Existing Building Commissioning Series Workshop

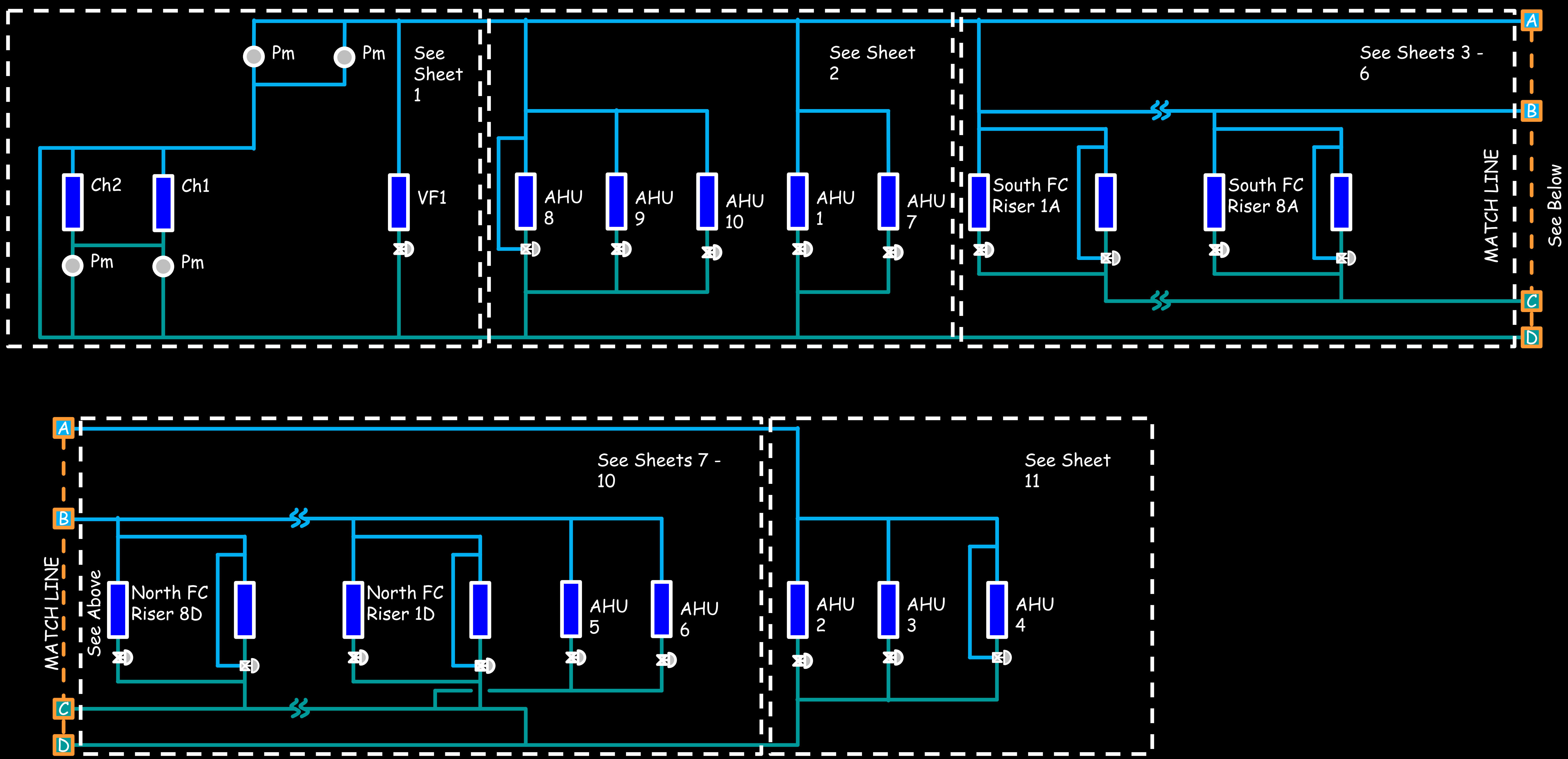
Sessions 3 and 4

Presented By:

David Sellers

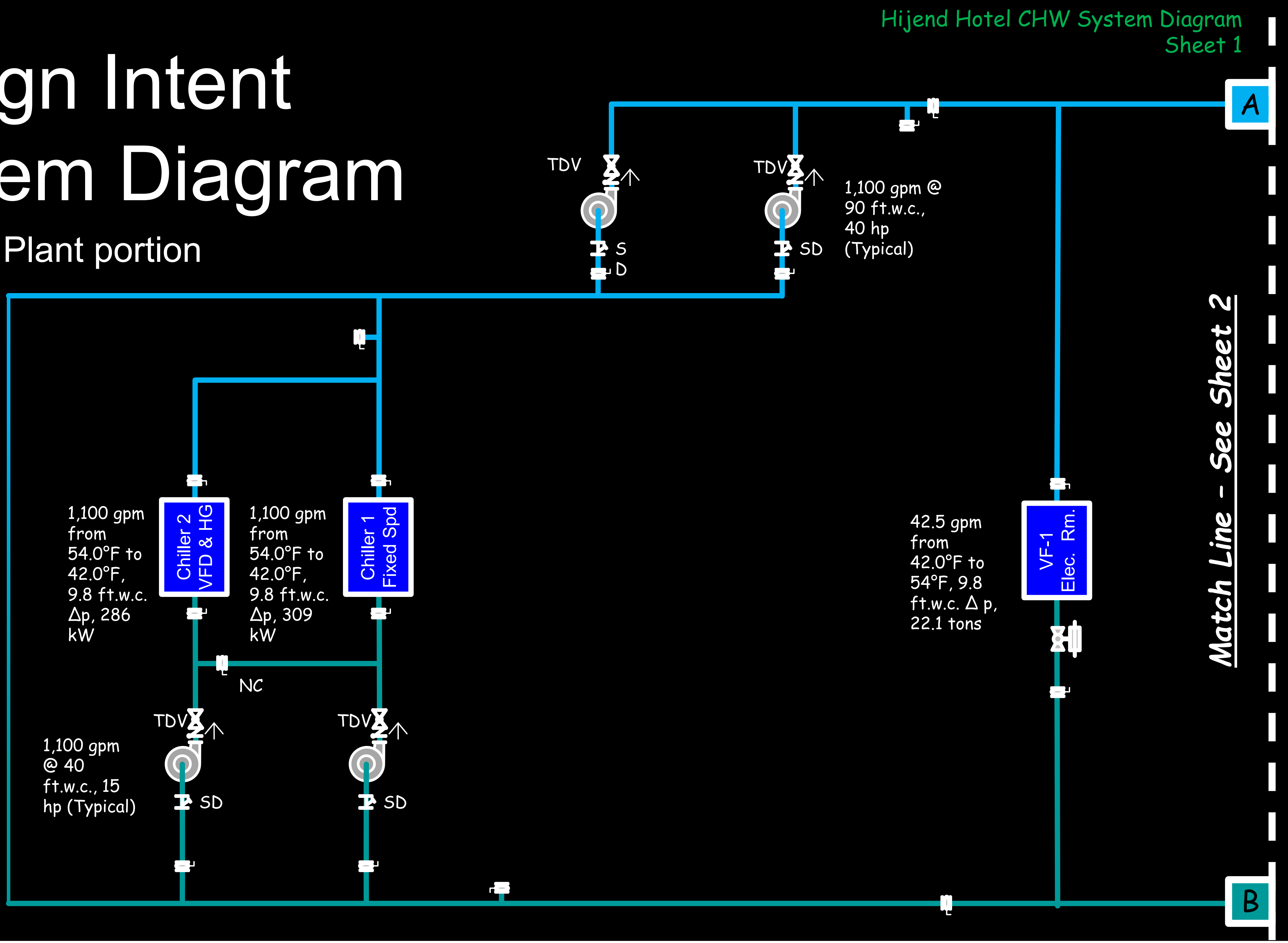
Senior Engineer, Facility Dynamics Engineering

