Optimization of chiller system's operating parameters through data analysis

吳孝修[1],連上舜[2], Tarun[3]

台積電三廠 sswuc@tsmc.com
台積電三廠 sslien@tsmc.com
台積電三廠anandani@tsmc.com

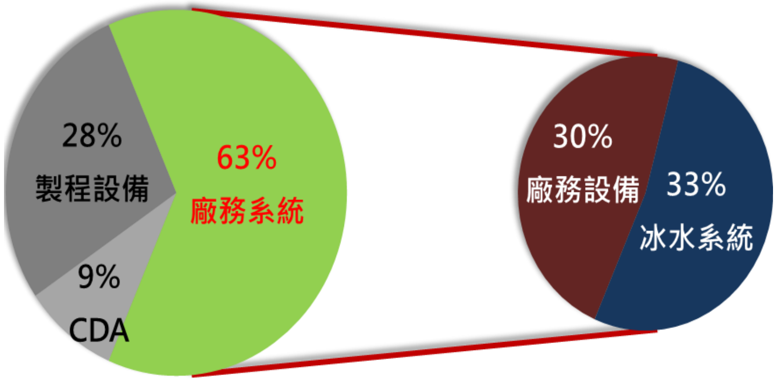
主要對策	節電	節電	節碳
冰水系統溫差控制	87萬度/年	210萬元	463 ton
溫水系統溫差控制	50萬度/年	87萬元	263 ton

