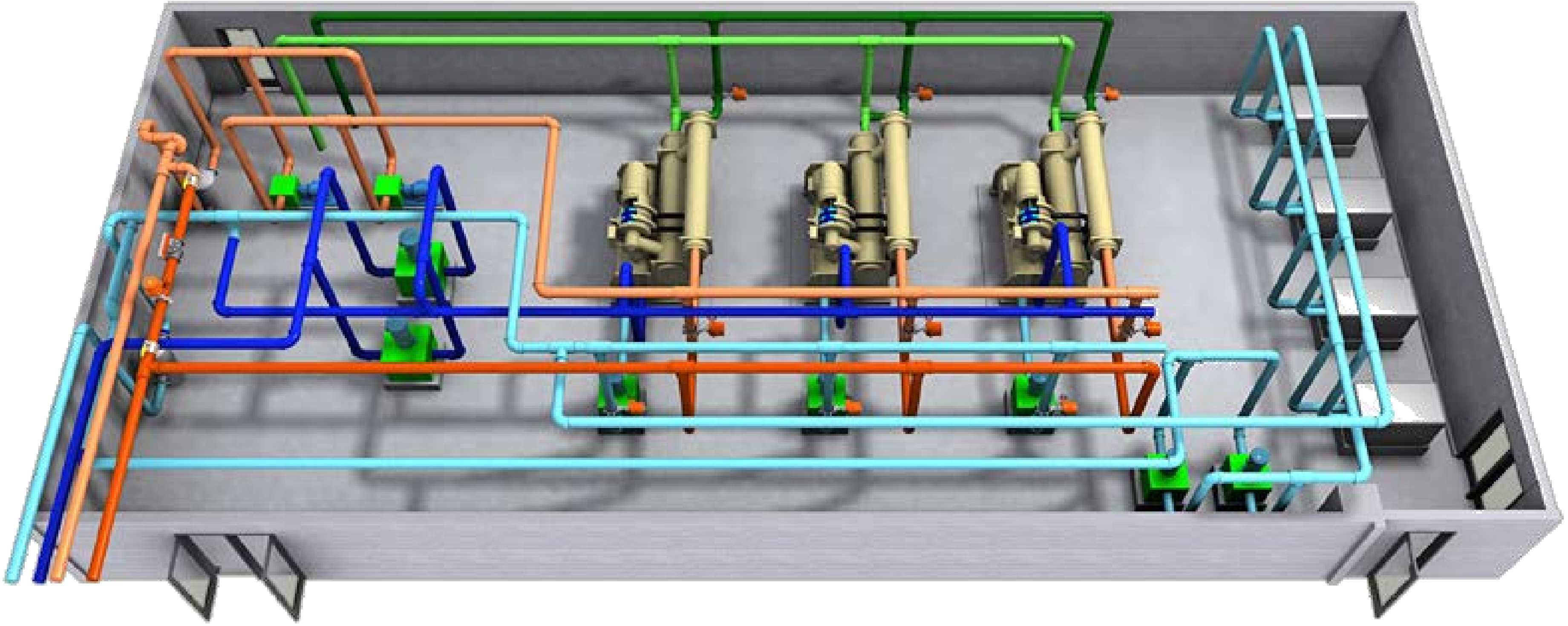
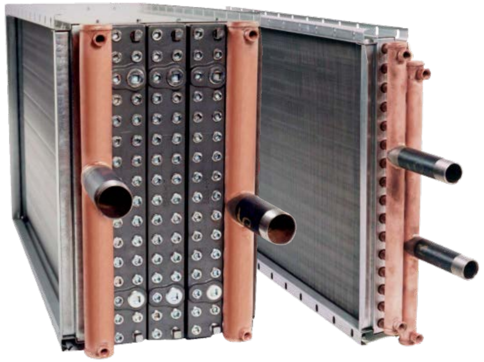
High-performance Chilled-water Systems
The Engineer's Role in Operation

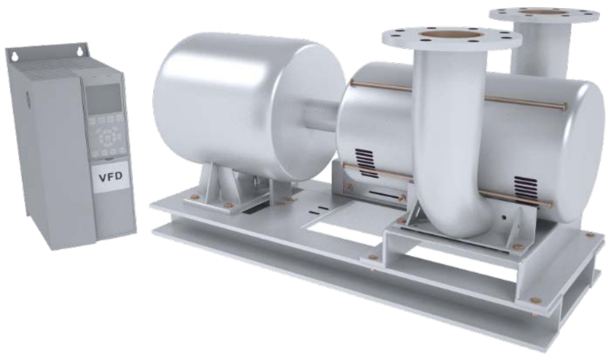
Susanna Hanson, CEM DGCP

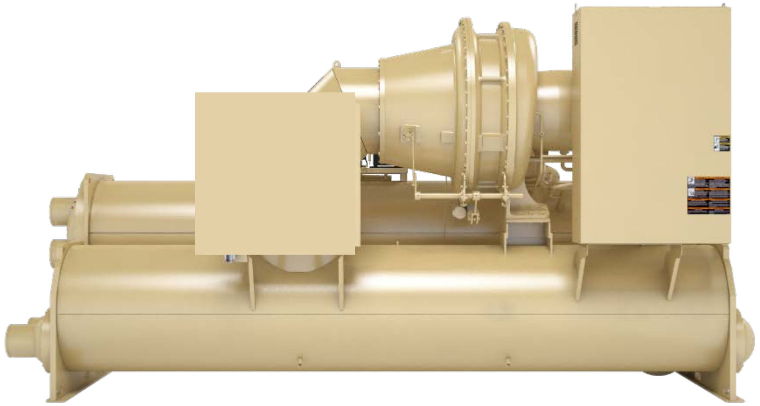
Chilled-water System



Chilled-water System Components

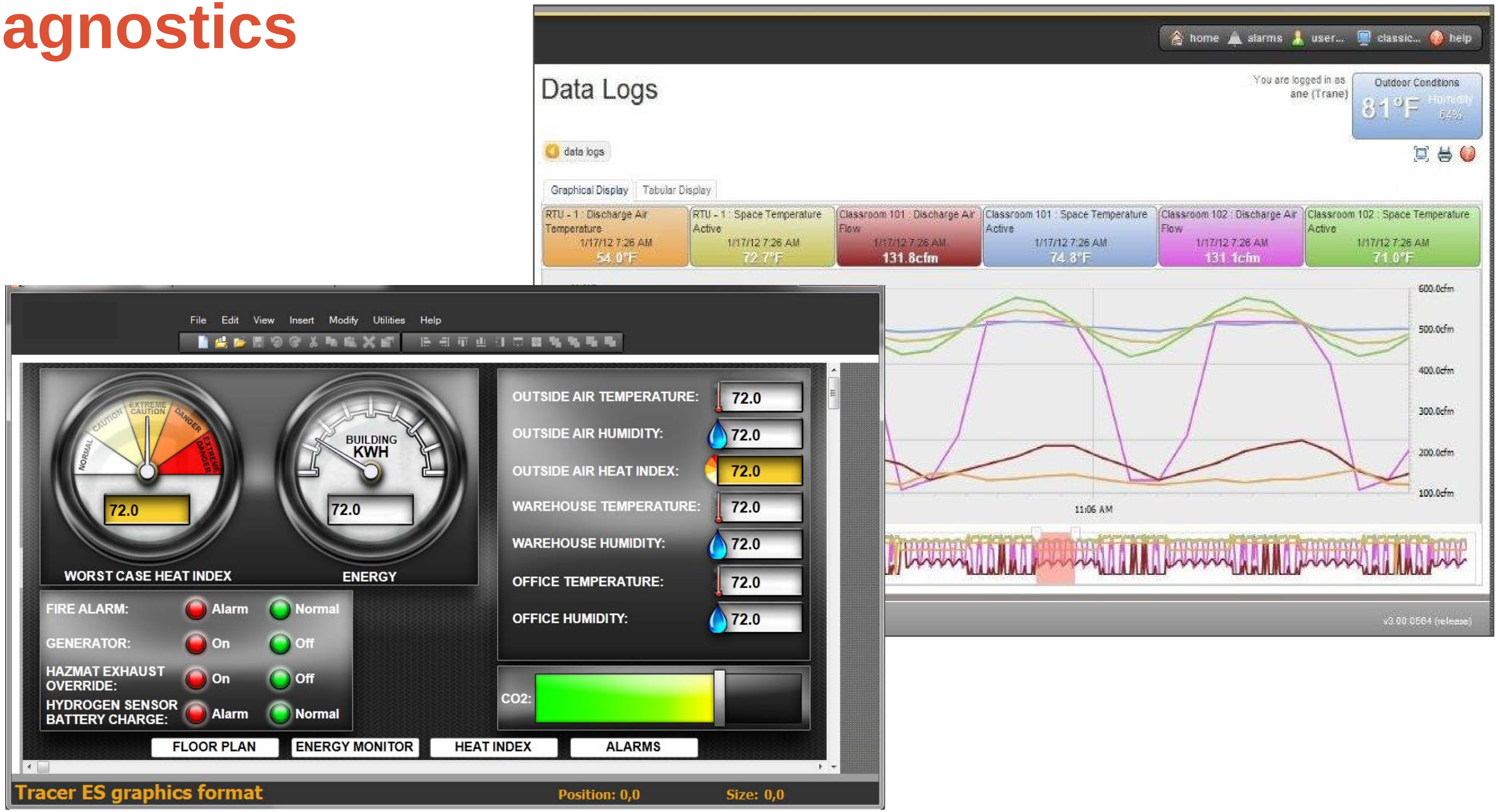






Connectivity

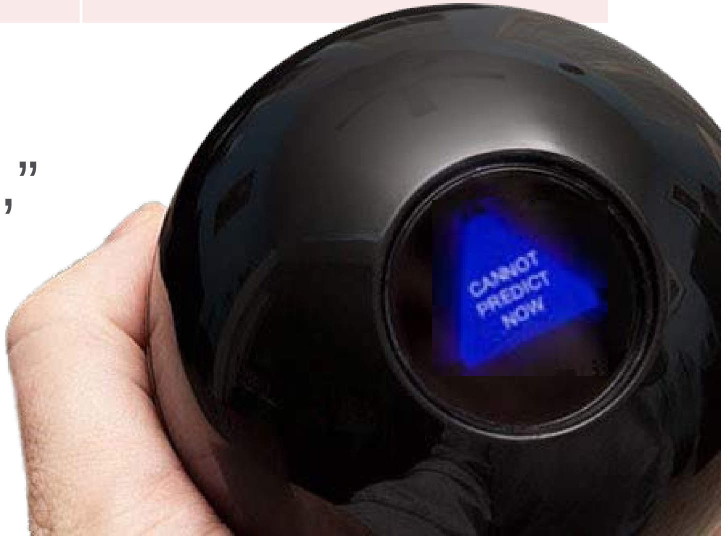
Diagnostics



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 model operation 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 valve 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

But Enough About Models

Effects of Responses to Discomfort

- Occupant
  - lower zone setpoint – increases GPM, may increase fan speed
  - supplement airflow – fans appear on or 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
- Spend money for balancing valves and balancers!

Step One: Pick the Right Heat Exchangers

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 DT or higher (57°F min return)