The Simplified Design Intent System Diagram

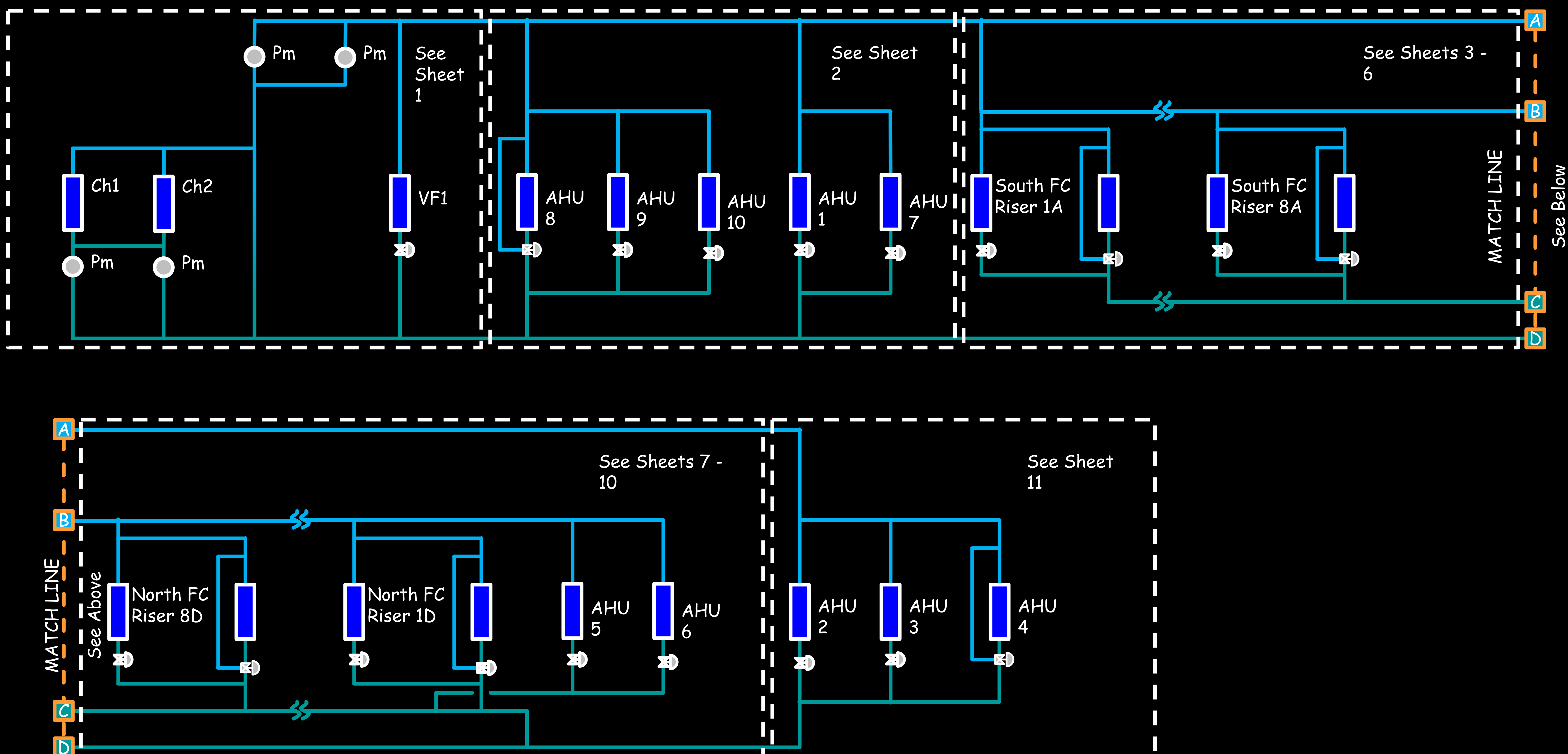


Design Intent System Diagram

- Central Plant portion

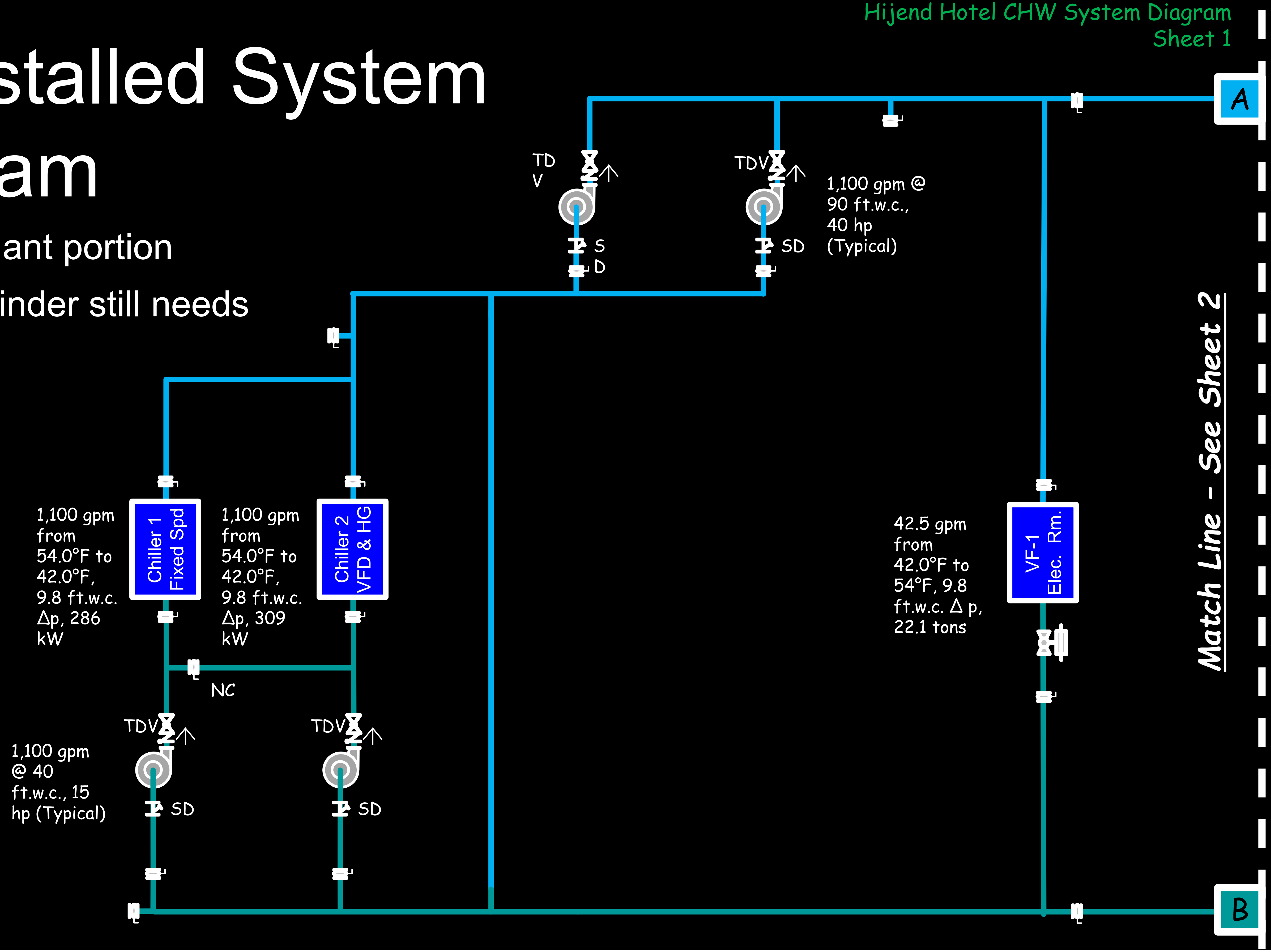


The Simplified As Installed System Diagram



As Installed System Diagram

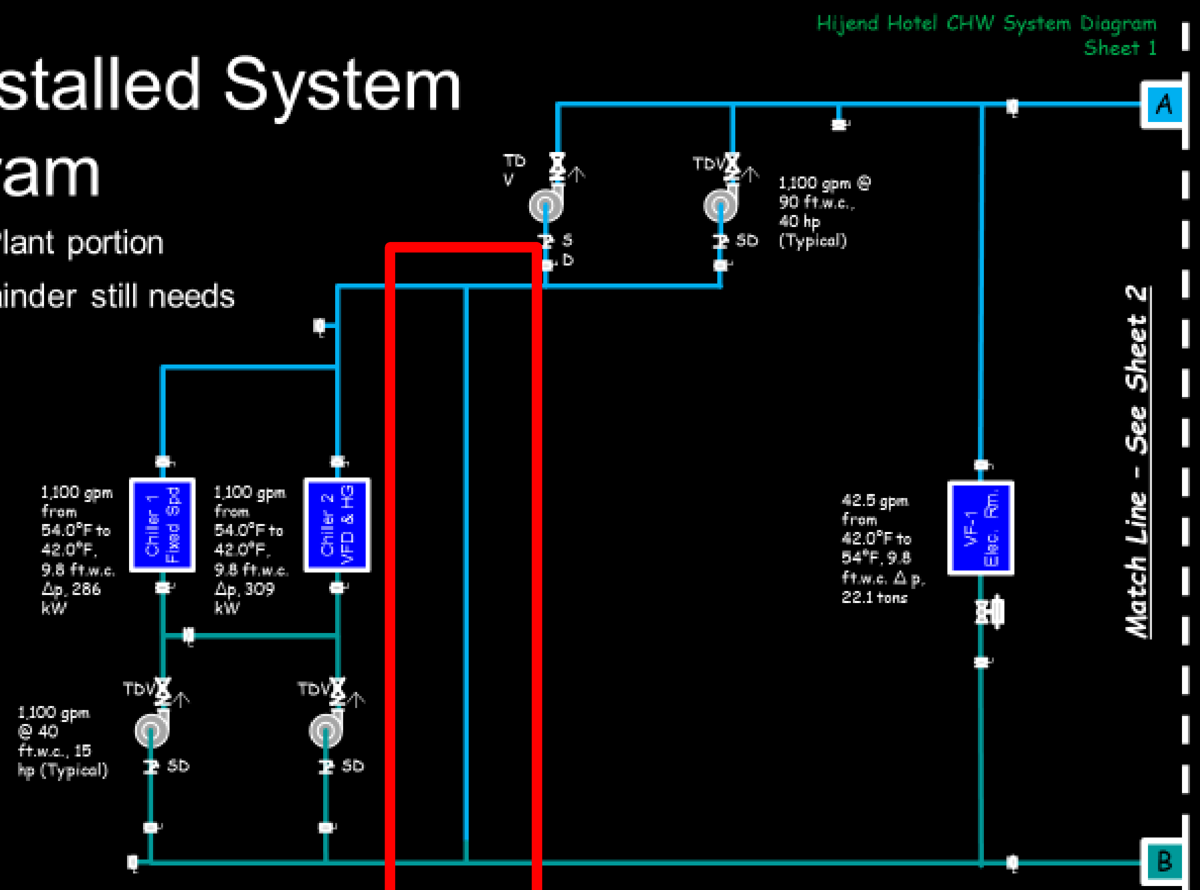
- Central Plant portion
- The remainder still needs verified



Does the Design Intent Match Reality?