Optimization of chiller system's operating parameters through data analysis

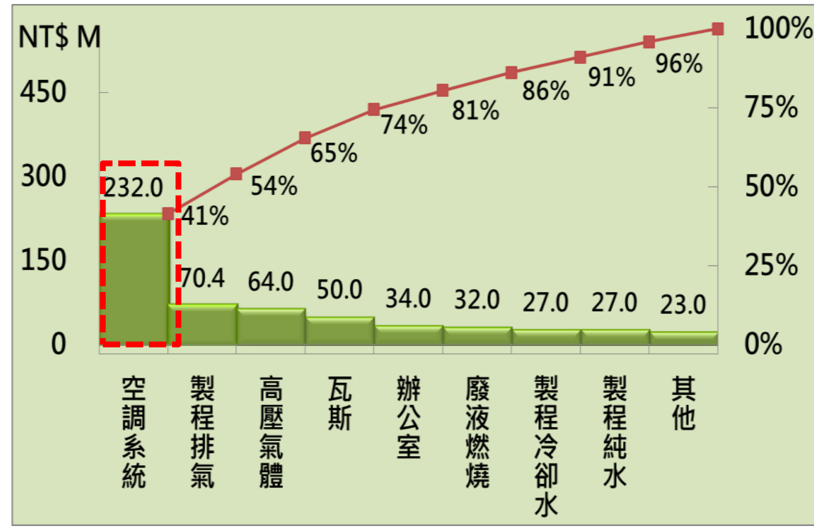
廠務所佔耗能比率達 63%, 冰水系統佔全廠耗電 33%

設備改善及裝設節能裝置,欠缺有效率系統整合

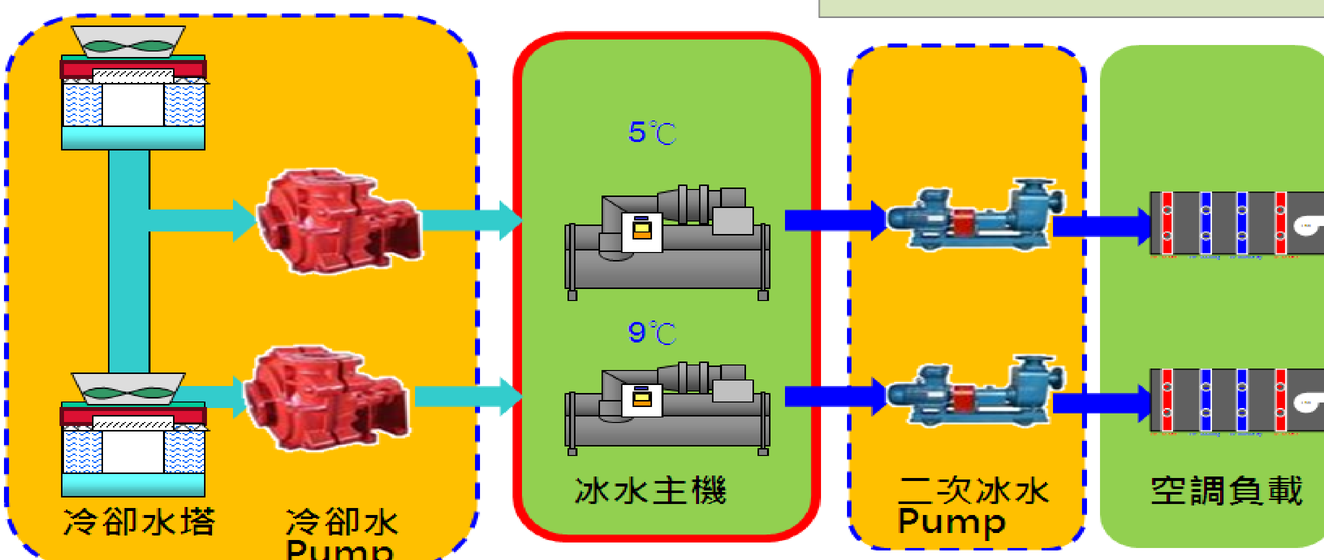
冰水系統佔整廠耗能比率



能耗博拉圖分析



流程圖：

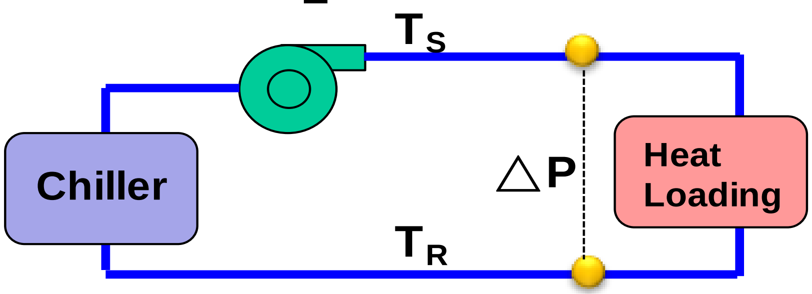


Optimization of chiller system's operating parameters through data analysis

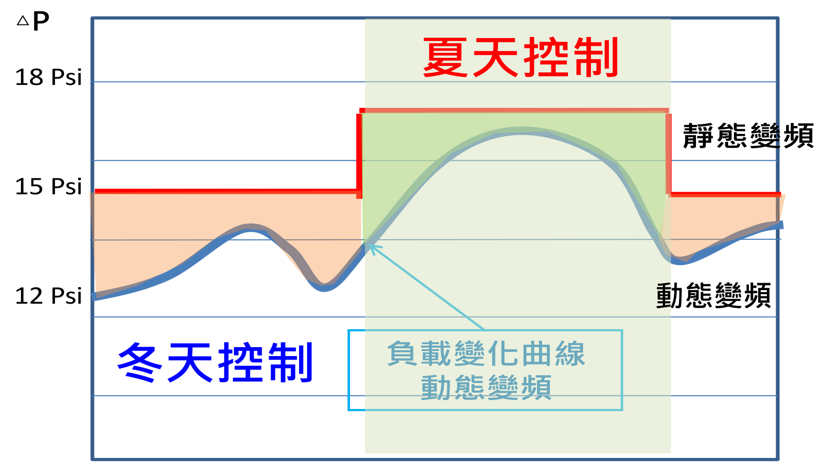
伯努力及連續方程式得知管末等押差控制末等流量控制

$$\frac{1}{2}\rho V^2 + \rho g h + P = Const$$

$$P_2 - P_1 = \frac{1}{2}\rho(V_2^2 - V_1^2)$$

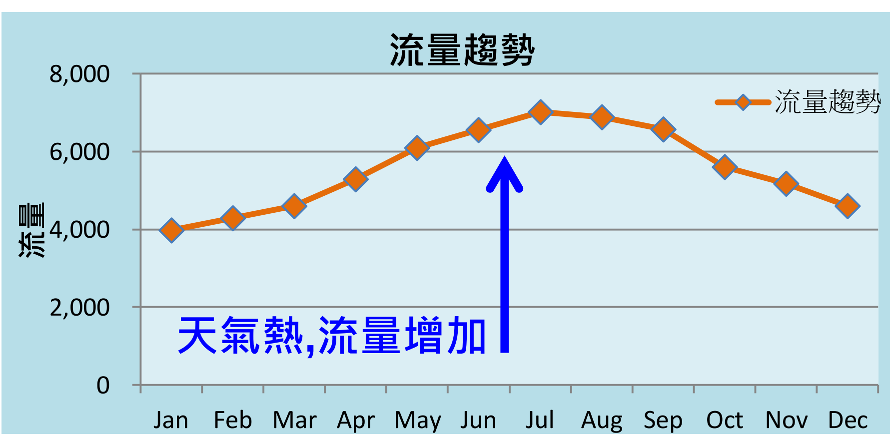


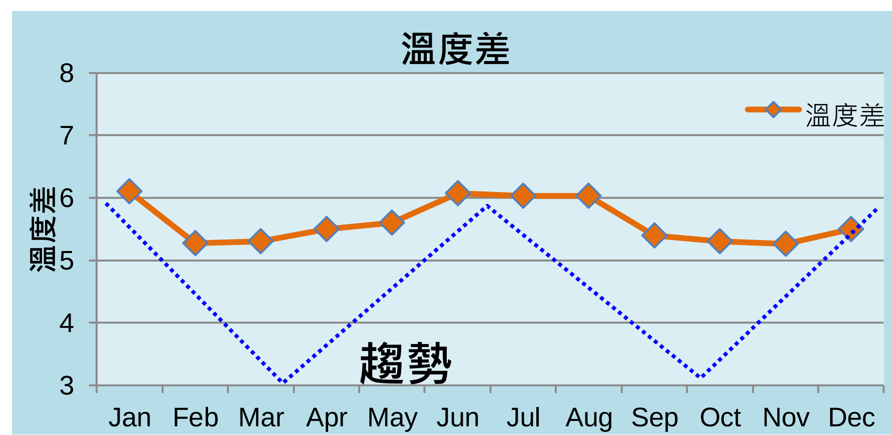
天氣條件多變化,非單一冬夏調整



流量層別：比較一年四季每個月平均流量,確認天氣越熱,冰水流量越高

溫度差層別：比較給個月溫度差分別為W型態轉換,表示現場供應需求有過剩現象





Optimization of chiller system's operating parameters through data analysis

供應壓力為主動控制參數,回水溫度差為被動表徵,藉由原理推估,將被動化為主動

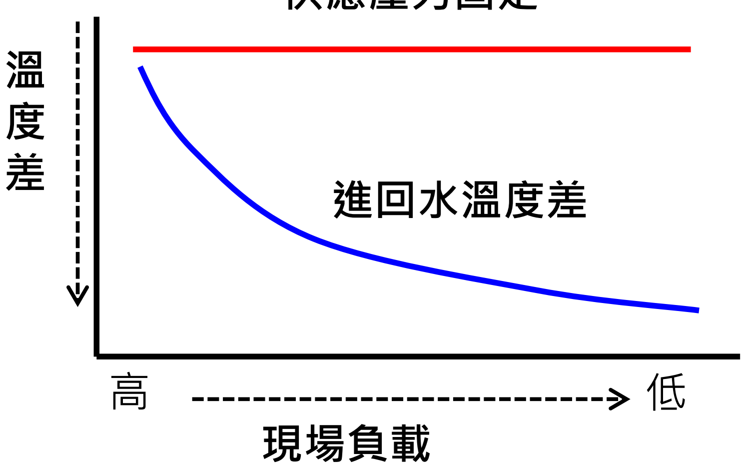
Before	After
△P 控制	T_R-T_S控制
供應流量過多	依現場用量供應
耗電量高	最省之用電量

