Using Water-Cooled Chillers to Exceed ASHRAE Minimum Efficiency Standard by > 50%

Presented by:
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Green Done Easy

Building Blocks:

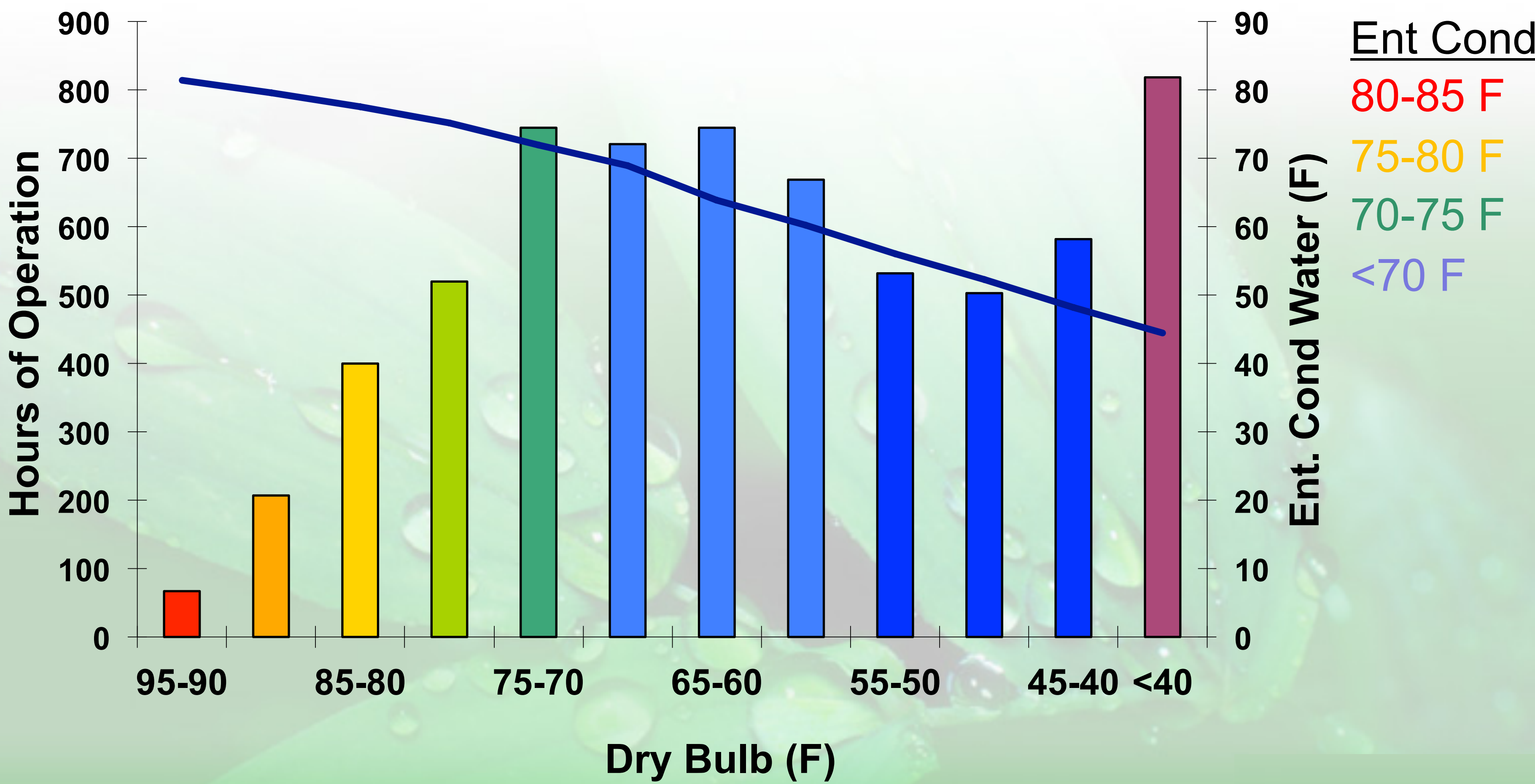
- Weather
- Determinants of Chiller Energy Consumption
- Variable Speed Screw Chillers
- Chiller Plant Design

Results:

- Test Data
- Energy Analysis

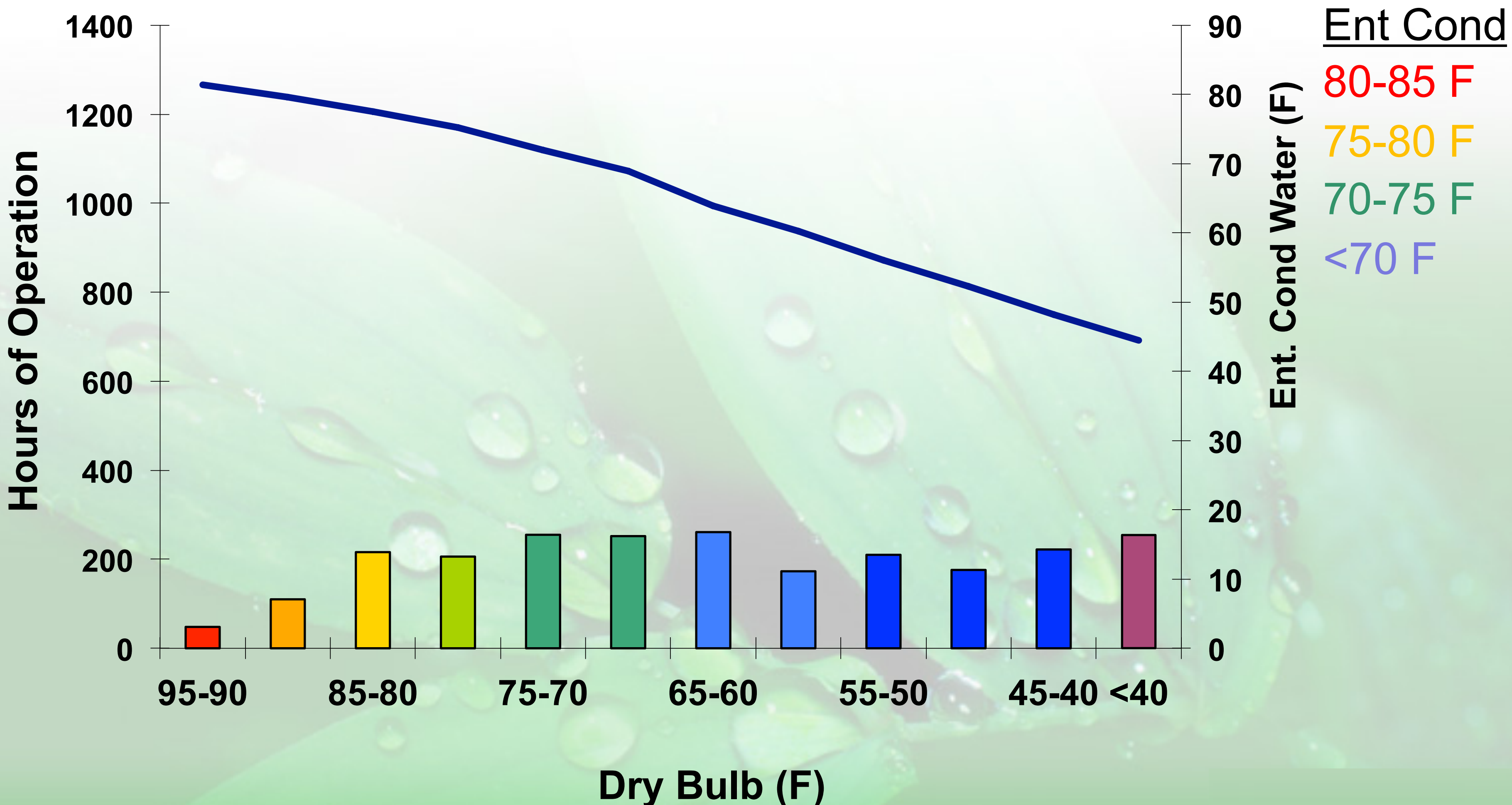
Chicago Weather 24 x 7

73.8% of hours have less than 70 F entering condenser water

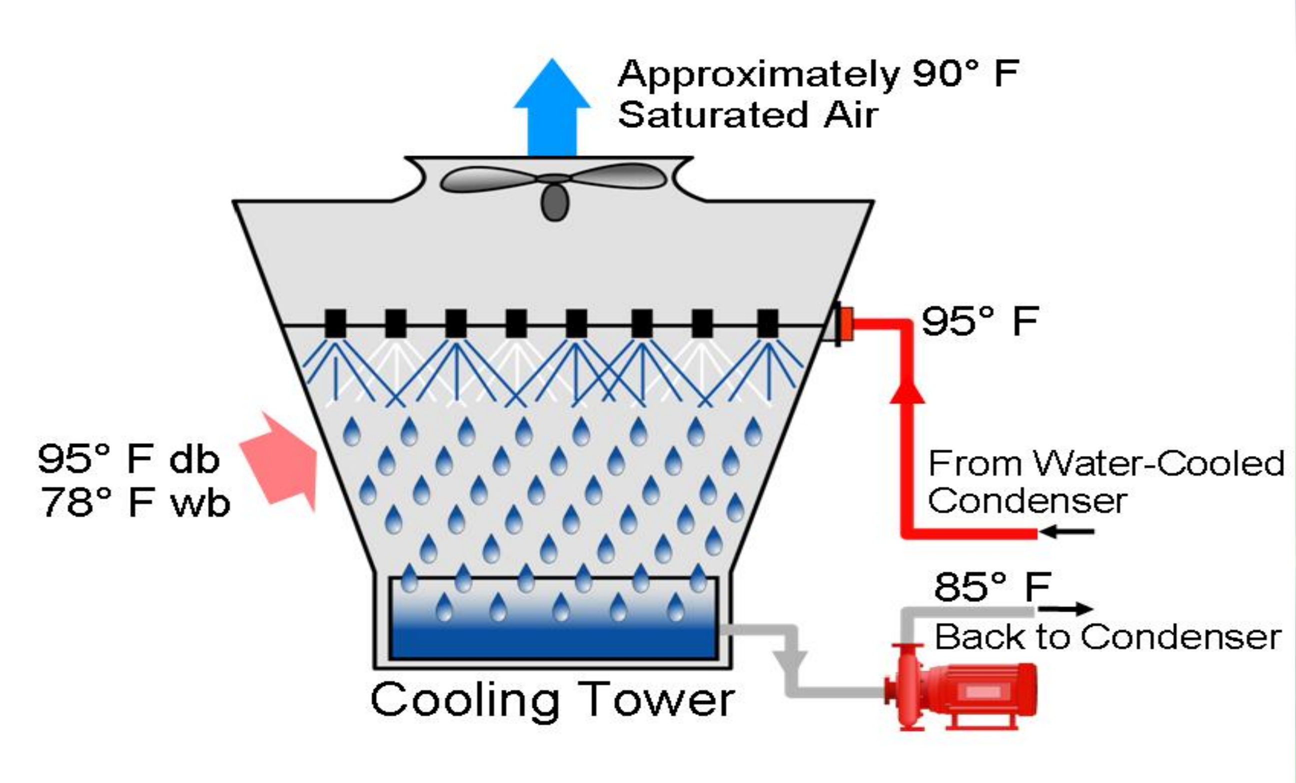


Chicago Weather 12 x 5

73.3% of hours have less than 70 F entering condenser water



Cooling Tower



- As the ambient wet bulb drops colder condenser water can be delivered to the chiller(s).

- VFD’s on centrifugal chillers track the weather.

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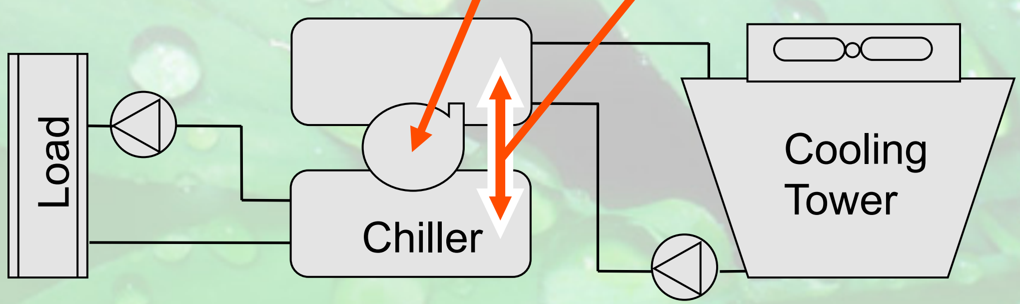
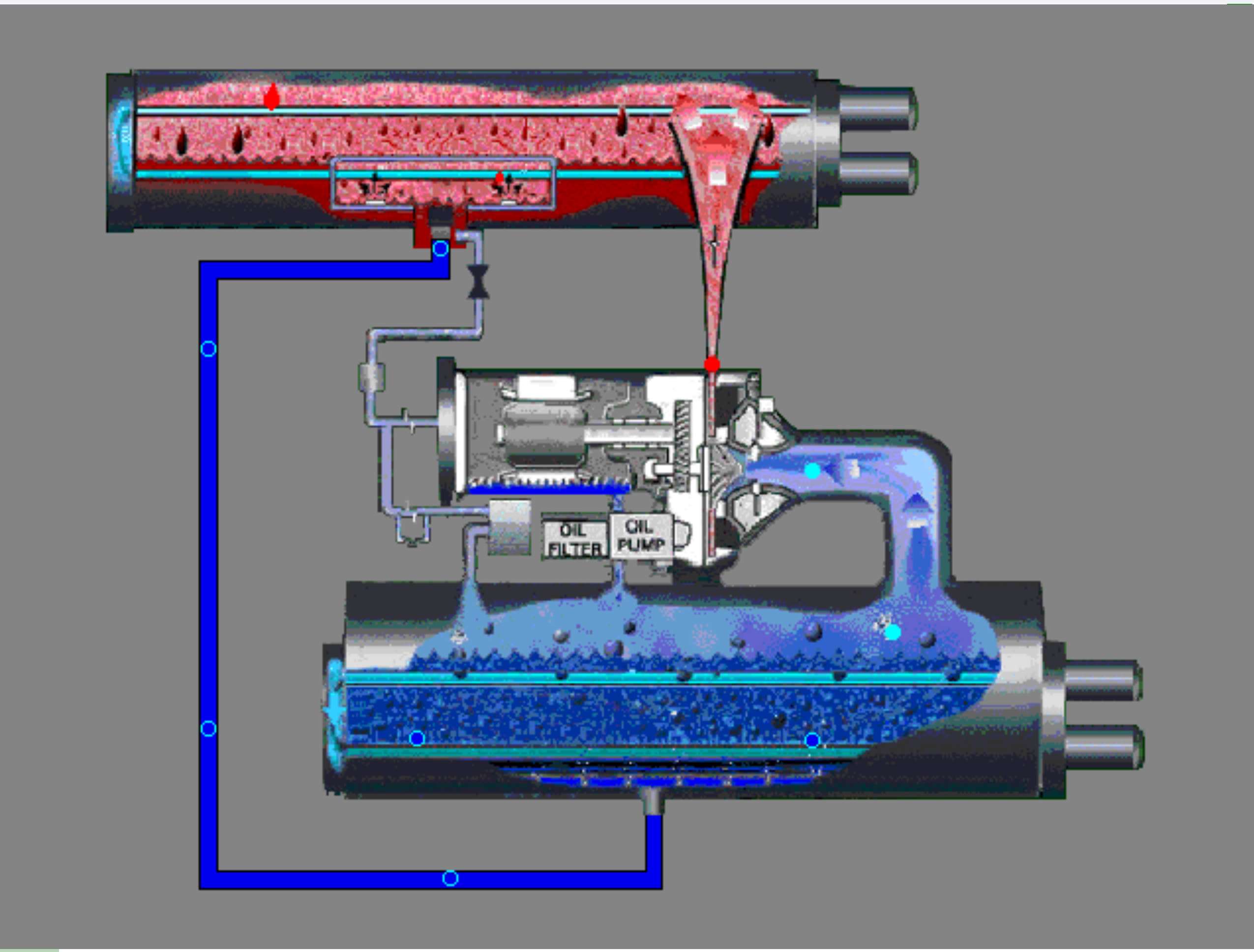
Chiller Energy

Like pumps, chiller energy consumption is a function of mass flow and differential pressure. KW = Tons x Lift

$$\textbf{Compressor Input kW} \sim \frac{\text{Mass Flow X Lift}}{\text{Compressor/Cycle Efficiency}}$$



Refrigerant Temperature



or refrigerant to
ondense, it must be
armer than *leaving*
ondenser water.

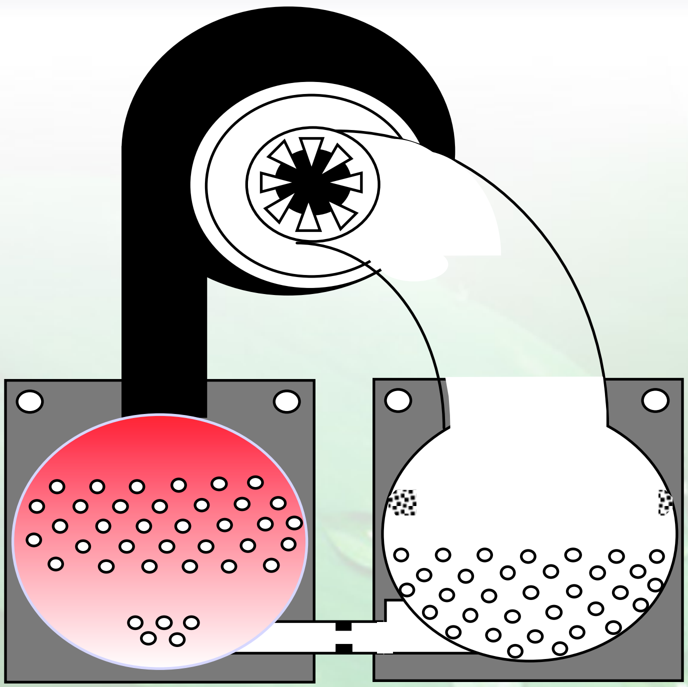
5 F + 2F approach = 97F

44F
54F

To boil, refrigerant must be colder than *leaving* chilled water. 44F – 2F approach = 42F

Refrigerant temperatures are based on *leaving* water temperatures!