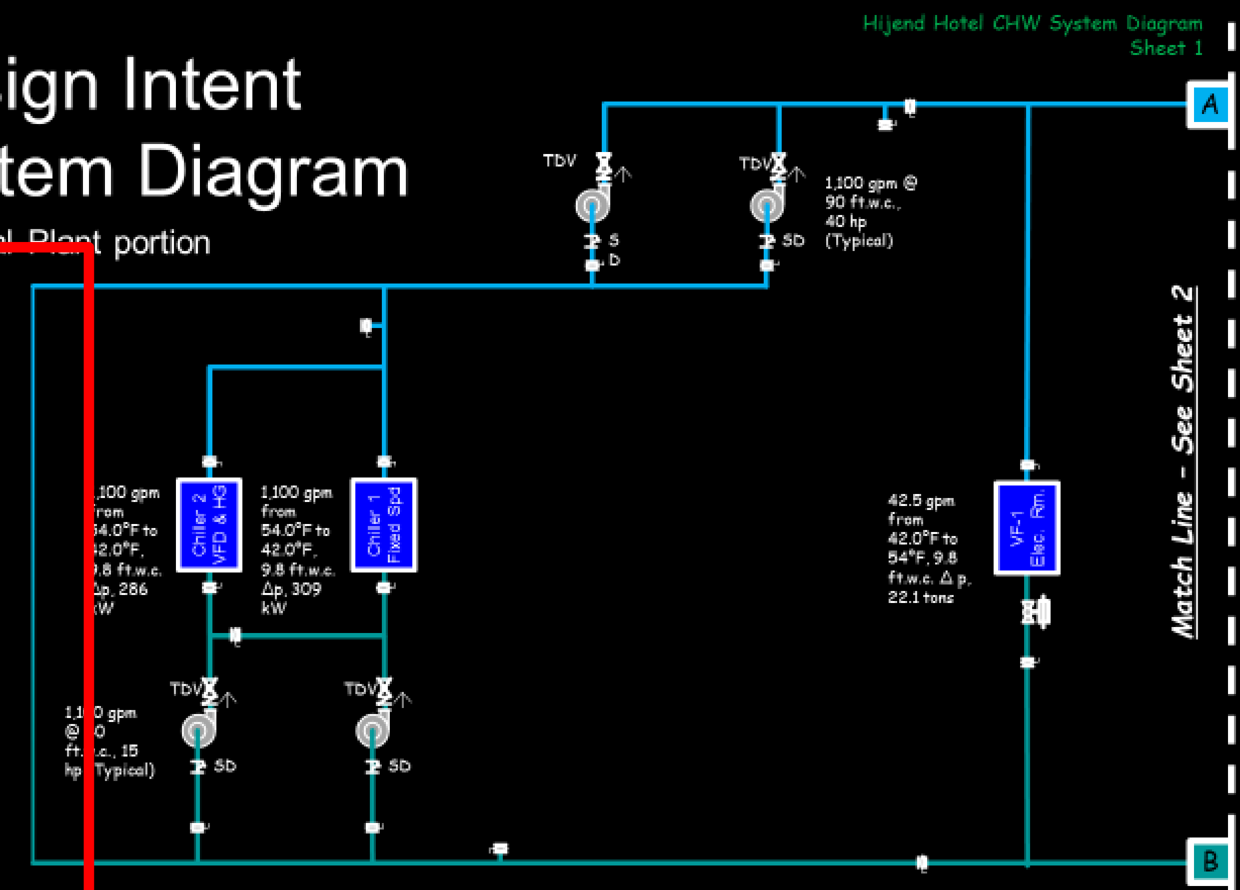
As Installed System Diagram

- Central Plant portion
- The remainder still needs verified



Design Intent System Diagram

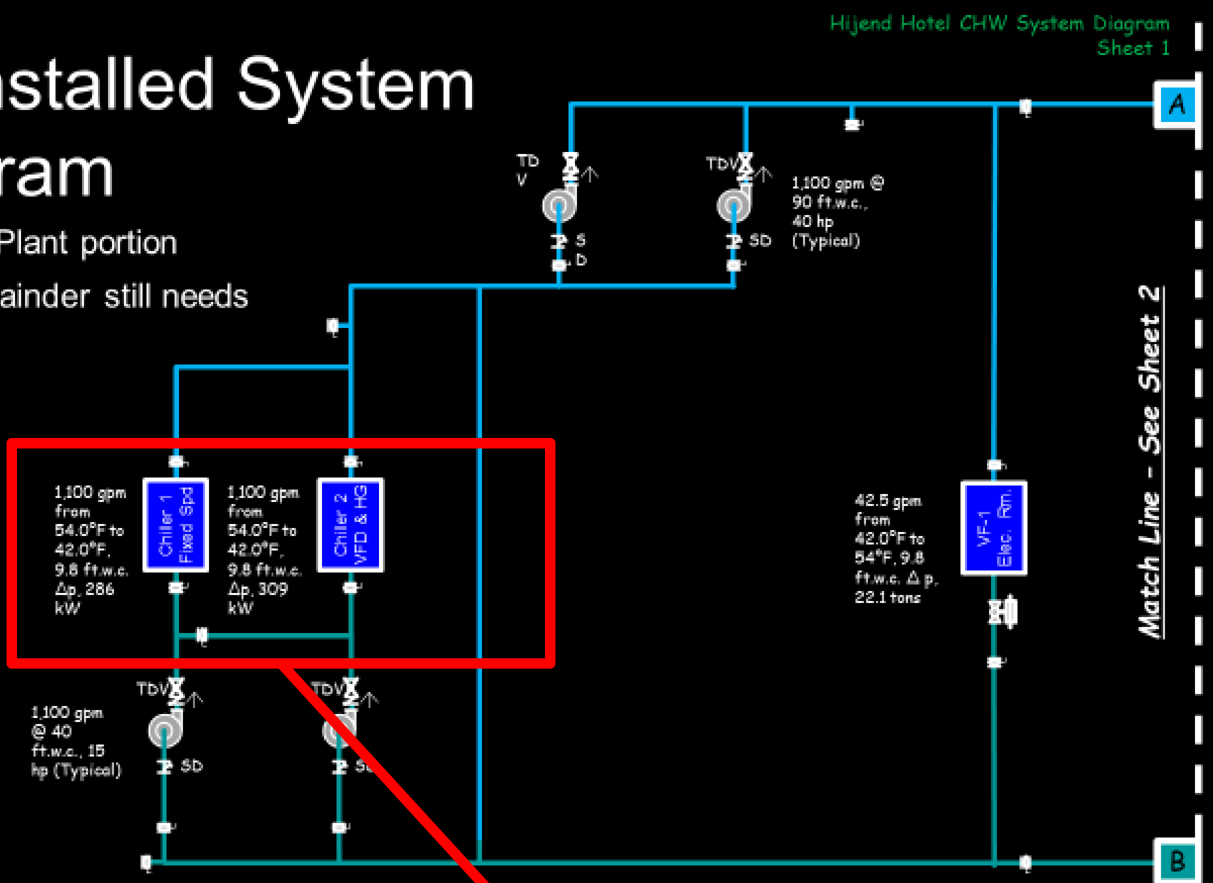
- Central Plant portion



The location of the bypass relative to where the chillers connect to the return main is different

