冷卻水系統節能控制

大綱

1. 冷卻水塔的性能曲線
2. 接近溫度的影響
3. 冷卻水對冰水主機的影響
4. 綠建築有關規定
5. 冷卻水塔的操作與保養

主辦單位: 台北市冷凍空調技師公會
承辦單位: 熱流工程 + 益美高(上海)製冷設備有限公司
時　　間: 2017.05.05

選擇冷卻水塔

- 冷卻水塔所需散熱量為 Q=ṁxCpxΔT
- 選機三要素
  - 冷卻水流量ṁ
  - 進出水溫差ΔT
  - 溼球溫度
- 蒸發器的冷噸+壓縮機輸入的功W=冷凝器需要散的
- 水塔的散熱能力約為冰機的1.25倍，視冰機效率COP而異 (Q=(1+COP)/COP)T

- 通常冰機冷卻水量為 >3gpm/tons or >11.4LPM/ton or >0.19LPS/ton,

  以10 °F (5 ℃)溫差計
- 綠能系統Green System以 >2gpm/ton or >7.57LPM/ton or >0.126LPS/ton

  以 14°F(7.8℃)溫差計
- ASHRAE Greenguide (ΔT = 12 °F -18 °F (7 ℃ ~10 ℃)

選擇冷卻水塔

- 冷凍噸是12,000 Btuh(ARI)
  水塔噸是15,000 Btuh(CTI)
  相差1.25倍
- 如果冷卻水量以每冷噸13LPM計算，5℃溫差(37℃/32℃)，散熱量為3900Kcal/hr (3024kcal/hr =1冷噸) 相差1.3倍
- 冷卻水塔散熱量以KW, MBH,Kcal/hr表示。
  用“噸”(ton)容易混淆
- 同樣散熱量時ΔT=5C (37C/32C)與ΔT=5.5C (100F/90F) 因為流量不同有時會有不同的選型結果
- 冷卻水塔進水溫度上限受制於散熱材的耐溫度
- 出水溫受溼球溫度影響(兩者的差叫“接近溫度)
- 冷卻水塔散熱量 Q=UArΔT
  U:熱交換係數
  Ar:熱交換面積(不是截面積)
  ΔT:對數平均溫差LMTD

選擇冷卻水塔

- 冷卻水塔的耗水量
  蒸發損失+飄散損失+定期排放+飛濺損失
- 蒸發損失是水塔吸入未飽和的空氣在與熱水做熱交換時吸收的水分，損失量與進出水溫差成正比，也是水塔耗水量的主要成分(99%)
- 飄散損失所佔的水量與蒸發損失比很小(0.001%流量)
- 補給水量是循環水量的
  0.72%(ΔT =5℃)
  0.97%(ΔT =7℃)
- 密閉式冷卻水塔用於冷卻水不宜與空氣直接熱交換造成水汙染時，常用於工業用冷卻系統(例如:大型空壓機冷卻)或水冷式直澎空調(水冷VRV)
- 密閉式冷卻水塔雖然冷卻水與空氣無接觸不會有損失但是水塔的內循環仍然會有蒸發+飄散+定期排放損失

濕球溫度對水塔散熱能力影響

Cooling Tower Data Sheet

evapco

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TW
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Date: 9/11/2015 Page: 1

選機條件
Selection Criteria

	Capacity (MBH):	3,000.00
	Capacity (kW):	878.00
	Capacity (kcal/h):	755,088
	Fluid Type:	Water
水量	Flow (LPS):	42.0
進水溫度	Entering Fluid Temp (°C):	37.00
出水溫度	Leaving Fluid Temp (°C):	32.00
濕球溫度	Wet Bulb (°C):	29.00

IBC設計條件
IBC Design Criteria

Seismic Design Force (g)	1g	耐震級數
Velocity Pressure (kPa) :	up to 2.87	耐風壓級數

Product line is CTI/ECC certified. Selection is rated in accordance with CTI Standard 201 RS.

依選機條件
所選出機型的冷卻%能量

Qty	Model		Capacity (kW)	Percent Capacity
1	AT-19-79	263T	926.3	105.5

冷卻能量

Selection Criteria

Capacity (MBH):	3,000.00
Capacity (kW):	878.00
Capacity (kcal/h):	755,088
Fluid Type:	Water
Flow (LPS):	42.0
Entering Fluid Temp (°C):	37.00
Leaving Fluid Temp (°C):	32.00
Wet Bulb (°C):	27.00

IBC Design Criteria

Seismic Design Force (g)	1g
Velocity Pressure (kPa) :	up to 2.87

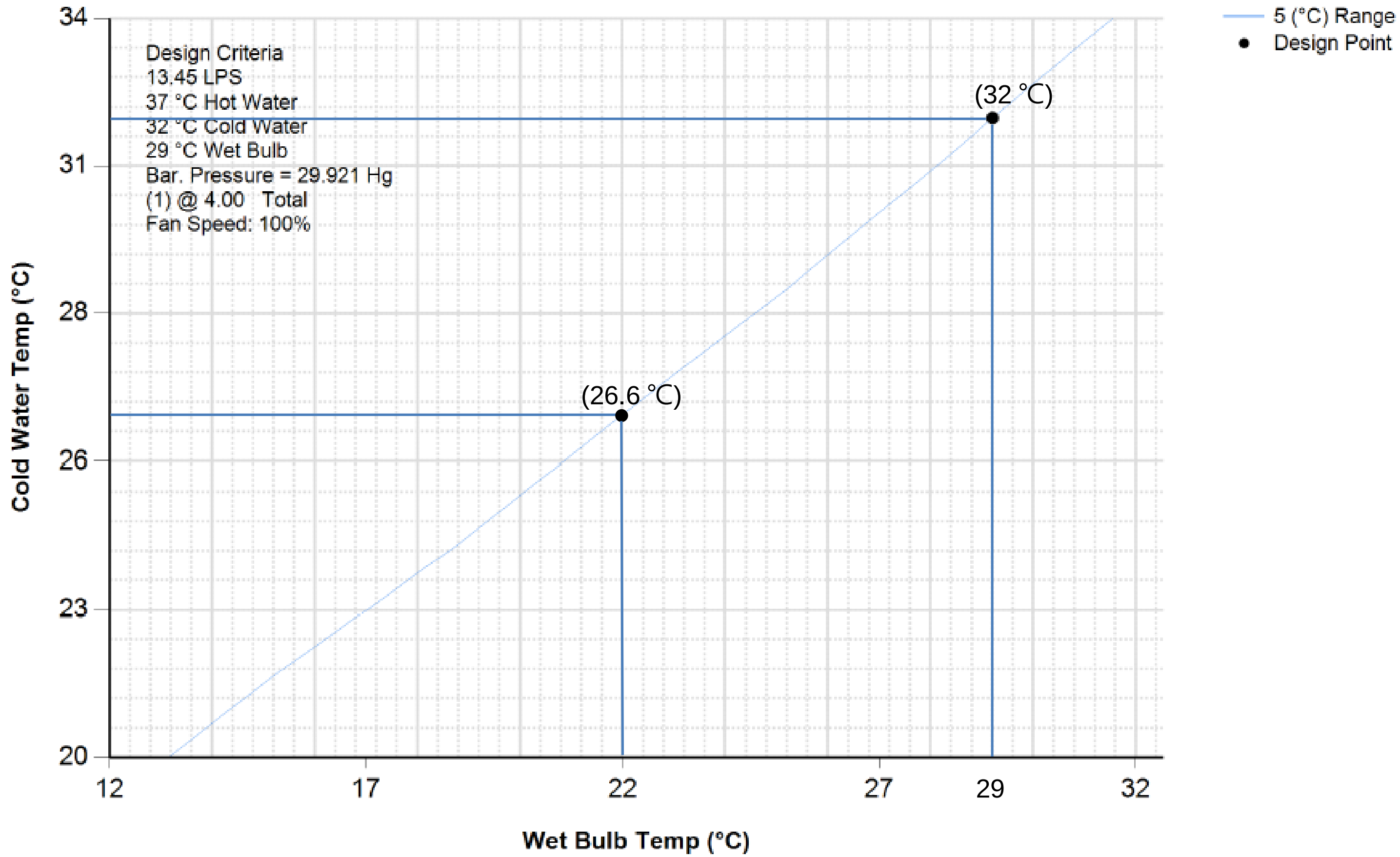
Product line is CTI/ECC certified. Selection is rated in accordance with CTI Standard 201 RS.

