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Chiller, Pumps and Cooling Tower Optimization

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AGENDA

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1. Overview of chiller plant optimization
2. Chiller Optimization
3. CHWP Optimization
4. CWP Optimization
5. Cooling Tower Optimization

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OVERVIEW OF CHILLER PLANT OPTIMIZATION

Chiller Plant Efficiency

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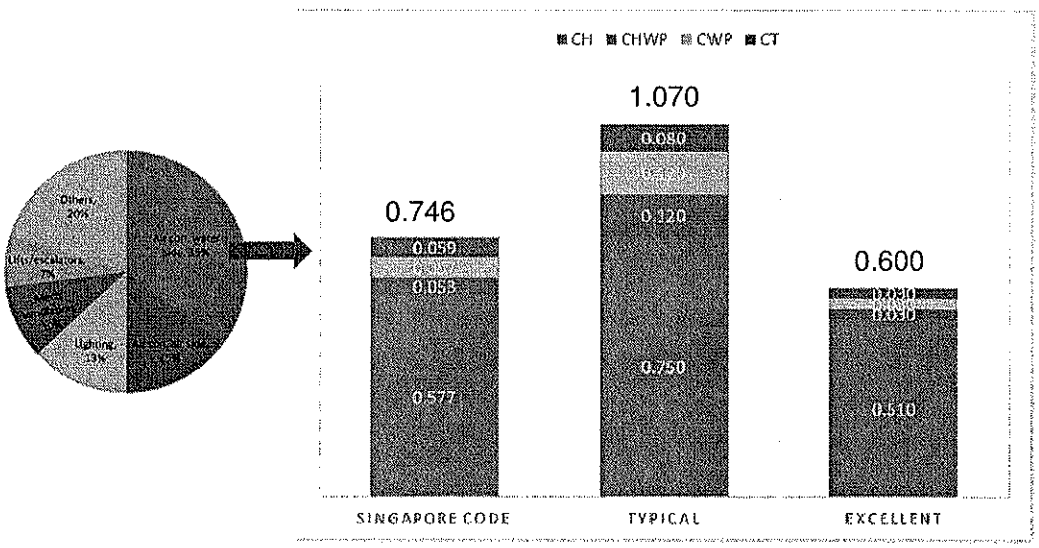
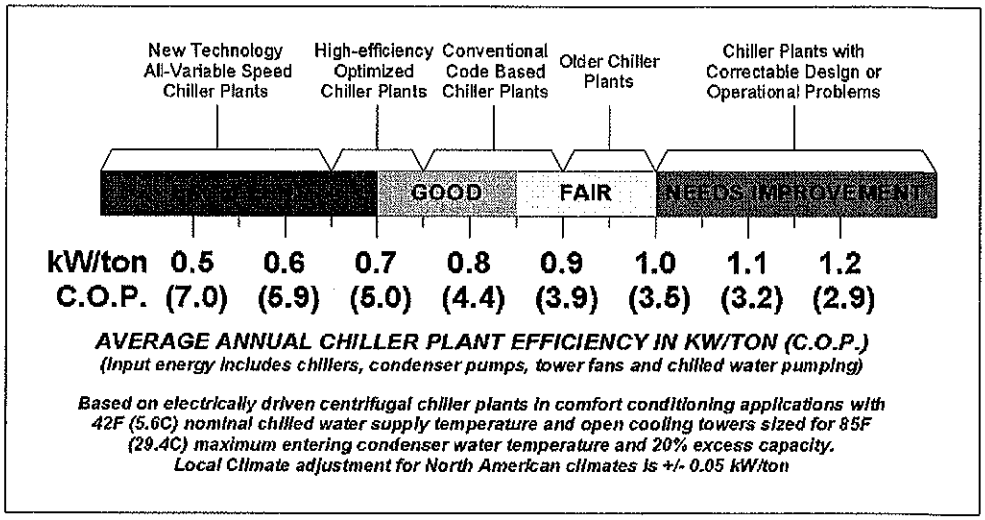


Chiller Plant Efficiency Benchmark

By Thomas Hartman Ashrae Journal



AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, condenser pumps, tower fans and chilled water pumping)

Based on electrically driven centrifugal chiller plants in comfort conditioning applications with 42F (5.6C) nominal chilled water supply temperature and open cooling towers sized for 85F (29.4C) maximum entering condenser water temperature and 20% excess capacity. Local climate adjustment for North American climates is +/- 0.05 kW/ton

CHILLER OPTIMIZATION

Chiller plant configuration

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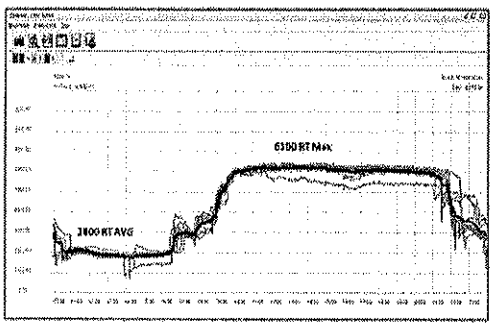
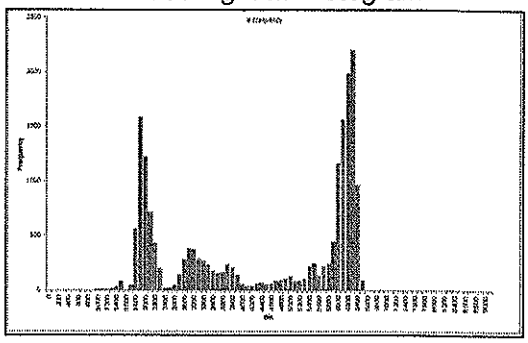
Get the chiller plant configuration optimized by plotting
- Minimum 1 week cooling load profile
- Cooling load histogram

1 week cooling load profile



Cooling load histogram



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Chiller plant configuration

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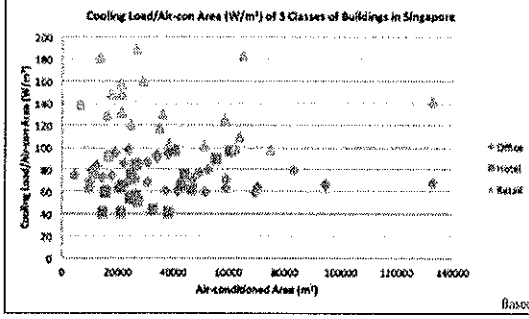
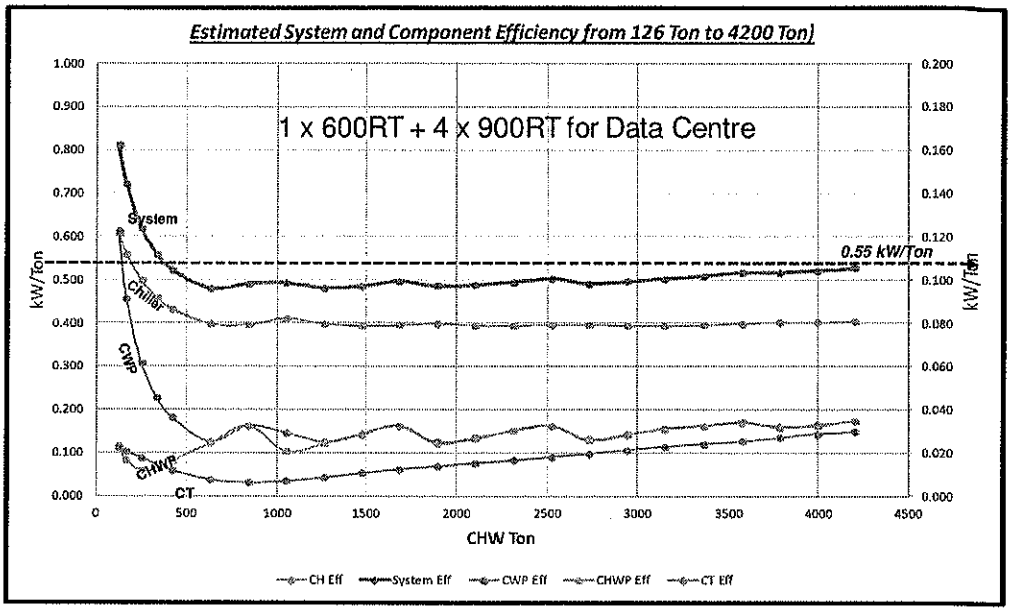
- Cooling load calculations for new buildings are for worst case scenarios.
- Bench mark design cooling load calculations with similar type of buildings to provide "sanity" check whether there are potential oversizing.
- While chiller plant may be <u>designed for maximum anticipated load</u>, it must also be <u>design to be efficient at minimum anticipated cooling load too</u>.

