



# Chilled Water Plants; Basic Principles, Ongoing Commissioning/Operation, and Optimization

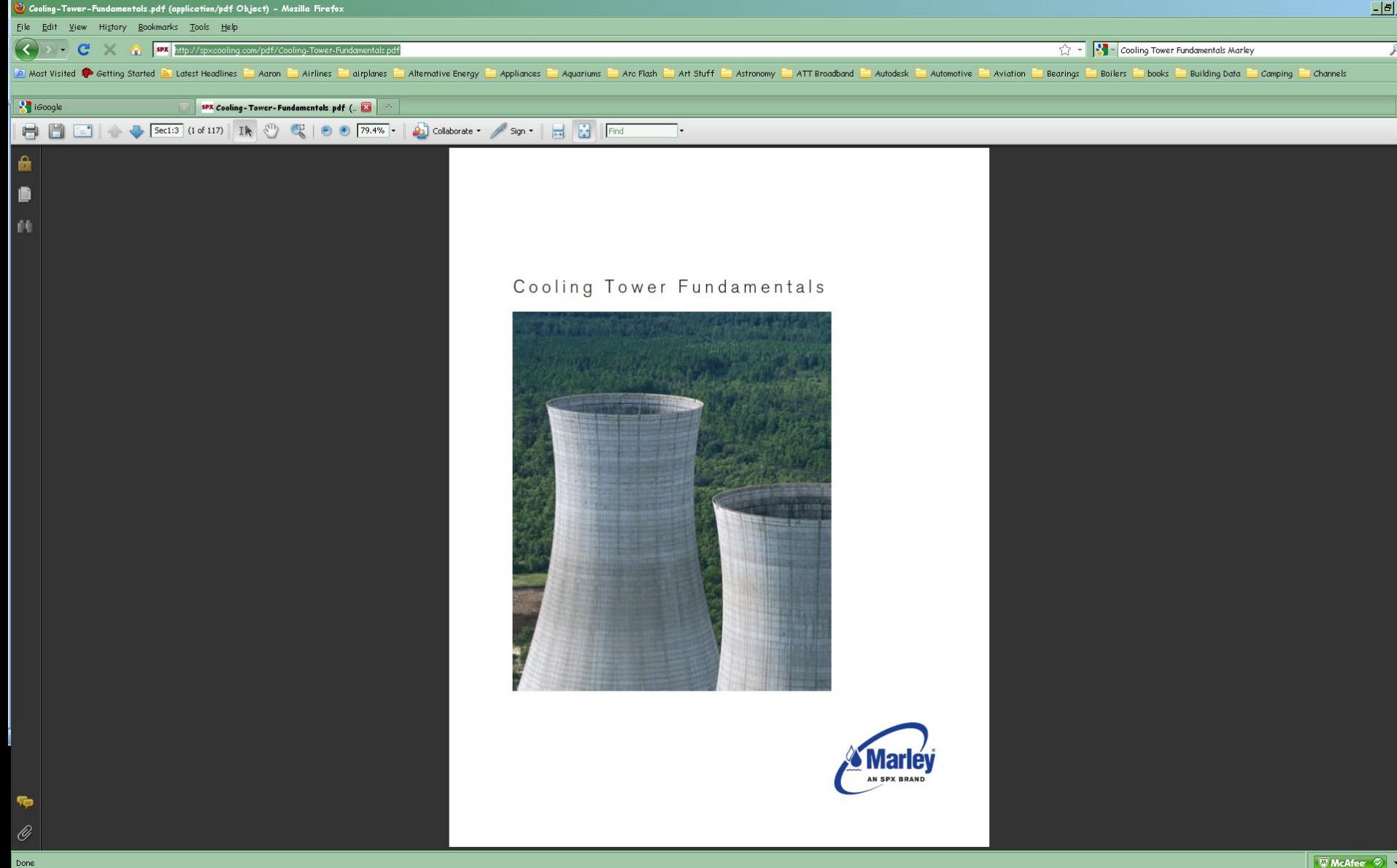
## Cooling Towers



Presented By:  
David Sellers  
Senior Engineer, Facility Dynamics Engineering

# Air Cooled Condensers



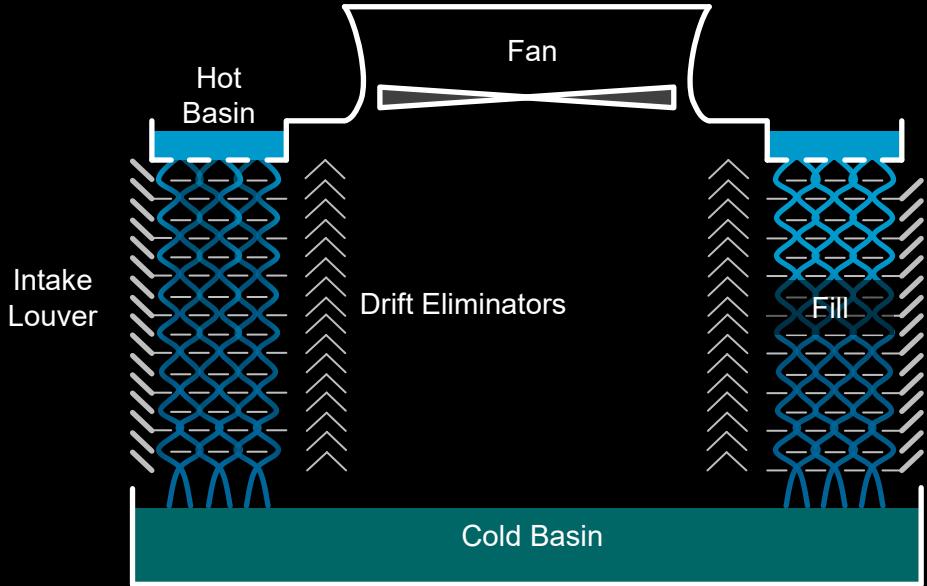


A Free Cooling Tower Resource  
<https://tinyurl.com/CoolingTowerFundamentals>

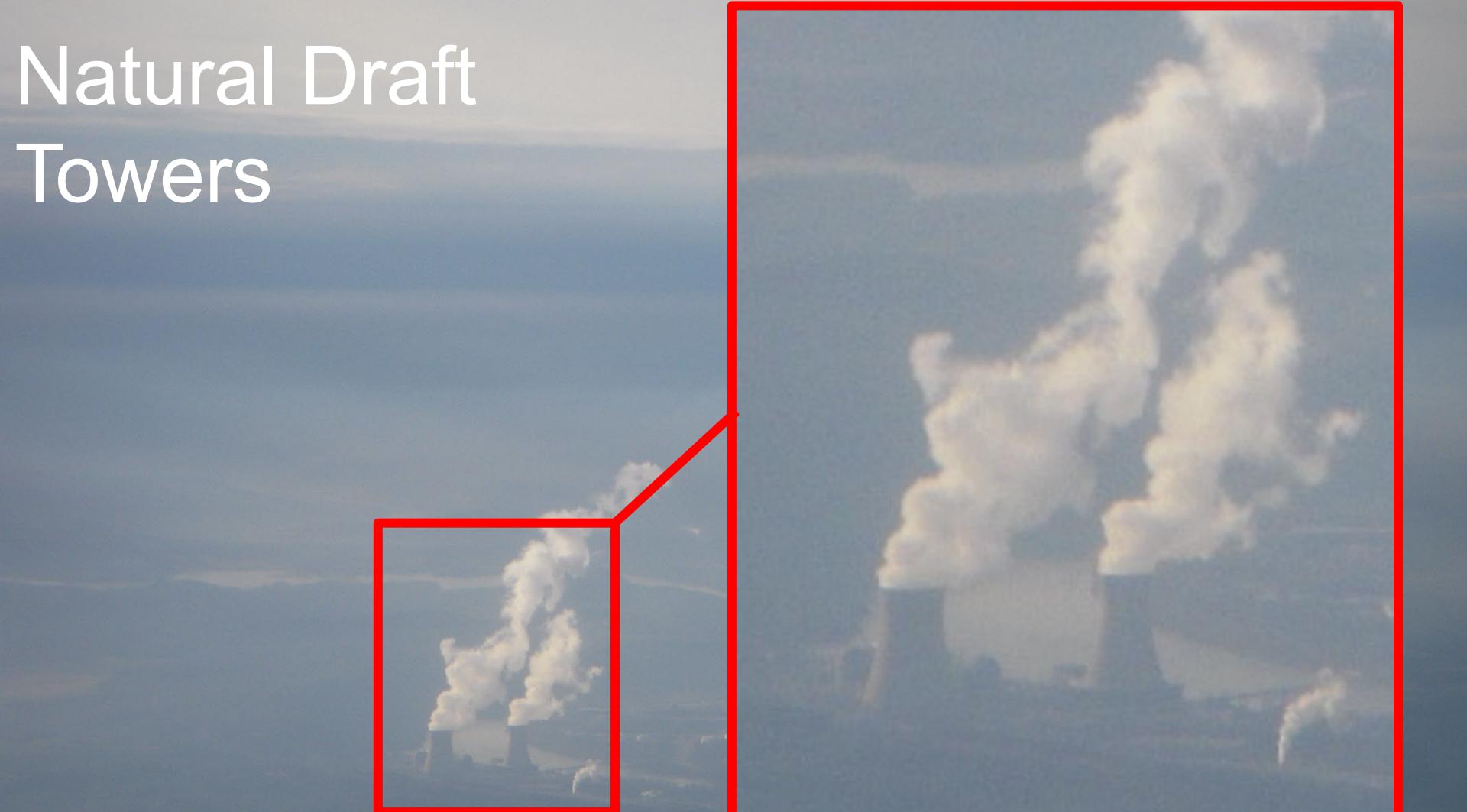


# Cooling Towers

- An optimized evaporative cooling system
  - Maximize contact between air and water
  - 15°F approach to ambient wet bulb is standard
  - Approach less than 5°F starts to become impractical
- Multiple types
  - Cross flow
  - Counter flow
  - Natural draft
  - Induced draft
  - Forced draft
  - Hybrid
- Water quality issues
  - Equipment life
  - Human life



# Natural Draft Towers



- No fans; operate on density difference like a chimney
- Not common for HVAC
- Typically found on large power plants

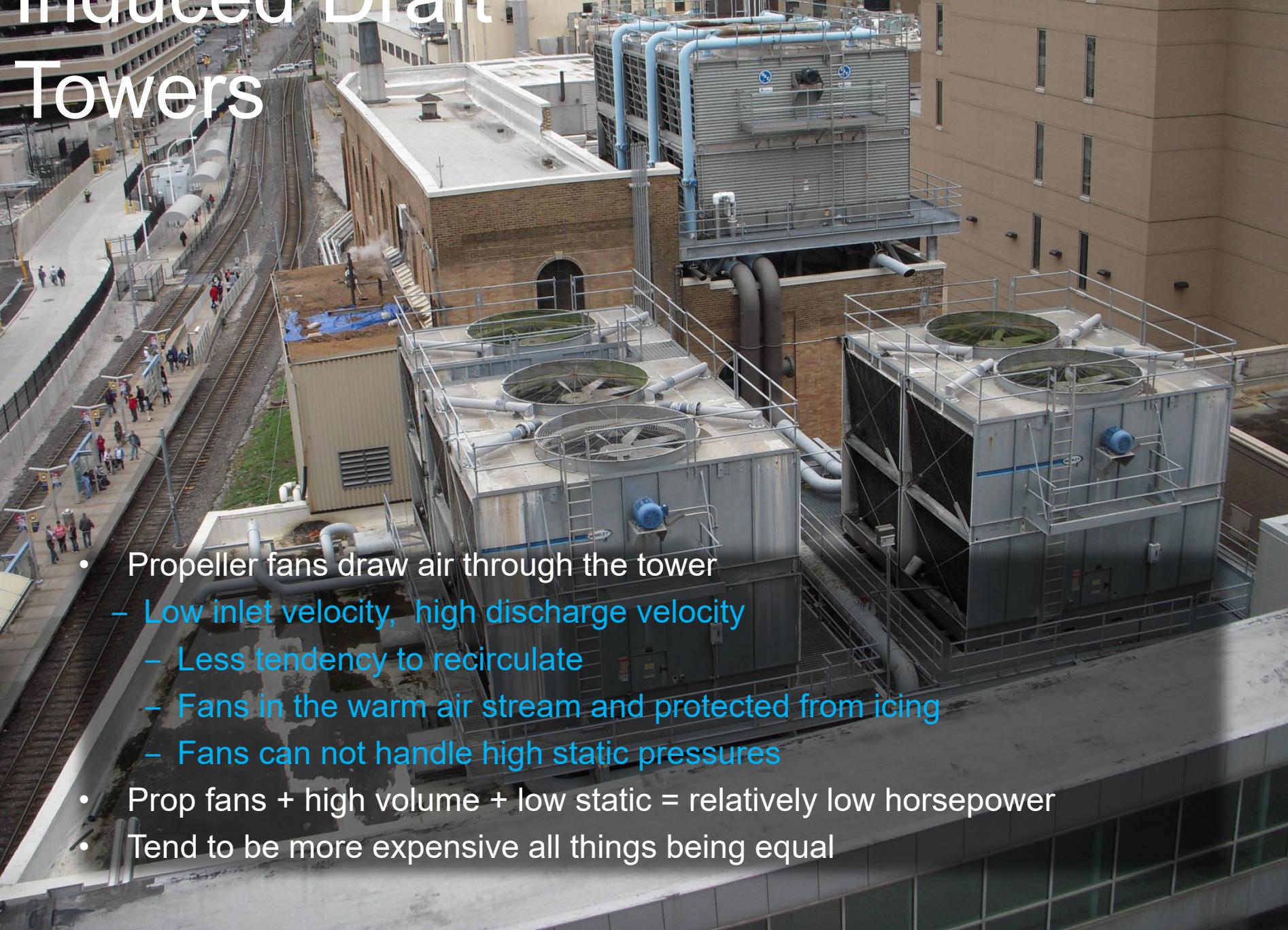
# Forced Draft Towers



- Centrifugal fans blow air through the tower
  - High inlet velocity, low discharge velocity
  - Tendency to recirculate
  - Fans in the cold air stream and can ice up
  - Fans can handle higher static pressures
- Poor fan inlet and discharge conditions mean relatively high horsepower
- Tend to be less expensive all things being equal



# Induced Draft Towers



- Propeller fans draw air through the tower
  - Low inlet velocity, high discharge velocity
  - Less tendency to recirculate
  - Fans in the warm air stream and protected from icing
  - Fans can not handle high static pressures
- Prop fans + high volume + low static = relatively low horsepower
- Tend to be more expensive all things being equal

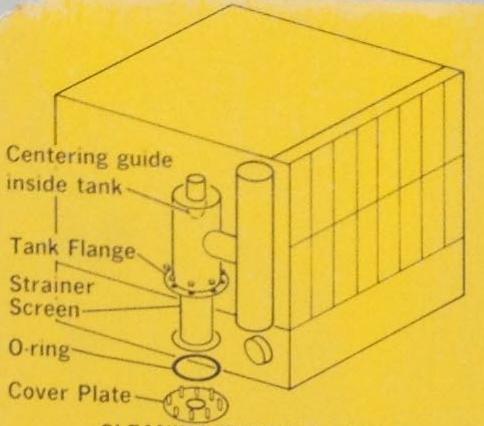
# A Hybrid Cooling Tower



# An Unusual Induced Draft Tower

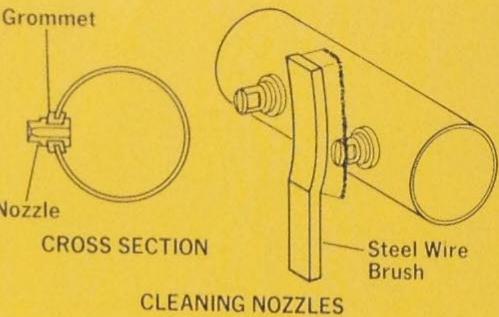






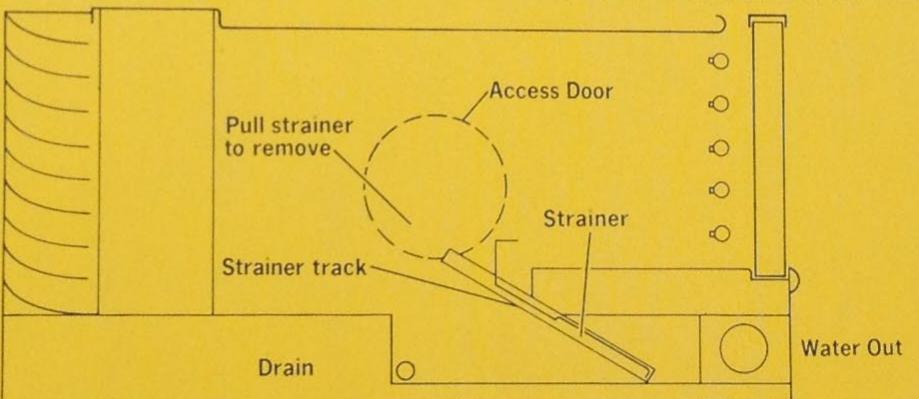
#### CLEANING THE FINAL STRAINER

1. Remove nuts holding cover plate. As cover plate is lowered, strainer screen will drop down with it.
2. Clean strainer using water spray or wire brush.
3. Slide strainer part way into tank body. Bring up cover plate with O-ring just inside bolt circle. Keeping all parts aligned, lift assembly up to tank flange. Install washers and nuts, tightening evenly.



#### CLEANING NOZZLES

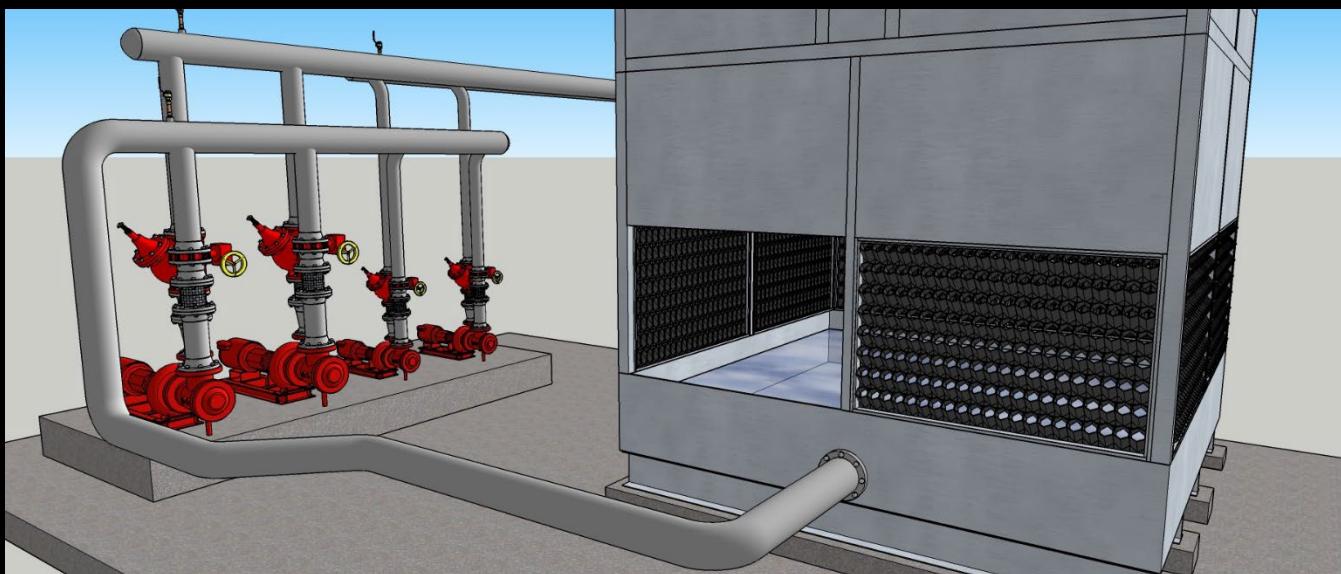
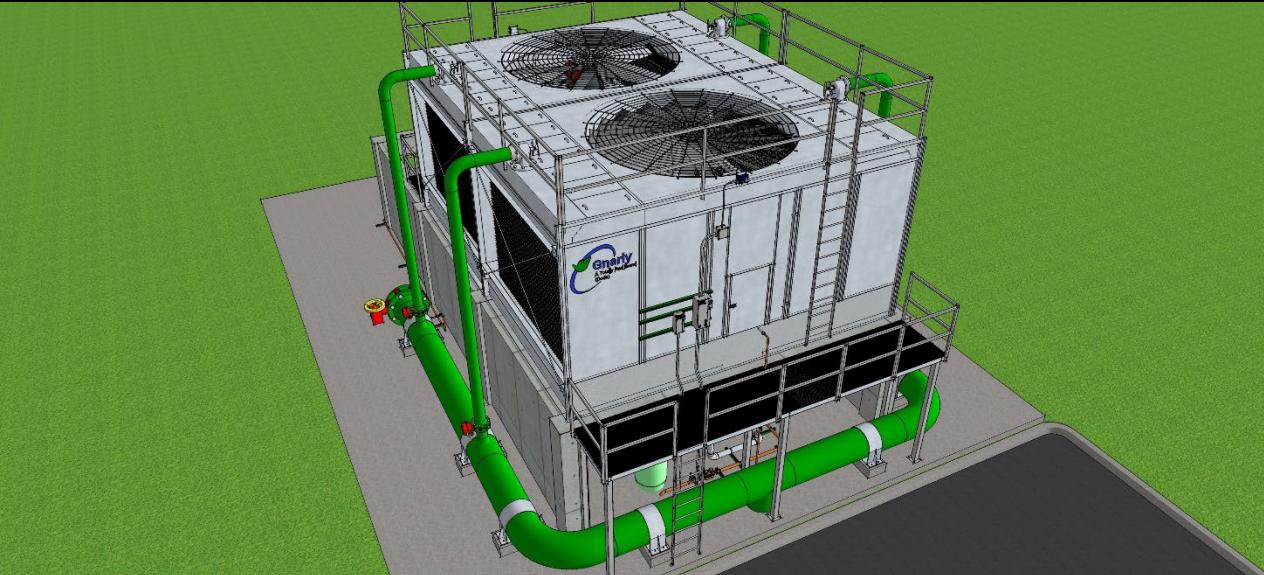
1. With water running, scrub clogged nozzles with wire brush. A toothpick or other non-metal object is helpful in cleaning completely plugged nozzles.
2. If some nozzles remain clogged or plugged, mark their location and shut down unit.
3. Remove marked nozzles by grasping their flat sides with pliers and pulling straight out. Clean nozzles
4. Reinsert nozzle using pliers, aligning orifice slit vertical. This is important for satisfactory unit performance.



#### SUMP CLEANING

1. Leaving the sump strainers in place, open the drain connection and drain all water from the sump.
2. Thoroughly clean sediment and debris from sump and step portion of pan.
3. Remove the sump strainers and clean, using a water spray or wire brush to remove sediment.
4. Slide sump strainers back into track channels, with edge flanges pointed down as shown.
5. Refill the sump with water.

# Cross Flow vs. Counter Flow



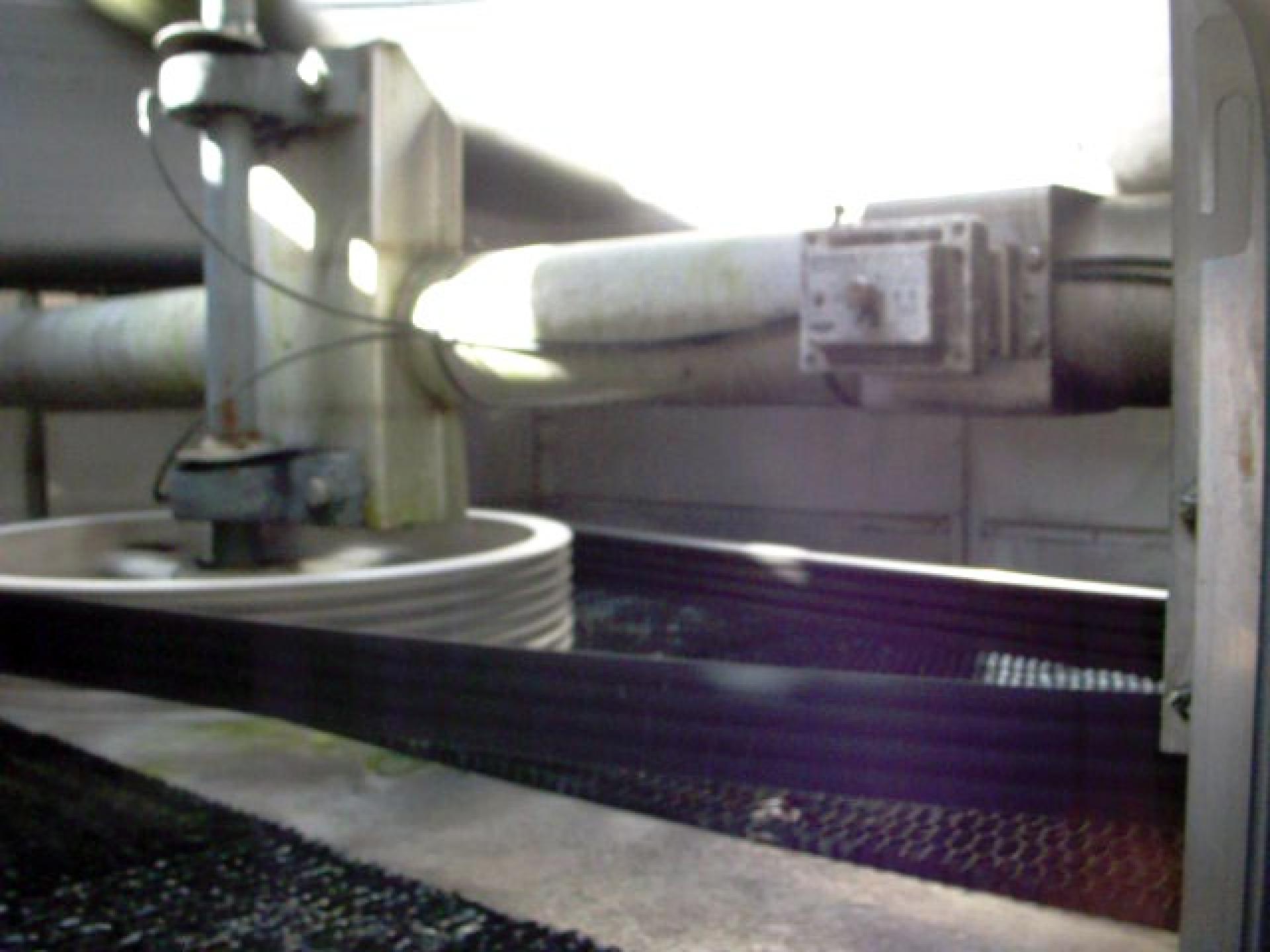
# Cooling Towers in Action

- <https://tinyurl.com/InsideCounterFlowTower>



- <https://tinyurl.com/ConterFlowTowerWater>







# A Comparison from a Recent Project

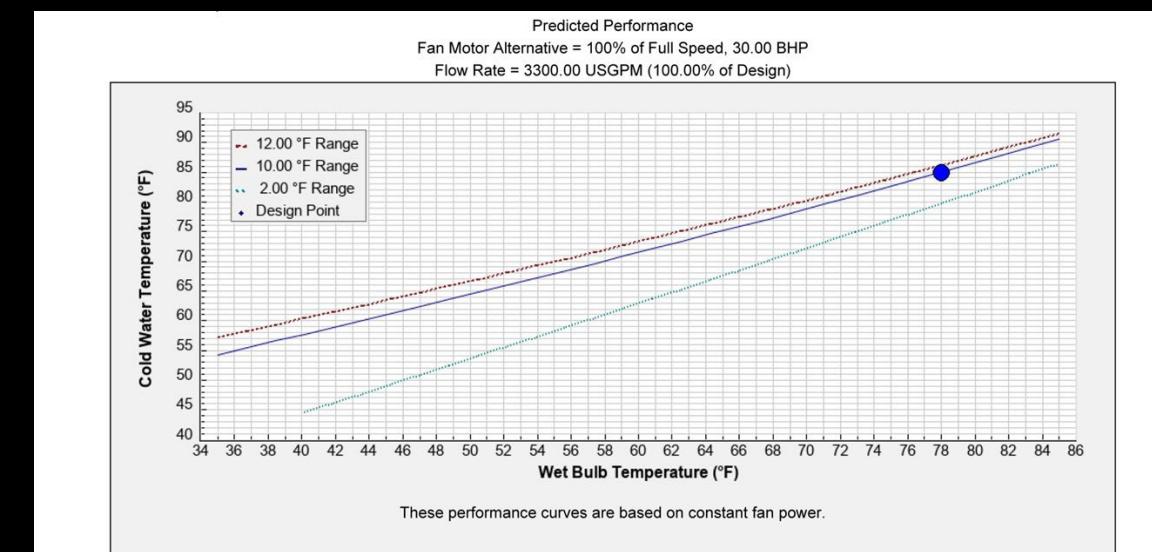
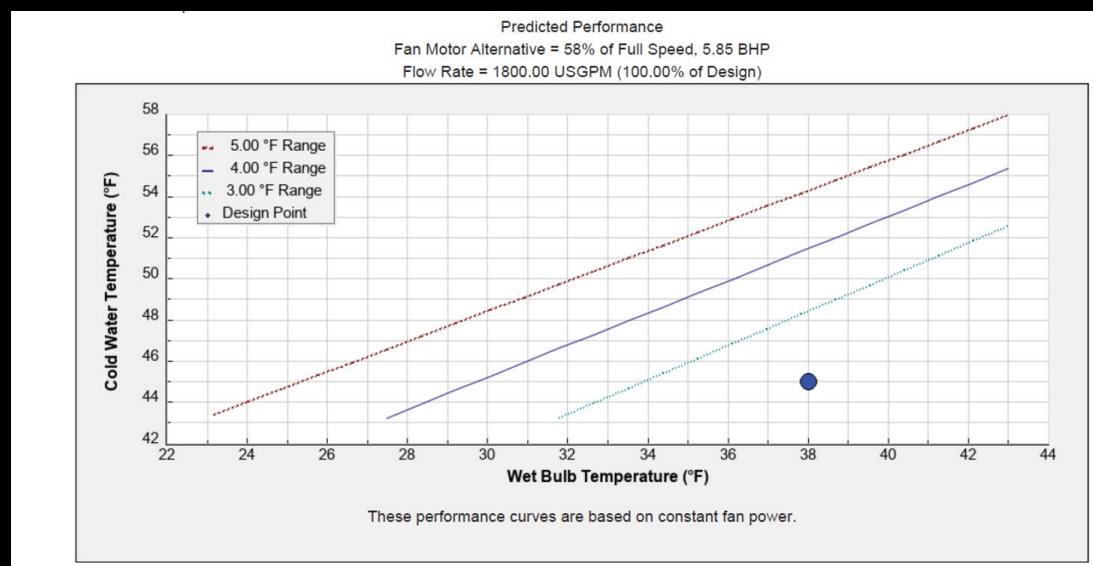
Tower Type Comparison at Cooling Design Conditions (3,330 gpm from 95°F to 85°F at 78°Ft<sub>wb</sub>)

Tower Type	Price Multiplier	Fan Power, hp	Pump Head, ft.w.c.	Sub-freezing Weather Operation
Induced Draft Counter Flow	Base	80	18.64	Second Best
Induced Draft Cross Flow	1.00	60	11.34	Best
Forced Draft Counter Flow	1.87	100	21.46	Worst

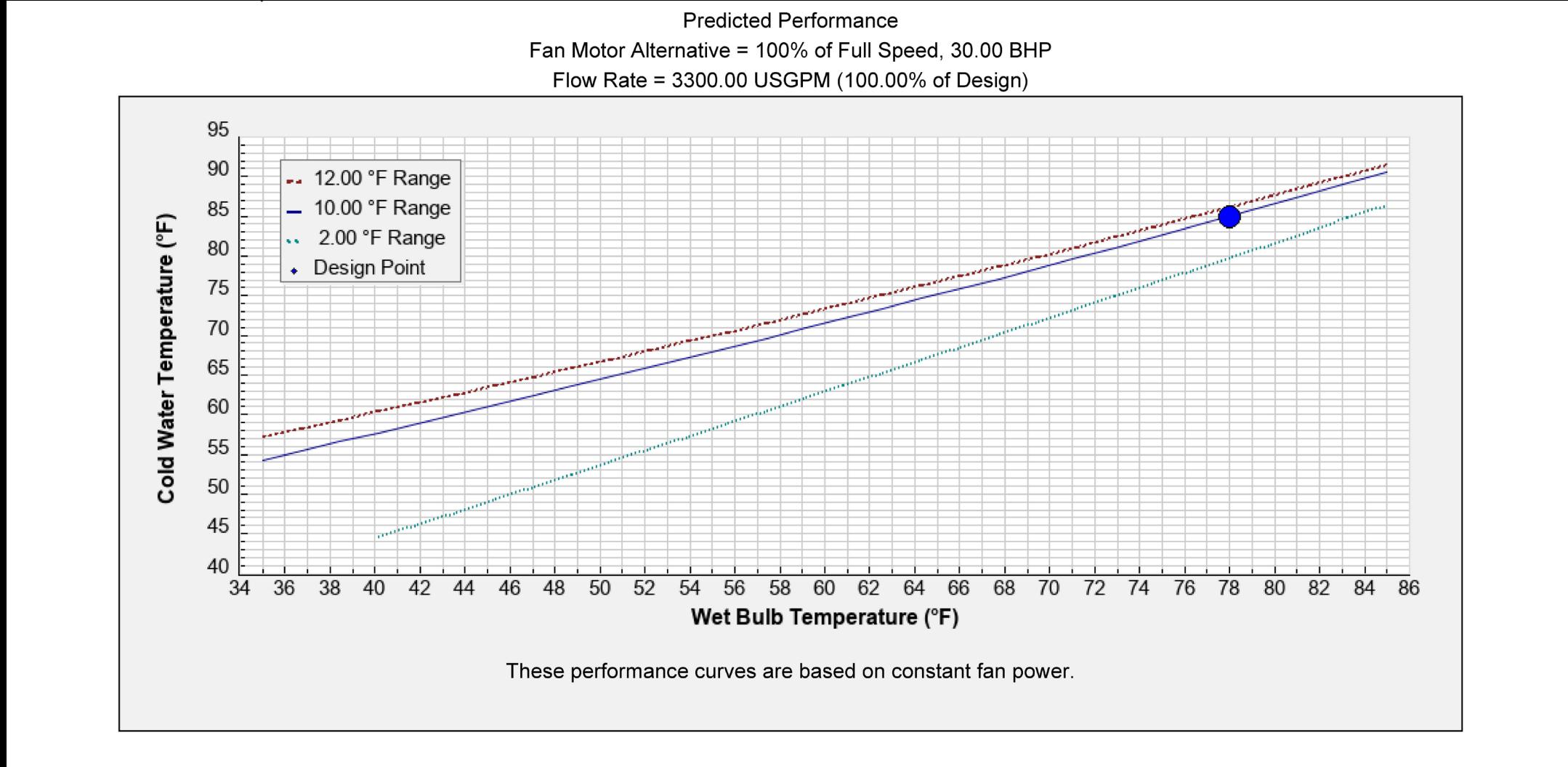
# Multiple Operating Requirements

Base Capacity - Targeted Operating Modes

Equipment On Line	Flow Rate, gpm	Return Temperature to the Tower, °F	Supply Temperature From the Tower, °F	Capacity, Btu/hr	Capacity, 15,000 Btu/hr tons	Ambient Wet Bulb Temperature, °F
Chiller 1 or Chiller 2	1,080	95.0	85.0	5,400,000	450	78.0
Chiller 1 and Chiller 2	2,160	95.0	85.0	10,800,000	900	78.0
Chiller 3	2,250	95.0	85.0	11,250,000	938	78.0
Chiller 3 and Chiller 1 or Chiller 2	3,330	95.0	85.0	16,650,000	1,388	78.0
Plate and Frame Hx	1,800	49.0	45.0	3,600,000	300	38.0



# Cooling Tower Performance Presentation



# Cooling Tower Performance

Cooling Tower Wet Bulb Approach

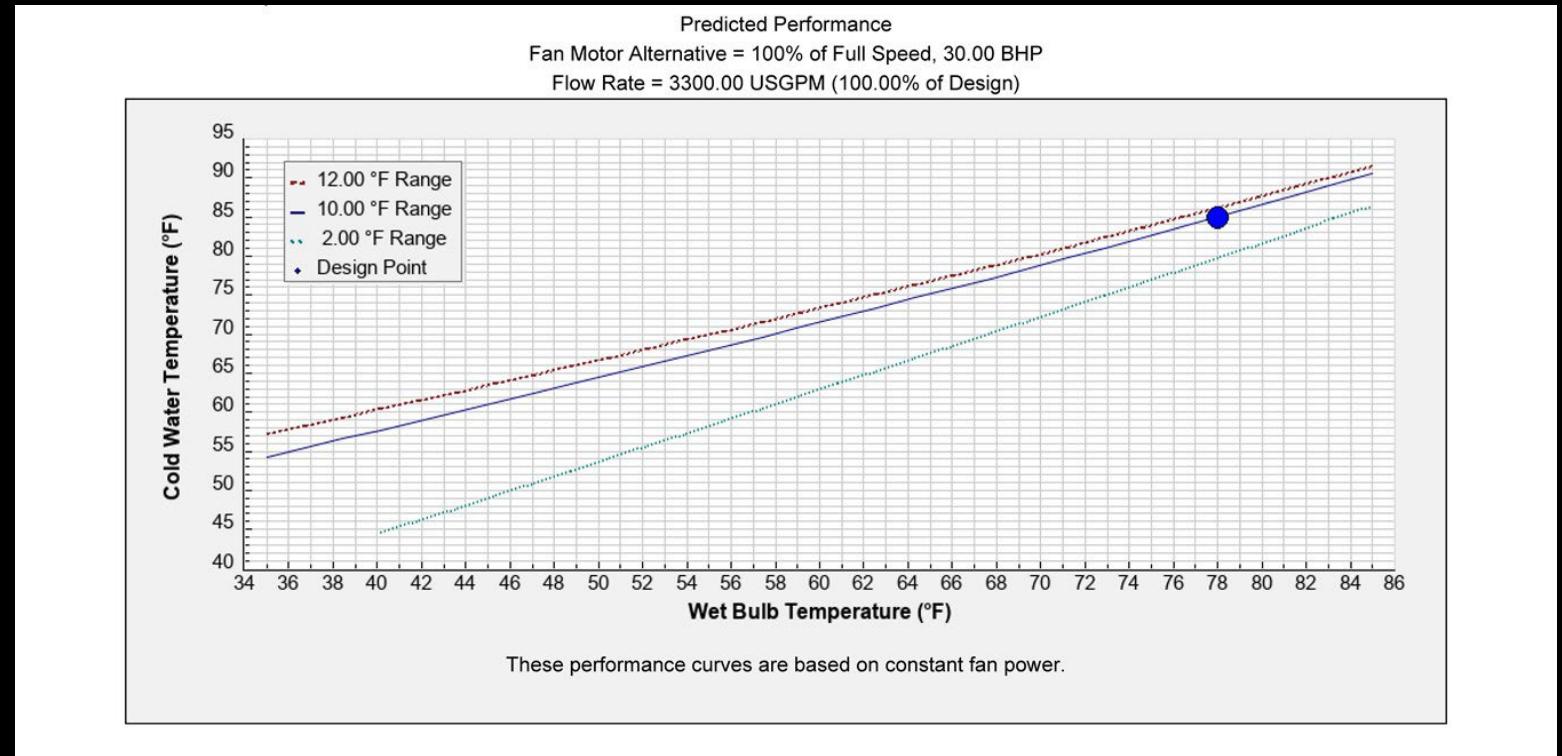
$$t_{Approach} = t_{ColdWater} - t_{WetBulb}$$

