System Diagram Workshop

Basic Principles

Presented By:
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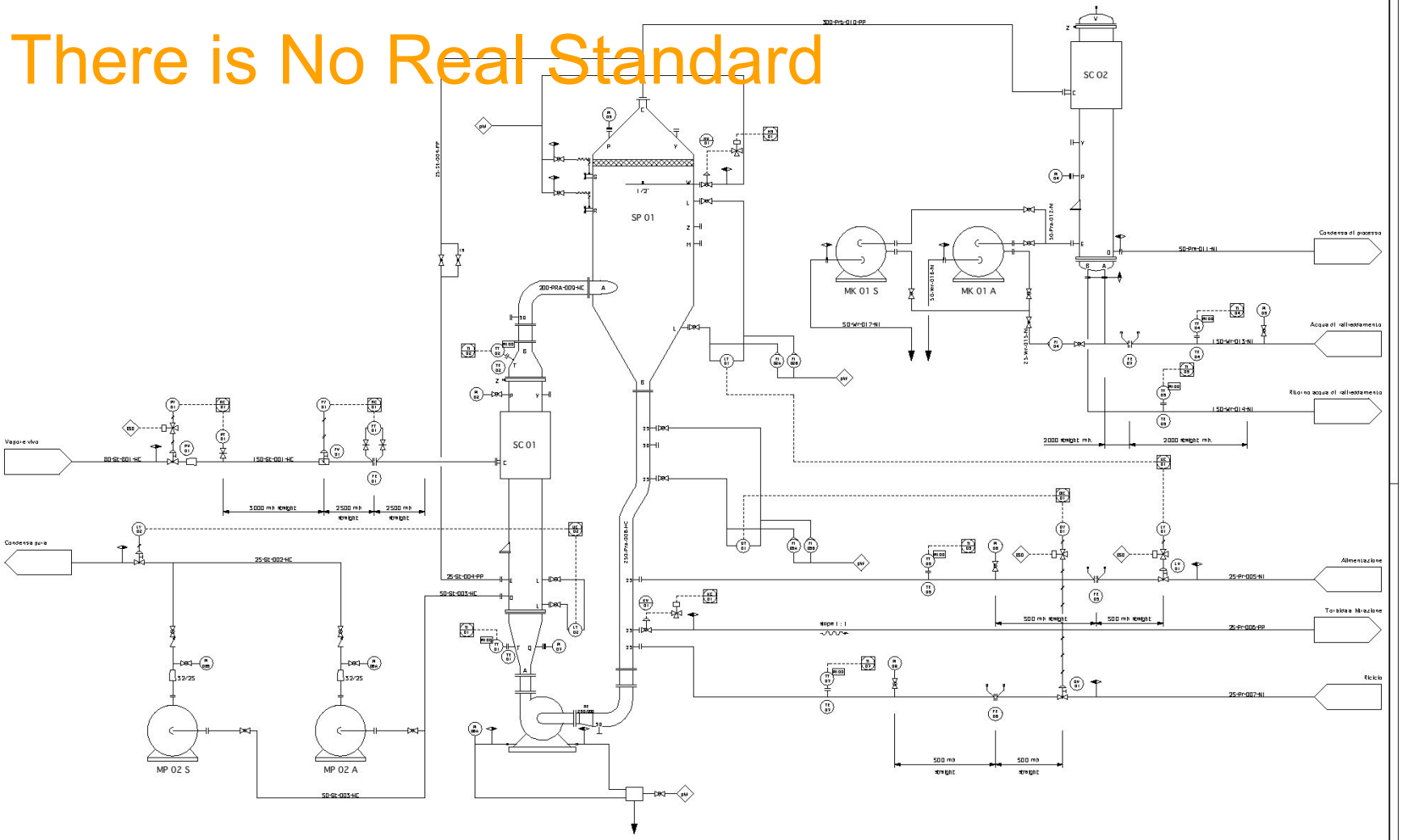
Senior Engineer, Facility Dynamics Engineering

Resource for Details Behind this Content

www.Av8rdas.Wordpress.com

Posts with the heading “System Diagrams: …”

There is No Real Standard

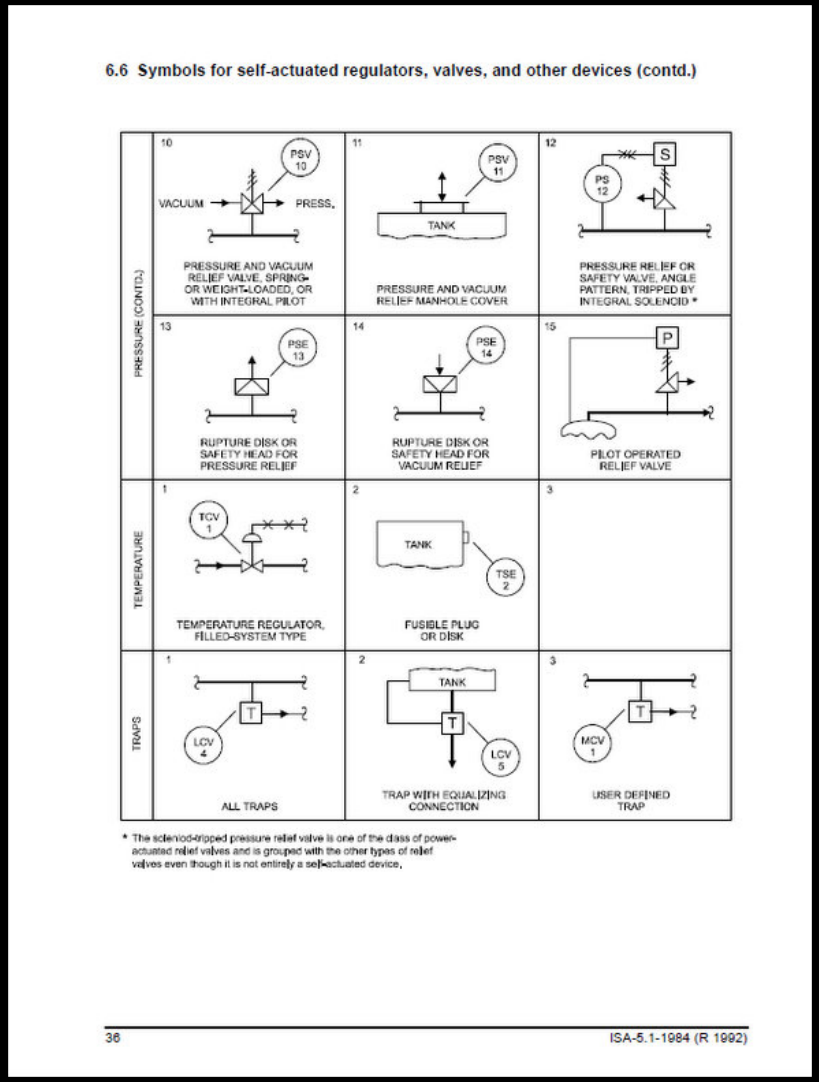


P&ID (Process and Instrumentation Diagrams) are a similar concept as is a PFD (Process Flow Diagram)

http://en.wikipedia.org/wiki/Piping_and_instrumentation_diagram - From the author's own work - Creative Commons Share Alike

Starting Points for Symbols

ISA-5.1-1984 Instrumentation Symbols and Identification



6.6 Symbols for self-actuated regulators, valves, and other devices (contd.)

PRESSURE (CONTD.)

10 — PSV 10 — VACUUM — PRESS. — PRESSURE AND VACUUM RELIEF VALVE, SPRING- OR WEIGHT-LOADED, OR WITH INTEGRAL PILOT

11 — PSV 11 — TANK — PRESSURE AND VACUUM RELIEF MANHOLE COVER

12 — S — PS 12 — PRESSURE RELIEF OR SAFETY VALVE, ANGLE PATTERN, TRIPPED BY INTEGRAL SOLENOID *

13 — PSE 13 — RUPTURE DISK OR SAFETY HEAD FOR PRESSURE RELIEF

14 — PSE 14 — RUPTURE DISK OR SAFETY HEAD FOR VACUUM RELIEF

15 — P — PILOT OPERATED RELIEF VALVE

TEMPERATURE

1 — TCV 1 — TEMPERATURE REGULATOR, FILLED-SYSTEM TYPE

2 — TANK — TSE 2 — FUSIBLE PLUG OR DISK

3

TRAPS

1 — T — LCV 4 — ALL TRAPS

2 — TANK — T — LCV 5 — TRAP WITH EQUALIZING CONNECTION

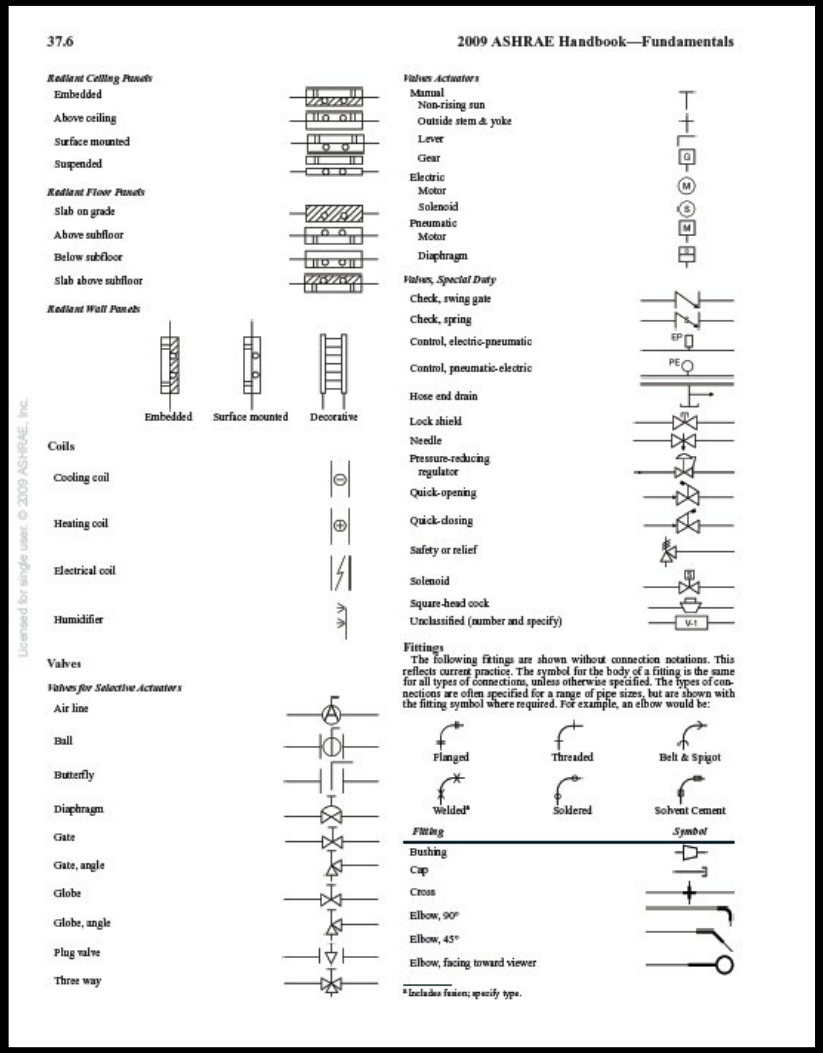
3 — T — MCV 1 — USER DEFINED TRAP

* The solenoid-tripped pressure relief valve is one of the class of power-actuated relief valves and is grouped with the other types of relief valves even though it is not entirely a self-actuated device.

36 ISA-5.1-1984 (R 1992)

Starting Points for Symbols

2009 (or earlier) ASHRAE Handbook of Fundamentals, Chapter 37



37.6 2009 ASHRAE Handbook—Fundamentals

Radiant Ceiling Panels
Embedded
Above ceiling
Surface mounted
Suspended

Radiant Floor Panels
Slab on grade
Above subfloor
Below subfloor
Slab above subfloor

Radiant Wall Panels
Embedded
Surface mounted
Decorative

Coils
Cooling coil
Heating coil
Electrical coil
Humidifier

Valves

Valves for Selective Actuators
Air line
Ball
Butterfly
Diaphragm
Gate
Gate, angle
Globe
Globe, angle
Plug valve
Three way

Valves Actuators
Manual
Non-rising stem
Outside stem & yoke
Lever
Gear
Electric
Motor
Solenoid
Pneumatic
Motor
Diaphragm

Valves, Special Duty
Check, swing gate
Check, spring
Control, electric-pneumatic
Control, pneumatic-electric
Hose end drain
Lock shield
Needle
Pressure-reducing regulator
Quick-opening
Quick-closing
Safety or relief
Solenoid
Square-head cock
Unclassified (number and specify)

Fittings
The following fittings are shown without connection notations. This reflects current practice. The symbol for the body of a fitting is the same for all types of connections, unless otherwise specified. The types of connections are often specified for a range of pipe sizes, but are shown with the fitting symbol where required. For example, an elbow would be:

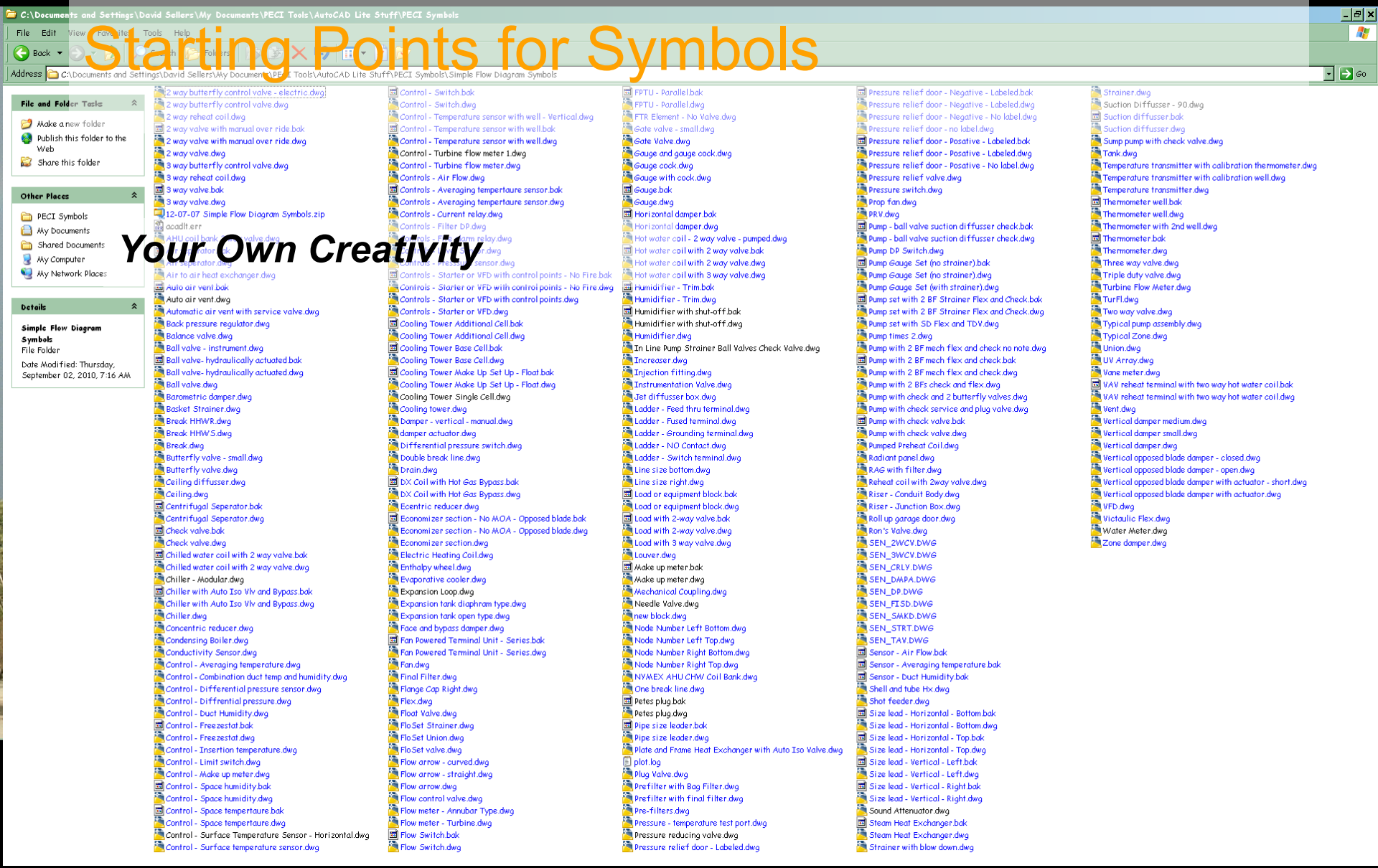
Flanged
Threaded
Belt & Spigot
Welded[a]
Soldered
Solvent Cement

Fitting	*Symbol*
Bushing	
Cap	
Cross	
Elbow, 90°	
Elbow, 45°	
Elbow, facing toward viewer	

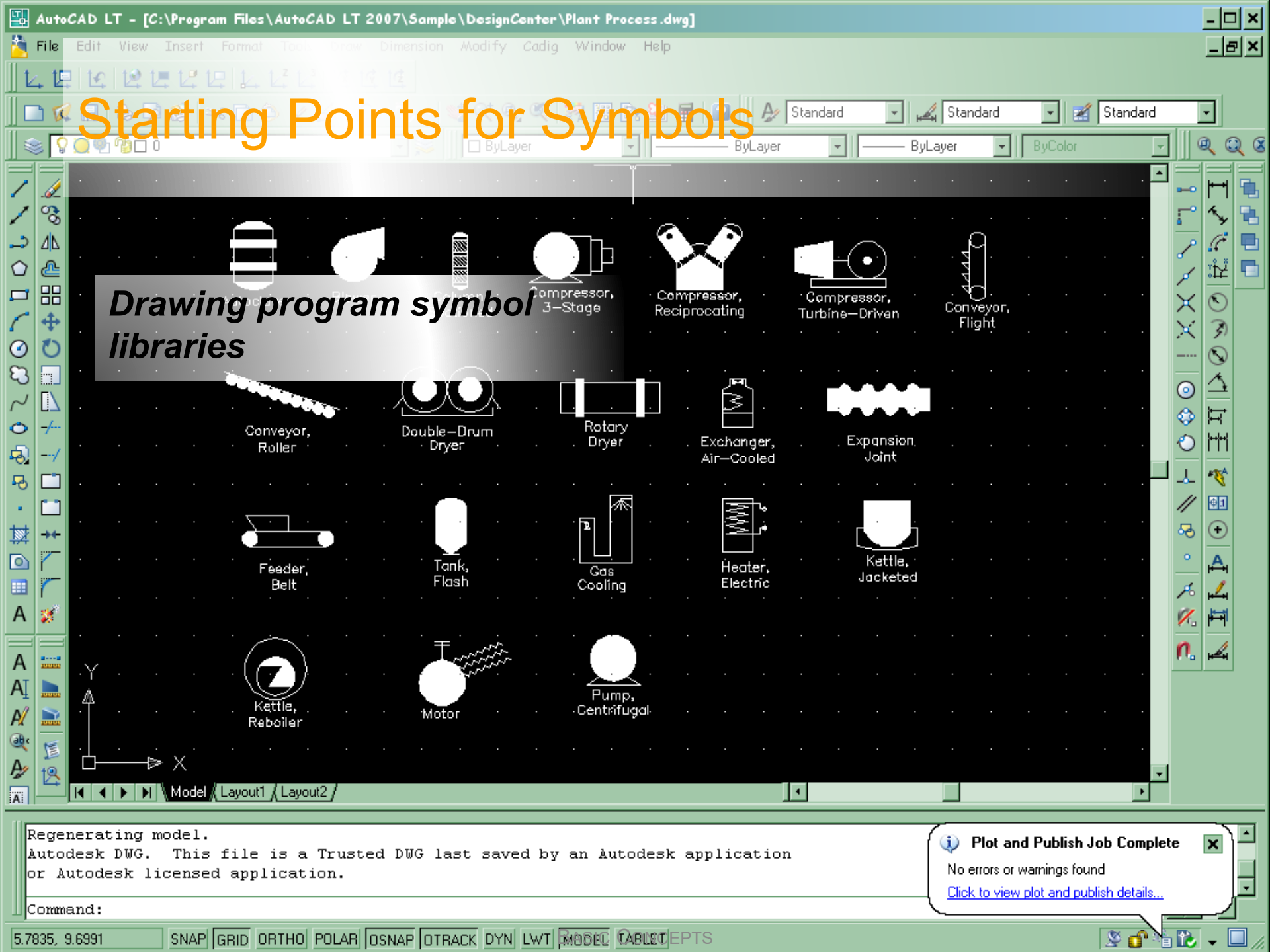
[a] Includes fusion; specify type.

Starting Points for Symbols

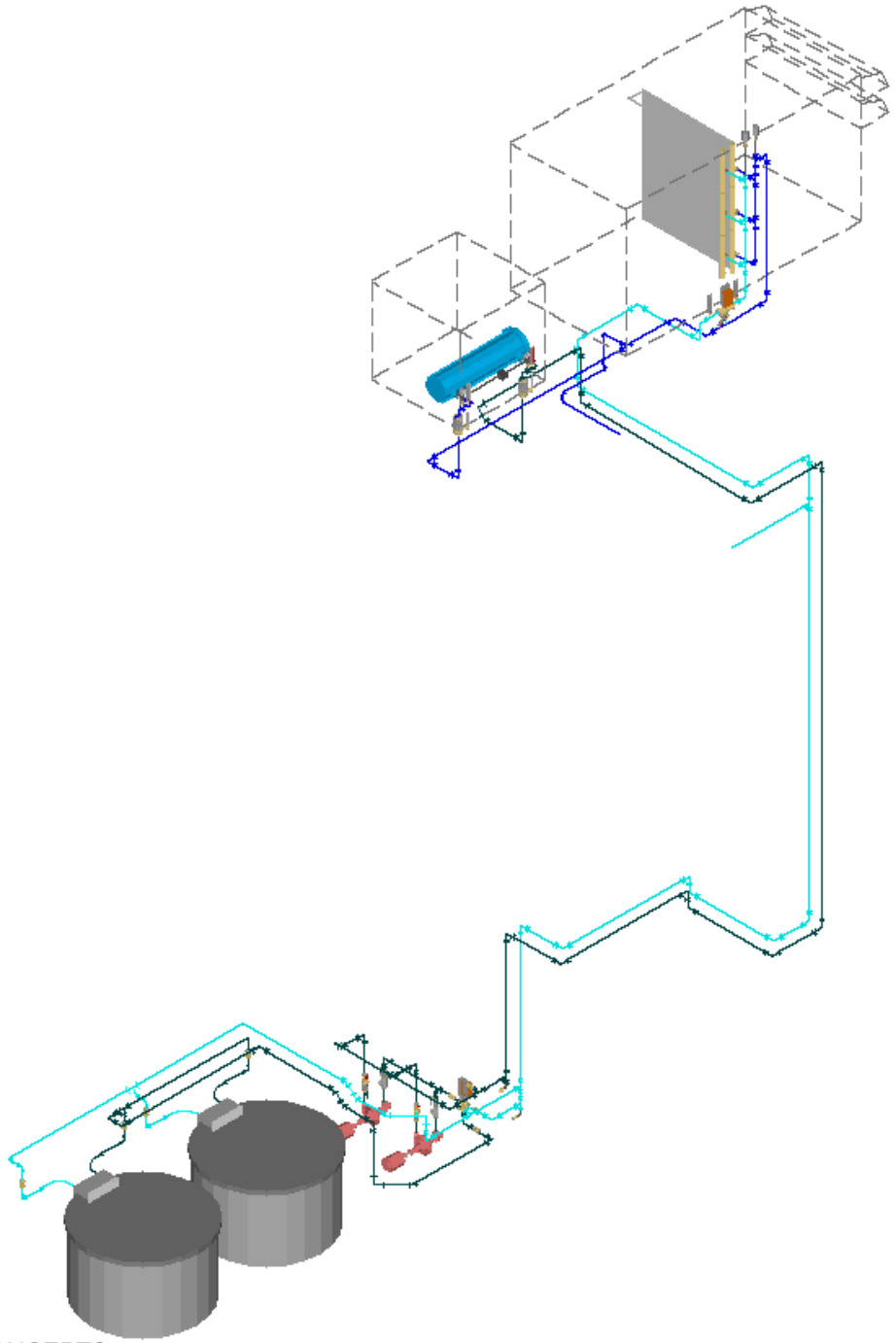
Your Own Creativity

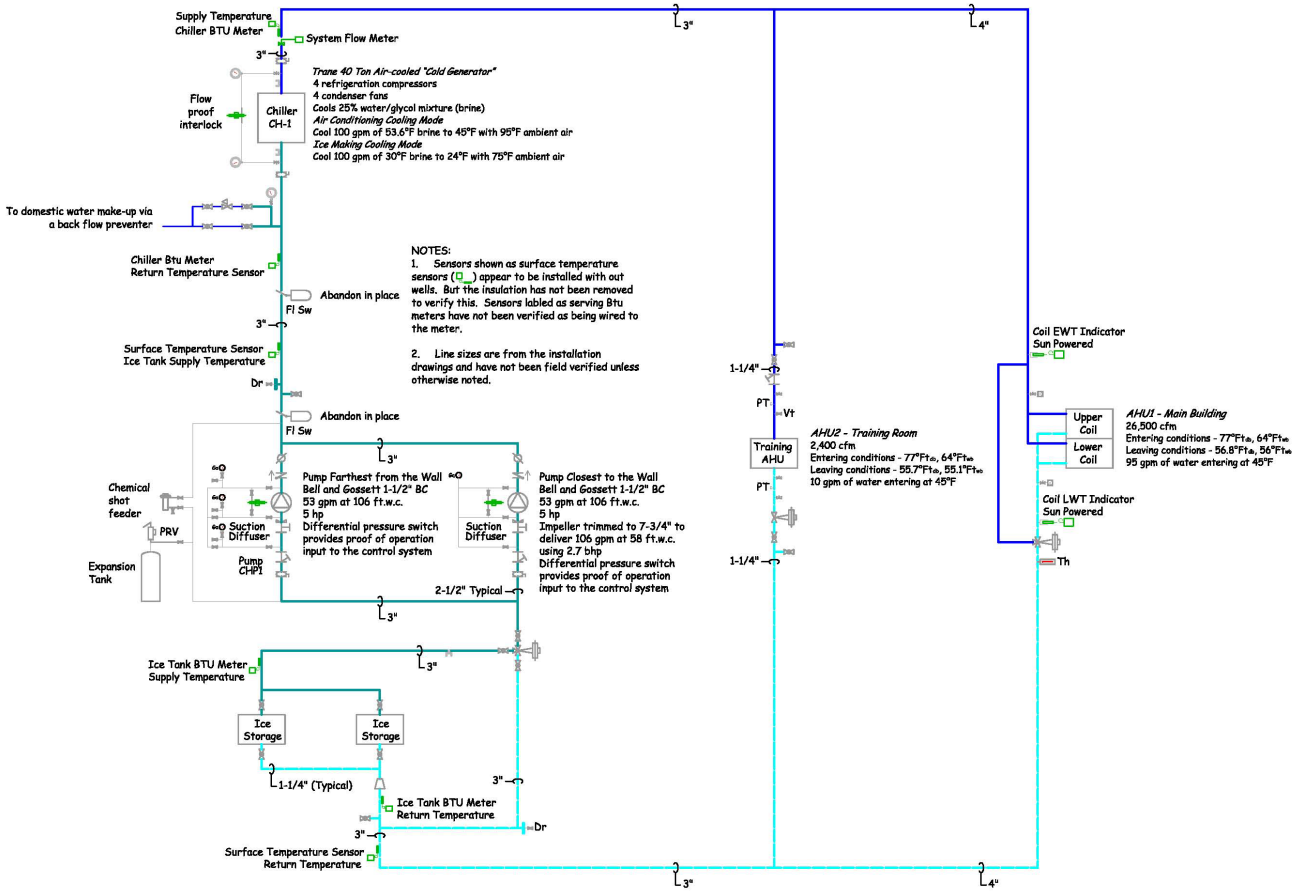


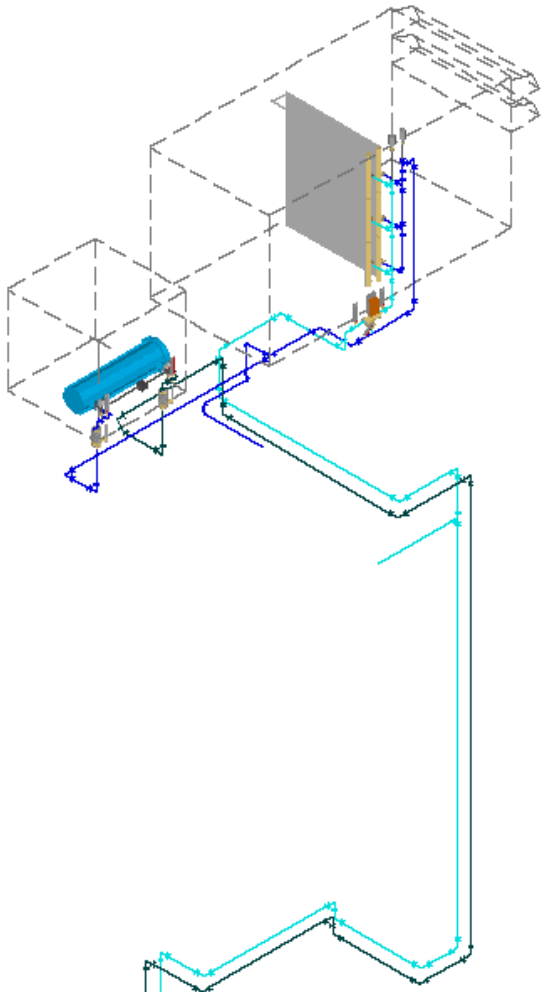
Starting Points for Symbols

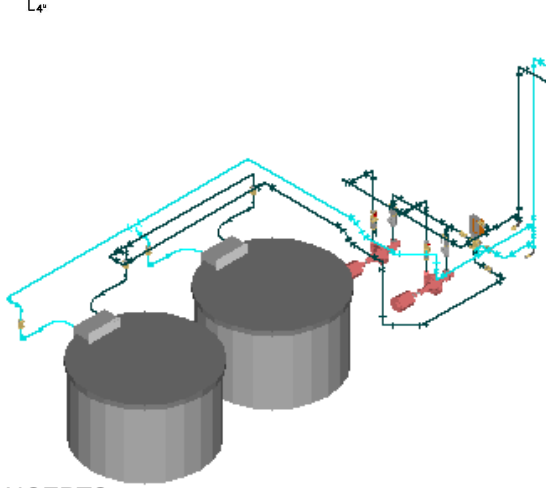


Physically Complex,









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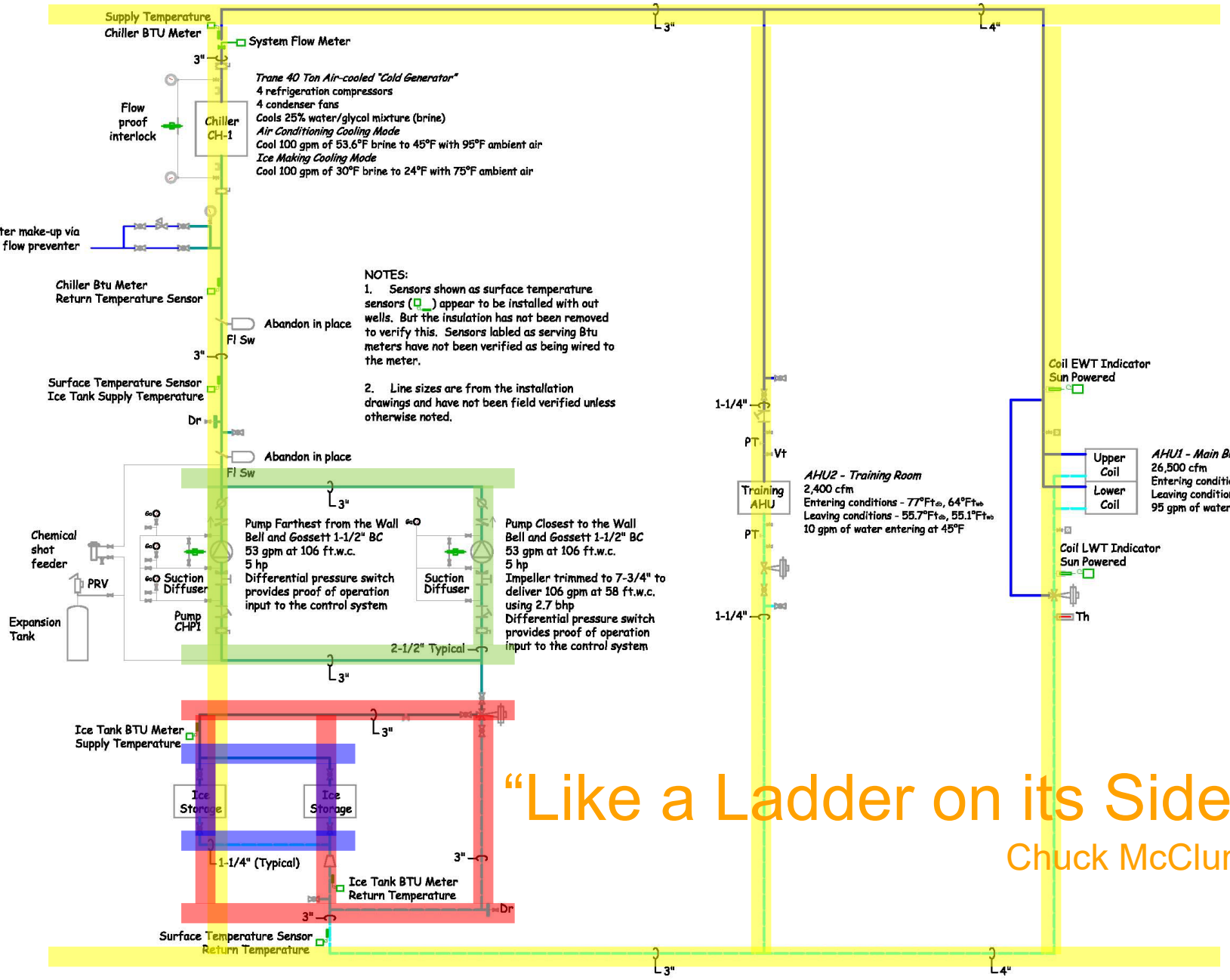
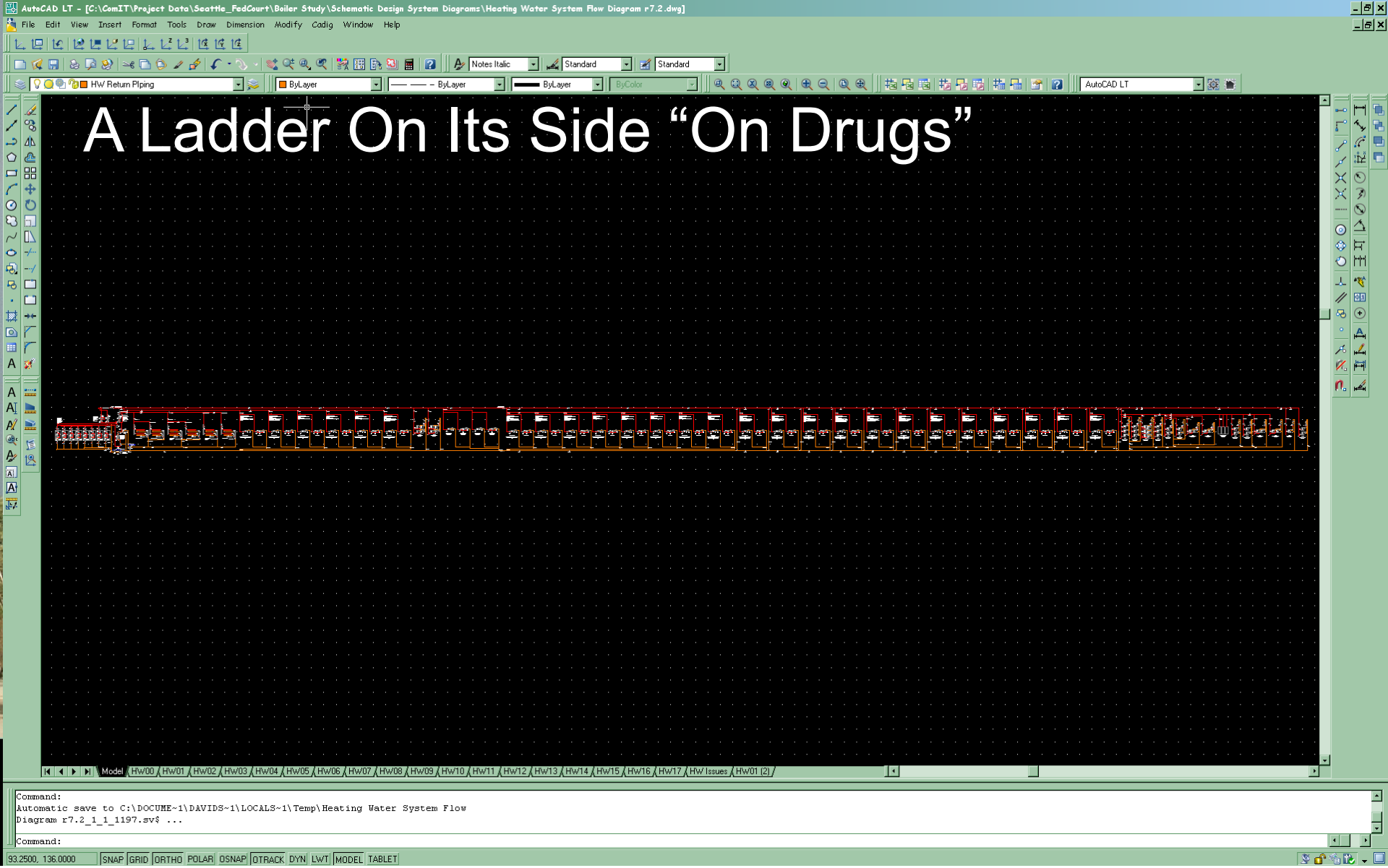


"Like a Ladder on its Side"

Chuck McClure

A Ladder On Its Side “On Drugs”



A Ladder On Its Side in Japanese

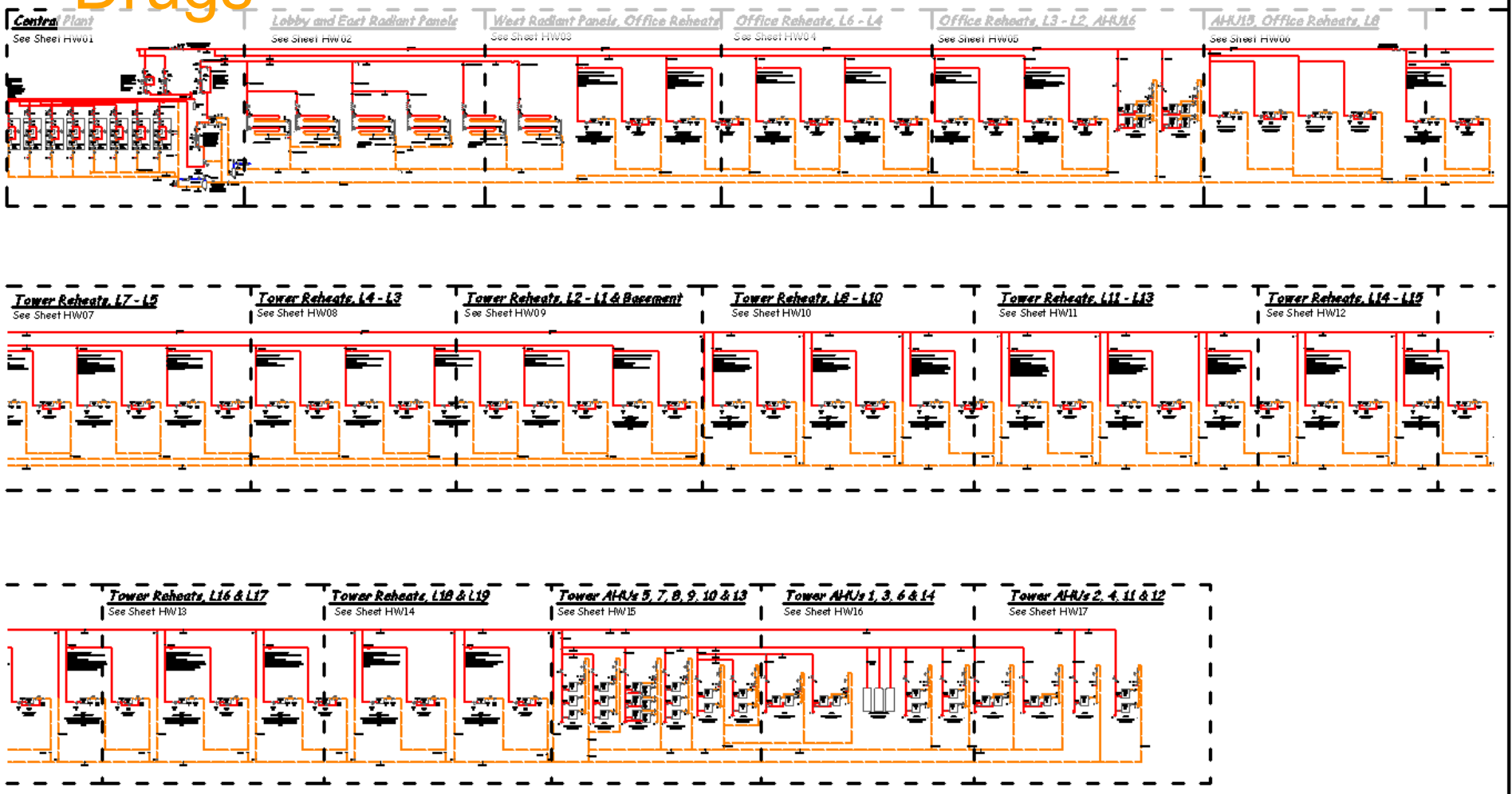
横にはしごのように

Yoko ni hashigo no yō ni

We're doing that Japan training this week .... Just thought you'd want to know that the phrase "Ladder on its side" has officially been translated into another language!!

