Centralizing, Upgrading, and Optimizing Chilled Water on Existing Campus

Presented by:

Colin Moyer

Affiliated Engineers

Michael Morehead

Genentech

Agenda

- **Existing Conditions**
- **Purpose**
- **New System**
- **Series Evaporator Optimization**
- **Results**

Existing HVAC Systems

EXISTING HYDRONIC WITH CENTRAL CHILLER PLANT (5 CHILLERS)

EXISTING HYDRONIC WITH BUILDING CHILLER PLANT (22 CHILLERS)

EXISTING ROOFTOP DX UNITS (94 UNITS)

PLUS 93 UNITS IN THE HYDRONIC BUILDINGS

214 TOTAL REFRIGERATION UNITS FOR HVAC

Purpose

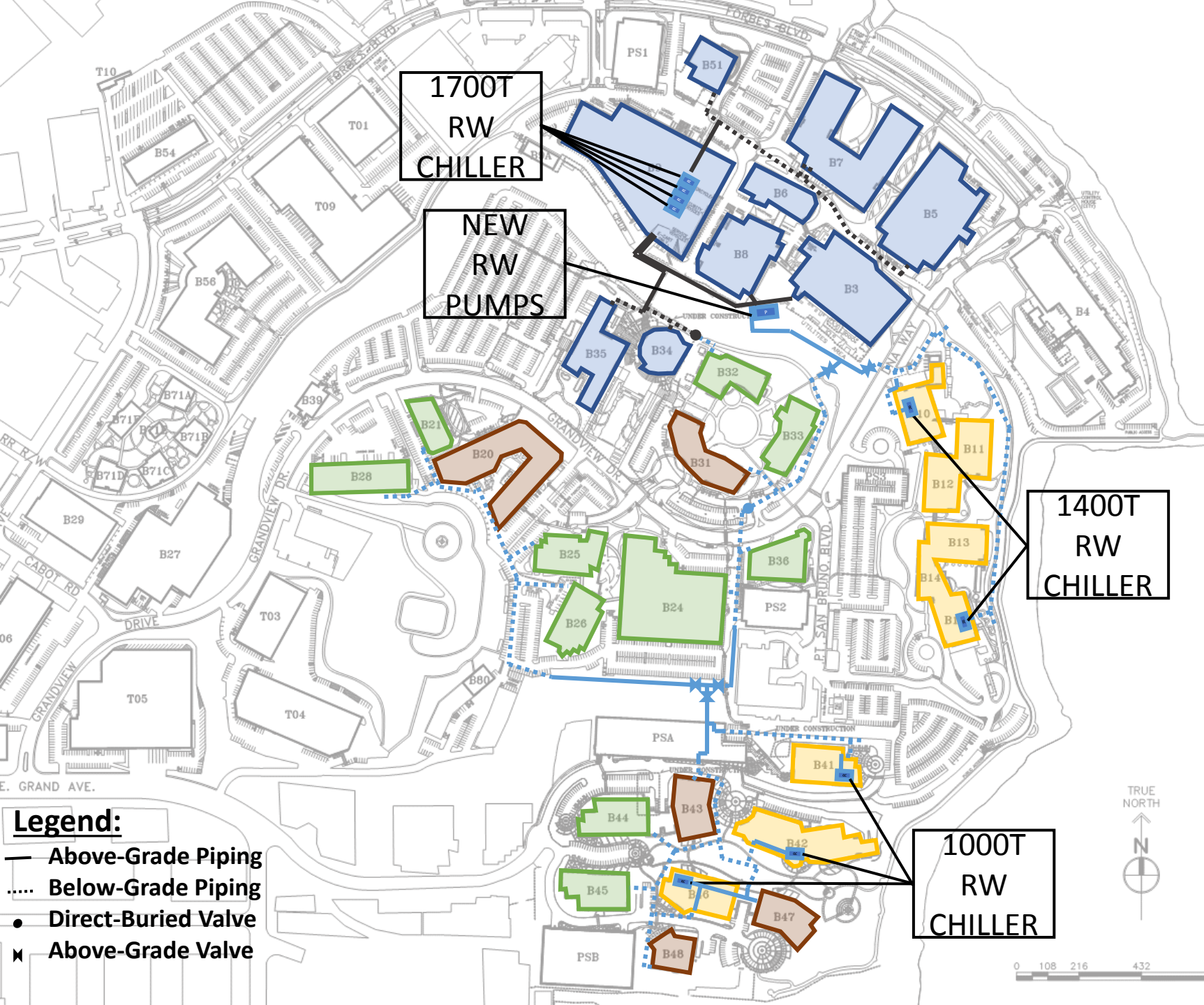
- Reduce Refrigerant Global Warming Potential (GWP)
- Upgrade existing infrastructure
- Improve energy efficiency
- Improve resiliency
- Reduce operations and maintenance

Purpose – Reduce Refrigerant GWP

Refrigerant Type	Refrigerant Number	ASHRAE 34 Code	Refrigerant Name	Refrigerant Formula	Atmospheric Lifetime	GWP_{100}	ODP	Charge (lbs)
HCFC	R-22	A1	Chlorodifluoromethane	$CHClF_2$	12 years	1810	0.05	5,290
HFC	R-134a	A1	1,1,1,2-Tetrafluoroethane	$C_2H_2F_4$	14 years	1430	0	36,110
HFC	R-404a	A1	44±2% C_2HF_5 ·52±1% $C_2H_3F_3$ ·4±2% $C_2H_2F_4$		40 years	3922	0	6
HFC	R-410a	A1	50+.5,–1.5% CH_2F_2 ·50+1.5,–.5% C_2HF_5		17 years	2088	0	120
Natural	R-717	B2L	Ammonia	NH_3	≈0	0.7	0	
Natural	R-744	A1	Carbon Dioxide	CO_2	30k years	1	0	
HFO	**R-1233zd(E)**	**A1**	**Solstice zd**	**$CF_3CH=CHCl$**	**26 days**	**1**	**0.00030**	**25,300**
HC	R-1270	A3	Propylene	C_3H_6	12 years	3	0	

27,885 MTCDE charge can be reduced to 11.5 MTCDE (GWP reduced by 99.96%)

New low pressure chillers also have lower leakage rates than existing aged and high pressure equipment



New HVAC System

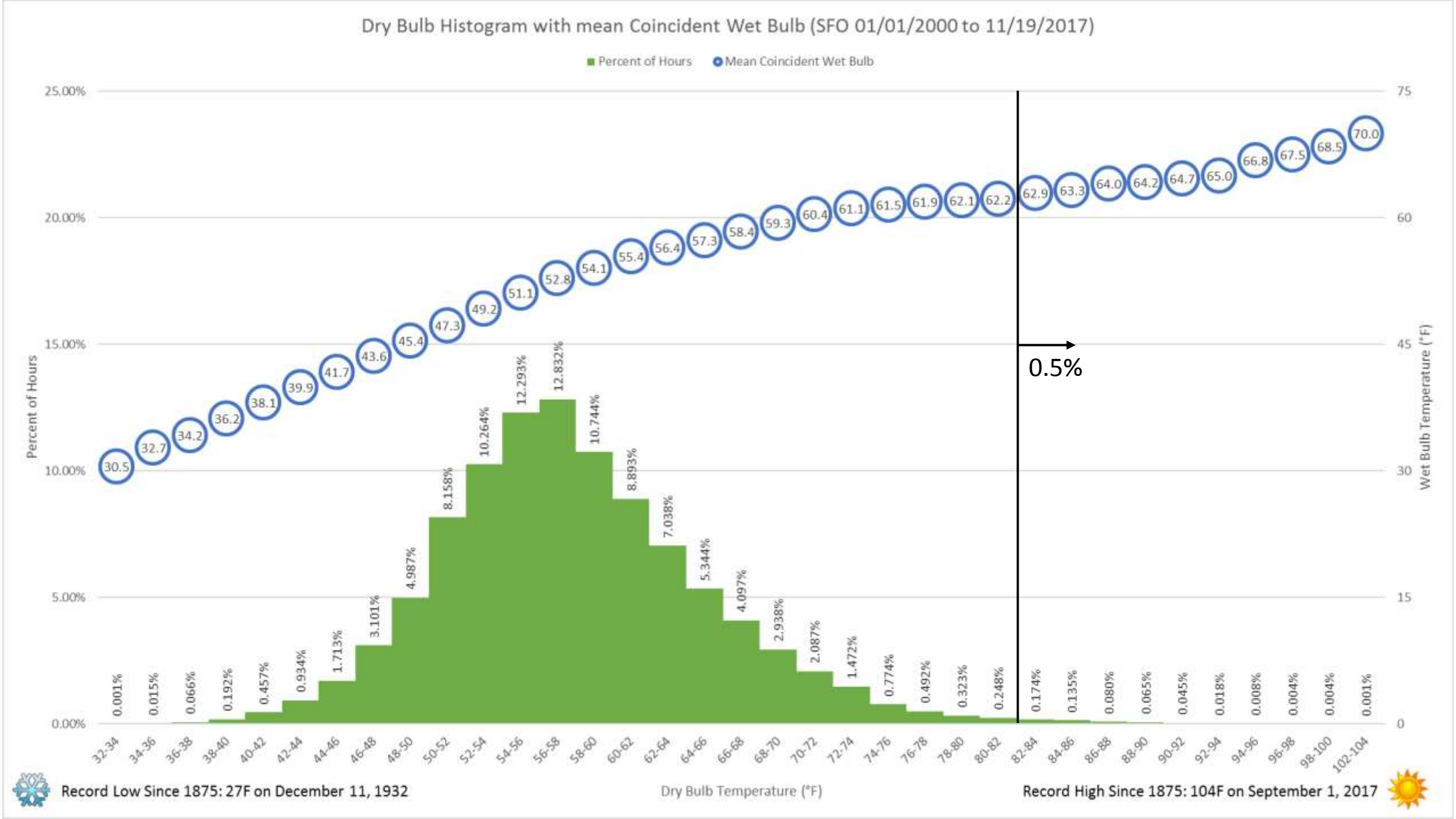
EXISTING HYDRONIC WITH CENTRAL CHILLER PLANT (4 NEW CHILLERS)