Where:

$t_{Approach}$  = Cooling tower approach temperature in consistent units

$t_{ColdWater}$  = Cooling tower leaving cold water temperature in consistent units

$t_{WetBulb}$  = Ambient wet bulb temperature in consistent units



# Cooling Tower Performance

## Cooling Tower Range

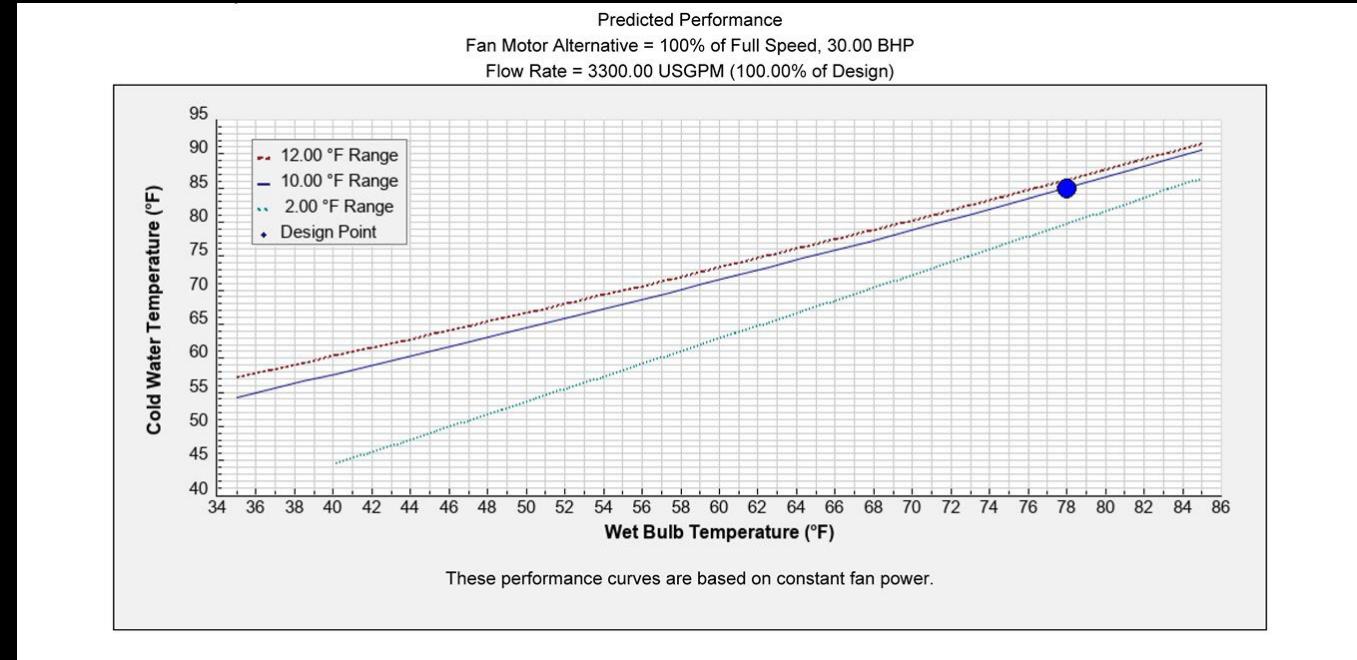
$$t_{\text{Range}} = t_{\text{WarmWater}} - t_{\text{ColdWater}}$$

Where:

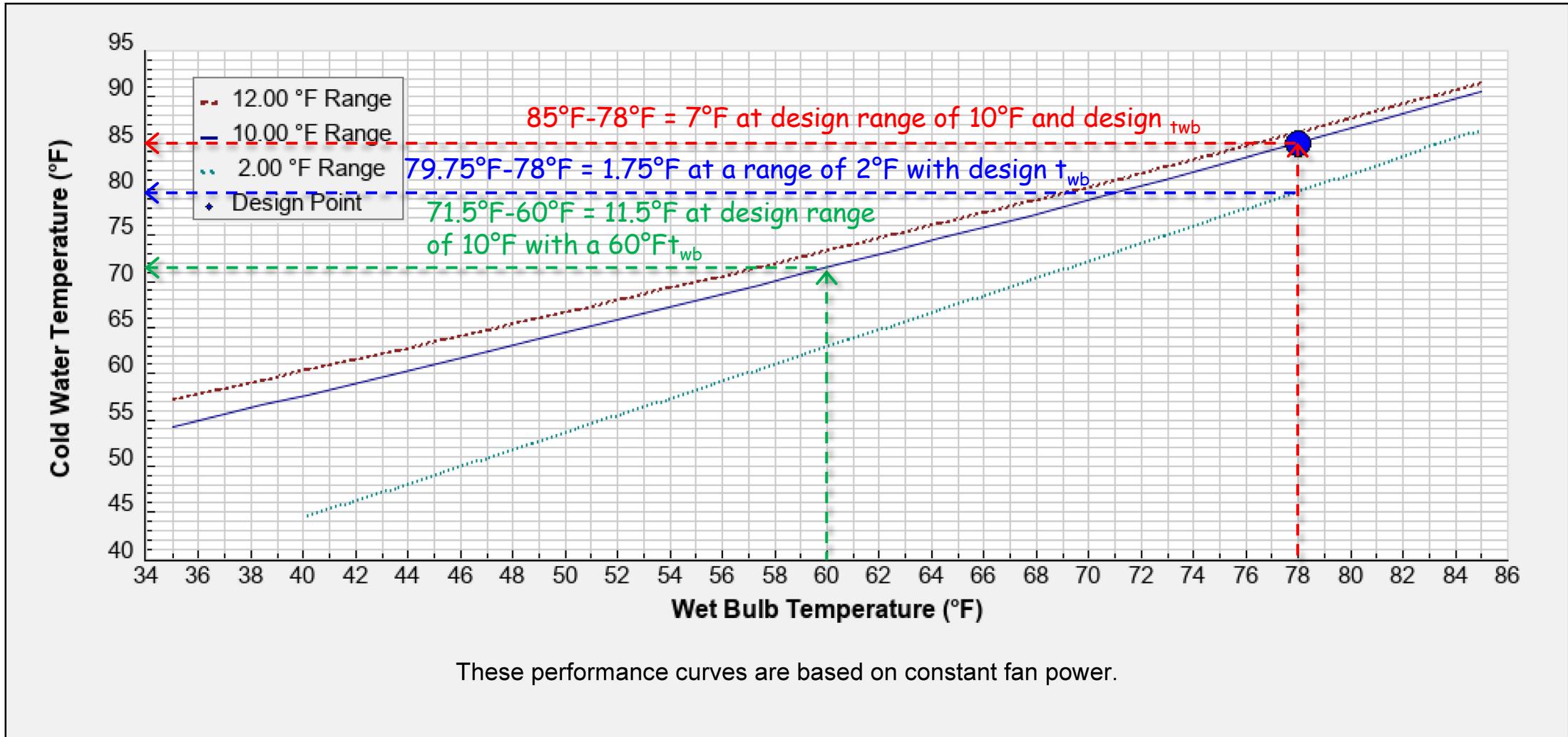
$t_{\text{Range}}$  = The temperature change that occurs across the cooling tower in consistent units.  
This represents the load on the cooling tower and is a direct function of the characteristics of the load it serves.

$t_{\text{WarmWater}}$  = Cooling tower entering water temperature in consistent units; i.e. the temperature of the water returning from the loads.

$t_{\text{ColdWater}}$  = Cooling tower leaving cold water temperature in consistent units; i.e. the temperature of the water supplied by the tower to the loads



Predicted Performance  
Fan Motor Alternative = 100% of Full Speed, 30.00 BHP  
Flow Rate = 3300.00 USGPM (100.00% of Design)



# Cooling Tower Performance

Cooling Tower Efficiency - Range and Approach Basis

$$\eta_{CoolingTower} = \frac{\left( (t_{HotWater} - t_{ColdWater}) \times 100 \right)}{\left( t_{HotWater} - t_{WetBulb} \right)}$$

Where:

$\eta_{CoolingTower}$  = Tower efficiency based on range and approach.

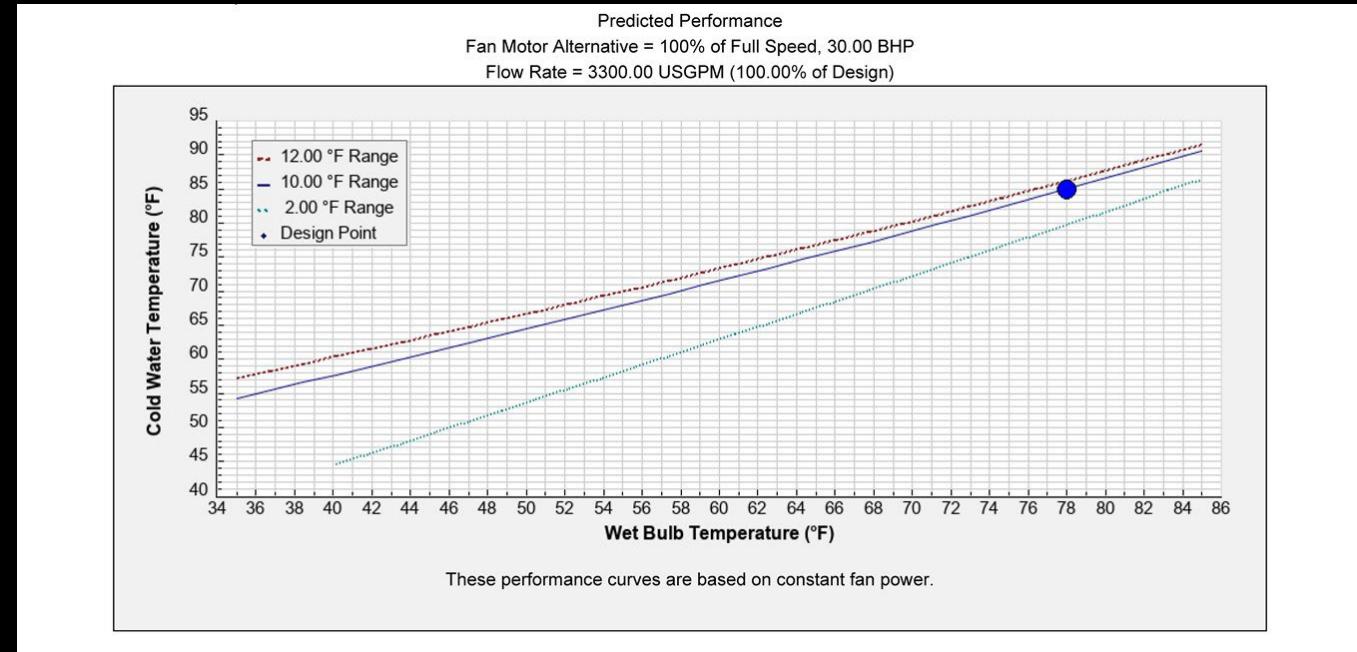
$t_{HotWater}$  = Hot water temperature returning to the tower from the load.

$t_{ColdWater}$  = Cold water temperature supplied to the load.

$t_{WetBulb}$  = Ambient wet bulb temperature.

This could also be written as:

$$\eta_{CoolingTower} = \left( \frac{Range}{Range + Approach} \right) \times 100$$



# Cooling Tower Performance

## Cooling Tower Efficiency - ASHRAE Definition

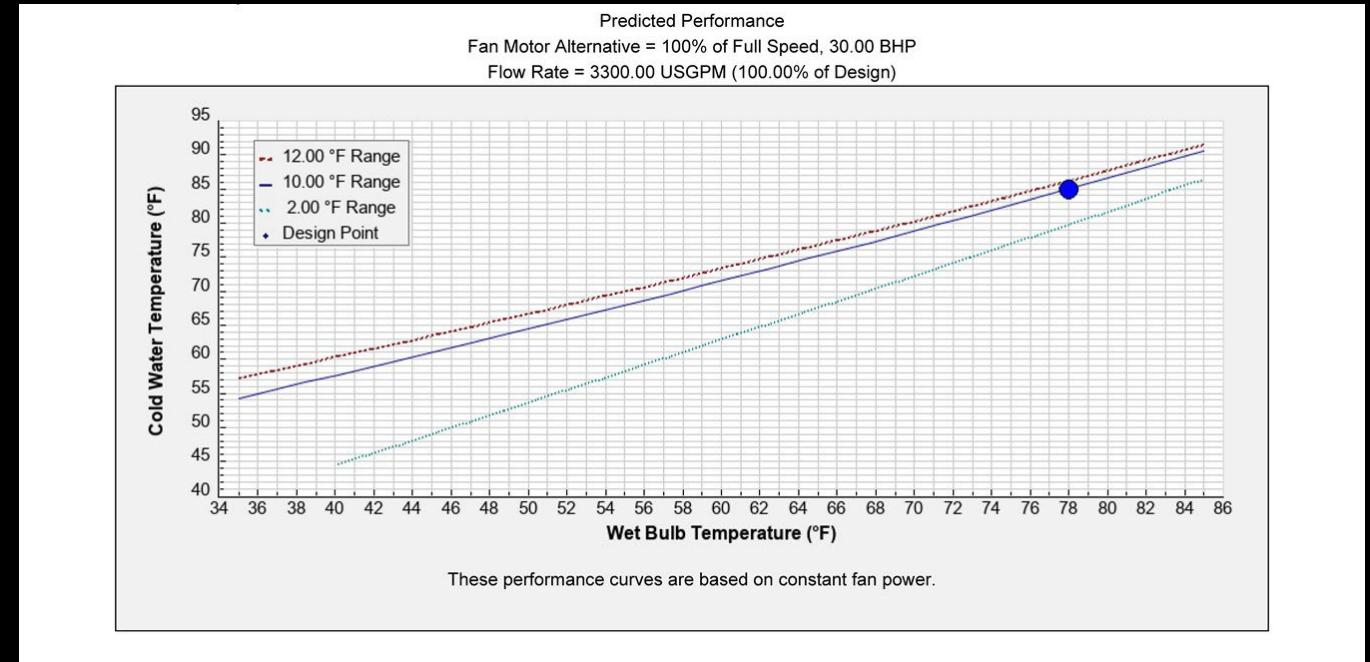
$$\eta_{CoolingTower} = \left( \frac{Flow_{Design}}{HP_{Fan_{Design}}} \right)$$

Where:

$\eta_{CoolingTower}$  = ASHRAE efficiency standard 90.1 cooling tower efficiency. The minimum requirement is 40.2 gallons per minute per horsepower for axial (propeller) fan cooling towers and 20.0 gallons per minute per horsepower for centrifugal fan cooling towers; both requirements are at the standard rating conditions of 95°F warm water, 85°F cold water, and 75°F ambient wet bulb temperature.

$Flow_{Design}$  = The design water flow rate that the tower is rated at for an application.

$HP_{Fan_{Design}}$  = The design fan horse power associated with the tower rating for an application.

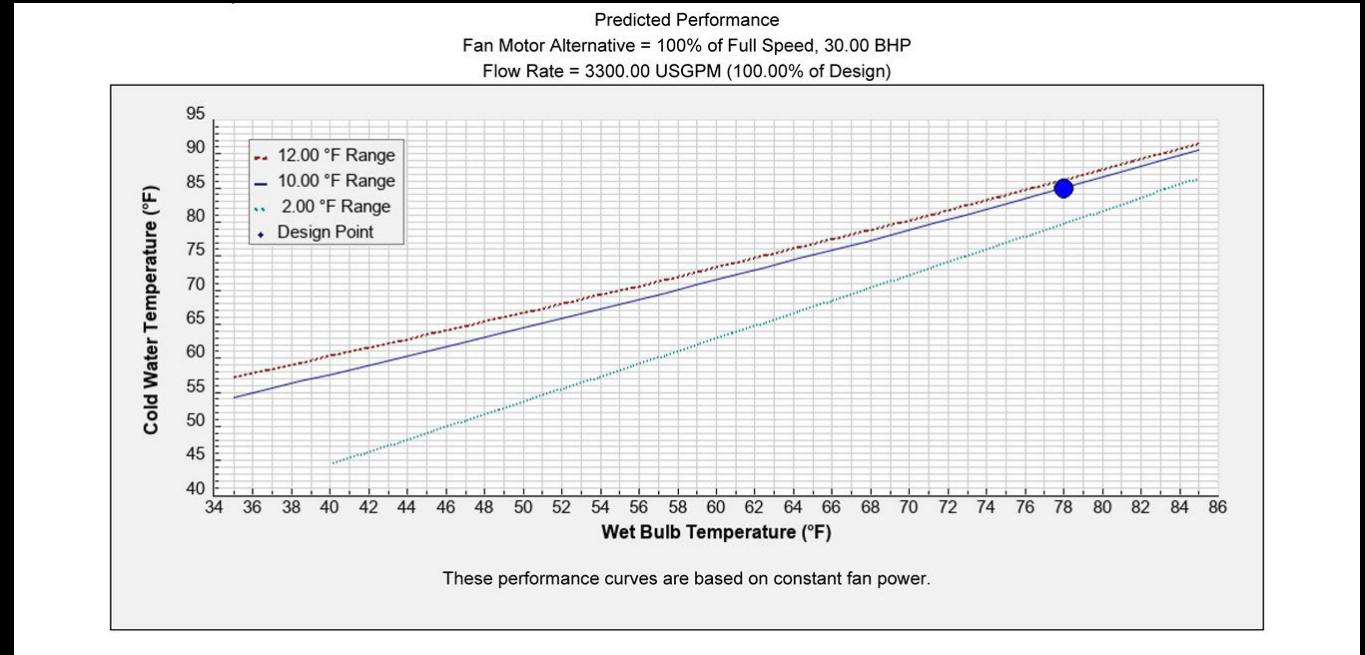


# Cooling Tower Performance

Cooling Tower Ton

$$Ton_{CoolingTower} = 15,000 \frac{\text{Btu}}{\text{hour}}$$

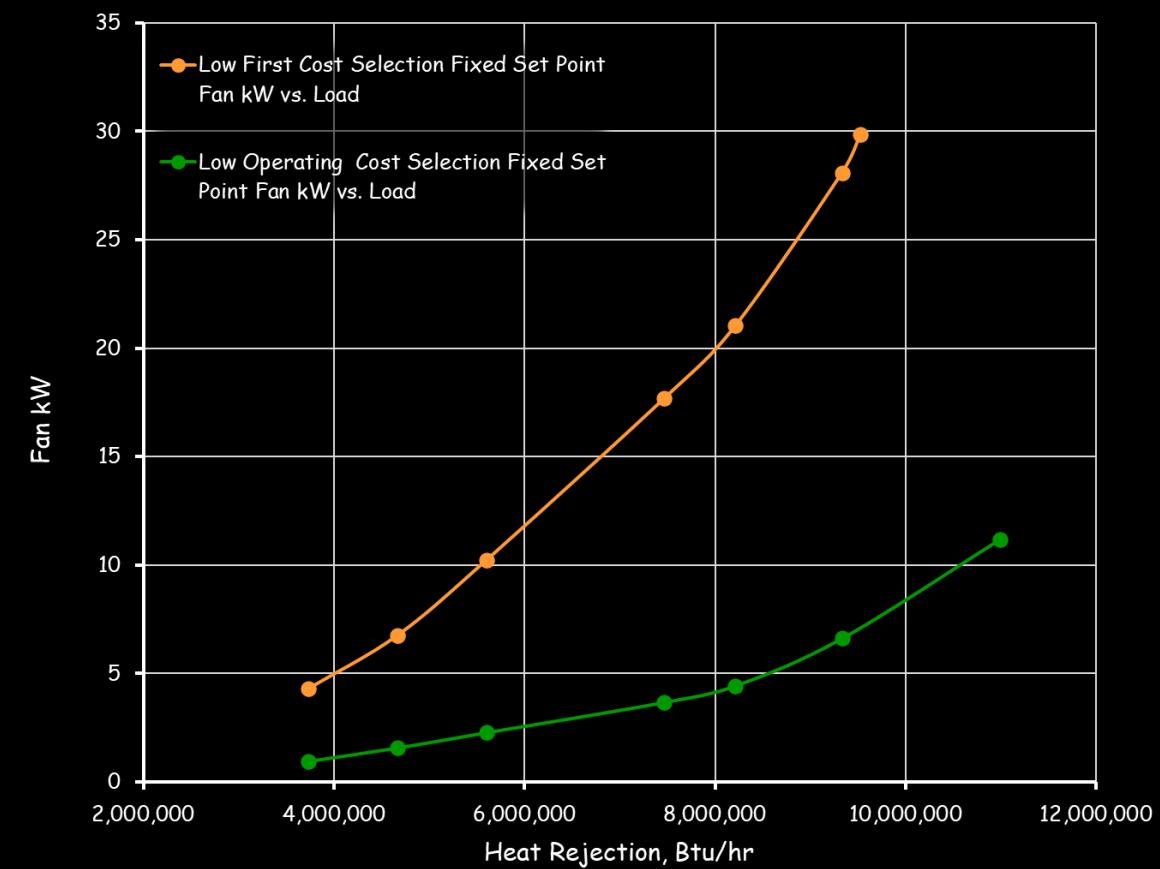
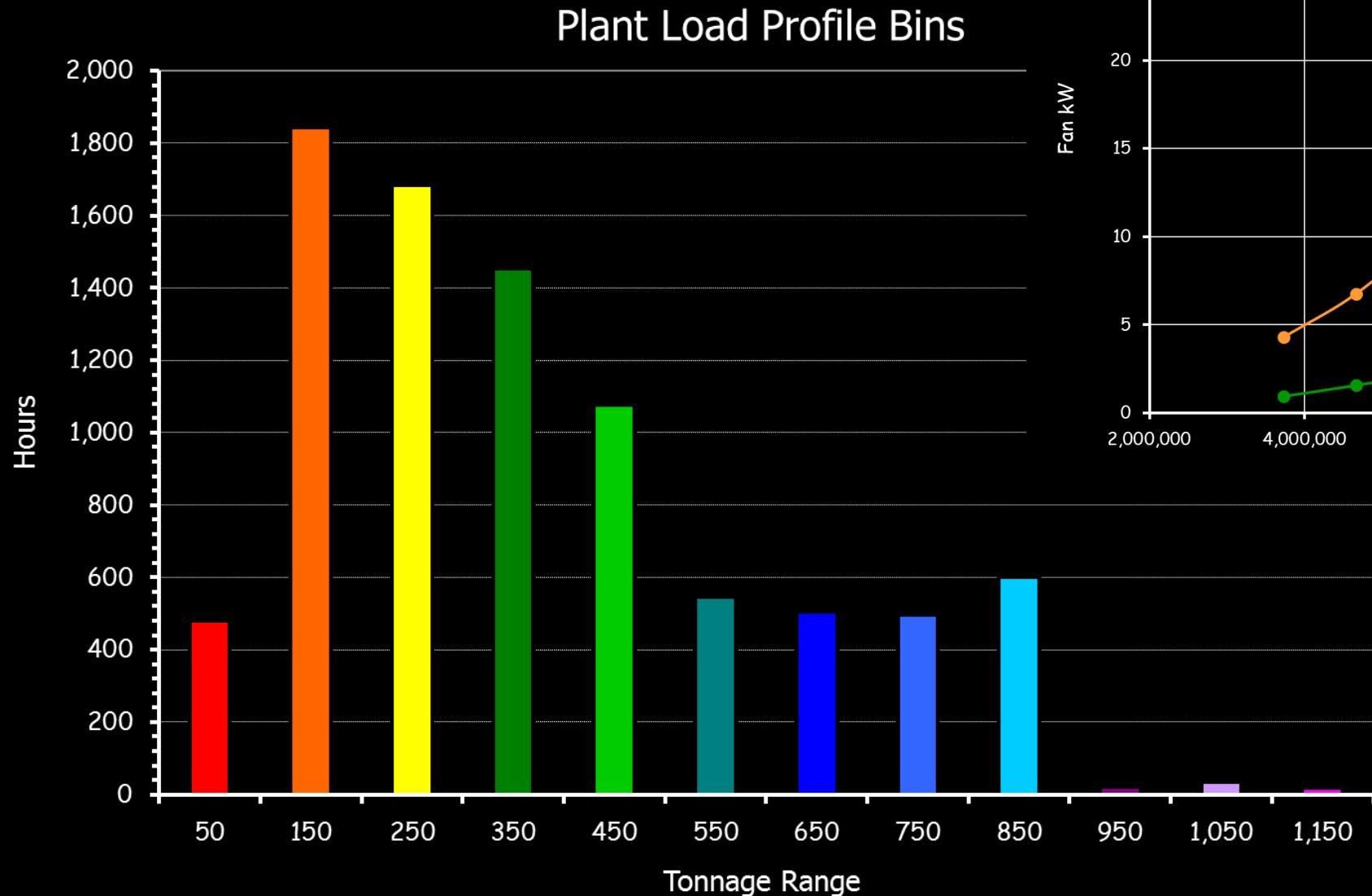
This is intended to represent the addition of a nominal 3,000 Btu/hr of heat rejection due to the work done by a compressor to provide 12,000 Btu/hr (a conventional cooling ton) of refrigeration



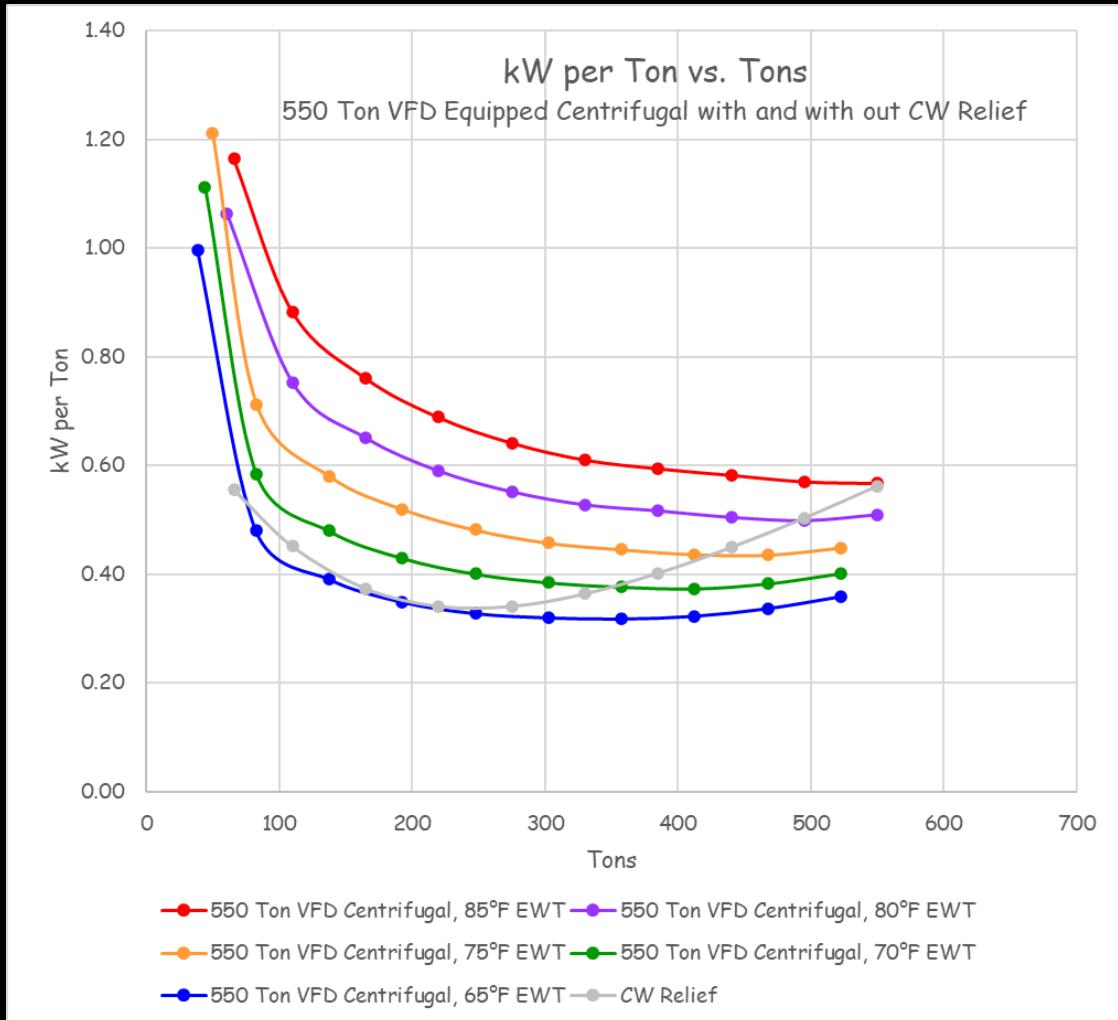
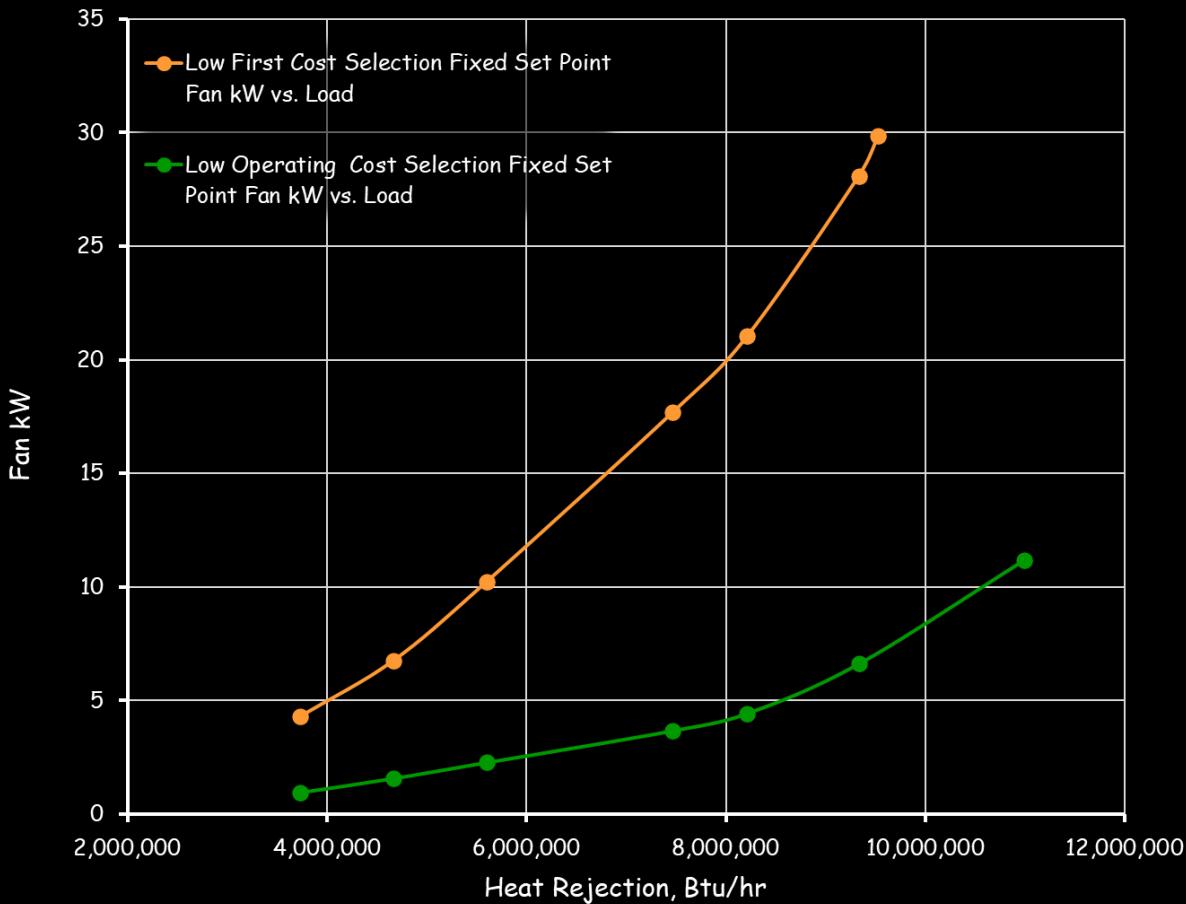
# Best First Cost vs Best Life Cycle Cost

Summary, Best Life Cycle Cost Selection				
Marley NC8403TLS1				
Design cell flow rate	1,873 gpm		Typical Price -	\$60,000
Design cell range	10 °F		Stainless basin -	\$68,000
Full load fan speed at design wet bulb temperature	214 rpm		All stainless tower -	\$82,000
Capacity relative to requirement	117.7%			
Cost premium relative to an exact capacity match	1.53			
Full capacity flow rate - gpm	2,205 gpm			
Full capacity heat rejection at design range -	10,986,010 Btu/hr ( $Q = 498.34 \times \text{gpm} \times (\text{tin-tout})$ )			
Full capacity approach at design flow and range	12 °F			
Full load bhp	15 bhp			
Full load kW	11 kW			
Same Load, Best First Cost Selection				
Marley NC8403TLS1				
Design cell flow rate	1,873 gpm		Typical Price -	\$39,000
Design cell range	10 °F		Stainless basin -	\$44,000
Full load fan speed at design wet bulb temperature	473 rpm		All stainless tower -	\$54,000
Capacity relative to requirement	102.1%			
Cost premium relative to an exact capacity match	1.01			
Full capacity flow rate - gpm	1,912 gpm			
Full capacity heat rejection at design range -	9,526,500 Btu/hr ( $Q = 498.16 \times \text{gpm} \times (\text{tin-tout})$ )			
Full capacity approach at design flow and range	12 °F			
Full load bhp	40 bhp			
Full load kW	30 kW			

# Best First Cost vs Best Life Cycle Cost



# Best First Cost vs Best Life Cycle Cost



# Optimizing Tower Fan Energy

## As Found

- 72°F CW supply fixed set point
- Theory

*Lower condensing temperature = Lower chiller kW/ton*

- Tower fans running full speed 24/7

## Functional Test

- Incrementally raise set point 1°F per hour
- At 80°F set point
  - Raised the chiller energy by 14 kW
  - Dropped out two 20 hp (39kW total) continuously running tower fans
  - Net savings of 25 kW

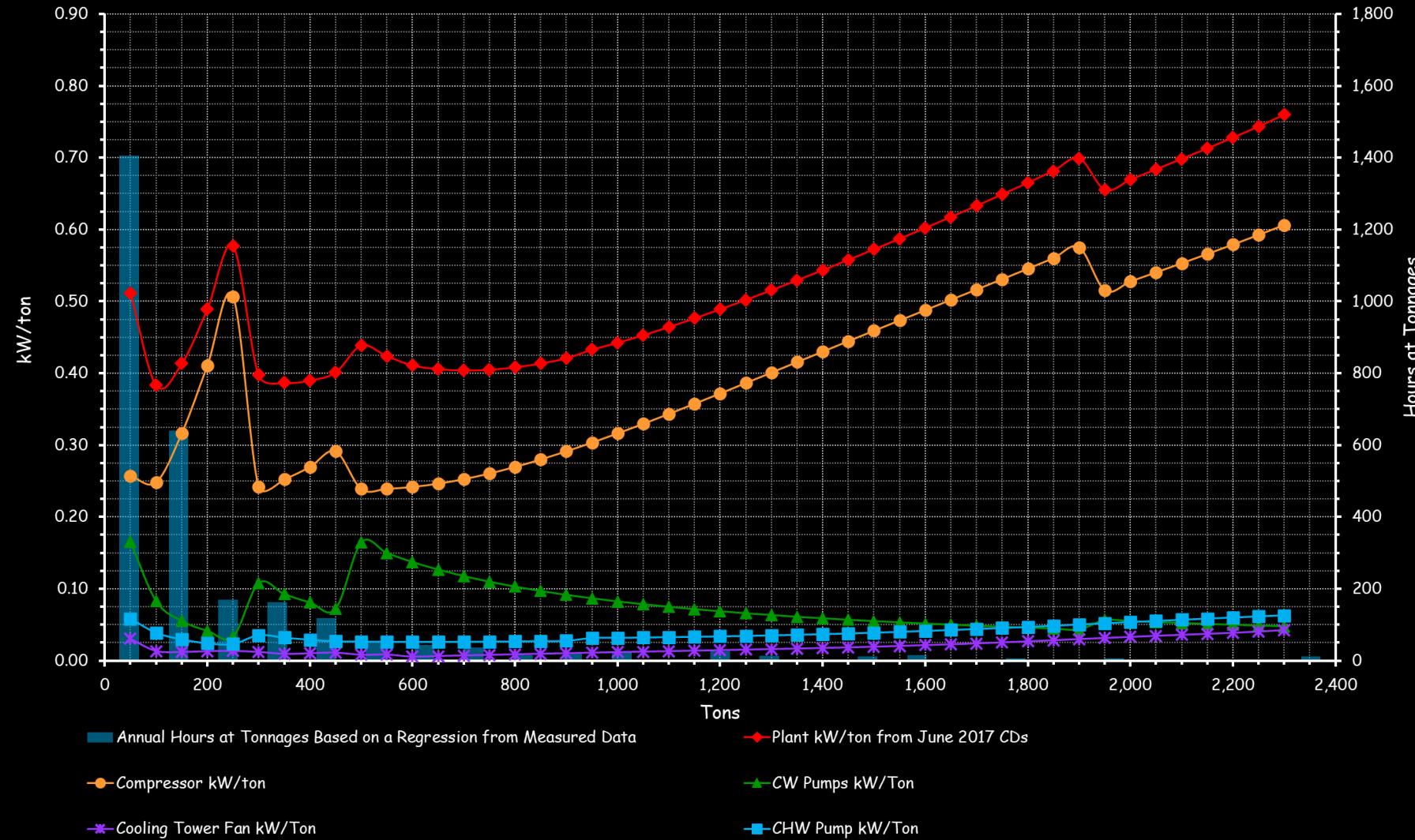


3. 25. 2003

Savings = \$18,000 - \$20,000 annually

*Based on \$.07/kWh electricity*

# Tower Fan Energy as a Portion of Over-all Plant Energy



# Determining a Resetting Parameter

## *Another challenge*



## Product Testing Report

Duct - Mounted Relative Humidity Transmitters

April 2004

### Table of Contents

- 1 Introduction**
  - How is Humidity Measured?
  - Types of Sensors
  - Capacitive Humidity Sensors
  - Resistive Humidity Sensors
- 2 Classification of Humidity Sensors**
- 4 Choosing the Right Humidity Transmitter**
  - Accuracy
  - Response Time
  - Resistance to Contaminants
  - Transducer Performance
  - Maintenance and Calibration
  - Long-term Stability
  - Humidity Transmitter Cost
- 6 NBCIP Testing**
  - Manufacturer Information
  - Testing Methods
- 10 Test Results**
  - Accuracy
  - Repeatability
  - Linearity
  - Hysteresis
- 15 Conclusions**
  - Next Steps
- 16 Terms and Definitions**

### Program Sponsors

Iowa Energy Center  
NSTAR Electric and Gas Corporation  
U.S. Environmental Protection Agency

### Introduction

Humidity transmitters are common components in building control systems and their performance can significantly impact energy use in heating, ventilating, and air-conditioning (HVAC) systems. In particular, relative humidity transmitters are used to monitor supply and return air conditions from air handling units, monitor conditions in occupied spaces, and control humidification and dehumidification processes as well as economizer cycles. In the case of economizers, relative humidity and temperature measurements of outdoor and return air conditions are used to calculate the enthalpies of the two air streams. The air stream with the least energy content is then selected to provide building cooling. If one or both of the computed enthalpies is wrong, as can happen when humidity transmitters are not accurate, significant energy penalties can result from cooling of the incorrect air stream.