Brian Clark
Mechanical Engineer, Energy Branch
Construction Engineering Research Laboratory
US Corps of Engineers
Former EBCx Workshop Student

Dealing With a Ladder On Its Side “On Drugs”

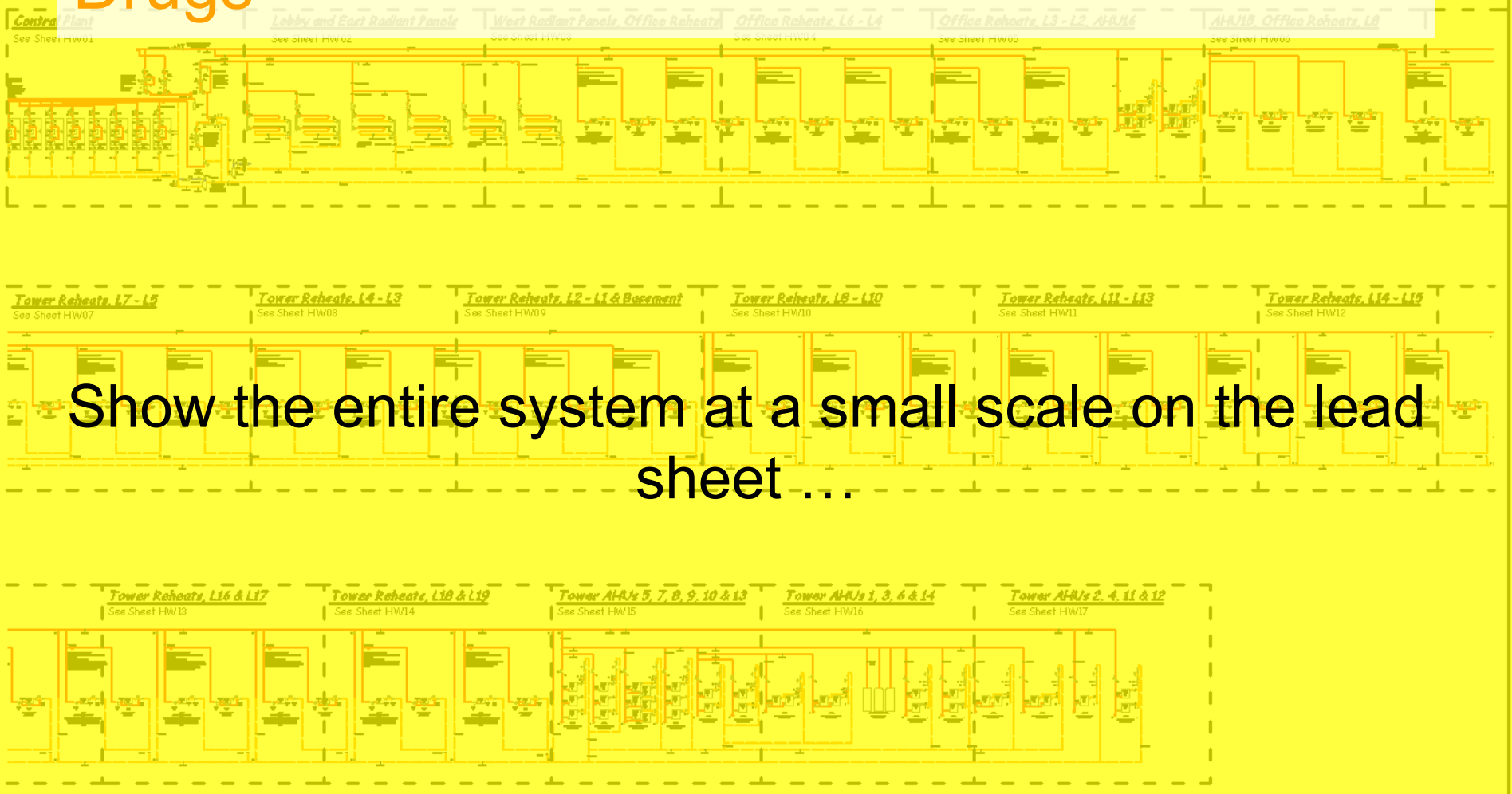


New Seattle Court House Heating Water System Flow Diagram

Revisions: 1 - Revised boiler piping to match actual factory piping.
Revisions: 2 - 1-24-02 - Modified arrangement of factory piping to make it clearer
Revisions: 3 - 12-15-03 - Updated and detailed to include radiant panel heat exchanger and HP12.
Revisions: 4 - Release 3/23/04
Revisions: 5 - Corrected return piping at boiler return headers

Drawn by: DAS	Date: April 29, 2002	HW00
Checked by:	Plot date: December 09, 2003	

Dealing With a Ladder On Its Side “On Drugs”



Show the entire system at a small scale on the lead sheet …

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HW00

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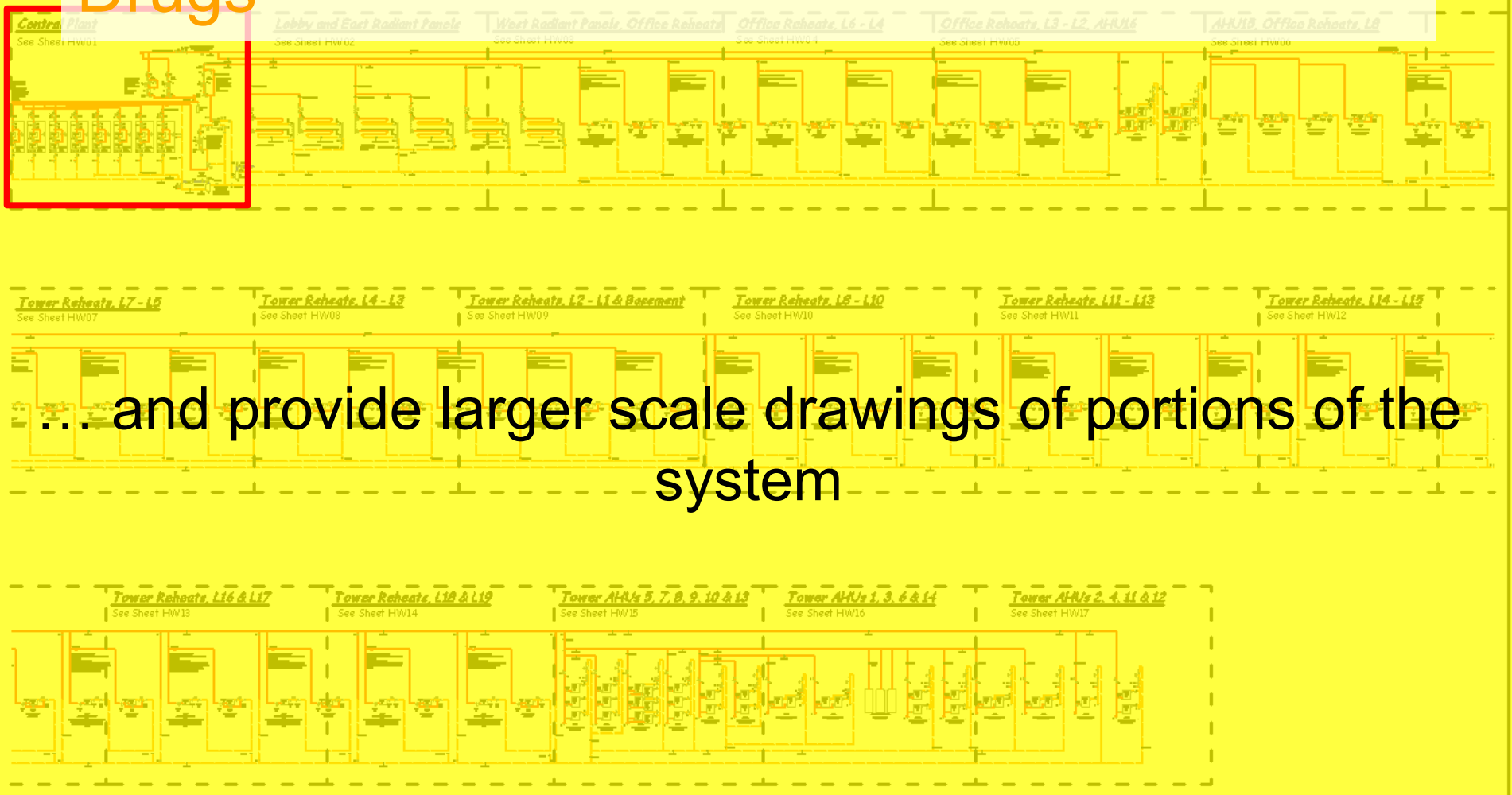
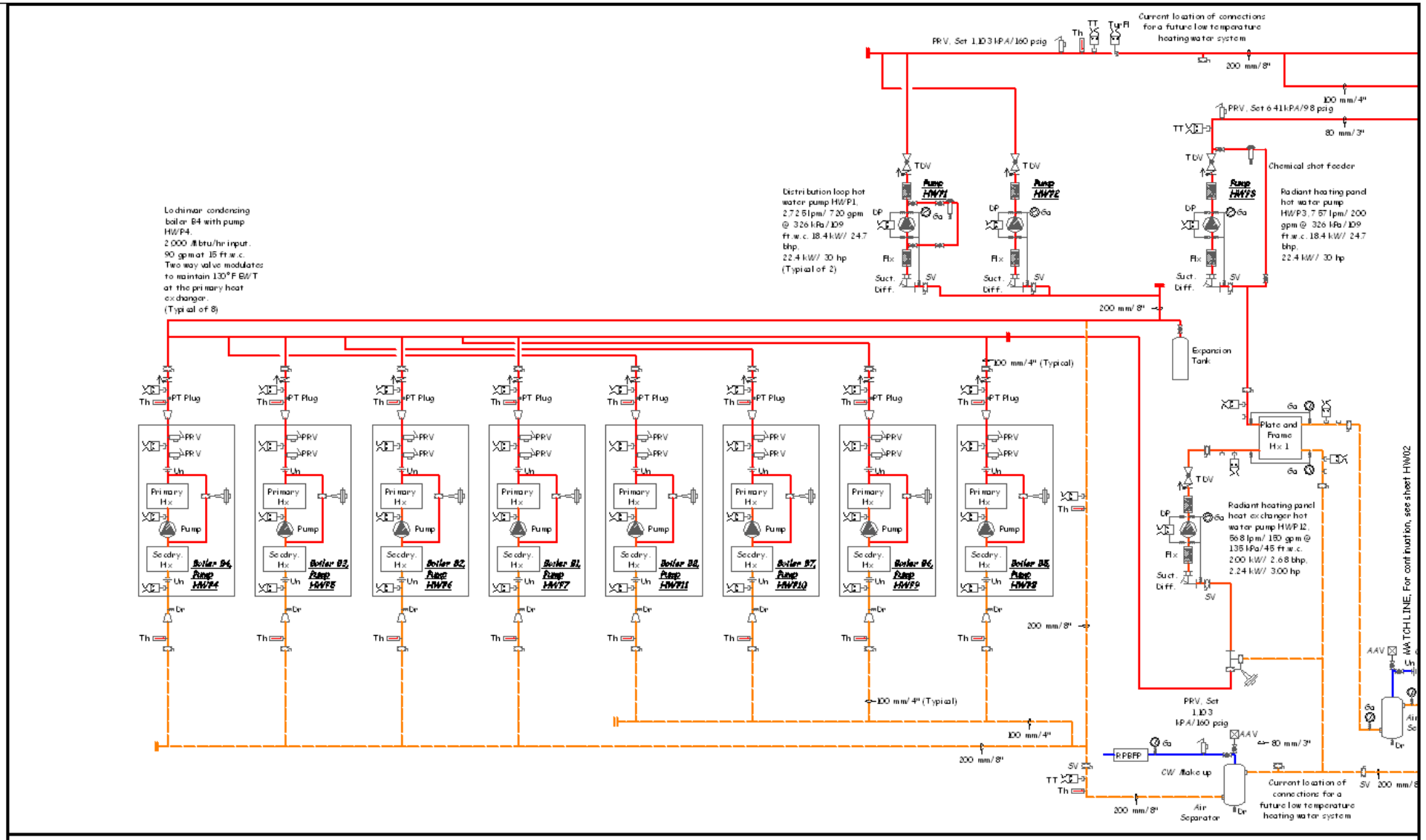


… and provide larger scale drawings of portions of the system



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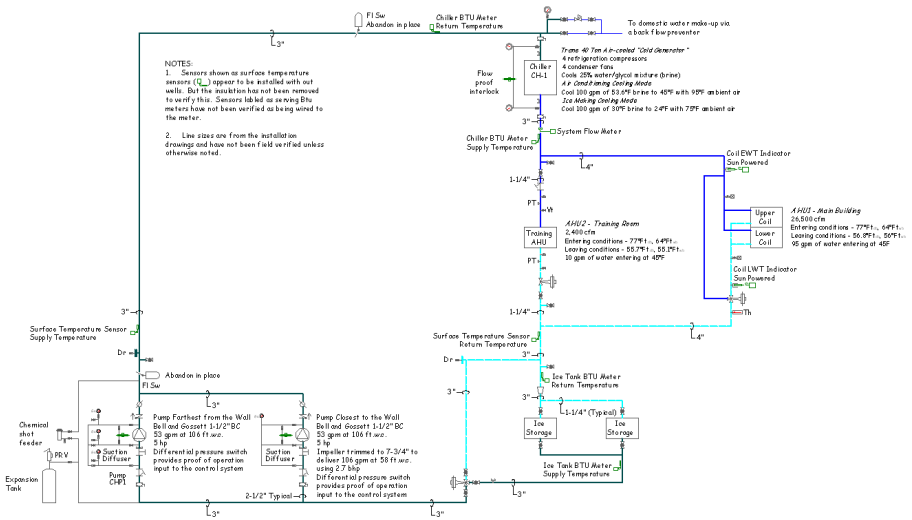
Revisions: 4 - Release 3/23/04
Revisions: 5 - 7-6-04 - Revised radiant panel pump connections.
Revisions: 5.1 - 7-7-04 - Revised radiant panel connection to the boiler header.

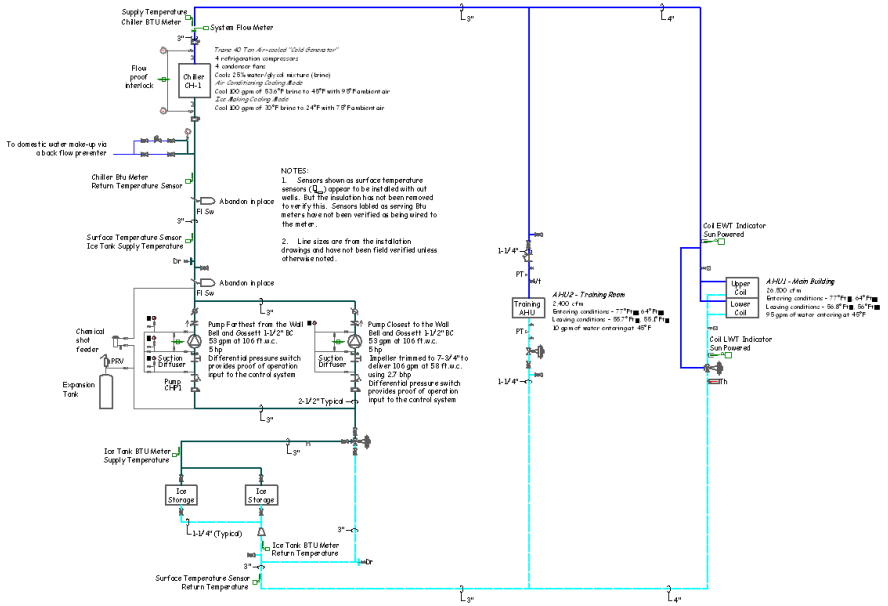
Drawn by: DAS	Date: April 29, 2002	HW01
Checked by:	Plot date: December 16, 2003	

What's on the Ladder Rungs and What's on the Ladder Rails Can Vary

"What's using up the pump head?" focus



"What's making and using cold glycol?" focus



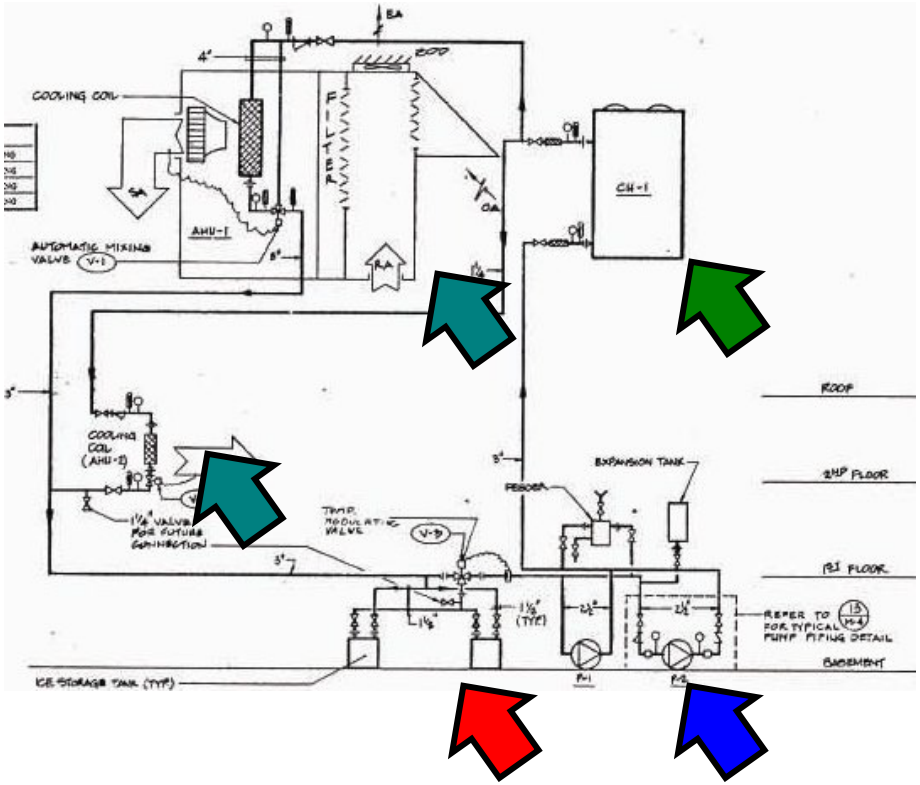
“Untangled” versus “Tangled”

tangled *adj*

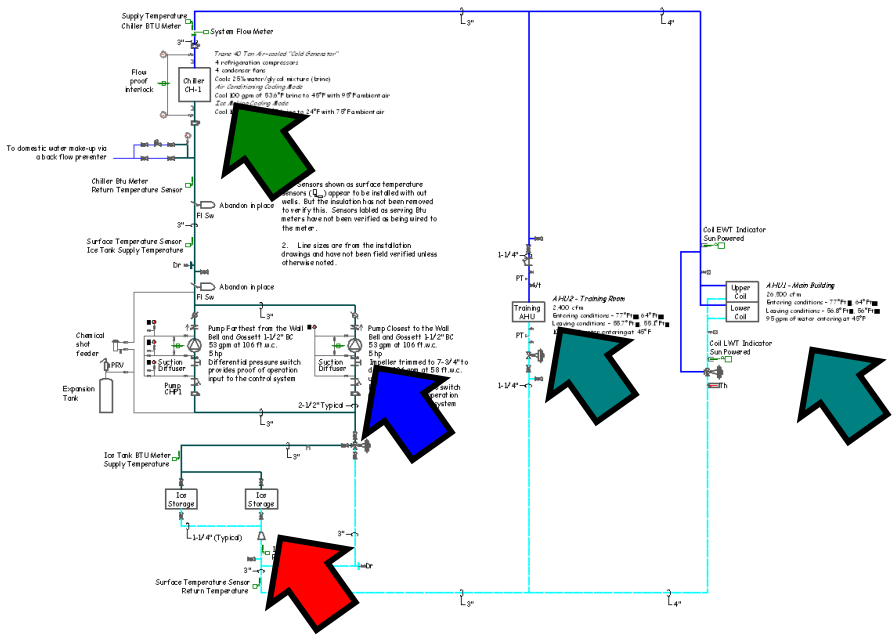
1. existing in or giving the appearance of a state of utter disorder
2. very involved : exceedingly complex

“Untangled” versus “Tangled”

Tangled



Untangled



“Untangled” versus “Tangled”

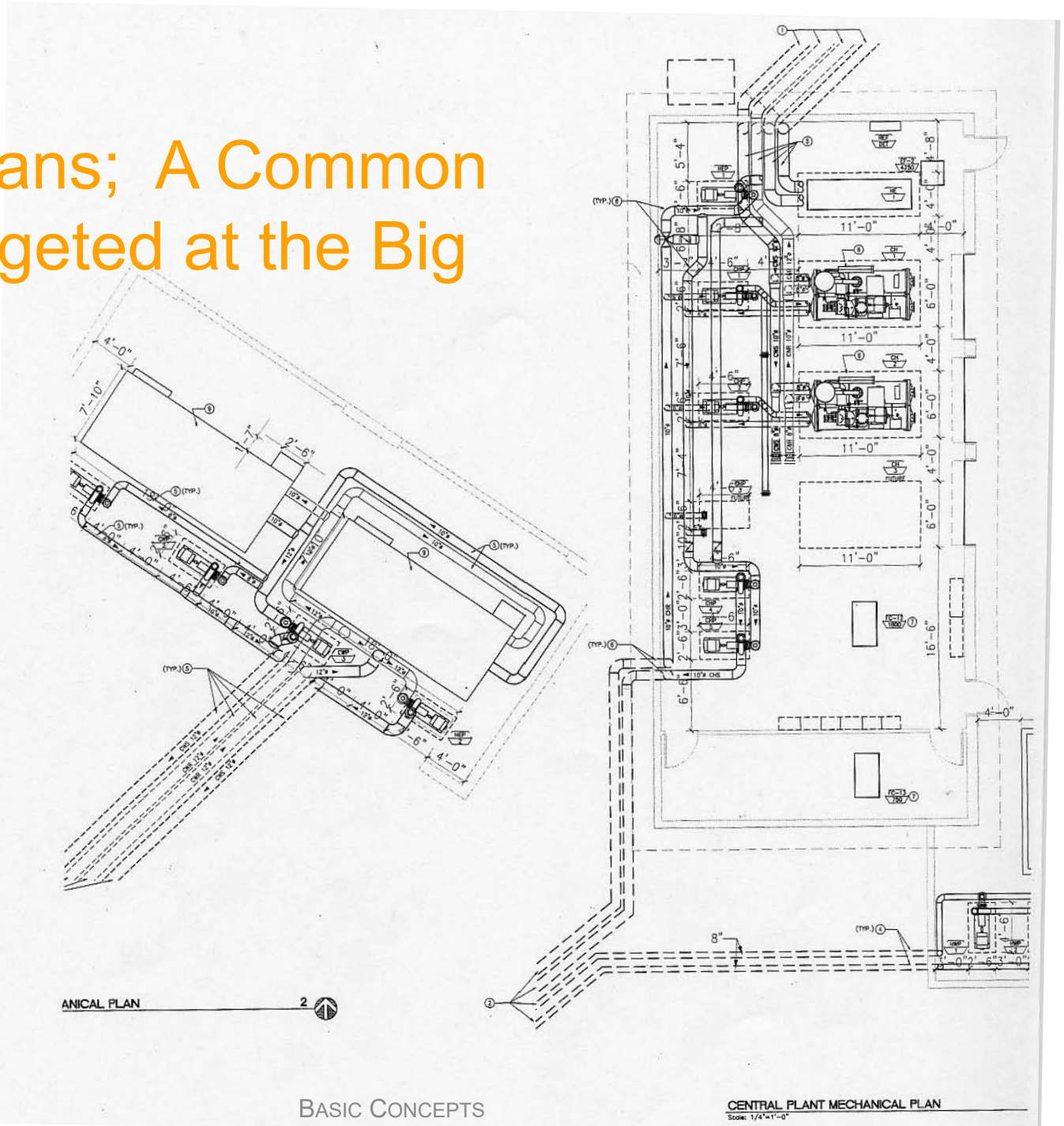
Keep simplifying things to minimize line crossings and head towards a “ladder on its side”

But remember:

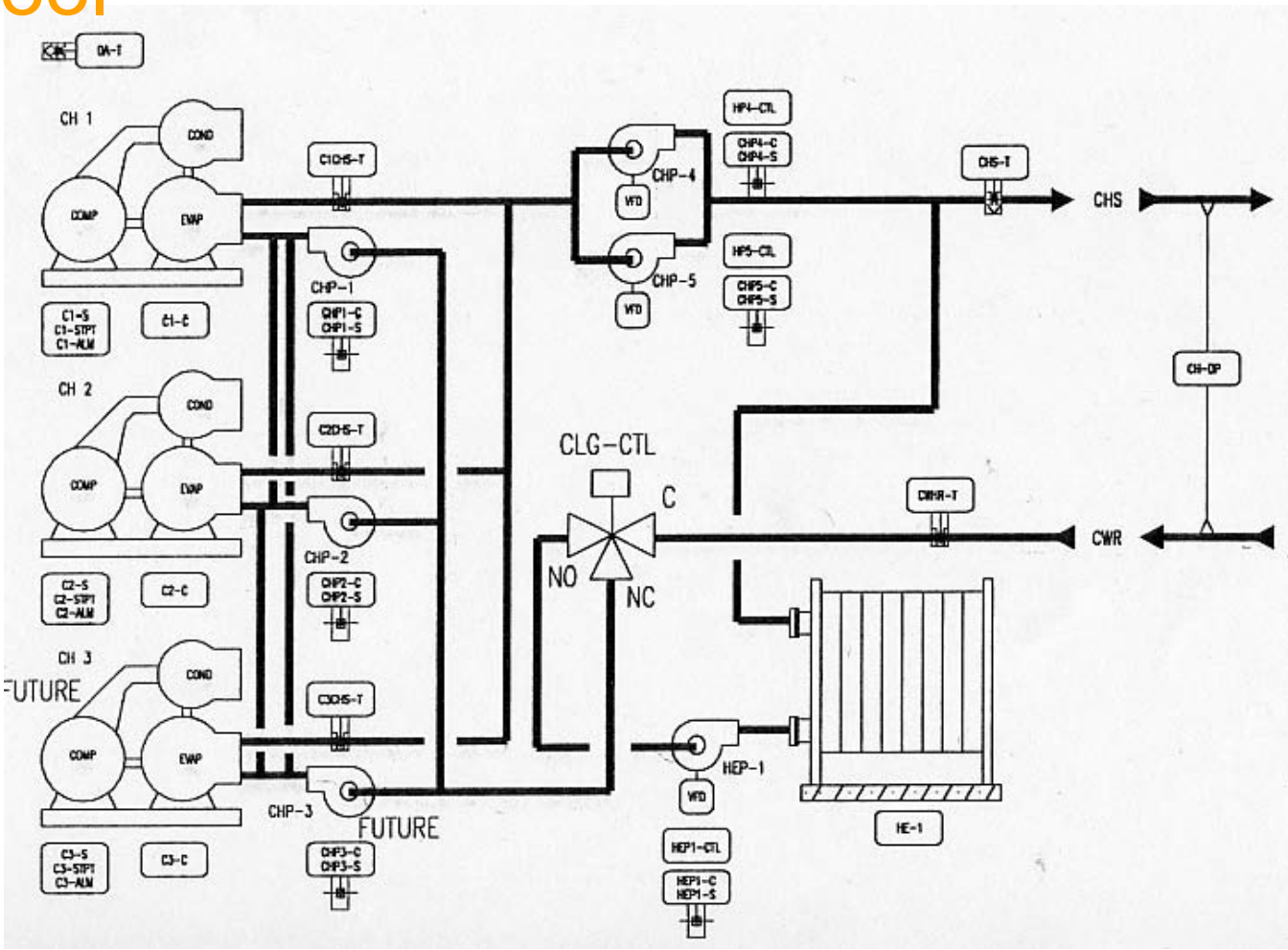
> *Things should be made as simple as possible, but not any simpler.*
>
> *Albert Einstein*

That means for a system diagram, order of connection “trumps” untangled

Floor Plans; A Common Tool Targeted at the Big Picture

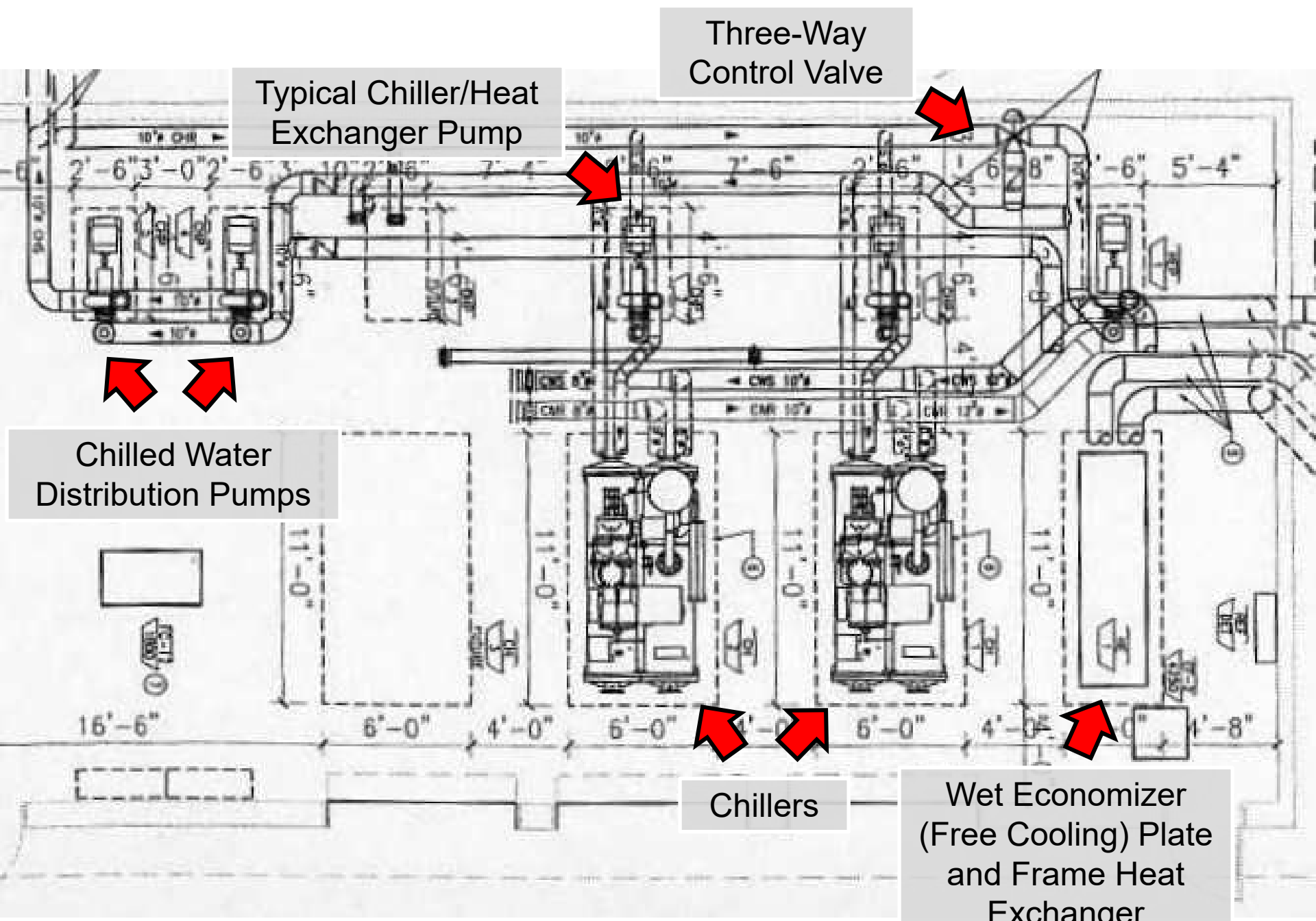


Schematics; Another Common Tool

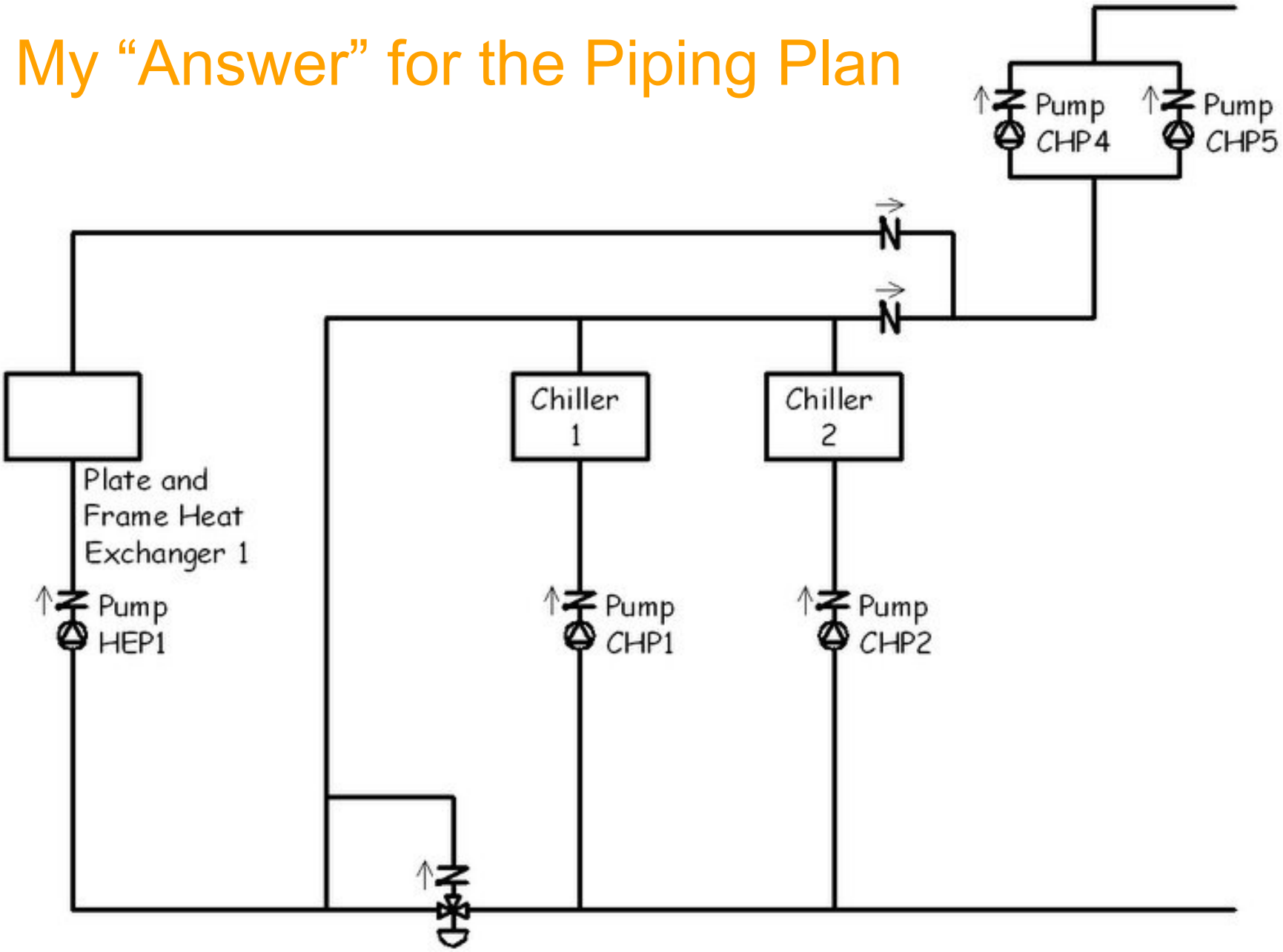


An Exercise Applying What You've Learned So Far

- *Half the class take the piping plan in the next slide and make a system diagram from it*
- *The other half of the class take the schematic in the previous slide and make a system diagram from it*
- *See if there are any problems that jump out at you from your system diagrams*
- *Did you recognize/understand them before you did the system diagram?*