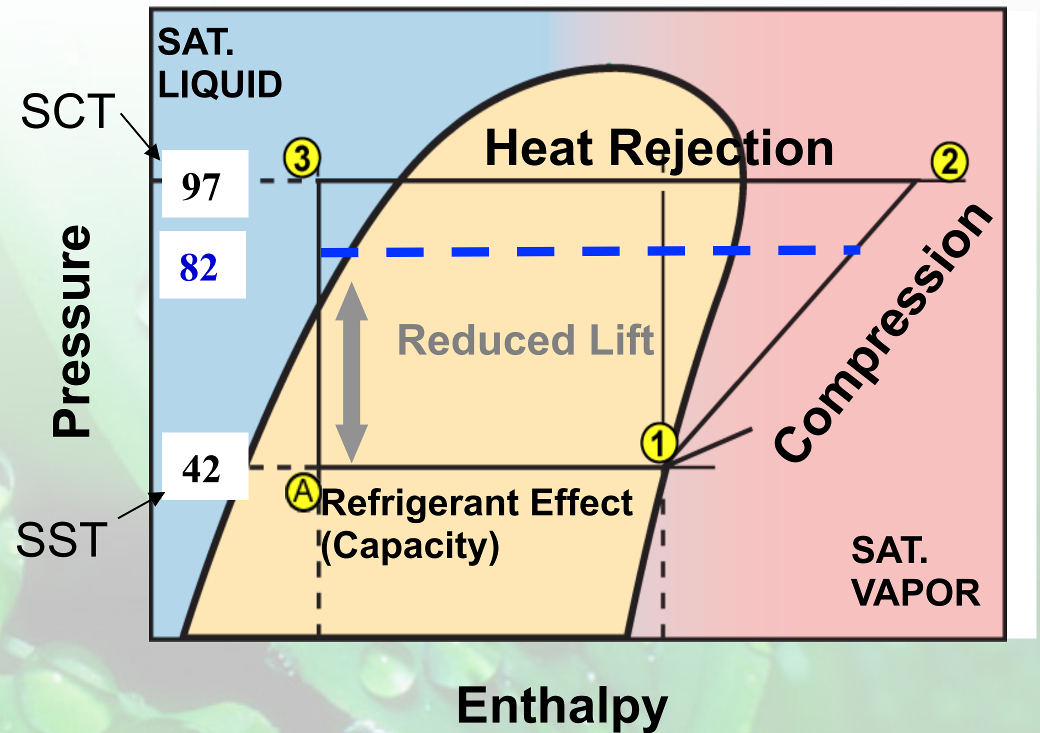
Pressure Enthalpy Chart



97 F / 120 PSI

82F / 90 PSI

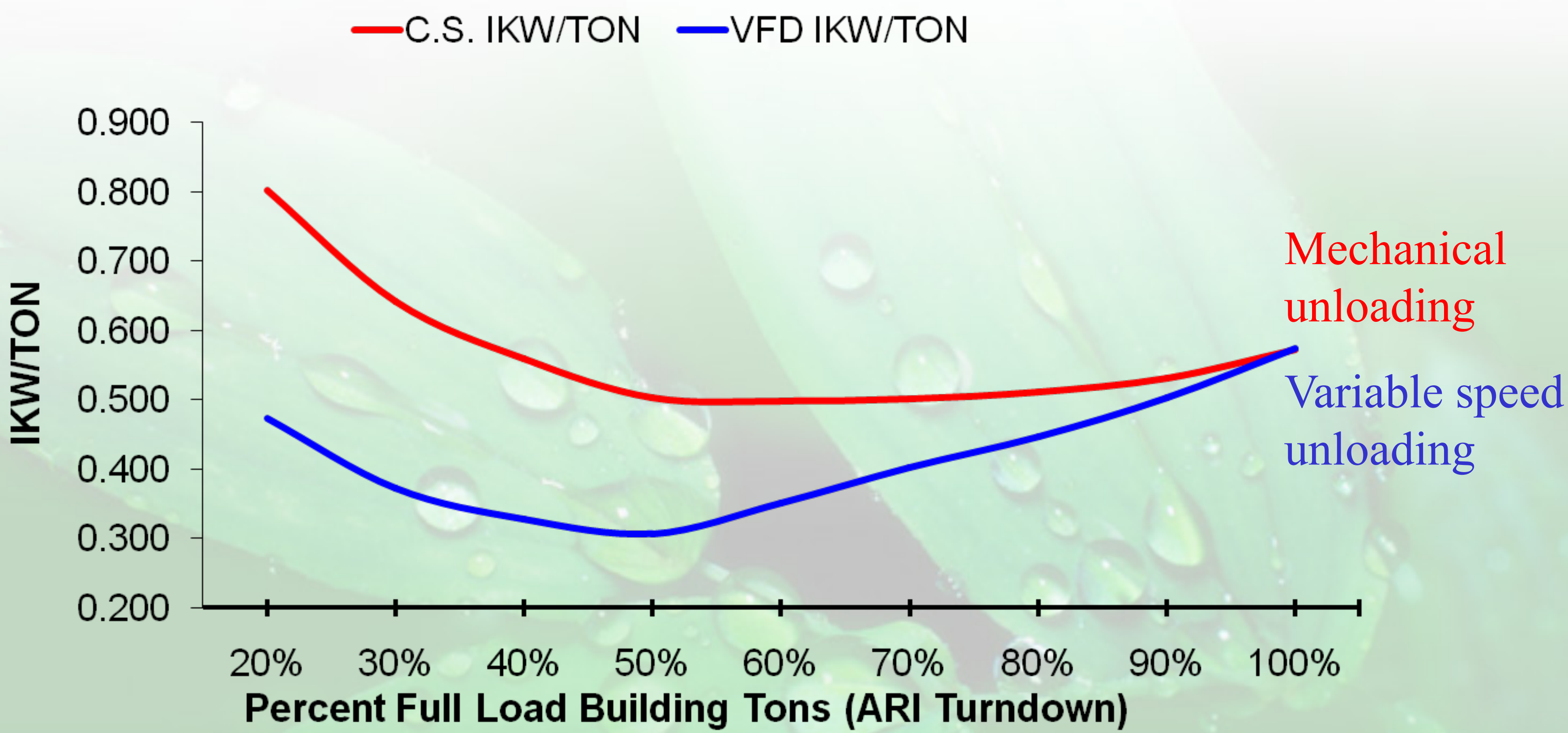
42 F / 40 PSI



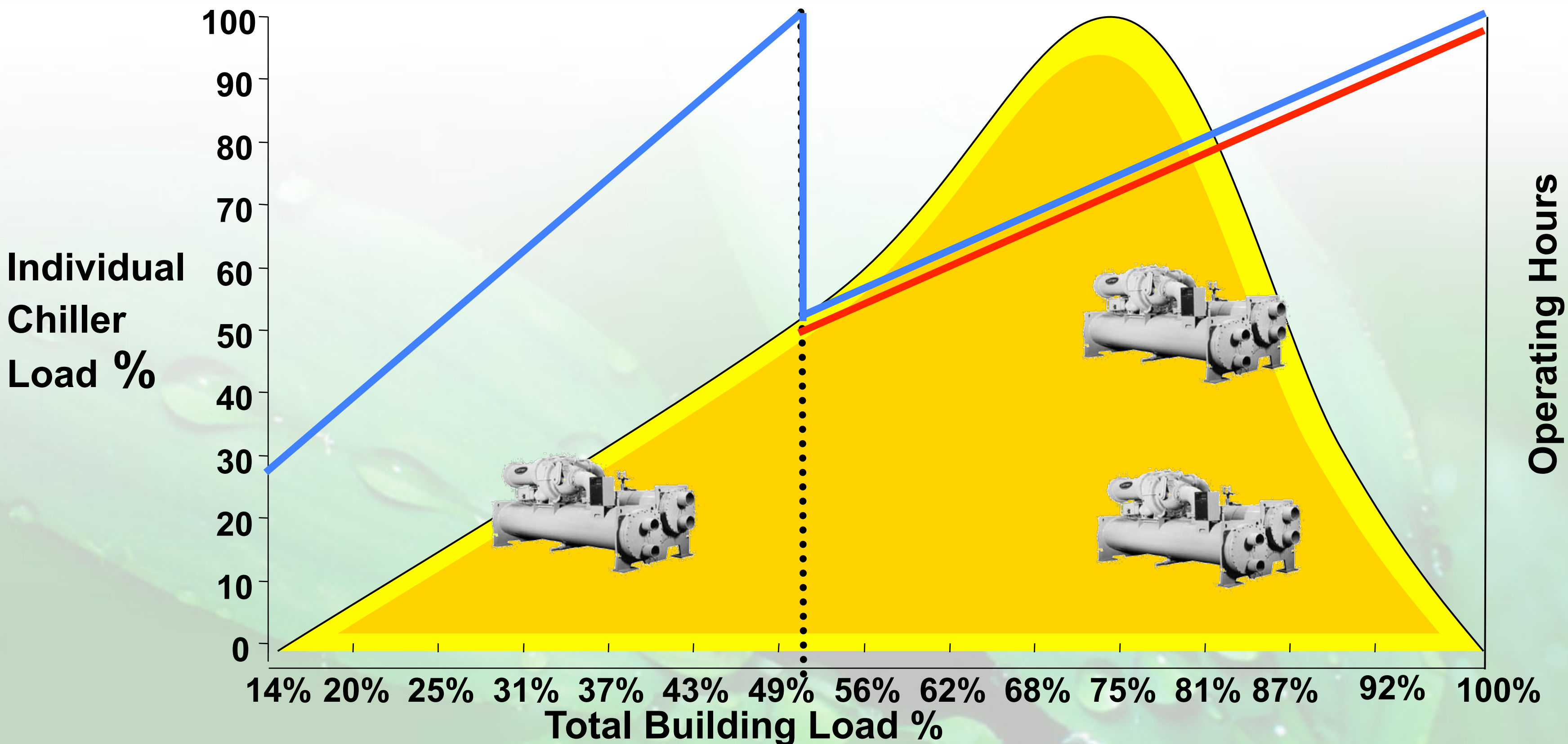
Lower Lift = Less Work = Lower kW

Single Chiller Efficiency

VFD Driven Chillers take advantage of lift and / or load reduction to reduce energy consumption.



