Condensing Boilers in Primary Variable Flow Piping Systems

Agenda

- Condensing Boilers vs. Non-Condensing Boilers
- High-Mass vs. Low-Mass Boilers
- Optimizing High-Mass Condensing Boilers
  - Operating Temperature and Input
  - Primary Variable Systems for High Mass Boilers
  - Matching System Flow to Boiler Turndown
- Hybrid Systems

Historical Design of Hydronic Systems

- Primary/secondary loop with non-condensing boilers
  - 180°F hydronic loop setpoints
  - High return temperature needed to protect boiler from condensing and corrosion
  - Primary/secondary pumping
  - Calculate “design day” load, select one large boiler, put in a second boiler for redundancy

Introduction to Condensing Boilers

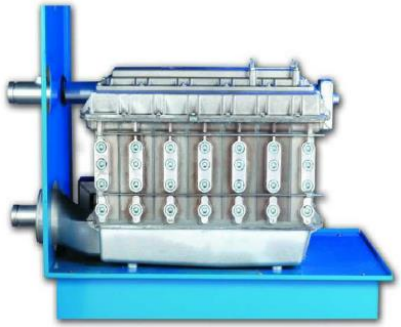
- What is a condensing boiler?
  - Boiler that extracts latent heat of vaporization (13% of energy content of natural gas) from flue gas and transfers it into the water source
  - Materials of construction to prevent corrosion as condensate is slightly acidic – 4 – 6 pH

Condensing Boilers: Different Boiler Designs

Firetube SS

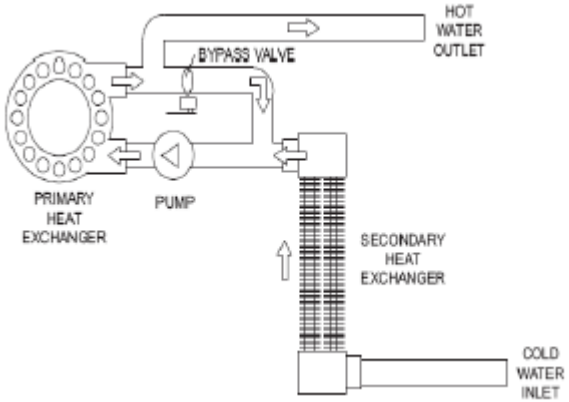
Watertube SS

Cast Aluminum



Cast Iron

Copper-Fin w/ Secondary HX



Advantages of Condensing Boilers

- Higher efficiencies (with proper operating conditions)
- Most designs offer no minimum return temperature
- Corrosion resistant
- More resistance to thermal shock or stress
- Potential for greater longevity and reliability
- Modular design provides better system turndown and redundancy

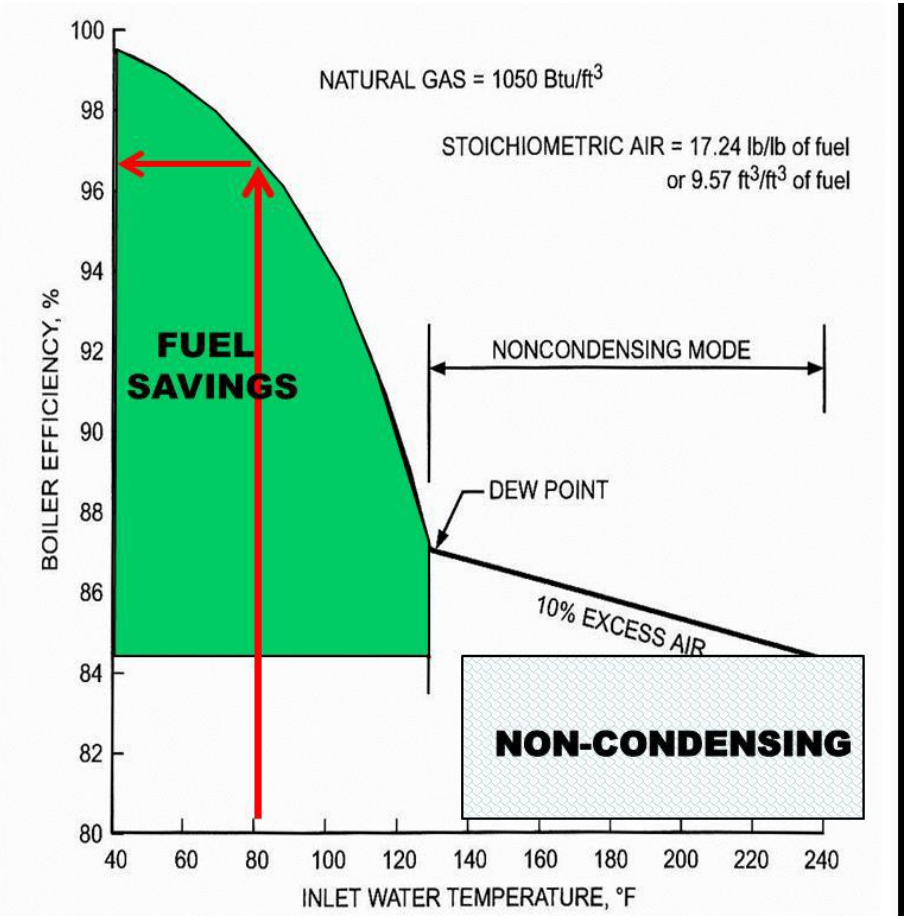
Operating Conditions

Specific operating conditions are necessary for a condensing boiler to operate at optimal efficiencies:

- Water temperature (set point, return water)
  - Lower water temperatures allow flue gases to condense
  - Flue gas temperature is directly related to return water temperature
- Firing rate (modulation)
  - Lower firing rate increases flue gas residence time in the heat exchanger meaning more heating surface relative to BTU input

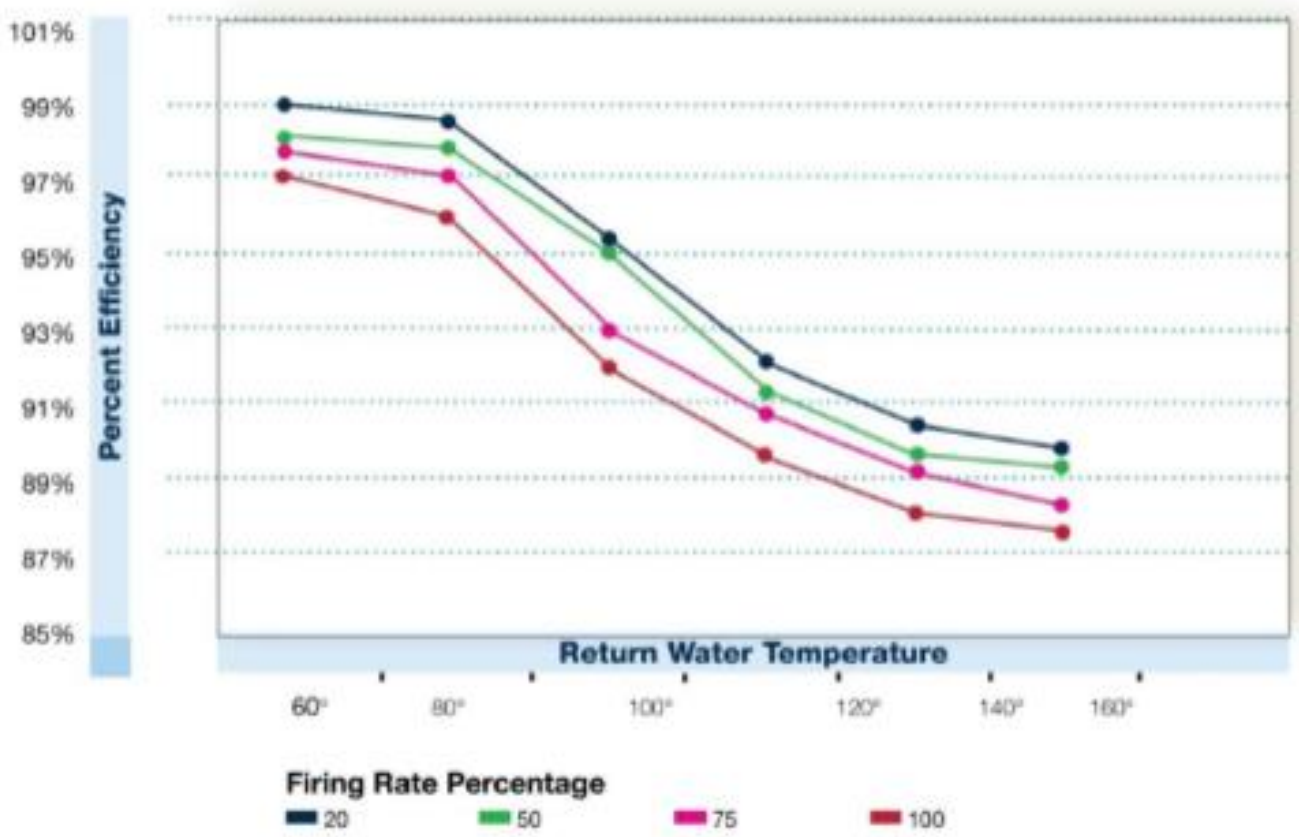
Efficiency Curve for Condensing Boilers

- Most efficient at lowest possible return water temperature
- Efficiencies above 87-88% only possible if return water temperatures are below the flue gas dew point
- Dew point = 127F for natural gas combustion