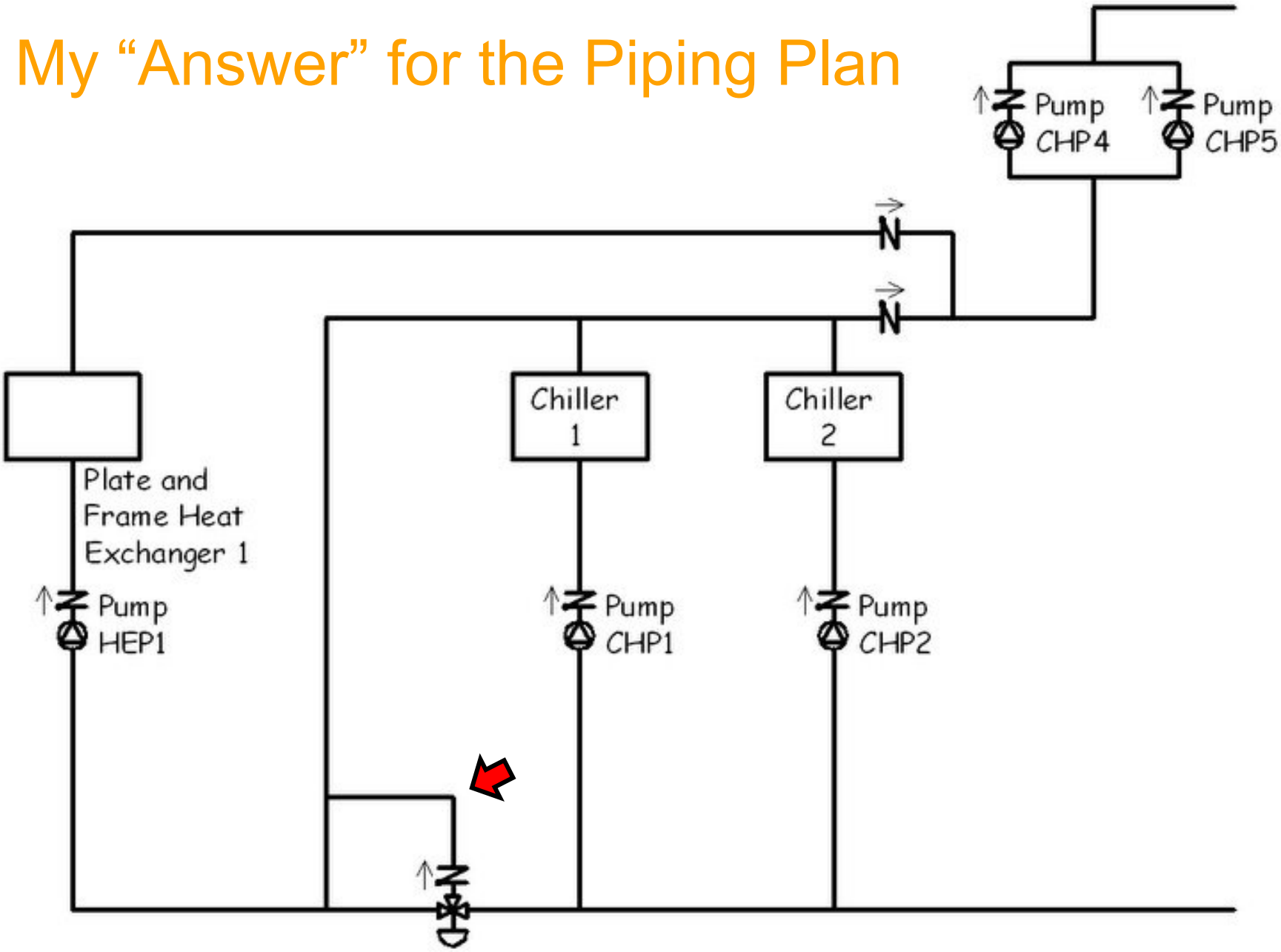

Three-Way Control Valve
Typical Chiller/Heat Exchanger Pump
Chilled Water Distribution Pumps
Chillers
Wet Economizer (Free Cooling) Plate and Frame Heat Exchanger

My “Answer” for the Piping Plan

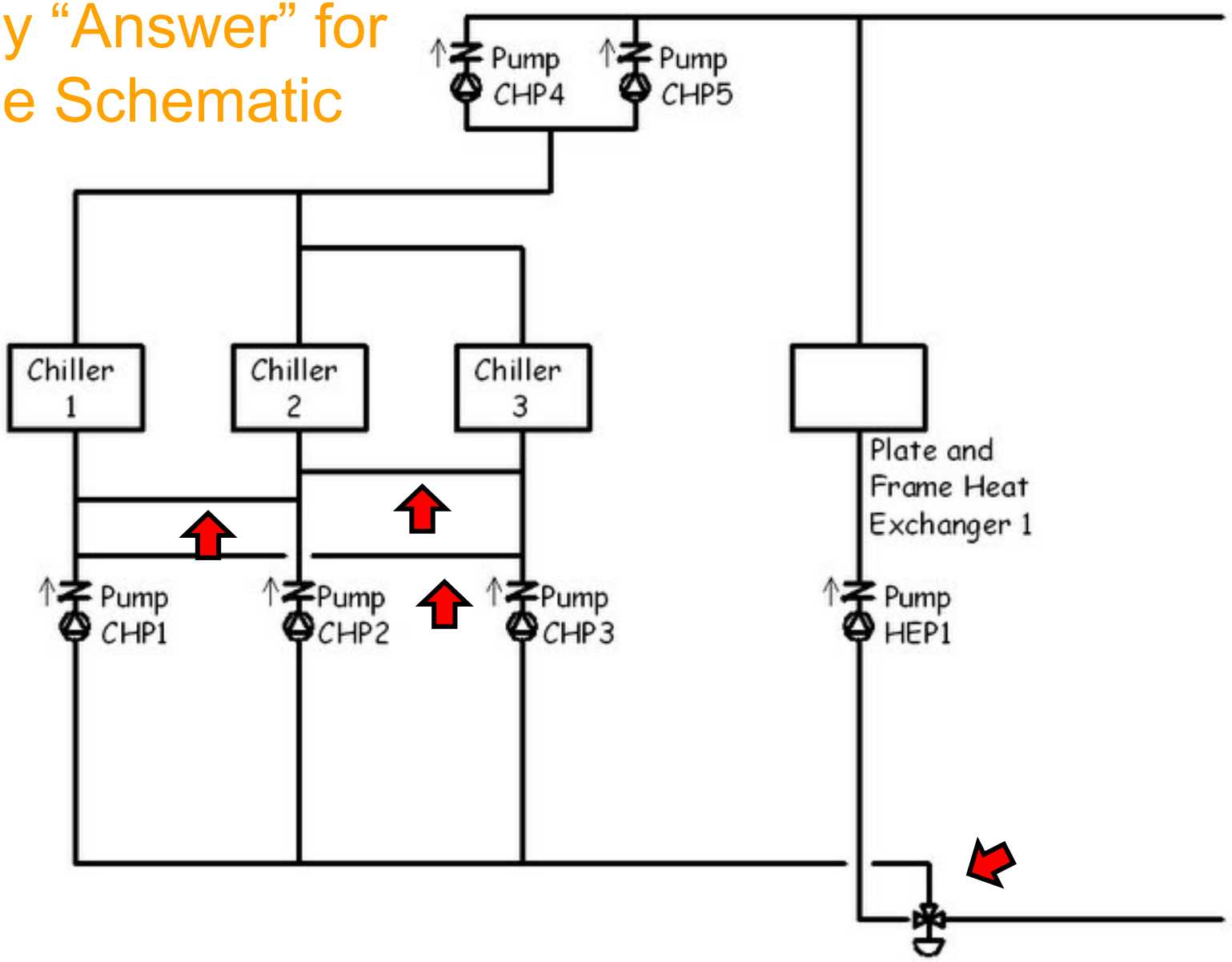


See Any Problems

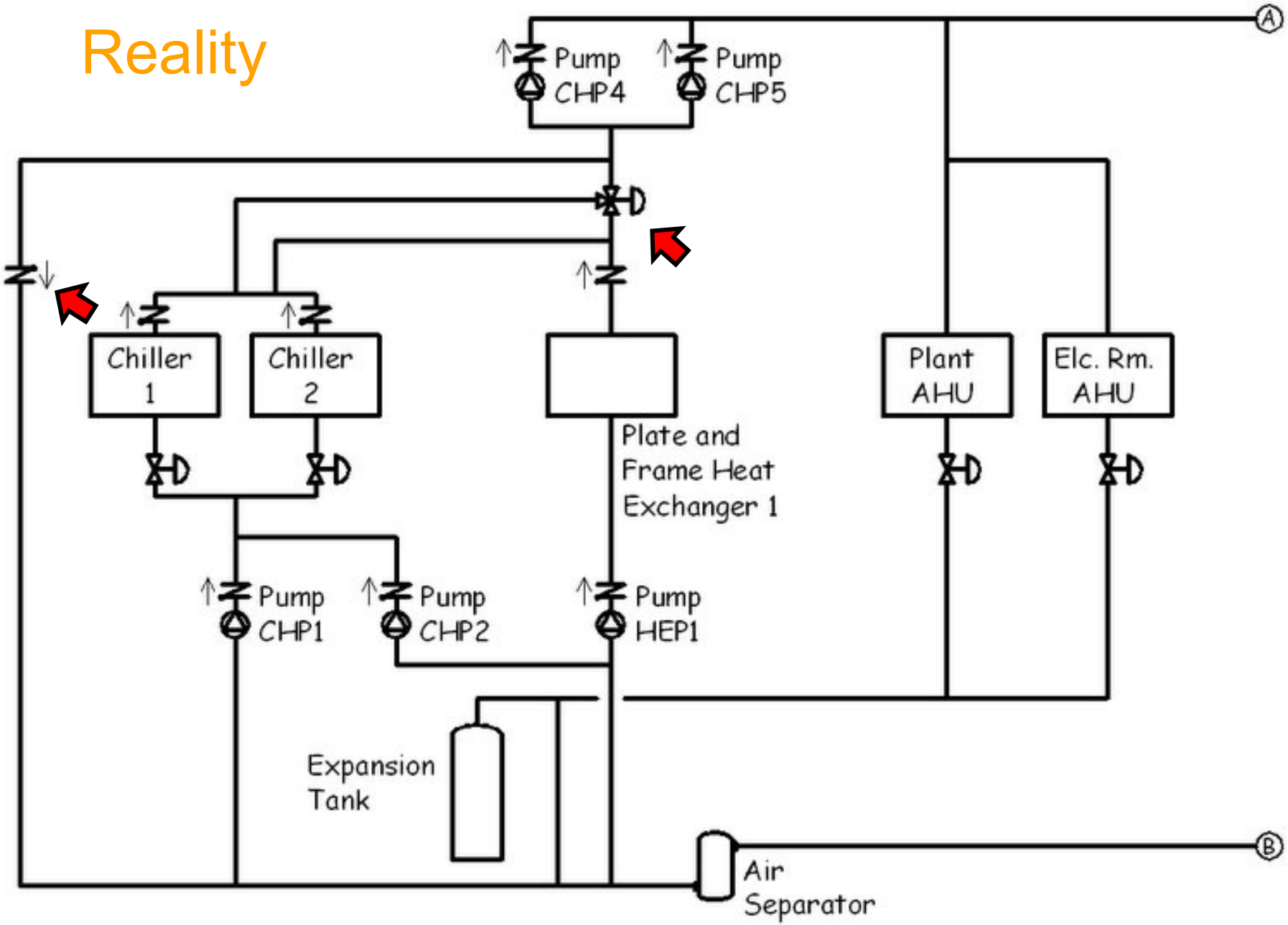
My “Answer” for the Piping Plan



My “Answer” for the Schematic

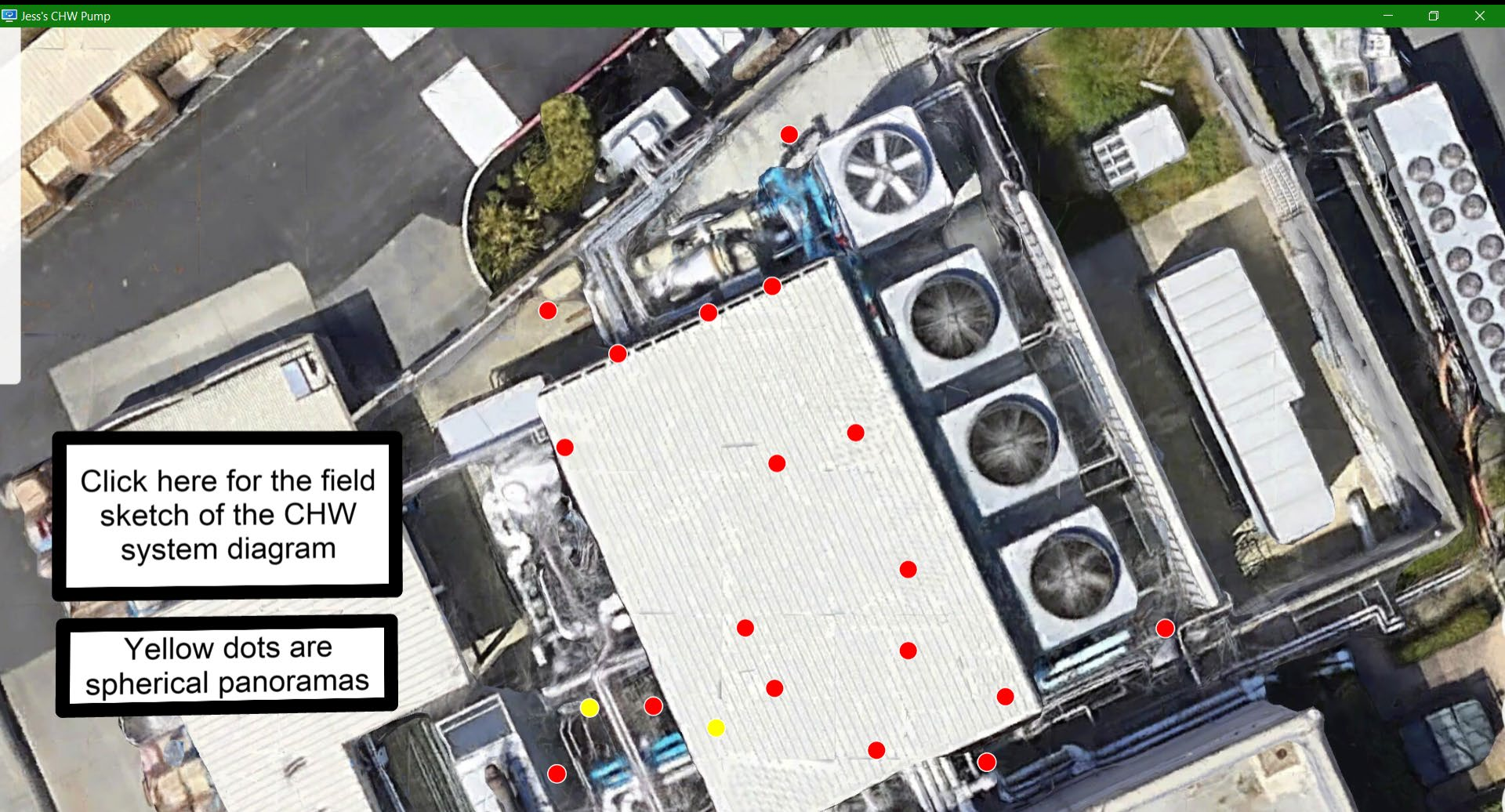


Reality

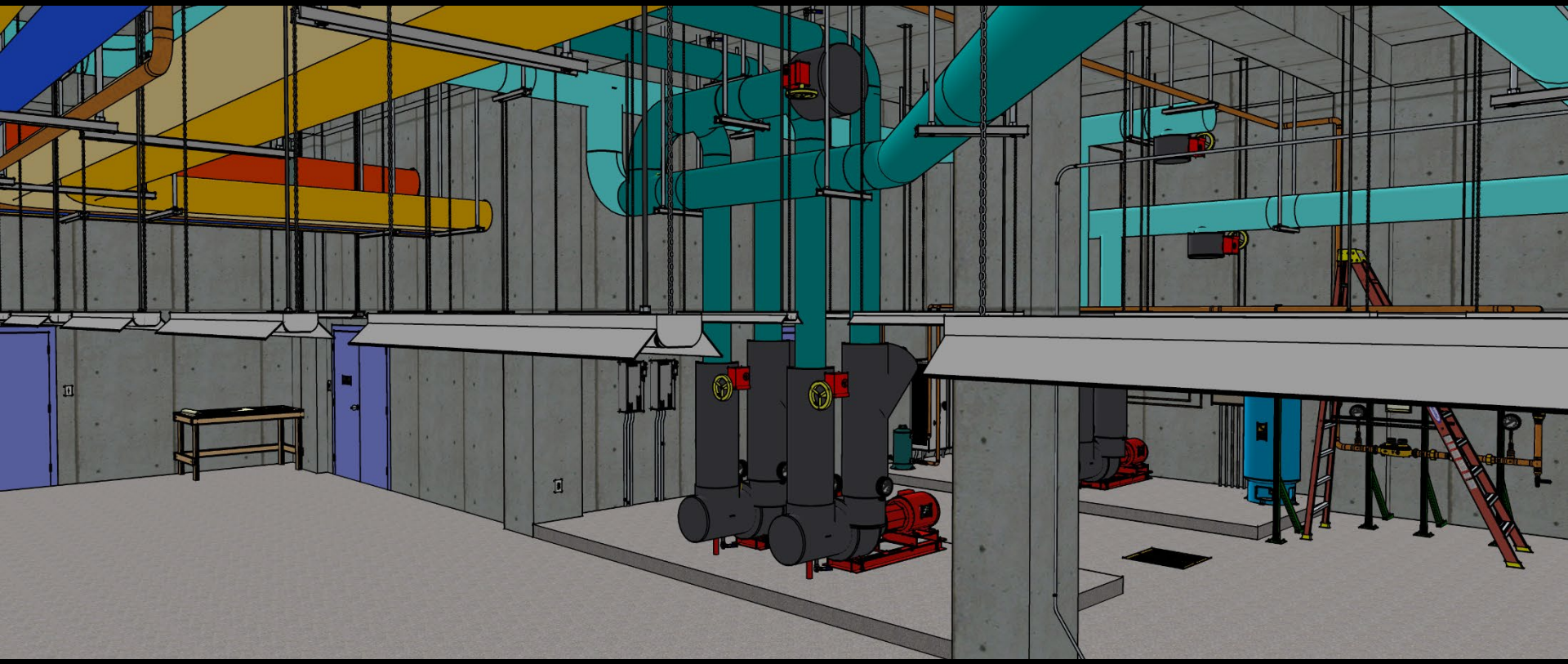

A
Pump
CHP4
Pump
CHP5
Chiller
1
Chiller
2
Plant
AHU
Elc. Rm.
AHU
Plate and
Frame Heat
Exchanger 1
Pump
CHP1
Pump
CHP2
Pump
HEP1
Expansion
Tank
Air
Separator
B

A Recent Field Experience

http://tinyurl.com/2023-09-20CHWPumpConnection



Order of Connection Matters



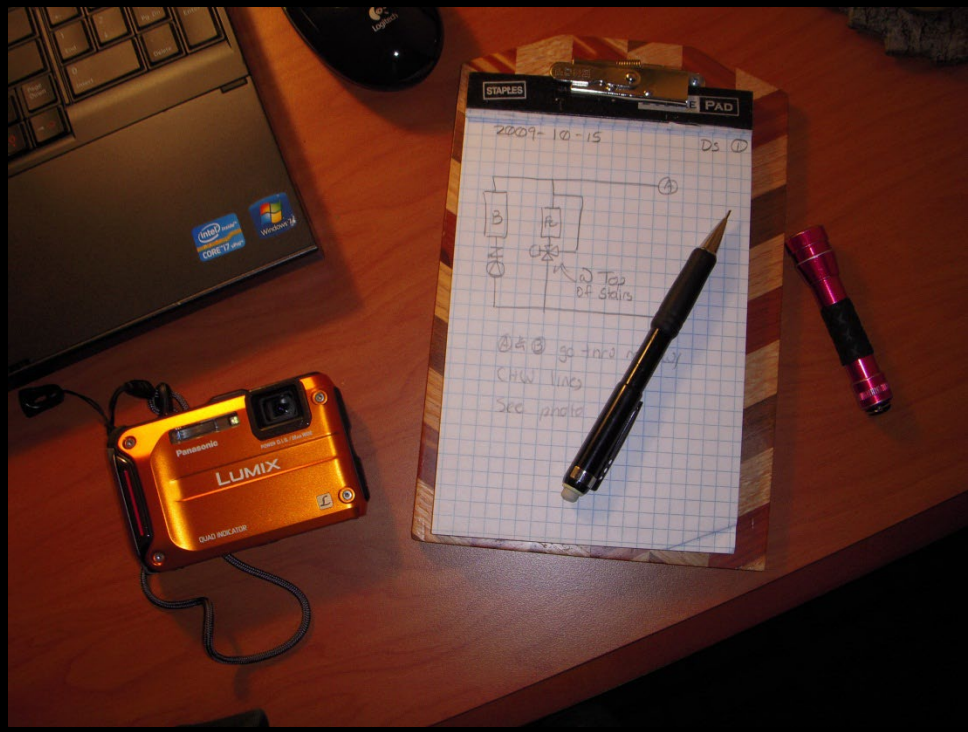
Getting Ready to Go Out in the Field

Study existing drawings if they exist

- May include a schematic
- May reveal issues
- Provides a first draft

Be ready for reality

- Clipboard
- Paper
- Flashlight
- Camera



Getting Started

Find something you can identify

- Nameplate data
- Labels
- Past experience

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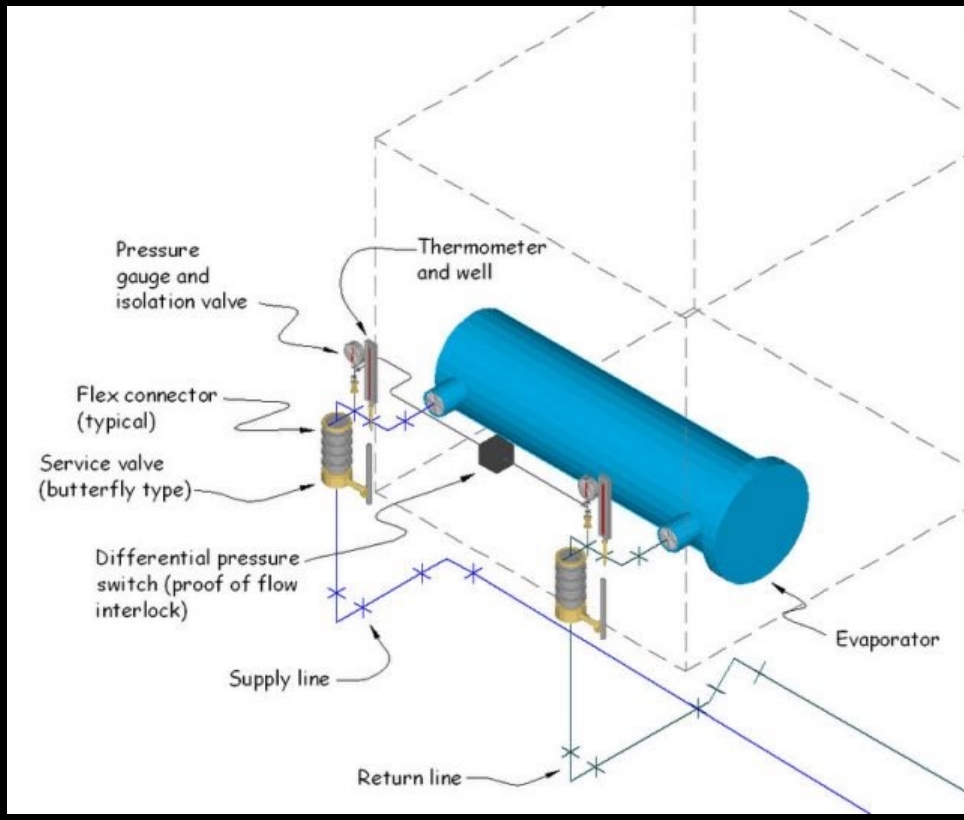

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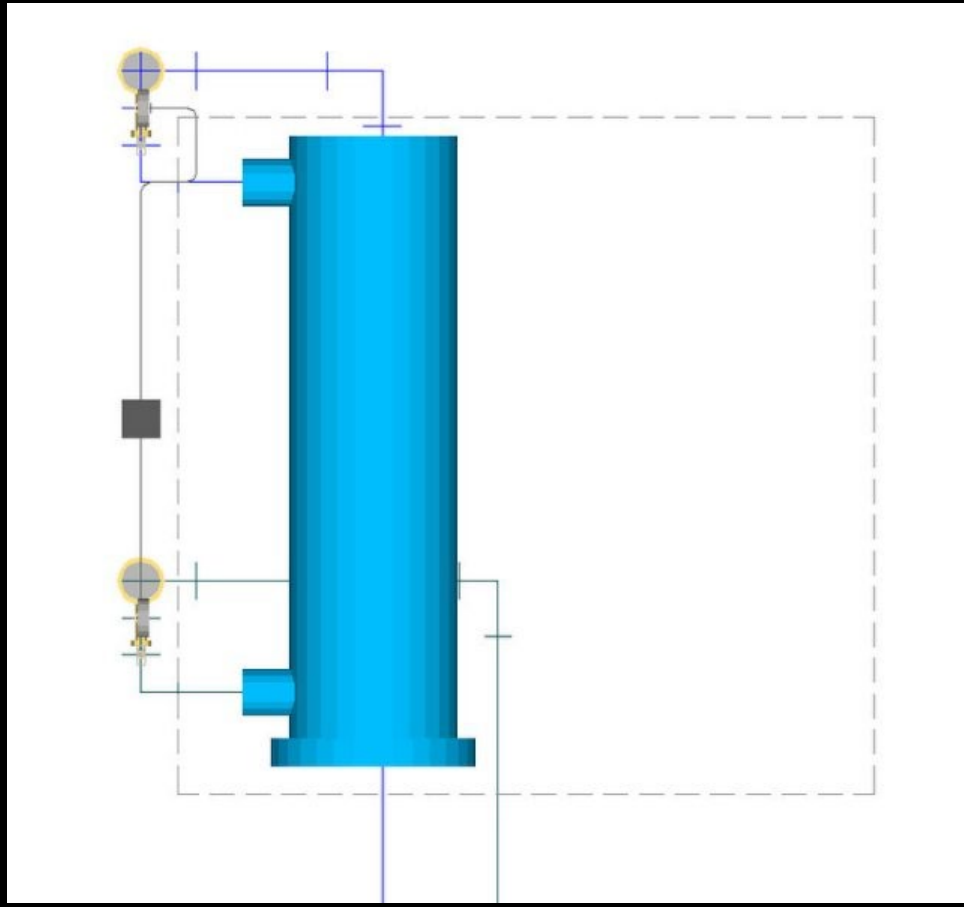

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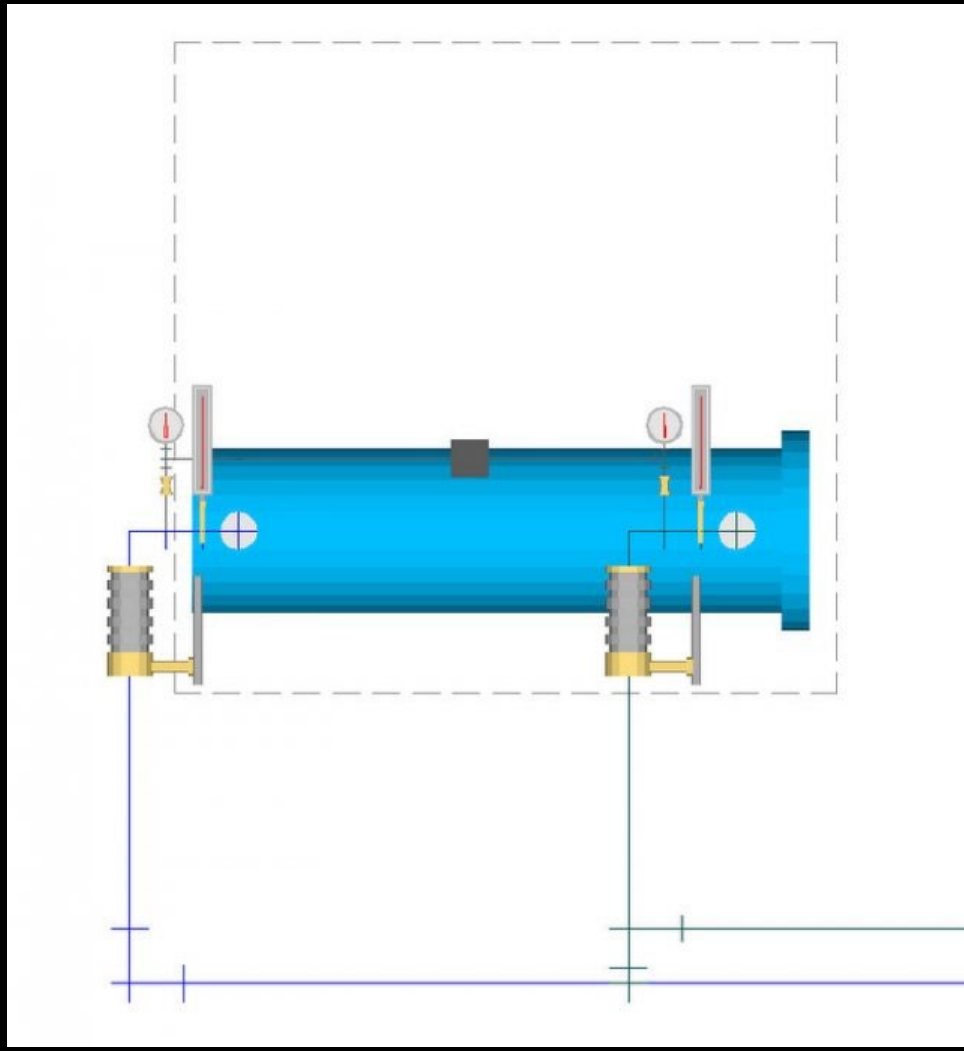

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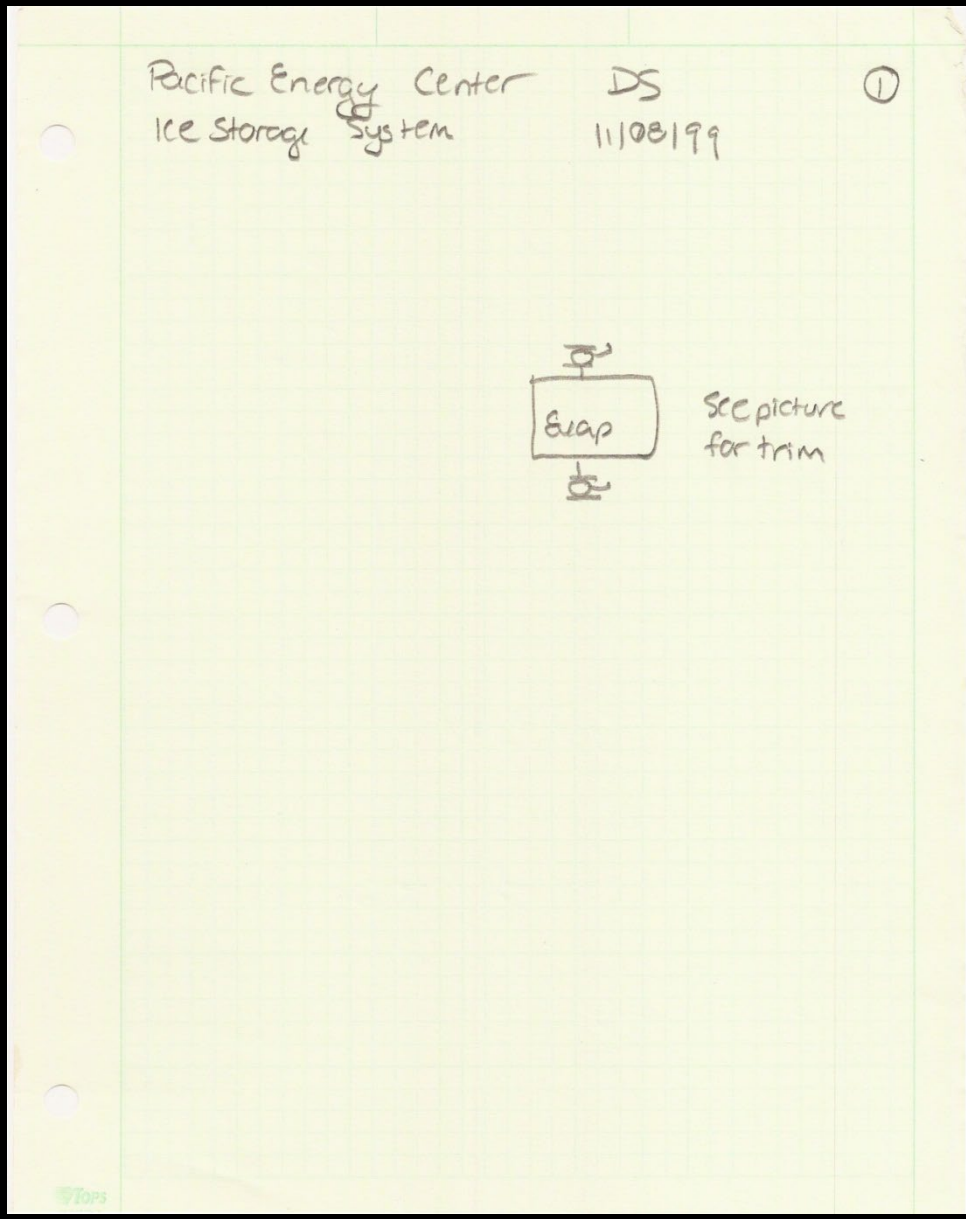
Start following the system of interest

- Your first effort will likely not be your last effort



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- “Follow your nose”

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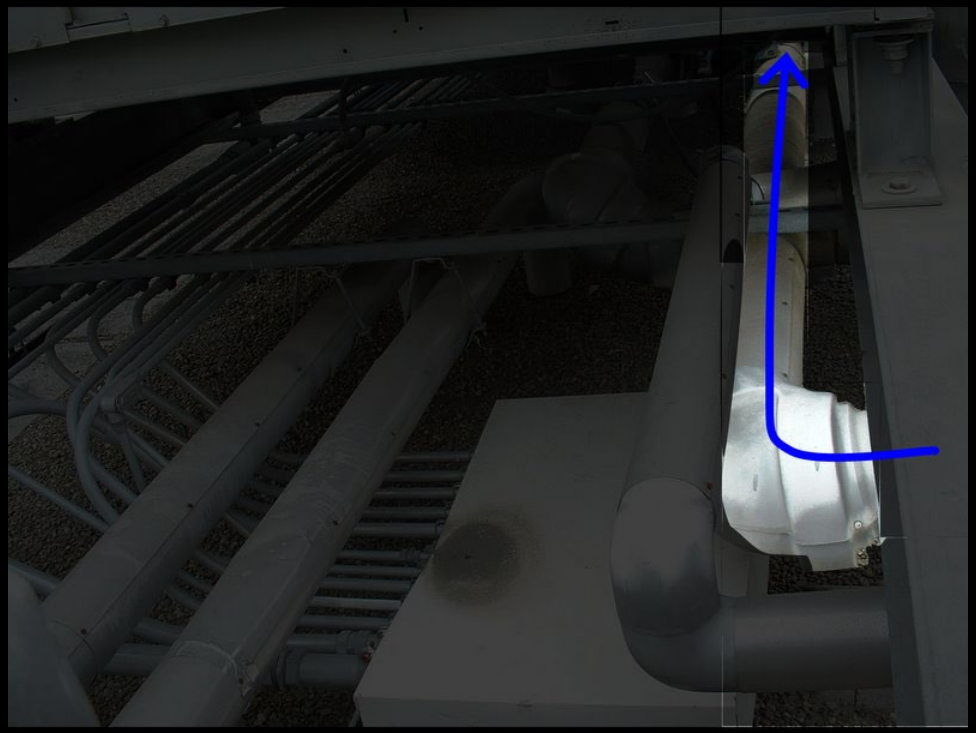