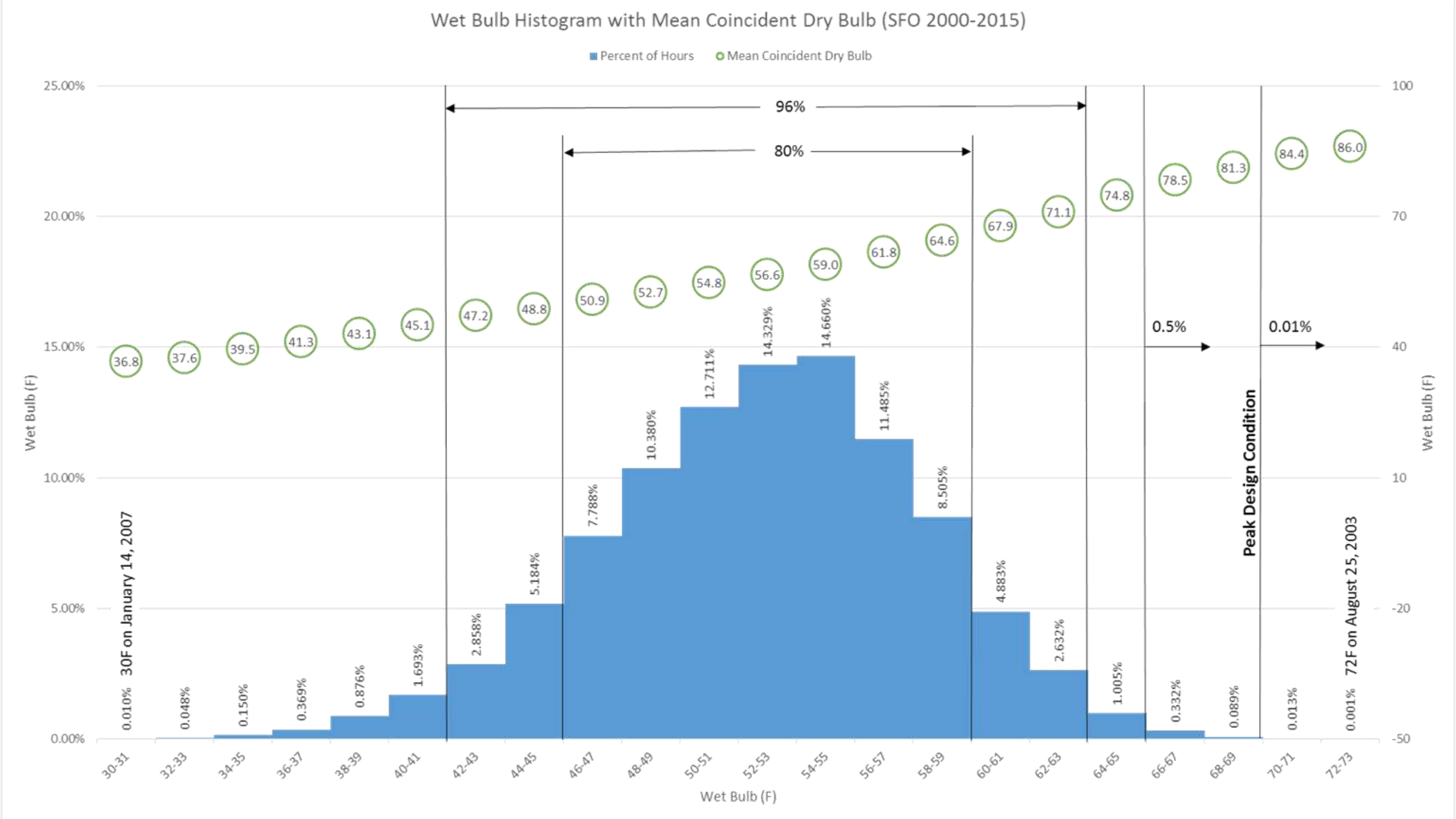
EXISTING HYDRONIC WITH BUILDING PLANT REPURPOSED AS REMOTE PLANT (5 NEW CHILLERS)

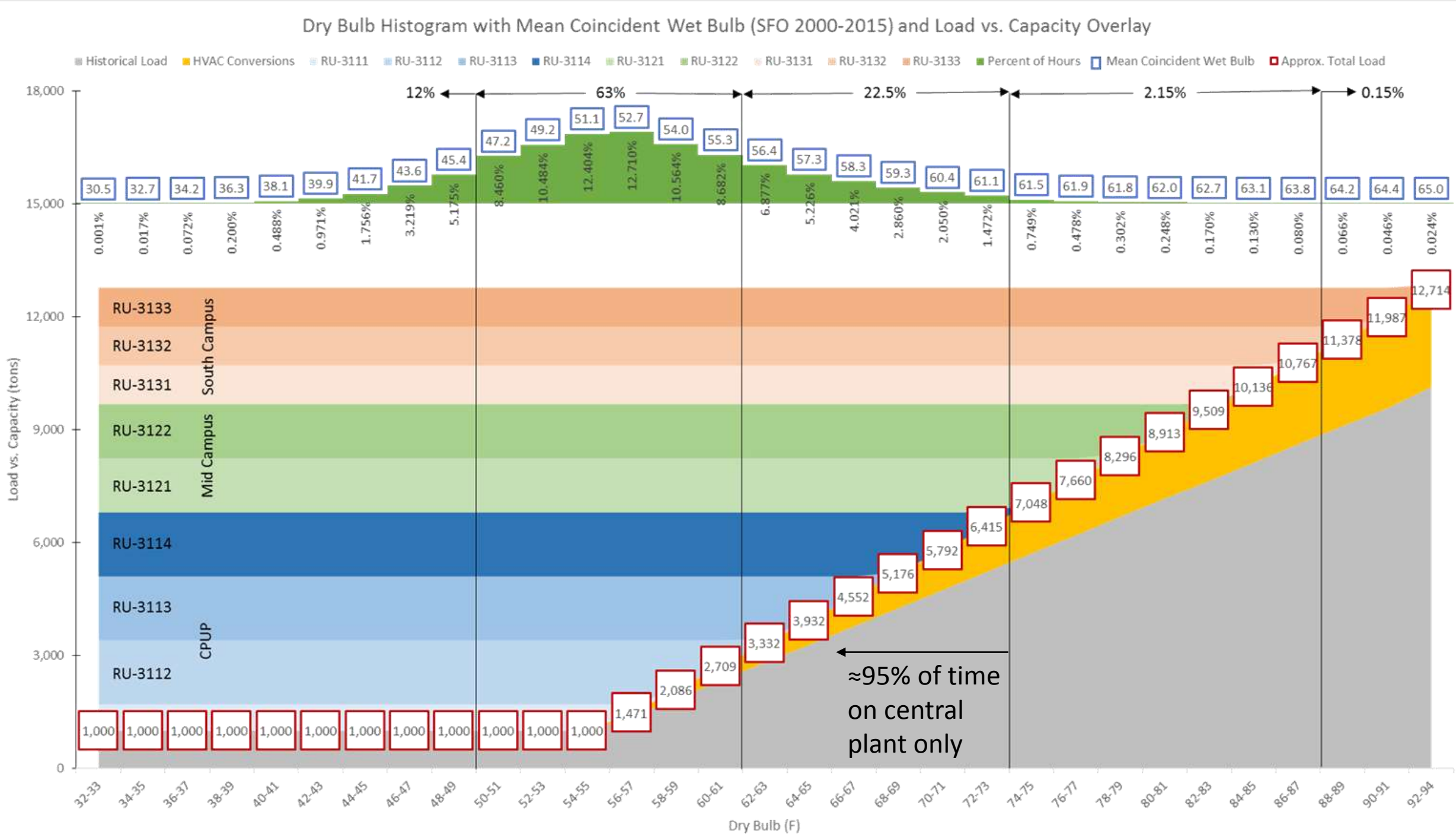
EXISTING HYDRONIC ADDED TO CAMPUS CHILLER SYSTEM

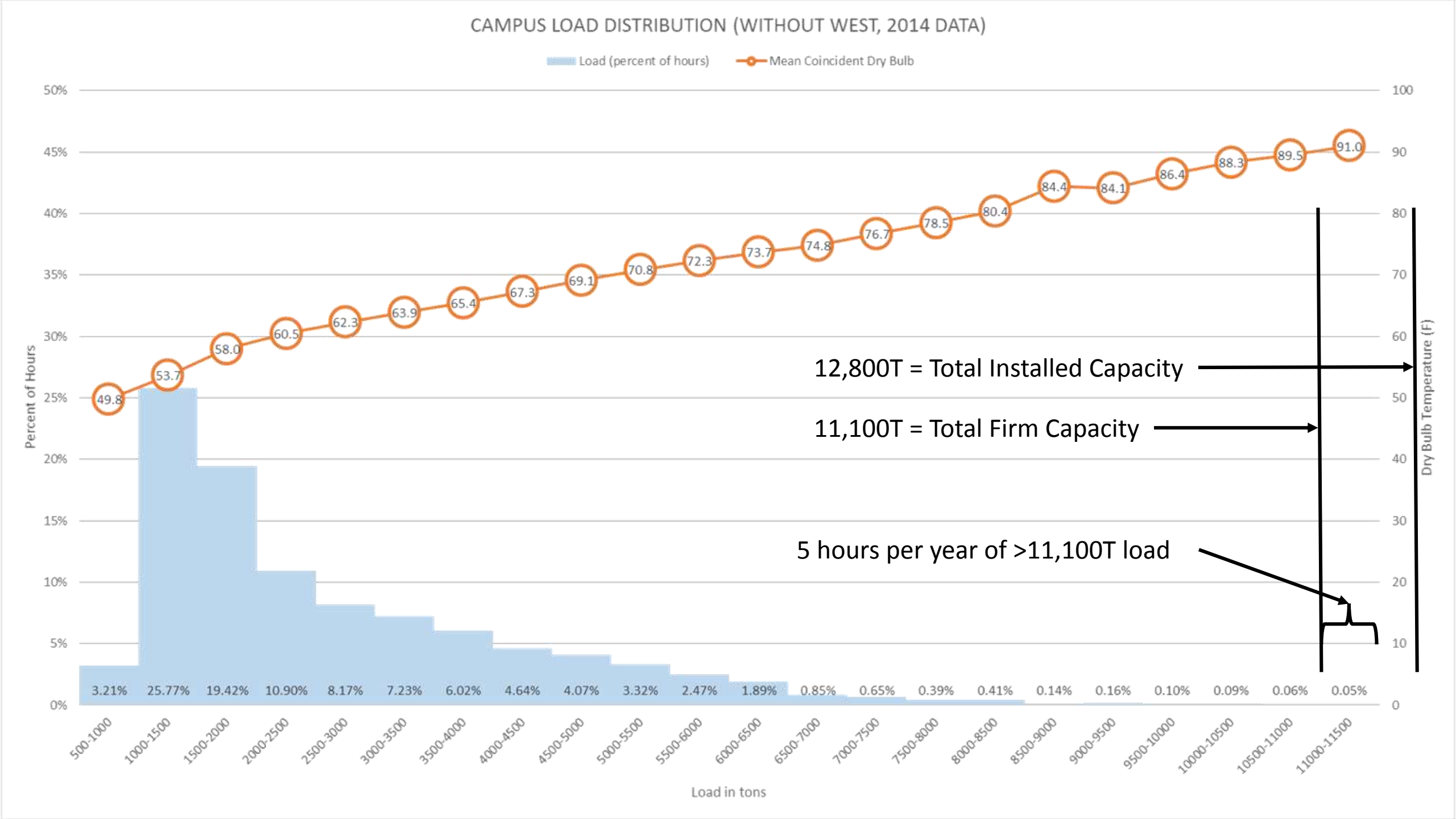
NEW HYDRONIC ADDED TO CAMPUS CHILLER SYSTEM