Efficiency Curve for Condensing Boilers

- Inverse relationship between firing rate and efficiency
- More efficient to run more boilers at lower firing rates



High Mass vs. Low Mass

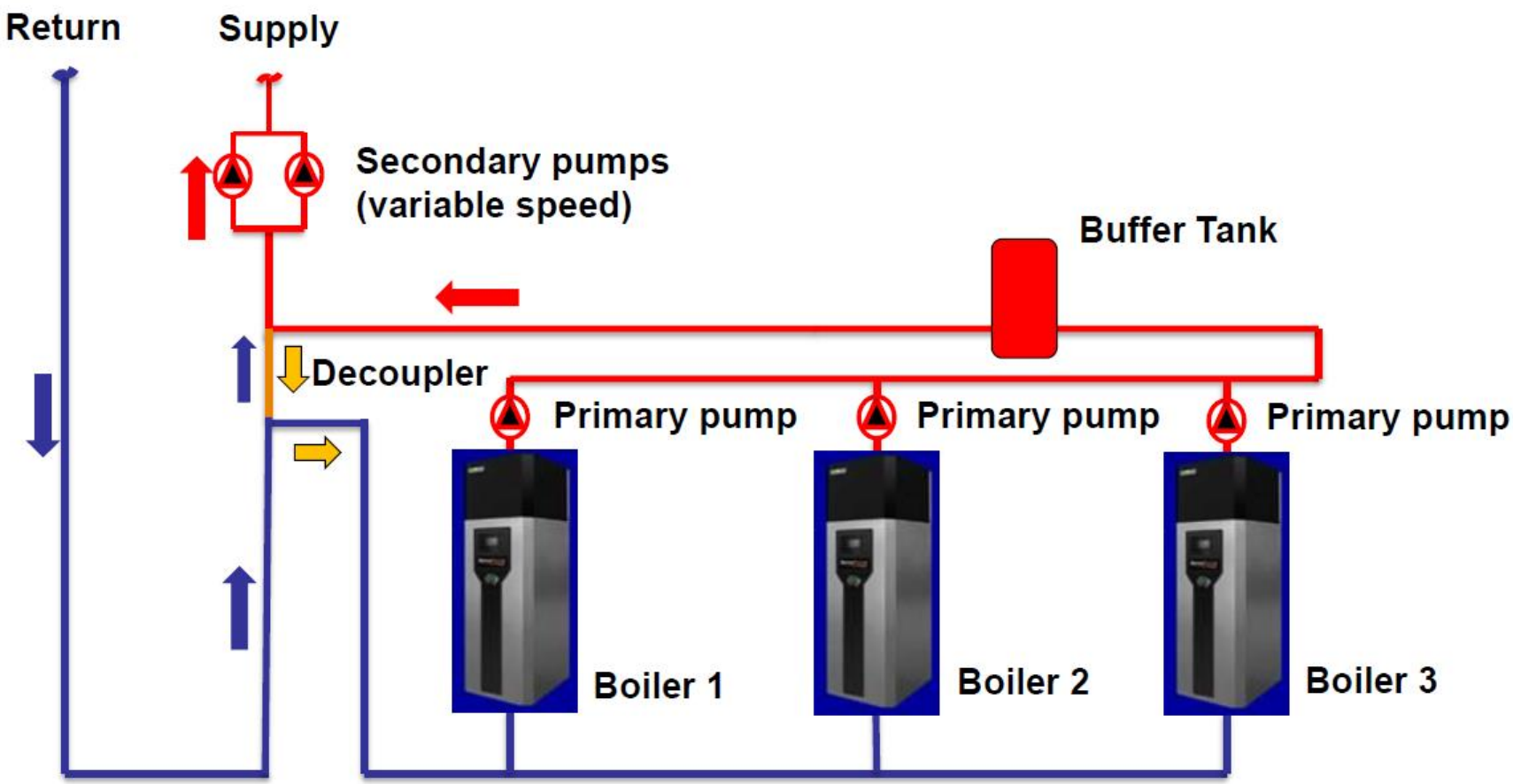
- Refers to mass of heat exchanger, and also water volume
- High Mass = More than 50 gallons per MMBTU
- Low Mass = Less than 25 Gallons per MMBTU

High Mass vs. Low Mass: Pros & Cons

- High Mass (3,640 lbs, 126 gal.)*
  - Advantages
    - Primary variable system
    - More tolerant of low or no flow
    - Low water side pressure drop
    - Greater delta T (up to 100F for condensing boilers)
    - Resistance to water quality
    - Less cycling
    - Longer life expectancy
  - Disadvantages
    - Higher initial equipment cost
    - Larger footprint
    - Heavier
- Low Mass (1,250 lbs, 13.2 gal.)*
  - Advantages
    - Lower initial equipment cost
    - Smaller footprint
  - Disadvantages
    - Primary/secondary system
    - High minimum flow requirements
    - High water side pressure drop
    - Smaller delta T (max. 30-35F)
    - Minimum pressure requirements
    - Sensitivity to water quality
    - More frequent cycling
      - Often needs buffering
    - More maintenance
    - Shorter life expectancy

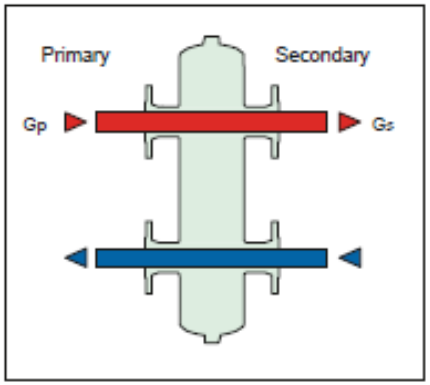
* Comparison of high-mass and low-mass 2,500 MBH boilers