Two Chiller Operation / Efficiency

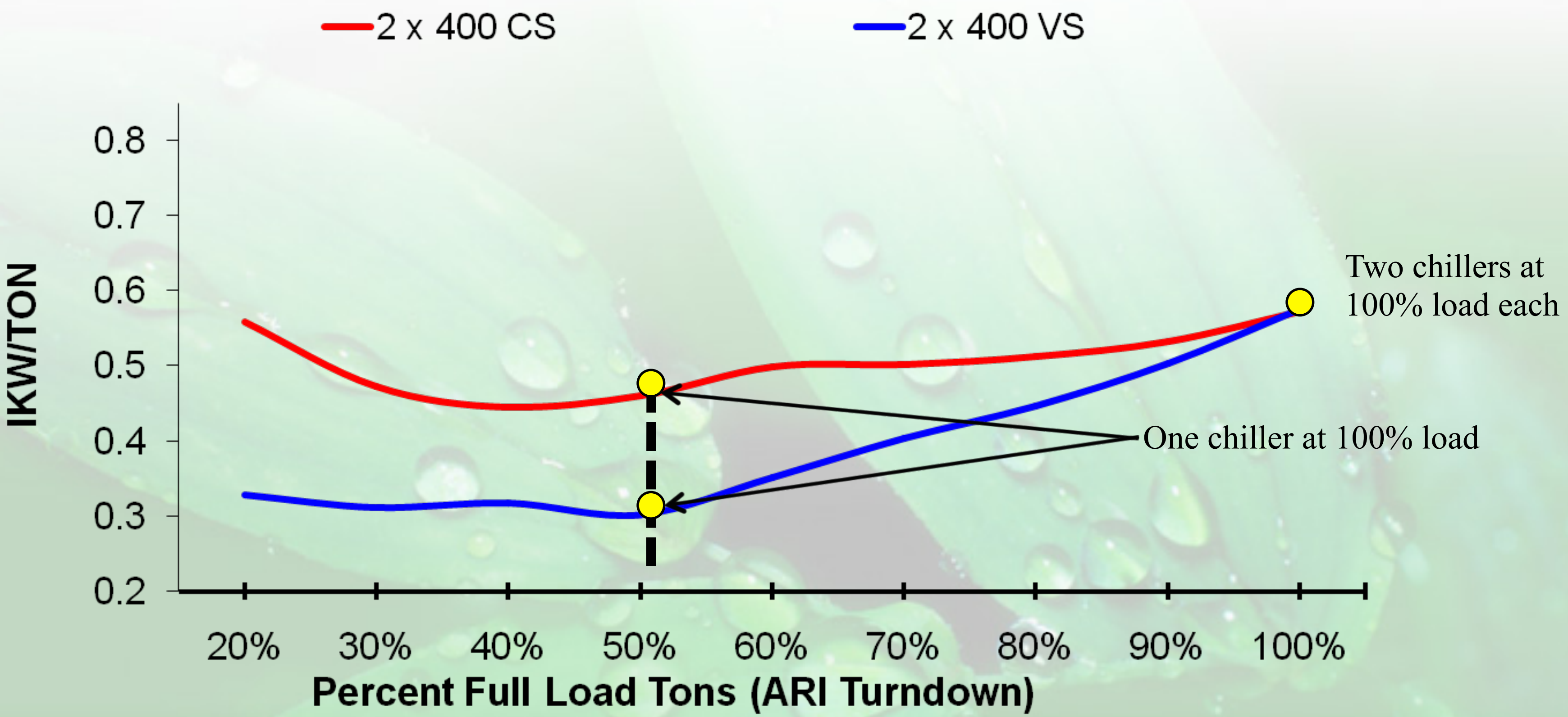


Min Tower 55 deg ECWT

Design Day 85 deg ECWT

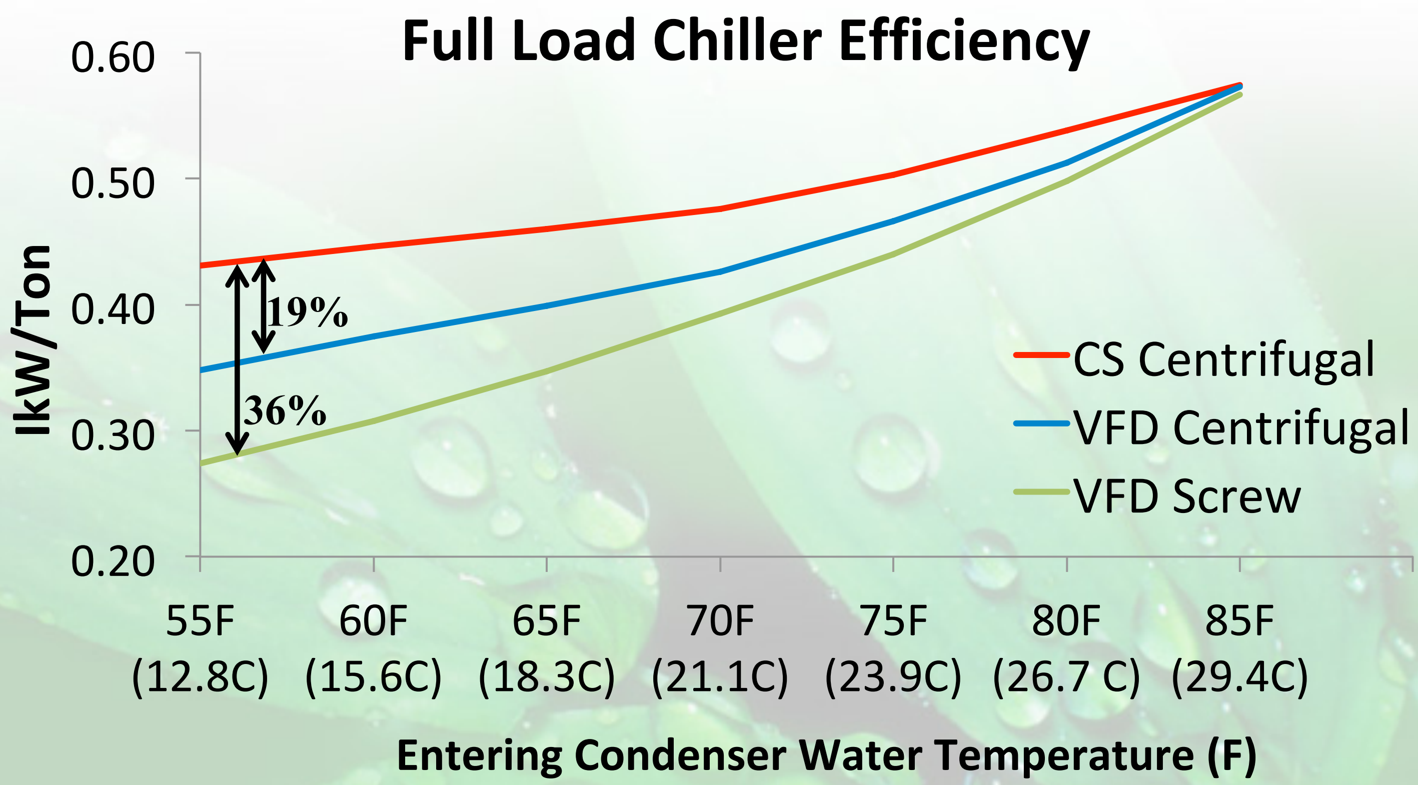
Efficiency

VFD Driven Chillers take advantage of lift and / or load reduction to reduce energy consumption.



