Trane invites you to step into the future with



THE NEXT GENERATION CHILLERS

TRANE

High Performance Chiller Plant

Search for Sustainable Efficiency – Practical Tips

K Y Yow
Dir, Technical Center of Excellence
Trane, Ingersoll Rand

Search for Efficiency- Focus on System

Pumps



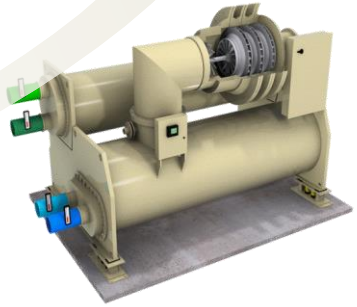


M&V

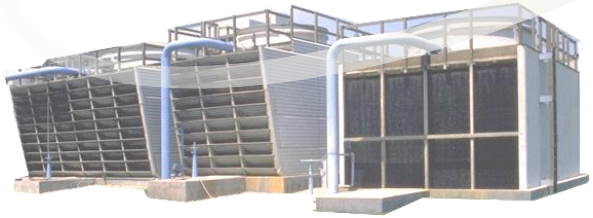
Controls



Chiller PLANT



Chillers



Cooling Towers

High Performance Chiller NOT = High Performance Chiller Plant

Holistic Approach to Building efficiency

High Performance Chiller Plant is a Necessary Attribute of HPB

Every Building can be a High Performance Building



By Design



Through Upgrade

Key: Energy Efficiency of HVAC System

Energy Use 

Cost 

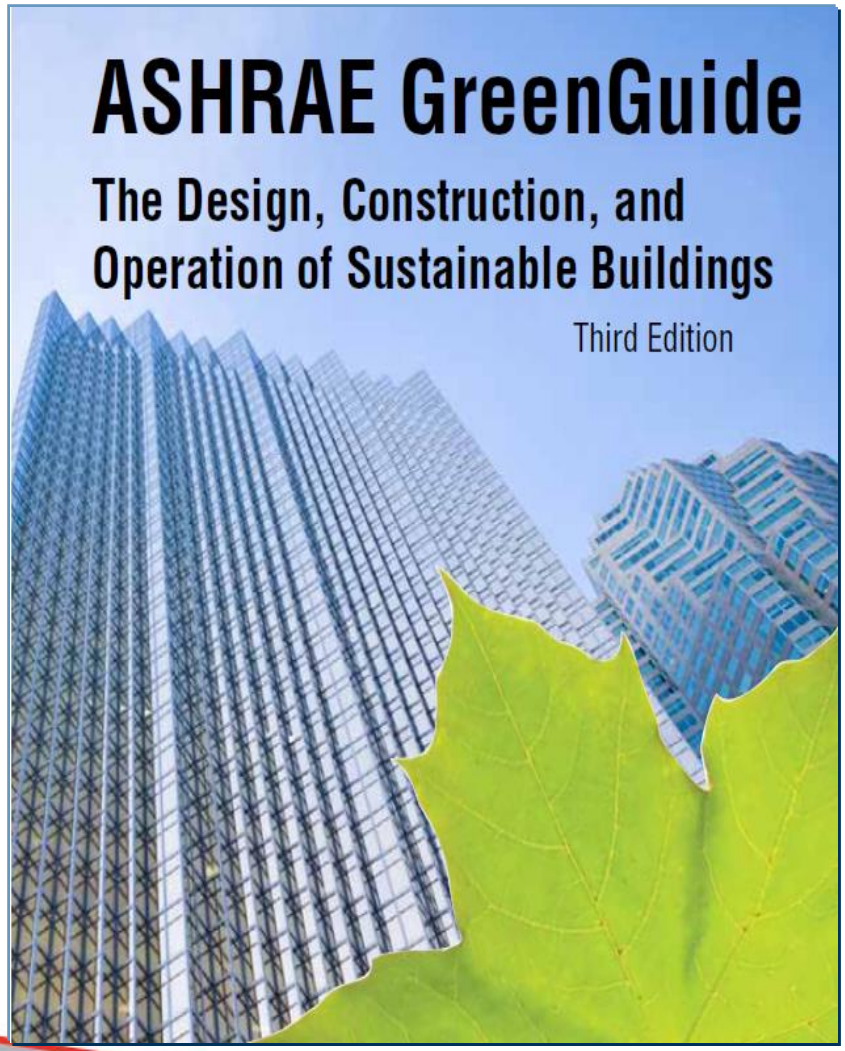
Emissions 

Without compromising comfort or productivity

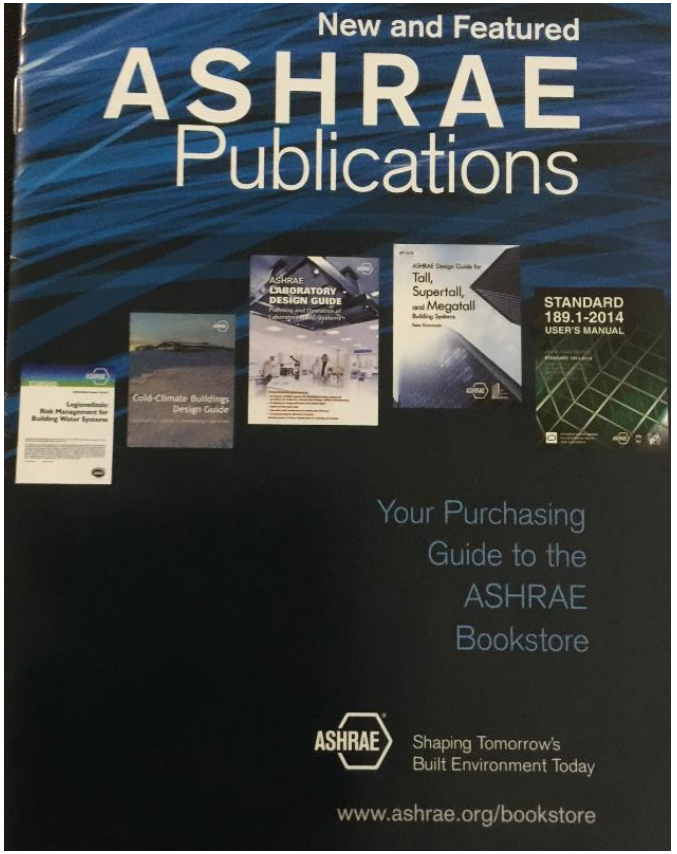
Agenda

- ASHRAE GreenGuide – Benchmark for HP Plant
- Pumping Efficiency (Huge Opportunity)
- Heat Rejection Efficiency - Cooling Tower (Critical but Neglected)
- Chiller Integrated Performance & configuration
- Chiller Plant Controls
- Measurement & Verification (M+V)
- Live DEMO of Singapore/ Local Site
- Q+A

ASHRAE GreenGuide



Available on Ashrae Bookstore



Chiller Plant Performance Goals

Table 10-1: Example Performance Goals

Component	Typical kW/ton (kW/kWR)	Efficient kW/ton (kW/kWR)	Delta	% Savings
Chiller	0.62 (0.1763)	0.485 (0.1379)	0.135 (0.0384)	22%
Cooling tower	0.045 (0.0128)	0.012 (0.0034)	0.033 (0.0094)	73%
Condenser water pump	0.0589 (0.0167)	0.022 (0.0063)	0.0369 (0.0104)	63%
Chilled-water pump	0.0765 (0.0218)	0.026 (0.0074)	0.0505 (0.0144)	66%
Total water-side system	0.8004 (0.2276)	0.545 (0.155)	0.2554 (0.0726)	32%

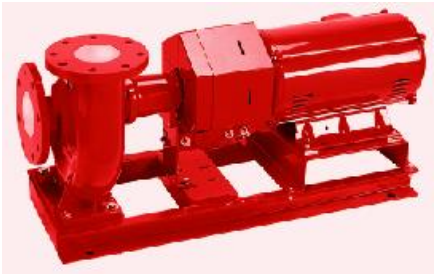
2/3 Reduction

Efficient Plant typically has Ratio 85:15 to 90:10 (chiller : Ancillary)

Can we do 0.55 Kw/RT Plant ?

1) CHW Pumping Efficiency

	Typical	GreenGuide Benchmark	Gap (Opportunity)
Kw/Rt	0.06 to 0.08	0.026	0.05 (70% reduction)



$$Kw/RT = \frac{(Lps\ per\ RT) \times Hd(m)}{100 \times EFFp \times EFFm}$$

Best : 0.013

Worst: 0.25

1) EFF (Pump) : 65% -87% (0.65-0.87)

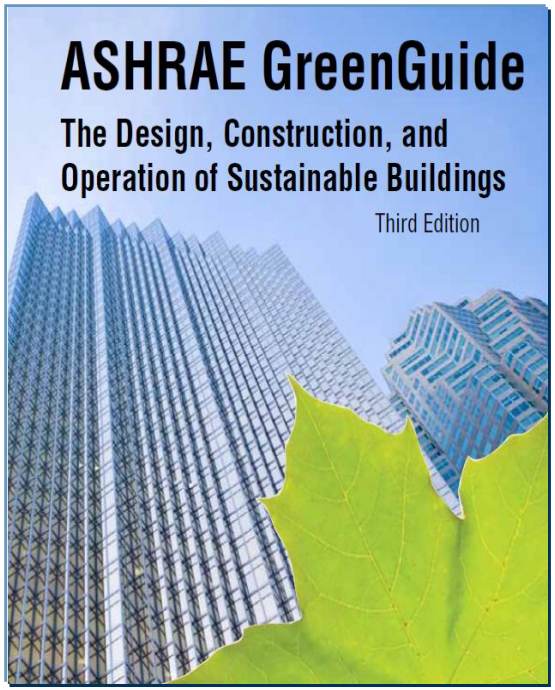
2) EFF (Motor) : 80%-93%% (0.80-0.93)

3) Flow per RT : 0.11 to 0.32 LPS/RT (DT : 2.8- 8C)

4) Pump Head : 10m to 40m

Understanding the Roots of Pumping Efficiency

ASHRAE GreenGuide



Green Guide advocates
CHW ΔT : 7-11C
CNW ΔT : 7-10C

CHW : 1.2 to 1.9 GPM/RT

CNW : 1.7 to 2.5 GPM/RT

ASHRAE 90.1 (2016)

Add new prescriptive requirement as follows (I-P and SI)

6.5.4.7 Chilled Water Coil Selection. Chilled-water cooling coils shall be selected to provide a 15°F (8.3°C) or higher temperature difference between leaving and entering water temperatures and a minimum of 57°F (14°C) leaving water temperature at design conditions.