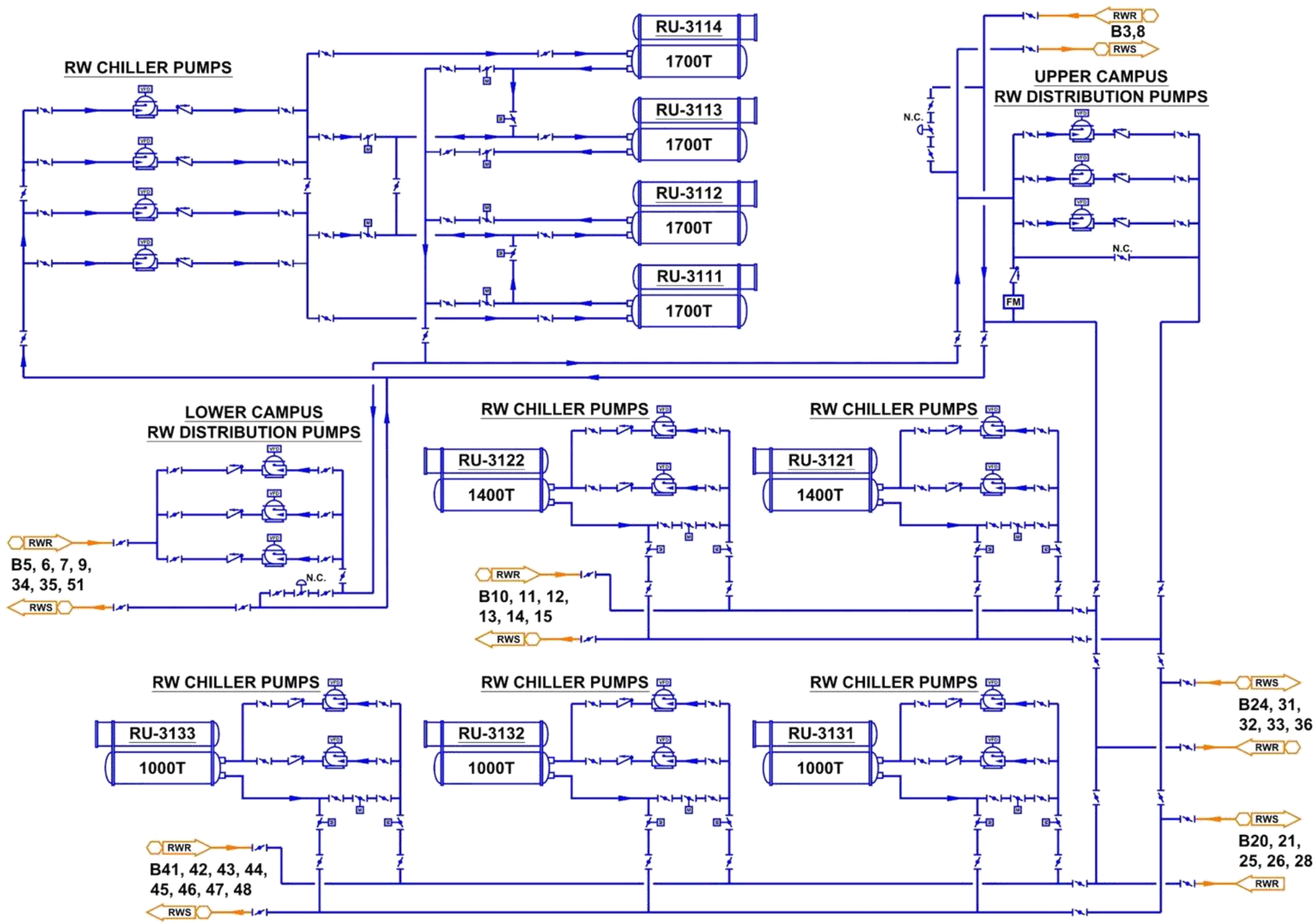
214 TOTAL REFRIGERATION UNITS FOR HVAC REDUCED TO 9


Dry Bulb Histogram with mean Coincident Wet Bulb (SFO 01/01/2000 to 11/19/2017)
Percent of Hours
Mean Coincident Wet Bulb
Percent of Hours
Wet Bulb Temperature (°F)
Dry Bulb Temperature (°F)
0.5%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
75
60
45
30
15
0
30.5
32.7
34.2
36.2
38.1
39.9
41.7
43.6
45.4
47.3
49.2
51.1
52.8
54.1
55.4
56.4
57.3
58.4
59.3
60.4
61.1
61.5
61.9
62.1
62.2
62.9
63.3
64.0
64.2
64.7
65.0
66.8
67.5
68.5
70.0
0.001%
0.015%
0.066%
0.192%
0.457%
0.934%
1.713%
3.101%
4.987%
8.158%
10.264%
12.293%
12.832%
10.744%
8.893%
7.038%
5.344%
4.097%
2.938%
2.087%
1.472%
0.774%
0.492%
0.323%
0.248%
0.174%
0.135%
0.080%
0.065%
0.045%
0.018%
0.008%
0.004%
0.004%
0.001%
32-34
34-36
36-38
38-40
40-42
42-44
44-46
46-48
48-50
50-52
52-54
54-56
56-58
58-60
60-62
62-64
64-66
66-68
68-70
70-72
72-74
74-76
76-78
78-80
80-82
82-84
84-86
86-88
88-90
90-92
92-94
94-96
96-98
98-100
102-104
Record Low Since 1875: 27F on December 11, 1932
Record High Since 1875: 104F on September 1, 2017

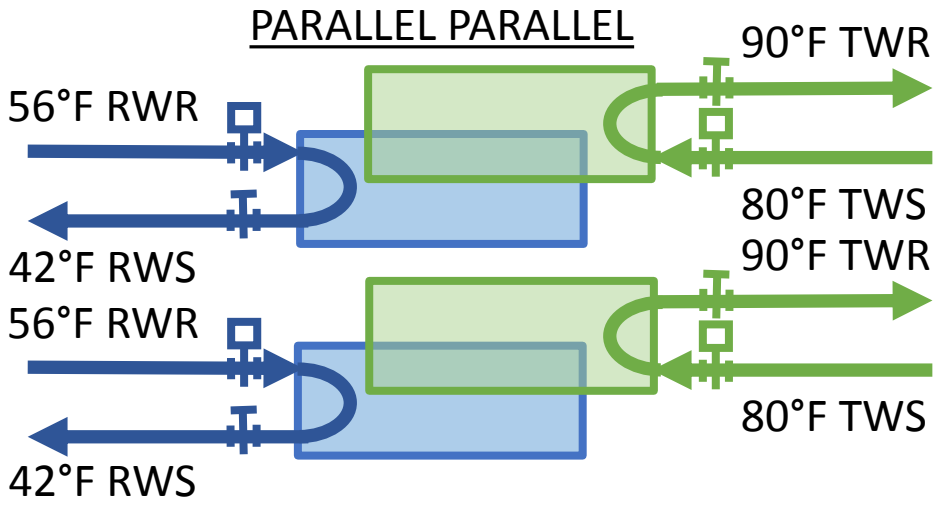

Wet Bulb Histogram with Mean Coincident Dry Bulb (SFO 2000-2015)
Percent of Hours
Mean Coincident Dry Bulb
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
100
70
40
10
-20
-50
Wet Bulb (F)
Wet Bulb (F)
96%
80%
0.5%
0.01%
Peak Design Condition
30F on January 14, 2007
72F on August 25, 2003
36.8
37.6
39.5
41.3
43.1
45.1
47.2
48.8
50.9
52.7
54.8
56.6
59.0
61.8
64.6
67.9
71.1
74.8
78.5
81.3
84.4
86.0
0.010%
0.048%
0.150%
0.369%
0.876%
1.693%
2.858%
5.184%
7.788%
10.380%
12.711%
14.329%
14.660%
11.485%
8.505%
4.883%
2.632%
1.005%
0.332%
0.089%
0.013%
0.001%
30-31
32-33
34-35
36-37
38-39
40-41
42-43
44-45
46-47
48-49
50-51
52-53
54-55
56-57
58-59
60-61
62-63
64-65
66-67
68-69
70-71
72-73
Wet Bulb (F)

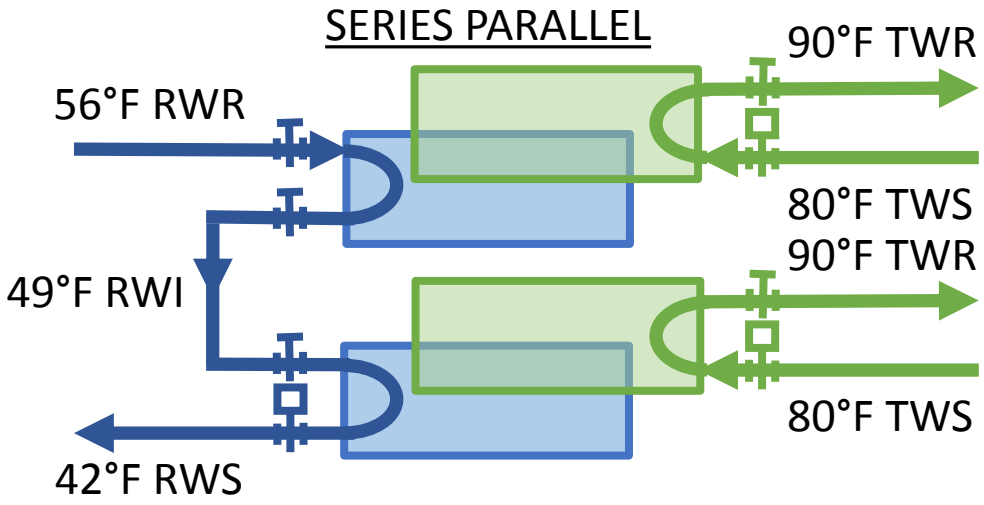

Dry Bulb Histogram with Mean Coincident Wet Bulb (SFO 2000-2015) and Load vs. Capacity Overlay
Historical Load
HVAC Conversions
RU-3111
RU-3112
RU-3113
RU-3114
RU-3121
RU-3122
RU-3131
RU-3132
RU-3133
Percent of Hours
Mean Coincident Wet Bulb
Approx. Total Load
12%
63%
22.5%
2.15%
0.15%
Load vs. Capacity (tons)
Dry Bulb (F)
South Campus
Mid Campus
CPUP
≈95% of time on central plant only

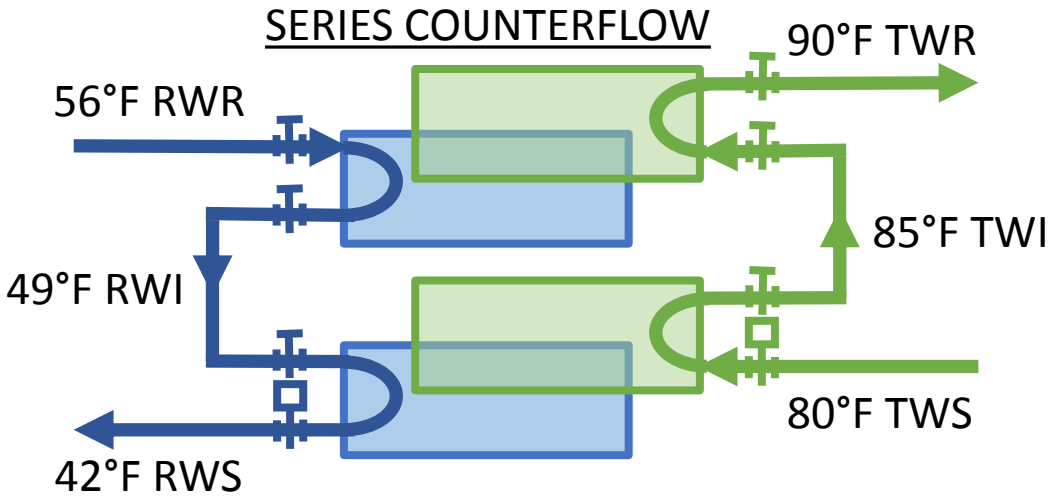

CAMPUS LOAD DISTRIBUTION (WITHOUT WEST, 2014 DATA)
Load (percent of hours)
Mean Coincident Dry Bulb
Percent of Hours
Dry Bulb Temperature (F)
Load in tons
12,800T = Total Installed Capacity
11,100T = Total Firm Capacity
5 hours per year of >11,100T load
49.8
53.7
58.0
60.5
62.3
63.9
65.4
67.3
69.1
70.8
72.3
73.7
74.8
76.7
78.5
80.4
84.4
84.1
86.4
88.3
89.5
91.0
3.21%
25.77%
19.42%
10.90%
8.17%
7.23%
6.02%
4.64%
4.07%
3.32%
2.47%
1.89%
0.85%
0.65%
0.39%
0.41%
0.14%
0.16%
0.10%
0.09%
0.06%
0.05%
500-1000
1000-1500
1500-2000
2000-2500
2500-3000
3000-3500
3500-4000
4000-4500
4500-5000
5000-5500
5500-6000
6000-6500
6500-7000
7000-7500
7500-8000
8000-8500
8500-9000
9000-9500
9500-10000
10000-10500
10500-11000
11000-11500

