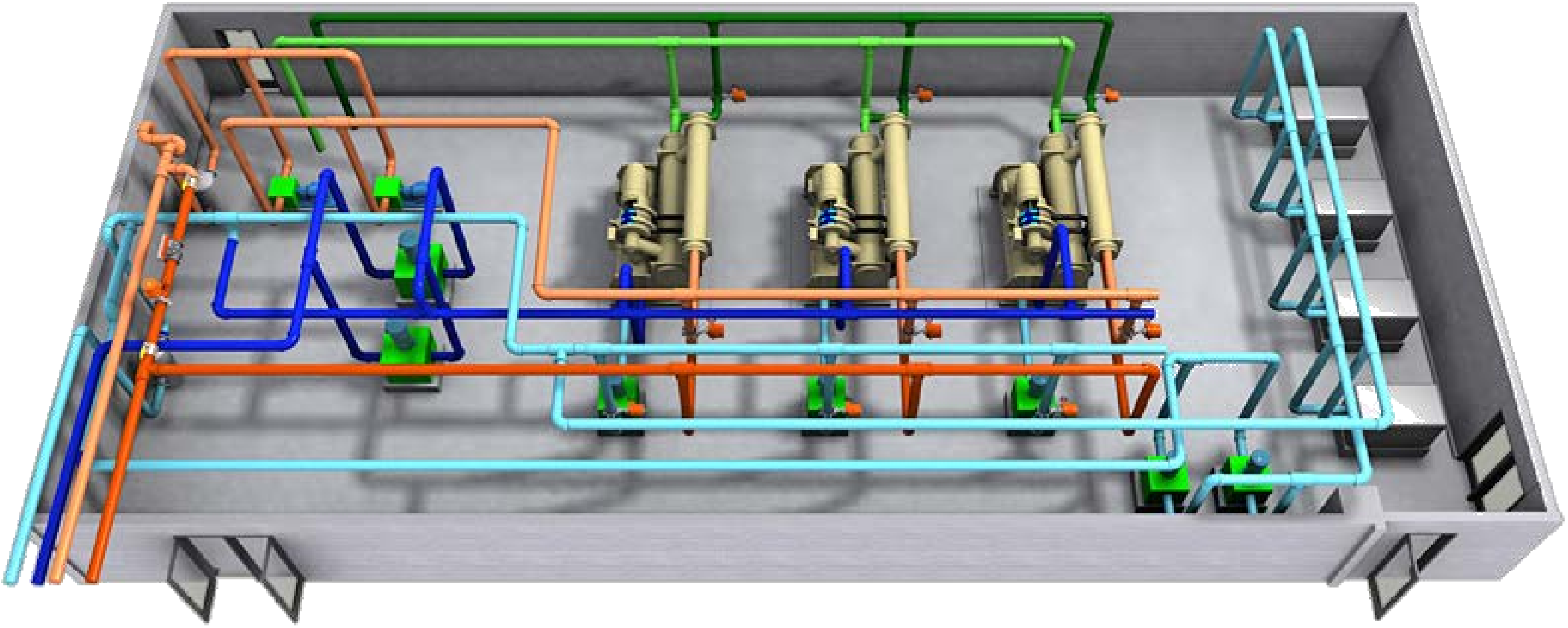
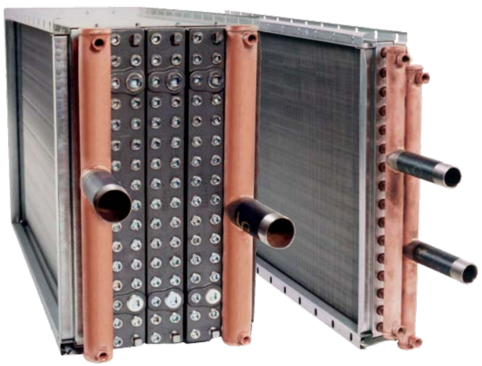
High-performance Chilled-water Systems

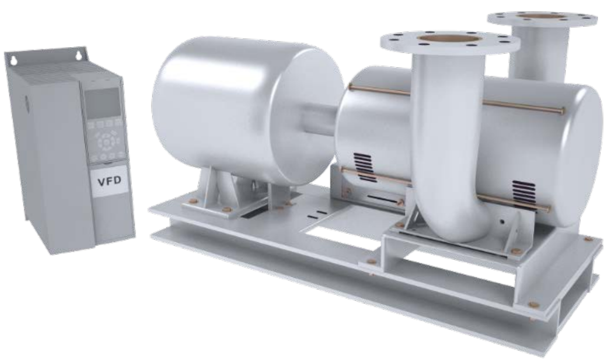
Susanna Hanson, CEM DGCP

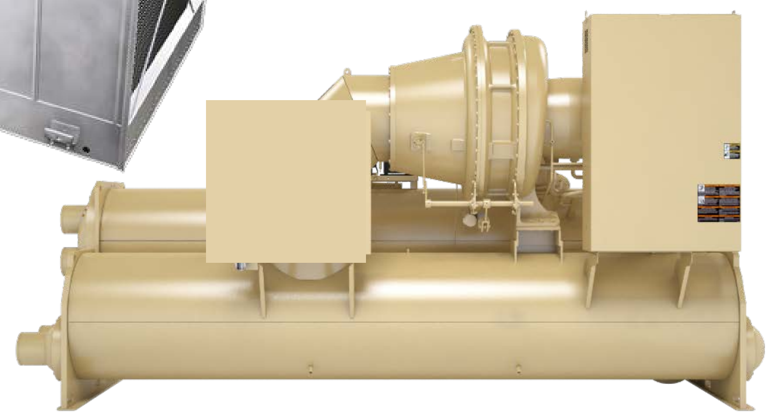
Chilled-water system



Chilled-water system components

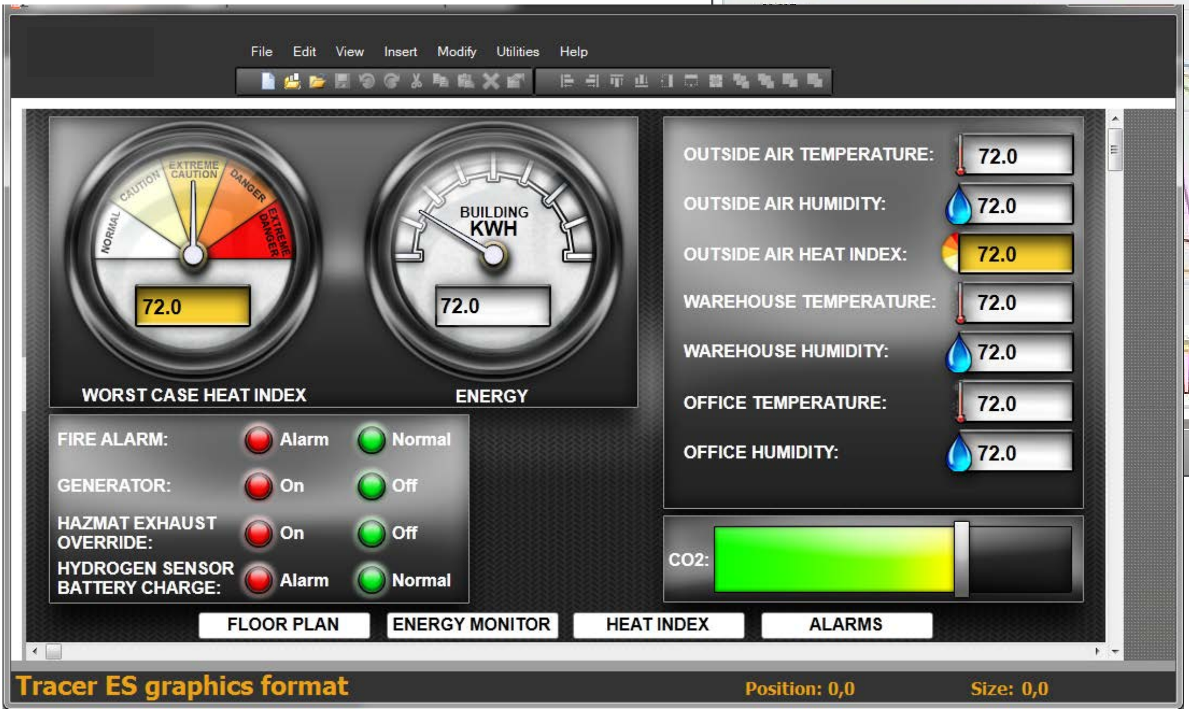






Connectivity

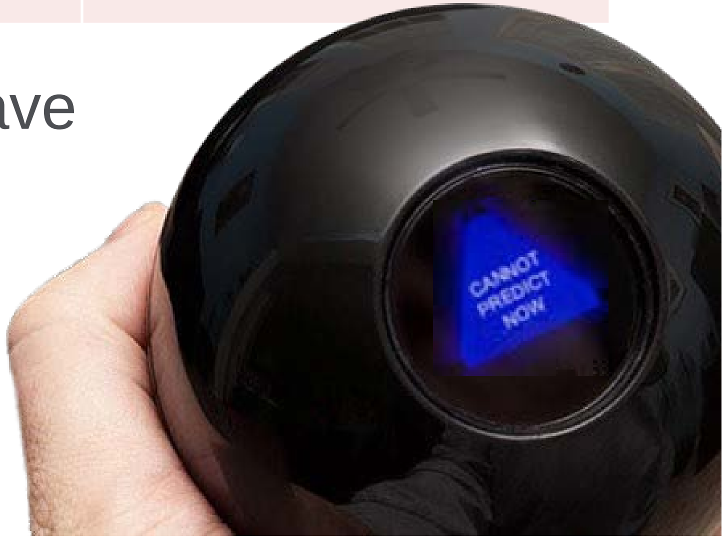
Diagnostics



Minimally-compliant Chiller Plant

Conventional assumption for code range		0.75-0.90 kW/ton (annual)
90.1-2010	Chillers + towers + CW pumps	.68-.88
90.1-2013	Chillers + towers + CW pumps	.66-.86

It's easy to operate in what would have been deemed "excellent," just by meeting code.