Qty	Model		Capacity (kW)	Percent Capacity
1	AT-19-79	350T	1,233.6	140.5

27C比29C 溼球 散熱能力差約35-40%

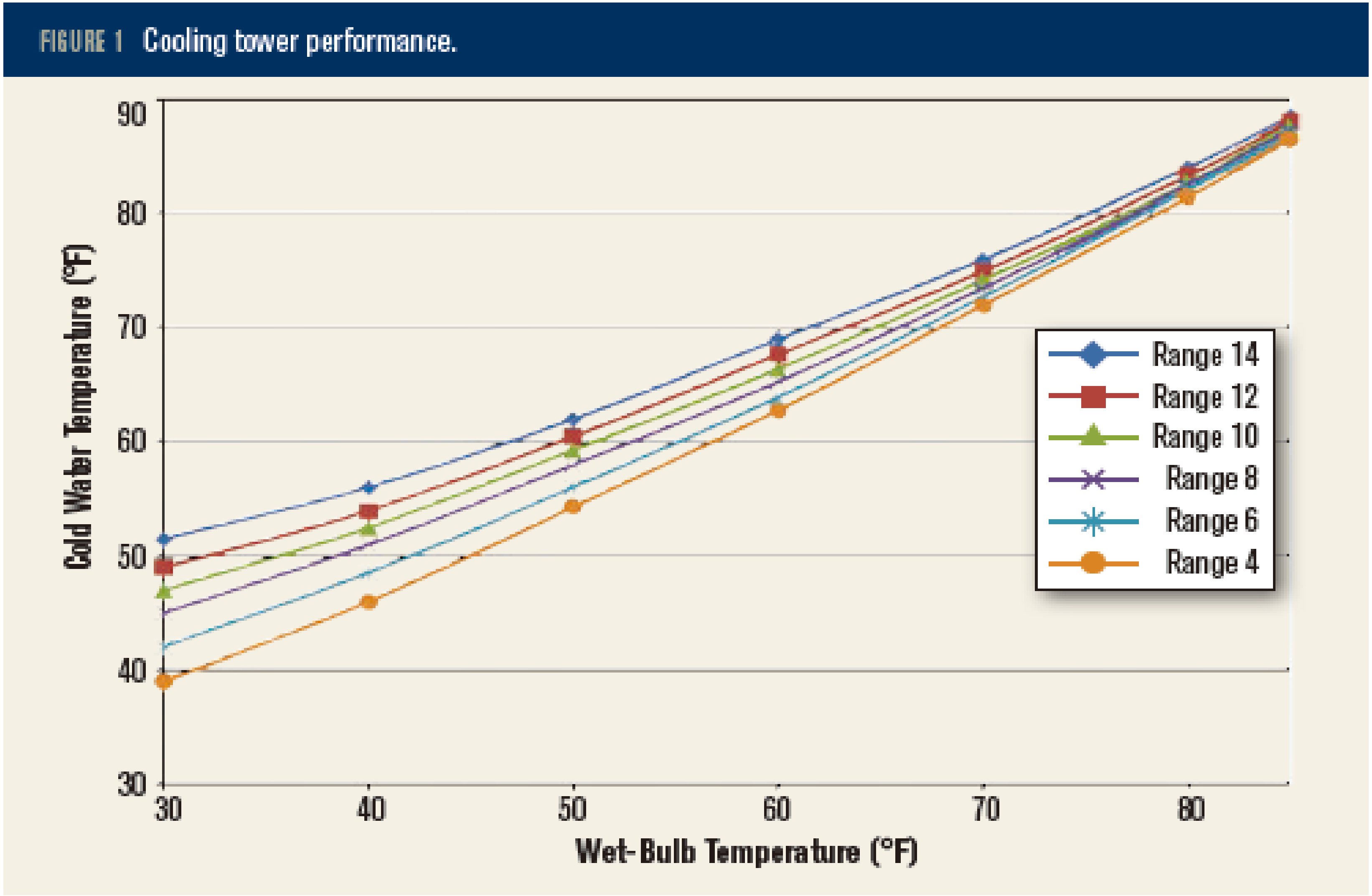
性能曲線

Performance Curve



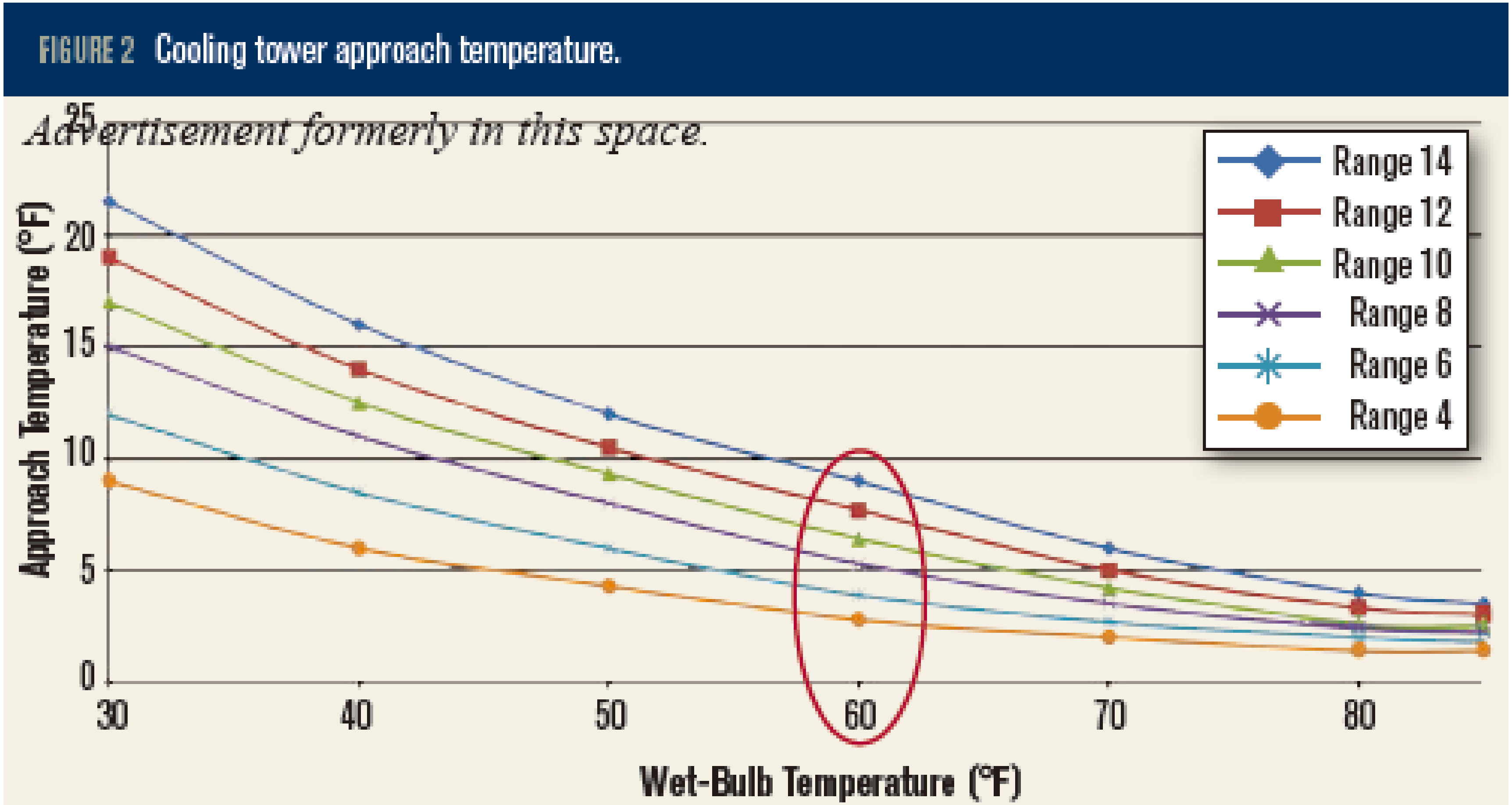
在進出水為固定溫差時溼球溫度對出水溫度的影響(接進溫度改變)

冷卻水塔的性能曲線



不同的溫差(range)對出水溫度的影響

冷卻水塔的接近溫度



溼球溫度下降時水塔的接近溫度也跟著變大
因為低溫的空氣含濕氣量少 大部分的散熱是顯熱

TABLE 1 Cooling tower design performance.	
Chiller Capacity (tons)	500
Colling Tower (Condenser) Flow Rabe (gpm)	1000
Chiller Efficiency (COP)	6.10
Design Wet Bulb (°F)	78
Design Appronach Temperature (°F)	4.5
Tower Entering Water Temperature (°F)	96.5
Tower Leaving Water Temperature (°F)	82.5
Design Range (Condenser Water△T) (°F)	14

TABLE 2 Cooling tower approach temperature at 60°F wet-bulb temperature.

RANGE (°F)	PERCENT LOAD	APPROACH (°F)
4	29%	2.8
6	43%	3.9
8	57%	5.3
10	71%	6.4
12	86%	7.7
14	100%	9.0

TABLE 3 Cooling tower approach temperature at constant load .

WET BULB (°F)	APPROACH (°F)
30	21.5
35	18.6
40	16.0
45	13.9
50	12.0
55	10.4
60	9.0
65	7.4
70	6.0
78	4.5
80	4.0
85	3.5

TABLE 4 Comparison of available Cooling tower Water temperatures.

	INCORRECTLY ASSUMED		ACTUAL (AT 60°F OAWB)	
PERCENT LOAD	APPROACH(°F)	TEMPERATURE AVAILABLE (°F)	APPROACH (°F)	TEMPERATURE AVAILABLE (°F)
29%	4.5	64.5	2.8	62.8
43%	4.5	64.5	3.9	63.9
57%	4.5	64.5	5.3	65.3
71%	4.5	64.5	6.4	66.4
86%	4.5	64.5	7.7	67.7
100%	4.5	64.5	9.0	69.0

錯估接近溫度減少了2.6%~8.5%節能 (Growther and Furlong)

接近溫度對熱回收裝置waterside economizer的 影響

TABLE 4 Comparison of tower approach temperatures.

	INCORRECTLY ASSUMED				ACTUAL			
WET-BULB TEMPERATURE (°F)	APPROACH (°F)	TOWER LEAVING (°F)	TOWER ENTERING (°F)	LOAD HANDLED	APPROACH (°F)	TOWER LEAVING (°F)	TOWER ENTERING (°F)	LOAD HANDLED
30	4.5	34.5	48.5	100%	21.5	51.5	65.5	100%
35	4.5	39.5	53.5	100%	18.6	53.6	67.6	84%
40	4.5	44.5	58.5	100%	16.0	56.0	70.0	60%
45	4.5	49.5	63.5	100%	13.9	58.9	72.9	31%
50	4.5	54.5	68.5	75%	12.0	62.0	76.0	0%
55	4.5	59.5	73.5	25%	10.4	65.4	79.4	0%
60	4.5	66.5	80.5	0%	9.0	69.0	83.0	0%
65	4.5	69.5	83.5	0%	7.4	72.4	86.4	0%
70	4.5	76.5	90.5	0%	6.0	76.0	90.0	0%
78	4.5	82.5	98.5	0%	4.5	86.5	98.5	0%