當供應壓力固定：
現場負載越低,回水溫度越低,溫差越高

當供溫度差固定：
現場負載越低,供應壓力越低,溫差固定,節能區間浮現

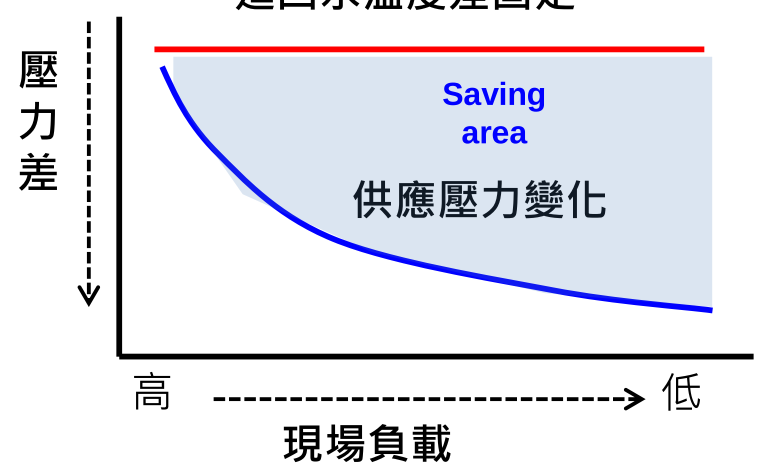
Before

供應壓力固定

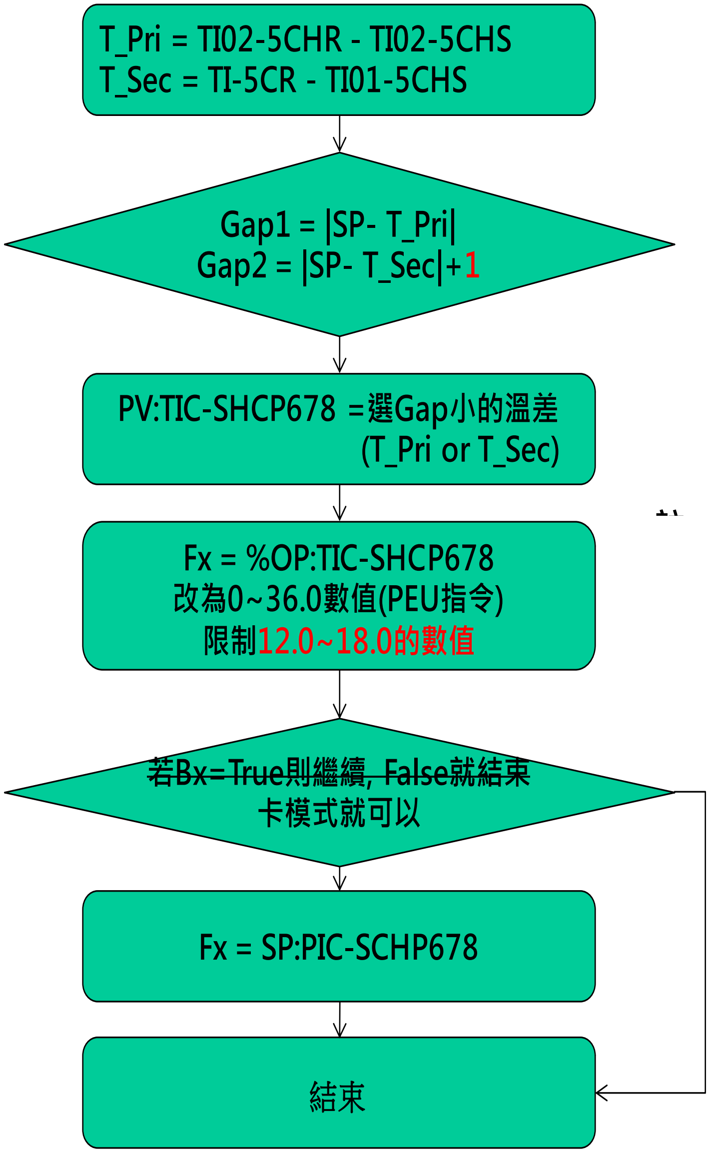


After

進回水溫度差固定



Optimization of chiller system's operating parameters through data analysis

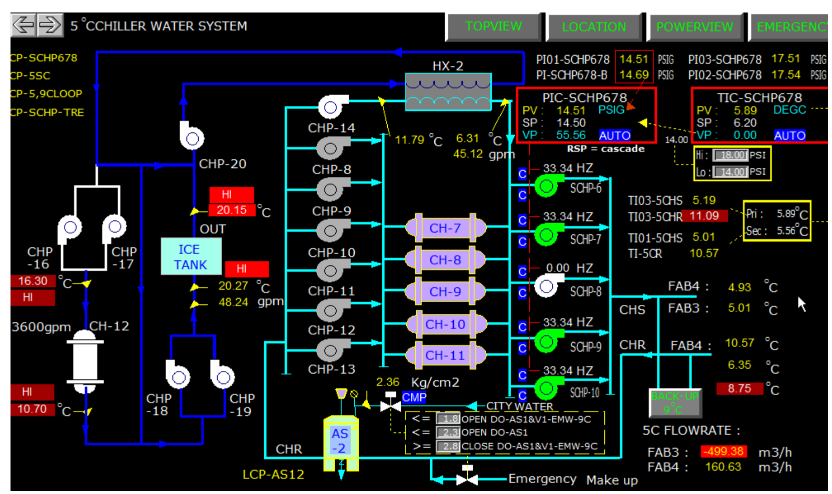


設置兩組進出水Sensor,並將其相減

避免反覆切換,將backup sensor group進行+1度之動作

選擇Gap 較小溫差,使系統控溫為pri,且控制較為穩定

寫入High low limit,並丟出運轉百分比供給壓力迴路進行調壓設定



Optimization of chiller system's operating parameters through data analysis

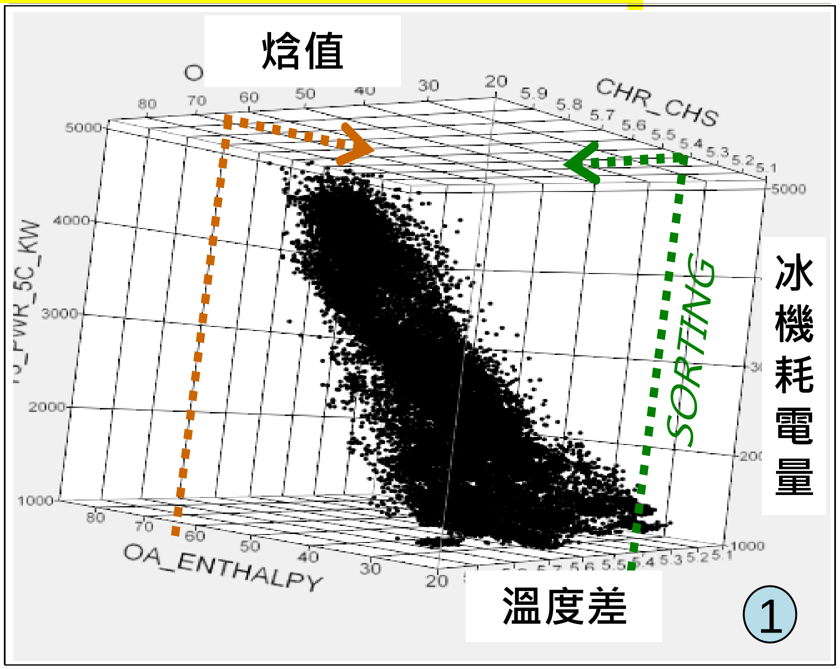
① 用電量分布：將冰水主機群組用電量,進回水溫度差及外氣焓值採用分布圖3D資料分布,尋找節能契機

② 切割焓質耗電：切割外氣焓值及耗電量關係,確認外氣焓值越高,耗電量越高,每區段焓值有高低耗電量分布關係

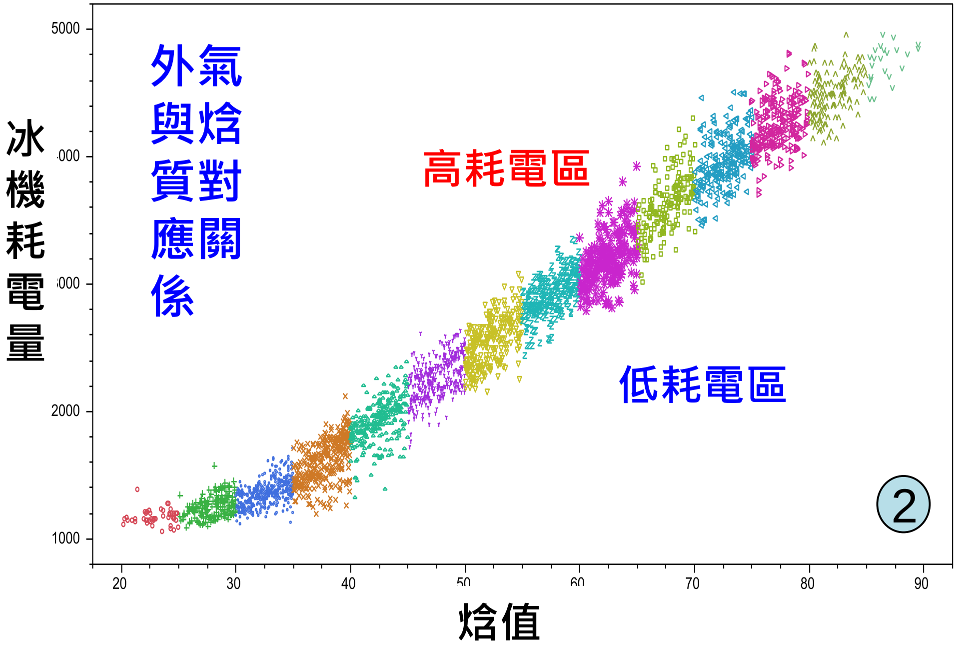
③ 切割溫度分布：切割個焓值區段的溫度分層,將其溫度差切分為5.0~6.0五個區 間進行解析

