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

LEARNING OBJECTIVES

At the end of this session you should be able to:

- Describe the difference in part load operation between centrifugal and screw chillers
- Explain how condenser water temperature impacts screw and centrifugal operation and efficiency
- Explain how a screw chiller in a series-counterflow arrangement can provide savings over centrifugals in standard parallel arrangement

AGENDA WEATHER

Designing for 50% Energy Savings:

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

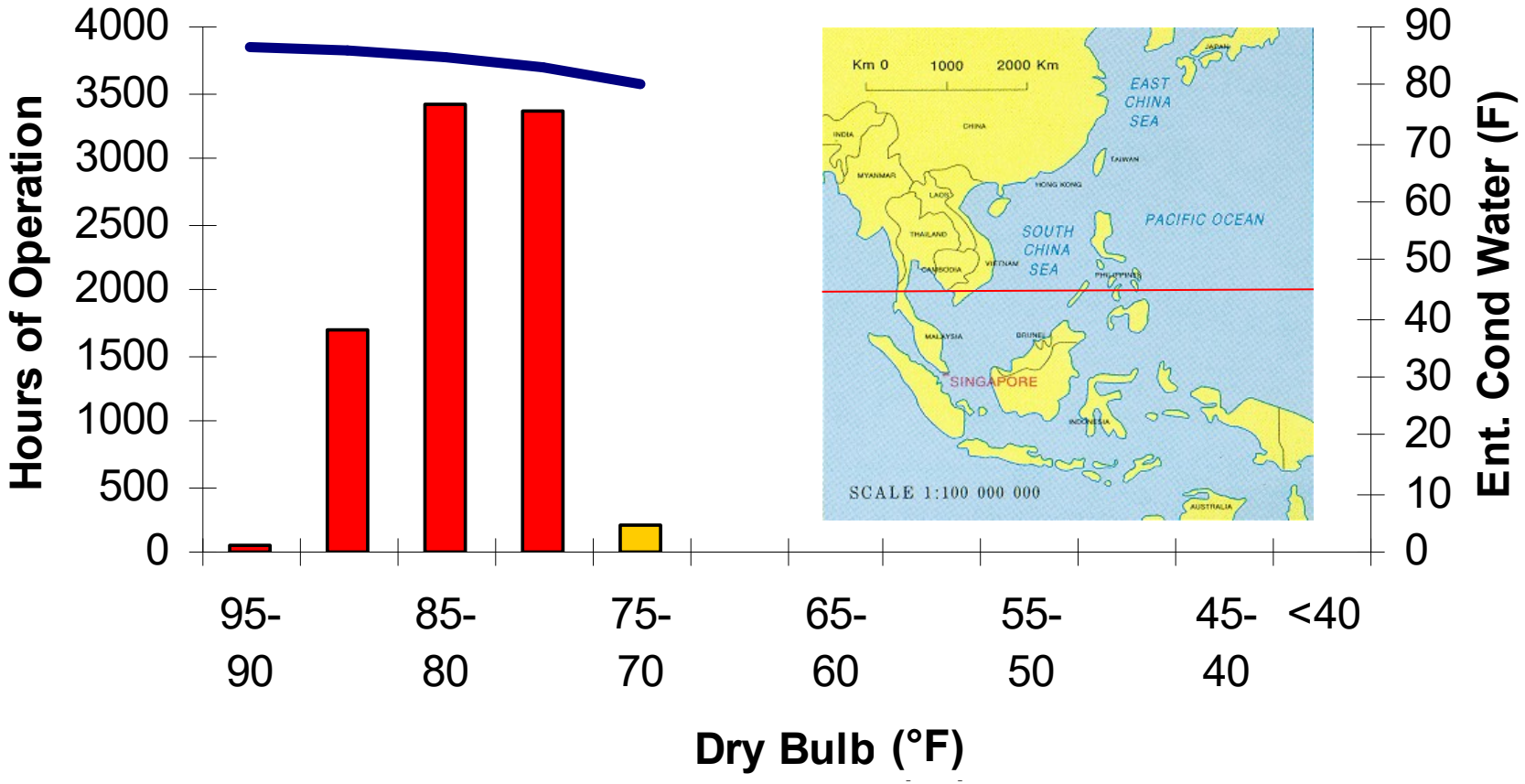
Results:

- Test Data
- Energy Analysis

Basic Building Blocks

SINGAPORE WEATHER 24 × 7

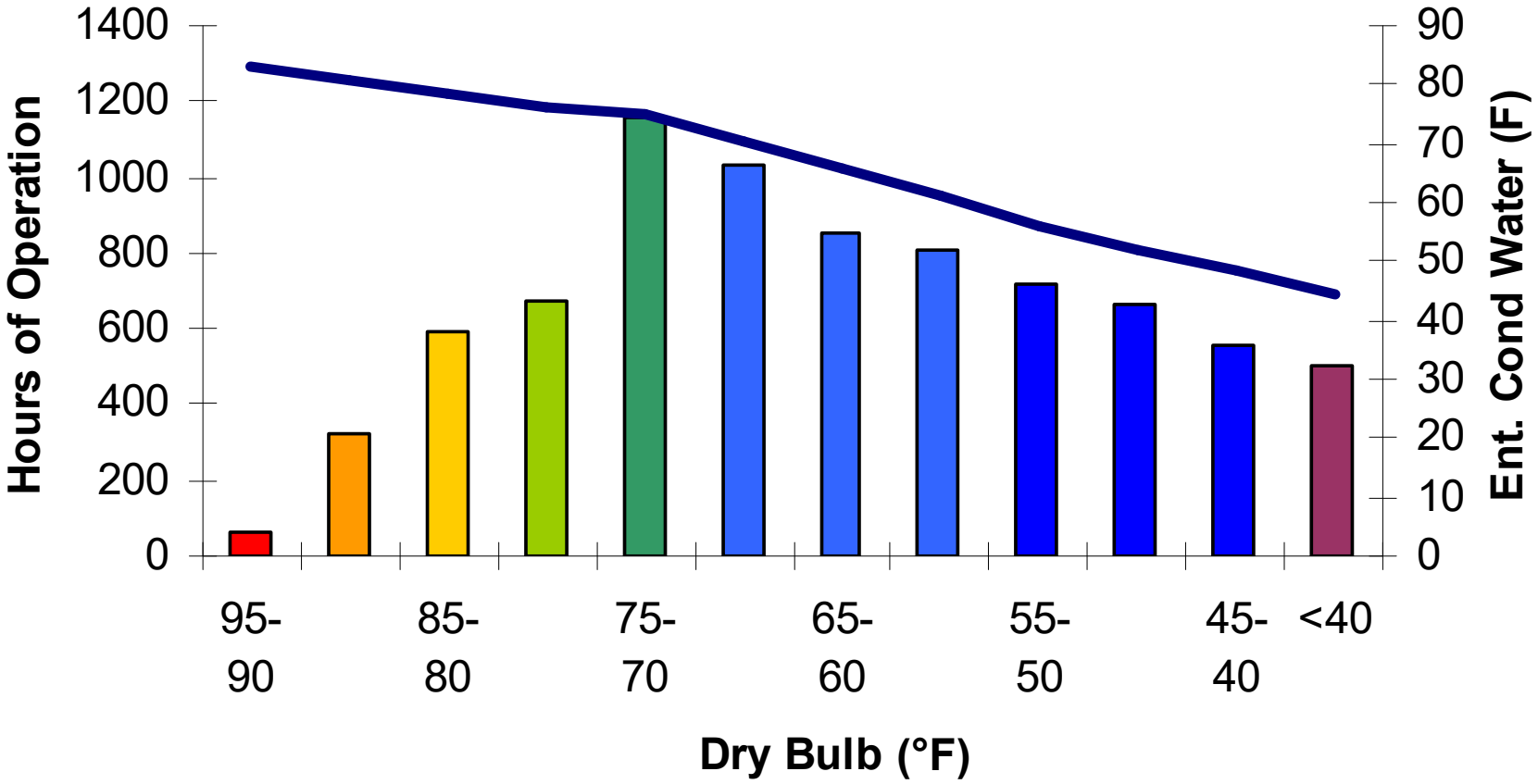
2% of hours have less than 80°F entering condenser water



Weather is a Key Design Factor

CHARLOTTE WEATHER 24 × 7

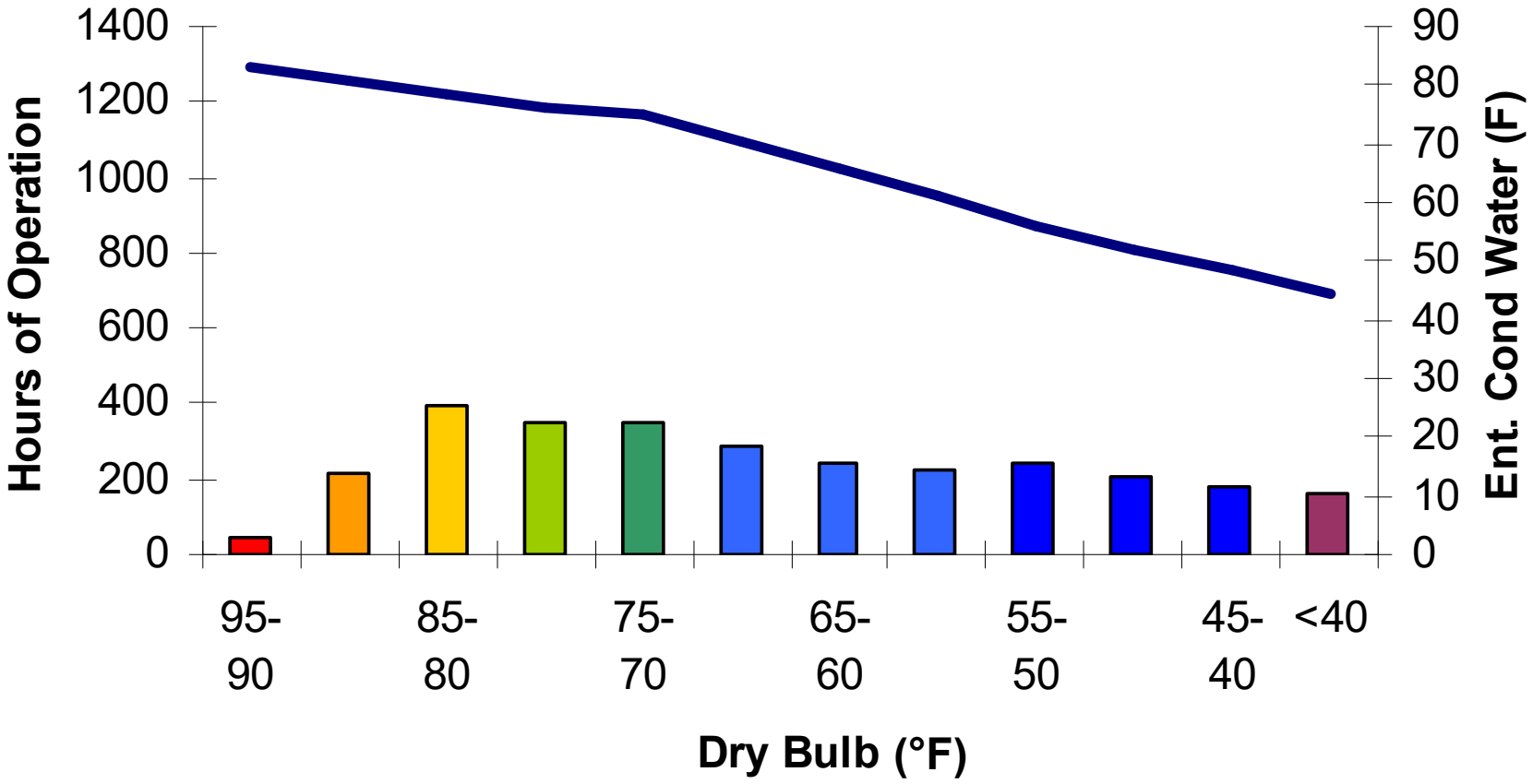
68% of hours have less than 70.4°F entering condenser water



