High Performance Chiller Plant in Green Building
Low Water Flow Design

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28 July 2022

High Performance Plant

Background and Requirements in Green Building

Green Building & Building Decarbonization

- **Building Decarbonization:**
  Play a key role in global carbon neutral initiative. Buildings in the U.S. account for 40% of carbon emissions. in China account for 46%.
  Reduction of building carbon emission includes two parts: embedded carbon and operating carbon emission**.** Embedded carbon: arising from new-build construction or refurbishment
  Operational carbon: arising from building operating energy consumption, continuously emitted and significantly outweighs the embodied carbon over a 50-year lifetime of a building. **30 - 65 % of energy consumption in buildings comes from HVAC, accounts for large percentage of building operating carbon emission.**
  High performance HVAC system and chiller plant is required for building decarbonizaiton

- **Green Building:**
  Addressing Energy, Water, Material and evaluating Environmental, Ecological Social impacts. Long term energy, health "Green" evaluation on buildings which includes economic, environmental, and social. building carbon emission reduction is one of its goals

- **Green Building Rating Systems:**
  USA: LEED(Leadership in Energy and Environmental Design)
  Sg: Green Mark, popular in Asia
  UK: BREEAM (Building Research Establishment's Environmental Assessment Method)

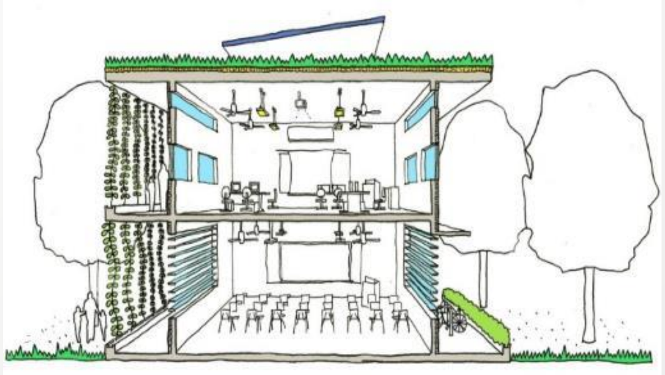
Singapore BCA Green Mark Scheme

Building Construction Authority(BCA)

- A green building rating system to evaluate building for its environmental impact and performance
- Launched in Jan 2005 – a rating system for the **tropical region**

Green Mark NRB 2015

- Climatic Responsive Design
- **Building Energy Performance**
- Resource Stewardship
- Smart & Healthy Building
- Advanced Green Efforts



Green Mark ENRB 2017

- Sustainable Management
- **Building Energy Performance**
- Resource Stewardship
- Smart & Healthy Building
- Advanced Green Efforts

80% OF BUILDINGS GREEN by 2030

BCA GREEN MARK

GM NRB2015: Section 2 Building Energy Performance

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P4 AC System & Component Efficiency

Minimum Design System Efficiency of **Water Cooled Chilled Water**

Green Mark Rating	Peak Building Cooling Load (RT)		Remarks
	<500 RT	≥500RT	(η_c, η_a) shall meet their respective thresholds η_c: System kW/ton excluding the air distribution equipment η_a: Air distribution equipment kW/ton $\eta_t = \eta_c + \eta_a$
	Minimum DSE η_t (kW/RT)		
Gold	NA (0.75, N.A.)	NA (0.68, NA)	
Gold^{PLUS}	0.95 (0.7, 0.25)	0.9 (0.65, 0.25)	
Platinum	0.93 (0.68, 0.25)		

For Platinum, chiller plant operating efficiency needs to be at least **0.65 kW/RT** with zero tolerance

2.1a Air Conditioning Total system efficiency (Capped at 5 Points)

	Peak Building Cooling Load (RT)	
	<500 RT	≥500RT
	Total Design System Efficiency (kW/RT)	
Baseline	1.08	0.98
Points scored = 0.2 x (% improvement from baseline)		

To get full points, AC total eff. should be 0.735kW/RT for >500 RT building, plant performance typically be less than **0.6kW./RT**

GM ENRB 2017: Chiller Plant Requirement

P2: Minimum System Efficiency:
Minimum Water-cooled chilled water system efficiency, For Platinum, chiller plant operating efficiency needs to be 0.65 kw/RT with zero tolerance

Green Mark Rating	Building Cooling Load (RT)	
	<500 RT	≥500RT
	Minimum Efficiency (kW/RT)	
Certified	0.85	0.75
Gold	0.75	0.70
Gold^{PLUS}	0.7	0.68
Platinum	0.68	0.65

2.2 Air Conditioning System Efficiency
Water-Cooled Chilled water system Efficiency (12 points)

	Building Cooling Load	
	< 500 RT	≥500 RT
Baseline	**0.85 kW/RT**	**0.75 kW/RT**

Point scored = 0.6 x (% improvement)
To get full point, for <500RT, plant efficiency ≤ 0.68kW/RT, **for ≥500RT, plant efficiency ≤ 0.60kW/RT**

Sg GM SLE Building

Green Mark for Super Low Energy Buildings (GM SLE): A rating tool that recognises projects that are on the path to net zero energy or have gone beyond this to be a positive energy building

GM SLE :use the same parallel pathways as GM for projects to demonstrate their energy performance.