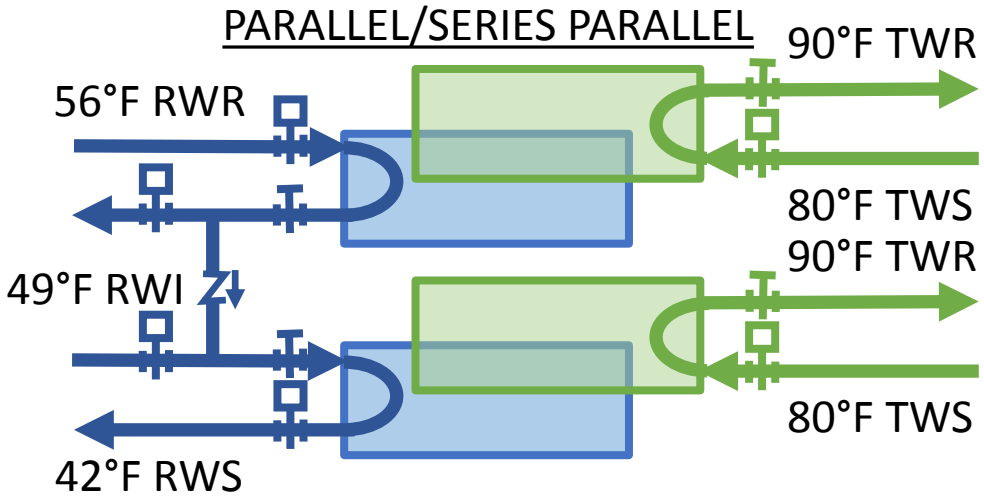

RW CHILLER PUMPS
RU-3114
1700T
RU-3113
1700T
RU-3112
1700T
RU-3111
1700T
RWR
B3,8
RWS
UPPER CAMPUS
RW DISTRIBUTION PUMPS
N.C.
N.C.
FM
LOWER CAMPUS
RW DISTRIBUTION PUMPS
RWR
B5, 6, 7, 9,
34, 35, 51
N.C.
RWS
RW CHILLER PUMPS
RU-3122
1400T
RWR
B10, 11, 12,
13, 14, 15
RWS
RW CHILLER PUMPS
RU-3121
1400T
RW CHILLER PUMPS
RU-3133
1000T
RWR
B41, 42, 43, 44,
45, 46, 47, 48
RWS
RW CHILLER PUMPS
RU-3132
1000T
RW CHILLER PUMPS
RU-3131
1000T
RWS
B24, 31,
32, 33, 36
RWR
RWS
B20, 21,
25, 26, 28
RWR

Parallel vs. Series



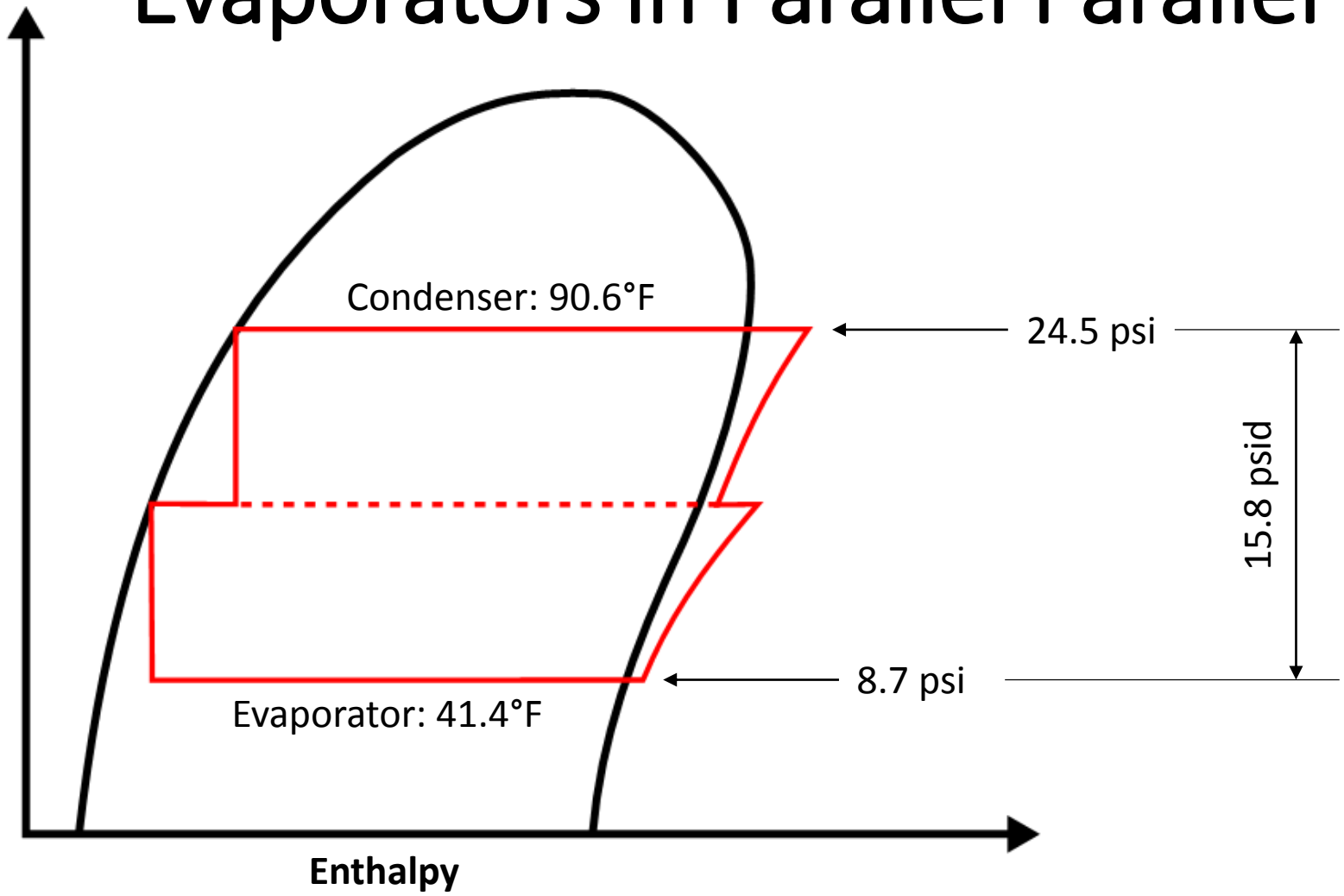






2-Stage Vapor Compression Refrigeration

Evaporators in Parallel Parallel

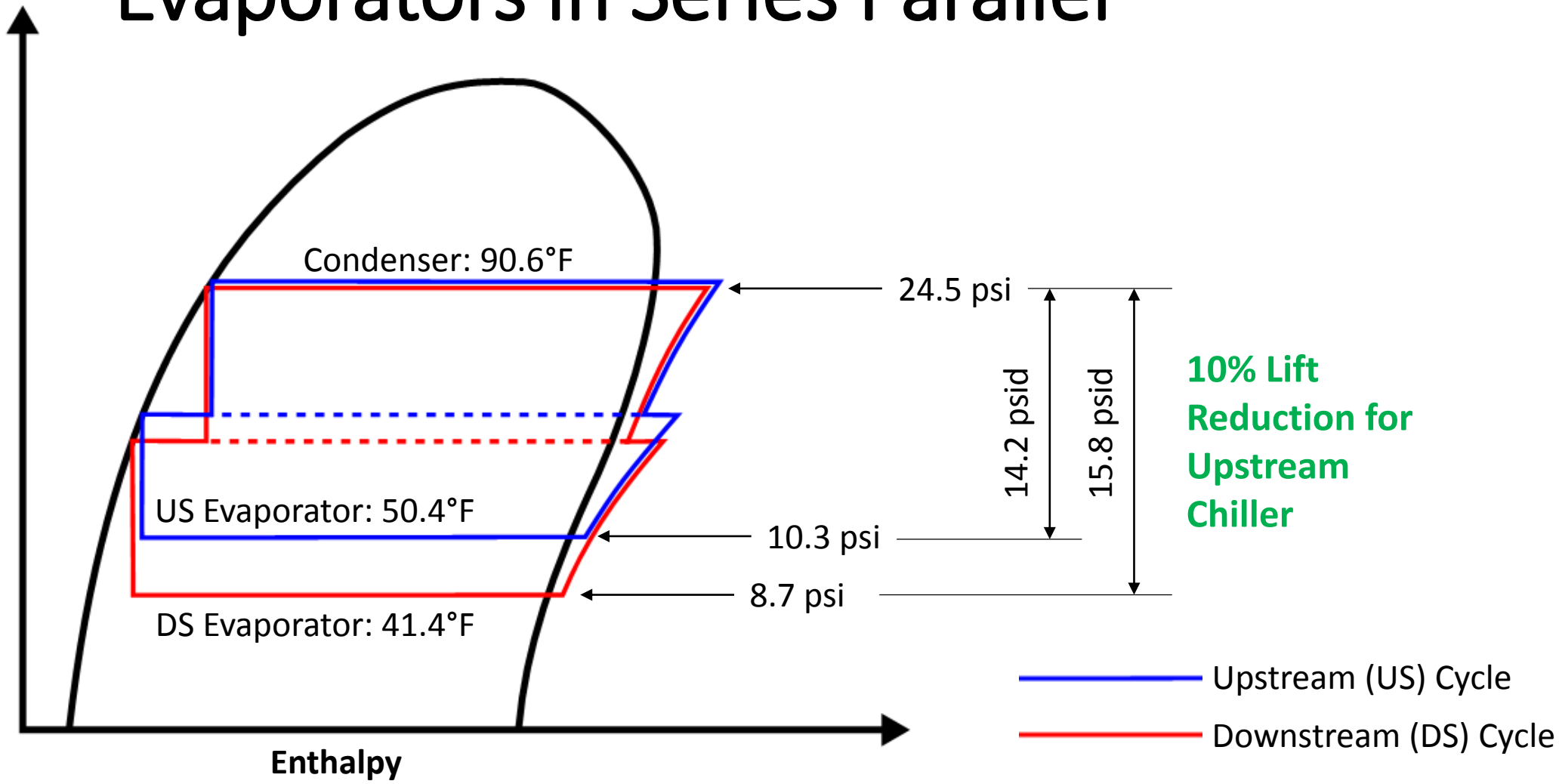


System Conditions:

EEWT:	60°F
LEWT:	42°F
Evap. Approach:	0.6°F
ECWT:	80°F
LCWT:	90°F
Cond. Approach:	0.6°F