④ 解析各溫度分布：檢查個焓值區段溫度分層溫度對應耗電量關係式

3D分佈原始資料



SORTING by Enthalpy



Optimization of chiller system's operating parameters through data analysis

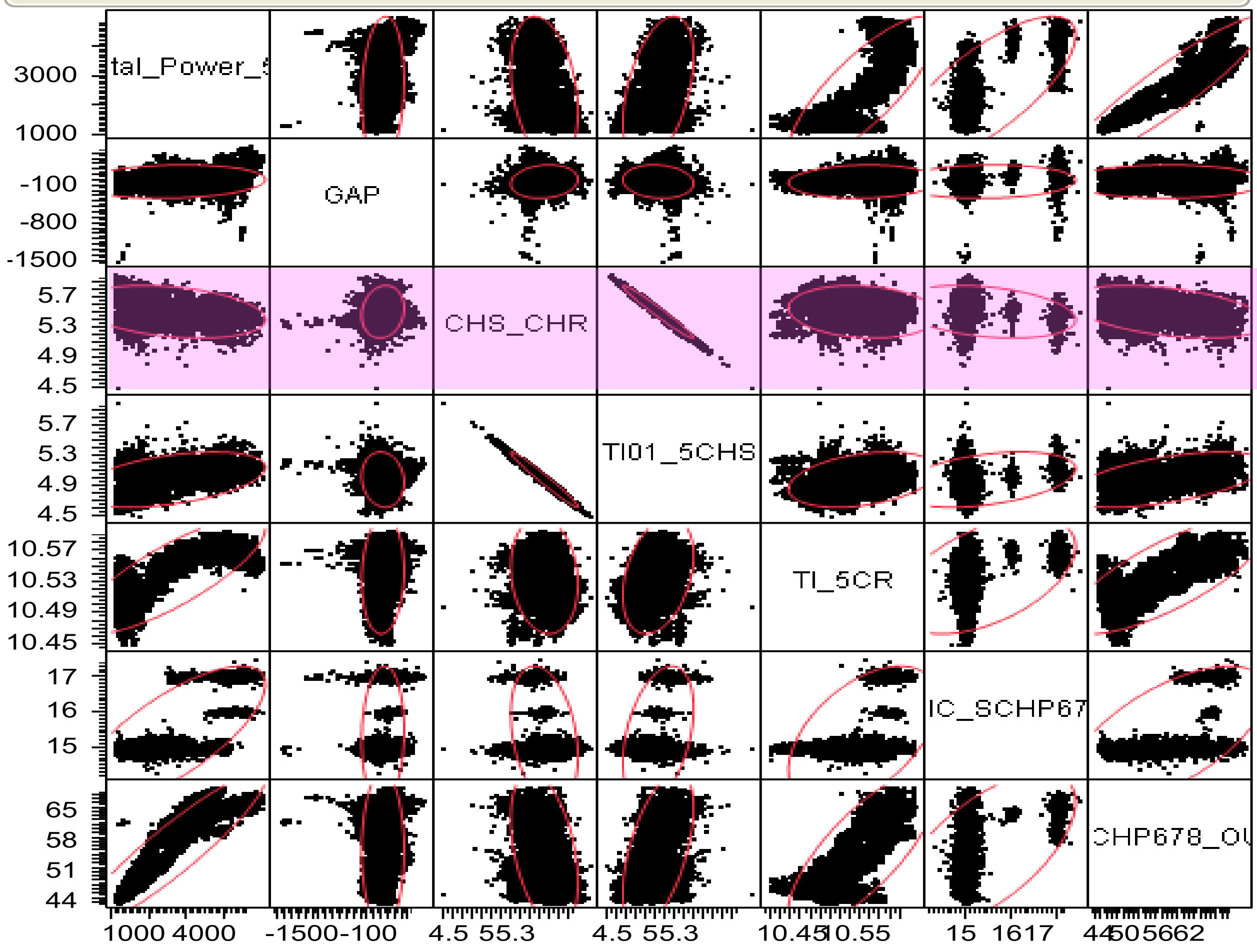
Multivariate charge=Normal

Correlations

	Total_Power_5C	GAP	CHS_CHR	TI01_5CHS	TI_5CR	PIC_SCHP678	PIC_SCHP678_OUTPUT
Total_Power_5C	1.0000	0.1252	-0.2979	0.4480	0.8085	0.7423	0.9226
GAP	0.1252	1.0000	0.1409	-0.1172	0.0809	0.0767	0.0028
CHS_CHR	-0.2979	0.1409	1.0000	-0.9794	-0.1462	-0.3030	-0.4116
TI01_5CHS	0.4480	-0.1172	-0.9794	1.0000	0.3430	0.3899	0.5479
TI_5CR	0.8085	0.0809	-0.1462	0.3430	1.0000	0.5003	0.7687
PIC_SCHP678	0.7423	0.0767	-0.3030	0.3899	0.5003	1.0000	0.6288
PIC_SCHP678_OUTPUT	0.9226	0.0028	-0.4116	0.5479	0.7687	0.6288	1.0000

R^2 最高0.4

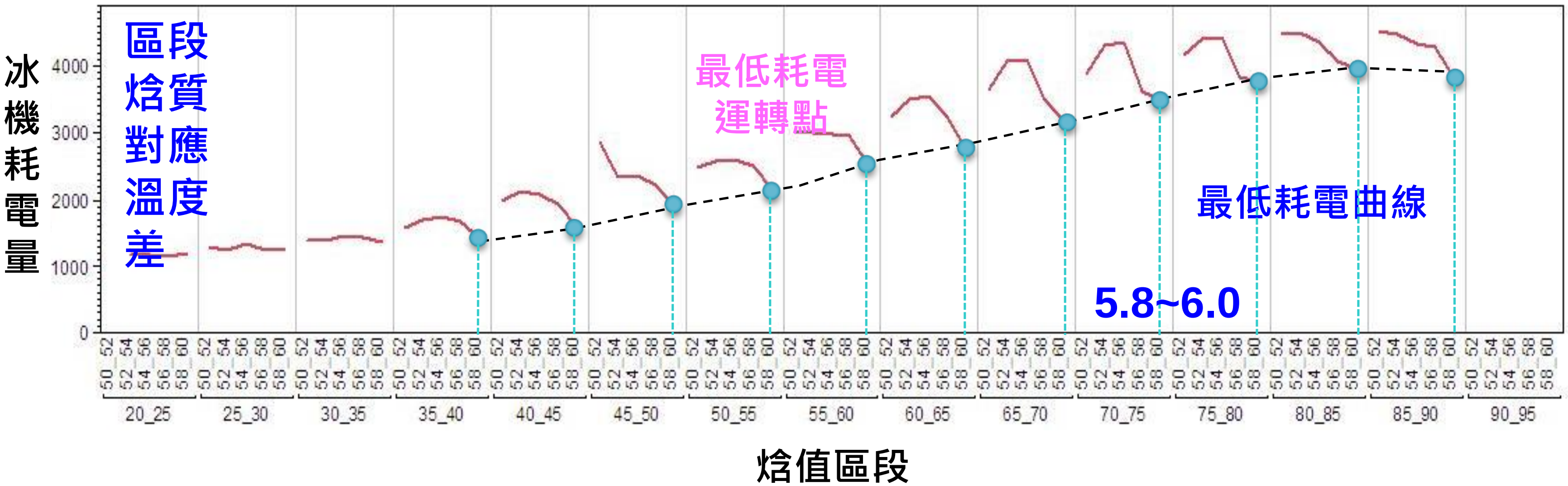
Scatterplot Matrix



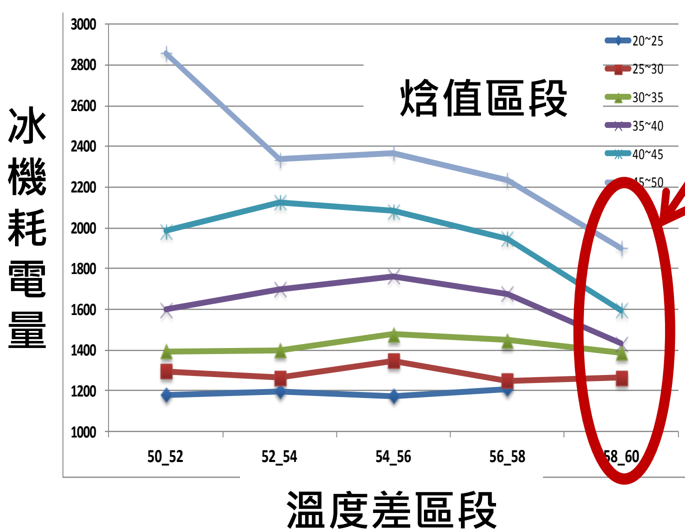
R^2 最高0.4

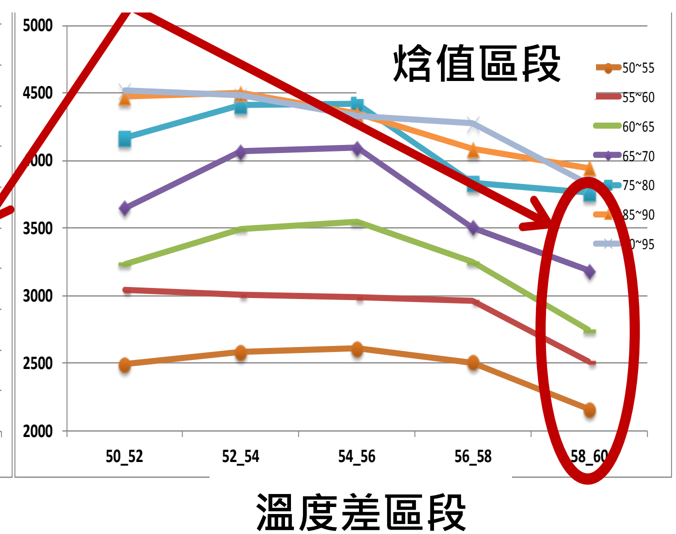
Optimization of chiller system's operating parameters through data analysis