Weather Varies by Location

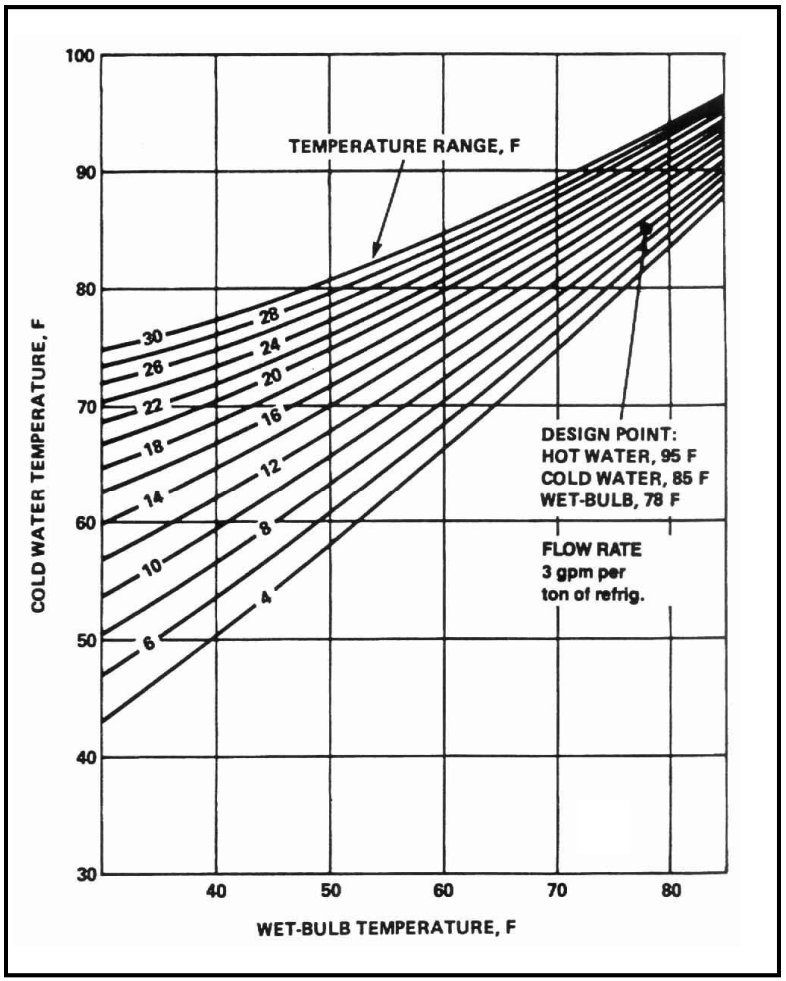
CHARLOTTE WEATHER 12 × 5

58% of hours have less than 70.4°F entering condenser water



Occupancy Schedule Relevant

COOLING TOWER



As outdoor wet bulb drops, approach rises slightly.

Approach = 7 + (78-WB)*0.08F

For constant flow:
As chiller load falls, range (LCWT-ECWT) decreases causing temperature levels to fall to a closer approach.

At 78 WB, approach decreases by 0.5 to 1.0 F per 10% load.

Local Weather and Tower Dictate ECWT

Chart source: ASHRAE Handbook

AGENDA ENERGY

Designing for 50% Energy Savings:

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

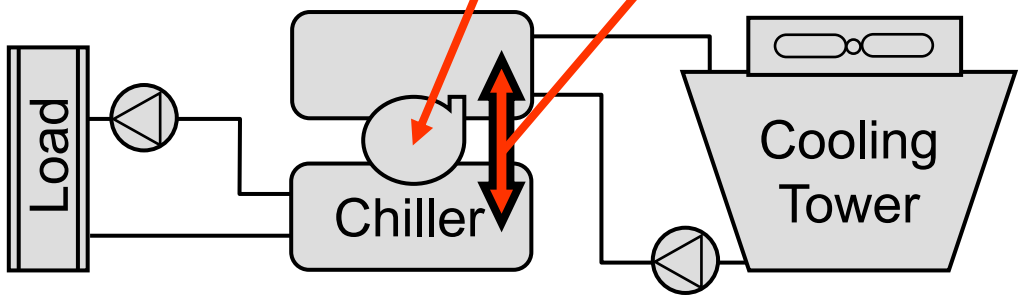
Results:

- Test Data
- Energy Analysis

CHILLER ENERGY

Like pumps, chiller energy consumption is a function of mass flow and differential pressure.

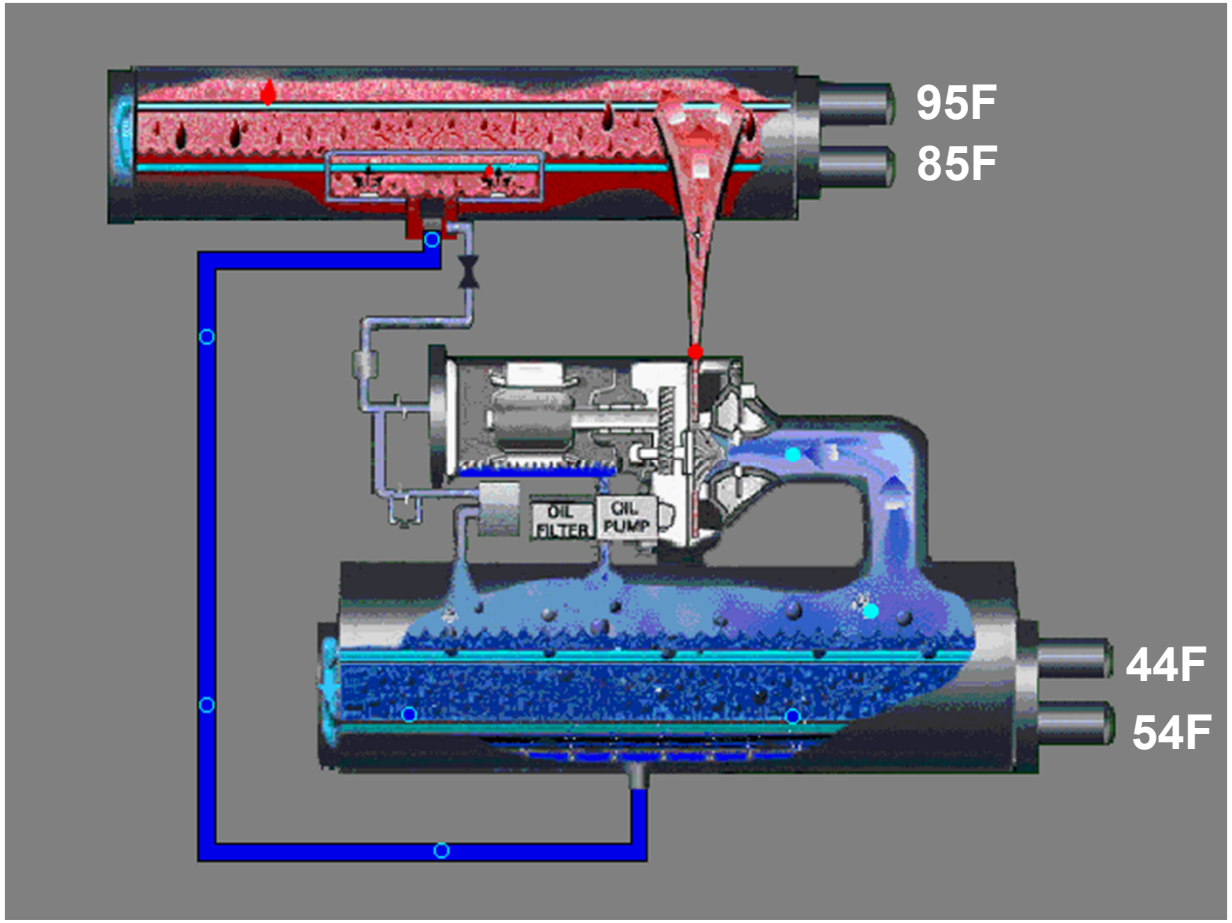
$$\text{Compressor Input kW} \sim \frac{\text{Mass Flow} \times \text{Lift}}{\text{Compressor/Cycle Efficiency}}$$



Chiller Energy (kW) ~ Tons x Lift

LIFT (PRESSURE DIFFERENCE)

Lift = SCT less SST



Saturated temperatures are surrogates for pressures

To condense, refrigerant must be warmer than the *leaving* condenser water.

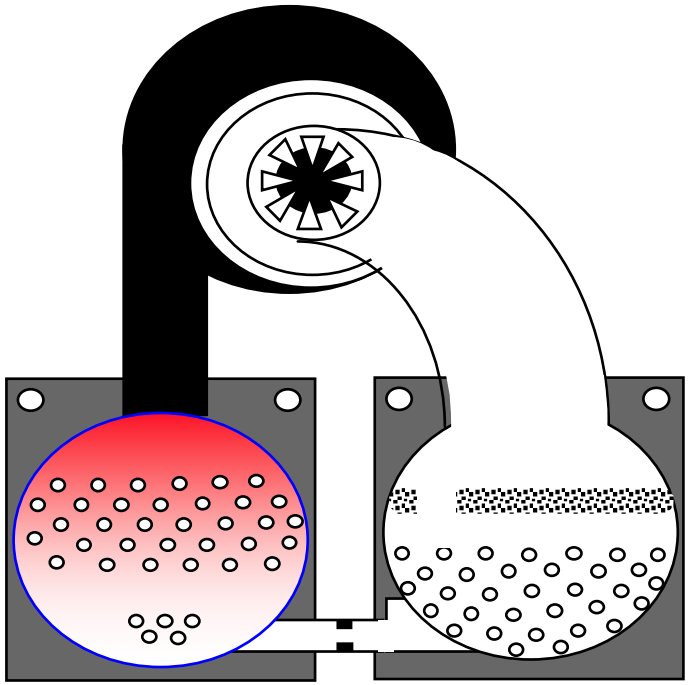
SCT = 95F + 2F approach = 97F

To boil, refrigerant must be colder than the *leaving* chilled water.