SS-553 (2016) : 6.5C DT

ASHRAE Guide & STD Driving Large DT Application

Singapore GM Site vs ASHRAE Benchmark

Component	Typical kW/ton (kW/kWR)	Efficient kW/ton (kW/kWR)
Chiller	0.62 (0.1763)	0.485 (0.1379)
Cooling tower	0.045 (0.0128)	0.012 (0.0034)
Condenser water pump	0.0589 (0.0167)	0.022 (0.0063)
Chilled-water pump	0.0765 (0.0218)	0.026 (0.0074)
Total water-side system	0.8004 (0.2276)	0.545 (0.155)

Source : ASHRAE GreenGuide Table

Spore Site

fficiency Table	
CHW Ton	3955
Chiller	0.493
CHWP	0.016
CWP	0.023
CT	0.019
SYSTEM	0.551

CHW : 6.2C
DT: 9C
CW: 28/33C

Source: M+V data

0.026 to 0.016 Kw/Rt => 40% less CHW Pumping KW

Going from Efficient to Ultra-Efficient CHW Pumping

Benefits of Excellent CHW Pumping Efficiency

Typical	GreenGuide	Best-of-Best
0.07 Kw/Rt	0.026 Kw/Rt	0.016 Kw/Rt
2,000 RT	2,000 RT	2,000 RT
140 KWI	52 KWI	32 KWI
200 HP pump/VSD	75 HP pump/VSD	50 HP pump/VSD
$$$$	$$	$
SPACE	SPACE	SPACE

Sustainable Design/Performance = Small Pumps

CHW Pumping Efficiency Index Table

$$Kw/Rt = \frac{\text{Flow Per RT (Lps/Rt) x Hd (m)}}{100 \times \text{EFF(P) X EFF(M)}}$$

0.85 Pump Eff

0.93 Mtr Eff

Hd varies with GPM $^{1.8}$

Delta T	Flow/Rt		Pump Kw/Rt at different Heads						
Deg C	Gpm/Rt	Lps/Rt	10	15	20	25	30	40	Head(m)
			127	190	253	316	380	506	Kw per /M3/S
3	4.45	0.280	0.035	0.053	0.071	0.089	0.106	0.142	
4	3.34	0.210	0.027	0.040	0.053	0.066	0.080	0.106	
5	2.67	0.168	0.021	0.032	0.043	0.053	0.064	0.085	
5.56	2.40	0.151	0.019	0.029	0.038	0.048	0.057	0.077	
6	2.22	0.140	0.018	0.027	0.035	0.044	0.053	0.071	
7	1.91	0.120	0.015	0.023	0.030	0.038	0.046	0.061	
8	1.67	0.105	0.013	0.020	0.027	0.033	0.040	0.053	
9	1.48	0.093	0.012	0.018	0.024	0.030	0.035	0.047	
10	1.33	0.084	0.011	0.016	0.021	0.027	0.032	0.043	

Low Pumping Kw/Rt = function of (Low Flow per RT & Low Head)

Roadmap to Higher Pumping Efficiency

Practical Tips to High performance CHW Pumping

Goal CHWP 0.016 to 0.026 Kw/RT

Low flow per RT

- ✓ Large DT (7-9C) coils
- ✓ Right Sizing of airside
- ✓ Proper Valve selection
- ✓ Proper CHW Temp setting (6-8C)
- ✓ Proper airside maintenance
- ✓ Pump Pressurization control
- ✓ Var Primary Flow

Low Pump Head

- ✓ Low Chiller WPD (<4m)
- ✓ Avoid Balancing Valves
- ✓ Low WPD Coils
- ✓ Avoid abrupt turns and 90 deg Bends
- ✓ Upsize Pipe Size
- ✓ Layout pipework first , than chillers

Darcy Eqn Friction = $f \times (L/D) \times V^2/2g$

Avoid Low DT Syndrome

Pipe Friction Inversely Proportional to $(D2/D1)^5$

10” to 12” => 60% **drop**

Low Pressure Resistance Design = Sustainable Design

To reduce pressure drop, pipes and ductwork should be laid out prior to locating pumps, chillers, and air handlers.





Local Example

Low PD piping

Conventional



Avoid 90% turns

No Balancing valves

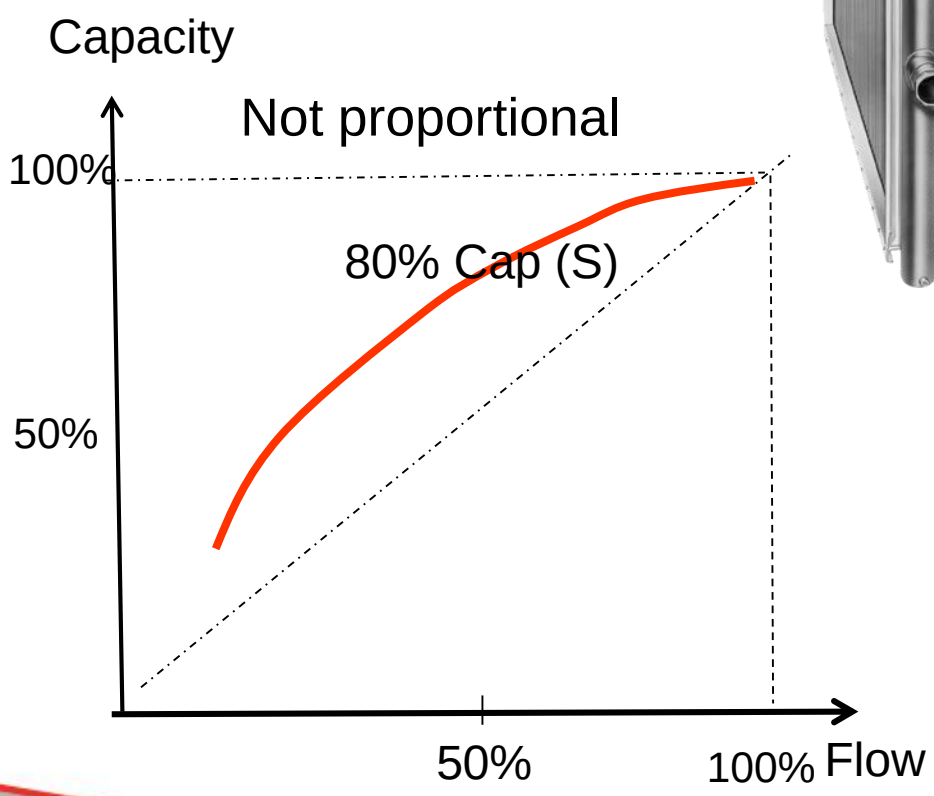
15 HP pump

Raised Foundation for pumps

Cooling Coil Performance

5C vs 6.7C => 37% Flow Reduction =>70% Reduction in KWI

Cap vs Flow





Cooling RT	42	42
EWT	44°F (6.7C)	41°F (5.0C)
GPM	101	63
GPM/ton	2.4	1.5
LWT	54°F	57°F
WTR	10°F (5.6C)	16°F (8.9C)

GPM reduction of 37.6%

Low Flow Low Temp should be considered if Pump Head is High

Condenser Pump Efficiency Index Table:

$$Kw/Rt = \frac{\text{Flow Per RT (Lps/Rt) x Hd (m)}}{100 \times \text{EFF(P) X EFF(M)}}$$

0.85 Pump Eff

0.93 Mtr Eff

GreenGuide : 0.022 Kw/Rt

Delta T	Flow/Rt		Pump Kw/Rt at different Heads					
Deg C	Gpm/R	Lps/Rt	10	15	20	25	30	35
			127	190	253	316	380	443
3	5.30	0.334	0.042	0.063	0.084	0.106	0.127	0.148
4	3.98	0.250	0.032	0.048	0.063	0.079	0.095	0.111
5	3.18	0.200	0.025	0.038	0.051	0.063	0.076	0.089
5.3	3.00	0.189	0.024	0.036	0.048	0.060	0.072	0.084
6	2.65	0.167	0.021	0.032	0.042	0.053	0.063	0.074
7	2.27	0.143	0.018	0.027	0.036	0.045	0.054	0.063
8	1.99	0.125	0.016	0.024	0.032	0.040	0.048	0.055
9	1.77	0.111	0.014	0.021	0.028	0.035	0.042	0.049
10	1.59	0.100	0.013	0.019	0.025	0.032	0.038	0.044

