINIMUM BOILER CYCLE TIME (MINUTES)} \times (\text{MINIMUM BOILER OUTPUT (BTU/HR.)} - \text{MINIMUM SYSTEM LOAD (BTU/HR.)})}{\text{TEMPERATURE DIFFERENTIAL WITHIN TANK (°F)}} \right) \times 500
\]
CONSIDERATIONS FOR CONDENSING BOILERS – BUFFER TANKS

Primary-Secondary Tank Location

Variable Primary Flow Tank Location
CONSIDERATIONS FOR
CONDENSING BOILERS –
FIRST COST CONSIDERATIONS

• Variable primary flow uses a single set of pumps
• Advantages:
  • Less pumps
  • Fewer electrical connections
  • Reduced piping
    • Initial layout
    • Larger ΔT
  • Elimination of hydronic accessories
  • Frees up equipment room space
CONSIDERATIONS FOR CONDENSING BOILERS – OPERATING COST CONSIDERATIONS

• Variable primary flow uses a single set of pumps
• Results in:
  • Higher efficiency pumps
  • Less total system horsepower
  • Better serviceability (located on ground in accessible location)
  • Less maintenance & material stock
  • Higher ΔT for smaller piping
  • Fewer valves to maintain and pump through
CONSIDERATIONS FOR CONDENSING BOILERS – COST CONSIDERATIONS

- Primary-Secondary Vs. Variable Primary Flow Case Study Example:

- 1500 MBH Boilers
  - Condensing
  - Non-Condensing

*Does not account for inefficiencies due to mixing that occurs in primary—secondary configurations

<table>
<thead>
<tr>
<th></th>
<th>Two (2) 1500 MBH Condensing Boilers</th>
<th>Two (2) 1500 MBH Non-Condensing Boilers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler &amp; System ΔT</td>
<td>140° – 100°</td>
<td>180° – 140°</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>92%+ depending on HWR temperature</td>
<td>88%</td>
</tr>
<tr>
<td>Boiler Output</td>
<td>2760 MBH</td>
<td>2640 MBH</td>
</tr>
<tr>
<td>Primary Pump Flow Rate</td>
<td>138 GPM</td>
<td>66 GPM</td>
</tr>
<tr>
<td>Primary Pump Head</td>
<td>70 FT HD</td>
<td>20 FT HD</td>
</tr>
<tr>
<td>Primary Pump Power</td>
<td>3.44 BHP 5 HP</td>
<td>0.46 BHP x 2 3/4 HP</td>
</tr>
<tr>
<td>Pump Efficiency</td>
<td>72%</td>
<td>75%</td>
</tr>
<tr>
<td>Secondary Pump Flow Rate</td>
<td>-</td>
<td>132 GPM</td>
</tr>
<tr>
<td>Secondary Pump Head</td>
<td>-</td>
<td>65 FT HD</td>
</tr>
<tr>
<td>Secondary Pump Power</td>
<td>-</td>
<td>3.01 BHP 5 HP</td>
</tr>
<tr>
<td>Pump Efficiency</td>
<td>-</td>
<td>72%</td>
</tr>
<tr>
<td>Total Pump Power</td>
<td>3.44 BHP 5 HP</td>
<td>3.93 BHP 6-1/2 HP</td>
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</table>
CONSIDERATIONS FOR CONDENSING BOILERS – FLUE STACK & DIRECT VENT

Flue Stack Temperatures & Materials:

• Condensing boilers:
  • Flue Gases are generally less than 200°F
  • Stainless Steel, Polypropylene, or CPVC
  • Highly recommend stainless steel (could always operate in non-condensing mode)

• Non-Condensing boilers:
  • Flue Gases are approximately 250°F to 350°F
  • Aluminum, galvanized, or stainless steel

• Consult the boiler manufacturer prior to choosing the stack material
CONSIDERATIONS FOR
CONDENSING BOILERS – ADDITIONAL CONSIDERATIONS

- Acid Neutralization
  - Condensate is at pH of 5
- Condensate is created:
  - During start-up
  - In condensing mode
- Neutralizes pH prior to discharge
- Requires monitoring & replacement
CONSIDERATIONS FOR CONDENSING BOILERS – ADDITIONAL CONSIDERATIONS

Heating Capacity with Low Temperature Hot Water

- Example of VAV box heat
  - 1000 CFM Design Cooling airflow
  - 300 CFM Minimum position heating airflow (30%)
  - Desired 95°F Supply air temperature
- Non-Condensing 180°F Hot Water Supply

<table>
<thead>
<tr>
<th>Heating Coil</th>
<th>Valve heating airflow</th>
<th>Unit LAT</th>
<th>Heating Cv</th>
<th>Connection side</th>
<th>Hot water coil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300 cfm</td>
<td>96.81 F</td>
<td>0.82</td>
<td>Left</td>
<td>1 Row hot water coil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.60 MBh</td>
<td>9.38 MBh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.60 gpm</td>
<td>45.34 F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>180.00 F</td>
<td>68.00 F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>55.00 F</td>
<td>0.224 in H2O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>1.23 ft H2O</td>
<td></td>
<td></td>
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</table>

- Condensing 140°F Hot Water Supply

<table>
<thead>
<tr>
<th>Heating Coil</th>
<th>Valve heating airflow</th>
<th>Unit LAT</th>
<th>Heating Cv</th>
<th>Connection side</th>
<th>Hot water coil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300 cfm</td>
<td>99.13 F</td>
<td>2.37</td>
<td>Left</td>
<td>4 Row hot water coil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.36 MBh</td>
<td>10.13 MBh</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>0.60 gpm</td>
<td>47.97 F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>140.00 F</td>
<td>68.00 F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>55.00 F</td>
<td>0.760 in H2O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>0.15 ft H2O</td>
<td></td>
<td></td>
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</tbody>
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CONSIDERATIONS FOR CONDENSING BOILERS – ADDITIONAL CONSIDERATIONS