Targeted plant efficiency: 0.55kW/RT

OFFICE	
PATHWAY 1 - EUI	
Large Office (with GFA > 15,000sqm)	115
Small Office (with GFA < 15,000sqm)	100

EUI: Energy use intensity, Total Building annual energy consumption over the gross floor area of the building (kWh/m₂/yr).

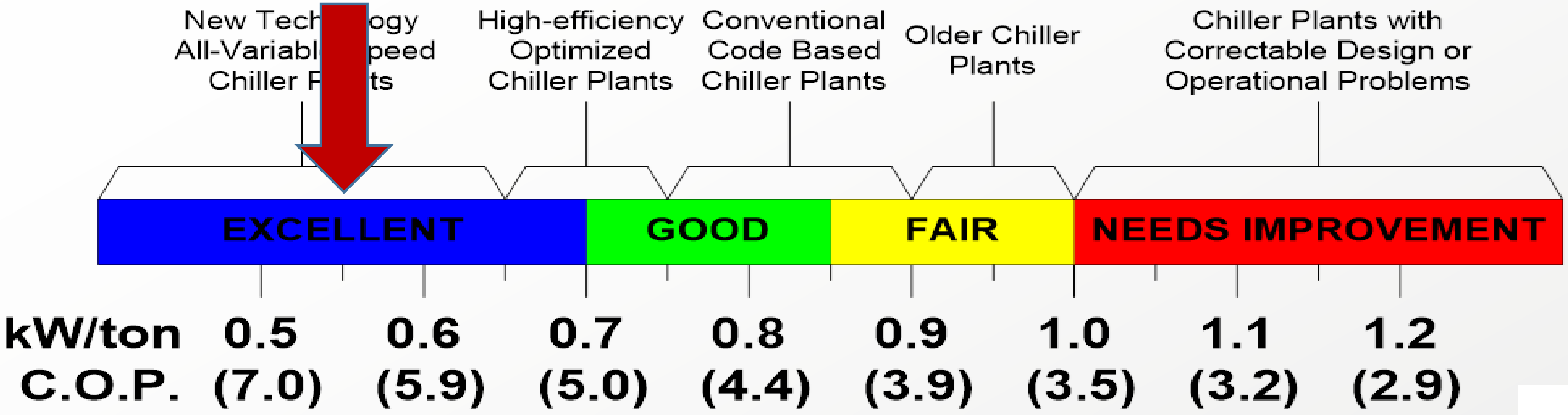
PATHWAY 2 - FIXED METRICS	
PARAMETER	
Reduced Heat Gain (ETTV) **[New Development only]**	38
[illegible]	25%
ACMV TSE	0.68
Lighting Power Budget	TABLE 2A
Mechanical Ventilation	TABLE 2B

PATHWAY 3 ENERGY SAVINGS	
Demonstrated Energy Savings	60%

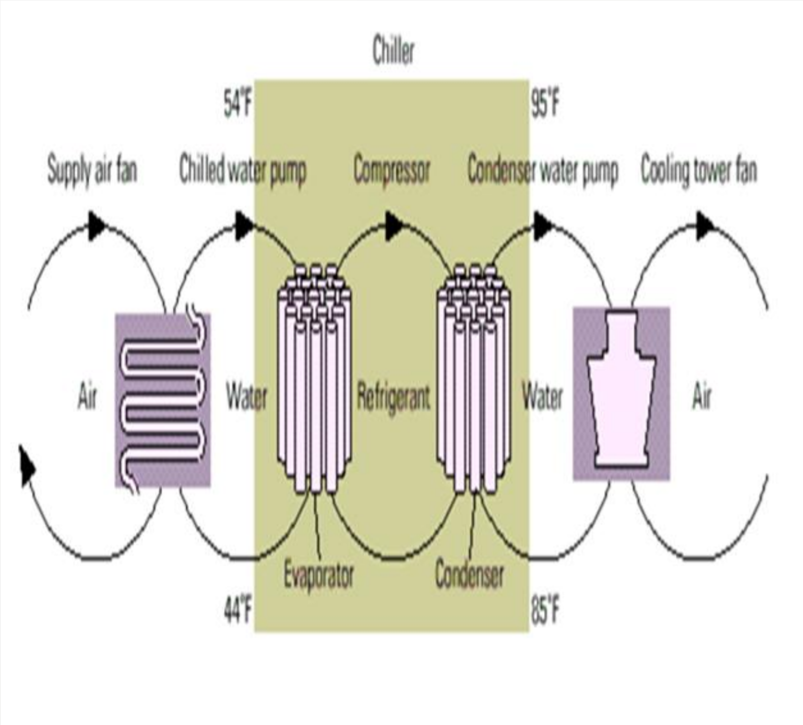
High Performance Plant

Low Water Flow Low Pressure Design

High Performance Chiller Plant Concept



- High performance equipment: Chiller@0.5kW/RT,CT@0.02-0.03kW/RT
- High performance system integrated design
- **Optimize Pump eff: Low water flow system, low pressure system @ 0.07-0.08kW/RT**
- Accurate measurement and continuous monitoring
- Optimized control system to ensure optimized plant performance over the whole operating period
- Professional maintenance and facility engineer's expertize