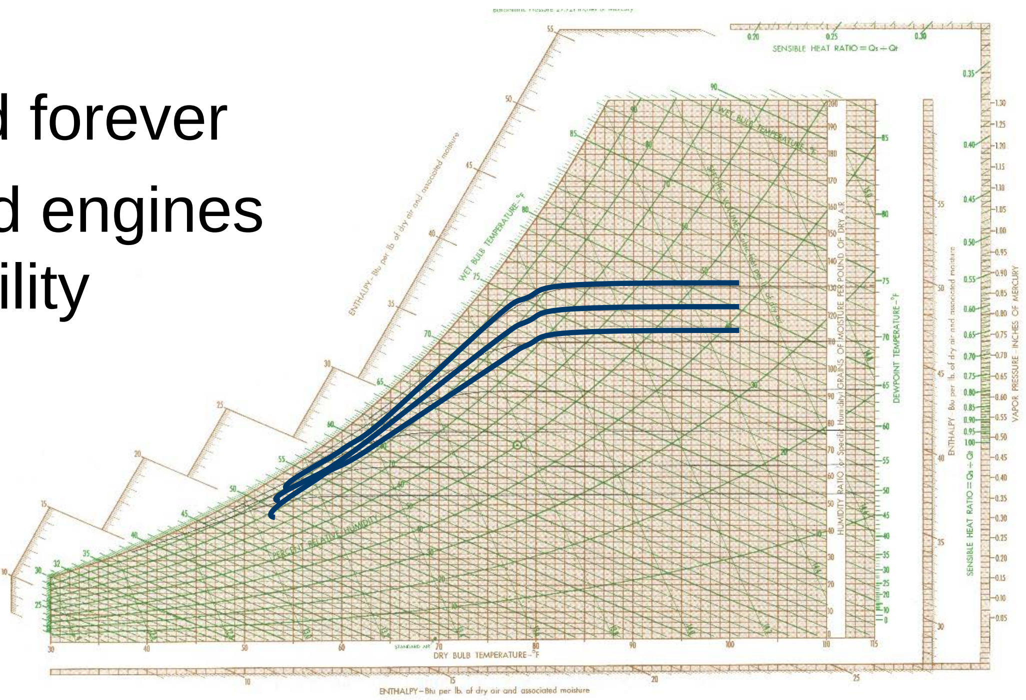


Model ≠ Reality

- Assumption that flow perfectly varies with load
  - Coil performance assumptions
  - Hydronic dynamics ignored
  - Low delta T “syndrome”
  - Effect of instability on coil performance
  - If flow is unpredictable, so is pump energy
- Effects of above on equipment (pump and chiller) staging
  - Running more chillers (and pumps, and towers) than necessary
  - Chiller capacity assumed to follow load
    - Advanced models use a function of load and condensing pressure
    - None reduce chiller capacity based on low distribution delta T
- Simplified chilled water reset effects on chiller energy
  - No coil performance adjustments

Coil Performance,
Traditional Energy Models

- Idealized generic coil curves
  - Models don't let waterside affect airside, vice versa
- Same method we used forever
- New EnergyPlus based engines have some new capability



Coil Performance, New Models

- Air and waterside connected better
- Still doesn’t model instability and overcooling
- Still doesn’t model effects of occupant behavior

Responses to Discomfort and Their Effects

- Occupant:
  - lower zone setpoint – increases GPM, may increase fan speed
  - supplement airflow – fans appear under desks
  - complain
- Operator:
  - lower leaving air setpoint – decreases coil performance
  - pumps in manual, raise setpoint/speed – increases GPM, pressure
  - disable SA reset – lowers leaving air temp and increases reheat
  - reduce ventilation – lowers coil entering air temp, degrades coil perf
- All reduce system performance
  - Low delta T and poorer coil performance
  - Increase overcooling/reheat
  - “Out of flow-- out of chiller-- need another chiller…”
  - “Maybe I just need the system balancer back out here”
  - “We must need tertiary pumps”

The Engineers’ Dilemma

- Conservatism and unknowns
- Low pressure drop waterside
- Low pressure drop airside
- Fit in the box!
- Fit it in the budget!
- And we don’t have money for reverse return piping
- Or pressure independent control valves
- But OK spend money for balancing valves and balancers!

Industry Recommendations

Source	Chilled Water ΔT (ºF)	Condenser Water ΔT (ºF)
ASHRAE 90.1-2016 requirement	≥15	NA
ASHRAE GreenGuide	12 – 20	12 - 18
Kelly and Chan	18	14
Taylor	>12	15

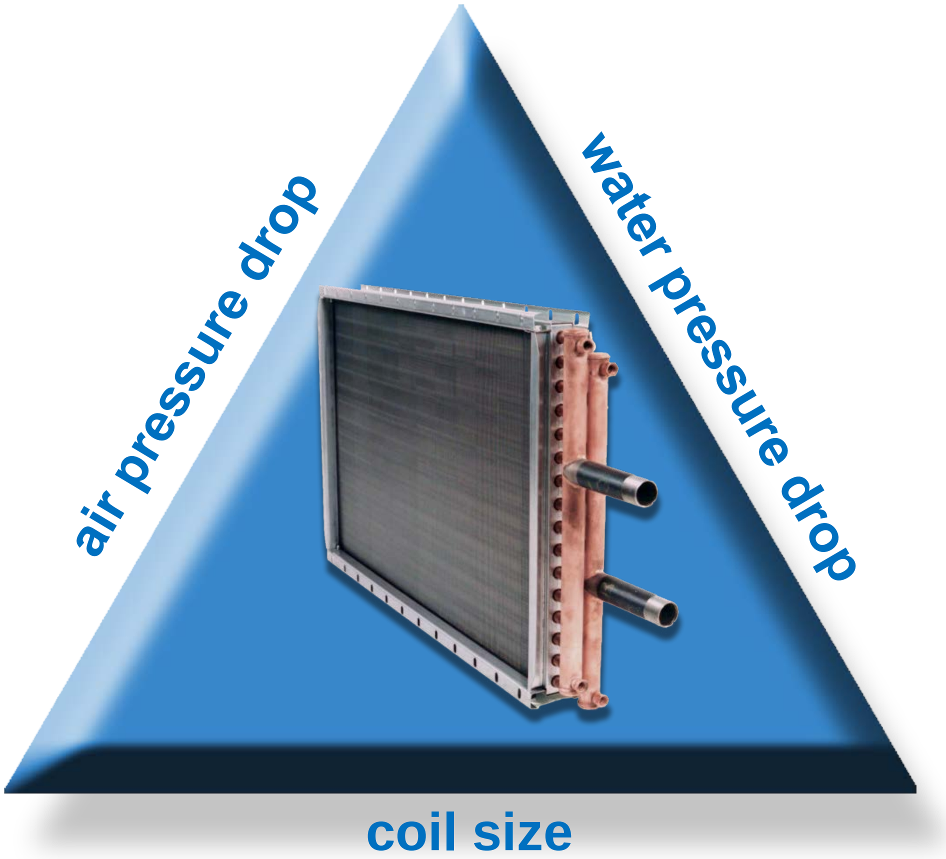
Chilled Water Optimizations – ASHRAE 90.1

- Coil selection for 15°F ΔT or higher (57°F min return)
- Chilled water reset based on critical valve position

-or-

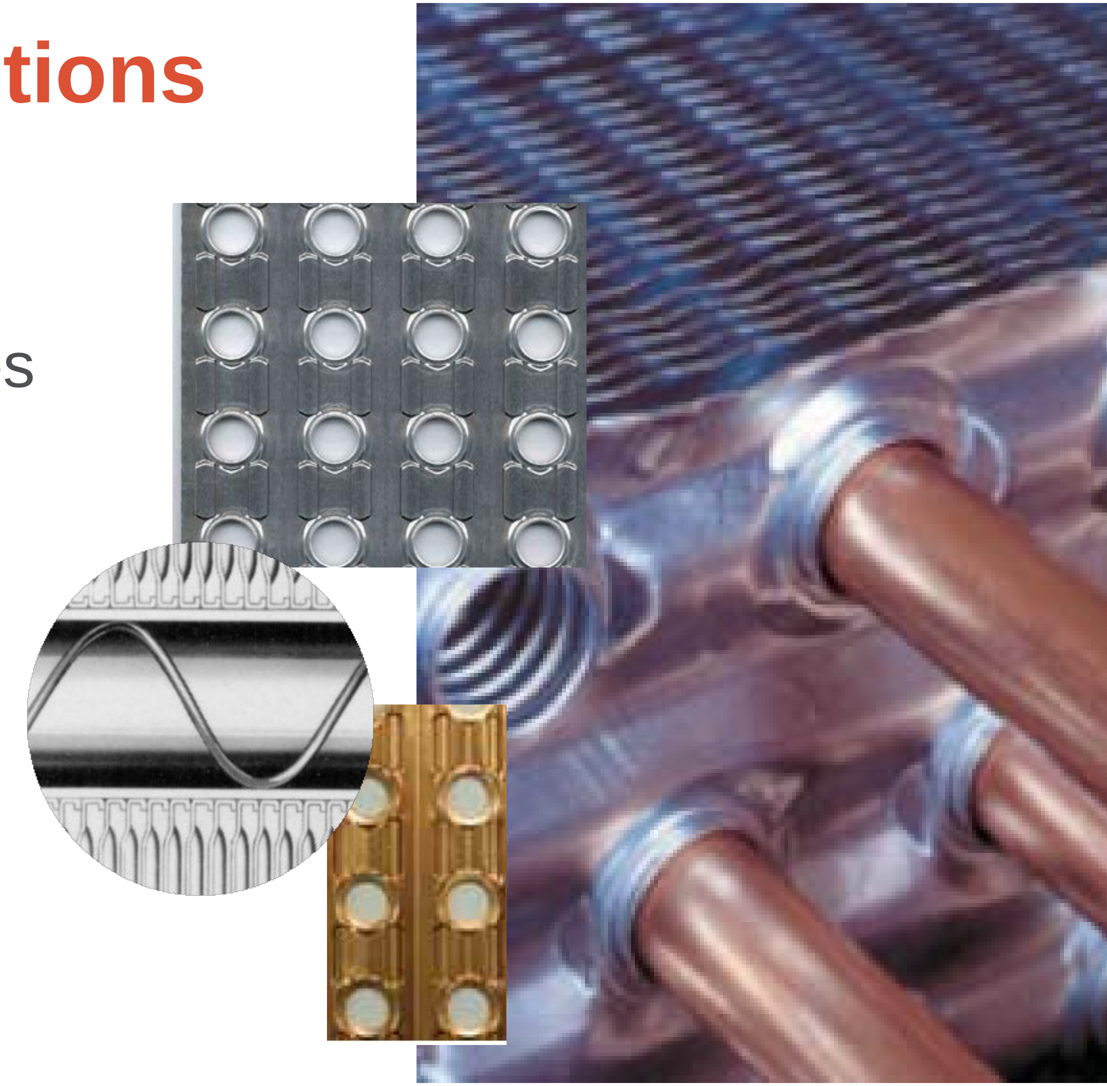
- Pump pressure reset based on critical valve position

APD versus WPD versus Size



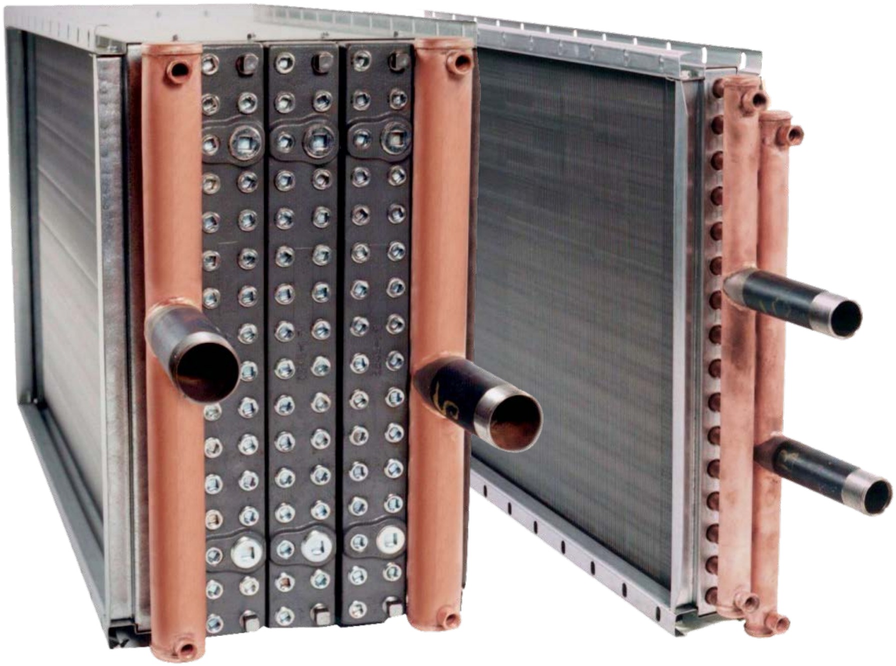
Configuration Options

- Coil face area
- Number of rows of tubes
- Tube diameter
- Number of fins
- Fin surface design
- Coil circuiting
- Turbulators

