Energy Optimization Mission Critical Facilities: Oak Ridge National Lab & Christ Hospital

Fosdick & Hilmer, Inc.
Cincinnati, Ohio

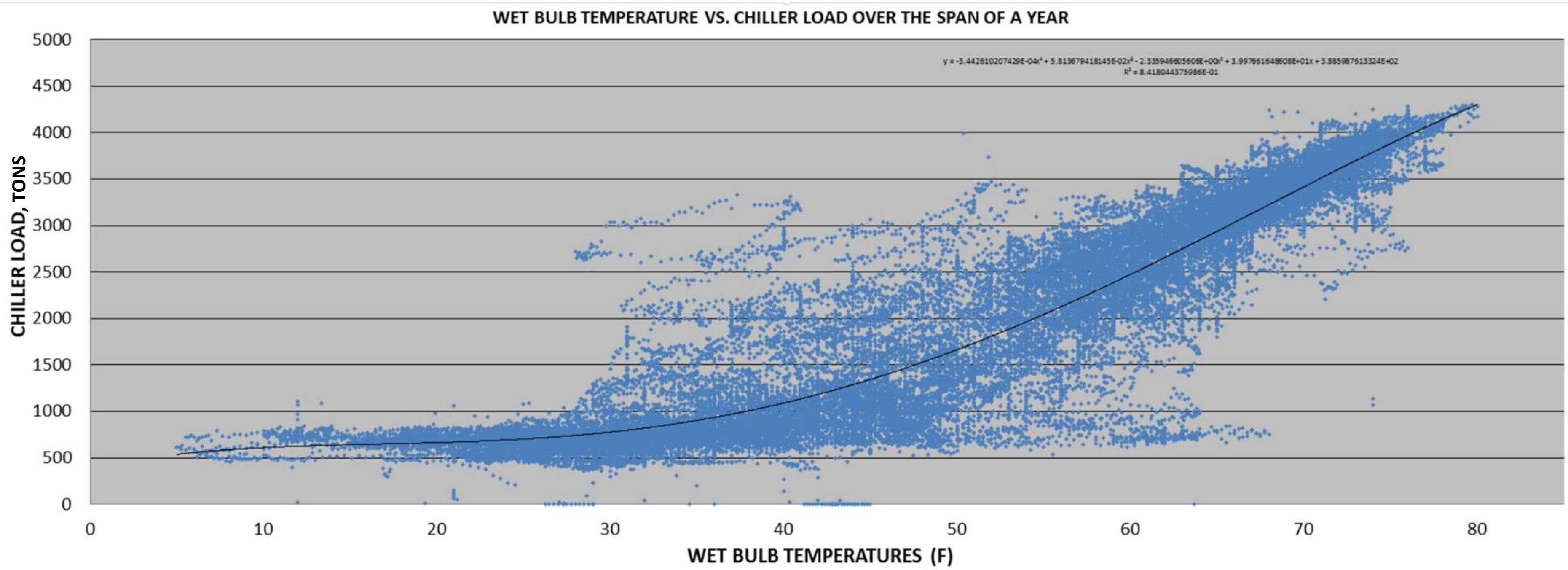
TAKE-AWAYS

- The impacts of increased chilled water temperature
- Effect of tower water temperature set-point on energy
- How we are converting an old chiller plant to variable flow
- Advantages of headered pumping
- Advantages of variable speed pumps for condenser water
- Energy consumption: “riding the pump curve” vs. VFD

