

環控農業工程學

濕空氣熱力特性

方煒

台大生機系



濕空氣

- 濕空氣：含有水蒸汽的空氣
- 乾空氣：不含水蒸汽的空氣
- 濕空氣 = 乾空氣 + 水蒸汽
- 乾空氣：混合氣體 (N_2 : 80%, O_2 : 19%, 其他...)
- 其他： CO_2 400 ppm = 0.04%



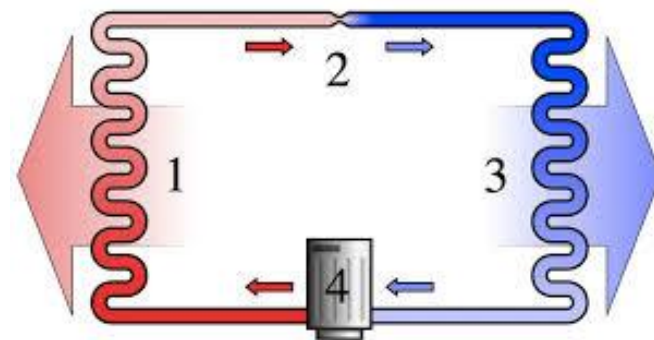
濕空氣的功用

- 可做為熱源（提供熱） / 熱匯（帶走熱）
- 可做為水源（加濕） / 水匯（除濕）
- 可做為 N_2 源 / O_2 源
- 可用於攜帶有機/無機微粒
- 其他

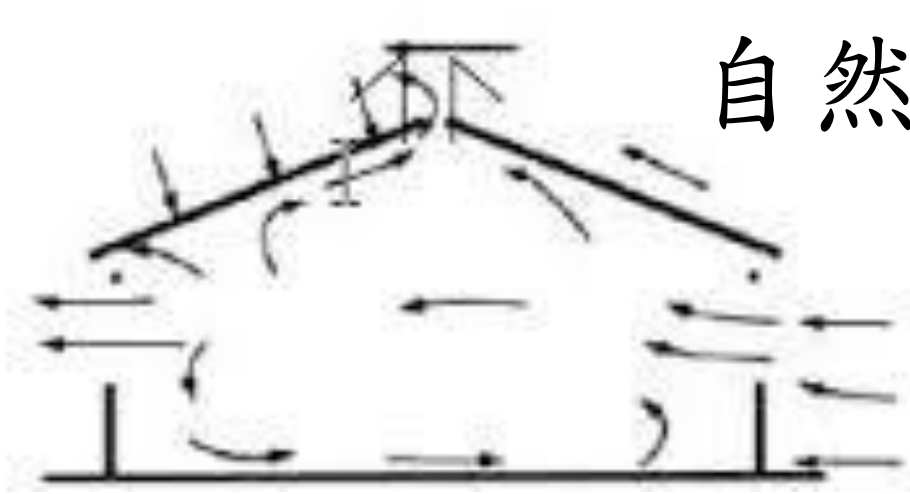


濕空氣相關之各種應用

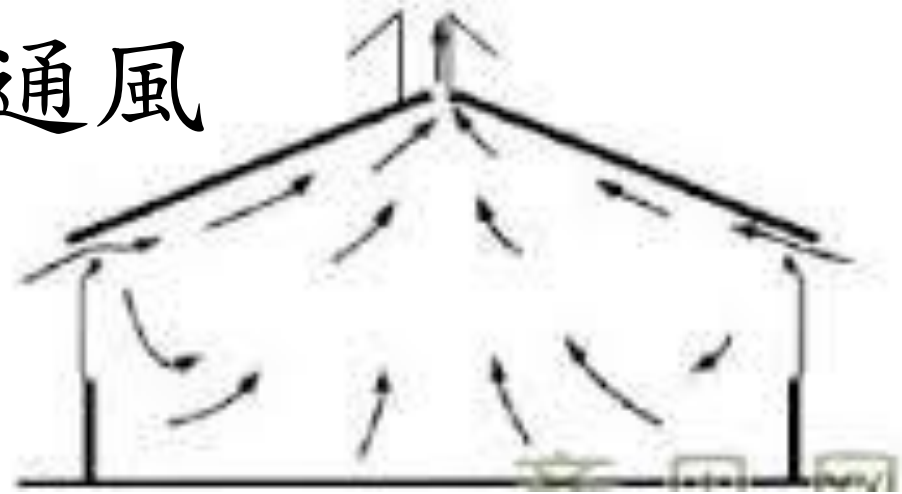
1. 冷凍空調
2. 通風
3. 加熱
4. 乾燥
5. 蒸發冷卻系統
 - 風扇濕簾系統
 - 噴霧降溫



自然通風

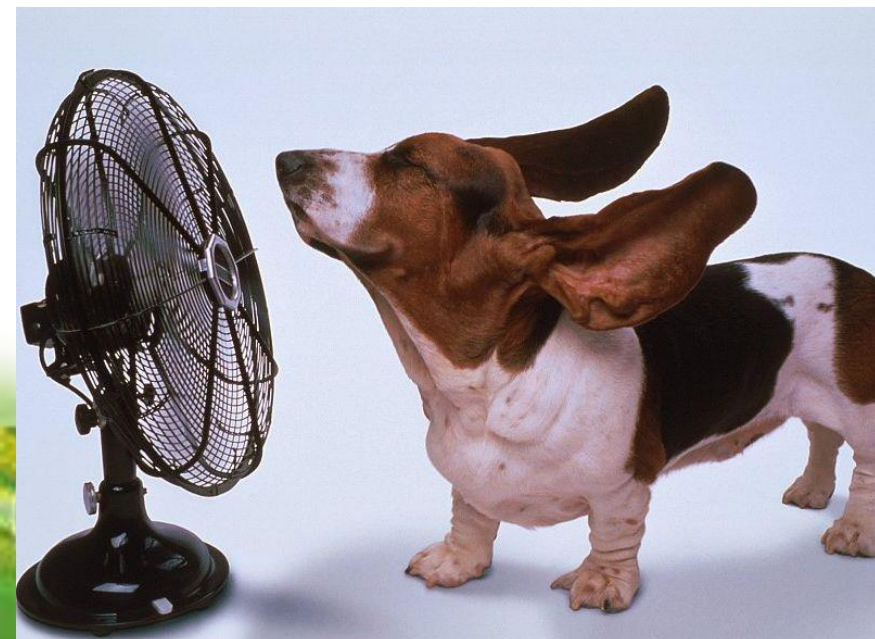


夏季通風

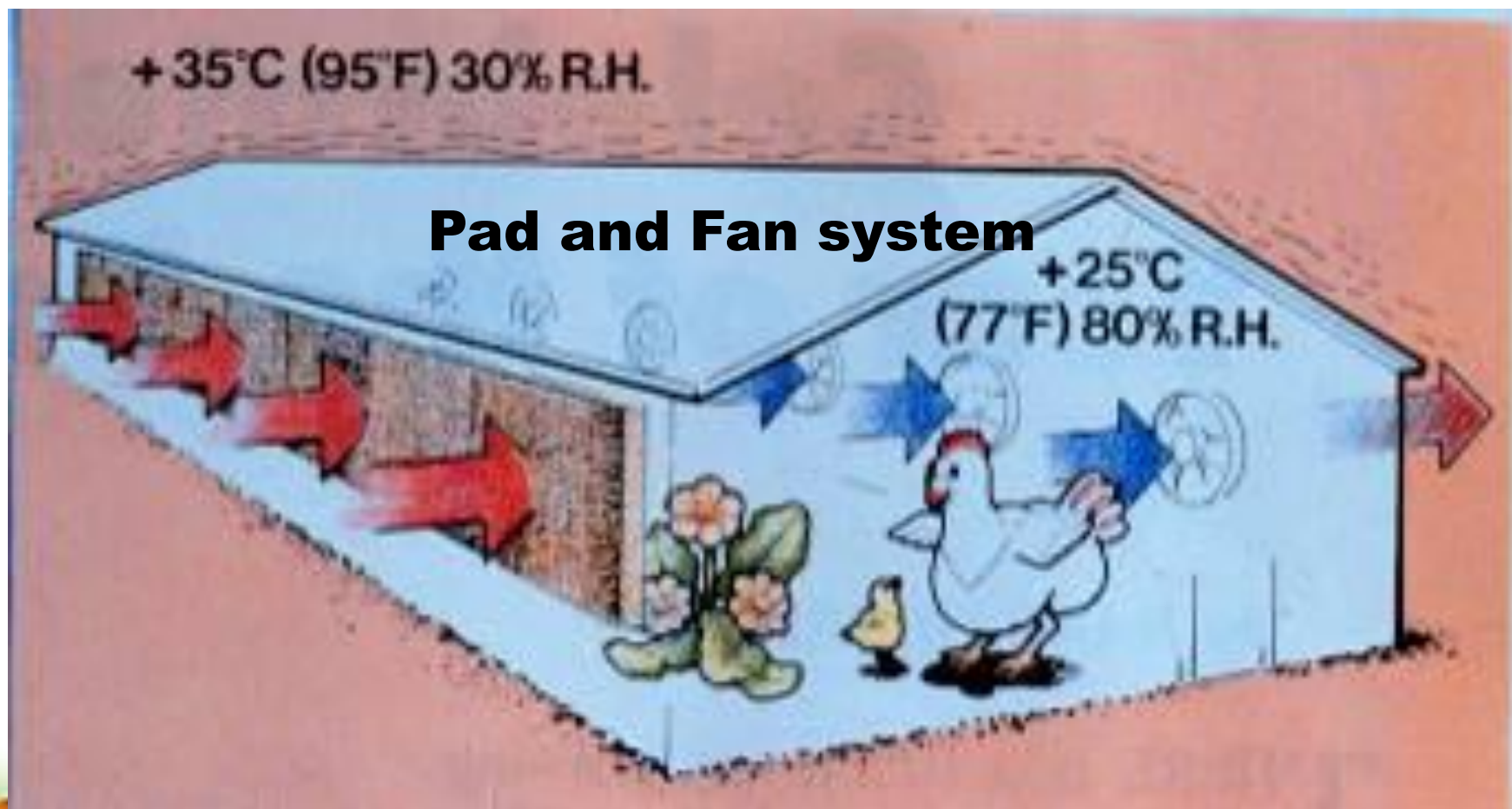


冬季通風

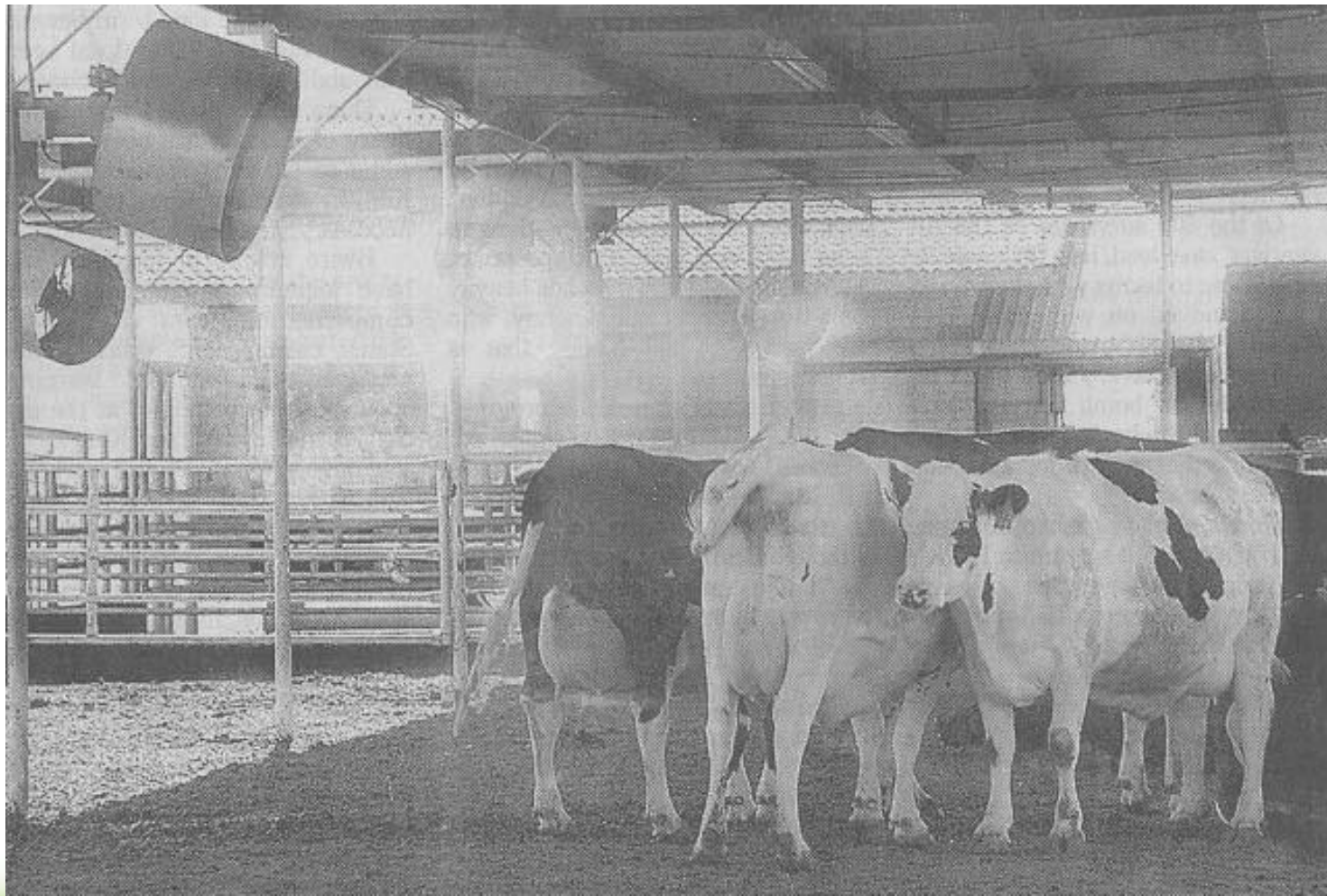
通風 (強制通風)



蒸發冷卻（溫室或禽畜舍之濕簾與風扇）



蒸發冷卻（畜舍噴霧）



溫室灑水



蒸發冷卻

溫室噴霧



蒸發冷卻（庭院之加濕/降溫）



濕空氣性質

1. 乾球溫度
dry bulb T
2. 濕球溫度
wet bulb T
3. 露點溫度
dew point T
4. 相對溼度
relative humidity
5. 絕對溼度
absolute humidity
(濕度比humidity ratio)
6. 比容 specific volume
7. 熱焓 enthalpy
8. 蒸汽壓vapor pressure
9. 飽和蒸汽壓 saturated vapor pressure

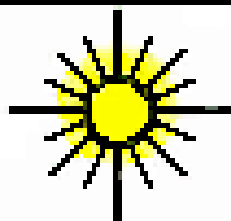


溫度影響濕度

- 所謂溫度指的是乾球溫度
- 所謂濕度指的是相對濕度



一天中的溫濕度變化



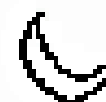
HIGH TEMPERATURE

高溫 / 低濕



LOW HUMIDITY

白 DAY 天



LOW TEMPERATURE

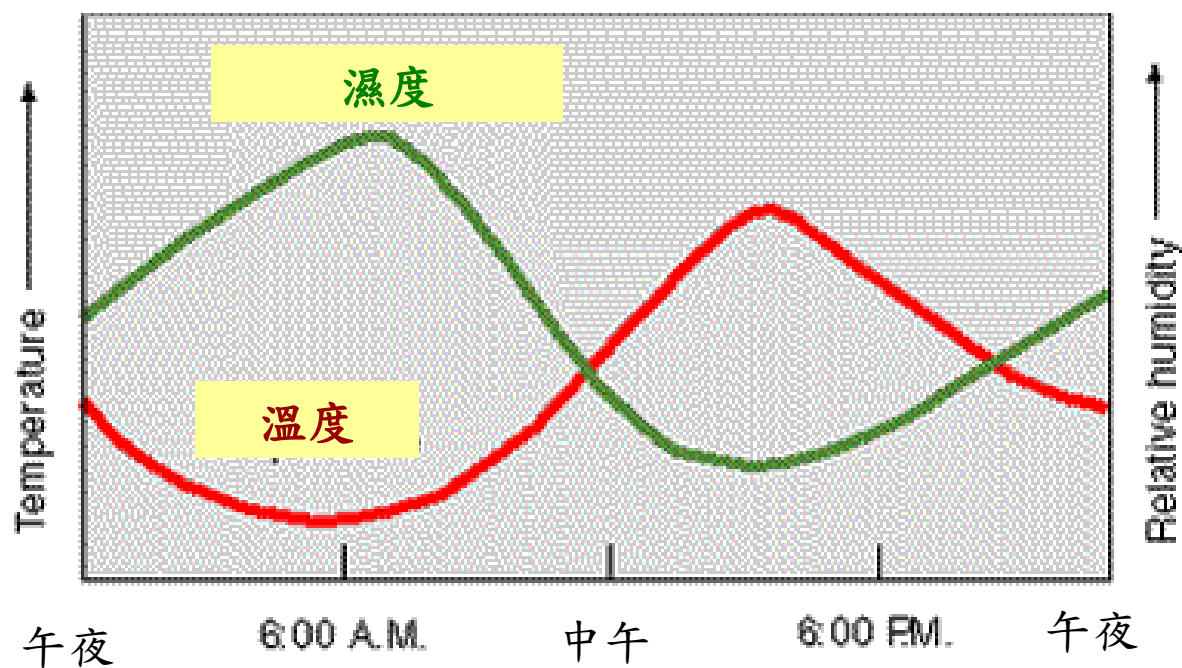
低溫 / 高濕



HIGH HUMIDITY

夜 NIGHT 晚

高溫時多半是低濕



哪一項不對？

低溫
高濕

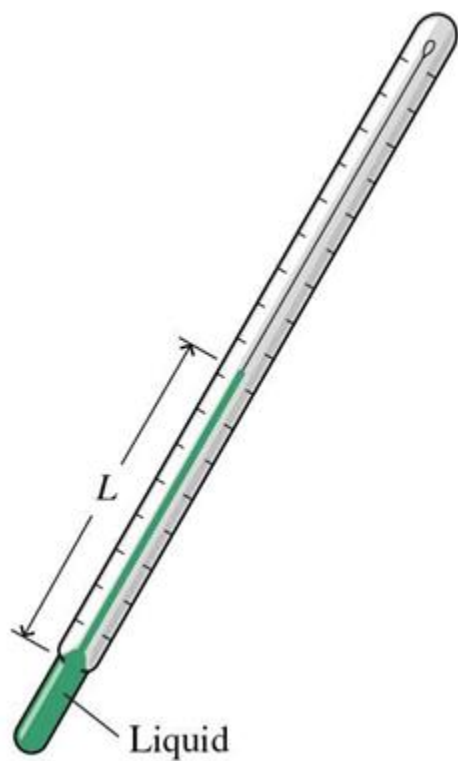


高溫
低濕



高溫
高濕

(乾球) 溫度計



相對溼度

- 空氣的水蒸汽分壓與相同溫度下飽和蒸汽壓的比值，單位：%
- 相對溼度代表空氣吸收水汽的程度
- 空氣吸飽了水汽，不能再吸了，此時相對溼度為100%
- 不同溫度下，空氣可以吸收水蒸汽的量不同，溫度越高，可吸得越多
- 相同溫度下，空氣濕度越高，空氣中還能吸收的水蒸汽量越少