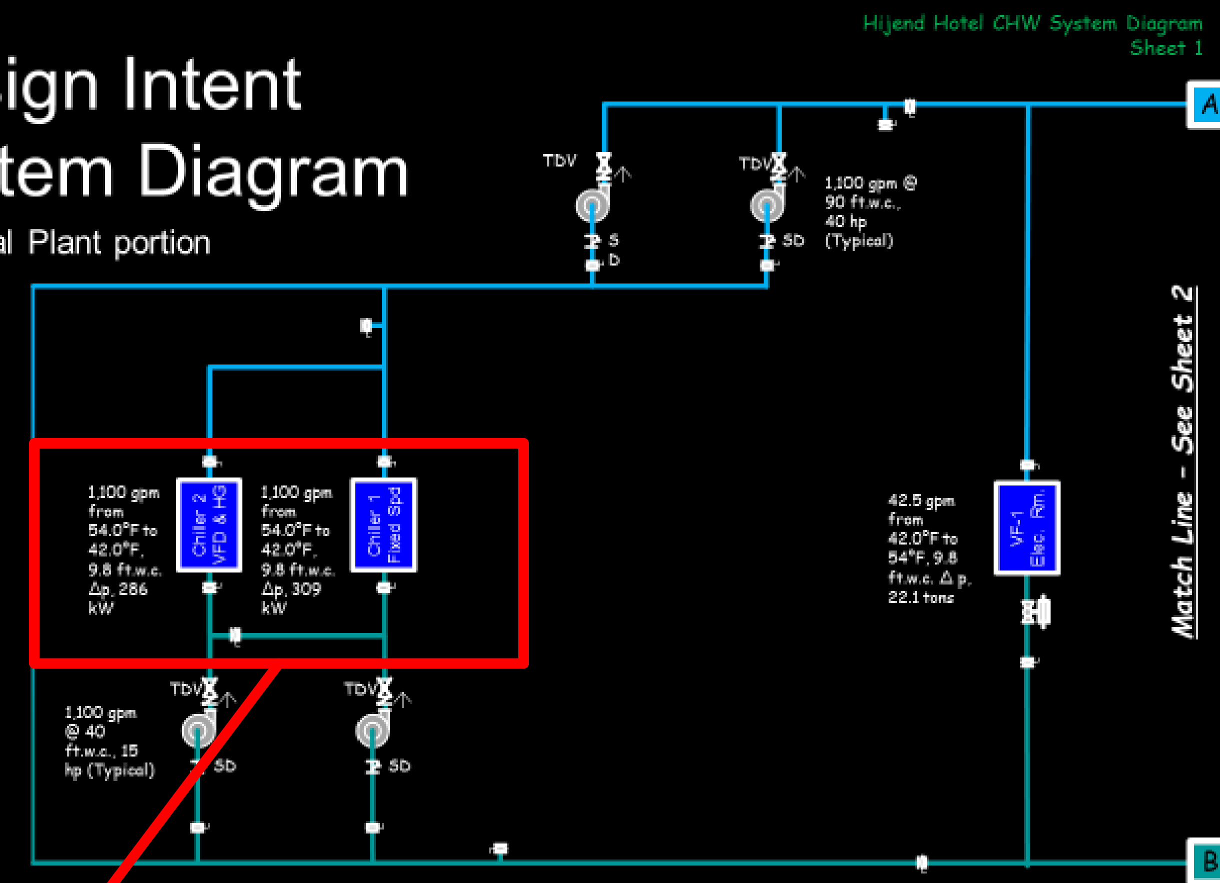
As Installed System Diagram

- Central Plant portion
- The remainder still needs verified



Design Intent System Diagram

- Central Plant portion

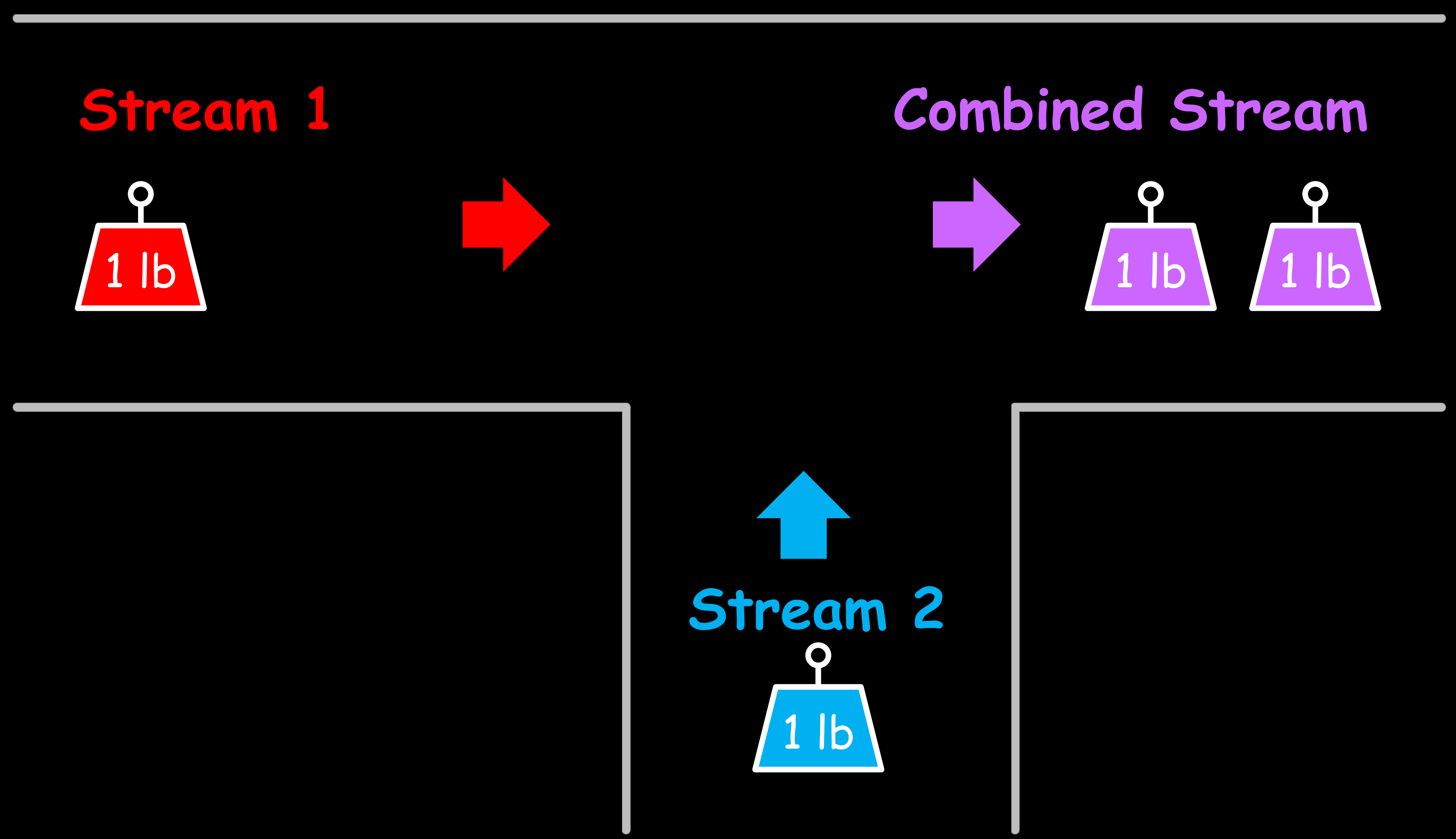


The order of connection of the chillers relative to the return mains is different

Nodes in HVAC

1. Nodes are points:
   a. Where two or more fluid streams meet at a common point and combine into one or more fluid stream leaving the common point
   b. Where a fluid stream diverges from a common point into two or more fluid streams
2. Examples
   - Tees in pipes and ducts
   - Mixed air plenums
3. Conservation of mass applies
4. Conservation of energy applies