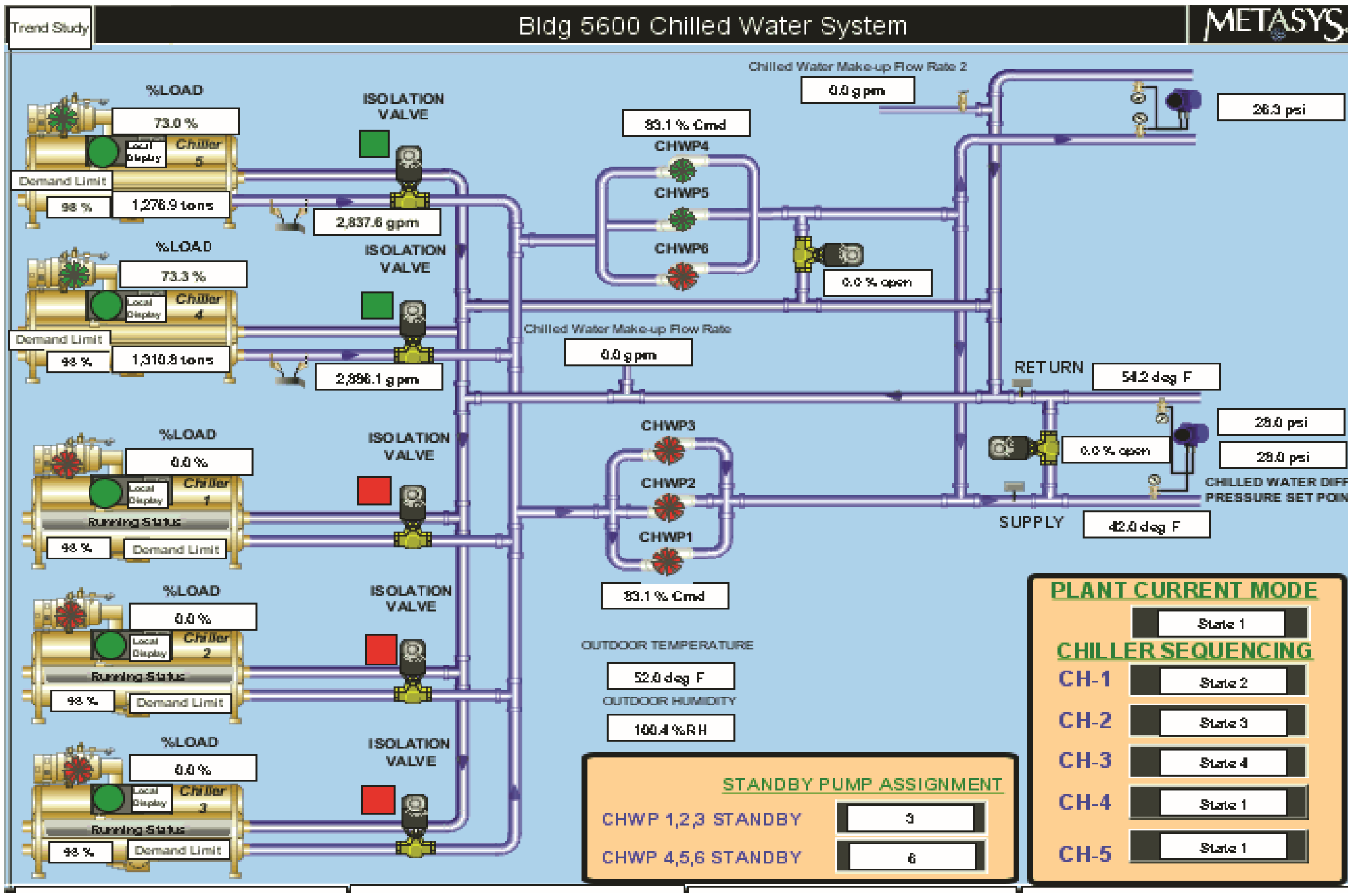
TYPICAL OF MISSION CRITICAL FACILITIES

- Disruption of equipment will result in failure of a critical mission
  - Hospital – surgeries & procedures
  - Data Center – “live” processes (ATMs, financial)
- Year-round Cooling Load
  - Hospital – small winter load
  - Data Center – relatively constant load 365 days
- Concurrent Maintenance can “save the day”

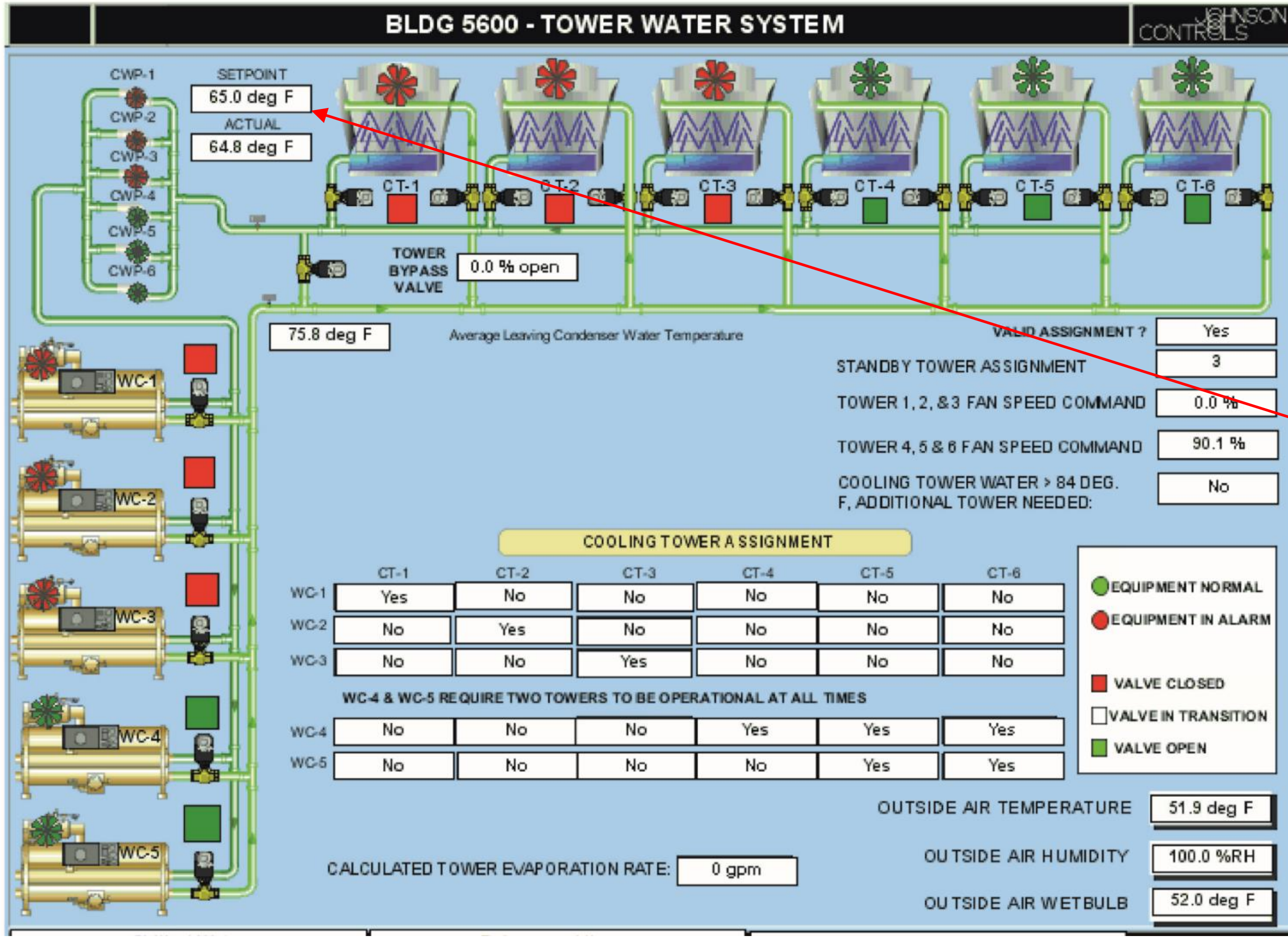
Christ Hospital Cooling Load



Oak Ridge Chiller Plant - CHW



Oak Ridge Chiller Plant - CW



	CT-1	CT-2	CT-3	CT-4	CT-5	CT-6
WC-1	Yes	No	No	No	No	No
WC-2	No	Yes	No	No	No	No
WC-3	No	No	Yes	No	No	No
WC-4	No	No	No	Yes	Yes	Yes
WC-5	No	No	No	No	Yes	Yes

Note Approach:

Set-point: 65^0F

Wet bulb: 52^0F

Approach: 13^0F

Can we increase the chilled water temperature to save energy?
-- ANALYSIS --

- Data from manufacturers:
  - BAC (towers)
  - B&G (pumps)
  - Carrier (chillers)
  - Liebert (CRACs)
  - Trane (Air handlers & fancoils)
- Locally gathered wet bulb data for Bin-hours
- Developed spreadsheet using component data

RESULTS – Chilled Water Supply 42F, 45F, 48F

	Totals		
	42	45	48
Chiller kW-hr Consumption	22,853,145	21,998,150	21,211,102
Cooling Tower kW-hr Consumption	2,325,206	2,290,118	2,271,207
CHW Pump kW-hr Consumption	4,394,811	6,177,446	7,817,962
CW Pump kW-hr Consumption	3,948,315	3,948,315	3,948,315
Total kW-hr Consumption	33,521,477	34,414,028	35,248,585
Chiller Energy Cost	$2,090,606	$2,012,391	$1,940,392
Cooling Tower Energy Cost	$212,710	$209,500	$207,770
CHW Pump Energy Cost	$402,037	$565,113	$715,187
CW Pump Energy Cost	$361,192	$361,192	$361,192
Total Energy Cost	$3,066,545	$3,148,195	$3,224,541