溼球溫度

相對溼度需要使用儀器來量測

沒有儀器時

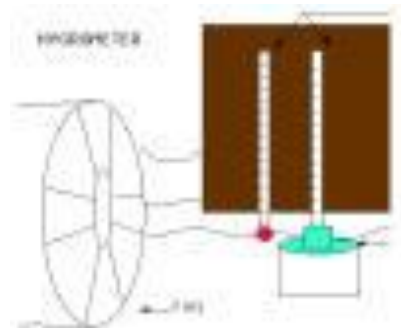
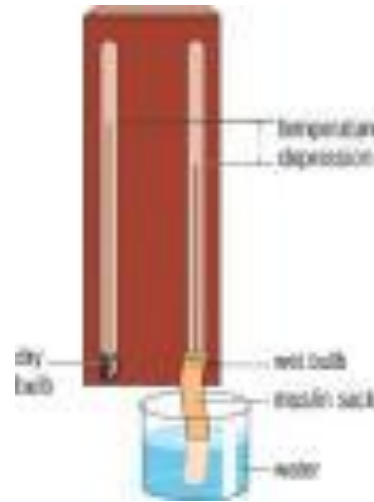
可以使用乾、濕球溫度計，

再間接求出相對溼度



乾、濕球溫度計

Dry and Wet Bulb Temperature



Swing type Tdb and Twb 手轉式乾濕球溫度計



°C 乾濕度表 %

乾 球 示 度	乾濕球溫差					
	1	2	3	4	5	6

35	93	87	80	74	68	63
34	93	86	80	74	68	62
33	93	86	80	73	67	61
32	93	86	79	73	67	61
31	93	86	79	72	66	60
30	93	85	78	72	65	59
29	92	85	78	71	65	58
28	92	85	77	70	64	57
27	92	84	77	70	63	56
26	92	84	76	69	62	55
25	92	84	76	68	61	54
24	91	83	75	68	60	53
23	91	83	75	67	59	52
22	91	82	74	66	58	51
21	91	82	73	65	57	49
20	91	81	73	64	56	48
19	90	81	72	63	55	46
18	90	80	71	62	53	45

°C 乾濕度表 %

乾 球 示 度	乾濕球溫差					
	1	2	3	4	5	6

35	93	87	80	74	68	63
34	93	86	80	74	68	62
33	93	86	80	73	67	61
32	93	86	79	73	67	61
31	93	86	79	72	66	60
30	93	85	78	72	65	59
29	92	85	78	71	65	58
28	92	85	77	70	64	57
27	92	84	77	70	63	56
26	92	84	76	69	62	55
25	92	84	76	68	61	54
24	91	83	75	68	60	53
23	91	83	75	67	59	52
22	91	82	74	66	58	51
21	91	82	73	65	57	49
20	91	81	73	64	56	48
19	90	81	72	63	55	46

50

40

30

20

30

20

乾溼球溫差（濕球降）

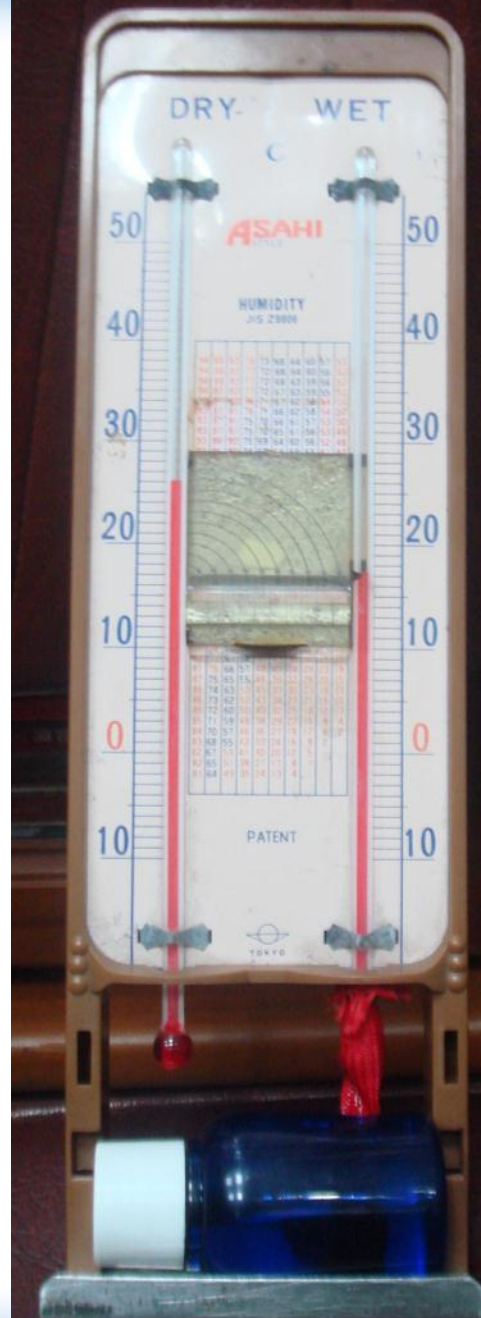
Wet bulb depression, WBD

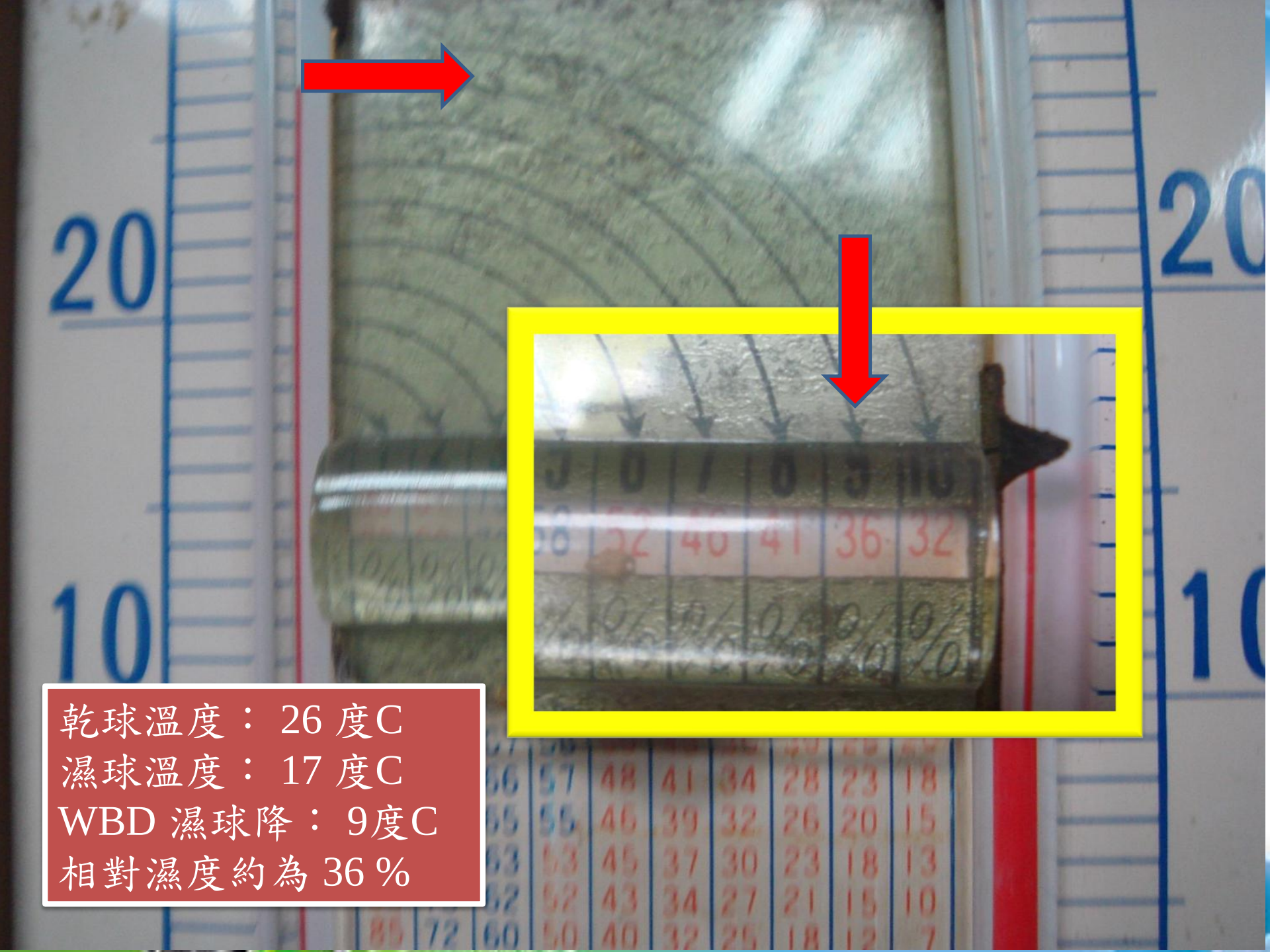
濕球降 = 乾球溫度 - 濕球溫度

蒸發冷卻系統的
降溫極限



乾、溼球溫度計





乾球溫度：26 度C
濕球溫度：17 度C
WBD 濕球降：9度C
相對濕度約為 36 %

	20	21	22	23	24	25	26	27	28	29	30
10	24.03	20.04	16.47	13.27	10.41	7.85	5.54	3.47	1.6	N/A	N/A
11	30.39	26.01	22.09	18.56	15.4	12.55	9.98	7.66	5.57	3.68	1.97
12	36.98	32.2	27.9	24.04	20.55	17.41	14.57	11.99	9.66	7.55	5.64
13	43.8	38.6	33.92	29.7	25.89	22.43	19.31	16.47	13.89	11.55	9.42
14	50.87	45.24	40.16	35.56	31.41	27.64	24.21	21.1	18.26	15.68	13.33
15	58.19	52.11	46.62	41.64	37.12	33.02	29.29	25.89	22.79	19.96	17.37
16	65.78	59.23	53.31	47.93	43.05	38.6	34.55	30.85	27.48	24.39	21.56
17	73.64	66.62	60.25	54.46	49.19	44.39	40.01	36	32.33	28.97	25.89
18	81.79	74.27	67.44	61.23	55.56	50.39	45.66	41.33	37.37	33.73	30.39
19	90.24	82.21	74.9	68.24	62.17	56.61	51.53	46.87	42.59	38.66	35.05
20	100	90.43	82.63	75.52	69.02	63.07	57.61	52.61	48.01	43.78	39.89
21	N/A	100	90.65	83.06	76.12	69.76	63.93	58.57	53.64	49.1	44.91
22	N/A	N/A	100	90.88	83.49	76.71	70.48	64.75	59.48	54.62	50.13
23	N/A	N/A	N/A	100	91.13	83.92	77.28	71.17	65.54	60.35	55.55
24	N/A	N/A	N/A	N/A	100	91.39	84.34	77.84	71.84	66.3	61.18
25	N/A	N/A	N/A	N/A	N/A	100	91.66	84.76	78.38	72.49	67.03
26	N/A	N/A	N/A	N/A	N/A	N/A	100	91.94	85.17	78.91	73.11
27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.22	85.58	79.42
28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.5	85.98
29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.79
30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100



$$RH = f(T_{db}, T_{wb})$$

相對溼度

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
15	89.98	80.72	72.4	64.92	58.19	52.11	46.62	41.64	37.12	33.02	29.29	25.89	22.79	19.96	17.37	15.01	12.85	10.87	9.06	7.41	5.9	4.52	3.25
16	100	89.95	81.04	73.01	65.78	59.23	53.31	47.93	43.05	38.6	34.55	30.85	27.48	24.39	21.56	18.97	16.6	14.42	12.43	10.6	8.93	7.39	5.98
17	N/A	100	89.98	81.4	73.64	66.62	60.25	54.46	49.19	44.39	40.01	36	32.33	28.97	25.89	23.07	20.48	18.1	15.91	13.9	12.06	10.36	8.81
18	N/A	N/A	100	90.09	81.79	74.27	67.44	61.23	55.56	50.39	45.66	41.33	37.37	33.73	30.39	27.32	24.5	21.9	19.52	17.32	15.3	13.44	11.73
19	N/A	N/A	N/A	100	90.24	82.21	74.9	68.24	62.17	56.61	51.53	46.87	42.59	38.66	35.05	31.73	28.67	25.85	23.26	20.86	18.66	16.63	14.75
20	N/A	N/A	N/A	N/A	100	90.43	82.63	75.52	69.02	63.07	57.61	52.61	48.01	43.78	39.89	36.3	33	29.95	27.14	24.54	22.14	19.93	17.89
21	N/A	N/A	N/A	N/A	N/A	100	90.65	83.06	76.12	69.76	63.93	58.57	53.64	49.1	44.91	41.06	37.49	34.21	31.17	28.36	25.76	23.36	21.14
22	N/A	N/A	N/A	N/A	N/A	N/A	100	90.88	83.49	76.71	70.48	64.75	59.48	54.62	50.13	45.99	42.16	38.63	35.35	32.33	29.52	26.93	24.52
23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	91.13	83.92	77.28	71.17	65.54	60.35	55.55	51.12	47.02	43.22	39.71	36.45	33.43	30.63	28.04
24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	91.39	84.34	77.84	71.84	66.3	61.18	56.45	52.06	48	44.23	40.74	37.49	34.49	31.69
25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	91.66	84.76	78.38	72.49	67.03	61.98	57.3	52.96	48.93	45.19	41.72	38.49	35.49
26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	91.94	85.17	78.91	73.11	67.74	62.75	58.12	53.83	49.83	46.12	42.66	39.45
27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.22	85.58	79.42	73.72	68.42	63.49	58.91	54.66	50.69	47	43.57
28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.5	85.98	79.93	74.3	69.07	64.21	59.67	55.45	51.52	47.85
29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.79	86.38	80.42	74.87	69.71	64.89	60.41	56.22	52.31
30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.09	86.78	80.91	75.43	70.32	65.56	61.11	56.95
31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.39	87.18	81.38	75.97	70.92	66.2	61.79
32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.69	87.56	81.84	76.49	71.49	66.81
33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.99	87.95	82.29	77	72.04
34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.29	88.32	82.73	77.49
35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.58	88.68	83.15
36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.87	89.03
37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.15
38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100

Patm = 101.325 kPa



相對濕度

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
10	24.03	20.04	16.47	13.27	10.41	7.85	5.54	3.47	1.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	30.39	26.01	22.09	18.56	15.4	12.55	9.98	7.66	5.57	3.68	1.97	0.43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12	36.98	32.2	27.9	24.04	20.55	17.41	14.57	11.99	9.66	7.55	5.64	3.9	2.33	0.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13	43.8	38.6	33.92	29.7	25.89	22.43	19.31	16.47	13.89	11.55	9.42	7.49	5.72	4.12	2.66	1.33	N/A	N/A	N/A	N/A	N/A
14	50.87	45.24	40.16	35.56	31.41	27.64	24.21	21.1	18.26	15.68	13.33	11.19	9.23	7.44	5.81	4.32	2.97	1.73	0.6	N/A	N/A
15	58.19	52.11	46.62	41.64	37.12	33.02	29.29	25.89	22.79	19.96	17.37	15.01	12.85	10.87	9.06	7.41	5.9	4.52	3.25	2.1	1.05
16	65.78	59.23	53.31	47.93	43.05	38.6	34.55	30.85	27.48	24.39	21.56	18.97	16.6	14.42	12.43	10.6	8.93	7.39	5.98	4.7	3.52
17	73.64	66.62	60.25	54.46	49.19	44.39	40.01	36	32.33	28.97	25.89	23.07	20.48	18.1	15.91	13.9	12.06	10.36	8.81	7.38	6.07
18	81.79	74.27	67.44	61.23	55.56	50.39	45.66	41.33	37.37	33.73	30.39	27.32	24.5	21.9	19.52	17.32	15.3	13.44	11.73	10.15	8.7
19	90.24	82.21	74.9	68.24	62.17	56.61	51.53	46.87	42.59	38.66	35.05	31.73	28.67	25.85	23.26	20.86	18.66	16.63	14.75	13.02	11.43
20	100	90.43	82.63	75.52	69.02	63.07	57.61	52.61	48.01	43.78	39.89	36.3	33	29.95	27.14	24.54	22.14	19.93	17.89	16	14.26
21	N/A	100	90.65	83.06	76.12	69.76	63.93	58.57	53.64	49.1	44.91	41.06	37.49	34.21	31.17	28.36	25.76	23.36	21.14	19.09	17.19
22	N/A	N/A	100	90.88	83.49	76.71	70.48	64.75	59.48	54.62	50.13	45.99	42.16	38.63	35.35	32.33	29.52	26.93	24.52	22.3	20.24
23	N/A	N/A	N/A	100	91.13	83.92	77.28	71.17	65.54	60.35	55.55	51.12	47.02	43.22	39.71	36.45	33.43	30.63	28.04	25.63	23.4
24	N/A	N/A	N/A	N/A	100	91.39	84.34	77.84	71.84	66.3	61.18	56.45	52.06	48	44.23	40.74	37.49	34.49	31.69	29.1	26.69
25	N/A	N/A	N/A	N/A	N/A	100	91.66	84.76	78.38	72.49	67.03	61.98	57.3	52.96	48.93	45.19	41.72	38.49	35.49	32.71	30.12
26	N/A	N/A	N/A	N/A	N/A	N/A	100	91.94	85.17	78.91	73.11	67.74	62.75	58.12	53.83	49.83	46.12	42.66	39.45	36.46	33.68
27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.22	85.58	79.42	73.72	68.42	63.49	58.91	54.66	50.69	47	43.57	40.37	37.38
28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.5	85.98	79.93	74.3	69.07	64.21	59.67	55.45	51.52	47.85	44.43	41.24
29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.79	86.38	80.42	74.87	69.71	64.89	60.41	56.22	52.31	48.66	45.26
30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.09	86.78	80.91	75.43	70.32	65.56	61.11	56.95	53.07	49.44
31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.39	87.18	81.38	75.97	70.92	66.2	61.79	57.66	53.8
32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.69	87.56	81.84	76.49	71.49	66.81	62.43	58.33
33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.99	87.95	82.29	77	72.04	67.4	63.05
34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.29	88.32	82.73	77.49	72.57	67.96
35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.58	88.68	83.15	77.95	73.07
36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.87	89.03	83.54	78.39
37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.15	89.36	83.92
38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.4	89.67
39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.64