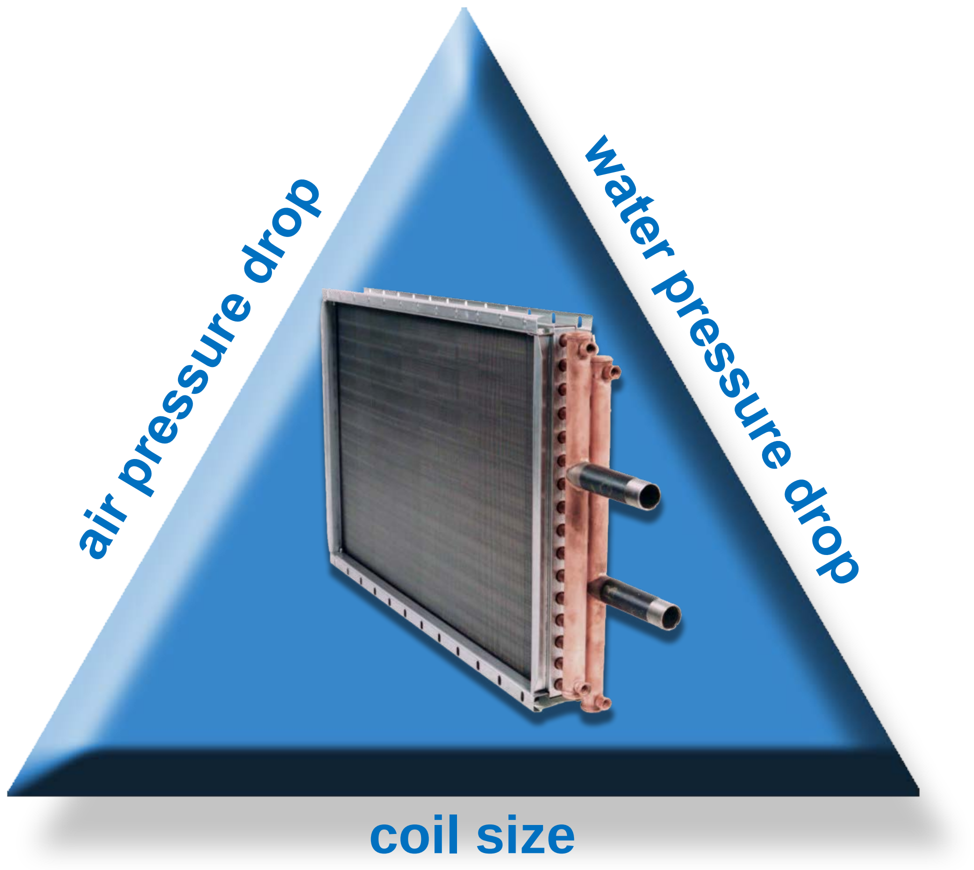
-and-

- Chilled water reset based on critical valve position

-or-

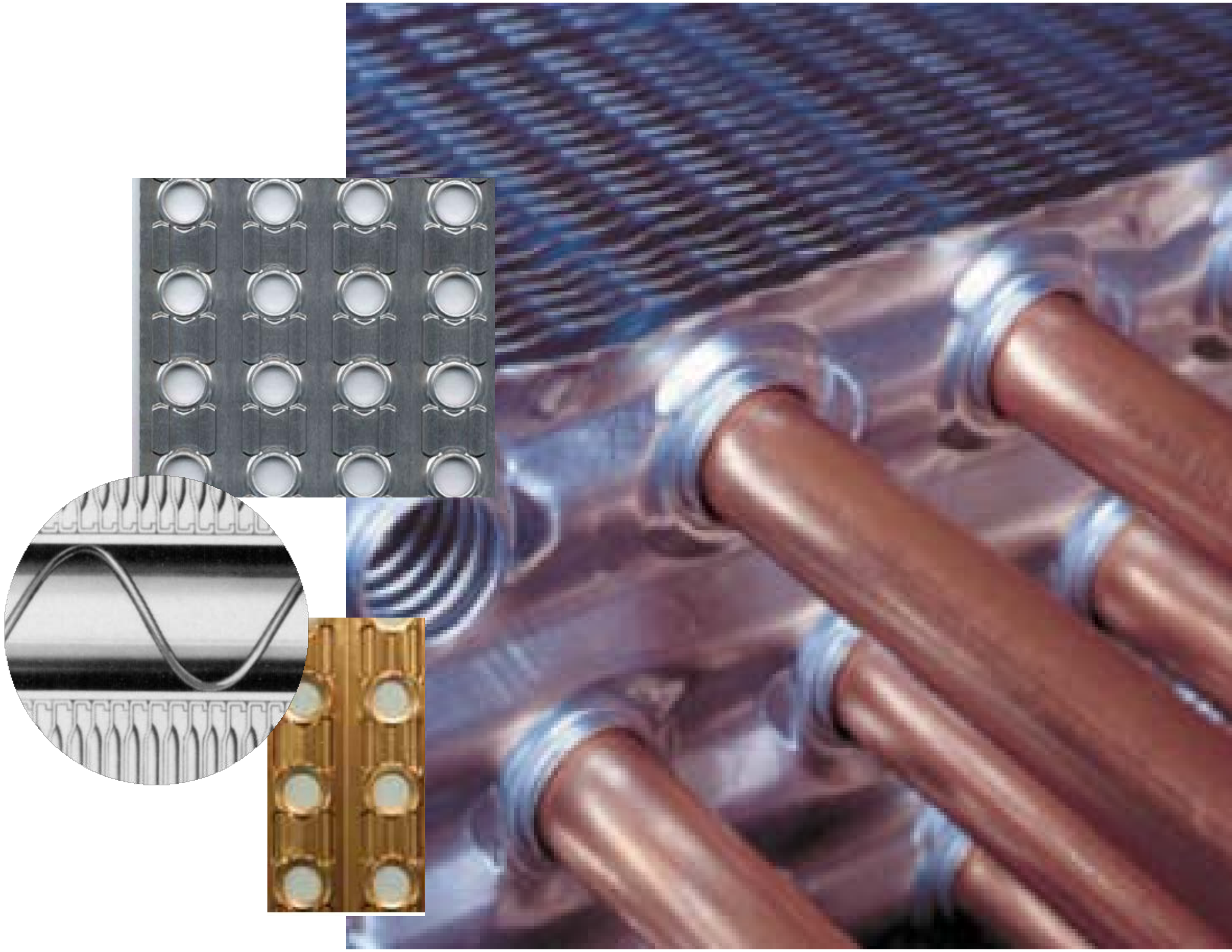
- Pump pressure reset based on critical valve position

Coil Selection: APD versus WPD versus Size



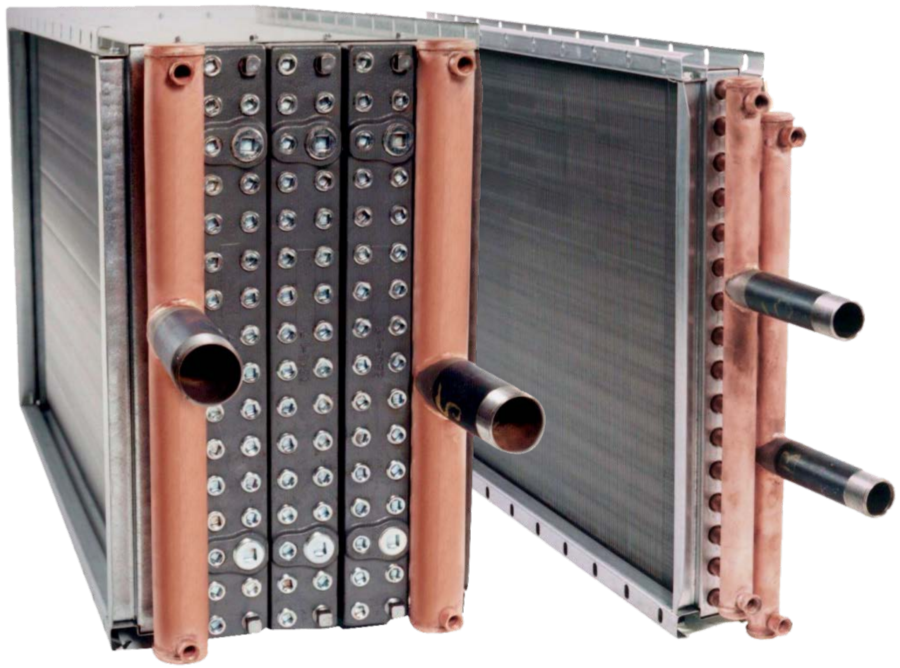
Configuration Options

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



Construction Options

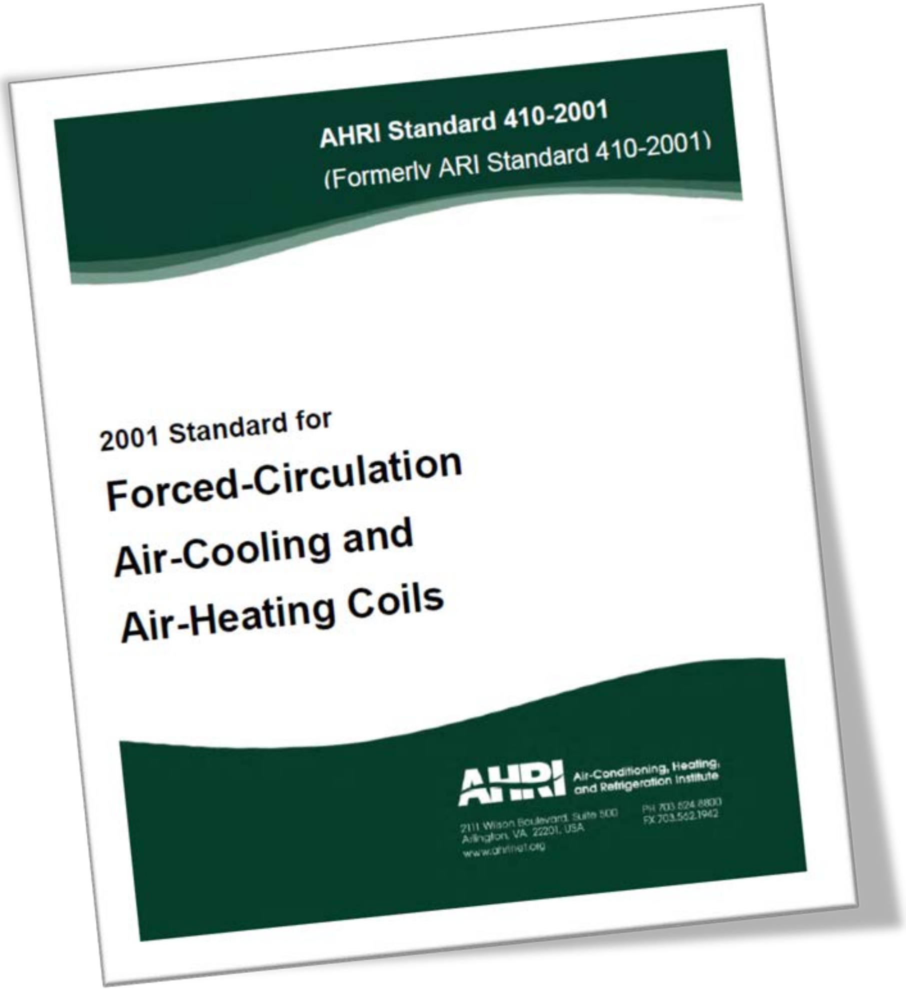
- Tube material
- Tube wall thickness
- Fin material
- Fin thickness
- Casing material
- Header type and material
- Coil coatings



Coil Certification Program

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

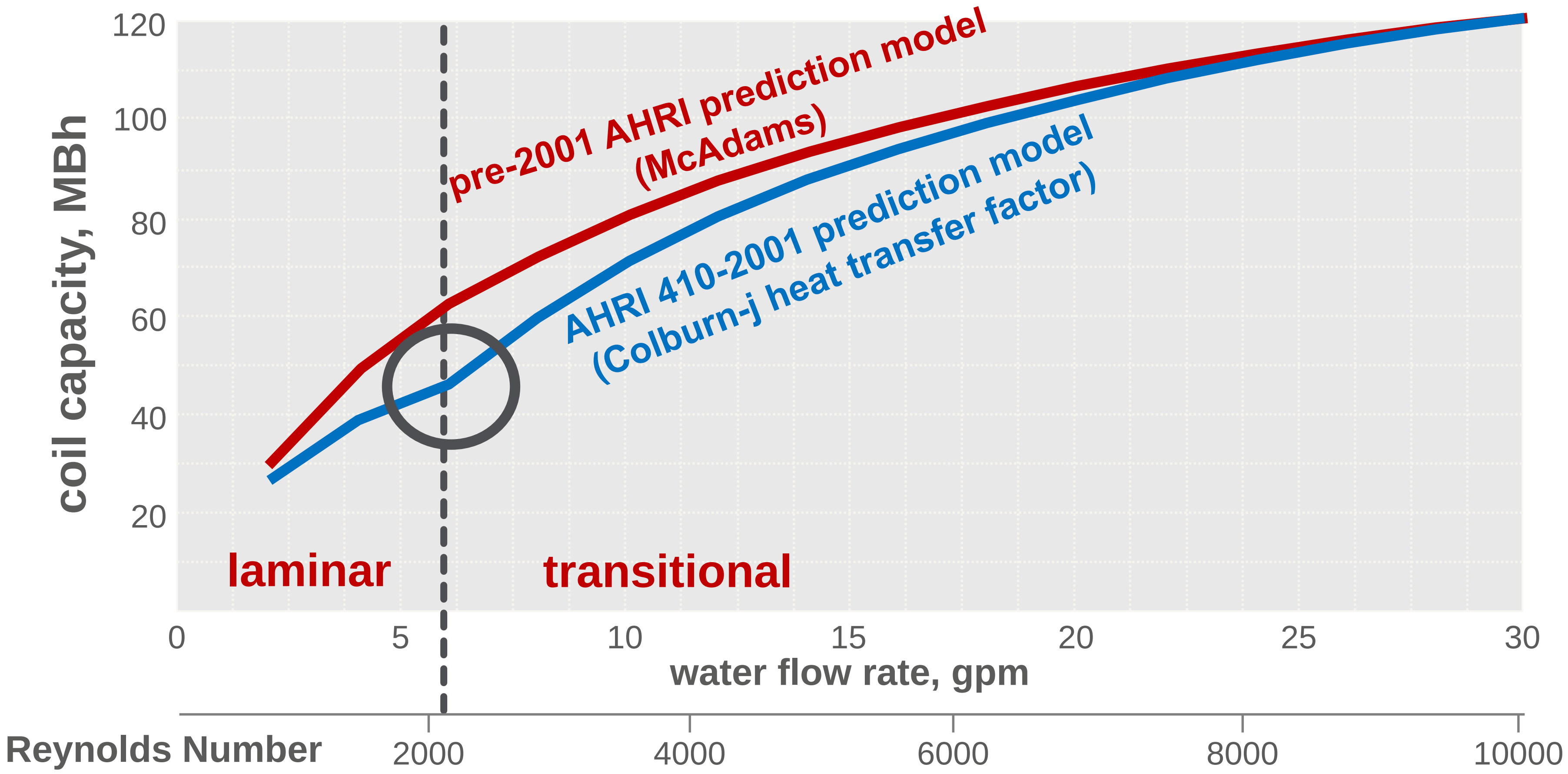
AHRI CERTIFIED™
www.ahridirectory.org
Air-Cooling and Air-Heating Coils
AHRI Standard 410