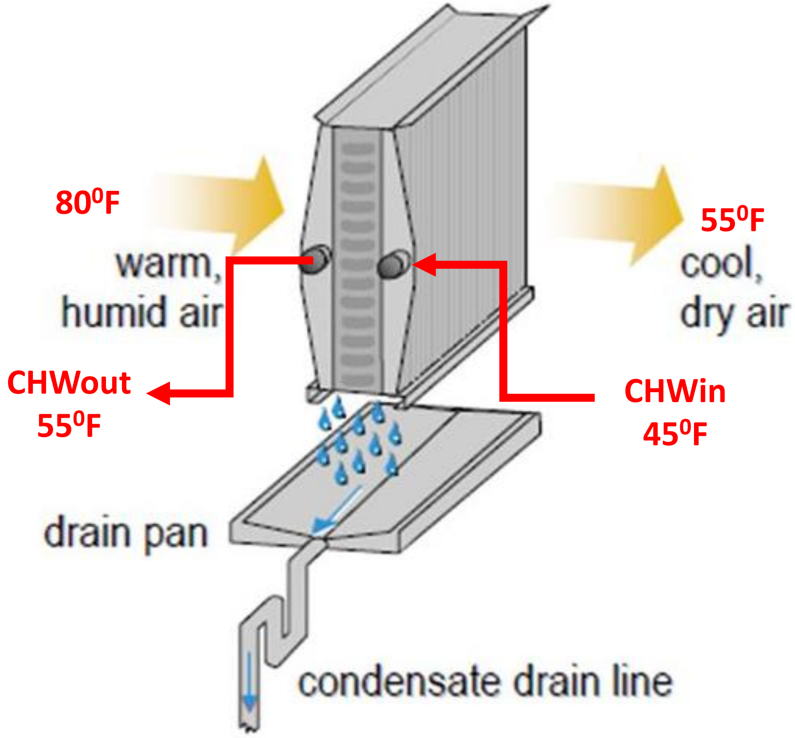
CONCLUSION: Pumping energy dominated.

WHY DID THE NUMBERS CHANGE?

- Chiller work less, because lift is reduced
- CHW pump must be larger because:
  - CHW**S** **T** - up, but CHW**R** **T** - no change, reducing DT
  - Q = 500 x GPM x DT >> DT down, GPM up
  - Note: at a specific condition, load does not change
- Staging & load are unchanged, so:
  - CW pump flow remains unchanged
  - Tower conditions unchanged

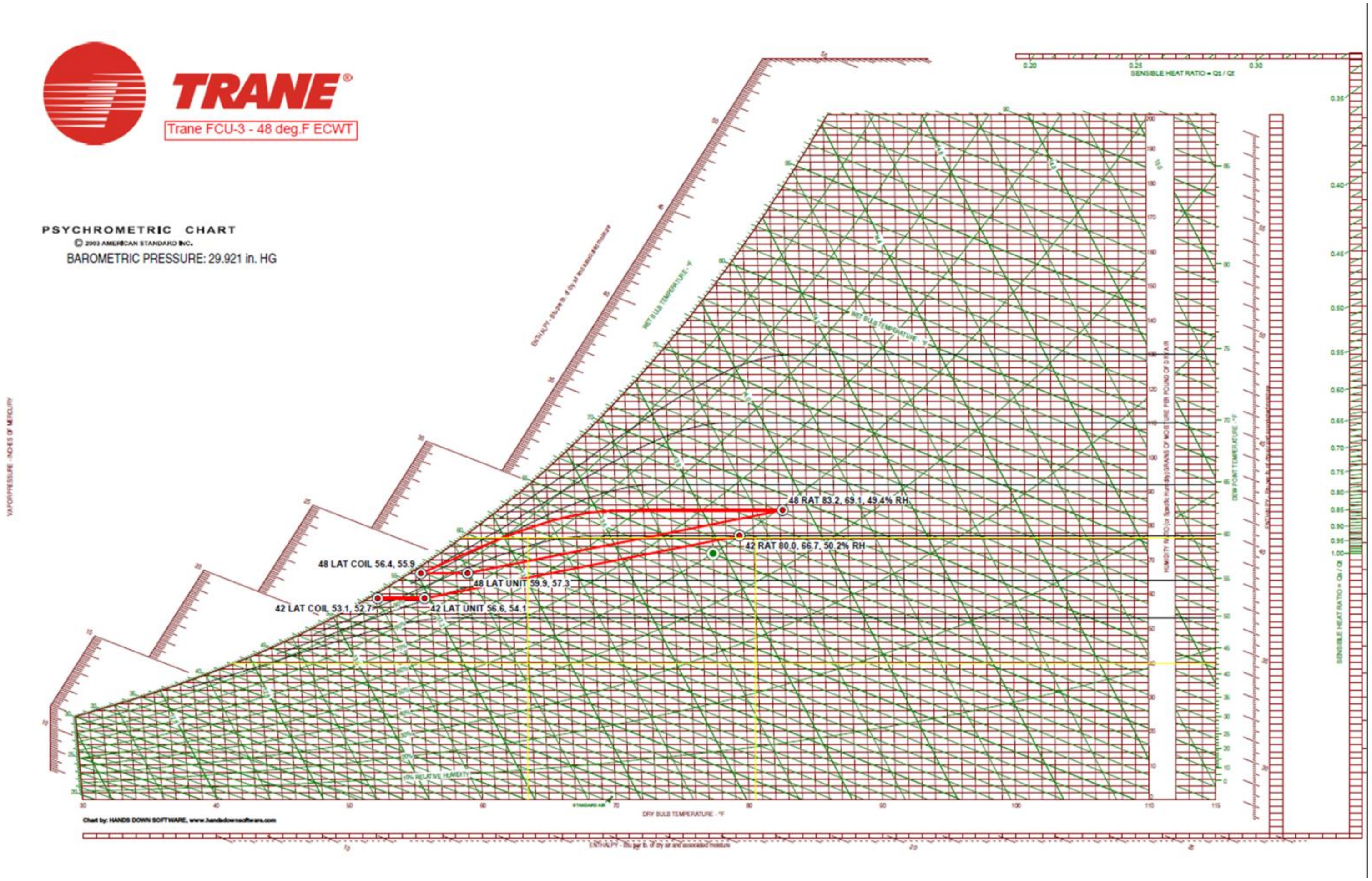
delta-T & Load

- CHW**R** temperature: no increase
  - @ 42^0F, 9,914 GPM, 14^0F dT
  - @ 45^0F, 14,185 GPM, 10^0F dT
  - @ 48^0F, 17,635 GPM, 8^0F dT
- Data from vendors determined pressure drop at each GPM condition