Minimize Pumping Energy : Plant Low Water Flow

- **Why low water flow?**

Pump KW = (L/s x kpa) / (1000*Peff*Meff)   Or KW = (0.746xgpmxftwg) / (3960*Peff*Meff)

↓ ↓ ↓

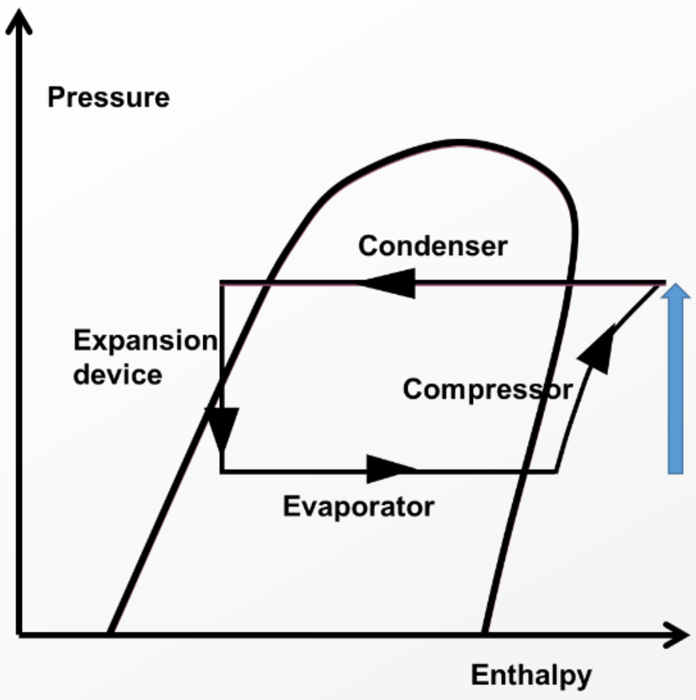
Pump energy consumption is minimized by reducing flow rate and pump head

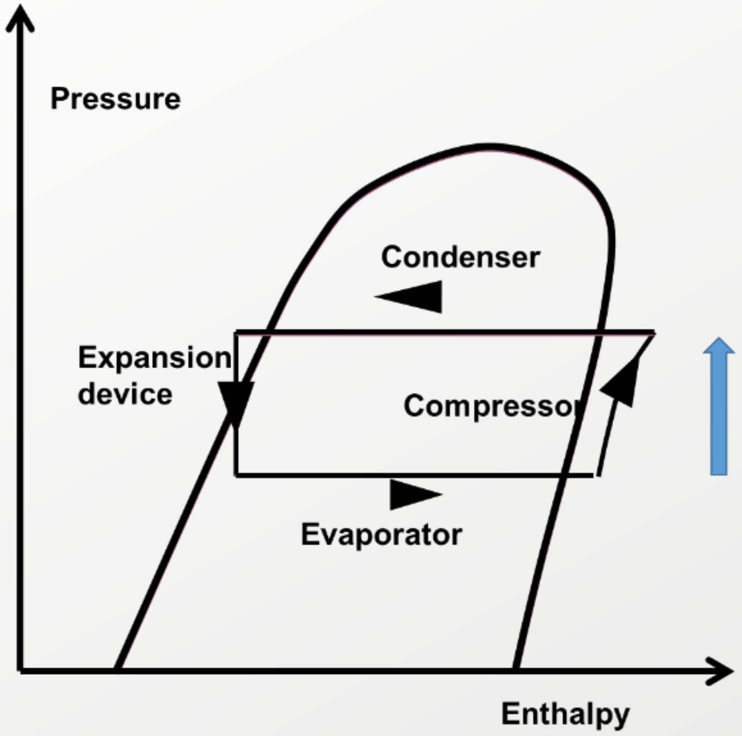
- **Conventional**
  - 44F/54F, 10°F delta T on chilled water : **2.4 GPM/ton**
  - 85F/94.3F, around 9°F delta T on condenser water : around **3.0 GPM/ton**

- **New: pumping less water flow**
  - Increase CHW delta T: Low flow on chilled water side   **Recommended**
  - Increase CW delta T: **Low flow on condenser water side   ?**
  - ASHRAE GreenGuide : Chilled water delta T: 12F(6.7C) to 20 F (11C)
  - Condenser water delta T: depends, 10F(5.6C)(single stage) to 18 F(10C) (multi-stage)

Compressor Lift Impact on Chiller Efficiency

kW = f(Load,Lift)





CSD chiller :

energy saving of 1 - 3% per 1 ˚C lift reduction

VSD chiller :

energy saving of 3%-5% per 1 ˚C lift reduction

Compressor **Lift: Leaving condenser water temp – leaving chilled water temp**

The higher the lift , the more compressor work done, the more energy consumed

Two ways to reduce lift: increase leaving chilled water temp, reduce leaving condenser water temp

Plant Low Flow: Design Water Temperature

- Low flow in CHW needs to increase CHW temperature difference:

  Chiller lift may or may not impact, but will impact coil performance

CHW delta temp

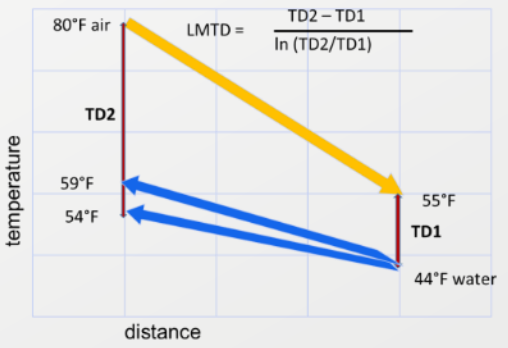
CHW leav. temp: 5 C ↔ 11 C

CHW temp: 10 C ↔ 18 C

5C/12C: chiller ↓ coil ↑

7C/14C: chiller — coil ↓

11C/18C: chiller ↑ coil ↓



- Low flow in CW needs to increase CW temperature difference:

  Chiller Lift will be increased, need to evaluate the total energy consumption of chiller, condenser pump, towers, as well as real operating and weather conditions,for HP plant whose condenser pump design head/kW has been minimized, the saving from small condenser pump most likely cannot offset the energy increase from chiller

CW delta temp

CW enter temp: 28C ↔ 33 C

CW leav. temp: 33 C ↔ 40 C

28C/35C: chiller ↓ CT ↑

30/37C: chiller ↓ CT ↑

33C/40C: chiller ↓ CT ↑

Low Chilled Water Supply Temp

Applications: ice storage system, cold air distribution system, district cooling, plant retrofit/expansion applications

- impact on cooling coils: reacts to colder entering water by returning warmer water, make same AHU cooling coil produce the same capacity with low flow, chiller water must be colder.
- Impact on chiller: efficiency drops
- Existing piping: same capacity, low flow with smaller pump energy (retrofitting)

  same flow rate with bigger capacity(expansion)
- System expansion: just need to replace old chiller with bigger one, the existing AHU, pump, and piping to deliver bigger capacity

Coil Performance:
Q= U x A x LMTD
Building Load:
Tons = GPM x DeltaT/24

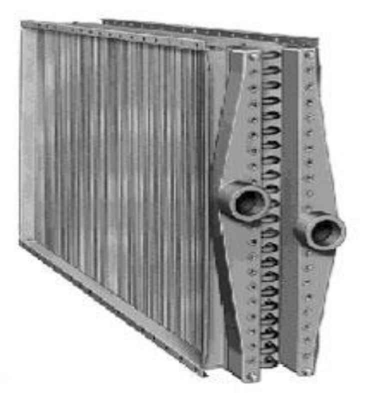
High Chilled Water Supply Temp

Applications: Normal mixed air AHU system ,DOAS systems, Datacenter, process cooling having less latent load,

Entering air:

25°C drybulb

18.5°C wetbulb



Target leaving air temp:
13°C db

Air flow: 5,000 l/s

6° C approach temperature

Or

4° C approach temperature

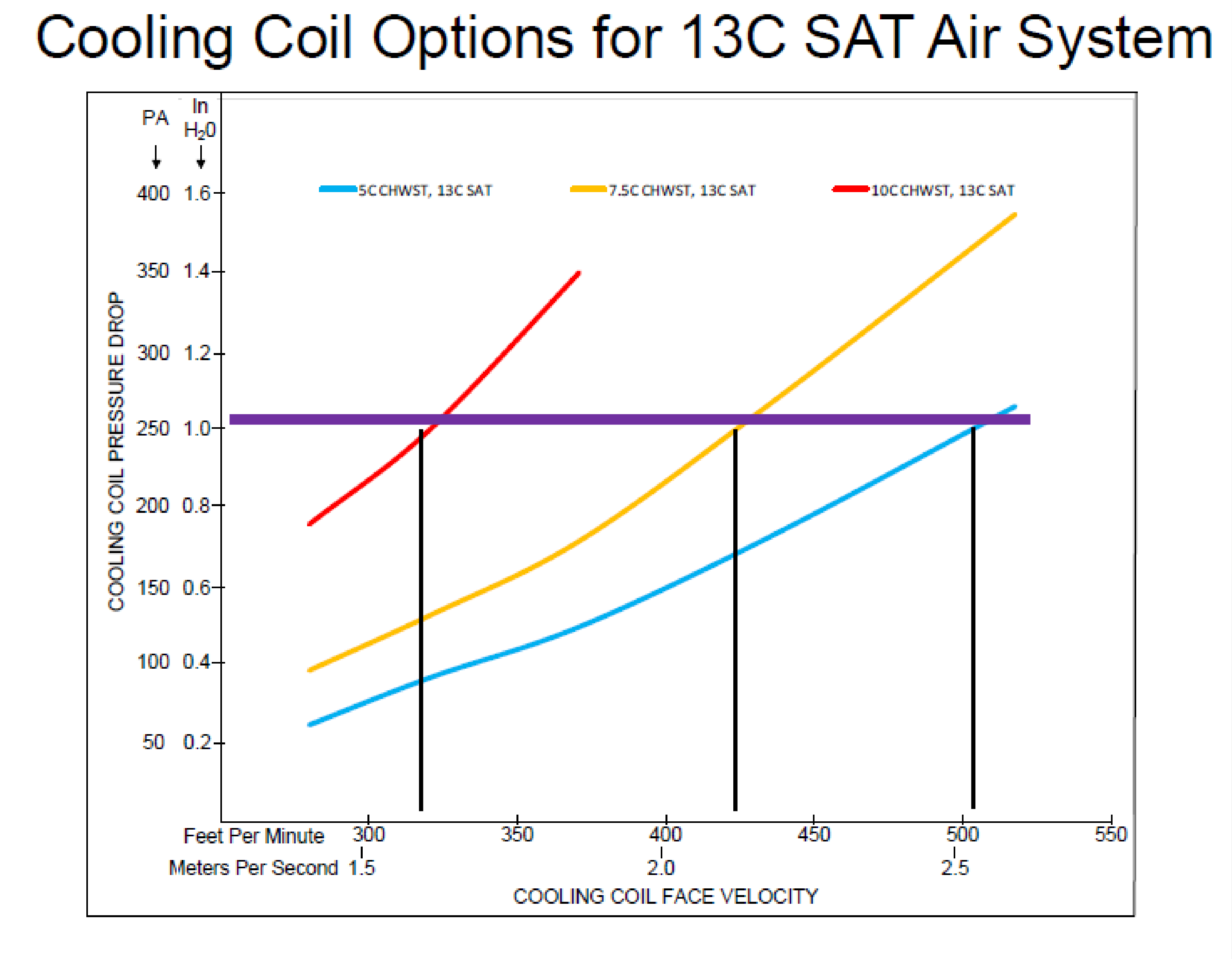
Bigger coil

Leaving temp – chilled water temp = required approach

	13°C	leaving air
-	7°C	CHW water
	6°C required approach	

	13°C	leaving air
-	9°C	CHW water
	4°C required approach	

Impact on AHU Coil



Commercial Office Building

- When chilled water temp increases, the selected cooling coil face velocity reduced
- If chilled water temp designed at 10C, with same coil pressure drop 250Pa design, the face velocity is about 320fpm(1.6m/s) which means bigger coil, compared with 5C water coil face velocity 2.6m/s(smaller coil)

High Condenser Water Temp

Applications: Retrofitting projects with increased load; multi-stage chiller

Plant cooling load (RT)	CT heat rejection load(RT)	Outside WB(F)	Condenser water flow rate(gpm)	Range(F)	Approach (F)	Entering condenser water temp(F)	Leaving condenser water temp(F)	
500	581	78	1500	9.3	7	94.3	85	Design Load
753	875	78	1500	14	9	101	87	150% Load
1000	1163	78	1500	18.6	11	107.6	89	200% Load

- With increase chiller leaving condenser water temp, cooling tower heat rejection load can be increased with same condenser pump, pipes, and CT
- The higher inlet temp, larger temp range, the better CT efficiency
- For expansion project, need to make sure existing chiller is able to operate at the high condenser
- water temp(screw chiller typically have the capability, centrifugal chiller need to be cautious)
- Chiller efficiency will become worse, condenser pump energy reduced, CT efficiency improved,
- need to evaluate the total saving.
- **For HP plant, condenser pump has been optimized small, the saving from low flow is not significant**

Low Condenser Water Temp

Applications: plants operating at part load or with oversized cooling tower

Plant cooling load (RT)	CT heat rejection load(RT)	Outside WB(F)	Condenser water flow rate(gpm)	Range(F)	Approach (F)	Entering condenser water temp(F)	Leaving condenser water temp(F)	
500	581	78	1500	9.3	7	94.3	85	Full Load
400	465	78	1500	7.44	5	90.4	83	Constant CNW control
400	465	78	1200	9.3	4	91.3	82	Variable CNW control

- During part load operating, **cooling tower is able to provide lower condenser water temp with or without variable condenser water flow control.**
- **Oversized cooling tower is able to provide lower condenser water temp**
- By varying condenser flow rate at part load, condenser water temp is higher than constant condenser flow, which makes chiller less efficient but condenser pump more efficient. Constant condenser flow rate vice versa
- **As load is reduced on the tower, the leaving water temperature will get closer to the entering wet bulb(full speed running), approach reduced (1-2.5ºC)**

Range = hot - cold water temperature
Approach = Wet Bulb temperature of Air - cold water temperature.