③ SORTING by Diff. Temp △T



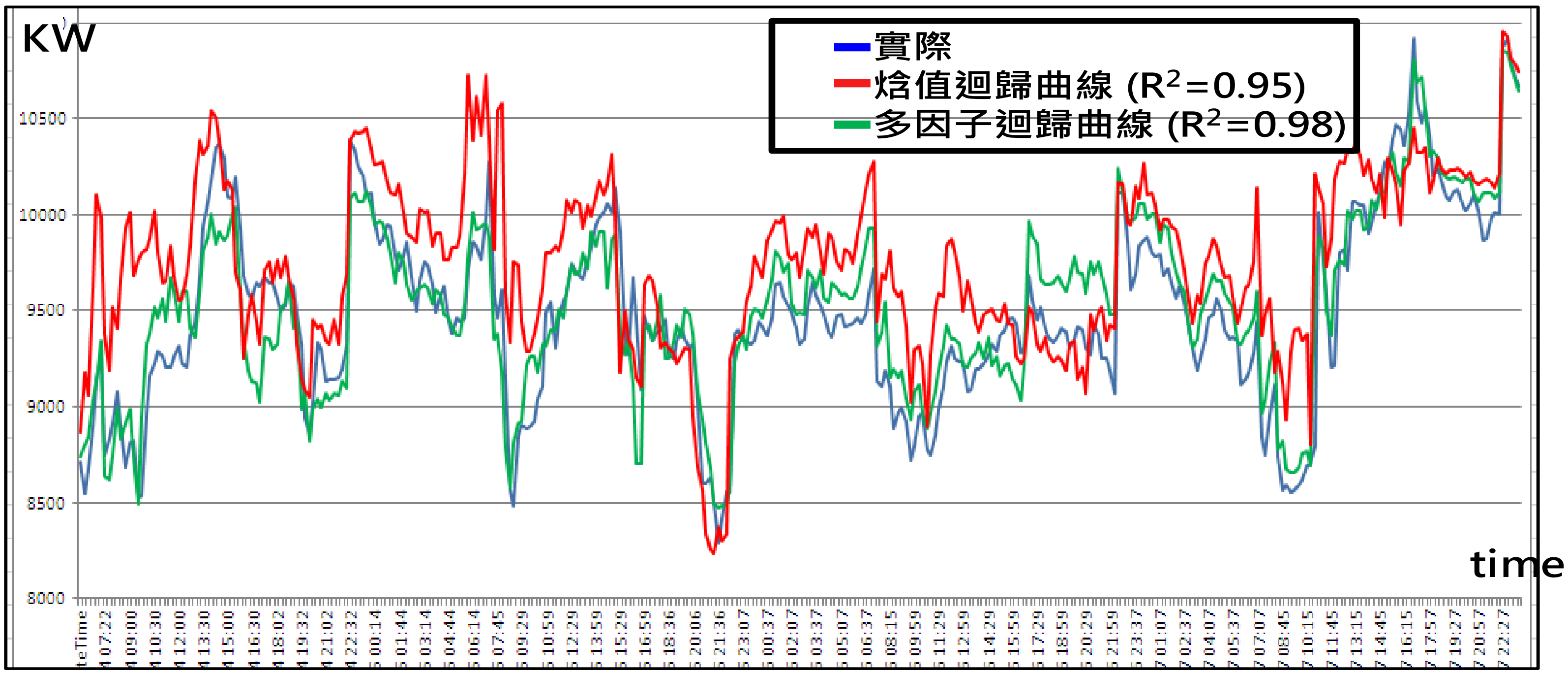
④ 進回水溫度差 5.8~6.0 之間耗電量最低





Optimization of chiller system's operating parameters through data analysis

- Fit Module 多因子迴歸預估曲線
  - 原冰機總耗電只參考外氣焓值(熱含量), 回歸得R^2=0.95,
  - 利用Fit Module多因子分析, R^2=0.98, 可精準分析冰水主機系統用電基線

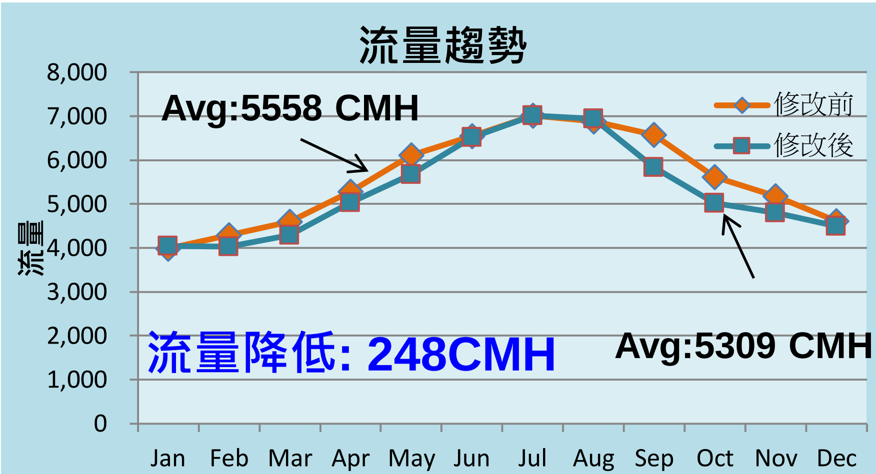


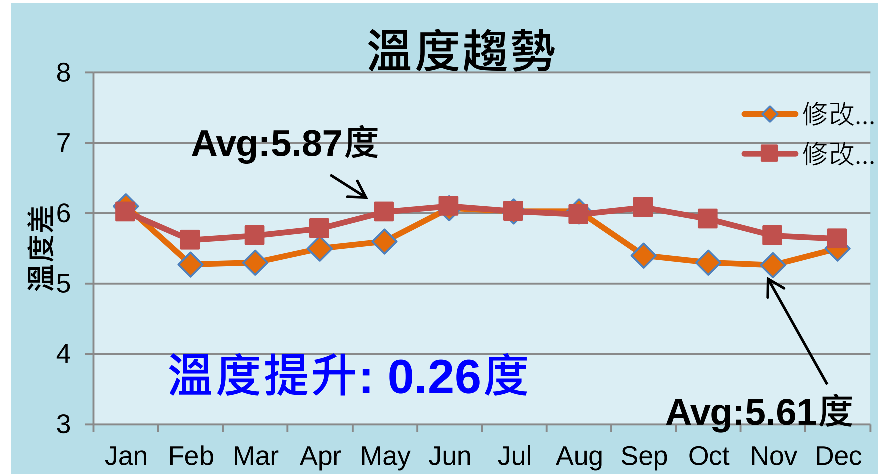
多因子迴歸模組程式

f(冰水系統總耗量) = f(外氣變化 (焓值,溫度,露點)) + f(PCW / CDA) + f(Tools....)