SST = 44F – 2F approach = 42F

Lift is Based on ***Leaving*** …

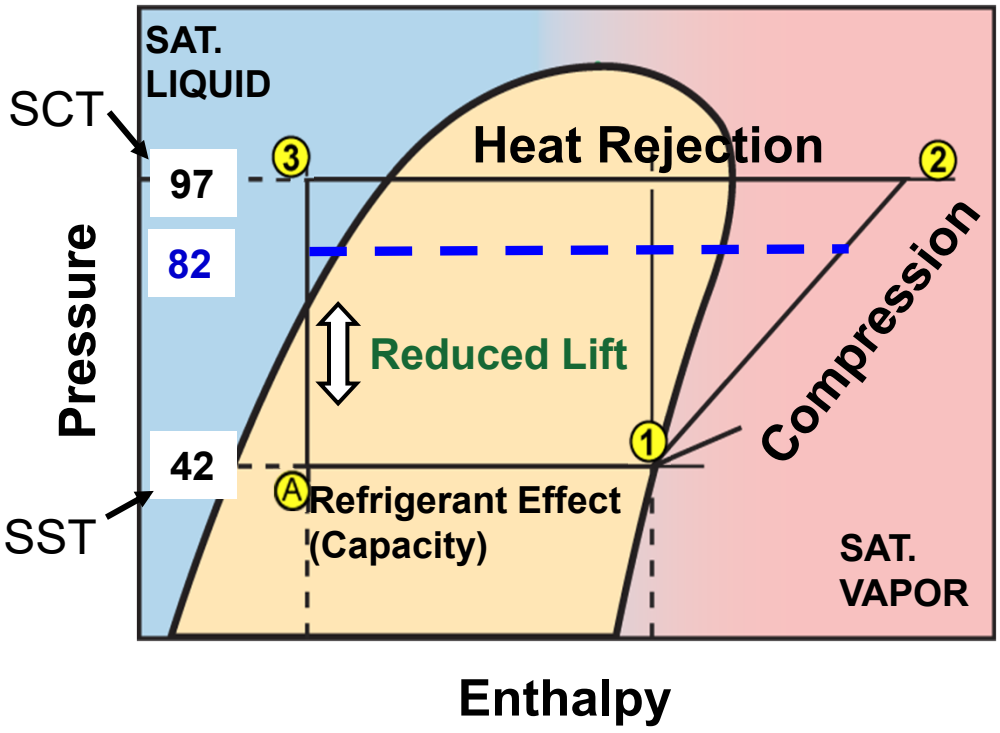
PRESSURE ENTHALPY CHART



97 F / 120 PSI

82F / 90 PSI

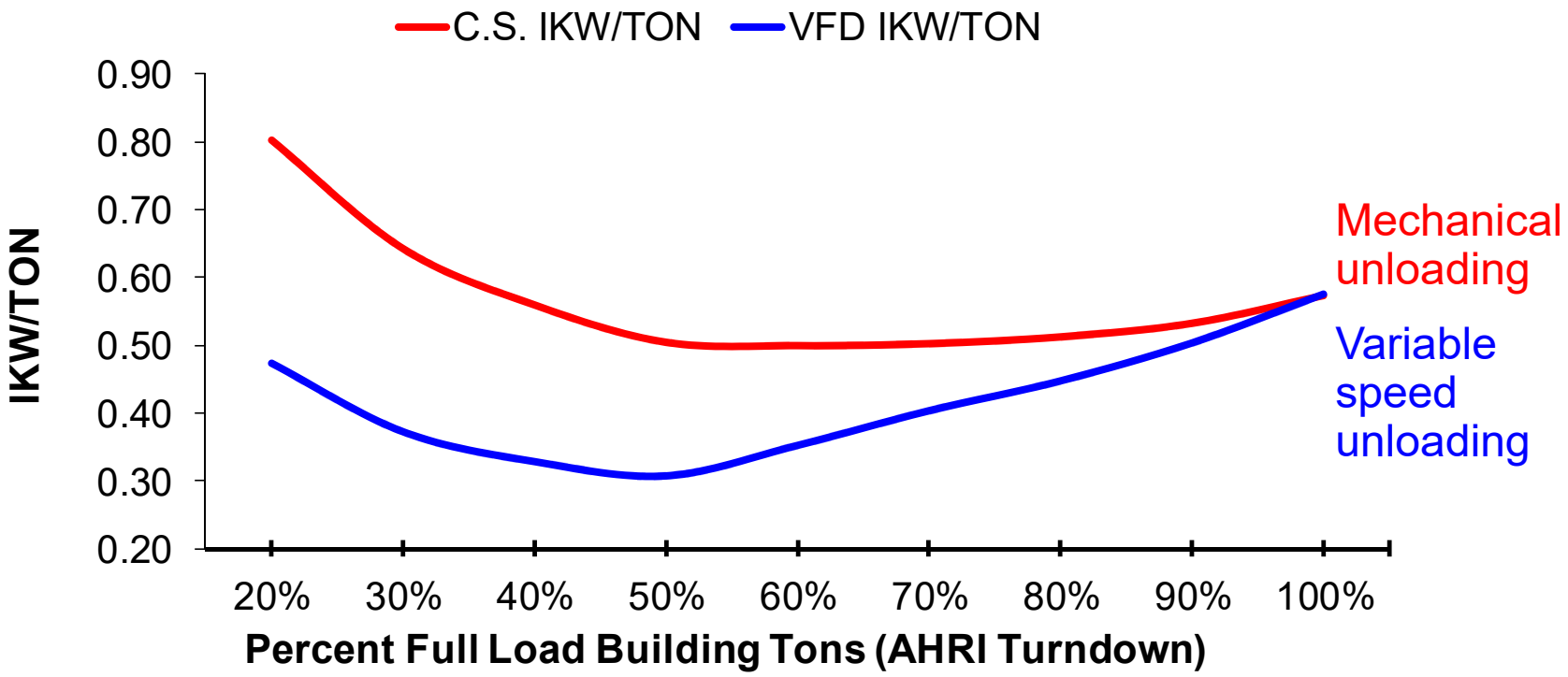
42 F / 40 PSI



Lower Lift = Less Work = Lower kW

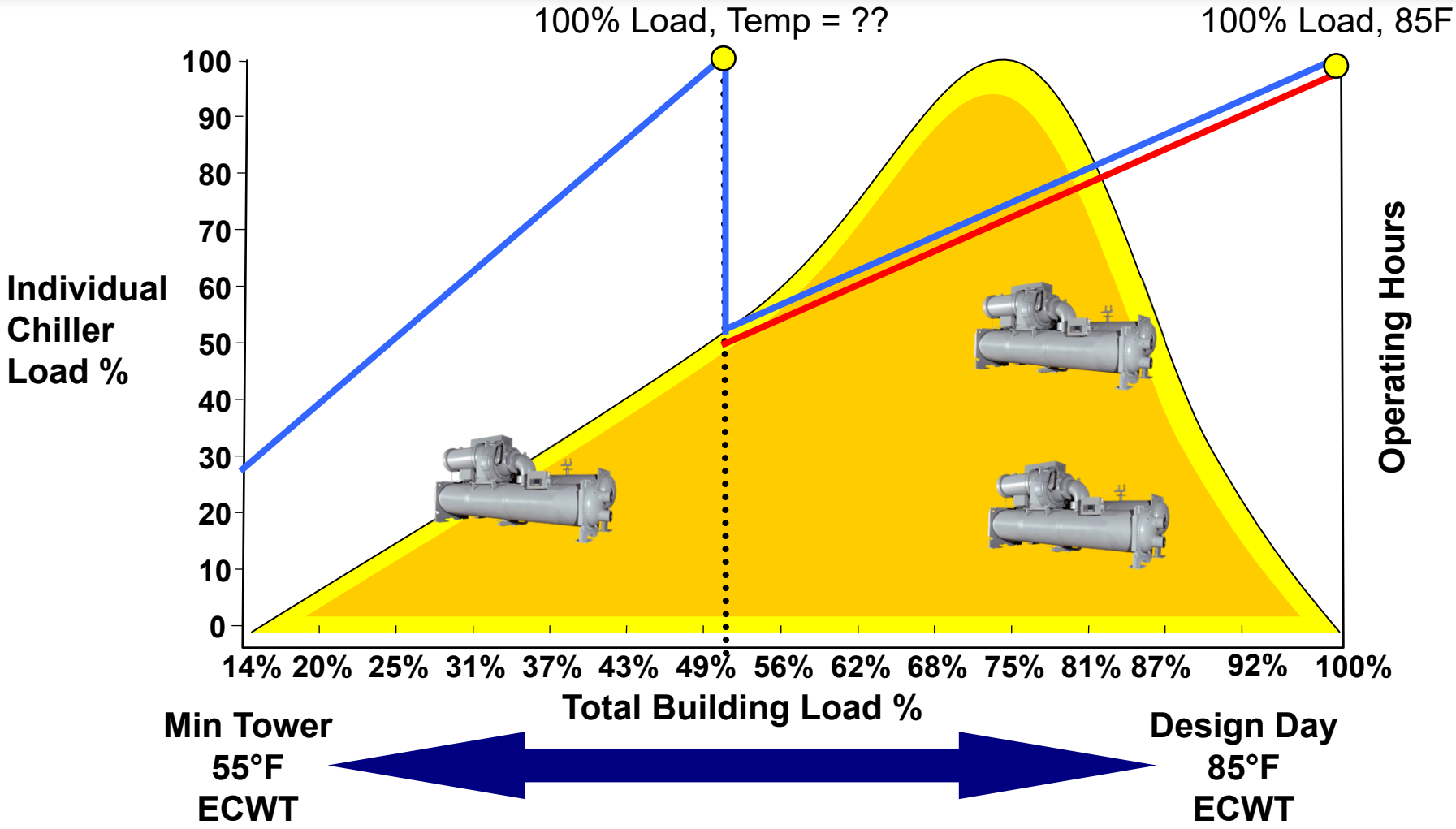
CHILLER EFFICIENCY

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



VFDs Do Less Lift (Work) More Efficiently

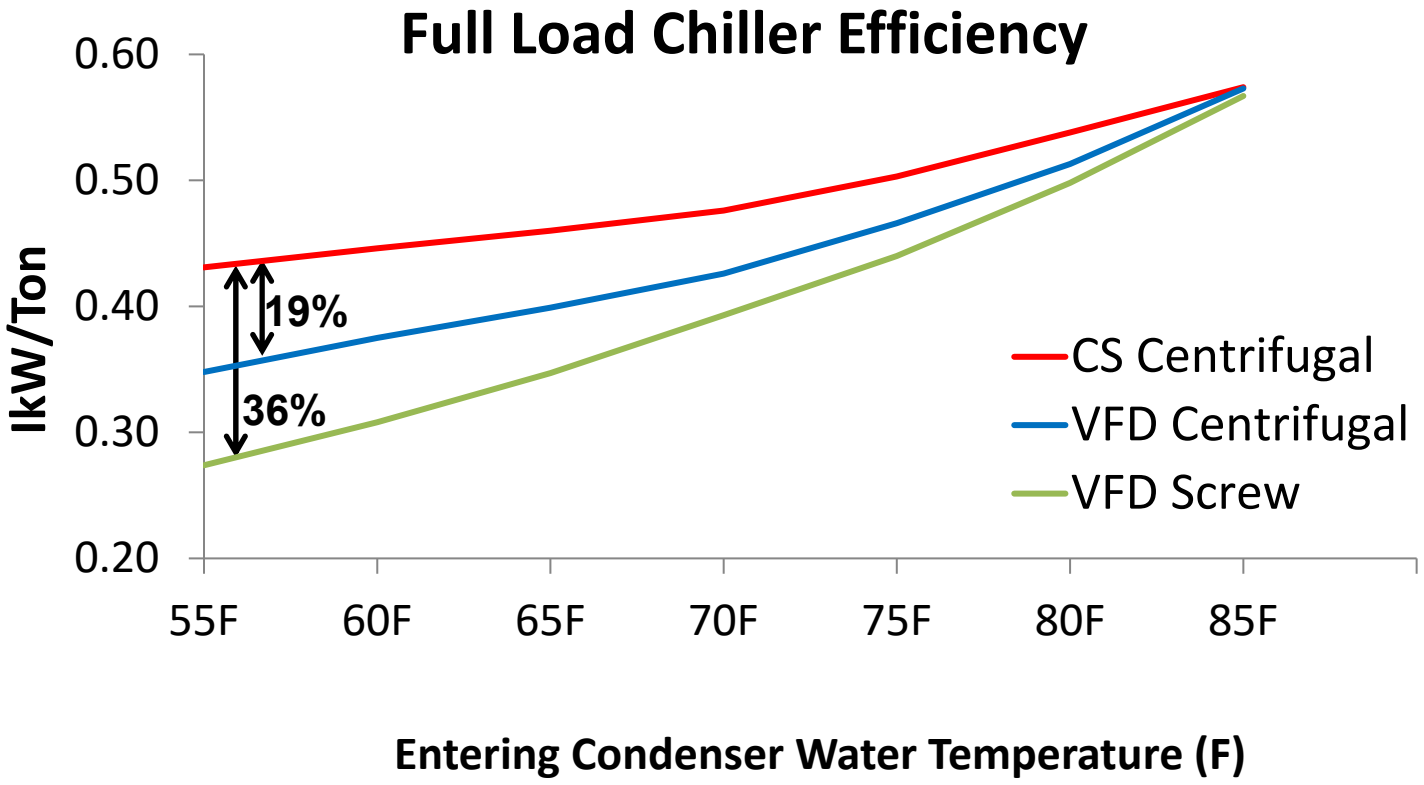
TWO CHILLER OPERATION / EFFICIENCY



Chiller Quantity Impacts Operating Profile

FULL LOAD CHILLER EFFICIENCY

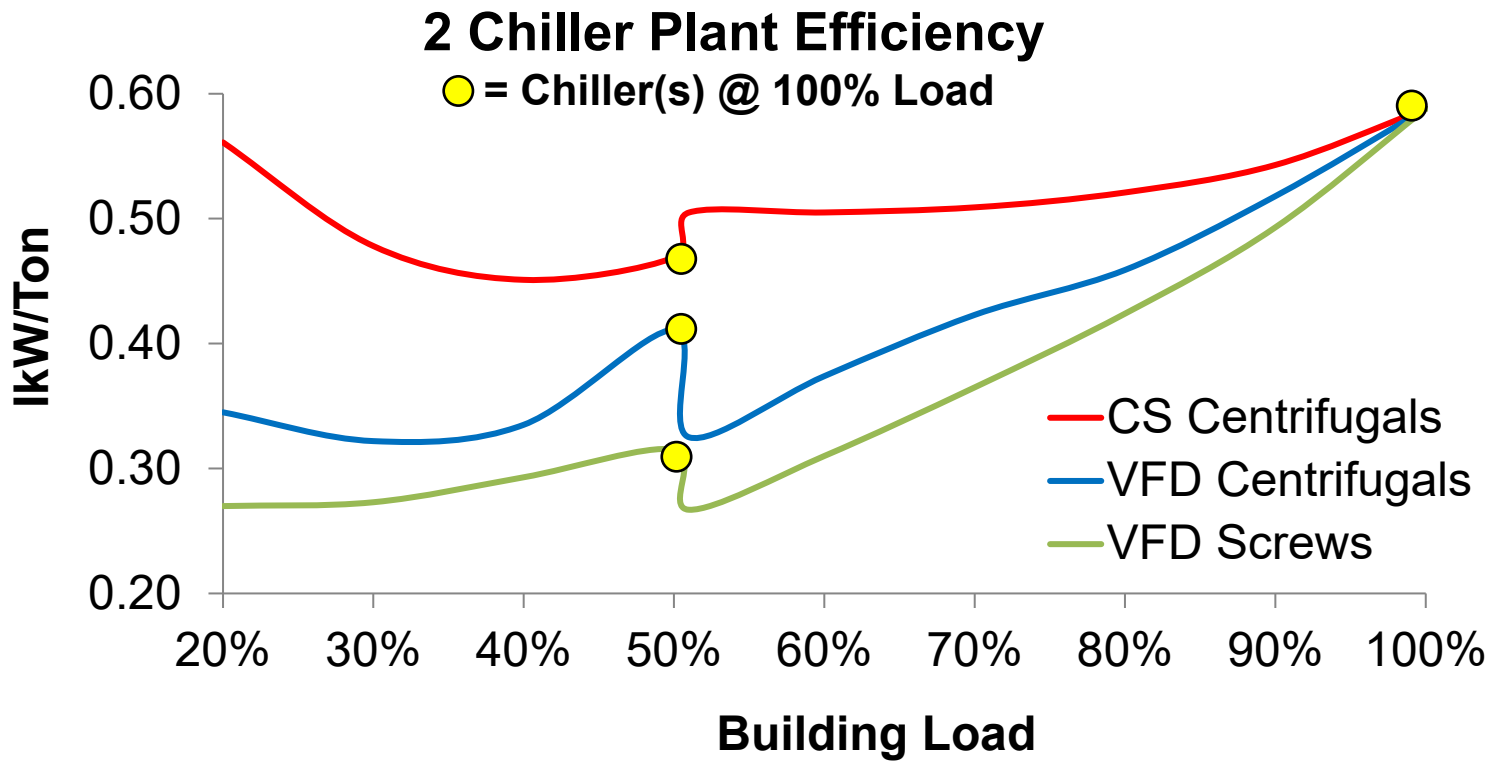