FULL LOAD CHILLER EFFICIENCY

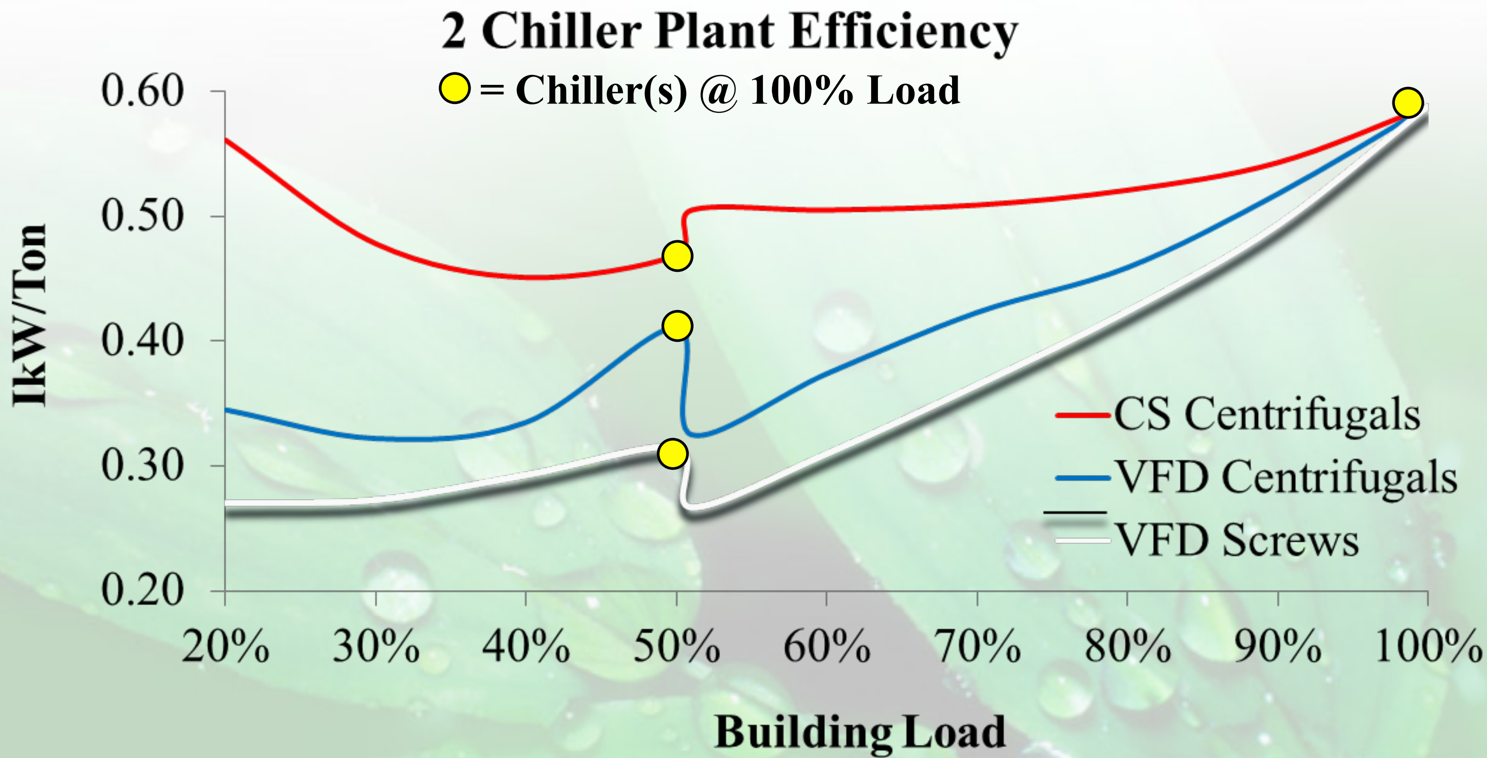
VFD Driven Chillers take advantage of lift reduction to reduce energy consumption *even at full capacity*.



Big VFDs Savings @ *Full Capacity*

EFFICIENCY

VFD Driven Chillers take advantage of lift and/or load reduction to reduce energy consumption.



Big FL VFD Savings in Real Plants

QUESTION #1

Which of the following is an accurate simplified view of lift?

A. *"Lift is based on leaving"* (leaving condenser water temperature less leaving evaporator water temperature)

B. *"Lift is based on entering"* (entering condenser water temperature less entering evaporator temperature)

C. *"Lift is based on quantity"* (the number of chillers in the building)

D. *"Lift is based on vertical"* (the height of the building)

QUESTION #2

When would variable speed chillers likely consume less energy than constant speed chillers?

A. At 100% capacity and design lift

B. At 100% capacity and reduced lift

C. At reduced capacity and reduced lift

D. Both b and c

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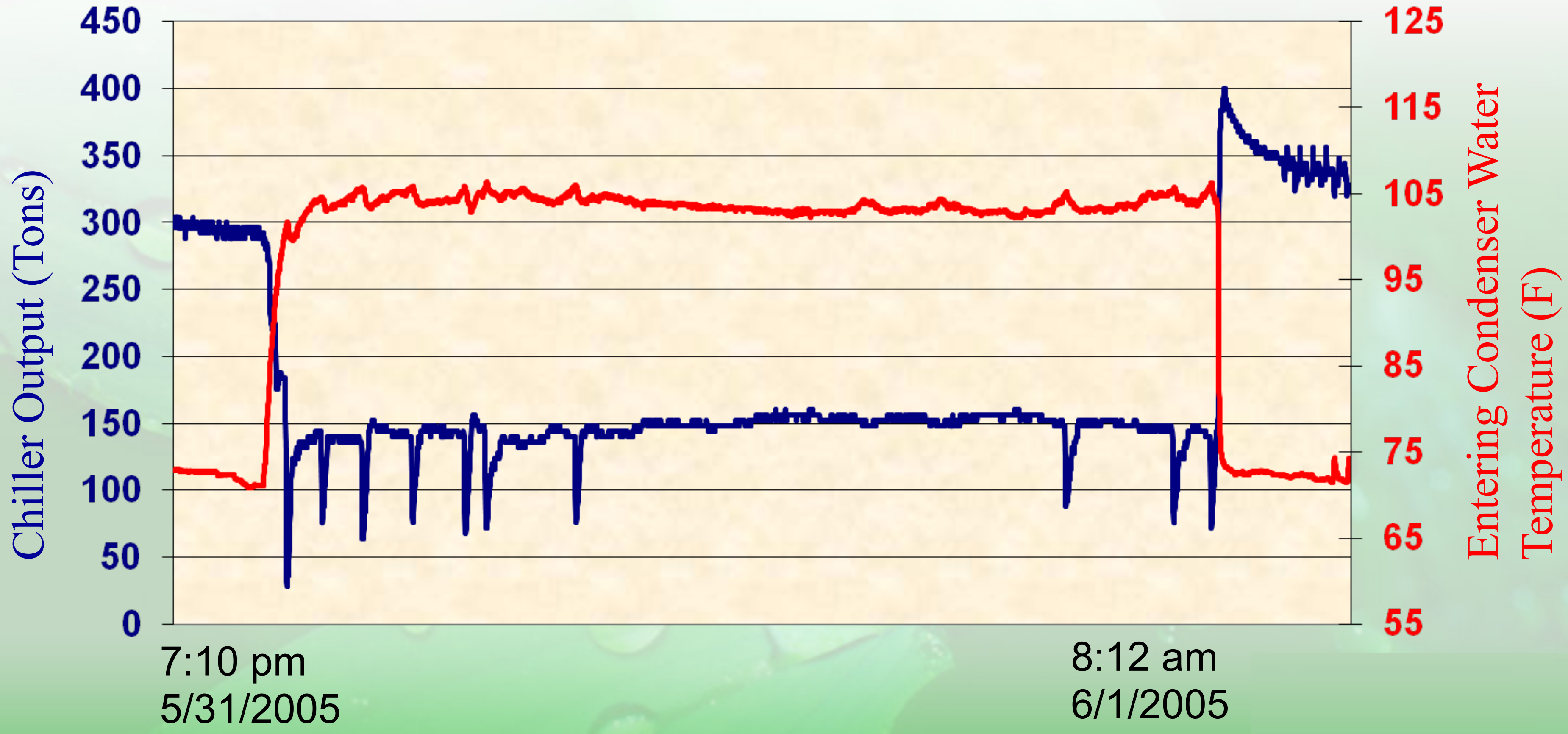
Tower Fan Failure

Actual Field Event – Cooling Tower Failure, Fayetteville, Arkansas, May 31, 2005



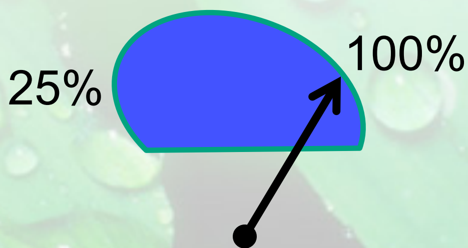
Unique Speed Reduction

Screw chillers can achieves up to 75% Speed Reduction

Ideal Fan Laws limit centrifugals to 35% speed reduction

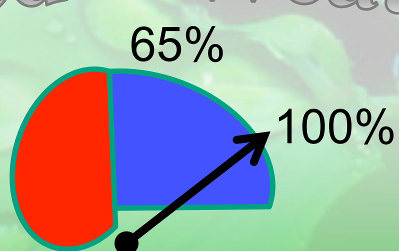
Speed = Load

Screw Chiller



Speed = Weather

ALL Centrifugals



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Parallel Flow Systems

Customer Request.

•Three 267 ton chillers in parallel to handle 700 ton load

•525 ton critical load

•Primary / secondary pumping system.