AHRI Standard 410-2001
(Formerly ARI Standard 410-2001)

2001 Standard for
Forced-Circulation
Air-Cooling and
Air-Heating Coils

AHRI Air-Conditioning, Heating, and Refrigeration Institute

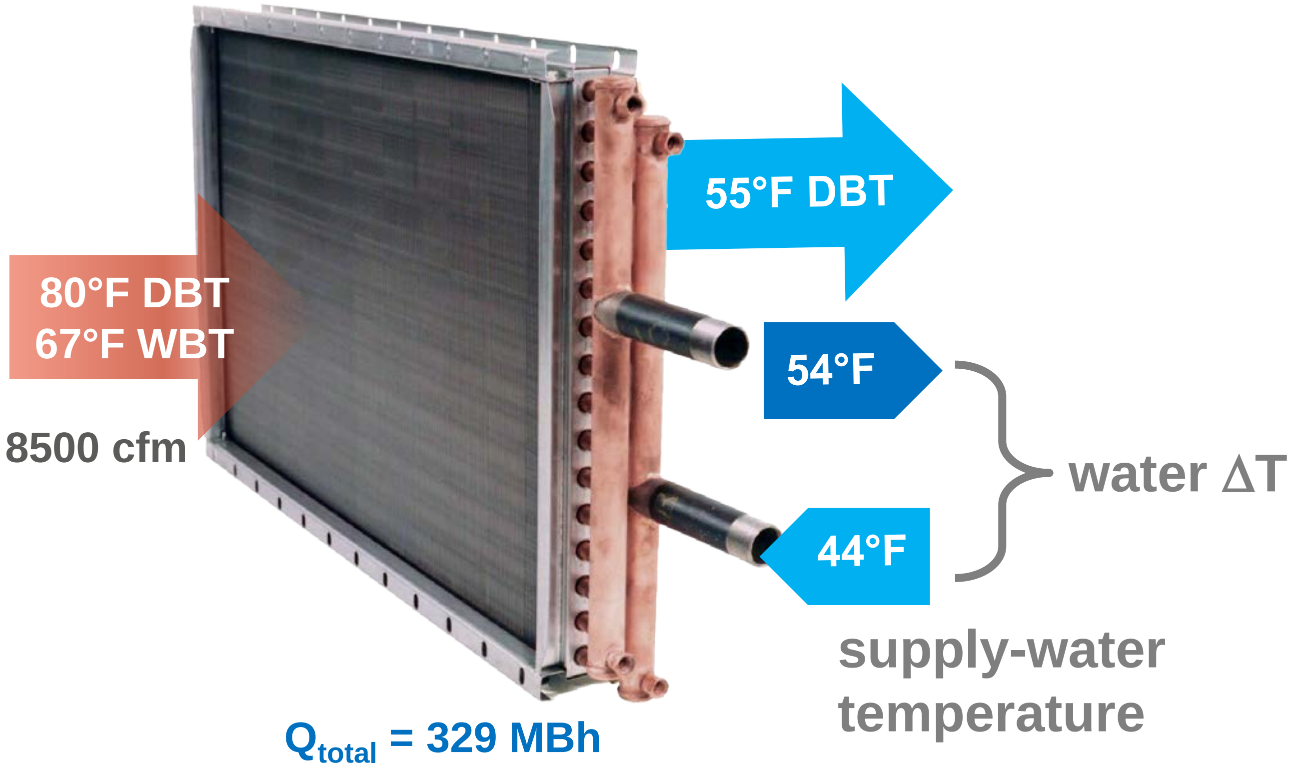
Laminar Flow ≠ Severe Capacity Drop-off



Conserve Energy Transporting Tons

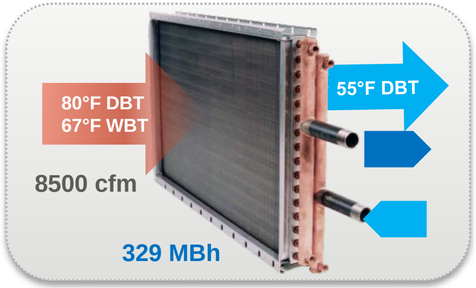
- $Tons = \frac{(\Delta T \times GPM)}{24}$
- Solving for gpm…
- $GPM = \frac{(Tons \times 24)}{\Delta T}$
- Pumping power…
- Frictional Head ; Flow 2
- $Water\ HP\ (bhp) = \frac{(GPM \times head\ (ft))}{3960}$
- Water HP ; Flow ^{3}; Delta T ^{3}

Supply-Water Temp and ΔT



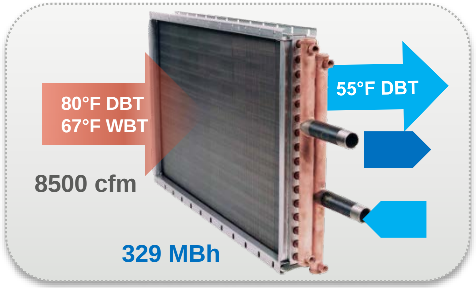
Lowest Cost?
Lowest Energy?
Neither

Supply-Water Temp and ΔT



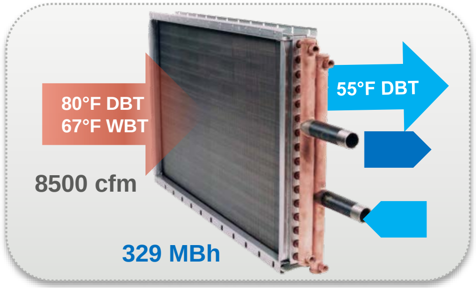
coil face area, ft^2	17	17
coil rows	6	6
coil fins, fins/ft	95	127
supply water temperature, °F	44	44
return water temperature, °F	54	57
water ΔT, °F	10	13
water flow rate, gpm	65.6	50.4
water velocity, ft/sec	3.6	2.8
water pressure drop, ft H_2O	8.2	5.1
air pressure drop, in H_2O	0.68	0.77
cost of the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

Supply-Water Temp and ΔT



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%

Supply-Water Temp and ΔT



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%

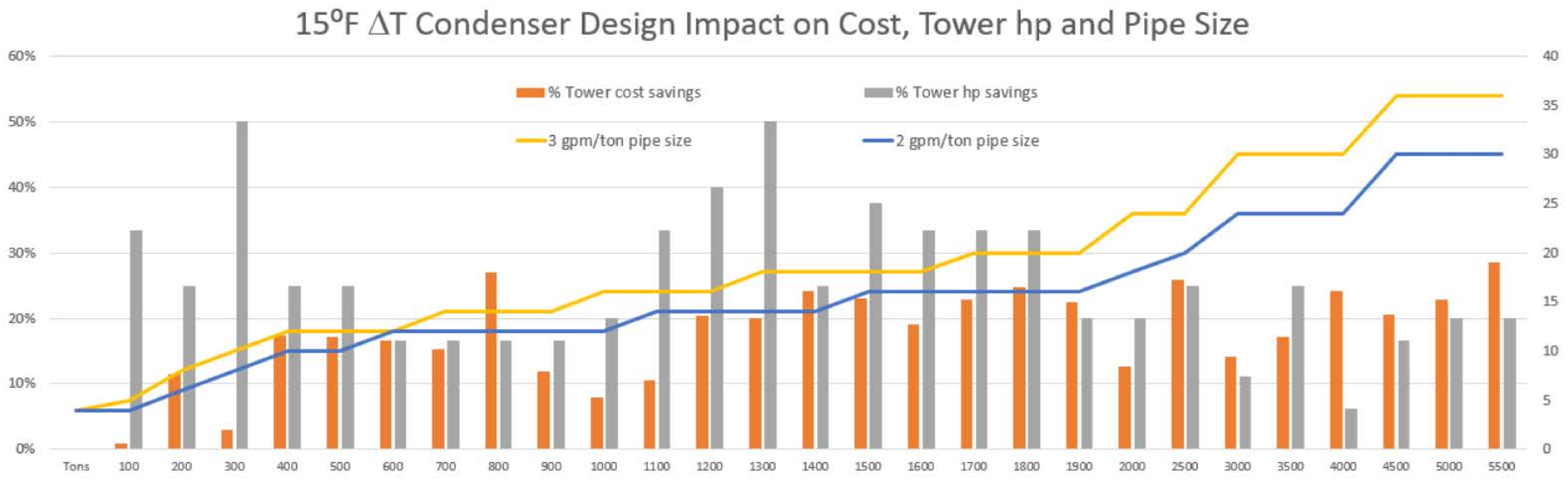
Going for Best Energy Efficiency?

entering water temp, °F	42	42	40
leaving water temp, °F	57	62	65
water ΔT, °F	15	20	25
tube diameter, in.	1/2	1/2	1/2
rows	6	8	8
fin density, fins/ft	124	114	135
fin design	high eff	high eff	high eff
turbulators	yes	yes	yes
water flow rate, gpm	40	30	24
water velocity, ft/sec	2.8	2.1	1.6
water pressure drop, ft. H_2O	11.1	8.4	5.8
air pressure drop, in. H_2O	0.71	0.88	0.92
cost of coil	base	base + 29%	base + 34%

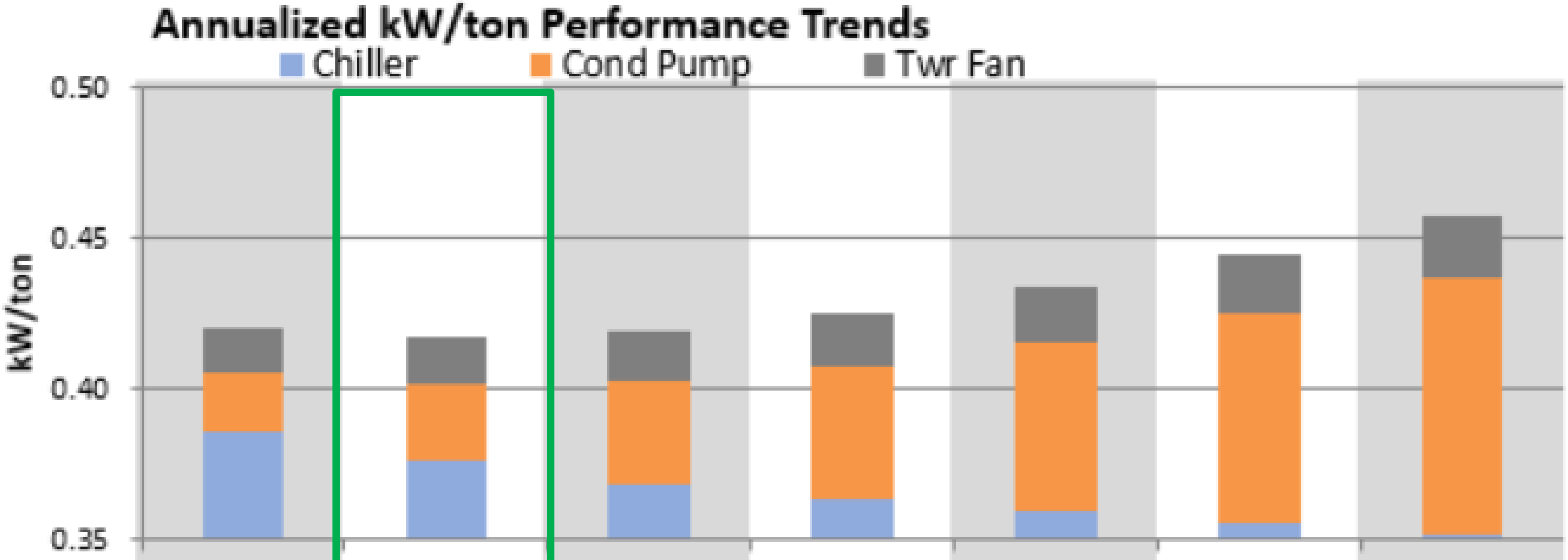
What Does High Delta T “Unlock”

- Heat recovery
  - Warmer return water lets us fully load the chillers = more free heat
- Series chillers
  - If we can’t get the DT we can’t load the chillers
- Longer economizer
  - Warmer return water temperature can be cooled by towers alone
- Chilled water storage
  - DT is the most critical factor in economics and operational success of chilled water storage
- Retrofits (pipes too small, expansion without more electrical, physical size)

15°F ΔT Works On Condenser Side Too – Cost



15°F ΔT For Tower and Chiller HX Too – Energy



Condenser (gpm/ton)	1.5	1.75	2	2.25	2.5	2.75	3
ualized Results							
Twr Fan (kW/ton)	0.0146	0.0158	0.0169	0.0177	0.0184	0.0192	0.0203
Cond Pump (kW/ton)	0.0196	0.0263	0.0346	0.0445	0.0562	0.0699	0.0858
Chiller (kW/ton)	0.3858	0.3755	0.3681	0.3628	0.3589	0.3556	0.3515
System (kW/ton)	0.4199	0.4177	0.4196	0.4251	0.4335	0.4448	0.4575
Savings	8.2%	8.7%	8.3%	7.1%	5.3%	2.8%	- -