VFD Driven Chillers take advantage of lift reduction to reduce energy consumption *even at full capacity*.



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

AGENDA VARIABLE SPEED

Designing for 50% Energy Savings:

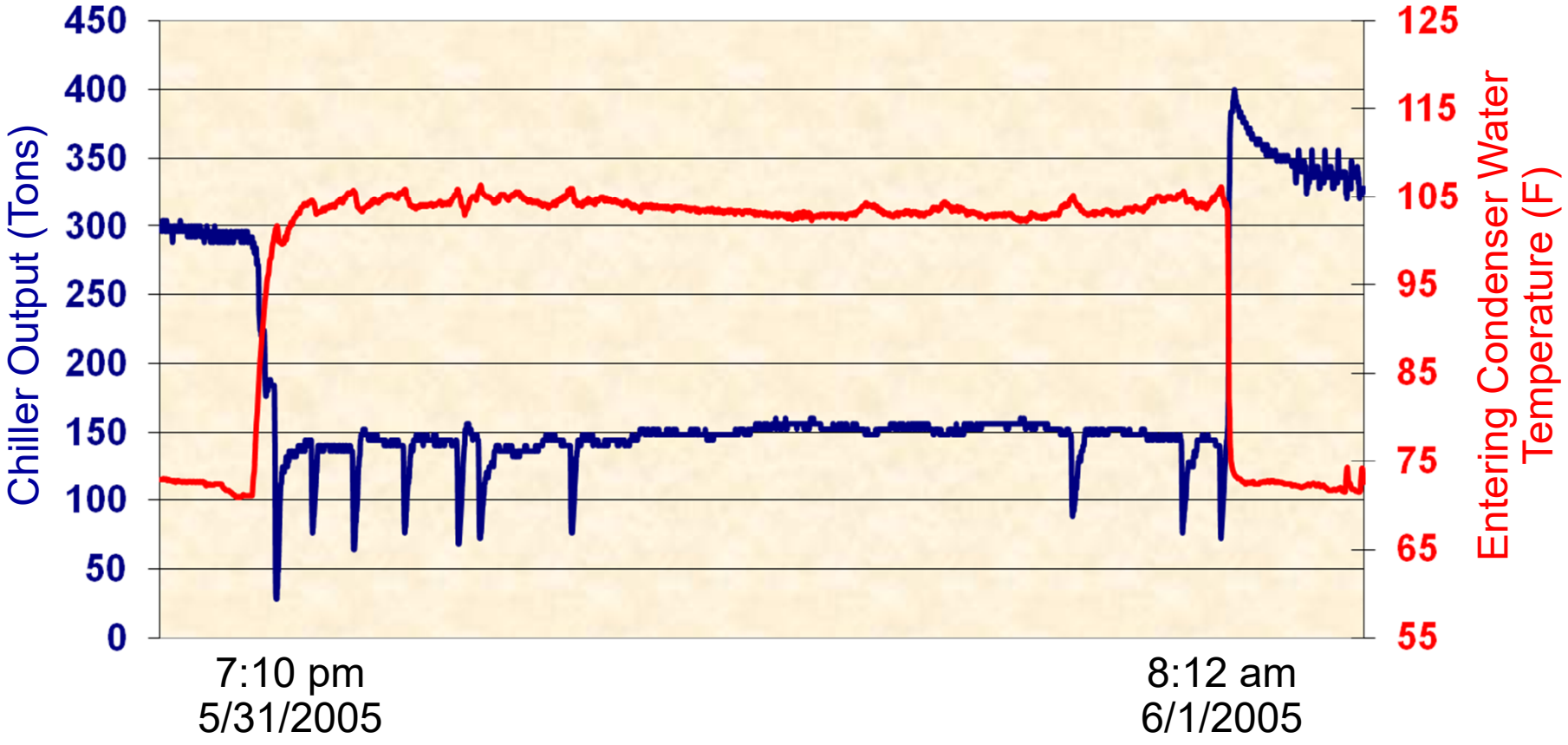
- ☑ Weather
- ☑ Determinants of Chiller Energy Consumption
- ➡ Variable Speed Screw Chillers
- Chiller Plant Design

Results:

- Test Data
- Energy Analysis

TOWER FAN FAILURE

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



AGENDA PLANT DESIGN

Designing for 50% Energy Savings:

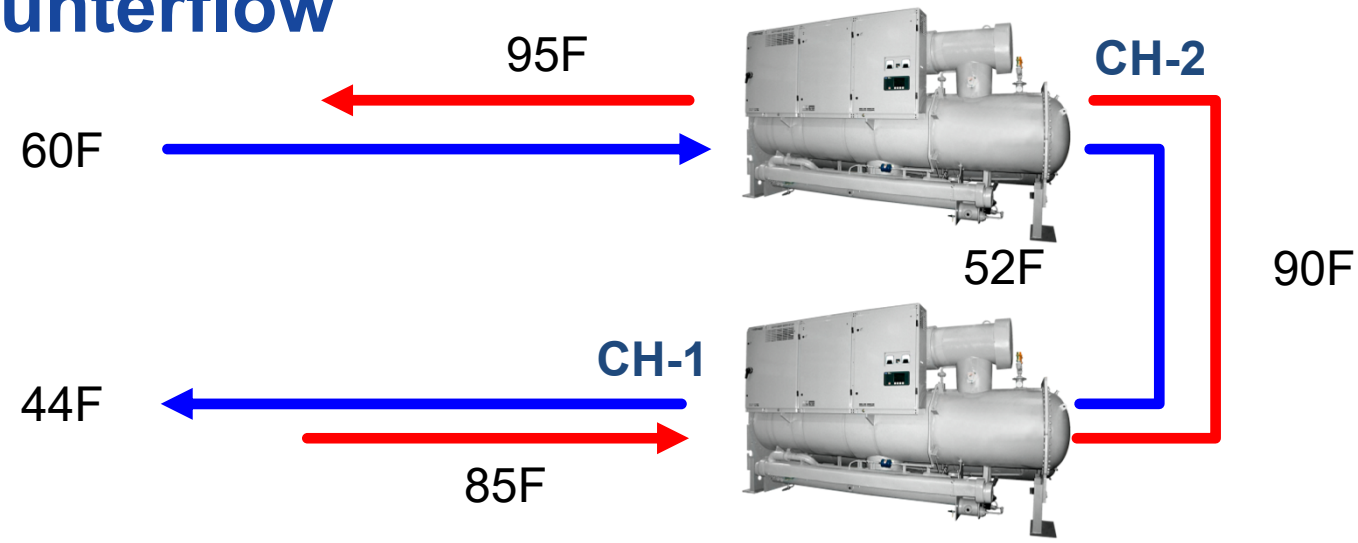
- ☑ Weather
- ☑ Determinants of Chiller Energy Consumption
- ☑ Variable Speed Screw Chillers
- ➡ Chiller Plant Design