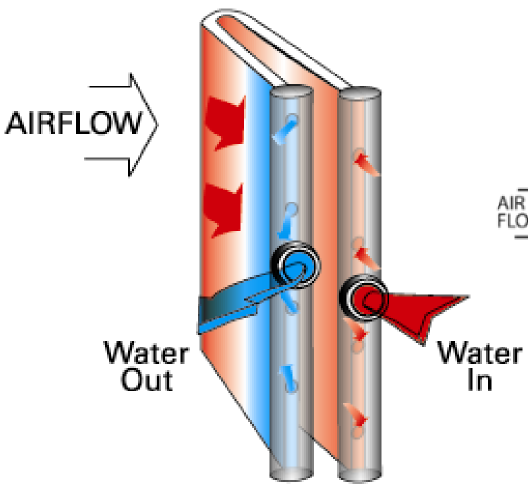


Construction Options

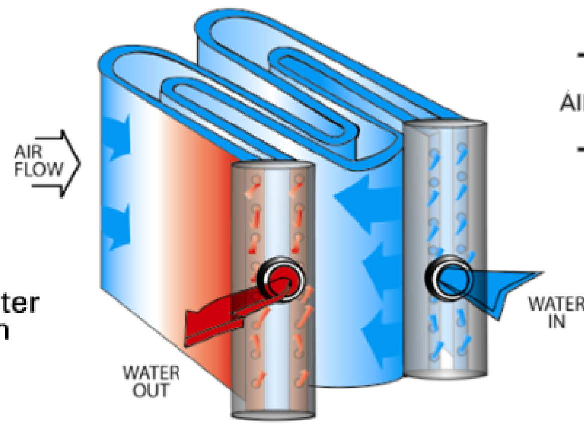
- Tube material
- Tube wall thickness
- Fin material
- Fin thickness
- Casing material
- Header type and material
- Coil coatings



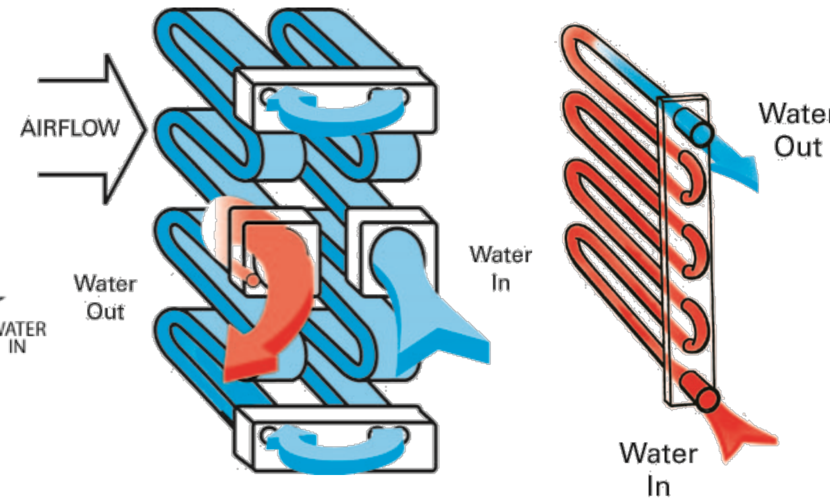
Coil circuiting



single-row serpentine



dual-row serpentine



partial-row serpentine

Water Velocity-Related Concerns

Water velocity too low:

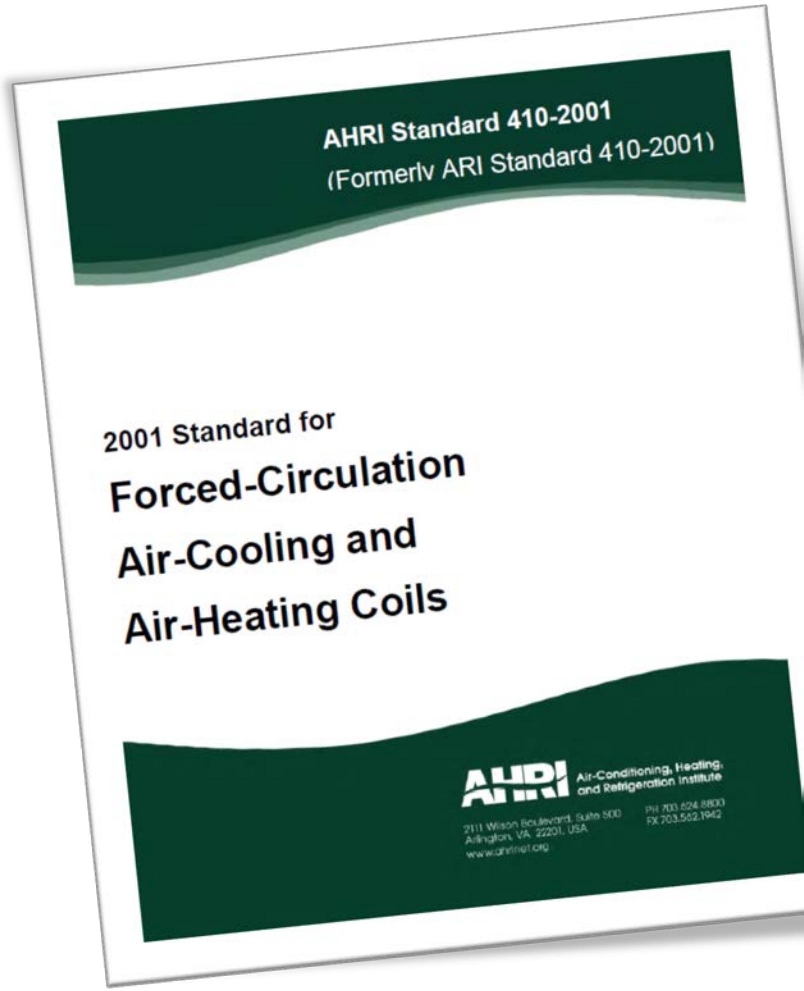
- Tube fouling
- Air trapped in the coil
- Poor water distribution
- Risk of freezing

Water velocity too high:

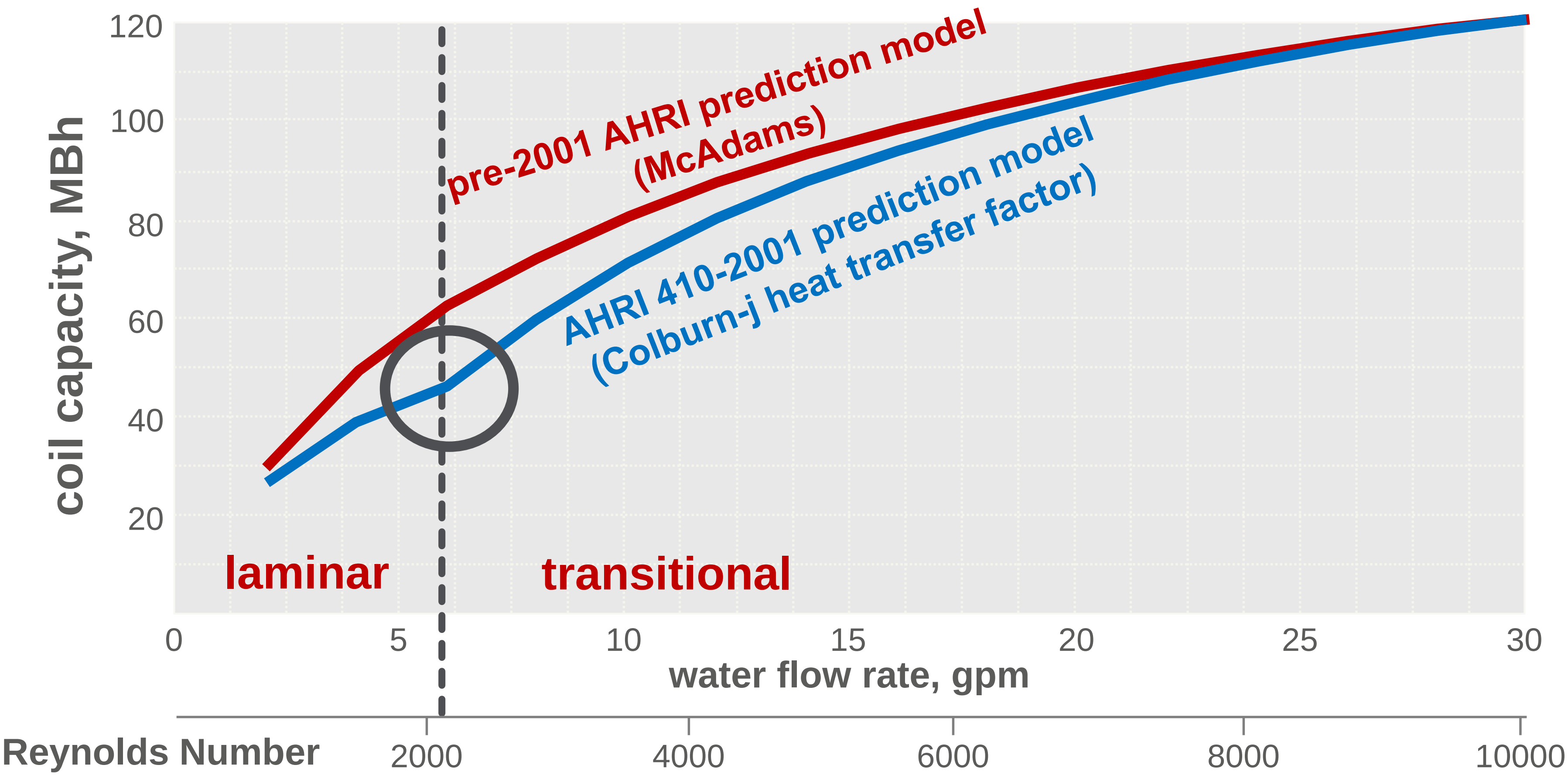
- Tube erosion
- High water pressure drop
- Noise