	B	C	D	E	F	G	H	I	J	K
1		Result Tags		FCU-1 42	FCU-1 43	FCU-1 44	FCU-1 45	FCU-1 46	FCU-1 47	FCU-1 48
2		Quantity		1	1	1	1	1	1	1
3		Model Number		FCCB0401C**F0A00AJ3M000001000**0000000	FCCB0401C**F0A00AJ3M000001000**0000000	FCCB0401C**F0A00AJ3M000001000**0000000	FCCB0401C**F0A00AJ3M000001000**0000000	FCCB0401C**F0A00AJ3M000001000**0000000	FCCB0401C**F0A00AJ3M000001000**0000000	FCCB0401C**F0A00AJ3M000001000**0000000
4		Clg fluid velocity	ft/s	2.85	3.14	3.55	4.10	4.95	6.23	7.70
5		Piping system/placement		W/o pipe, rt hand, w/ aux drn pan	W/o pipe, rt hand, w/ aux drn pan	W/o pipe, rt hand, w/ aux drn pan	W/o pipe, rt hand, w/ aux drn pan	W/o pipe, rt hand, w/ aux drn pan	W/o pipe, rt hand, w/ aux drn pan	W/o pipe, rt hand, w/ aux drn pan
6		Unit mounted disconnect switch		Without disconnect switch	Without disconnect switch	Without disconnect switch	Without disconnect switch	Without disconnect switch	Without disconnect switch	Without disconnect switch
7		Fresh air damper		Without fresh air damper	Without fresh air damper	Without fresh air damper	Without fresh air damper	Without fresh air damper	Without fresh air damper	Without fresh air damper
8		Main coil type		4 row cooling only	4 row cooling only	4 row cooling only	4 row cooling only	4 row cooling only	4 row cooling only	4 row cooling only
9		Filter type		1" throwaway	1" throwaway	1" throwaway	1" throwaway	1" throwaway	1" throwaway	1" throwaway
10		Fluid freeze pt	F	32.00	32.00	32.00	32.00	32.00	32.00	32.00
11		Cooling LWB	F	52.71	52.71	52.66	52.59	52.52	52.48	52.68
12		Cooling LDB	F	53.22	53.22	53.17	53.10	53.03	52.98	53.19
13		Cooling flow rate	gpm	1.90	2.09	2.36	2.73	3.30	4.15	5.13
14		Cooling delta T	F	13.81	12.51	11.10	9.60	7.96	6.33	5.05
15		Cooling EWB	F	67.00	67.00	67.00	67.00	67.00	67.00	67.00
16		Cooling EDB	F	80.00	80.00	80.00	80.00	80.00	80.00	80.00
17		Motor speed		High	High	High	High	High	High	High
18		Motor type		Free discharge ECM	Free discharge ECM	Free discharge ECM	Free discharge ECM	Free discharge ECM	Free discharge ECM	Free discharge ECM
19		Motor hp #1	hp	0.130	0.130	0.130	0.130	0.130	0.130	0.130
20		Cooling fluid PD	ft H2O	7.44	8.82	10.95	14.19	19.83	29.90	43.72
21		Cooling lvg fluid temp	F	55.81	55.51	55.10	54.60	53.96	53.33	53.05
22		Sensible capacity	MBh	8.63	8.63	8.62	8.61	8.60	8.59	8.52
23		Total cooling capacity	MBh	12.97	12.97	12.97	12.97	12.97	12.97	12.81
24		Cooling ent fluid temp	F	42.00	43.00	44.00	45.00	46.00	47.00	48.00
25		FLA motor option		Standard FLA ECM	Standard FLA ECM	Standard FLA ECM	Standard FLA ECM	Standard FLA ECM	Standard FLA ECM	Standard FLA ECM
26		Shipping weight	lb	89.9	89.9	89.9	89.9	89.9	89.9	89.9
27		Unit width	in	25.000	25.000	25.000	25.000	25.000	25.000	25.000
28	Base Unit	Unit height	in	10.000	10.000	10.000	10.000	10.000	10.000	10.000
29		Unit length	in	38.000	38.000	38.000	38.000	38.000	38.000	38.000
30		Min circuit ampacity	A	2.75	2.75	2.75	2.75	2.75	2.75	2.75
31		Motor power	W	58.0	58.0	58.0	58.0	58.0	58.0	58.0
32		Motor hp #2	hp	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33		Motor rpm #1	rpm	1079	1079	1079	1079	1079	1079	1079
34		ESP	in H2O	0.020	0.020	0.020	0.020	0.020	0.020	0.020
35		Design airflow	cfm	341	341	341	341	341	341	341
36		Unit cabinet size		Size 040	Size 040	Size 040	Size 040	Size 040	Size 040	Size 040
37		Operating weight	lb	102.9	102.9	102.9	102.9	102.9	102.9	102.9
38		Max fuse size	A	15.00	15.00	15.00	15.00	15.00	15.00	15.00
39		Motor rpm #2	rpm	0	0	0	0	0	0	0
40		Reheat		Without	Without	Without	Without	Without	Without	Without
41		Electric preheat		Without electric heat	Without electric heat	Without electric heat	Without electric heat	Without electric heat	Without electric heat	Without electric heat
42		Basis of selection		Cooling	Cooling	Cooling	Cooling	Cooling	Cooling	Cooling

Sheet1


TRANE
Trane FCU-3 - 48 deg.F ECWT
PSYCHROMETRIC CHART
© 2003 AMERICAN STANDARD INC.
BAROMETRIC PRESSURE: 29.921 in. HG
48 RAT 83.2, 69.1, 49.4% RH
42 RAT 80.0, 66.7, 50.2% RH
48 LAT COIL 56.4, 55.9
48 LAT UNIT 59.9, 57.3
42 LAT COIL 53.1, 52.7
42 LAT UNIT 56.6, 54.1
DRY BULB TEMPERATURE - °F

Tower Strategy - 5F approach vs. 83F set-point

	Totals	
	42 w/ 5 Deg. DT	42 w/ 83 SP
Chiller kW-hr Consumption	22,853,145	25,491,484
Cooling Tower kW-hr Consumption	2,325,206	408,111
CHW Pump kW-hr Consumption	4,394,811	4,394,811
CW Pump kW-hr Consumption	3,948,315	2,791,447
Total kW-hr Consumption	33,521,477	33,085,854
Chiller Energy Cost	$2,090,606	$2,331,961
Cooling Tower Energy Cost	$212,710	$37,334
CHW Pump Energy Cost	$402,037	$402,037
CW Pump Energy Cost	$361,192	$255,362
Total Energy Cost	**$3,066,545**	**$3,026,694**

Full year data

- Note that tower supply temperature drifts downward on colder days

WHY DID THE NUMBERS CHANGE?