2-Stage Vapor Compression Refrigeration

Evaporators in Series Parallel

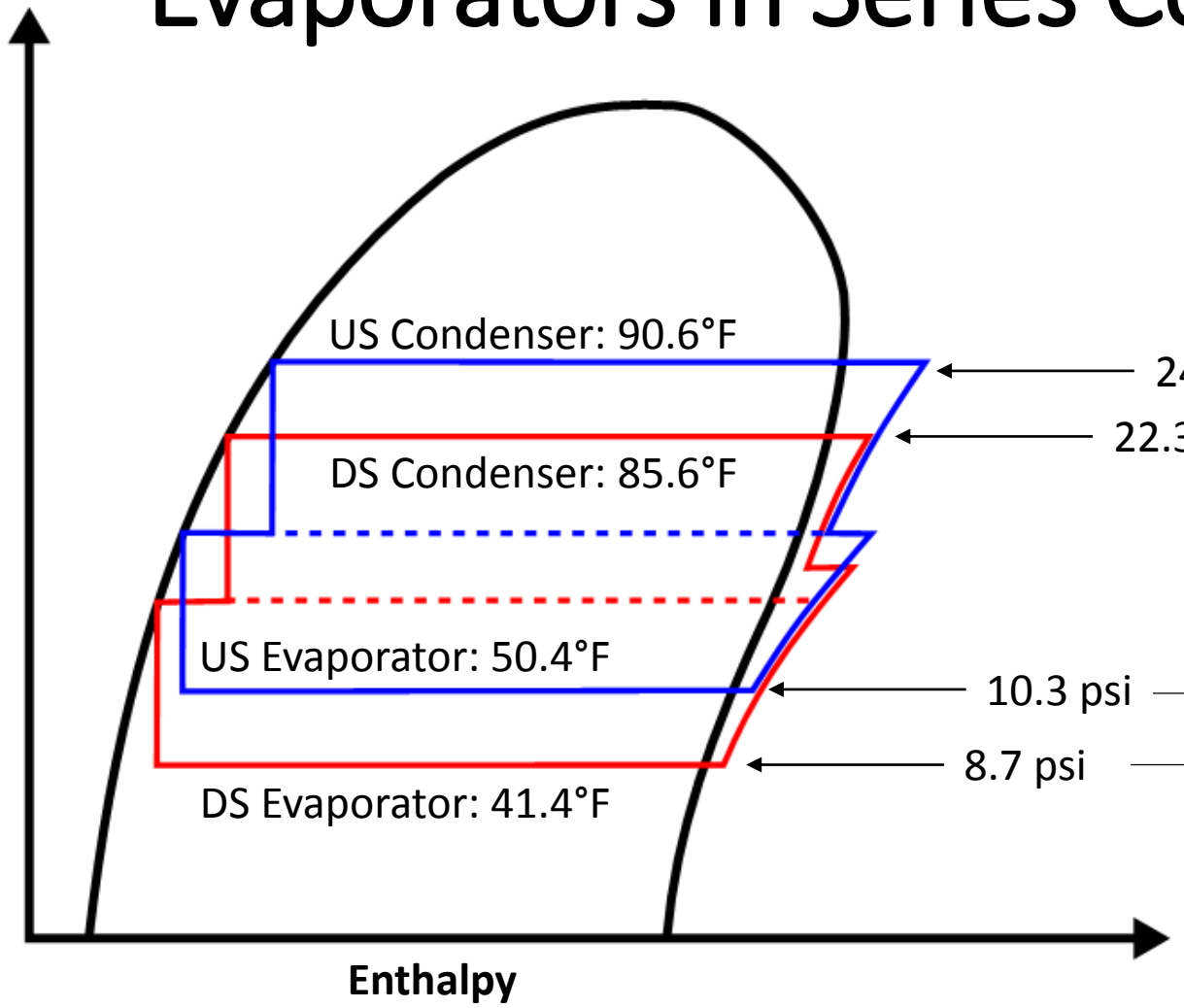


System Conditions:

EEWT:	60°F
LEWT:	42°F
Evap. Approach:	0.6°F
ECWT:	80°F
LCWT:	90°F
Cond. Approach:	0.6°F

2-Stage Vapor Compression Refrigeration

Evaporators in Series Counterflow



14% Lift Reduction for Downstream Chiller

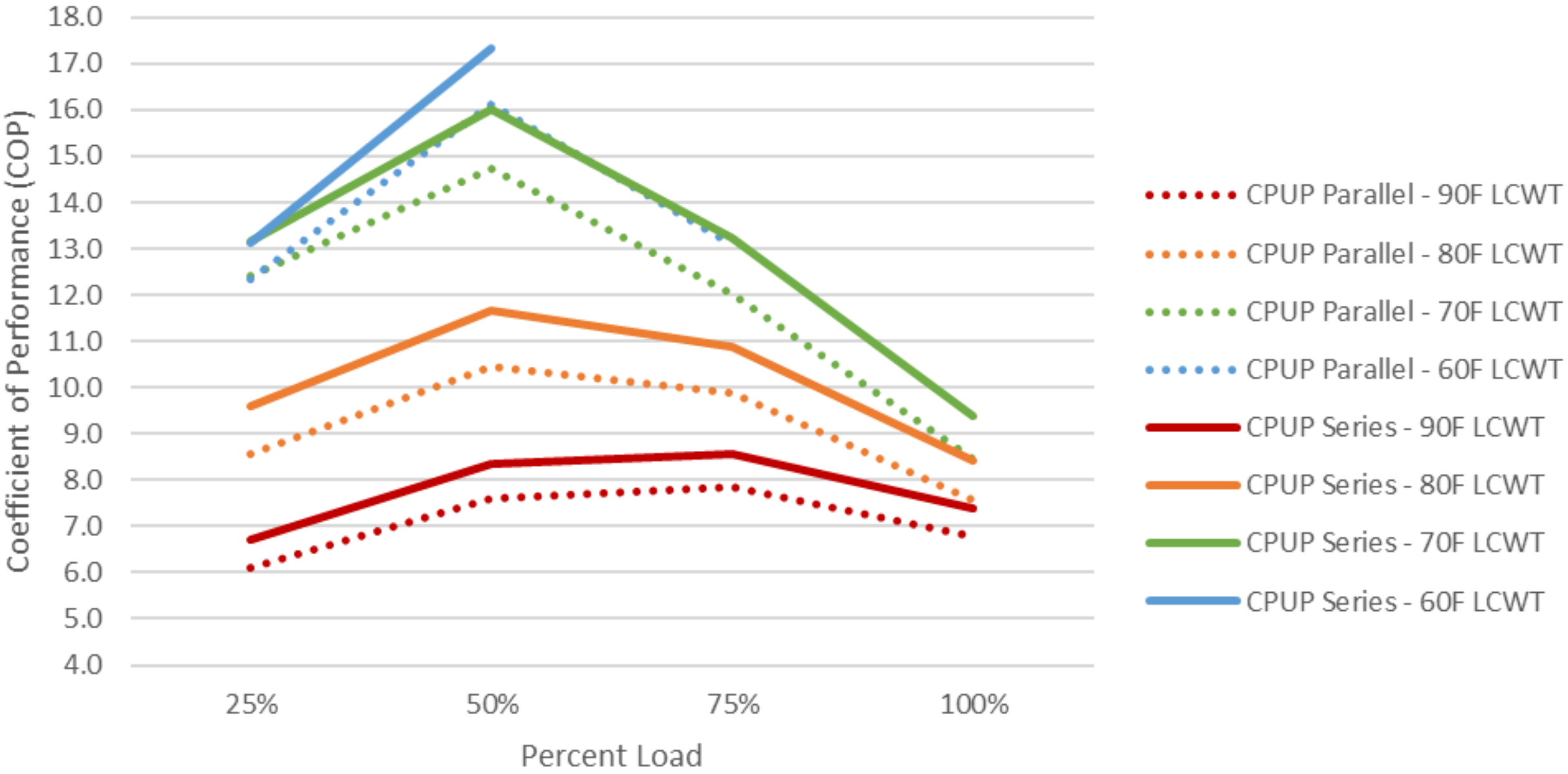
10% Lift Reduction for Upstream Chiller

<u>System Conditions:</u>

EEWT:	60°F
LEWT:	42°F
Evap. Approach:	0.6°F
ECWT:	80°F
LCWT:	90°F
Cond. Approach:	0.6°F

Upstream (US) Cycle

Downstream (DS) Cycle


CPUP - RW Chiller COP at Various Load and Lift and 42°F LEWT
Coefficient of Performance (COP)
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
25%
50%
75%
100%
Percent Load
CPUP Parallel - 90F LCWT
CPUP Parallel - 80F LCWT
CPUP Parallel - 70F LCWT
CPUP Parallel - 60F LCWT
CPUP Series - 90F LCWT
CPUP Series - 80F LCWT
CPUP Series - 70F LCWT
CPUP Series - 60F LCWT

Total Chiller Plant kW/T @14F dT

Parallel

OA WB (°F)	325 Tons kW/T	650 Tons kW/T	975 Tons kW/T	1,300 Tons kW/T	1,625 Tons kW/T	1,950 Tons kW/T	2,275 Tons kW/T	2,600 Tons kW/T	2,925 Tons kW/T	3,250 Tons kW/T	3,575 Tons kW/T	3,900 Tons kW/T	4,225 Tons kW/T	4,550 Tons kW/T	4,875 Tons kW/T	5,200 Tons kW/T	5,525 Tons kW/T	5,850 Tons kW/T	6,175 Tons kW/T	6,500 Tons kW/T
30	0.525	0.345	0.316	0.348	0.292	0.319	0.299	0.319	0.321	0.297	0.320	0.324	0.330	0.336	0.343	0.389	0.411	0.434	0.457	0.481
35	0.498	0.336	0.308	0.339	0.291	0.311	0.314	0.311	0.313	0.299	0.314	0.319	0.325	0.332	0.339	0.385	0.407	0.431	0.454	0.478
40	0.456	0.323	0.297	0.326	0.286	0.300	0.306	0.297	0.303	0.298	0.304	0.311	0.319	0.328	0.338	0.378	0.400	0.424	0.447	0.472
45	0.426	0.316	0.300	0.318	0.286	0.303	0.303	0.288	0.306	0.299	0.306	0.314	0.323	0.333	0.344	0.372	0.395	0.421	0.448	0.474
50	0.399	0.310	0.308	0.312	0.287	0.311	0.301	0.289	0.313	0.300	0.309	0.323	0.333	0.345	0.358	0.385	0.411	0.438	0.465	0.492
55	0.387	0.329	0.333	0.332	0.312	0.336	0.324	0.317	0.336	0.324	0.335	0.347	0.358	0.370	0.380	0.407	0.432	0.459	0.484	0.510
60	0.428	0.365	0.365	0.368	0.349	0.368	0.363	0.354	0.371	0.362	0.371	0.380	0.389	0.397	0.405	0.430	0.456	0.481	0.505	0.530
65	0.471	0.407	0.397	0.410	0.386	0.400	0.402	0.391	0.403	0.398	0.404	0.411	0.419	0.427	0.435	0.460	0.483	0.507	0.529	0.550
70	0.521	0.451	0.434	0.454	0.429	0.438	0.446	0.438	0.447	0.444	0.449	0.456	0.461	0.467	0.471	0.493	0.513	0.534	0.554	0.573
75	0.581	0.508	0.480	0.501	0.479	0.484	0.486	0.486	0.490	0.491	0.494	0.498	0.500	0.503	0.508	0.527	0.545	0.561	0.578	0.598