$$T_{wb} = f(T_{db}, RH)$$

濕球溫度

Twb Table

	20	21	22	23	24	25	26	27	28	29	30	31	32	
50	13.79	14.59	15.39	16.2	17	17.8	18.61	19.41	20.22	21.03	21.84	22.65	23.46	
55	14.47	15.3	16.12	16.95	17.77	18.6	19.43	20.26	21.08	21.91	22.75	23.58	24.42	
60	15.15	15.99	16.84	17.68	18.53	19.38	20.23	21.07	21.93	22.78	23.63	24.49	25.34	
65	15.81	16.67	17.54	18.4	19.27	20.14	21.01	21.87	22.75	23.62	24.49	25.37	26.25	
70	16.45	17.34	18.22	19.11	19.99	20.88	21.77	22.66	23.55	24.44	25.33	26.23	27.13	
75	17.09	17.99	18.9	19.8	20.7	21.61	22.51	23.42	24.33	25.24	26.15	27.07	27.99	
80	17.71	18.63	19.56	20.48	21.4	22.32	23.25	24.17	25.1	26.03	26.96	27.89	28.82	
85	18.33	19.27	20.2	21.14	22.08	23.02	23.96	24.91	25.85	26.8	27.74	28.69	29.64	
90	18.93	19.89	20.84	21.8	22.75	23.71	24.67	25.63	26.59	27.55	28.51	29.48	30.45	
95	19.53	20.5	21.47	22.44	23.41	24.38	25.36	26.33	27.31	28.29	29.27	30.25	31.24	
100	20	21	22	23	24	25	26	27	28	29	30	31	32	



$$WBD = T_{db} - T_{wb} = f(T_{db}, RH)$$

Web Bulb Depression 濕球降

	20	22	24	26	28	30	32	34	36	38	40	42	44
50	6.21	6.61	7	7.39	7.78	8.16	8.54	8.91	9.27	9.62	9.96	10.3	10.62
55	5.53	5.88	6.23	6.57	6.92	7.25	7.58	7.91	8.22	8.53	8.82	9.11	9.38
60	4.85	5.16	5.47	5.77	6.07	6.37	6.66	6.94	7.21	7.47	7.72	7.96	8.19
65	4.19	4.46	4.73	4.99	5.25	5.51	5.75	5.99	6.22	6.44	6.65	6.84	7.03
70	3.55	3.78	4.01	4.23	4.45	4.67	4.87	5.07	5.26	5.44	5.61	5.76	5.91
75	2.91	3.1	3.3	3.49	3.67	3.85	4.01	4.17	4.33	4.47	4.6	4.72	4.83
80	2.29	2.44	2.6	2.75	2.9	3.04	3.18	3.3	3.41	3.52	3.61	3.7	3.77
85	1.67	1.8	1.92	2.04	2.15	2.26	2.36	2.44	2.52	2.59	2.65	2.7	2.74
90	1.07	1.16	1.25	1.33	1.41	1.49	1.55	1.61	1.65	1.69	1.72	1.73	1.74
95	0.47	0.53	0.59	0.64	0.69	0.73	0.76	0.79	0.8	0.81	0.8	0.79	0.76
100	0	0	0	0	0	0	0	0	0	0	0	0	0



濕空氣熱力學

Psychrometrics

- 給定大氣壓力值，知道獨立的兩個熱力學性質，可求出其他所有性質
- 乾球、濕球溫度 $\rightarrow$ 相對溼度
- 乾球、相對溼度 $\rightarrow$ 濕球溫度
- 相對溼度、濕球溫度 $\rightarrow$ 乾球溫度



濕空氣熱力學

Psychrometrics

- 必須要懂的 **三溫兩濕兩壓**
 - 乾球溫度、濕球溫度、露點溫度
 - 乾球溫度 $\geq$ 濕球溫度 $\geq$ 露點溫度
 - 相對溼度、絕對溼度
 - 飽和蒸汽壓、蒸汽分壓



三溫

- 乾球溫度
- 濕球溫度
- 露點溫度則決定了是否會發生結露現象
 - 當空氣的露點溫度高於物體的表面溫度，結露就會發生在該物體表面(譬如葉片、花朵)
 - 眼鏡鏡片會起霧，杯子會流汗都相關
 - 設施內部一旦發生結露，就容易發生病害

數位式/攜帶式溫、濕度感測器



紅外線溫度感測器

Infra-red Dry Bulb Temperature

只能量測某實體的**表面溫度**



紅外線溫度感測器使用注意事項

- 耳溫槍只能用於量耳溫，無法用於量物體之表面溫度
- 需要知道量測物體表面的放射率（耳溫槍除外），才能量測出正確的溫度值
- 大多數物體之放射率接近 1
- 但易反光的金屬表面之放射率通常偏低，用來量測金屬表面溫度容易偏低
- 通常需要在表面黏貼放射率接近1的黑色專用貼紙或噴不反光的黑漆



放射率

放射率（ ε ）：物體輻射能量與同溫度的黑體輻射能量的比值

它是物質吸收與輻射能量能力的指標，
黑體的放射率為1

被測物	放射率	被測物	放射率
瀝青、柏油	0.90~0.98	橡膠(黑)	0.95
混凝土	0.94	塑膠(不透光)	0.95
水泥	0.95	油漆(亮光漆)	0.80~0.95
沙	0.90	鉛(已氧化)	0.20~0.60
土壤	0.90~0.98	黃銅(磨光)	0.01~0.05
水	0.92~0.96	黃銅(光滑)	0.30
冰	0.96~0.98	黃銅(已氧化)	0.50
雪	0.90	碳	0.80~0.90
玻璃	0.90~0.95	石墨	0.70~0.80
陶瓷	0.90~0.95	木材	0.90~0.95
石膏	0.80~0.95	皮革	0.75~0.80
紅磚	0.93~0.95	黑布	0.98

熱像儀 Thermal Imager



<http://us.fluke.com/user/products/CategoryTI/>



http://www.landinst.com/infrared/products/thermal_imaging/tp8_portable_imager.htm



http://www.landinst.com/infrared/products/thermal_imaging/guide_M4_thermal_imager.htm



兩濕

相對濕度：in %

絕對濕度：in g vapor/kg dry air

空氣中所含水蒸汽的重量

空氣中所含水蒸汽的蒸汽壓（重量 or 絕對濕度）

與

相同溫度下飽和水蒸汽的蒸汽壓（重量 or 絕對濕度）的比值

稱為 相對溼度（飽和度）



絕對溼度

- 常溫範圍下，每公斤乾空氣中的含水量為 0 ~ 30 g 水蒸汽
- 此數值稱為絕對溼度，單位為 kg/kg 乾空氣或 g/kg 乾空氣
- 相同溫度時，空氣的相對溼度越高，空氣中的含水量也就越高，絕對溼度越大
- 相同相對溼度時，空氣的溫度越高，絕對溼度越大



回憶一下，
你學了幾個空氣熱力學的專有名詞了？

- 3 乾球、濕球、露點溫度
- 2 相對濕度 (RH)、絕對溼度 (AH)
- 2 飽和蒸汽壓、蒸汽分壓
- 1 飽和度
- 1 濕球降



濕空氣熱力性質

濕氣圖 (Psychrometric Chart)



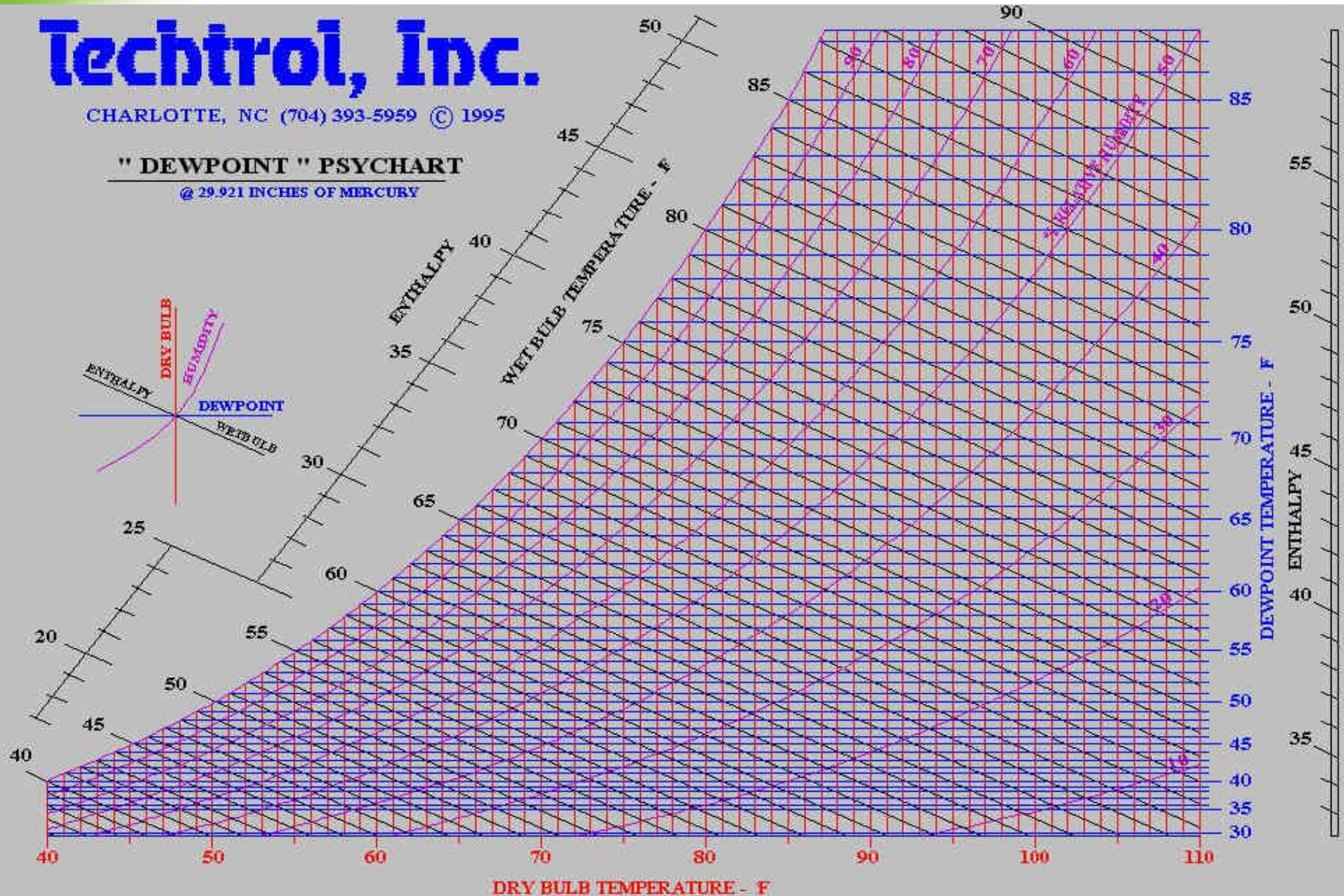
Psychrometric Chart

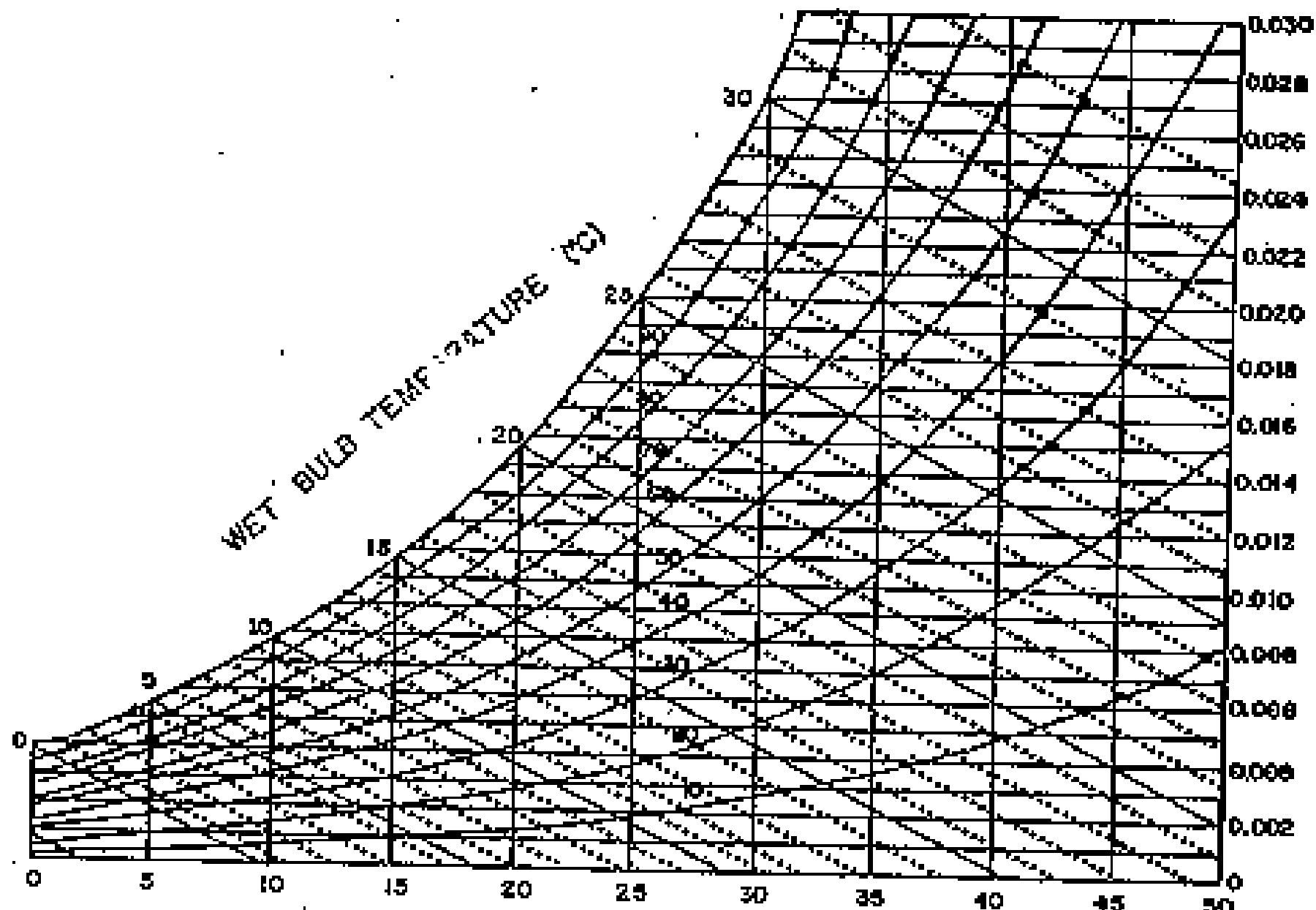
Techtrol, Inc.