	Measured Cooling Load/Air-con Area (W/m²)	
	Range	Average
Office (35 projects)	60 – 92	76
[illegible]	[illegible]	[illegible]
Retail (21 projects)	93 – 190	135



Based on data from BCA and NEA

Chiller plant configuration



Chiller plant configuration

Data Centre example

1 x 600RT + 4 x 900RT configuration

Energy efficient over wide range

Load (RT)	Operation stage	Chiller loading range	range	Chiller efficiency 600RT KW/RT range		900RT KW/RT range	
4200	1 x 600 + 4 x 900	100%	86%	0.412	0.418	0.400	0.395
3600	4 x 900	100%	75%	-	-	0.400	0.397
2700	3 x 900	100%	67%	-	-	0.400	0.403
1800	2 x 900	100%	50%	-	-	0.400	0.427
900	1 x 900	100%	67%	-	-	0.400	0.403
600	1 x 600	100%	50%	0.412	0.450	-	-

Chiller plant configuration

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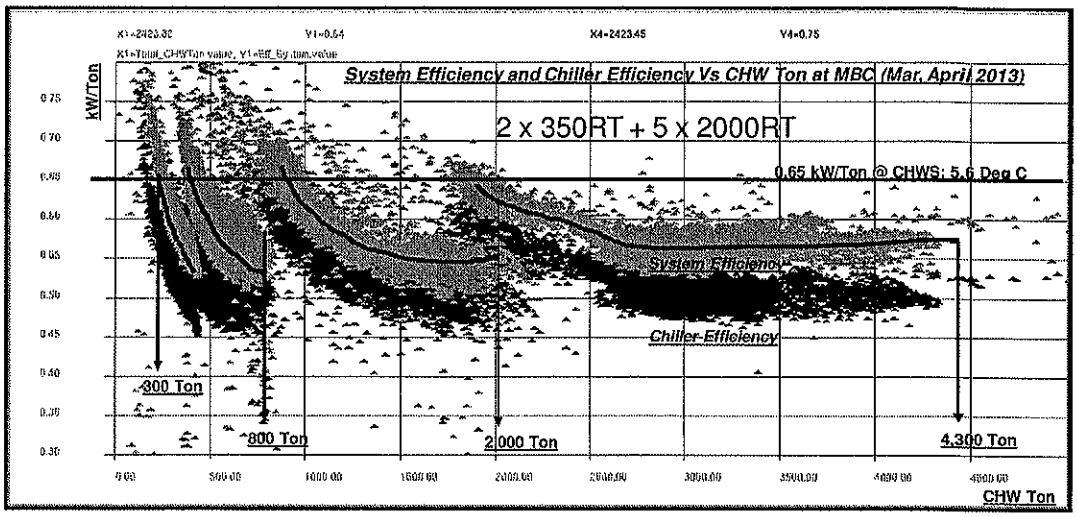
Accurate sensing and Optimization Control can optimize the system efficiency not only at 1 point but almost 90% of the load range.



W/C Chiller part load performance

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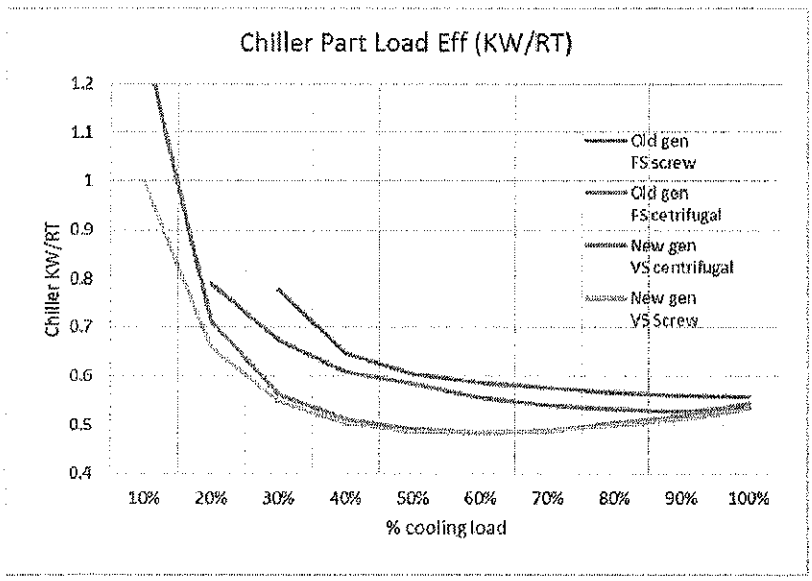


Old gen fixed speed chillers (R134a)
Peak eff: ~ 0.530 to 0.54 KW/RT
Peak eff point: 80-90% load

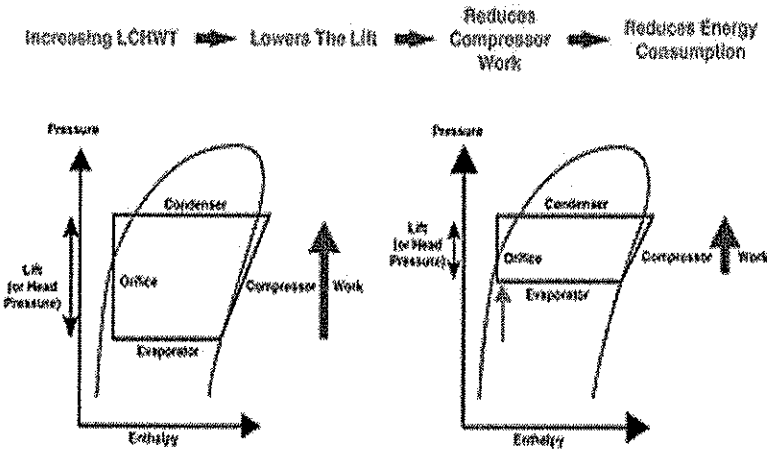
New gen variable speed chillers (R134a)
Peak eff: ~ 0.49 to 0.50 KW/RT
Peak eff point: 50-60% load

Performance rated at
CHW: 6.70C at fixed 2.4gpm/RT
CW: 29.4C at fixed 3.0 gpm/RT

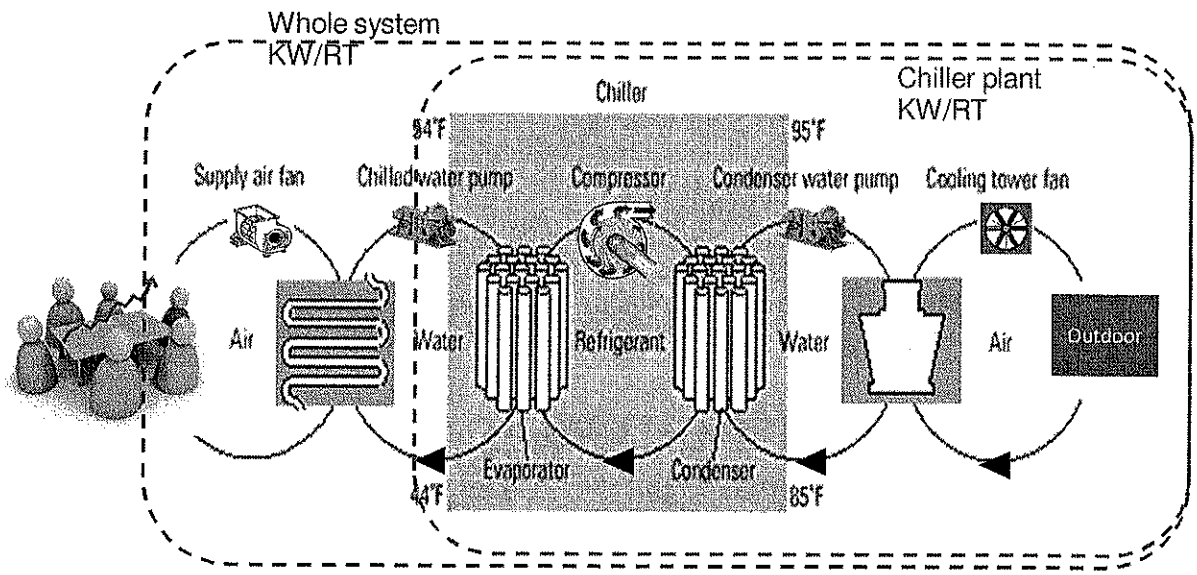
Chiller performance are indicative and do not represent any particular brand.