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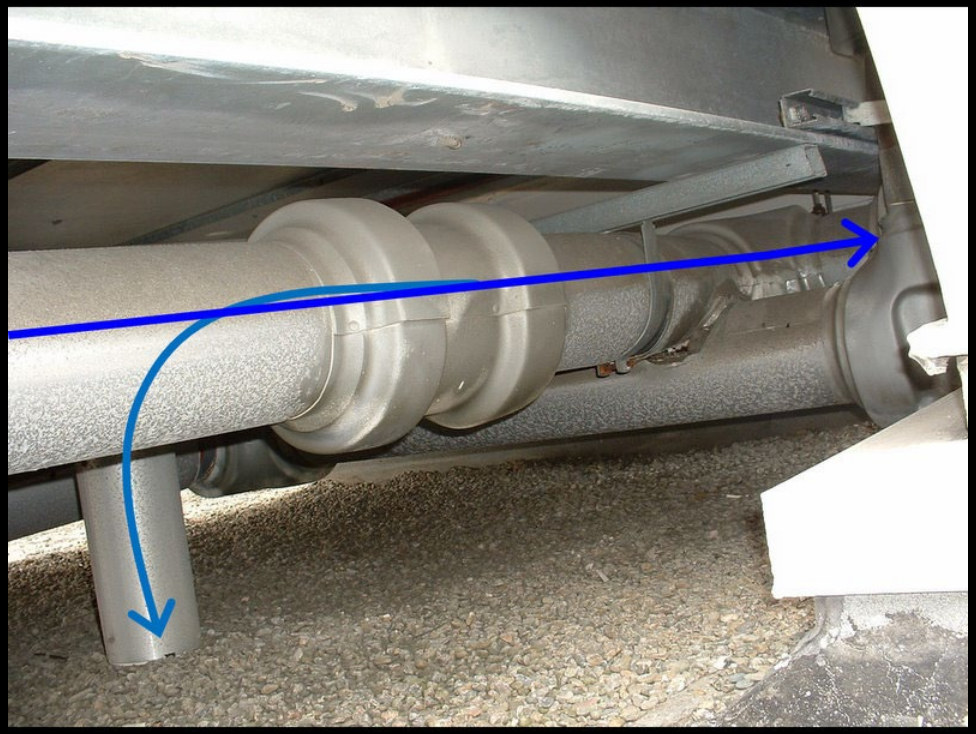
- Make decisions at tees



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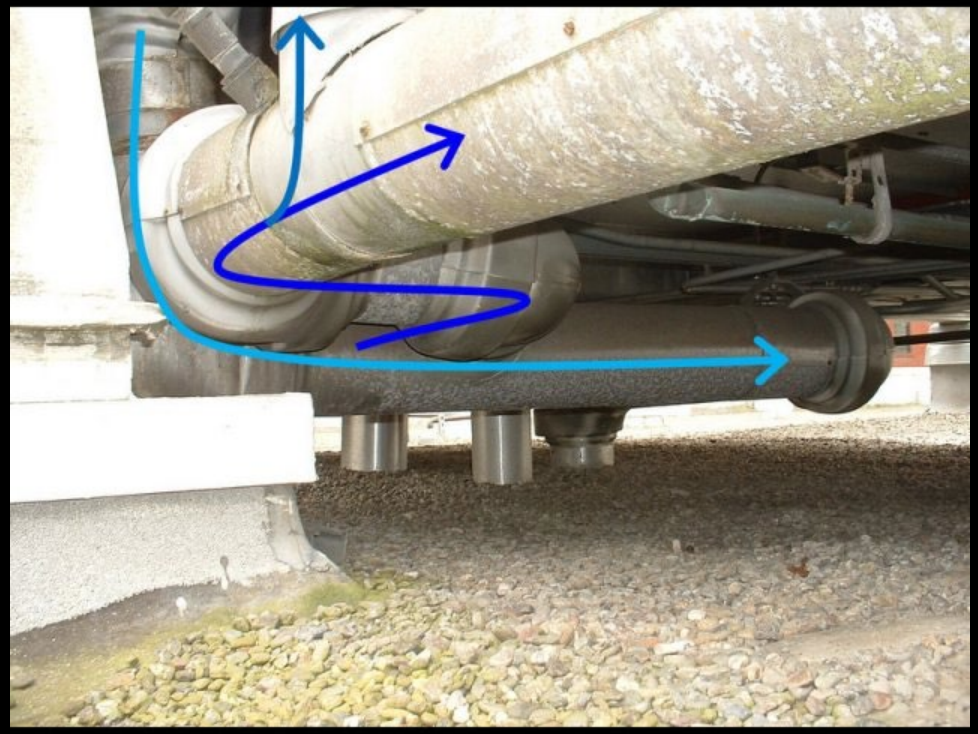

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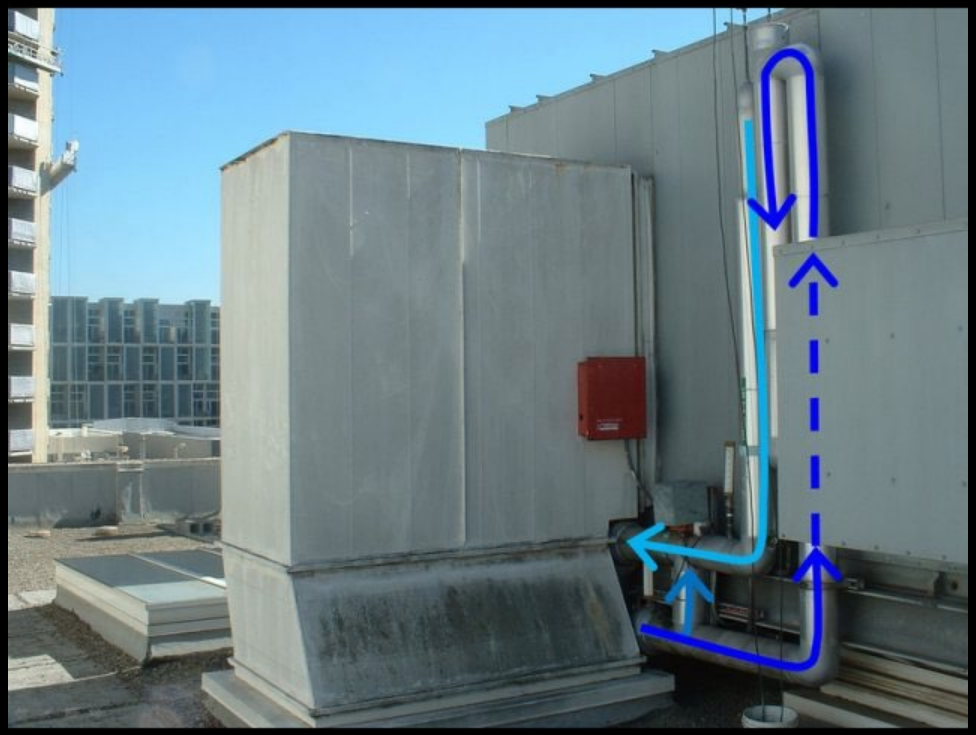

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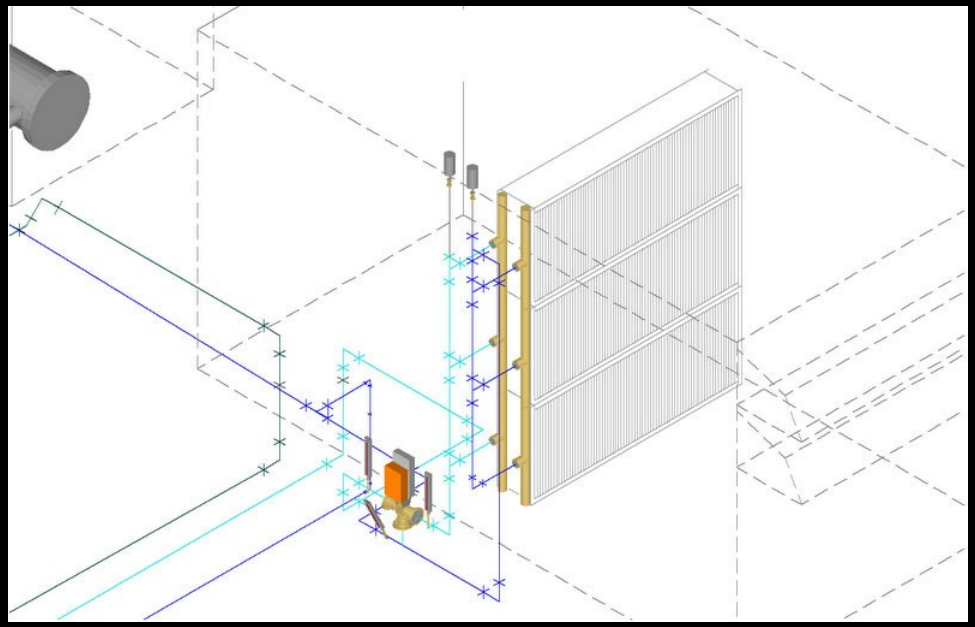

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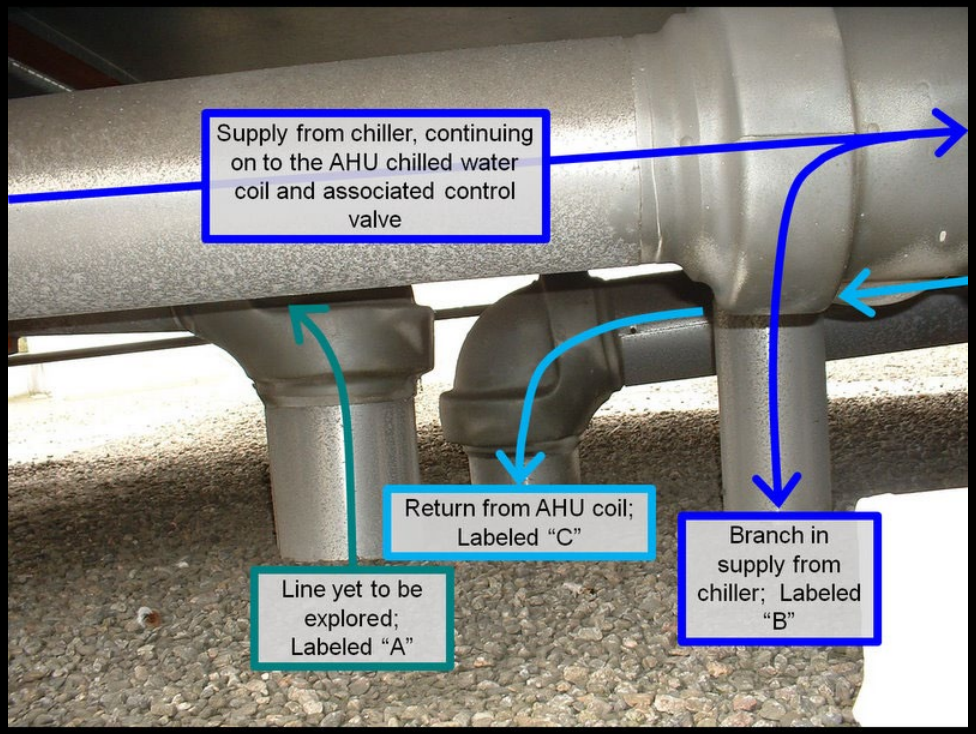

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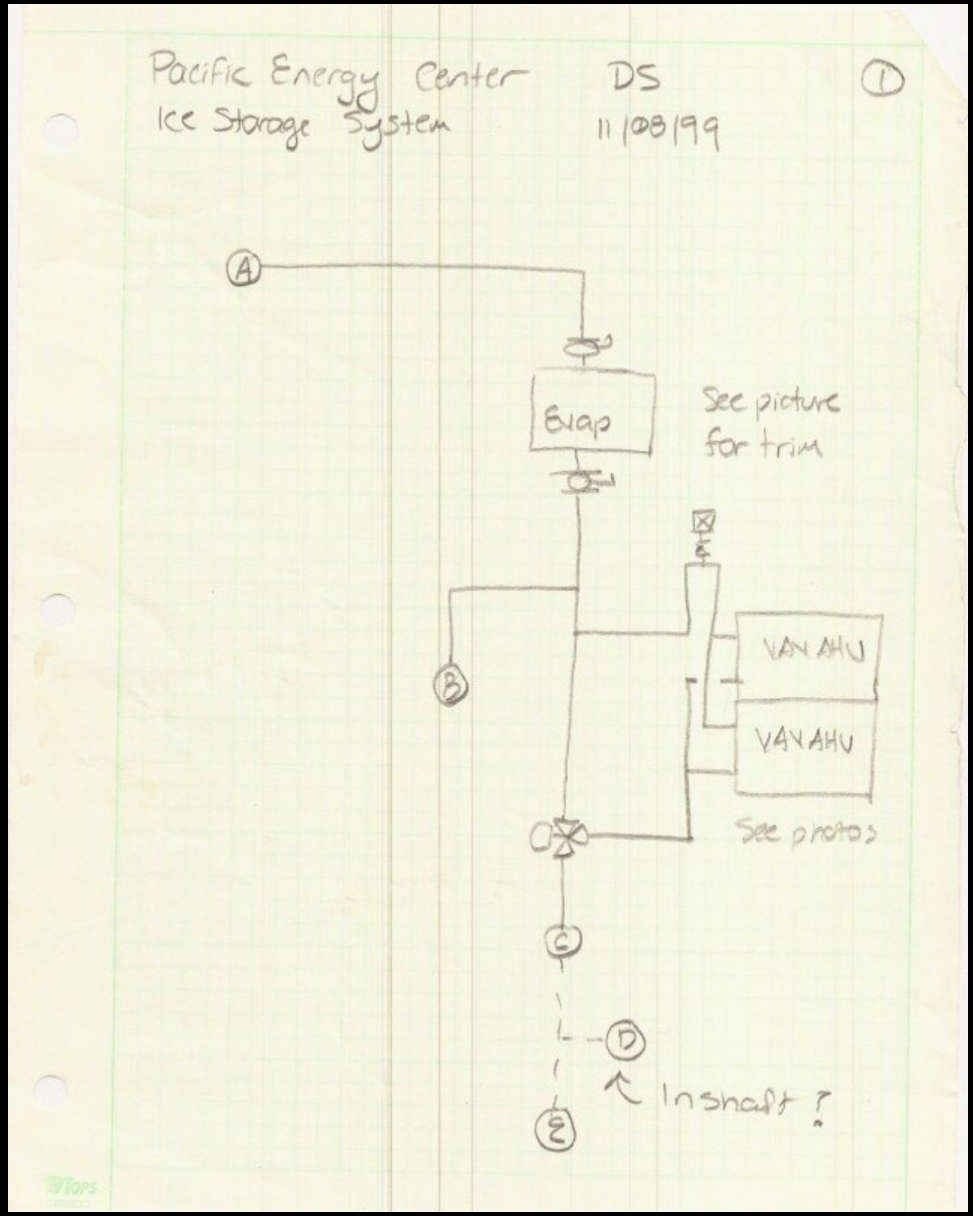


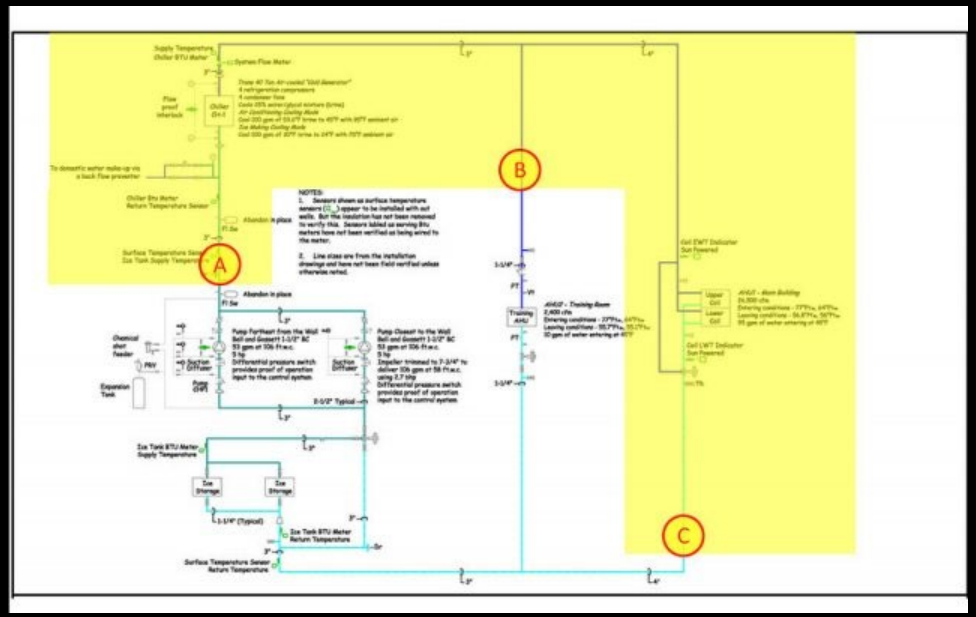
Getting Started

Find something you can identify

- Nameplate data
- Labels
- Past experience

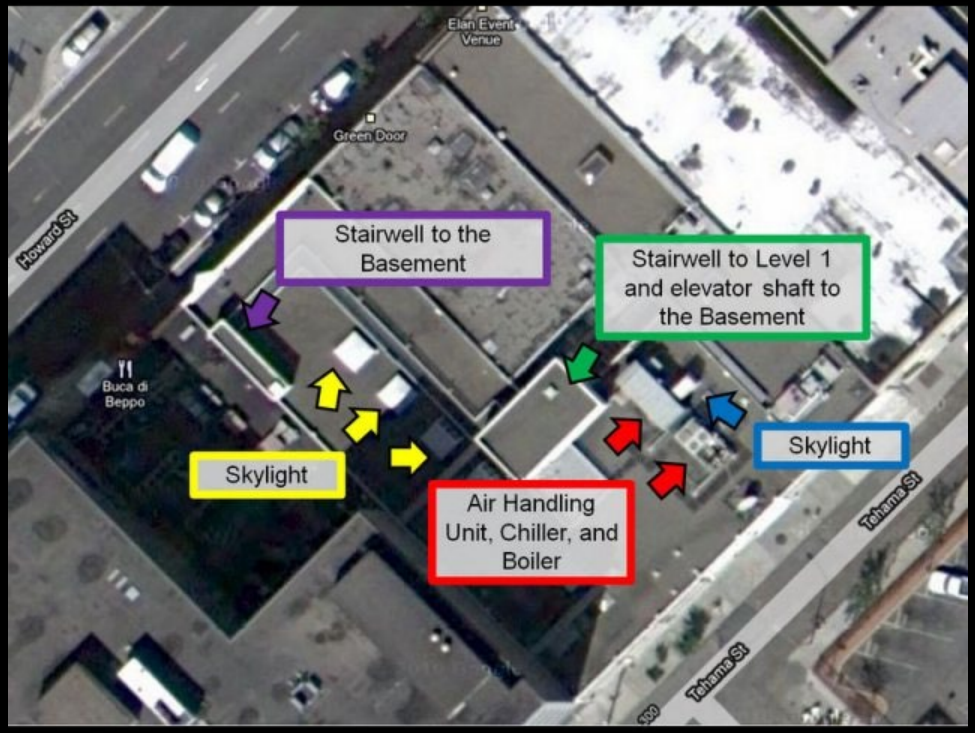
Start following the system of interest

- Your first effort will likely not be your last effort
- “Follow your nose”
- Make decisions at tees



Getting Off the Roof

- Identify a Point of Reference



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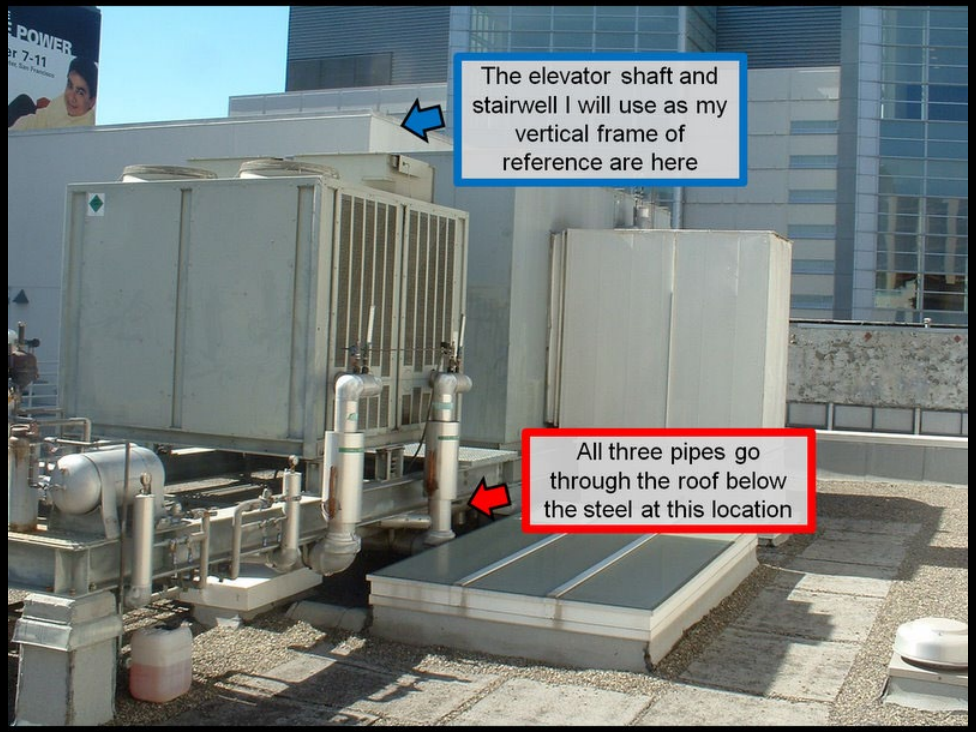
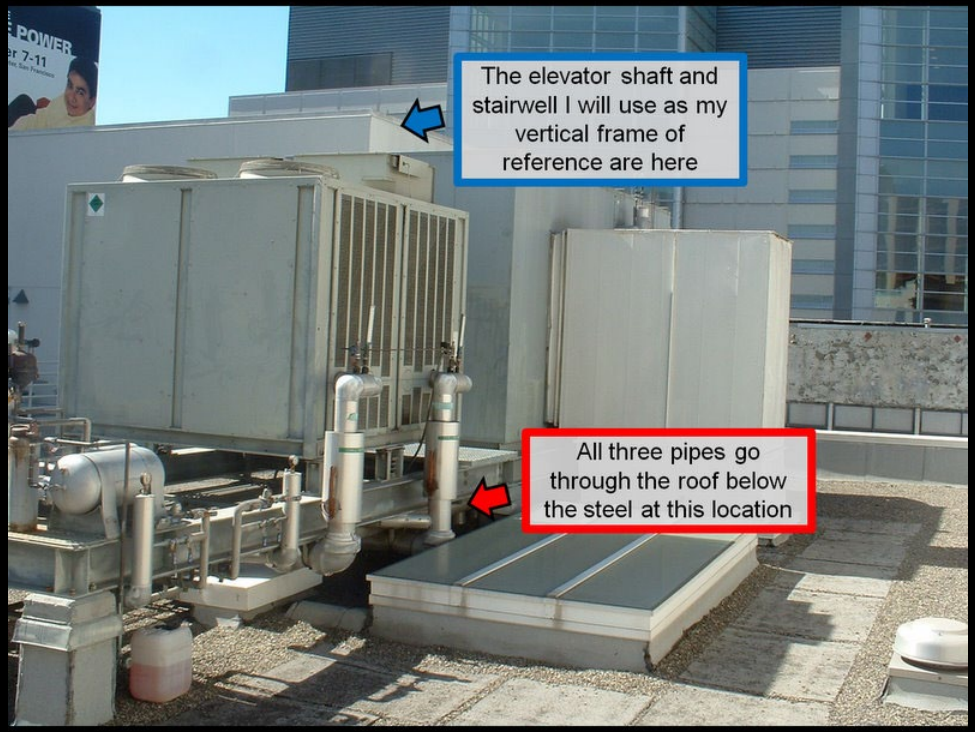


Getting Off the Roof

- Identify a Point of Reference
- Identify Your “Pace”
- Use Your “Pace” to Develop Coordinates Relative to the Point of Reference



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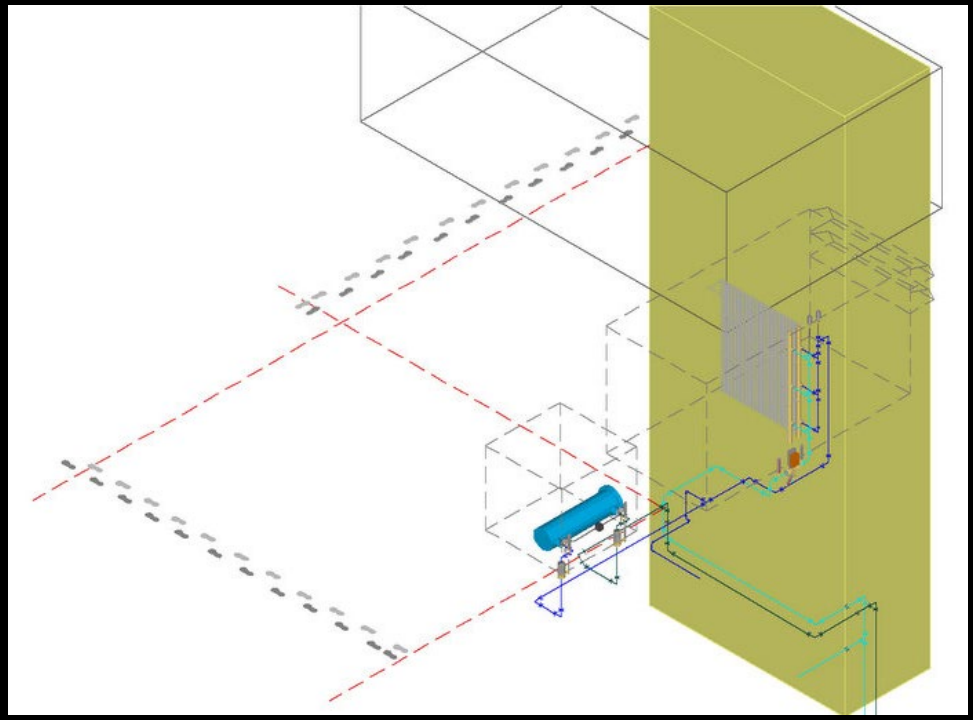

Getting Off the Roof

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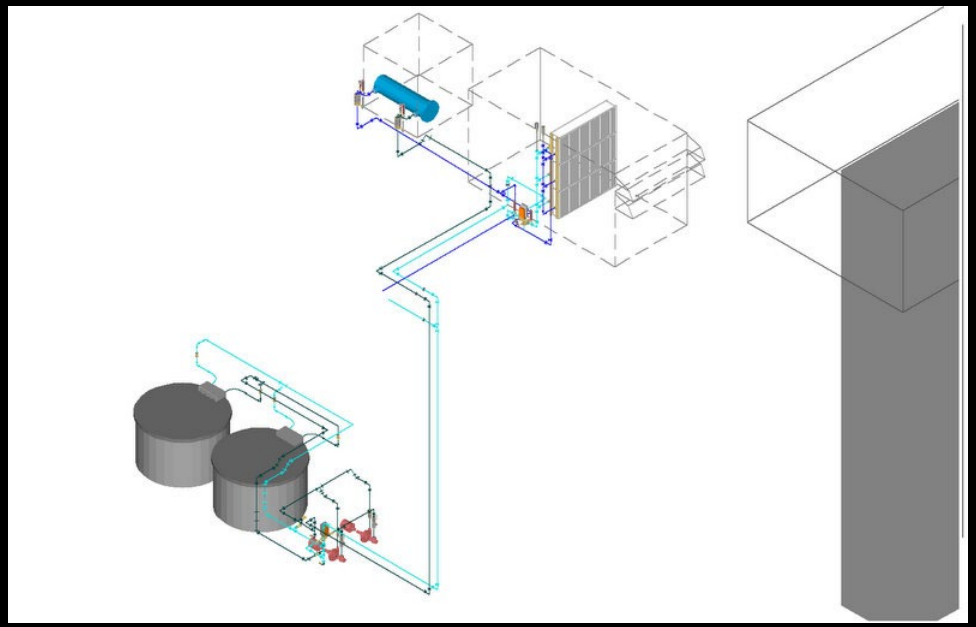


Getting Off the Roof

- Identify a Point of Reference
- Identify Your “Pace”
- Use Your “Pace” to Develop Coordinates Relative to the Point of Reference
- Apply Your Coordinates on a Different Floor
- Leverage Existing Labels (Maybe)
  - Cutting a hole in the wall or shaft may or may not be warranted
  - Leverage other clues
  - Some of them may be misleading

What About Drawing Programs?

AutoCAD and AutoCAD LT

- Quasi-standard in the industry
- Full version $3 – $4K
- Factor of 4 price difference between full and LT version
- LT probably sufficient for most Cx providers
- Steep learning curve
- Can do more than diagrams
  - Drafting
  - Some 3-D
  - Automation

Visio

- Microsoft family
- Full version about $1K
- Factor of 4 price difference between low end and high end versions
- Geared toward diagrams
  - Not as universally applicable
  - Faster to pick up
- Basic wire-frame capabilities in higher end products
- Interfaces with other Microsoft products directly

What About Drawing Programs?

Draw – OpenOffice.org

- Free
- Limited page size (about 12” x 12”)
- Basic diagramming features
- 3D capabilities

Word/PowerPoint Drawing Utilities

- Part of the Office package
- Difficult to use for complex drawings
- Relatively easy to pick up for basic shapes
- Some issues with alignment in 2007 versions

What About Drawing Programs?

Sketch-up

- Google/Trimble
- Free
- Using 3D model to convey 2D information

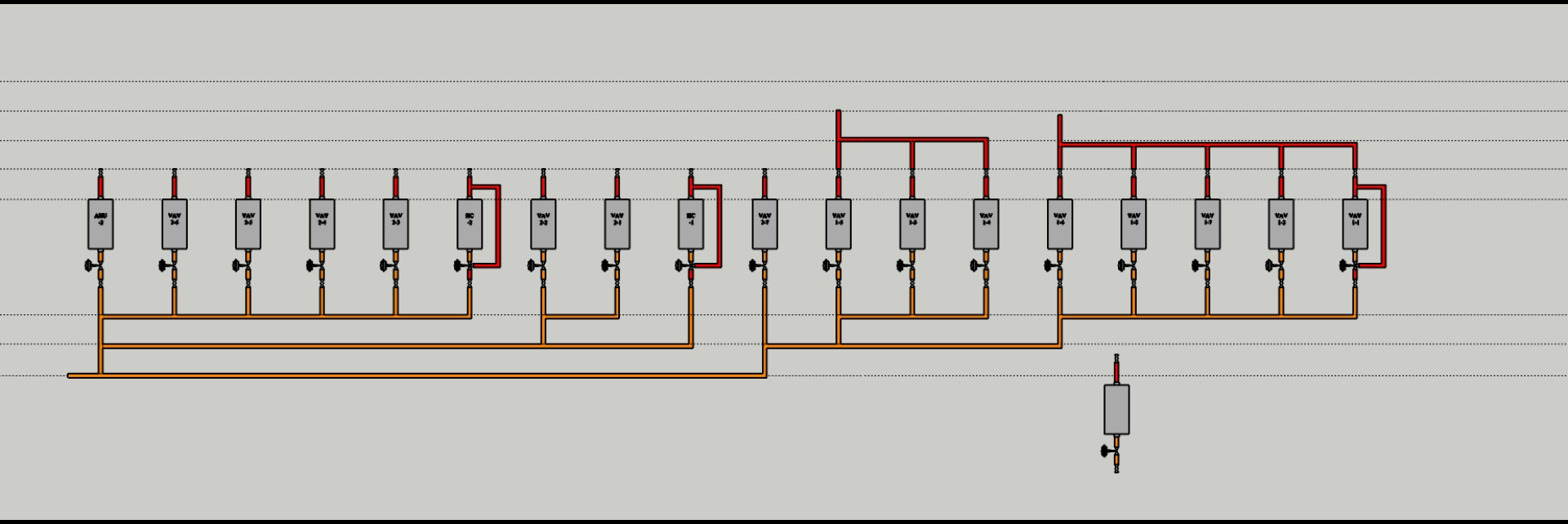


Diagram Drawing 101

Get in the habit of drawing on a grid

- "Electronic graph paper"
- Orderly drawings
- Alignment is easier
- Can be "on" or "off" for printing

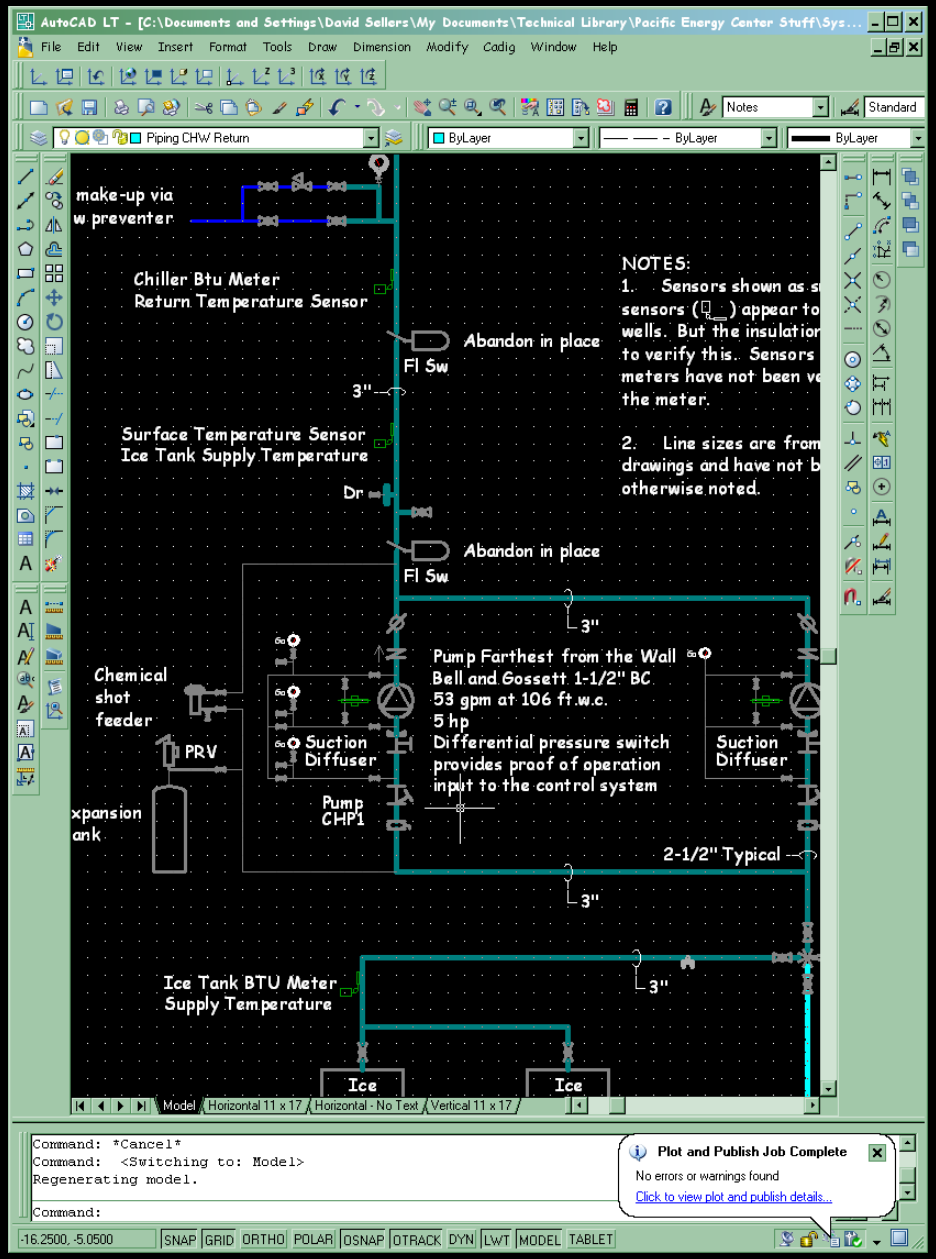


Diagram Drawing 101

Colors can be used to advantage

- Distinguish different types of fluids (chilled water, hot water, condenser water)
- Distinguish hot from cold, warmer from cooler, supply from return