Heating Capacity with Low Temperature Hot Water

- Example of fin pipe radiation heat
  - Room dimensions 16’-0” x 12’-0”
  - Heat loss of 6,000 BTU/H
  - Satisfy heat loss with radiation
  - $\Delta T$ of 20°F (typical of radiation)
- Non-Condensing 180°F Hot Water Supply
  - $AWT = 170\,\text{°F}$
  - Requires ~ 7.5’ radiation
- Condensing 140°F Hot Water Supply
  - $AWT = 130\,\text{°F}$
  - Requires ~ 14’ radiation

<table>
<thead>
<tr>
<th>Steam Capacity</th>
<th>Hot Water Heat Average Water Temperature</th>
</tr>
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<tbody>
<tr>
<td>factor of 1.00</td>
<td>factor of 0.78</td>
</tr>
<tr>
<td>215 °F</td>
<td>190 °F</td>
</tr>
<tr>
<td>1,299</td>
<td>1,020</td>
</tr>
</tbody>
</table>
Low grade heating is a perfect application for condensing boilers:

- Water source heat pumps
- Geothermal heat pumps
- Heat recovery chillers
- Radiant Systems
  - Ceiling Panels
  - In-Floor Heating
  - Snow Melt
- Pool Heating
- Series Loop
NON-TRADITIONAL SYSTEMS
WITH CONDENSING BOILER – WATER SOURCE HEAT PUMPS

- Self-contained, individual zone control
- Transfers energy zone to zone
- Heat is added when loop temperature falls below pre-determined limit
- Boiler piping is simplified
NON-TRADITIONAL SYSTEMS
WITH CONDENSING BOILER –
WATER SOURCE HEAT PUMPS
NON-TRADITIONAL SYSTEMS WITH CONDENSING BOILER – GEOTHERMAL HEAT PUMPS

• Similar to water source heat pumps
• Use of ground, geothermal well, or body of water acting at heat source/sink
• First cost of ground source can be a deal breaker
• Use condensing boilers as a peak/load shaving device
• Operating limits within typical ranges of heat pump loop
NON-TRADITIONAL SYSTEMS
WITH CONDENSING BOILER – LOW GRADE HEATING

• In-Floor Radiant
  • Hot water supply temperatures around 100 – 120°F
  • Excellent thermal comfort in space

• Snow Melt
  • Hot water supply temperatures around 120 – 140°F
  • Ice or snow melting depending on application

• Pool Heating
  • Pool water temperature around 90°F
NON-TRADITIONAL SYSTEMS WITH CONDENSING BOILER – SERIES LOOP

- Coils in series
- Eliminates control valves with coil pumps
- Cascade approach increases system ΔT
- Requires careful coil selection
NON-TRADITIONAL SYSTEMS WITH CONDENSING BOILER – DUAL RETURN SYSTEMS

- Accepts hot water return from two sources
- Eliminates mixing high hot water return with low hot water return
- Promotes condensing that would otherwise be lost
- Use with any low temperature system described above
NON-TRADITIONAL SYSTEMS
WITH CONDENSING BOILER – DUAL RETURN SYSTEMS

• Requires keeping two loops separated in building layout
• At least 10% flow to low temperature connection (bottom)
• Cap top connection if not required
• Provides combined affect of condensing & non-condensing
THE HYBRID SYSTEM – PIPING & PUMPING CONFIGURATIONS

- Combine condensing & non-condensing in one plant for improved efficiency
- Full condensing systems may not be feasible or practical
- Condensing boilers are first inline
- Non-condensing boilers are second – stay above condensing temperature tipping point

Non-Condensing + Condensing = Hybrid
THE HYBRID SYSTEM – PIPING & PUMPING CONFIGURATIONS
THE HYBRID SYSTEM –
SYSTEM CONTROL & ADVANTAGES

• Controls – Maintain Header Temperature:
  • If satisfies the building load:
    • Non-condensing boiler remains off
  • If doesn’t satisfy the load:
    • Enable non-condensing boiler & pump

• Advantages:
  • Provides condensing efficiency with reduced first cost
  • Protects non-condensing boiler
  • Decouples condensing & non-condensing boilers
SUMMARY

• Utilizing high mass condensing boilers in a variable flow primary system when possible will lead to the greatest overall efficiency.

• Recommendations for boiler and system control: The boiler manufacturer supplies the control for boiler operation, firing rate, sequencing, an interface for enabling and disabling boilers and pumps, and a tie to the BMS for other system control points and monitoring.

• Buffer tank sizing and location: Sizing: Min. boiler cycling time, min. boiler output, min system load, Delta T in Tank. P/S: Locate @ common pipe location (de-coupler). VFP: Downstream of the boiler.

• First cost considerations for condensing boiler systems. Advantages with VFP Systems due to lower material/install costs. Operating costs are also less.

• Existing system heating coil boxes can still be used with lower supply water temperatures though specific conditions need to be evaluated such as the number of coils needed to accommodate acceptable room heating losses.
SUMMARY

• Condensing boiler venting: Category IV vent materials are required. CPVC is discouraged.

• Non-traditional systems with condensing boilers
  • Water source heat pumps
  • Geothermal heat pumps
  • Heat recovery chillers
  • Radiant systems
  • Pool heating
  • Series loop

• Advantages of dual return systems: Two sources of hot water returns maximizes efficiency by eliminating blending; Maintaining high Delta T’s.

• Hybrid system overview; A mix of condensing and noncondensing boilers saves first cost and maximizes efficiency.
QUESTIONS?

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