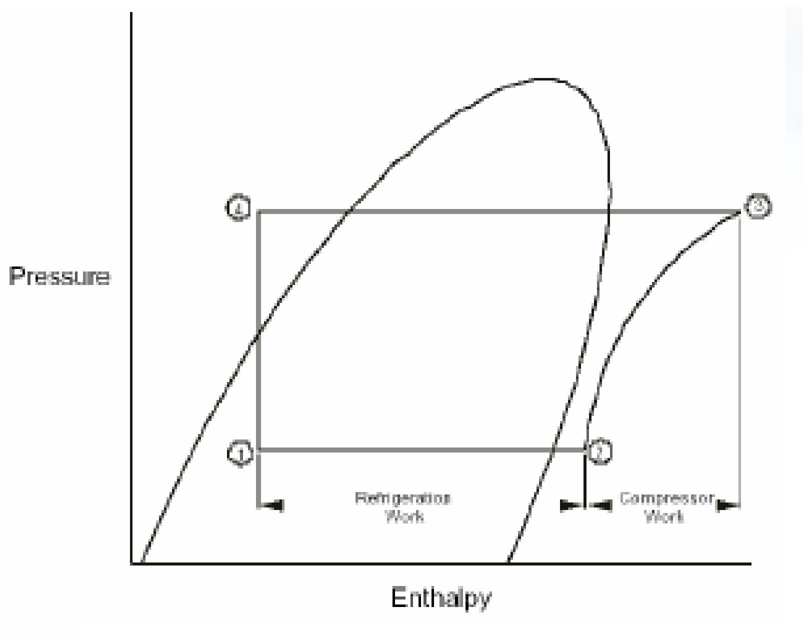
冷卻水出水溫度節能控制

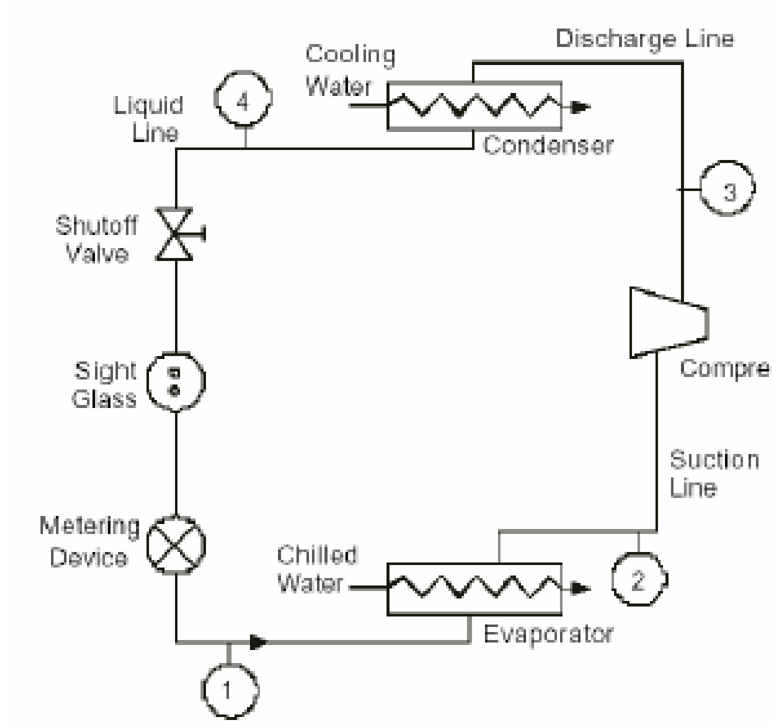
考量的因素:

- 冷卻水塔的選型
- 主機(壓縮機)的型式
- 負載的變化
- 外氣的溼球溫度

可能的控制方式:

1. 維持32℃的出水溫(主機不會出狀況)
2. 出水溫越低越好(主機越省電??)
3. 溼球溫度+接近溫度 or 3℃(控制廠商最愛)
4. 固定主機壓差的出水溫度





<u>冷媒循環圖</u>
冷凝溫度(壓力)與蒸發溫度差就是壓縮機要做的功(耗電量)

<u>冷凍機循環圖</u>
壓縮機需提供冷媒循環的最小壓力

冷卻水出水溫度節能控制

可能的控制方式:

1. 維持32℃的出水溫(主機不會出狀況)
2. 出水溫越低越好(主機越省電??)
3. 溼球溫度+接近溫度(控制廠商最愛)
4. 固定主機壓差的出水溫度

系統最適化

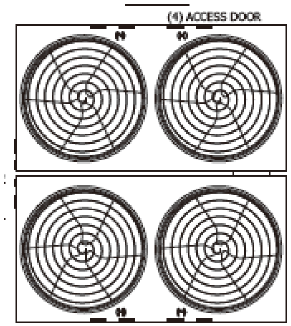
1. 選機:
   - ✓ 冰水主機
   - ✓ 冷卻水塔
   - ✓ 循環泵
2. 順序控制
3. 設定點的選擇

水塔接近溫度的變化

1. 空調負荷下降(散熱量減少時接近溫度減低
2. 空調負荷不變溼球溫度下降時接近溫度增加
3. 冷卻水量減少時接近溫度減少
4. 水塔風車速下降時接近溫度增加

冷卻水塔的選擇

1. 水塔溫差大可以減小冷卻水塔
   a) 降低成本
   b) 提高滿載及輕載的效率
2. 選擇多風機組合
3. 採用變風量VFD裝置



順序控制

Load	Sequencing%
50	50
100	50/50
200	66/66/66
300	75/75/75/75
400	100/100/100/100

順序控制

1. 先用低轉速啟動有水的槽
2. 然後才提高轉速
3. 轉速提高到50%~60%時再啟動下一台(或槽)
4. 當有多台在運轉時要用同一轉速可確保同溫度的出水
5. 用多台低轉速比單台高轉速省電 但是水塔的流量範圍不大所以彈性不多
6. 負載減小時先減速風扇到零再關水
7. 盡量不要調節冷卻水量避免主機壓差不夠(調節冷卻水量會影響主機及水塔的效率)

不要給做控制的技術員決定順序控制

節能控制-最適化

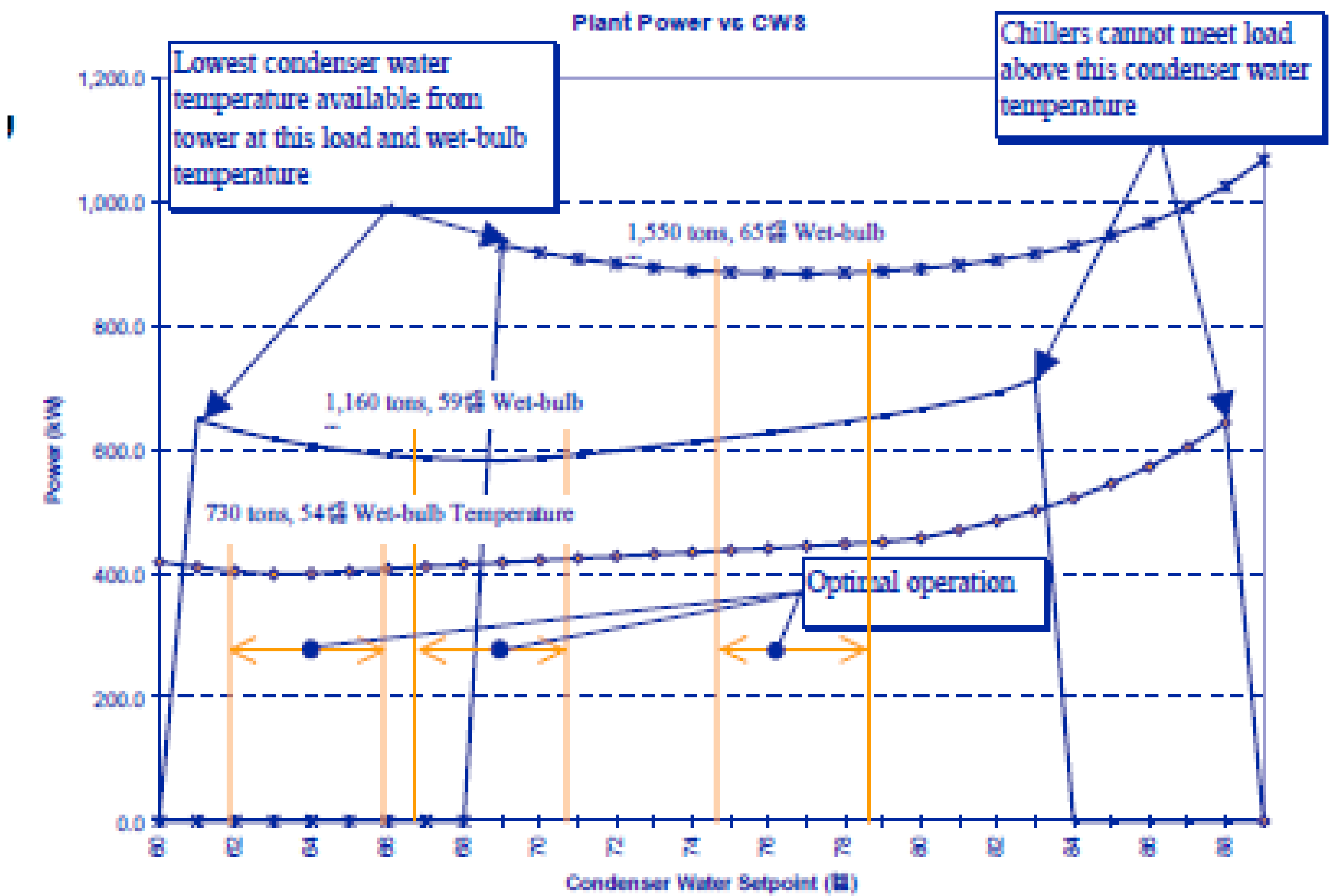
系統最適化

1. 選機：冰水主機 冷卻水塔 循環泵
2. 順序控制
3. 設定點的選擇

設定點的決定:

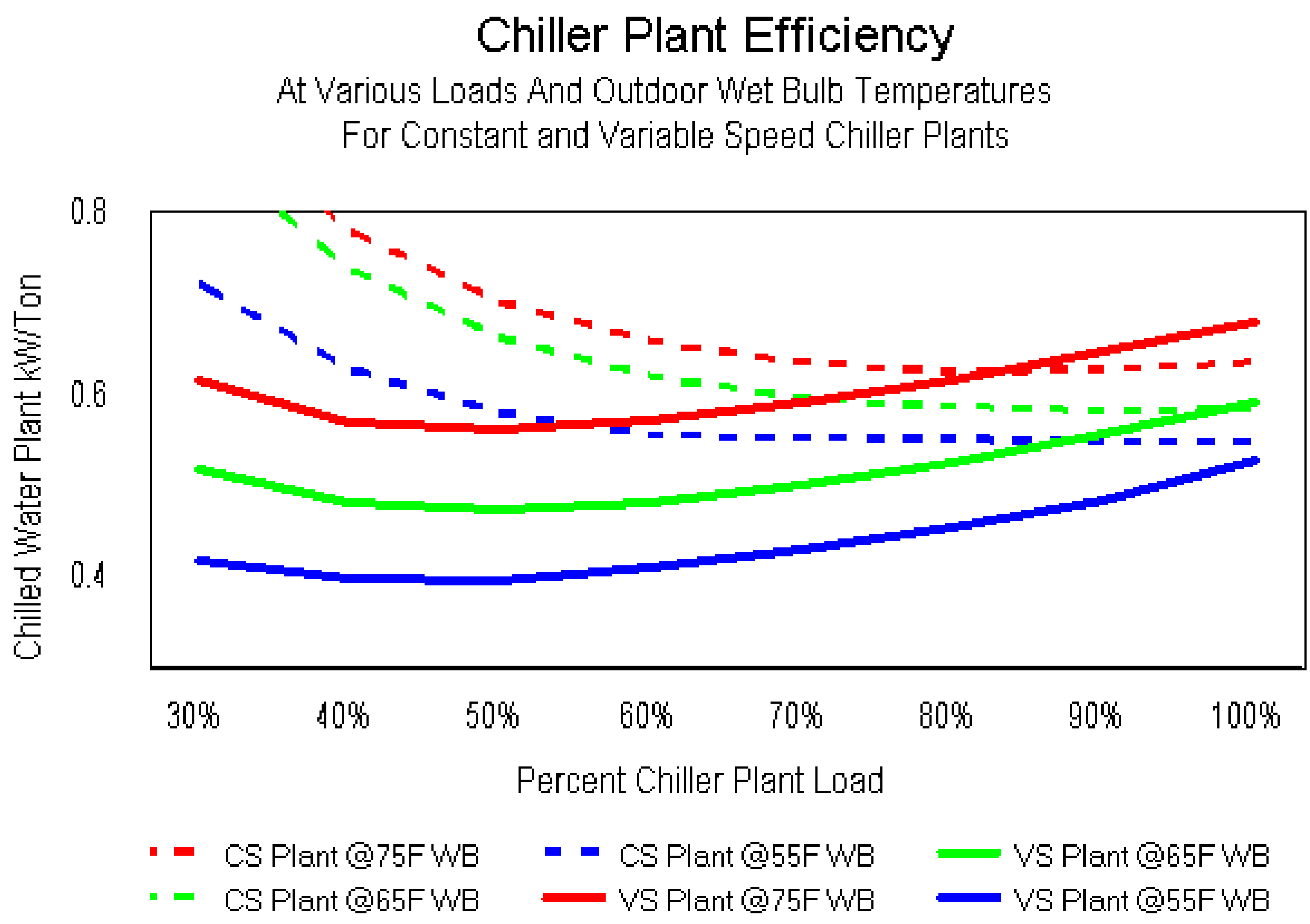
1. 不是所有的冰機在冷卻水溫下降時效率變高
2. 螺旋機在水溫下降一段距離後耗電變高
3. 接近溫度在溼球溫降低時會變大
4. 溫差越大的改變越大

最佳設定點是動態的:隨著溼球溫度，系統負荷，主機，和水塔的效率變動。

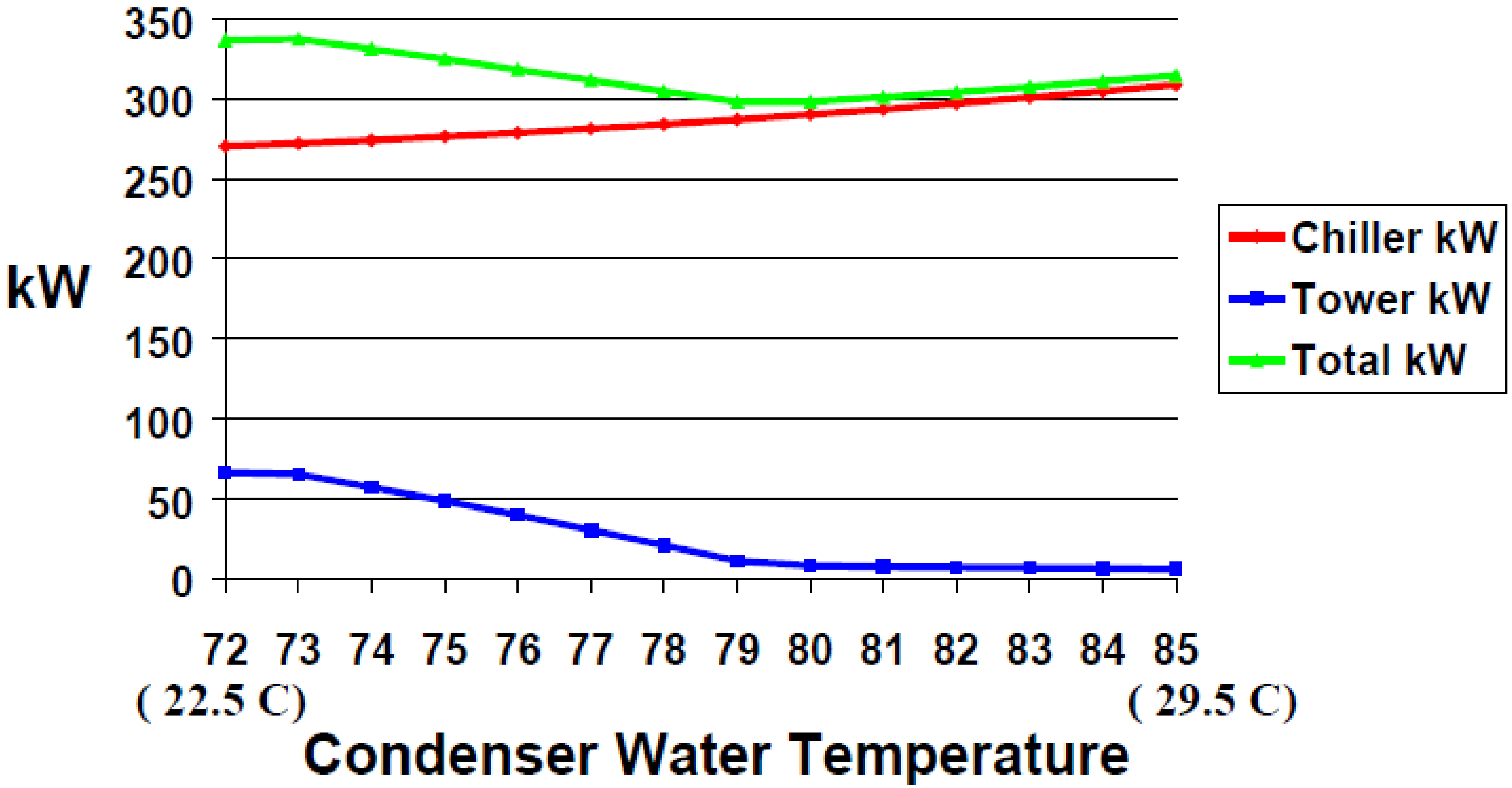


Hydeman, et. al. Pacific Gas and Electric. Used with permission.

圖示有三種不同的負荷在一年間(8760hr)耗電量的變化
每一種負荷狀態都有不同的最省電區間

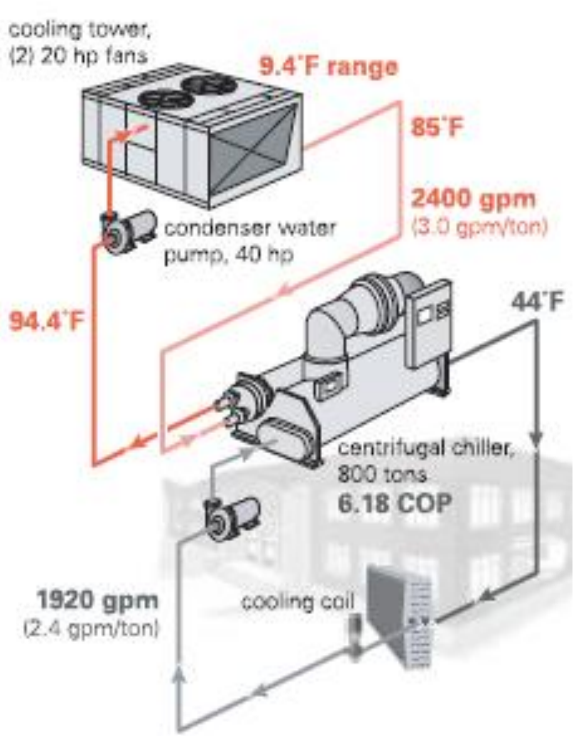


Chiller Plant Efficiency
At Various Loads And Outdoor Wet Bulb Temperatures
For Constant and Variable Speed Chiller Plants
Chilled Water Plant kW/Ton
0.8
0.6
0.4
30%
40%
50%
60%
70%
80%
90%
100%
Percent Chiller Plant Load
CS Plant @75F WB
CS Plant @55F WB
VS Plant @65F WB
CS Plant @65F WB
VS Plant @75F WB
VS Plant @55F WB

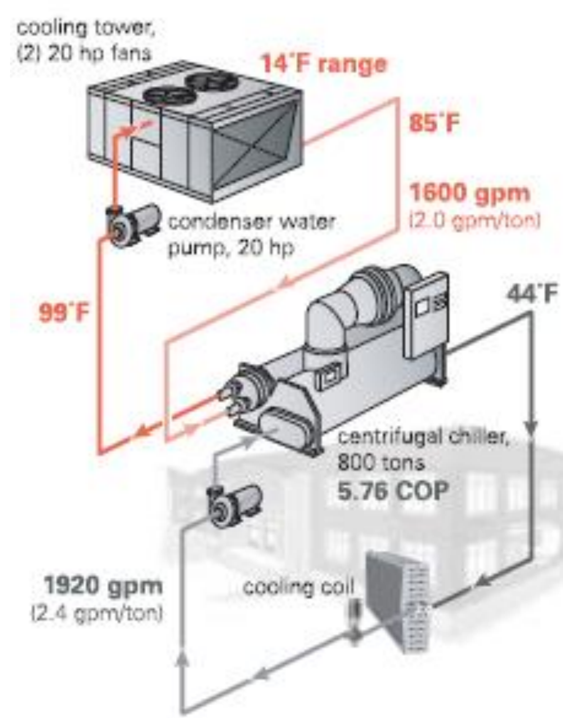

350
300
250
200
150
100
50
0
kW
72
73
74
75
76
77
78
79
80
81
82
83
84
85
(22.5 C)
(29.5 C)
Condenser Water Temperature
Chiller kW
Tower kW
Total kW