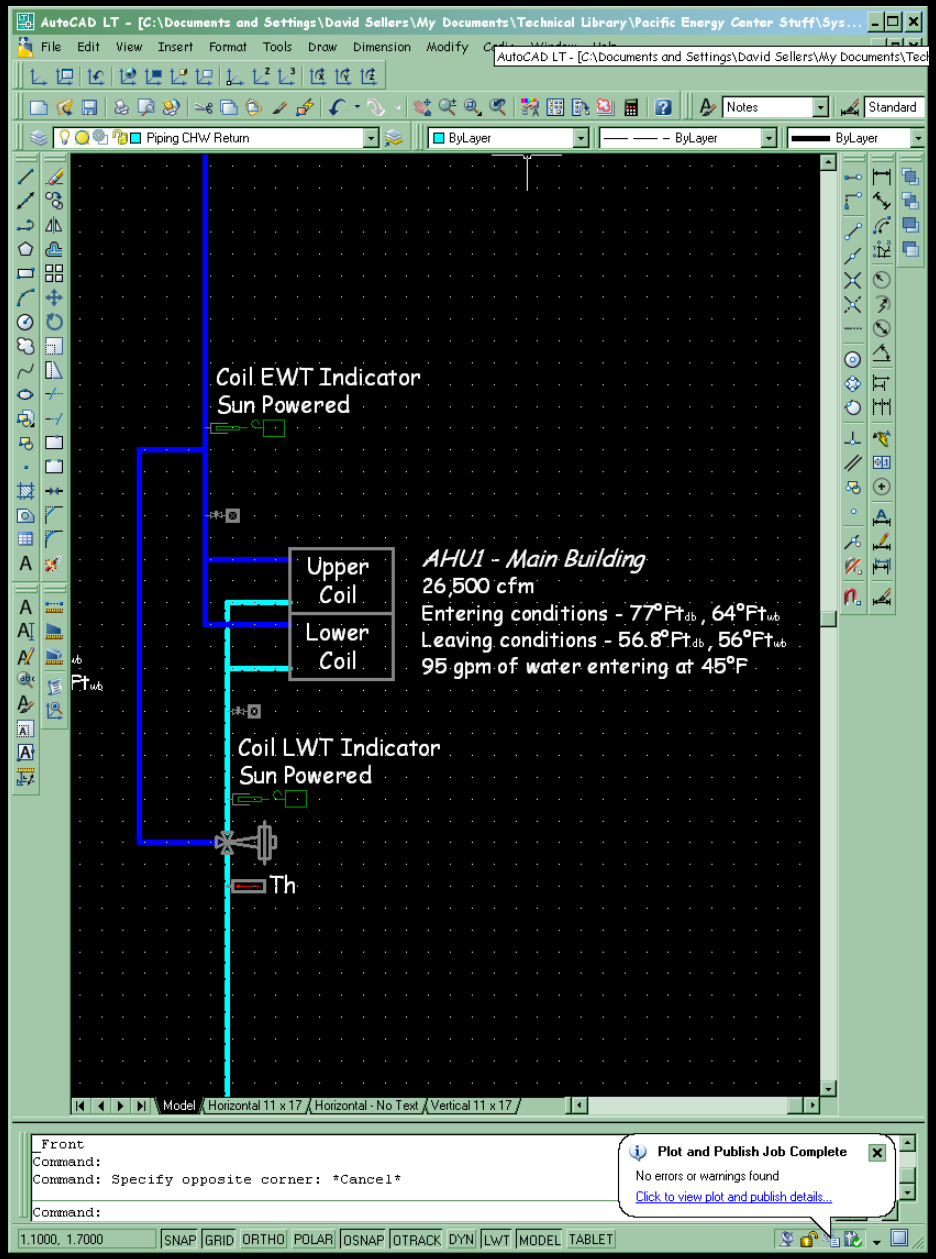


Diagram Drawing 101

Colors can be used to advantage

- Distinguish different types of fluids (chilled water, hot water, condenser water)
- Distinguish hot from cold, warmer from cooler, supply from return
- Enhance understanding

  Outside Air mixing with Return Air makes Mixed Air

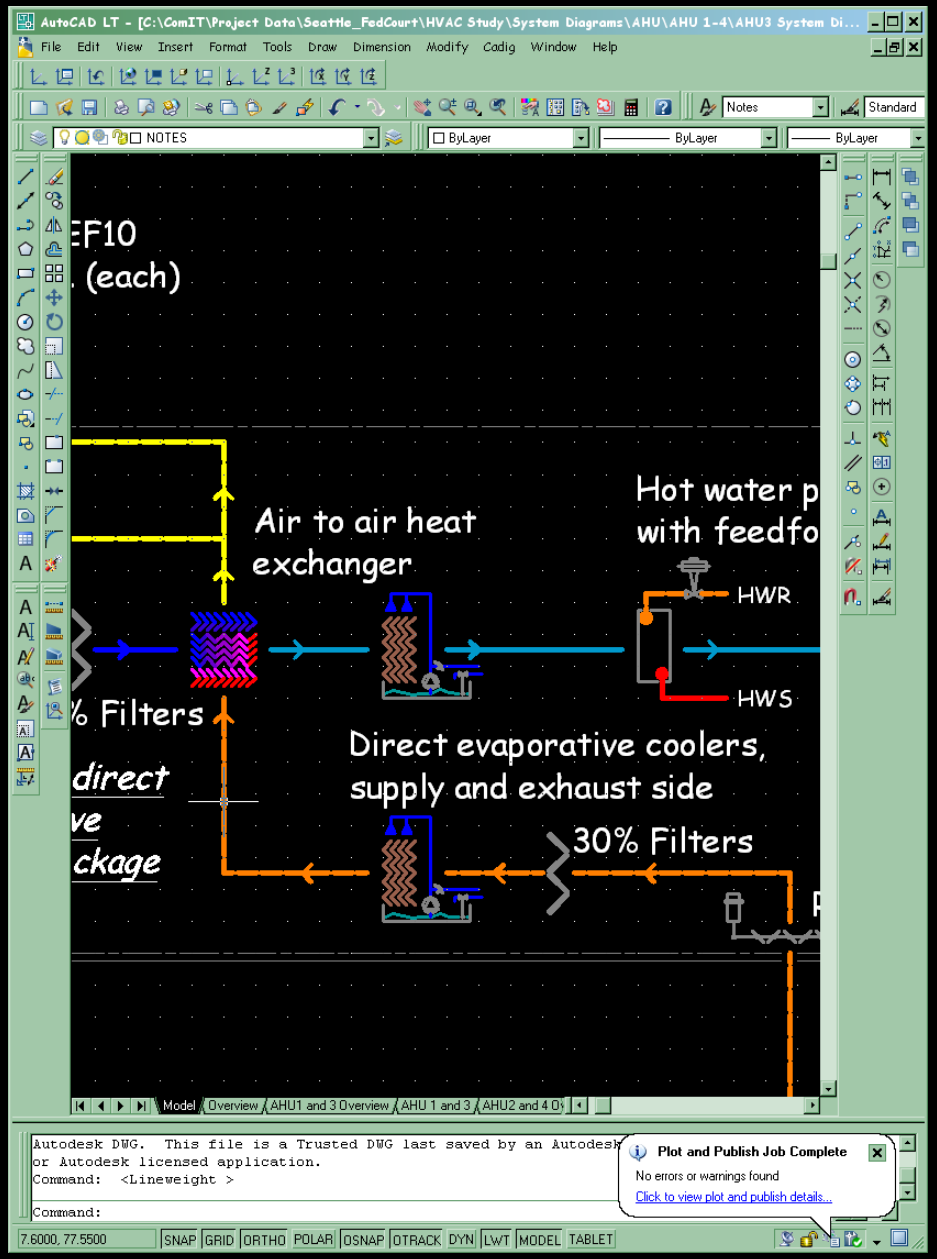
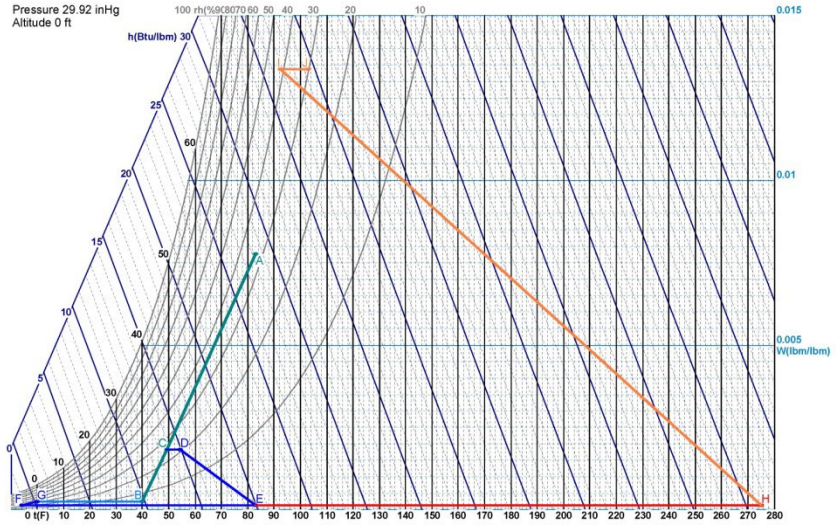


Diagram Drawing 101



90 cfm A

Outdoor air intake at 1st floor roof level serving AH-C, DH2, and DH-3. 90 cfm taken in for DH-1 reactivation air

Colors can be used to advantage

Outdoor air to AH-C and DH-2

90 cfm J

Open shaft to roof level provides relief path for AH-C as well as DH-2 and DH-3 reactivation air exhaust. DH-3 exhausts 90 cfm

Freezer Room Cooling and Dehumidification System DH-3

Thermocouple

SWSI supply fan with current switch
90 cfm at 2.85 in. w.c.
1.86 in.w.c external static pressure
1 hp, 0.4 bhp, 3,450 rpm

M I

Thermocouple H

Electric reactivation heater 8.7 kW

Metal mesh filter

Temperature switch, set -6°F

Temperature switch, set -15°F

Duct temperature and relative humidity monitor

M D

C

E

F

30% Prefilter and 95% final filter with differential pressure switch

Variable speed, SWSI supply fan with air flow switch
400 cfm at 4.24 in. w.c.
1.12 in.w.c external static pressure
1 hp, 0.7 bhp, 3,450 rpm

Titanium silica gel (TiGel) type dessicant wheel
11 revolutions per hour
0.29 in.w.c. process air pressure drop
0.26 in.w.c. reactivation air pressure drop

Carbon filter with differential pressure switch

65% final filter with differential pressure switch

Direct expansion cooling coil with 5 hp water cooled condensing unit and hot gas bypass
Refrigerant 404
6 row, 30,848 btu/hr
83°F entering air temperature
-6°F leaving air temperature
-15° saturated suction temperature

– *Color code a process*

Freezer Room

310 cfm total flow
0°F plus or minus 1°F
30-35% relative humidity

G

310 cfm

310 cfm

Reheat coil RC-1
Maintains a 40°F discharge temperature to prevent snow when the freezer return air mixes with the outdoor air brought in for reactivation

B

HWR

HWS

Diagram Drawing 101

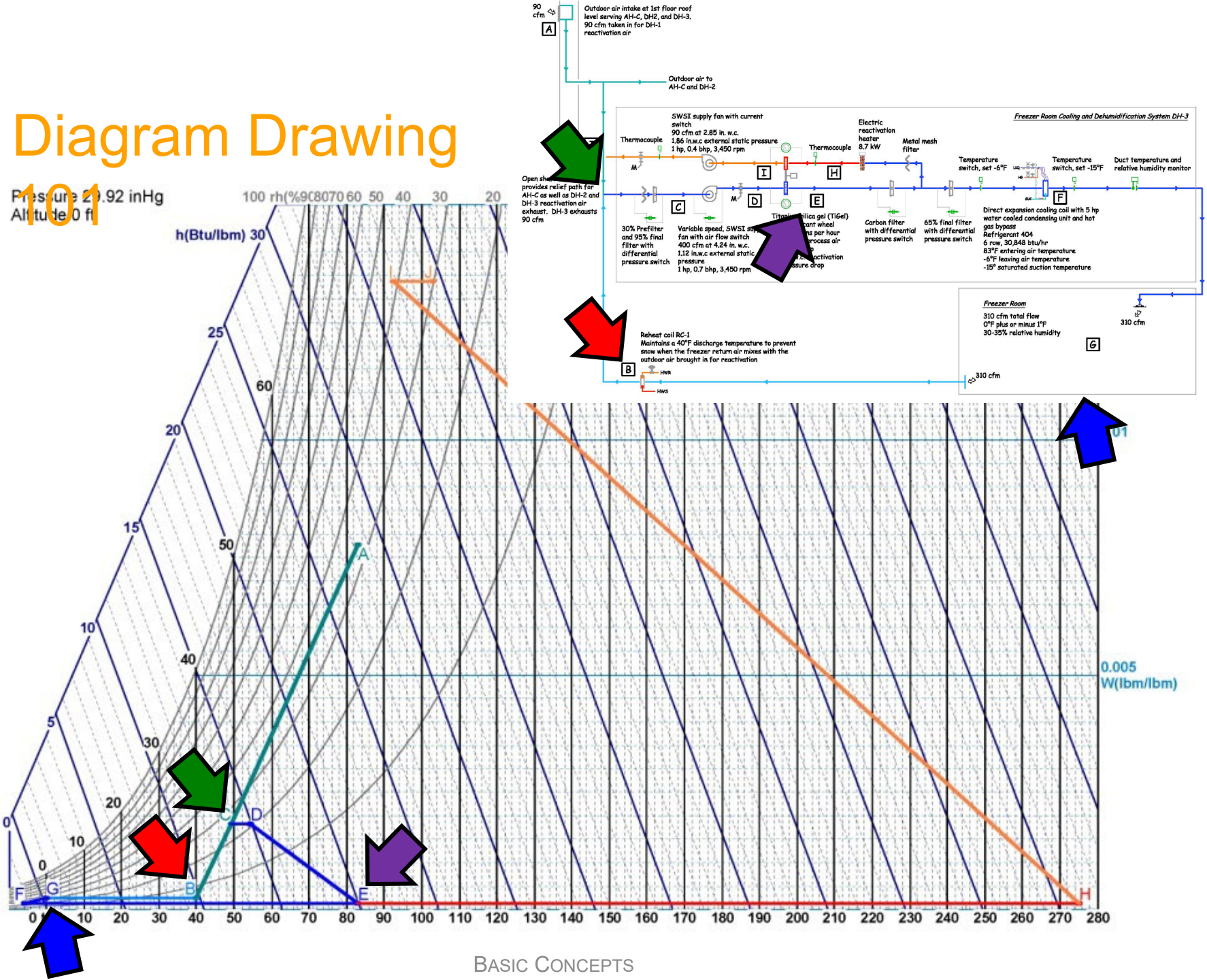


Diagram Drawing 101

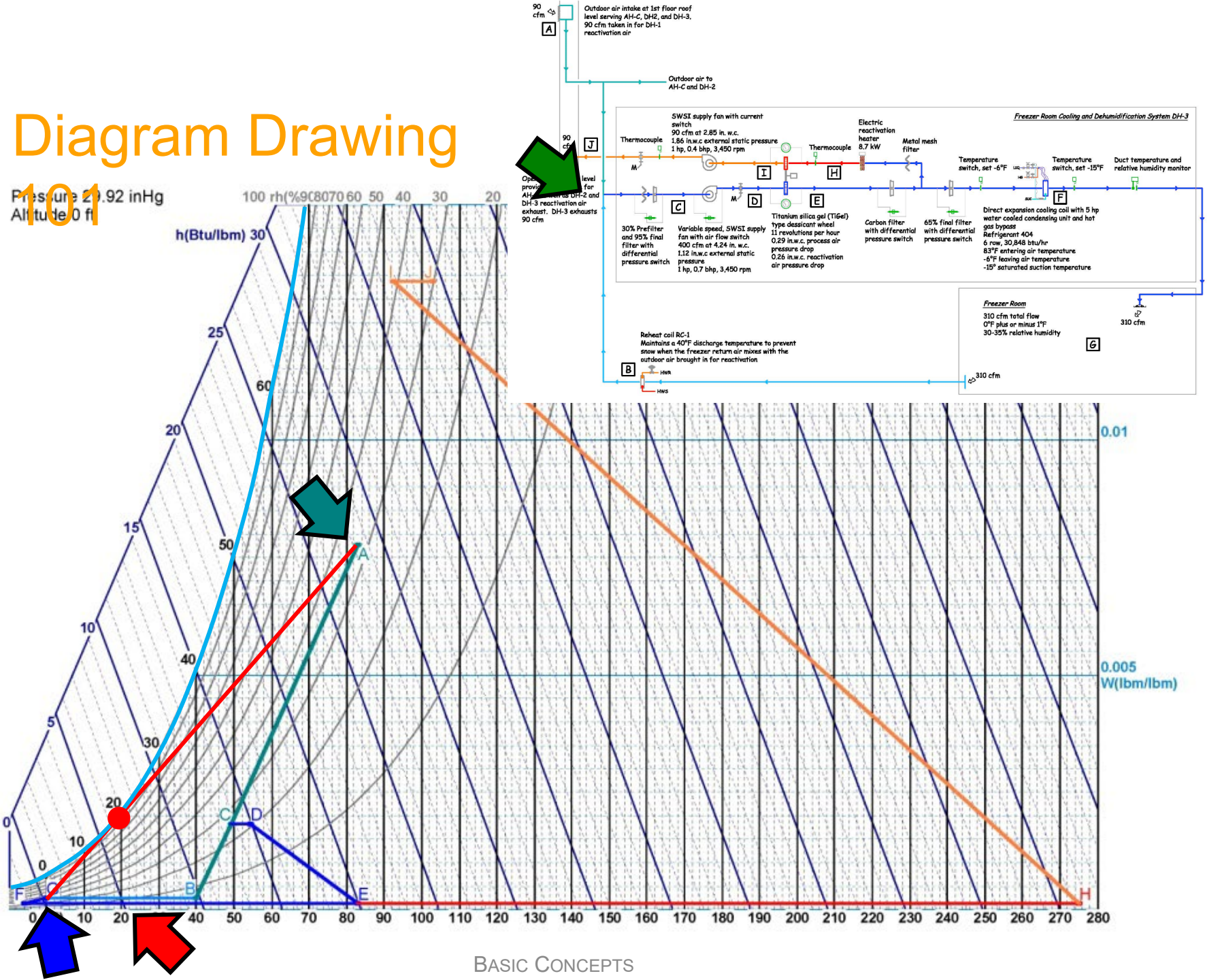


Diagram Drawing 101

Line weights can be important

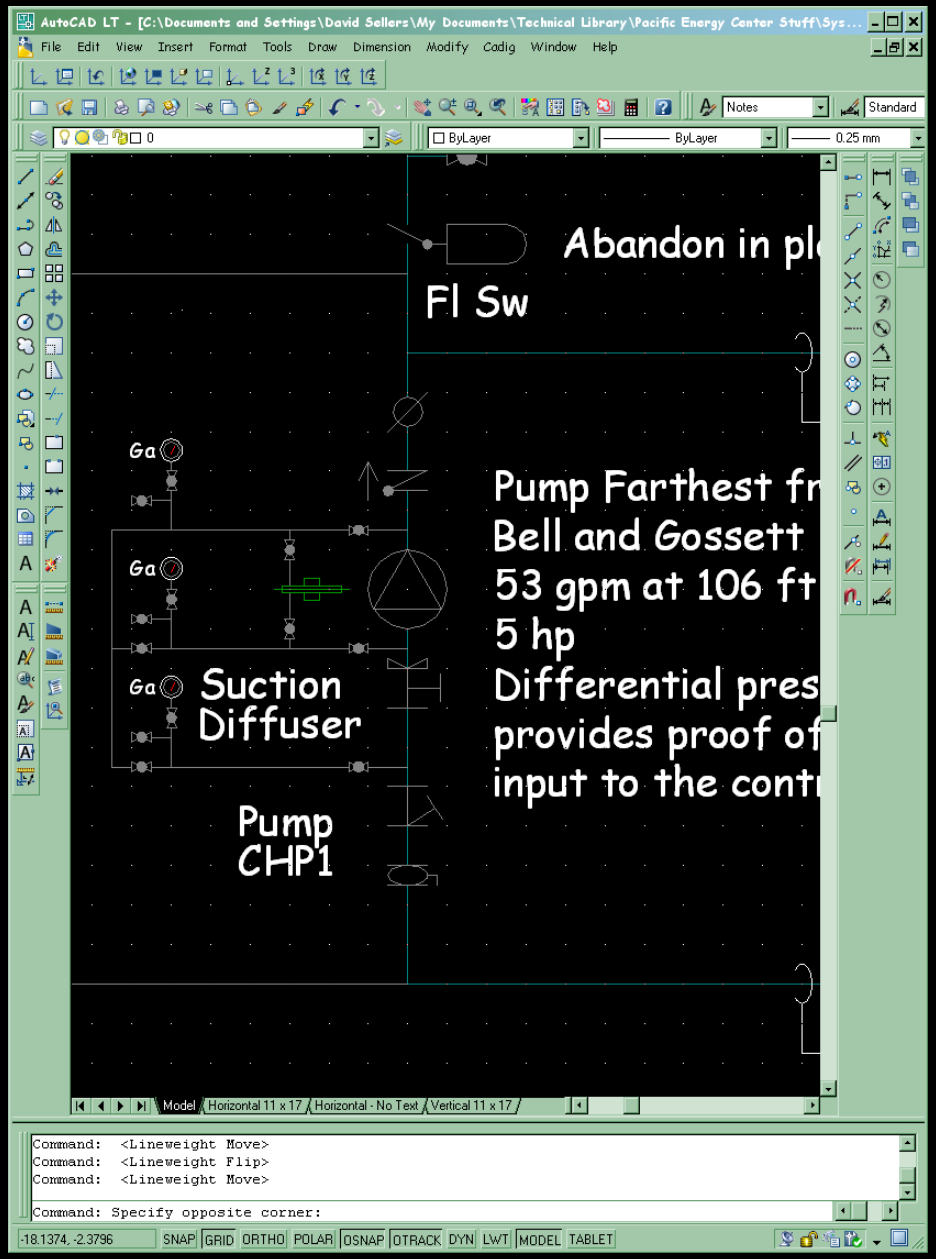


Diagram Drawing 101

Line weights can be important

- Heavier lines draw the eye towards the major system elements
- Lighter line weights show related equipment that is auxiliary to the main system elements

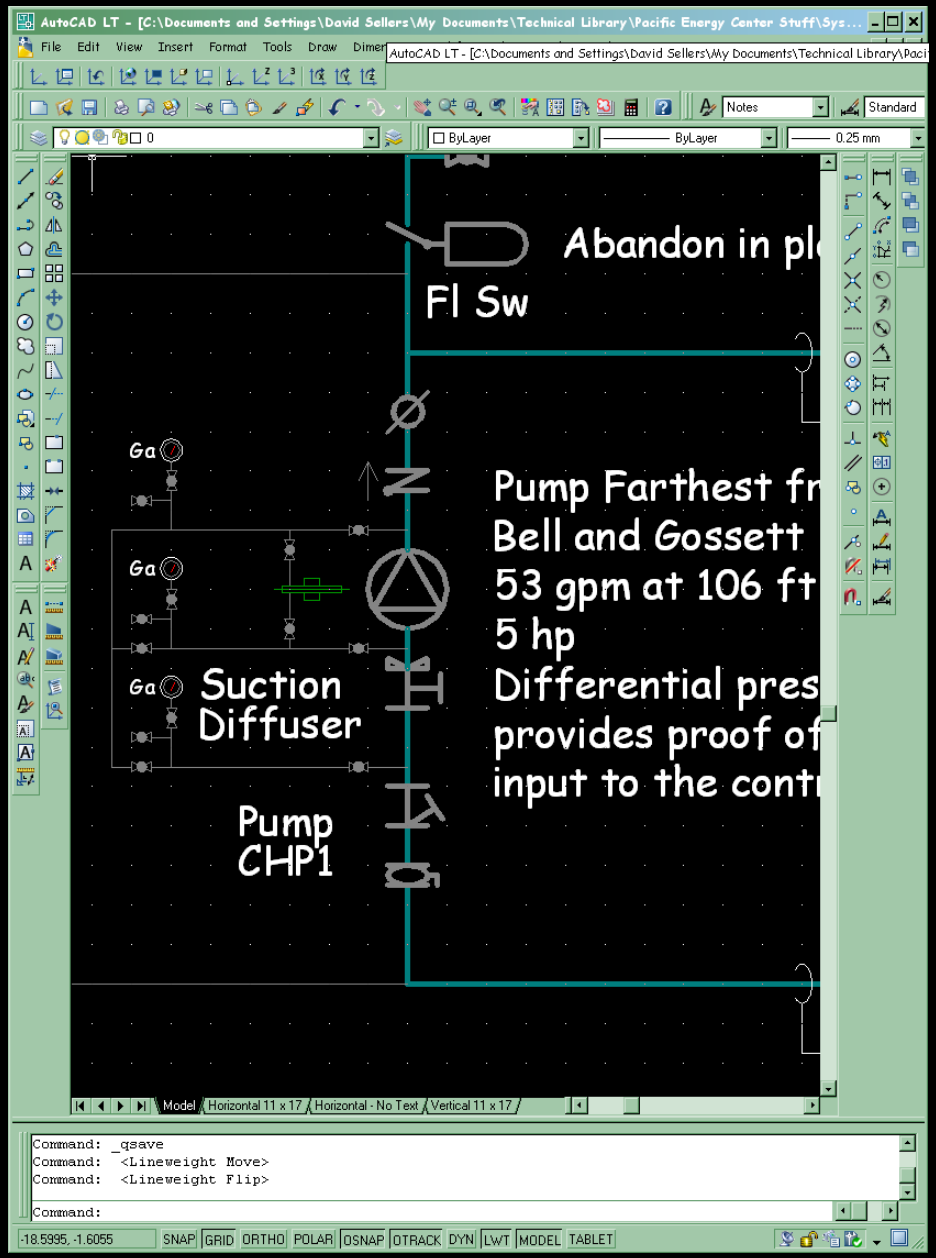
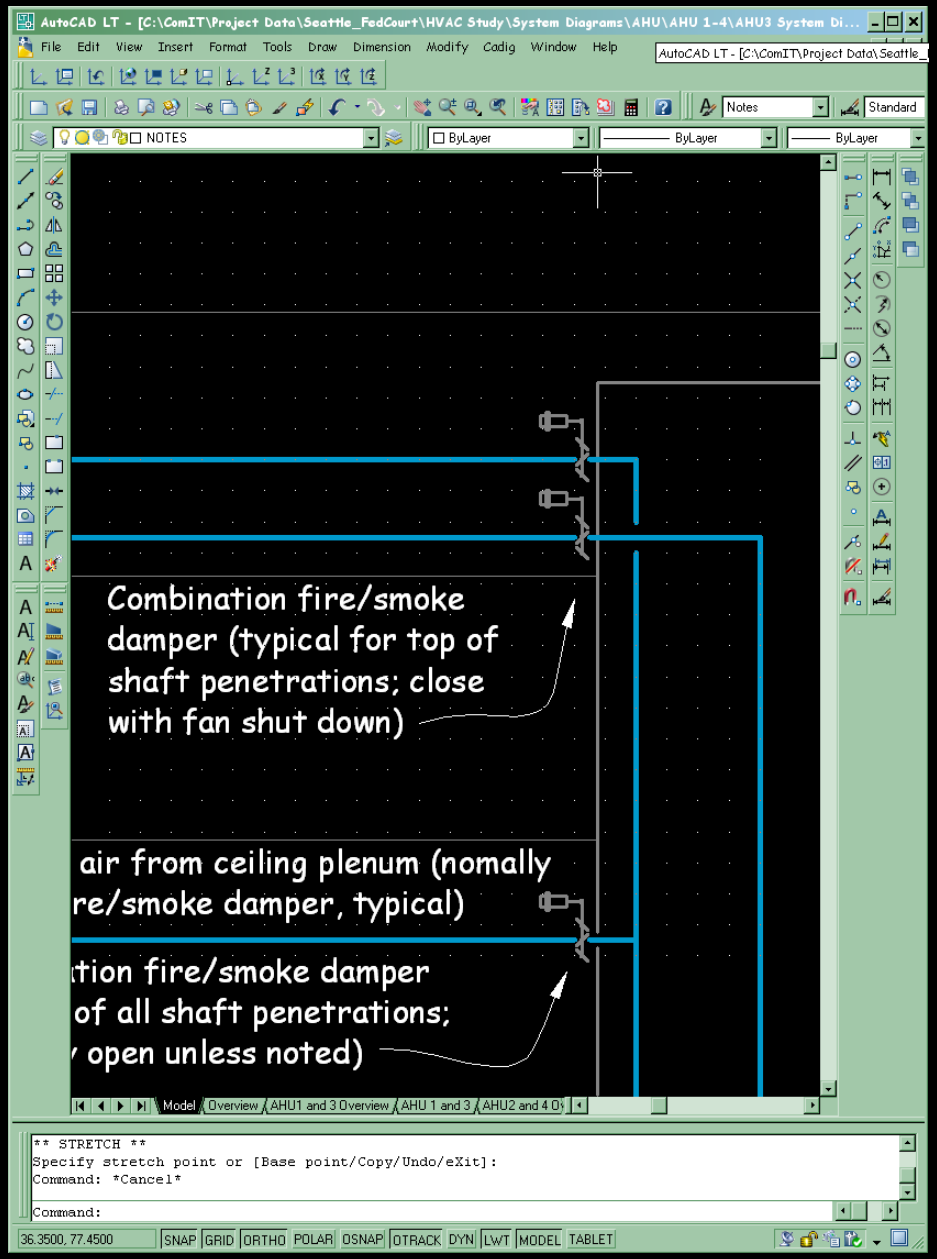


Diagram Drawing 101

Points where lines cross vs. connect should be clear



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Points where lines cross vs. connect should be clear

- Gaps where lines cross need to consider the plot scale relative to the line weight

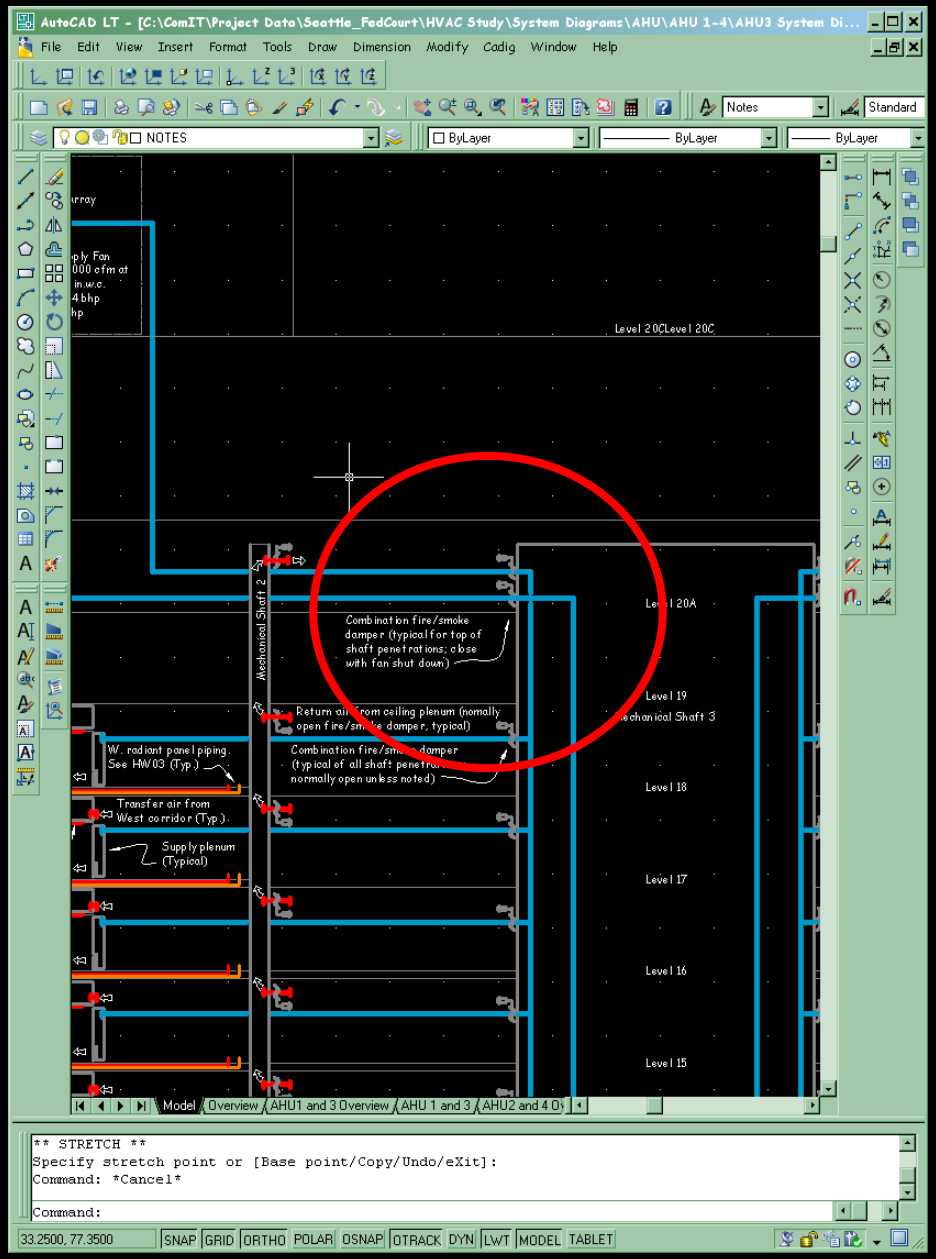


Diagram Drawing 101

Points where lines cross vs. connect should be clear

- Gaps where lines cross need to consider the plot scale relative to the line weight
- “Bumps” can be used to clarify line crossings but can become tedious to draw

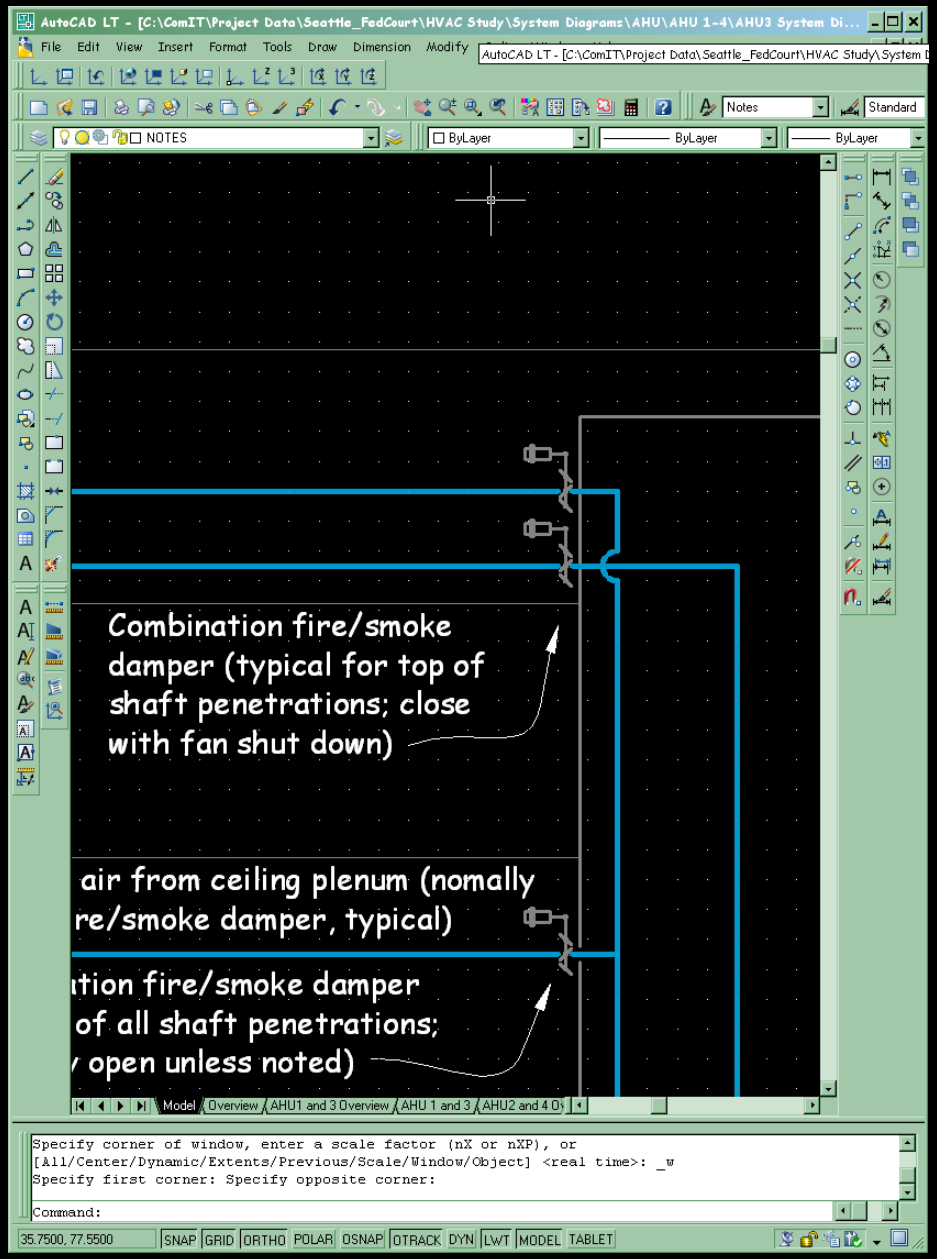
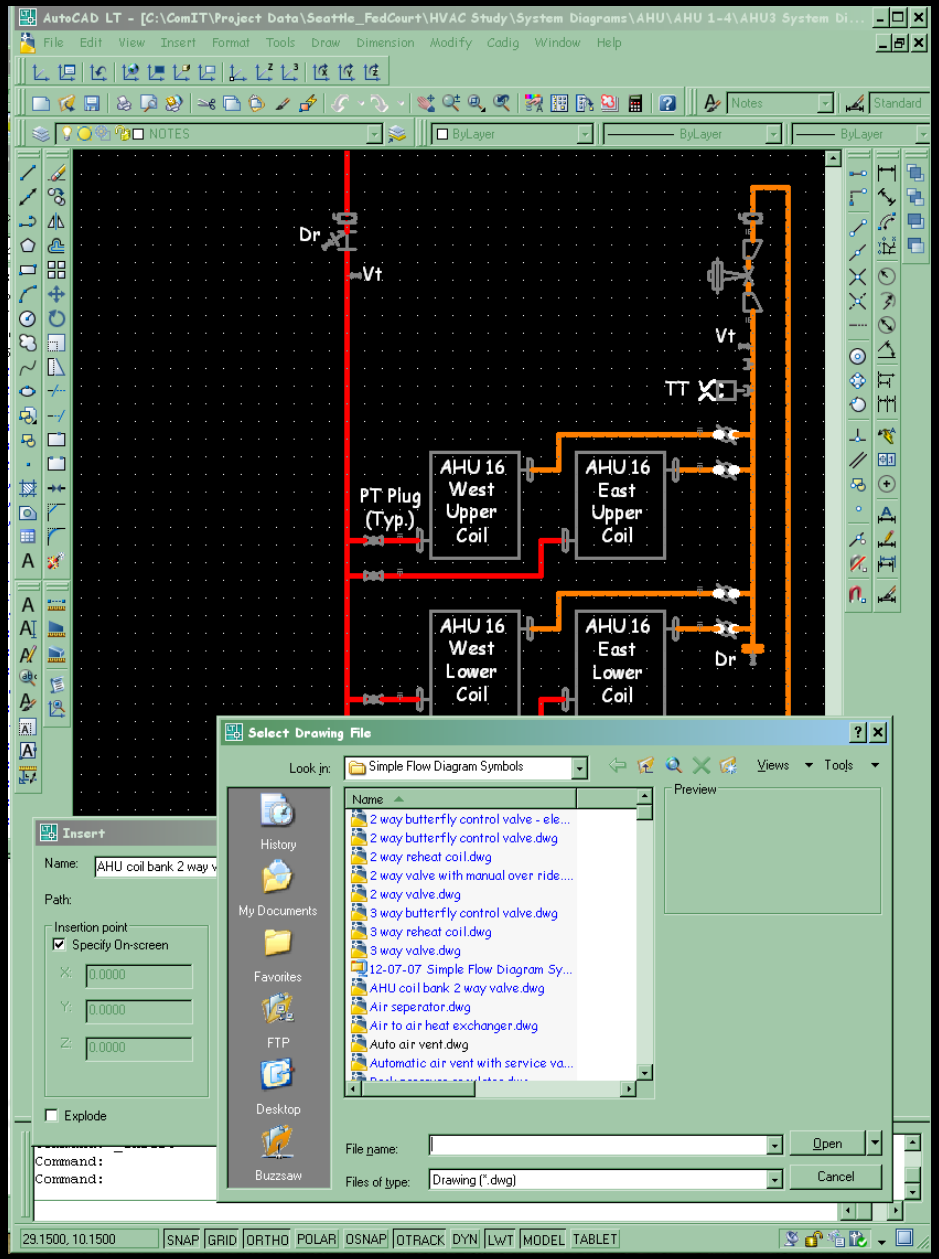


Diagram Drawing 101

Create symbols

- Most programs allow you to take collections of objects, given them a name, and save them as a more complex object
- AutoCAD blocks are an example



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- This data can then be extrapolated to generate equipment schedules, point lists, etc.