Microsoft Excel Worksheet

Chilled water supply temperature



Chilled water supply temperature



Consider whole system energy efficiency and cost

CHW temp (supply / return)	Option #1 6.7 / 12.2C		Option #2 8.0 / 15.0C	
Description	Eff (KW/RT)	Cost (S$)	Eff (KW/RT)	Cost (S$)
1 x 600RT Chiller	0.530	305,000	0.516 ↓	305,000 —
1 x CHW pump	0.042	9,200	0.023 ↓	8,500 ↓
20 x 30RT AHUs	0.227	200,000	0.236 ↑	220,000 ↑
Total	**0.799**	**514,200**	**0.775** ↓	**533,500** ↑
Annual energy cost	301,616		292,747	
Simple payback	Base		**2.2**	

Based on 55 hrs/ week and $0.22/kwh

Every 1°C increase in CHW temp ⇒ 2-3% chiller efficiency improvement.

chiller cost $500/RT

Chilled water supply temperature

- Potential to reset CHW temperature upwards when the cooling coils are oversized.
- Especially so at off-peak periods.
- Consider whole system efficiency. Eg Higher CHW temp will save chiller energy but may increase CHWP and VAV AHU fan energy.
- Consider humidity when raising CHW temperature.

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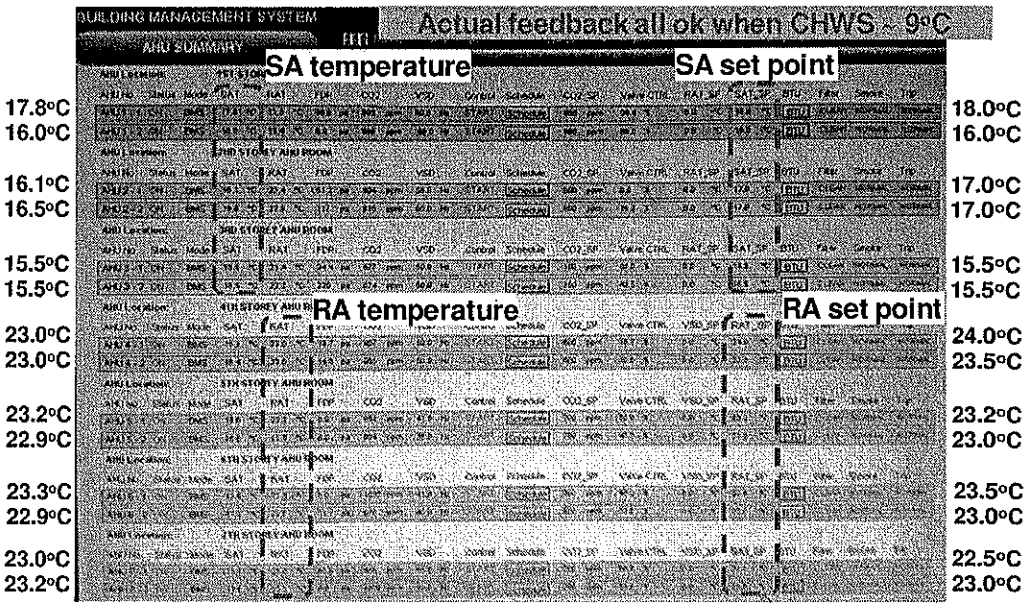
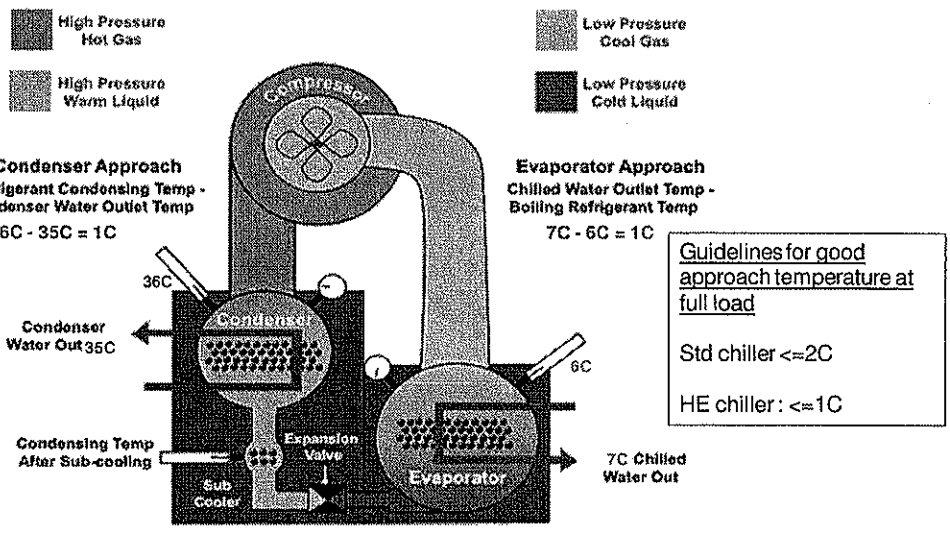
Chilled water supply temperature



Hx Efficiency and Approach Temperature



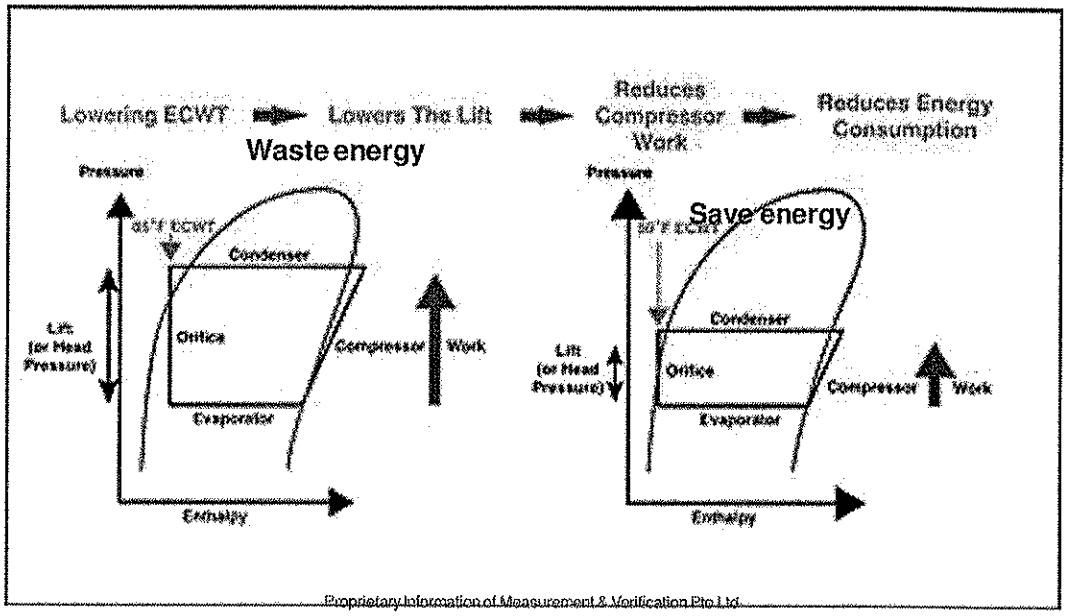
indicator of coil condition.

Guidelines for good approach temperature at full load

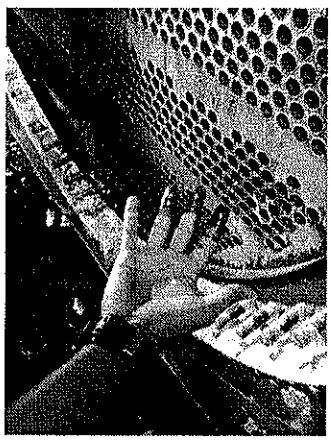
Std chiller <=2C

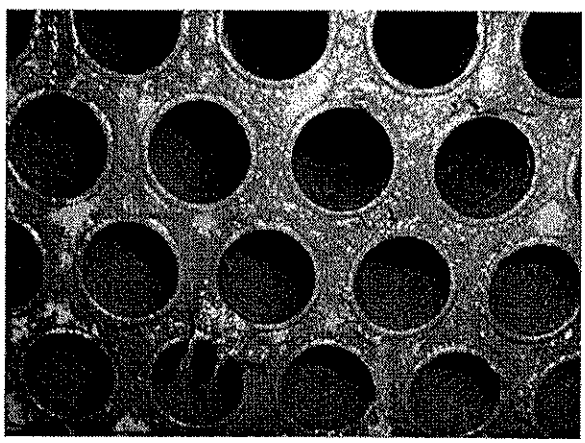
HE chiller : <=1C

Compressor Lift (Condenser Side)



Dirty Evaporator





Dirty Condenser

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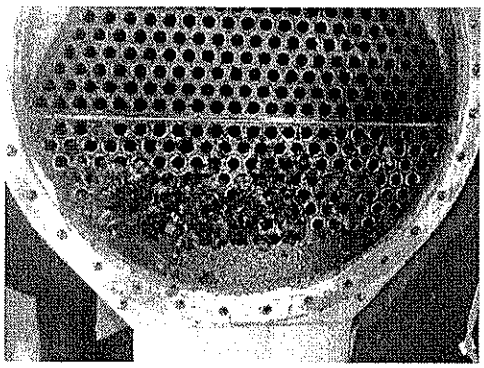