Series

30	0.525	0.345	0.316	0.315	0.264	0.286	0.281	0.298	0.294	0.269	0.288	0.291	0.295	0.300	0.305	0.345	0.363	0.383	0.402	0.423
35	0.498	0.336	0.308	0.310	0.266	0.278	0.287	0.290	0.291	0.274	0.282	0.285	0.290	0.295	0.301	0.341	0.359	0.379	0.399	0.420
40	0.456	0.323	0.297	0.295	0.256	0.265	0.276	0.276	0.279	0.268	0.271	0.275	0.281	0.287	0.293	0.333	0.352	0.373	0.393	0.414
45	0.426	0.316	0.300	0.285	0.252	0.256	0.269	0.264	0.270	0.265	0.263	0.268	0.274	0.280	0.287	0.327	0.347	0.349	0.370	0.392
50	0.399	0.310	0.308	0.277	0.248	0.260	0.277	0.254	0.274	0.262	0.266	0.271	0.277	0.293	0.301	0.323	0.344	0.365	0.385	0.405
55	0.387	0.329	0.329	0.292	0.272	0.287	0.299	0.289	0.296	0.284	0.290	0.294	0.305	0.314	0.321	0.341	0.361	0.381	0.400	0.420
60	0.428	0.365	0.354	0.317	0.294	0.308	0.322	0.317	0.320	0.308	0.313	0.320	0.326	0.334	0.341	0.360	0.380	0.400	0.419	0.439
65	0.471	0.407	0.373	0.338	0.319	0.333	0.346	0.348	0.342	0.332	0.339	0.344	0.352	0.360	0.368	0.388	0.407	0.427	0.445	0.463
70	0.520	0.434	0.396	0.373	0.356	0.367	0.376	0.387	0.379	0.369	0.375	0.383	0.389	0.396	0.402	0.420	0.438	0.456	0.472	0.487
75	0.563	0.480	0.444	0.425	0.401	0.408	0.413	0.431	0.426	0.413	0.416	0.421	0.426	0.430	0.438	0.455	0.469	0.483	0.498	0.514

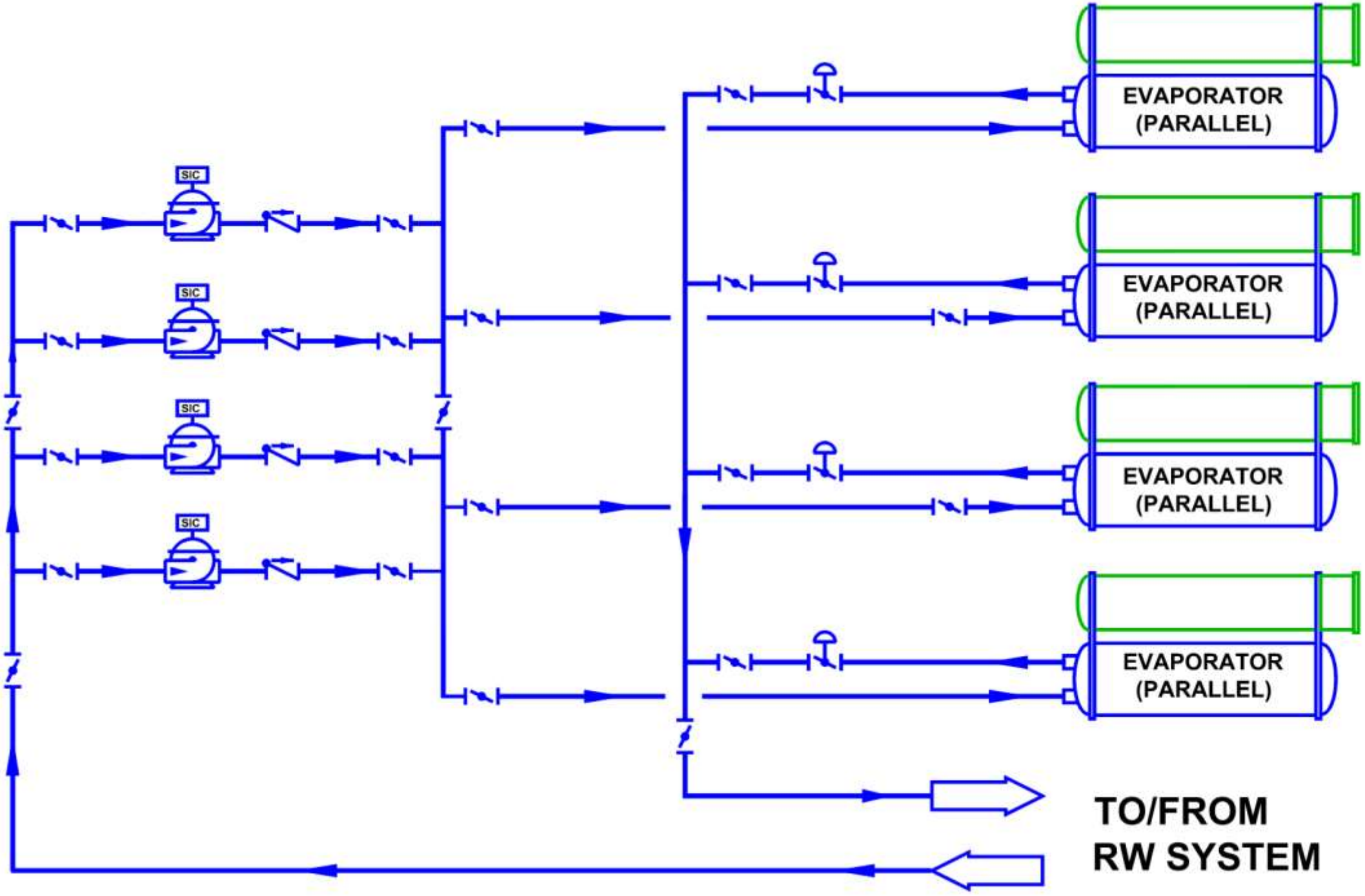
Series Mode is more efficient at every point

Annual Weighted Total Chiller Plant kW/T

RW Differential Temperature (°F)	Parallel CPLV (kW/ton)	Series CPLV (kW/ton)	Series vs. Parallel CPLV (kW/ton)	Series vs. Parallel CPLV (%)
12	0.335	0.311	-0.024	7.2%
13	0.333	0.307	-0.026	7.8%
14	0.332	0.304	-0.028	8.3%
15	0.331	0.301	-0.030	9.1%
16	0.330	0.298	-0.032	9.7%
17	0.329	0.295	-0.034	10.3%
18	0.329	0.293	-0.036	10.9%

Series evaporator chiller plant is more efficient than parallel evaporator chiller plant, especially with higher differential temperatures.

Estimated annual electricity cost savings: $50,000
25-year present value: $1,000,000


SIC
SIC
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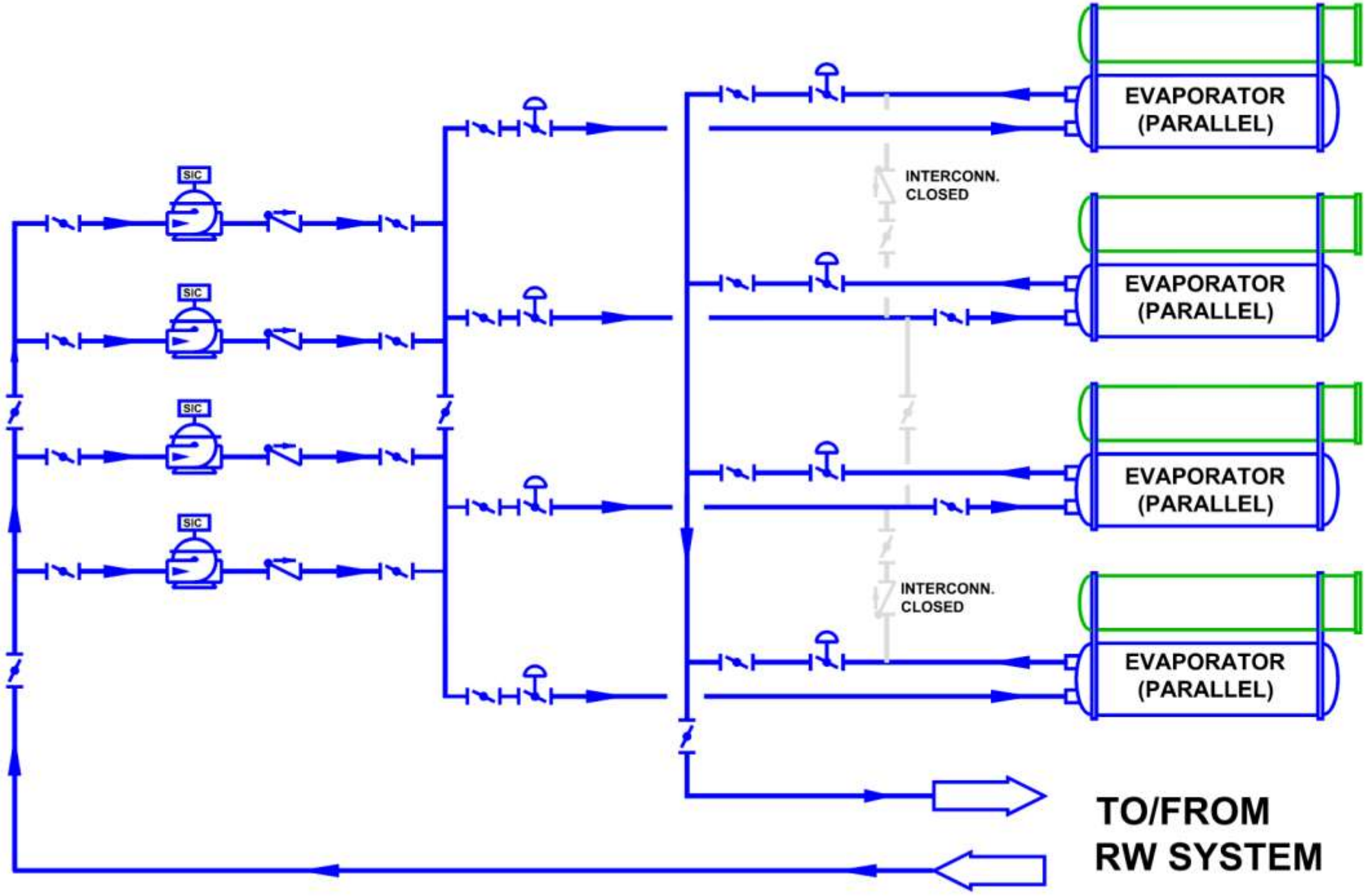
SIC
EVAPORATOR
(PARALLEL)
EVAPORATOR
(PARALLEL)
EVAPORATOR
(PARALLEL)
EVAPORATOR
(PARALLEL)
TO/FROM
RW SYSTEM