CHARLOTTE, NC (704) 393-5959 © 1995

" DEWPOINT " PSYCHART

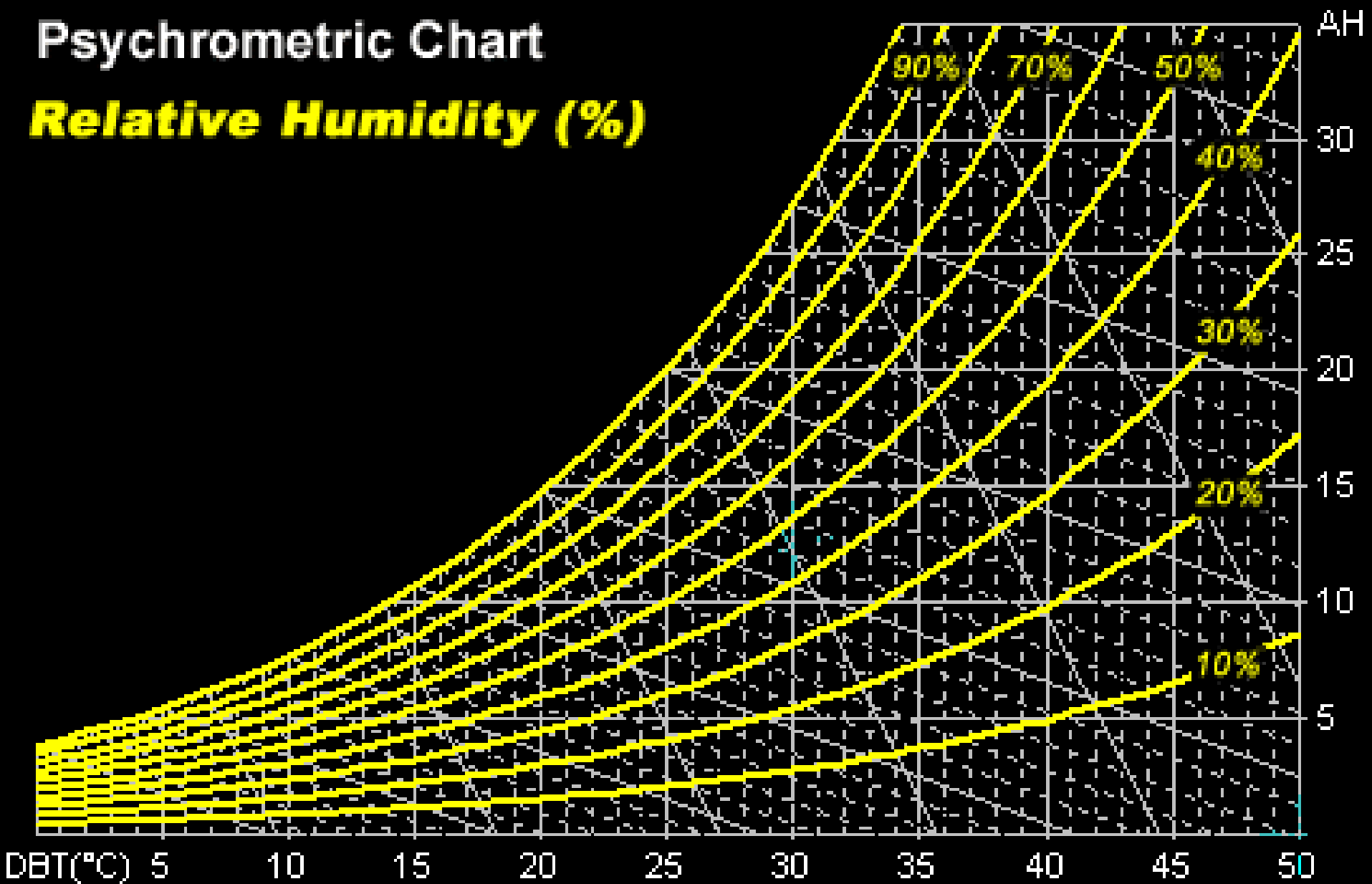
@ 29.921 INCHES OF MERCURY



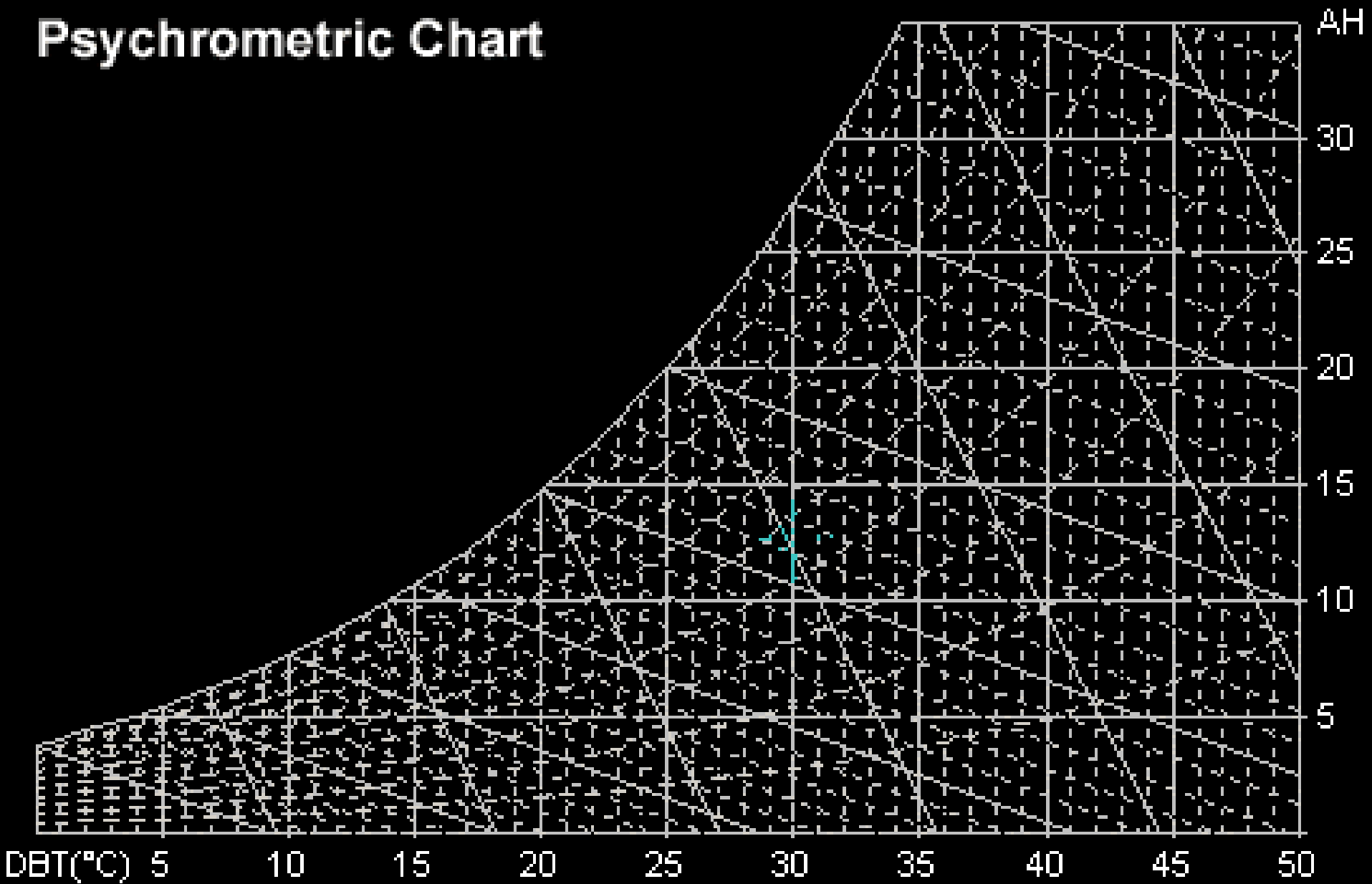


Psychrometric Chart

Relative Humidity (%)



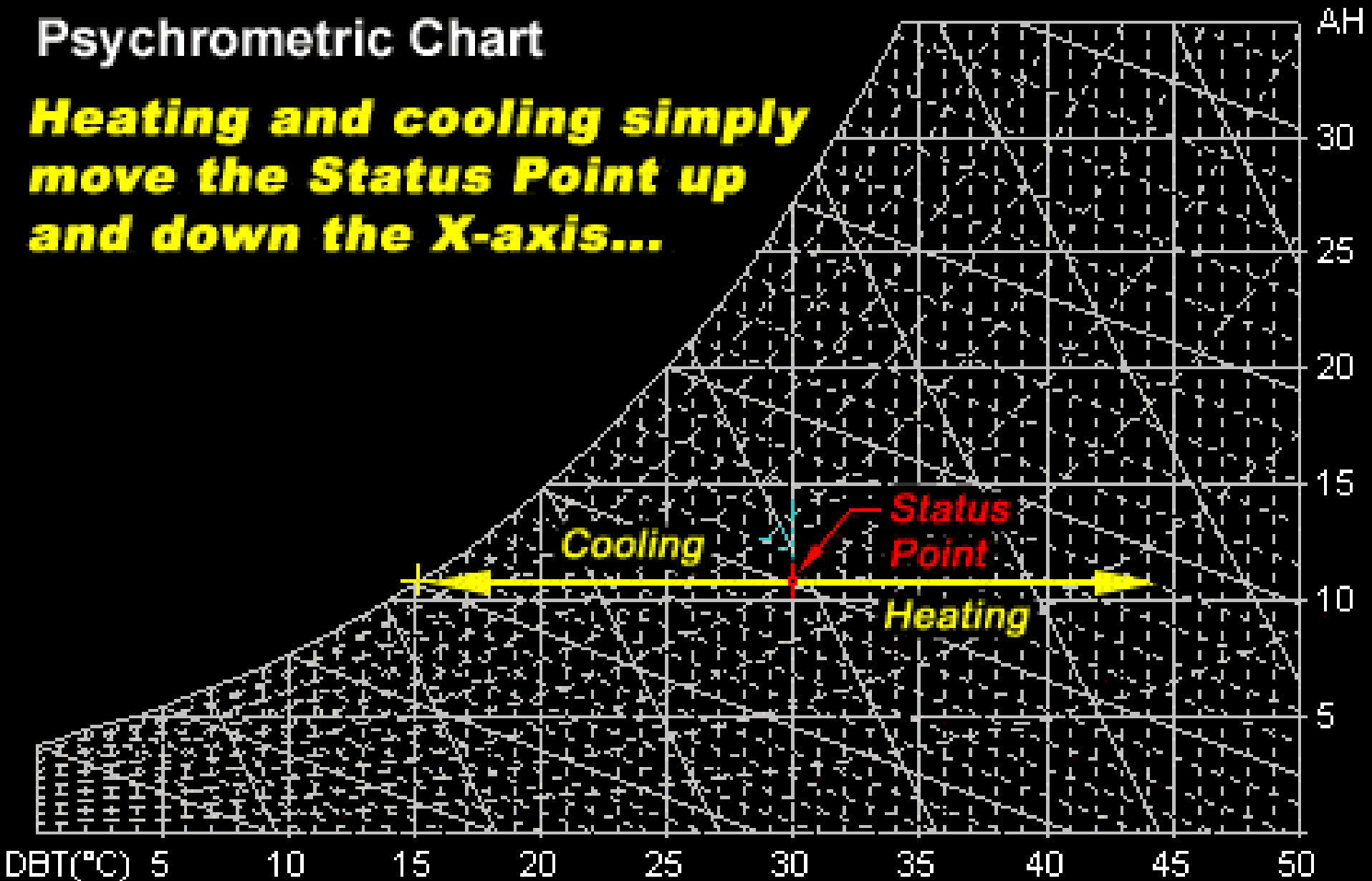
Psychrometric Chart



Process: from one state to another

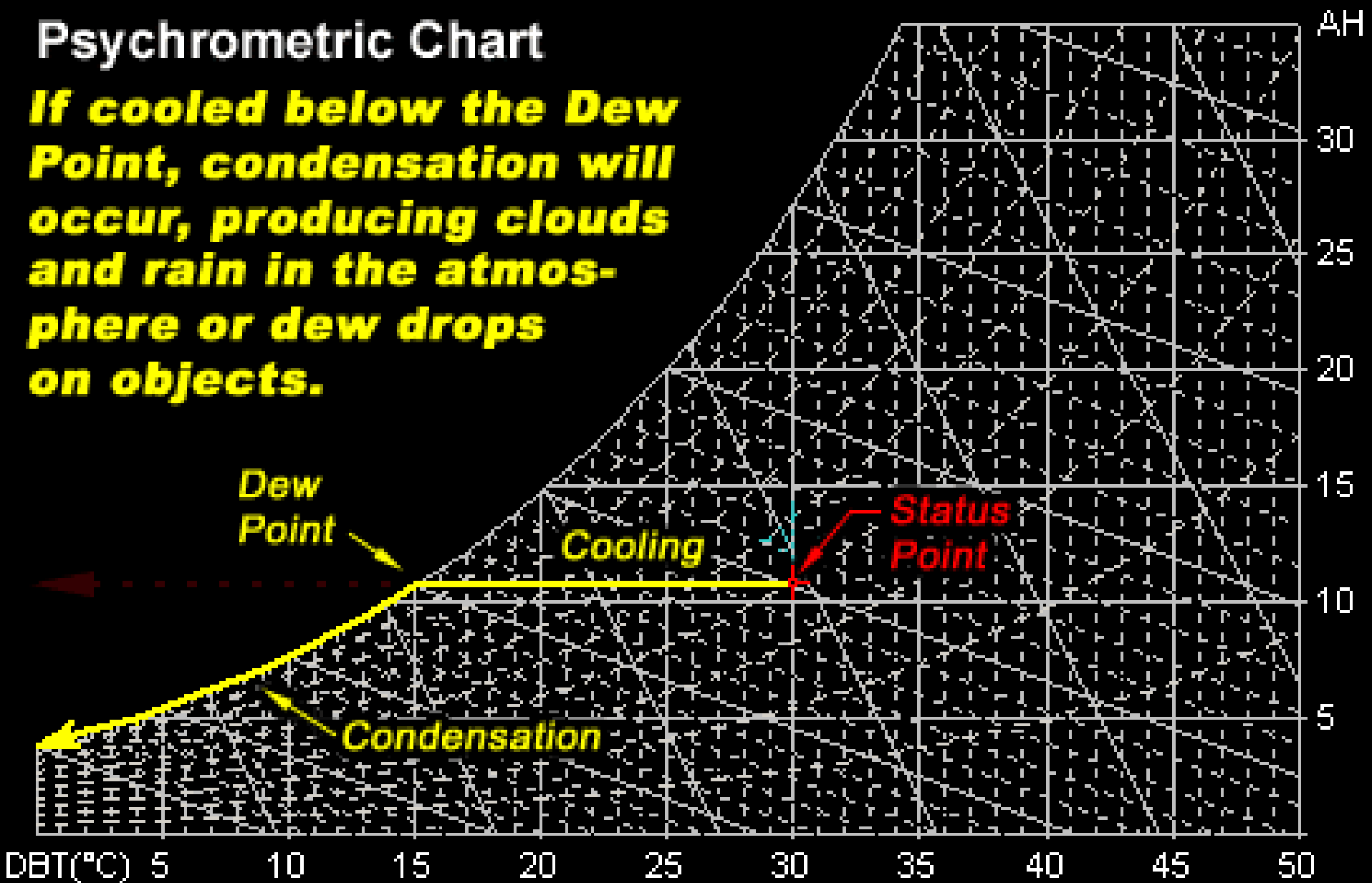
Psychrometric Chart

Heating and cooling simply move the Status Point up and down the X-axis...



Psychrometric Chart

If cooled below the Dew Point, condensation will occur, producing clouds and rain in the atmosphere or dew drops on objects.



Psychrometric Chart

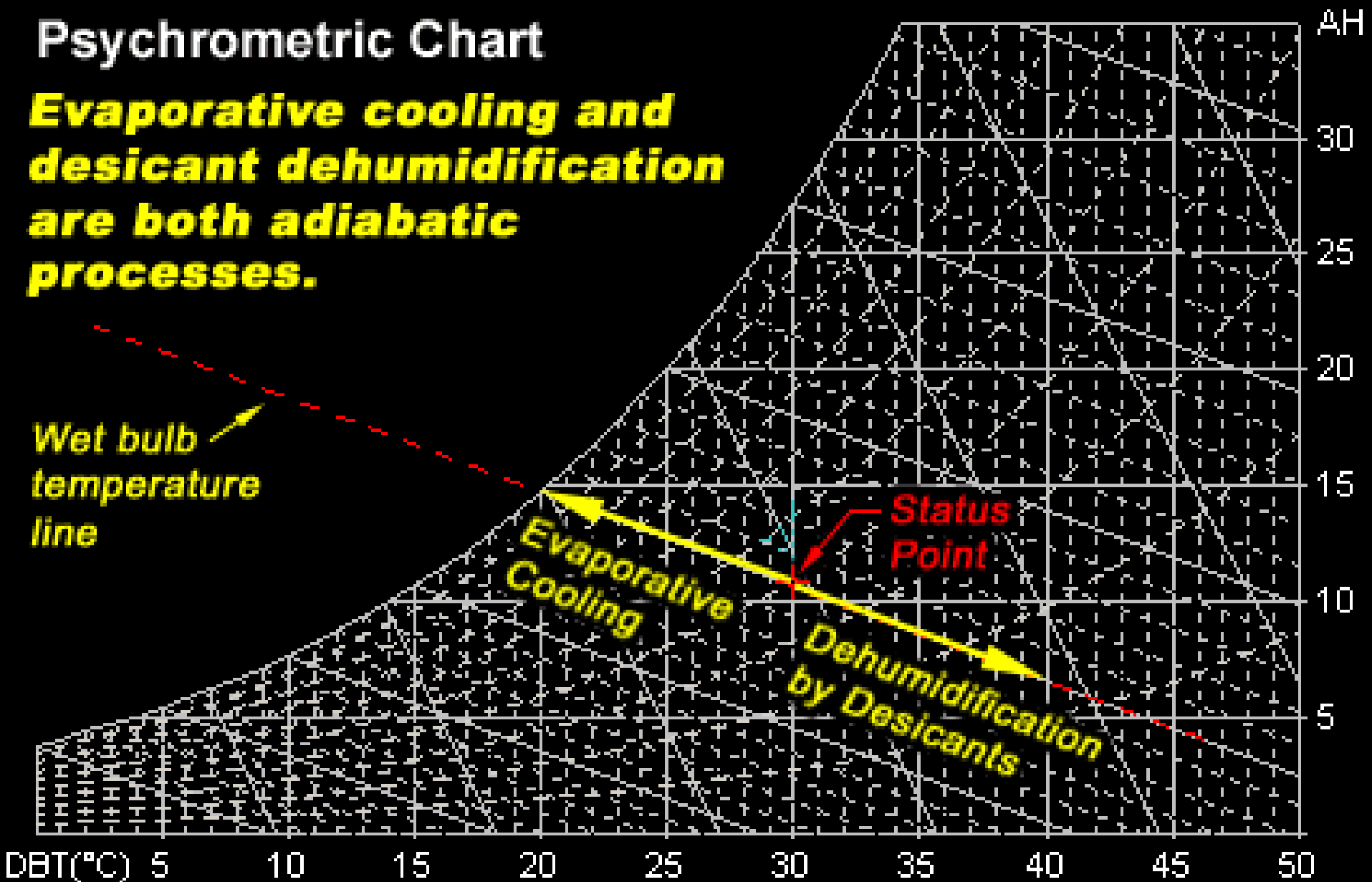
Evaporative cooling and desiccant dehumidification are both adiabatic processes.