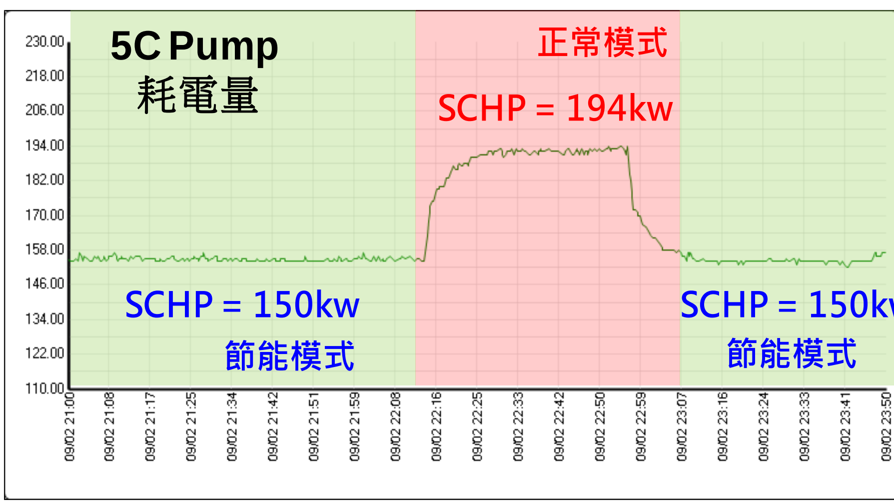
Optimization of chiller system's operating parameters through data analysis

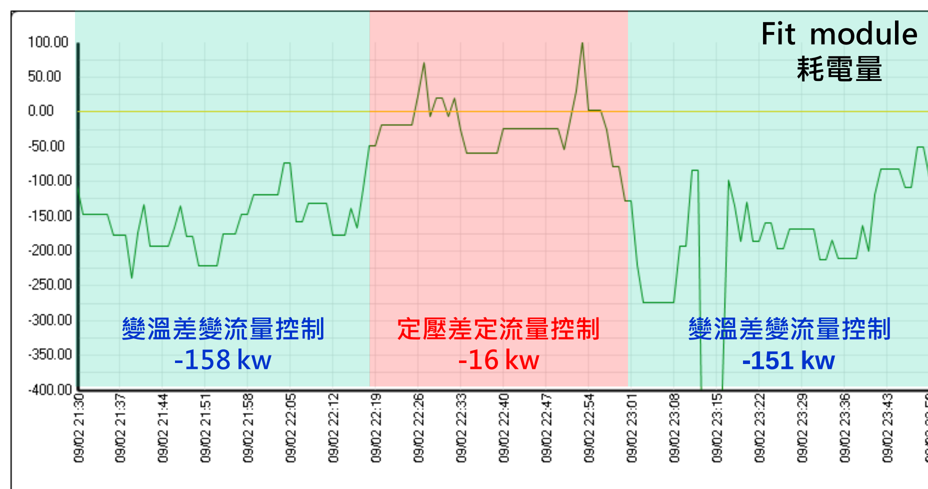
流量層別：修改前：5558CMH,修改後：5309CMH, 流量下降248CMH,
溫度差層別：修改前：5.61度,修改後：5.87度, 溫度差提升：0.26度





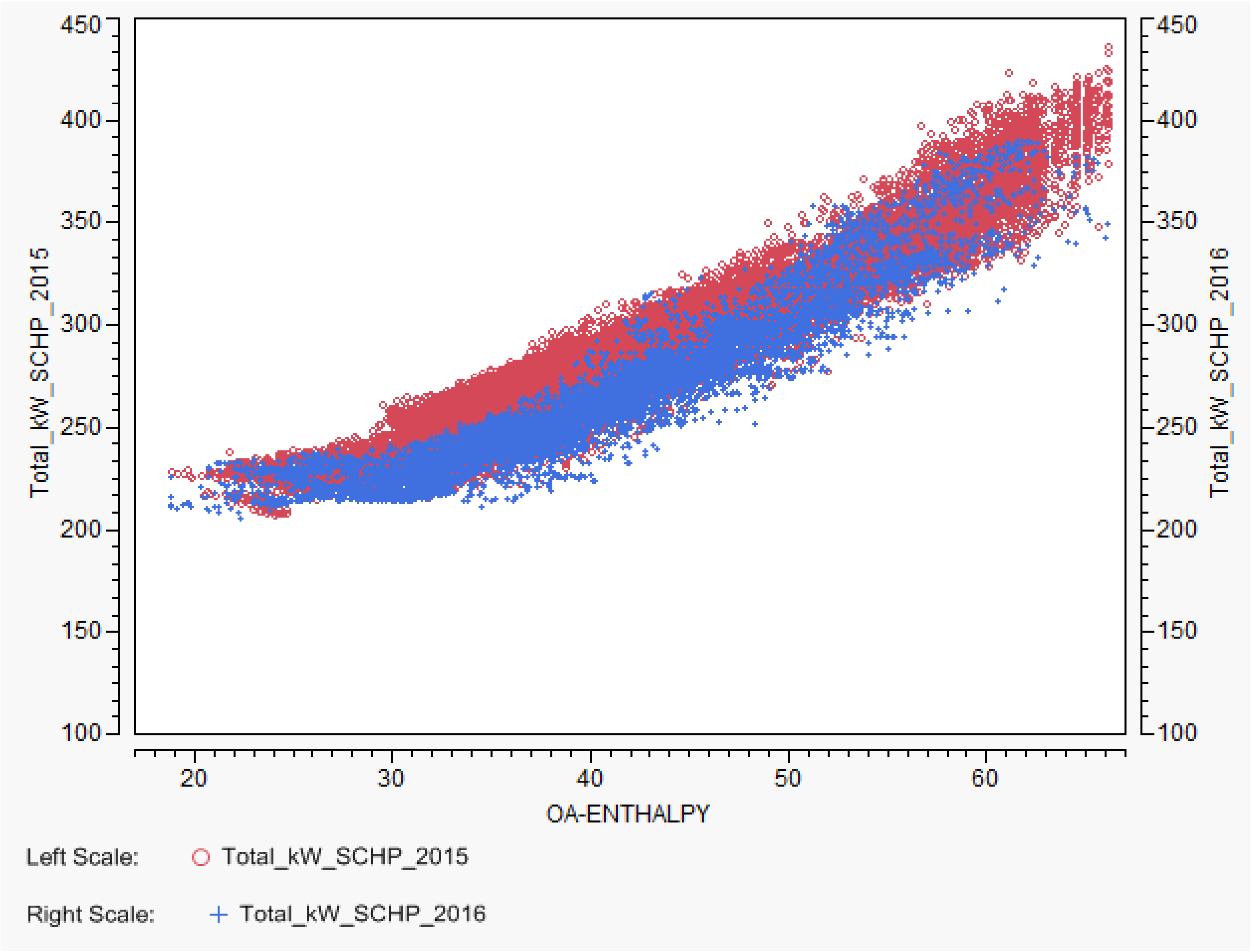
耗電量層別：節能模式：150kw, 正常模式：194kw, 節省pump 做功：44kwh
Fit module：變壓差變流量：-158kw,定壓差定流量：-16kw,節省系統做功：-130kw