Cooling Tower can Deliver Colder Water at Part Load

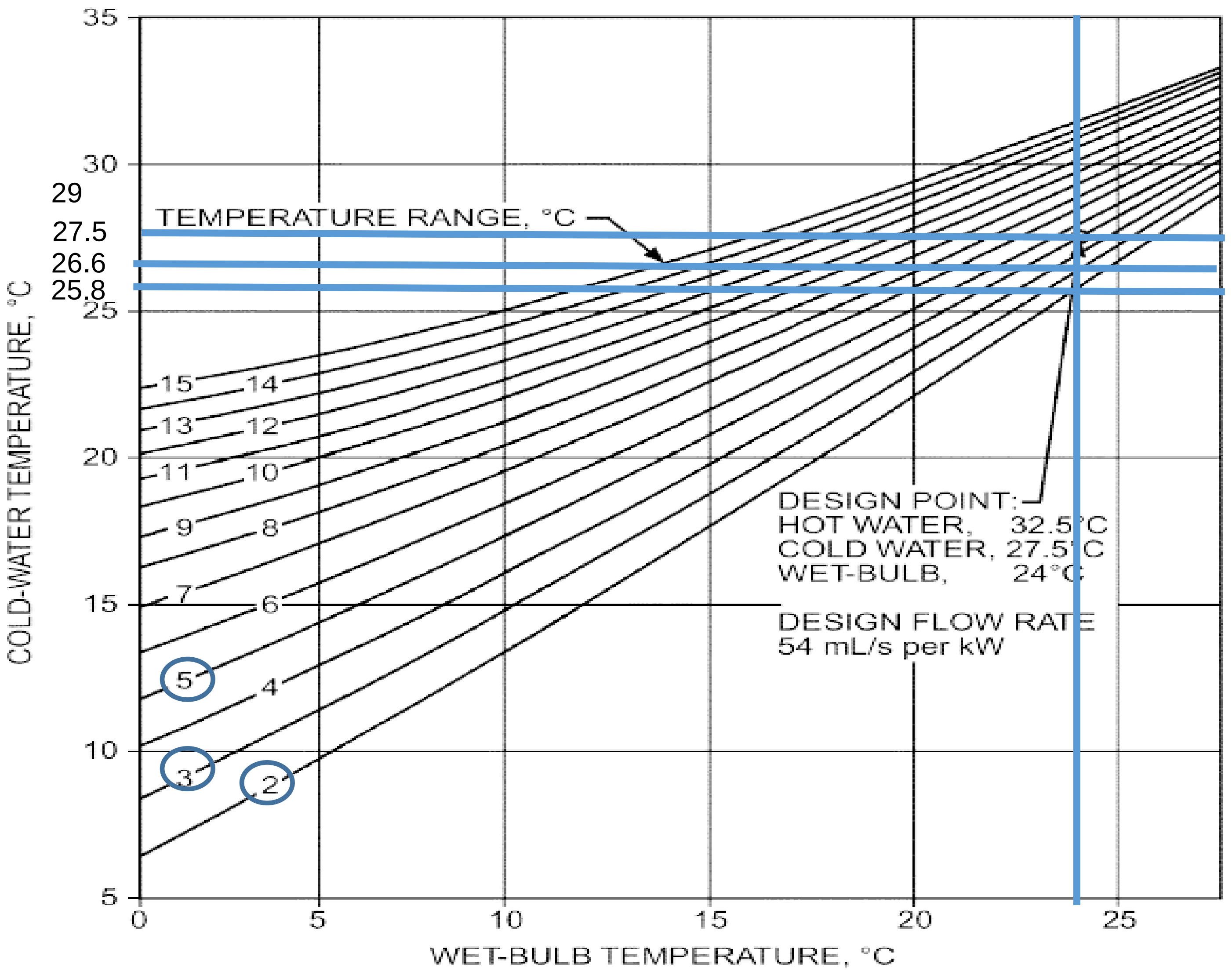


Fig. 32 Cooling Tower Performance: 100% Design Flow

ASHRAE Handbook-HVAC Applications 2019 Chapter 40

- These curves are based on typical mechanical draft, film filled cross flow medium sized air conditioning cooling tower
- CT selected at design 32.5/27.5 water entering/leaving temp, WB at 24C
- when the building load is reduced to **60%** and with constant flow and WB, this tower is able to deliver **colder water at 26.6C** and closer **approach 2.6C**, when reduced to **40%**, **colder water at 25.8C** ,**approach at 1.8C**
- At part load, tower **approach reduced (1-2.5C)**
- Oversized cooling tower is able to provide lower condenser water temp