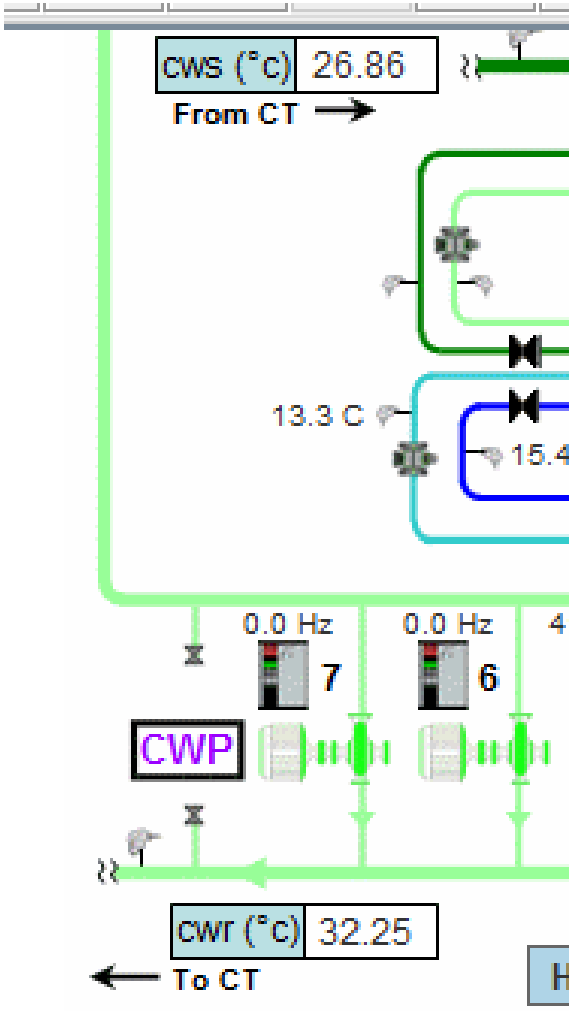
Hd(m)

Kw per /M3/S

Migrate from typical 0.05 to 0.022 = Manage Flow/Rt and Head

Path to High performance CW Pumping Efficiency

Example of Efficient CW pumping



Efficiency Table		
Total CHW Ton		3914
kW/Ton	Chiller	0.497
	CHWP	0.016
	CWP	0.024
	CT	0.022
	SYSTEM	**0.559**
kW	Chiller	1944
	CHWP	62
	CWP	93
	CT	87
	SYSTEM	**2187**

CW DT = 5.4C
LPS/RT= 0.185

Kw/RT = 0.024
Est Hd = 10 m

Manage Delta T and Head

Practical Tips to High performance CW Pumping

Goal CHWP 0.020 to 0.025 Kw/RT

Low flow per RT

- ✓ Design < 3.0 Gpm/Rt (DT 6-7C)
- ✓ VSD Pump
- ✓ Provision for Variable Flow Control
- ✓ Avoid chiller low load at Constant Flow

Low Pump Head

- ✓ Low Chiller WPD (<4m)
- ✓ Locate CT close to Chiller Plant
- ✓ Avoid Balancing Valves
- ✓ Avoid abrupt turns and 90 deg Bends
- ✓ Upsize Pipe

Low DT (Range) penalizes CT efficiency)

16.2.8 The effect of changes in pipe diameter on the friction in a system

$$\left[\frac{D_1}{D_2}\right]^5 = \frac{Hf_2}{Hf_1}$$

where D = Pipe Diameter

Hf = Friction Loss

Strive for <12m Condenser Pump Head

Managing Condenser Water Flow per RT (DT)

Impact of High CW Flow per RT

CW DT = 2.9C (29/31.9C)

LPS/RT = 0.345
GPM/RT = 5.5

Est Hd = 11.0 m
(potential to come down to 7-8m)

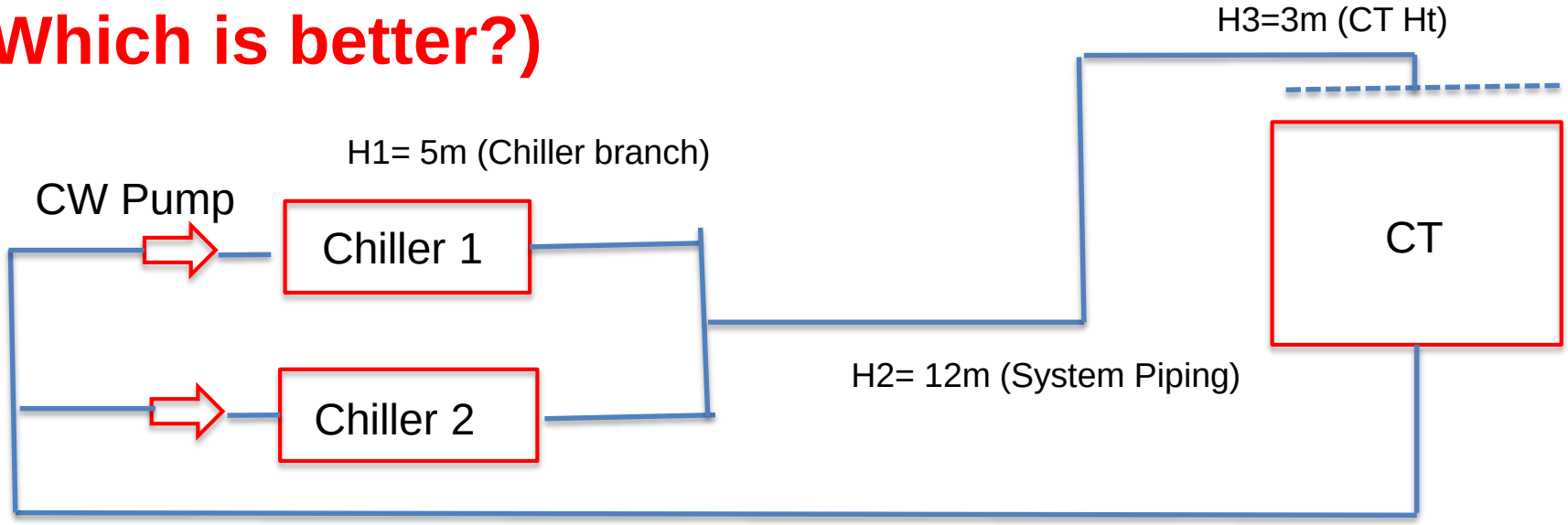
KWI % = (Flow %)$^{2.6}$

TOTAL TON	1,688.97	
EQUIPMENT	ELECTRICAL POWER	EFFICIENCY
CHILLER	879.82	0.521
CHWP	62.85	0.037
CNWP	85.45	0.051
CT	37.43	0.022
SYSTEM	1,064.79	0.630

Consider reduce Flow to expand DT to 4 or 5C (28.5/33.5C)
CWP Kw/Rt should cut to around 1/3 => 0.016 to 0.020
CT EFF will improve with larger RANGE (DT)

Opportunity to Trade off Chiller EFF for Pumping/CT EFF

Running 1 x 100% vs 2 X 50% (Which is better?)



Design Head = 5 + 12 + 3 = 20m 3 gpm/rt (0.189 Lps/Rt)

Kw/Rt $\frac{\text{Flow Per RT (Lps/Rt) x Hd (m)}}{100 \times 0.80 \times 0.90}$

RANGE

2 chiller at 50% : Kw/Rt = (2x 0.189Lps/Rt x 20m)/72
= 2 x 0.053 = 0.106 (increase of 0.066)

DT=2.6C

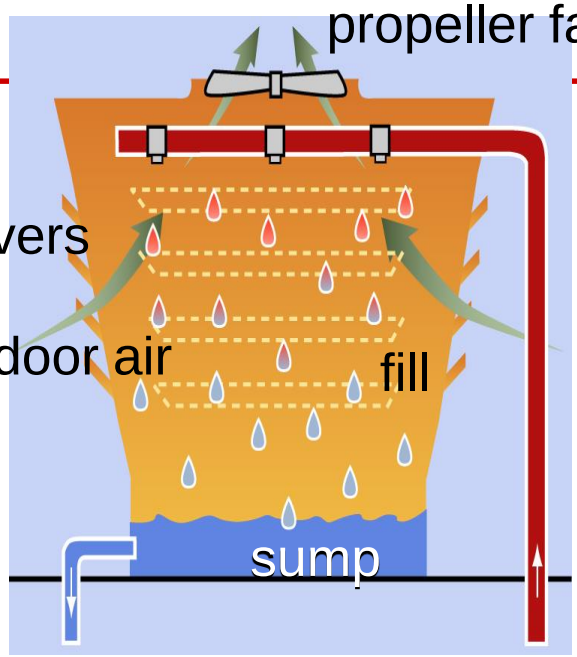
1 chiller at 100% : Kw/Rt = 0.189Lps/Rt x (5+12/4+3)/72
= (0.189 x 15)/72 = 75% x 0.053 = 0.040

DT=5.3C

Be Careful about Running Extra Chiller at excessive CNW flow
Smaller CT Range impacts Cooling Tower Kw/Rt

Cooling Tower Fan KWI





Fan Laws:

Cfm α rpm

Δp α rpm^2
α cfm^2

Hp α rpm^3

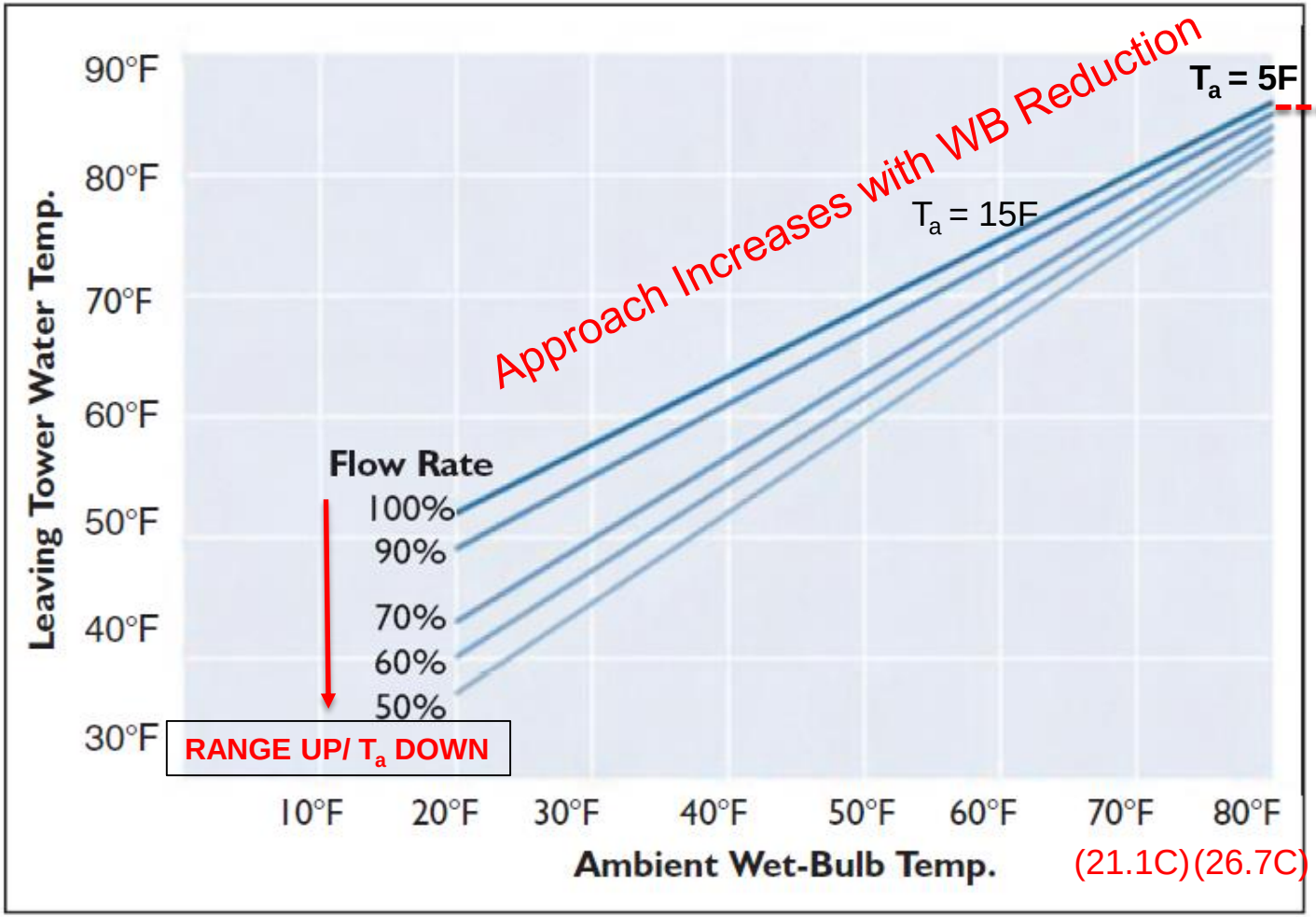
Heat Rejection Capacity

- WB
- Approach (Leaving temp – WB)
- Range (5C to 10C)

Given a WB (say 27C) & Approach (3 C)
RANGE 30/38C (8C DT): 115 % HR Cap
RANGE 30/35C (5C DT) : 100 % HR
RANGE 30/32C (2C DT) : 75% HR

Low RANGE can impact 0.01 to 0.02 Kw/RT

Impact of Flow & WB on Approach Temperature



Practical Tips to Cooling Tower Design & Operation

Goal → CT : 0.012 to 0.022 Kw/RT

- ✓ Select Reputable Brands that delivers Performance (CTI Certified)
- ✓ Approach 2.5C (Bigger Tower)
- ✓ Install More CTs (150%-200%) vs Design if Space allows
- ✓ Good Clearance for air flow
- ✓ VSD on CT fans (Can group them)
- ✓ Run at 20-40 Hz (can be lowered to 15Hz during night)
- ✓ Manage RANGE (4- 8C)
- ✓ Regular Maintenance & Inspection of Performance

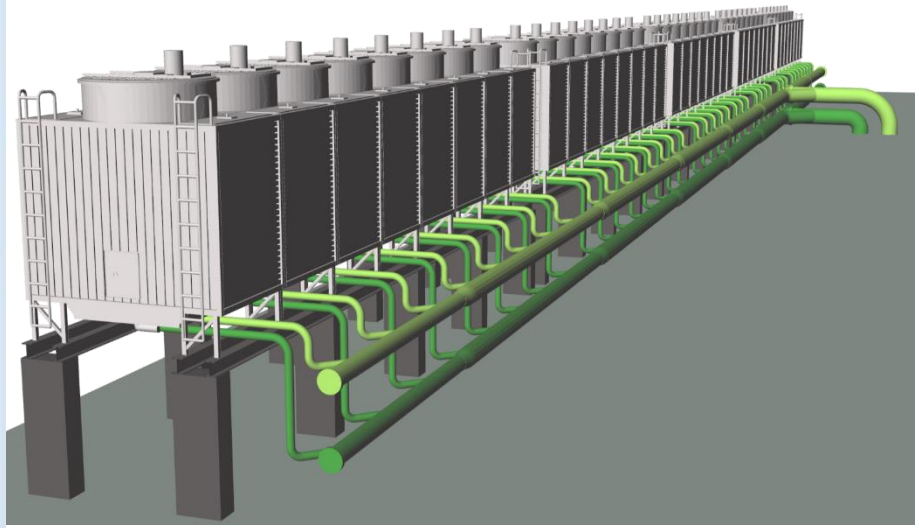
Bigger CTs and More (if Space Allows) but Smaller Fan Motor

CT performance can make a HUGE Difference

Proper Cooling Tower Installation



Poor Installation



Good Clearance on ALL Sides

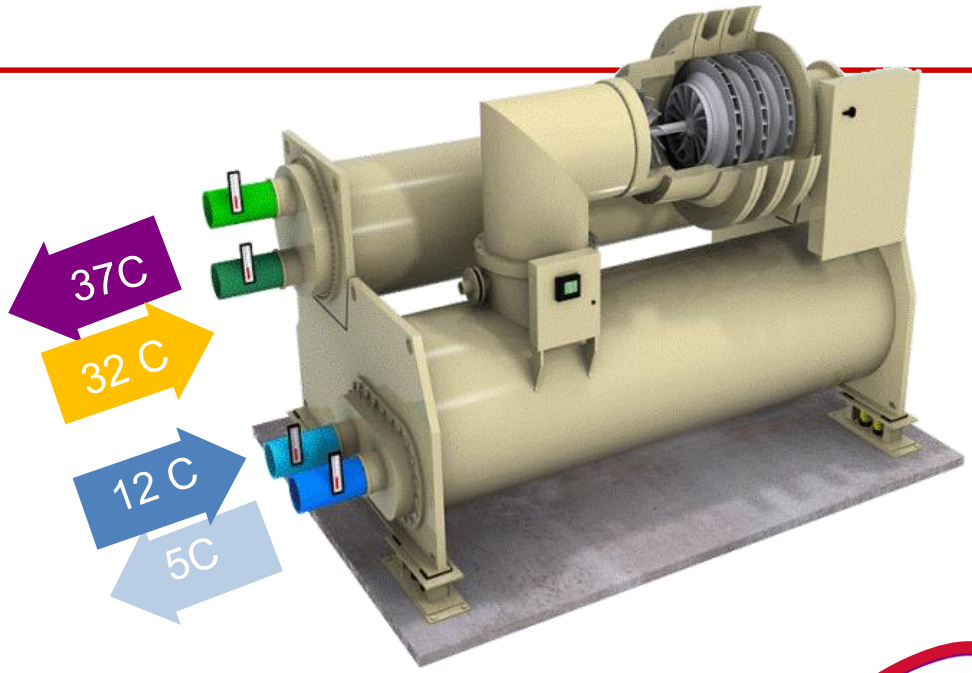
Chiller

Chiller KWI

lvg condenser water

lift ($_{approx}\Delta T$)