Guidelines for Water Velocity

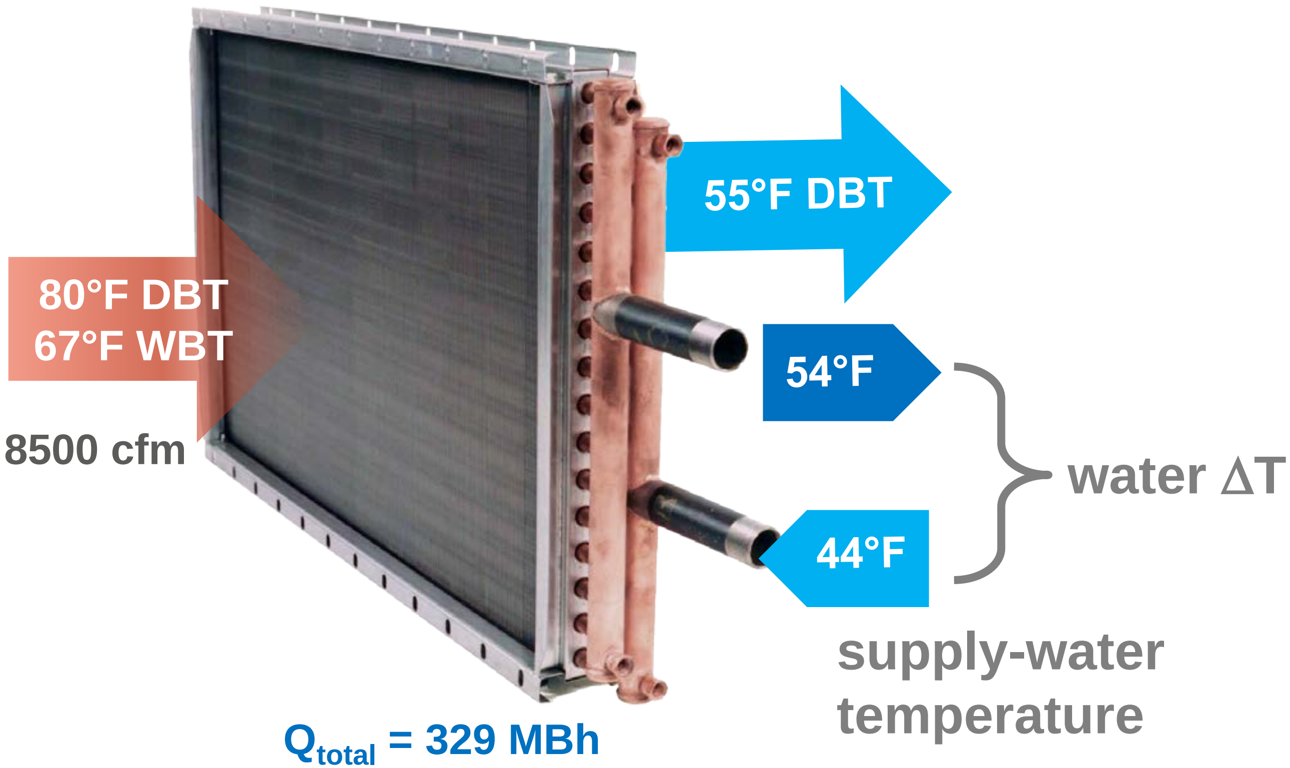
AHRI Standard 410
Forced-Circulation Air-Cooling and Air-Heating Coils

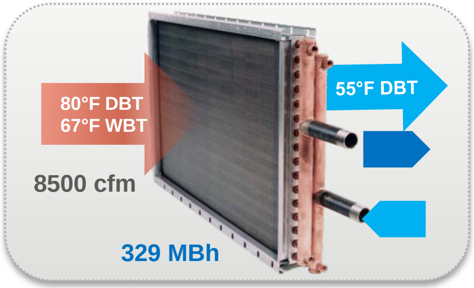


Laminar Flow ≠ Severe Capacity Drop-off

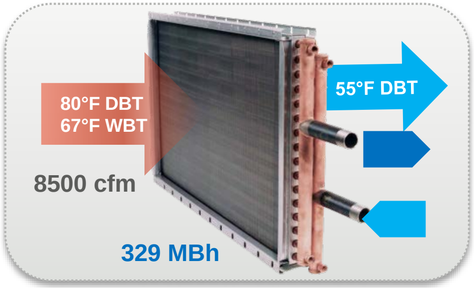


Supply-Water Temp and ΔT

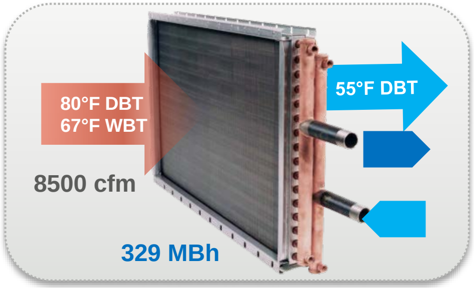




coil face area, ft^2	17	17
coil rows	6	6
coil fins, fins/ft	95	127
supply water temperature, °F	44	44
return water temperature, °F	54	57
water ΔT, °F	10	13
water flow rate, gpm	65.6	50.4
water velocity, ft/sec	3.6	2.8
water pressure drop, ft H_2O	8.2	5.1
air pressure drop, in H_2O	0.68	0.77
cost of the coil	base	base + 7%

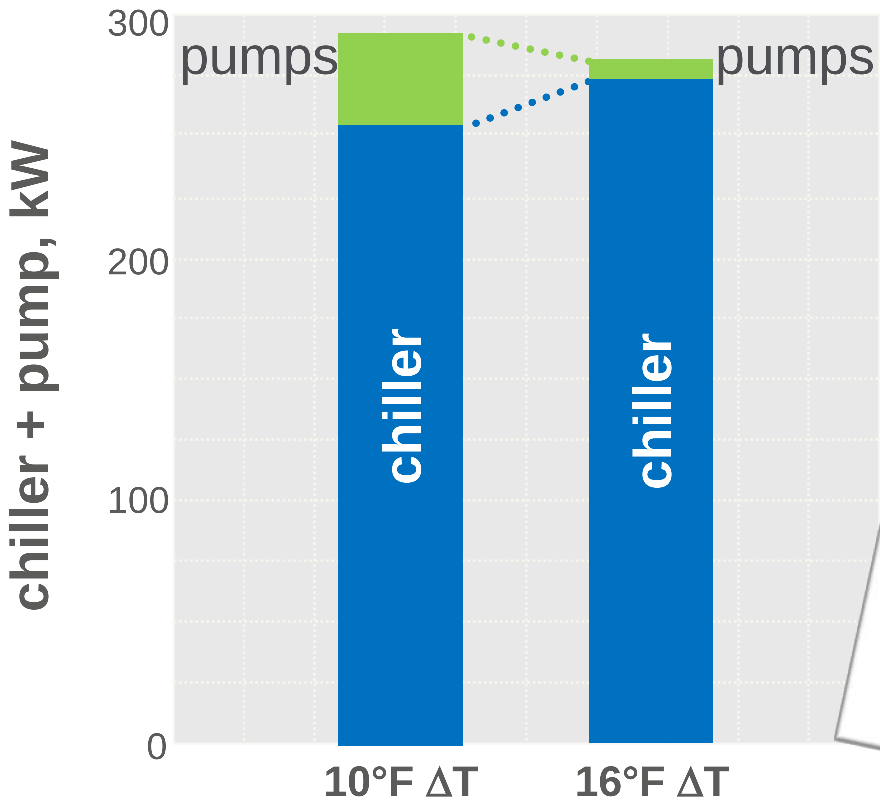


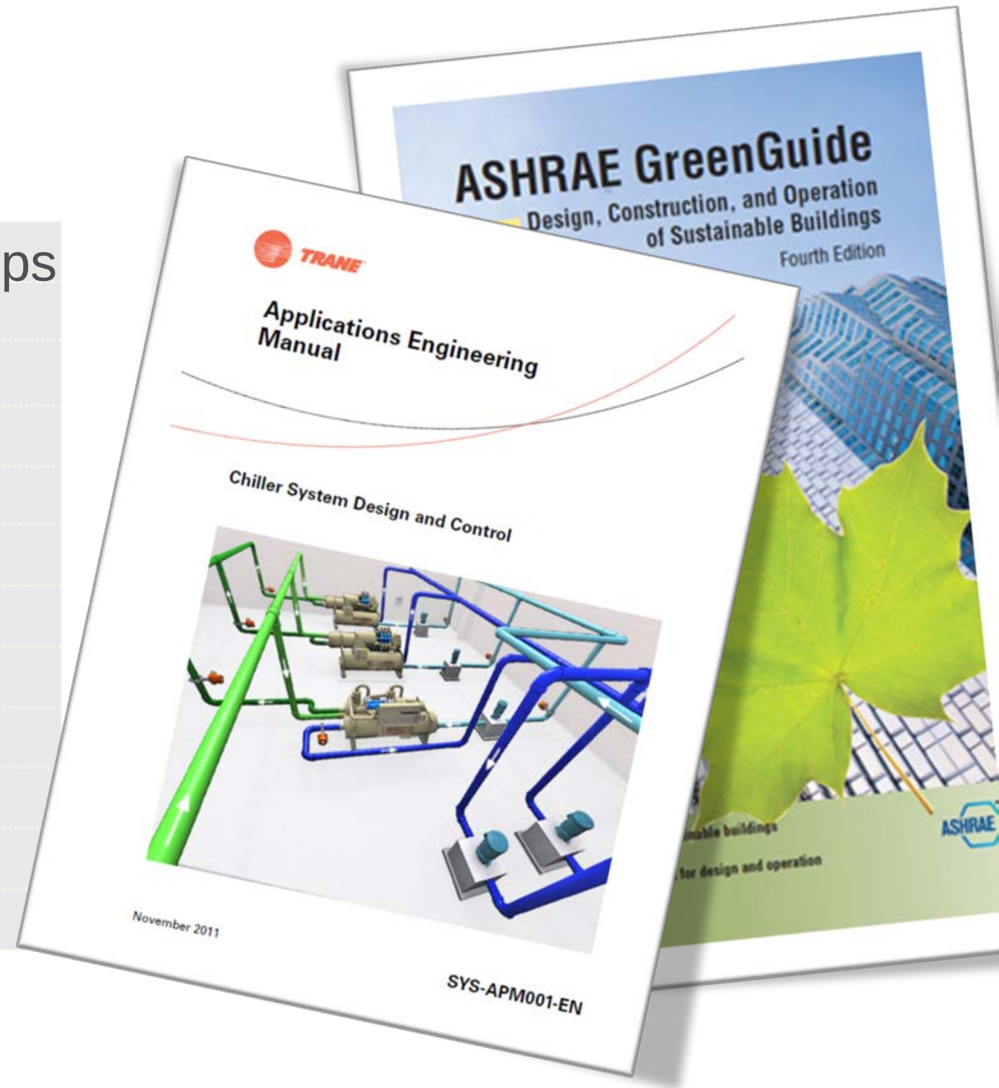
coil face area, ft^2	17	17	17
coil rows	6	6	6
coil fins, fins/ft	95	127	99
supply water temperature, °F	44	44	42
return water temperature, °F	54	57	55
water ΔT, °F	10	13	13
water flow rate, gpm	65.6	50.4	50.4
water velocity, ft/sec	3.6	2.8	2.8
water pressure drop, ft H_2O	8.2	5.1	5.1
air pressure drop, in H_2O	0.68	0.77	0.68
cost of the coil	base	base + 7%	base + 1%



coil face area, ft^2	17	17	17	17
coil rows	6	6	6	4
coil fins, fins/ft	95	127	99	141
supply water temperature, °F	44	44	42	40
return water temperature, °F	54	57	55	56
water ΔT, °F	10	13	13	16
water flow rate, gpm	65.6	50.4	50.4	41.0
water velocity, ft/sec	3.6	2.8	2.8	2.3
water pressure drop, ft H_2O	8.2	5.1	5.1	5.8
air pressure drop, in H_2O	0.68	0.77	0.68	0.56
cost of the coil	base	base + 7%	base + 1%	base – 16%

Low-Flow Chiller Plants





Low Delta-T (High Flow) Syndrome

- Symptom of poor heat transfer at the coil and impacts:
- Energy
  - Excessive pump energy
  - Excessive fan energy
  - Excessive chiller energy
- Comfort
  - Degrades dehumidification and temperature control
- Capacity
  - Running out of chilled water distribution capacity

Why is Low Delta T Bad?