Growing concern about indoor environmental quality issues, including mold, mildew and moisture problems also emphasize the need for accurate humidity sensing devices. In many cases, humidity control is the primary means of system control in laboratories, humidity sensitive spaces, museums, and computer rooms. The consequences of poor humidity transmitter performance in these applications can outweigh energy concerns and result in costly damage.

Because of their impact on energy use and the quality of the indoor environment, the National Building Controls Information Program (NBCIP) tested and evaluated the performance of resistive and capacitive duct-mounted relative humidity transmitters used in typical building HVAC applications. NBCIP developed an experimental procedure for testing the humidity transmitters, and used this procedure to test products from six leading manufacturers.→

# It's Complicated Inside There

## Tower Water Side Conditions

- EWT - 85°F
- LWT - 75°F
- 10°F approach to wet bulb
- Flow rate - 3,300 gpm

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

- Btu/hr - 16,500,000 Btu/hr (Energy removed from the water)

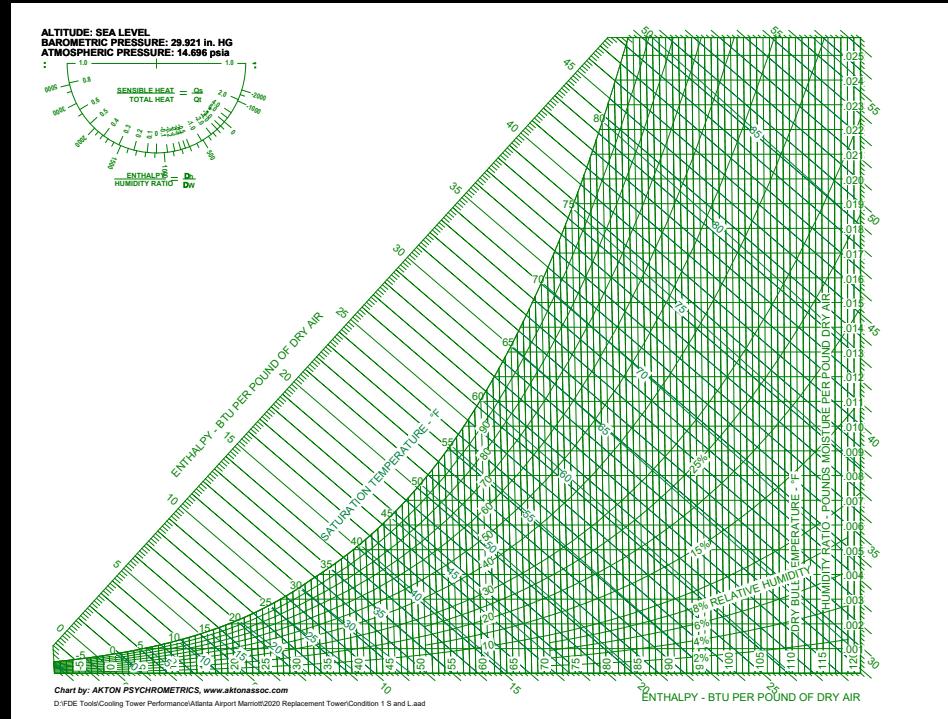
# It's Complicated Inside There

Conservation of mass and energy says that the energy removed from the water is added to the air

$$Q_{Btu/hr} = 4.5 \times Flow_{cfm} \times (h_{In, Btu/lb} - h_{Out, Btu/lb})$$

Air flow rate - 285,780 cfm

Air flow rate - 1,311,730 lb/hr



# It's Complicated Inside There

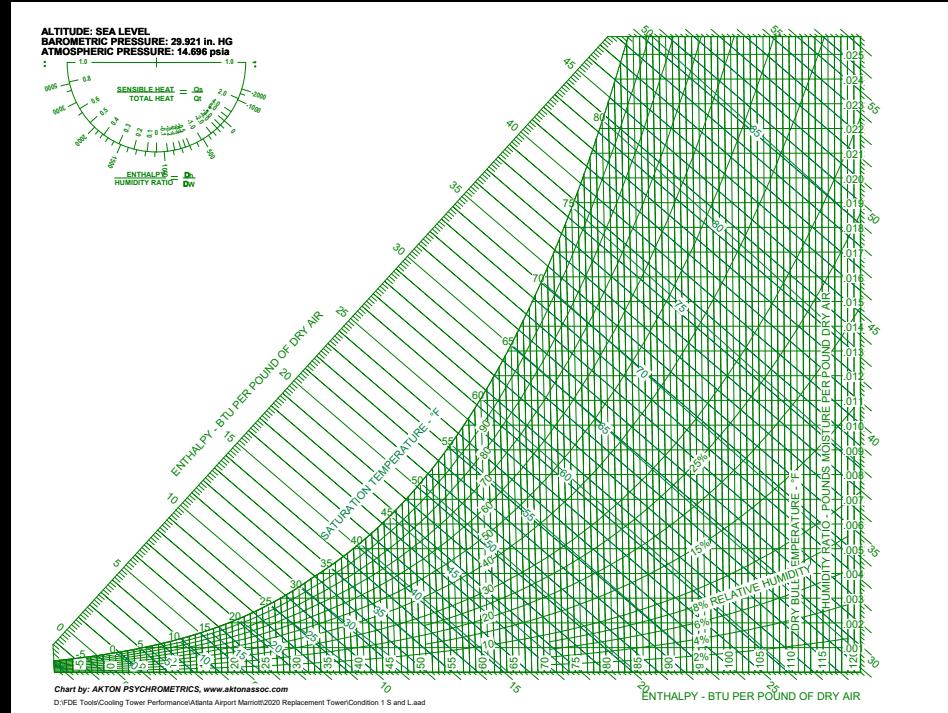
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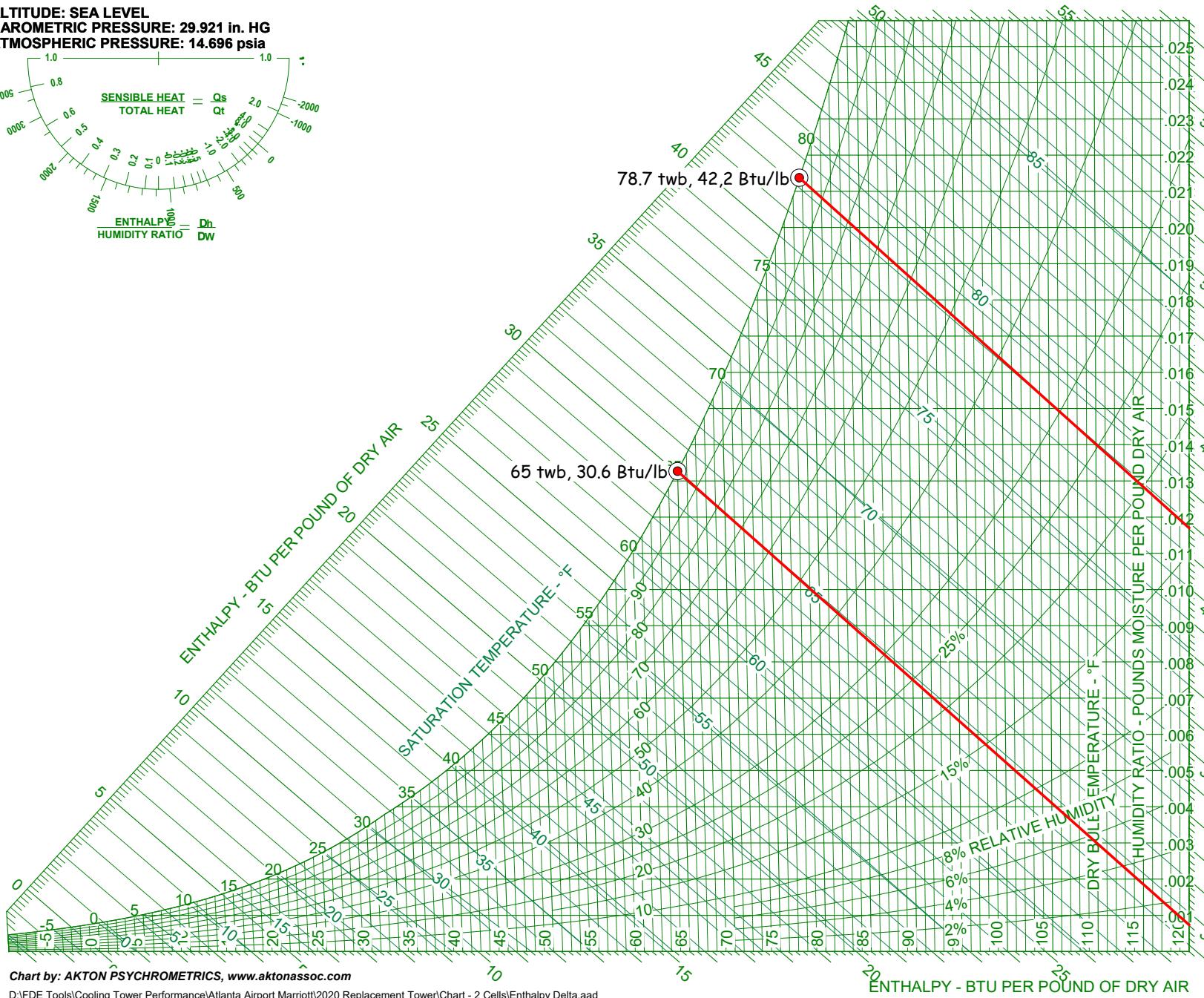
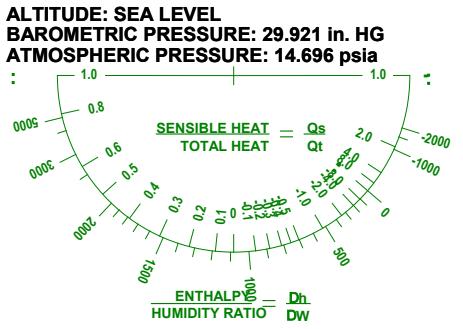
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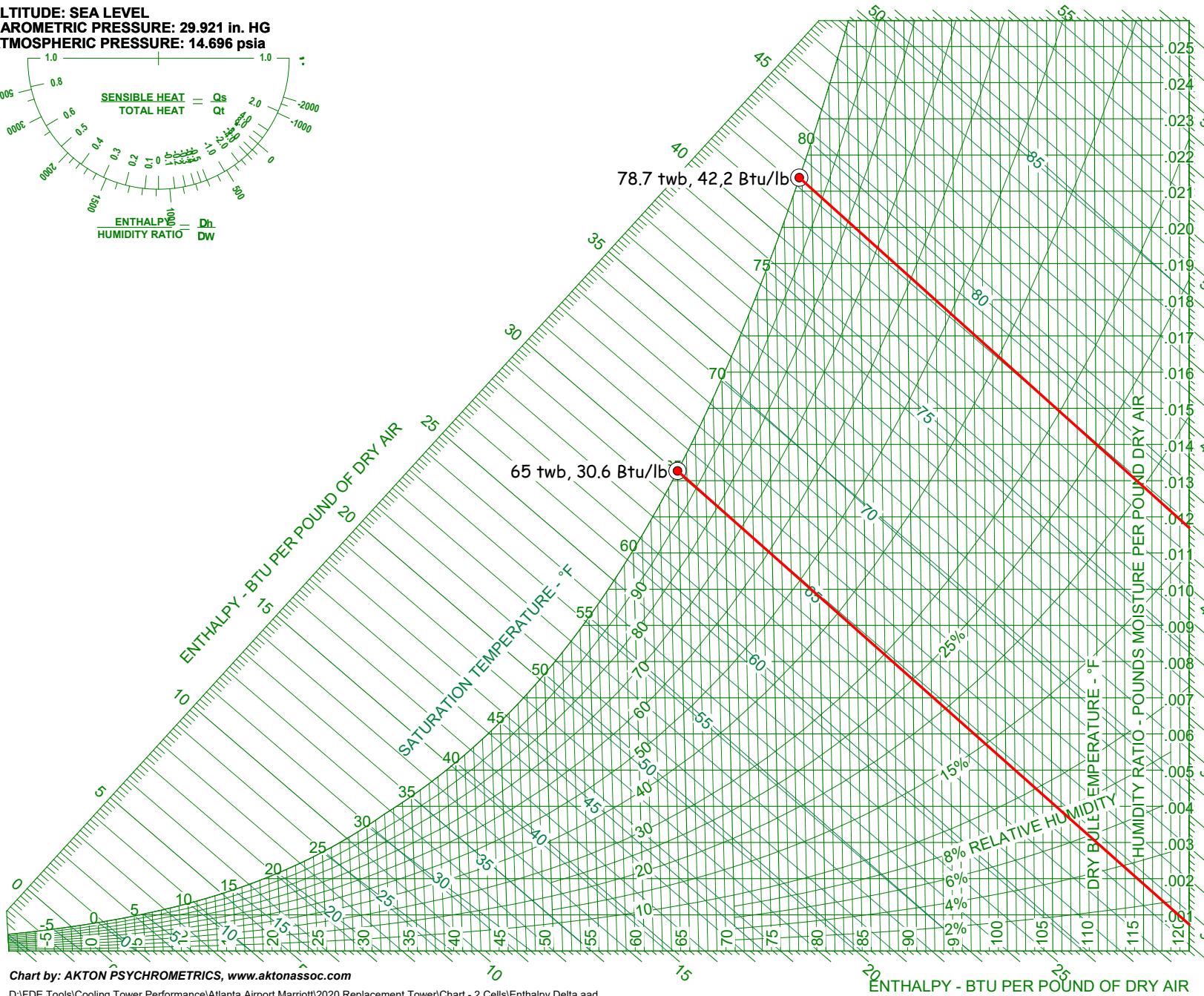
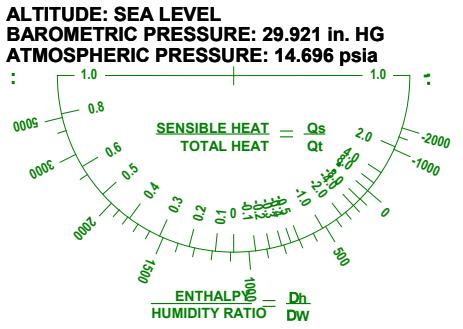
Air flow rate - 285,780 cfm

Air flow rate - 1,311,730 lb/hr

Enthalpy change - 12.6 Btu/lb







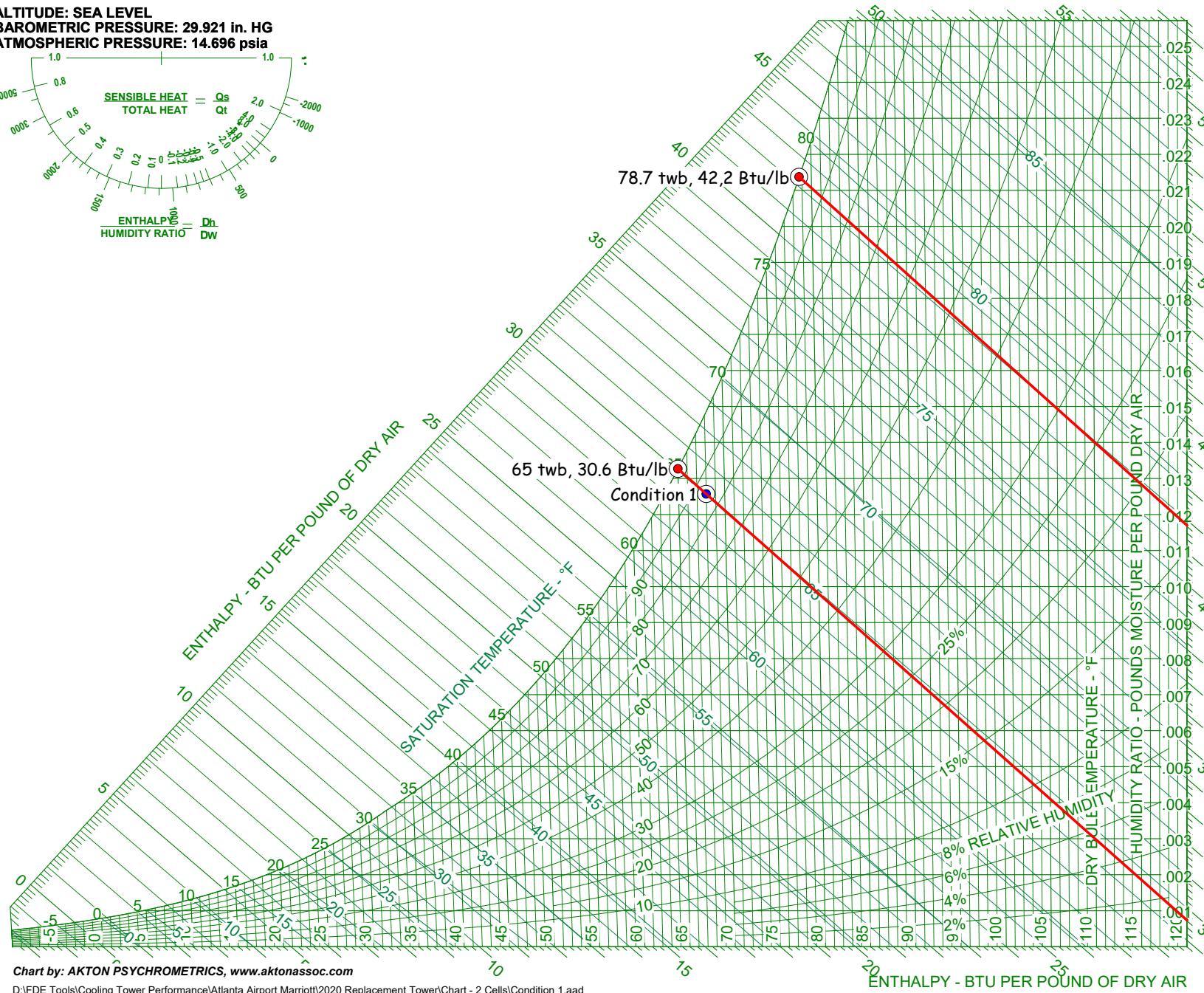
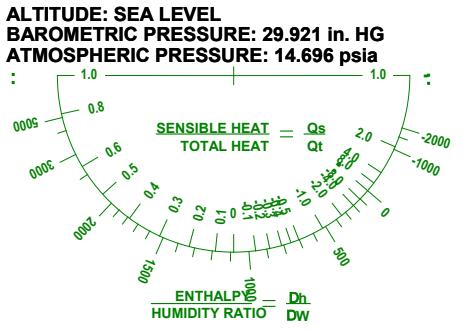
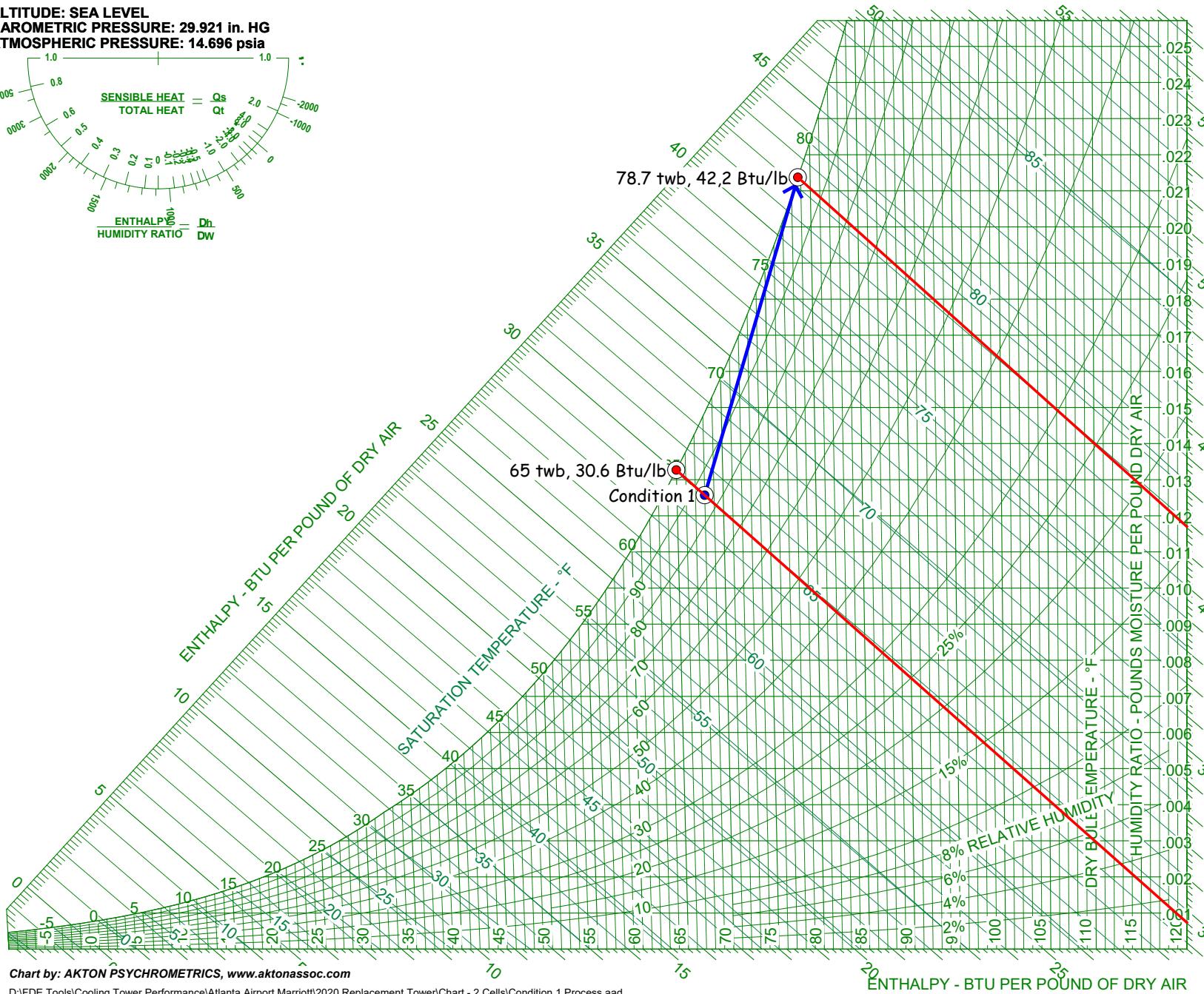
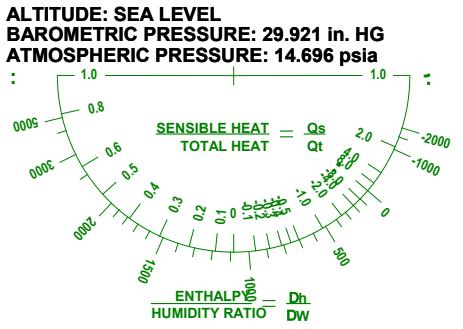


Chart by: AKTON PSYCHROMETRICS, [www.aktonassoc.com](http://www.aktonassoc.com)

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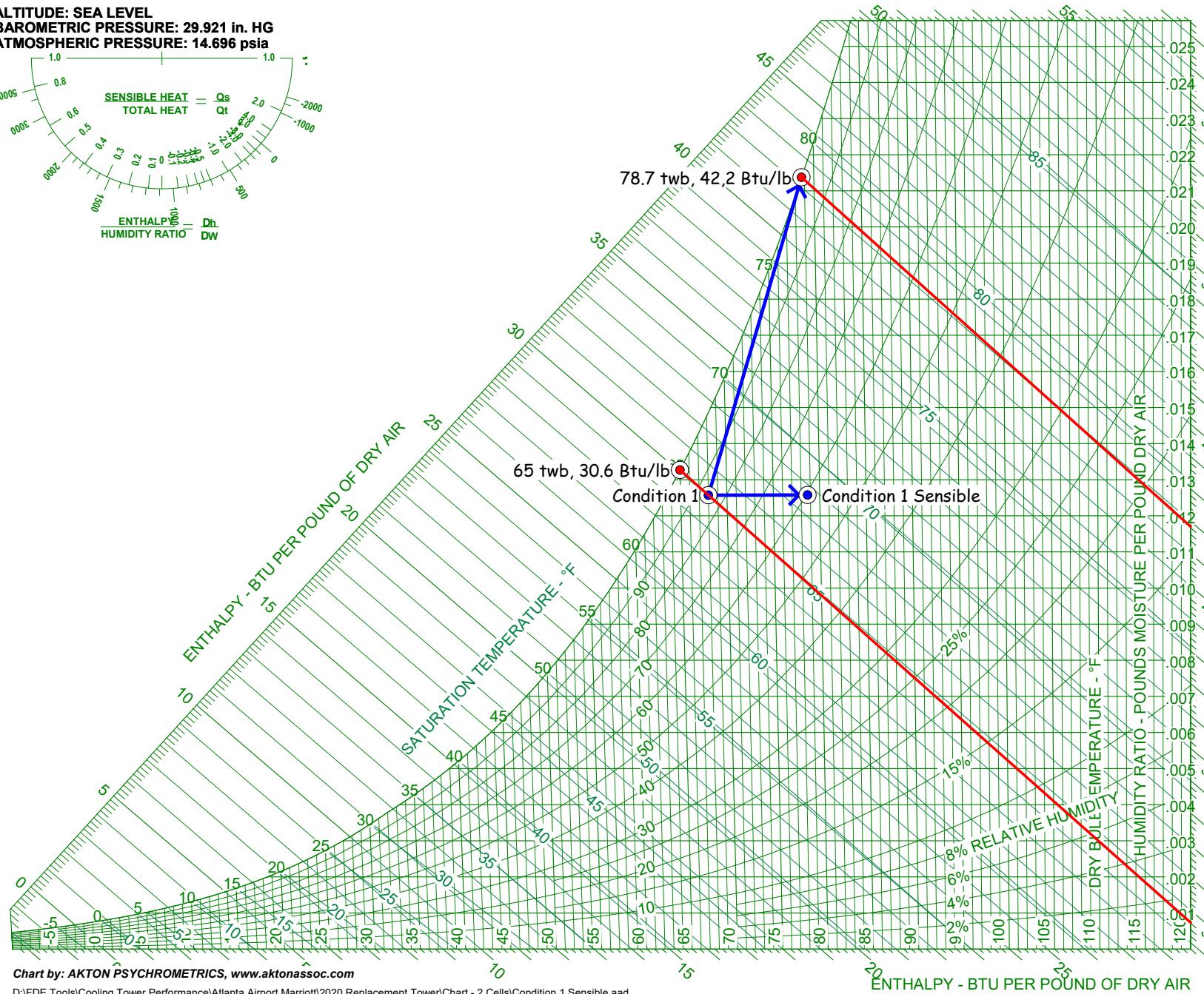
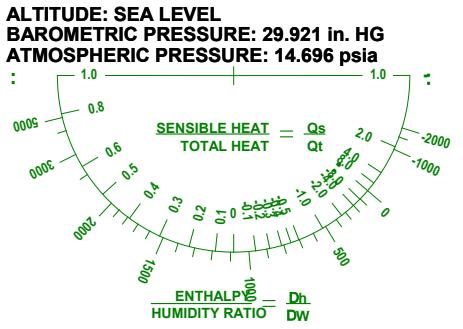


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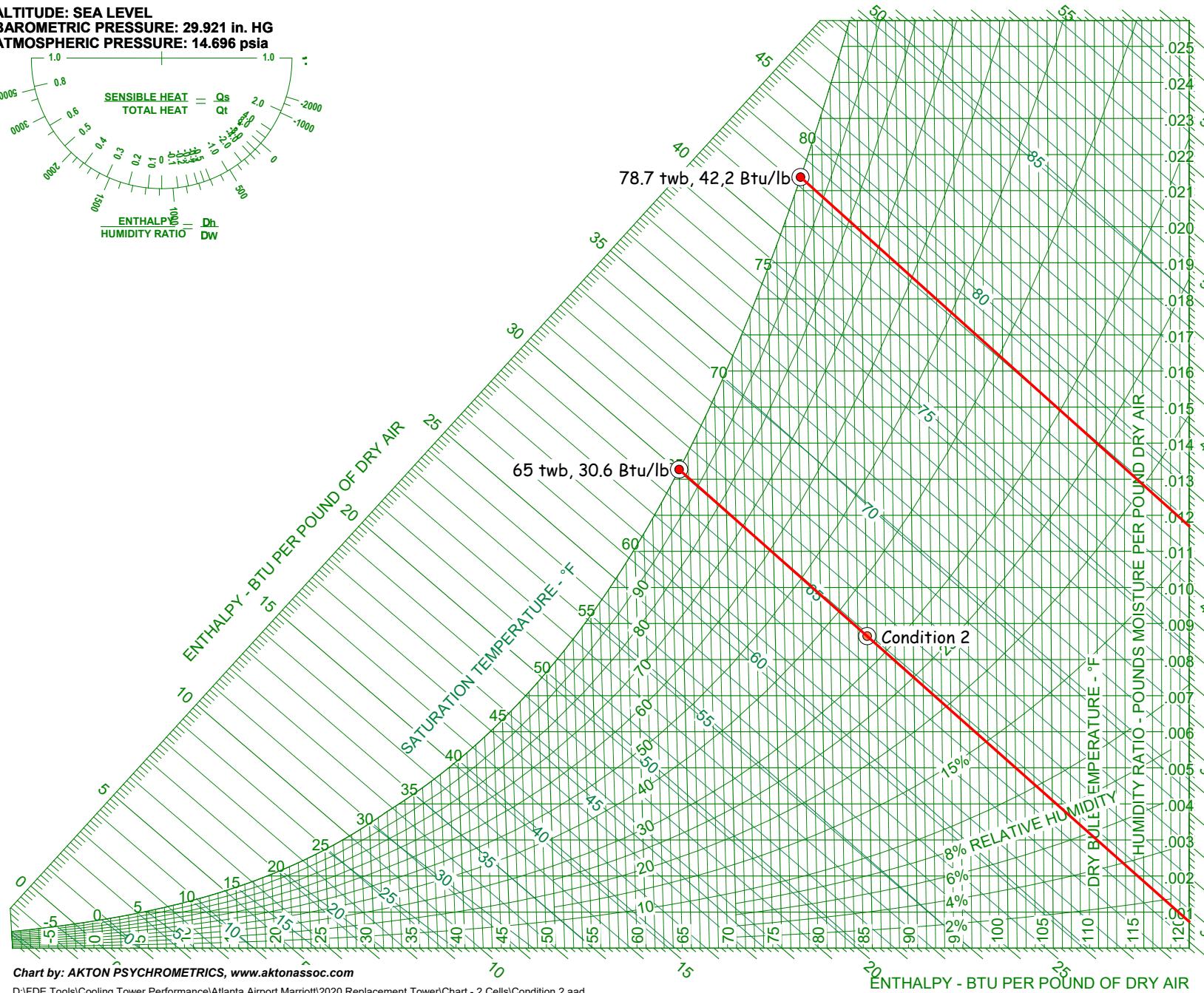
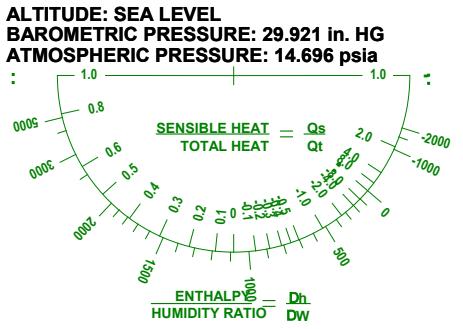
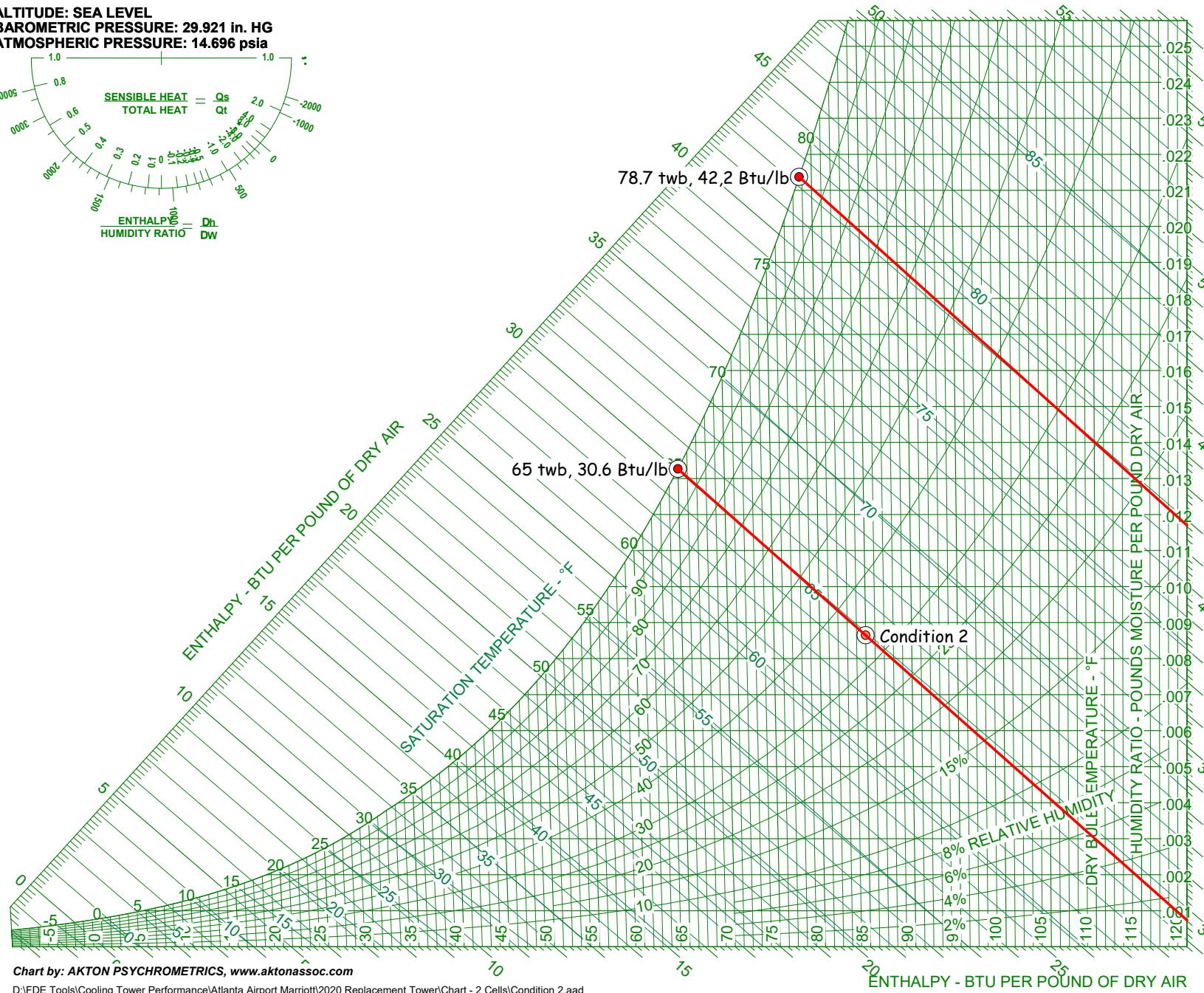
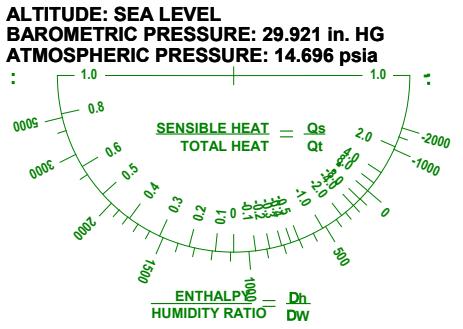
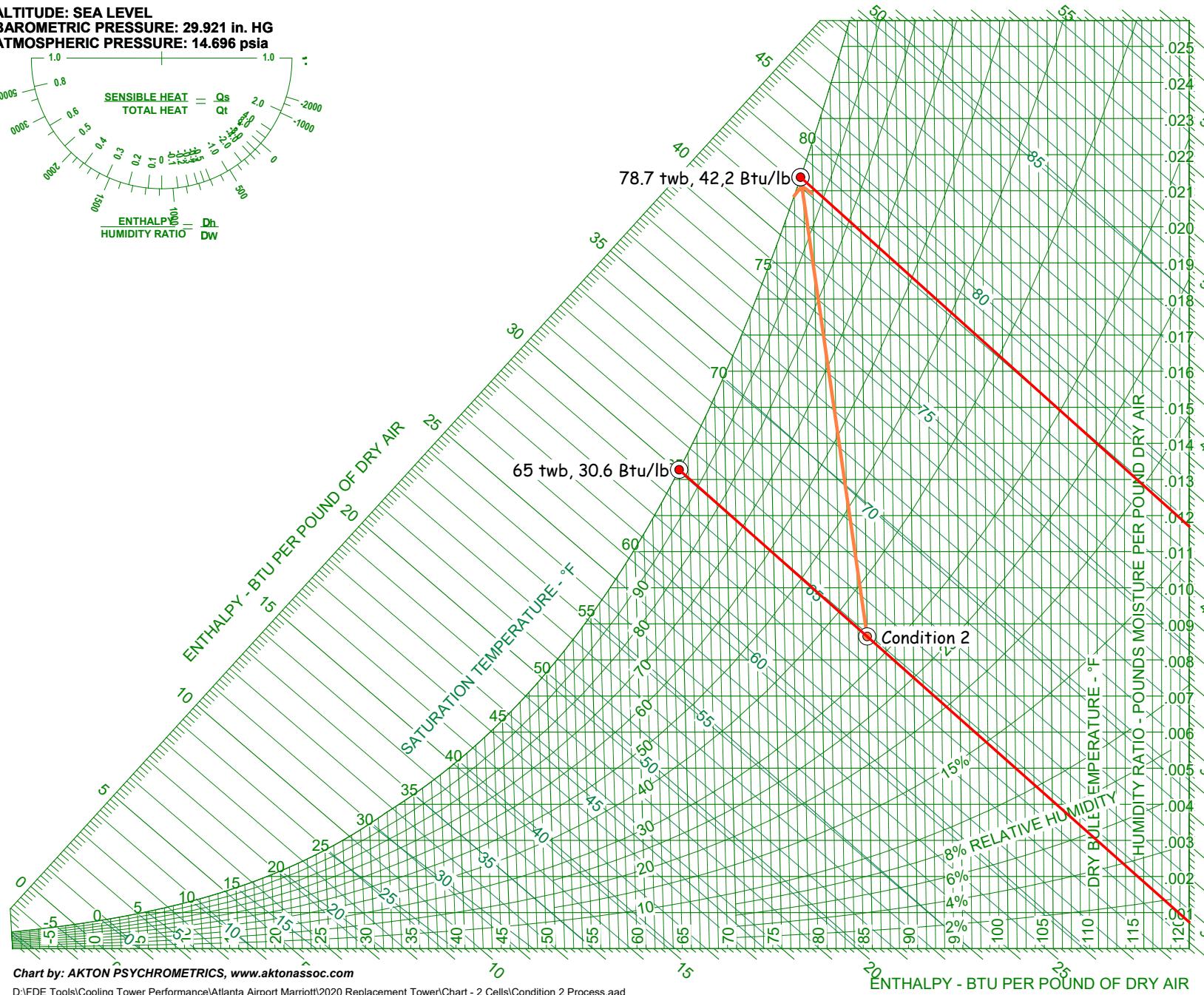
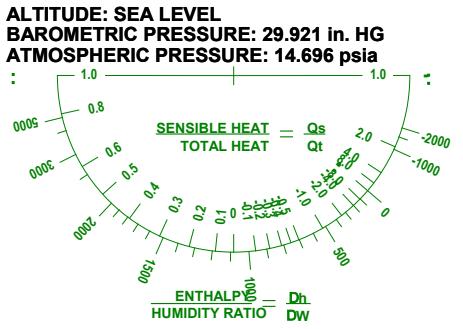