•60 / 44 Evaporator

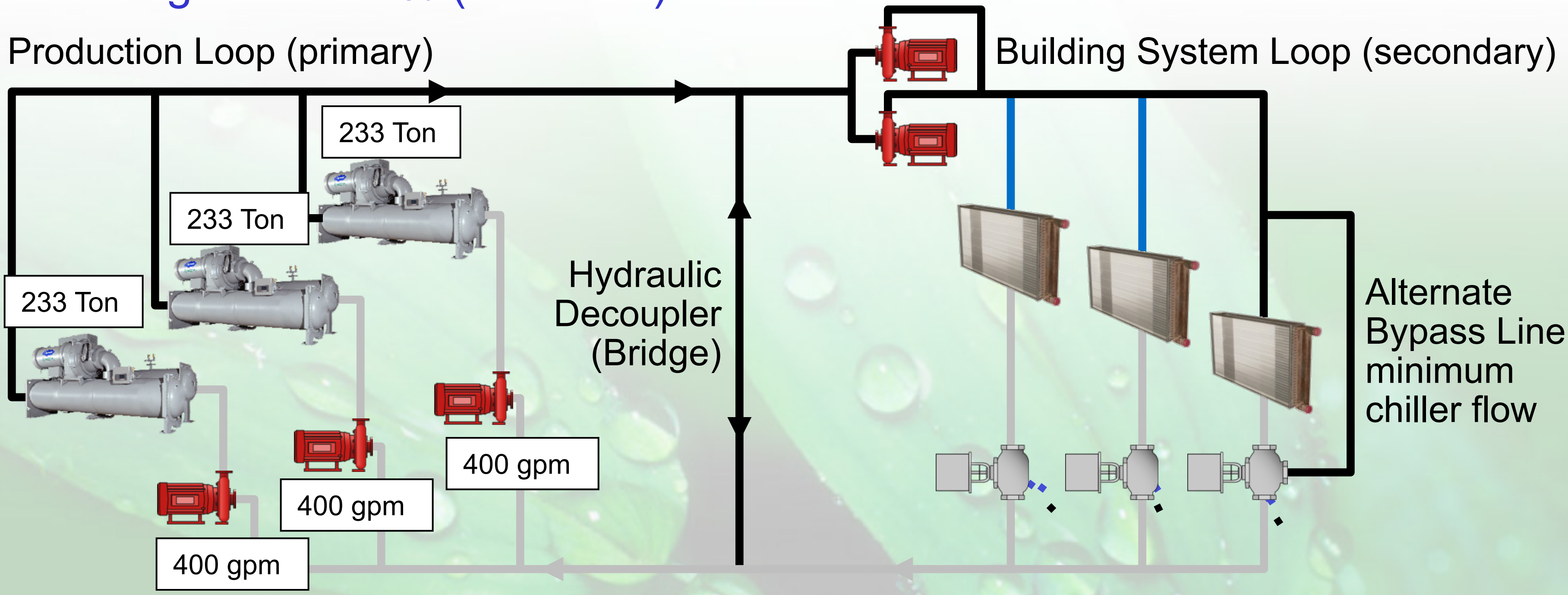
•85 / 3.0 gpm per ton in condenser

•Energy efficiency a priority

Any two chillers must provide > 75% capacity

3 x 267 Ton, Primary/Secondary

Building Load 100% (700 Tons)



700 tons / 3 chillers = 233 tons per chiller

When building 100% loaded, entering condenser water = 85F

2 x 525 Ton, Variable Primary

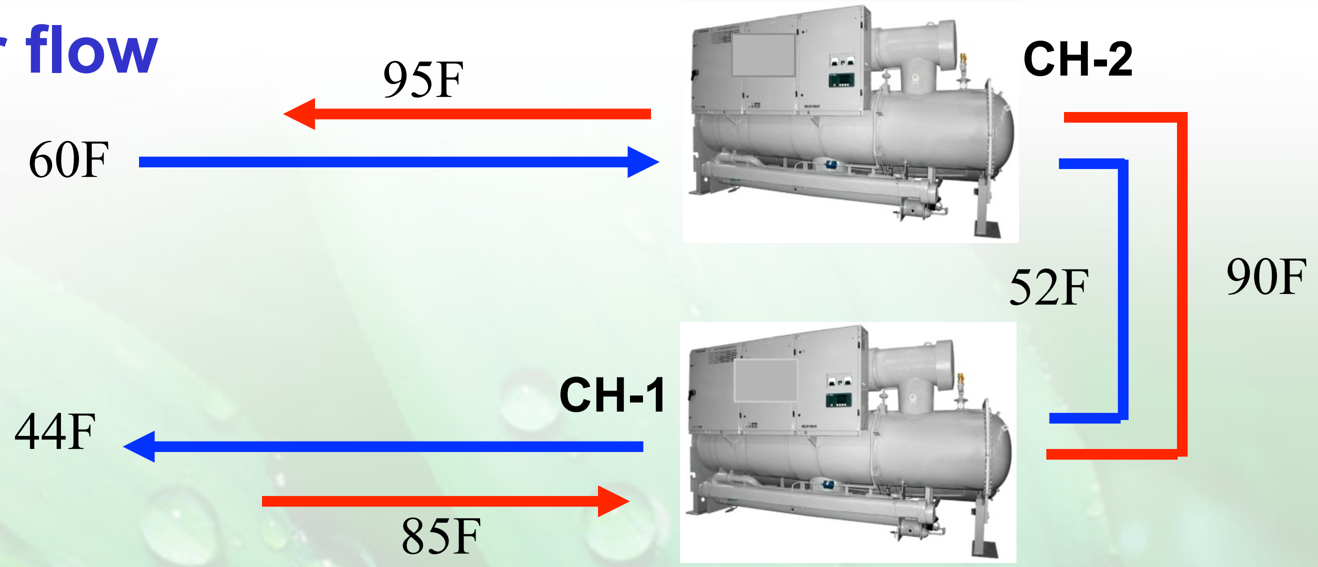
Alternative Design.

- Two 525 ton chillers in Series Counter Flow
- One chiller meets 525 ton critical load – Running redundancy
- Variable primary pumping system.
- 60 / 44 Evaporator
- 85 / 3.0 gpm per ton in Condenser
- Energy Efficiency a priority

Any one chiller can provide > 75% capacity

Basic Series Counter Flow Diagram

Series Counter flow



Upstream chiller (CH-2) cools 60F – 52F

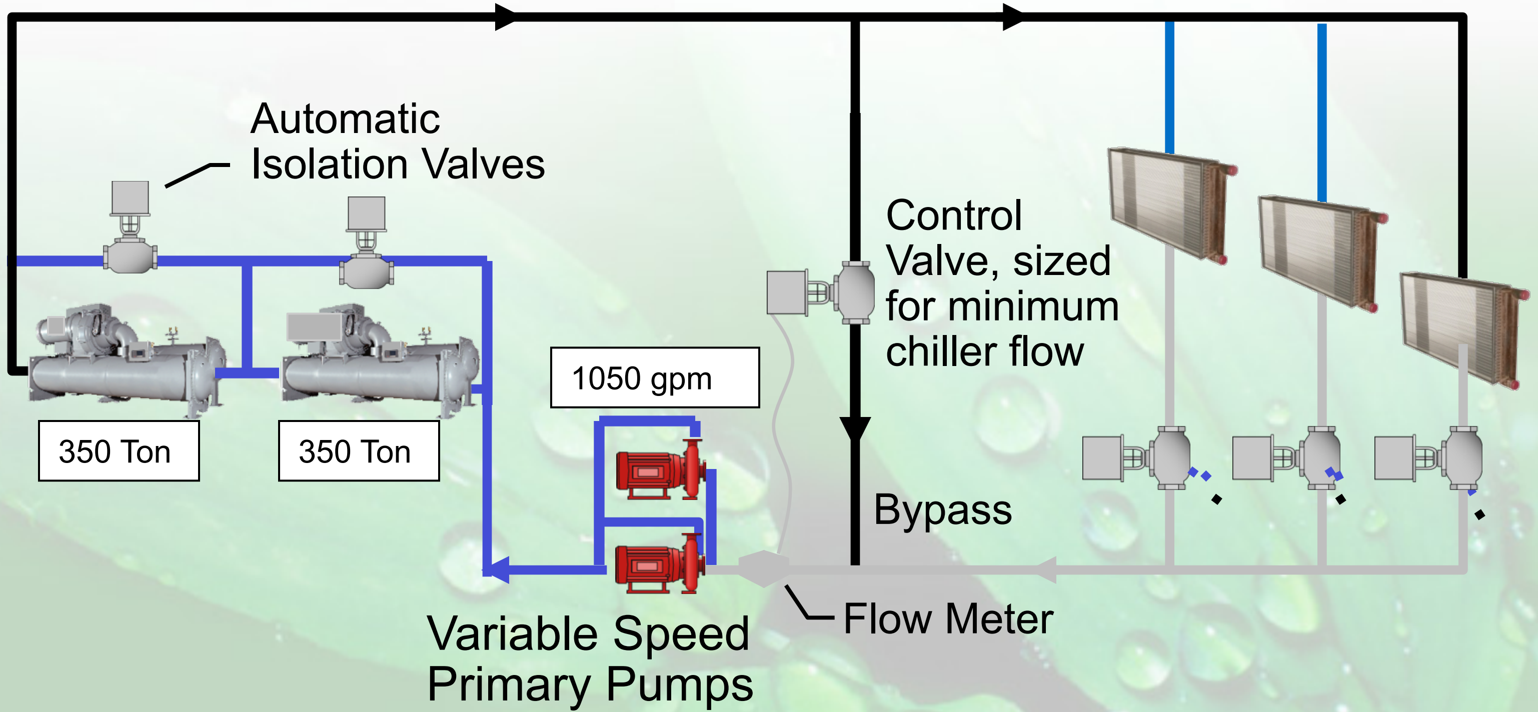
Downstream chiller (CH-1) cools 52F – 44F

Evaporator water flows thru CH-2 and then CH-1

Condenser water flows thru CH-1 and then CH-2

2 x 525, Ton Variable Primary

Building Load 100% (700 Tons)



700 tons / 2 chillers = 350 tons per chiller

When building 100% loaded, entering condenser water = 85F

Comparison of Two Systems

Chiller Performance

	Full Load	IPLV	Evap gpm	Cond gpm
3 x 267 parallel CS	0.650	0.566	1200	2400
3 x 267 parallel VS	0.629		1200	2400
2 x 525 SCF CS Cent	0.631		1200	2400
2 x 525 SCF VS Screw	0.496		1050	2100