Optimization of chiller system's operating parameters through data analysis

供應SCHP 耗電量明顯下降

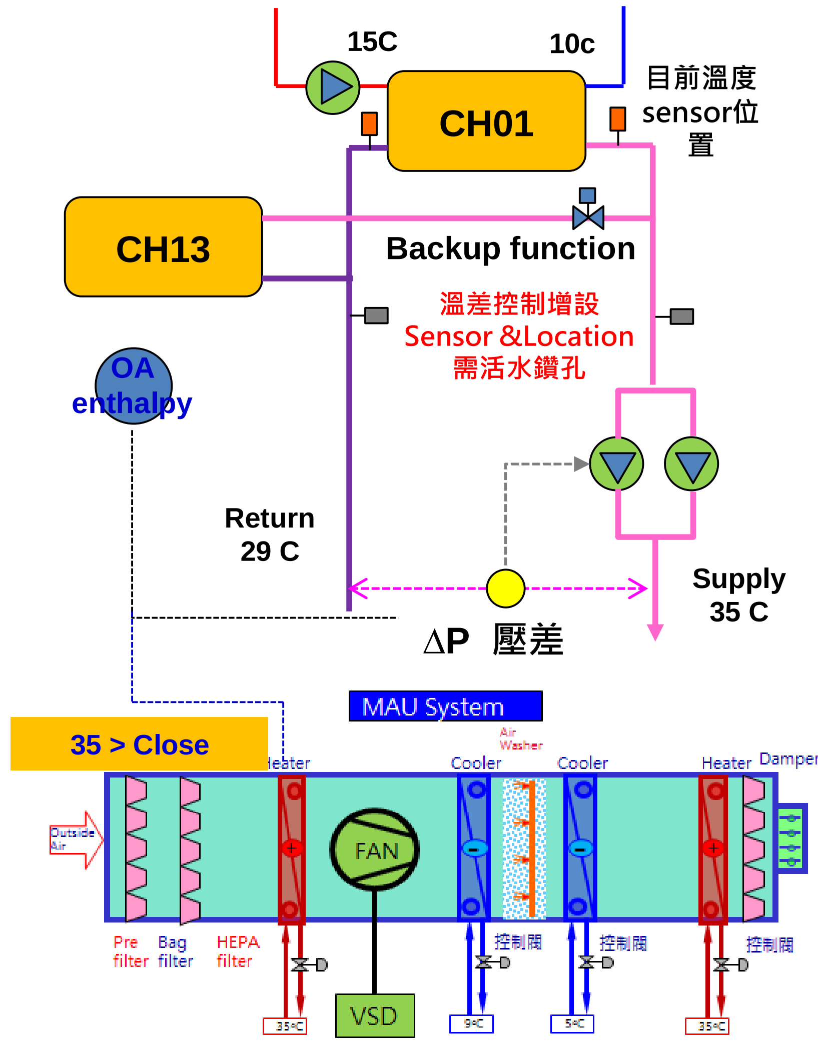


HWP Case

Optimization of chiller system's operating parameters through data analysis

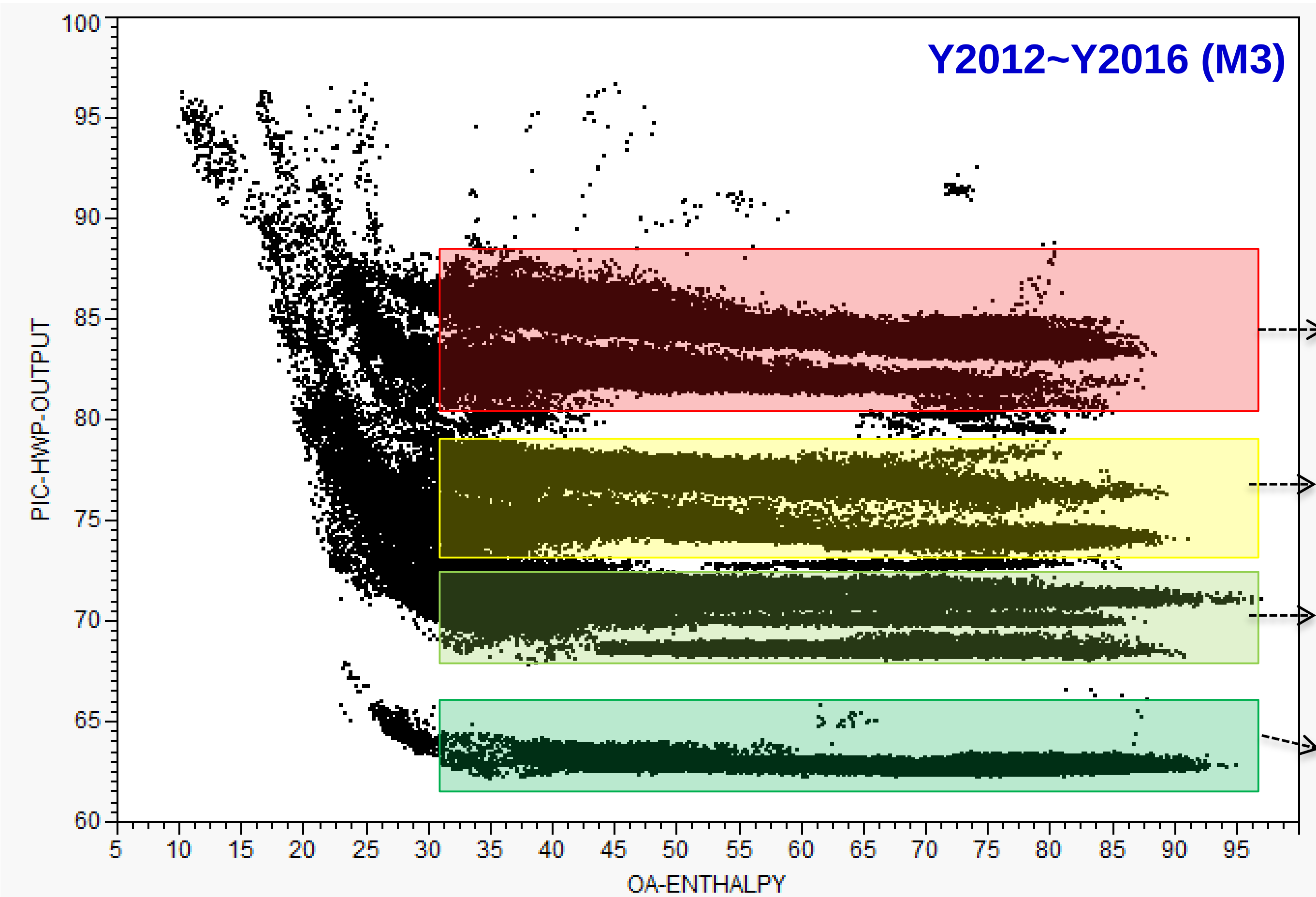
- Background
  - HWP 過往十年來為滿足冬季需求,單一設定供應壓力3 bar,導致夏季供應水量過多,造成能源浪費

- Methodology
  - HWP 供應為MAU pre-heater & re-heater 控制閥使用,由於pre-heater MAU 設定為進風enthalpy 35kj/kg , 故當外氣>35kj/kg既不進行水溫加熱 ,故可簡易使用enthalpy 進行壓力調控
  - 檢視溫差控制節能效益,確認溫差反應直接反應現場需求,故節省效益較enthalpy高出一些