Results:

- Test Data
- Energy Analysis

BASIC SERIES COUNTER FLOW DIAGRAM

Series Counterflow



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

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

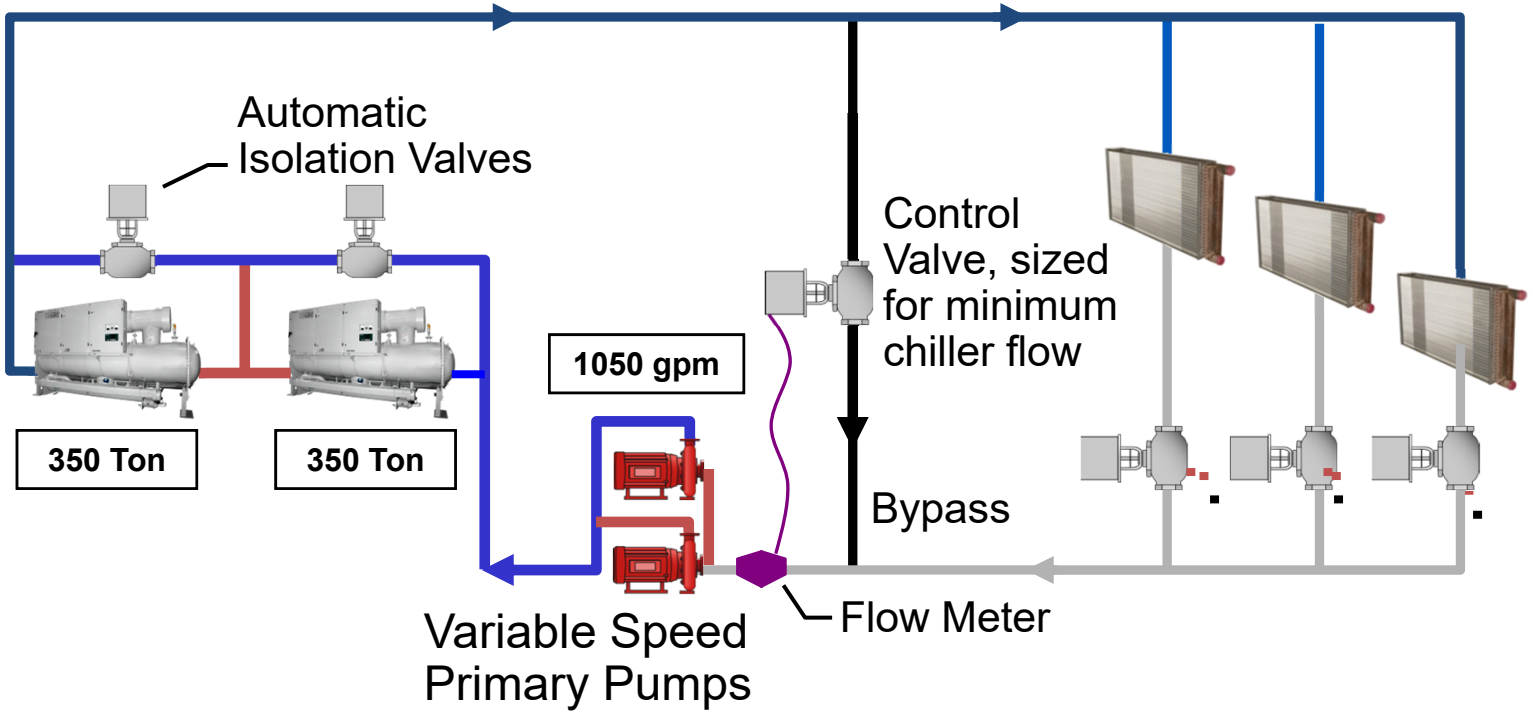
Evaporator water flows thru CH-2 and then CH-1

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

One pass heat exchangers for water side pressure drop

2 × 350 TON, VARIABLE PRIMARY

Building Load 100% (700 Tons)

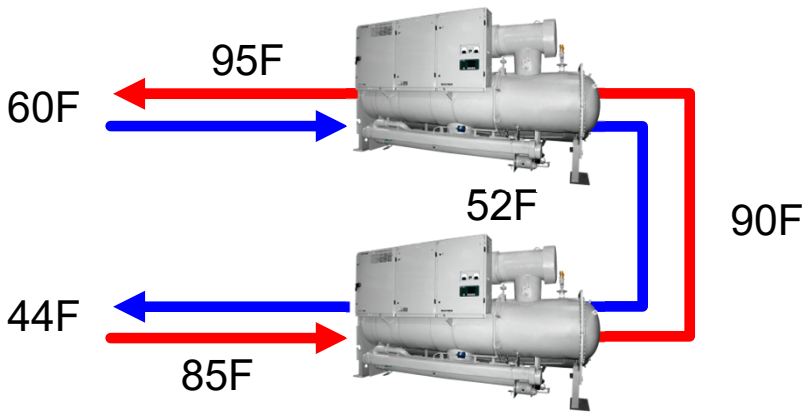


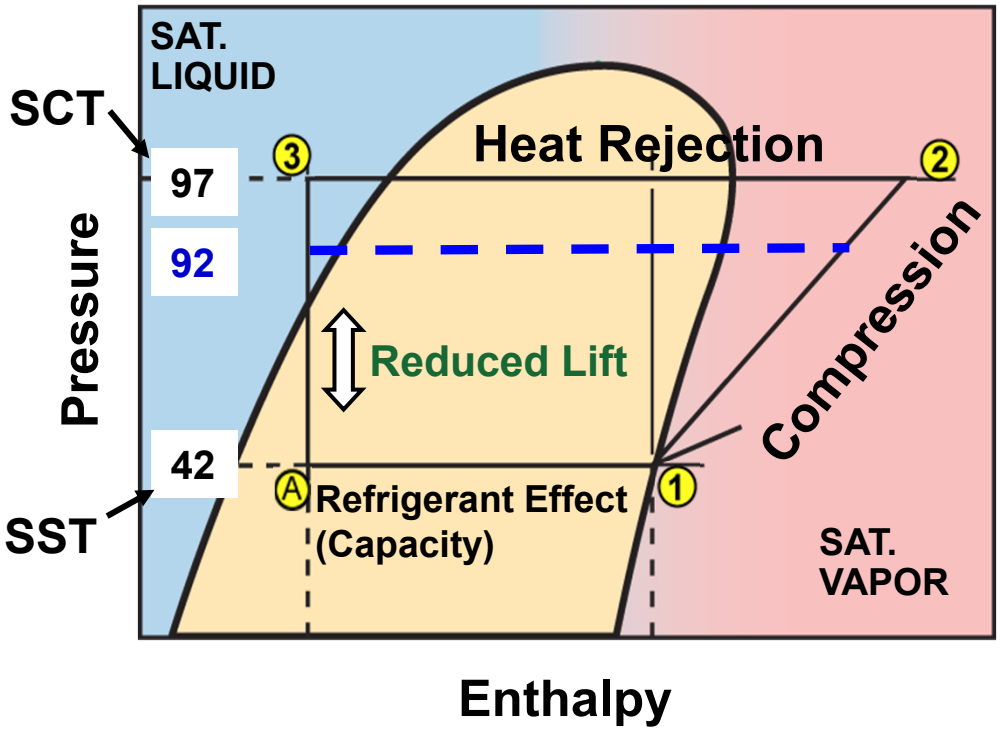
700 tons / 2 chillers = 350 tons per chiller

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

SERIES COUNTERFLOW REDUCES LIFT

Downstream Chiller



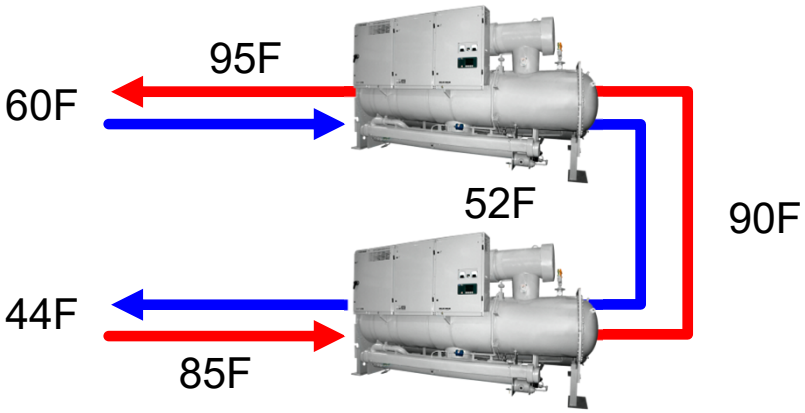


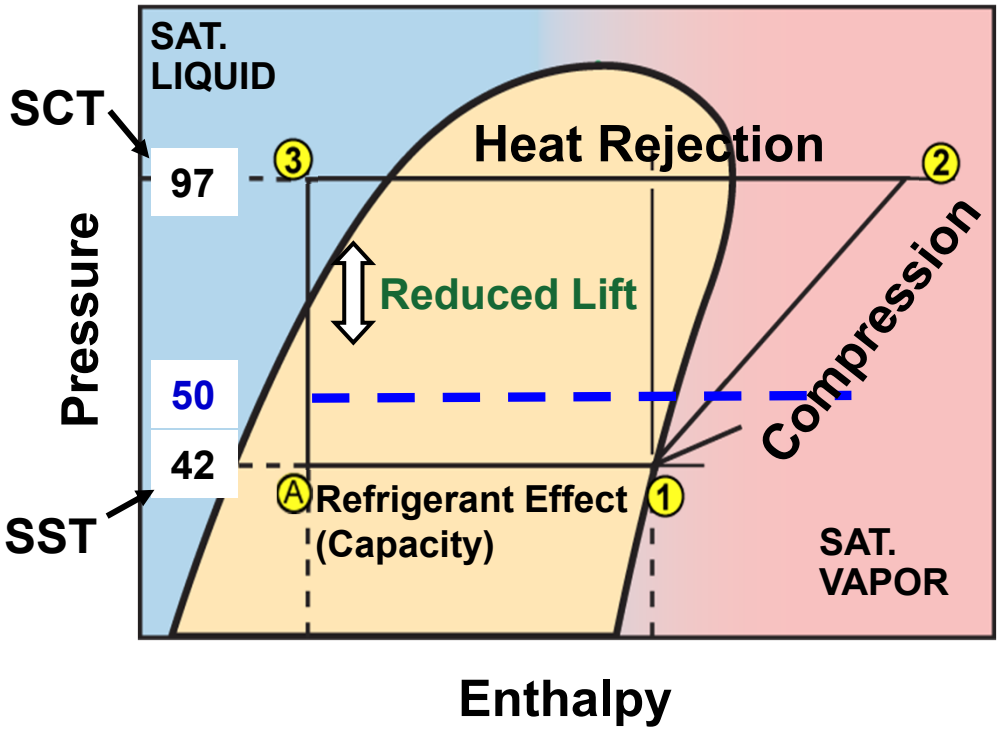
System	SST	SCT	Lift
Parallel	42	97	55
SCF	42	92	50

Lower Lift = Less Work = Lower kW

SERIES COUNTERFLOW REDUCES LIFT

Upstream Chiller





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

Lower Lift = Less Work = Lower kW

SERIES CHILLERS / LARGE DELTA T

Efficiency Benefit:

Series chiller efficiency improves with high return water temperatures because the upstream chiller produces warmer water.