- Tough to model = tough business case
- Chillers get blamed
- Fouling gets blamed
- Filters get blamed
- System balancer gets blamed
- Engineer gets blamed
- Customers and occupants unhappy

Wasted Energy Transporting Tons

- $Tons = \frac{(\Delta T \times GPM)}{24}$

Solving for gpm…

- $GPM = \frac{(Tons \times 24)}{\Delta T}$

Pumping power…

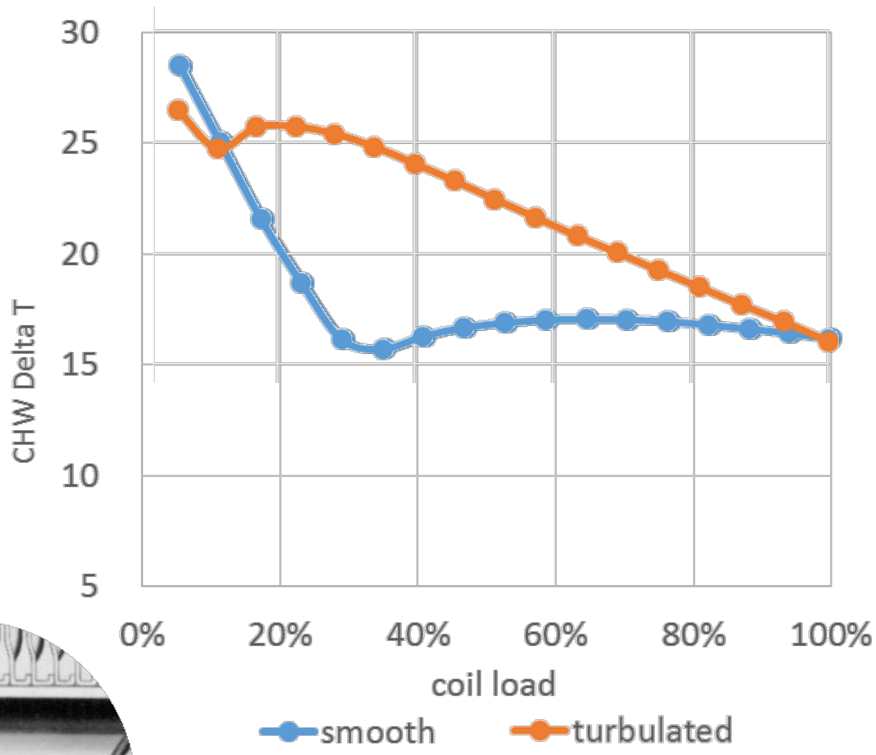
- $Frictional\ Head\ ;\ Flow^2$
- $Water\ HP\ (bhp) = \frac{(GPM \times head\ (ft))}{3960}$
- $Water\ HP\ ;\ Flow^3;\ Delta\ T^3$

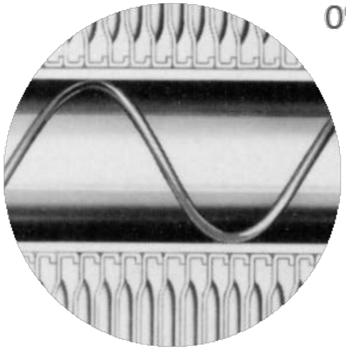
Yes BUT, Coil Delta T is lower at Part Load

Is it physics or is it something else?

- AHRI Certified Coil
- Air Flow (VAV) unloading
- Entering air conditions matter

  f(OA%, OA temp)



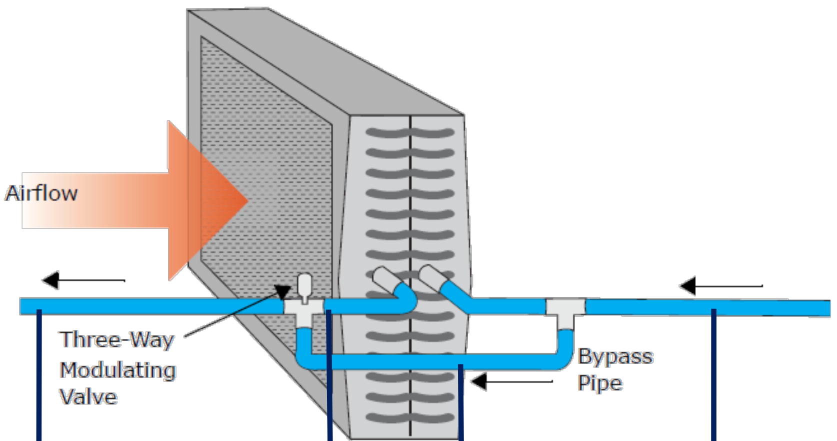


Reason 1: 3-Way control valves

undesirable mixing in variable flow systems

- *Eliminate them!*

50% Coil Load



Coil Delta T = 17°F

System Delta T = 8.5°F

CHWR
50.5°F

Coil LVG
59°F

Bypass
42°F

CHWS
42°F

CHWR = [(42° x 50) + (59° x 50)] / 100 = 50.5°

Reason 2: Supply air setpoint depression

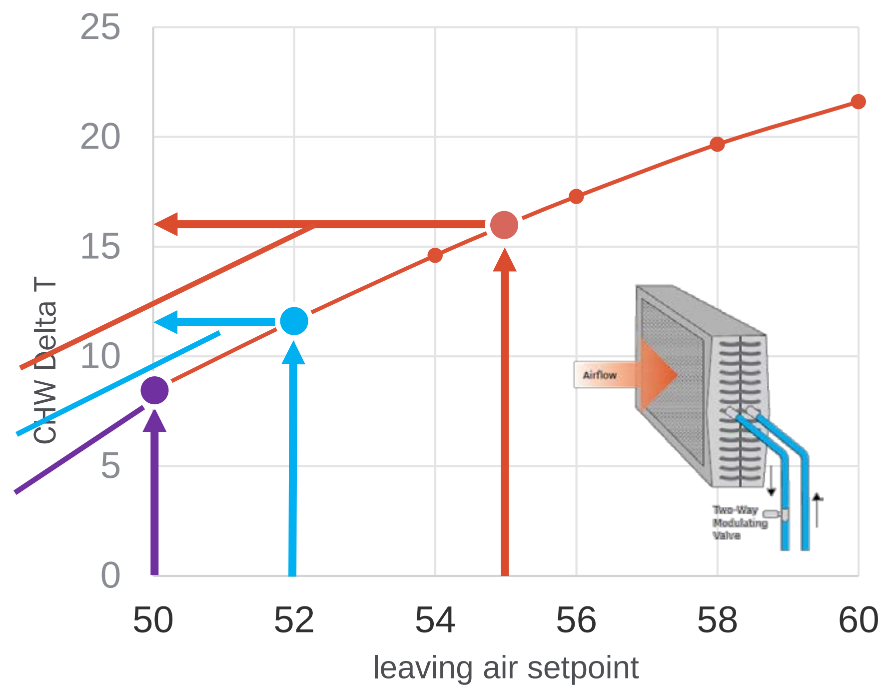
overdriving coil capacity

1. 3-way control valves
2. Control setpoint depression
   - *Avoid, limit and restore*

55° LAT = 16° DT = 1.5 gpm/ton

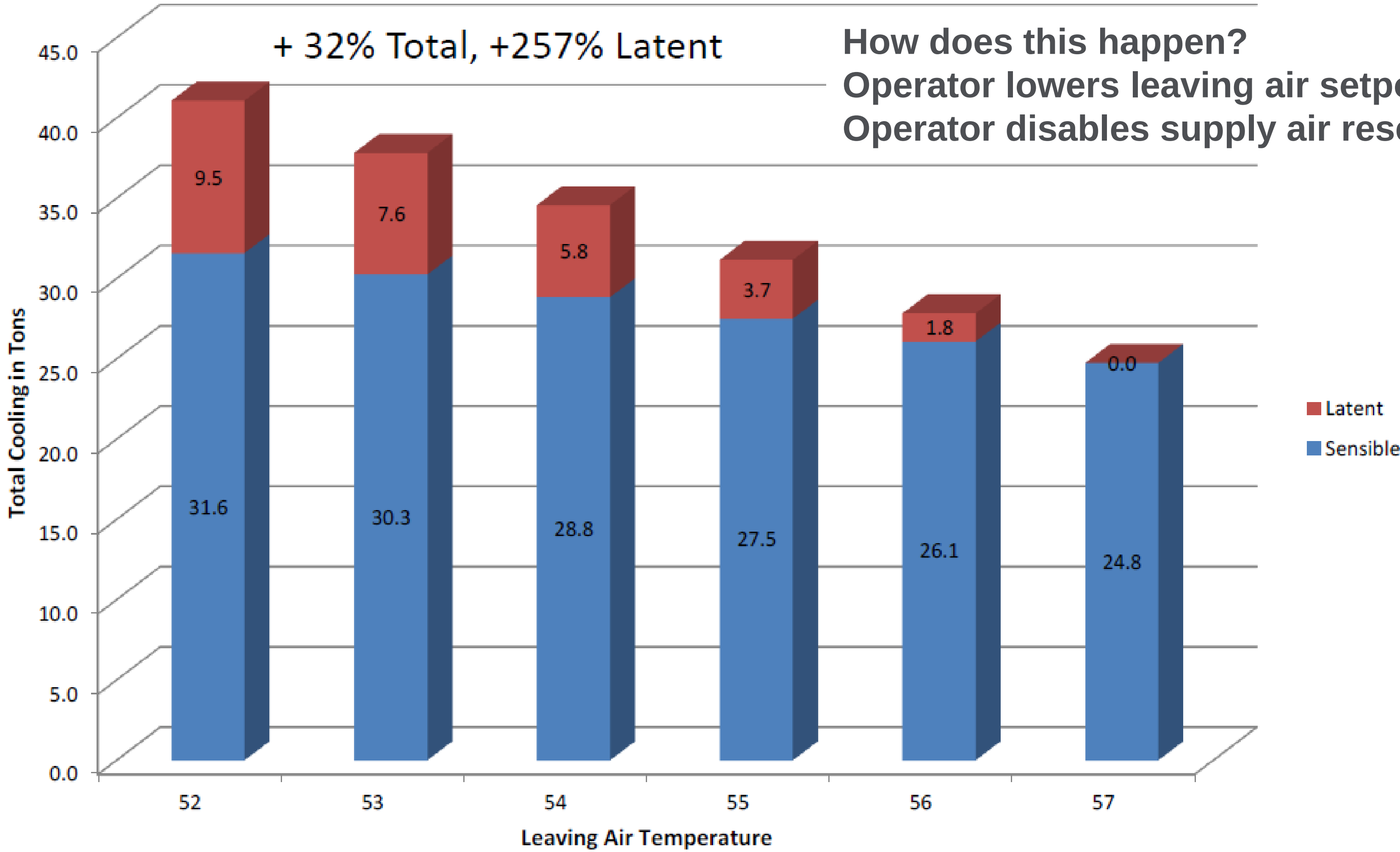
52° LAT = 11° DT = 2.2 gpm/ton

50° LAT = 8.5°DT = 2.8 gpm/ton



Effect of responses to discomfort

How does this happen?
Operator lowers leaving air setpoint
Operator disables supply air reset