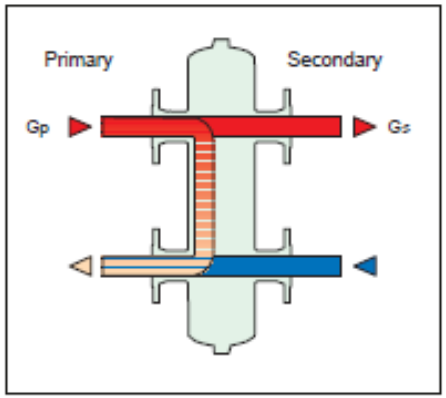
Traditional Primary/Secondary System

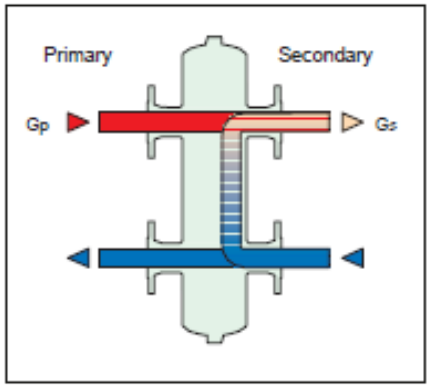


Traditional Primary/Secondary System

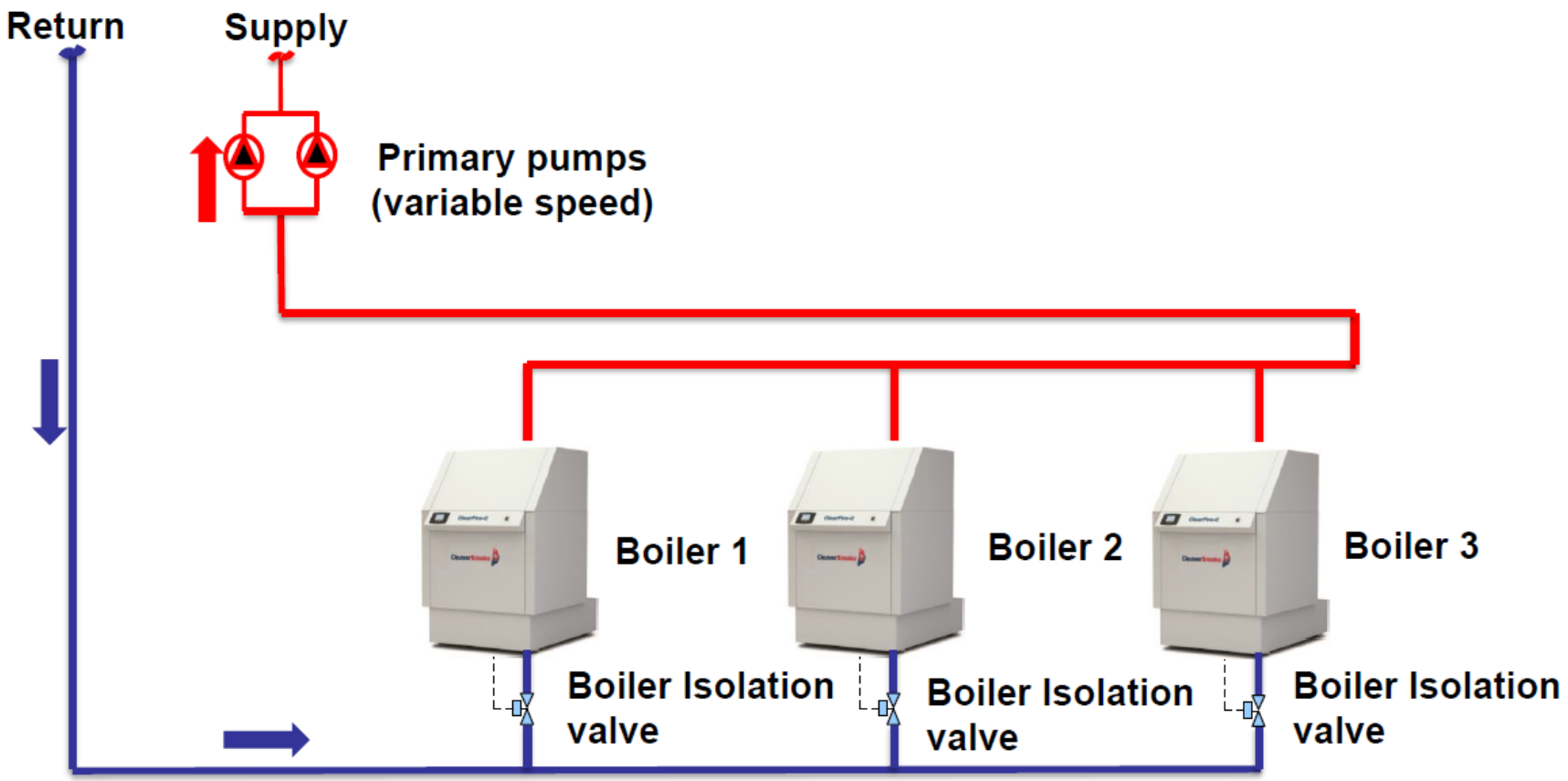
- Decouples or “hydraulically separates” the primary *(boiler)* and secondary *(system)* loops
  - Closely spaced tees or a mixing manifold
- Prevents flow in one circuit from interfering with another
  - Example: As zone valves open, close, or modulate, and as system pumps vary speed, the boiler loop is not impacted.







Primary Variable Flow



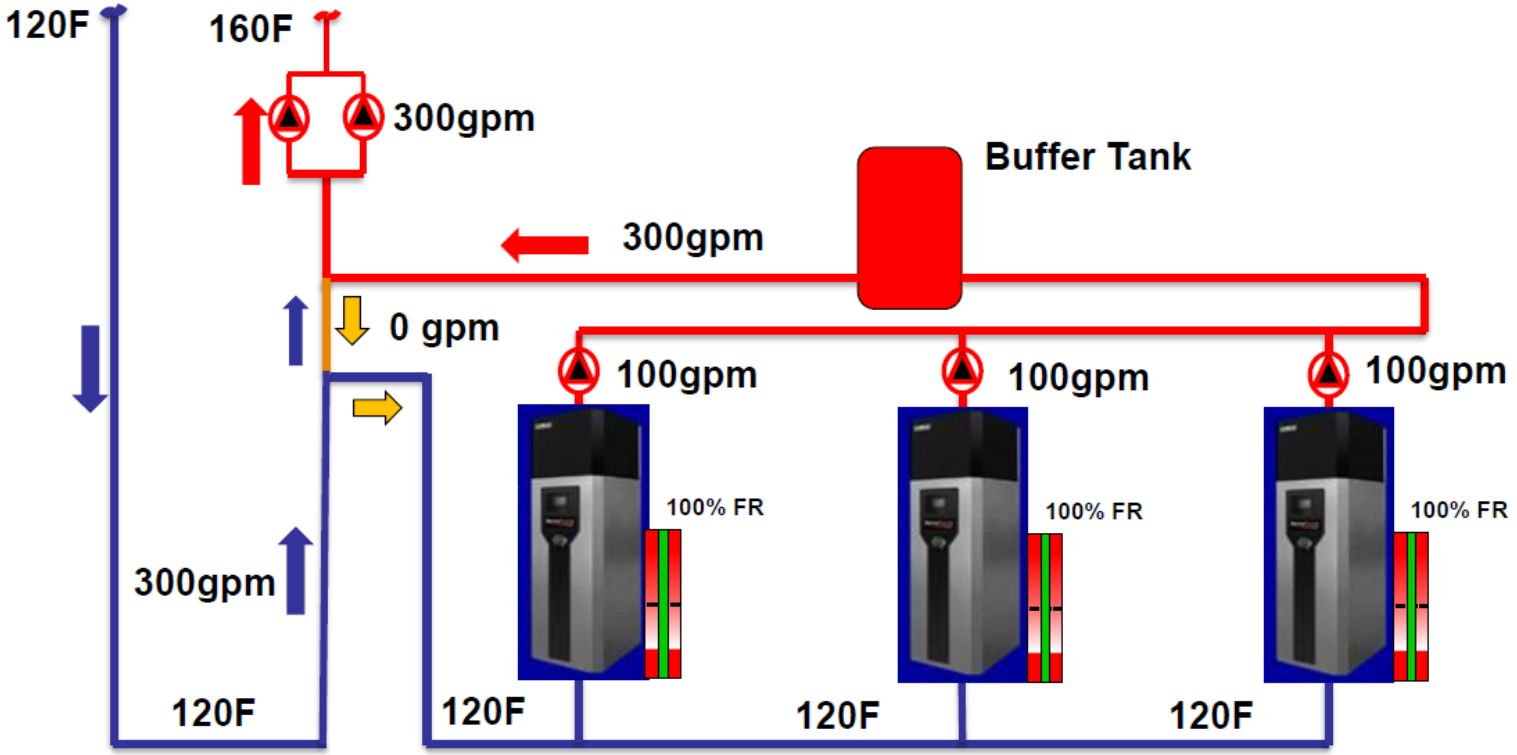
Benefits of Primary Variable Systems

Benefits of high mass boilers utilizing primary variable systems include:

- Less piping, no dedicated primary pump or buffer tank
- Increased overall system efficiency.
  - Save electrical energy required to run dedicated primary pump.
  - None of the efficiency penalties as related to fixed primary flow
    - No blending of primary and secondary loops (results in elevated return water temperatures)
    - Large mass allows modularity and lower firing rates