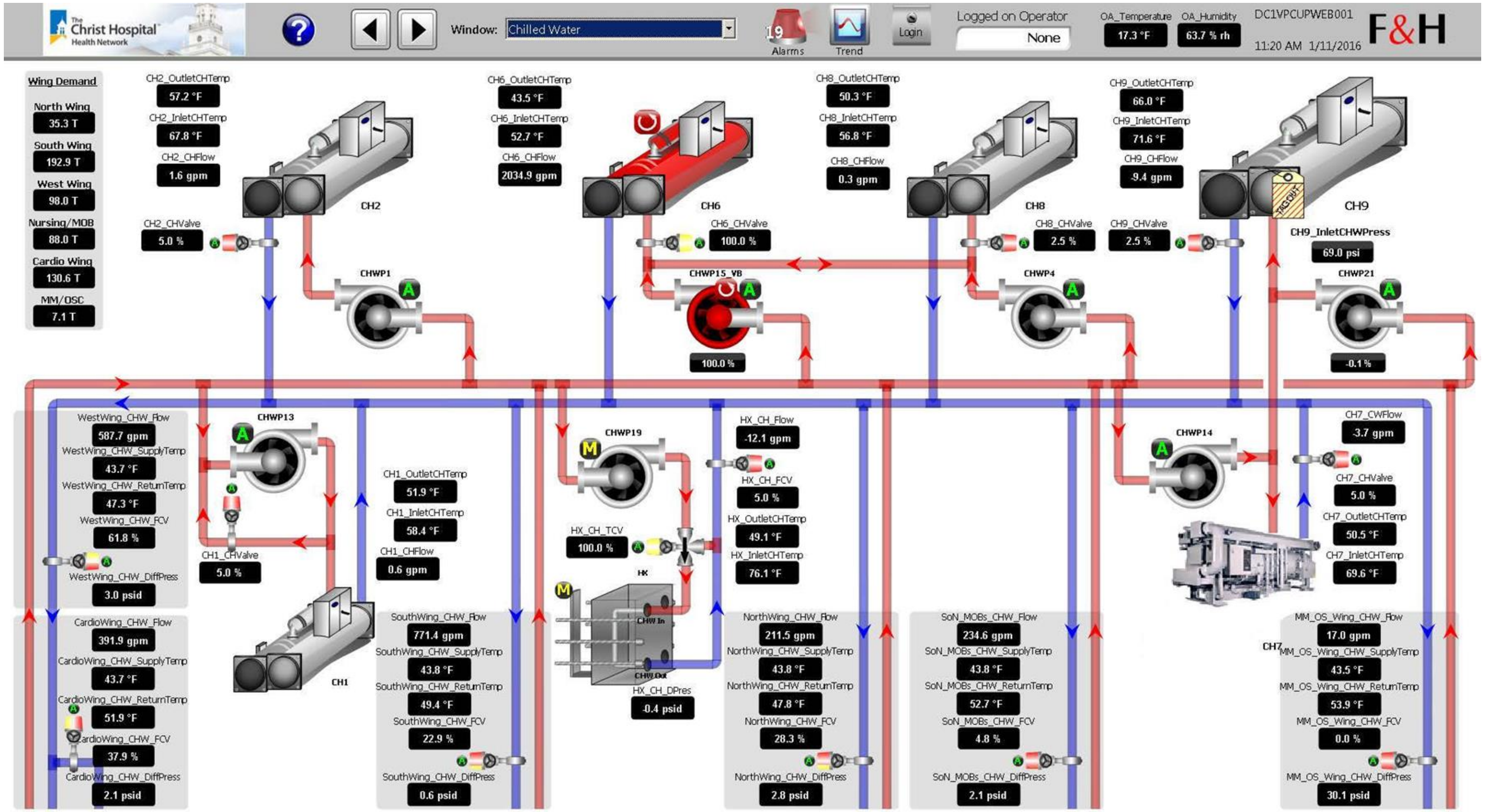
- Chillers: Due to a higher entering condenser water temperature (83^{0}F) for many hours, energy goes up.
- CHW pumps: no change in load, so no change in GPM.
- Towers: Easy for towers to attain set-point of 83^{0}F when wet bulb is much lower for most hours. (Fan laws: HP = speed to 3rd power.) At some conditions, fan speed was so low that sequences required one tower to shut off.
- CW pumps: one pump is turned off for many hours (due sequences)

Recommendations

- Cost-benefit analysis determined it was not feasible to install VFDs without a comprehensive approach
- Results could favor “Approach” method, **if** minor adjustments are made:
  - Modify tower sequences based on load
  - Dynamic re-balancing of flows to towers (flow control)
  - Dynamically adjust set-points

These analyses helped in explaining and guiding work that had been underway at Christ Hospital

Christ Hospital Chiller Plant - CHW



First Year Changes

Actions

- Turned off Absorption Chiller
- Added a cooling tower
- Re-balanced condenser water
- Added 1 VFD condenser water pump for off-peak variability

Results

- One boiler & turned down
- From N (@ max) to N+1
- GPM too high for 4 towers
- Before: Chillers current limited
  - After: all chillers < 97% load