Conservation of Mass at a Node



Conservation of Mass at a Node

$$\dot{m}_{Stream1} + \dot{m}_{Stream2} = \dot{m}_{CombinedStream}$$

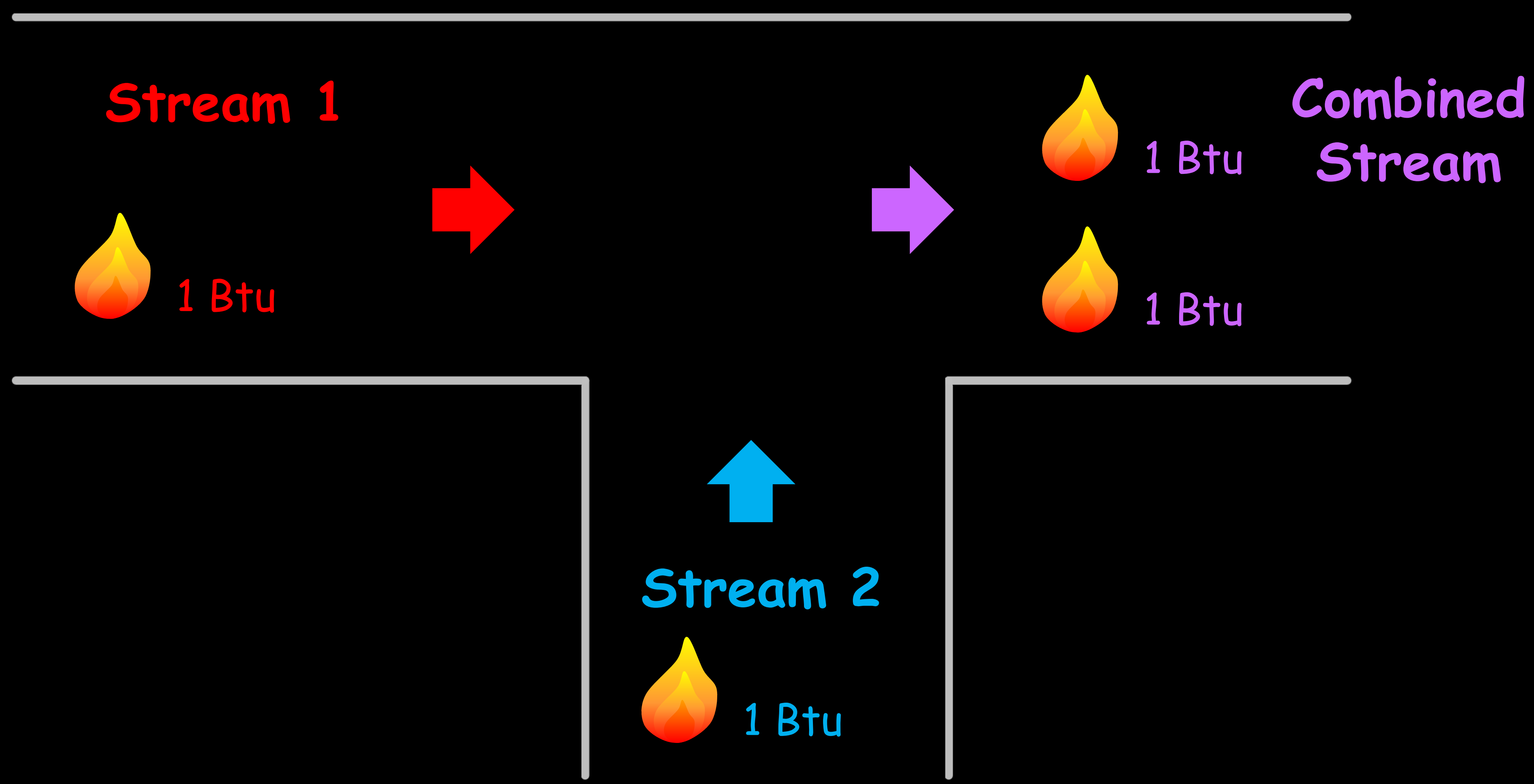
Where:

$\dot{m}_{Stream1}$ = Mass flow rate for stream 1 in consistent units

$\dot{m}_{Stream2}$ = Mass flow rate for stream 2 in consistent units

$\dot{m}_{CombinedStream}$ = Mass flow rate for stream 3 in consistent units

Conservation of Energy at a Node



This is the first law of thermodynamics

Conservation of Energy at a Node

$$Q + u_1 + \frac{p_1 v_1}{J} + \frac{z_1}{J} + \frac{V_1^2}{2gJ} = \frac{W}{J} + u_2 + \frac{p_2 v_2}{J} + \frac{z_2}{J} + \frac{V_2^2}{2gJ}$$

Where:

Q = Heat in Btu/lb

W = Shaft work, ft-lb/lb

u = Internal energy, Btu/lb

pv = Flow work; pressure in lb/ft^2 x specific volume in ft^3/lb, ft-lb/lb

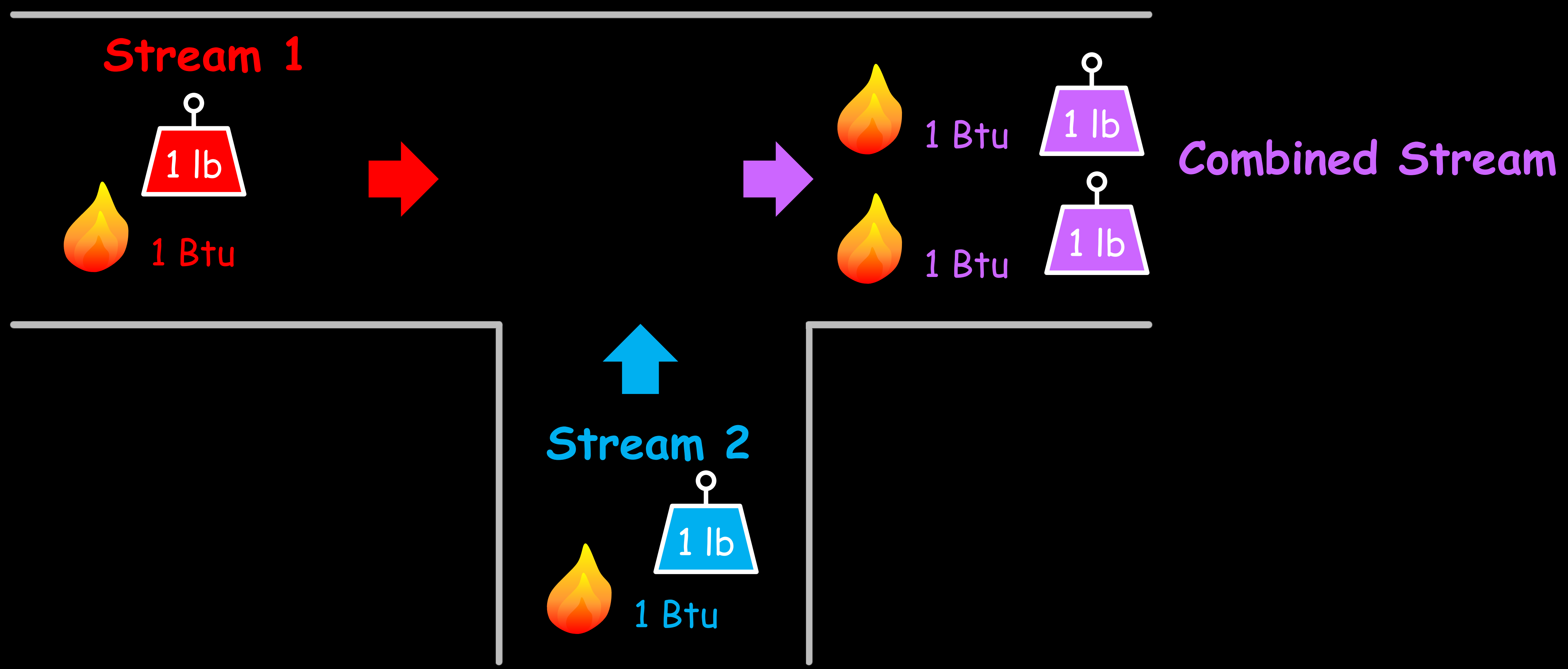
J = Mechanical equivalent of heat; 778 ft-lb/Btu

V = Velocity in feet per second

g = gravitational constant, 32 ft/sec/sec

This is the first law of thermodynamics stated mathematically

Conservation of Mass and Energy At a Node



Conservation of Mass and Energy at a Node

$$\bar{Q} + \sum_1 \left[\dot{m} \times \left(u_1 + \frac{p_1 v_1}{J} + \frac{z_1}{J} + \frac{V_1^2}{2gJ} \right) \right] = \frac{\bar{W}}{J} + \sum_2 \left[\dot{m} \times \left(u_2 + \frac{p_2 v_2}{J} + \frac{z_2}{J} + \frac{V_2^2}{2gJ} \right) \right]$$

Where the bar over the Q and W terms ($\bar{Q}$ and $\bar{W}$) means that the heat transfer and/or work are being done at some sort of rate, like Btu/hr or ft-lb/hr, and the dot over the m term ($\dot{m}$) means a mass flow rate, like pounds per hour.

The $\sum$ symbol means that the parameters inside the parenthasis are totalled up for all of the fluid streams on each side of the equation.

Conservation of Mass and Energy at a Node - *Simplified*

$$\left(Temperature_{Stream1} \times Flow_{Stream1}\right) + \left(Temperature_{Stream2} \times Flow_{Stream2}\right) = \left(Temperature_{Stream3} \times Flow_{Stream3}\right)$$

Where temperatures and flows are in consistent units

Conservation of Mass and Energy at a Node - Simplified

$$\left(Temperature_{Stream1} \times Flow_{Stream1}\right) + \left(Temperature_{Stream2} \times Flow_{Stream2}\right) = \left(Temperature_{Stream3} \times Flow_{Stream3}\right)$$

Where temperatures and flows are in consistent units

This relationship can be applied at nodes in pipe and duct systems to help us understand how a system works under different operating conditions

For more details see http://tinyurl.com/OAPctDerived

An Example

Using node analysis to understand how the Hijend Hotel central chilled water plant works in the design intent configuration.

An Assumption We Will Make

1. The design theory for a variable flow system is that the flow will vary directly with the load as can be seen from the water side load equation.

$$Q_{Btu/Hr} = 500 \times Flow_{gpm} \times \left(t_{Entering,\circ F} - t_{Leaving,\circ F}\right)$$

2. Thus, in theory, the temperature rise across a variable flow chilled water load will hold constant and the flow rate will vary in a linear fashion with the load; 50% load would correspond with 50% flow, etc.

An Assumption We Will Make

3. For a cooling coil, the heat transfer from the air stream into the chilled water will be driven by the temperature difference between the chilled water and the air as they pass through the coil.
4. For a 100% outdoor air system, the entering air conditions on the design day will be significantly different from what they are on a mild day.
5. Thus, the force driving heat transfer from the air to the chilled water will vary with the outdoor conditions, even if the chilled water temperature is held constant through the seasons.

An Assumption We Will Make

6. As a result of item 5, the performance of the coil in terms of flow variation with load will deviate from the linear relationship implied by the waterside load equation.
7. In turn the temperature rise across the coil will not hold constant and will vary with the load condition:
   a. Especially at low load conditions, and
   b. Especially when the entering air condition approaches the leaving air condition

An Assumption We Will Make

The phenomenon described in the preceding slides is one of the major reasons that variable flow primary/secondary chilled water systems have a tendency towards “low delta t” syndrome. For more information on this visit the following link.