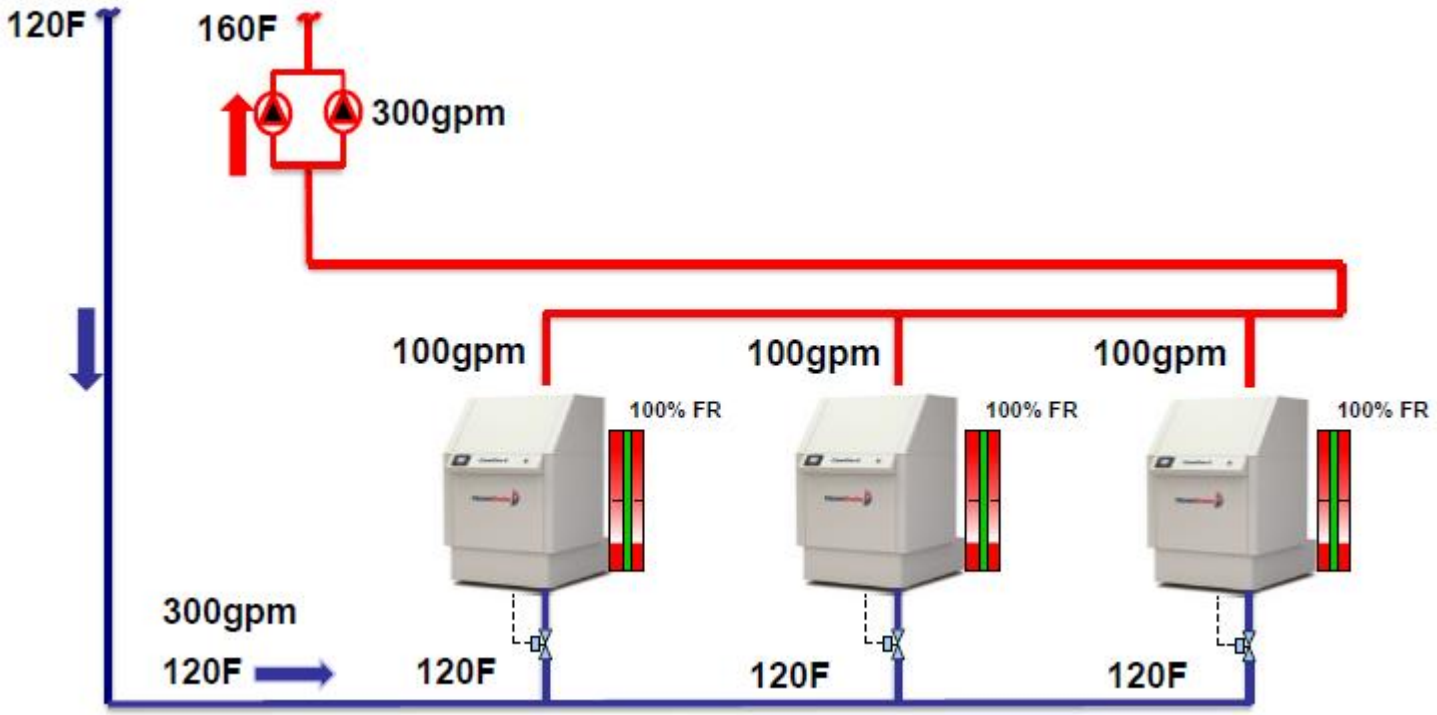
System Comparison: 100% Design Load

- Primary-Secondary: 100% Design Load = 6000 MBH



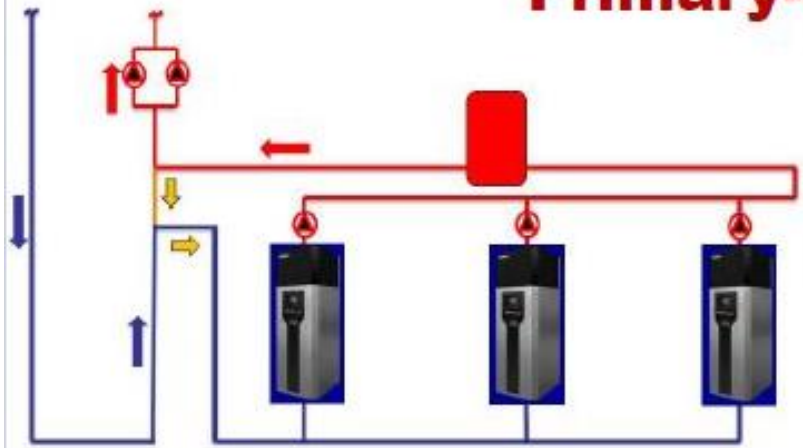
System Comparison: 100% Design Load

- Primary Variable: 100% Design Load = 6000 MBH



System Comparison: 100% Design Load

Primary-Secondary



Boiler Inlet Temperature: 120F
Boiler Firing Rate: 100%

Boiler Efficiency: 90%
Boiler Input: 6700 MBH

Pumping Energy: 10.5 HP

Variable Flow Primary w/ High Mass Boilers

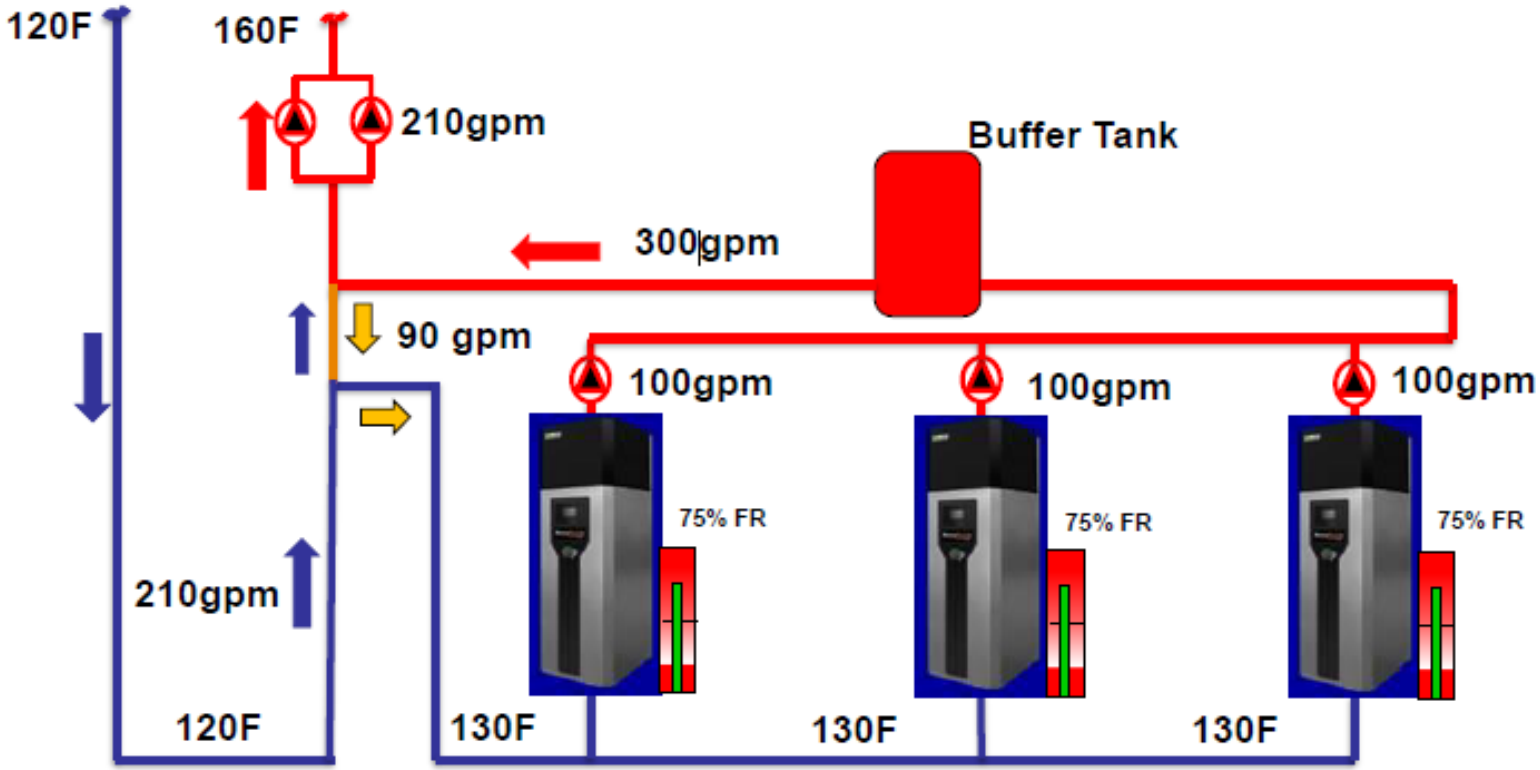
Boiler Inlet Temperature: 120F
Boiler Firing Rate: 100%