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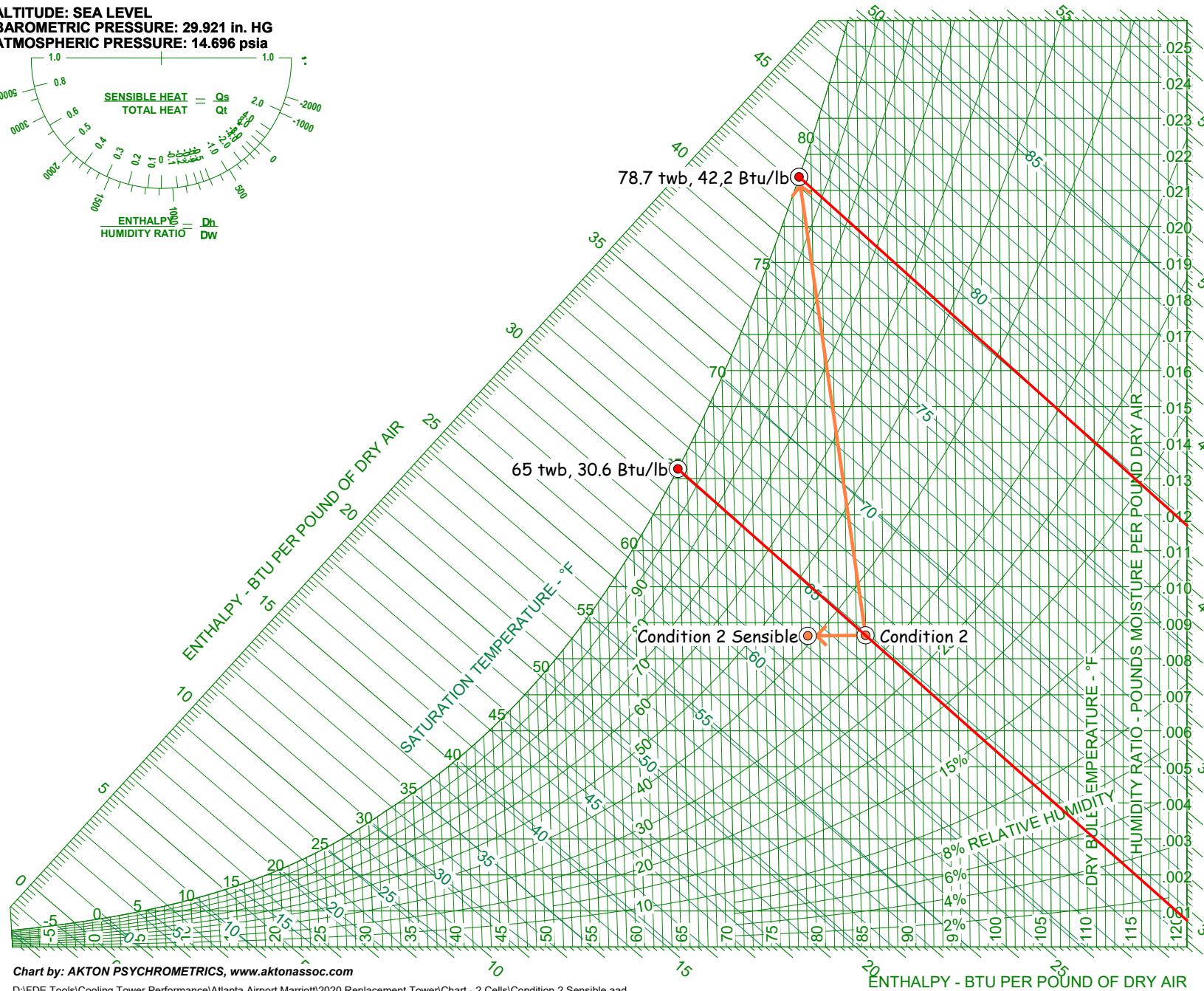
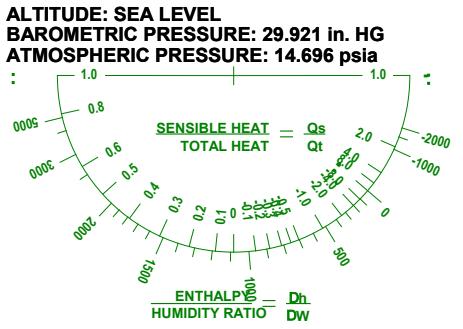
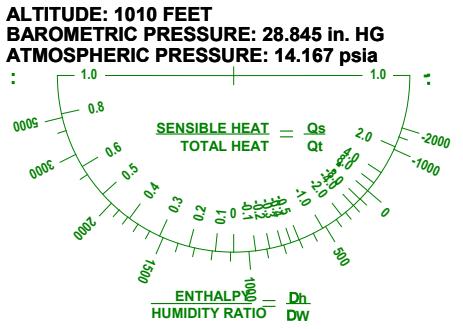


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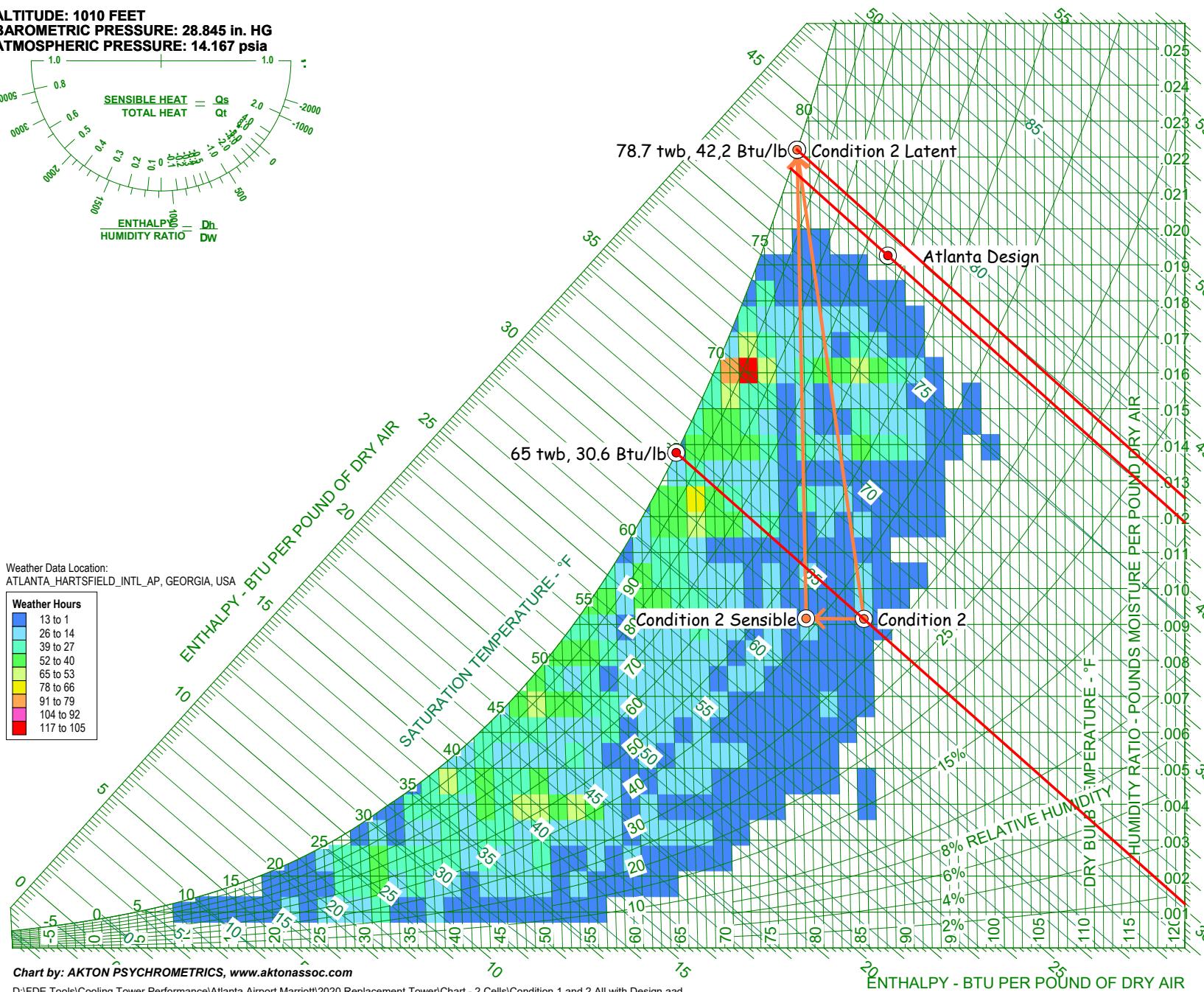


Weather Data Location:  
ATLANTA\_HARTSFIELD\_INTL\_AP, GEORGIA, USA

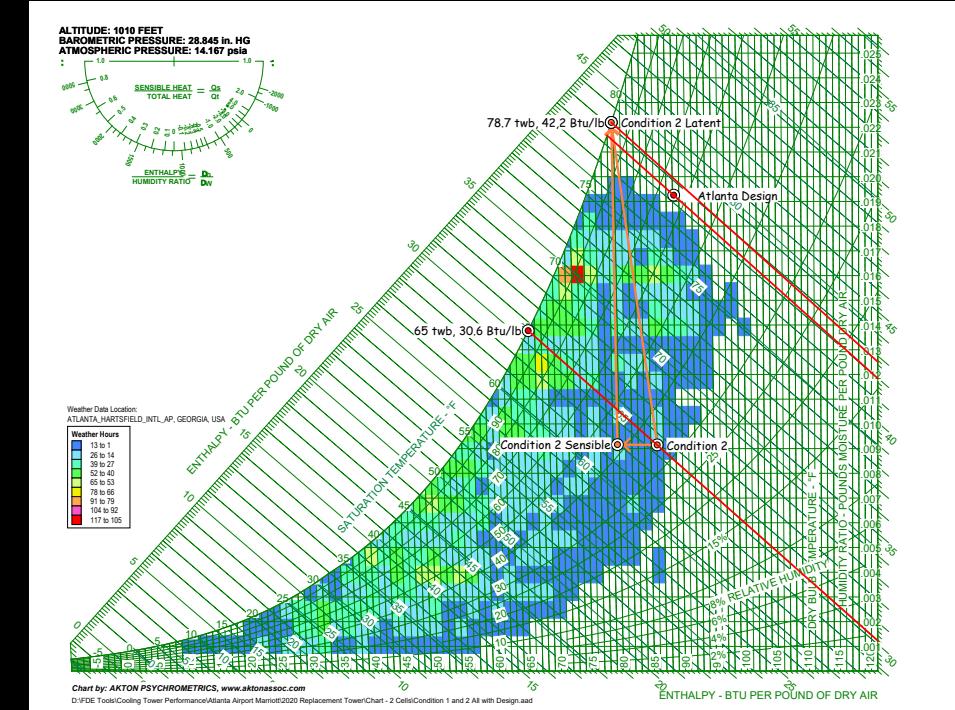
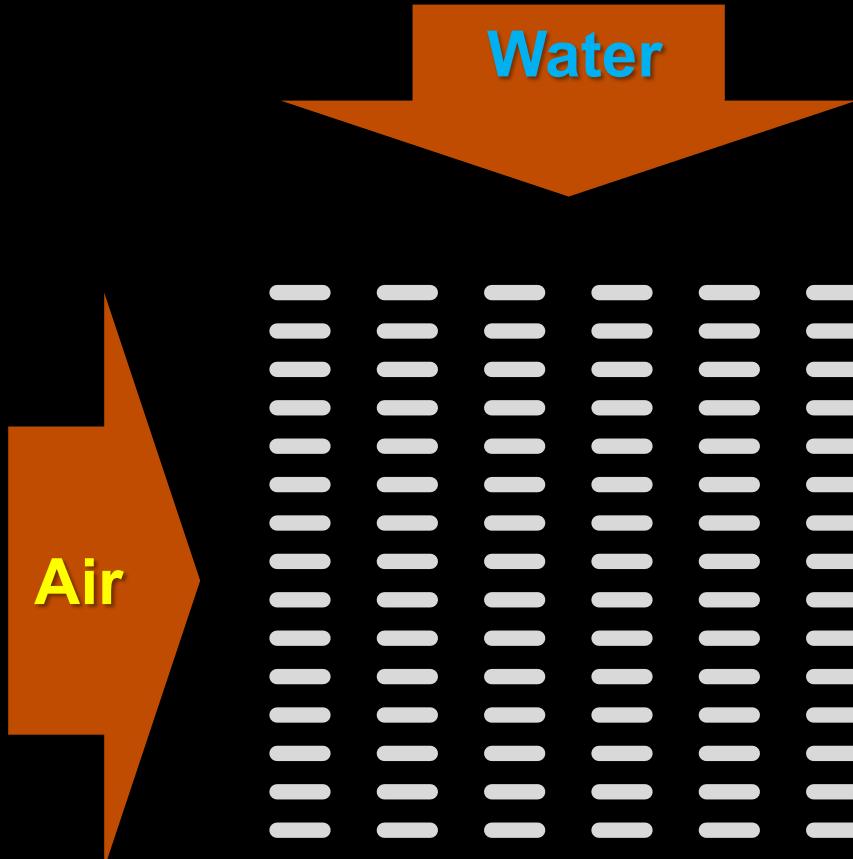
Weather Hours	
13 to 1	
26 to 14	
39 to 27	
52 to 40	
65 to 53	
78 to 66	
91 to 79	
104 to 92	
117 to 105	

Chart by: AKTON PSYCHROMETRICS, [www.aktonassoc.com](http://www.aktonassoc.com)

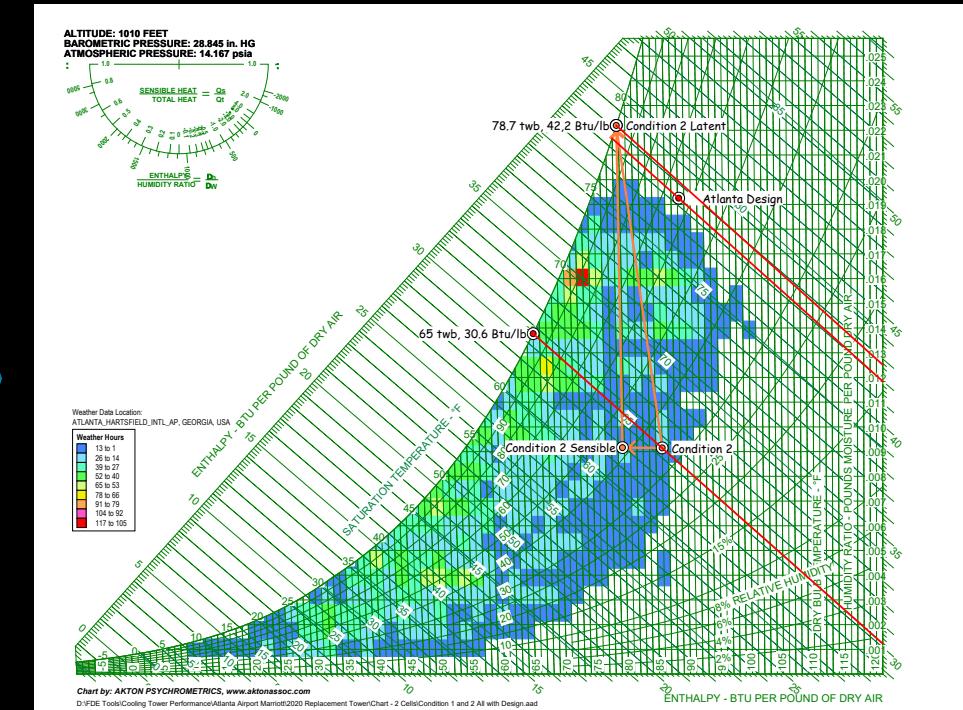
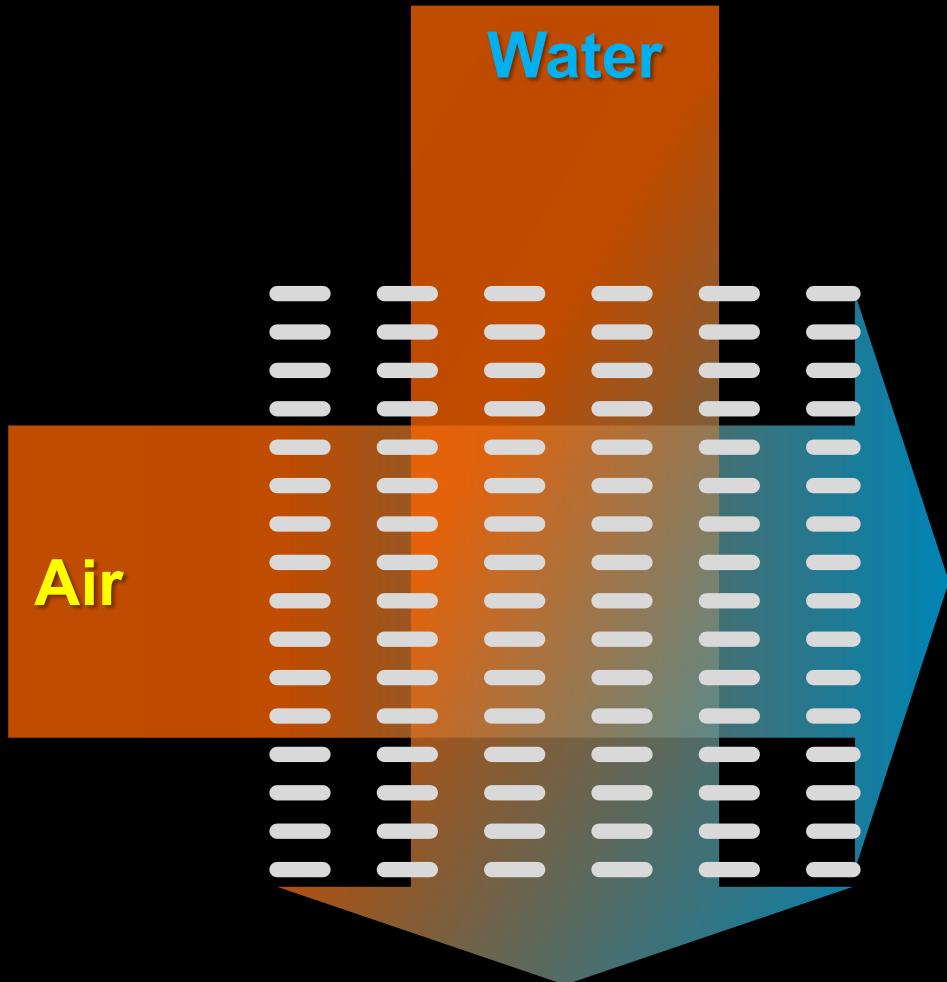
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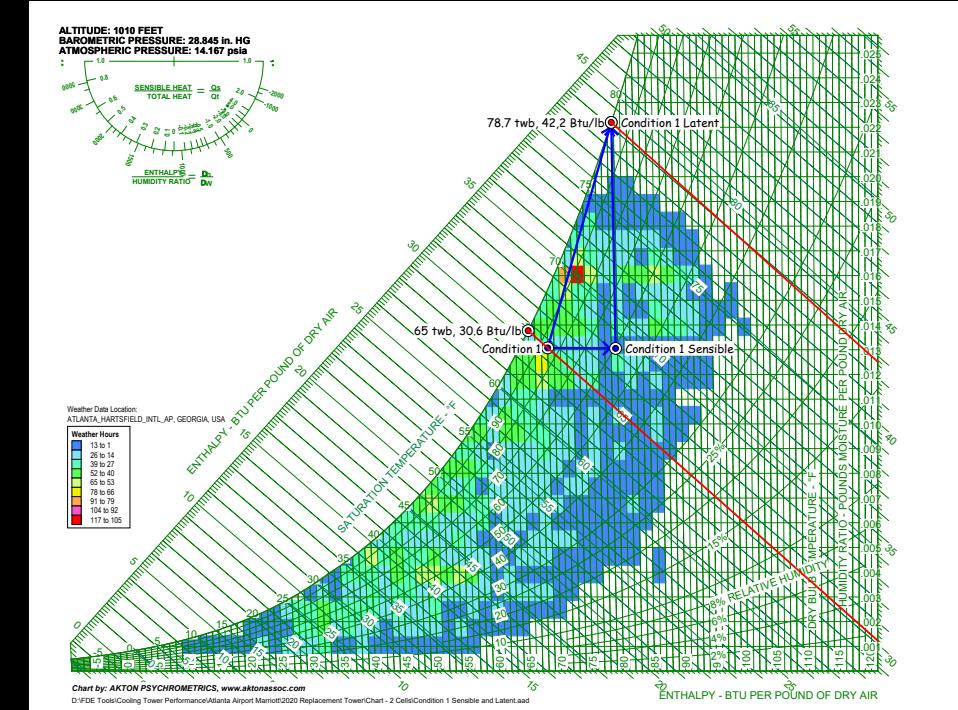
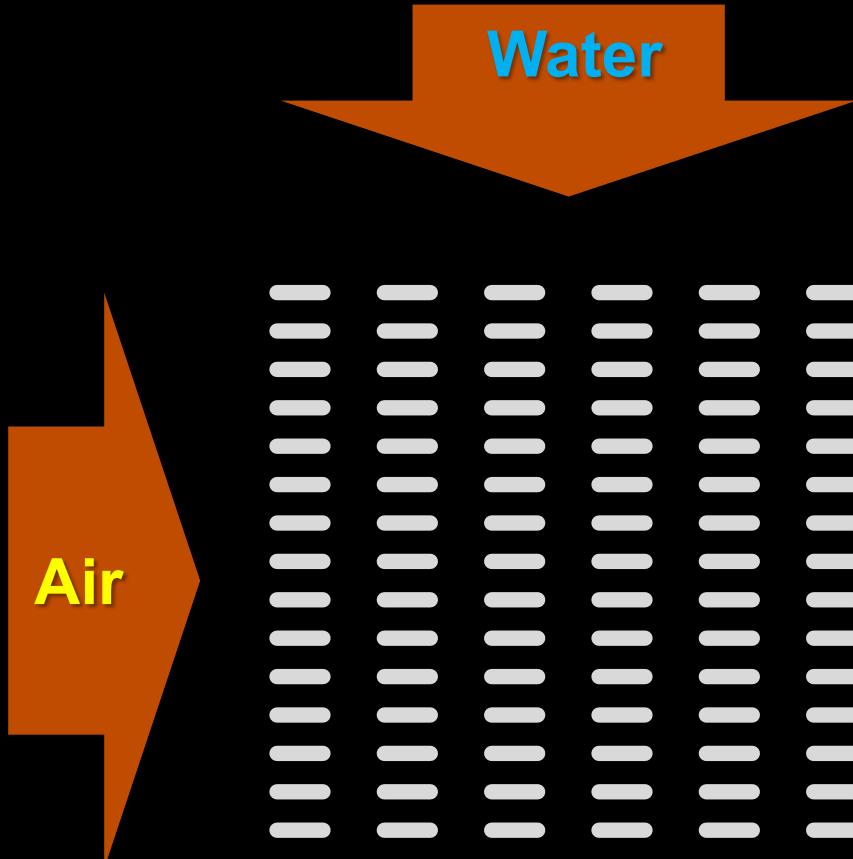
# It's Complicated Inside There



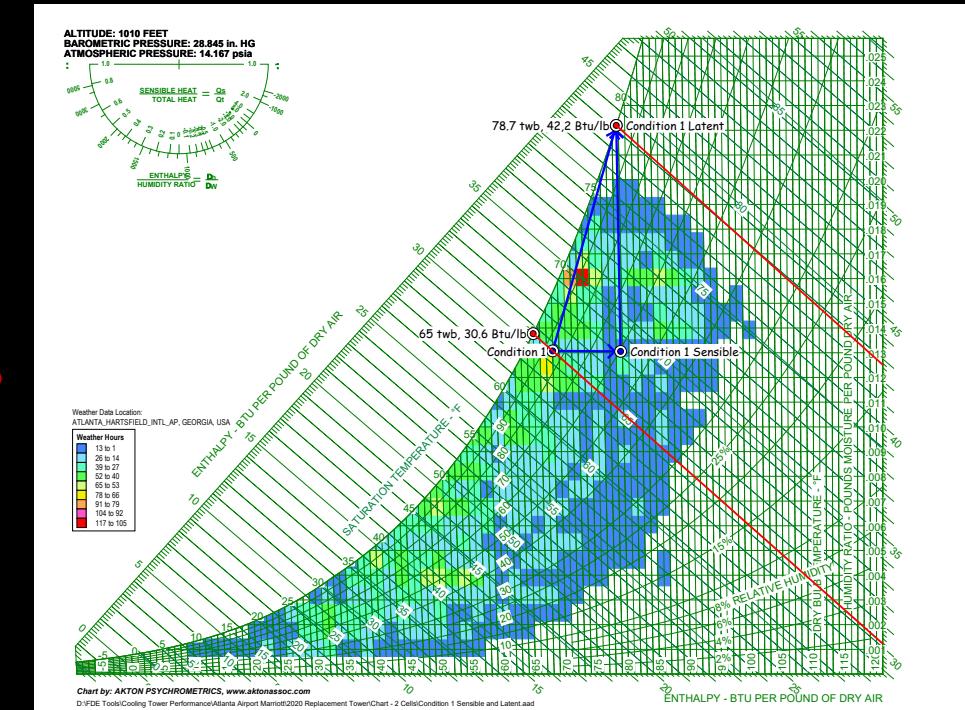
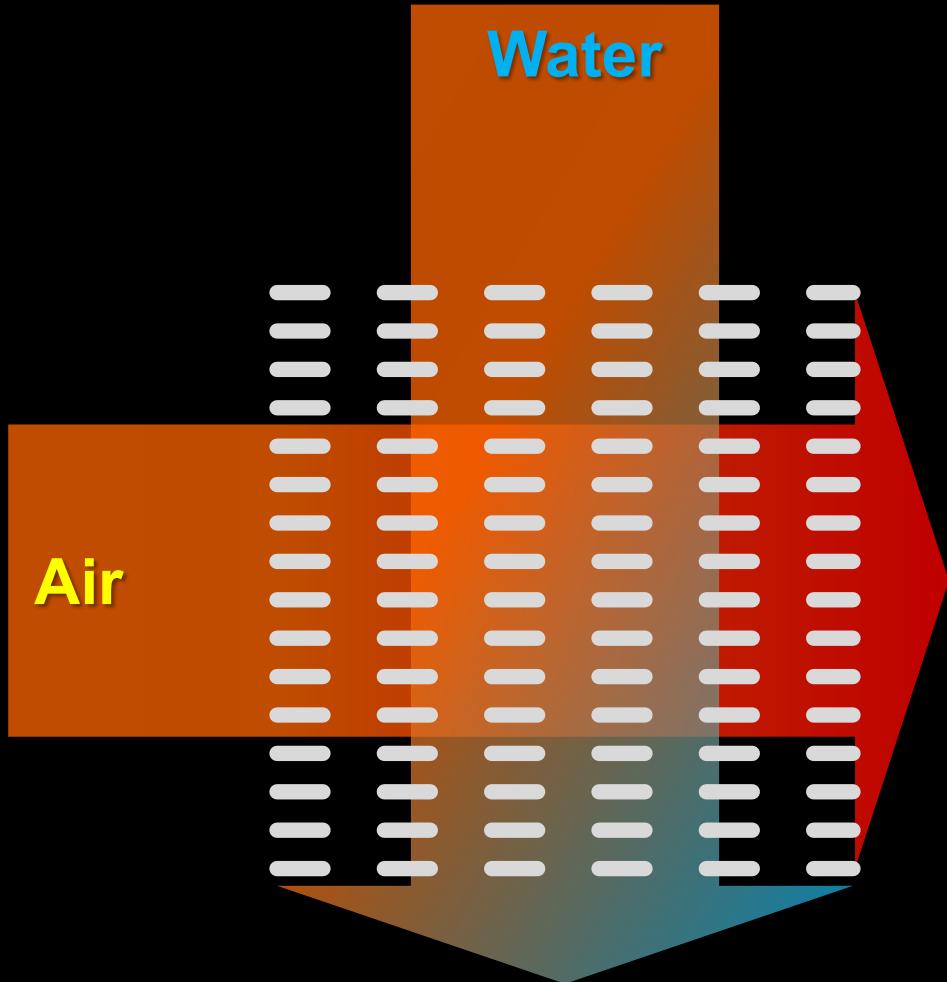
# It's Complicated Inside There



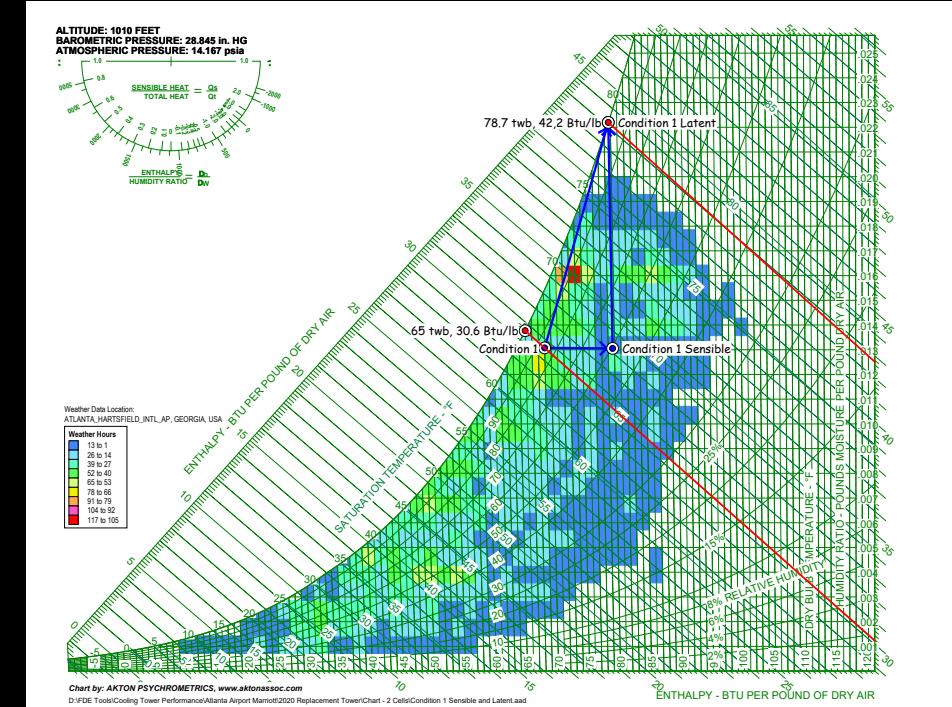
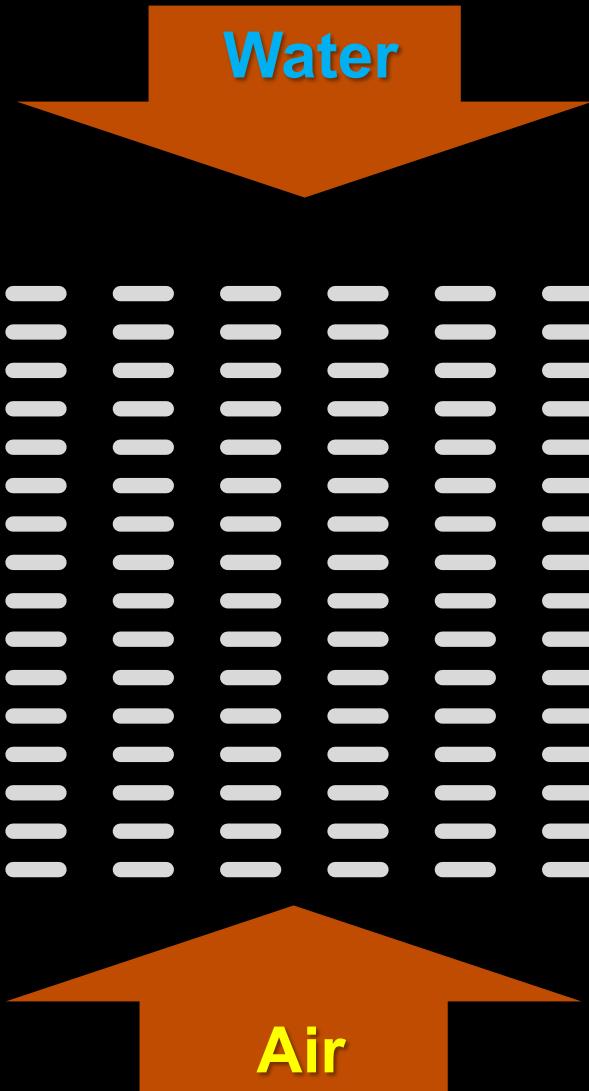
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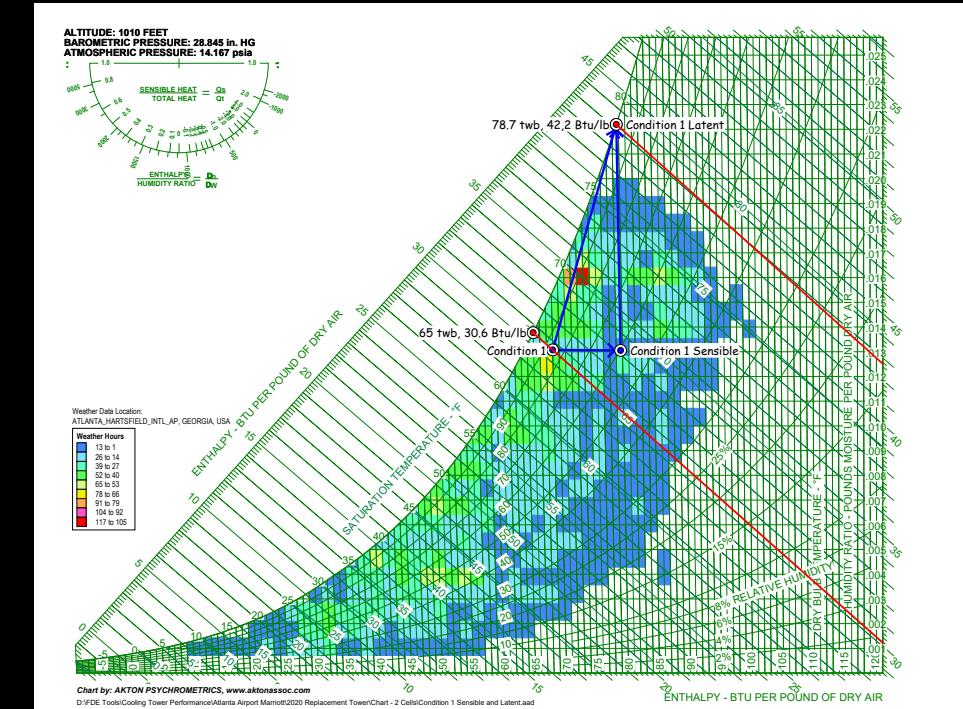
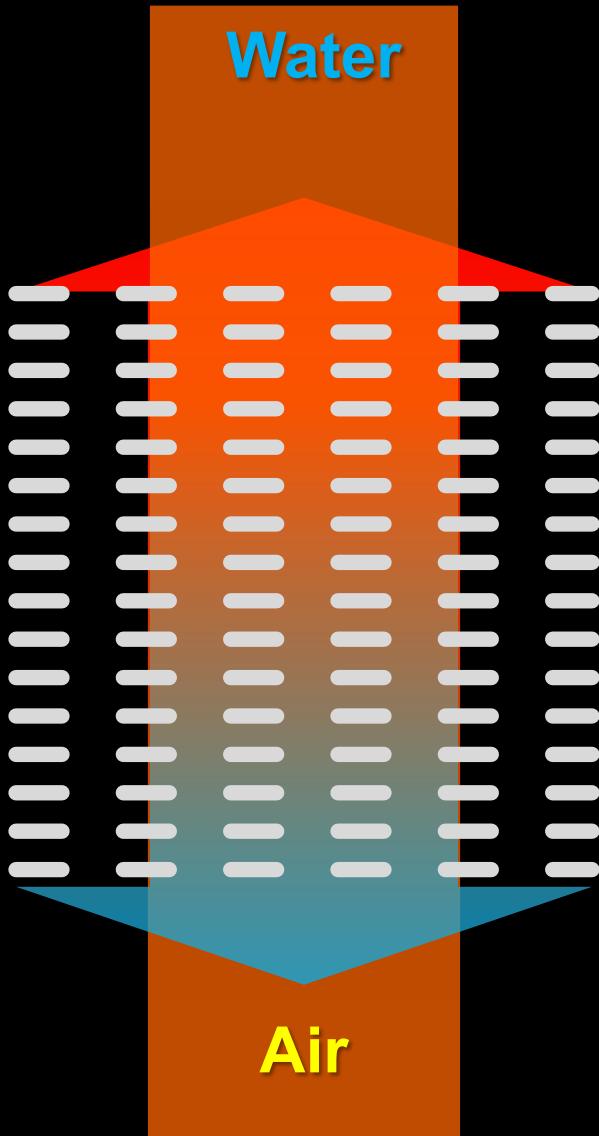
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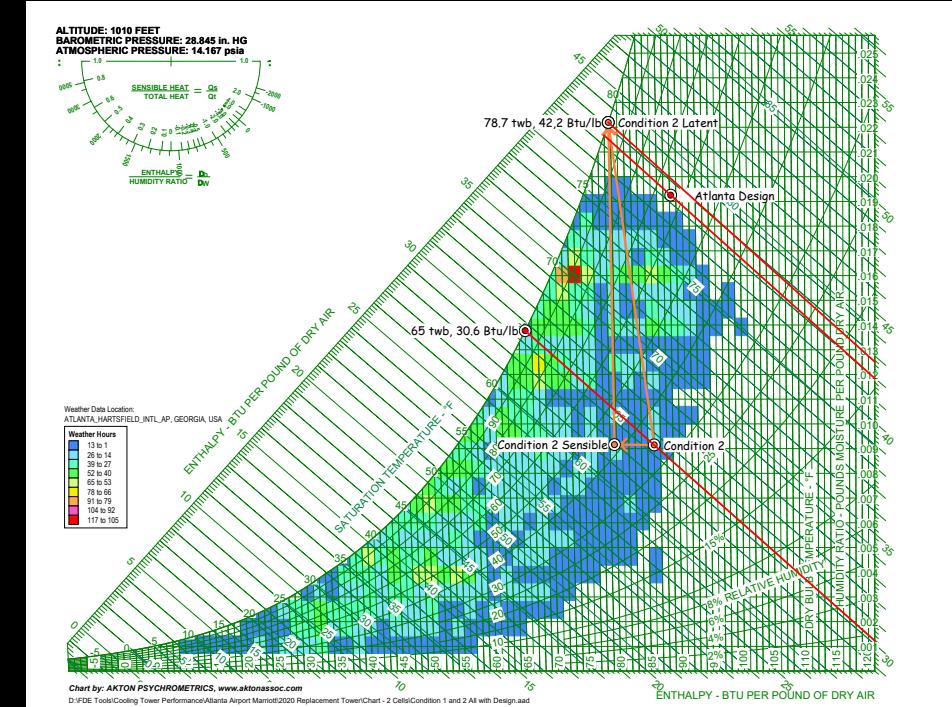
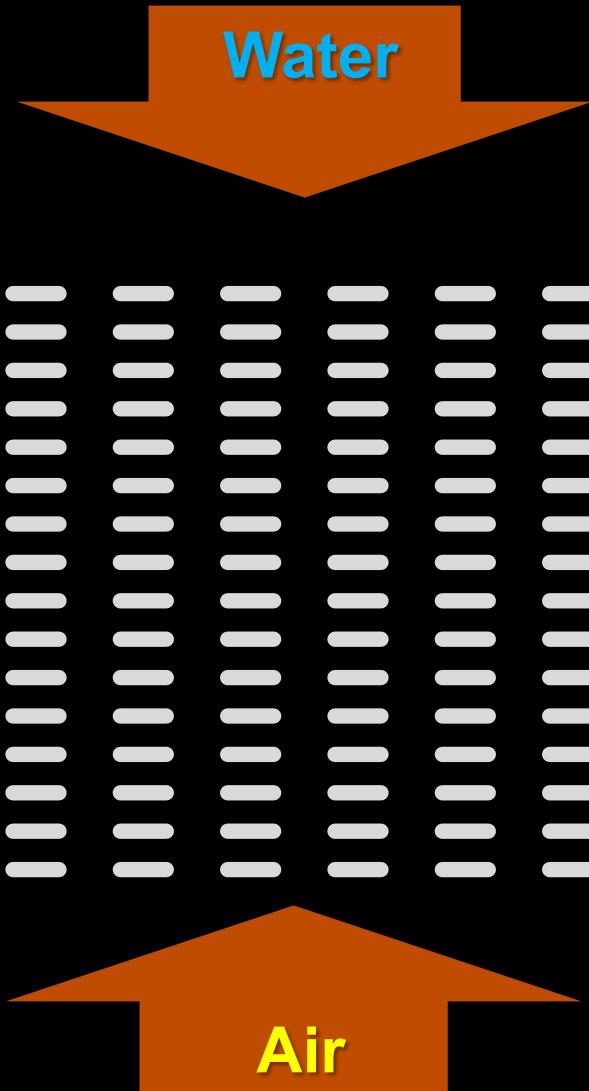
# It's Complicated Inside There