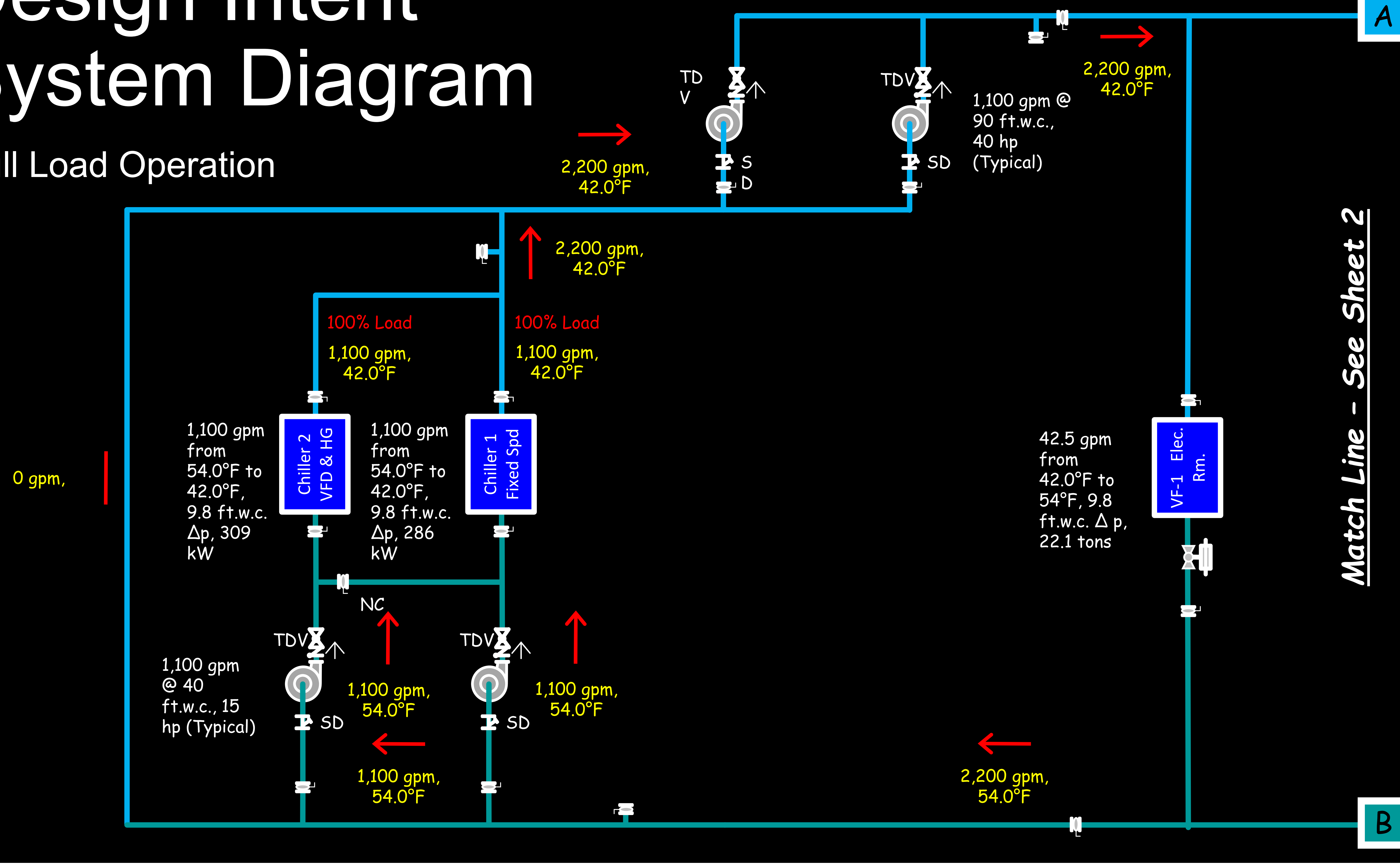
http://tinyurl.com/VariableFlow

For the purposes of our discussion, we will assume that the load temperature rise holds constant, which will tend to be true at the load conditions we will consider.

Hijend Hotel CHW System Diagram
Sheet 1

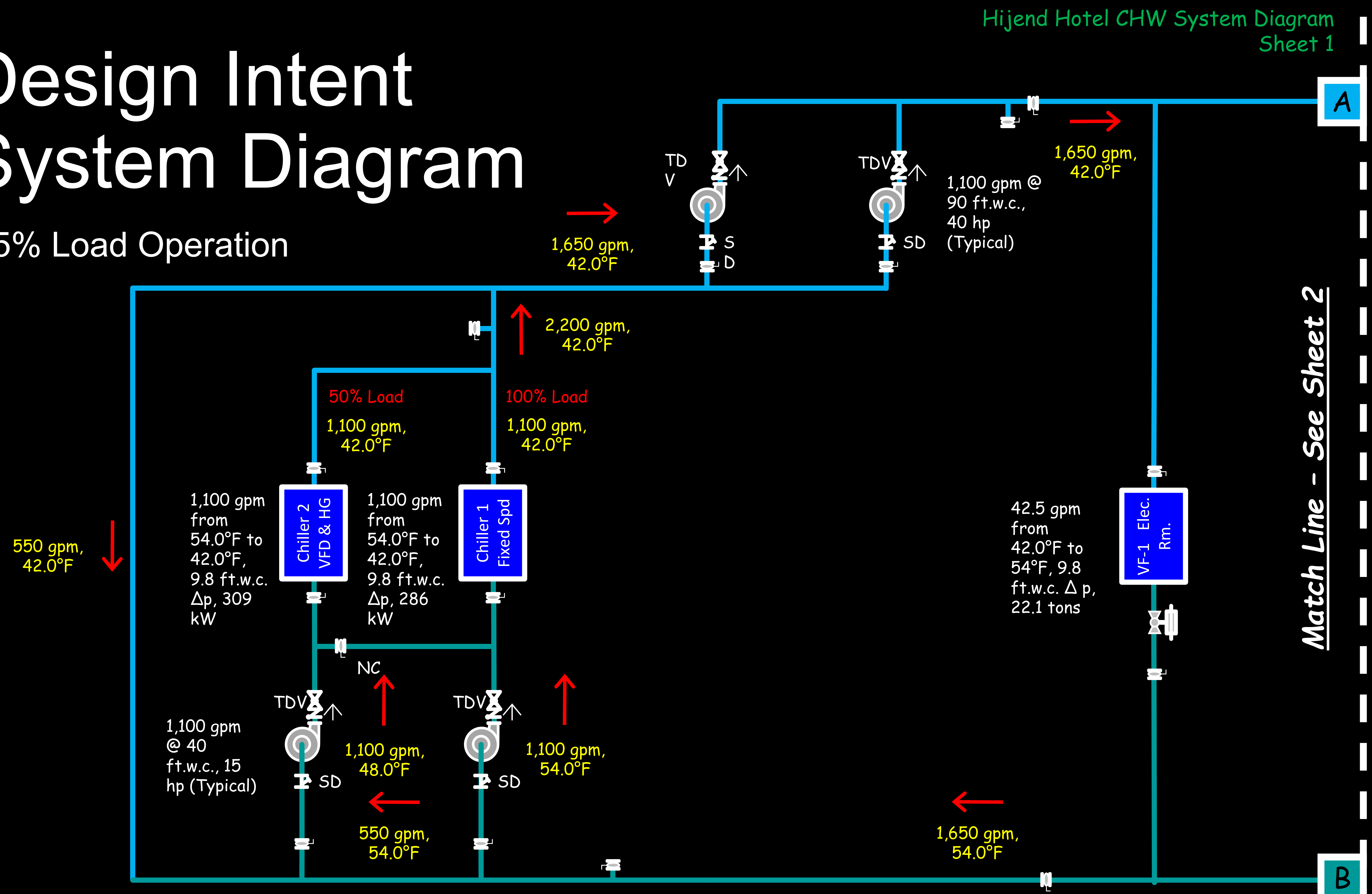
Design Intent System Diagram

Full Load Operation



Design Intent System Diagram

75% Load Operation



Key Points

At part load, due to the configuration of the plant, Chiller 1 continues to run at full load while Chiller 2 carries the load swings:

1. Chiller 1 has better full load efficiency than Chiller 2 because it does not have a VFD.
2. Chiller 2 has better part load efficiency because of the VFD.
3. Chiller 2 has better turn down capability because of the VFD and hot gas bypass.

Bottom Line

This piping configuration exploits the characteristics of each of the chillers to optimize plant efficiency and turn down capabilities.