System Design	Downstream	Upstream
44-54°F	44°F	49°F
44-56°F	44°F	**50°F**
44-58°F	44°F	**51°F**
44-60°F	44°F	**52°F**

SERIES CHILLERS / VARIABLE FLOW

Efficiency Benefit:

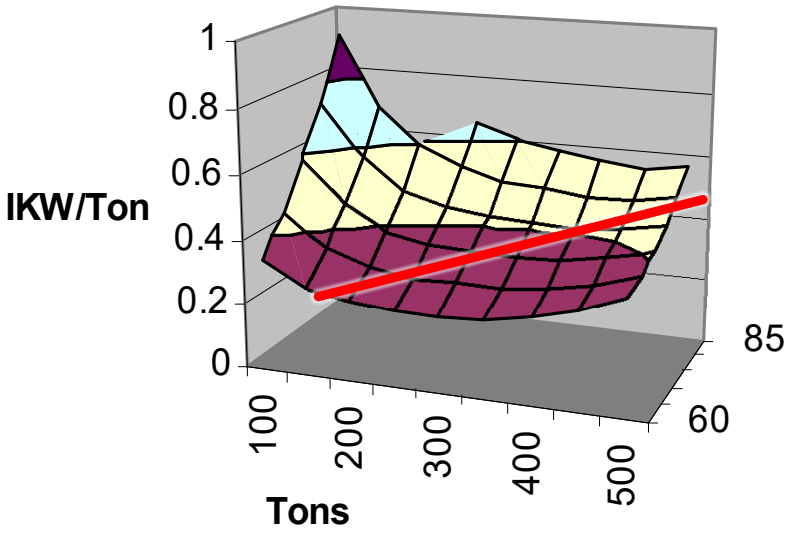
Series chiller efficiency improves with variable flow because the upstream chiller leaving water temperature remains constant.

Var. Flow	100%	75%	50%	25%
Return	60°F	60°F	60°F	60°F
US Lvg	52°F	52°F	52°F	Off
DS Lvg	44°F	44°F	44°F	44°F

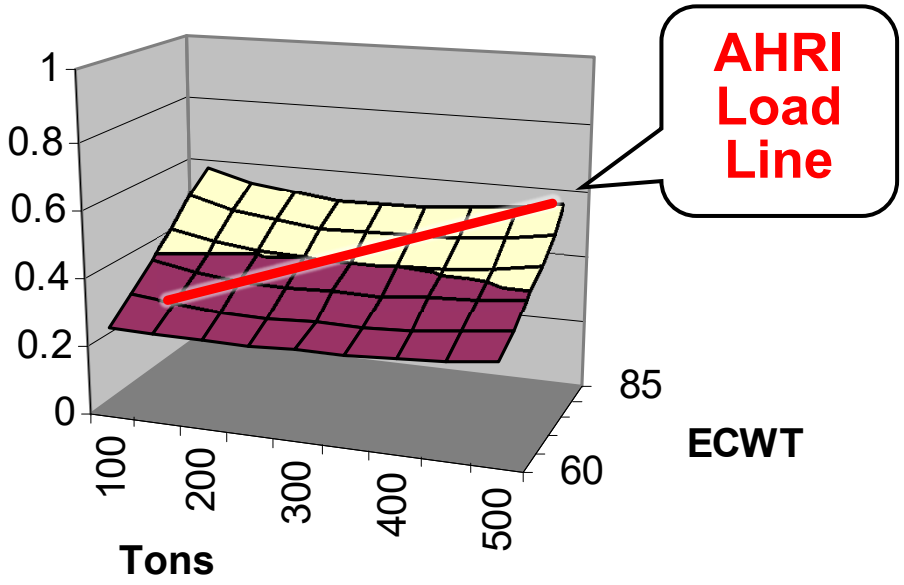
Const. Flow	100%	75%	50%	25%
Return	60°F	56°F	52°F	48°F
US Lvg	52°F	50°F	48°F	Off
DS Lvg	44°F	44°F	44°F	44°F

ARE ALL IPLV'S EQUAL?

Chiller A

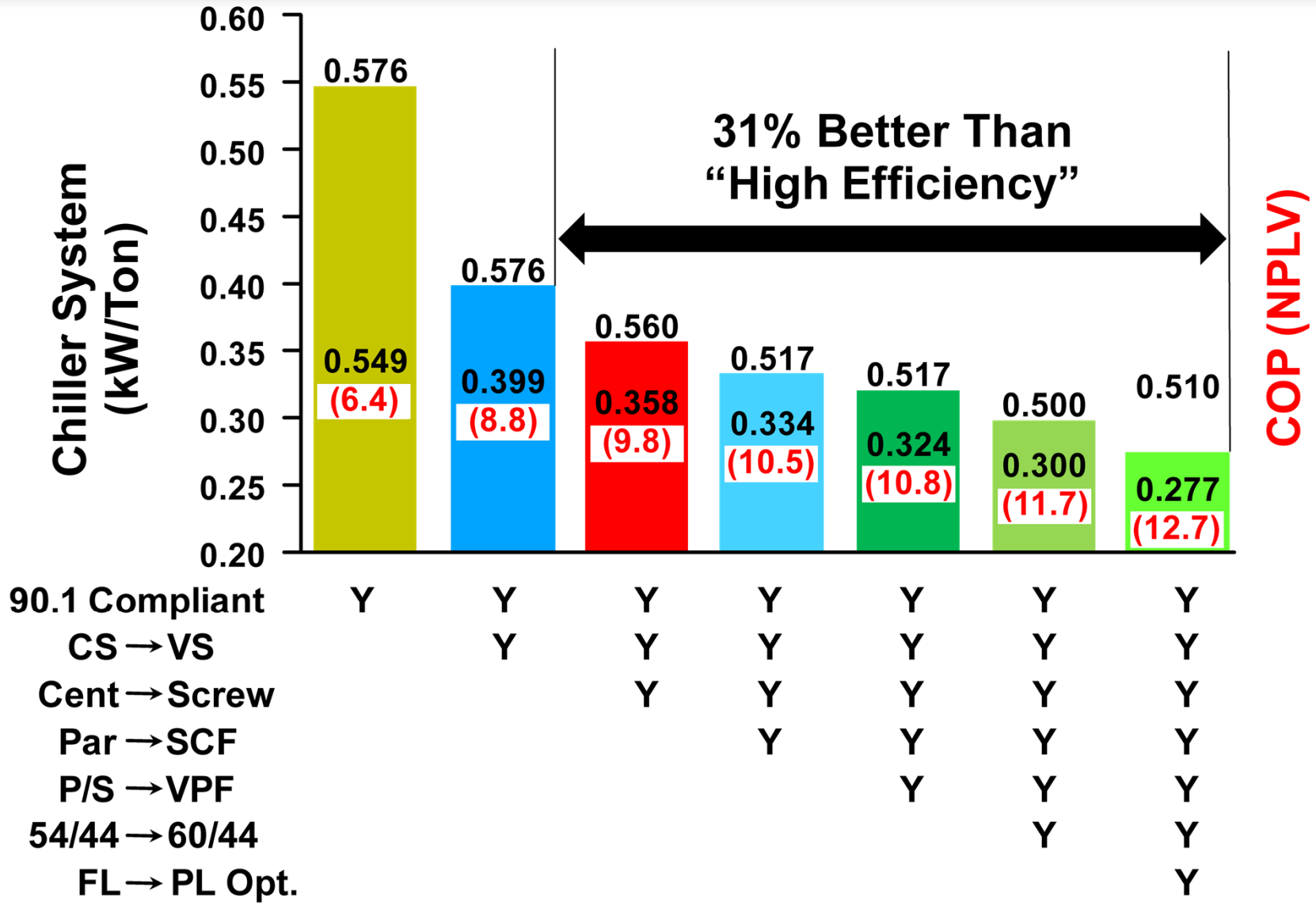


Chiller B

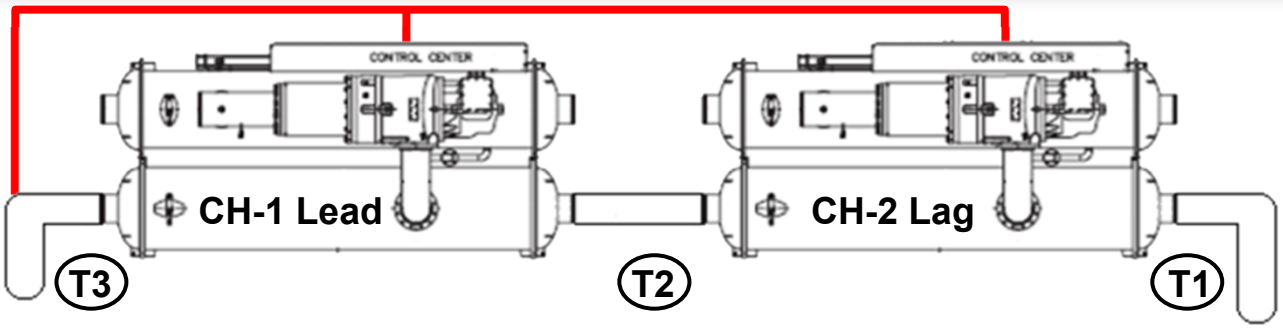


If both machines were 0.35 IPLV (10.0 COP) would you consider them equal?

MOVING THE FRONTIER



CHILLER STAGING



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 indicates 2nd chiller appropriate

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

CH-1 and CH-2 operate together to regulate T3 to set point.

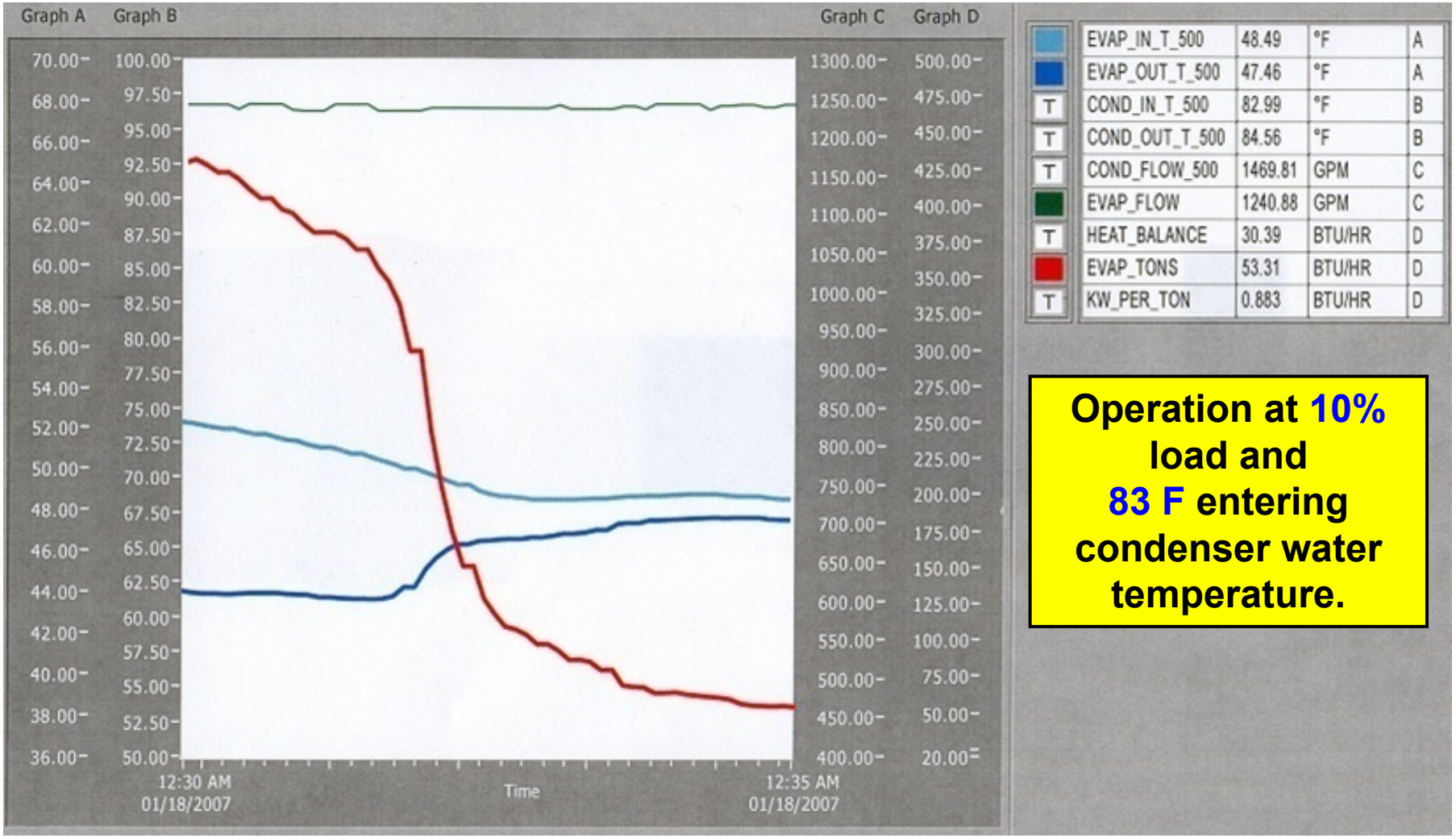
At appropriate compressor speed, CH-1 commands CH-2 to turn off.