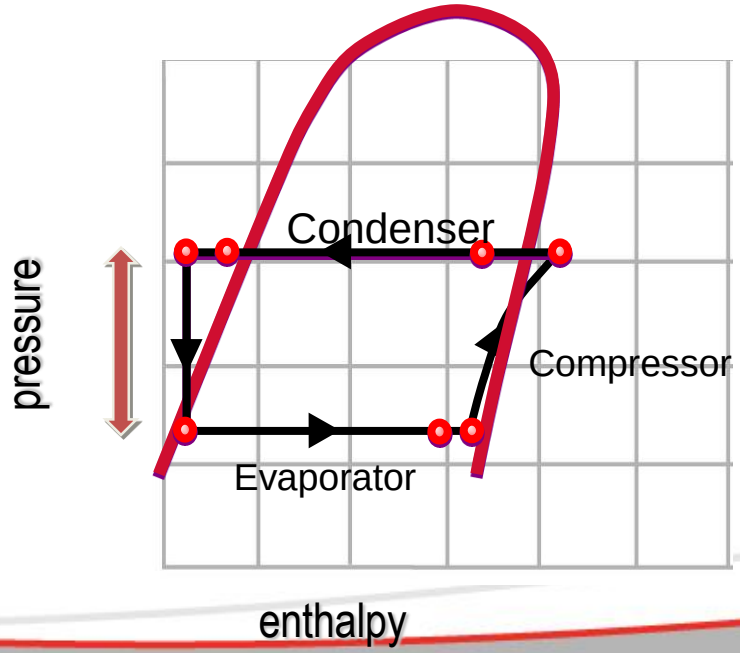
lvg evaporator water



$EFF_{chiller}$ = f(Loading & LIFT)

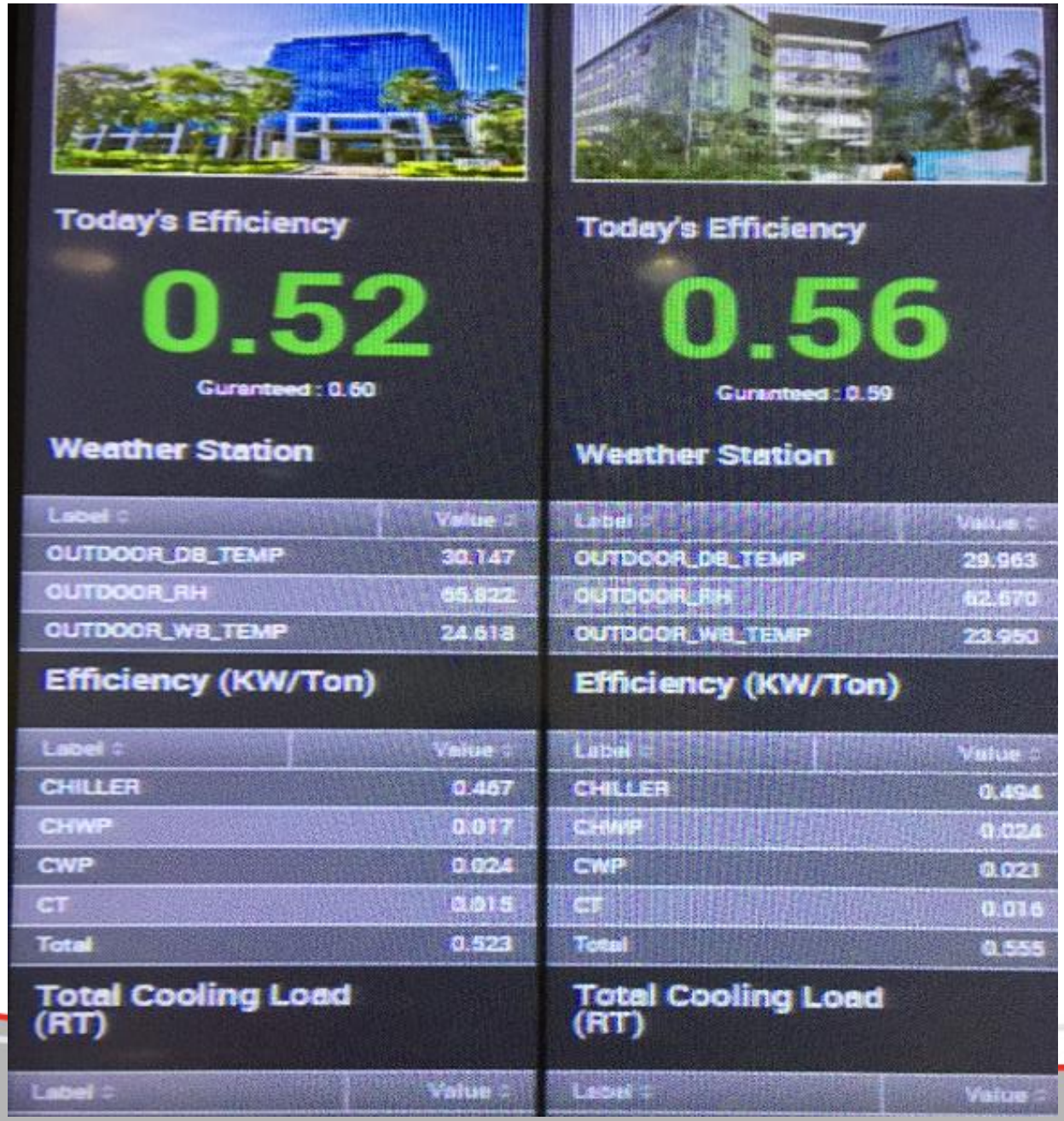
Optimised Loading
- Fixed Speed 65%-105% Loading
  (VSD Chiller 40-80%)….. Beware Pumping EFF