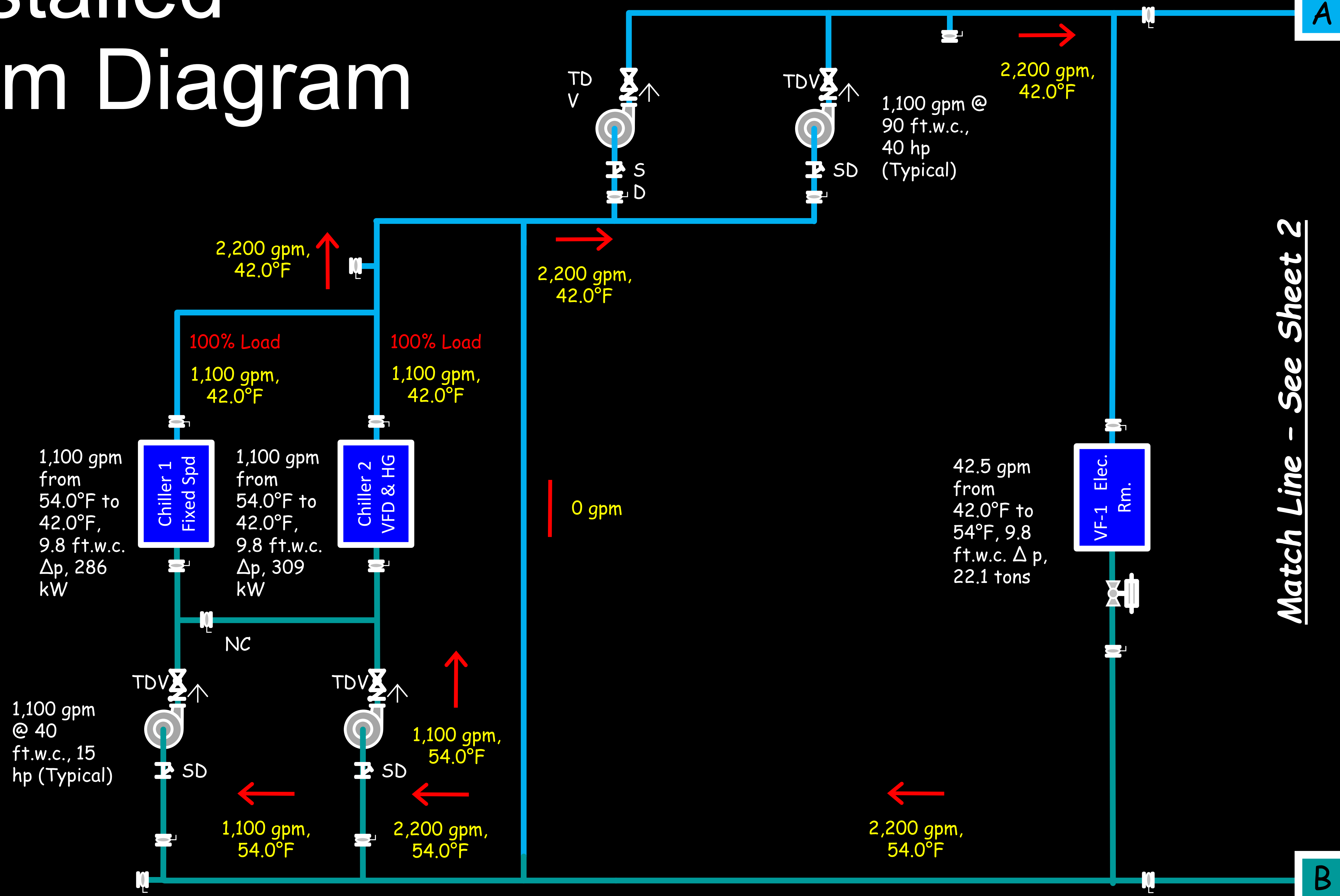
Now A Contrast

Using node analysis to understand how the Hijend Hotel central chilled water plant works in the as installed configuration.

Hijend Hotel CHW System Diagram
Sheet 1

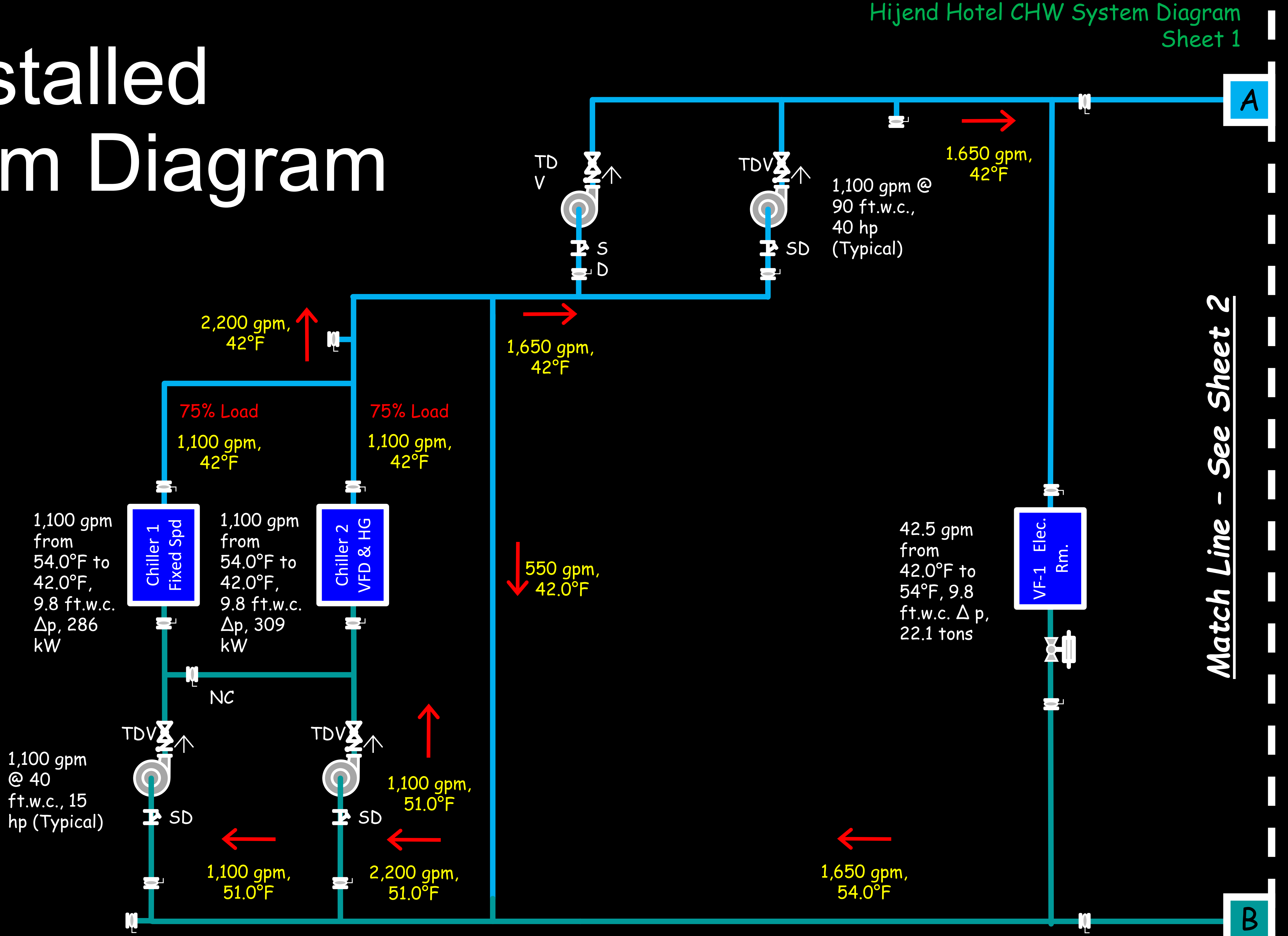
As Installed System Diagram

100% load



As Installed System Diagram

75% load



Key Points

Even though the as installed plant operation at full load is identical to the design intent, as the load drops off there are differences relative to the design intent:

1. Both chillers unload at the same rate.
2. Thus, the full load and part load capabilities of each of the chillers are not taken advantage of.
   a. Part load plant efficiency may be compromised.
   b. Chiller 1 will likely short cycle when it is the lead chiller at low load conditions.

Bottom Line

This piping configuration does not fully realize the design intent, resulting in higher energy consumption do to lower part load efficiency and more wear and tear on chiller1 when it operates at low load conditions.

Experience suggests that the wear and tear on chiller 1 could increase the overhaul cost by 50% or more compared to chiller 2.