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.

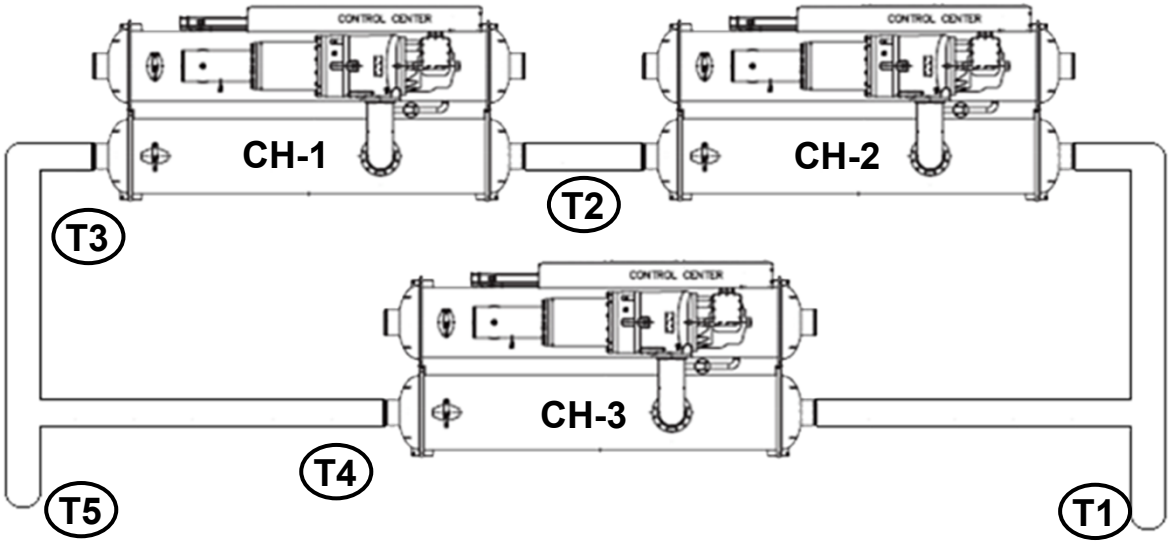
No Human Intervention Required

LOW LOAD OPERATION



Operation at 10% load and 83 F entering condenser water temperature.

SPARE CHILLER



Variable Flow Scenarios	T1	T2	T3	T4	T5
100% Load, CH-1 disabled	60	44	44	44	44
100% Load, CH-2 disabled	60	60	40	44	44

BSM enables LEAD/LAG Chillers (CH-1 and CH-2) as Required to meet T5.

LEAD chiller stages, optimizes both compressors for maximum operating efficiency.

If CH-1 disabled, CH-2 chiller becomes LEAD,
CH-3 becomes LAG.

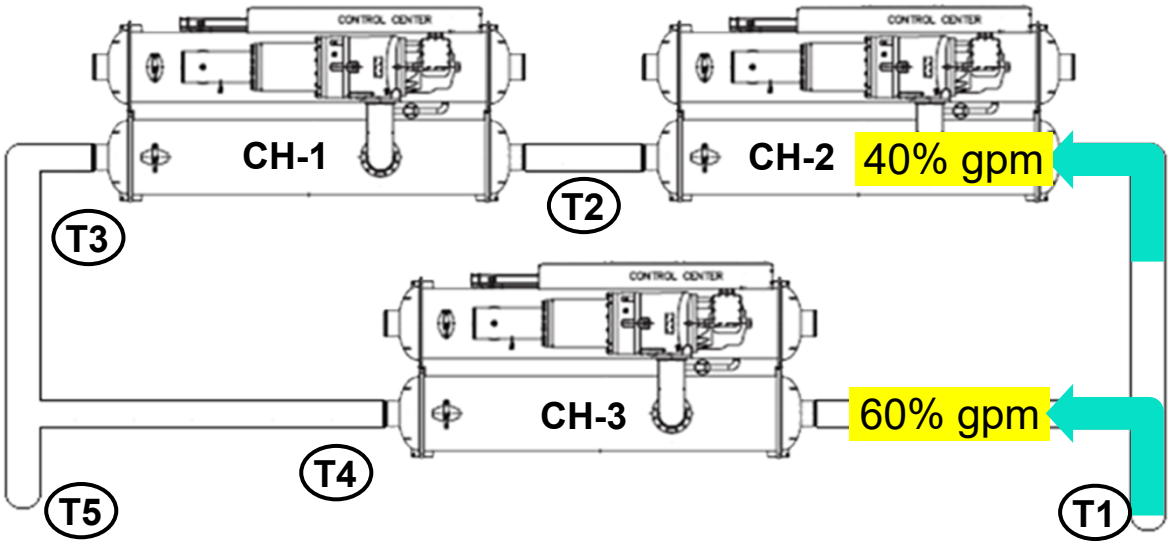
LEAD chiller stages, optimizes both compressors for maximum operating efficiency.

Condenser piping not shown.

Bypass piping, isolation valves not shown.

No Human Intervention Required

SPARE CHILLER



Variable Flow Scenarios	T1	T2	T3	T4	T5
100% Load, CH-1 disabled	60	40	40	48	44
100% Load, CH-2 disabled	60	60	40	48	44

When standby chiller enabled, flow may not be balanced between branches.

LEAD chiller stages, optimizes both compressors for maximum operating efficiency.

If CH-1 disabled, CH-2 chiller becomes LEAD,
CH-3 becomes LAG.

LEAD chiller stages, optimizes both compressors for maximum operating efficiency.

Leaving temps may vary, but T5 will be met.

Condenser piping not shown.

Bypass piping, isolation valves not shown.

SCHEDULE

			Evaporator Data					
Mode	Capacity (Tons)	Efficiency (kW/Ton)	Entering Temp (F)	Leaving Temp (F)	Flow Rate (gpm)	Pressure Drop (Ft wg)	Passes	Fluid Type
Cooling	450	0.524	52	44	1350	6.2	1	Freshwater
Cooling	450	0.483	60	52	1350	6.1	1	Freshwater
Cooling	450	0.672	60	40	540	1.2	1	Freshwater

Condenser Data										
Entering Temp (F)	Leaving Temp (F)	Flow Rate (gpm)	Pressure Drop (Ft wg)	Passes	Fluid Type	Voltage	MCA	MOCP	Manu.	Operating Weight (lbs)
85	89.6	2700	14.2	1	Freshwater	460-3-60	495	700		22849
89.6	94.2	2700	14.1	1	Freshwater	460-3-60	495	700		22849
85	94.5	1350	3.9	1	Freshwater	460-3-60	495	700		22849

Notes:
CH-1,CH-2, CH-3 shall utlize screw compressors
CH-1 and CH-2 shall operate in series counterflow.
CH-1 and CH-3 shall operate in parallel if CH-2 disabled.
CH-2 and CH-3 shall operate in parallel if CH-1 disabled.
CH-1, CH-2, CH-3 shall all be identical.
Chillers shall operate down to 40% of design evaporator flow (525 gpm).

VENDOR DATA SHEET

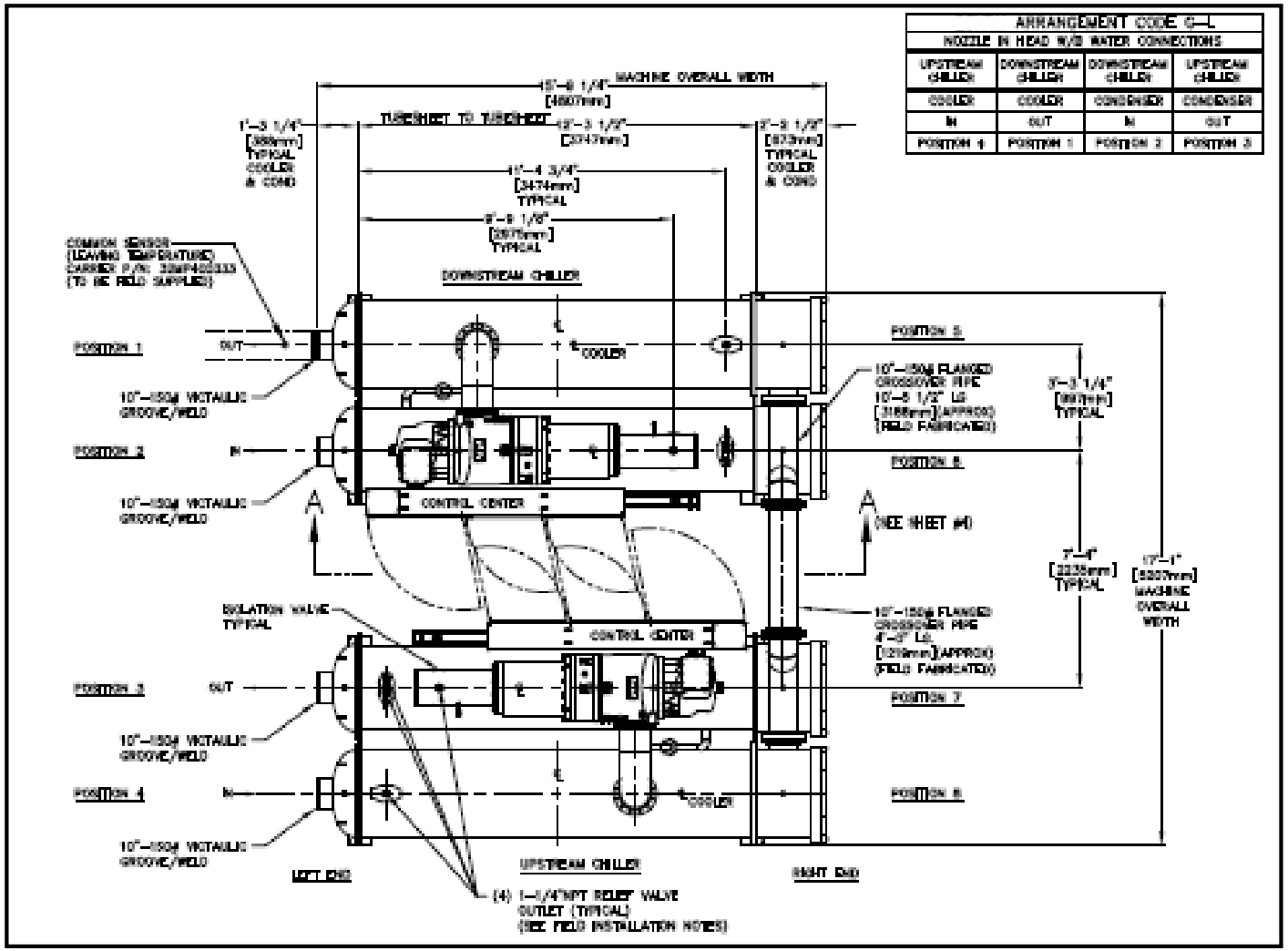
Date: 20-Jul-11

	Load	LCHWT	Evap GPM	ECdWT	Cond GPM	Chiller Model #		
						lkW/Ton	Evap PD (ft)	Cond PD (ft)
(*)	100%	44F	1350	85F	2700			
(*)	100%	52F	1350	89.6F	2700			
	75%	44F	1013	75F	2700			
	75%	52F	1013	78.3F	2700			
(*)	50%	44F	675	65F	2700			
	50%	52F	675	67.2	2700			
	25%	44F	540	65F	1350			
(*)	100%	40F	540	85F	1350			
(*)	20%	40F	540	85F	1350			