For constant flow,
temperature range linear with **tower load**

5C ⟹ **100%**
3C ⟹ **60%**
2C ⟹ **40%**

Low Cond Water Temp is Achievable in Hot and Humid Region

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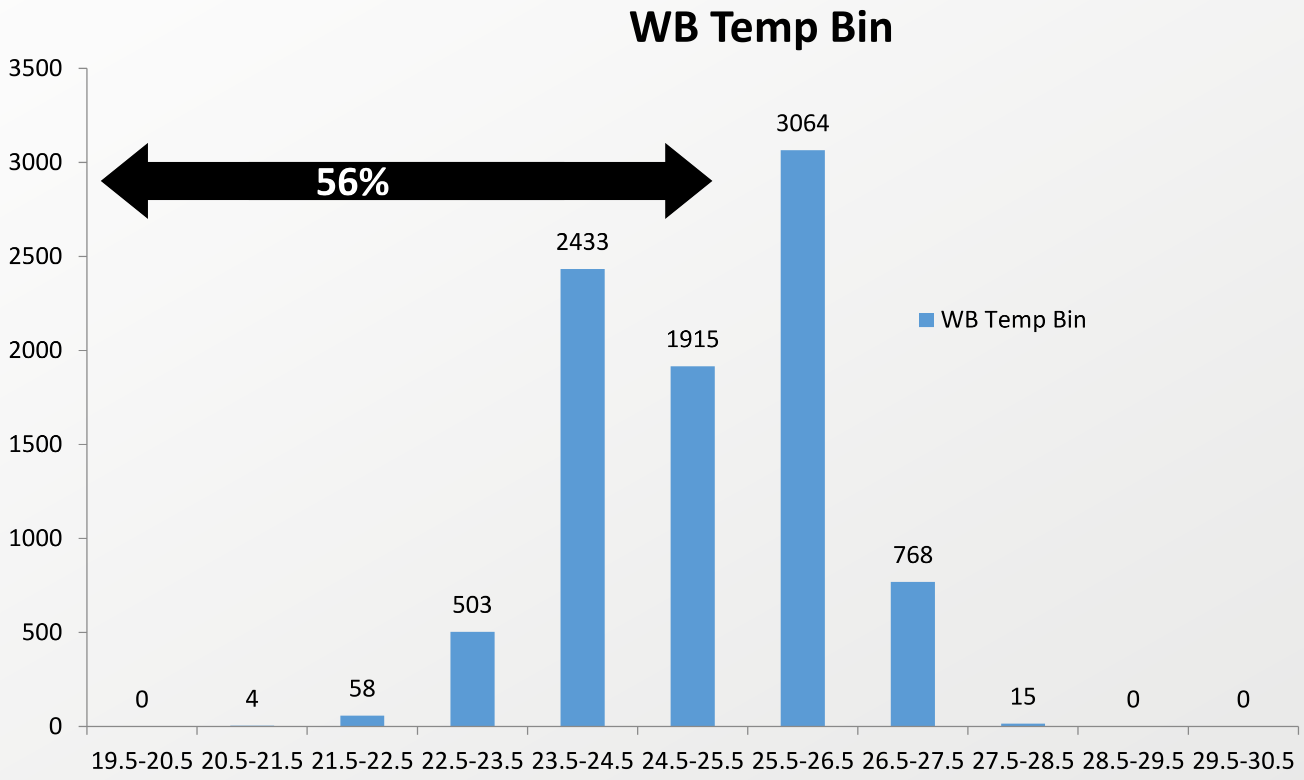
Zone 1A (Singapore, Malaysia, Indonesia,etc)

Assumption: If cooling tower of 1.5C approach

Chiller would be able to operate at ECWT (entering condenser water temperature) lower than 27C for 56% of the time, lower than 26C for 34% of the time



- **ECWT=WB+1.5C**
- Zone 1A means very hot humid zone based on the definition of climate zone from ASHRAE90.1 standard

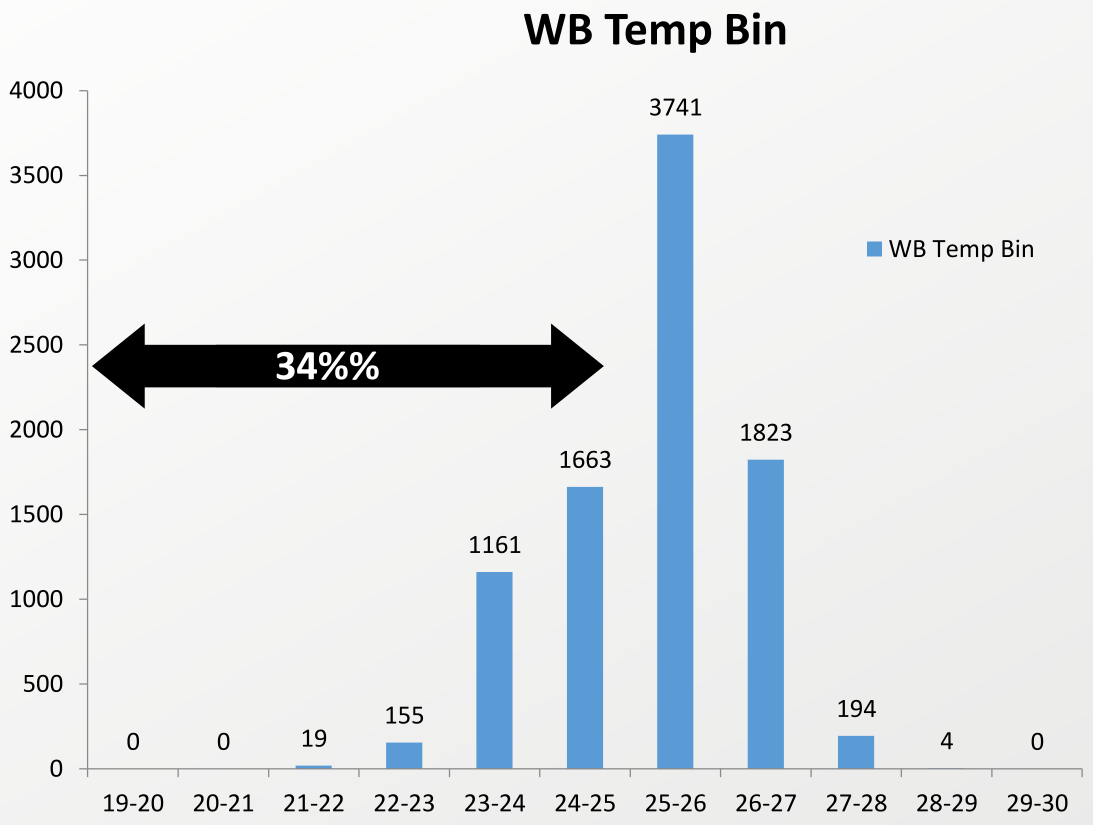
Have Ambient Relief to make condenser water temp lower to 27C for more than half of operating hours