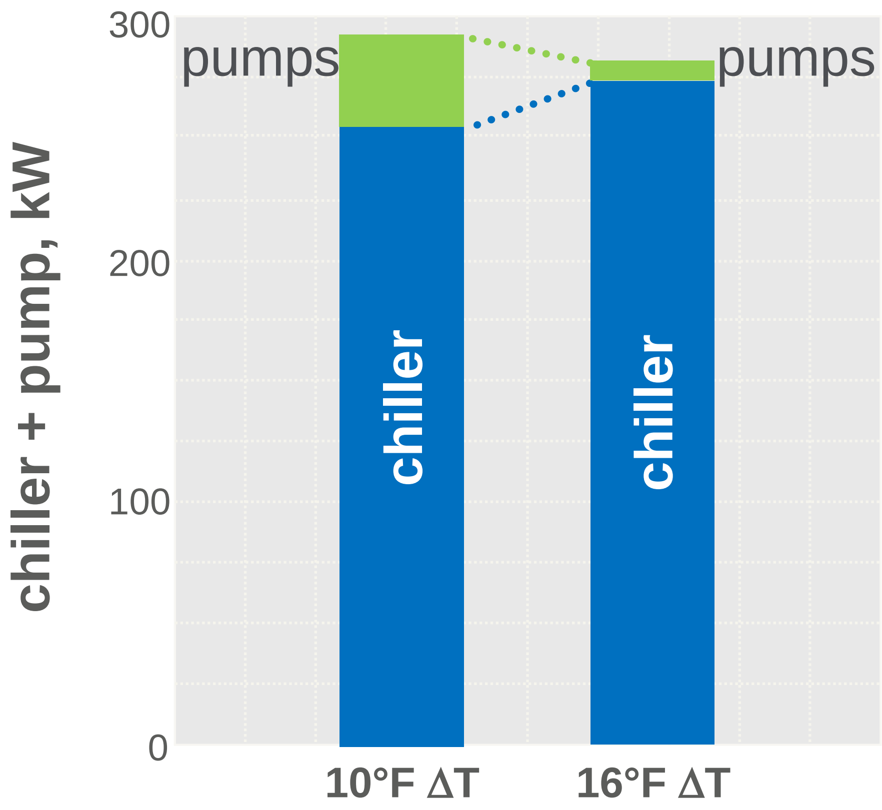
15°F ΔT For Tower and Chiller HX Too – Energy

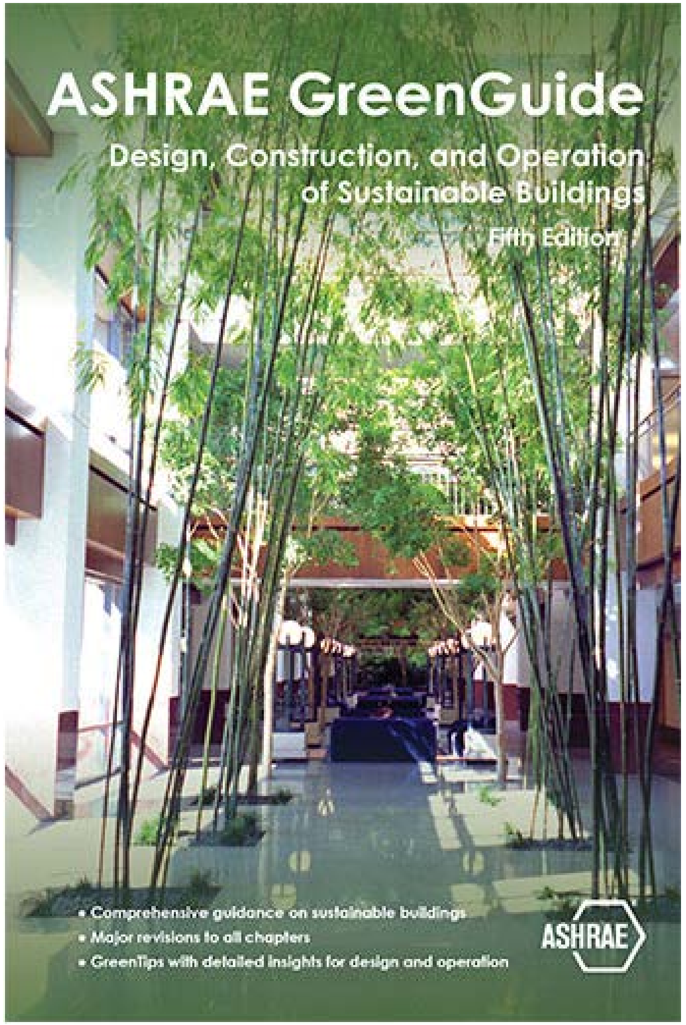
Controls are more persistent with low flow all the time

Annualized System Performance

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method
VS	VS	3	CF	85°F
VS	VS	3	CF	Opt
VS	VS	2	CF	Opt
VS	VS	3	VF	Opt

Higher ΔT Chilled Water Systems





Operation

Low Delta-T (High Flow) Syndrome

- Symptom of poor design and operation
- Excessive energy
  - Excessive pump energy
  - Excessive fan energy
  - Excessive chiller energy
- Decreased comfort
  - Degrades dehumidification and temperature control
- Decreased Capacity
  - Running out of chilled water capacity
  - “My Pipes Is Out of Tons”

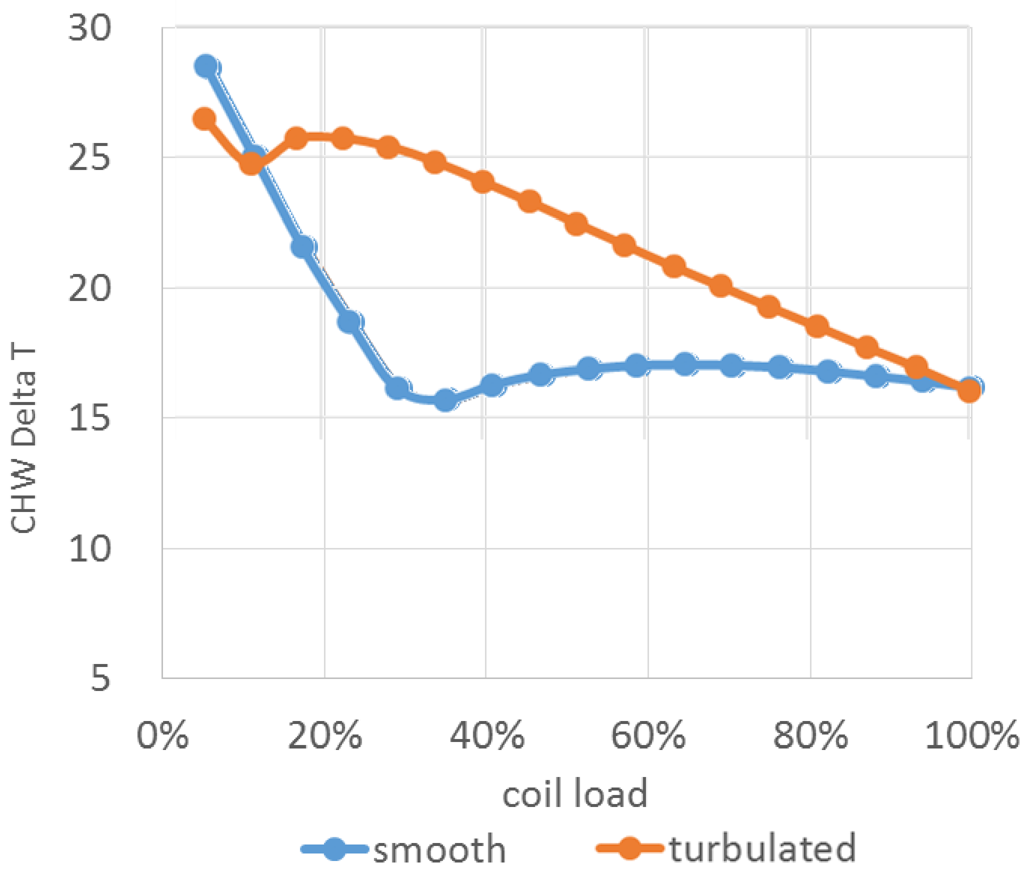
Why is Low Delta T Bad?

- 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

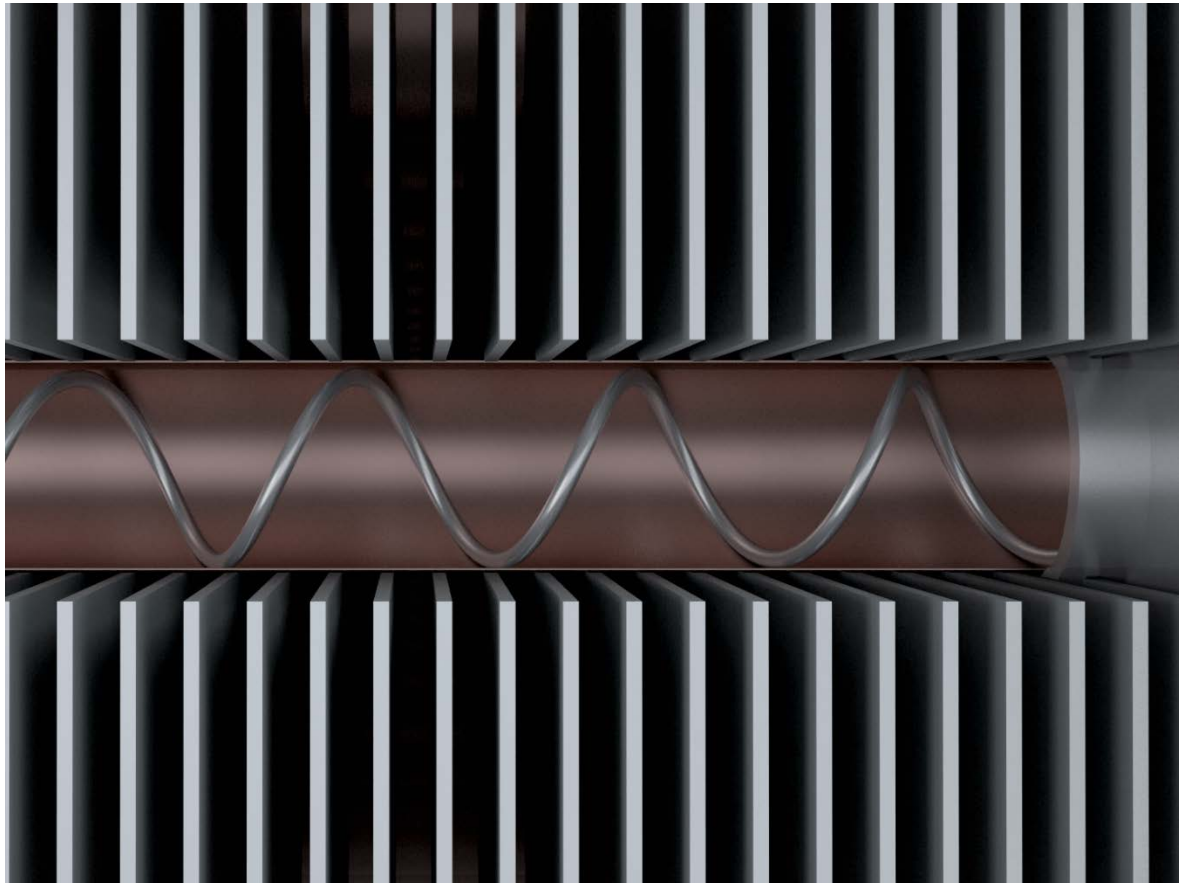
Yes BUT, Coil Delta T is lower at Part Load

Is it physics or is it something else?

- AHRI Certified Coil
- Air Flow (VAV) unloading



Turbulators Help Maintain ΔT at Reduced Flows

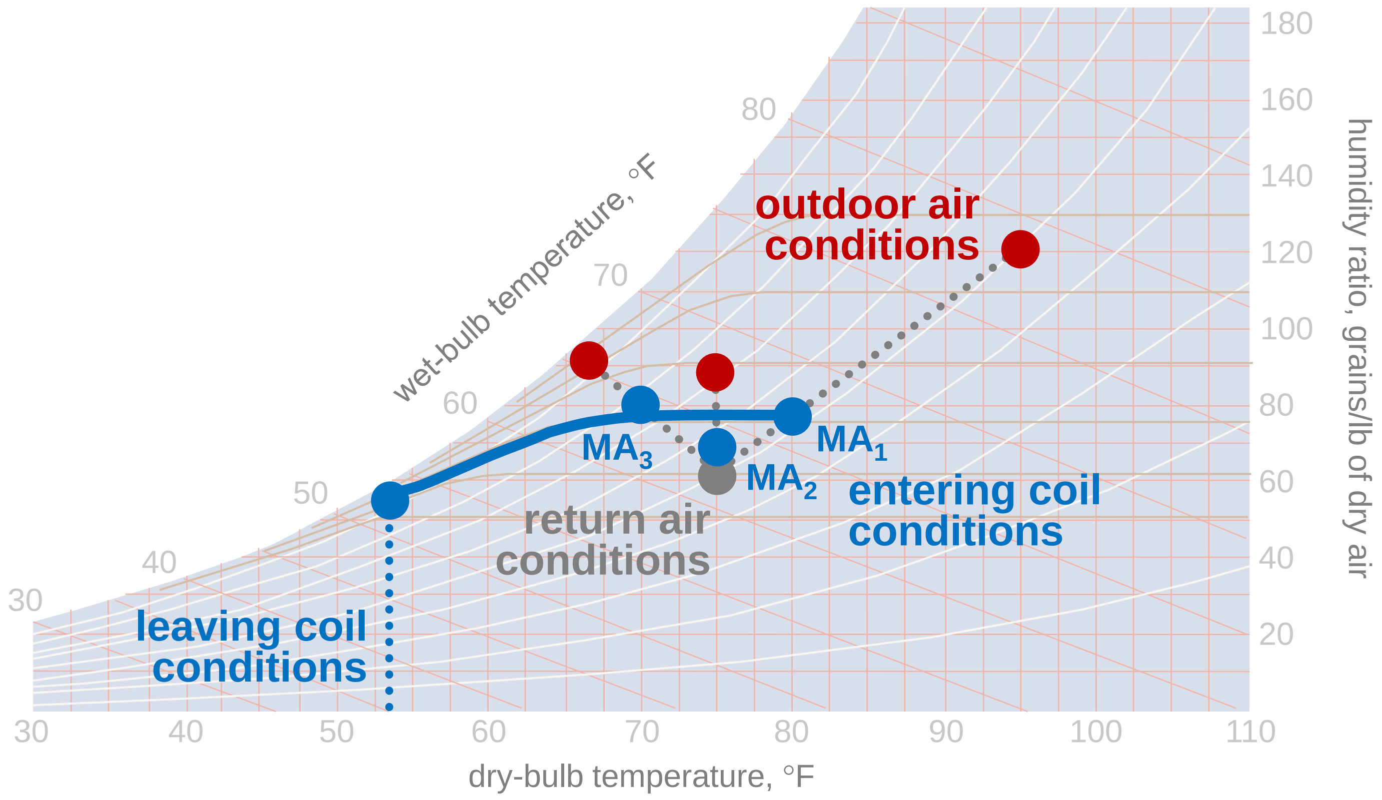


Turbulators...