冰機+冷卻水塔+循環泵組合

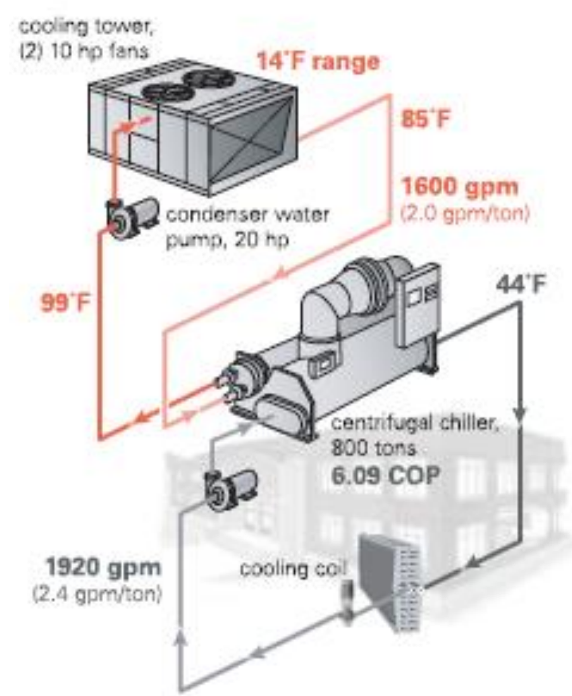
Alternative 1: Base design



Alternative 2: Wider range, smaller tower



Alternative 3: Wider range, optimized system



Chiller 77% Pumps 15% Tower 8%

Table 1. Summary of selection results for example chilled water system			
	Alternative 1: Base design	*Alternative 2: Smaller tower*	*Alternative 3: Optimized system*
Cooling tower range	*9.4°F*	*14°F*	*14°F*
Condenser water flow	*2400 gpm*	*1600 gpm*	*1600 gpm*
Cooling tower parameters			
Footprint	18.75 × 22.08 ft	17.0 × 18.08 ft	18.75 × 22.08 ft
Weight	38,050 lb	29,136 lb	37,726 lb
Cells	2	2	2
Fan power (total)	40 hp	40 hp	20 hp
Static lift	12.23 ft	12.16 ft	12.23 ft
Pressure drops			
Condenser	26.41 ft	12.34 ft	20.68 ft
Cooling tower	12.23 ft	12.16 ft	12.23 ft
Pipes, valve fittings	11.56 ft	5.32 ft	5.32 ft
Pump power required	40.16 bhp	15.90 bhp	20.39 bhp
Chiller efficiency	6.18 COP	5.76 COP	6.09 COP
Annual energy consumption			
Centrifugal chiller	259,776 kWh	278,389 kWh	263,325 kWh
Cooling tower	66,911 kWh	64,878 kWh	32,437 kWh
Condenser water pump	85,769 kWh	33,936 kWh	43,547 kWh
Total for system	412,456 kWh	377,203 kWh	339,309 kWh

Table 1. Summary of selection results for example condenser water systems for 700-ton building load			
	AHRI Standard 550/590 9.3°F ΔT*	**ASHRAE GreenGuide 14°F ΔT, same tower, smaller pipes**	**ASHRAE GreenGuide 14°F ΔT, oversized tower, smaller pipes**
CW flow rate	2100	1400	1400
CW pipe size	10	8	8
CW system PD	30	30	30
condenser PD	24	11	15.6
tower static lift	12.3	12.3	19.2
chiller power	398.9	410.7	411.9
CW pump power	37.6	20.2	24.5
tower fan power	32.1	32.1	16.0
total (kW)	468.6	456.7	452.4

*At the AHRI Standard flow rate of 3 gpm/ton, using today's efficient chillers, the ΔT is 9.3°F rather than the 10°F often assumed.

Figure 3. Chiller-plus-tower operating costs

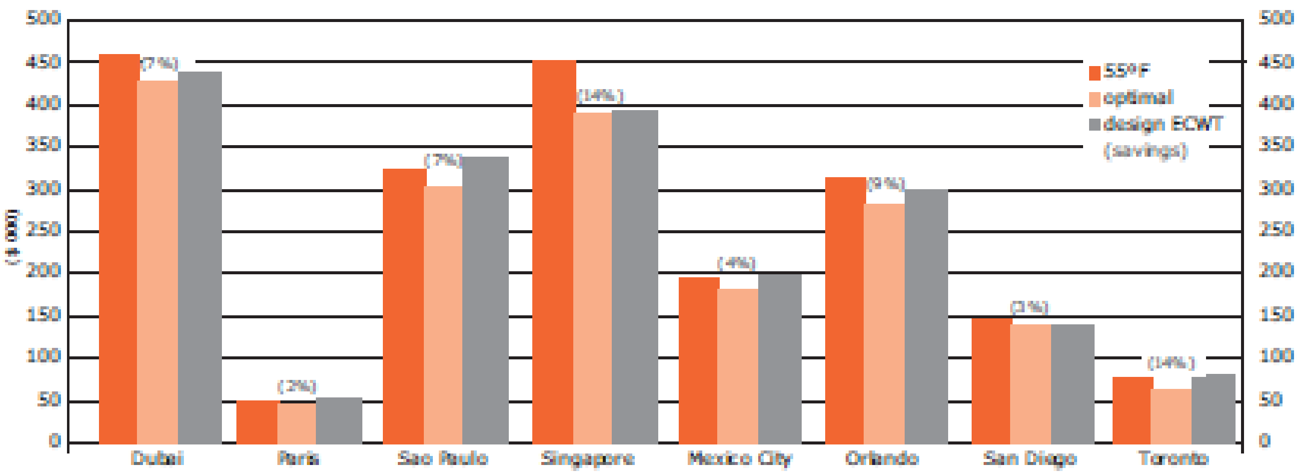


Table 2. Study trends

Operating Mode		AHRI Standard Conditions 3 gpm/ton design condenser water flow rate				GreenGuide Conditions 2 gpm/ton condenser water flow rate; oversized cooling tower			
		System kW range	Potential % savings	Water flow control	Tower speed control	System kW range	Potential % savings	Water flow control	Tower speed control
Figures 4-5	90% load 75°F WB	393-412	4.6	Some savings by reducing flow to 70%	Little savings by reducing speed	380-399	4.8	Reducing flow increases energy usage	Reducing speed increases energy usage
Figures 6-7	70% load 65°F WB	271-303	10.6	Reasonable savings by reducing flow to 60%	Some savings by reducing speed to 70%	271-314	13.6	Some savings by reducing flow to 80%	No savings by reducing fan speed. Fan speeds below 70% increase energy usage significantly
Figures 8-9	70% load 55°F WB	246-282	12.8	Reasonable savings by reducing flow to 60%	Some savings by reducing speed to 70%	245-278	11.8	Some savings by reducing flow to 80%	No savings by reducing fan speed. Fan speeds below 70% increase energy usage significantly
Figures 10-11	50% load 65°F WB	205-243	15.6	Significant savings by reducing flow to 60%	Significant savings by reducing speed to 60%	207-224	7.6	Some savings by reducing flow to 70%	Minimal savings by reducing fan speed. Fan speeds below 70% increase
Figures 12-13									
Figures 14-15	30% load 55°F WB	125-172	27.3	Reducing flow saves significant energy	Reducing speed saves significant energy	126-144	12.5	Some savings by reducing flow to 70%	Some savings by reducing speed to 70%

- 變水量系統受到冰水主機冷凝器需要量的限制
- 改變冷卻水量時也會改變水塔、冷卻水泵、和冰機的效率
- 控制的方式不易懂

Figure 2: Chiller + tower energy consumption at various loads and condenser water temperatures.