Optimised LIFT
- Manage CW Flow and CT Optimisation



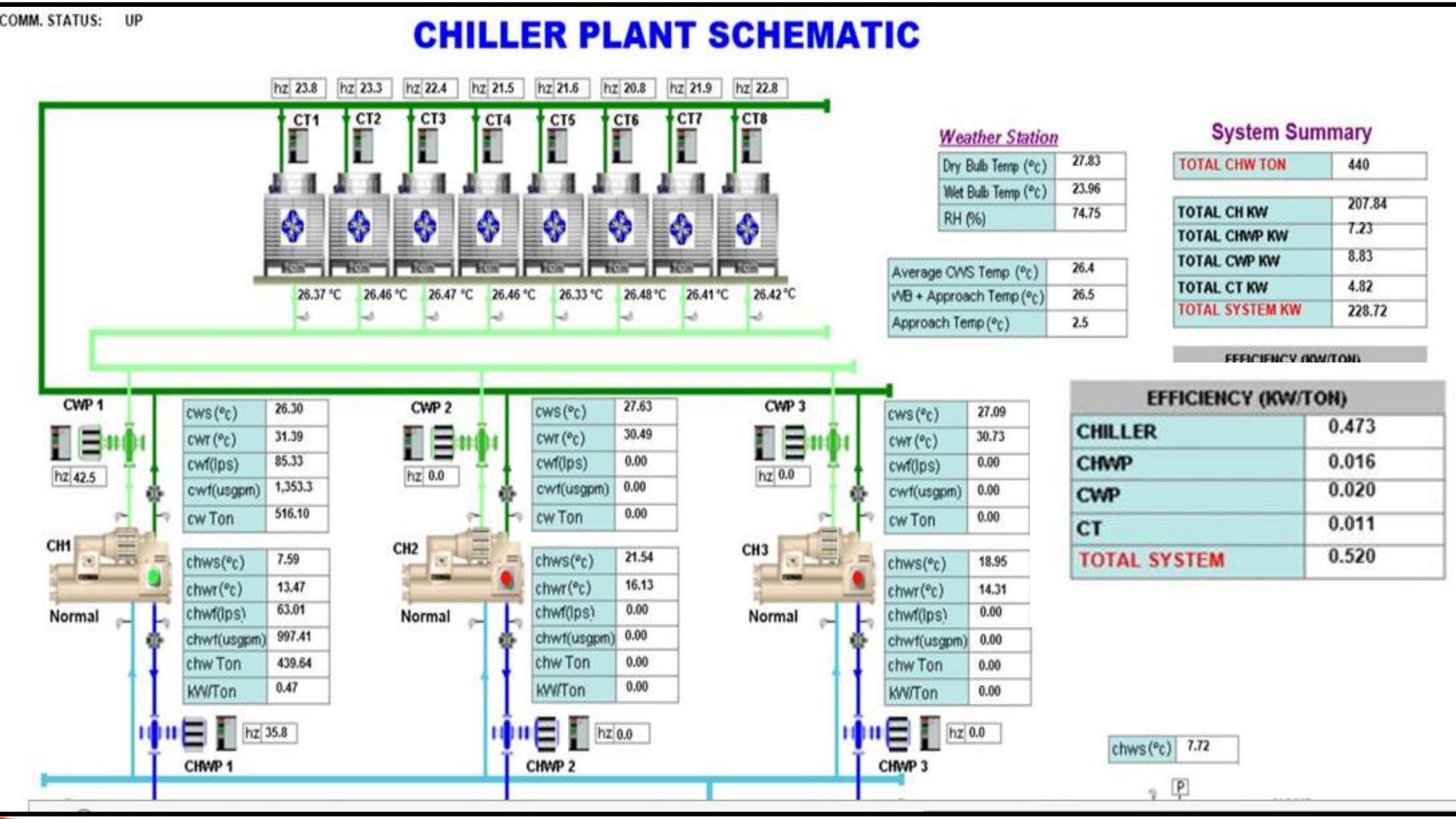
Chillers to Deliver 0.47 to 0.52 Kw/Rt

Chiller
0.467 Kw/Rt

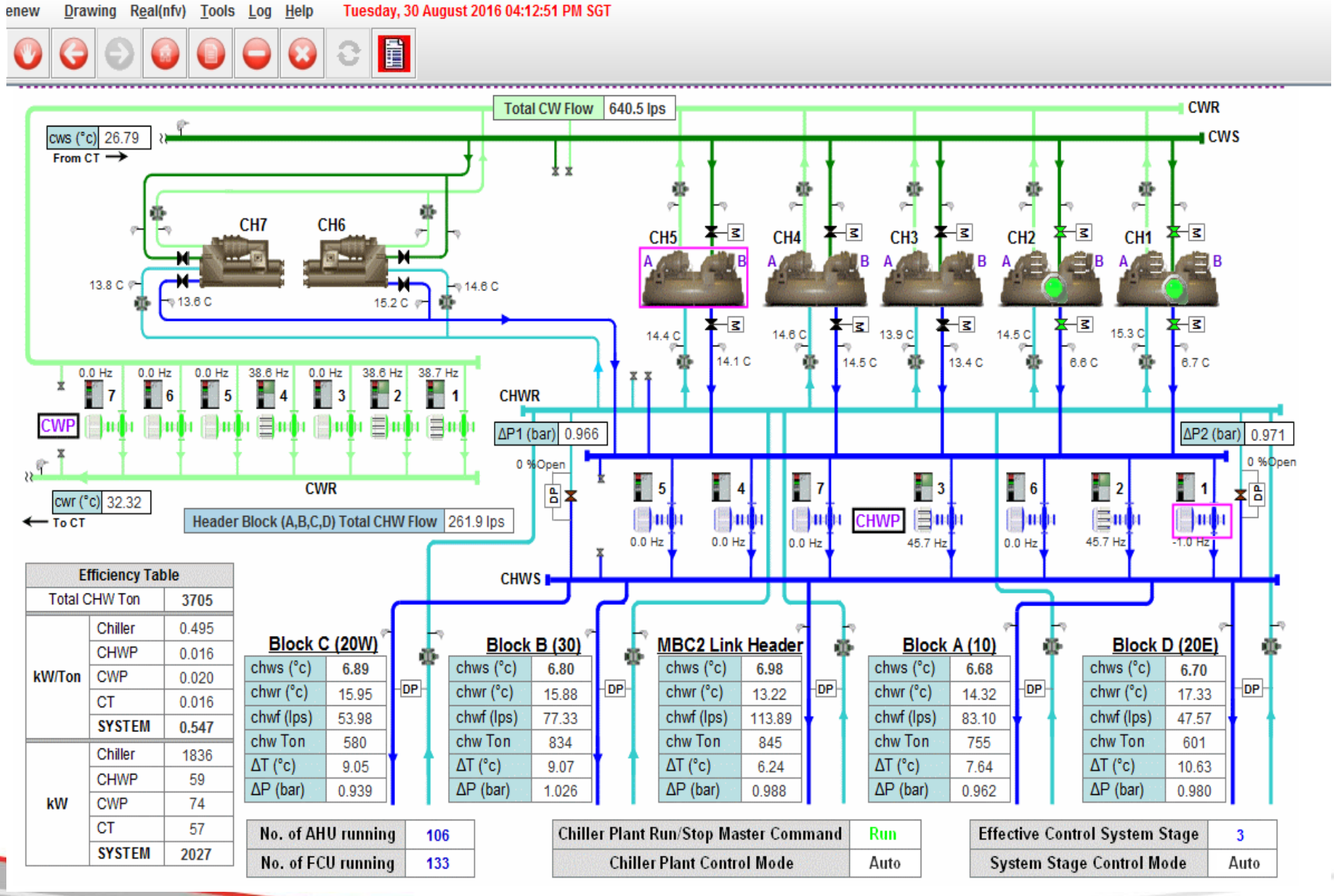


Chiller
0.494 Kw/Rt

Site at 0.52 Kw/Rt (7.6C CHW)



500RT CTV loaded to 88% =>0.47 Kw/RT (7.5C, 26.4/31.4C)



2X2000RT Loaded to 92% => 0.49 Kw/RT (6.8C, 26.8/32.3C)

TRANE

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FULL LOAD. PART LOAD. **ANY LOAD.**

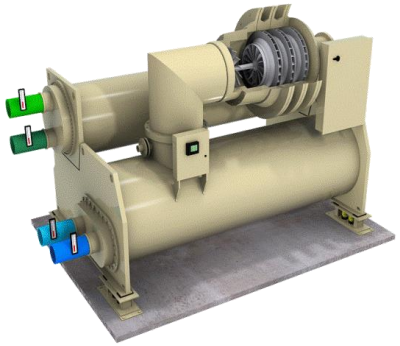
No chiller line is more efficient.



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Chiller Integrated performance （CIP）=



Chiller Kw/RT +
Harmonics Filter Losses (1.5%) if VSD

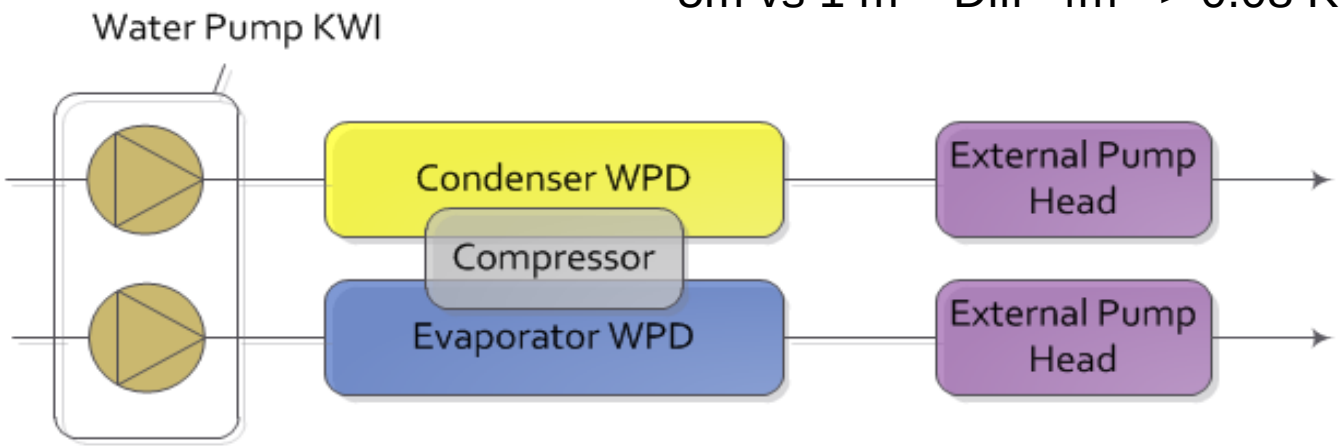
+



Pump Kw/Rt to overcome
Chiller Pressure Drop

1m = 0.002 Kw/Rt

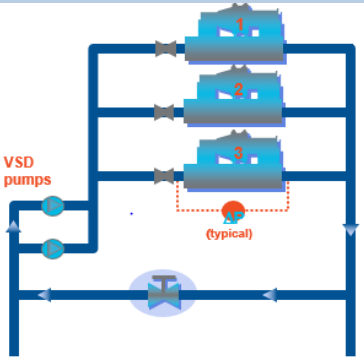
5m vs 1 m = Diff 4m => 0.08 Kw/RT



Evaluate Chiller Performance Holistically

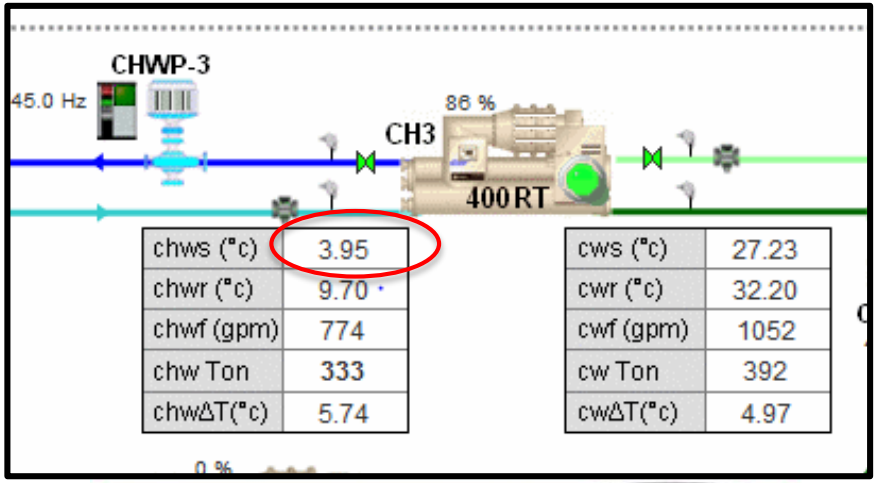
Robustness and Versatility of Trane 3-stage Centrifugal Chillers

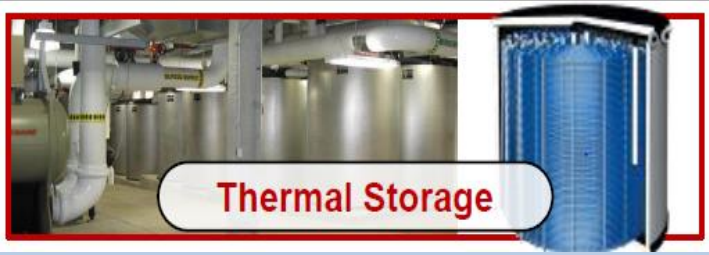
Variable flow at 50% per Min (Std 30%)