Wet bulb temperature line

Evaporative Cooling

Status Point

Dehumidification by Desiccants



人體的溫溼度舒適帶

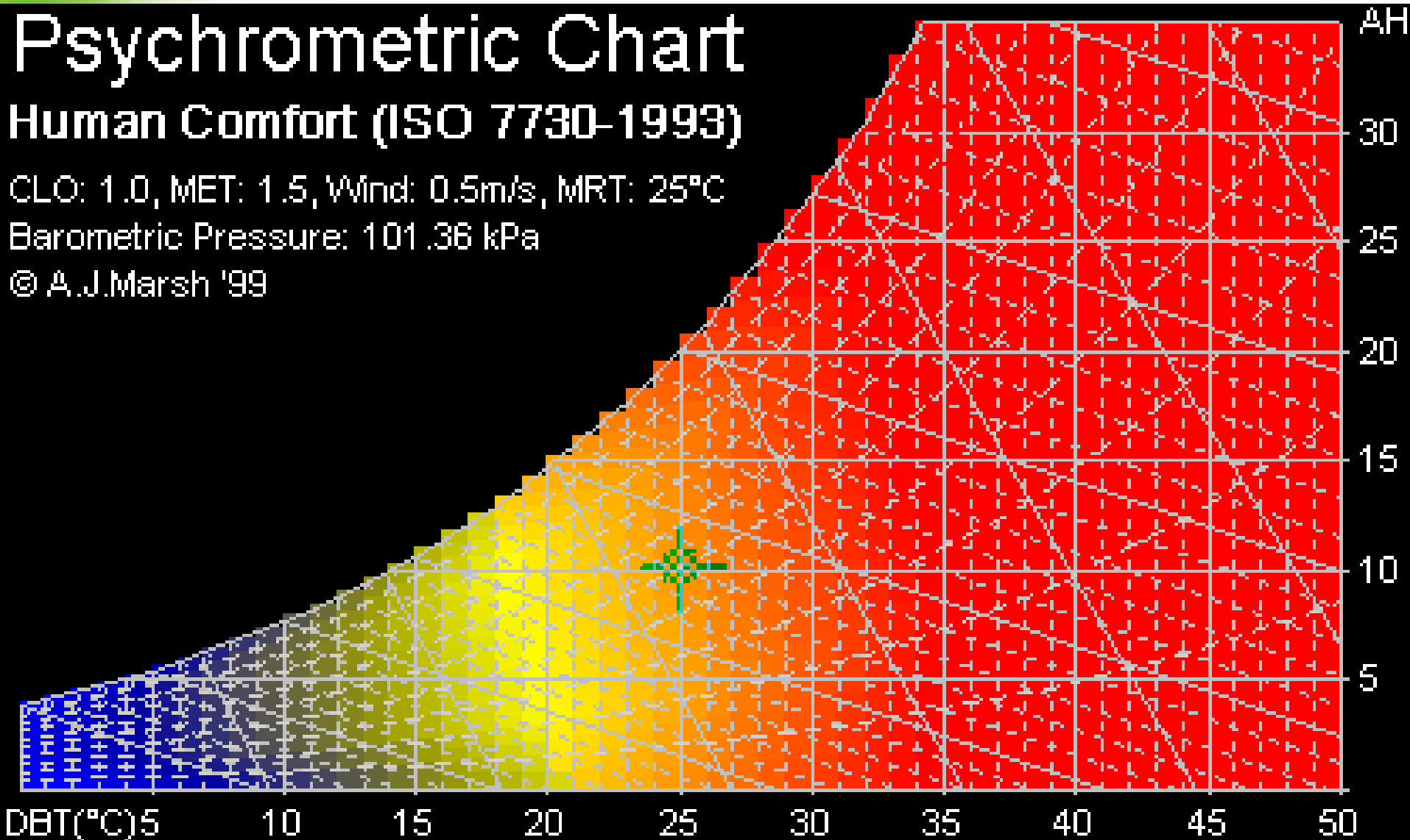
Psychrometric Chart

Human Comfort (ISO 7730-1993)

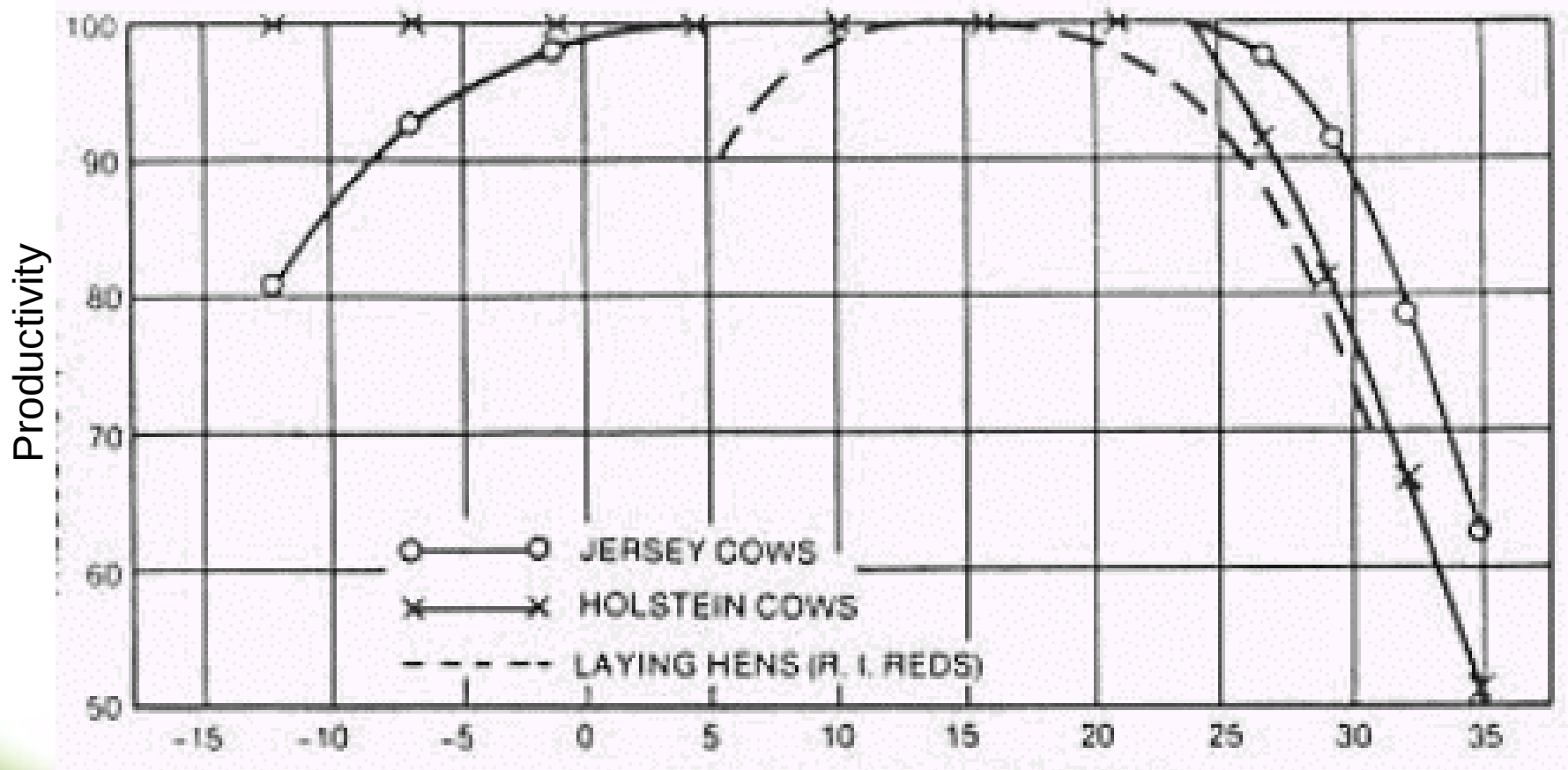
CLO: 1.0, MET: 1.5, Wind: 0.5m/s, MRT: 25°C

Barometric Pressure: 101.36 kPa

© A.J.Marsh '99



三種經濟動物的溫度舒適帶



Psychart 軟體

Psytable

Patm : 101.325 kPa

Twb = f(Tdb, RH)

Lower Limit Upper Limit Interval Units

Col : Tdb 20 40 1 degree C

Row : RH 50 100 5 %

Message

Twb:
Wet Bulb Temperature
(in degree C)

Twb WBD RH VPD VPD' Tdp1 Tdp2 TH1 T

List Clear Quit

Twb Table

	20	21	22	23	24	25	26	27	28	29	30	31	32
50	13.79	14.59	15.39	16.2	17	17.8	18.61	19.41	20.22	21.03	21.84	22.65	23.46
55	14.47	15.3	16.12	16.95	17.77	18.6	19.43	20.26	21.08	21.91	22.75	23.58	24.42
60	15.15	15.99	16.84	17.68	18.53	19.38	20.23	21.07	21.93	22.78	23.63	24.49	25.34
65	15.81	16.67	17.54	18.4	19.27	20.14	21.01	21.87	22.75	23.62	24.49	25.37	26.25
70	16.45	17.34	18.22	19.11	19.99	20.88	21.77	22.66	23.55	24.44	25.33	26.23	27.13
75	17.09	17.99	18.9	19.8	20.7	21.61	22.51	23.42	24.33	25.24	26.15	27.07	27.99
80	17.71	18.63	19.56	20.48	21.4	22.32	23.25	24.17	25.1	26.03	26.96	27.89	28.82
85	18.33	19.27	20.2	21.14	22.08	23.02	23.96	24.91	25.85	26.8	27.74	28.69	29.64
90	18.93	19.89	20.84	21.8	22.75	23.71	24.67	25.63	26.59	27.55	28.51	29.48	30.45
95	19.53	20.5	21.47	22.44	23.41	24.38	25.36	26.33	27.31	28.29	29.27	30.25	31.24
100	20	21	22	23	24	25	26	27	28	29	30	31	32

Psychart 軟體

$$RH = f(T_{db}, T_{wb})$$

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
10	24.03	20.04	16.47	13.27	10.41	7.85	5.54	3.47	1.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	30.39	26.01	22.09	18.56	15.4	12.55	9.98	7.66	5.57	3.68	1.97	0.43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12	36.98	32.2	27.9	24.04	20.55	17.41	14.57	11.99	9.66	7.55	5.64	3.9	2.33	0.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13	43.8	38.6	33.92	29.7	25.89	22.43	19.31	16.47	13.89	11.55	9.42	7.49	5.72	4.12	2.66	1.33	N/A	N/A	N/A	N/A	N/A
14	50.87	45.24	40.16	35.56	31.41	27.64	24.21	21.1	18.26	15.68	13.33	11.19	9.23	7.44	5.81	4.32	2.97	1.73	0.6	N/A	N/A
15	58.19	52.11	46.62	41.64	37.12	33.02	29.29	25.89	22.79	19.96	17.37	15.01	12.85	10.87	9.06	7.41	5.9	4.52	3.25	2.1	1.05
16	65.78	59.23	53.31	47.93	43.05	38.6	34.55	30.85	27.48	24.39	21.56	18.97	16.6	14.42	12.43	10.6	8.93	7.39	5.98	4.7	3.52
17	73.64	66.62	60.25	54.46	49.19	44.39	40.01	36	32.33	28.97	25.89	23.07	20.48	18.1	15.91	13.9	12.06	10.36	8.81	7.38	6.07
18	81.79	74.27	67.44	61.23	55.56	50.39	45.66	41.33	37.37	33.73	30.39	27.32	24.5	21.9	19.52	17.32	15.3	13.44	11.73	10.15	8.7
19	90.24	82.21	74.9	68.24	62.17	56.61	51.53	46.87	42.59	38.66	35.05	31.73	28.67	25.85	23.26	20.86	18.66	16.63	14.75	13.02	11.43
20	100	90.43	82.63	75.52	69.02	63.07	57.61	52.61	48.01	43.78	39.89	36.3	33	29.95	27.14	24.54	22.14	19.93	17.89	16	14.26
21	N/A	100	90.65	83.06	76.12	69.76	63.93	58.57	53.64	49.1	44.91	41.06	37.49	34.21	31.17	28.36	25.76	23.36	21.14	19.09	17.19
22	N/A	N/A	100	90.88	83.49	76.71	70.48	64.75	59.48	54.62	50.13	45.99	42.16	38.63	35.35	32.33	29.52	26.93	24.52	22.3	20.24
23	N/A	N/A	N/A	100	91.13	83.92	77.28	71.17	65.54	60.35	55.55	51.12	47.02	43.22	39.71	36.45	33.43	30.63	28.04	25.63	23.4
24	N/A	N/A	N/A	N/A	100	91.39	84.34	77.84	71.84	66.3	61.18	56.45	52.06	48	44.23	40.74	37.49	34.49	31.69	29.1	26.69
25	N/A	N/A	N/A	N/A	N/A	100	91.66	84.76	78.38	72.49	67.03	61.98	57.3	52.96	48.93	45.19	41.72	38.49	35.49	32.71	30.12
26	N/A	N/A	N/A	N/A	N/A	N/A	100	91.94	85.17	78.91	73.11	67.74	62.75	58.12	53.83	49.83	46.12	42.66	39.45	36.46	33.68
27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.22	85.58	79.42	73.72	68.42	63.49	58.91	54.66	50.69	47	43.57	40.37	37.38
28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.5	85.98	79.93	74.3	69.07	64.21	59.67	55.45	51.52	47.85	44.43	41.24
29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	92.79	86.38	80.42	74.87	69.71	64.89	60.41	56.22	52.31	48.66	45.26
30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.09	86.78	80.91	75.43	70.32	65.56	61.11	56.95	53.07	49.44
31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.39	87.18	81.38	75.97	70.92	66.2	61.79	57.66	53.8
32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.69	87.56	81.84	76.49	71.49	66.81	62.43	58.33
33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	93.99	87.95	82.29	77	72.04	67.4	63.05
34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.29	88.32	82.73	77.49	72.57	67.96
35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.58	88.68	83.15	77.95	73.07
36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	94.87	89.03	83.54	78.39
37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.15	89.36	83.92
38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.4	89.67
39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	95.64



Psychart 軟體

$$WBD = T_{db} - T_{wb} = f(T_{db}, RH)$$

	20	22	24	26	28	30	32	34	36	38	40	42	44
50	6.21	6.61	7	7.39	7.78	8.16	8.54	8.91	9.27	9.62	9.96	10.3	10.62
55	5.53	5.88	6.23	6.57	6.92	7.25	7.58	7.91	8.22	8.53	8.82	9.11	9.38
60	4.85	5.16	5.47	5.77	6.07	6.37	6.66	6.94	7.21	7.47	7.72	7.96	8.19
65	4.19	4.46	4.73	4.99	5.25	5.51	5.75	5.99	6.22	6.44	6.65	6.84	7.03
70	3.55	3.78	4.01	4.23	4.45	4.67	4.87	5.07	5.26	5.44	5.61	5.76	5.91
75	2.91	3.1	3.3	3.49	3.67	3.85	4.01	4.17	4.33	4.47	4.6	4.72	4.83
80	2.29	2.44	2.6	2.75	2.9	3.04	3.18	3.3	3.41	3.52	3.61	3.7	3.77
85	1.67	1.8	1.92	2.04	2.15	2.26	2.36	2.44	2.52	2.59	2.65	2.7	2.74
90	1.07	1.16	1.25	1.33	1.41	1.49	1.55	1.61	1.65	1.69	1.72	1.73	1.74
95	0.47	0.53	0.59	0.64	0.69	0.73	0.76	0.79	0.8	0.81	0.8	0.79	0.76
100	0	0	0	0	0	0	0	0	0	0	0	0	0



作物栽培環境內 不同溫度下適宜的相對濕度

溫度，度C	最低濕度 (可啟動噴霧 系統 加濕)	適宜 相對濕度	最高濕度 (超過就容易 發生病蟲害)
15	-	50 %	73
20	46	64	80
25	60	73	86
30	70	80	89



不同溫度及相對濕度下的蒸氣壓差 (豪巴, millibars)

大部分作物於蒸氣壓差 8-10 生長最好 (綠底)；藍底部分需要加濕；紅底部分需要除濕。

溫度		相對溼度													
°C	°F	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%
15	59	0.0	0.0	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6	8.5	9.4	10.2	11.1
16	81	0.0	0.0	1.8	2.8	3.7	4.6	5.5	6.4	7.3	8.2	9.1	10.0	10.9	11.8
17	83	0.0	1.0	2.0	2.9	3.9	4.8	5.8	6.8	7.8	8.8	9.7	10.6	11.5	12.6
18	84	0.0	1.1	2.0	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4
19	88	0.0	1.2	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.3
20	88	0.0	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7	12.8	14.0	15.2
21	70	0.0	1.2	2.4	3.7	4.9	6.2	7.4	8.8	9.9	11.1	12.4	13.7	14.9	16.1
22	72	0.0	1.3	2.8	3.8	5.3	6.6	7.9	9.2	10.5	11.9	13.2	14.5	15.8	17.2
23	73	0.0	1.4	2.8	4.3	5.6	7.0	8.5	9.9	11.3	12.7	14.1	15.4	16.8	18.2
24	75	0.0	1.5	3.0	4.5	5.9	7.4	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.4
25	77	0.0	1.6	3.2	4.8	6.4	8.0	9.5	11.1	12.7	14.3	15.9	17.4	19.0	20.5
26	79	0.0	1.7	3.4	5.1	6.7	8.4	10.1	11.8	13.4	15.1	16.8	18.4	20.1	21.8
27	81	0.0	1.8	3.5	5.3	7.1	8.6	10.7	12.4	14.2	16.0	17.8	19.6	21.3	23.1
28	82	0.0	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.1	17.0	18.9	20.7	22.6	24.5
29	84	0.0	2.0	3.8	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.1	24.1	26.1
30	88	0.0	2.1	4.2	6.4	8.5	10.9	12.7	14.8	17.0	19.1	21.2	23.3	25.4	27.5
31	88	0.0	2.2	4.2	6.7	9.0	11.2	13.4	15.7	17.9	20.2	22.4	24.6	26.9	29.1
32	90	0.0	2.4	4.7	7.1	9.5	11.9	14.2	16.6	19.0	21.3	23.7	26.1	28.4	30.8
33	91	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.6	20.1	22.6	25.1	27.8	30.1	32.6
34	93	0.0	2.7	5.3	8.0	10.6	13.3	15.9	18.6	21.2	23.9	26.5	29.2	31.8	34.5
35	95	0.0	2.8	5.6	8.4	11.2	14.0	16.8	19.6	22.4	25.2	28.0	30.8	33.6	36.4

millibar 的單位轉換表

Your value (millibar):

Convert Me

Ads by Google

[► PSI](#)

[► Pressure](#)

[► KG](#)

[► Bar Table](#)

Metric

bar	0.001
kilopascal (kPa)	0.1
hectopascal (hPa)	1
megapascal (MPa)	0.0001
pascal (Pa)	100
kilogram per square centimeter (kgf/cm ²)	0.00102
kilogram per square meter (kgf/m ²)	10.2
newton per square meter (N/m ²)	100
kilonewton per square meter (kN/m ²)	0.1
meganewton per square meter (MN/m ²)	0.0001
newton per square centimeter (N/cm ²)	0.01
newton per square millimeter (N/mm ²)	0.0001

British and U.S. (Imperial system)

ounce per square inch (osi, oz/in ²)	0.2321
ounce per square foot	33.42
pound per square inch (psi)	0.0145
pound per square foot	2.089
thousand pounds per square inch (ksi)	0.0000145
ton (U.S.) per square inch	0.000007252
ton (U.S.) per square foot	0.001044
long ton (U.K.) per square inch	0.000006475
long ton (U.K.) per square foot	0.0009324



Found an error? Want to suggest more conversions?
[Contact us on Facebook.](#)



蒸氣壓差 (VPD)

1 millibar = 0.1 kPa

過大的VPD值
(過熱且過乾—
可啟動噴霧加濕)

**適當的
VPD值**

過低的VPD值
(過冷與過濕—
可啟動加熱或除濕)

1.25 kPa

0.85 kPa

0.45 kPa



蒸氣壓差 (VPD)

病菌生存的 VPD值 (VPD值越低表示 濕度越高)	適當的 VPD值 (濕度適當適 合作物蒸散)	病菌入侵的 VPD值 (VPD值更低表示 濕度更高)
< 0.43 kPa	0.85 kPa	< 0.20 kPa



$$VPD = f(T_{db}, RH)$$

	20	21	22	23	24	25	26	27	28	29	30
60	0.936	0.995	1.058	1.124	1.194	1.268	1.345	1.427	1.513	1.603	1.698
62	0.889	0.945	1.005	1.068	1.134	1.204	1.278	1.356	1.437	1.523	1.613
64	0.842	0.896	0.952	1.012	1.075	1.141	1.211	1.284	1.362	1.443	1.529
66	0.795	0.846	0.899	0.956	1.015	1.078	1.143	1.213	1.286	1.363	1.444
68	0.748	0.796	0.846	0.899	0.955	1.014	1.076	1.142	1.21	1.283	1.359
70	0.702	0.746	0.793	0.843	0.896	0.951	1.009	1.07	1.135	1.202	1.274
72	0.655	0.697	0.741	0.787	0.836	0.887	0.942	0.999	1.059	1.122	1.189
74	0.608	0.647	0.688	0.731	0.776	0.824	0.874	0.927	0.983	1.042	1.104
76	0.561	0.597	0.635	0.675	0.716	0.761	0.807	0.856	0.908	0.962	1.019
78	0.515	0.547	0.582	0.618	0.657	0.697	0.74	0.785	0.832	0.882	0.934
80	0.468	0.498	0.529	0.562	0.597	0.634	0.673	0.713	0.756	0.802	0.849
82	0.421	0.448	0.476	0.506	0.537	0.57	0.605	0.642	0.681	0.721	0.764
84	0.374	0.398	0.423	0.45	0.478	0.507	0.538	0.571	0.605	0.641	0.679
86	0.327	0.348	0.37	0.393	0.418	0.444	0.471	0.499	0.53	0.561	0.594
88	0.281	0.299	0.317	0.337	0.358	0.38	0.404	0.428	0.454	0.481	0.51
90	0.234	0.249	0.264	0.281	0.299	0.317	0.336	0.357	0.378	0.401	0.425