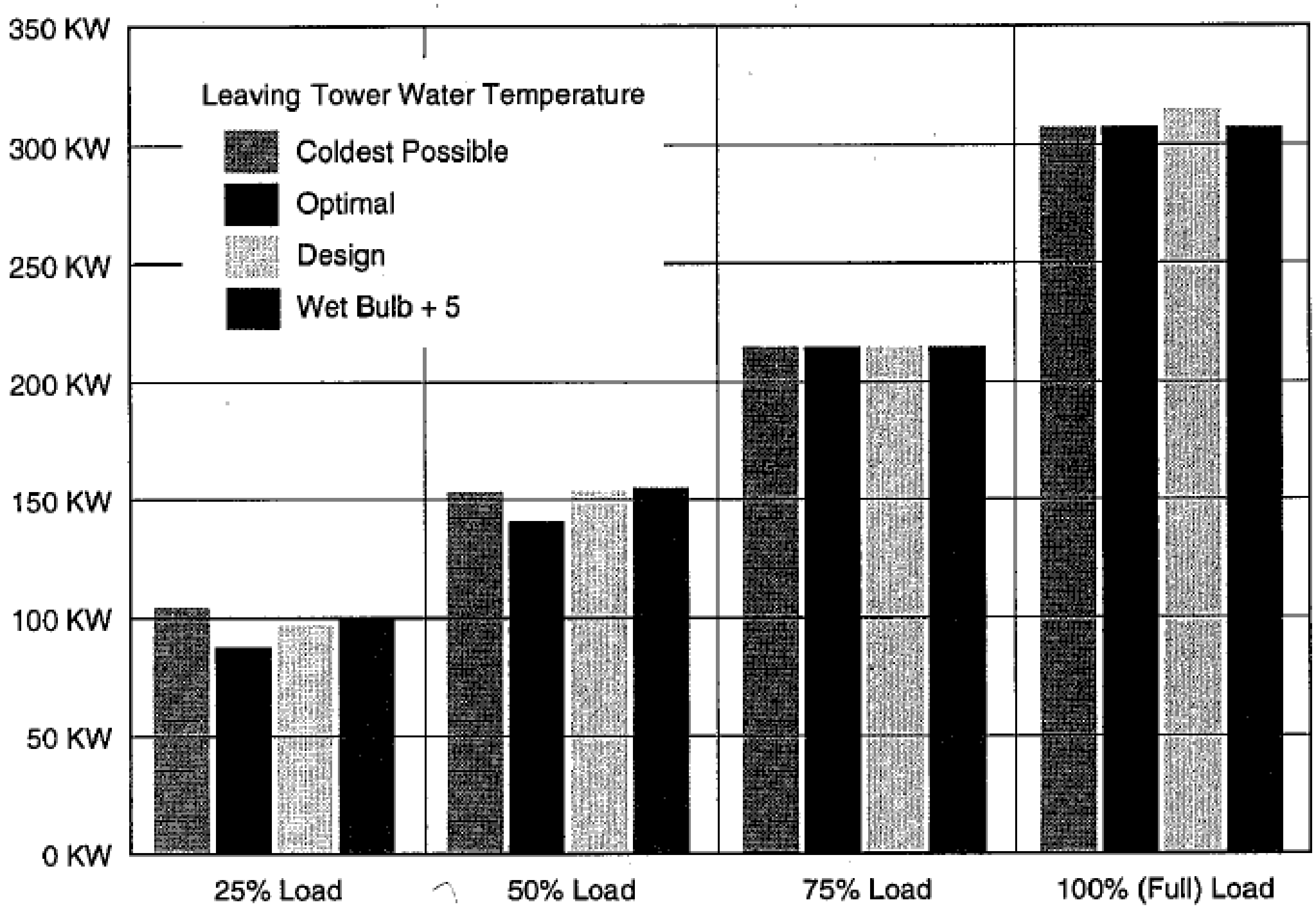
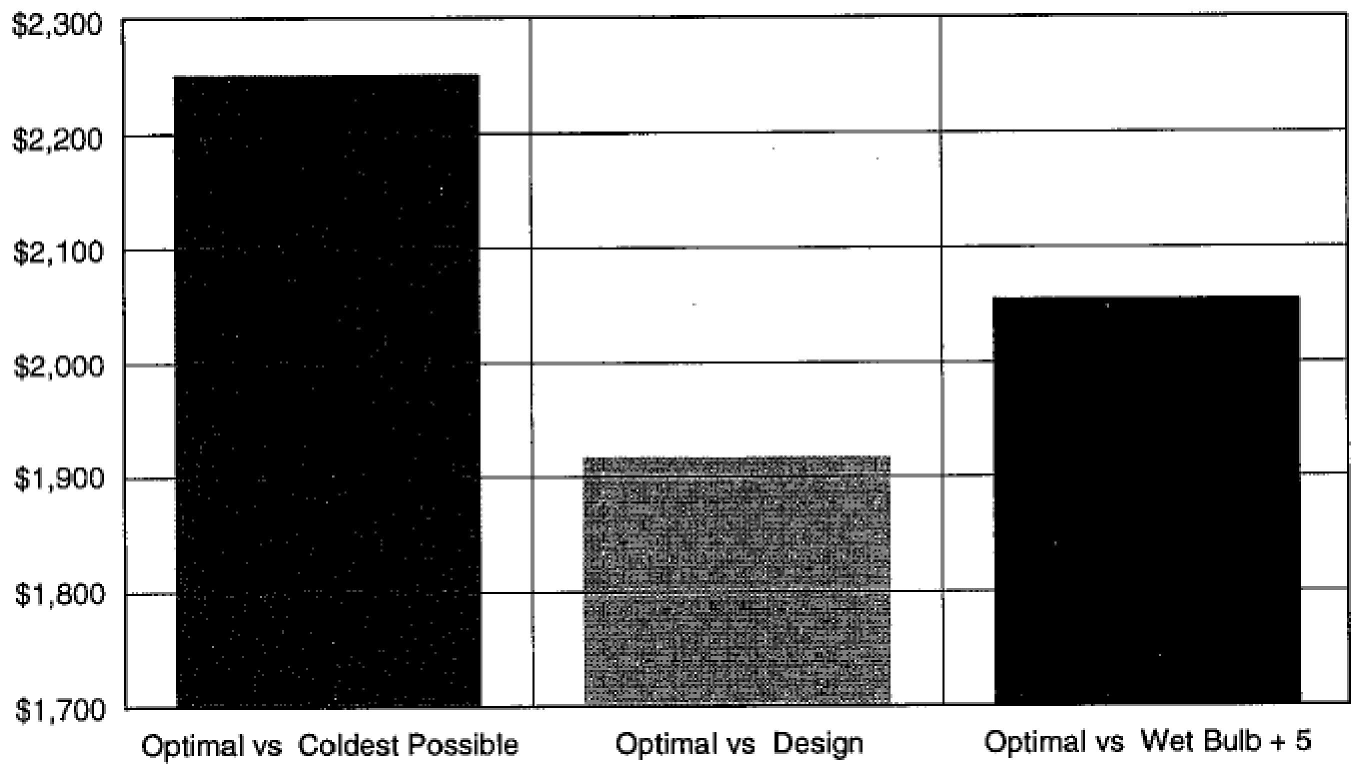


Figure 4: Energy savings comparison of tower leaving water control strategies.



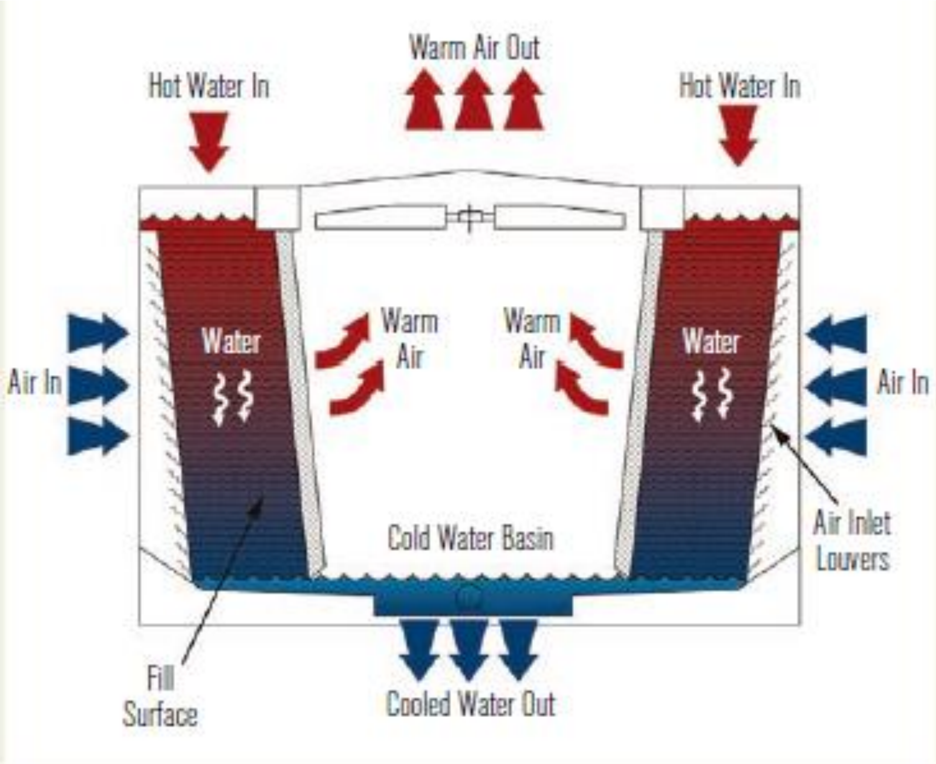


FIGURE 1 Induced draft, axial fan, crossflow open circuit cooling tower.

直交流式冷卻水塔

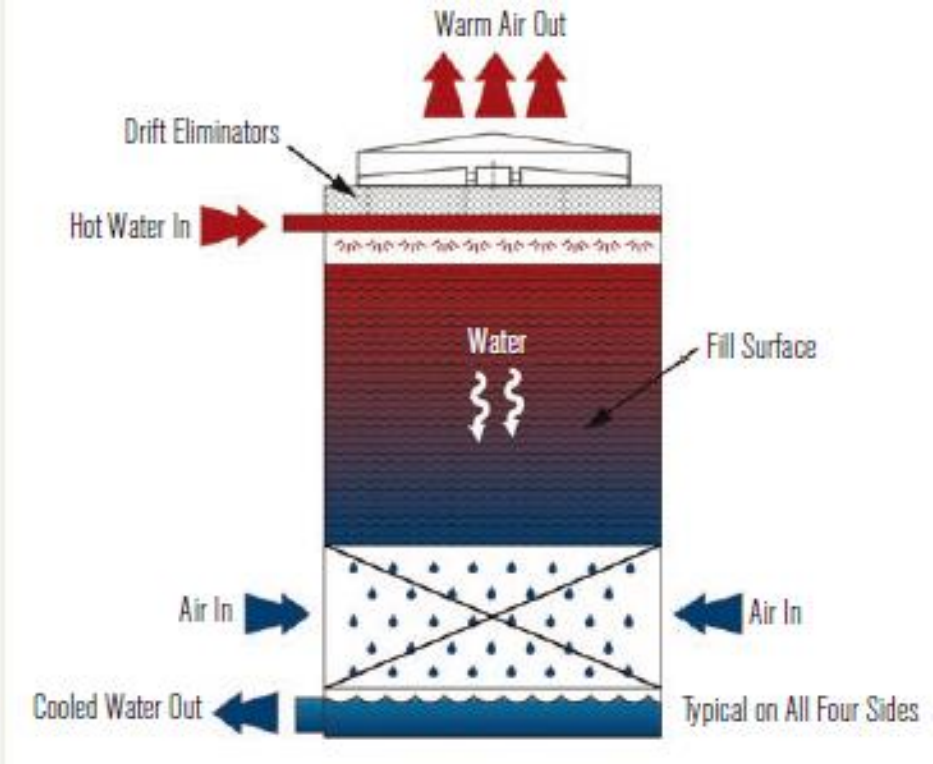


FIGURE 2 Induced draft, axial fan, counterflow open circuit cooling tower.