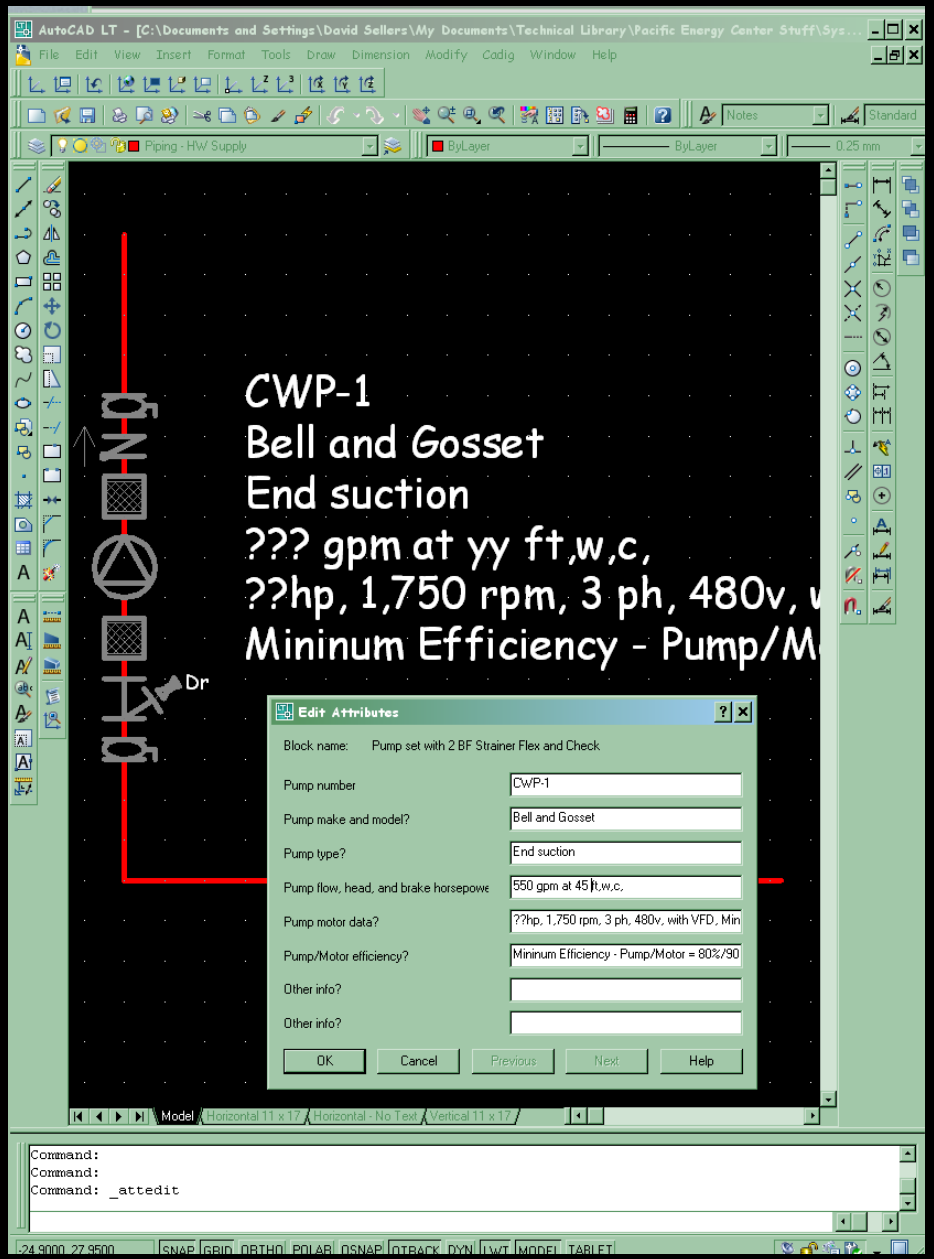

Diagram Drawing 101

Create symbols

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- AutoCAD blocks are an example
- AutoCAD allows you to assign “fill in the blank” field for data associated with the block
- This data can then be extrapolated to generate equipment schedules, point lists, etc.
- You can also edit blocks after they are inserted

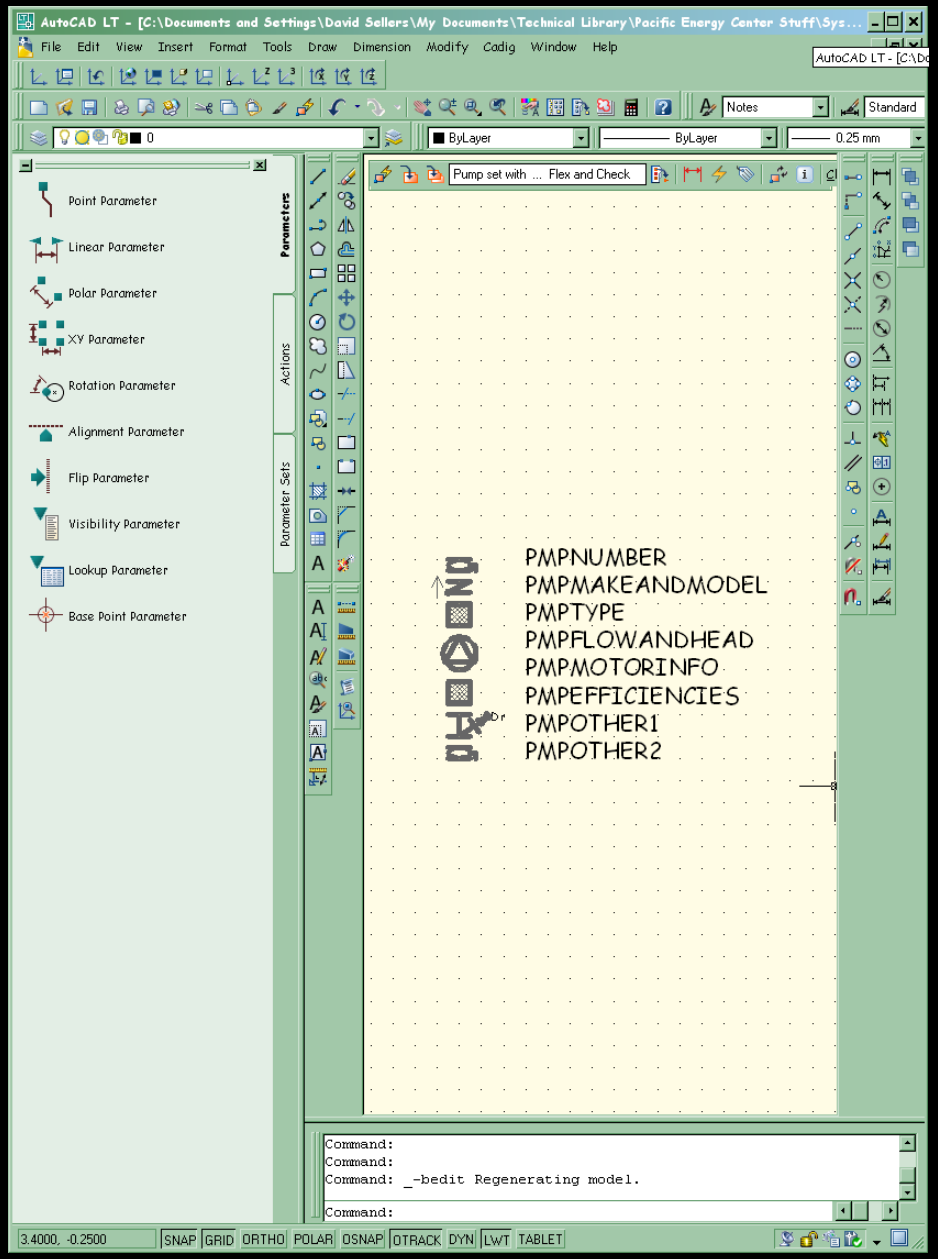
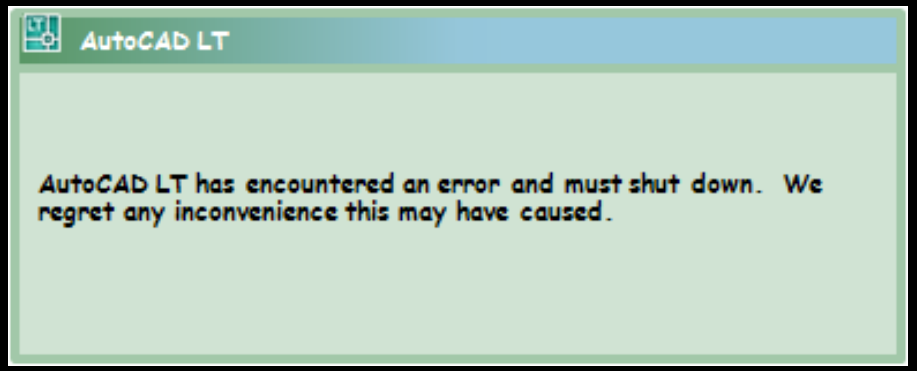


Diagram Drawing 101

Desirable habits/features

- Frequent “saves”
- Enable “auto-save”
- Regular back-ups



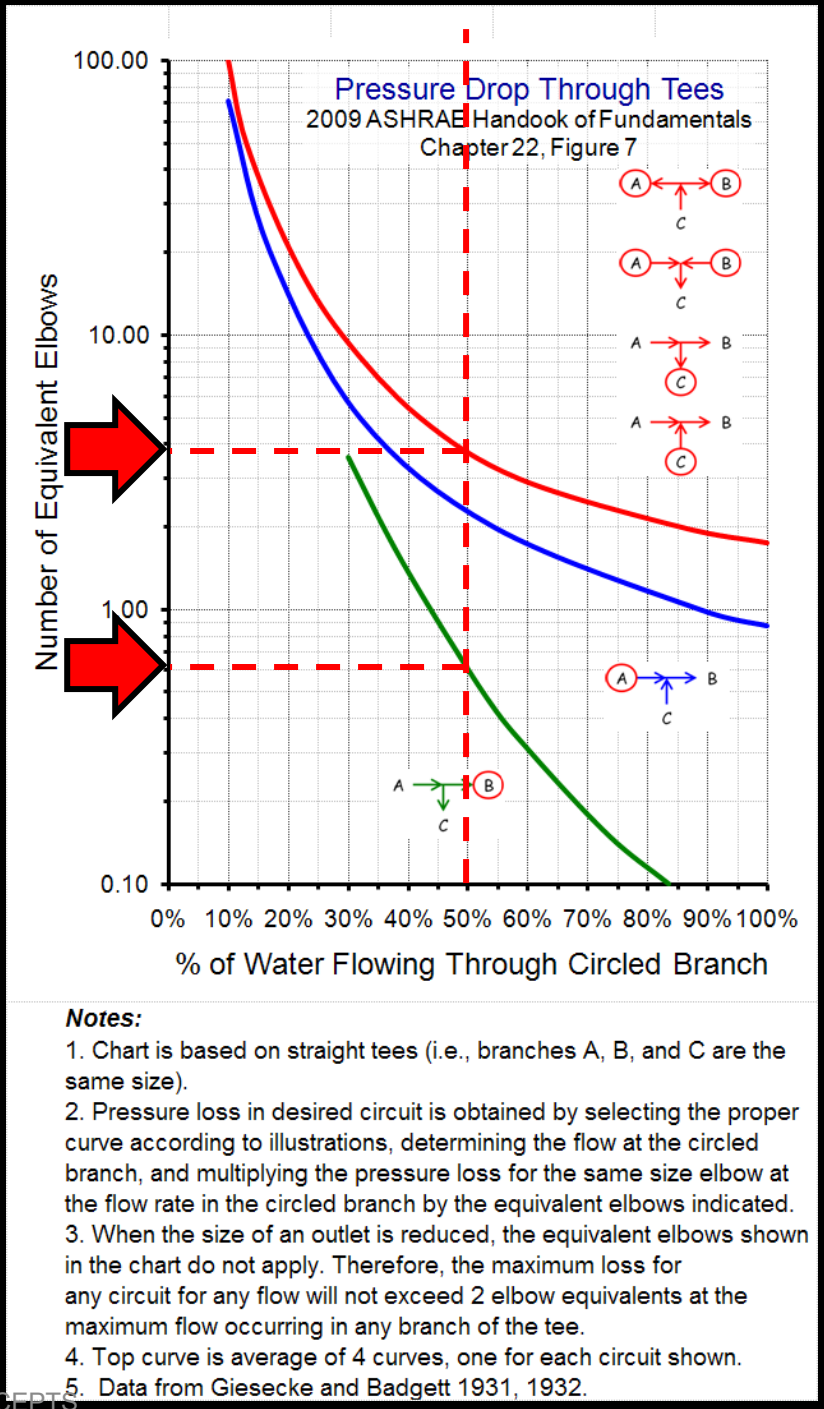
Tee's are Important

For both the physical system and the system diagram:

- Divergence or convergence of flow
- An opportunity to introduce a problem if the order of connection is not correct

For the physical system, they represent a pressure drop

- Significant
- Highly variable with configuration



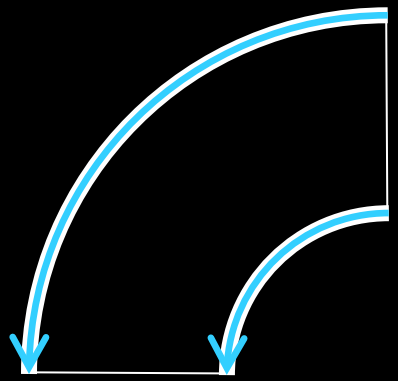
Notes:

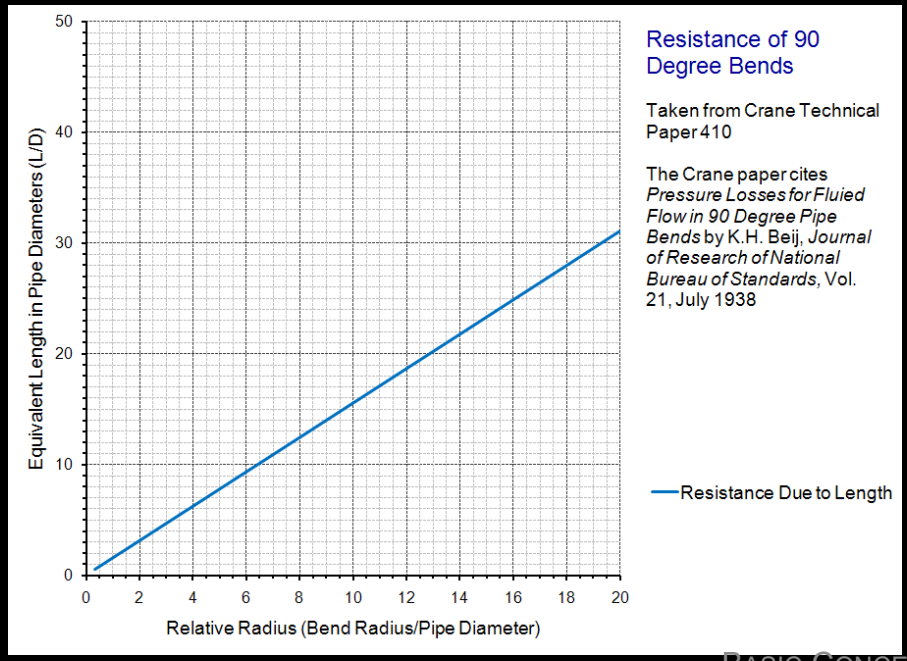
1. Chart is based on straight tees (i.e., branches A, B, and C are the same size).
2. Pressure loss in desired circuit is obtained by selecting the proper curve according to illustrations, determining the flow at the circled branch, and multiplying the pressure loss for the same size elbow at the flow rate in the circled branch by the equivalent elbows indicated.
3. When the size of an outlet is reduced, the equivalent elbows shown in the chart do not apply. Therefore, the maximum loss for any circuit for any flow will not exceed 2 elbow equivalents at the maximum flow occurring in any branch of the tee.
4. Top curve is average of 4 curves, one for each circuit shown.
5. Data from Giesecke and Badgett 1931, 1932.

Elbows; Not So Much Maybe

From the perspective of the system diagram:

- Just a bent piece of straight pipe
- Water in = Water out





One way to think of elbow resistance is to consider it as composed of:

Resistance due to interaction with the pipe wall

Elbows; Not So Much Maybe

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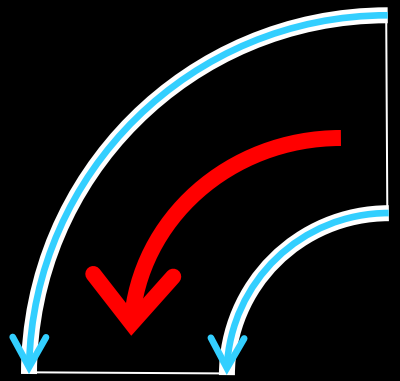

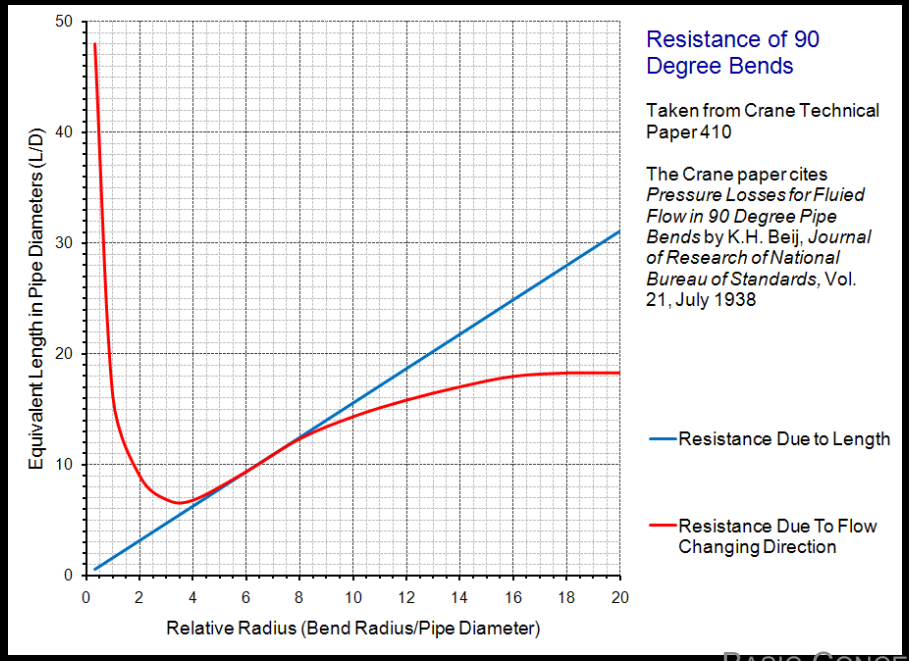

One way to think of elbow resistance is to consider it as composed of:

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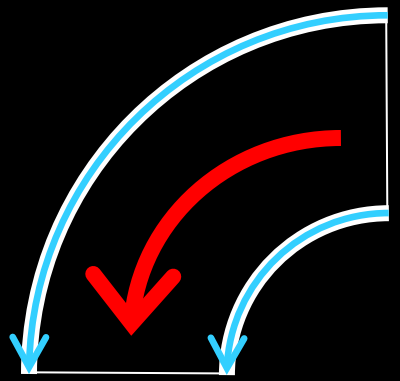

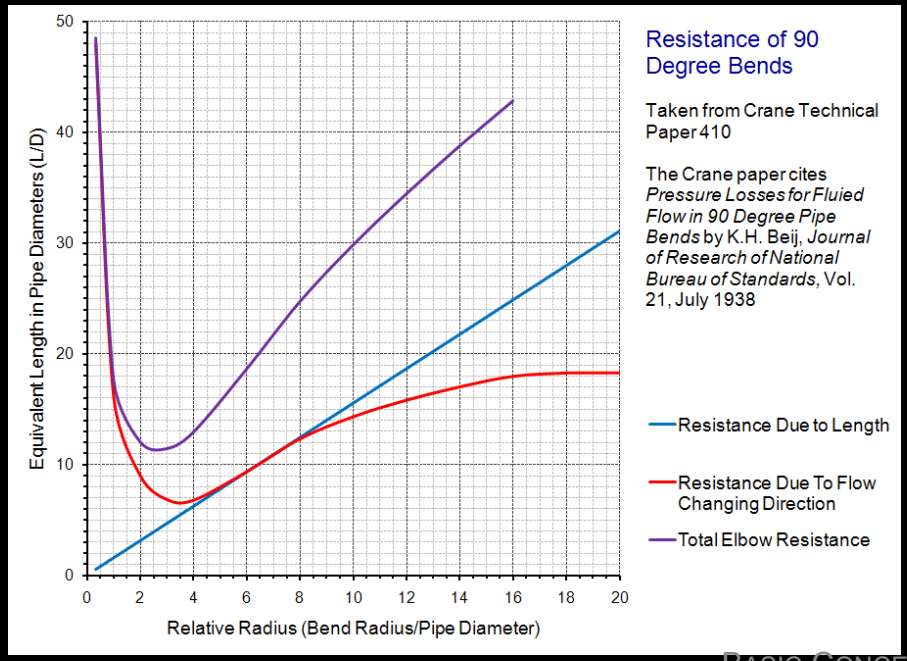

One way to think of elbow resistance is to consider it as composed of:

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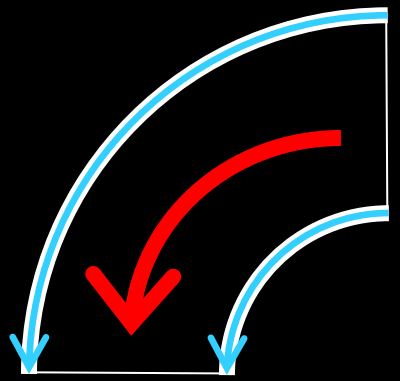
\+ Resistance due to a change in direction

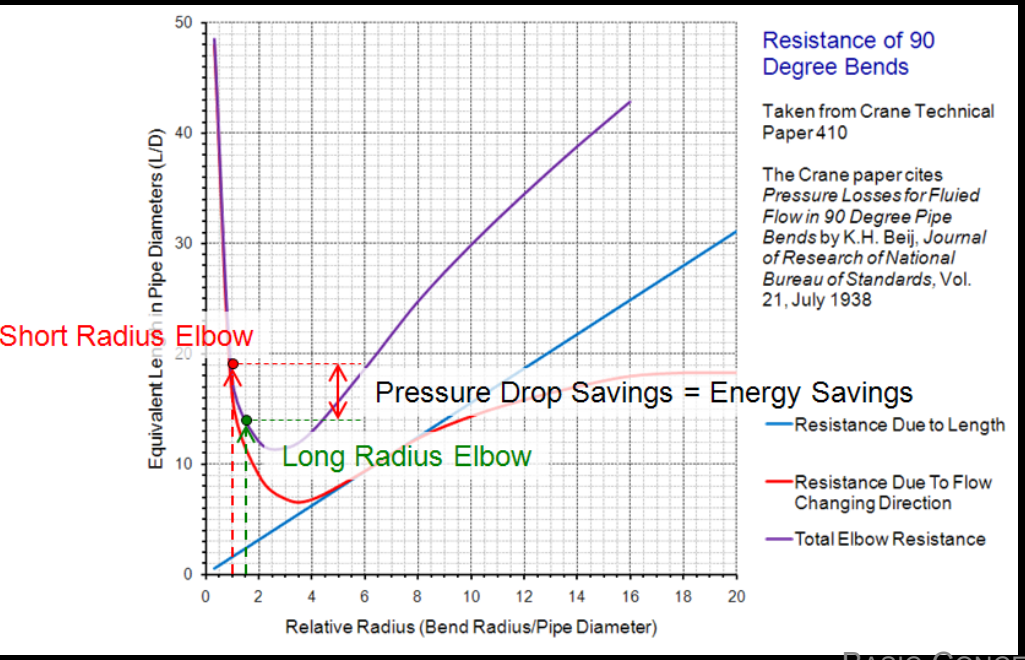
Total Resistance for the Elbow

Elbows; Not So Much Maybe

From the perspective of the physical system:

- Pump energy required
- Long radius = optimized loss = energy savings





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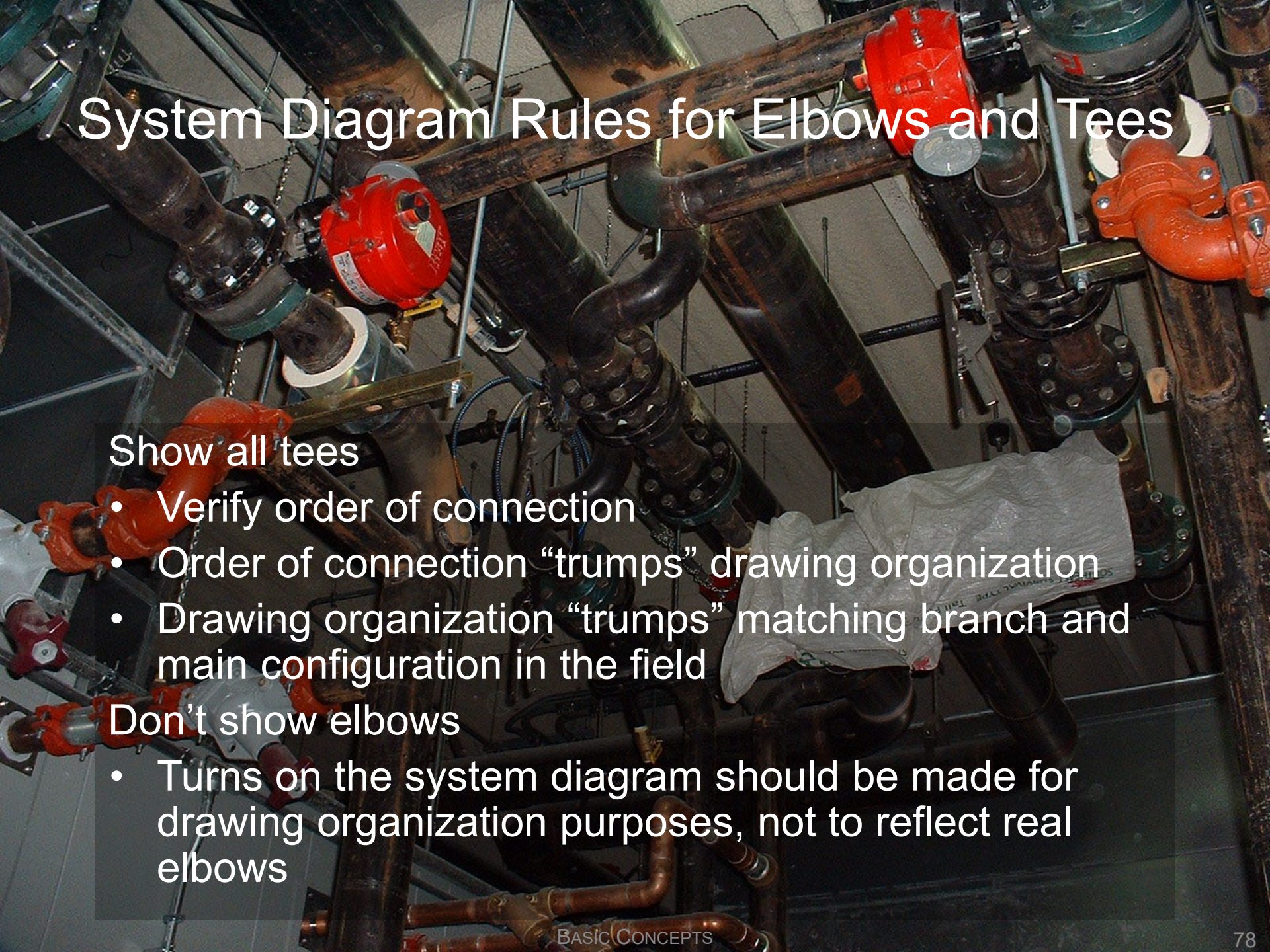
Total Resistance for the Elbow

System Diagram Rules for Elbows and Tees



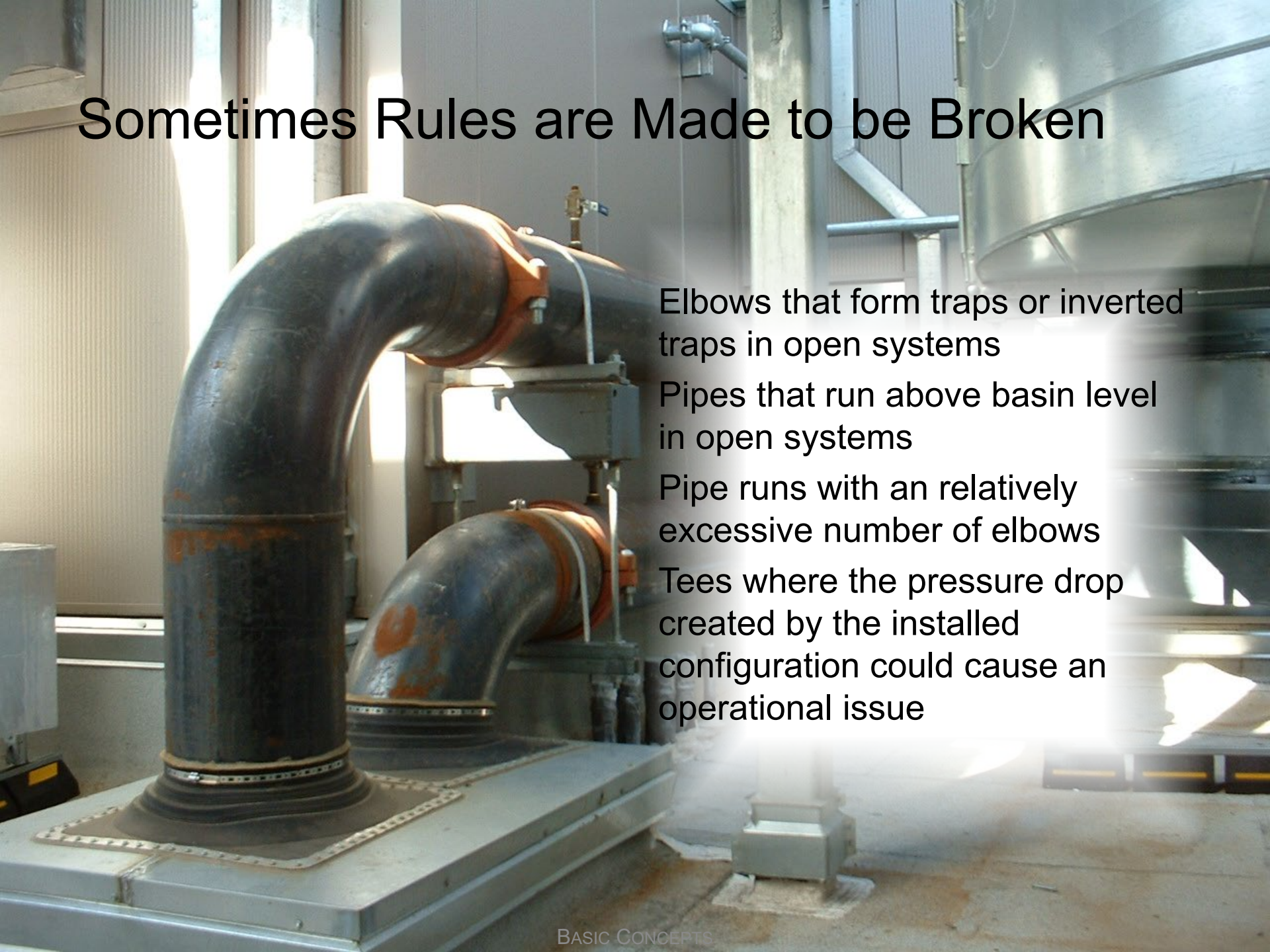
Show all tees

- Verify order of connection
- Order of connection “trumps” drawing organization
- Drawing organization “trumps” matching branch and main configuration in the field

Don’t show elbows

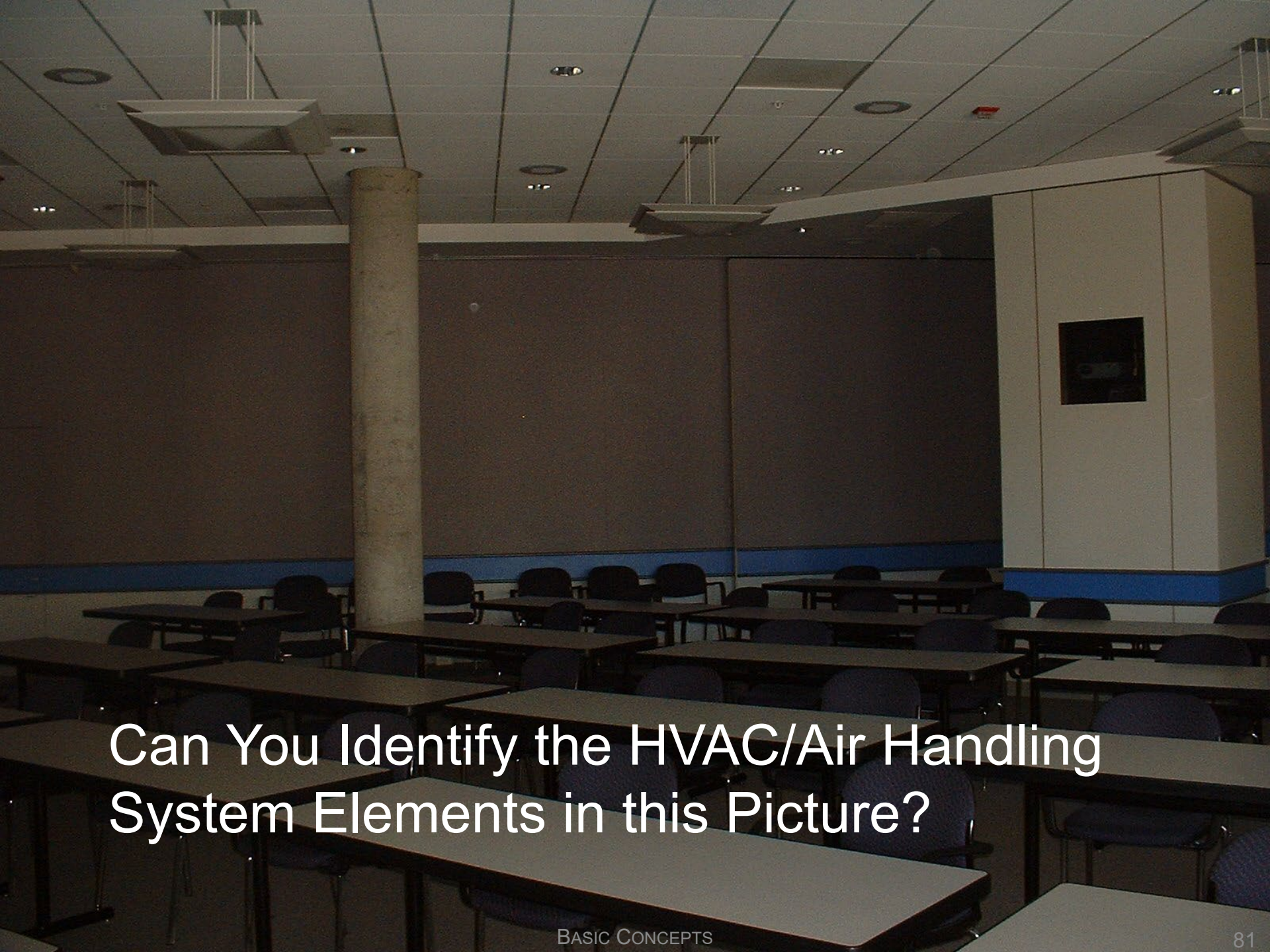
- Turns on the system diagram should be made for drawing organization purposes, not to reflect real elbows

Sometimes Rules are Made to be Broken



- Elbows that form traps or inverted traps in open systems
- Pipes that run above basin level in open systems
- Pipe runs with an relatively excessive number of elbows
- Tees where the pressure drop created by the installed configuration could cause an operational issue


So Far, Our Focus Has Been Hydronic Systems; What About Air Systems?