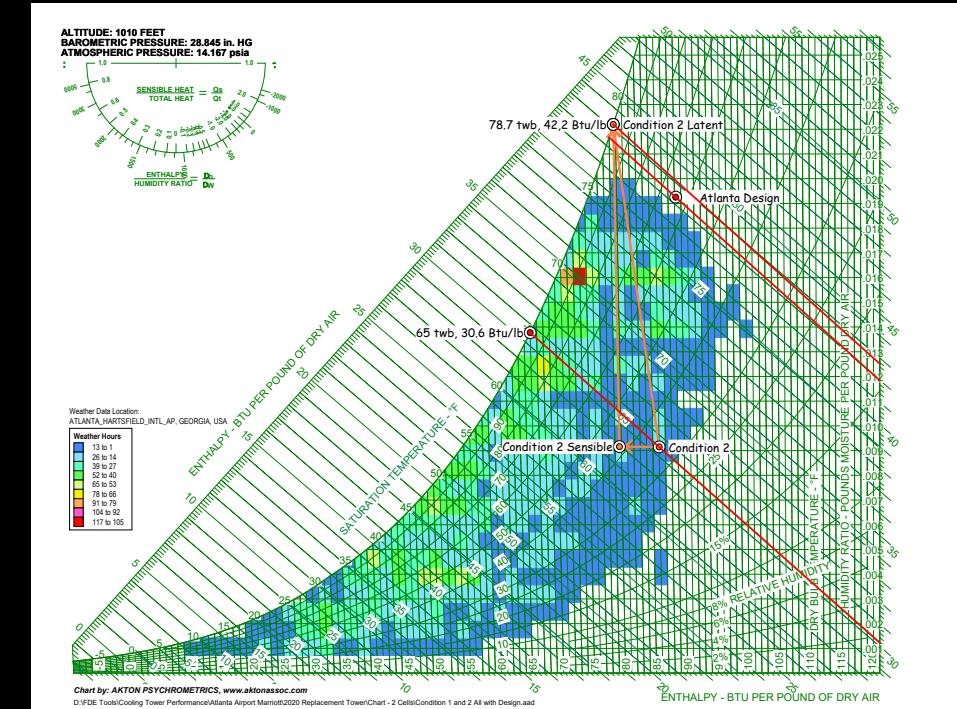
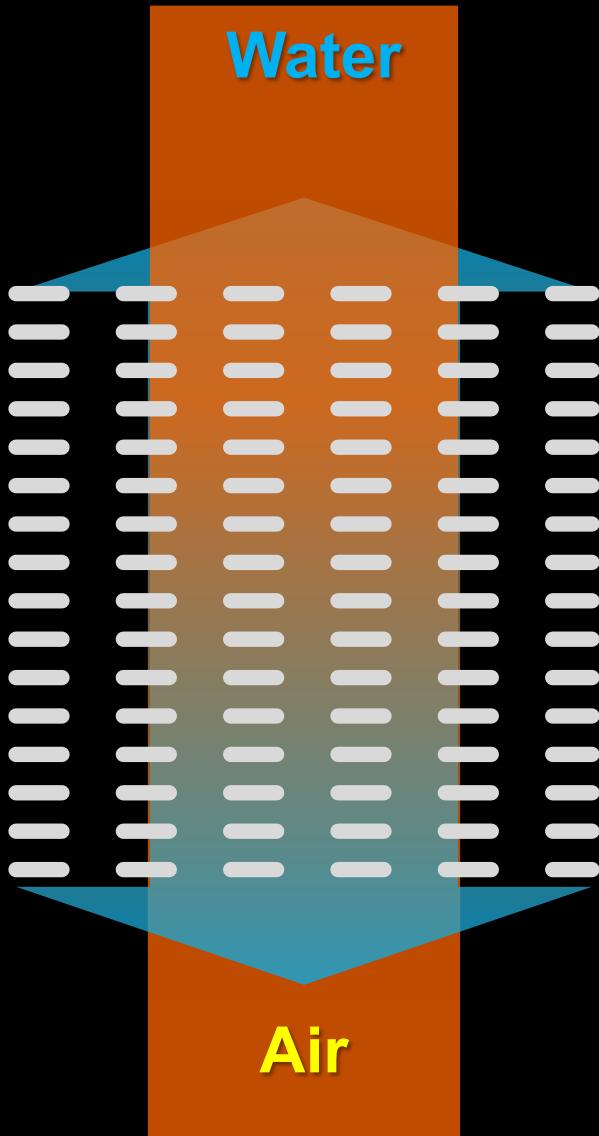
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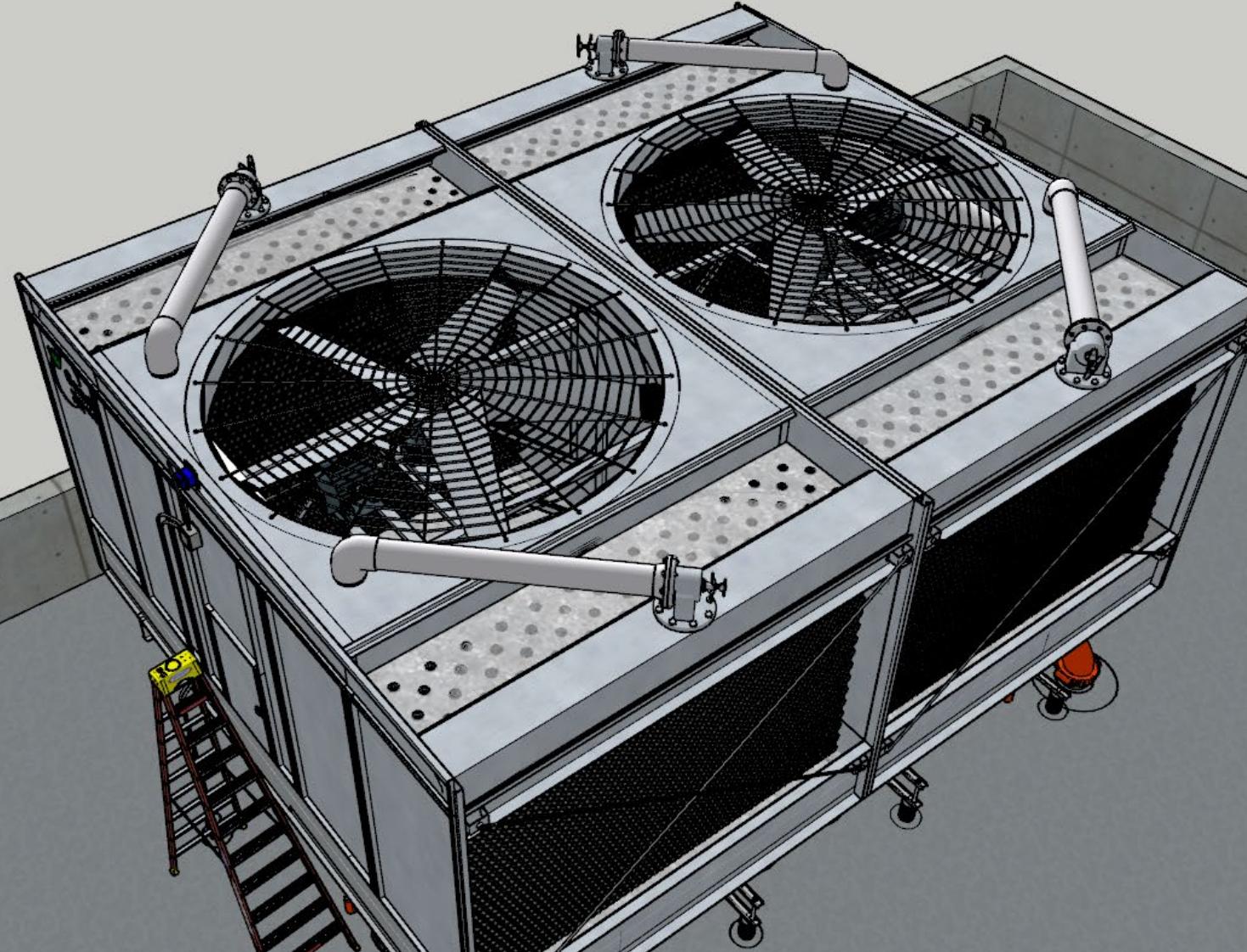


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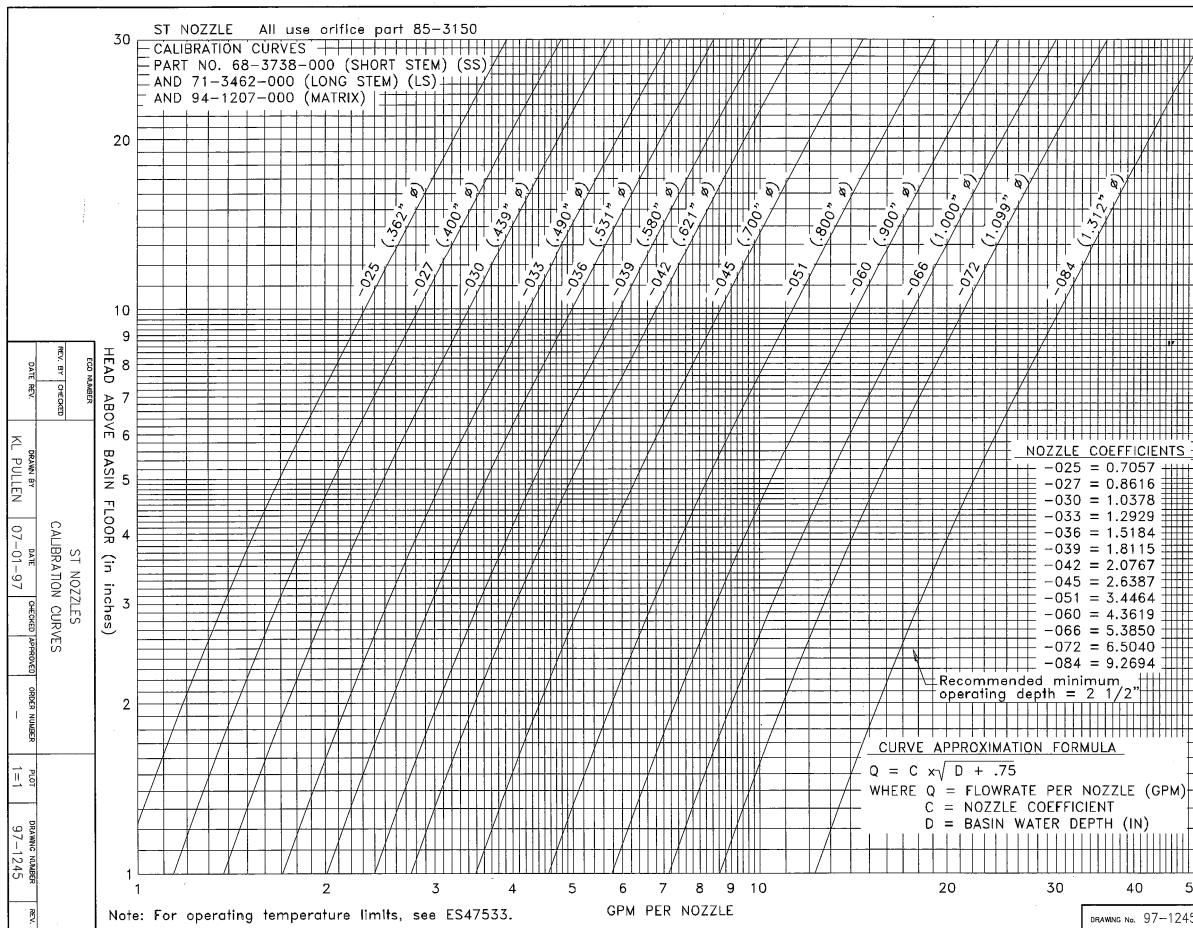


# Flow Distribution is Critical

<https://tinyurl.com/CoolingTowerFlowVariation>

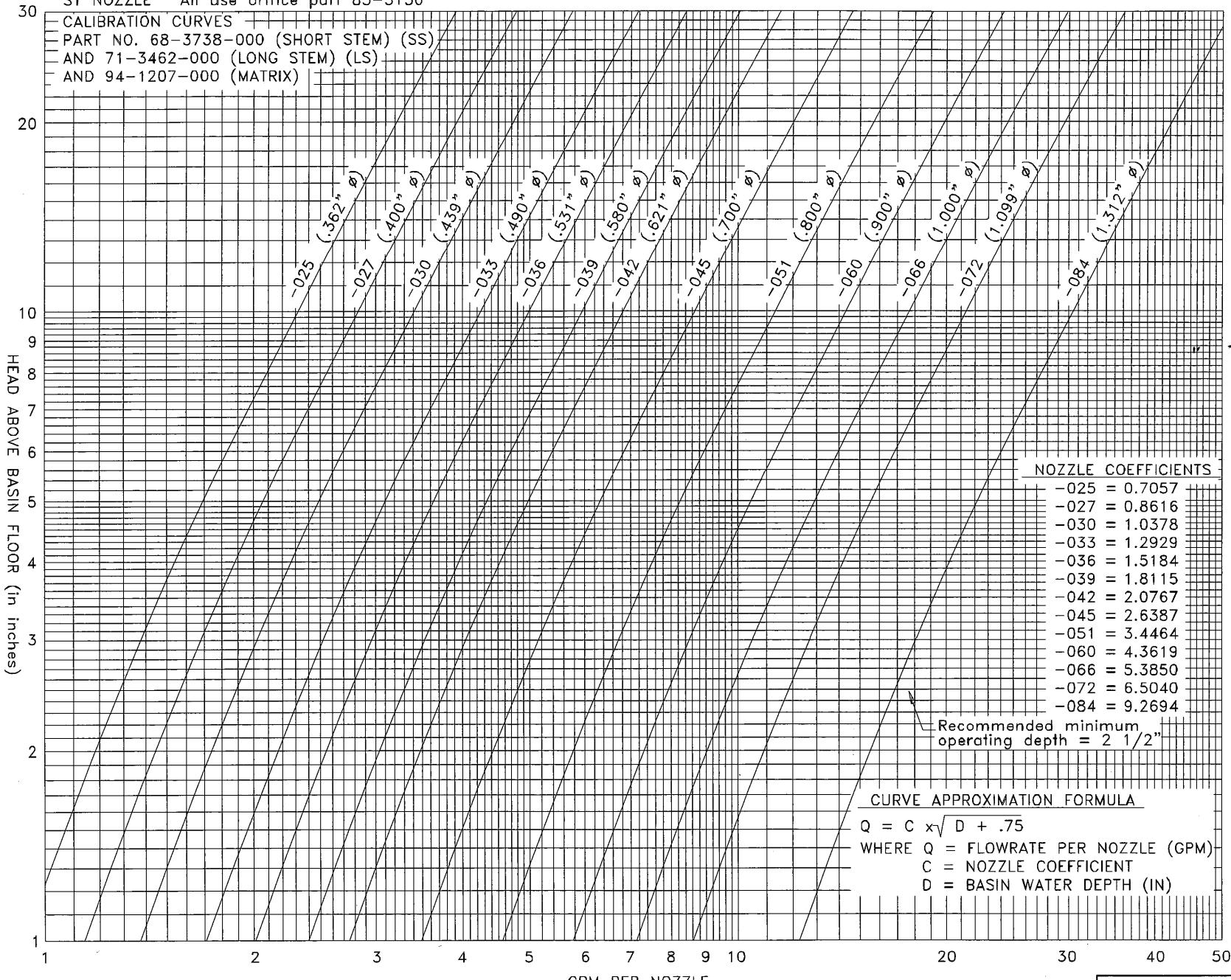


# Marley Nozzle Curves



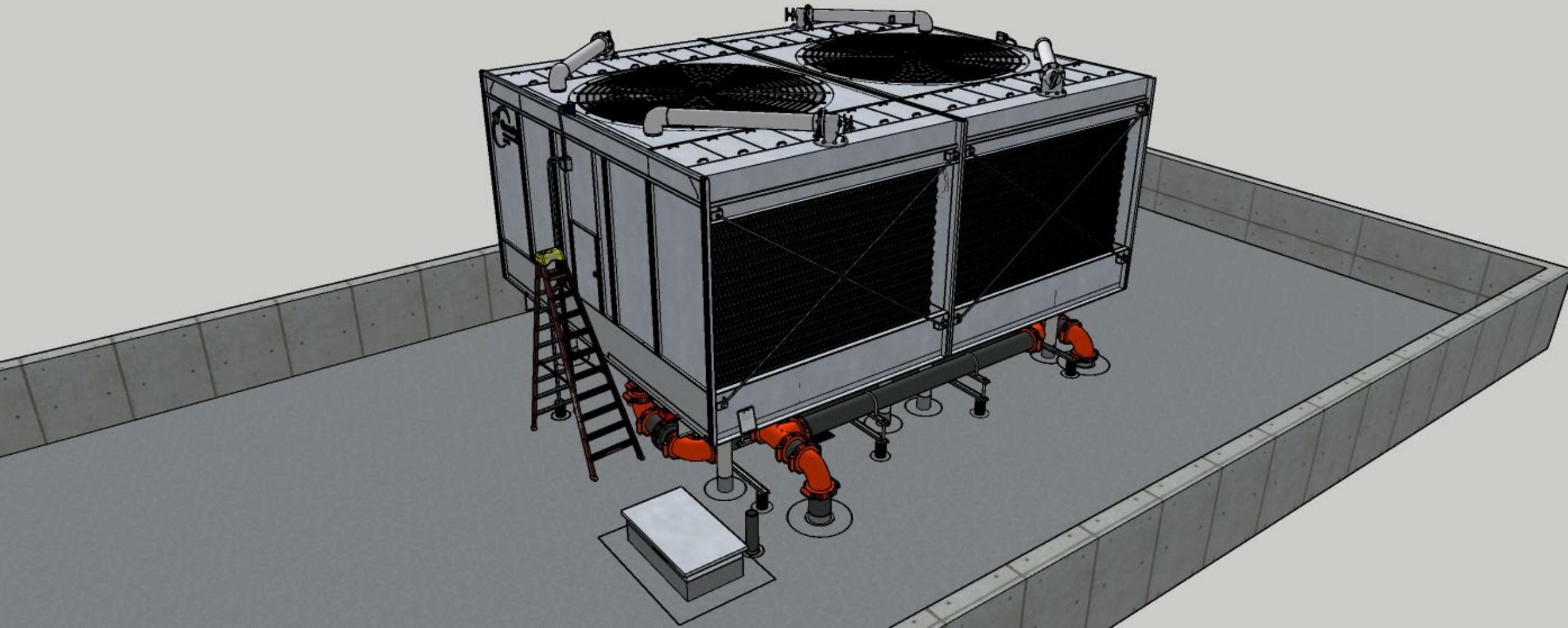
ST NOZZLE All use orifice part 85-3150

CALIBRATION CURVES  
PART NO. 68-3738-000 (SHORT STEM) (SS)  
AND 71-3462-000 (LONG STEM) (LS)  
AND 94-1207-000 (MATRIX)



# Basin Water Level Control; a Game of Inches

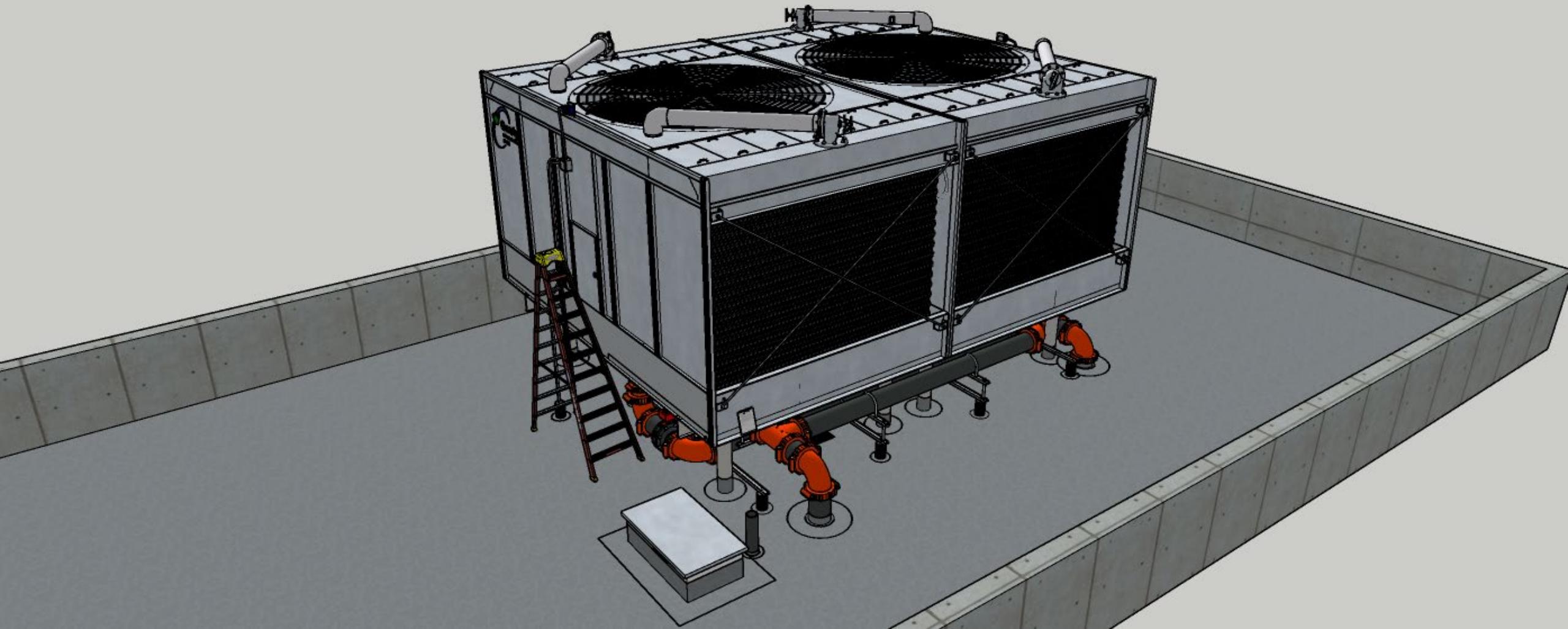
<https://tinyurl.com/BasinLevelManagement>



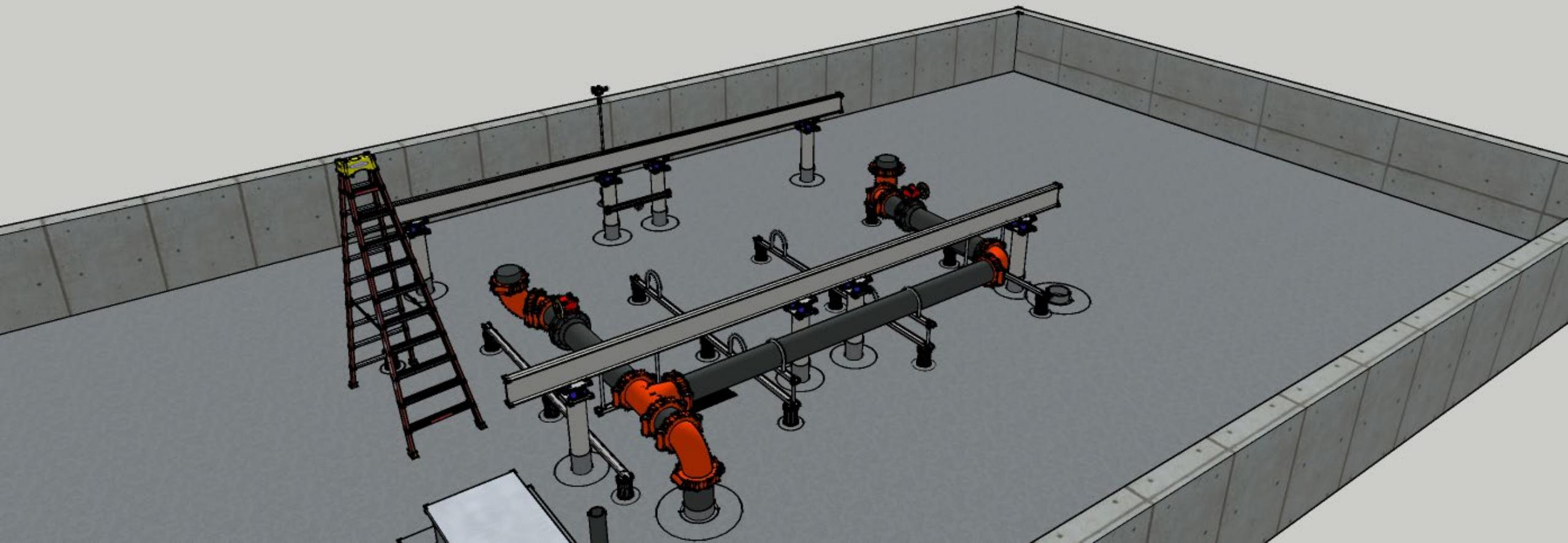
# A Few Cold Basin Level Control Questions

1. How would you figure out the minimum water level in the tower (the level that would open the make-up valve)?
2. What sets the level at which you would close the make-up valve?
3. What sets the maximum water level in the tower (the level that would cause water to run out the overflow)?

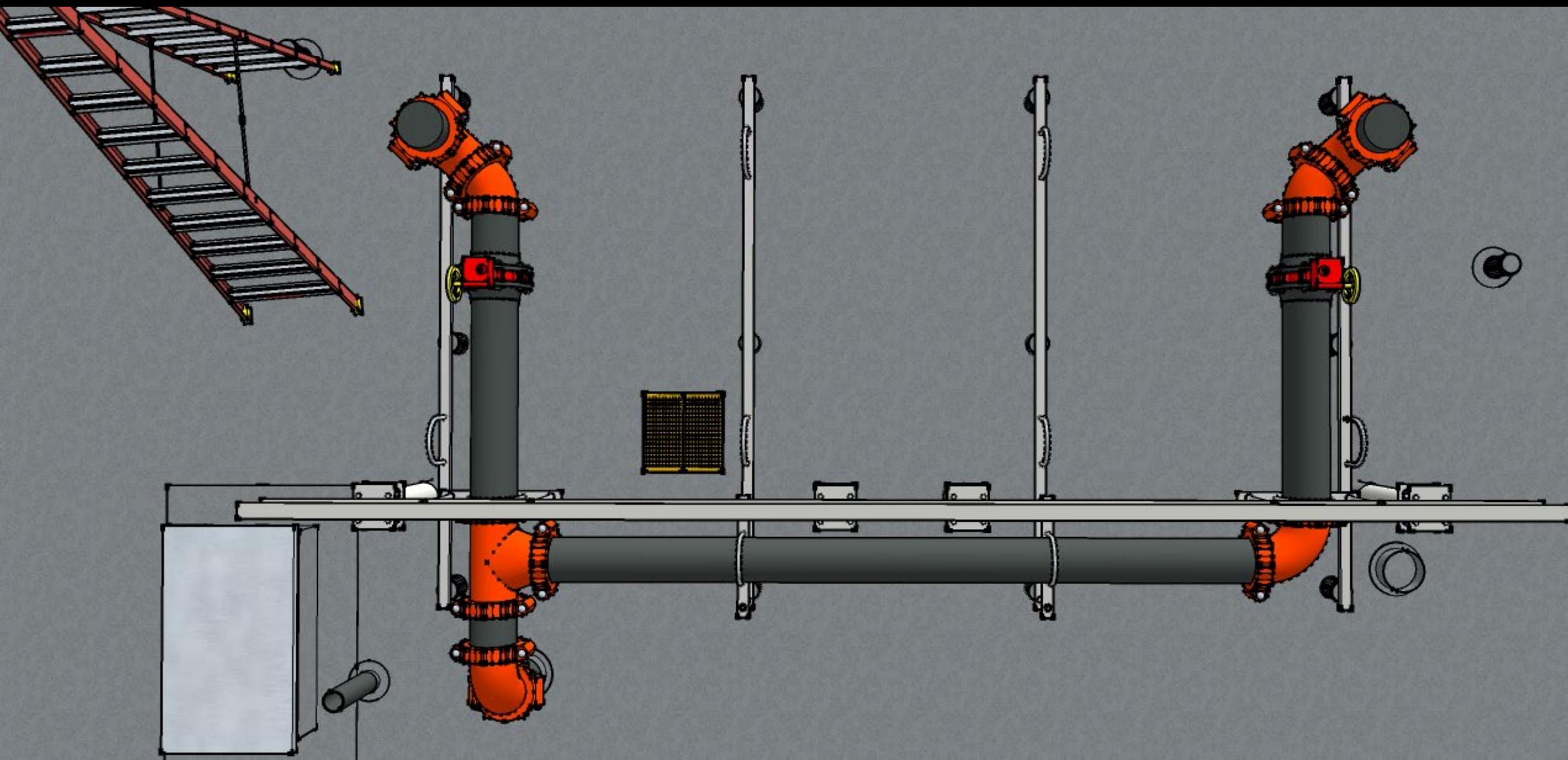
# Cooling Tower Overview



# CW Supply Piping

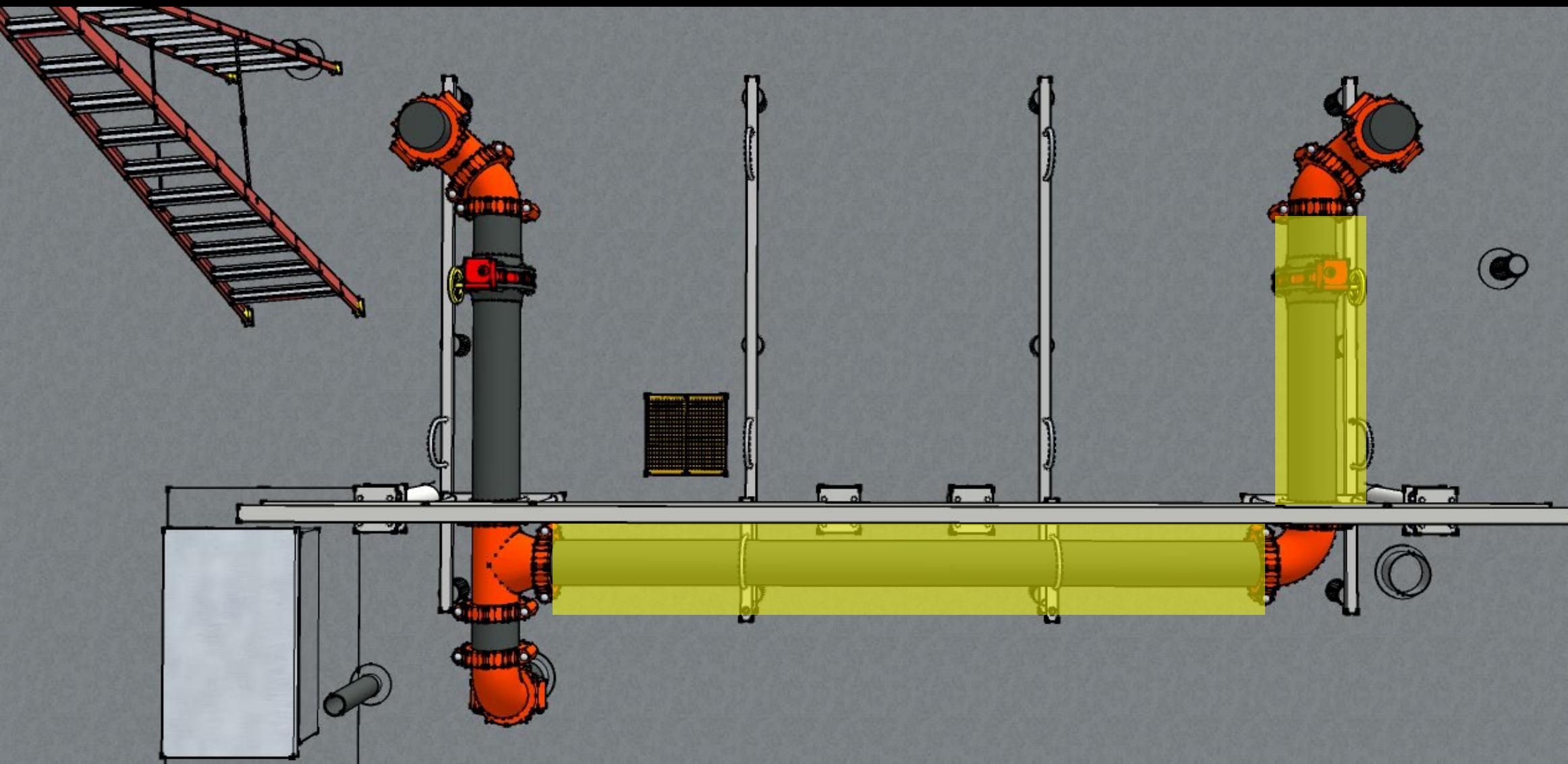


# CW Supply Piping



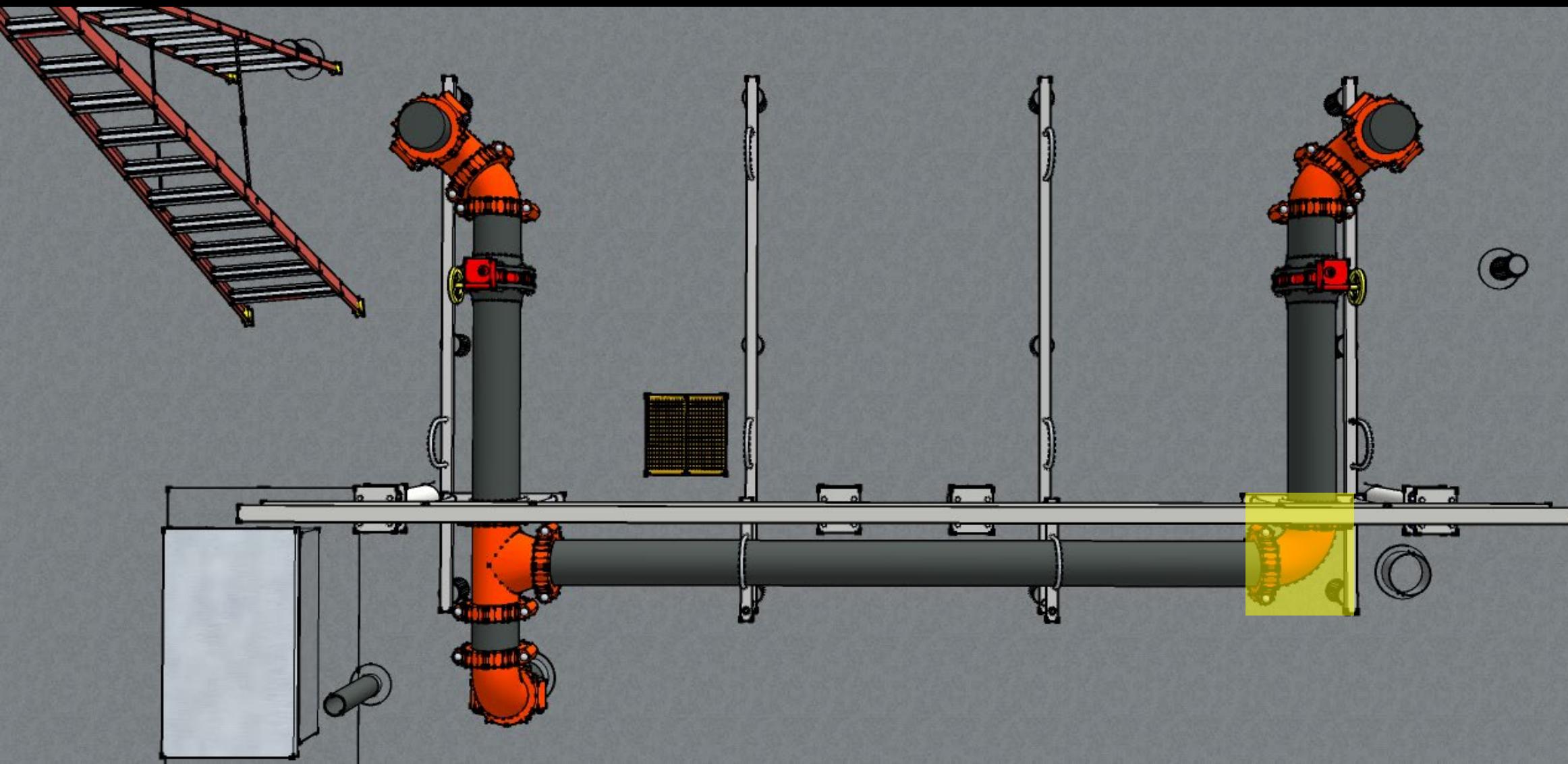
# CW Supply Piping

Item	Flow rate, gpm	Pressure drop - ft.w.c.	Friction Rate, ft.w.c./100 ft.	Equivalent feet of pipe	Equivalent Feet per Elbow	Equivalent Elbows
Pipe	535	0.01	0.07	15.75		