逆流式冷卻水塔

水分配系統

逆流式

- 加壓設計水分配系統，灑水面積大
- 可拆卸螺紋端帽，能清潔噴淋管內雜物，防止堵塞
- 可移除噴嘴

直交流式

- 重力供水
- 各水盤間需保持精確的平衡，避免水跑到位置最低的水盤，造成散熱不良
- 配管需有平衡閥，增加施工成本

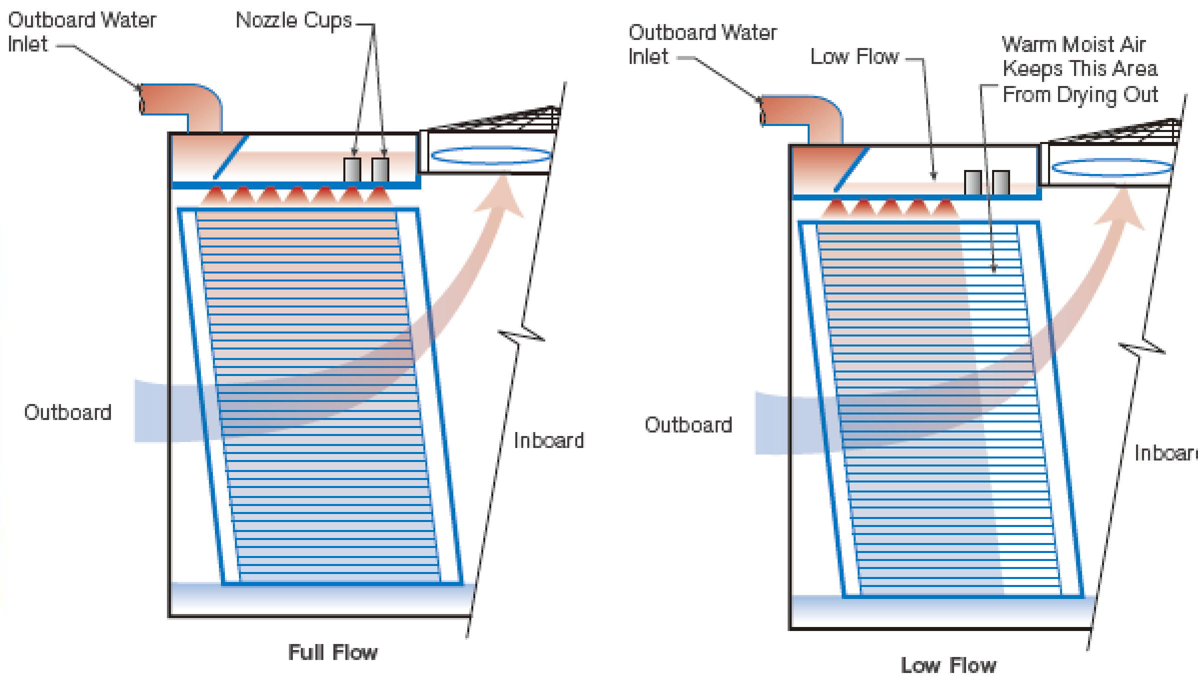


FIGURE 6 *Full design flow rate*

直交流式水塔在低水量時處理方式
水量最好不低於設計流量的50%

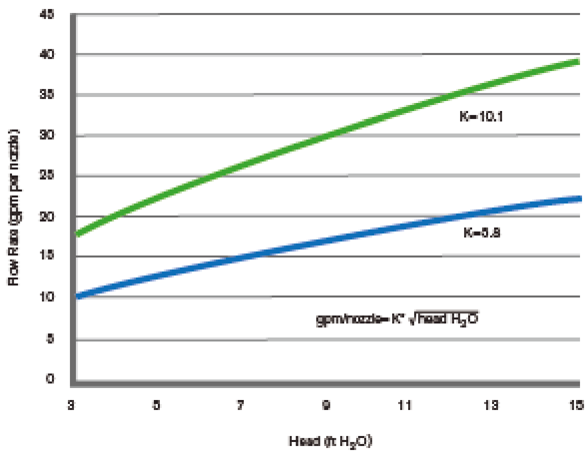


FIGURE 5 *Counterflow nozzle chart*

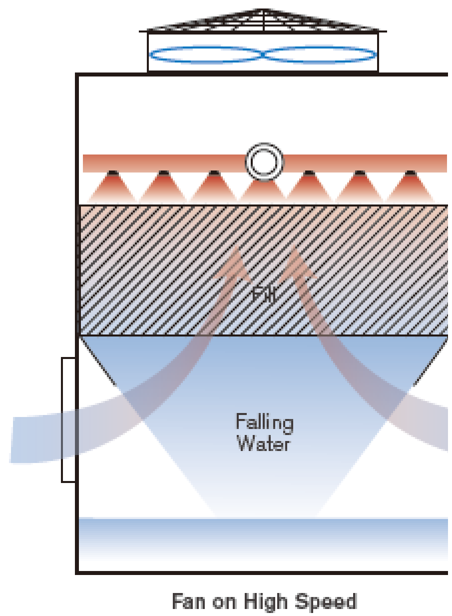


FIGURE 17 *Counterflow design*

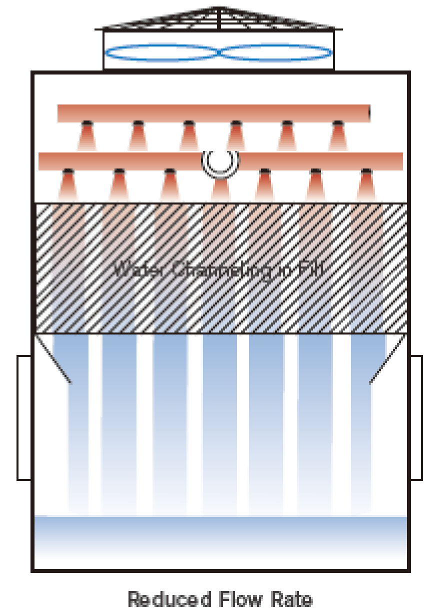


FIGURE 18 *Counterflow design with reduced flow*

逆流式水塔在低水量時處理方式
水量最好不低於設計流量的50%

冷卻水塔的操作與保養

- 定期維護保養和適當水處理是保持冷卻水塔效率和延長使壽命最重要的兩個方式
- 冷卻水如因保養不良導致水溫升高，每升高1°F冰機的效率下降2%
- 水塔如因裝設不良導致排風回流，回流造成進風溫度上升
- 1°F散熱能力下降8%
- 2°F散熱能力下降19%

冷卻水塔綠建築有關規定

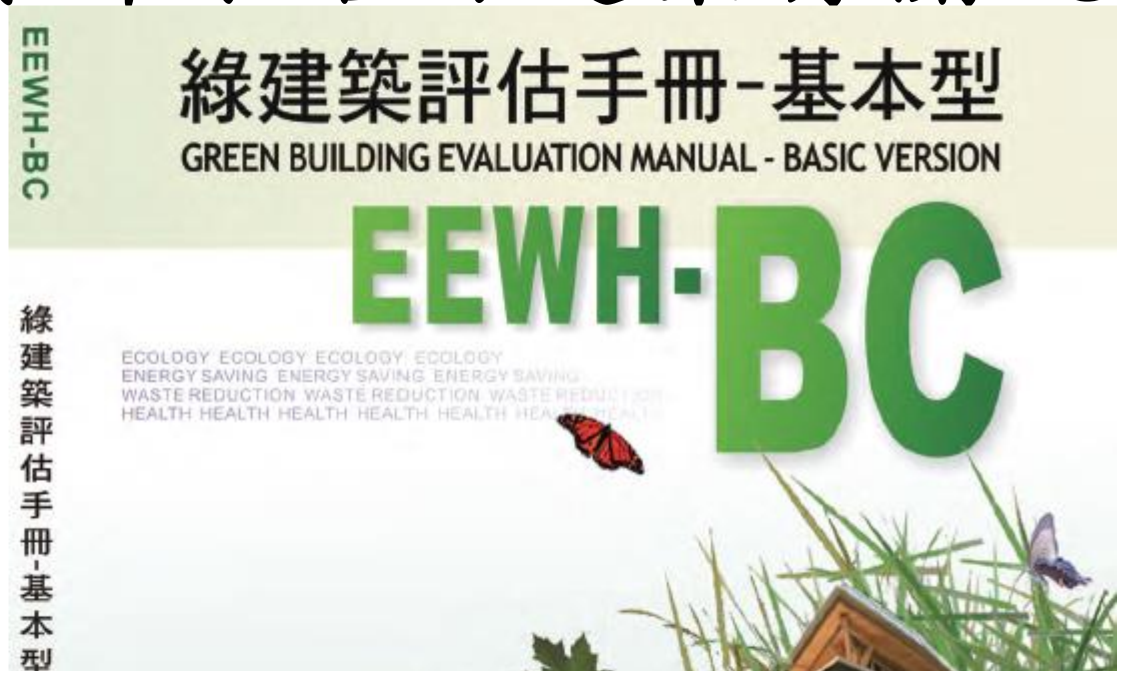


表2-4.10 空調節能技術簡易評估表

節能對象	空調節能技術	效率	效率標準值	採用率(*1)	送審設計圖說(*2)
冷卻水塔節能技術	冷卻水塔節能優惠	α 12	出水溫度控制：0.2	r12 ＝	採用率計算書、系統流程及控制規範圖說
			濕球接近溫度控制：0.35		
			最佳策略控制：0.5		
	冷卻水塔節能效率 ＝Rt ＝1.0 － α 12x r12＝				

結語

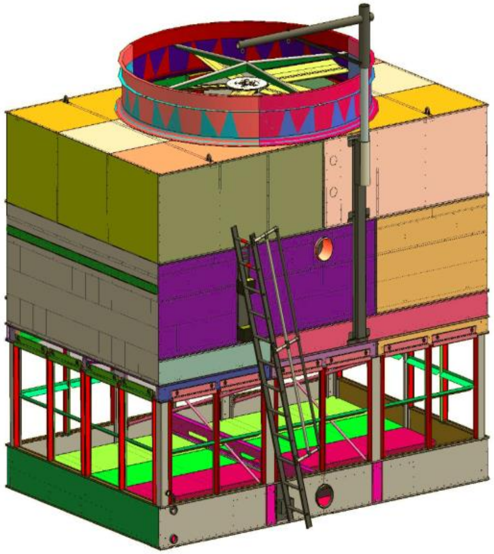
- 冷卻水塔的選機要配合系統操作需求
- 冷卻水塔大部分時間在輕載運轉，選機時不宜過大(水量)
- 冷卻水系統管路與控制閥件也要能配合系統操作需求
- 冷卻水塔要定期清洗
- 冷卻水塔的噪音防制
- 冷卻水系統最佳的溫度控制點是浮動的，隨溼球溫度、系統負荷、主機型式而異。
- 冷卻水塔供應商能提供在不同負荷、溼球溫度時的出水溫度預測，作為操作者的節能控制參考。
- 適當的水溫控制是節能操作的重要一環。