Can You Identify the HVAC/Air Handling System Elements in this Picture?

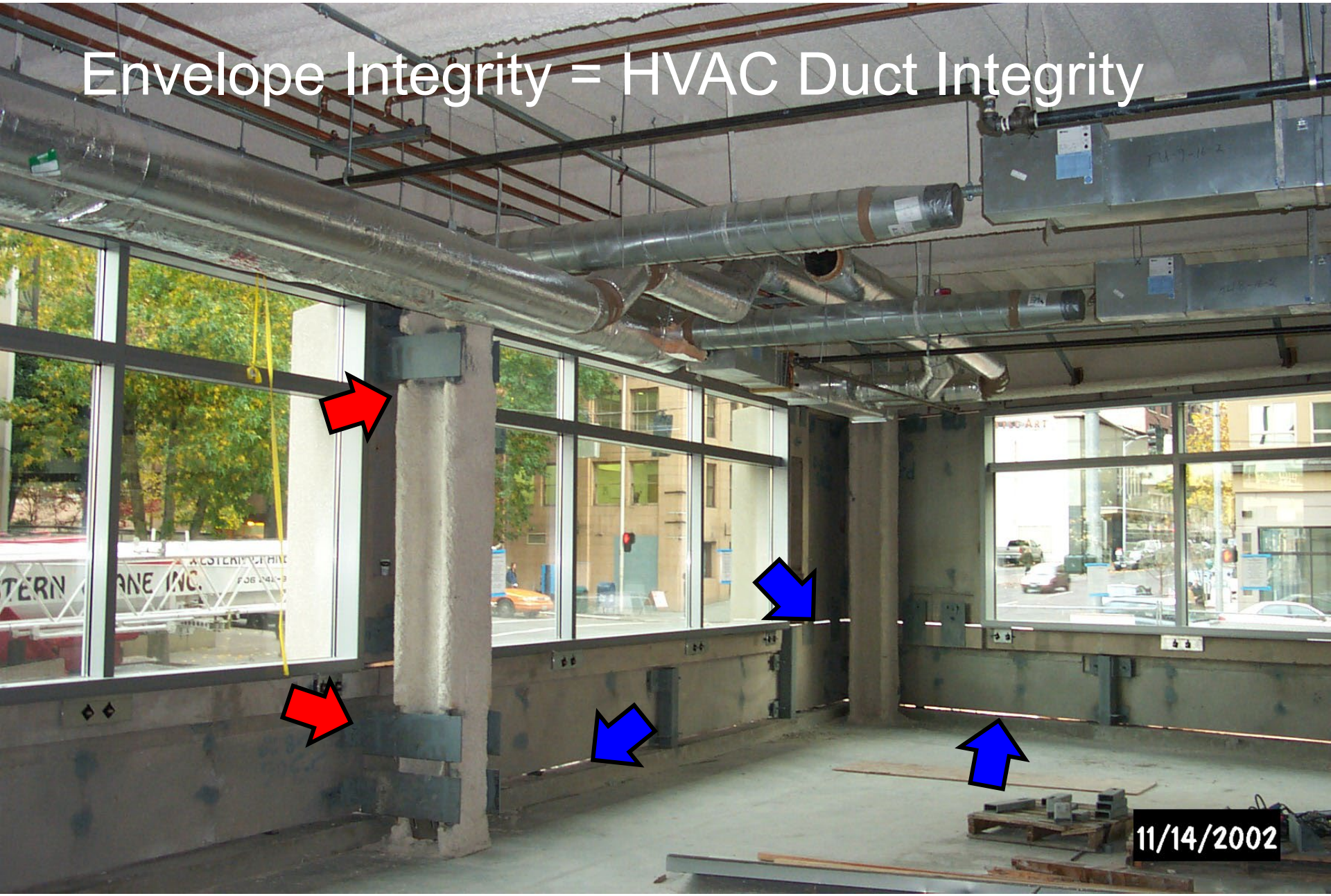
Air Handling Systems and System Diagrams

The same general rules apply

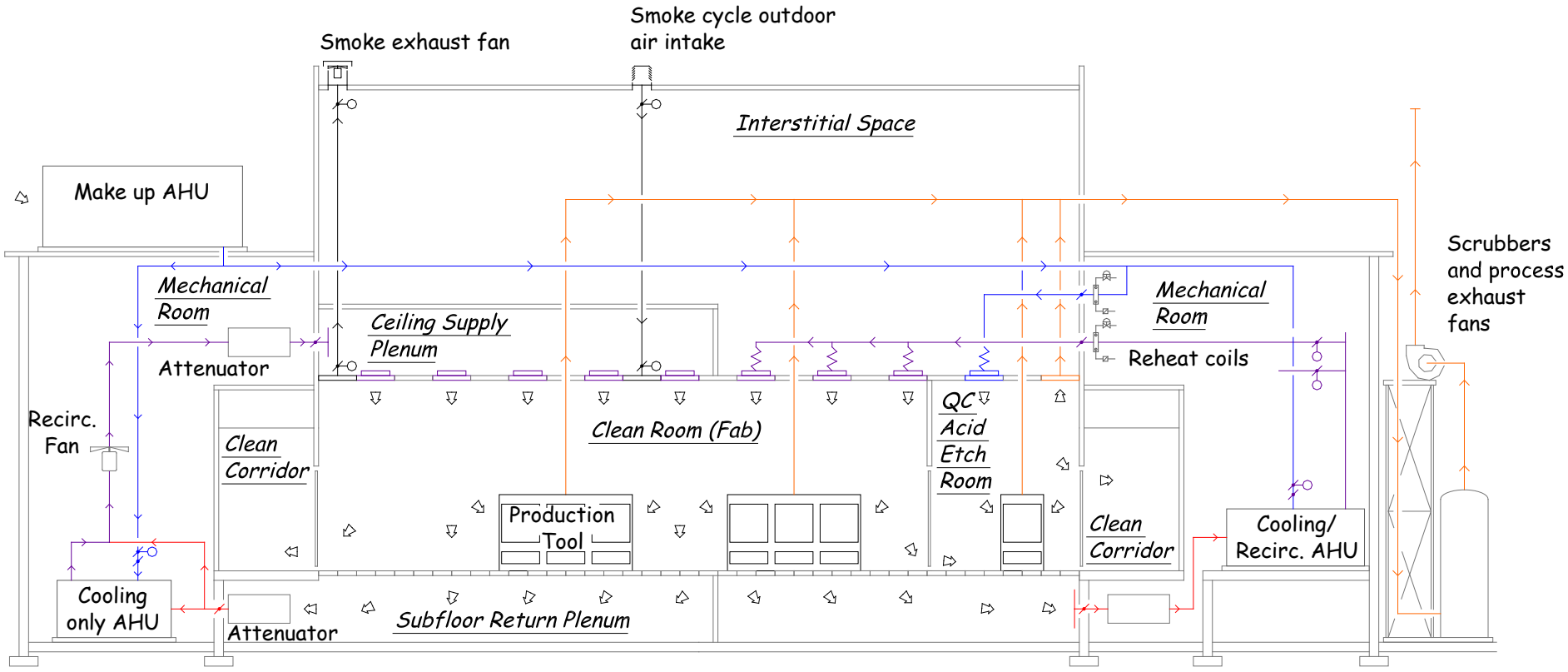
Significant differences from piping systems

- Envelope is a part of the system
- Mass (air and water vapor) are actively moved across the system boundary by the operation of the system
- The water vapor can change state in the system
- People move around inside the systems
- Building processes occur inside the system

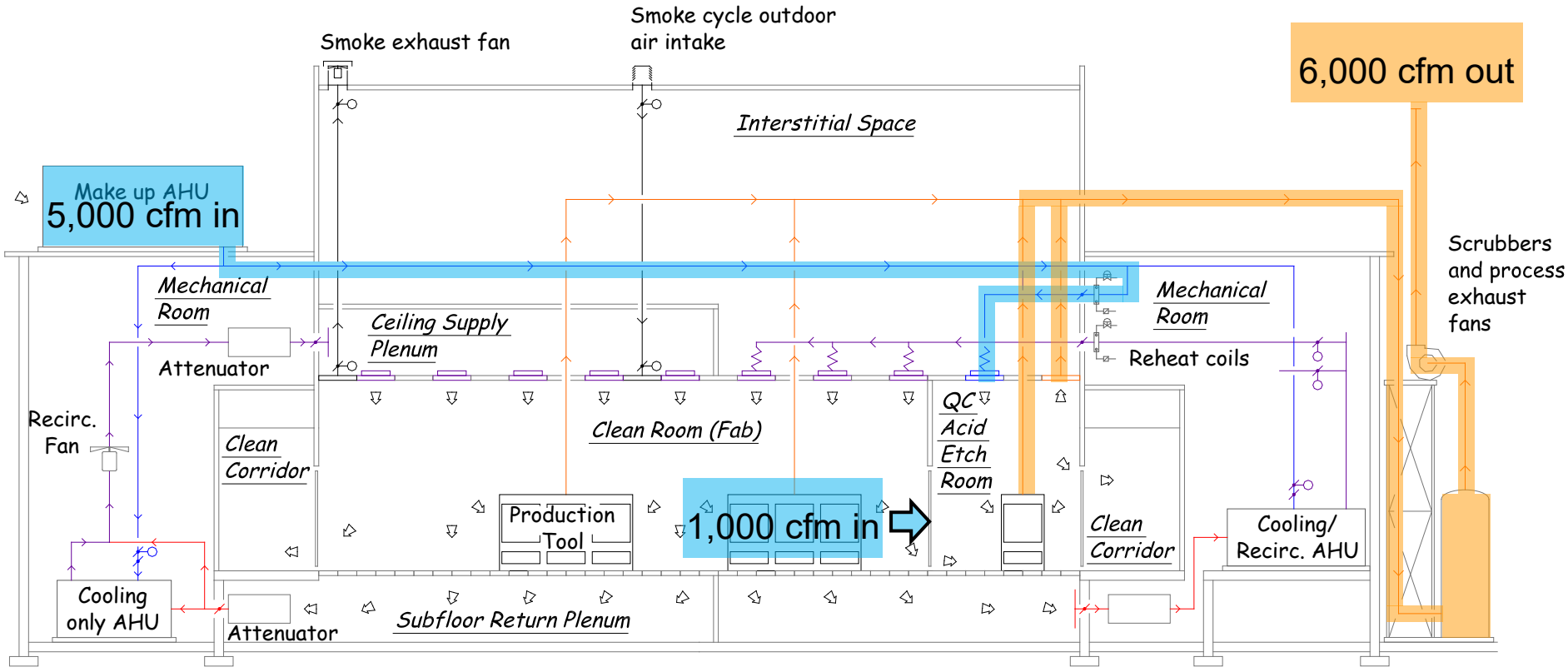
Envelope Integrity = HVAC Duct Integrity



Envelope Integrity = Process Integrity = Cash Flow Integrity

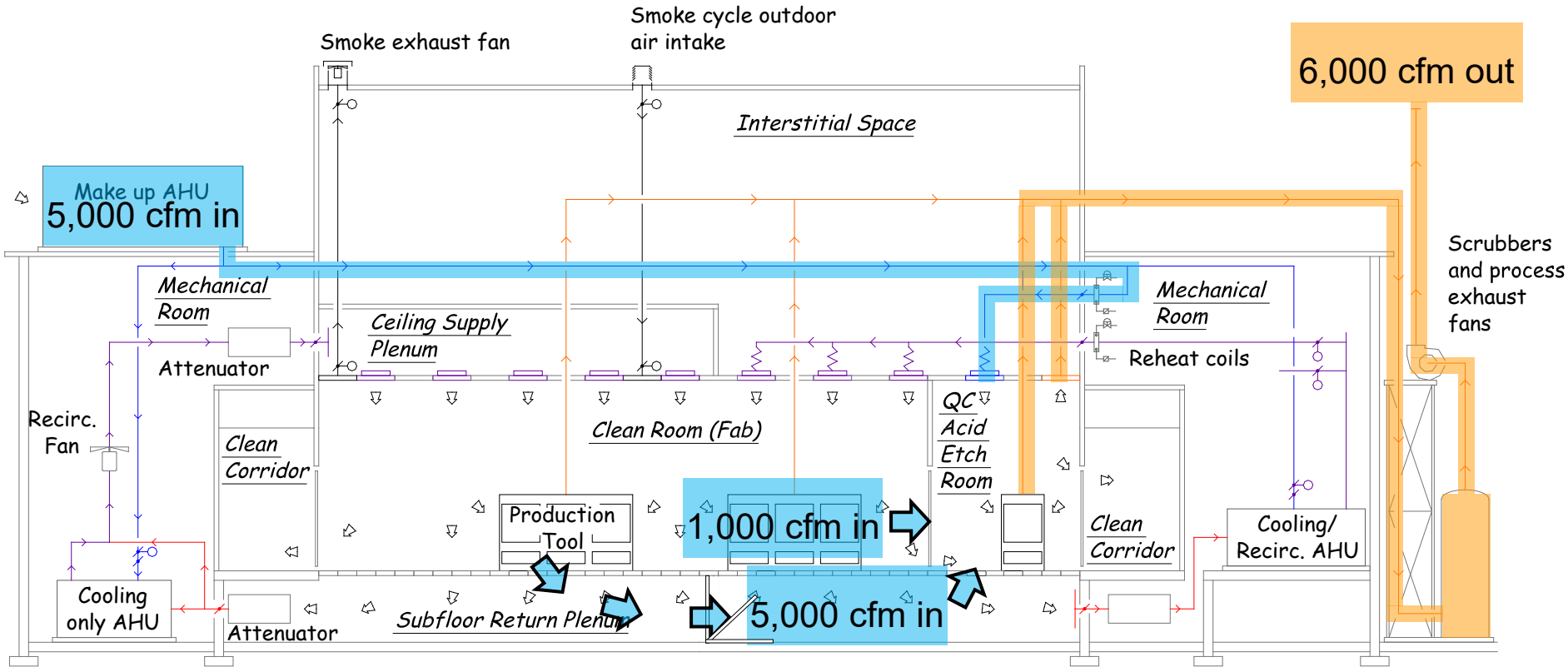


A Demonstration of Fundamental Principles



Conservation of Mass;

A.K.A *The Goes Intas gotta equal the Goes Outa's*



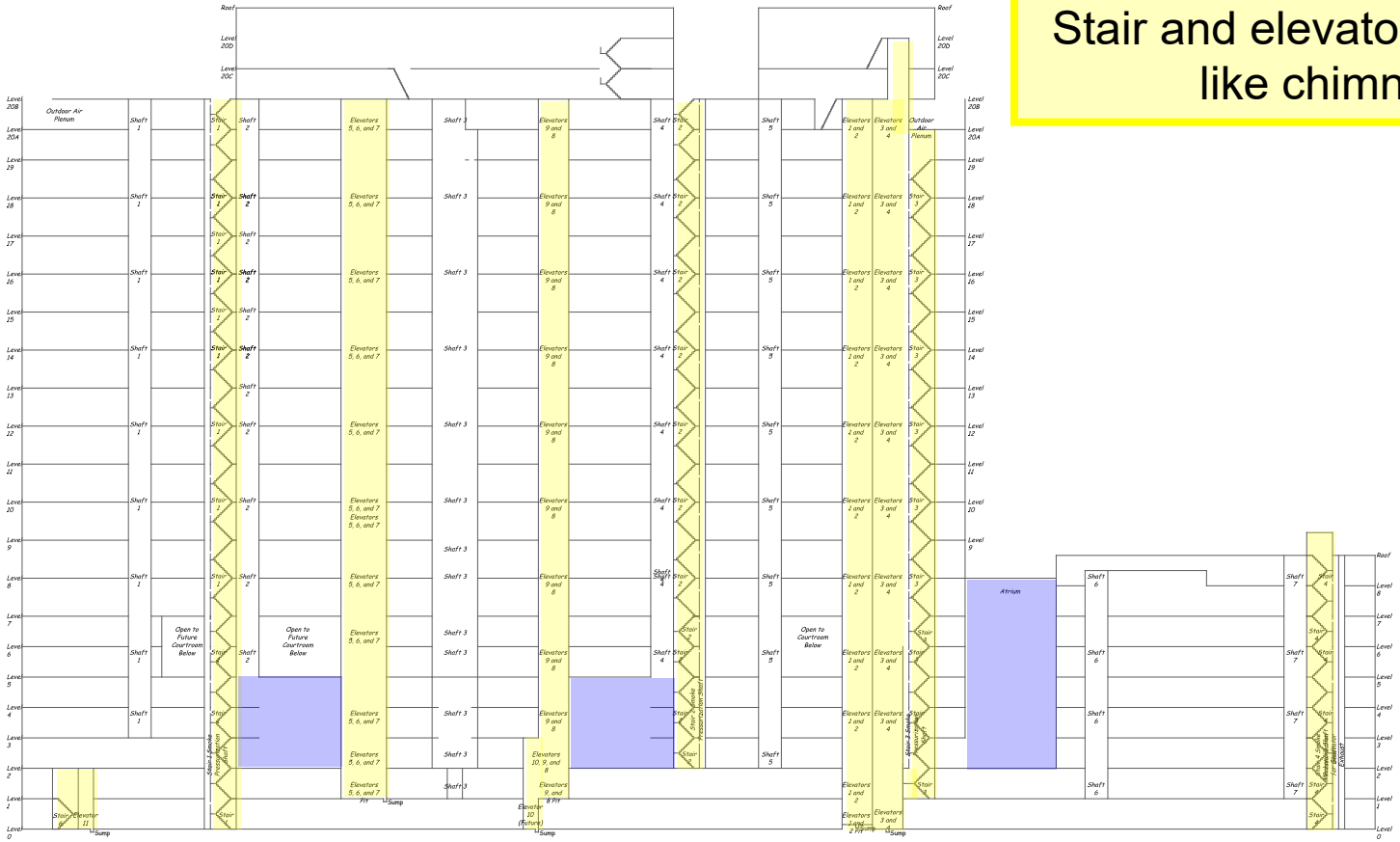
The Envelope is Significant(I

Atriums interconnect floors

The Envelope is Significantly Complex

Atriums interconnect floors

Stair and elevator shafts act like chimneys

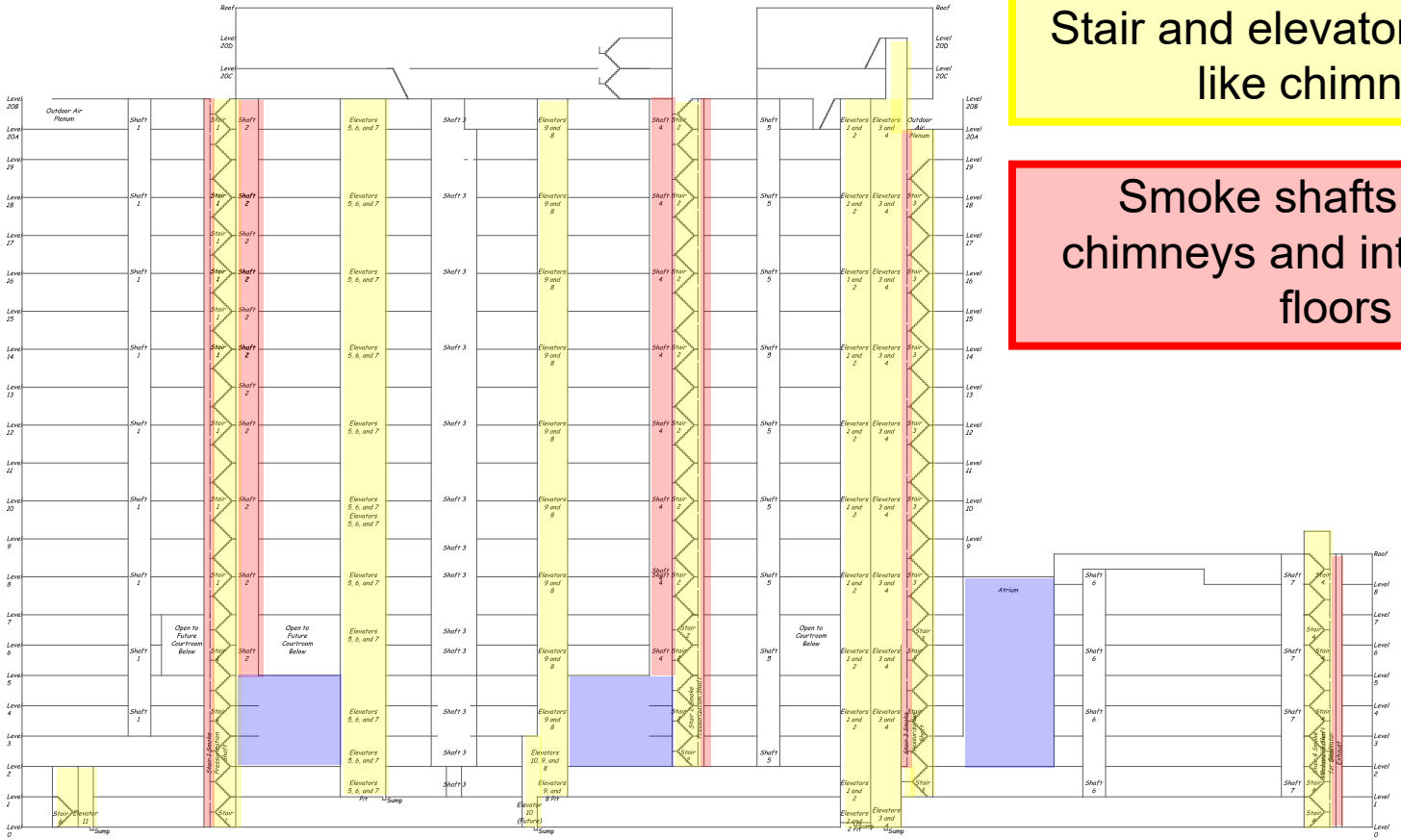


The Envelope is Significantly Complex

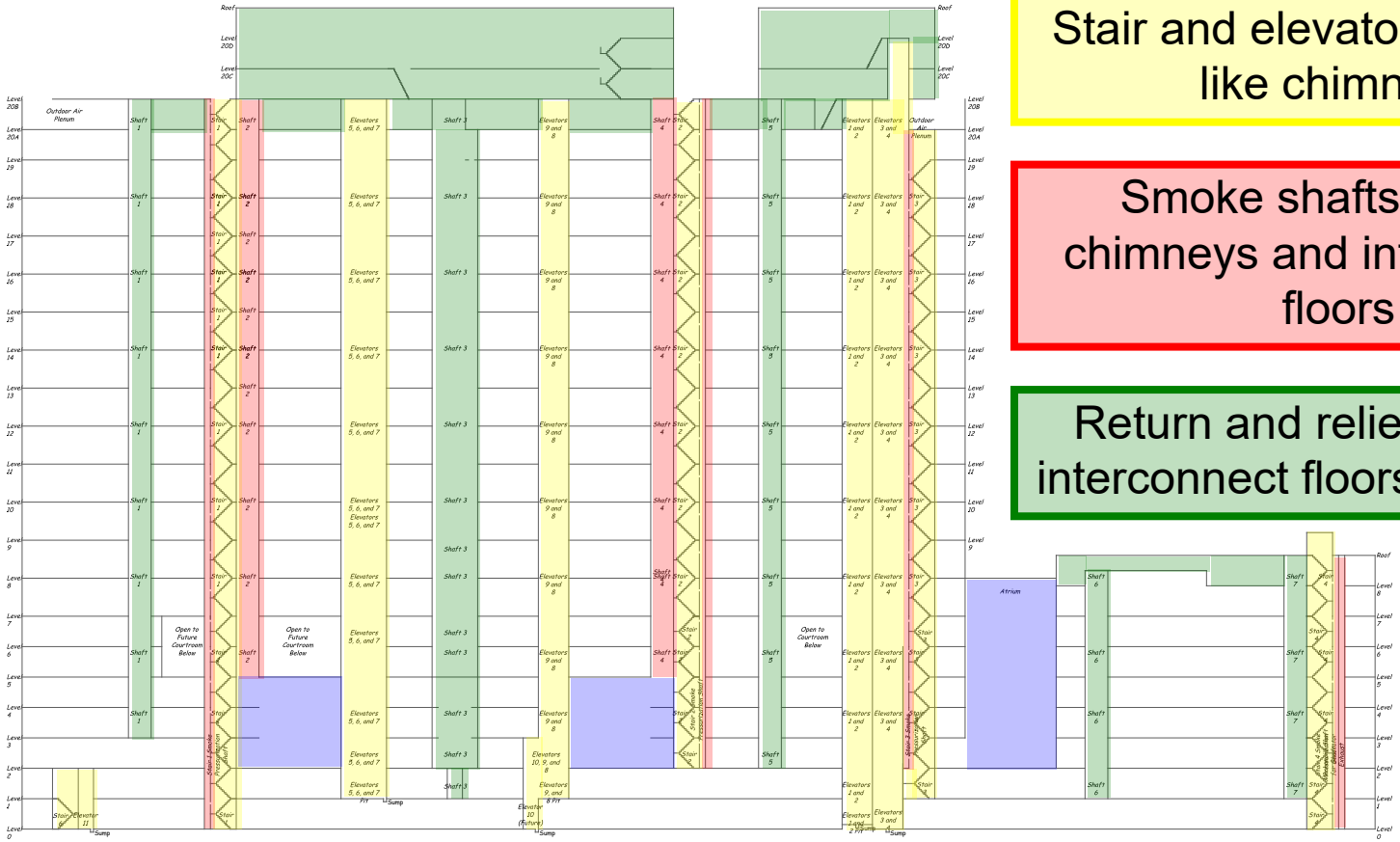
Atriums interconnect floors

Stair and elevator shafts act like chimneys

Smoke shafts act like chimneys and interconnect floors



The Envelope is Significantly Complex



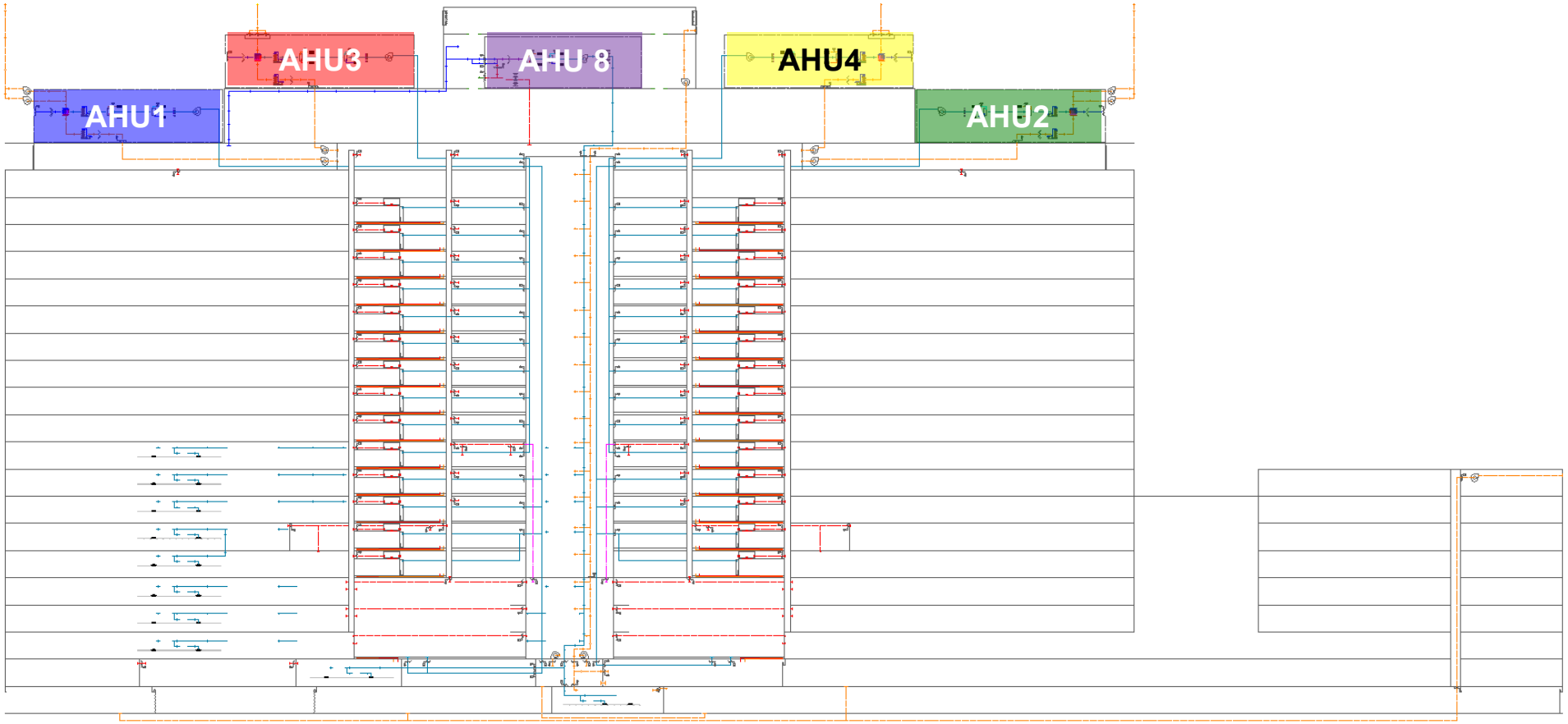
Atriums interconnect floors

Stair and elevator shafts act like chimneys

Smoke shafts act like chimneys and interconnect floors

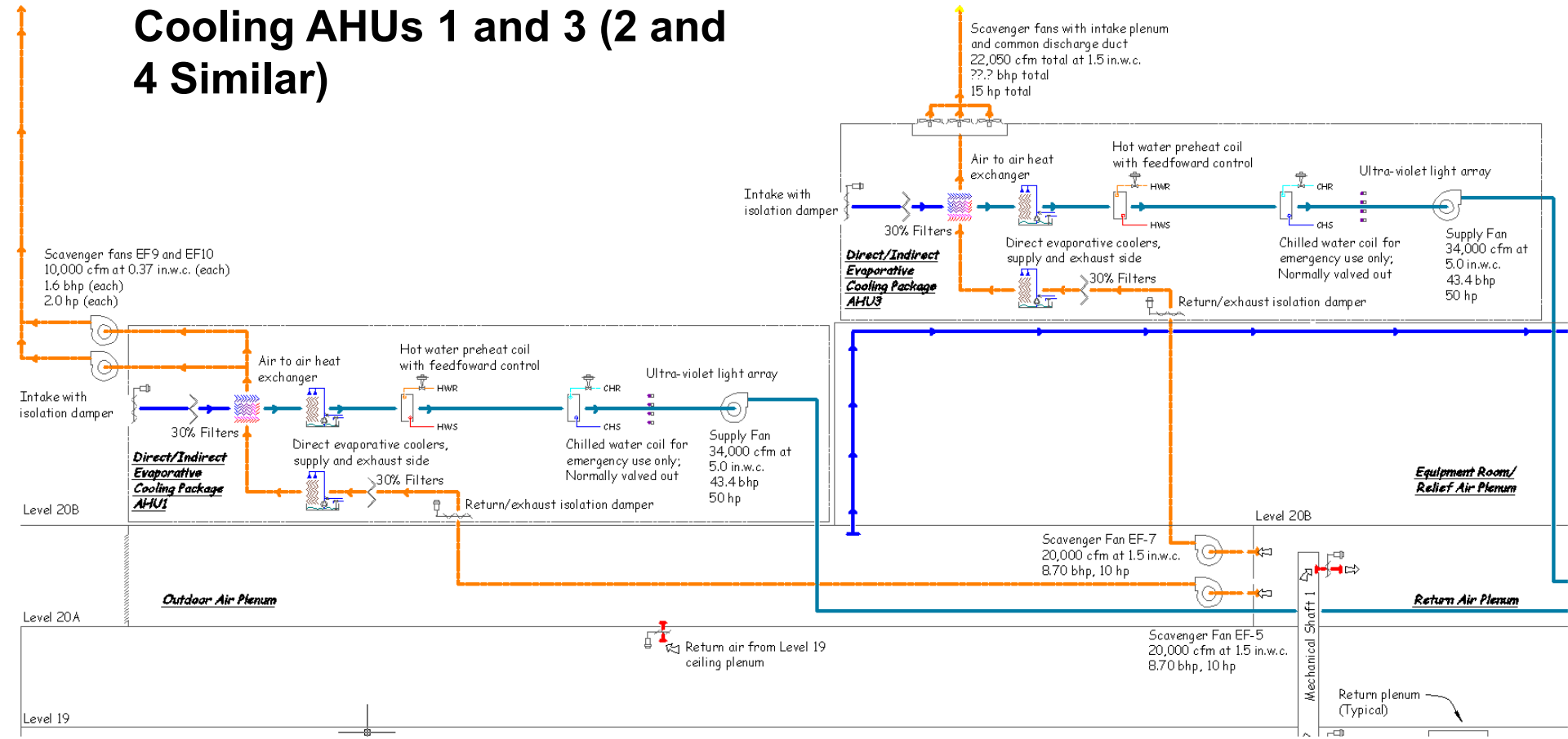
Return and relief plenums interconnect floors and shafts

The Envelope as the Framework for the Air Handling System Diagram

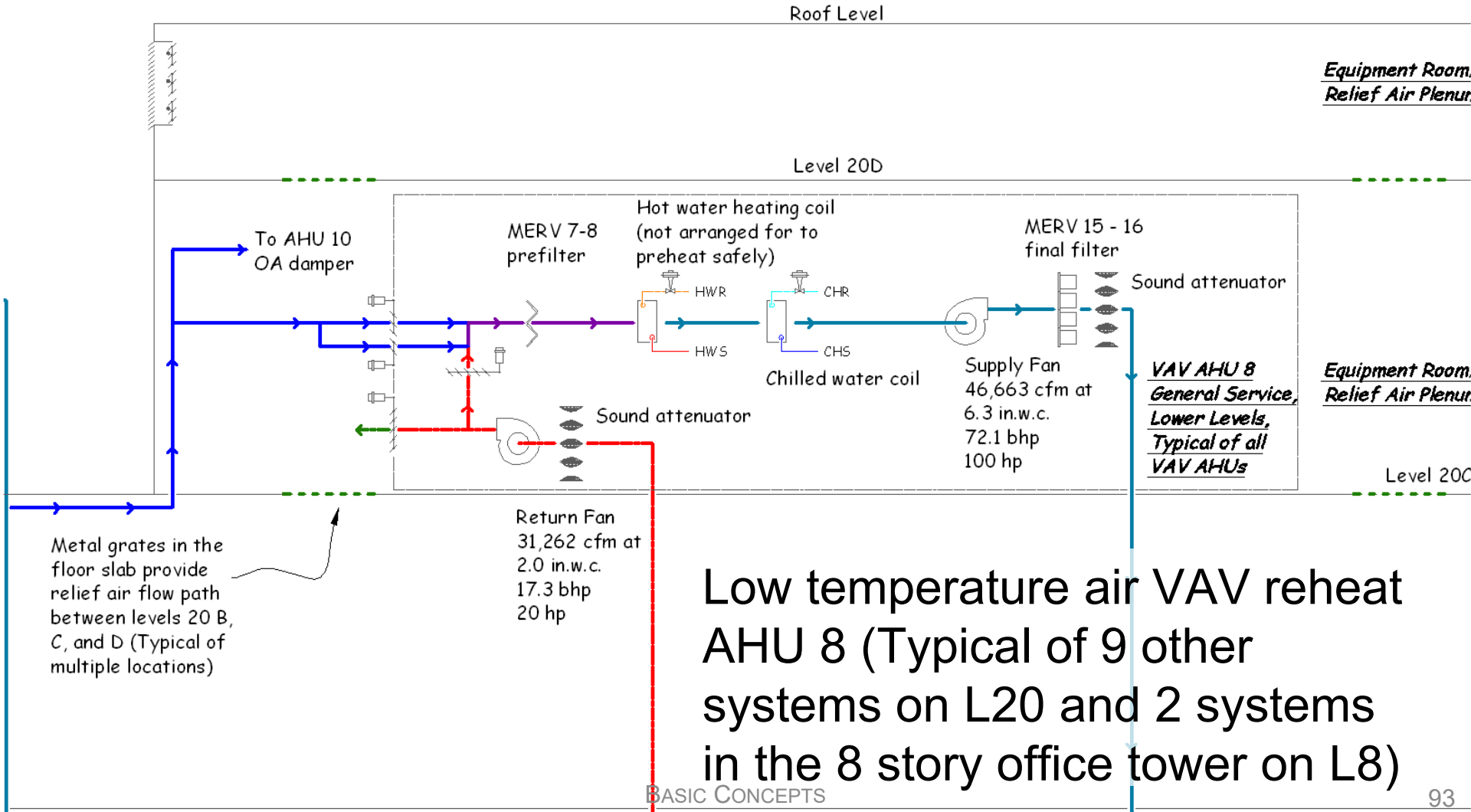


The Envelope as the Framework for the Air Handling System Diagram

Direct/Indirect Evaporative Cooling AHUs 1 and 3 (2 and 4 Similar)