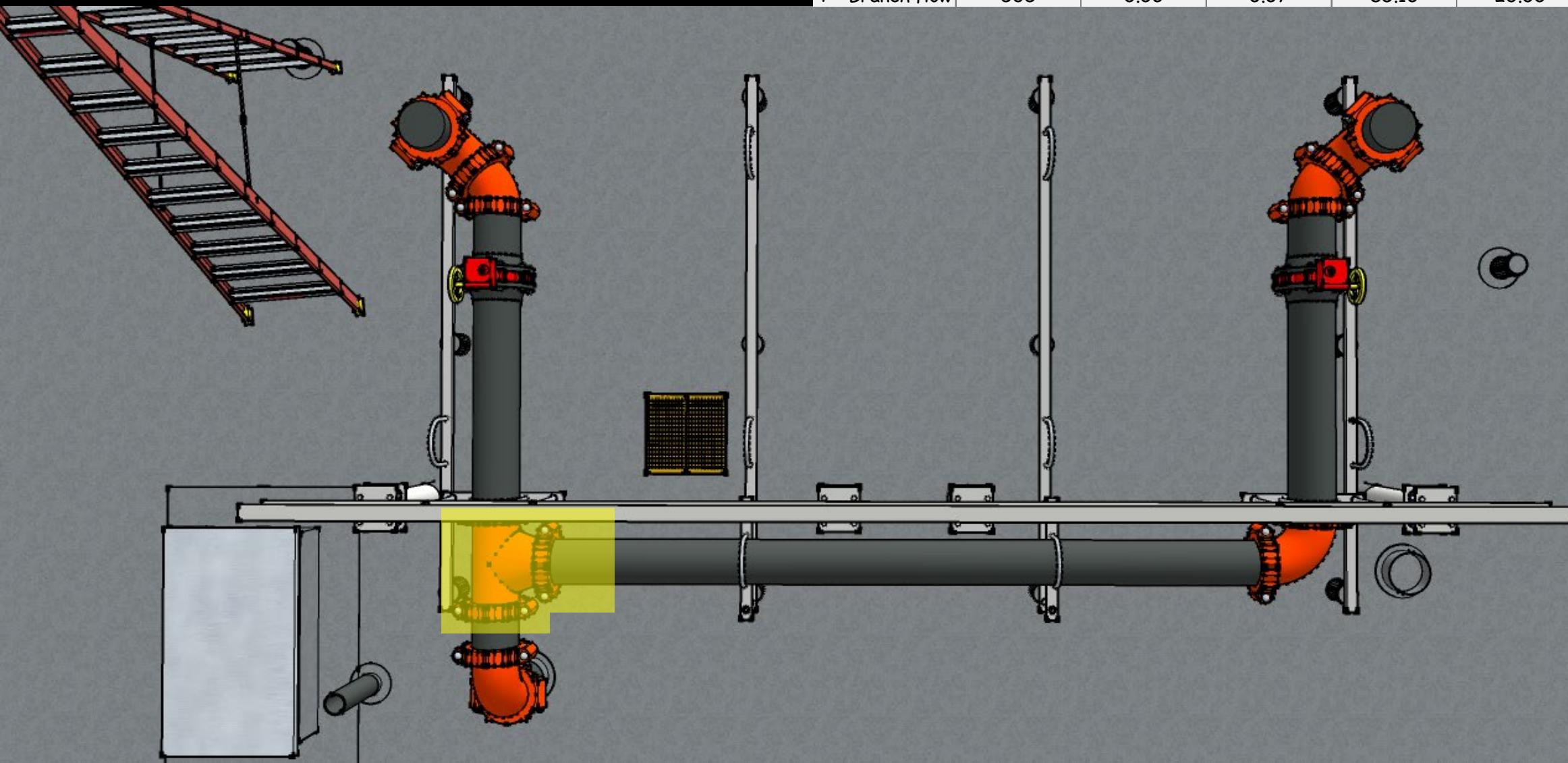


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LR Elbow	535	0.02	0.07	23.00	23.00	1.00

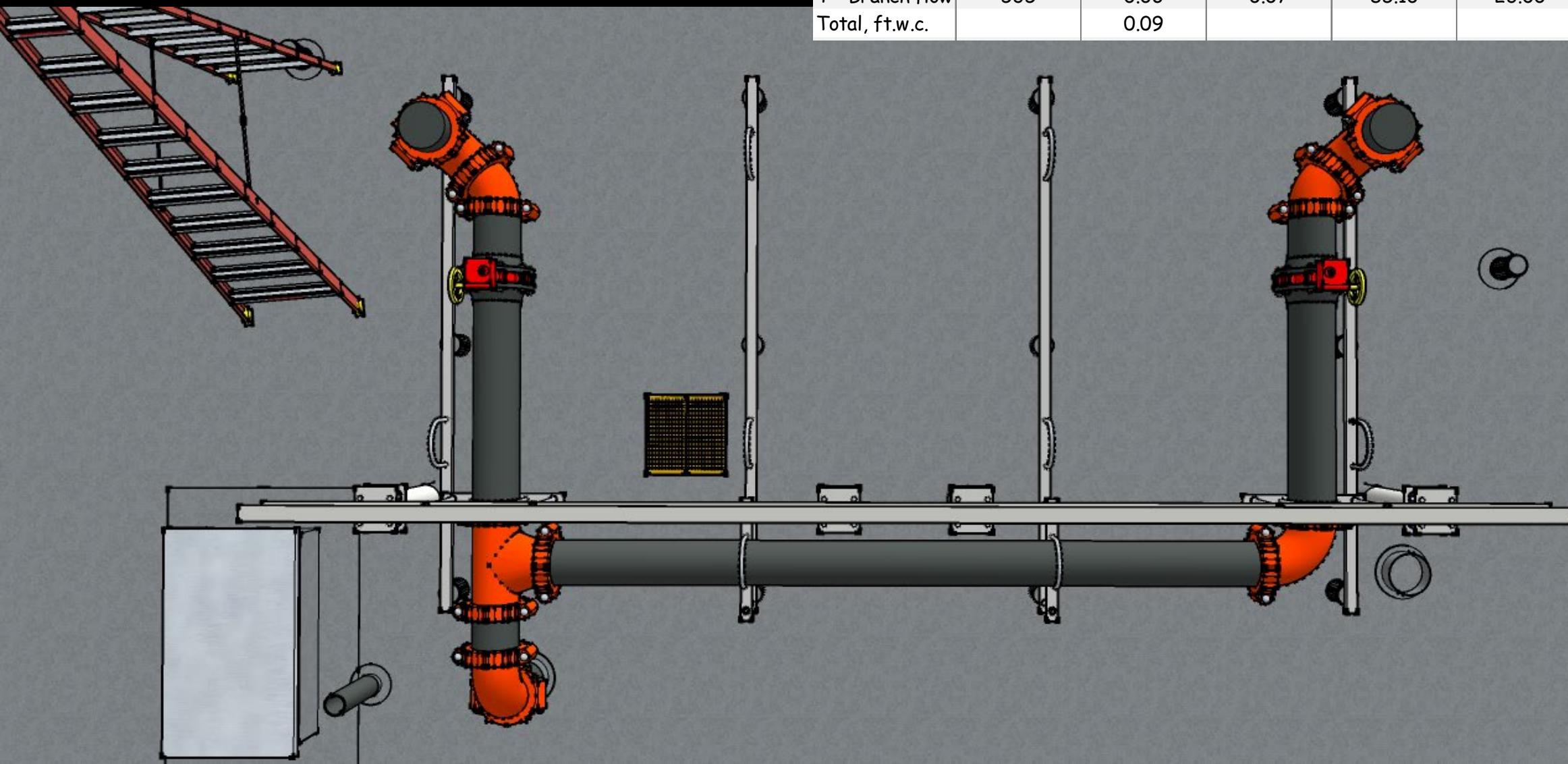


# CW Supply Piping



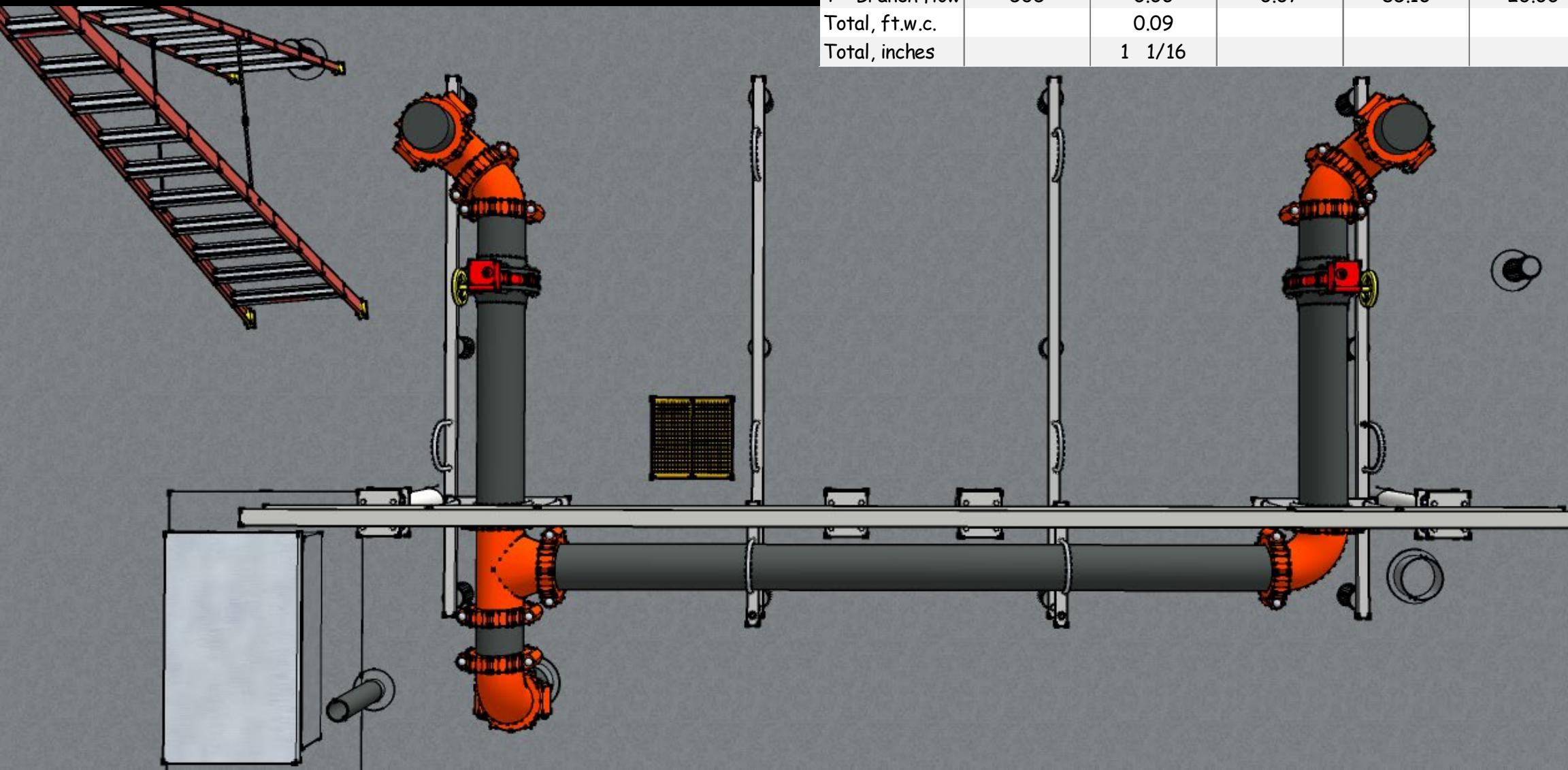
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LR Elbow	535	0.02	0.07	23.00	23.00	1.00
T - Branch flow	535	0.06	0.07	85.10	23.00	3.70

# CW Supply Piping



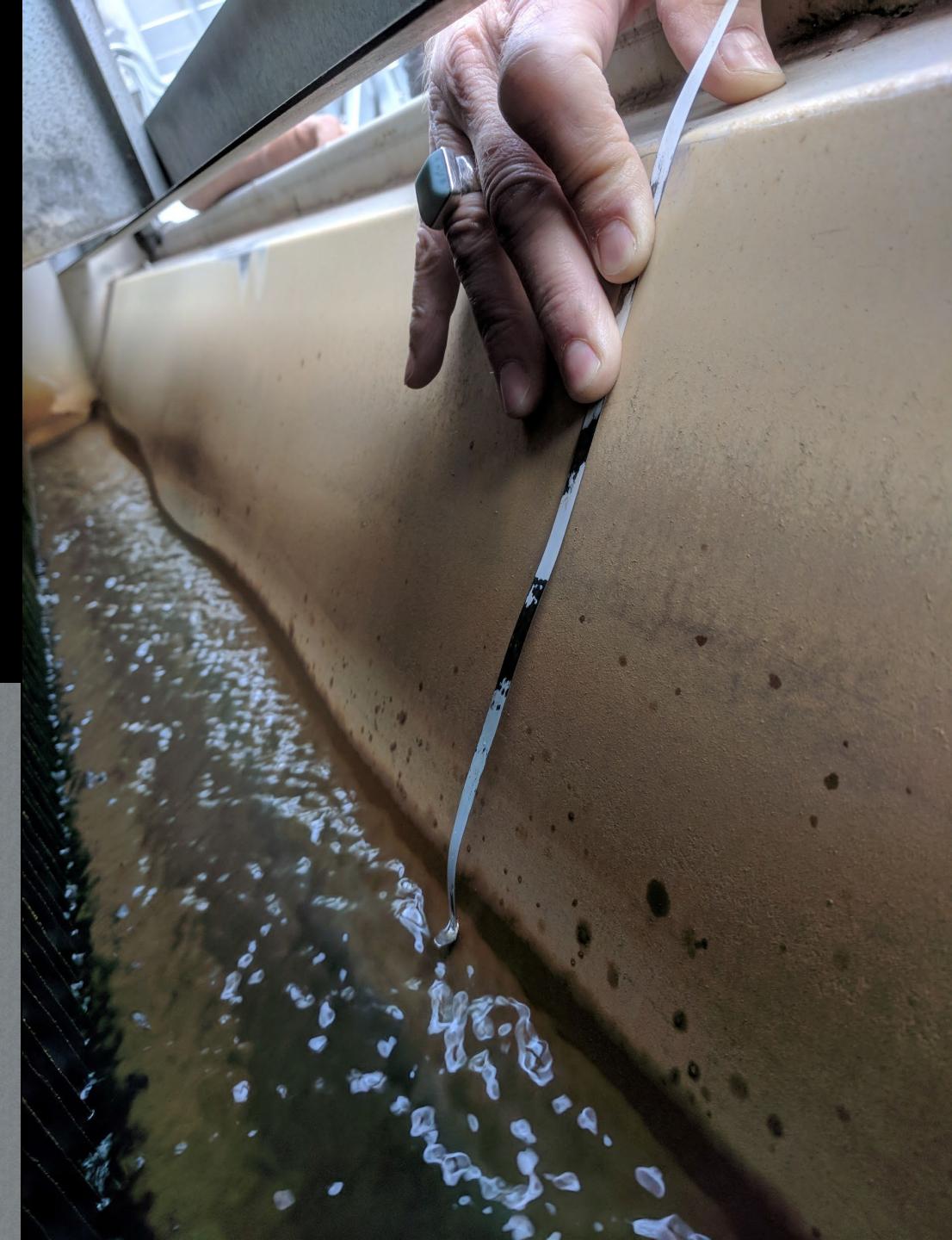
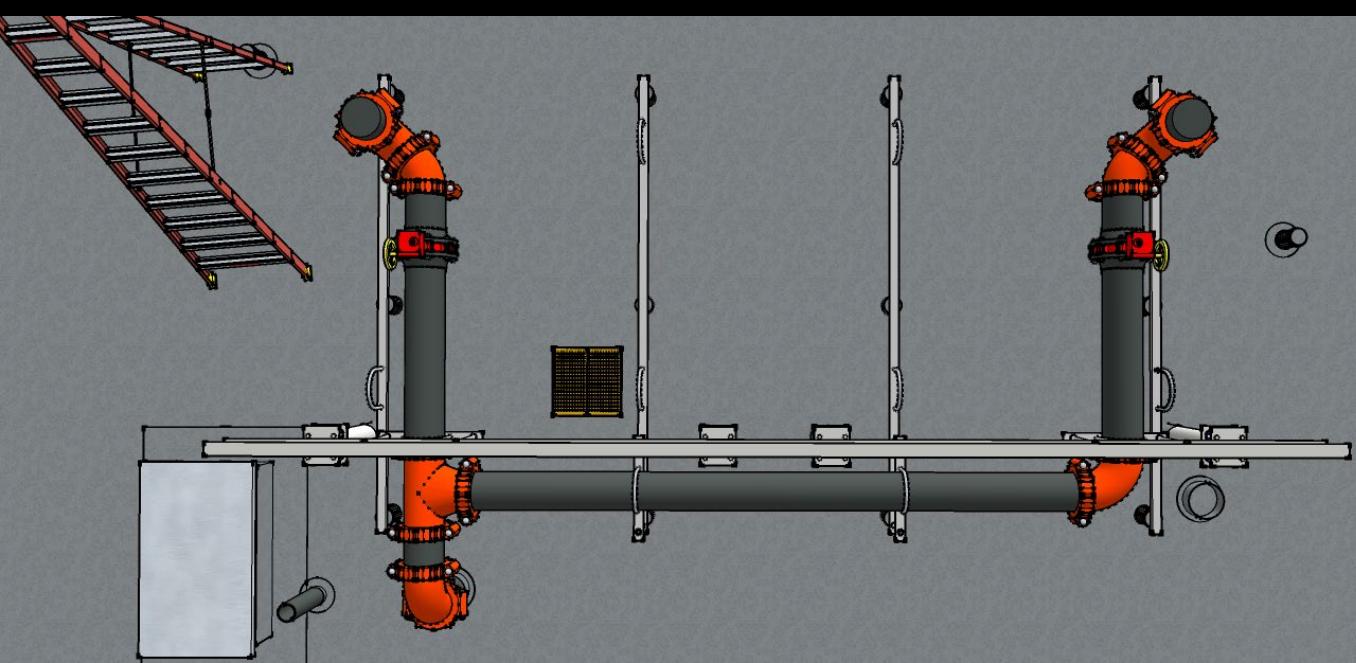
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Total, ft.w.c.		0.09				

# CW Supply Piping

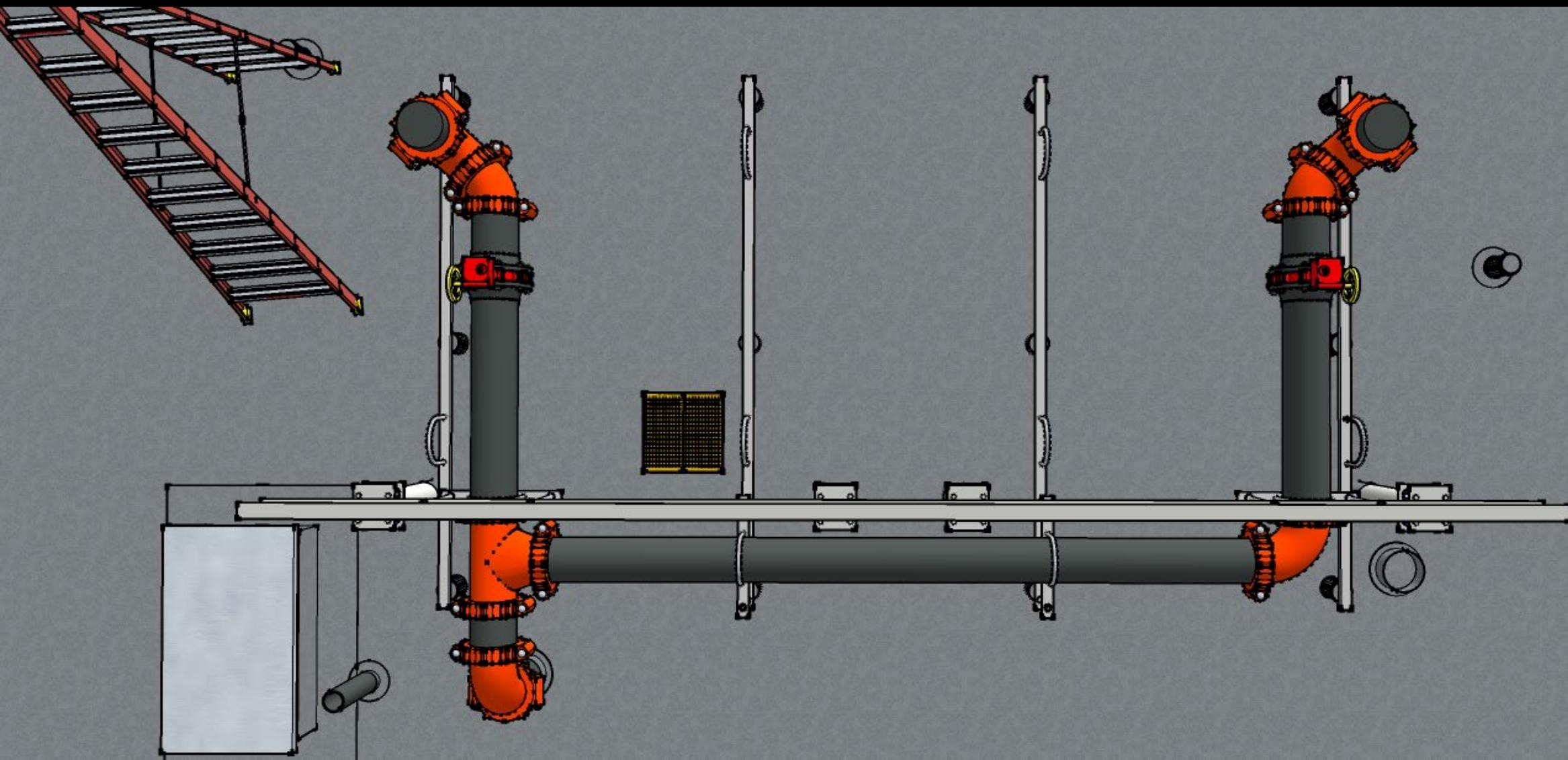


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T - Branch flow	535	0.06	0.07	85.10	23.00	3.70
Total, ft.w.c.		0.09				
Total, inches	1 1/16					

# CW Supply Piping



# CW Supply Piping





# A Common Cooling Tower Opportunity



# Inside the Tower



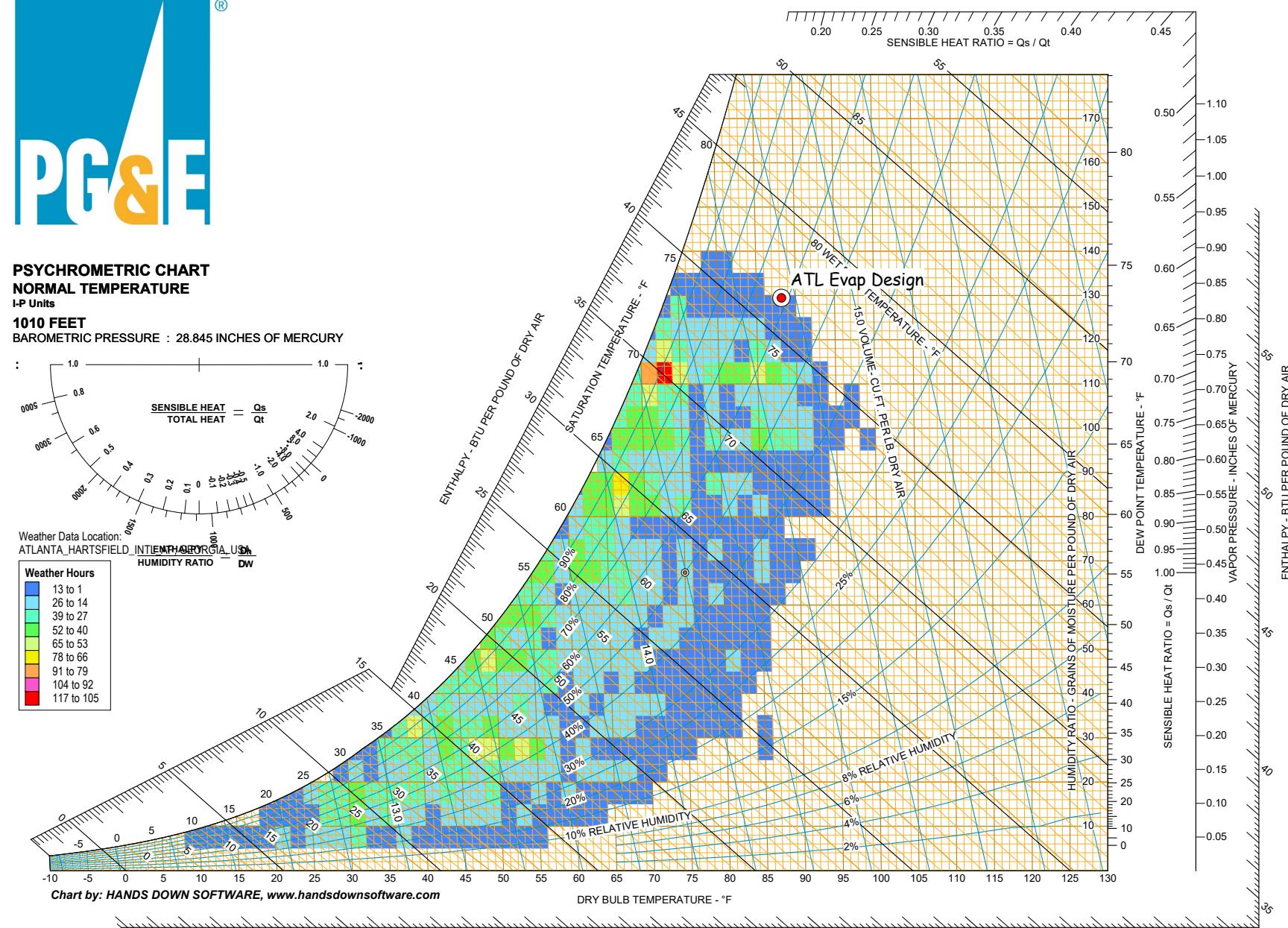
# Inside the Tower



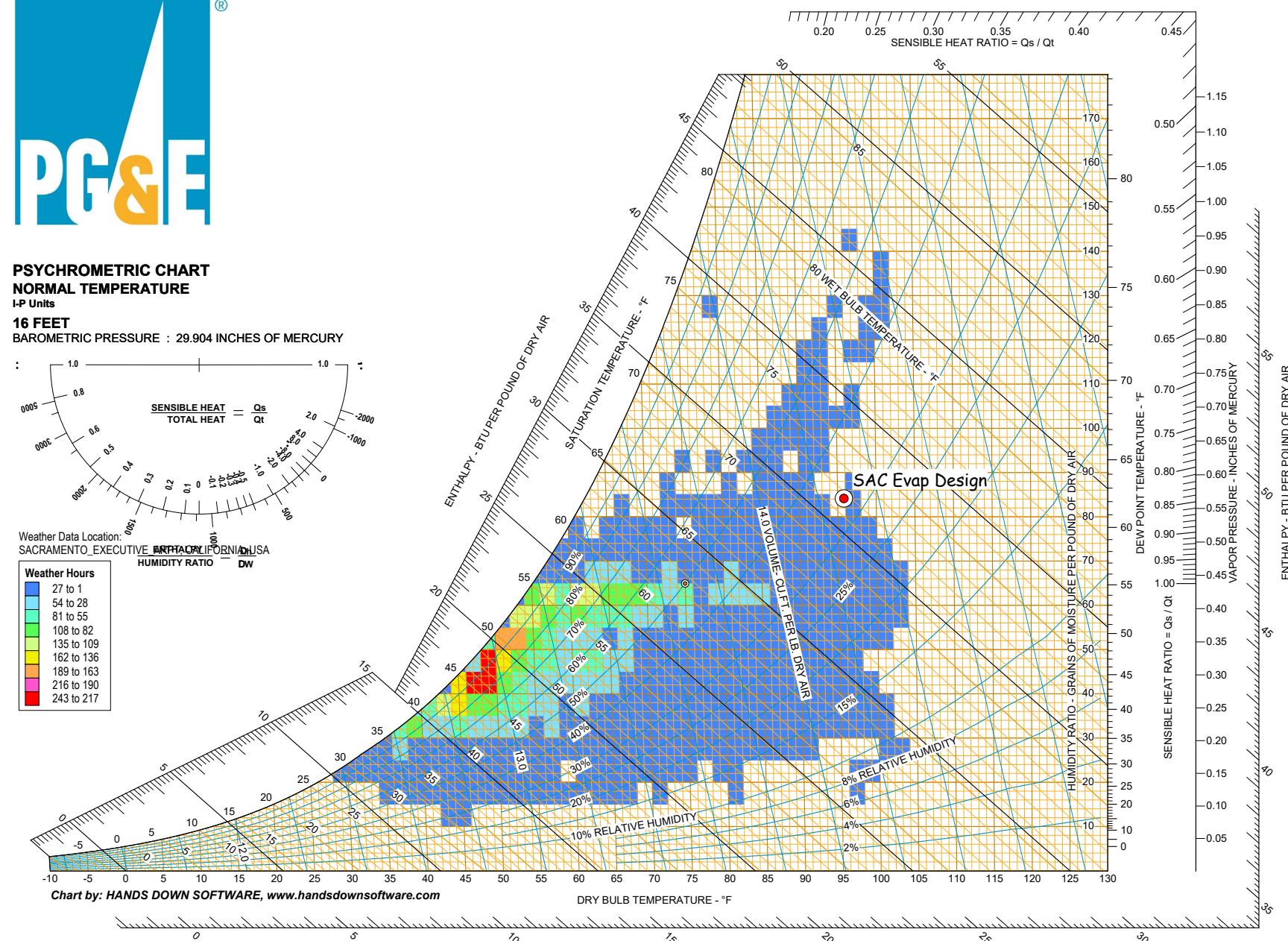
# Inside the Tower



# Cooling Tower Design Point vs. Performance Window – Atlanta, GA



# Cooling Tower Design Point vs. Performance Window – Sacramento, CA



# Volumetric Flow Meter



# Volumetric Flow Meter



# Costs

Item	Min	Max	
Leakage rate -	1	2	oz per second
Conversion factor -	0.0078	0.0078	Gallons per ounce
Leakage rate -	0.0078125	0.015625	Gallons per second
Leakage rate -	0.4687	0.9375	Gallons per minute
Leakage rate -	28	56	Gallons per hour
Leakage rate -	20,531	41,062	Gallons per month
Leakage rate -	246,375	492,750	Gallons per year
Water cost -	\$0.0028	\$0.0028	\$/gallon
Sewer charges -	\$0.0048	\$0.0048	\$/gallon
Water and sewer costs -	\$0.0076	\$0.0076	\$/gallon
Monthly cost -	\$156	\$312	
Annual cost -	\$1,870	\$3,740	

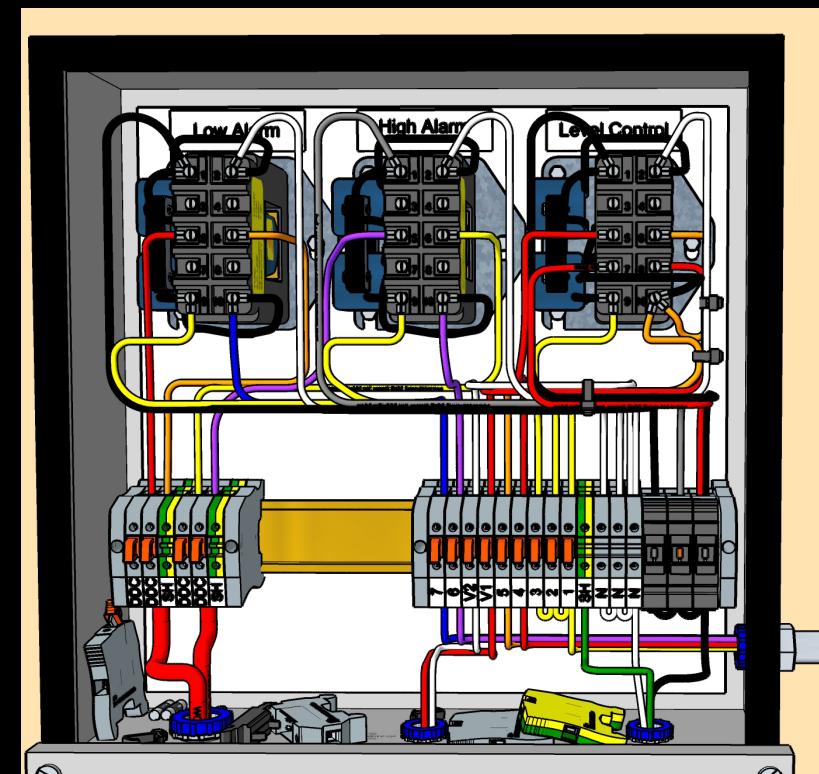


1-1/2 Float Valve - \$67

# Costs

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Water and sewer costs -	\$0.0076	\$0.0076	\$/gallon
Monthly cost -	\$156	\$312	
Annual cost -	\$1,870	\$3,740	
Simple Payback - Materials -	0.87	0.44	years
Simple Payback - Materials plus Installation -	3.05	1.53	years

Level Relay -	\$400
Electrode Holder -	\$320
Electrodes -	\$310
Ball valve with actuator -	\$350
Misc. Materials -	\$250
Materials Total -	\$1,630
Installation -	\$4,075
Total -	\$5,705
1-1/2 Float Valve -	\$67



# Question

Is there a minimum speed you would not allow the tower fans to drop below?



# Question

Is it better to run one fan up  
and then the other or run both  
fans up together?



# A True Application for the Cube Rule

Energy Efficiency Baselines for Data Centers - Adobe Acrobat Standard DC

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Bookmarks

Document Data Center Definition Loads Redundancy Baseline Costs Space Design Conditions Air Delivery Systems Hydronic Systems (Chilled Water, Condenser Water, Hot) Cooling Systems Heating Systems Humidity Control Systems Electrical Telecom Facilities Containerized Data Centers Calculation Assumptions Commercial Space Load Cooling System Performance Performance at Part Load Abbreviations

## Performance at Part Load

### Affinity Law

It is a common practice to use the Affinity Law to model the part-load power draw of a centrifugal pump or fan. The Affinity Law describes the relationship between flow rate and power demand as

$$\frac{kW_1}{kW_2} = \left( \frac{gpm_1}{gpm_2} \right)^n \quad \text{OR} \quad \frac{kW_1}{kW_2} = \left( \frac{cfm_1}{cfm_2} \right)^n$$

where kW = the shaft brake power of the pump or fan, and n = 3.0.

However, the Affinity Law is not a law, it is merely a calculation tool. It applies only in a narrow, theoretical case, because it assumes:

- Fully turbulent flow.
- An incompressible fluid.
- No "system effects".
- A closed loop that does not change shape (no modulating valves or dampers).
- When the flow goes to zero, the brake power goes to zero (no constant static head or pressure setpoint).
- Constant pump/fan efficiency.

Most real-world pump and fan systems do not meet all these criteria. The Affinity Law can still be applied in many cases, but it must be modified to better represent the situation. A common method is to reduce the exponent n. The recommended exponents to use are as follows.

March 1, 2013

Page 54



# Staging Fans



# Taking a Look at Some Field Data

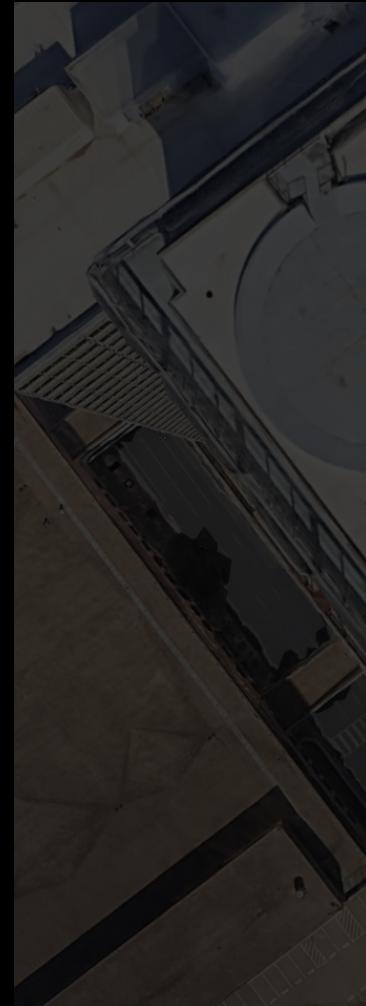


Would this be a good location to take our ambient wet bulb temperature reading?