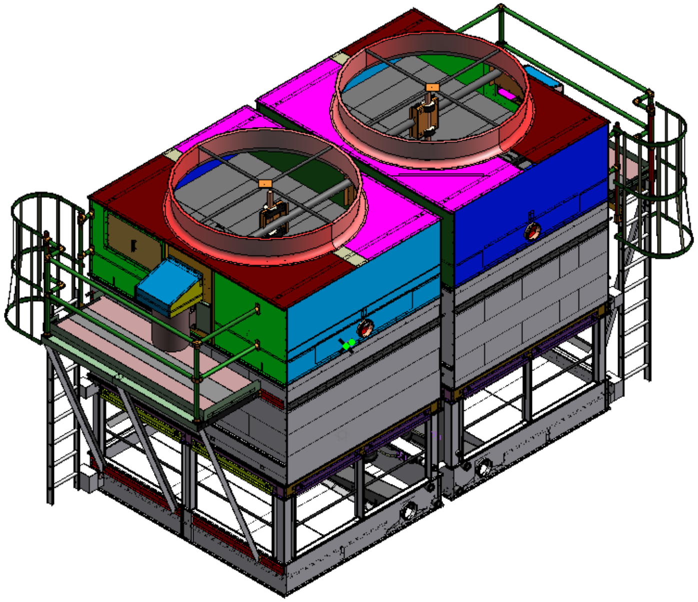
單風車

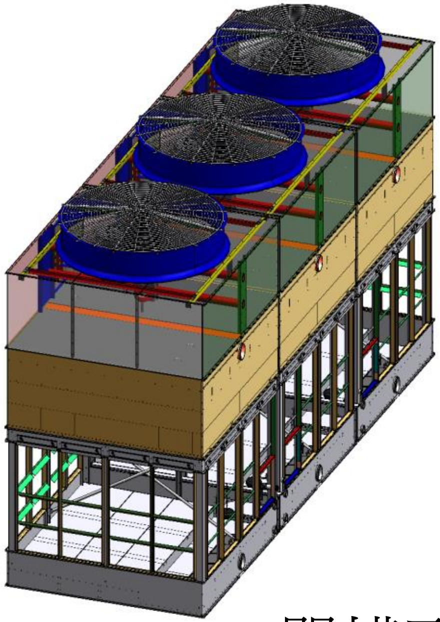
雙風車

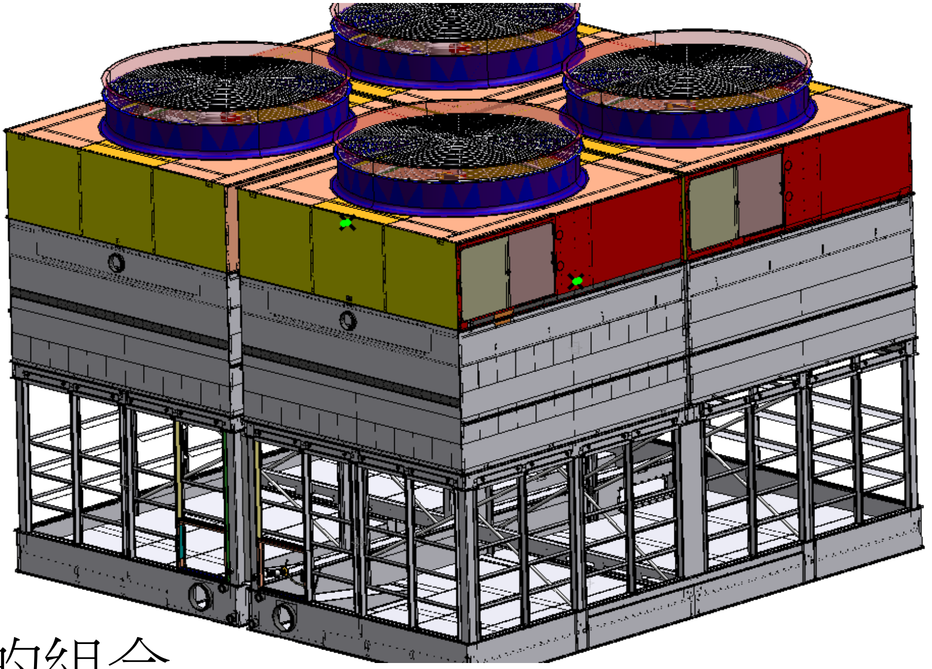
三風車

四風車









單槽到四槽的組合

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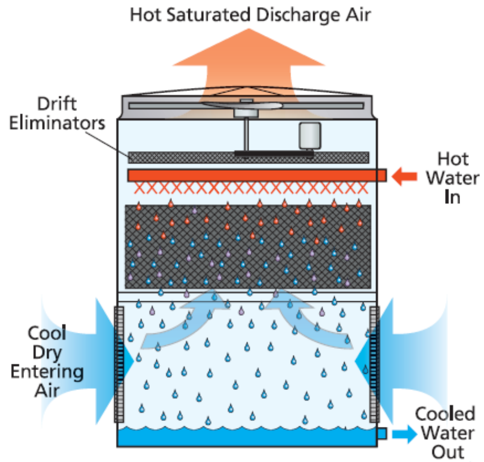
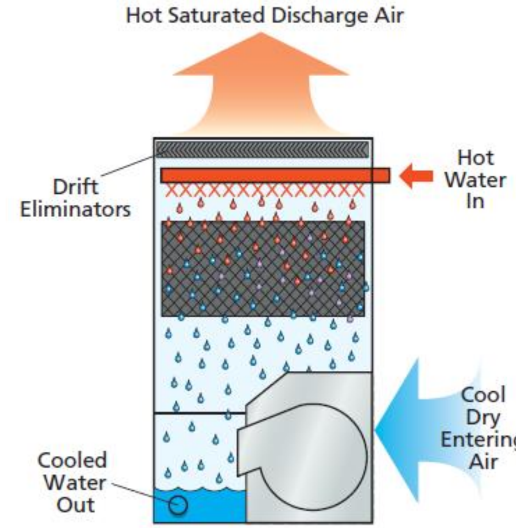
熱流工程/冷暖工房 任又慶 編撰

Open Cooling Tower

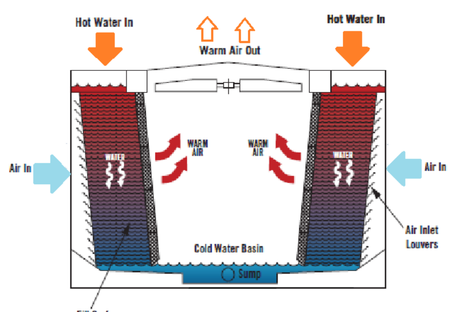
開放逆流式
UT/USS/UT



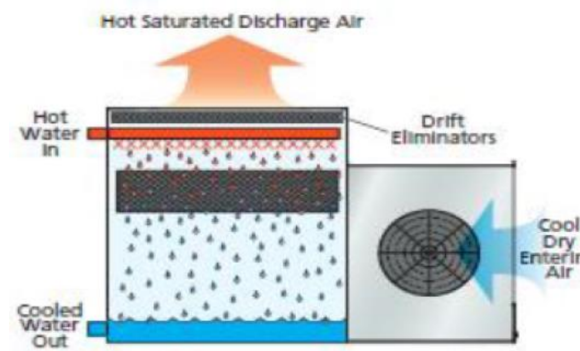
開放吹壓式
LSTE



開放直交流式
AXS

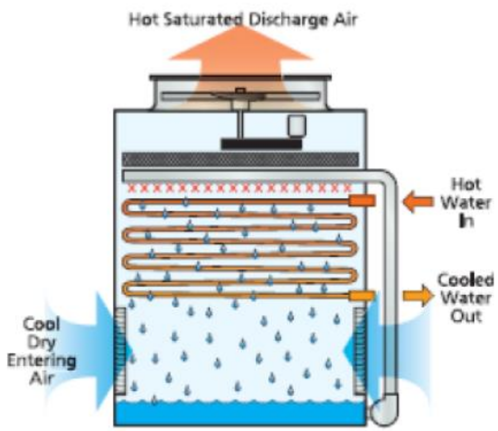


開放吹壓式
LPT

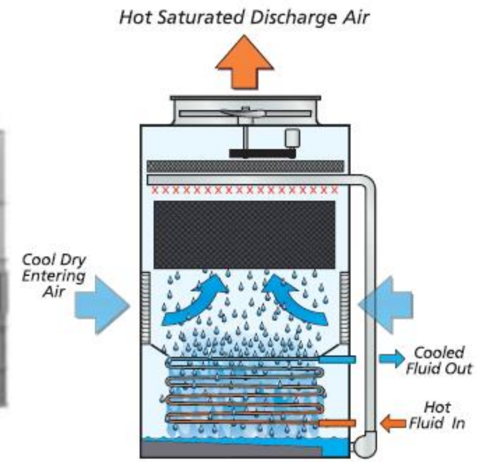


Closed Circuit Cooler

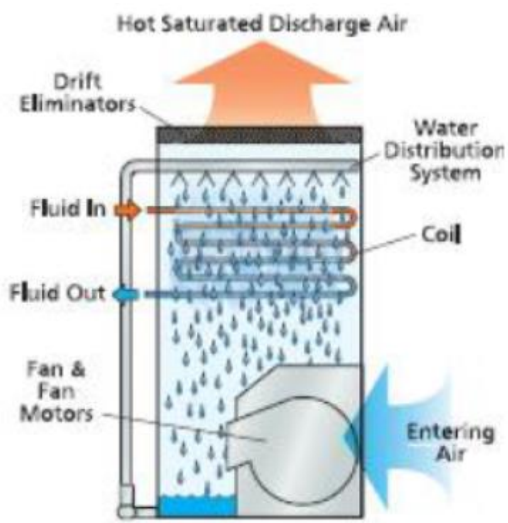
密閉逆流式
ATW



密閉逆流式
ESWA



密閉吹壓立式
LSWA



密閉吹壓臥式
LRW