- Increase fluid turbulence, which improves heat transfer
- Allows coil to provide required capacity with a lower GPM

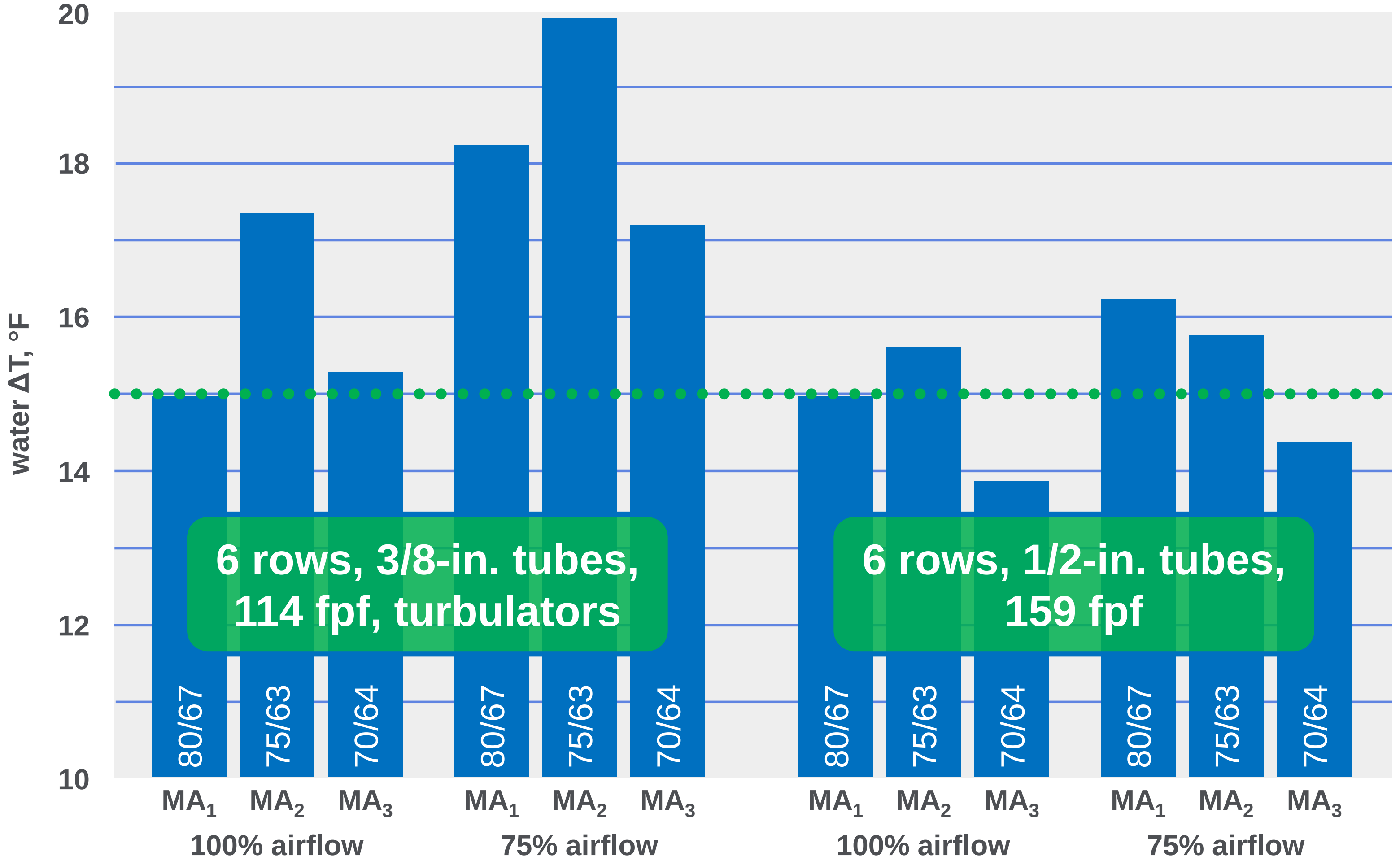
Coil Conditions Change @ Part Load

Impact of Entering Air Temps, Lower Airflow on ΔT



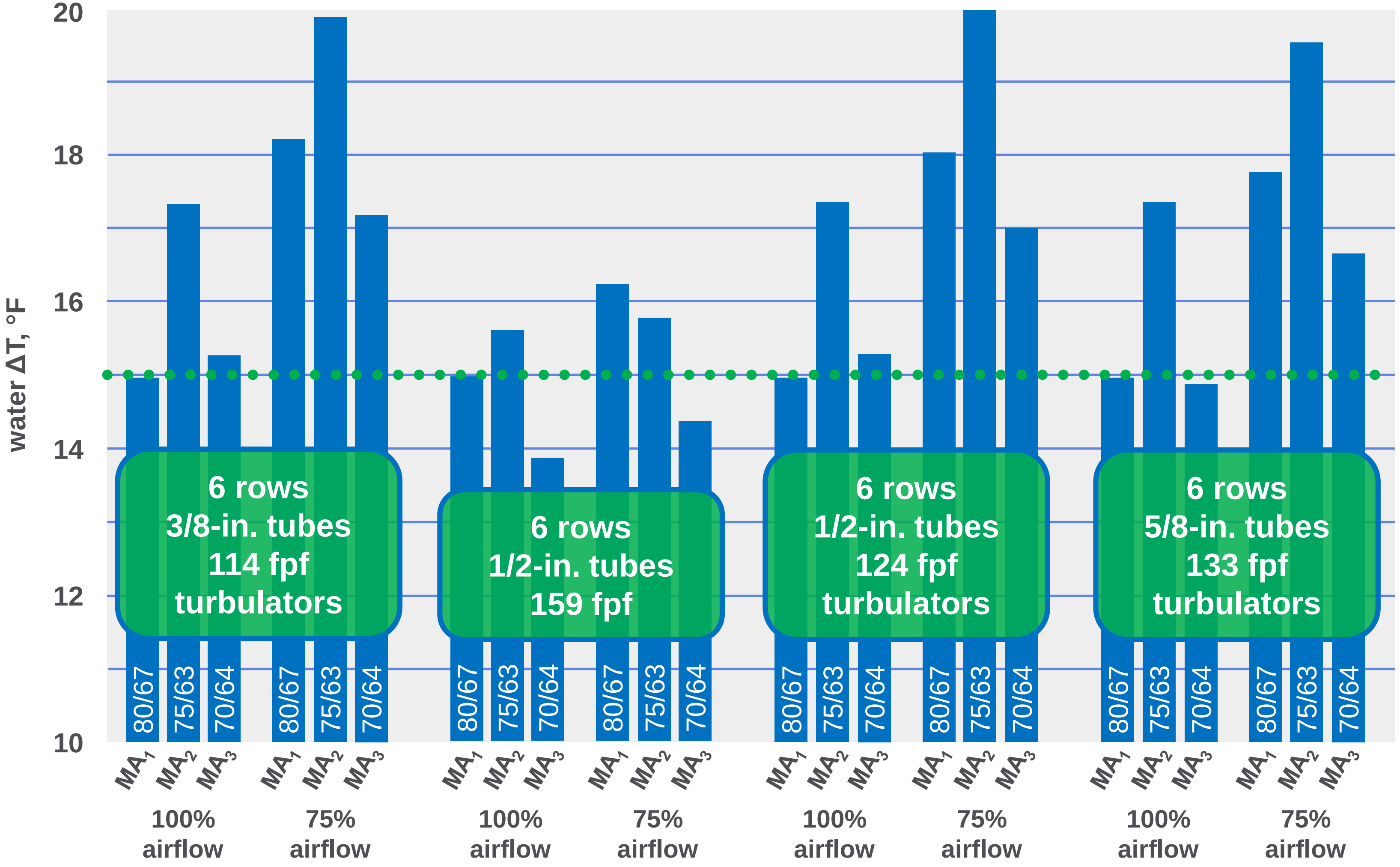
Coil Conditions Change @ Part Load

Impact of Entering Air Temps, Lower Airflow on ΔT



Coil Conditions Change @ Part Load

Impact of Entering Air Temps, Lower Airflow on ΔT



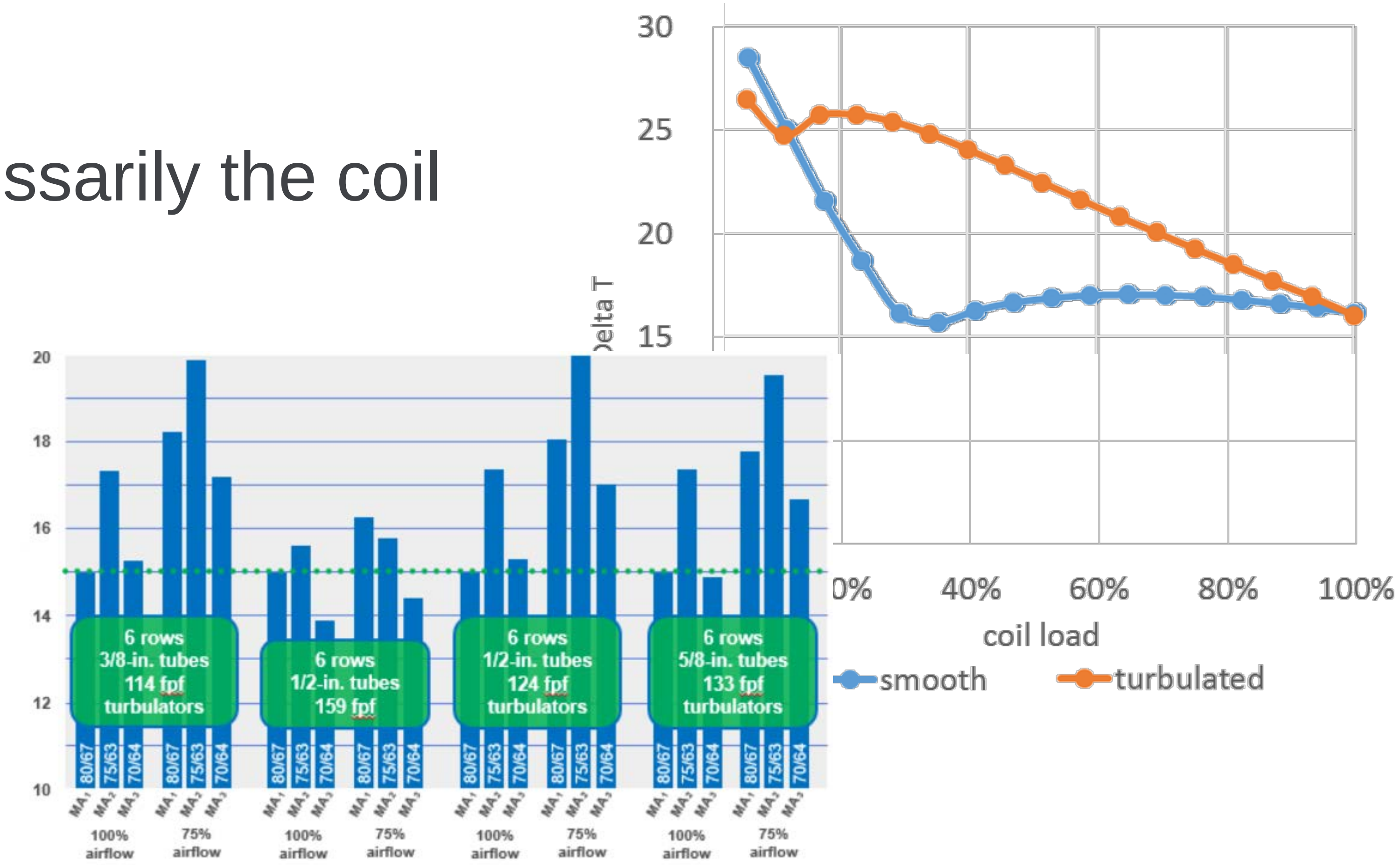
Coil Selection Cost, Fan and Pump Energy

entering water temp, °F	42	42	42	42
leaving water temp, °F	57	57	57	57
water ΔT, °F	15	15	15	15
tube diameter, in.	3/8	1/2	1/2	5/8
rows	6	6	6	6
fin density, fins/ft	114	159	124	133
fin design	high cap	high cap	high eff	high eff
turbulators	yes	no	yes	yes
water flow rate, gpm	40	40	40	40
water velocity, ft/sec	2.7	2.8	2.8	2.1
water pressure drop, ft. H_2O	11.2	4.7	11.1	5.2
air pressure drop, in. H_2O	0.81	0.95	0.71	0.71
cost of coil	base - 30%	base	base + 8%	base + 15%

So WHY, is System Delta T Low?