溫度 °C	最低濕度 (可啟動 加濕系統)	適當 濕度	最高濕度 (超過就容易 發生病虫害)
15	-	50 %	73
20	46	64	80
25	60	73	86
30	70	80	89

過大的 VPD值 (過熱且過 乾-可啟動 噴霧加濕系 統)	適當的 VPD值 (濕度適當 適合作物蒸 散)	低的VPD (適合病菌生存) (過冷與過濕- 可啟動加熱或 除濕系統)	過低的 VPD (適合病菌入 侵)
1.25 kPa	0.85 kPa	< 0.45 kPa	< 0.20 kPa

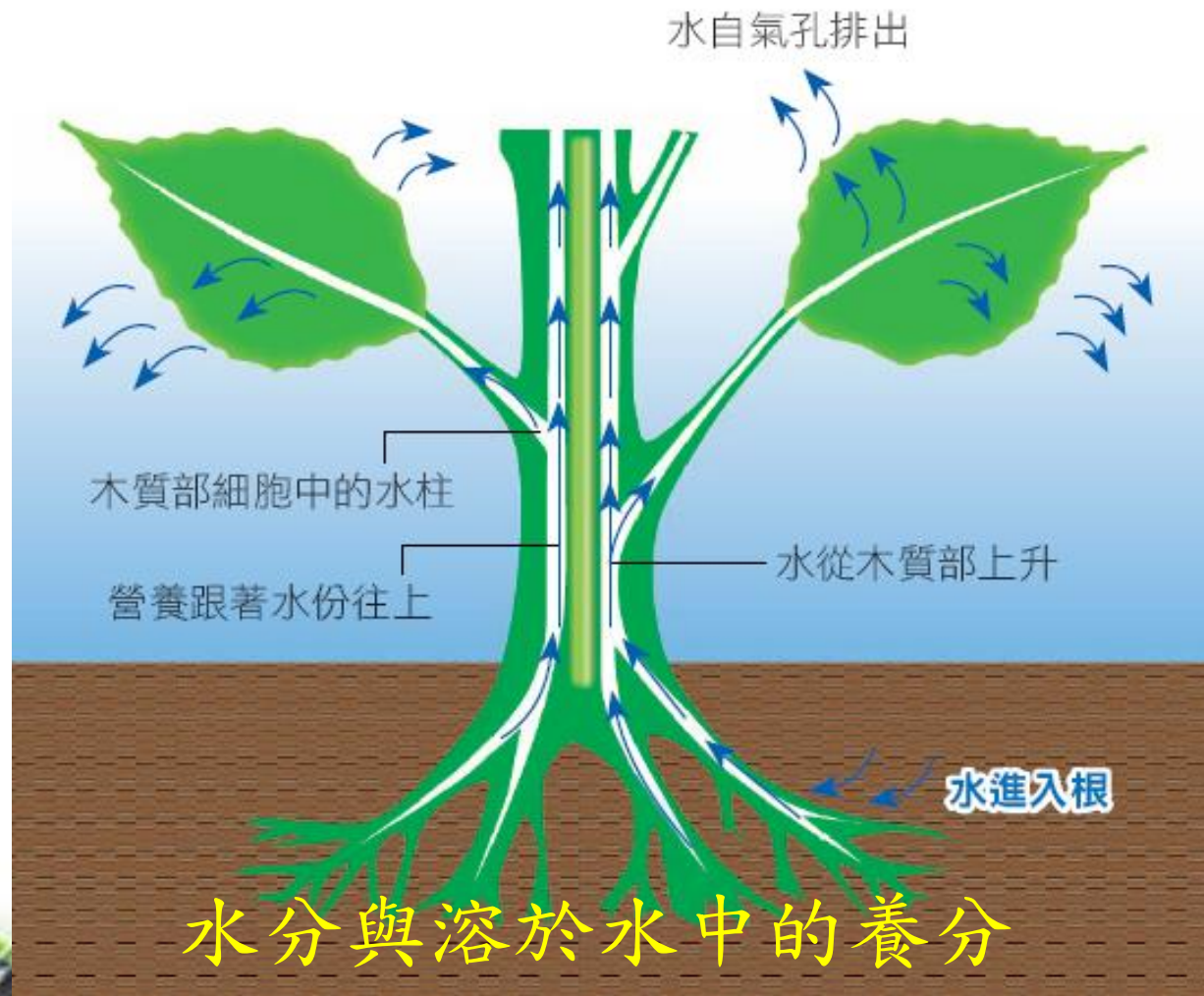
VPD 是比較好的指標

Vapor Pressure Deficit

蒸汽壓差

記住這第十個熱力學性質

蒸氣壓差適當，蒸散較旺盛
營養吸收較多，成長可加速

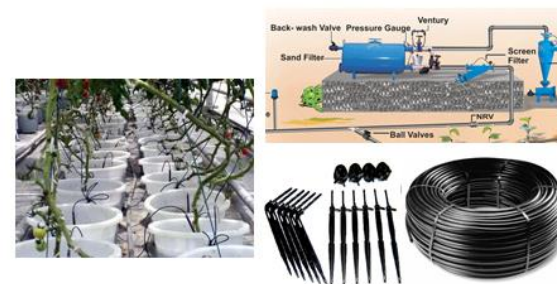


不同灌溉方式造成作物附近的相對濕度有很大的不同

漫灌、澆灌



地上滴灌



地下滴灌



對水質要求高
易被根部侵入或因積垢而堵塞



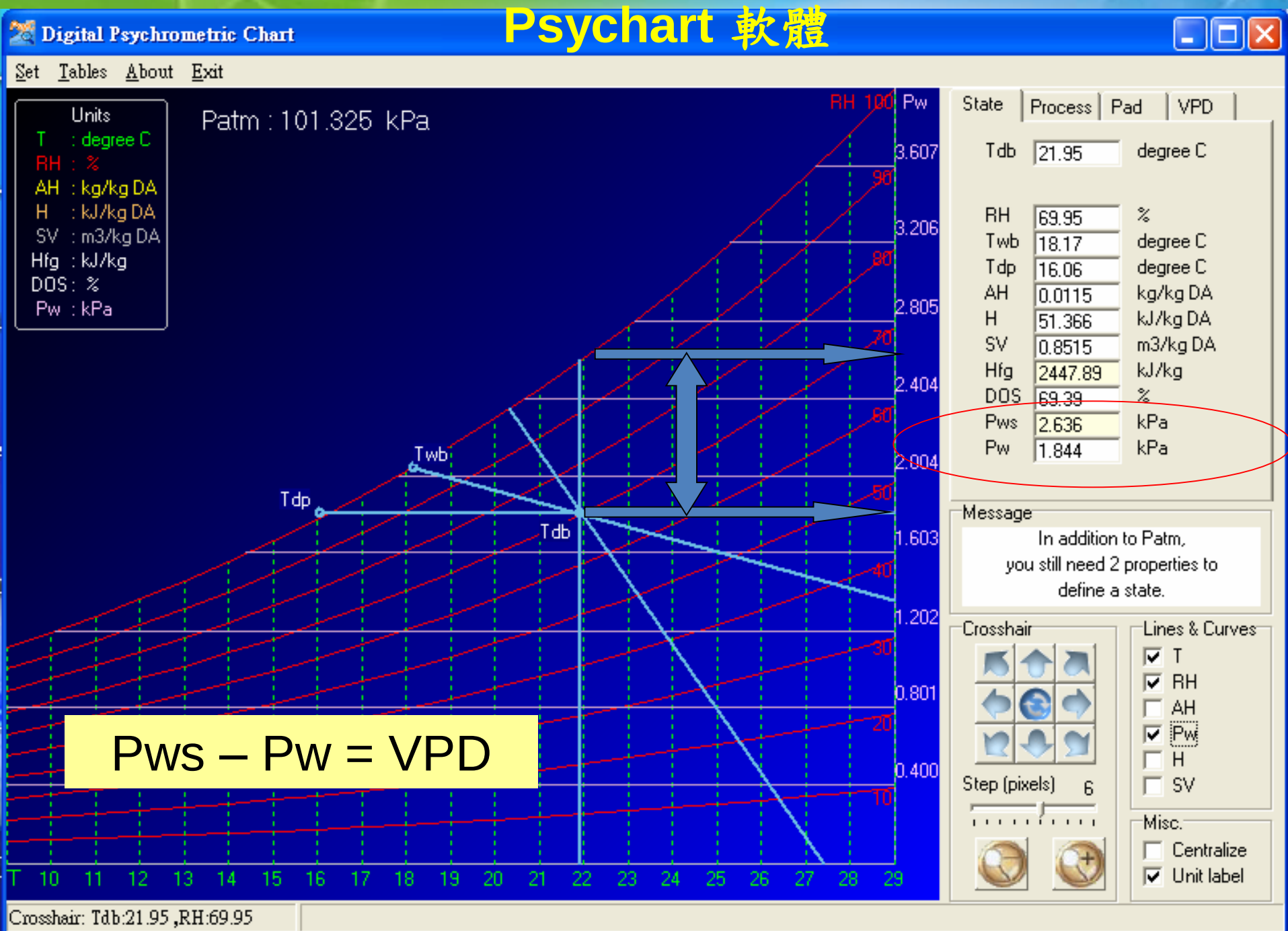
地下滲灌



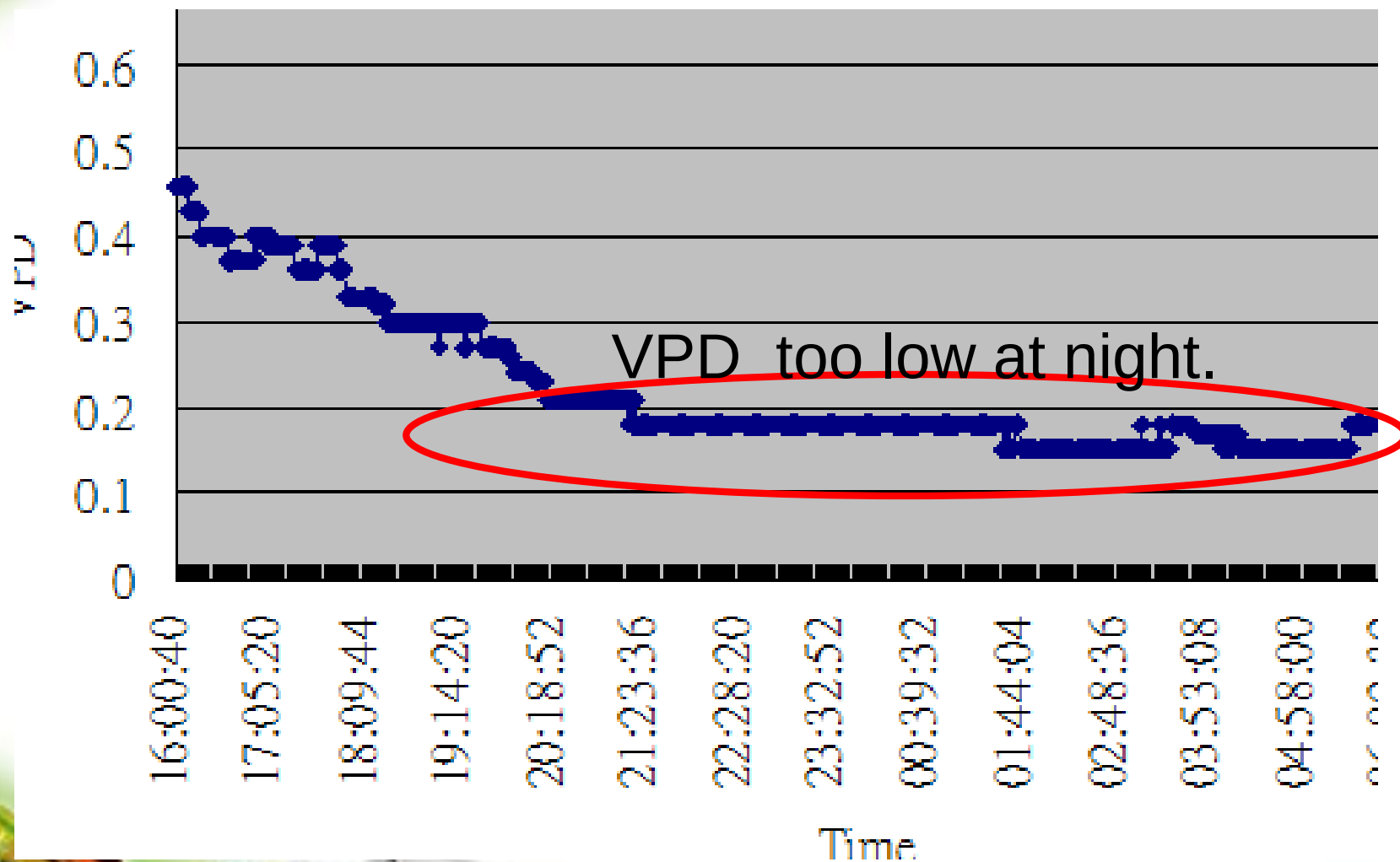
可維持地面乾燥的最好

	地下滲灌		一般有機		慣行農法	
	維生素C (mg/L)	硝酸鹽 (mg/L)	維生素C (mg/L)	硝酸鹽 (mg/L)	維生素C (mg/L)	硝酸鹽 (mg/L)
青江菜	3483	1510	1556	2615	-	-
地瓜葉	2176	643	1493	1770	1226	913
小松菜	1903	1016	-	-	1673	2940
菠菜	1893	173	-	-	1590	210
油菜	2523	1020	1330	1440	-	-
高麗菜	803	466	653	876	456	253
山茼蒿	1736	716	-	-	-	-
A菜	1500	1153	-	-	-	-