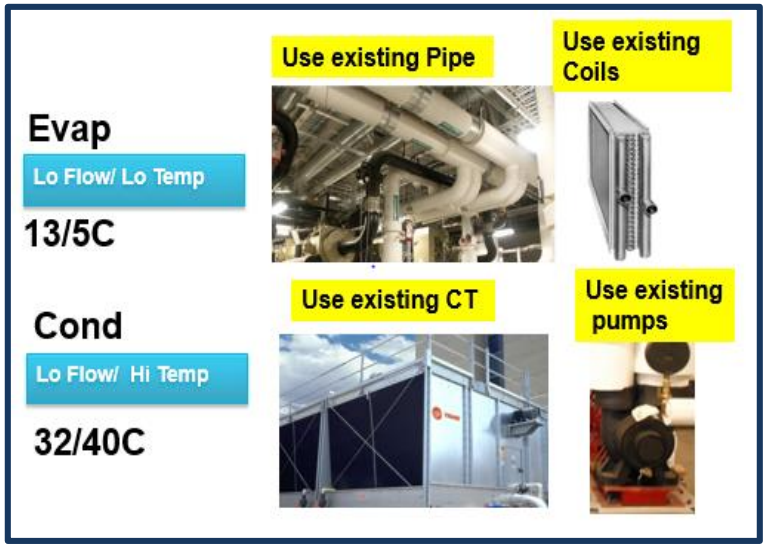
VPF System

6.7C Selection operates at 4C





Operate down to 2C without Glycol



Low Flow Low Temp Application

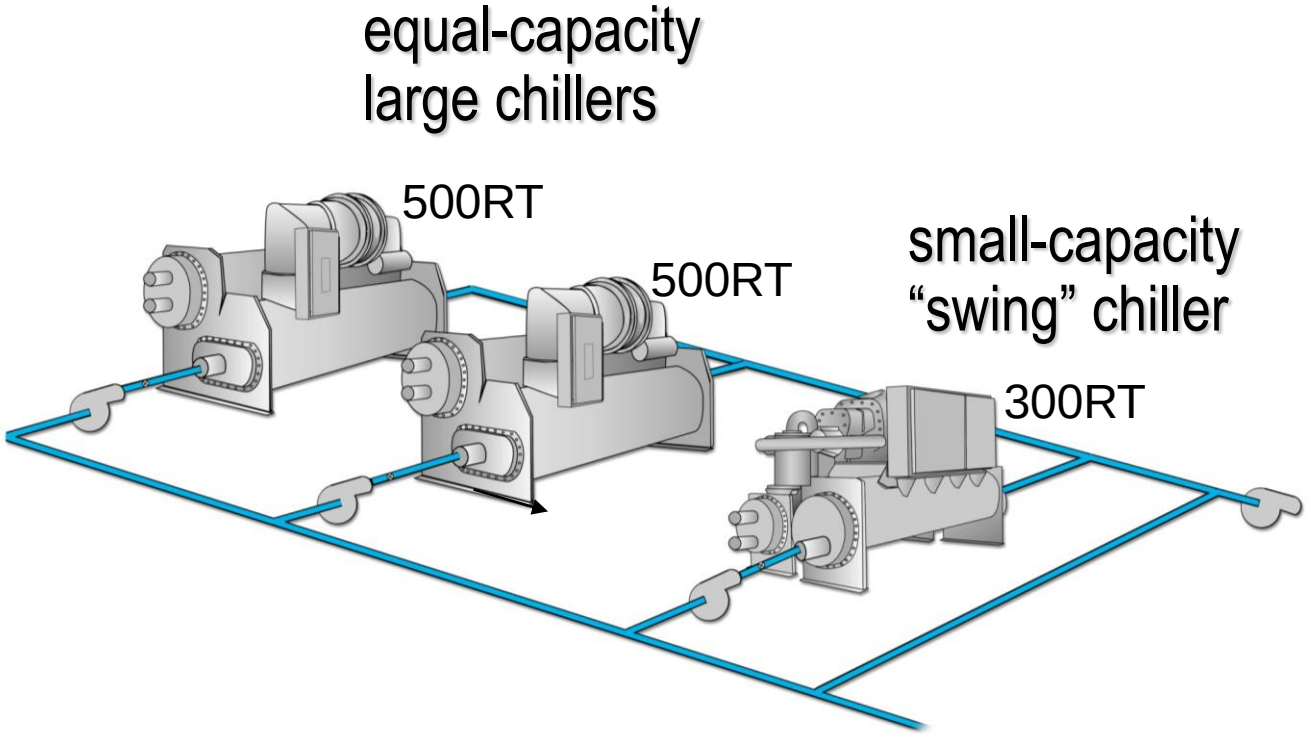


HR temperature up to 45C

Efficient Compressor and Smart Controls

Asymmetric Chiller Configuration

- Different chiller capacities
- Different chiller efficiencies
- Smaller chiller, smaller ancillary equipment
- Operating the least number of chillers, and the smallest chiller possible



•Unequal chiller capacities to match system load closely
•Increase overall system efficiency

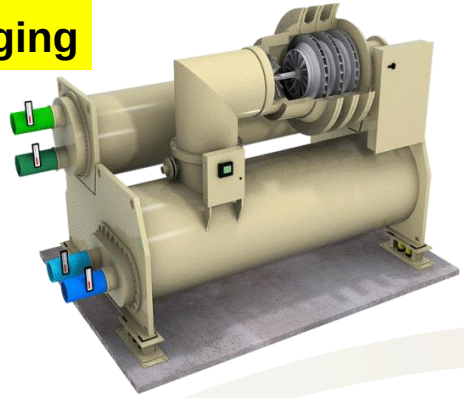
- **Stretch Chiller to 105% of Design RT**

Asymmetric Design For Optimisation

Optimisation Control

Optimisation Controls is Key to System Performance

Chiller Staging



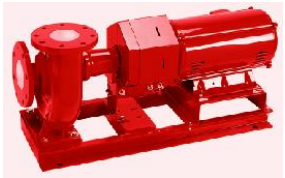
Chiiller Plant Controls

Tracer Summit

Pump Pressurisation Controls

Chiller Plant Controls

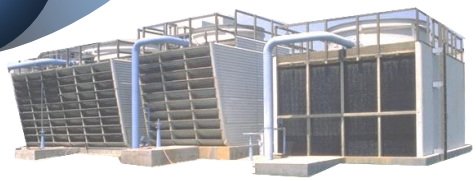
Chiller Tower Optimisation



CTO

(Var Pri Flow)

VPF



Cooling Tower

M+V requirements (Singapore SS 591)