Is it physics or is it something else?

It’s not necessarily the coil

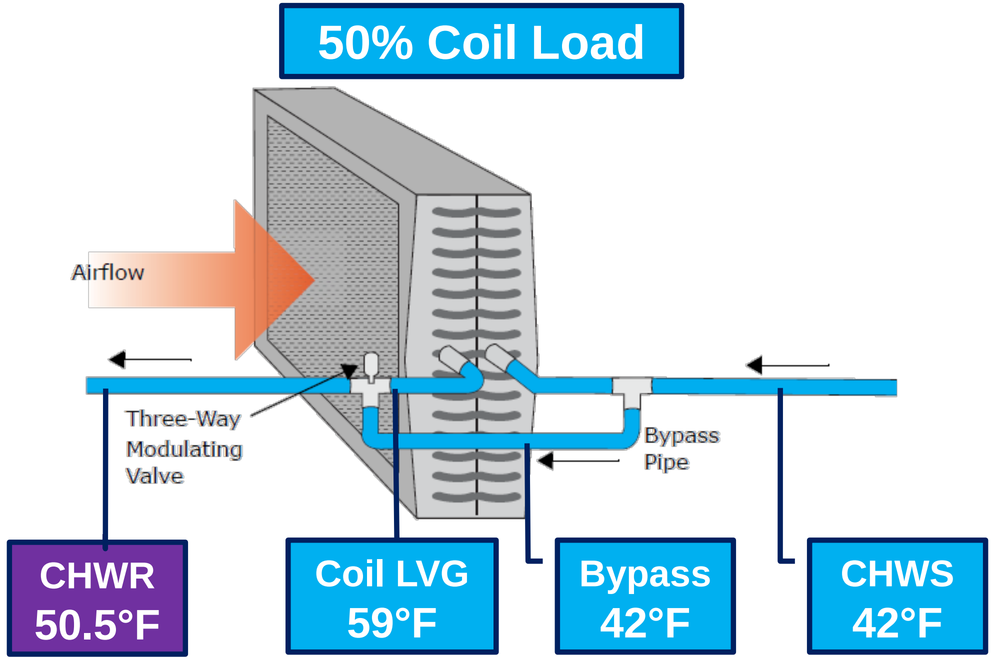


Reason 1: 3-Way control valves

undesirable mixing in variable flow systems

- *Eliminate them!*

Coil Delta T = 17°F
System Delta T = 8.5°F



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

Reason 2: Supply air setpoint depression

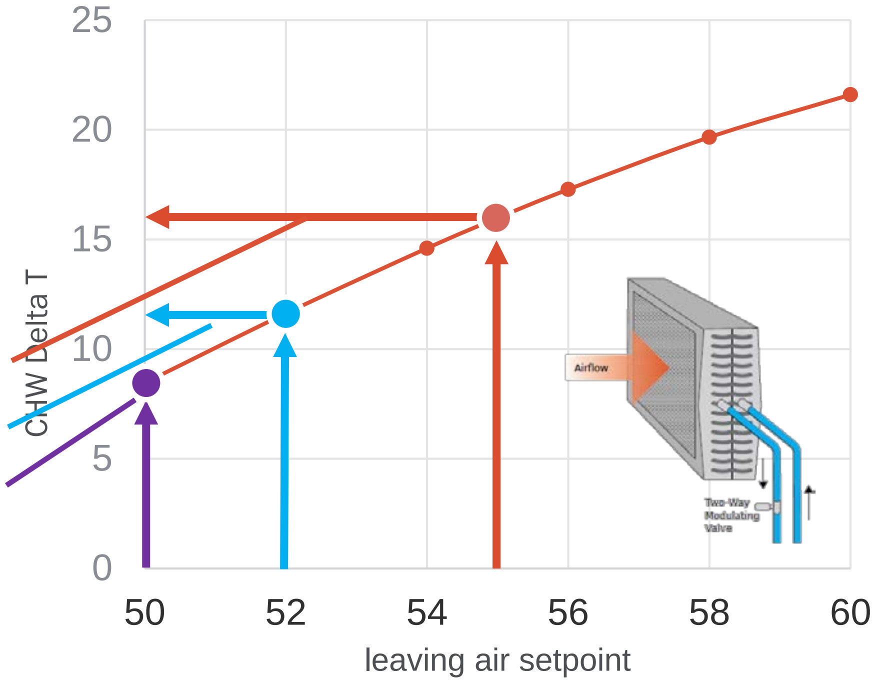
overdriving coil capacity

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

55° LAT = 16° DT = 1.5 gpm/ton

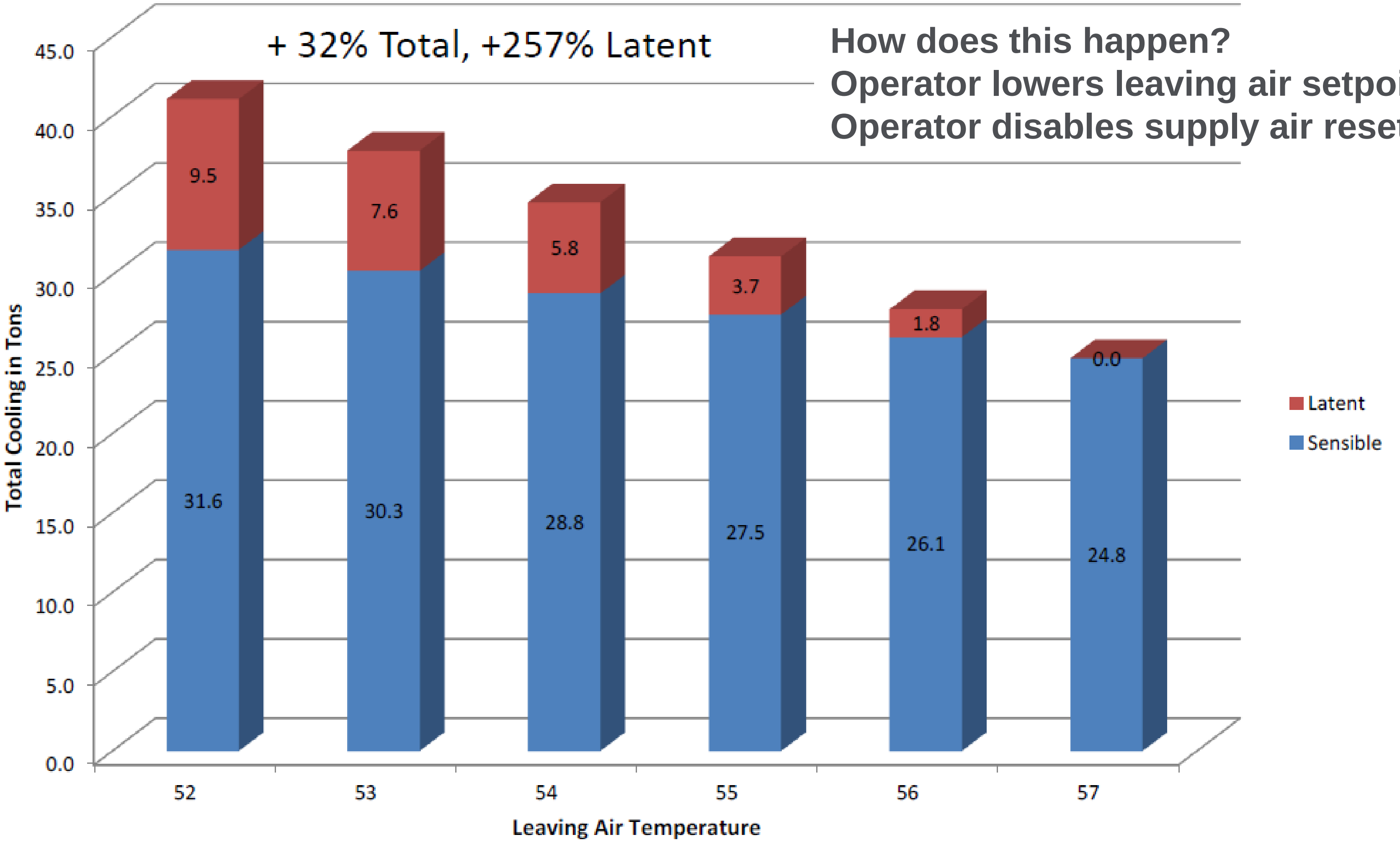
52° LAT = 11° DT = 2.2 gpm/ton

50° LAT = 8.5°DT = 2.8 gpm/ton



Overdriving Coil Capacity

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



Reason 3: Warmer chilled water supply

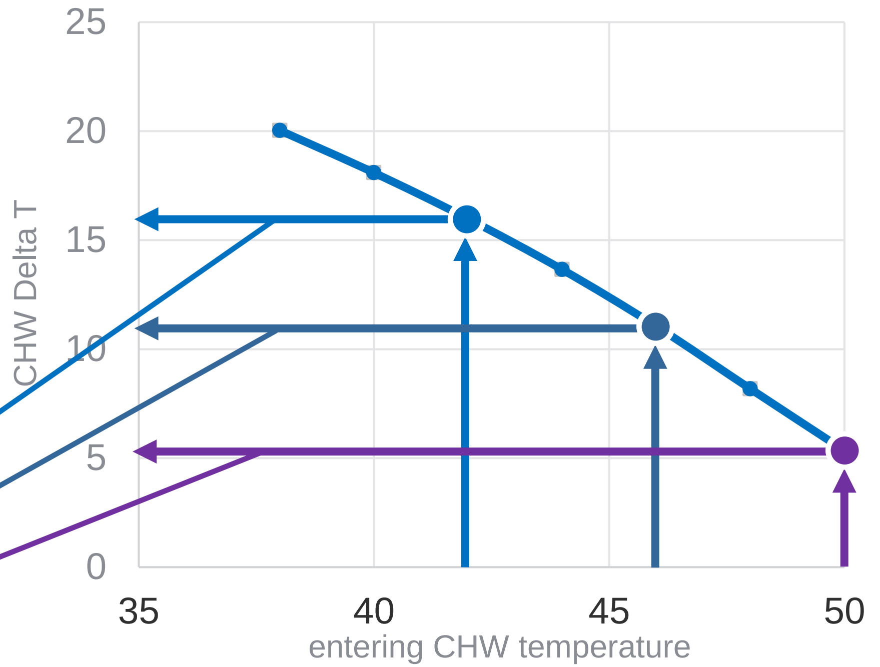
reduced heat transfer driving force "LMTD"

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



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

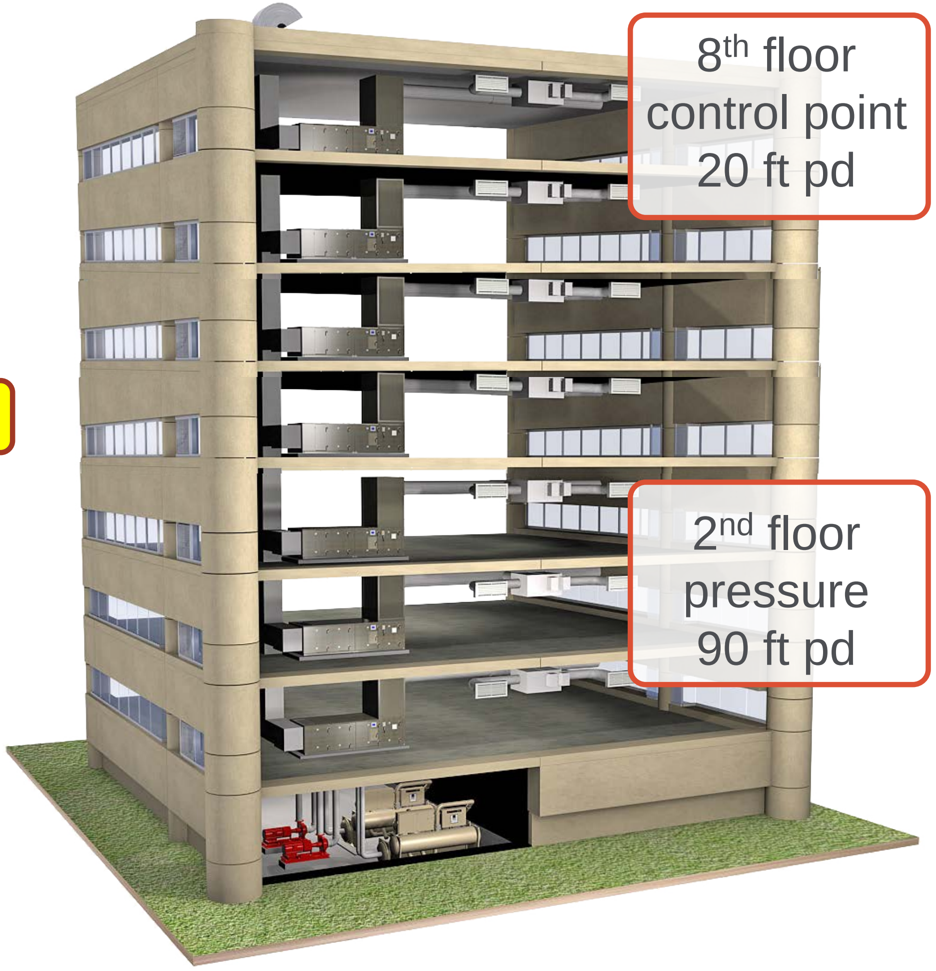
Control Valve Issues

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

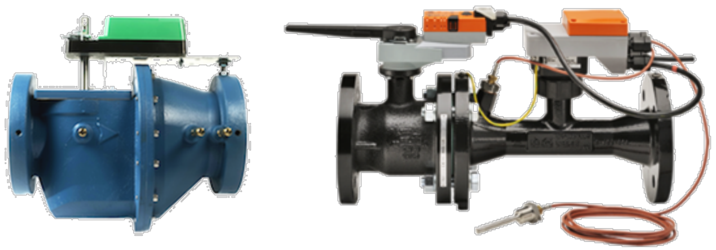
poor flow control

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

Pressure independent valves? (PICV)