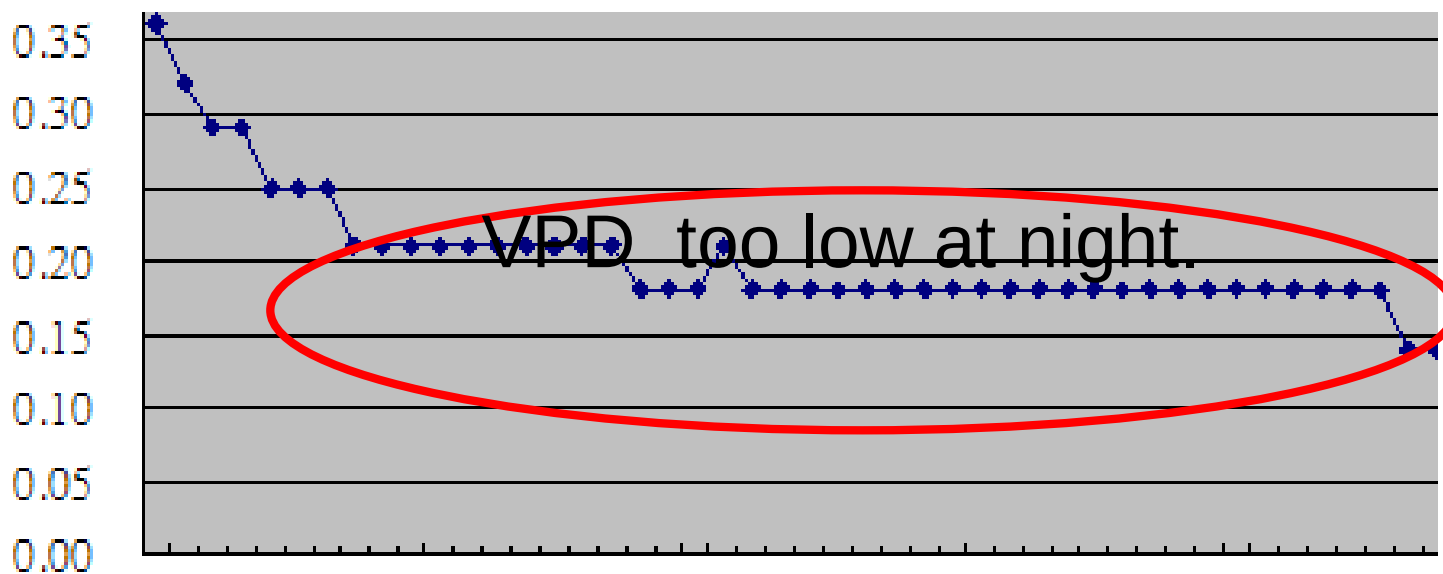


溫室A夜間量測的VPD



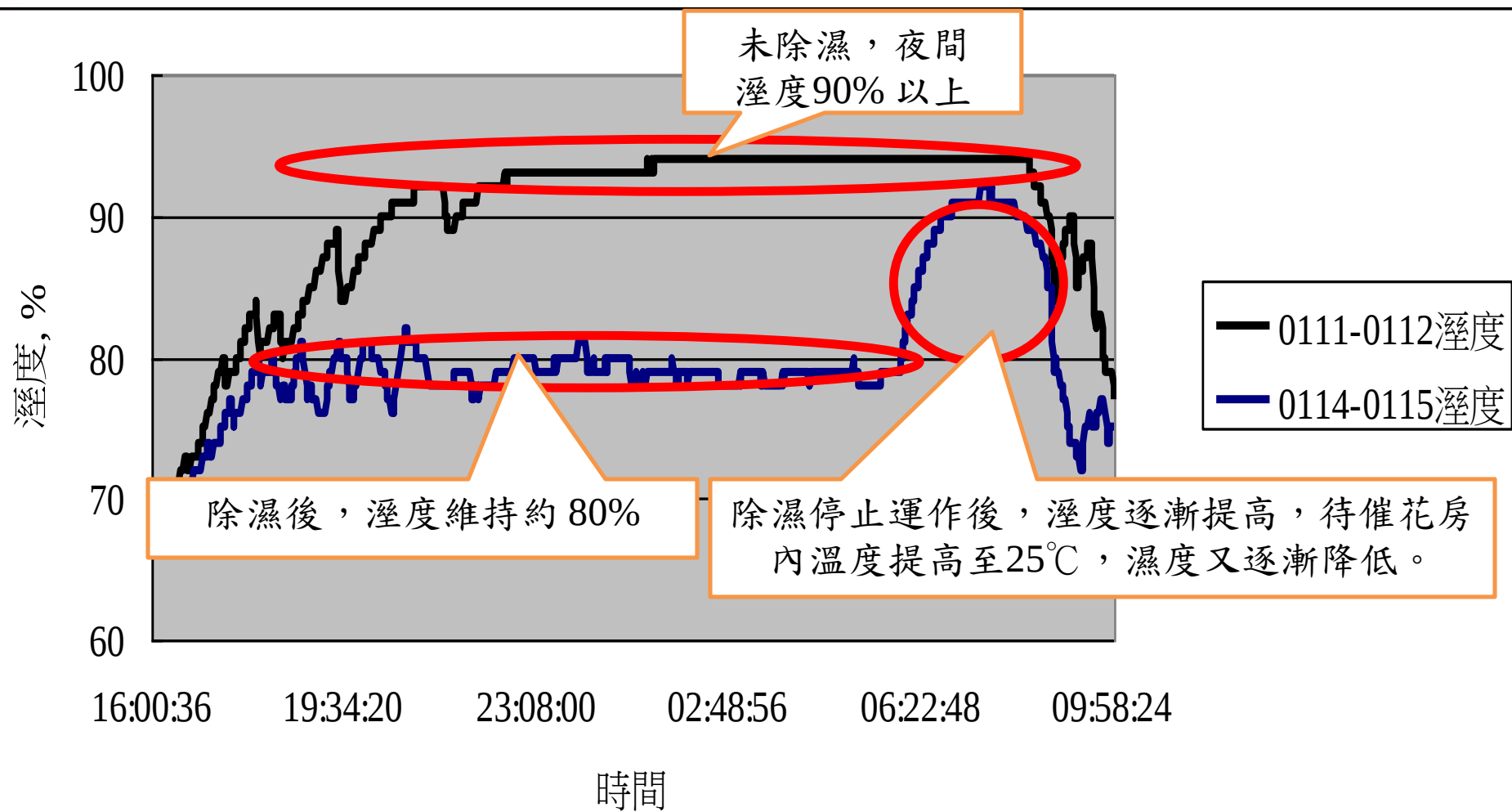
溫室B夜間量測的VPD

VPD

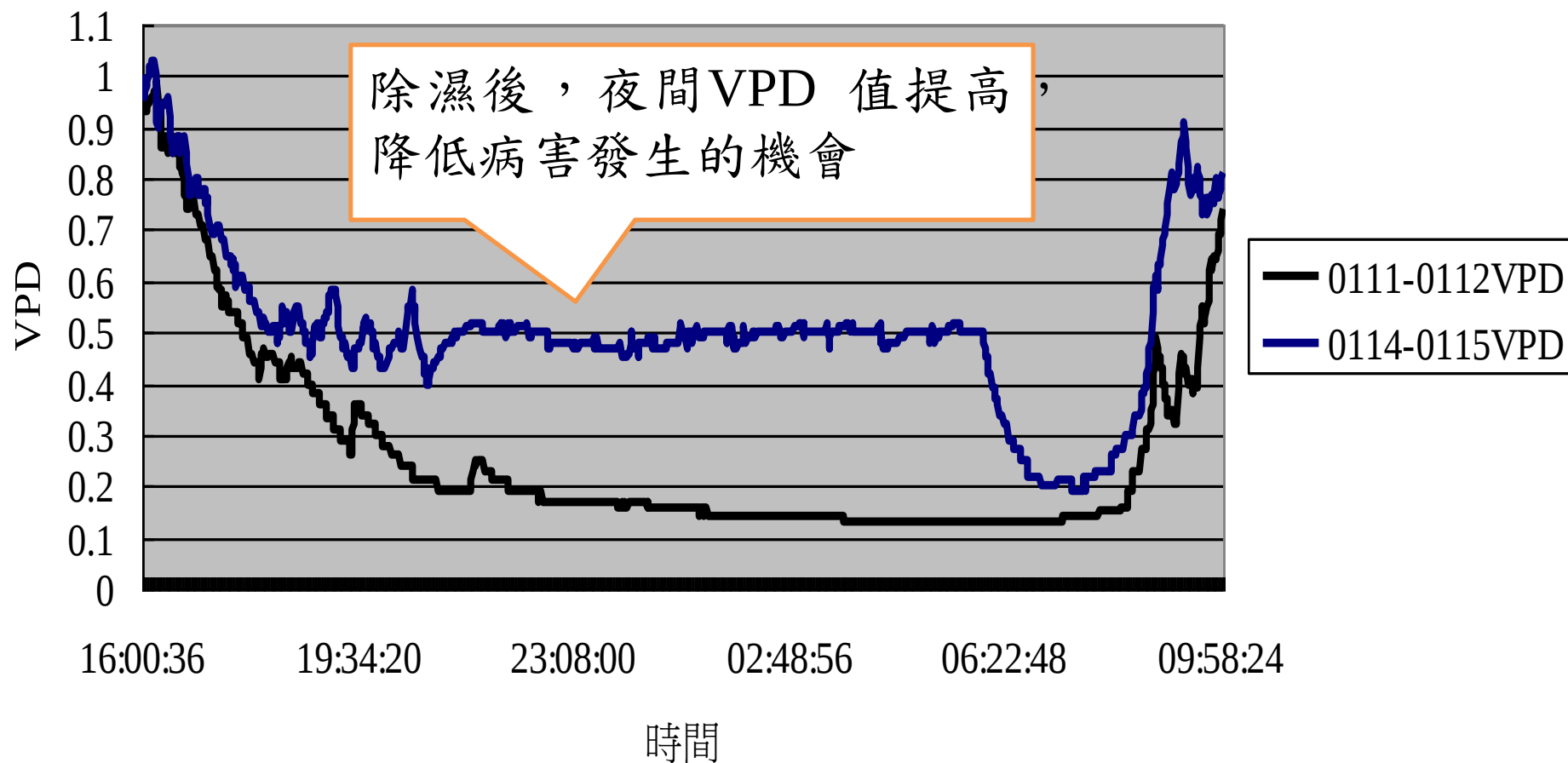


Time

晚上6點至隔日早上6點 進行除濕



除濕前後 夜間VPD 值的變化



溫溼度感測儀器與設備

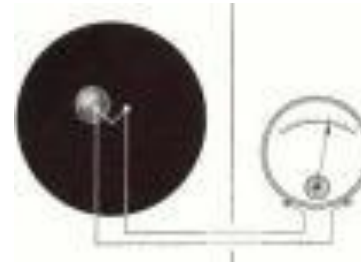
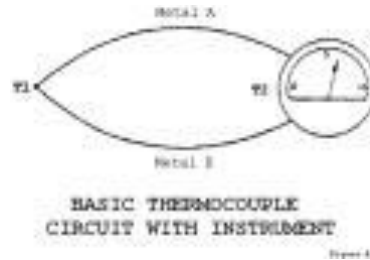


溫度的量測

- 感測器需離作物愈近愈好，但不可被光源(陽光或燈具)直射
- 通風的溫度計
 - 需要有風扇強制讓空氣通過感測頭
 - 避免在感測頭產生靜滯的空氣區，可正確取得有代表性的溫度讀值
 - 空氣為吸入
 - 空氣先經過乾球溫度計感測頭，再經過濕球溫度計感測頭

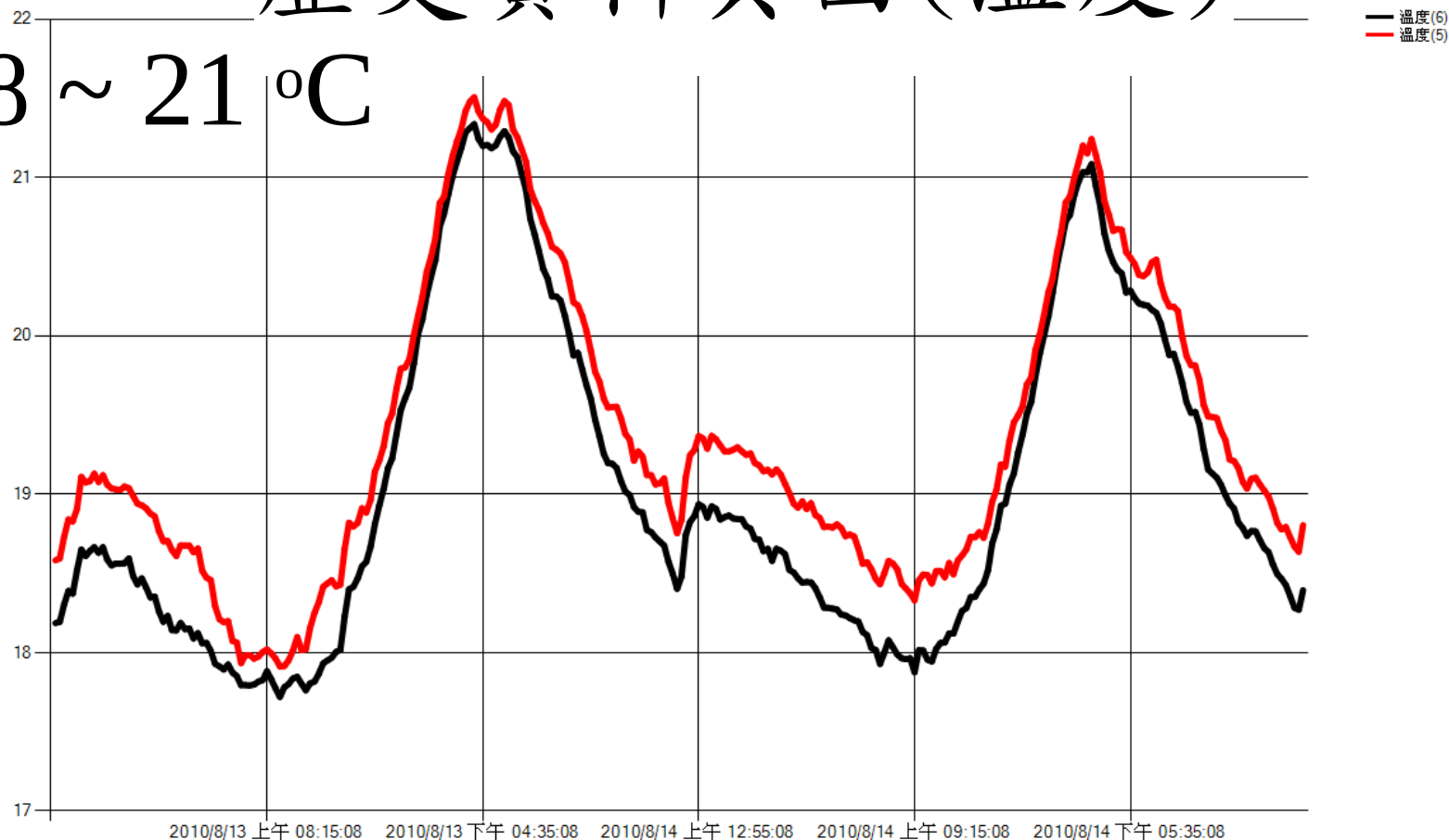


感測元件 Sensing element



歷史資料頁面(溫度)

18 ~ 21 °C



顯示項目選擇

日期範圍選擇

XY軸修改

選擇裝置 新世紀育苗室

	線寬	線條色彩
☒ 溫度(6)	5	Black
☒ 溫度(5)	5	Red
☐ 溼度	2	
☐ 二氧化碳	2	

起始日期

2010年8月						
<	1	2	3	4	5	6
星期日	星期一	星期二	星期三	星期四	星期五	星期六
25	26	27	28	29	30	31
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	1	2	3	4

結束日期

2010年8月						
<	1	2	3	4	5	6
星期日	星期一	星期二	星期三	星期四	星期五	星期六
25	26	27	28	29	30	31
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	1	2	3	4

Y Axis

☒ Grid
☐ Auto Scale
Maximum 22
Minimum 17

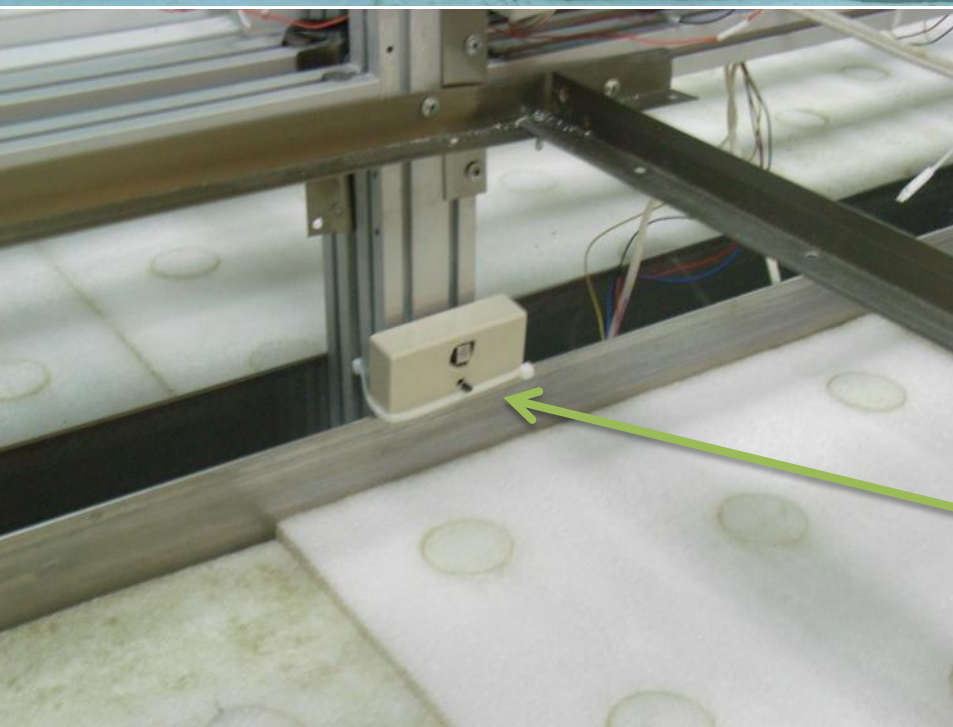
X Axis

☒ Grid
--

關閉



溫度感測器
吊掛於床架上
接近作物區



溫溼度感測器
安裝在床架內
接近作物底部

T_{db} and RH Sensors

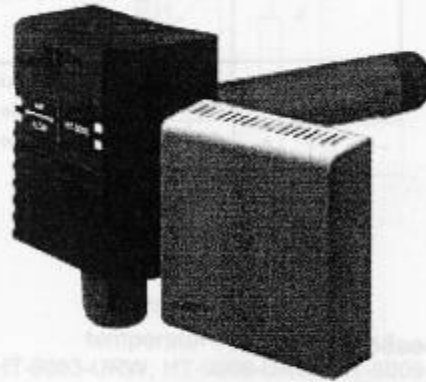
Introduction

The Johnson Controls humidity transmitter is based on a new "state of the art" humidity sensing element. It measures humidity over the entire range of 0 to 100% RH (non condensing) and has a wide operating temperature range.

Its fast response, reliable long-term performance makes this transmitter well suited for refrigeration and HVAC installations.

This range also includes models with an integrated temperature sensing element.

It is recommended to use the humidity transmitter with Johnson Controls controllers such as the TC/SC/DC/DX-9100 series and System 27 Nova/MS series or with other systems having compatible input and output voltages.



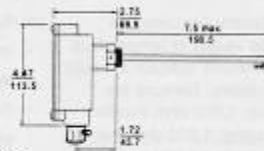
HT-9000 Electronic Humidity Transmitter



TE-6300 Series Temperature Sensor (Continued)

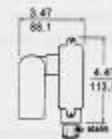
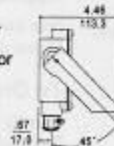
Well insertion sensor includes:

- 6 in. or 8 in. nickel or platinum, 8 in. thermistor
- quick mount sensor holder
- conduit enclosure with cover
- 1/2 in. EMT conduit connector
- wire nuts (2)



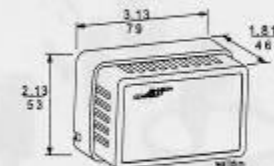
Outdoor air sensor includes:

- 3 in. nickel, platinum, or thermistor sensor
- outdoor air shield
- conduit enclosure with cover
- 1/2 in. EMT conduit connector
- wire nuts (2)



Wall mount sensor includes:

- nickel, platinum, or thermistor sensor
- white T-4000 style cover and base with silver faceplate and horizontal logo
- mounting screws (2)
- wall anchors (2)
- wire nuts (2)



Dimensions are given as in./mm

Accessories (Optional)

Code No.	Description
ADP11A-601R	BX adapter (10 / package)
TE-6001-8	Element holder for mounting an averaging sensor (10 / package)

Repair Parts

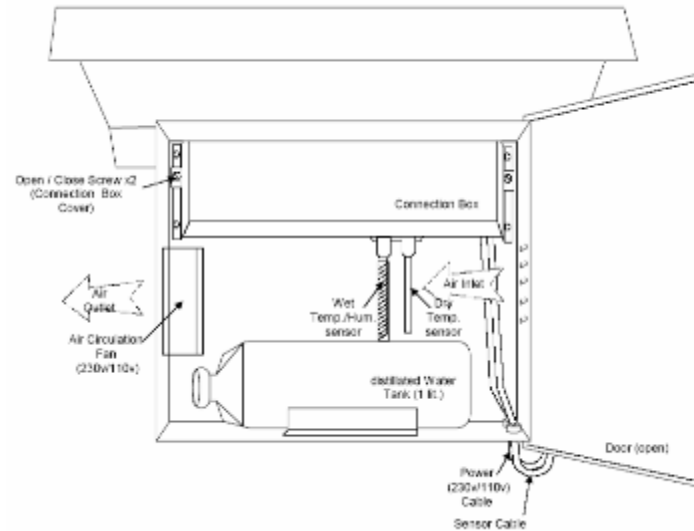
溫濕度感測器

用於溫室與植物工廠內



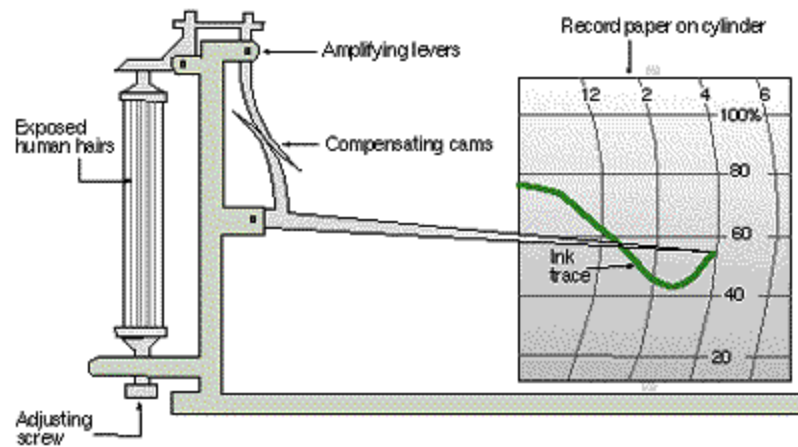
用於氣象站與溫室內的乾濕球溫度感測器

Dry and wet Bulb Temperature sensors in Weather station and greenhouse



The Ventilated cell is a closed shaded box equipped with an 80 x 80 mm fan. The fan provides a constant flow of air in the cell. This is the recommended way to monitor temperature in greenhouses and other sunlight effected places. The ventilated cell is also the ideal way to monitor Humidity in particular for controllers that can handle a dry-wet bulb calculation according to the psychrometric table.