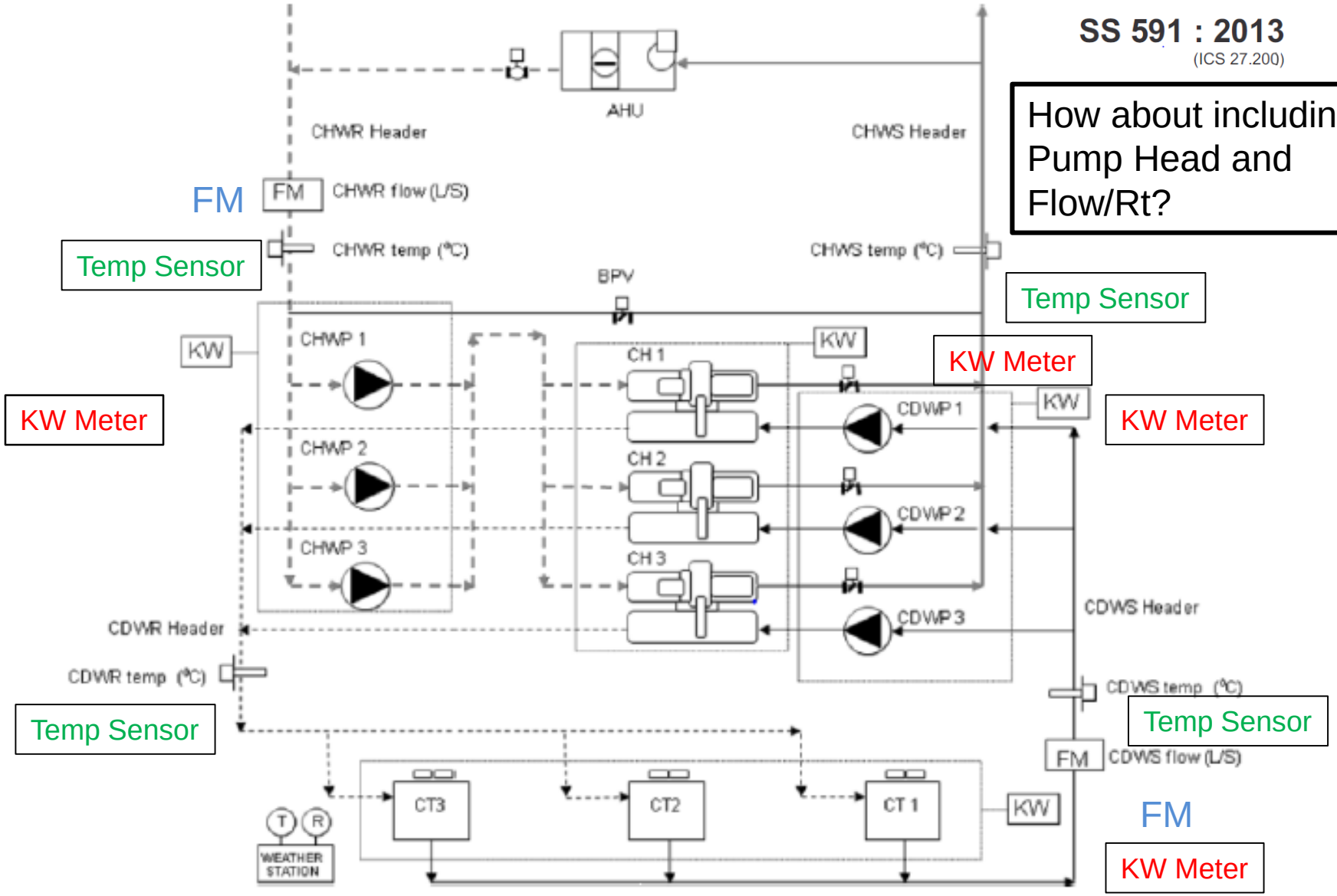
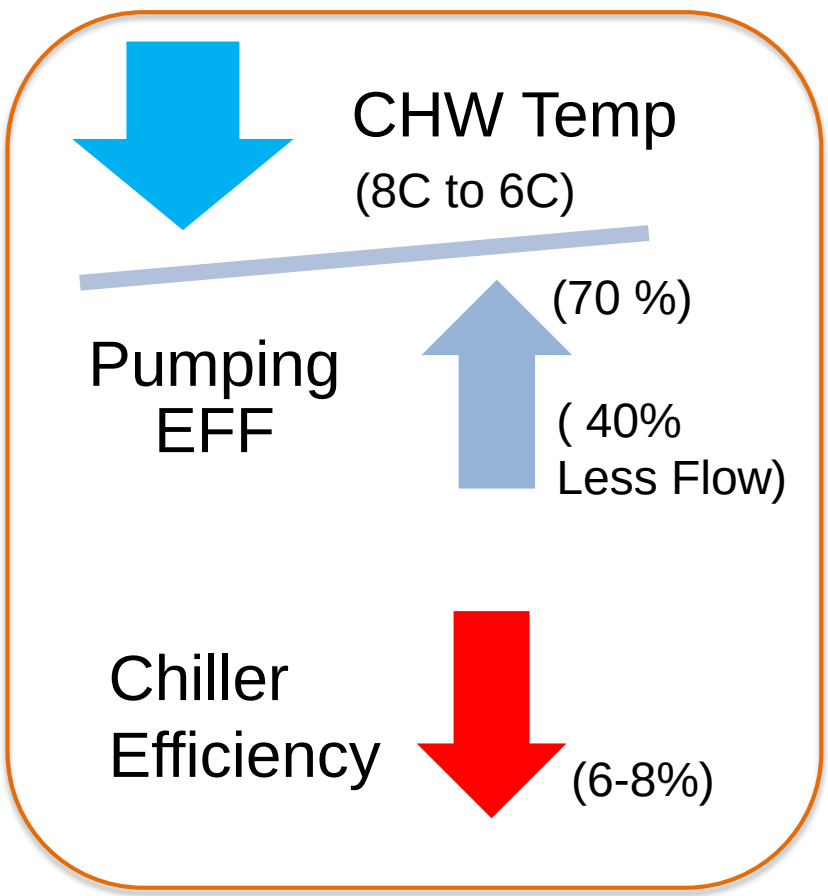
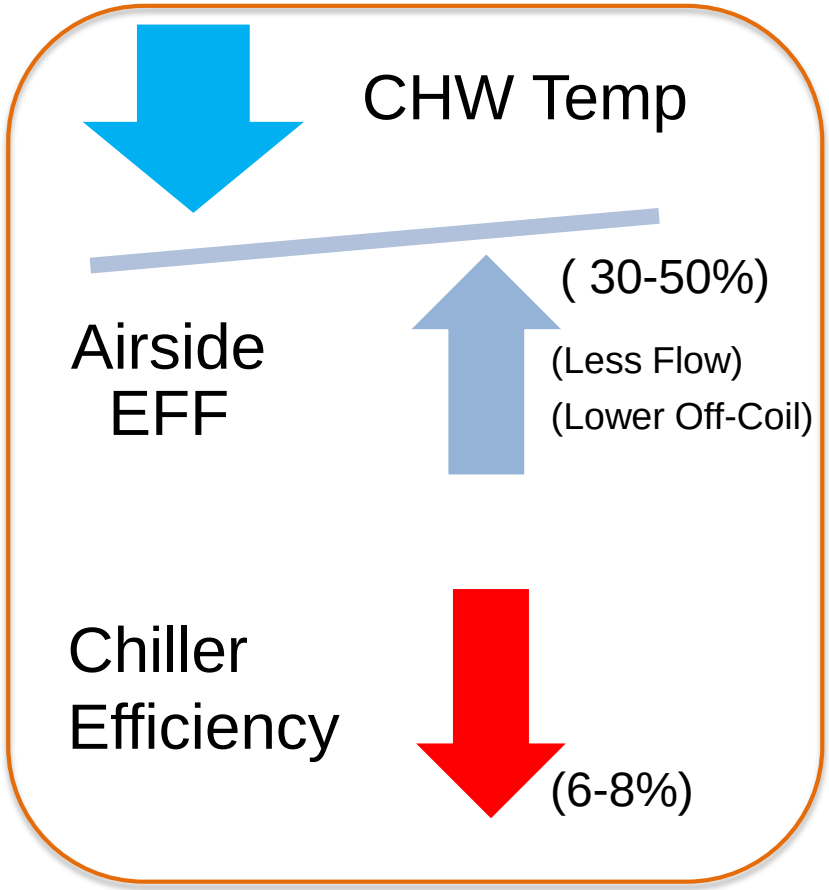


Figure A.3 – Example of a variable primary water-cooled central chilled water system

Impact of COLDER CHW on Plant and Airside





CHW Temp Reset for Optimisation can be Warmer or Colder water temp

COLDER Water can be a Powerful Lever for Optimisation

LIVE DEMO of M+V Site

Recommended Design Strategies for HP Chiller Plant

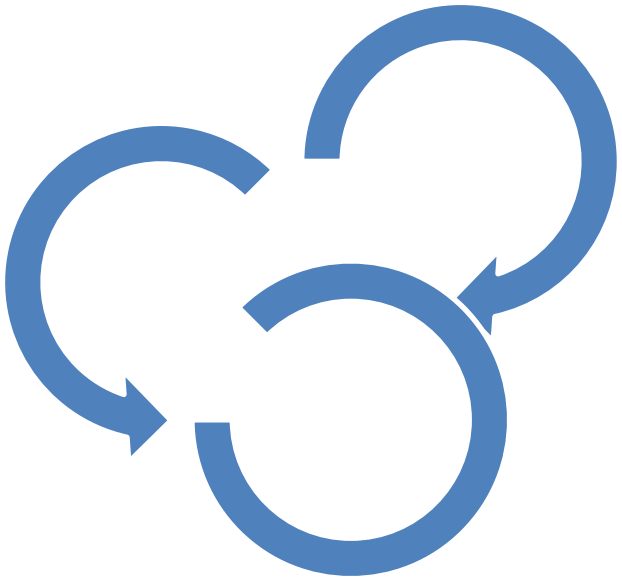
1. Use super high efficiency chillers, Pumps, CTs *(Do better than ASHRAE 90.1 Requirements)*
2. Low flow low pressure CHW and CW system *(Large DT where Necessary)*
3. Variable primary CHW flow system *(saves 20-25% VS Pri-Sec)*
4. Chiller tower optimization *(Add VSD + extra HR capacity)*
5. *Chiller Configuration (Asymmetric Design)*
6. Extensive continuous high precision monitoring *(SS 591-2013)*

GOOD DESIGN + SMART OPERATION = SUSTAINABLE Performance

Underlying Elements of Optimisation

Three Parameters that drives Performance of Chiller plant component equipment

Temperature
(CHW/CW/WB)



FLOW
(CHW/CW/CT Fan)

Pressure
(Refrigerant/Pump Hd)

Optimsation is about the tradeoffs between these parameters

Designing for High Performance HVAC System

Ready for Breakthrough : 0.90 to 0.70 Kw.Rt HVAC system ?

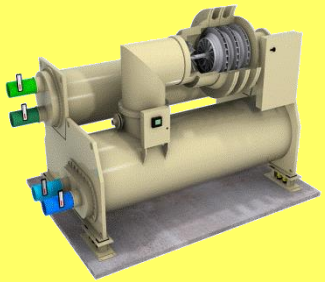
Waterside 0.55 Kw/Rt	+	Airside 0.15 Kw/Rt	=	HVAC Total 0.70 Kw/Rt

- **IR/Trane - A global leader dedicated to creating and sustaining safe, comfortable and efficient environments. Strong expertise in energy efficient HVAC equipment systems , application knowledge and comprehensive solutions.**

Partner for your High Performance building

Equipment

- Chillers
- Air Handlers
- Packaged AC/Splits
- Controls



Design

- HVAC selection
- System integration
- Design & layout



Solutions

- Turnkey installation
- Commissioning
- Performance guarantees



Services

- O&M
- Monitoring,
- Parts



Trane makes your building work better, for life



Thank You

Trane invites you to step into the future with



THE NEXT GENERATION CHILLERS

TRANE