Boiler Efficiency: 90%
Boiler Input: 6700 MBH

Pumping Energy: 6.2 HP

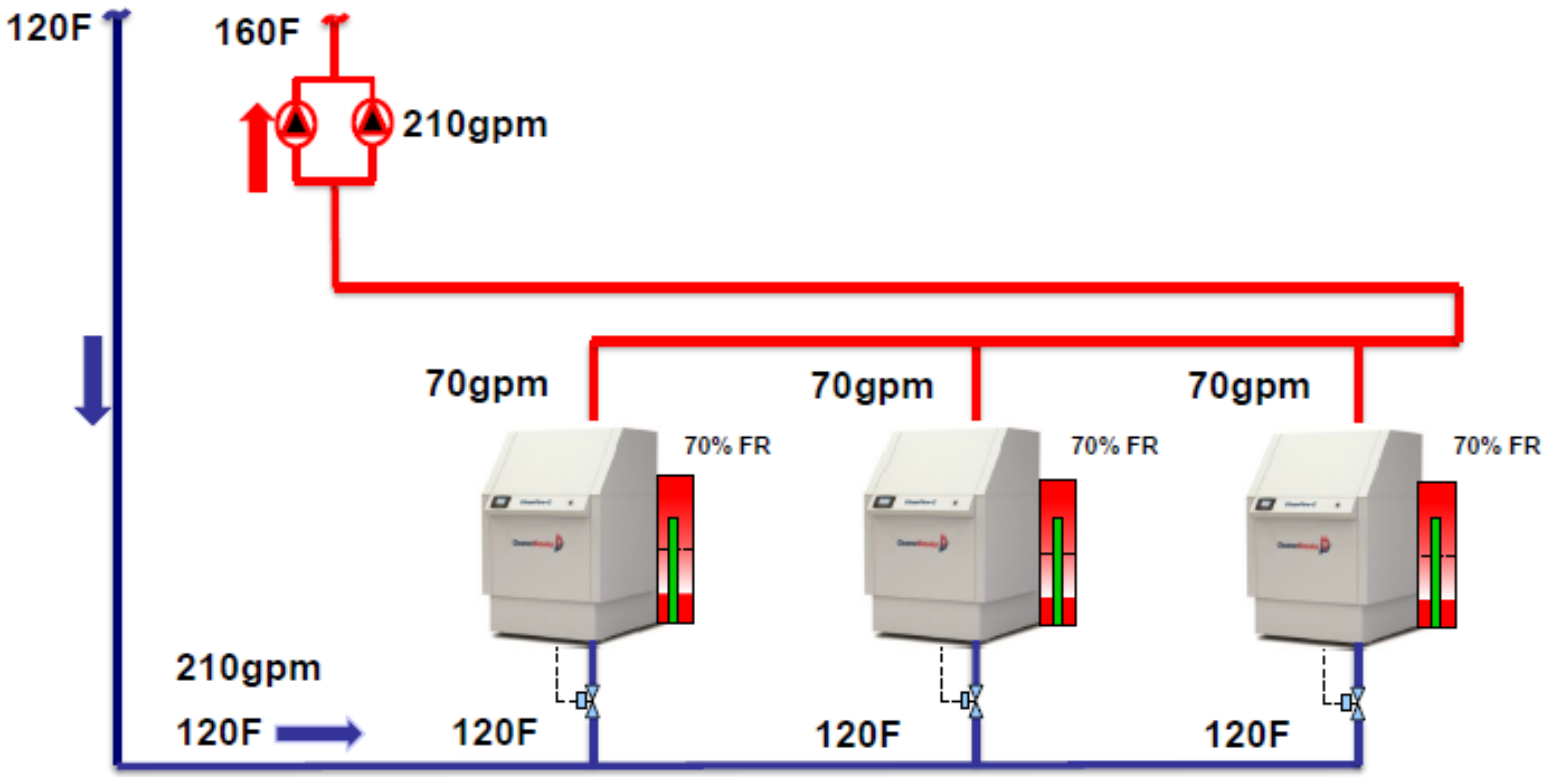
System Comparison: 70% Part Load

- Primary-Secondary: 70% Part Load = 4200 MBH



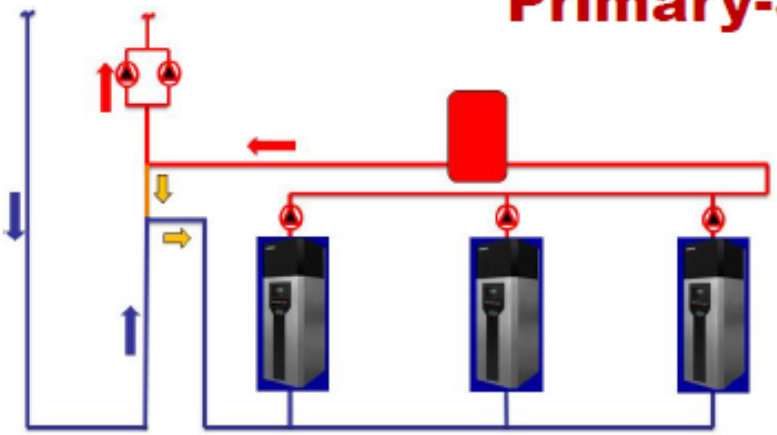
System Comparison: 70% Part Load

- Primary Variable: 70% Part Load = 4200 MBH



System Comparison: 70% Part Load

Primary-Secondary

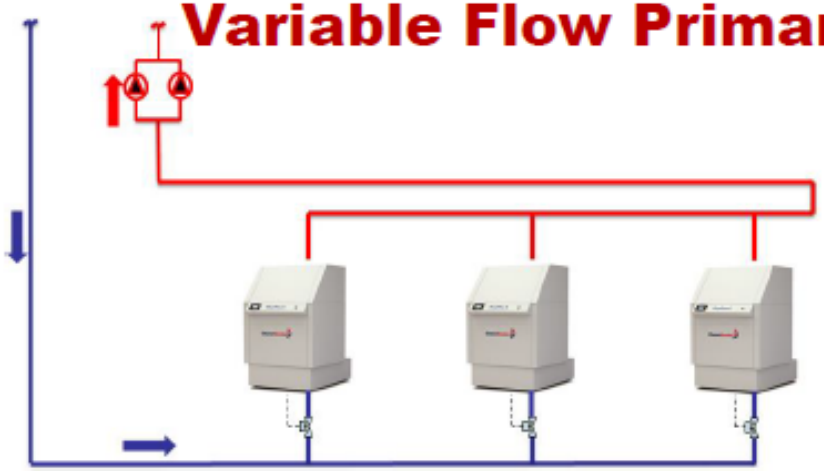


Boiler Inlet Temperature: 130F
Boiler Firing Rate: 75%

Boiler Efficiency: 88%
Boiler Input: 4775 MBH

Pumping Energy: 6.6 HP

Variable Flow Primary w/High Mass Boilers

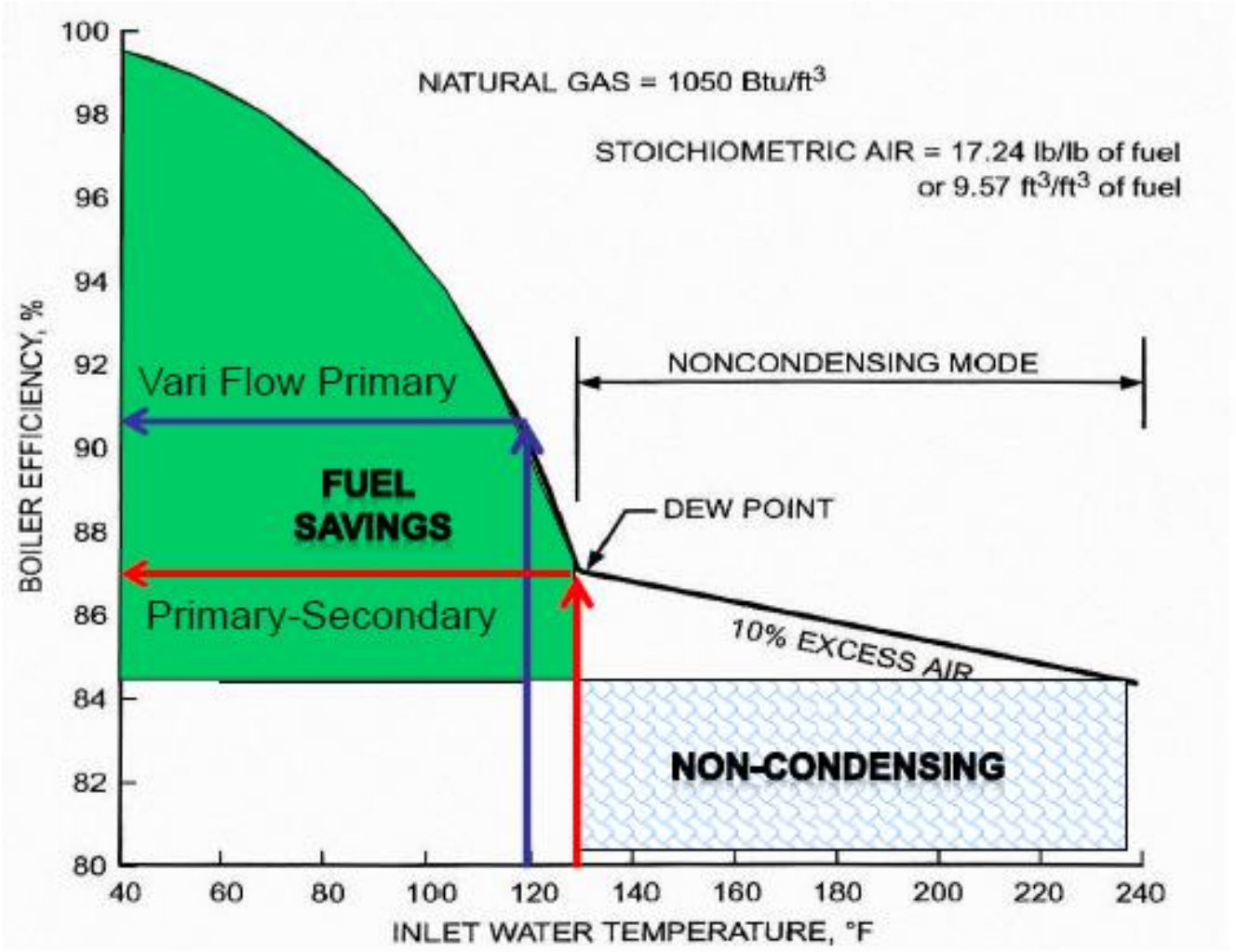


Boiler Inlet Temperature: 120F
Boiler Firing Rate: 70%

Boiler Efficiency: 91%
Boiler Input: 4600 MBH