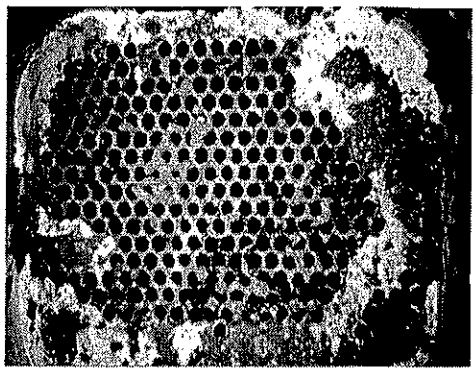

Auto tube cleaners

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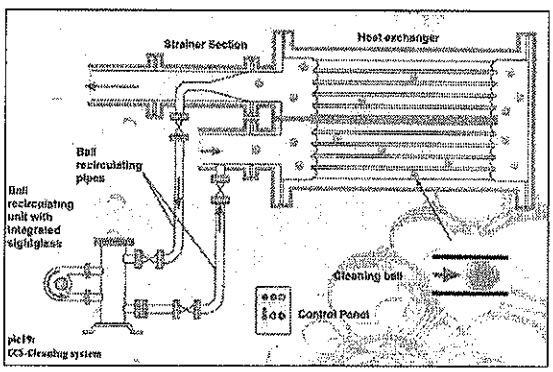
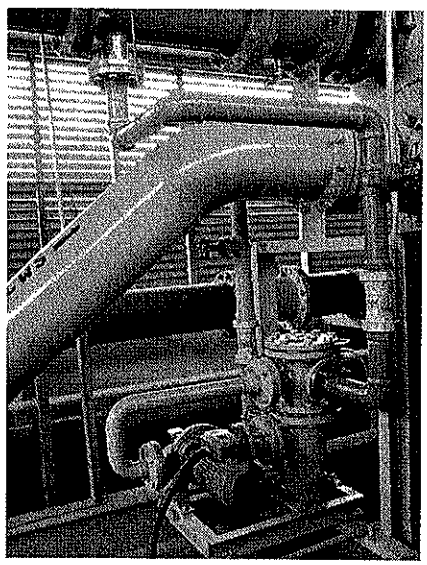
Your teeth if you only brush once a year



Auto tube cleaners for chillers





Hx Efficiency and Approach Temperature

- Use EMS to monitor and trend approach temperatures
  - Via high level interface with chiller
  - Evaporator approach (< 1C)
  - Condenser approach (< 1C)

- Use EMS to monitor and trend condenser water quality
  - Via analog output from water treatment system
  - pH (Control limits: 7-9)
  - Total Dissolved Solids TDS (< 2500 µS/cm)

Penalty for performance ~~based~~ guarantee

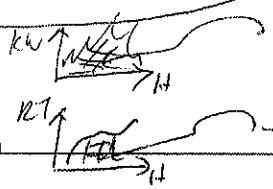
Contract

$1000_{RT} \times 8760\ hrs \times (0.7 - 0.6\ kW/RT) \times 0.20¢/kWHr$

$\Delta\ kW/RT$

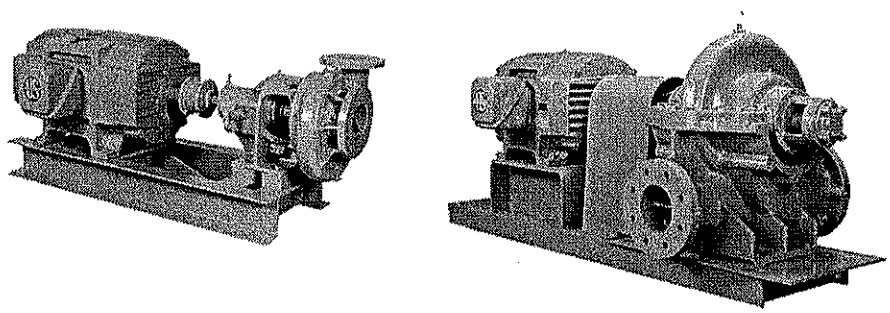
← Continuous monitoring.

kW/RT < Elec consumption, Cooling load (RT)

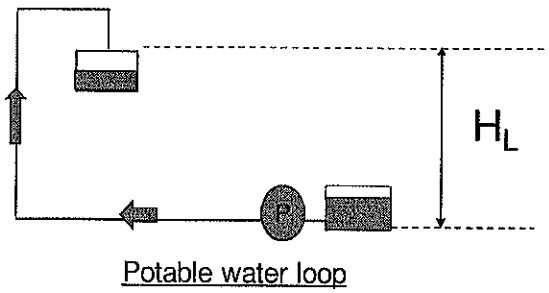


Area under curve ⇒ $\frac{kW \times Hr}{RT \times Hr}$

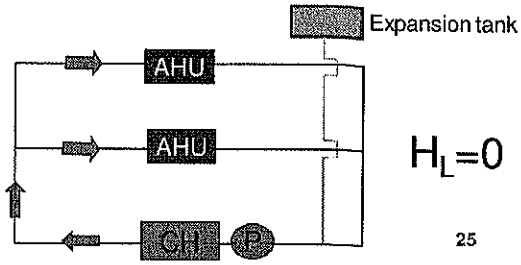
CHWP OPTIMIZATION



Right size pump head



Potable water loop



CHW water loop

25

$H_p = H_L + H_E + H_F$

H_p: Pump head
H_L: Static lift
H_E: Equipment friction loss at design flow
H_F: Pipe and fitting friction loss at design flow

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Right size pump head

- Design "fat & straight pipe and small pump" instead of "spaghetti pipe and big pump".
- Size pipe to be between pressure drop of 1 to 2 ft / 100ft
- Design for high DT cooling coil to get lower flow per KWc (gpm/RT)
- Select low pressure drop evaporators : < 10' WG (36 kpa)
- Select low pressure drop cooling coils: < 12' WG (36kap)
- Select low pressure drop control valves: < 10' WG (30kpa)

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Select HE pump and motors

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Small size pumps (700 to 1200 gpm)
End suction pump
Pump Efficiency >82%
Motor Efficiency> 92%

Medium size pump (1200 to 2000 gpm)
End suction or Split casing pump
Efficiency > 84%
Motor Efficiency > 93%

Large size pump (>2000 gpm)
Split casing
Efficiency > 85%
Motor Efficiency > 95%

Case Comparison

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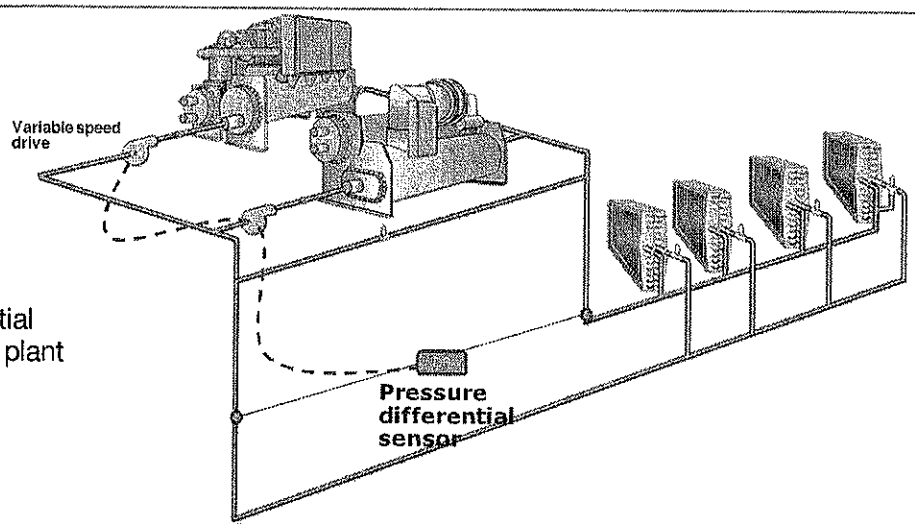
Description	Units	Conventional design	Low pressure design	Remarks
Flow rate	Gpm	2,400	2,400	
Chiller evaporator pressure drop	Ft wg	25	12	
AHU coil pressure drop	Ft wg	25	10	
Control valve pressure drop	Ft wg	25	10	
Pipe and fittings	Ft wg	150	30	Spaghetti vs fat & straight
Resulting pump head	Ft wg	225	62	
Pump eff	%	75%	85%	
motor eff	%	90%	95%	

Microsoft Excel Worksheet

Case Comparison

Description	Units	Conventional design	Low pressure design	Savings
Power Input	KW	150.7	34.7	116.0
Operating hours / year	Hrs	8,760	8,760	-
Annual Energy	KWH	1,320,194	304,094	1,016,100
Elect tariff	$/kwh	0.25	0.25	-
Annual operating cost	S$	330,048	76,024	254,025
CO2 emission	kg	660,097	152,047	508,050