# Taking a Look at Some Field Data



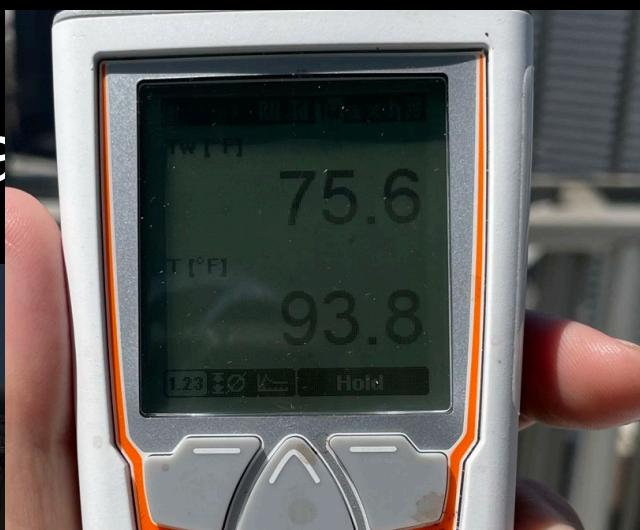
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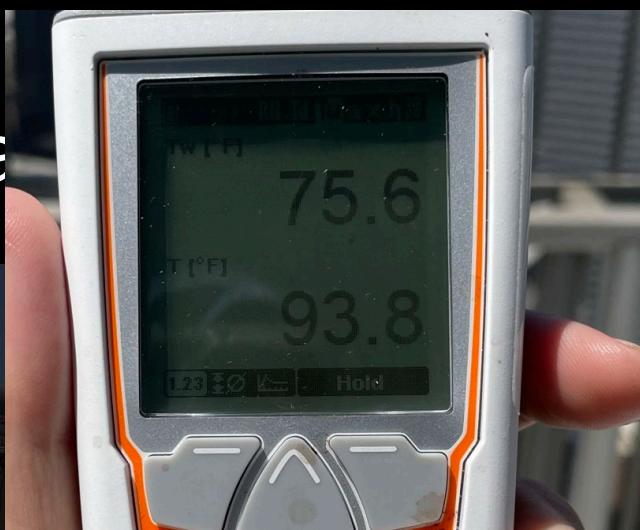
# Taking a Look at a [REDACTED]



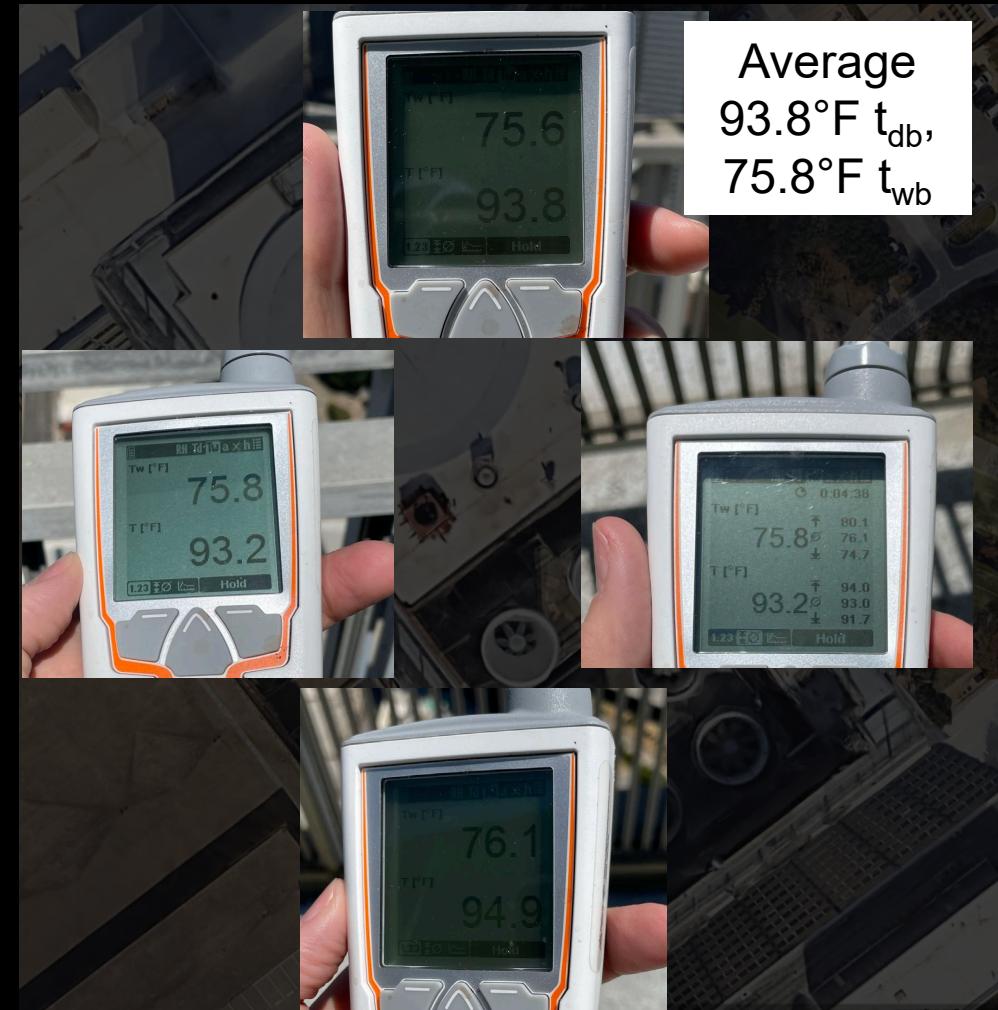
# Taking a Look at a Thermal Camera



# Taking a Look at the Weather



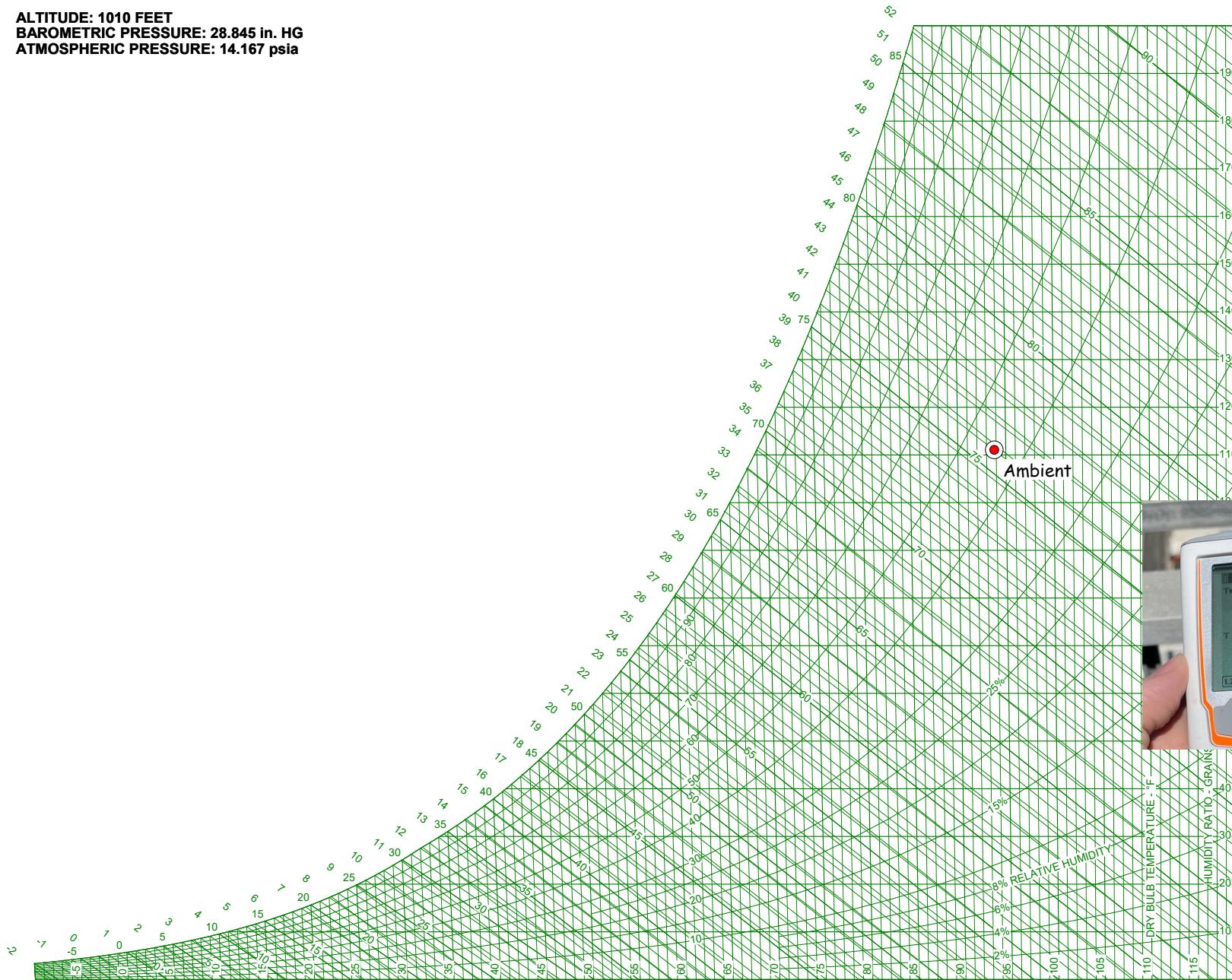
# Taking a Look at Some Field Data



# Taking a Look at Some Field Data



ALTITUDE: 1010 FEET  
BAROMETRIC PRESSURE: 28.845 in. HG  
ATMOSPHERIC PRESSURE: 14.167 psia



ALTITUDE: 1010 FEET  
BAROMETRIC PRESSURE: 28.845 in. HG  
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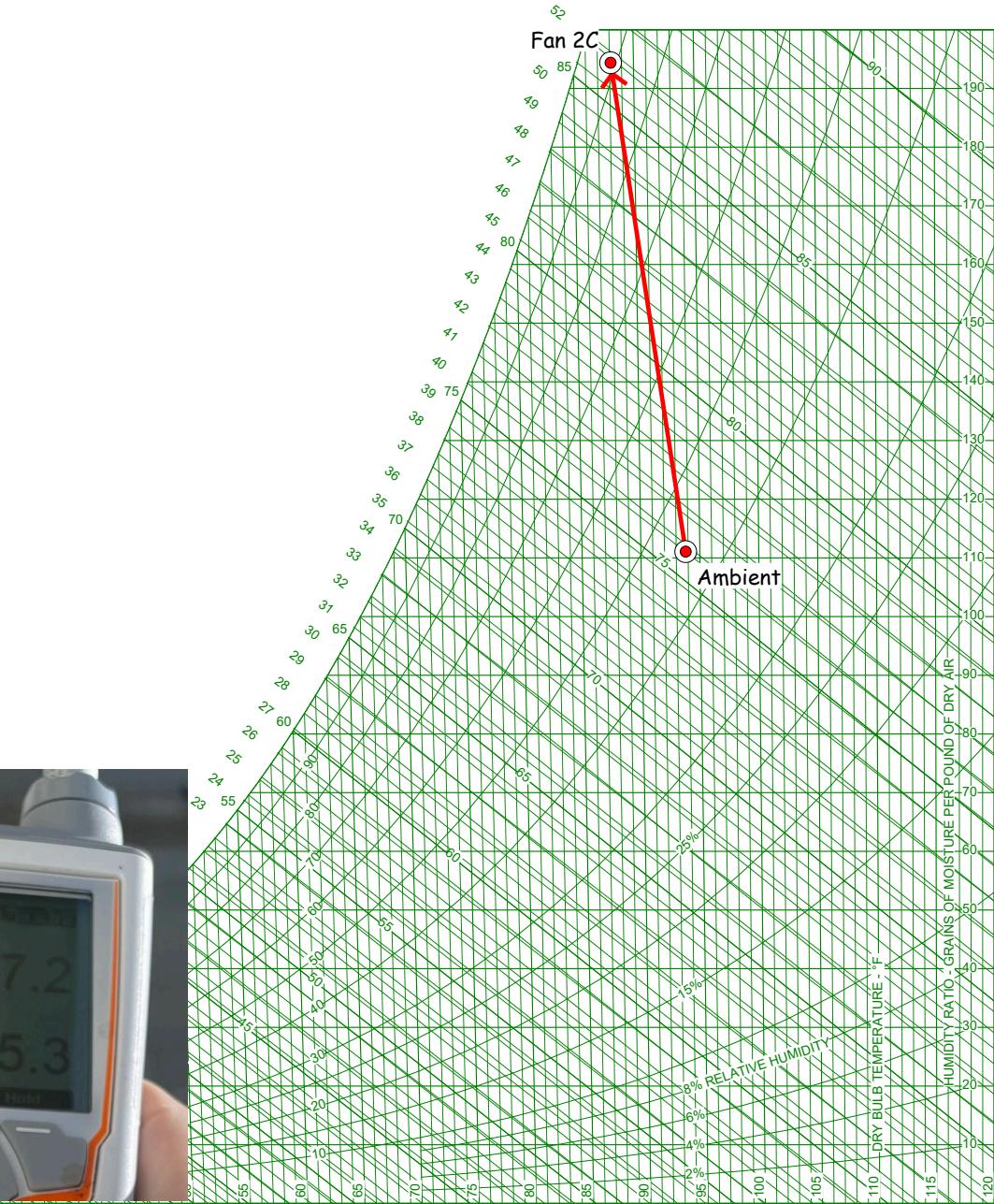
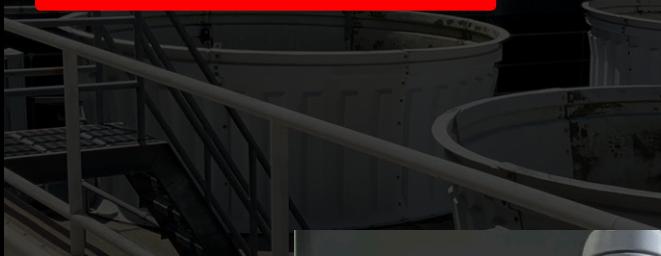


Chart by: AKTON PSYCHROMETRICS, [www.aktonassoc.com](http://www.aktonassoc.com)

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BAROMETRIC PRESSURE: 28.845 in. HG  
ATMOSPHERIC PRESSURE: 14.167 psia

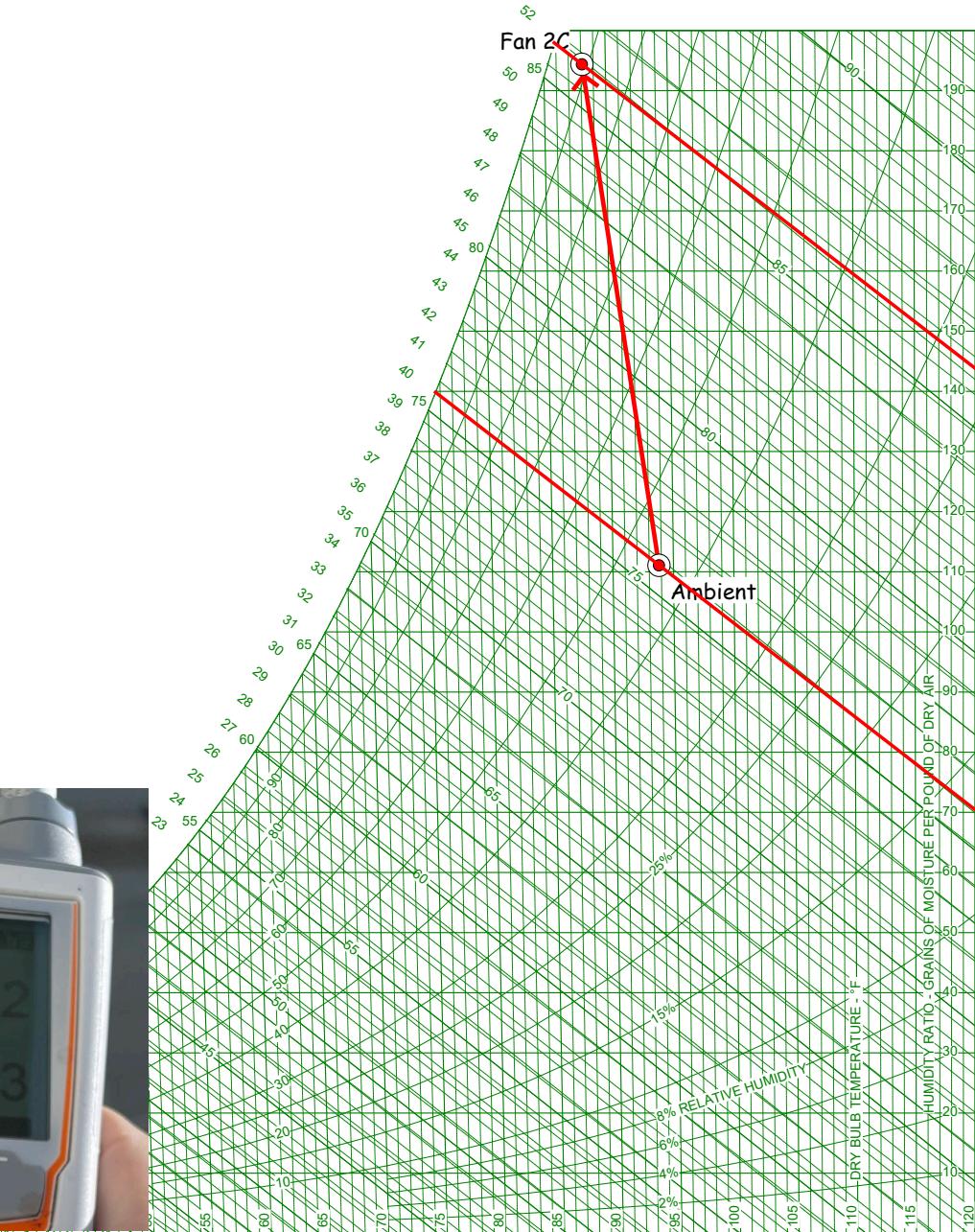
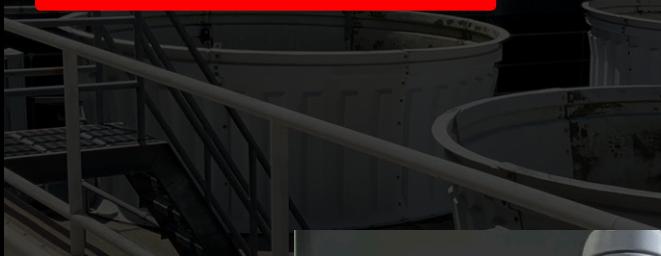


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ATMOSPHERIC PRESSURE: 14.167 psia

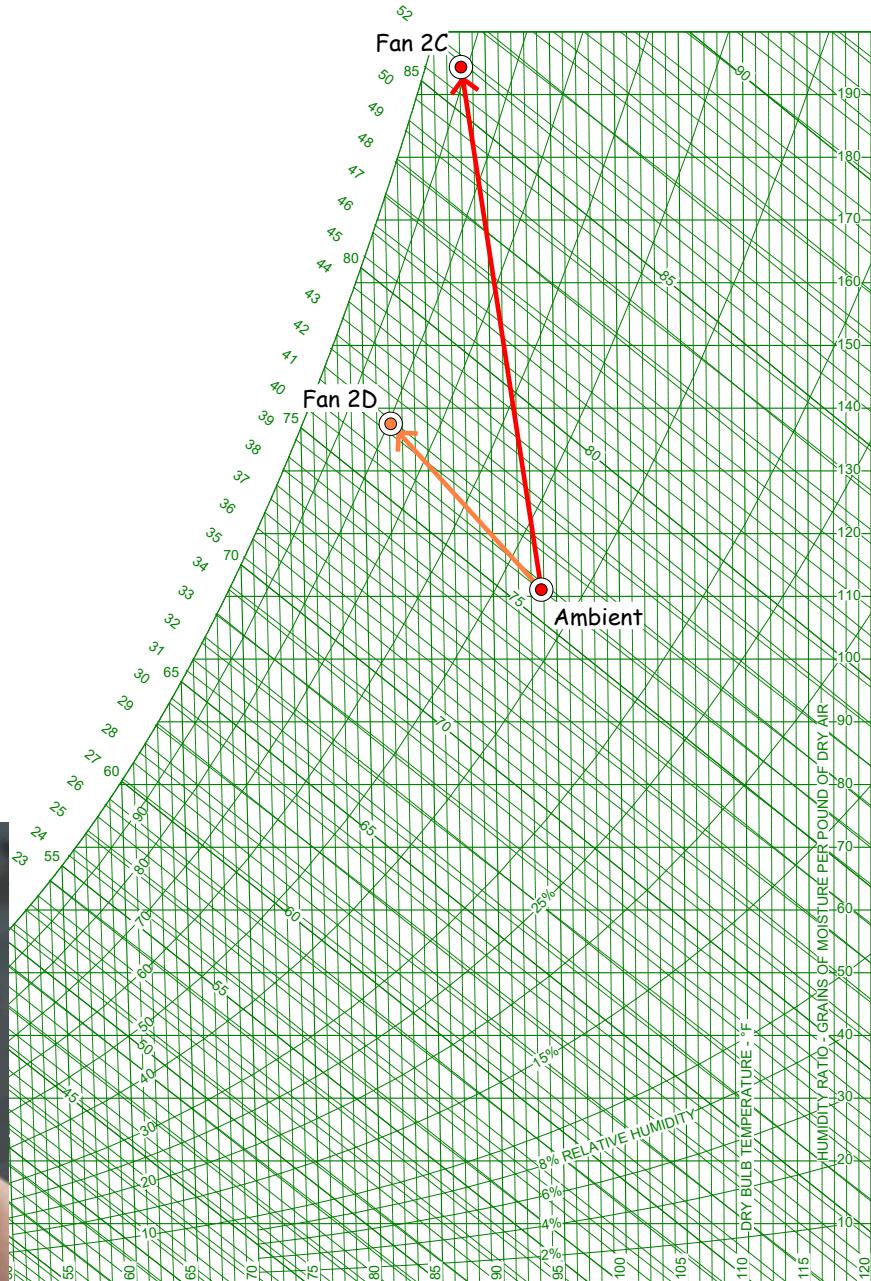


Chart by: AKTON PSYCHROMETRICS, [www.aktonassoc.com](http://www.aktonassoc.com)

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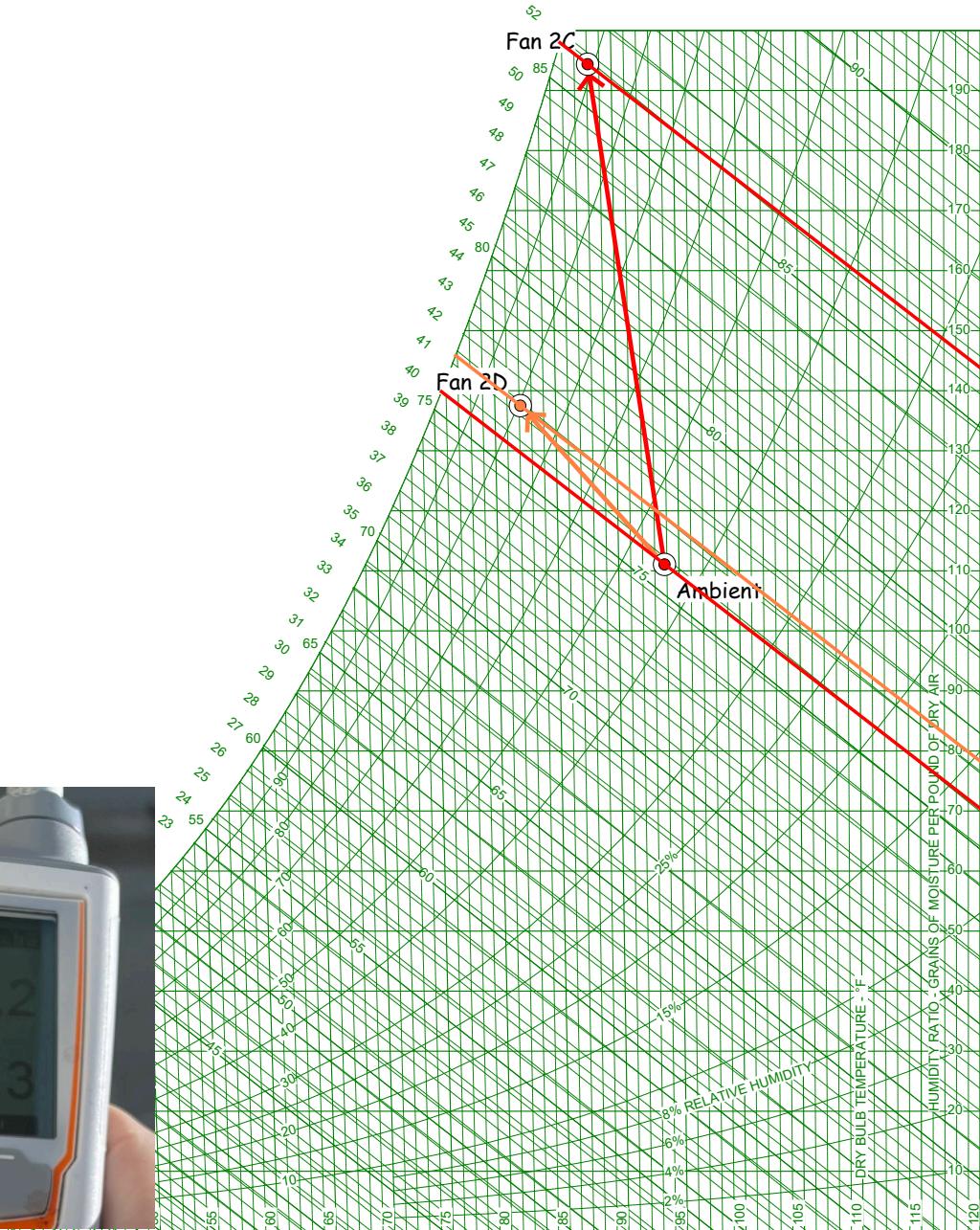


Chart by: AKTON PSYCHROMETRICS, [www.aktonassoc.com](http://www.aktonassoc.com)

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ALTITUDE: 1010 FEET  
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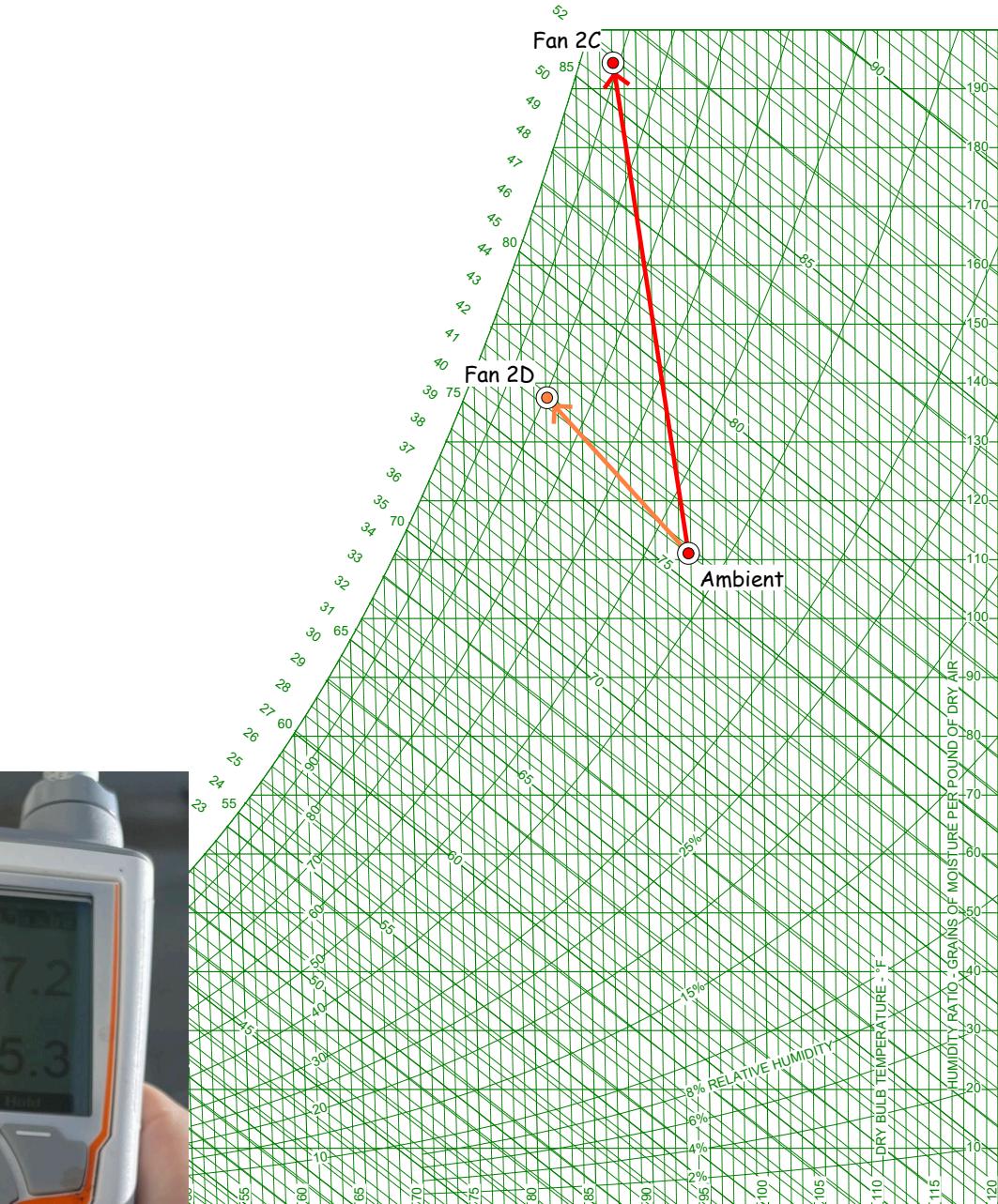


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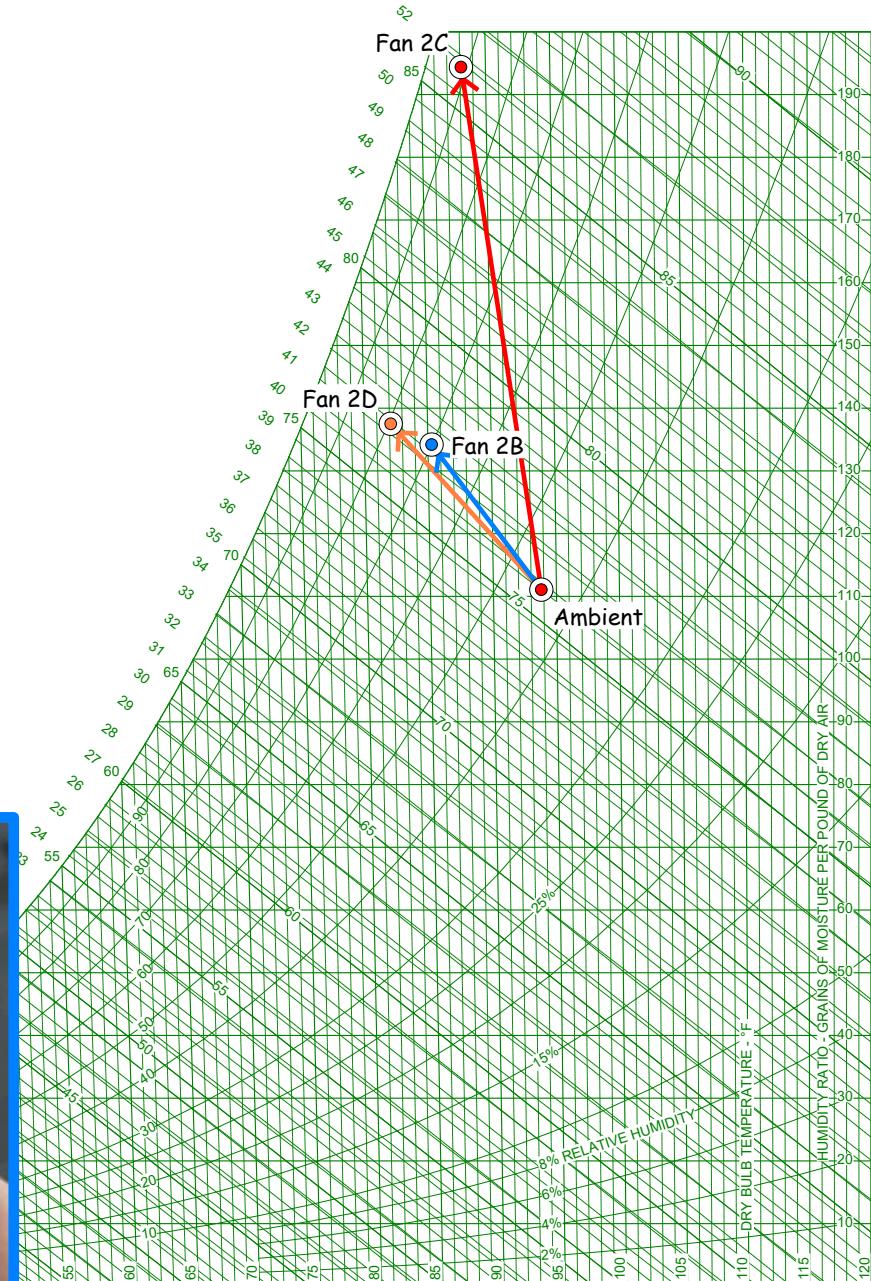


Chart by: AKTON PSYCHROMETRICS, [www.aktonassoc.com](http://www.aktonassoc.com)

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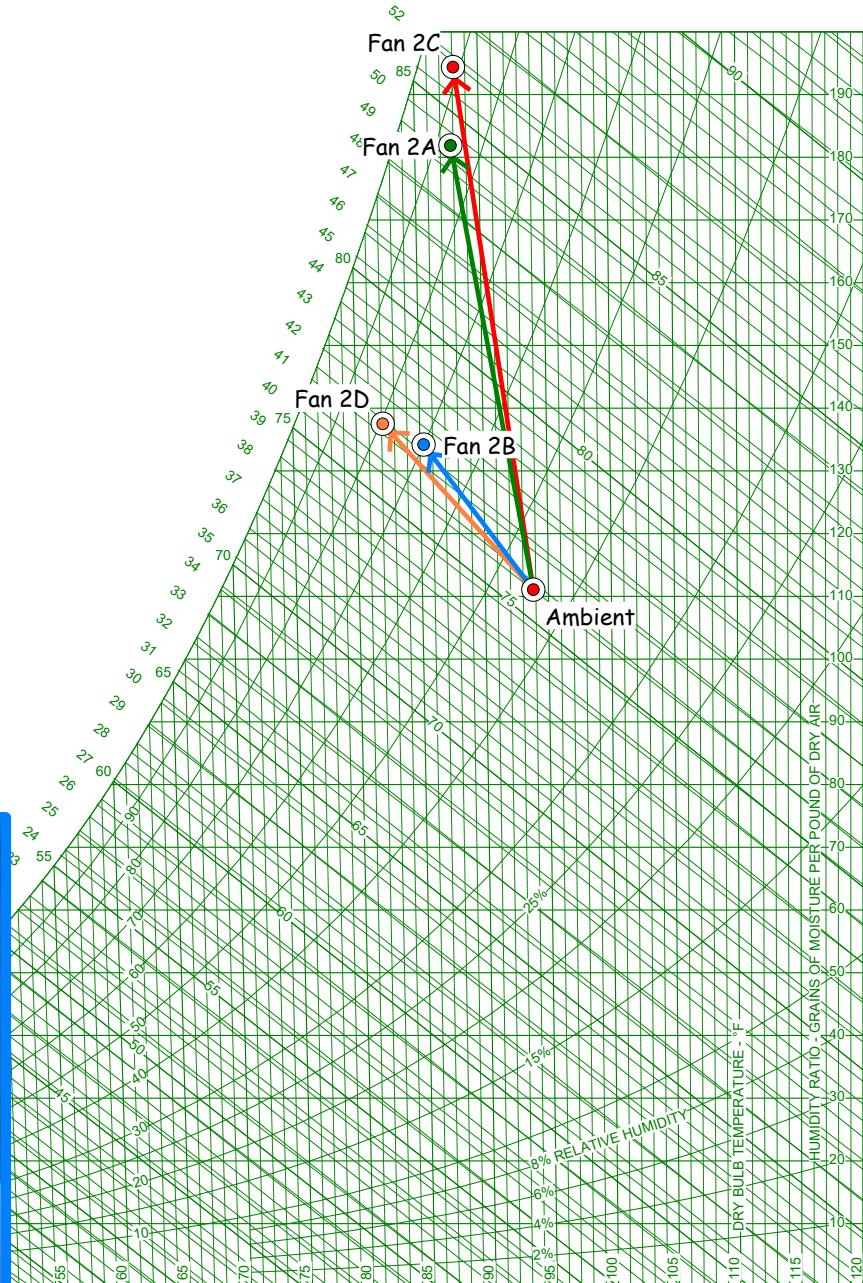
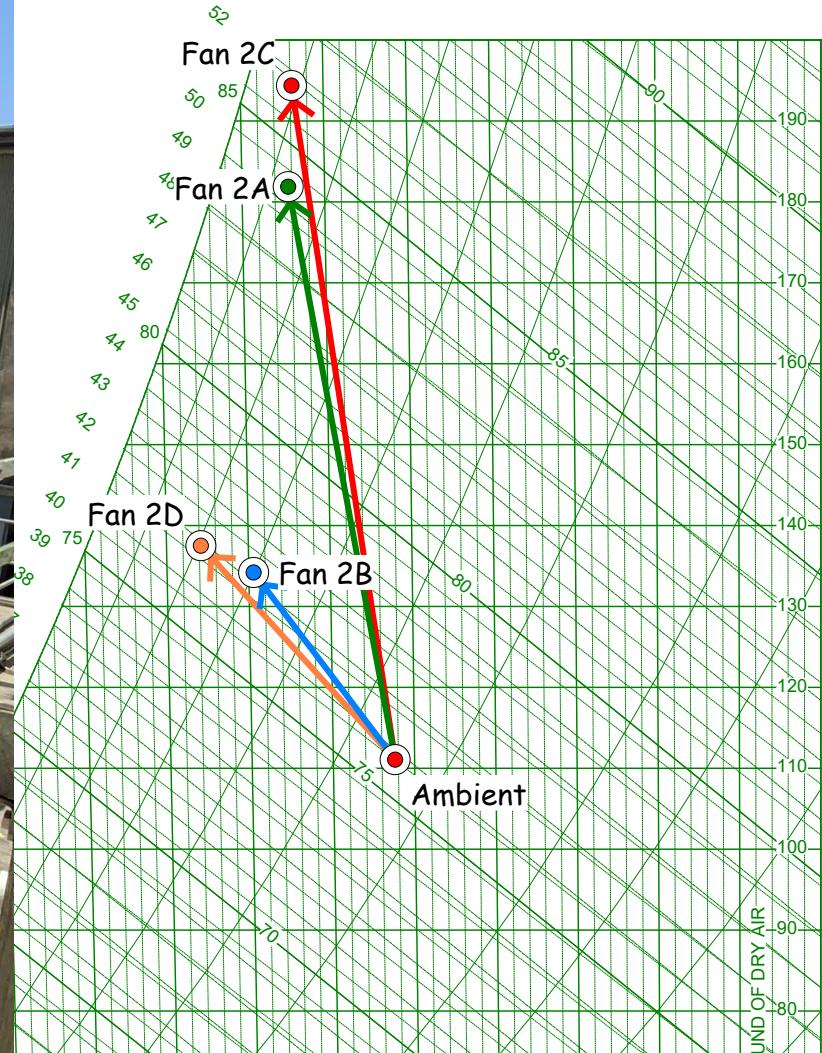


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# What Does This Suggest is Going On in the Tower?