Christ Hospital Energy Costs

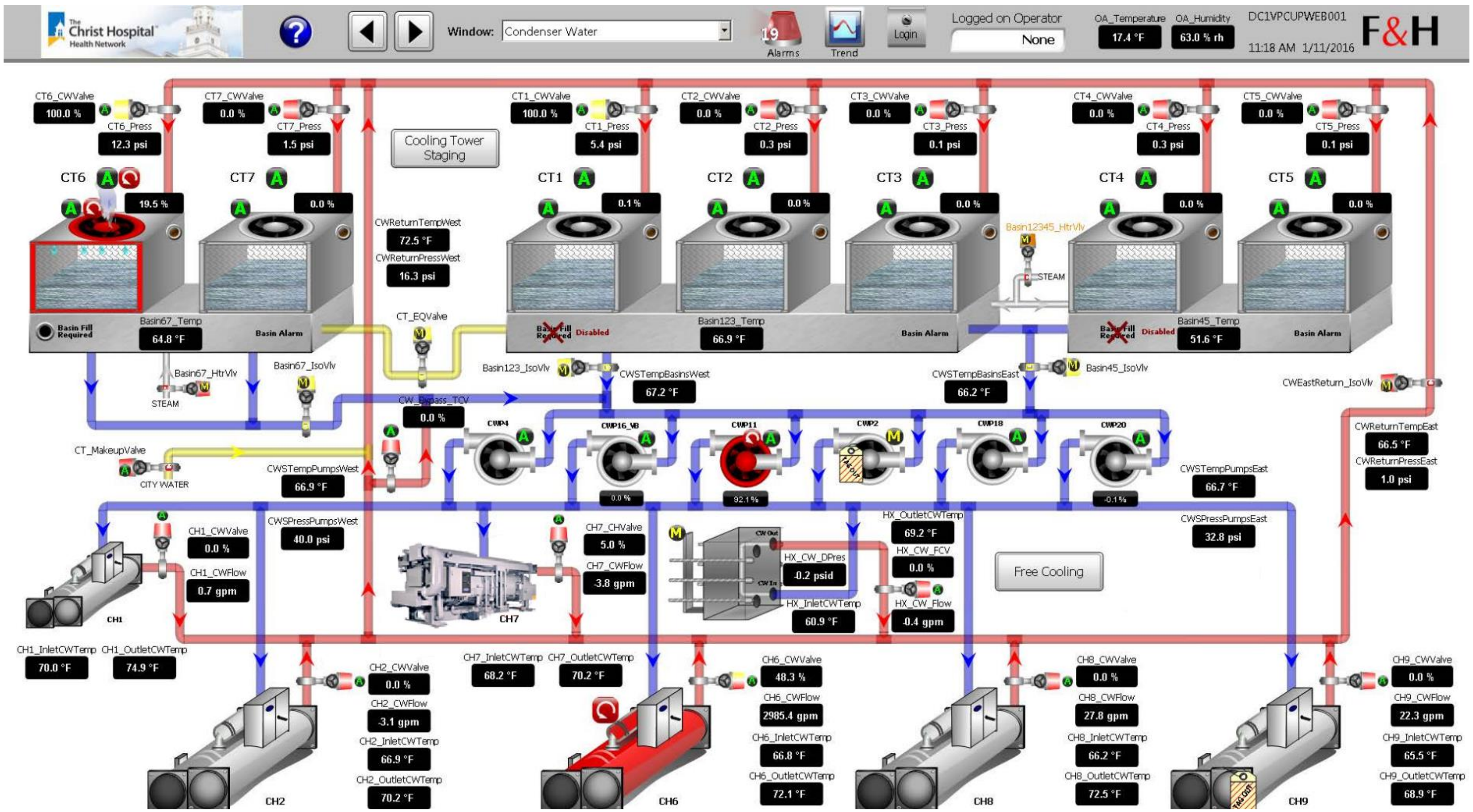
ELECTRICITY	July	August	September	October	November	December
Cost of Chiller Plant Operations - Prior Year	$277,784	$236,652	$232,829	$200,843	$207,605	$203,152
Cost of Chiller Plant Operations - Next Year	$235,196	$207,343	$211,953	$187,859	$183,064	$185,344
Year-to-year savings	**$42,588**	**$29,309**	**$20,876**	**$12,984**	**$24,541**	**$17,808**
NATURAL GAS	July	August	September	October	November	December
Cost of Chiller Plant Operations - Prior Year	$128,236	$131,739	$132,287	$159,959	$145,596	$156,235
Cost of Chiller Plant Operations - Next Year	$80,756	$89,108	$85,648	$102,849	$140,978	$146,038
Year-to-year savings	**$47,480**	**$42,631**	**$46,639**	**$57,110**	**$4,618**	**$10,197**
ENERGY SAVINGS, MO/YEAR-TO-MO/YEAR	**$90,068**	**$71,940**	**$67,516**	**$70,094**	**$29,159**	**$28,005**
TOTAL ENERGY SAVINGS, YEAR-TO-YEAR						**$356,781**

Follow-on Changes

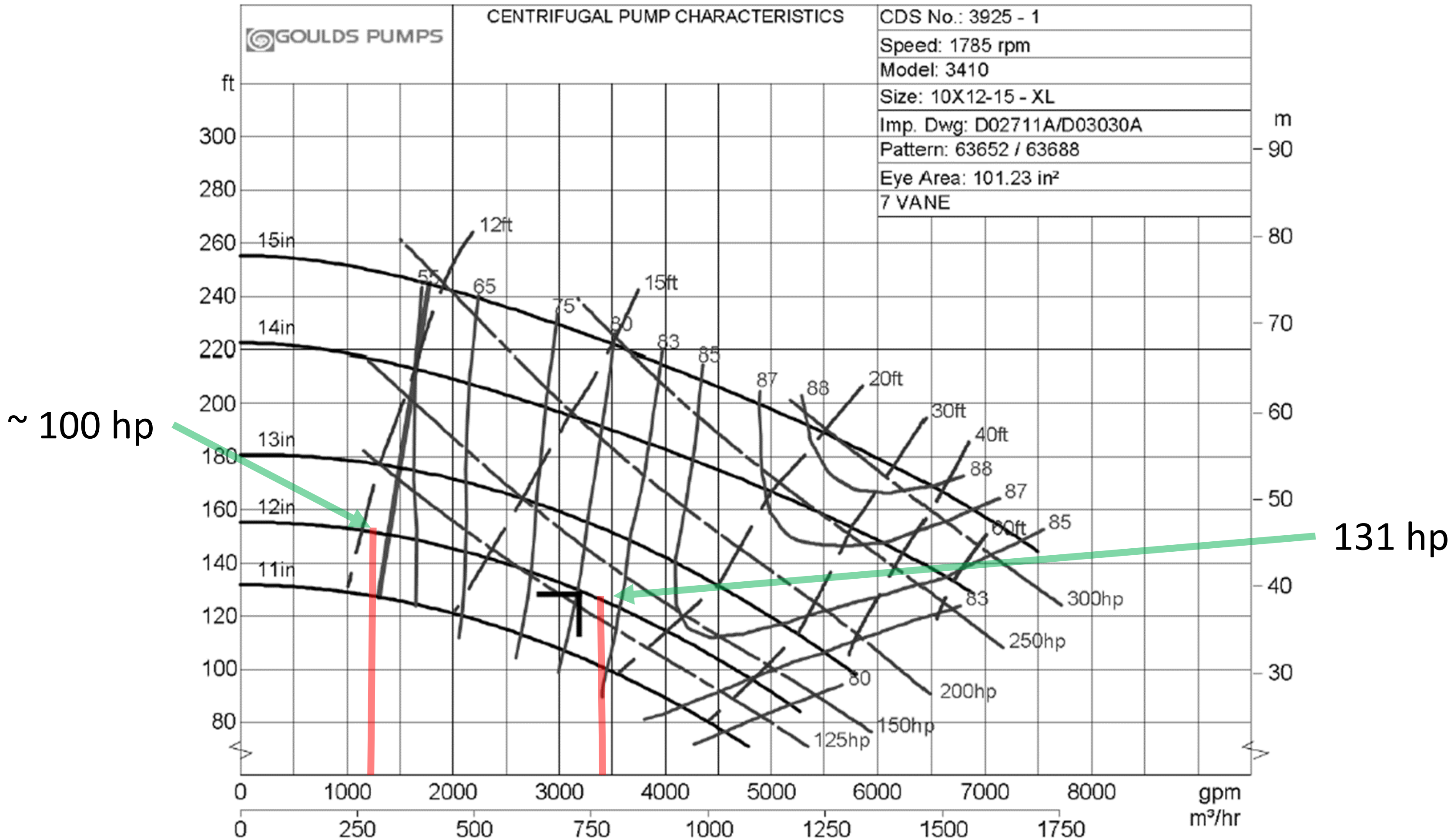
- 2,500 ton variable speed chiller
- VFD condenser water pumps
- VFD chilled water pump
- 2 VFD towers