Low Cond Water Temp is Achievable in Hot and Humid Region

Zone 1A (Singapore, Malaysia, Indonesia,etc)

Assumption: If cooling tower of 2.0C approach

Chiller would be able to operate at ECWT (entering condenser water temperature) lower than 27C for 34% of the time, lower than 26C for 15% of the time



- **ECWT=WB+2C**
- Zone 1A means very hot humid zone based on the definition of climate zone from ASHRAE90.1 standard

Have Ambient Relief to make condenser water temp lower to 27 C for more than one third operating hours

Chiller Real Operating Conditions

- **Chiller not operating at 100% full load because:**
  1. Chiller selection normally oversized for safety factors
  2. Chillers sequencing could be optimized based on chiller performance curve to let more chiller running at part load
- **Condenser water temp could be reduced to 29-26C for most of times in tropical regions**
- Multiple compressor would have much better part load efficiency due to improved compressor eff from compressor staging and more available heat exchanger surface. Part load eff can be improved more for multiple compressor VSD chiller design
- Both VSD centrifugal and positive displacement chillers have effi advantage from part load and reduced condenser water temp due to speed control
- **Design chiller condition, especially condenser water temp, should consider the actual operating condition**
- **Even some plant designed at low condenser flow high entering condenser water temp, the real operating temp is still optimized to low condenser water temp in order to take advantage of the excellent part load eff.**
- **Chiller Actual Operating Conditions Matters. Optimized design temp should consider the actual available conditions.**

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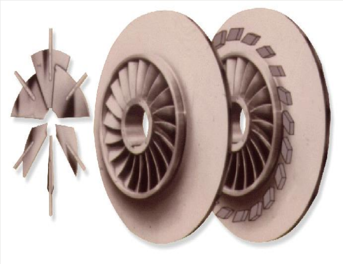

Low Pressure Piping Design

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- Big main pipe

  Conventional design for piping

  Piping friction loss: 2-5m/100m , Water velocity: 3m/s-5m/s

  Optimum design of flow rate & Velocity

  Piping friction loss : 1 m/100m, Water Velocity : 1.5 m/s

TABLE 6.5.4.6 Piping System Design Maximum Flow Rate in L/s

Operating Hours/Year	≤2000 Hours/Year		>2000 and ≤4400 Hours/Year		>4400 Hours/Year	
Nominal Pipe Size, mm	Other	Variable Flow/ Variable Speed	Other	Variable Flow/ Variable Speed	Other	Variable Flow/ Variable Speed
75	8	11	5	8	4	7
90	1	17	9	13	7	11
110	22	33	16	25	13	20
140	26	39	20	30	16	23
160	47	69	36	54	28	43
225	76	114	57	88	44	69
280	114	170	82	126	63	101
315	158	240	120	183	95	145
Maximum velocity for pipes over 355–600 mm in size	2.6 m/s	4.0 m/s	2.0 m/s	2.9 m/s	1.5 m/s	2.3 m/s

- Low pressure smooth fitting connections
- No unnecessary balancing valves (can reduce 1-3m PD each)
- No constant flow valves
- Select low pressure drop chillers wisely
- Avoid turbulence in the inlet and outlet of pumps, smooth pump connection
- Reduce elbow quantity as can as possible

By designing low water flow rate and low pressure piping system, pump kW is minimized:

Chilled water pump head: 15 -25m

Condenser water pump head: 10 -15m

Pumping Energy Comparison at Low CHW Flow

500RT x 2 unit at CHW 2.4 gpm/RT(10F deltaT) vs. CHW 1.6gpm/RT(15F deltaT)

	2.4gpm/RT	1.6 gpm/RT
Plant capacity RT	2 x 500RT	2 x 500RT
Flow rate gpm	2400	1600
Pump head ft	120	80
Pump eff %	84	84
motor eff %	95	95
CHW Pump kW	68.0	30.2
Pump eff kW/RT	0.0680	0.0302

56% Saving

Pump KW = (L/s x kpa) / (1000*Peff*Meff)   Or KW = (0.746xgpmxftwg) / (3960*Peff*Meff)

Note:

- Assume same pipe sizing
- To be conservative, assume pump head reduction is proportional to flow rate reduction
- Low flow design will end up low pressure piping system

High Performance Chiller Plant

Optimized design

LOW FLOW LOW PRESSURE(minimized design pump kW)

right equipment sizing(optimized chiller/CT capacity and types based on load profile and weather condition)

+

Continuous accurate M&V(monitoring plant parameter and managing to the optimum) **and Optimized plant control** (optimized chiller and CT sequencing,pump speed control,condenser/chilled water temp control)

+

Professional service and maintenance

↓

Guaranteed High Performance Chiller Plant at 0.6kW/RT or less

Thank You!

Q&A