Pump speed control

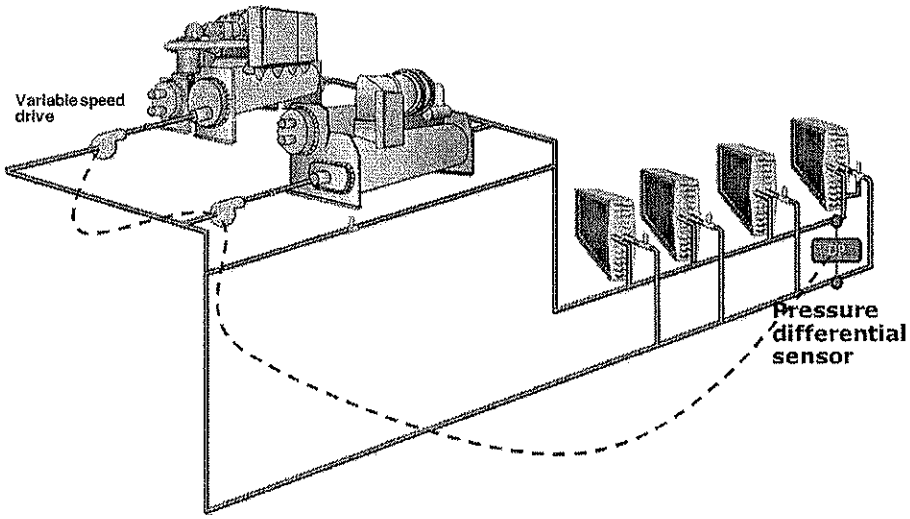


Pressure differential sensor located at plant room

1-way modulating valve for variable primary sys

The distribution pump is typically equipped with a variable-speed drive that is controlled to maintain a certain pressure difference between the supply- and return-water piping. In response to a reduced cooling load, the two-way valve modulates closed, restricting the flow of water through the coil. This causes an increase in system differential pressure, which can be measured and used to signal a reduction in the speed of the distribution pump. In many CHW plants, the differential pressure sensor is located in the chiller plant room out of convenience.

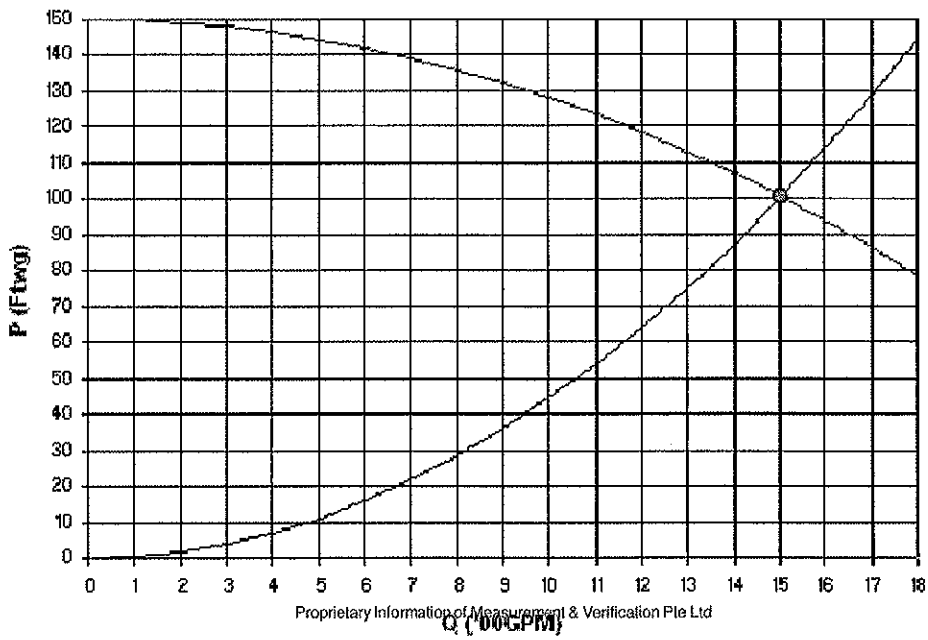
Pump speed control



Pressure differential sensor located at remote AHU

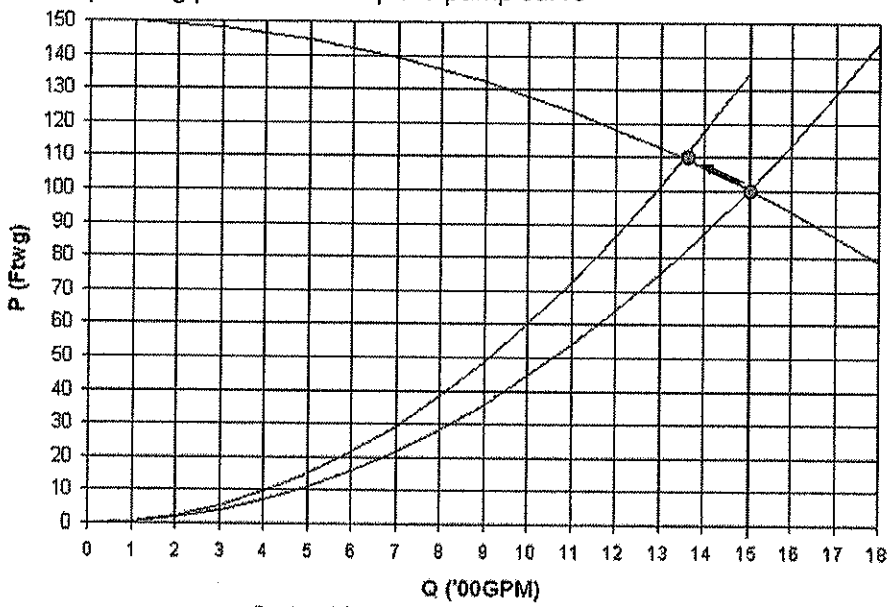
The differential pressure senor could also be place at a remote AHU location. However this entails more wiring.

CHWP speed control using DP sensor Full load



CHWP speed control
Part load

Operating point will ride up the pump curve



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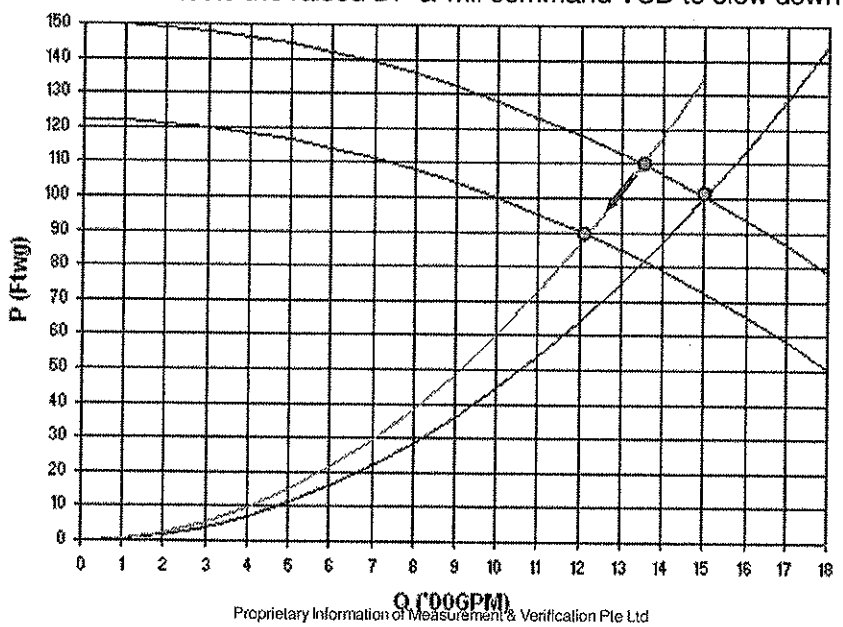
CHWP speed control
Part load

The DP sensor detects the raised DP & will command VSD to slow down



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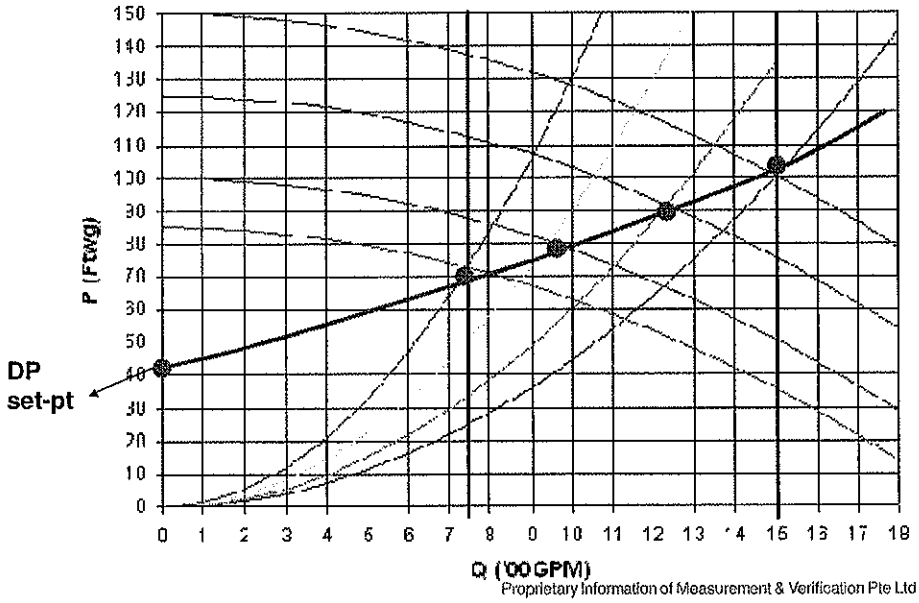
CHWP speed control
Part load



The system unloading curve is represented by the red line which ends at the DP set-point.