44%

<u>New System:</u>

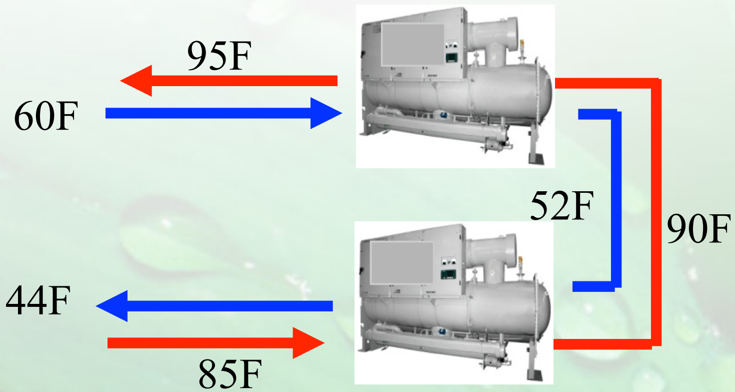
- 22 % better IPLV than original VS lay out
- 21 % better F.L. than original VS lay out

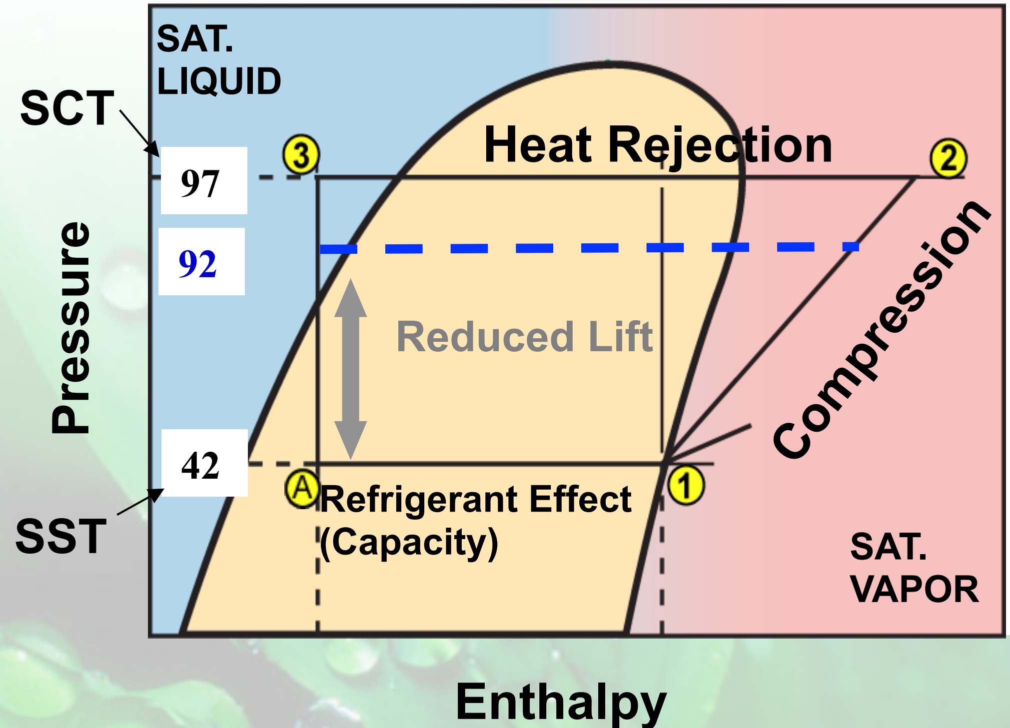
Tailored Solution Summary

- Fewer Chillers / Fewer Pumps
- Same Redundancy
- Better Efficiency
- Better Reliability
- Less Floor Space

Series Counter Flow Reduces Lift

Downstream Chiller



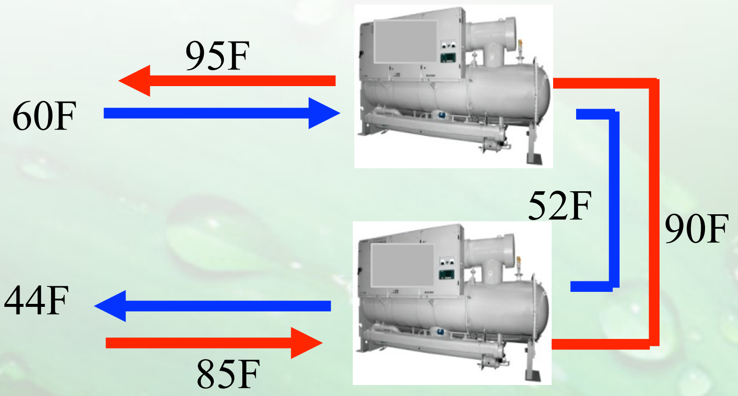


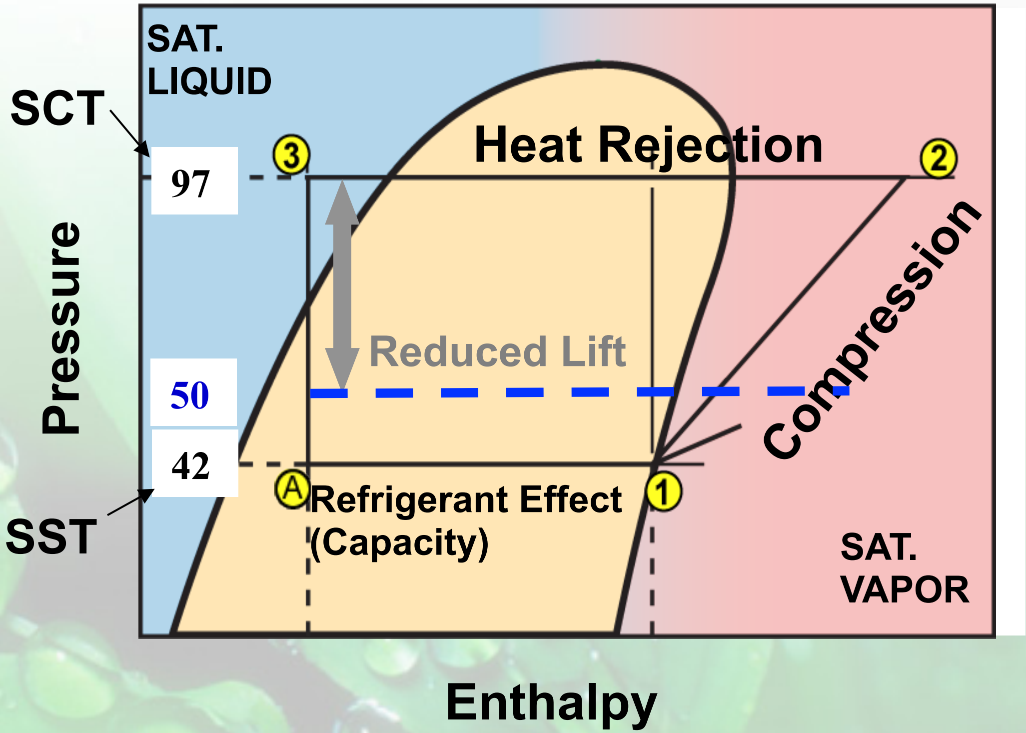
System	SST	SCT	Lift
Parallel	42	97	55
SCF	42	92	50

Lower Lift = Less Work = Lower kW

Series Counter Flow Reduces Lift

Upstream Chiller





System	SST	SCT	Lift
Parallel	42	97	55
SCF	50	97	47

Lower Lift = Less Work = Lower kW

Larger Delta T's Decreases Lift Further

As Delta T goes up, the lift on the upstream machine decreases.

System Design	DS	US
44 – 54	44	49
44 – 56	44	50
44 – 58	44	51
44 – 60	44	52

Series designs tend to have higher delta T's.

SCF VPF Decreases Lift Further Still

VPF	**100%**	**75%**	**50%**	**25%**
DS Lvg	44	44	44	44
US Lvg	52	52	52	Off
Return	60	60	60	Off

With constant speed pumping delta T drops with load.

Const. Flow	100%	75%	50%	25%
DS Lvg	44	44	44	44
US Lvg	52	50	48	Off
Return	60	56	52	Off

So the lift is reduced on the upstream chiller improving chiller efficiency. Oh by the way – your pumping less water saving pump energy too!

QUESTION #3

Why does a series counter flow plant save energy?

A. "*Less lift, means less work, means less kW*" (The lift on each chiller is reduced through the series design, lowering compression power, even on a design day)

B. "*Split the chillers, split the load*" (The building design load is reduced due to the series chiller arrangement)

C. "*Make hay when the sun shines*" (The weather and ambient wet bulb change due to the series chiller arrangement)

D. "*Educate and Influence*" (Plug loads decrease when occupants learn that the chillers are installed in series)

QUESTION #4

Which of the following is <u>NOT</u> an advantage of high delta T, variable evaporator flow in series counter flow chilled water plants?