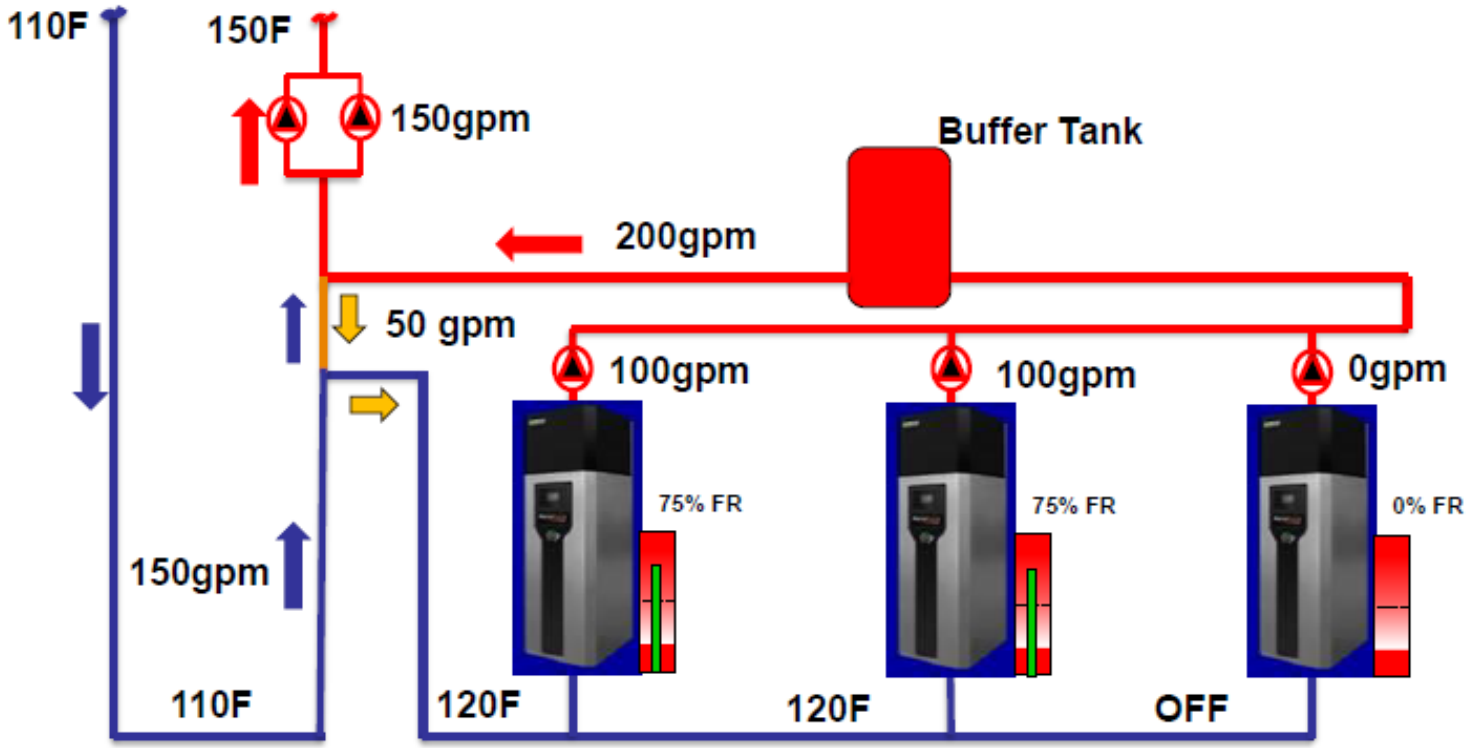
Pumping Energy: 2.1 HP

Impact of Higher Return Temp on Efficiency



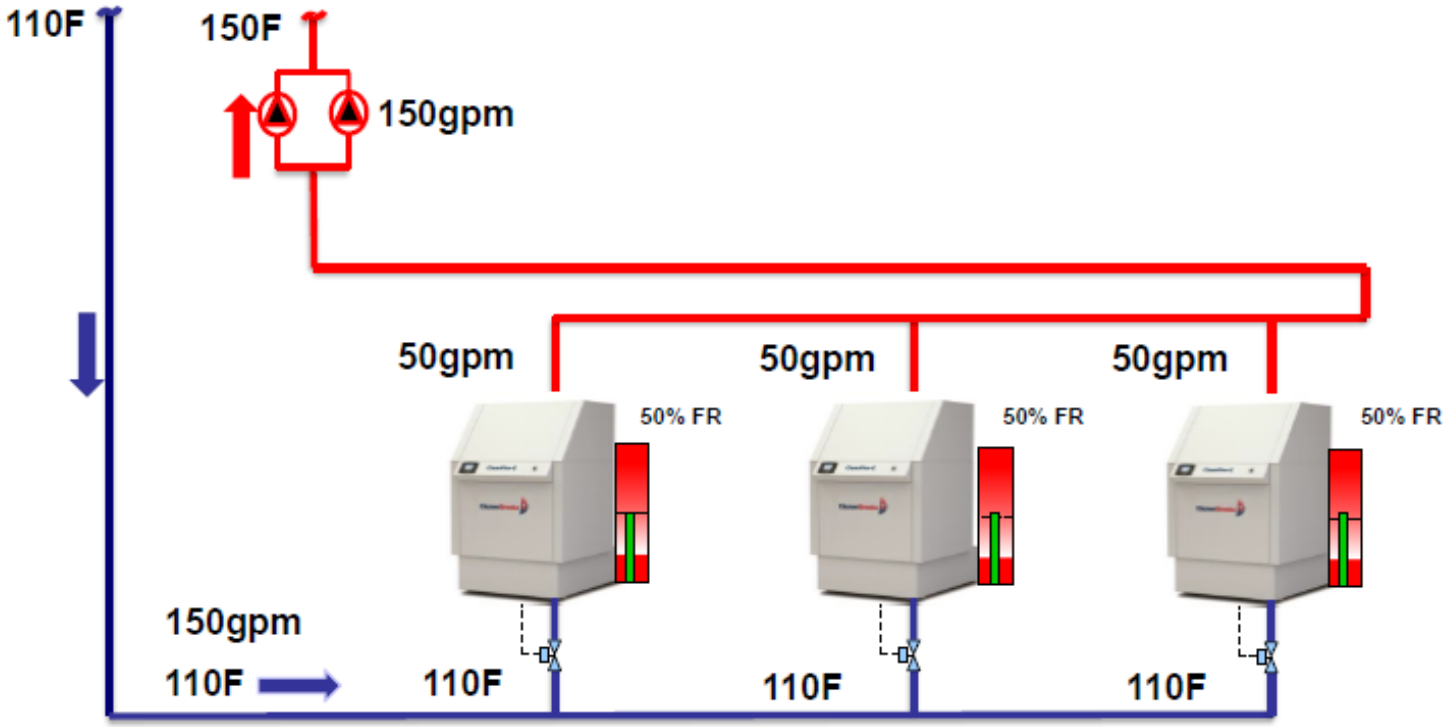
System Comparison: 50% Part Load

- Primary-Secondary: 50% Part Load w/ Outdoor Reset = 3000 MBH



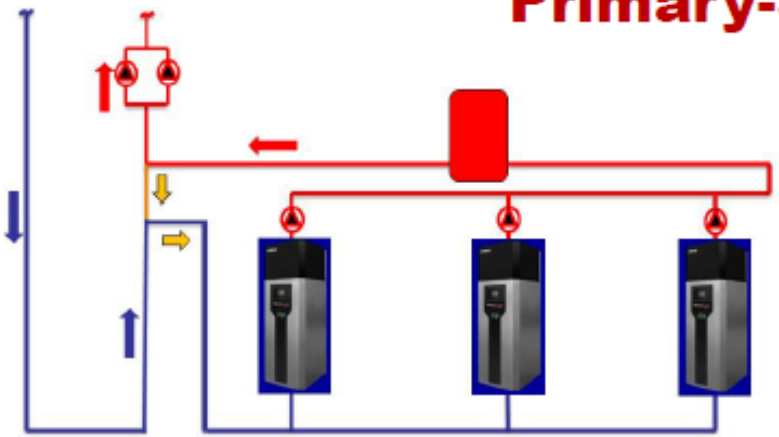
System Comparison: 50% Part Load

- Primary Variable: 50% Part Load w/ Outdoor Reset = 3000 MBH



System Comparison: 50% Part Load

Primary-Secondary

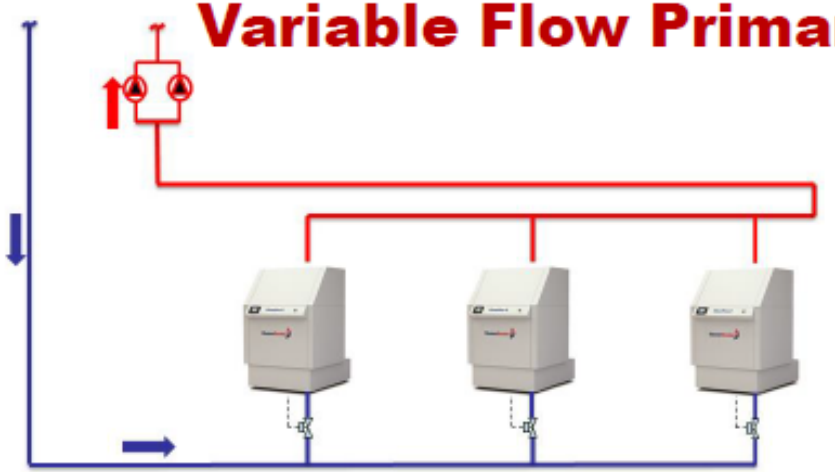


Boiler Inlet Temperature: 120F
Boiler Firing Rate: 75%

Boiler Efficiency: 90%
Boiler Input: 3330 MBH

Pumping Energy: 3.8 HP

Variable Flow Primary w/ High Mass Boilers



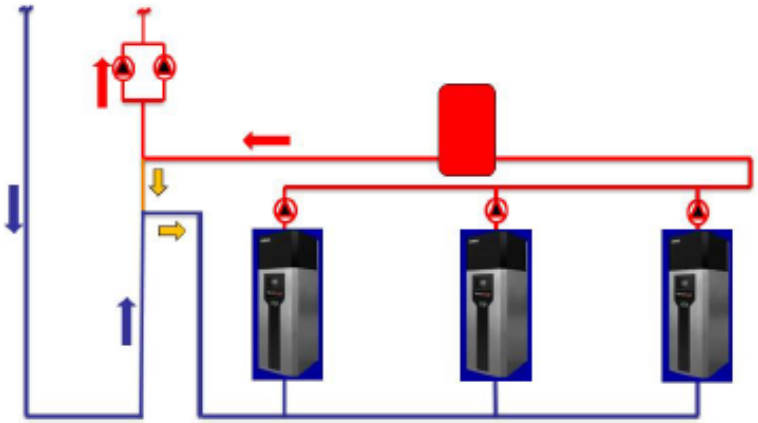
Boiler Inlet Temperature: 110F
Boiler Firing Rate: 50%