To optimize the pumping energy at part load, the DP sensor should be placed at the most remote AHU. If the DP sensor is placed near the pumps, the DP sensor set-point will have to be higher. This will reduce the unloading potential of the pumps.

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CHWP speed control
Dynamic set-point

The building automation system shall monitor the valve position of all valves and determine the system's critical zone valve (CZ), which is the valve that is the widest open.

instead of pressure at remote most

Critical zone valve position	
>95% open	Reset pump DP pressure set-point upwards
	Do nothing
<85% open	Reset pump DP pressure set-point downwards

Beware: Just one wrong valve position or feedback can lead to wrong CHWP speed control

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wrong thermostat setpoint also (ie. low temperature setpoint)

CHWP speed control

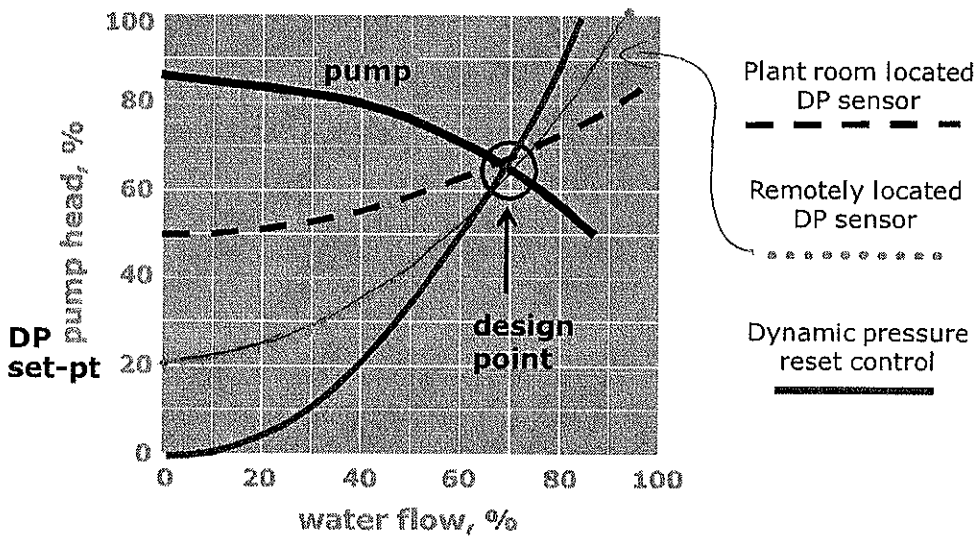
Dynamic set-point

The DP set-point can by dynamically set based on other parameters such as:

1. # of chillers operating
2. Cooling load
3. Peak period and off peak period

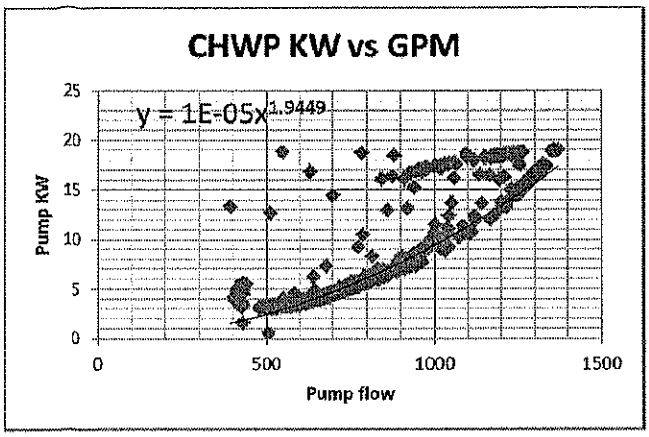
The set-point has to be optimized and fine tuned for each project to attain the sweet spot.

CHWP speed control



CHWP Part Load Efficiency

Actual measurement where pump speed is controlled by DP at riser.



Pump affinity law only applies when system curve does not change as flow varies.

In most CHW systems, the system curve becomes steeper during part load as modulating valves throttle to reduce cooling.

<u>If pump speed is controlled by DP,</u>

KW $\propto$ (flow) $^{1.5 \text{ to } 2.3}$

<u>If pump speed is controlled by dynamic reset,</u>

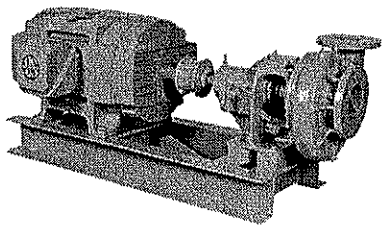
KW $\propto$ (flow) $^{2.5 \text{ to } 3}$

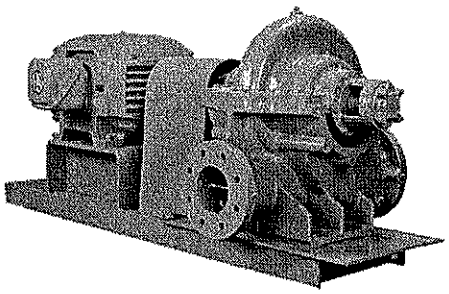
Pump law
$\Rightarrow kW \propto Q^3$

CHWP speed control

- CHWP speed turn-down ratio is limited by Chiller Min Allowable Flow.
- Typical min allowable flow is 50 to 75% range. for evaporator
- Chiller efficiency is typically unaffected when flow is above the minimum so VPF is always recommended.
- Chiller with lower minim allowable flow is preferred as it can help save pump power.
- EMS must be programmed to modulate open the by-pass pipe control valve to keep the flow through each chiller above the minimum limit.

CWP OPTIMIZATION





Right size pump head

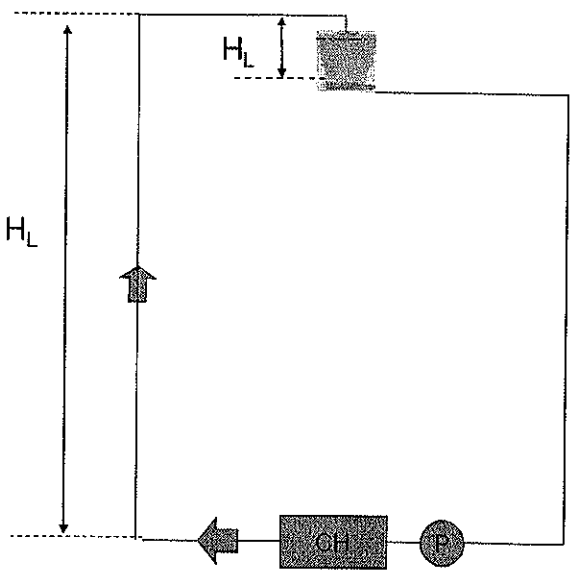
$H_p = H_L + H_E + H_F$

H_p: Pump head

H_L: Static lift

H_E: Equipment friction loss at design flow

H_F: Pipe and fitting friction loss at design flow



Common mistake to assume HL is = height of building because CW loop is open

Right size pump head

- Design "fat & straight pipe and small pump" instead of "spaghetti pipe and big pump".
- Size pipe to be between pressure drop of 1 to 2 ft / 100ft
- Select low pressure drop condenser: < 12' WG (36 kpa)
- Select low pressure drop cooling tower: < 10' WG (30kpa)