Reason 3: Warmer chilled water supply

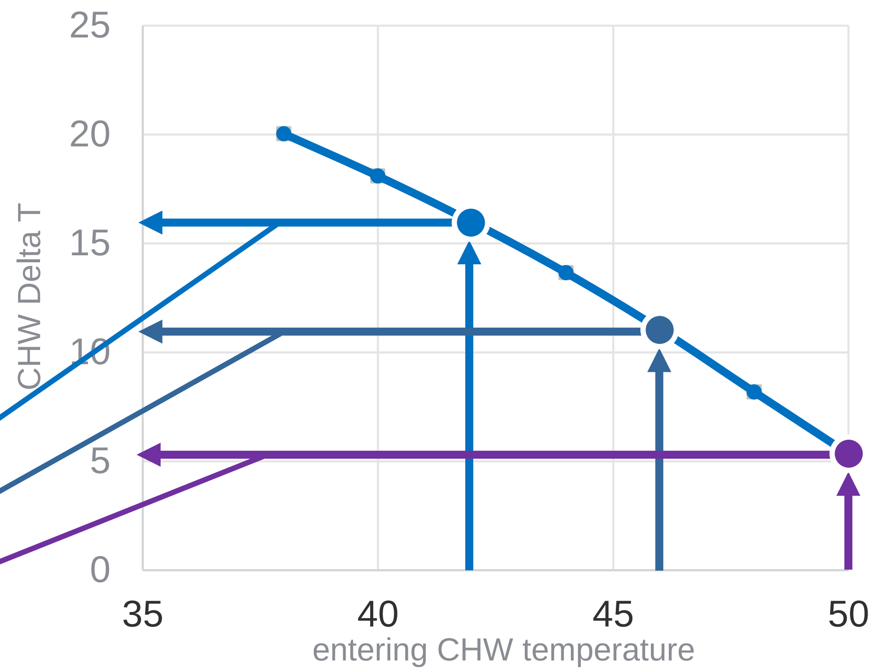
reduced heat transfer driving force “LMTD”

1. 3-way control valves
2. LAT setpoint depression
3. **Warmer chilled water**
   - *Chilled water reset only at part load*

42° CHWS = 16° DT = 1.5 gpm/ton

47° CHWS = 7.5° DT = 3.2 gpm/ton

50° CHWS = 5°DT = 4.8 gpm/ton



Excessive CHW reset

- Warm supply water temperature causes Low ΔT, High Flow
- Entering air temp is reduced at part load

8000 cfm Cooling Coil

Total Capacity (MBh)	Coil Entering Water (°C)	Coil Leaving Water (°C)	Delta T (°C)	Flow (gpm)
315	4.4	13.3	8.9	39.36
315	6.7	12.2	5.6	62.53

CHW reset OK in high DT designs and at chiller min flow in VPF system

Reason 4: Deficient control valves

poor flow control at full and part loads

1. 3-way control valves
2. LAT setpoint depression
3. Warmer chilled water
4. Deficient control valves

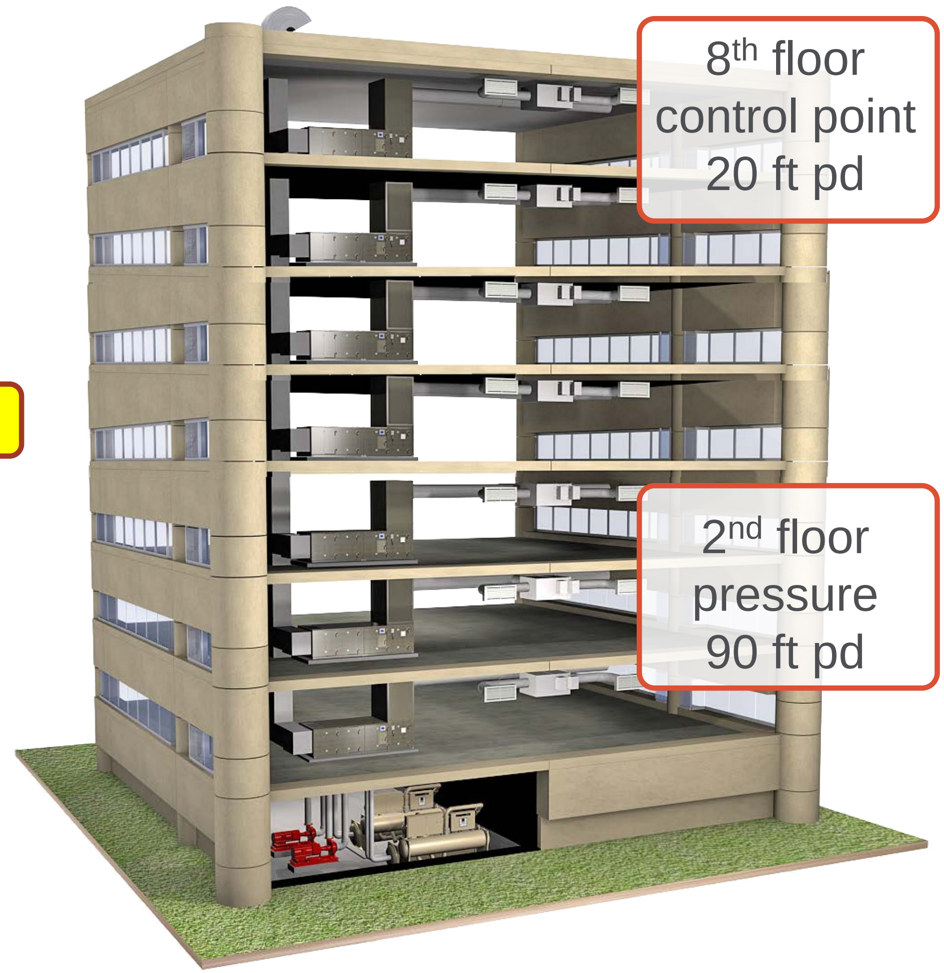
Control Valve Issues

1. Improperly Selected / Oversized
2. Worn-out
3. Unstable control
4. $29.95 (cheap)
5. 3-way valves

Reason 4: Deficient control valves

poor flow control

1. 3-way control valves
2. LAT setpoint depression
3. Warmer chilled water
4. Deficient control valves
    - *Specify quality valves specific to use*

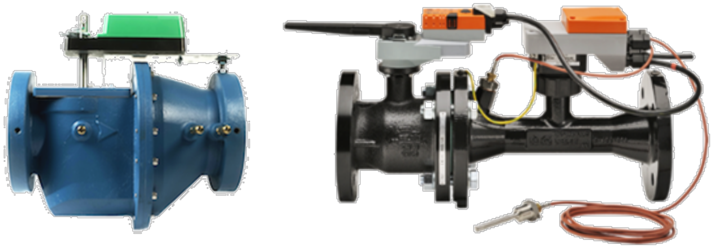


Reason 4: Deficient control valves
poor flow control

1. 3-way control valves
2. LAT setpoint depression
3. Warmer chilled water
4. Deficient control valves

Pressure independent valves? (PICV)
- Not always required
- Reverse return piping can help
- Can be beneficial

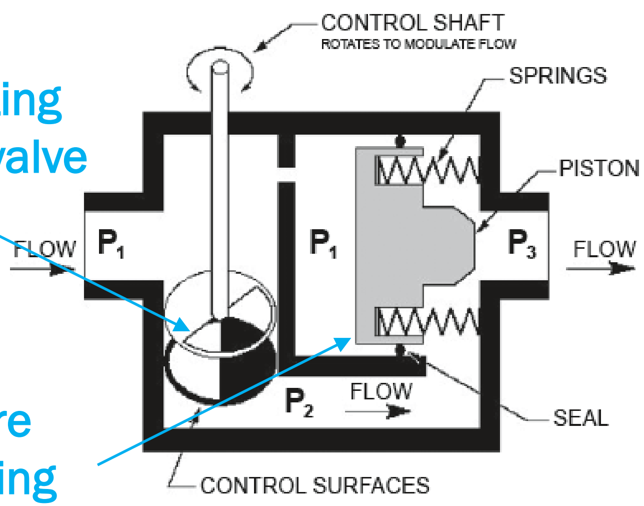
1. Mechanical
2. Electronic



Pressure Independent Control Valves

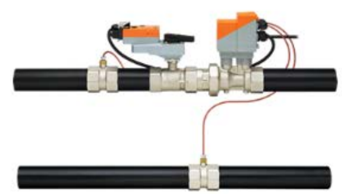
mechanical PI valve

modulating control valve



pressure regulating valve

electronic PI valve



½" - 2"

1.65 -100 GPM

2½" - 6"

80-713 GPM

Mechanical PI Valves

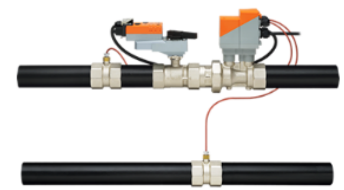
Advantages:

- More compact
- Will accept any rotary actuator
- Easier to select
- No additional power, programming, or sensor installation
- Now available with data sharing

Electronic PI Valves

Advantages:

- Potential for lower hardware costs
- Provides load measurement
- Programmable for various operation methods:
    - Flow limiting
    - ΔT limiting
    - Energy limiting
- BACnet™ Communication to BAS system for data sharing. (requires licensing and commissioning another BACnet device)



½" - 2"

1.65 -100 GPM

2½" - 6"

80-713 GPM

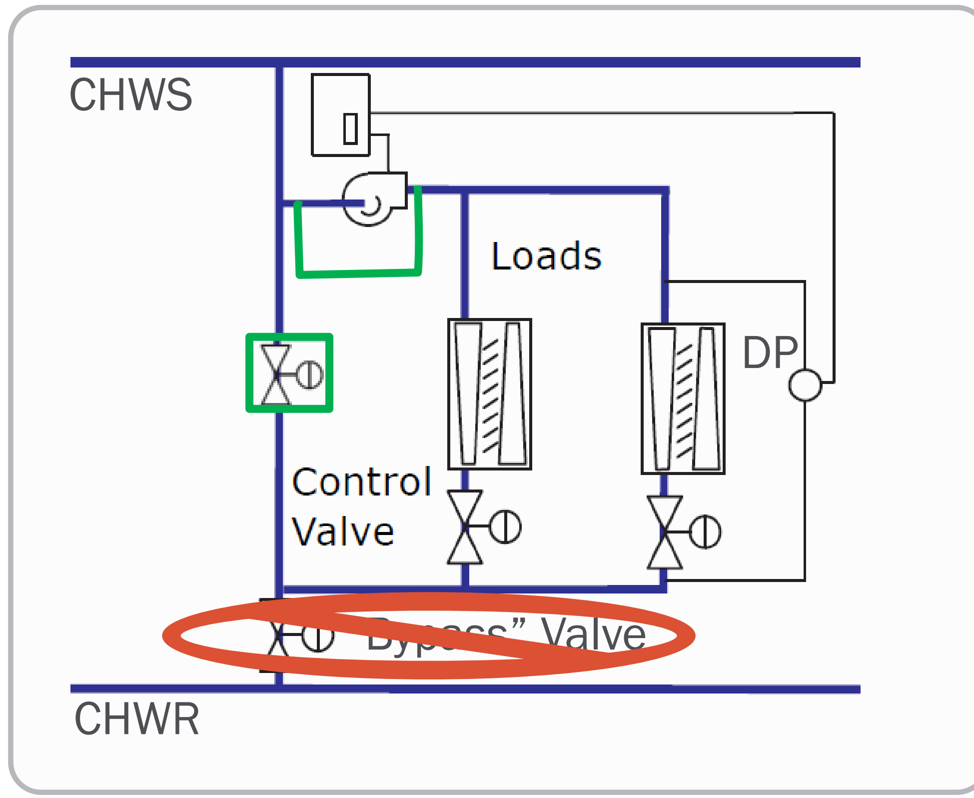
PI Valves— Summary

- Advantages:
- More stable and accurate
  - Increased delta T
- Easier to select
- Easier to install
- May be cost neutral