SIC
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INTERCONN.
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INTERCONN.
CLOSED
EVAPORATOR
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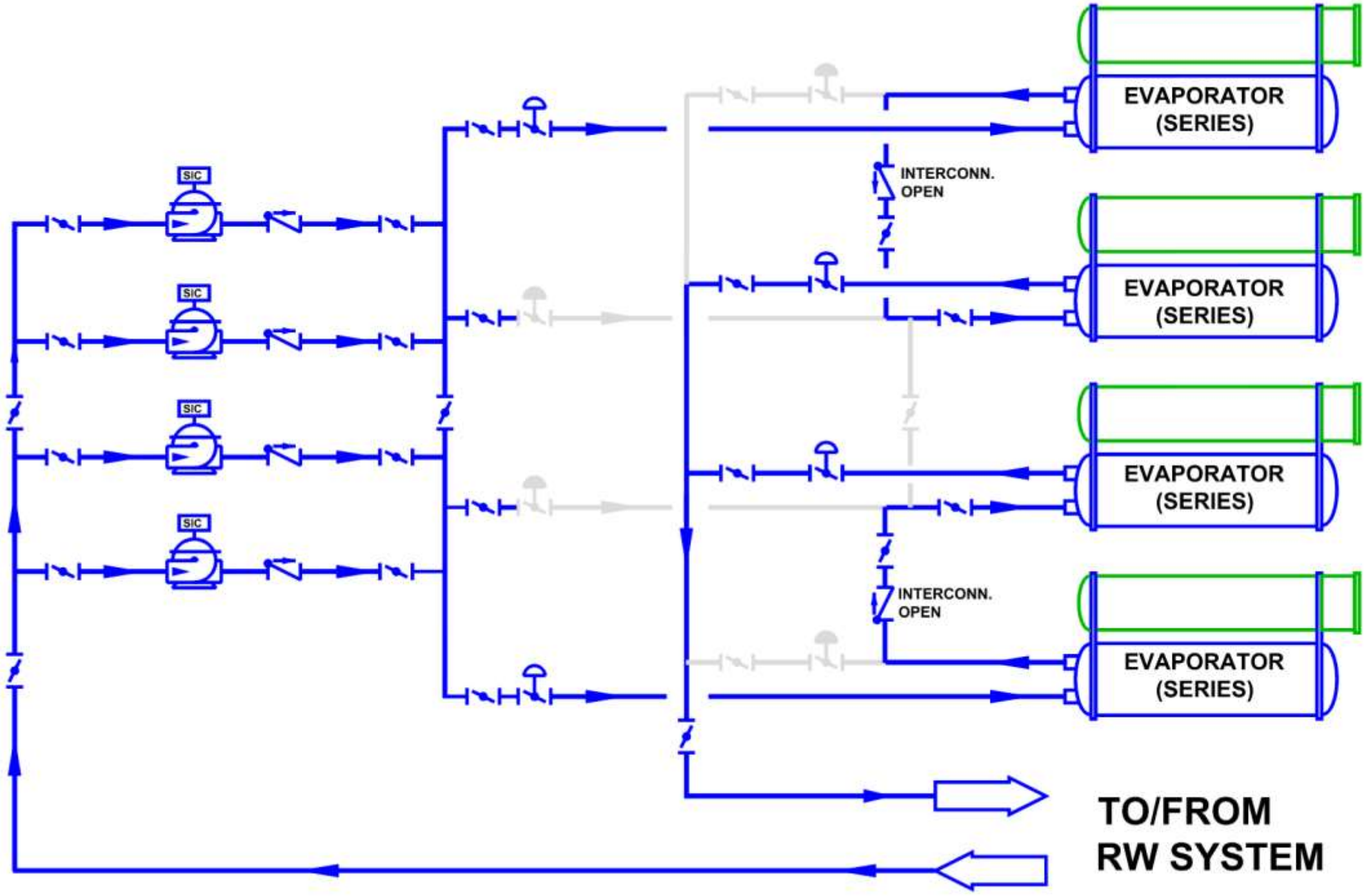
EVAPORATOR
(PARALLEL)
TO/FROM
RW SYSTEM


SIC
SIC
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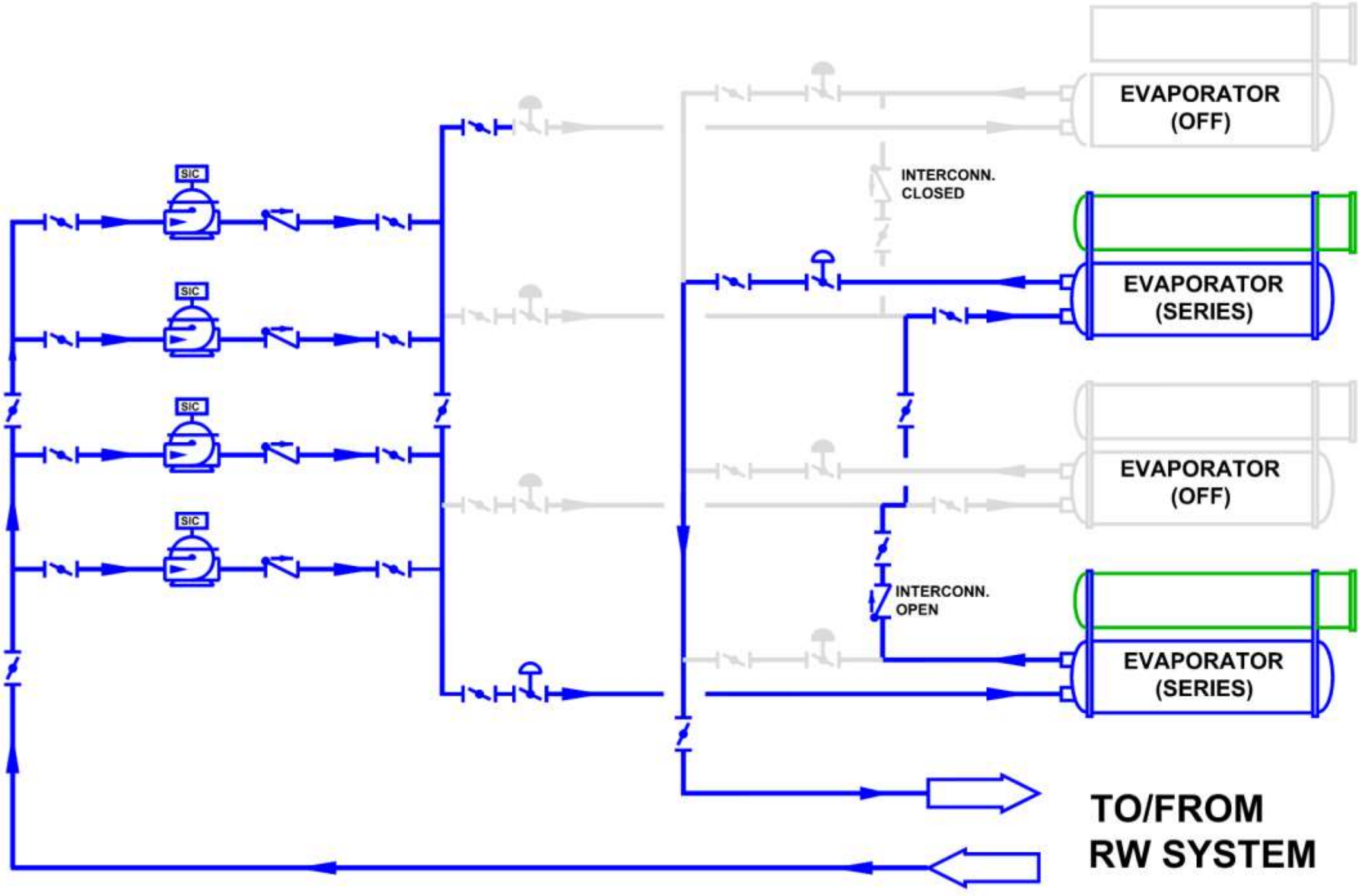
SIC
INTERCONN.
OPEN
INTERCONN.
OPEN
EVAPORATOR
(SERIES)
EVAPORATOR
(SERIES)
EVAPORATOR
(SERIES)
EVAPORATOR
(SERIES)
TO/FROM
RW SYSTEM


SIC
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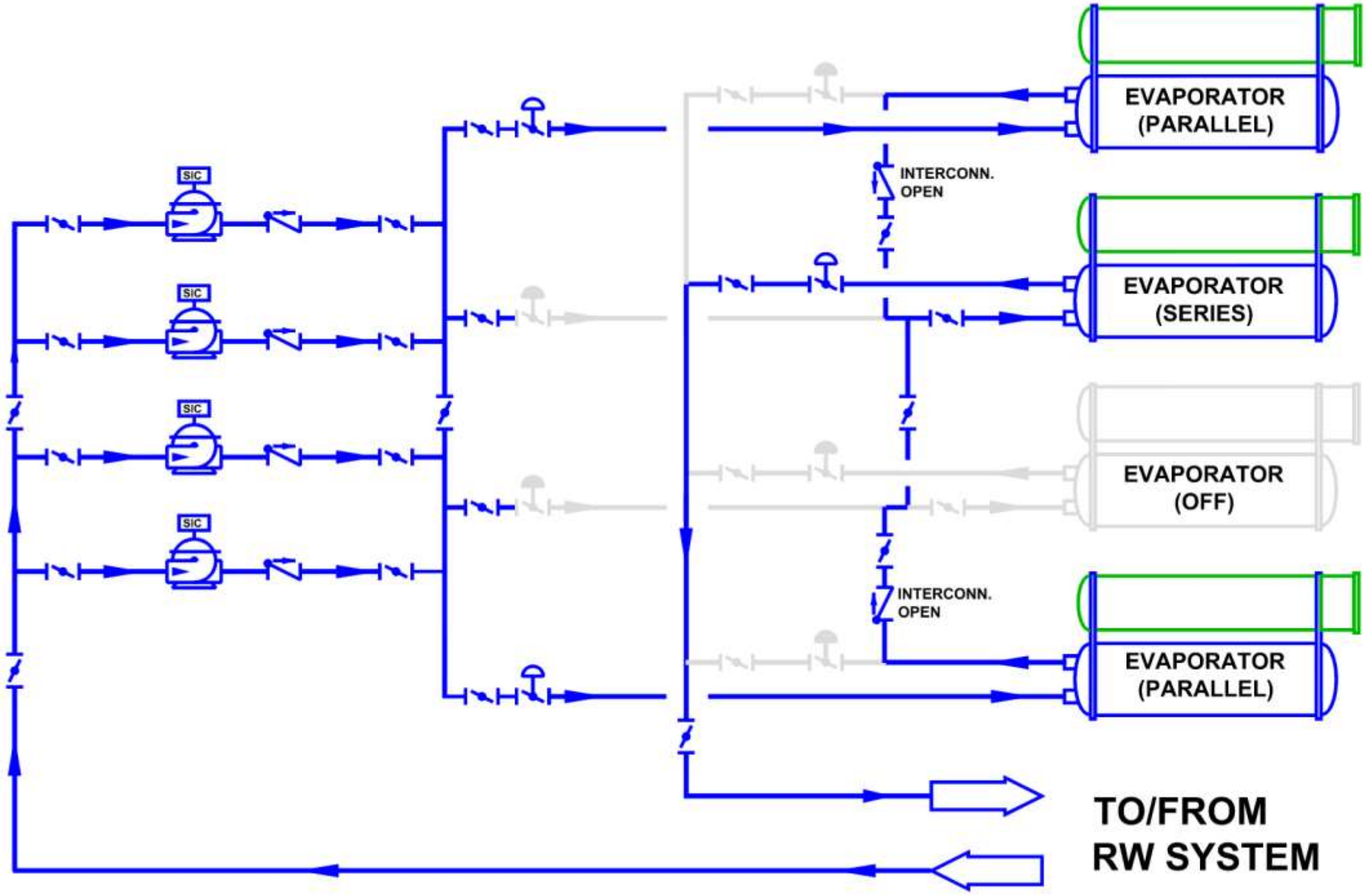
OPEN
EVAPORATOR
(OFF)
EVAPORATOR
(SERIES)
EVAPORATOR
(OFF)
EVAPORATOR
(SERIES)
TO/FROM
RW SYSTEM