Optimization of chiller system's operating parameters through data analysis

HWP: OA-Enthalpy Control Pressure Variation



PIC: 2.9~3.1 kg/cm2
ΔT: 3.0~5.2° C

PIC: 2.5~3.1 kg/cm2
ΔT: 5.5~9.1° C

PIC: 2.4~2.7 kg/cm2
ΔT: 4.5~6.8° C

PIC: ~2 kg/cm2
ΔT: 5.5~6.5° C

For OA Enthalpy >=40 kJ/kg and PIC ~2.0 kg/cm2,
ΔT ~ Optimum

Optimization of chiller system's operating parameters through data analysis

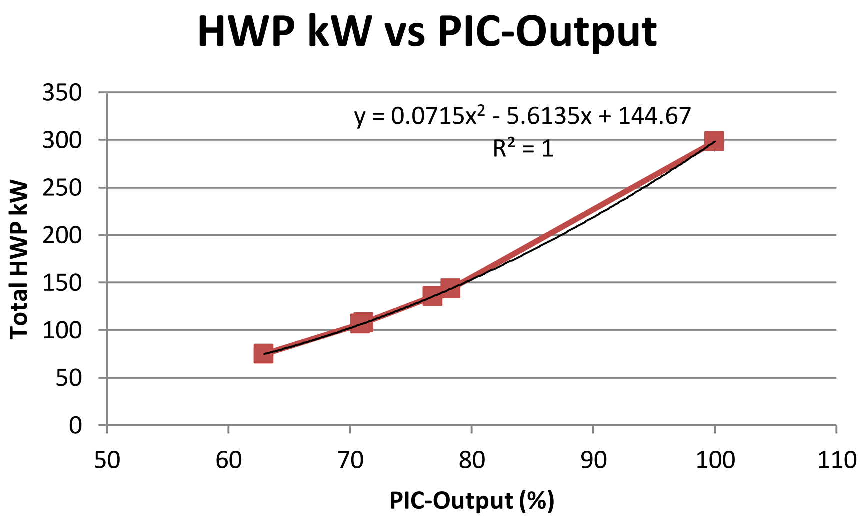
HWP: OA Enthalpy Control Pressure Setting

- At least for 78% of a year OA Enthalpy >=40kJ/kg
- Preheater consumption is almost negligible for OA Enthalpy >= 40kJ/kg
- So, HWP pressure setting can be brought down to 2.0 kg/cm^2
- Can have an annual cost savings of around 1.20 MNT$

For OA-Enthalpy >= 40kJ/kg

	As is	To be
PIC	2.95	2.00
HWP KW	133	75
Savings (NT$)	Base	1,219,558

PIC (mbar)	PIC-OUTPUT (%)	Hz	HP (1 set)	HWP total kW
	100	60	200	298
3.05	78.3	47	96	143
2.98	76.9	46	91	135
2.65	71.1	43	72	107
2.49	70.9	43	71	106
2.00	63.0	38	50	75



System Performance Test over last 4 years: No impact due to PIC setting variation

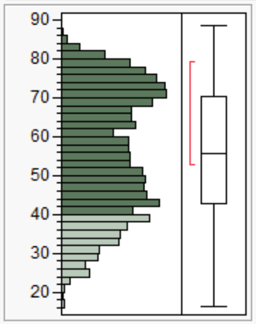
Year	Total Data Points	OA Enthalpy >=40 kJ/kg				
		Data points	% Time	Avg. PIC	Avg. PIC-Output	Avg. HWP kW (2 sets)
2016 (M1~M3)	13102	5896	45.0	2.95	76.3	132.8
2015	52202	43307	83.0	2.70	72.5	113.5
2014	52125	40947	78.6	2.21	65.9	85.4
2013	52556	41953	79.8	2.68	76.4	133.0
2012	52679	42226	80.2	2.98	83.9	176.9

Optimization of chiller system's operating parameters through data analysis

HWP Pressure Setting and OA Data Distribution

Before

OA-ENTHALPY



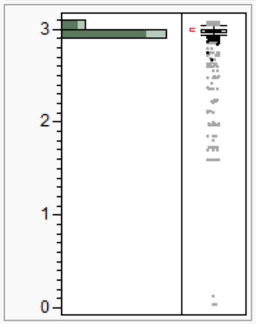
Quantiles

100.0%	maximum	88.4391
99.5%		83.6156
97.5%		80.6859
90.0%		76.3313
75.0%	quartile	70.1625
50.0%	median	55.5938
25.0%	quartile	42.8391
10.0%		34.2844
2.5%		26.7938
0.5%		23.3625
0.0%	minimum	16.3781

Moments

Mean	55.674659
Std Dev	15.830614
Std Err Mean	0.068973
Upper 95% Mean	55.809846
Lower 95% Mean	55.539471
N	52679

PIC-HWP



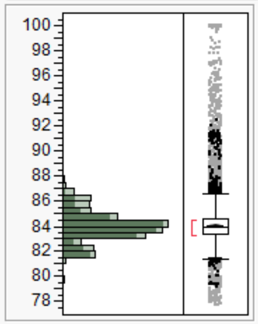
Quantiles

100.0%	maximum	3.08717
99.5%		3.03384
97.5%		3.02359
90.0%		3.00325
75.0%	quartile	2.99572
50.0%	median	2.9906
25.0%	quartile	2.97026
10.0%		2.93983
2.5%		2.90299
0.5%		2.90171
0.0%	minimum	0.03091

Moments

Mean	2.980235
Std Dev	0.0530179
Std Err Mean	0.000231
Upper 95% Mean	2.9806878
Lower 95% Mean	2.9797823
N	52679

PIC-HWP-OUTPUT



Quantiles

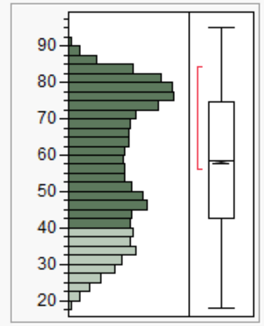
100.0%	maximum	100
99.5%		92.8766
97.5%		86.7734
90.0%		85.9375
75.0%	quartile	84.6563
50.0%	median	83.9727
25.0%	quartile	83.3633
10.0%		82.2188
2.5%		81.6836
0.5%		80.9125
0.0%	minimum	77.75

Moments

Mean	84.10897
Std Dev	1.6650039
Std Err Mean	0.0072543
Upper 95% Mean	84.123188
Lower 95% Mean	84.094751
N	52679

After

OA-ENTHALPY



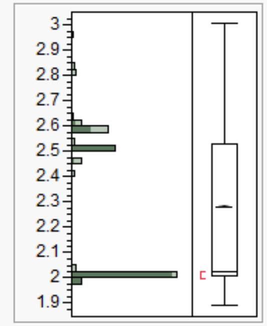
Quantiles

100.0%	maximum	95.0156
99.5%		88.5844
97.5%		85.0922
90.0%		80.8313
75.0%	quartile	74.8219
50.0%	median	58.5938
25.0%	quartile	42.4453
10.0%		32.5688
2.5%		25.8469
0.5%		21.466
0.0%	minimum	17.8688

Moments

Mean	57.833732
Std Dev	18.208035
Std Err Mean	0.0797517
Upper 95% Mean	57.990046
Lower 95% Mean	57.677418
N	52125

PIC-HWP



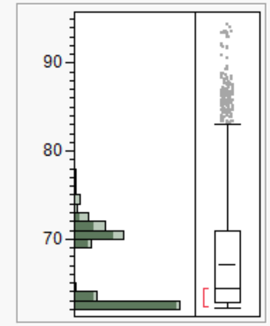
Quantiles

100.0%	maximum	3.00837
99.5%		2.87625
97.5%		2.81266
90.0%		2.59405
75.0%	quartile	2.53319
50.0%	median	2.02742
25.0%	quartile	2.00964
10.0%		2.0058
2.5%		1.99939
0.5%		1.99939
0.0%	minimum	1.89145

Moments

Mean	2.2824023
Std Dev	0.2851135
Std Err Mean	0.0012488
Upper 95% Mean	2.2848499
Lower 95% Mean	2.2799546
N	52125

PIC-HWP-OUTPUT



Quantiles

100.0%	maximum	94.3594
99.5%		80.6078
97.5%		75.1563
90.0%		72.1133
75.0%	quartile	70.9141
50.0%	median	64.3984
25.0%	quartile	62.7617
10.0%		62.5742
2.5%		62.457
0.5%		62.3672
0.0%	minimum	62.1484

Moments

Mean	67.134033
Std Dev	4.6262415
Std Err Mean	0.0202631
Upper 95% Mean	67.173749
Lower 95% Mean	67.094317
N	52125

供應 HWP 耗電量明顯下降