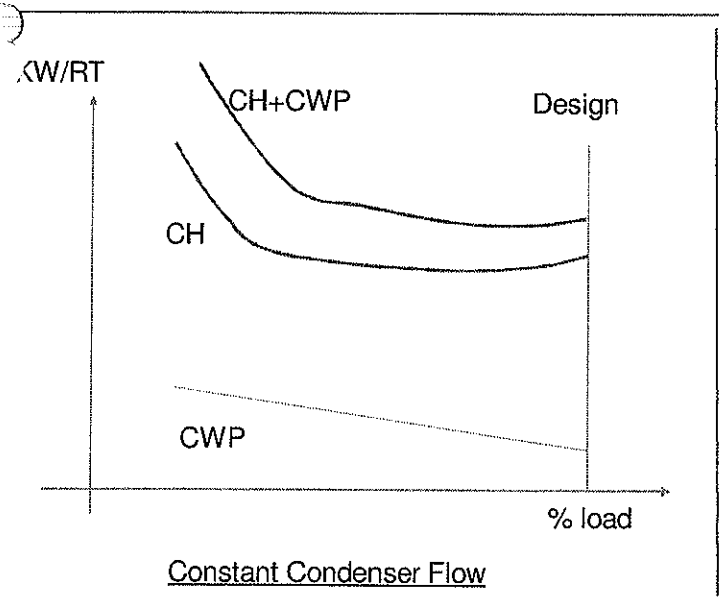
CWP Part Load Efficiency

- There are no control valves CW system, so the system curve does not change at part load.
- Therefore, for variable condenser flow system, the pump affinity laws applies:
  - Head $\propto$ $(\text{flow})^2$
  - Power $\propto$ $(\text{flow})^3$

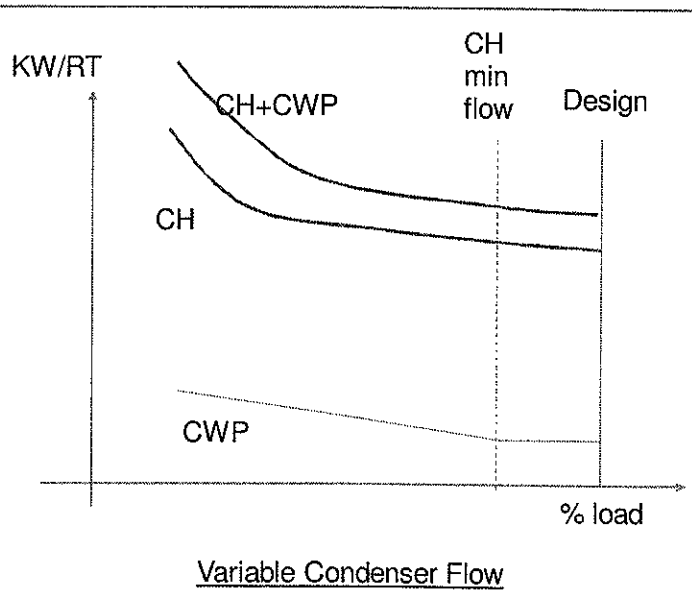
CWP speed control

- Chiller efficiency is sensitive to reduction in condenser water flow. Need to consider the net benefit when applying variable condenser water flow.
- Most projects use CWP VSD as only "adjustable only" ie adjust VSD speed to achieve design flow only.
- Variable flow control method can be gpm/RT.
- The set point needs to be fine tuned at site. Depends on chiller characteristics and pump size.
- Flow turn-down is limited by Chiller Allowable Min Flow.
- Typically minimum allowable is only about 80% of design flow.

CWP speed control

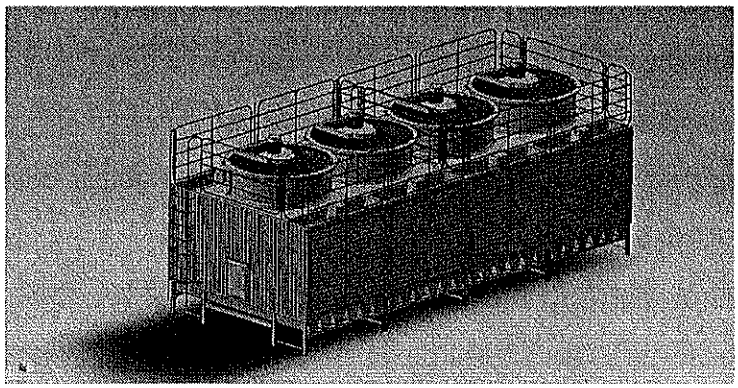


Constant Condenser Flow



Variable Condenser Flow

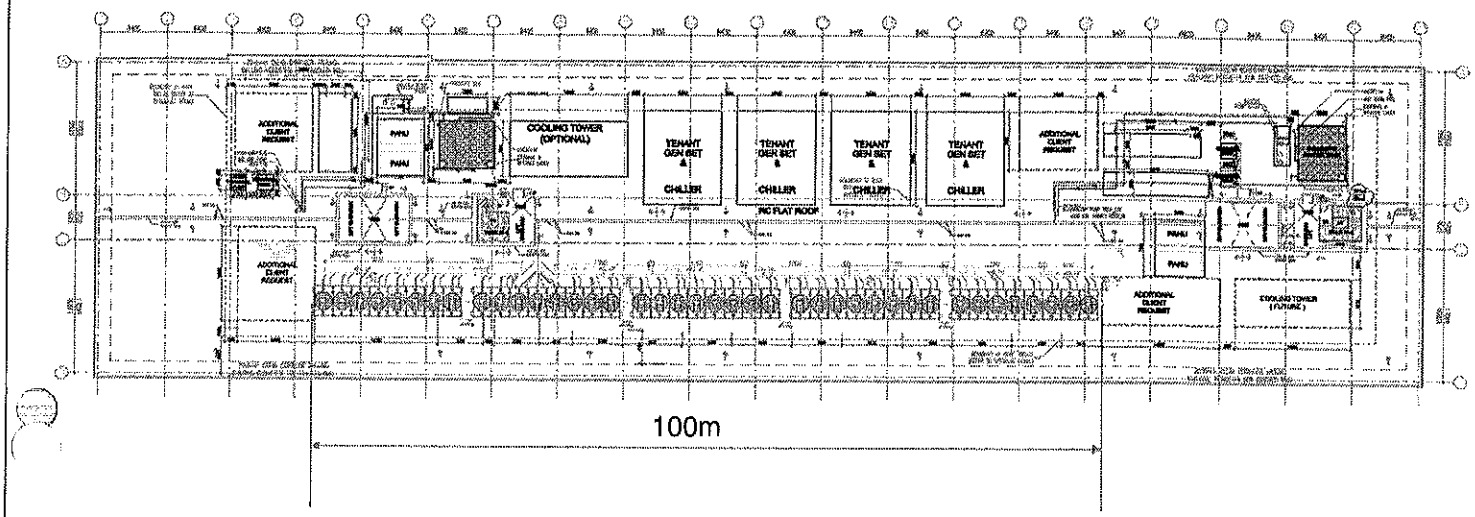
COOLING TOWER OPTIMIZATION



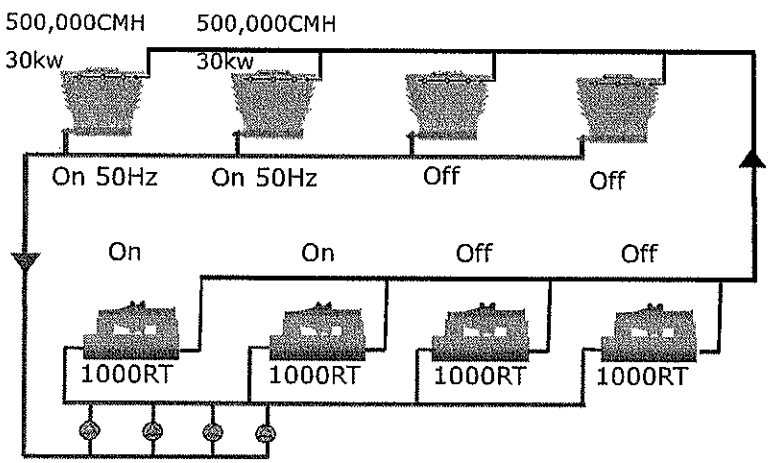
Cooling tower layout

- High efficiency chiller plant is not possible if CT heat rejection path is congested.
- This message has to "hammered" into owners and architects who are used to cramming and camouflaging cooling towers.
- The ideal CT layout is in a straight row with at least "1H" of clearance on the air intake side.
  - Where 1H is the height of the cooling tower infill.