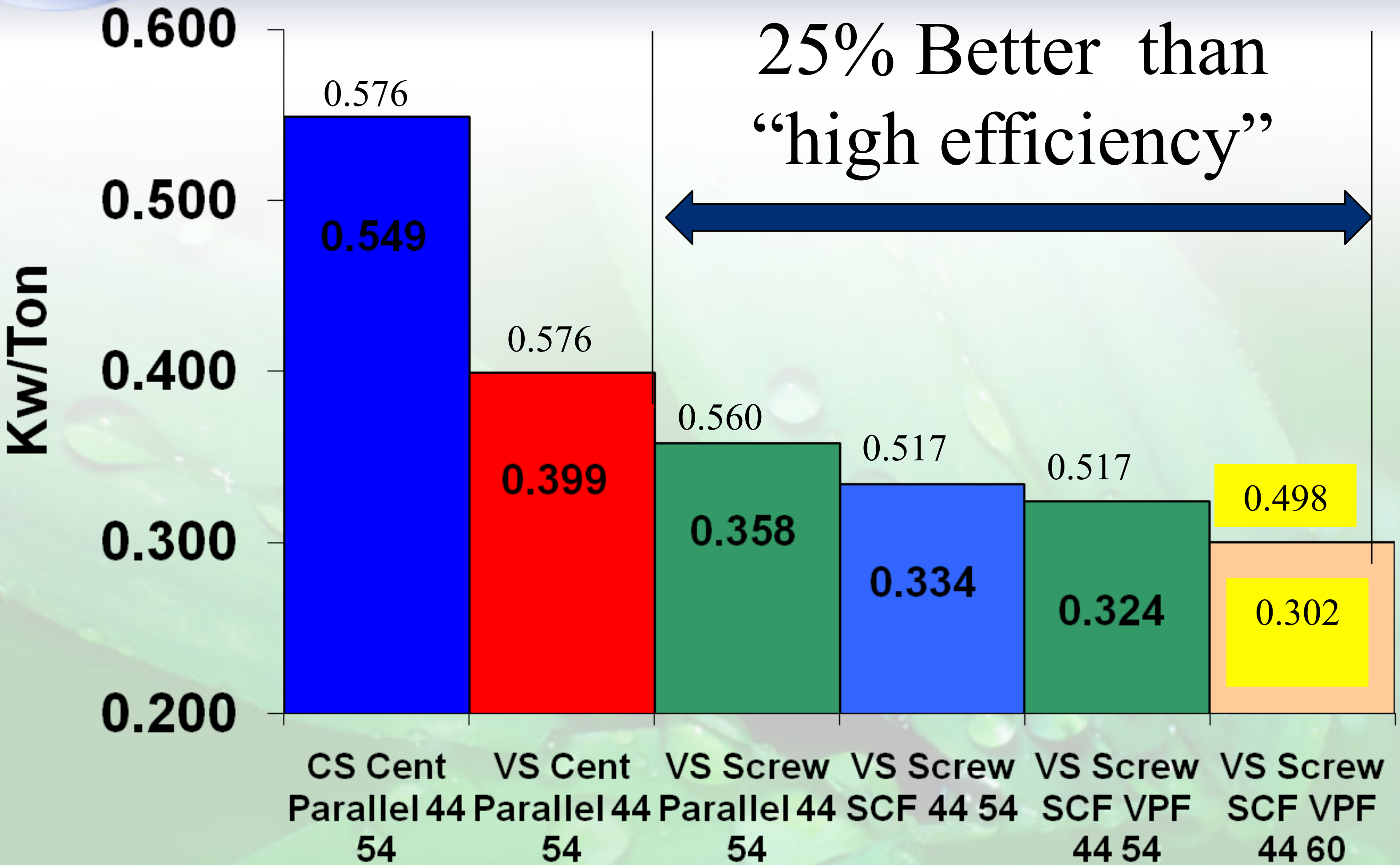
A. Variable evaporator flow reduces pump power by reducing the flow rate at part loads

B. Higher evaporator delta T reduces the flow rate and resulting pressure drop through the series heat exchangers

C. Raising the return water temperature reduces the lift on the upstream chiller, increasing efficiency

D. Lowering the leaving water temperature increases the lift on the downstream chiller, decreasing efficiency

Moving the Frontier



Series vs. Parallel

Parallel Screw Chiller Performance 400 Tons Each

Output Type	Full Load	Part Load	Part Load	Part Load
Percent Load	100.00	75.00	50.00	25.00
Chiller Capacity	400 Tons	300 Tons	200 Tons	100 Tons
Chiller Input kW	250 kW	122 kW	55 kW	31 kW
Chiller Input Power	0.625 kW/Ton	0.405 kW/Ton	0.273 kW/Ton	0.305 kW/Ton
Chiller COP	5.6	8.7	12.9	11.5
IPLV	0.324 kW/Ton	N/A	N/A	N/A
Cooler				
Entering Temp.	53.97 F	51.48 F	48.99 F	46.49 F
Leaving Temp.	44.00 F	44.00 F	44.00 F	44.00 F
Flow Rate	960.0 gpm	960.0 gpm	960.0 gpm	960.0 gpm
Pressure Drop	18.2 ft wg	18.3 ft wg	18.3 ft wg	18.4 ft wg
Condenser				
Leaving Temp.	94.44 F	81.70 F	69.31 F	67.17 F
Entering Temp.	85.00 F	75.00 F	65.00 F	65.00 F
Flow Rate	1200.0 gpm	1200.0 gpm	1200.0 gpm	1200.0 gpm
Pressure Drop	19.2 ft wg	19.7 ft wg	20.3 ft wg	20.3 ft wg

Series vs. Parallel

Series Counterflow Screw Chiller

Downstream Chiller – 44 LWT – 50 EWT / 85 ECWT – 90 LCWT

Output Type	Full Load	Part Load	Part Load	Part Load
Percent Load	100.00	75.00	50.00	25.00
Chiller Capacity	400 Tons	300 Tons	200 Tons	100 Tons
Chiller Input kW	234 kW	116 kW	52 kW	29 kW
Chiller Input Power	0.584 kW/Ton	0.386 kW/Ton	0.262 kW/Ton	0.293 kW/Ton
Chiller COP	6.0	9.1	13.4	12.0
NPLV	0.309 kW/Ton	N/A	N/A	N/A

Upstream Chiller – 50 LWT – 56 EWT / 90 ECWT – 95 LCWT

Output Type	Full Load	Part Load	Part Load	Part Load
Percent Load	100.00	75.00	50.00	25.00
Chiller Capacity	400 Tons	300 Tons	200 Tons	100 Tons
Chiller Input kW	218 kW	102 kW	41 kW	23 kW
Chiller Input Power	0.546 kW/Ton	0.340 kW/Ton	0.205 kW/Ton	0.231 kW/Ton
Chiller COP	6.4	10.3	17.2	15.2
NPLV	0.252 kW/Ton	N/A	N/A	N/A

Full Load Efficiency = .565 (Series) vs. .625 (Parallel)
Part Load Efficiency = .281 (Series) vs. .324 (Parallel) – 13.3% Improvement
Total pressure drop through the cooler = 15.4 feet
Total pressure drop through the condenser = 21.2 feet

Series Counter-Flow

Added Benefit to Series Counter Flow

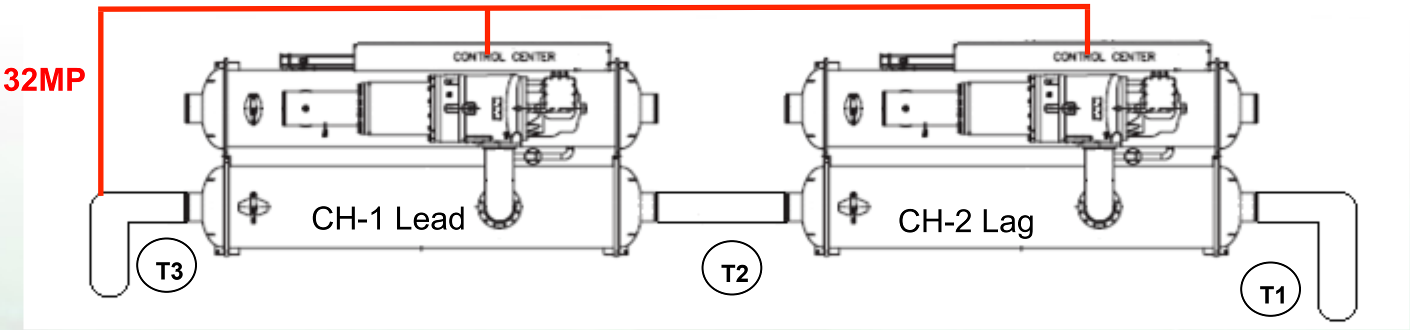
- Low delta T syndrome is one of the biggest problem in chiller plants.
  - Ability to get full flow with only one chiller running (Fan coil projects).
  - Replace chillers and then replace AHU’s in the building (Most projects).
    - The chiller plant gets more efficient as the delta T increases as they change out AHU’s.

- LEED Projects

- Com Ed Dollars

Series Counter Flow - VPF

Capacity Control



Condenser piping not shown

Bypass piping, isolation valves not shown

CH-1 Programmed as lead chiller, CH-2 programmed as lag chiller

CH-1 loads up until compressor speed = 80%.

At 80% of compressor speed, CH-1 commands CH-2 to turn on. Since chillers are in series, pump flows are already established.

CH-1 sends a demand limit signal to CH-2, thereby ensuring both chillers are running at the same % of nameplate kW. CH-1 increases or decreases the demand limit to regulate T3 to set point.

At 35% of compressor speed, CH-1 commands CH-2 to turn off.

If CH-1 becomes disabled, the on board controls rotate CH-2 as the lead chiller. CH-2 regulates to the leaving temperature T3 via the 32MP sensor.

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