Reason 5: Tertiary pumping

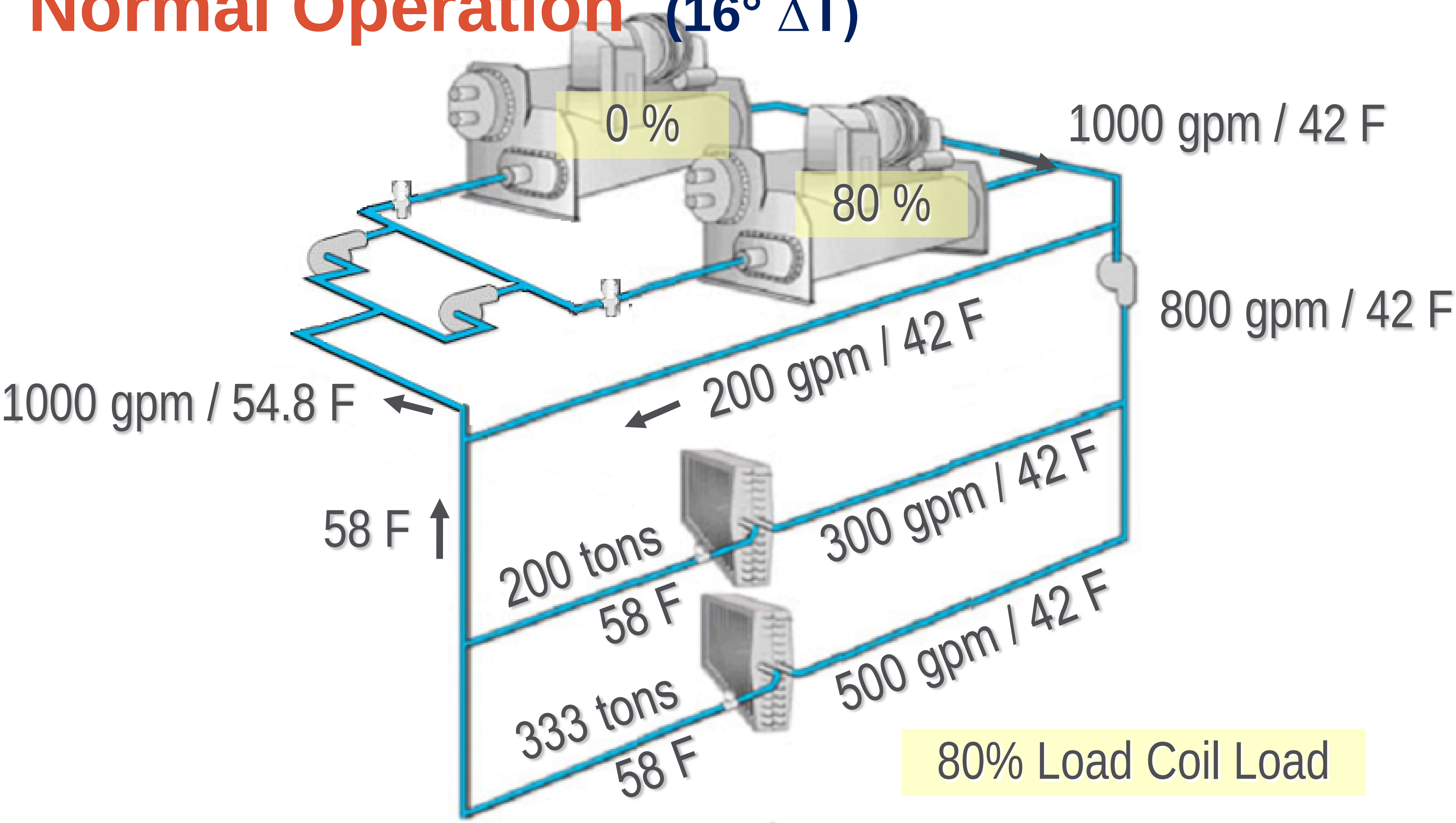
undesirable mixing is hard to prevent

1. 3-way control valves
2. LAT setpoint depression
3. Warmer chilled water
4. Deficient control valves
5. Tertiary pumping / bridge tender circuits
    - *Don't mix to the return - simply pressure boost*



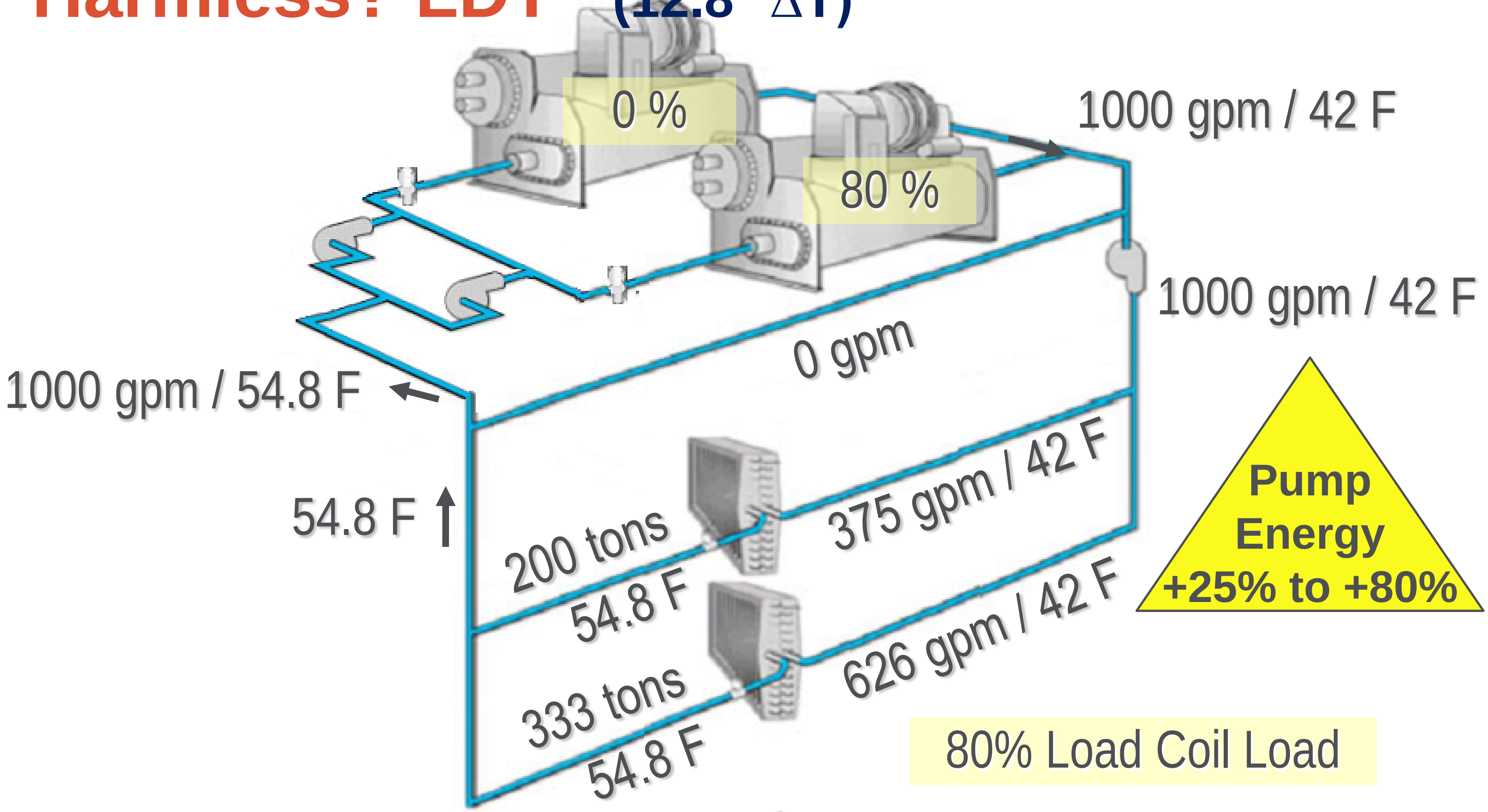
Why is Low Delta T Bad for the chiller plant?

Normal Operation (16° ΔT)



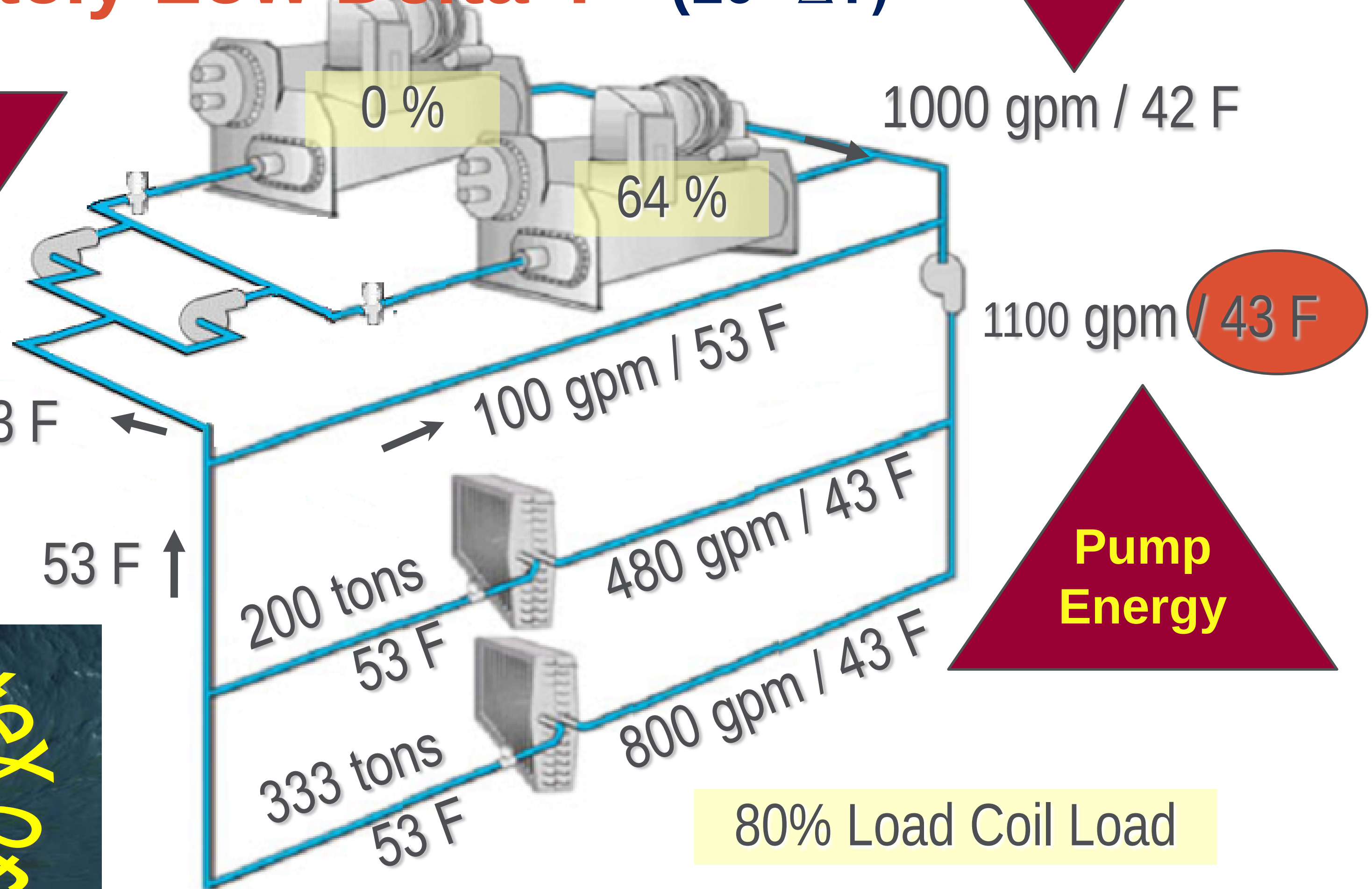
Why is Low Delta T Bad for the chiller plant?