Cooling tower layout



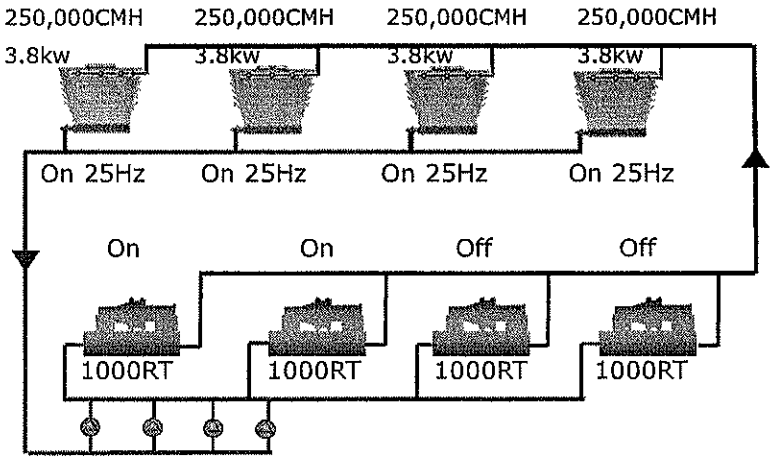
Conventional Cooling Tower Operation



Total CMH=1,000,000

Total KWi = 60

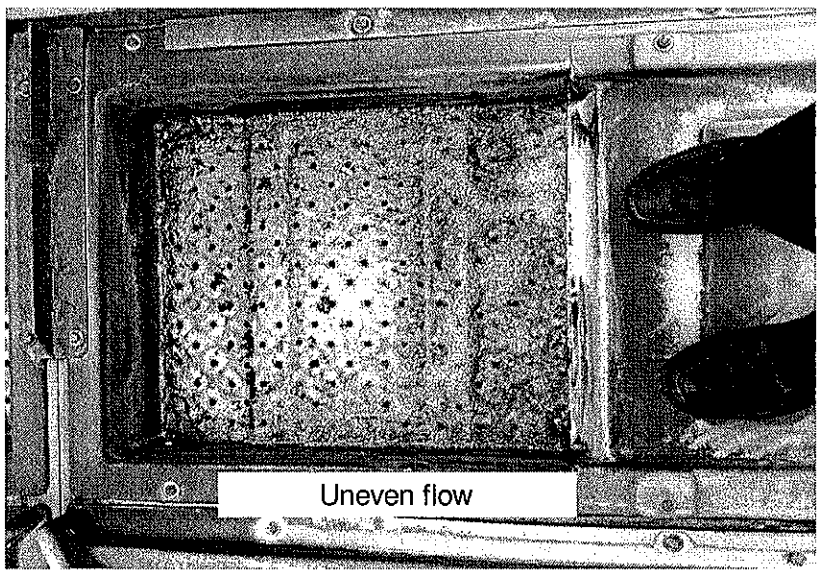
Cooling Tower Operation Optimization



$$\text{Individual CT KW} = \left(\frac{250{,}000}{500{,}000}\right)^3 \times 30\text{KW} = 3.8\text{KW}$$

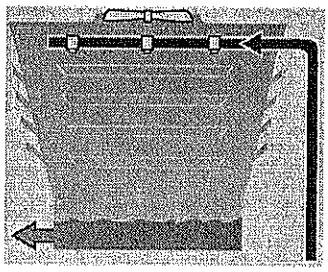
Total CMH=1,000,000
Total KWi = 15.2

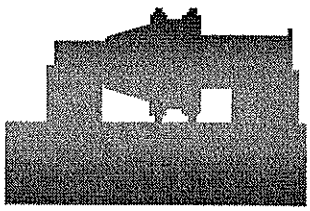
Cooling Tower Operation



Beware of uneven flow into cooling towers infills when there are many more CTs in operation for lesser chillers

Operating Dependencies

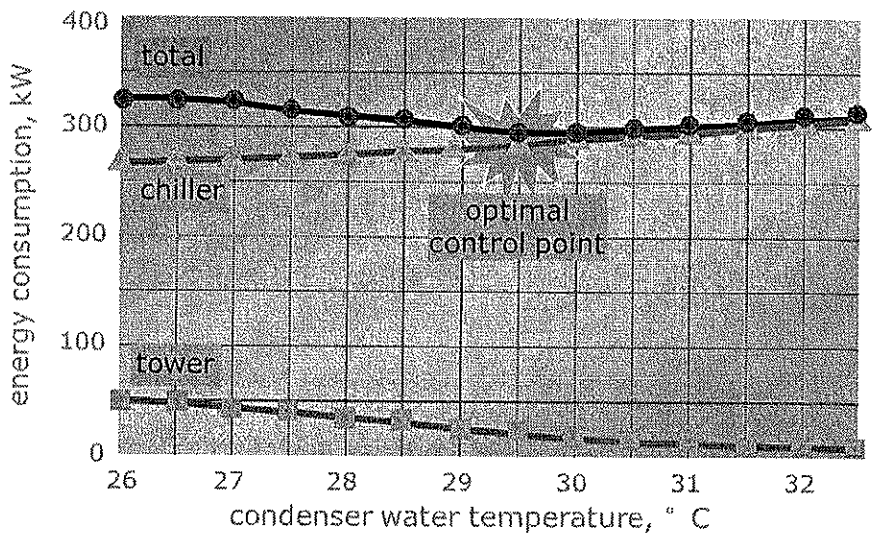




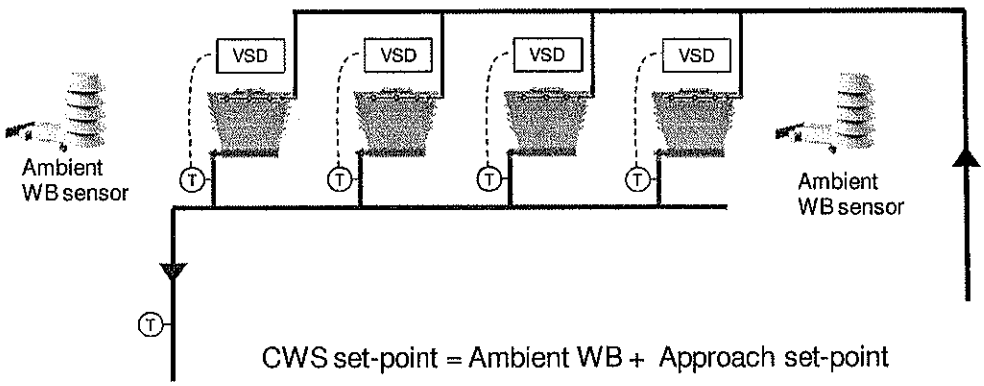
- Wet bulb
- Condenser water temperature
- Load
- Tower design

- Load
- Condenser water temperature
- Chiller design

Chiller–Tower Interaction

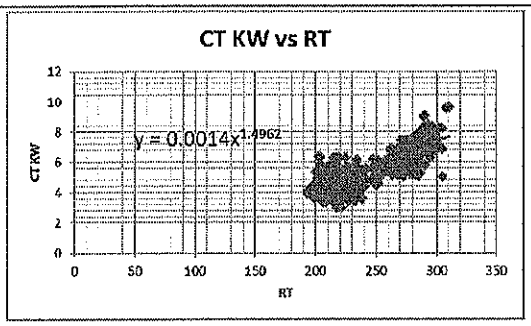


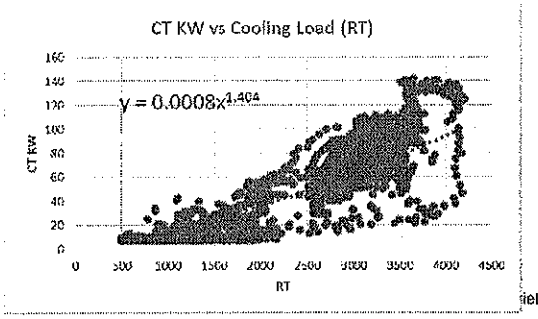
Cooling Tower Fan Speed Control



- Where ambient WB is favorable, CWS temperature set-point is lowered to reduce chiller energy.
- Approach set-point is fine-tune at site for best overall CT and chiller energy net efficiency.
- Approach set-point can be variable based on # of CTs, cooling load or on/off peak period.
- Good practice to have multiple sensors to enable continuous consistency checks.

CT Part Load Efficiency





The cooling tower fan head and fan power follows closely to the affinity law as airflow is reduced.

However, the CW evaporation effect is affected at part load because less air crosses the water.

Furthermore, when more cooling towers are operated in parallel, the CW evaporation effect is affected as the flow down the infill is less turbulent.

Heat rejection is also affected by WB. Therefore, the relationship between CT KW and RT varies widely. Often CT part load performance is not available from suppliers.

KW $\propto$ (RT) $^{1.0 \text{ to } 2.0}$

Optimization of chiller plant

There is no off-the-shelf solution to optimization of a chiller plant.

Optimal efficiency requires each plant to be fine tuned:

- Experienced engineer is essential
- Experienced EMS programmer is essential
- Accurate instruments installed properly is essential
- User friendly EMS is essential
- Powerful graphical trending is essential
- Remote monitoring is essential

THANK YOU