Boiler Efficiency: 93%
Boiler Input: 3225 MBH

Pumping Energy: 0.8 HP

System Comparison: 50% Part Load

Primary-Secondary w/ 3 boilers operating

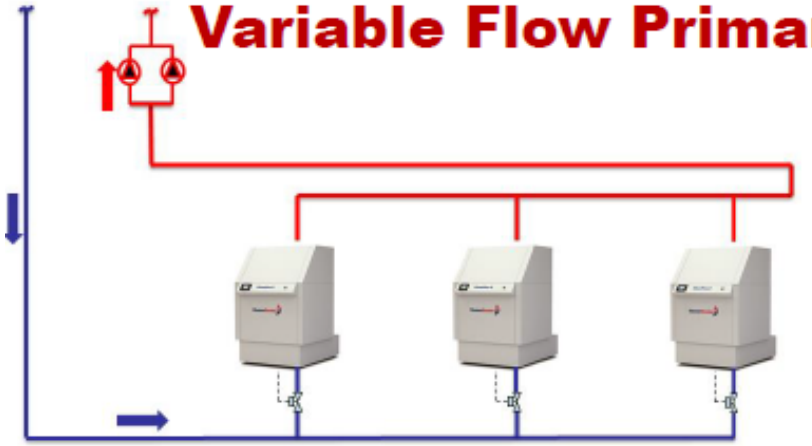


Boiler Inlet Temperature: 137F
Boiler Firing Rate: 55%

Boiler Efficiency: 88%
Boiler Input: 3400 MBH

Pumping Energy: 5.3 HP

Variable Flow Primary w/ High Mass Boilers



Boiler Inlet Temperature: 110F
Boiler Firing Rate: 50%

Boiler Efficiency: 93%
Boiler Input: 3225 MBH

Pumping Energy: 0.8 HP

Fireside Turndown vs. Waterside Turndown

- Boiler turndown of no benefit if it exceeds system turndown.
  - Plus, modular boiler configurations collectively have a higher turndown ratio
- Similarly, boiler minimum flow requirements limit ability to take advantage of high boiler turndown.
  - Once flow is at minimum, further turndown of boiler will force a lower delta T.

Example: High Turndown Boiler with Minimum Flow Requirement

- 1,000,000 BTU/HR input boiler
- Assume 92% efficiency, design delta T of 30°F
- Boiler has 20:1 turndown and minimum flow requirement of 25 gpm

Formula

$$Q = C_p \times m \times \Delta T$$

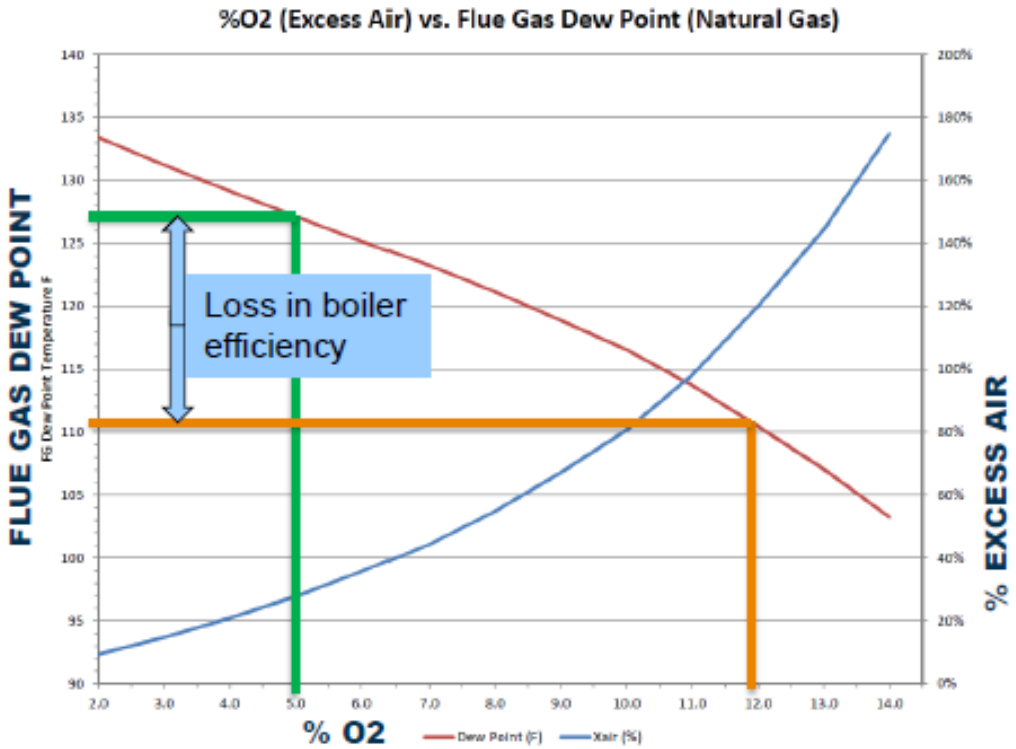
Design conditions at high fire:
920,000 = 8.34 x 60 x m x 30
m = 61.3 gpm

Keeping delta T constant:
Q = 8.34 x 60 x 25 x 30
Q = 375,300 BTU/HR
Turndown ratio = 2.5:1

Applying 20:1 turndown:
46,000 = 8.34 x 60 x 25 x ΔT
ΔT is only 3.7°F

Excess Air & Dew Point

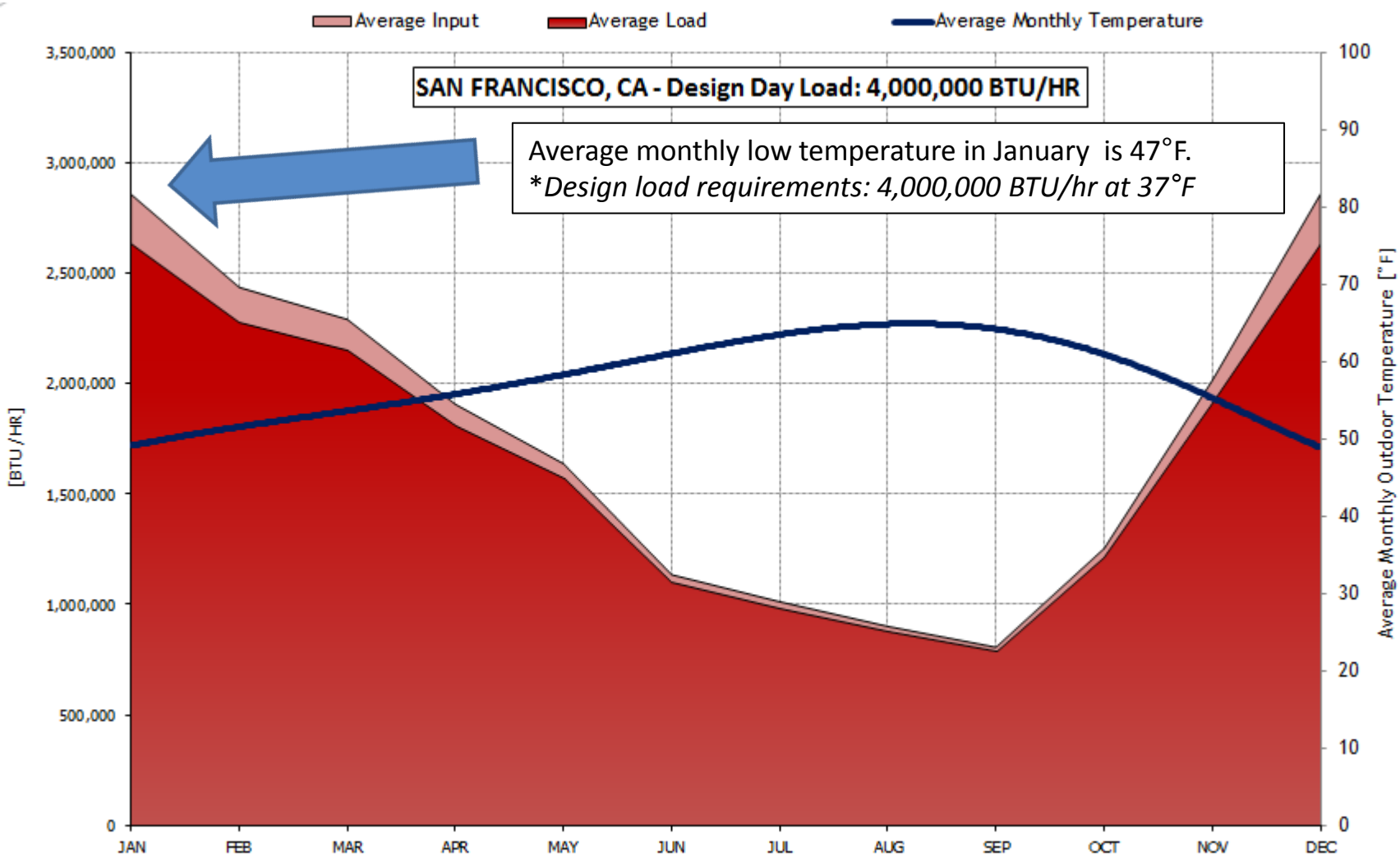
- High turndown burners typically have high excess air at low firing rates
- Negative relationship between excess air and dew point