Harmless? LDT (12.8° ΔT)



Why is Low Delta T Bad for the chiller plant?

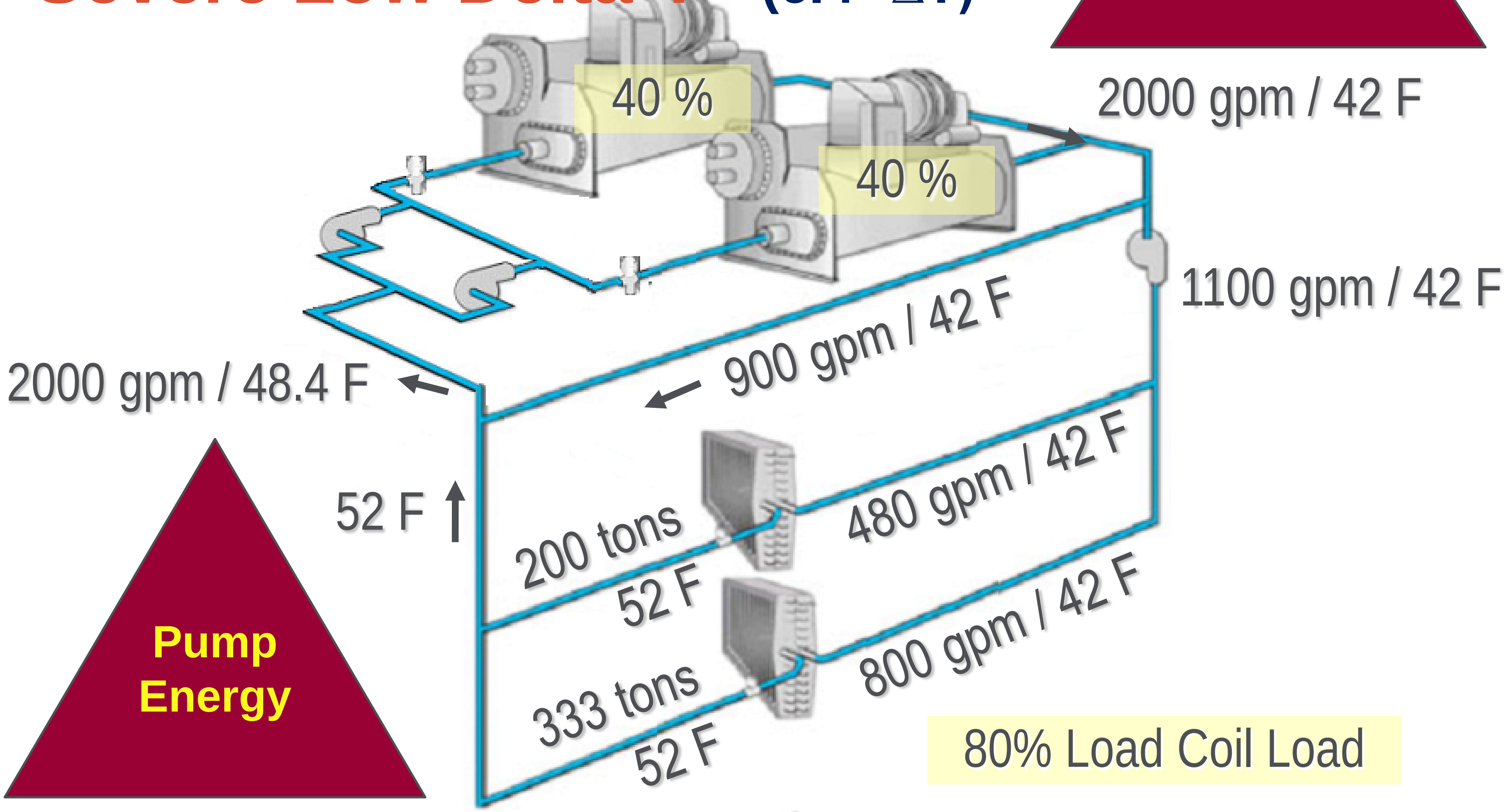
Moderately Low Delta-T (10° ΔT)



Why is Low Delta T Bad for the chiller plant?

Severe Low Delta-T (6.4° ΔT)

Chiller Energy



Pump Energy

Why is Low Delta-T Bad?

Energy

- Excessive pump energy
- Increased chiller plant energy
  - More pumping energy
  - Chillers running at inefficient load points.

Capacity

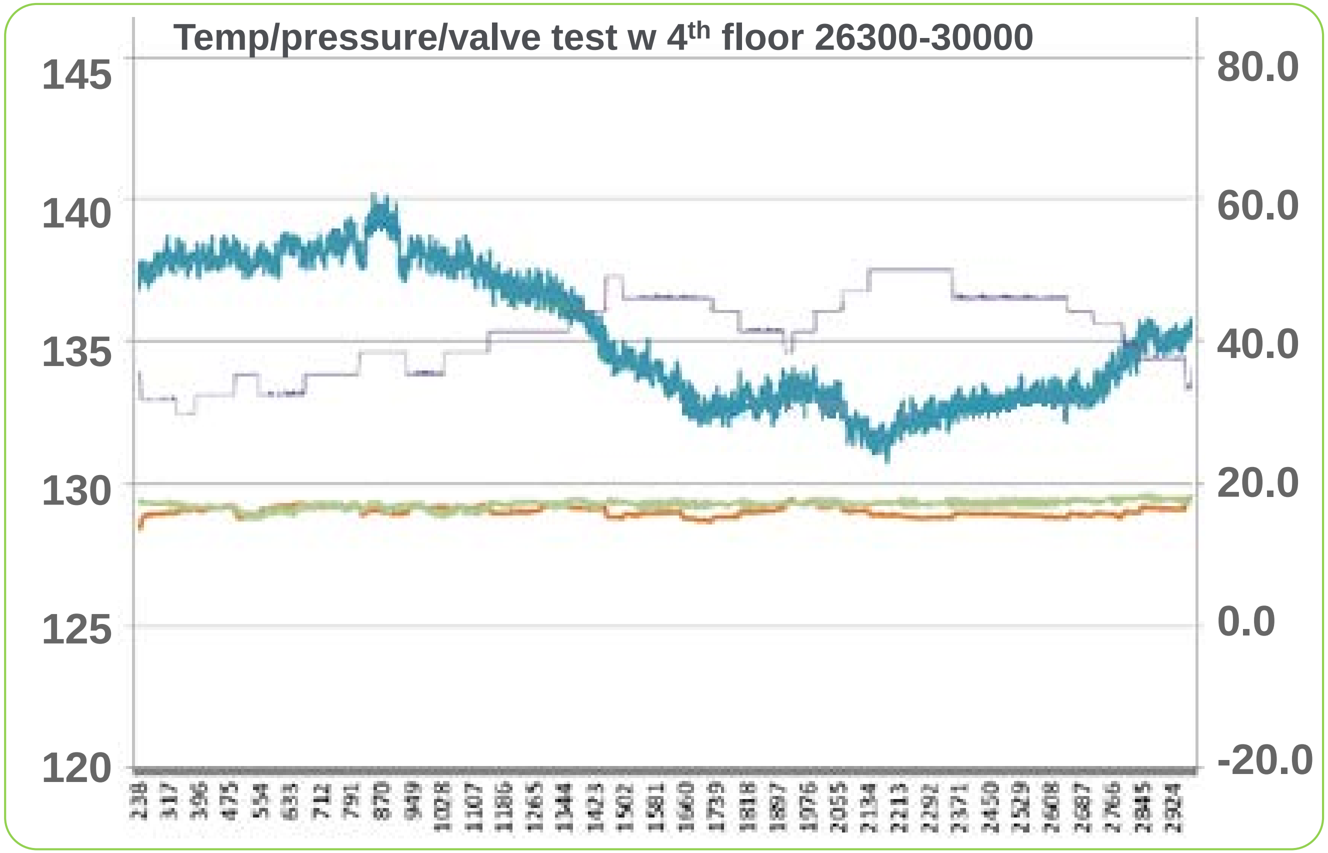
- Running out of distribution capacity
- Chiller won’t load

Leads to overrides/manual operation

Case Study

- Demonstrated some AHU control problems
- Two floors:
    - 3rd floor AHU kept existing conventional valves
    - 4th floor AHU retrofitted with PI valves

Case Study



3rd floor (conventional)

4th floor (PI valve)

3rd floor CHW Delta T

4th floor CHW Delta T

Some Causes of Low Delta T

Flow Control

- Three-way valves
- Cheap control valves
- Uncontrolled loads
- Excessive pump pressure
- Building “bridge circuits”

Load

- Undersized coils
- Improper AHU setpoints

Maintenance

- Dirty filters or coils
- Coils piped backwards

Control

- Low AHU set points
- Unstable valve control
- Control calibration
- Improper CHW reset
- Diluted CHW supply temp

Low Delta-T Syndrome

What is the number one thing
you can do
to improve the performance of a
chiller plant?

FIX THE AIR SIDE !

Low Delta-T Syndrome

Some Band-Aids...

- Lower the chiller's setpoint
- Open the chiller balancing valves to allow more "constant" flow to the chillers
- Convert to Variable Primary / Variable Secondary
- Convert to Variable Primary Flow

But the best thing to do is:

FIX THE AIR SIDE !

Avoiding Low Delta-T is a *Discipline*

- AHU maintenance
- AHU setpoint vigilance
- Pumping pressure vigilance
- Coil selection requirement compliance
- Coil control valve specification compliance
    - “Pressure independent” valves help
- AHU control commissioning

All Systems Have Issues

- All systems require attention to maintain peak performance
- All systems have deficiencies in their energy models
- Most energy can be saved in operation
- Better design choices make it easier to do so
- Get more data and turn it into intelligence

Questions...