# Let's Take a Look

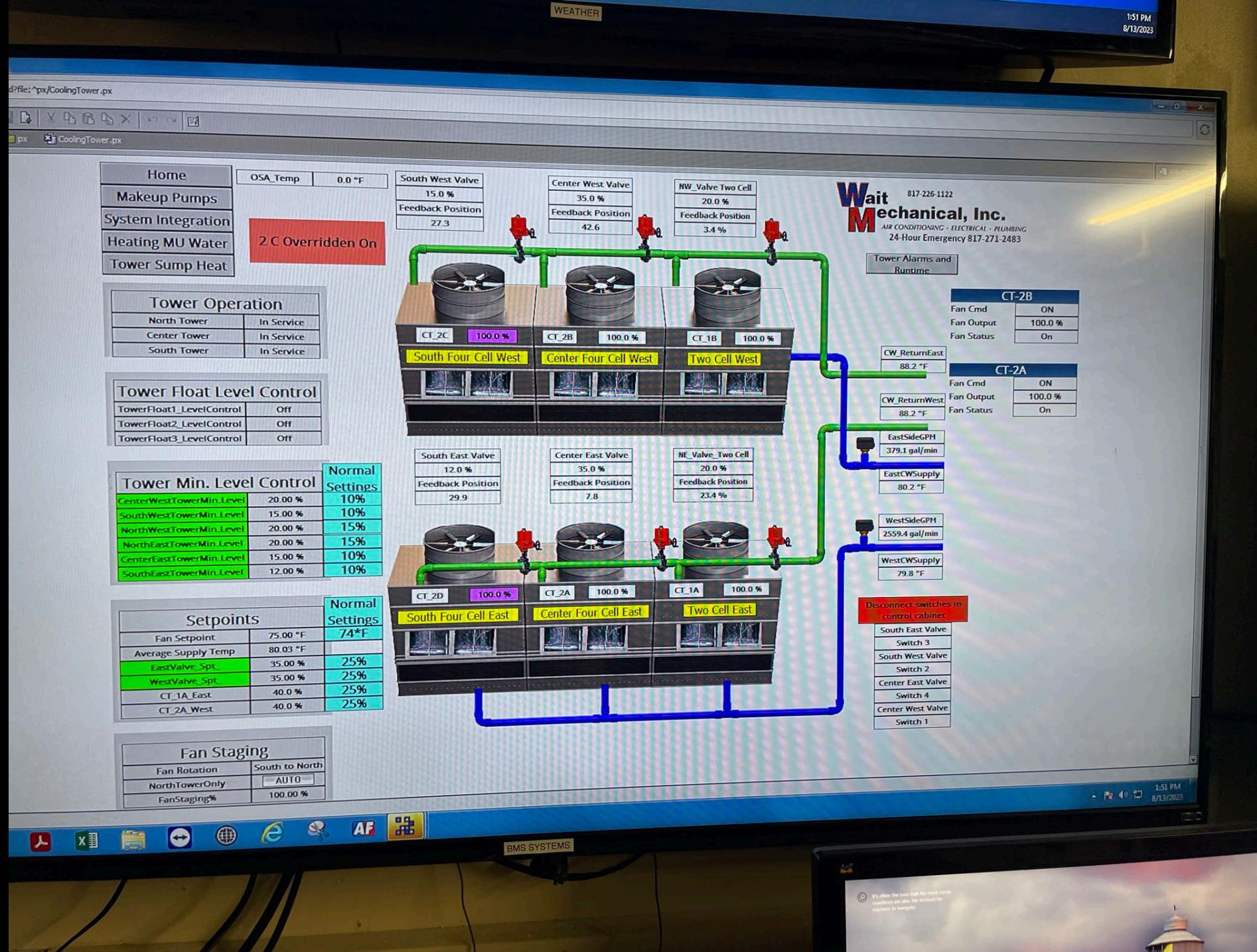


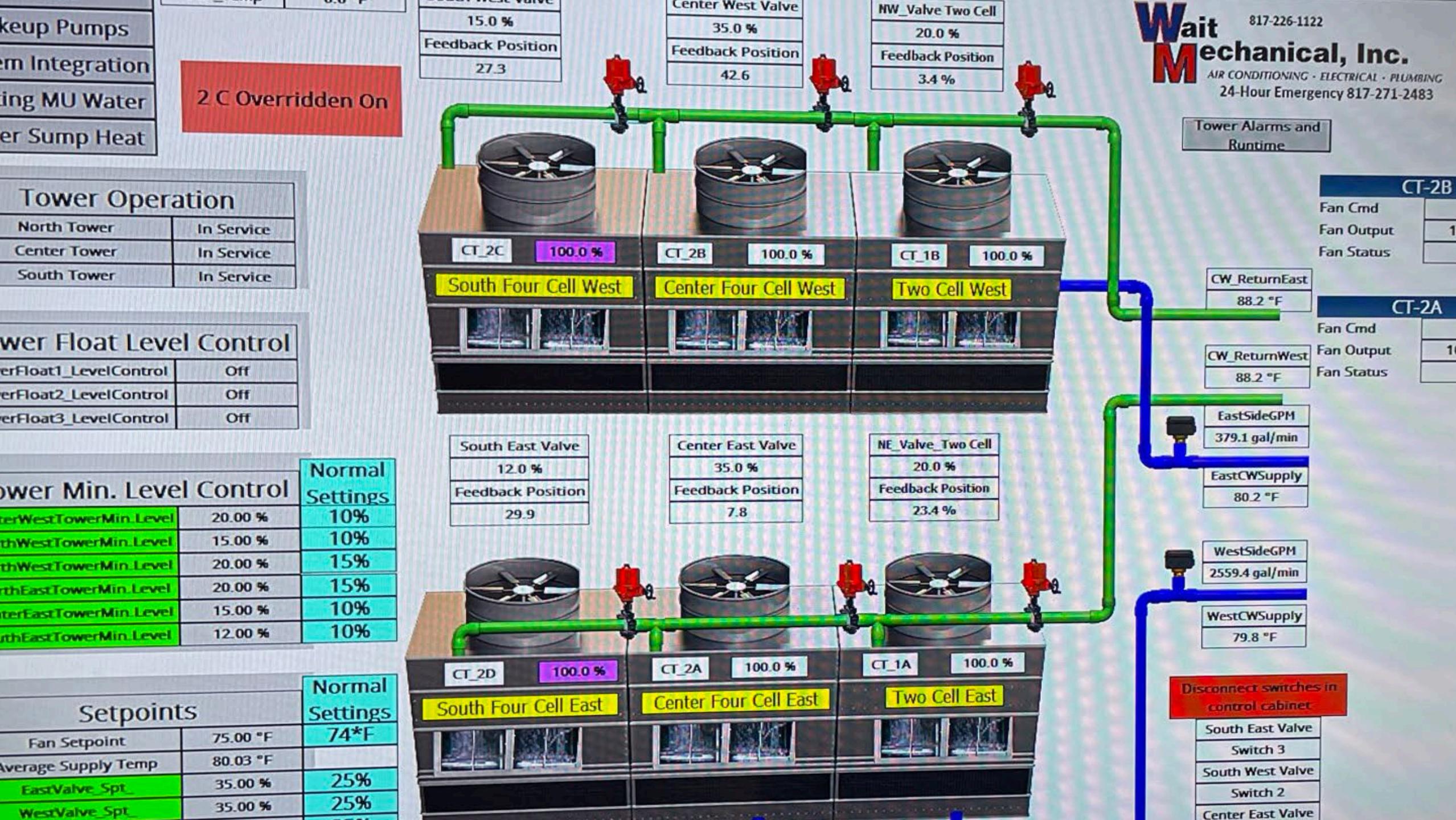
Let's Take a Look



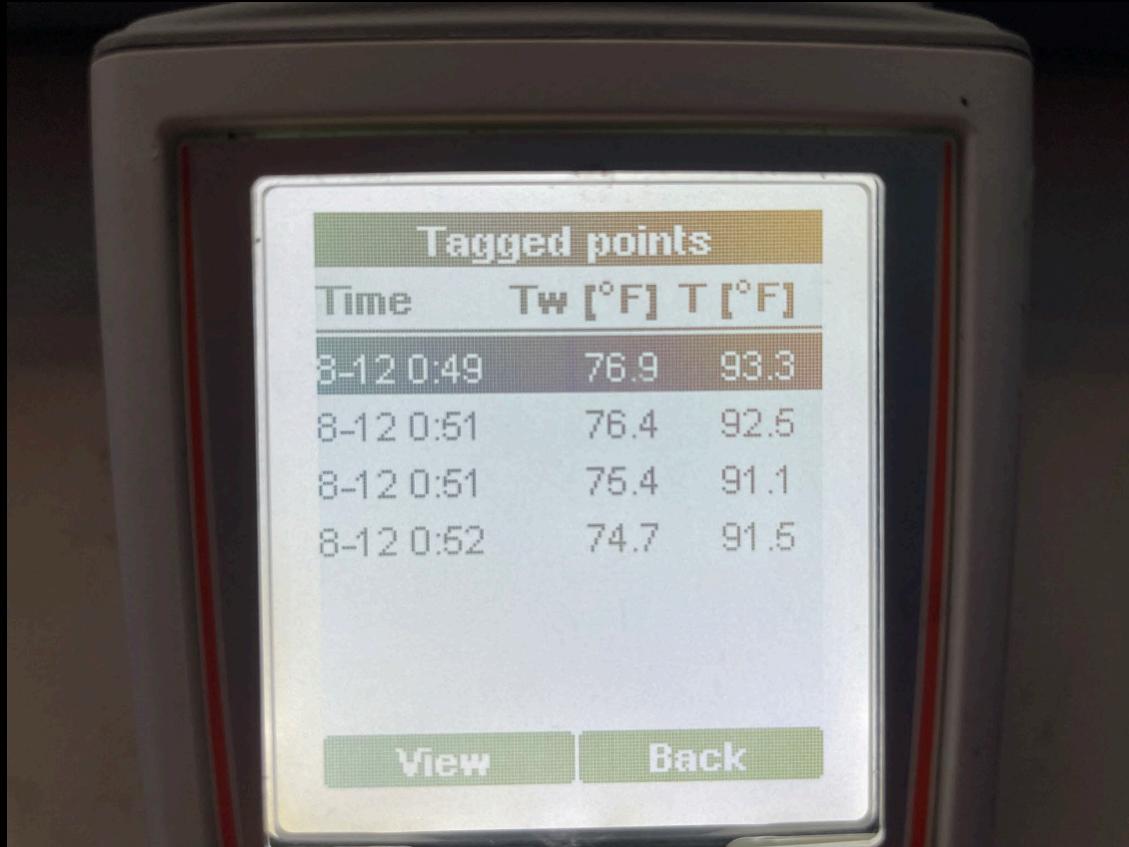
Let's Take a Look







# The Good News



Average 93.8°F  $t_{db}$ , 75.8°F  $t_{wb}$



Average 81.1°F, 5.3°F  $t_{wb}$  Approach  
Cell 2C (most water) - 3.5°F  $t_{wb}$  Approach



# Relative Calibration is Important

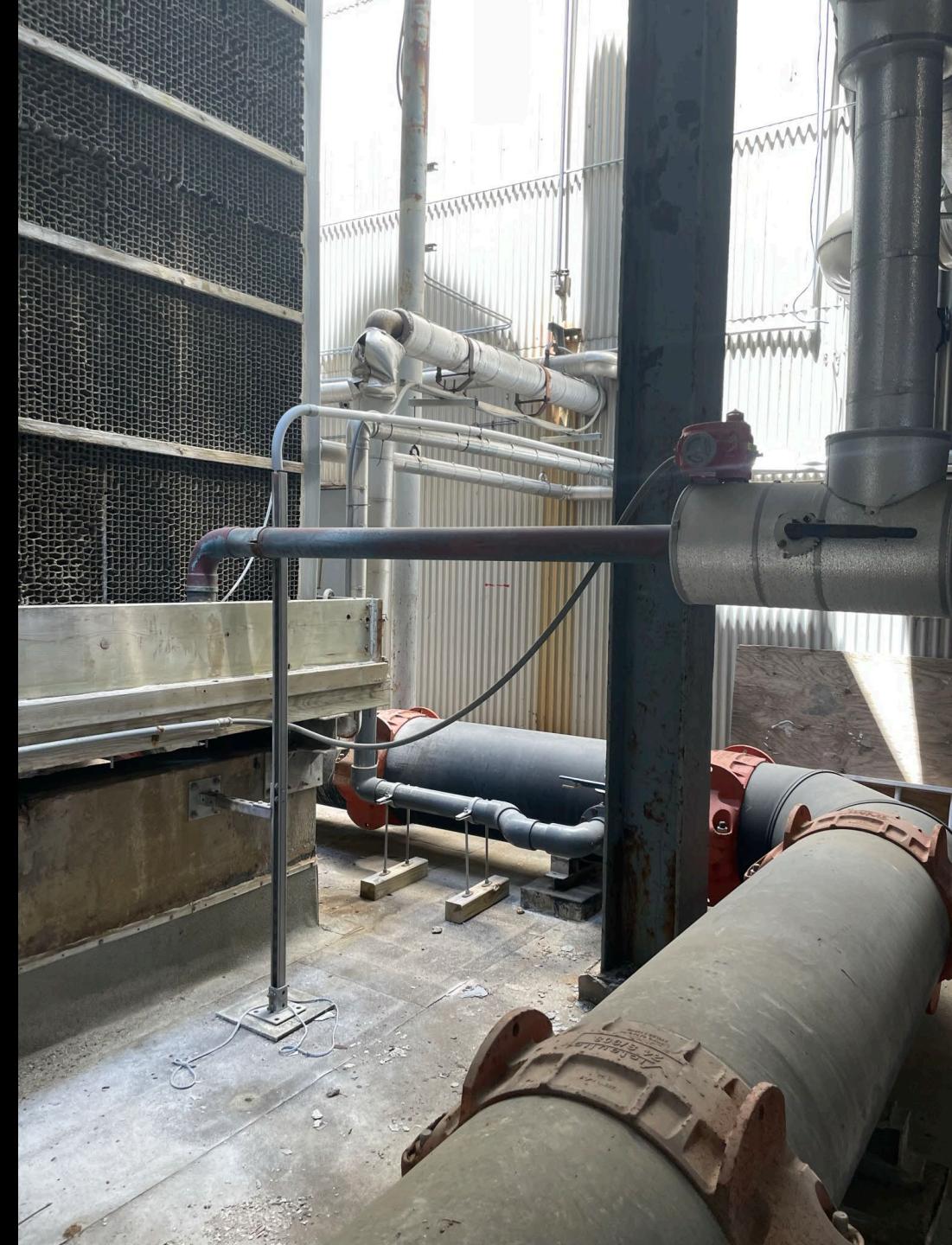
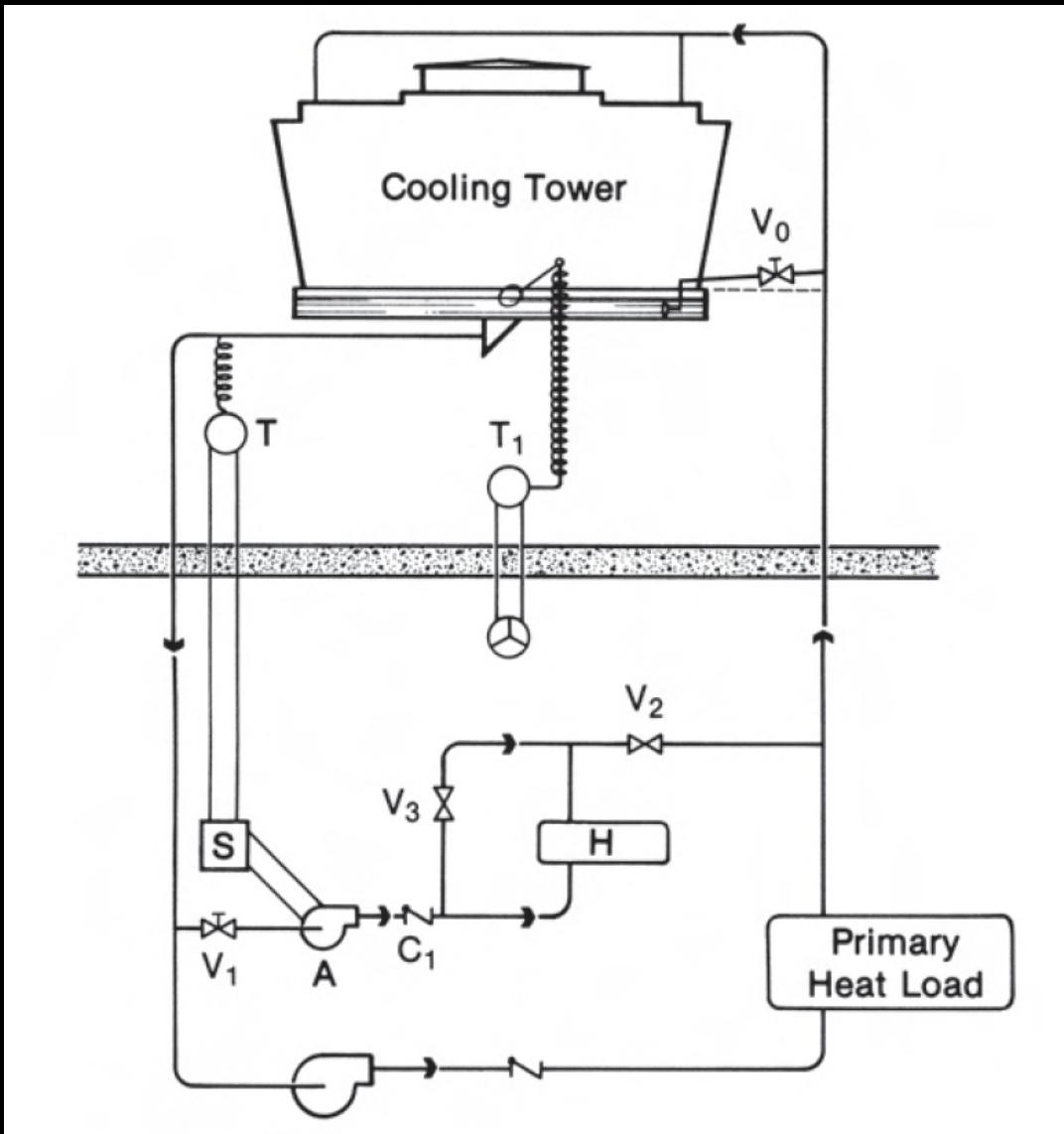




# What is This and Why is It an Asset?



# Hot Water Basin Heat



Wood  
Construction =  
Fire Hazard =  
Dry Pipe  
Sprinklers



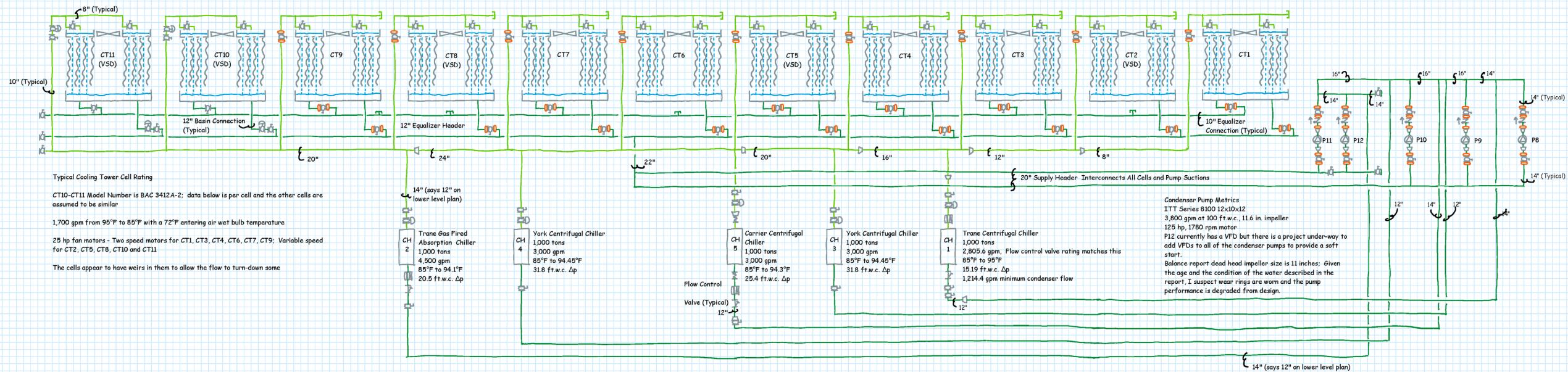
# Another Recent Experiment



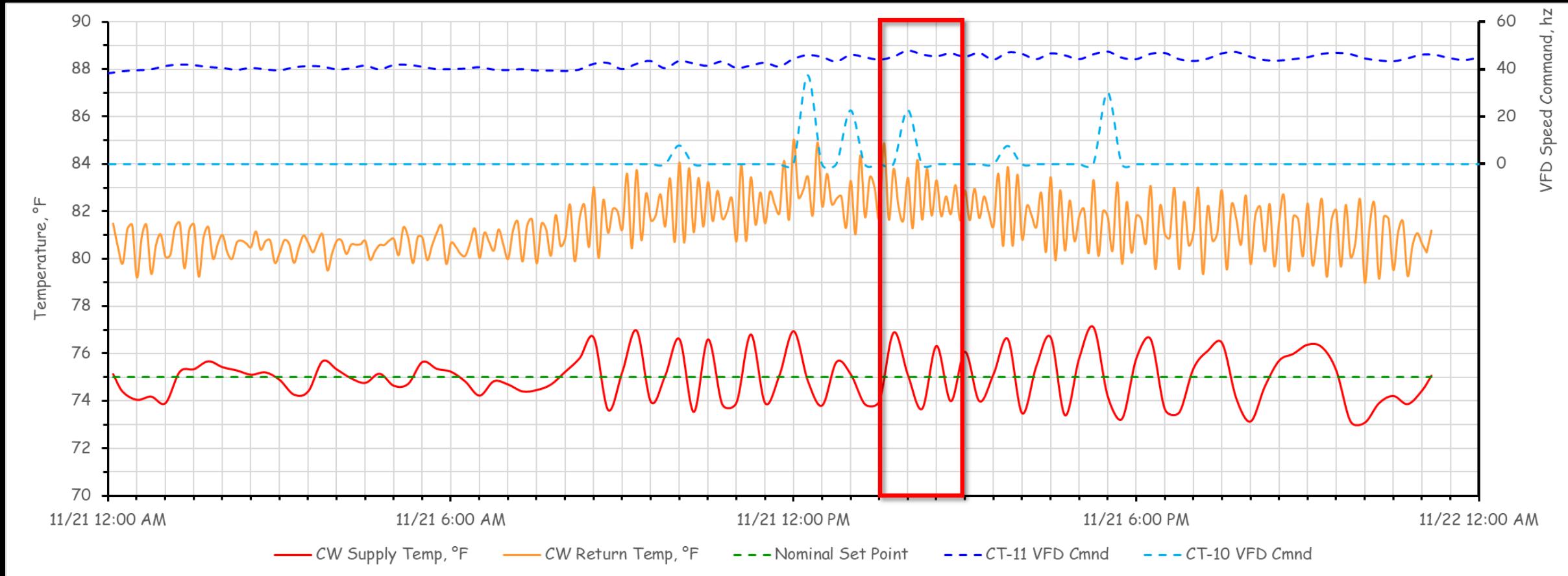
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Google Earth

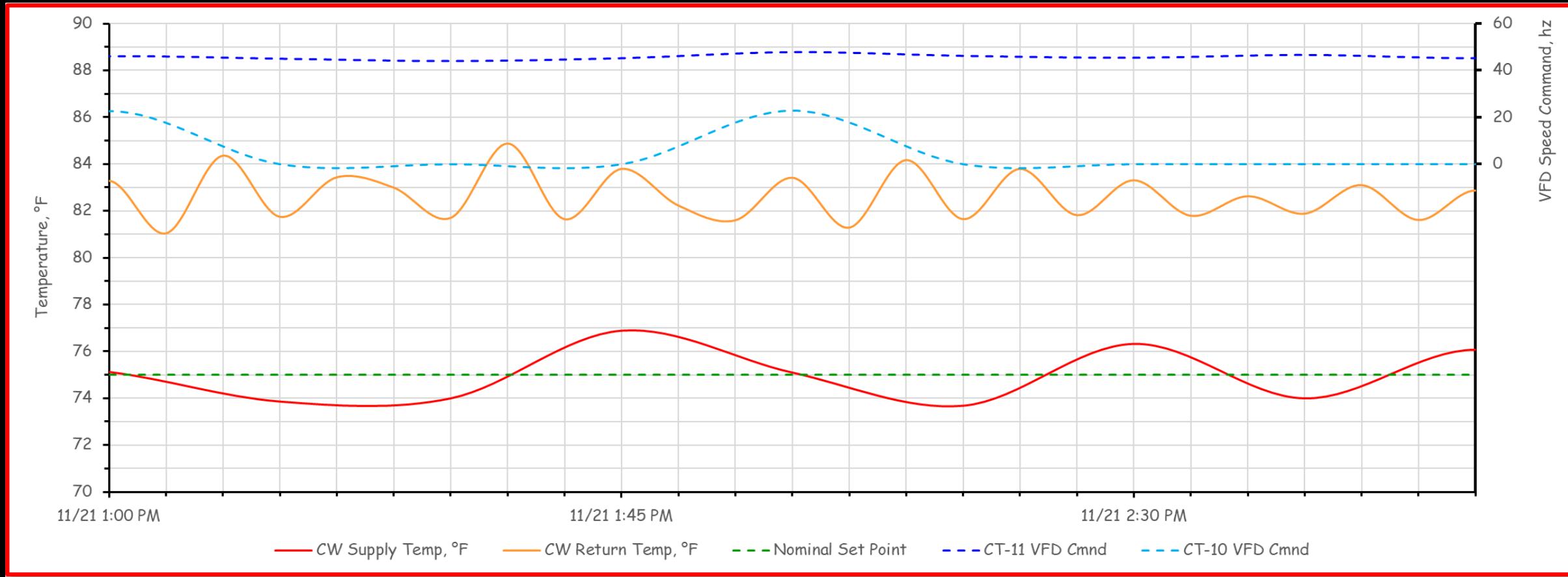
# A Recent Experiment

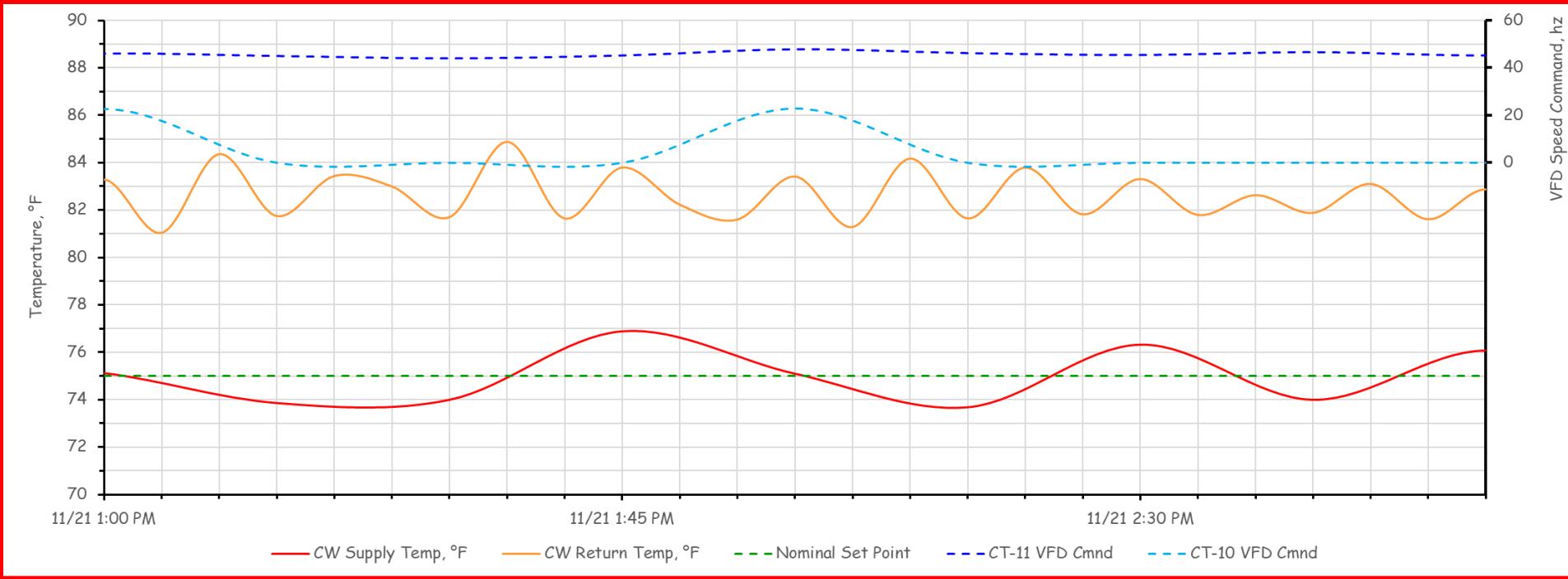


# A Recent Experiment



# A Recent Experiment





Cooling Tower Fan Staging Lead/Lag Sequence 02 Based On PPCL Program PPCL\_MBC12 Lines 900 - 1042

Condenser Water Temperature Loop Output	0	10	10	20	20	30	40	40	50	50	60	60	70	70	80	80	90	90	100	100	110	110	120	120	130	130	140	140	150	150	160	160	170	170	180
Cooling Tower Stage	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	(Note 1)	(Note 3)	(Note 4)														
Cooling Tower Fan Status and Local Variable																																			
CT9 Slow	\$LOC1	Off	On	On	On	On	On	On	Off																										
CT9 Fast	\$LOC2	Off	On																																
CT8 On	\$LOC3	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off											
CT8 Speed	0	0	0	0	0	0	0	0	0	0	Modulating	0	0	Modulating	0	0	Modulating	0	Modulating	0	Modulating														
CT7 Slow	\$LOC4	Off	Off	On	On	On	On	On	On	Off																									
CT7 Fast	\$LOC5	Off	On																																
CT6 Slow	\$LOC6	Off	Off	Off	On	On	On	On	On	On	On	Off	On	On	On	On	On	On	Off																
CT6 Fast	\$LOC7	Off	Off	Off	Off	On																													
CT5 On	\$LOC11	Off	On	Off	Off	Off	On																												
CT5 Speed	0	0	0	0	0	0	0	0	Modulating	0	0	Modulating	0	0	Modulating	0	0	Modulating																	
CT4 Slow	\$LOC12	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	Off																		
CT4 Fast	\$LOC13	Off	Off	Off	Off	Off	Off	Off	Off	On																									
CT3 Slow	\$LOC14	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	Off																
CT3 Fast	\$LOC15	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	On																					
CT2 On	LOC16	Off	Off	Off	Off	Off	Off	Off	Off	On	Off	Off	On	Off	Off	On																			
CT2 Speed	0	0	0	0	0	0	0	0	0	Modulating	0	0	Modulating	0	0	Modulating	0	Modulating	0	Modulating															
CT1 Slow	LOC17	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	Off																	
CT1 Fast	LOC18	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	On																							
CT11 On	LOC19	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off										
CT11 Speed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
CT10 On	LOC20	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	On	On										
CT10 Speed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Modulating		

Notes

- From what we can tell in the PPCL, stage 7 seems to be skipped in terms of assigning tower fans to it. We believe the software just jumps from Stage 6 to Stage 8 and that is what is reflected in the table.
- Cells with an orange border represent cooling towers with 2 speed fans. For a given stage, they should never both be "On".
- The status of CT6 is assumed; there is an issue with the PPCL that does not properly set it to this value, unlike the other stages, where every point is given a specific assignment.
- The status of CT9 is assumed. Nothing positively commanded it low speed off, but high speed was positively commanded on this stage. So maybe the starter interlocks let that happen, but it should be checked out and the status we show here is a "best guess" based on assuming that if you commanded the fan to high speed, the hard wired starter interlocks would drop out the low speed winding.

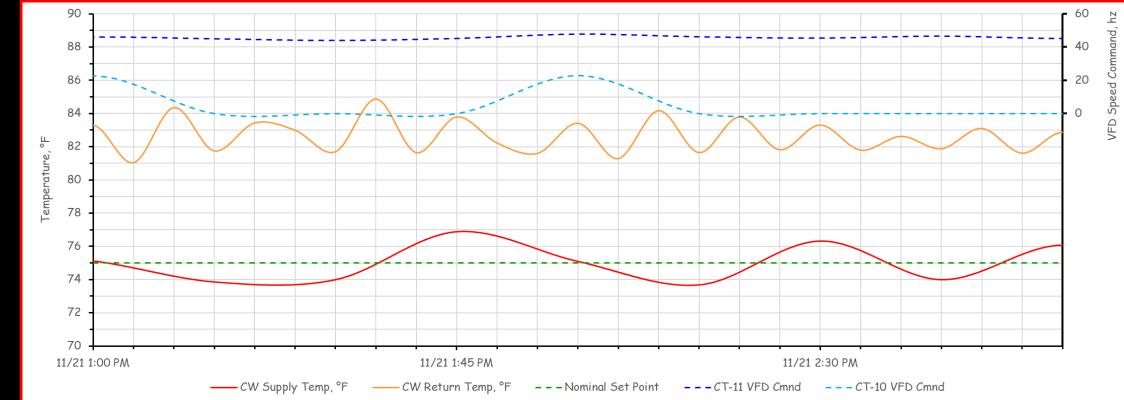
# A Recent Experiment

Savings Summary						
kWh Savings						
Item	Time of Use Window					
	Super Off Peak		Off Peak		On Peak	
	Summer	Winter	Summer	Winter	Summer	Winter
Existing	79,608	74,075	244,312	189,460	113,019	106,505
Improved	41,511	44,381	123,975	106,147	57,310	58,203
Savings	38,097	29,694	120,337	83,313	55,709	48,302
Rate, \$ per kWh	\$0.09836	\$0.09954	\$0.12003	\$0.11334	\$0.14111	\$0.12579
Savings, Dollars	\$3,747	\$2,956	\$14,444	\$9,443	\$7,861	\$6,076
Total Savings - kWh	375,452	Murph -	452,871 before interaction factor			
Total Savings - \$	\$44,527	Murph -	384,940 after interaction factor			

kW Savings						
Item	Time of Use Window					
	Super Off Peak		Off Peak		On Peak	
	Summer	Winter	Summer	Winter	Summer	Winter
Existing	168	186	233	210	233	204
Improved	82	89	120	100	120	97
Savings	87	97	113	111	113	107
Rate, \$ per kW	\$51.88	\$41.30	\$51.88	\$41.30	\$51.88	\$41.30
Savings, Dollars	\$4,493	\$4,002	\$5,883	\$4,569	\$5,883	\$4,428
Maximum kW Savings	113					
Total Savings - \$	\$14,379					
Total Dollar Savings -	\$58,906					

Green House Gas Emissions Savings		
Rate	0.630	lb CO <sub>2</sub> /kWh
Savings	236,535	lb CO <sub>2</sub>

Rough Cost/Benefit Calculations			
Contractor cost projection -	\$106,000		
Simple payback -	1.8	years	



Cooling Tower Fan Staging Lead/Lag Sequence 02 Based On PPCL Program PPCL_MBC12 Lines 900 - 1042																	
Condenser Water Temperature Loop Output 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 Cooling Tower Stage																	
Cooling Tower Fan Status and Local Variable																	
CT9 Slow	\$LOC1	Off	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off	Off	Off	Off
CT9 Fast	\$LOC2	Off	On	On	On	On	On	On	On	On	On						
CT8 On	\$LOC3	Off	Off	Off	Off	Off	Off	Off	Off	Off							
CT8 Speed	0	0	0	0	0	0	0	0	0	Modulating	0	0	Modulating	0	Modulating	0	Modulating
CT7 Slow	\$LOC4	Off	Off	Off	Off	Off	Off	Off	Off	Off							
CT7 Fast	\$LOC5	Off	Off	Off	Off	Off	Off	Off	Off	Off							
CT6 Slow	\$LOC6	Off	On	On	On	On	On	On	On	On	On						
CT6 Fast	\$LOC7	Off	Off	Off	Off	Off	Off	Off	Off	Off							
CT5 On	\$LOC11	Off	On	On	On	On	On	On	On	On	On						
CT5 Speed	0	0	0	0	0	0	0	0	Modulating	0	0	Modulating	0	0	Modulating	0	Modulating
CT4 Slow	\$LOC12	Off	On	On	On	On	On	On	On	On	On						
CT4 Fast	\$LOC13	Off	Off	Off	Off	Off	Off	Off	Off	Off							
CT3 Slow	\$LOC14	Off	On	On	On	On	On	On	On	On	On						
CT3 Fast	\$LOC15	Off	Off	Off	Off	Off	Off	Off	Off	Off							
CT2 On	\$LOC16	Off	On	On	On	On	On	On	On	On	On						
CT2 Speed	0	0	0	0	0	0	0	0	Modulating	0	Modulating	0	Modulating	0	Modulating	0	Modulating
CT1 Slow	LOC17	Off	On	On	On	On	On	On	On	Off	Off						
CT1 Fast	LOC18	Off	Off	Off	Off	Off	Off	Off	On	On							
CT11 On	LOC19	Off	Off	Off	Off	Off	Off	Off	Off	On							
CT11 Speed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Modulating	Modulating
CT10 On	LOC20	Off	Off	Off	Off	Off	Off	Off	Off	On							
CT10 Speed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Modulating

Notes

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# A Few Bottom Lines

1. Cooling towers leverage evaporative cooling to improve chiller efficiency relative to what you would achieve with an air-cooled condenser

*But they use water to do that*
2. Cooling towers come in a variety of “flavors”
3. Cooling tower performance is driven by wet bulb temperature
  - a. Approach to wet bulb varies with wet bulb temperature
  - b. Cooling tower capacity is a direct function of cooling tower air flow
4. Cooling towers are incredibly dynamic
5. Good flow distribution is crucial; with-out it:
  - a. Cube rule savings will not accrue
  - b. Reset schedules will be somewhat fruitless