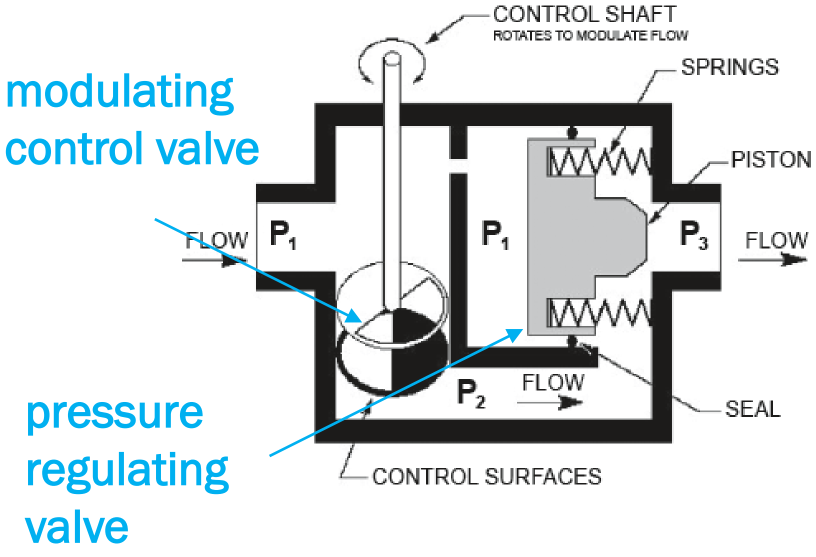
- Not always required
- Reverse return piping can help
- Cures many problems

1. Mechanical
2. Electronic



Pressure Independent Control Valves

mechanical PI valve



electronic PI valve

½" - 2"

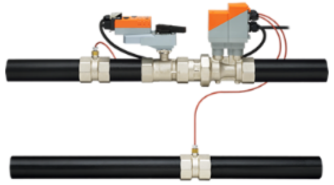
1.65 -100 GPM

2½" - 6"

80-713 GPM

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

PIC Valves



Mechanical

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

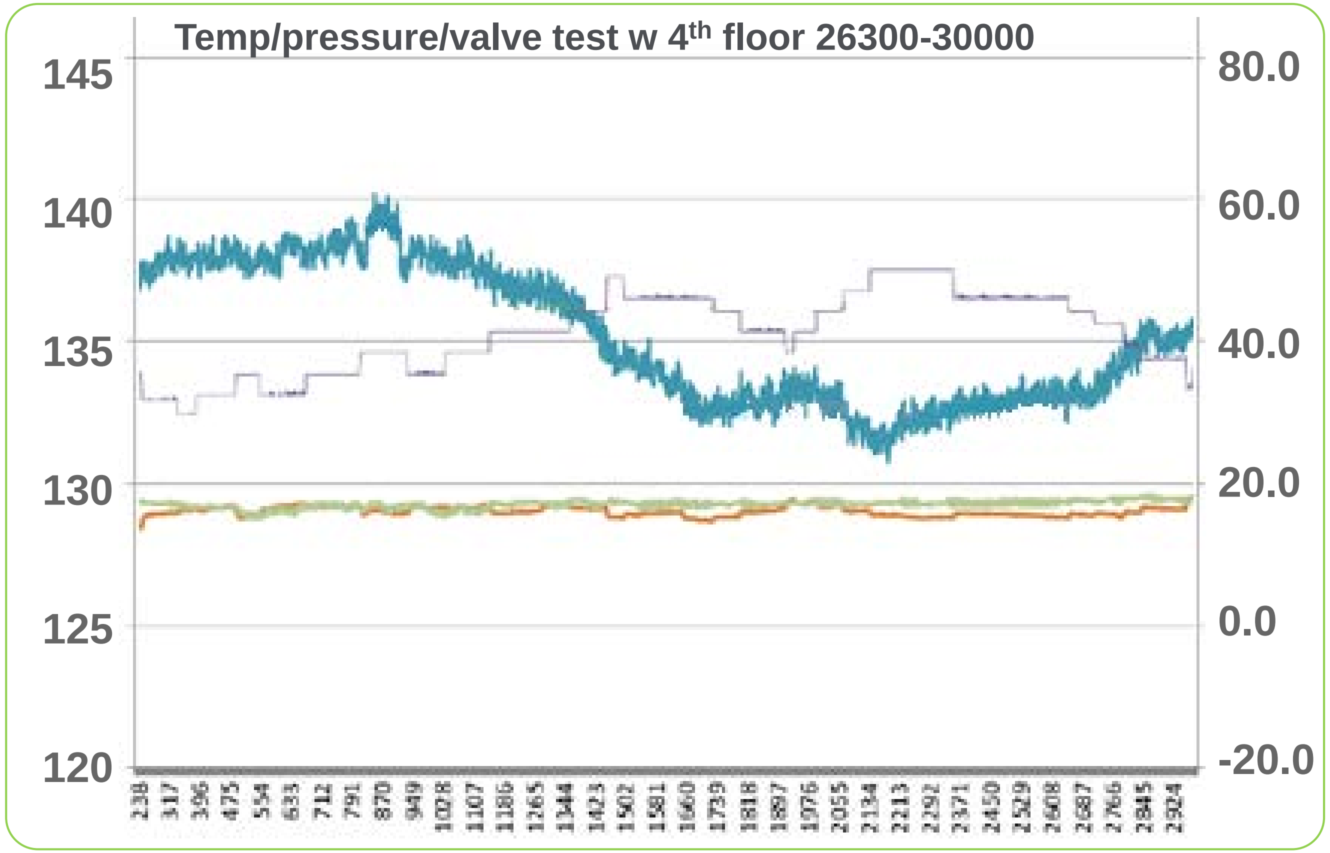
Electronic

- 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)

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

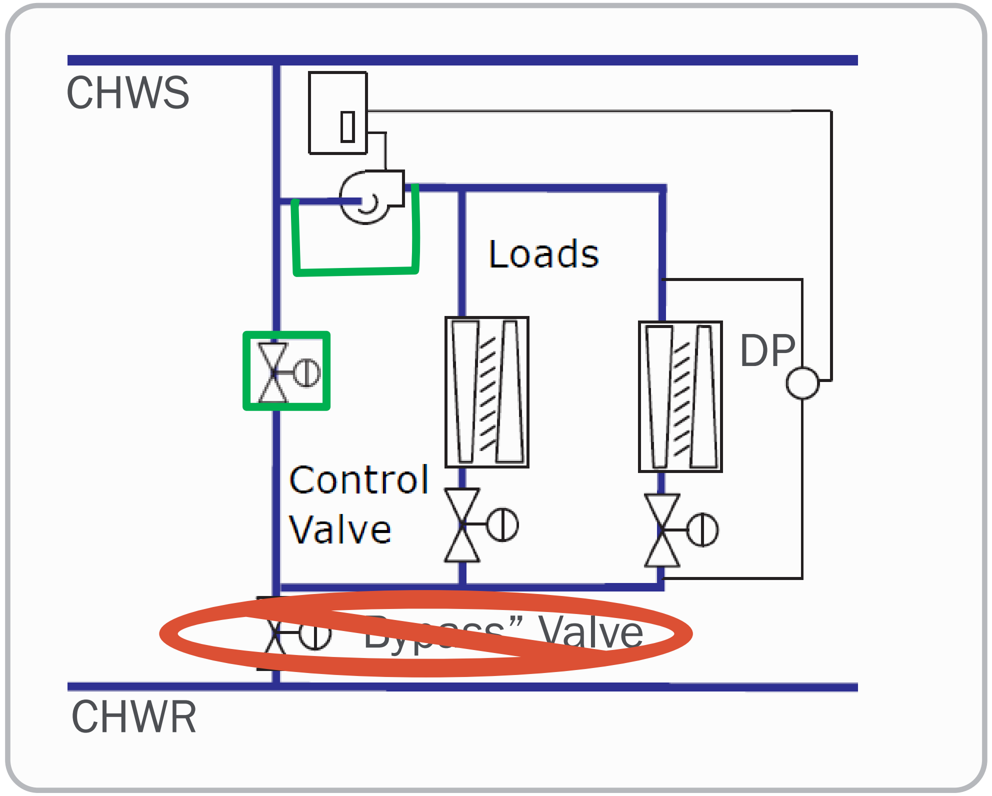
Reason 5: Tertiary pumping

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 from the return, simply boost pressure

- *Move bypass valve*
- *Bypass the pump (only use when needed)*



Why is Low Delta-T Bad?

Energy

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

Capacity

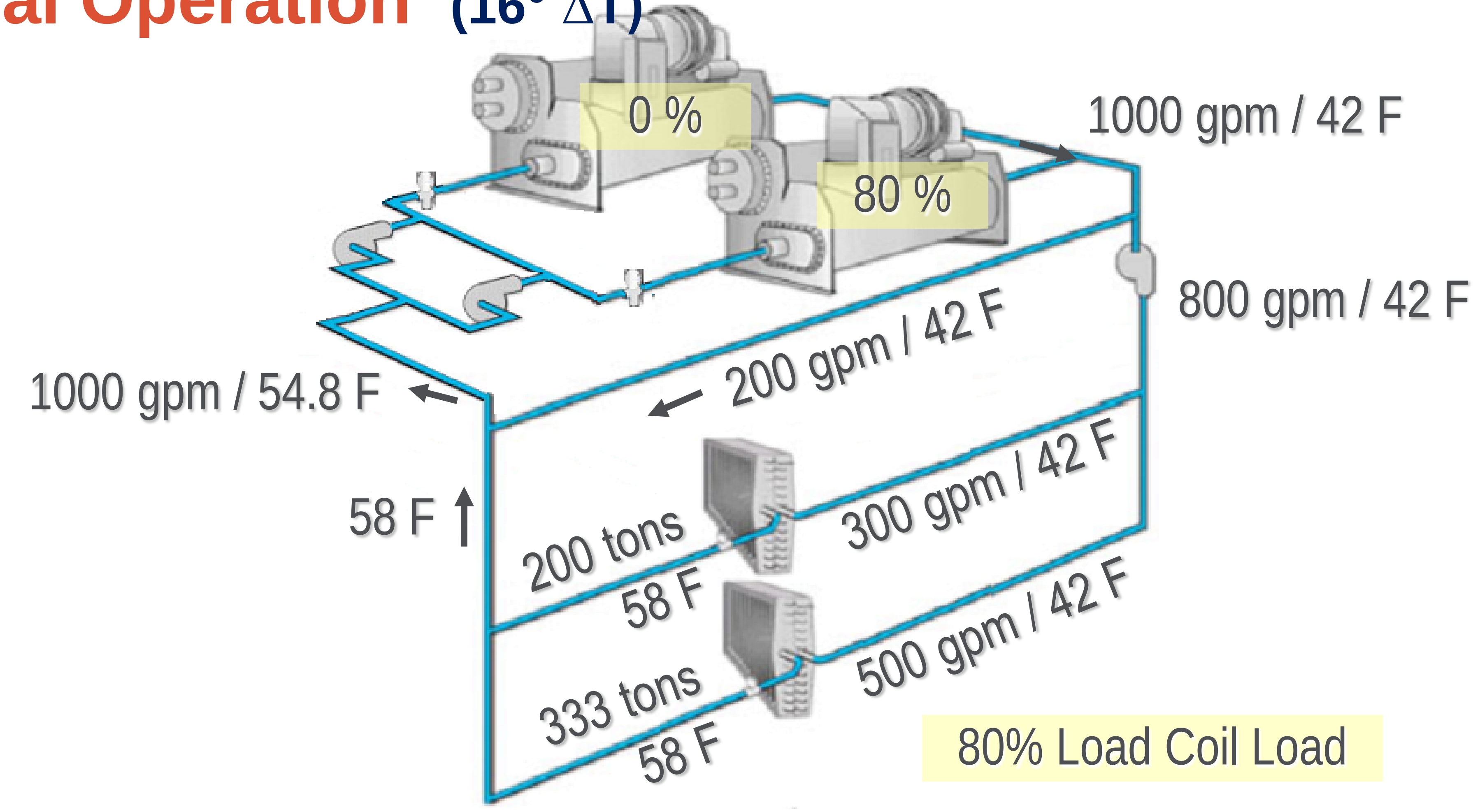
- Running out of distribution capacity
- Chiller won’t load