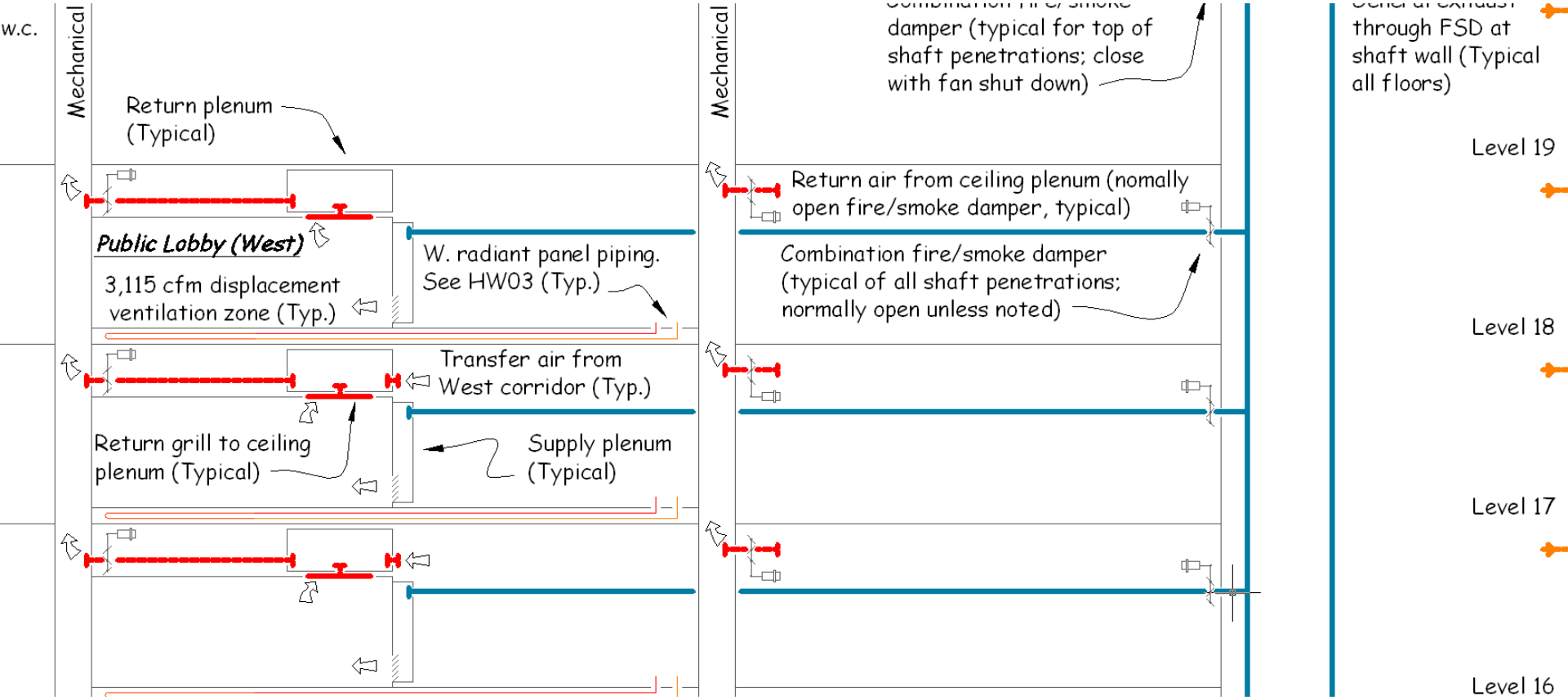


The Envelope as the Framework for the Air Handling System Diagram



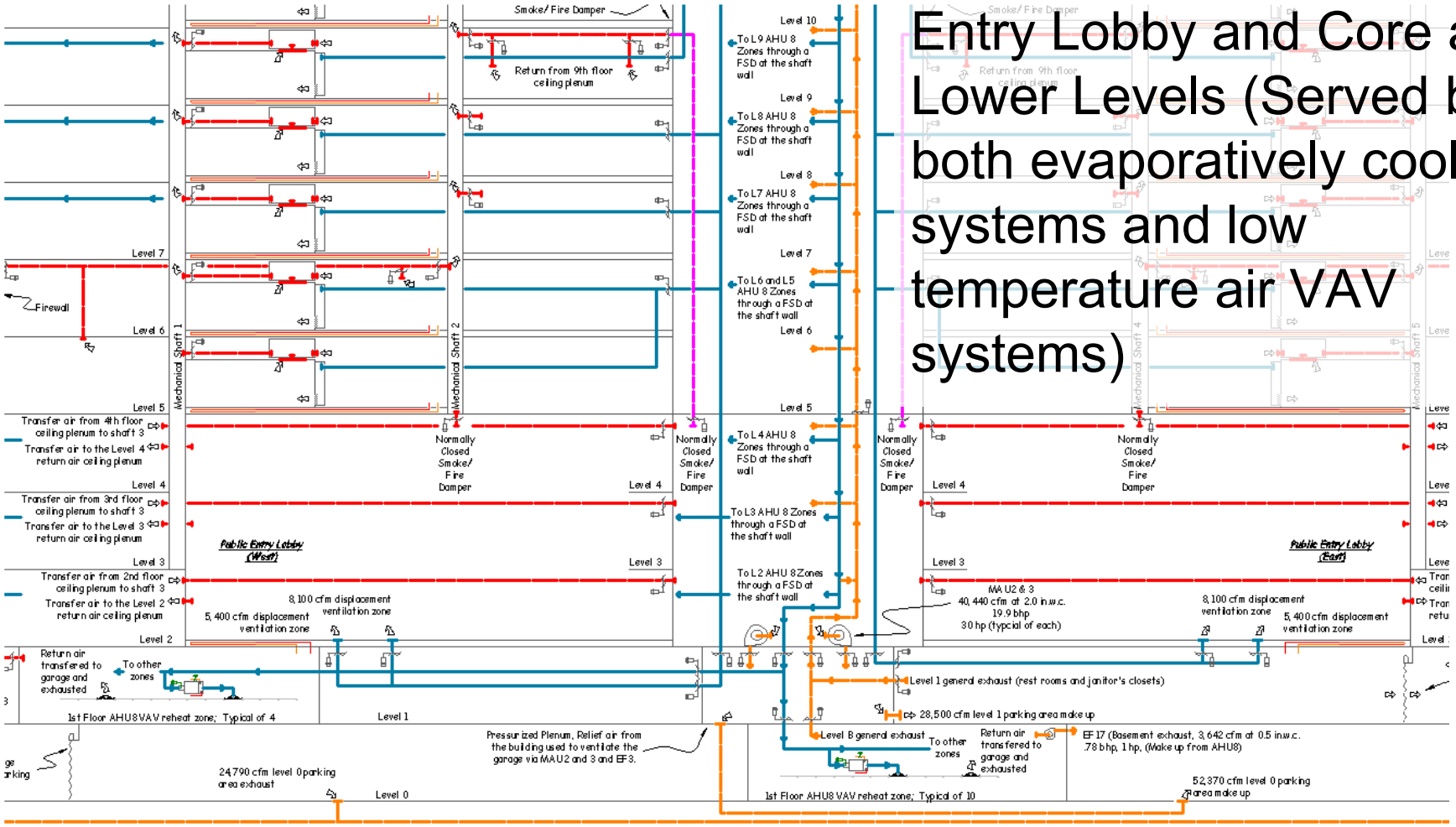
Low temperature air VAV reheat AHU 8 (Typical of 9 other systems on L20 and 2 systems in the 8 story office tower on L8)

The Envelope as the Framework for the Air Handling System Diagram



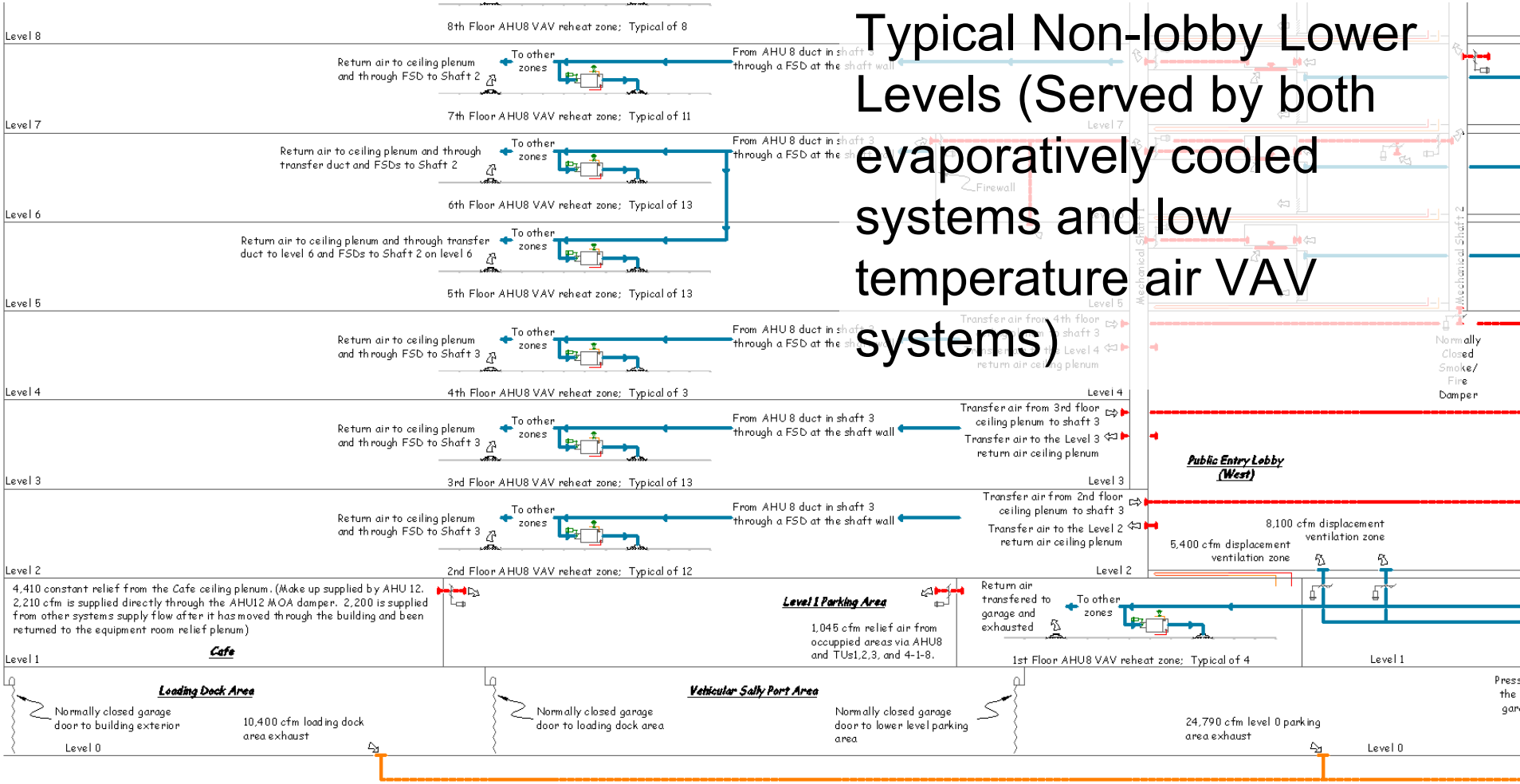
Typical Public Lobby Area (Served Direct/Indirect Evaporative Cooled AHU)

The Envelope as the Framework for the Air Handling System Diagram



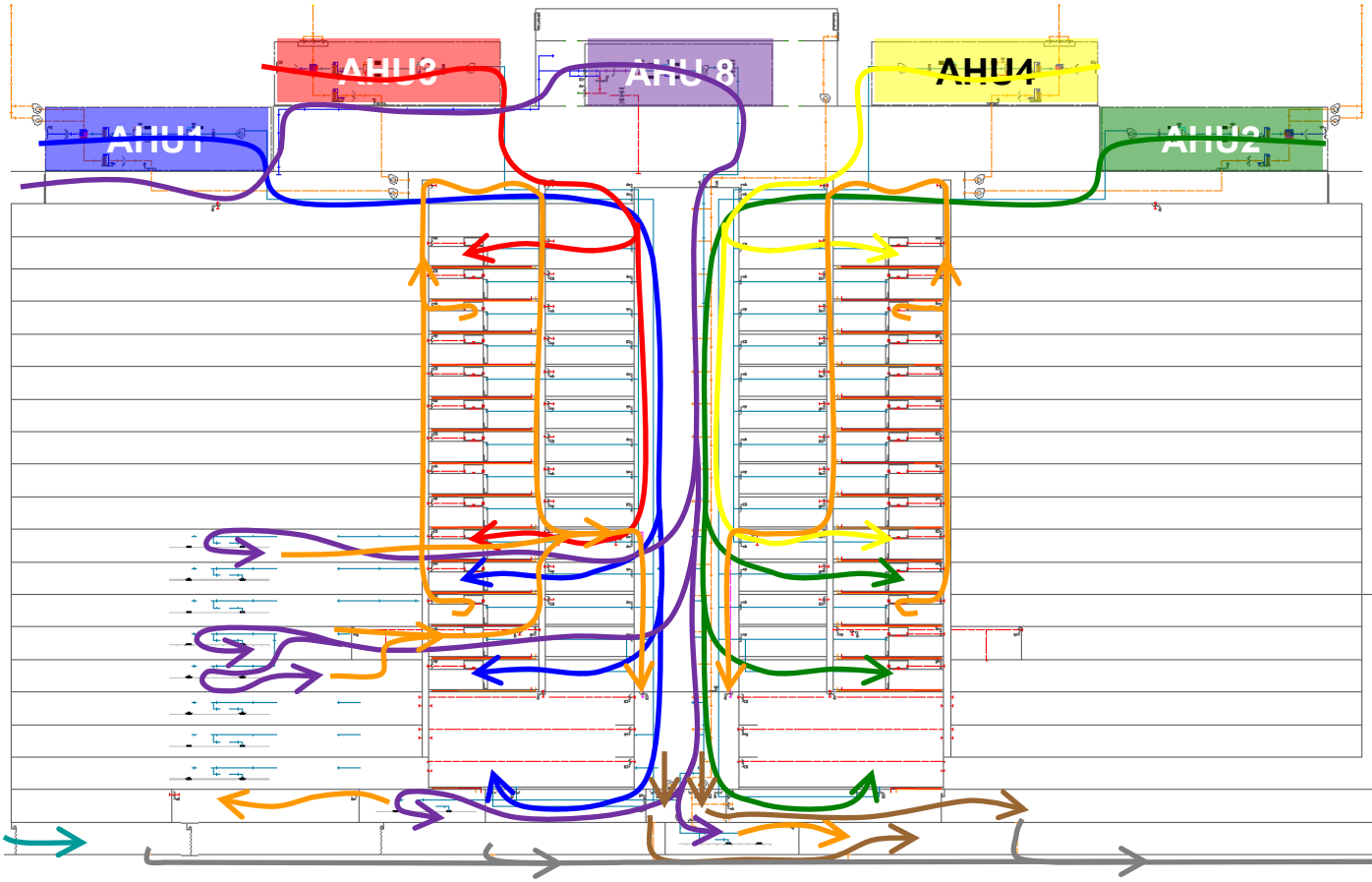
Entry Lobby and Core at Lower Levels (Served by both evaporatively cooled systems and low temperature air VAV systems)

The Envelope as the Framework for the Air Handling System Diagram



Typical Non-lobby Lower Levels (Served by both evaporatively cooled systems and low temperature air VAV systems)

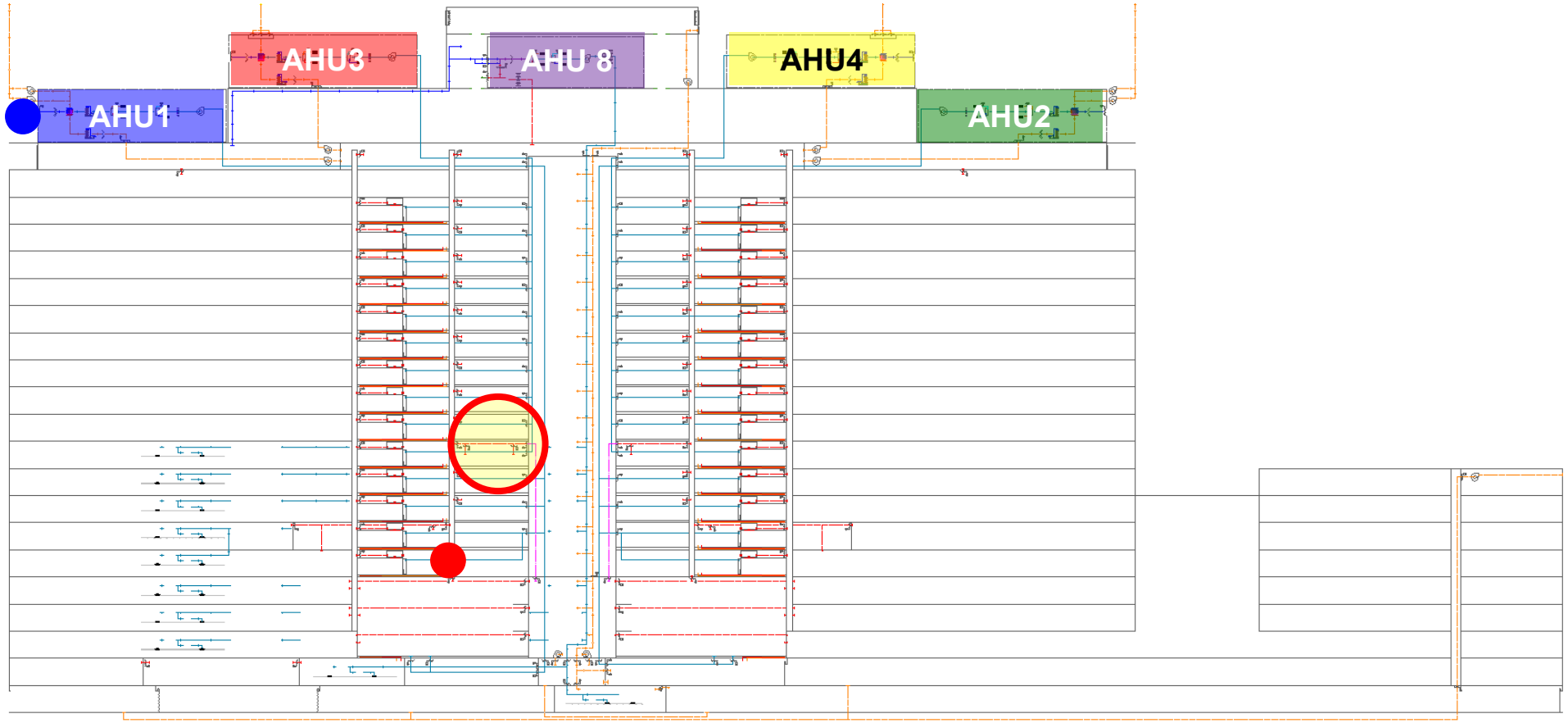
The Envelope as the Framework for the Air Handling System Diagnostics



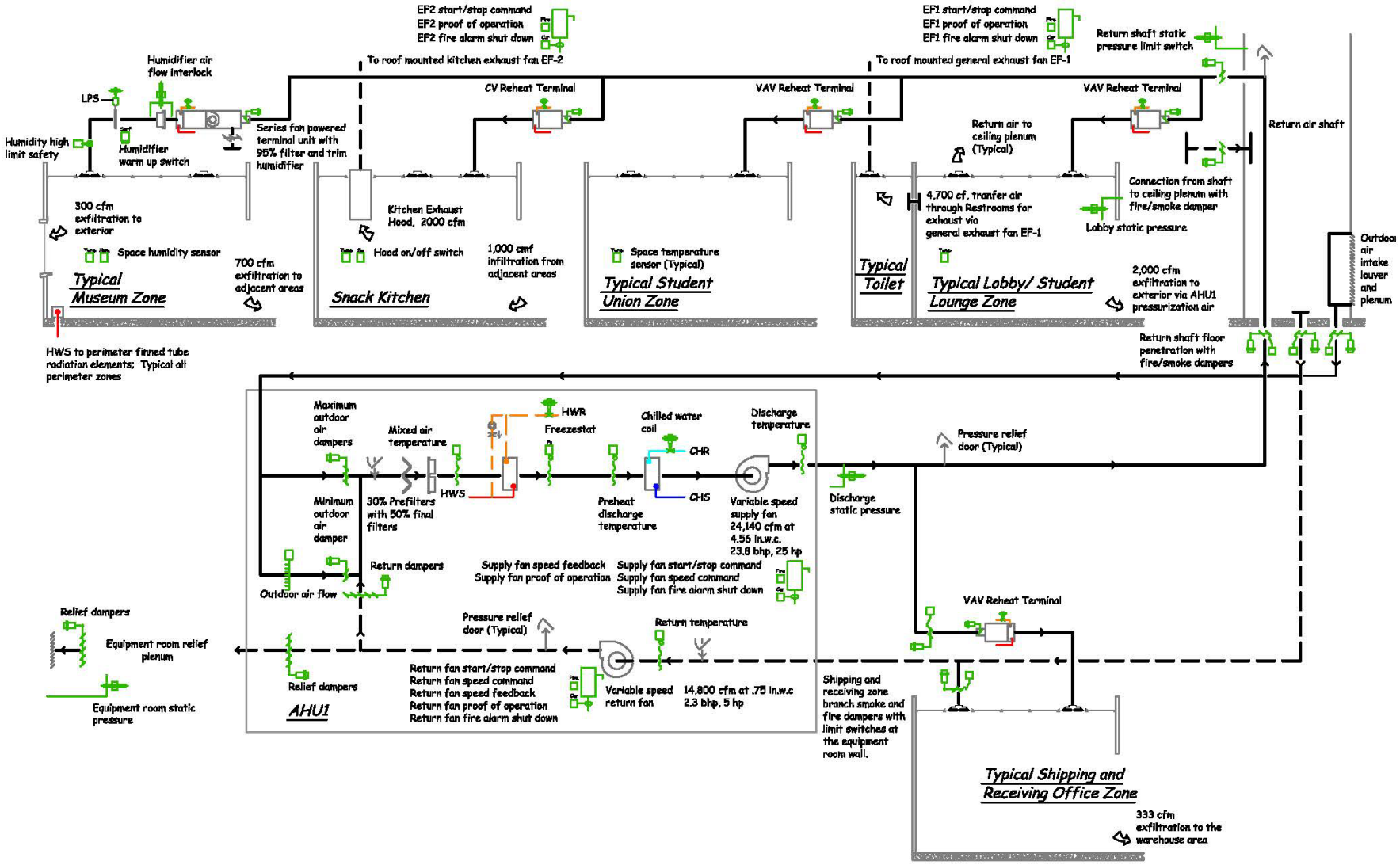
Flow Arrow Color Codes

- **AHU1**
- **AHU2**
- **AHU3**
- **AHU4**
- **AHU8 (Note AHU7 is not shown but serves a similar area and function for the other half of the building)**
- **Return air (all systems)**
- **Transferred air**
- **Outdoor air infiltration**
- **Garage exhaust**

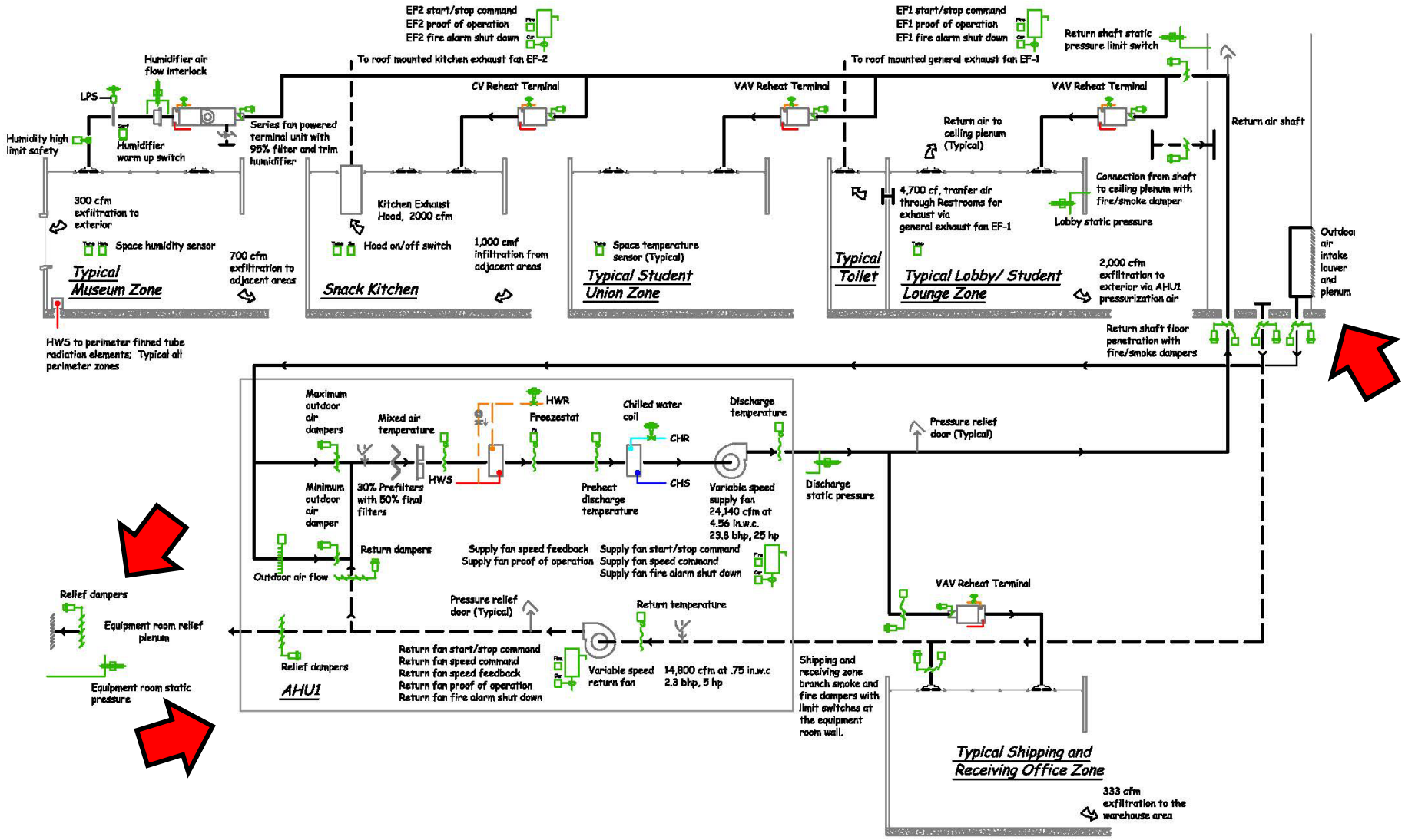
The Envelope as the Framework for the Air Handling System Diagnostics



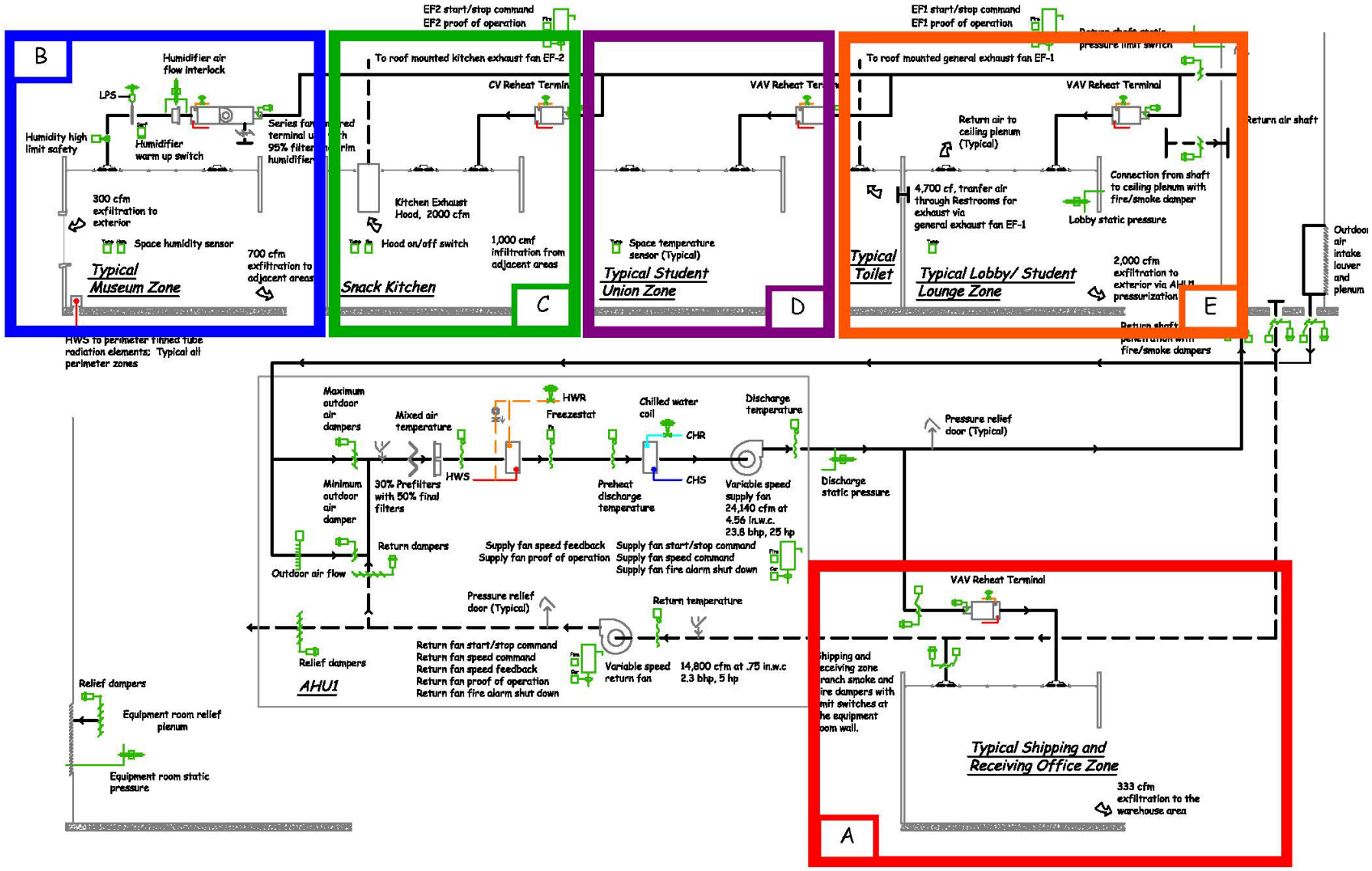
Air Handling System Diagram Characteristics



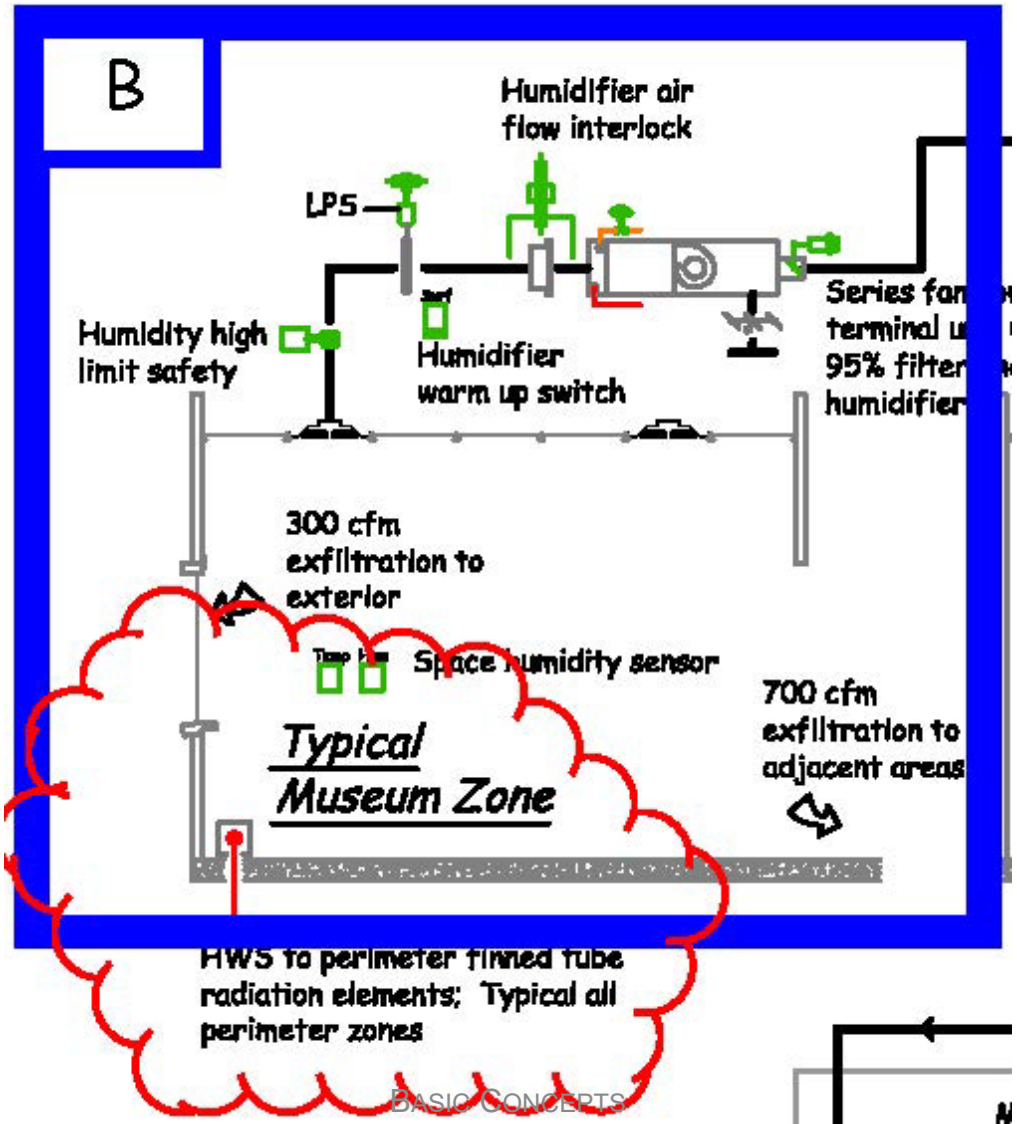
Reflect the Building Physical Arrangement



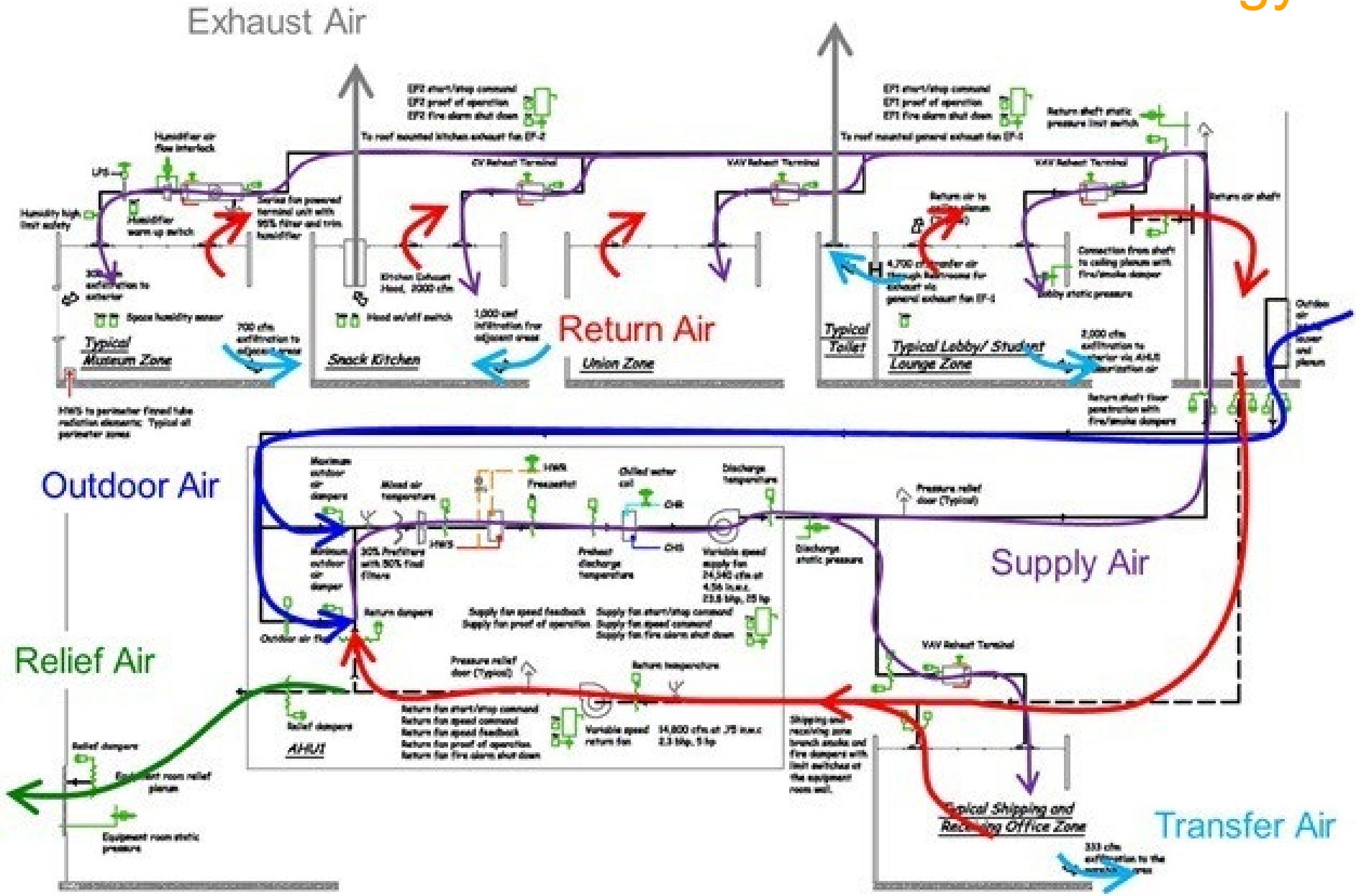
Include Examples of Each Zone Type



Include the Impacts of Other Systems



Document Conservation of Mass and Energy



Let’s Try Applying What We’ve Learned