- CURRENTLY IN DESIGN:
- Another chiller, pumps
- Larger free cooling heat exchanger

Christ Hospital Chiller Plant - CW

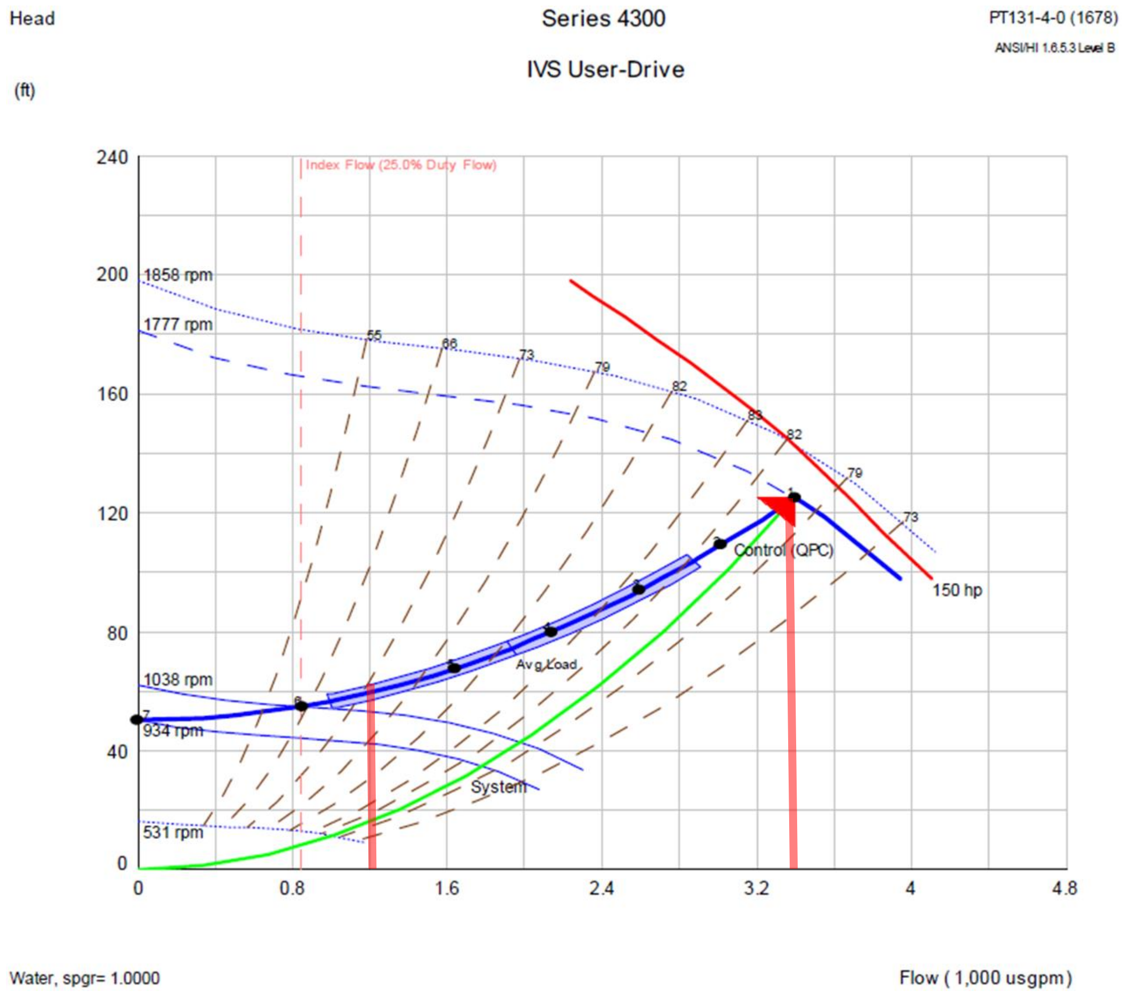


CS Pump Curve



VS Pump Curve

(Variable Speed)



--- Admin Data ---
Tag Num: CP-11
Service:
Location:

--- Motor Data ---
Motor Size: 150 hp
Motor Speed: 1800 rpm

--- Design Duty Point ---
Flow: 3400 usgpm
Head: 125 ft
Impeller: 13.188 in

--- Control Data ---
1. Hmax @ 1777 rpm (60.2 Hz):
• 3400 @ 125, 134.16 hp
2. Control (QPC) @ 1610 rpm (54.6 Hz):
• 2960.7 @ 106.9, 98.21 hp
3. Control (QPC) @ 1440 rpm (48.8 Hz):
• 2480.5 @ 89.9, 68.23 hp
4. Control (QPC) @ 1270 rpm (43.1 Hz):
• 1938.5 @ 74.4, 44.31 hp
5. Control (QPC) @ 1100 rpm (37.3 Hz):
• 1229.7 @ 59.8, 24.92 hp
6. Index @ 935 rpm (31.7 Hz):
• 0 @ 50, 0 hp
7. Hmin: 50 ft @ 934 rpm (31.7 Hz):
• Setting= 40.00% Hmax

Riding the Pump Curve vs. VFD

- Cooler months: towers achieve lower supply temps & higher dTs
- Based on First Law (Q = c M dT) for same load (Q): lower dT results in lower GPM, thus low pump energy

	CS Pump	**VFD Pump**
Design	131 HP, 125 FT HD, 3,200 GPM	134 HP, 130 FT HD, 3,400 GPM
Off-design	**100 HP**, **155** FT HD, 1,230 GPM	**25 HP, 60** FT HD, 1,230 GPM

Cubic Effect of Pump/Fan Laws

RPM ~ GPM (or CFM)