Hybrid Retrofit

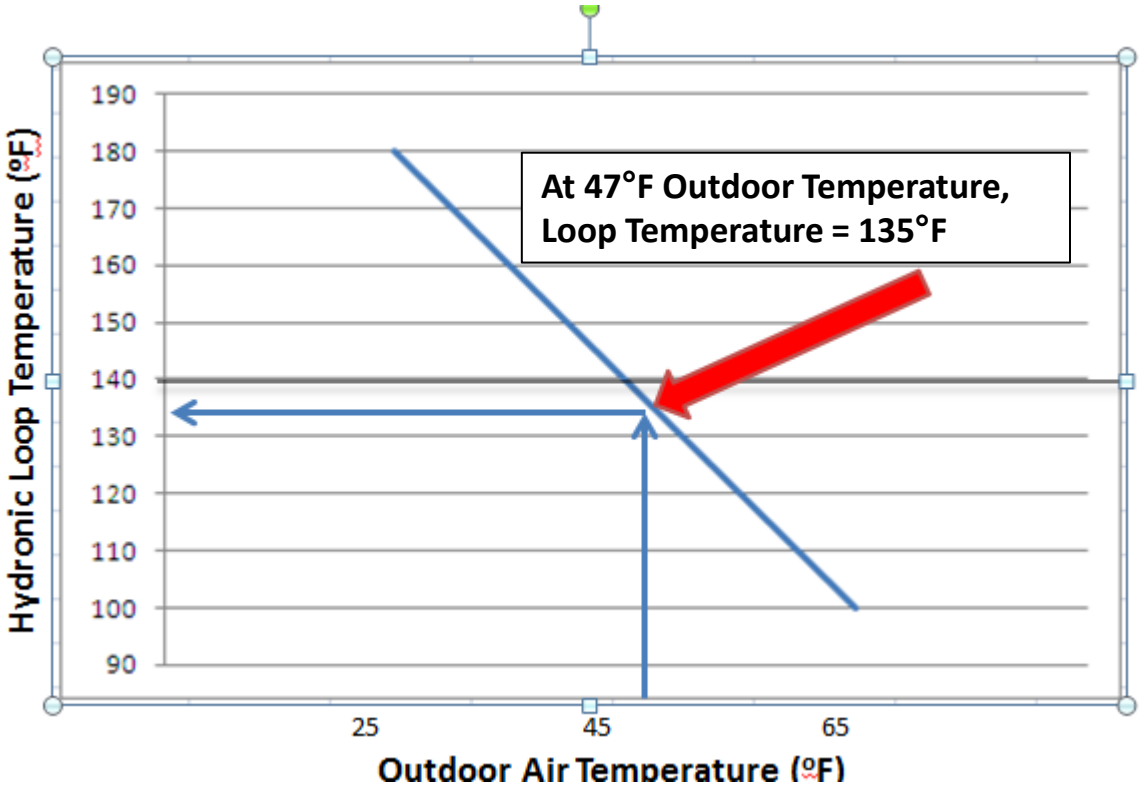
- Hybrid systems allow for much better return on investment as well as flexibility on project size.
  - Replace just a portion of the existing equipment.
  - During daily or seasonal low load periods – shut down the primary boiler plant

Condensing Boilers Sized Based on Shoulder Loads

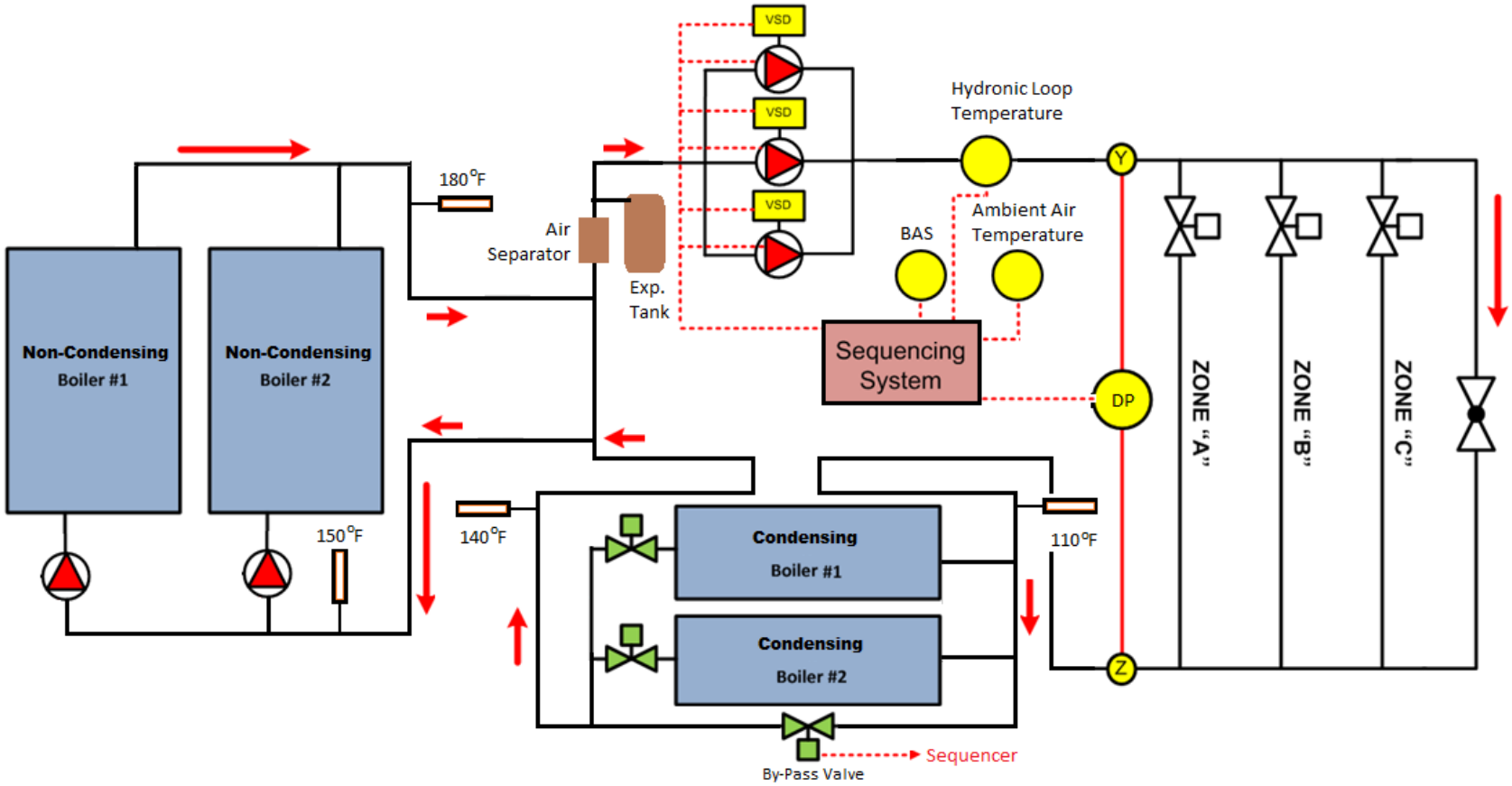


Outdoor Reset Schedule

January is San Francisco's coldest month.



Hybrid Retrofit: Primary Variable



Why Use a Hybrid System?

- Savings for owners
  - Initial costs
  - Operating costs
  - Reduce excessive fuel consumption
  - Take advantage of outdoor reset
- Alternate fuel back-up (e.g., oil)
- Improve ambient comfort throughout the heating season
- Operate the system more efficiently through proper controls

Thank You

Thank you for your time!

Questions?