SIC
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EVAPORATOR
(PARALLEL)
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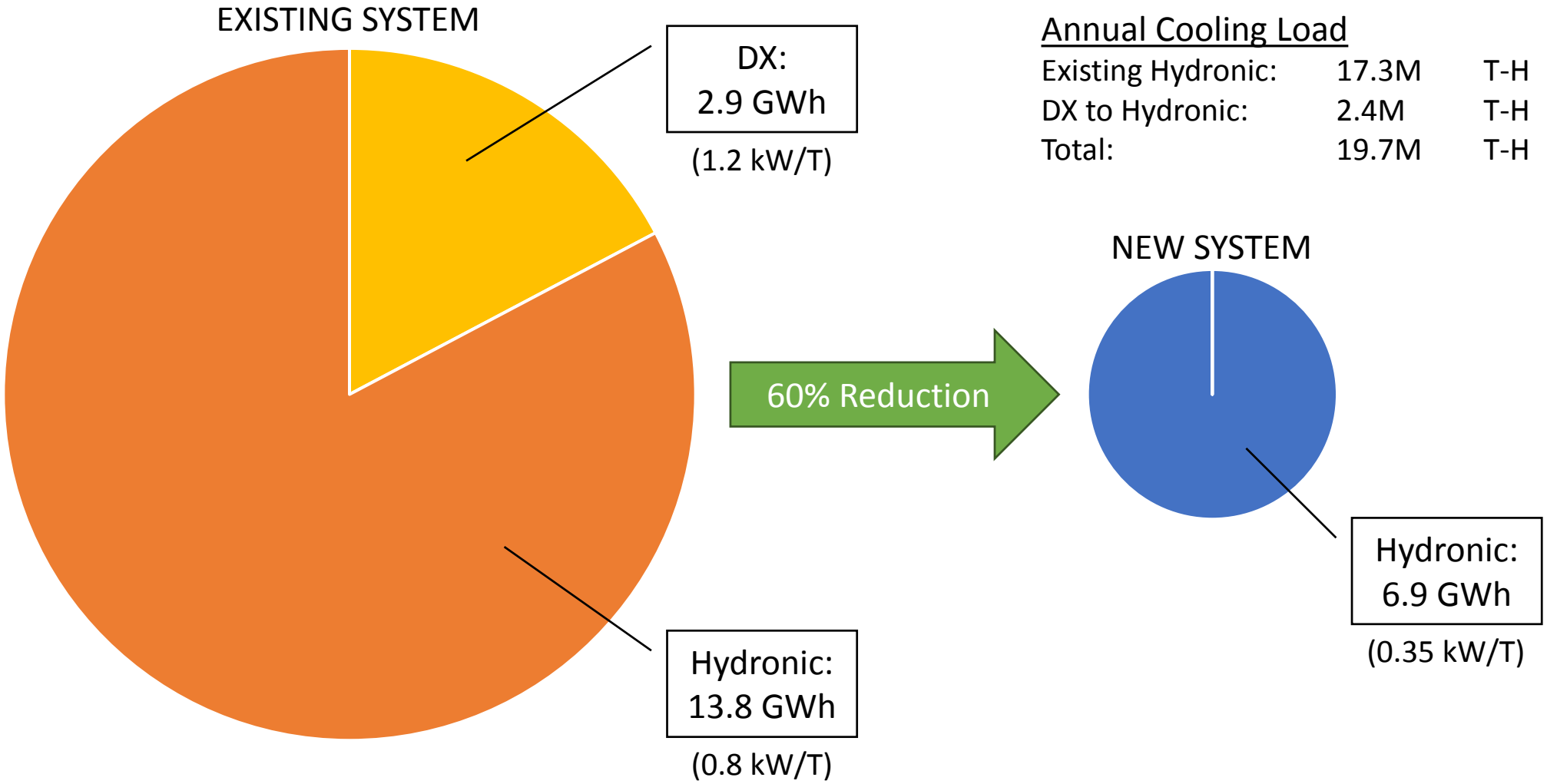
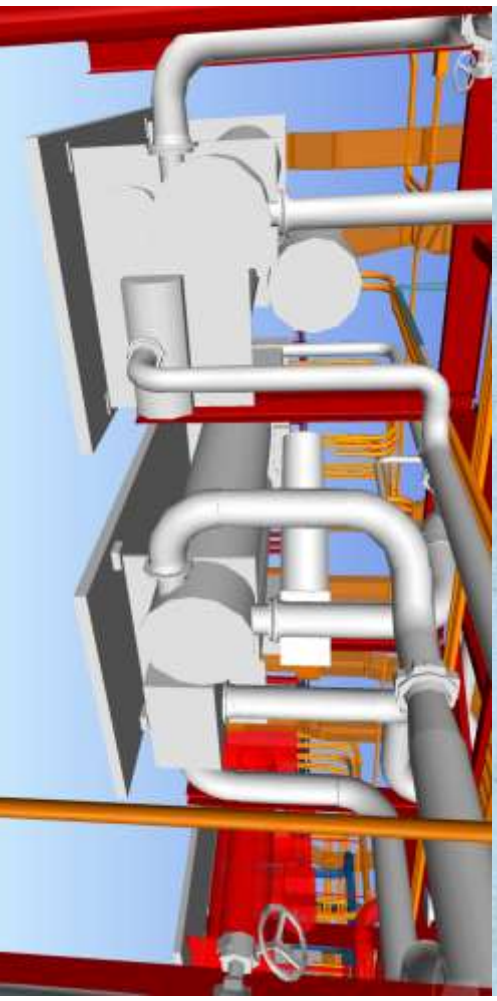
(SERIES)
EVAPORATOR
(OFF)
EVAPORATOR
(PARALLEL)
TO/FROM
RW SYSTEM

Annual Cooling System Energy Consumption



Annual Cooling Load

Existing Hydronic:	17.3M	T-H
DX to Hydronic:	2.4M	T-H
Total:	19.7M	T-H

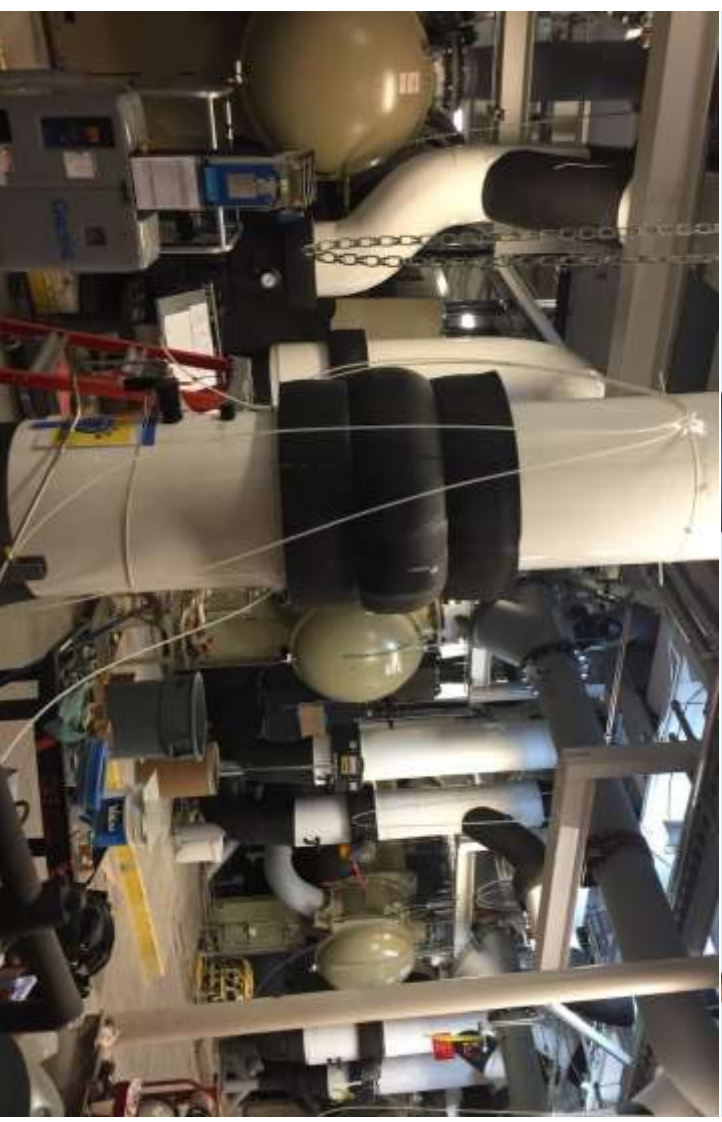


Existing Model

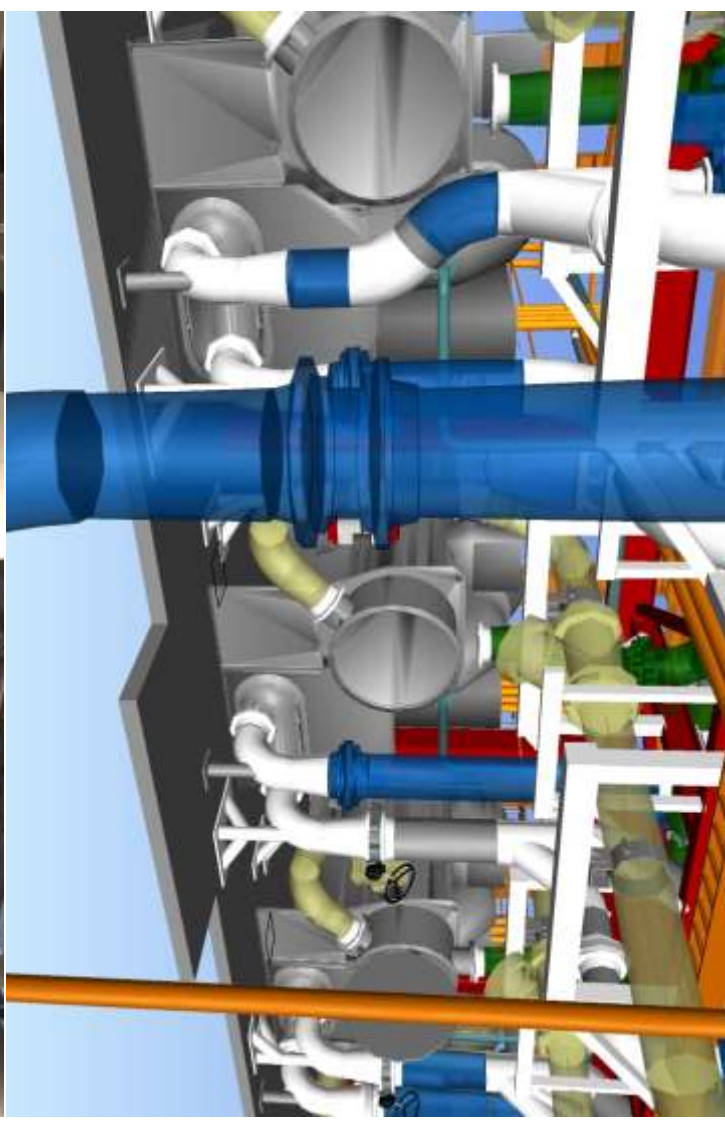
3D Scan

Original

Installation



New Model




TOWER WATER SUPPLY
CHILLED WATER SUPPLY


RWR
RWS

Summary

- 27,885 MTCDE total refrigerant charge reduced to 11.5 MTCDE
  - A 99.96% reduction
- 214 total refrigeration units for HVAC reduced to 9
- 18,940 installed tons reduced to 12,800
- New system is 60% more efficient than existing system
  - ≈25% savings by converting DX to new hydronic
  - ≈25% savings by centralizing existing hydronic
  - ≈10% savings by configuring central plant with series evaporators
  - 10 GWh annual energy savings

Questions?

Contact:

Colin Moyer

cmoyer@aeieng.com

Affiliated Engineers

Michael Morehead

Genentech