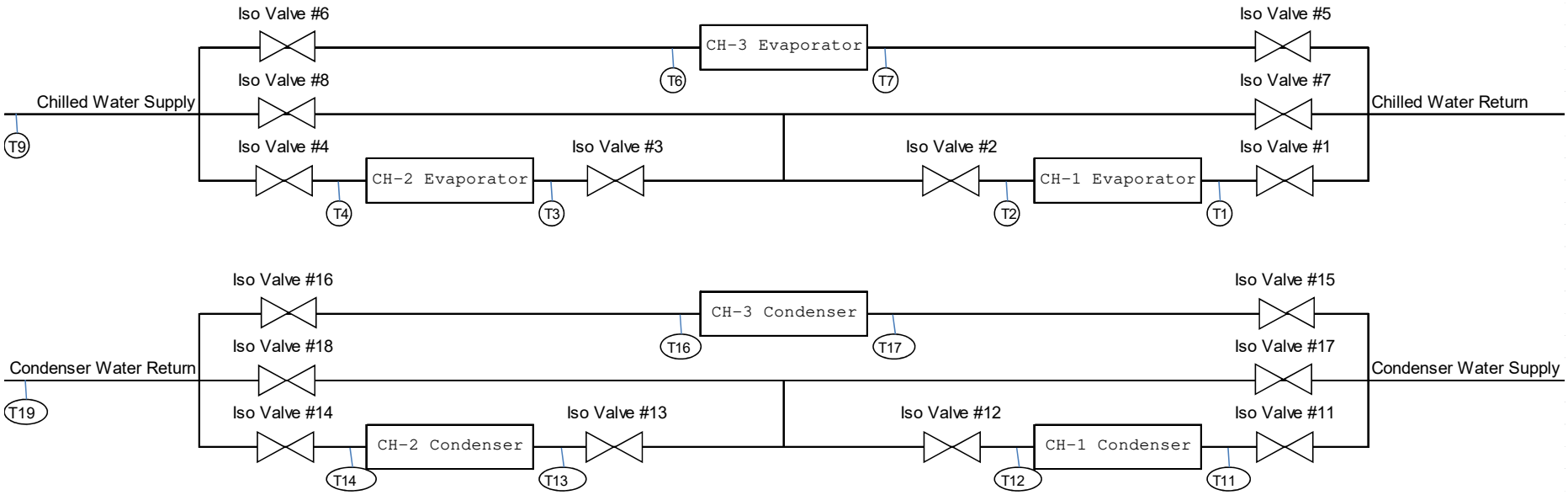
Notes:

1. (*) Indicates factory test point per AHRI 550/590
2. Since all three chillers are the same, only one of the chillers will be tested
3. Chillers shall be operated for a period of two hour at each point during the factory test

DRAWINGS


ARRANGEMENT CODE G-L
NOZZLE IN HEAD W/2 WATER CONNECTIONS
UPSTREAM CHILLER
DOWNSTREAM CHILLER
DOWNSTREAM CHILLER
UPSTREAM CHILLER
COOLER
COOLER
CONDENSER
CONDENSER
IN
OUT
IN
OUT
POSITION 1
POSITION 2
POSITION 3
POSITION 4
MACHINE OVERALL WIDTH
TUBESHEET TO TUBESHEET
TYPICAL COOLER & COND
COMMON SENSOR (LEAVING TEMPERATURE)
(TO BE FIELD SUPPLIED)
DOWNSTREAM CHILLER
OUT
IN
OUT
IN
10"-150# VICTAULIC GROOVE/WELD
CONTROL CENTER
ISOLATION VALVE TYPICAL
COOLER
10"-150# FLANGED CROSSOVER PIPE
(FIELD FABRICATED)
POSITION 5
POSITION 6
POSITION 7
POSITION 8
(SEE SHEET #4)
TYPICAL
MACHINE OVERALL WIDTH
LEFT END
RIGHT END
UPSTREAM CHILLER
(4) 1-1/4"NPT RELIEF VALVE OUTLET (TYPICAL)
(SEE FIELD INSTALLATION NOTES)

ISOLATION VALVES



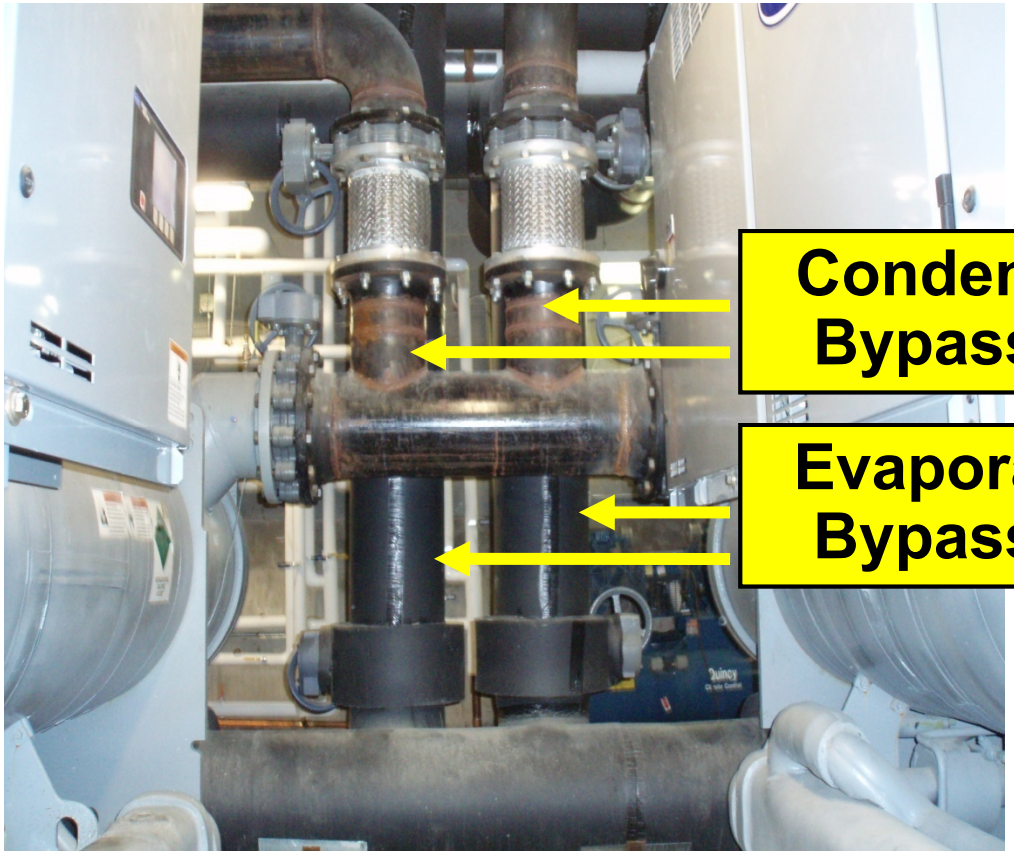
ISOLATION VALVES

Isolation Valve Table (Evaporator)				
CH-1	On	Off	On	Off
CH-2	On	On	Off	Off
CH-3	Off	On	On	Off
#1	Open	Closed	Open	Closed
#2	Open	Closed	Open	Closed
#3	Open	Open	Closed	Closed
#4	Open	Open	Closed	Closed
#5	Closed	Open	Open	Closed
#6	Closed	Open	Open	Closed
#7	Closed	Open	Closed	Closed
#8	Closed	Closed	Open	Closed

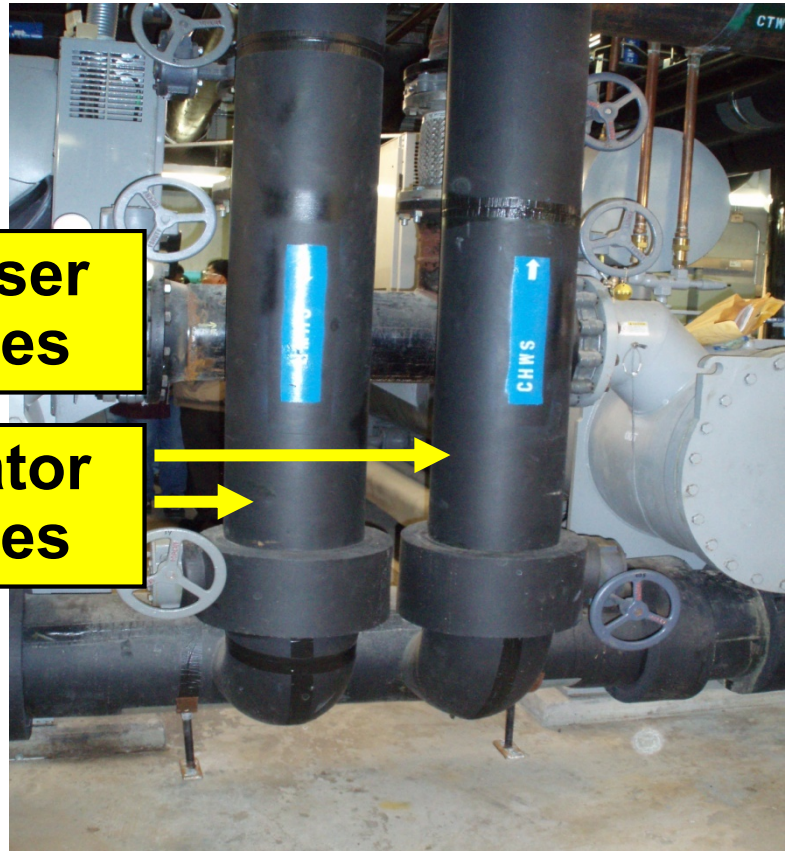
Isolation Valve Table (Condenser)				
CH-1	On	Off	On	Off
CH-2	On	On	Off	Off
CH-3	Off	On	On	Off
#11	Open	Closed	Open	Closed
#12	Open	Closed	Open	Closed
#13	Open	Open	Closed	Closed
#14	Open	Open	Closed	Closed
#15	Closed	Open	Open	Closed
#16	Closed	Open	Open	Closed
#17	Closed	Open	Closed	Closed
#18	Closed	Closed	Open	Closed

PHOTOS DRAWINGS

PHOTOS DRAWINGS



Inside View



Outside View


QUESTIONS


Thank
You!