Leads to overrides/manual operation

Meanwhile in the Chiller Plant

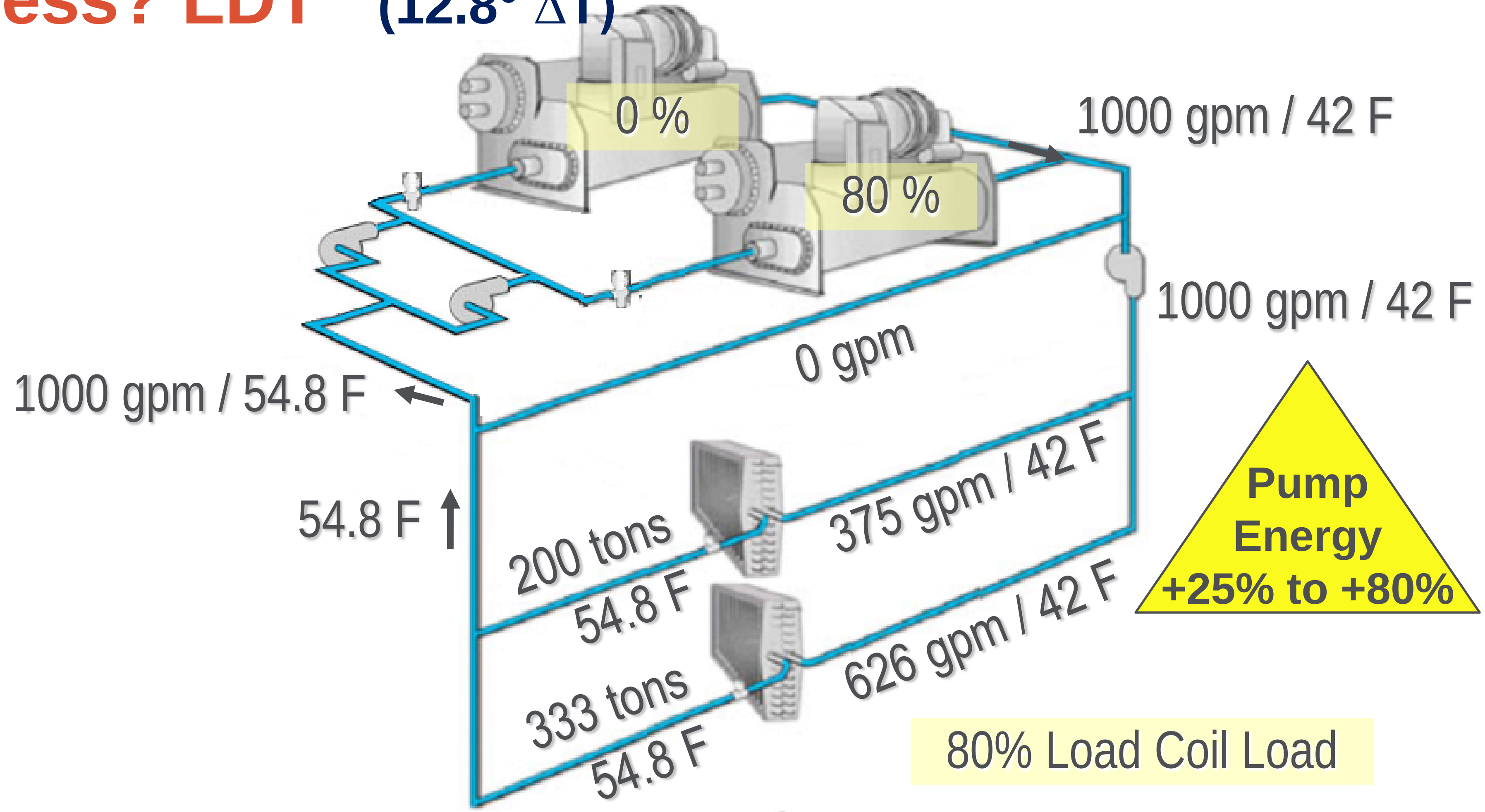
Why is Low Delta T Bad for the chiller plant?

Normal Operation (16° ΔT)



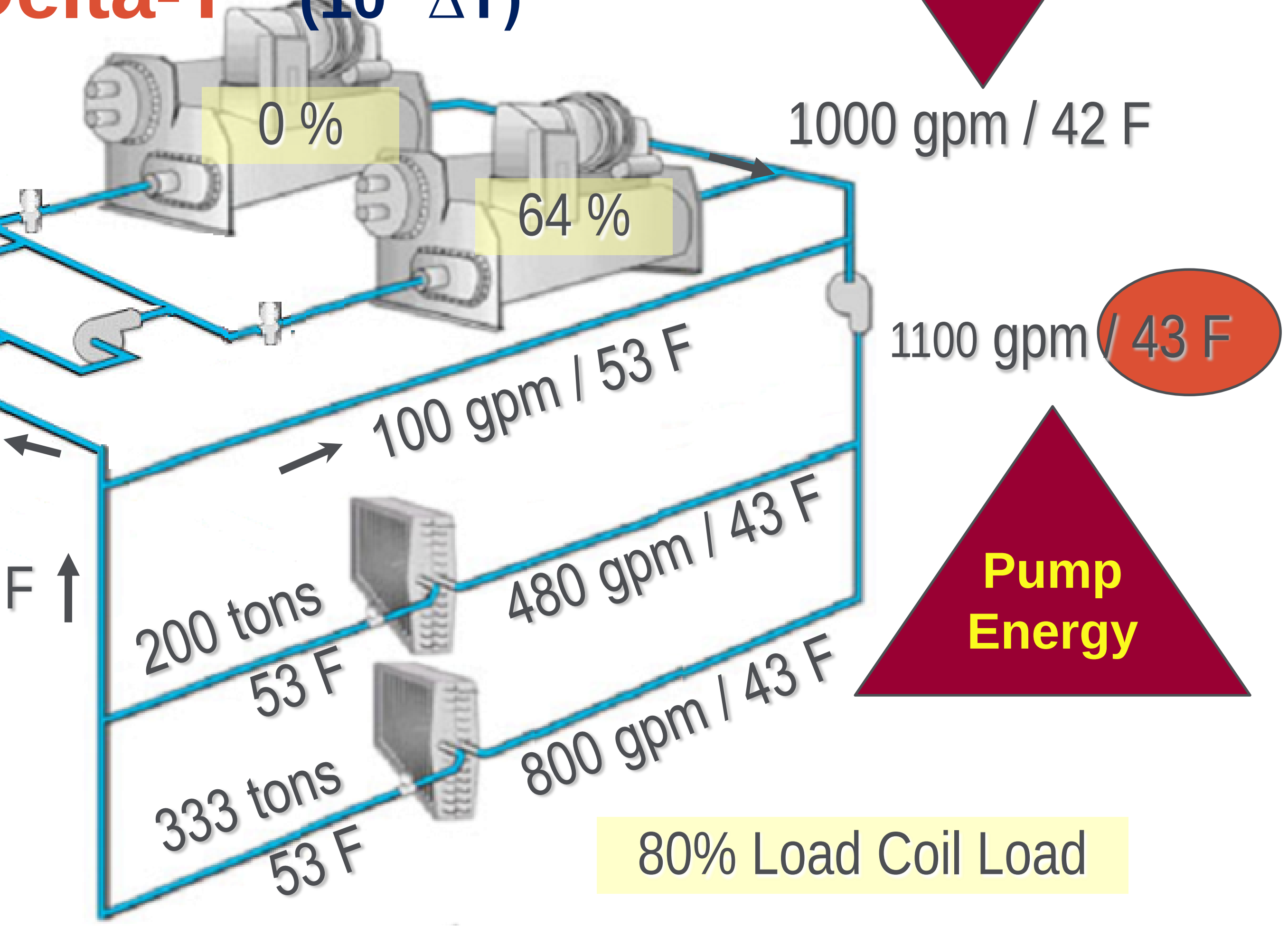
Why is Low Delta T Bad for the chiller plant?

Harmless? LDT (12.8° ΔT)



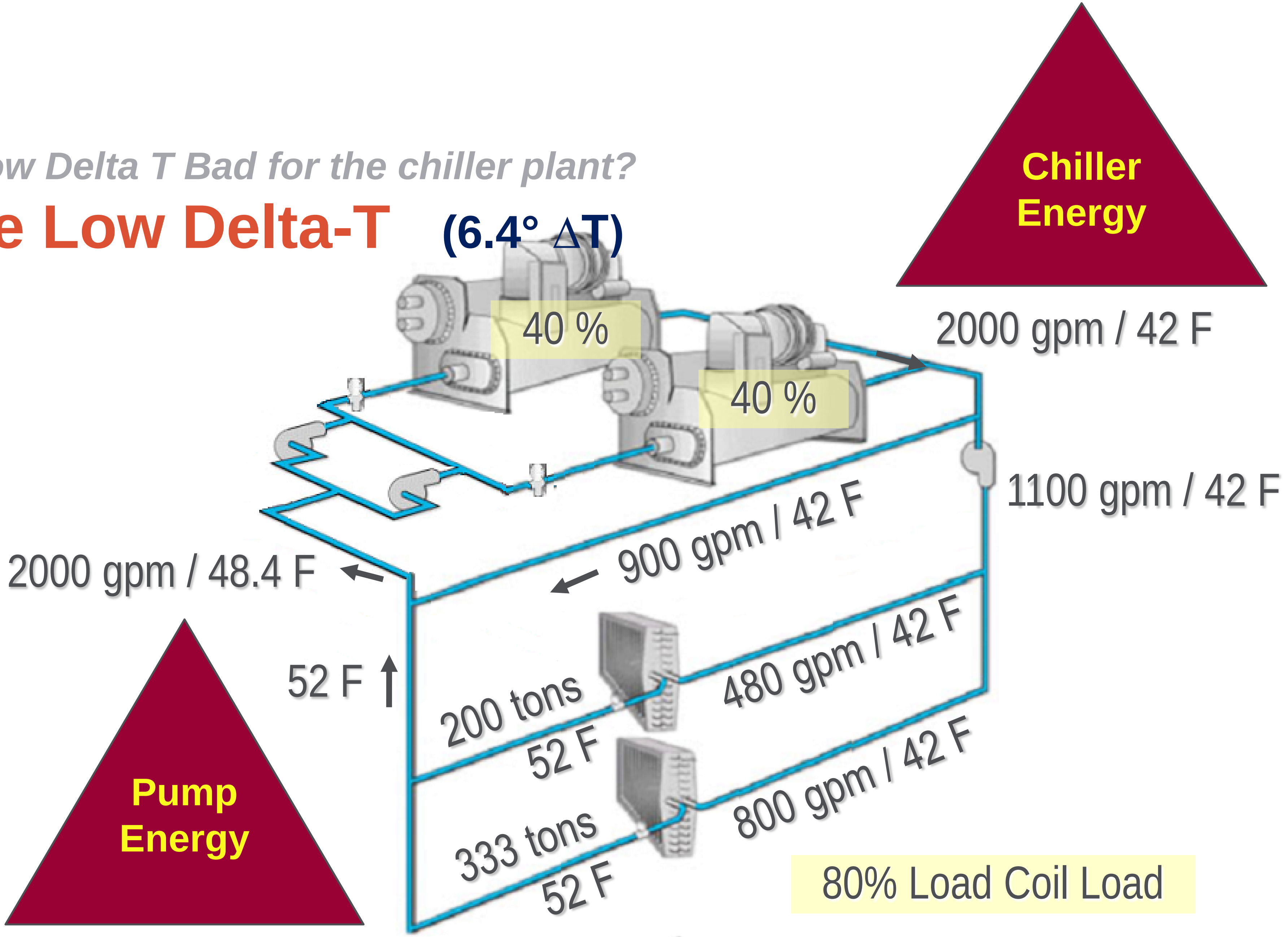
Why is Low Delta T Bad for the chiller plant?

Moderately Low Delta-T (10° ΔT)



Why is Low Delta T Bad for the chiller plant?

Severe Low Delta-T (6.4° ΔT)



Some Causes of Low Delta T

Flow Control

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

Load

- Oversized 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

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

FIX THE THINGS OUTSIDE THE PLANT

Low Delta-T Syndrome

Some Band-Aids...

- Lower the chiller’s setpoint
  - Existing chiller maybe can – new chiller certainly can
  - Purchase new chillers that can work at harder than design conditions – also helps avoid surge and prepare for climate change
- Open the chiller balancing valves to allow more, “constant” flow to the chillers
- Convert to Variable Primary Flow
  - From constant flow this will be replacing valves
- Convert to Variable Primary / Variable Secondary
  - From primary-secondary flow this will be adding drives and maybe new pumps

Summary

- Most energy can be saved in operation
  - All systems require attention to maintain peak performance
- Bake high efficiency into the design
  - Pick the right heat exchangers (coils, chillers, towers) with high ΔT
  - Use PIC valves
  - Get extra chiller ‘lift’ capability rather than excessive spare tons
- Harvest more data and turn it into intelligence
  - Find and remove overrides that are unhelpful
  - Trend and review at regular intervals

Questions...