HP ~ RPM^3

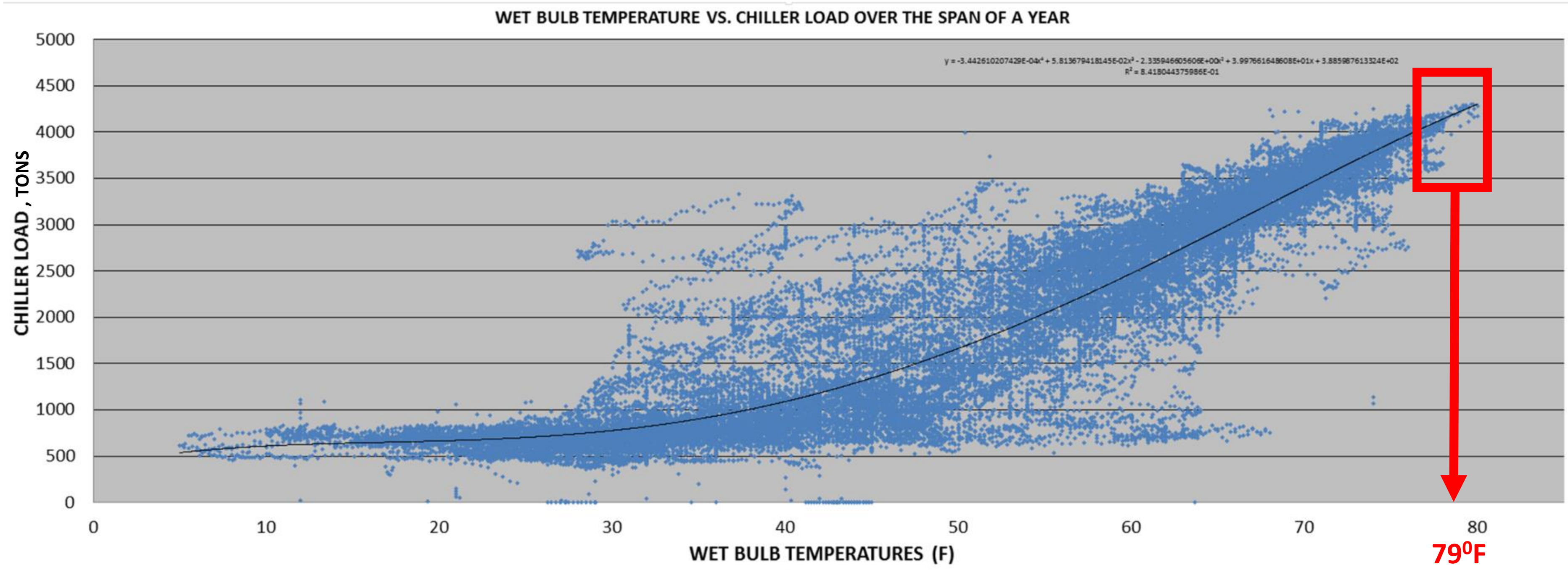
HP @ 100% RPM = 200

@ 80% = 102

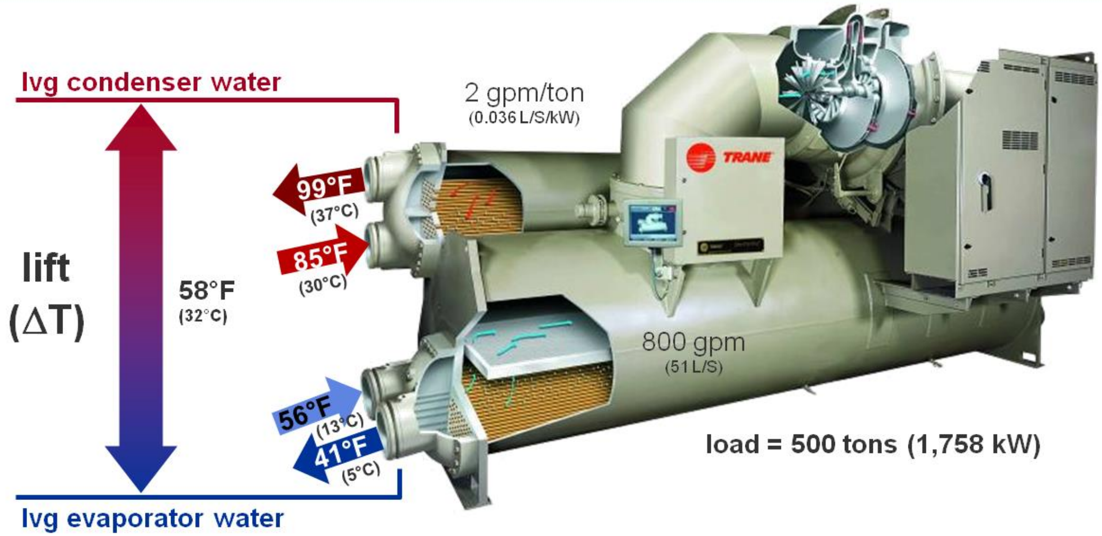
@ 60% = 43

@ 40% = 13

Christ Hospital Cooling Load



Lift Versus Load



lift α $P_{cnd} - P_{evp}$

lift α $T_{lvg\ cnd} - T_{lvg\ evp}$

load α gpm × $(T_{ent\ evp} - T_{lvg\ evp})$

Higher lift

=

Higher energy

CONCLUSIONS

TAKE ADVANTAGE OF THE FAN & PUMP LAWS:

- Consider operating towers at a 5^0F approach to wet bulb
- If you have redundant towers and pumps, operate all when hot
- VFDs on condenser water pumps (match GPM to load)
- Operate 1 additional tower to reduce fan speed (of all)
- Increase water-side delta-T on towers to reduce GPM
- Chiller staging to keep chillers operating at low percent loads
- Higher delta-T on condenser has no effect on leaving (LCWT) water, **if** the incoming water temperature is **DYNAMICALLY RESET**
- **EXISTING:** If you plan to operate at conditions that are different than the design, re-balancing & retro-commissioning will pay for themselves quickly. Re-balancing is the minimum requirement if you want to realize any energy savings without major changes to hardware.
- **NEW:** Install VFDs on almost ALL components. Sequences of Operations should focus on part load conditions.

MISSION CRITICAL CONCLUSIONS

- Design should include **header**s between pumps, towers, and chillers. This allows any combination of towers, pumps, or chillers to be operated together, improving uptime.
- Design should include **dynamic balancing** to get the proper GPMs allocated to the towers and chillers, and to operate the condenser water pumps at a GPM that is proportional to the load.
- We have found that **PLC**s allow for more control options, greater accuracy, and much more flexibility.