T_{db} and RH data logger 溫溼度數據紀錄器



溫濕度紀錄器

溫度

- Measurement range: -40° to 70° C (-40° F to 158° F)
- Accuracy: $\pm 0.18^{\circ}$ @ 25° C ($\pm 0.32^{\circ}$ @ 77° F)
- Resolution (12-bit): 0.02° @ 25° C (0.04° @ 77° F)
- Response time: 40 minutes (to 90% in airflow of $1 \text{ m} \cdot \text{s}^{-1}$)



相對溼度(RH)

- Measurement range: 0 to 100% RH
- Accuracy: $\pm 2.5\%$ RH from 10% to 90%
- Resolution (12-bit): 0.03% RH
- Response time: U23-001: 10 minutes (90% in airflow of $1 \text{ m} \cdot \text{s}^{-1}$; RH change only)
- U23-002: 4 minutes (90% in airflow of 1 m/s ; RH change only)

溫溼度之外

- 空氣相關的性質之外除了溫、溼度之外
 - 是否有空氣在流動？
 - 流速是多少？也非常重要
 - 風速、風量雖然不屬於熱力學性質
 - 但是風速、風量影響溫度、濕度
 - 最終影響光合作用速率，影響植物的表現
-
- 溫室需要通風
 - 沒有對外通風也需要有內循環通風
 - 植物工場更需要有內循環通風



簡易風速計

找找看

照片上有

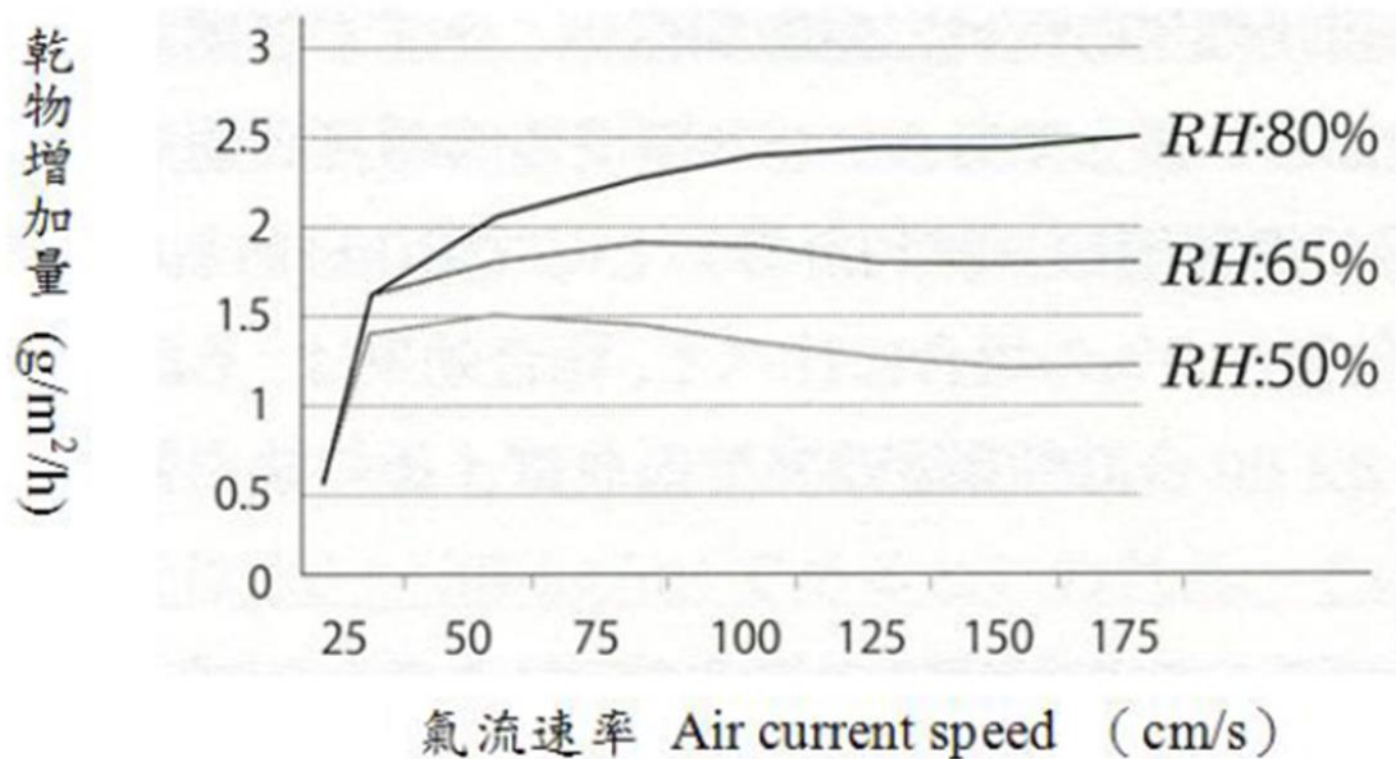
九個

風速指示器

使用衛生紙 + 膠帶



氣流速率與相對濕度對葉片乾物增加量的影響



引用：Yabuki (2004)

光合作用有效輻射：420Wm⁻²、氣溫：25℃、小黃瓜葉



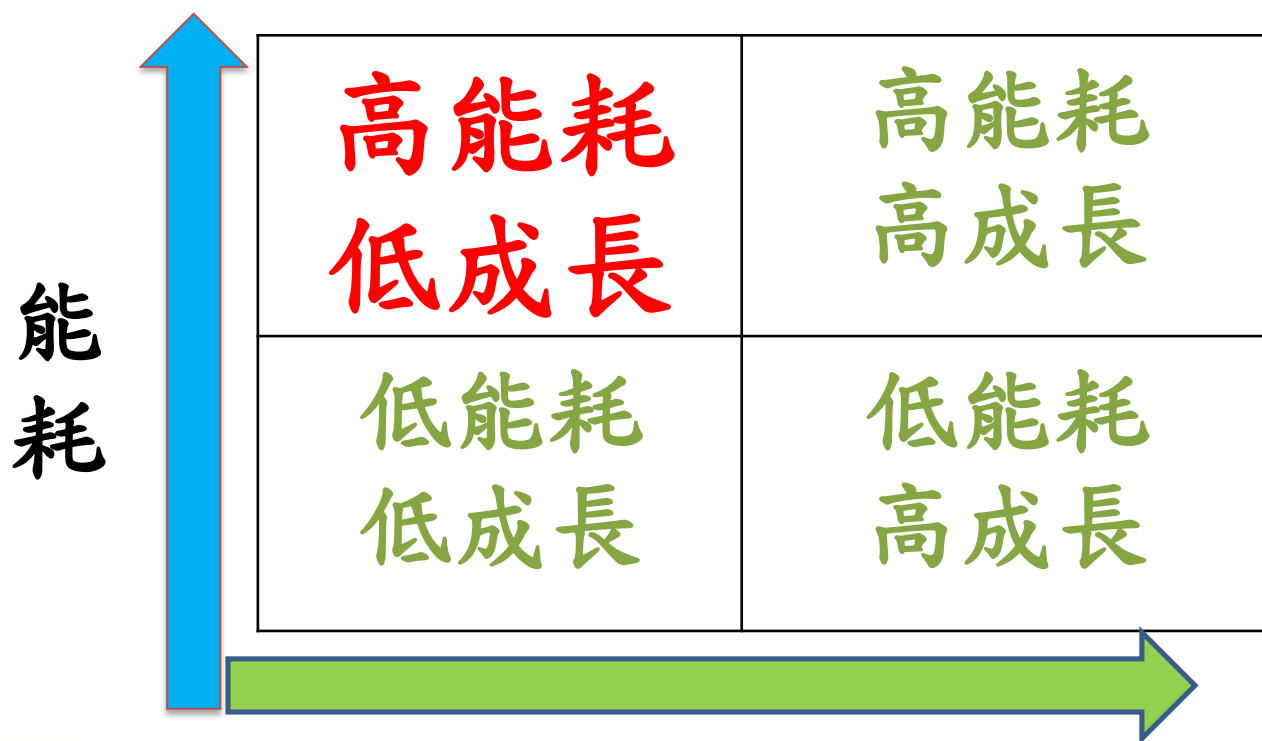
沒做好環境控制的下場

比較不嚴重的



沒做好環境控制的下場

比較難看的



確保品質的成長速率

生長遲緩、耗能大

- 某業者 vs. 台大團隊
 - 播種後 35 天收穫
萵苣鮮重 25 g vs. 80 ~ 120 g
 - 播種後 44 天收穫，萵苣鮮重 60 g
- 某公家研究單位 vs. 台大團隊
 - 由播種到收穫 (35 天)
一株菜平均耗電 12 度 vs. 1 度



沒做好環境控制的下場

嚴重一點

可能種越多賠越多

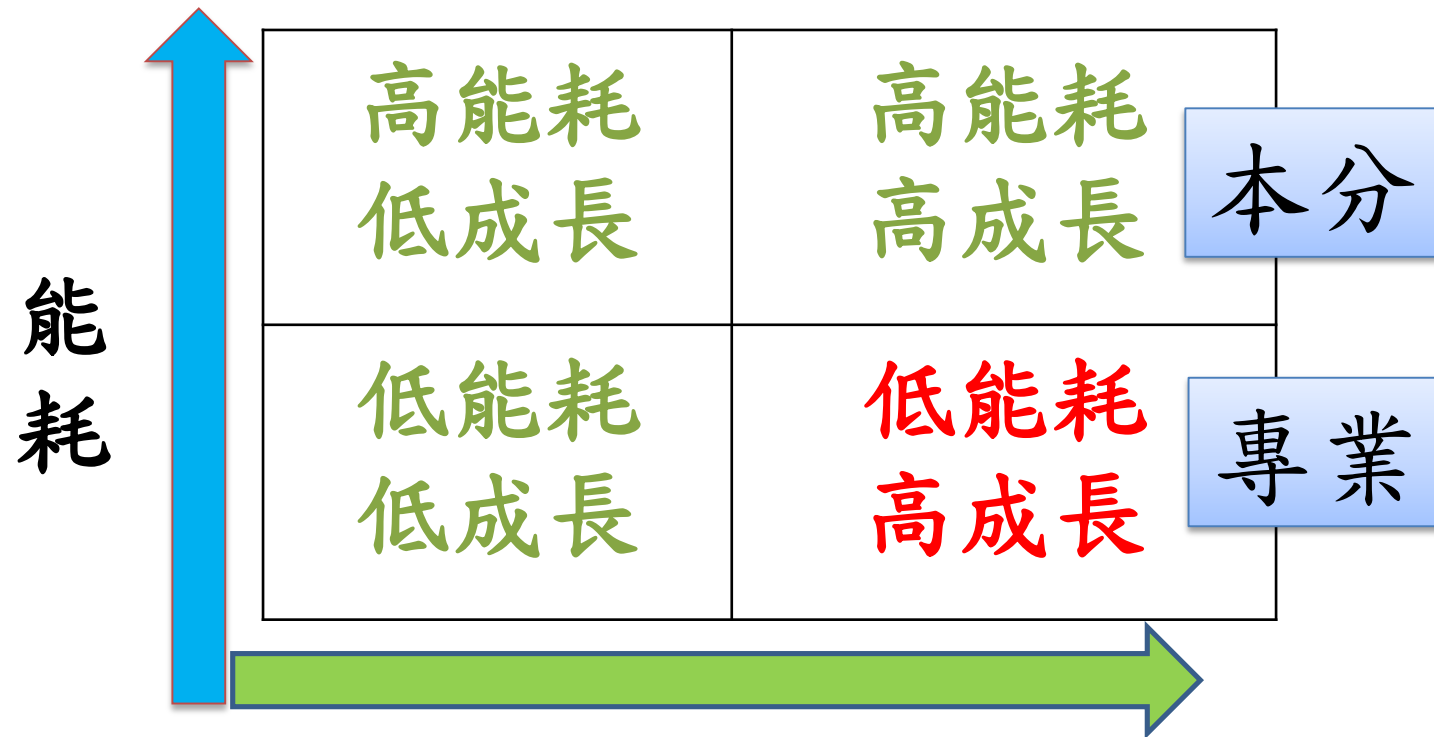
可能商譽受損

可能血本無歸

→ 低品質



甚麼是專業



確保品質的成長速率

Tutorial for Psyc0226

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Dept. of Bio-Industrial Mechatronics Engineering
National Taiwan University

Software last updated: 2002/02/26



Psyc0226

- Allow alteration on atmospheric pressure
- Provide handy PsyTables
 - Totally 11 tables are available
- Provide PsyCharts
 - State calculation: besides $AtmP$, values of 2 independent states are required to calculate others
 - Process calculation: find differences between 2 states
 - More process calculation:
 - Evaporative cooling
 - Vapor pressure deficit on leaf



Psyc0226 軟體使用的參數代號說明

State	Process	Pad	VPD
Tdb	30	degree C	
RH	60	%	
Twb	23.63	degree C	
Tdp	21.26	degree C	
AH	0.016	kg/kg DA	
H	71.169	kJ/kg DA	
SV	0.881	m3/kg DA	
Hfg	2428.4	kJ/kg	
DOS	58.97	%	
Pws	4.246	kPa	
Pw	2.548	kPa	

Message

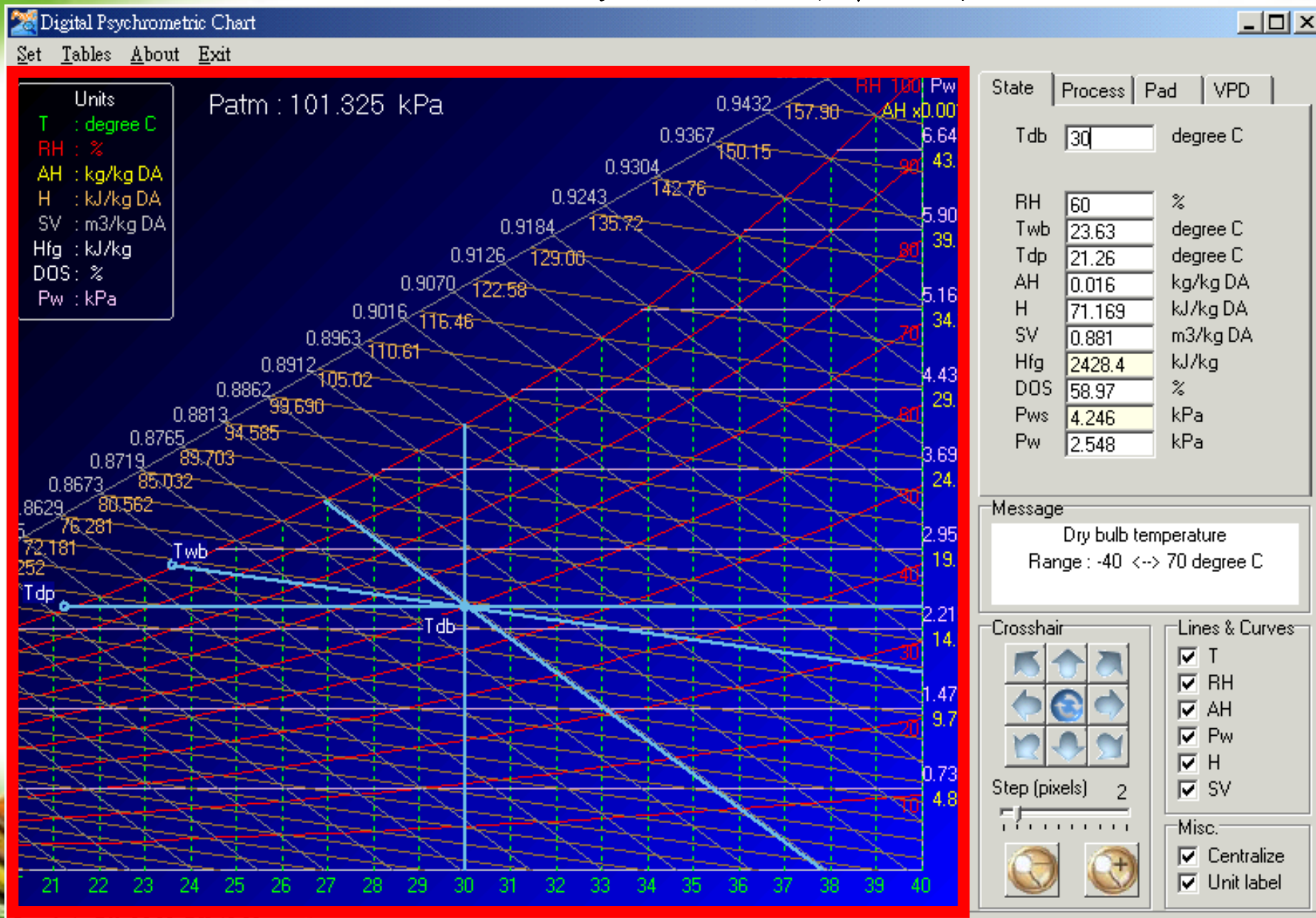
Dry bulb temperature
Range : -40 <--> 70 degree C

1. Tdb: dry bulb Temp. 乾球溫度
2. RH : relative humidity 相對溼度
3. Twb: Wet bulb Temp. 濕球溫度
4. Tdp: dew point Temp. 露點溫度
5. AH : absolute humidity 絕對溼度
6. H: Enthalpy 熱焓
7. SV : specific volume 比容
8. Hfg: Saturated 飽和熱焓
9. DOS: degree of Saturation 飽和度
10. Pws: saturated vapor pressure 飽和蒸汽壓
11. Pw: vapor pressure 蒸汽分壓

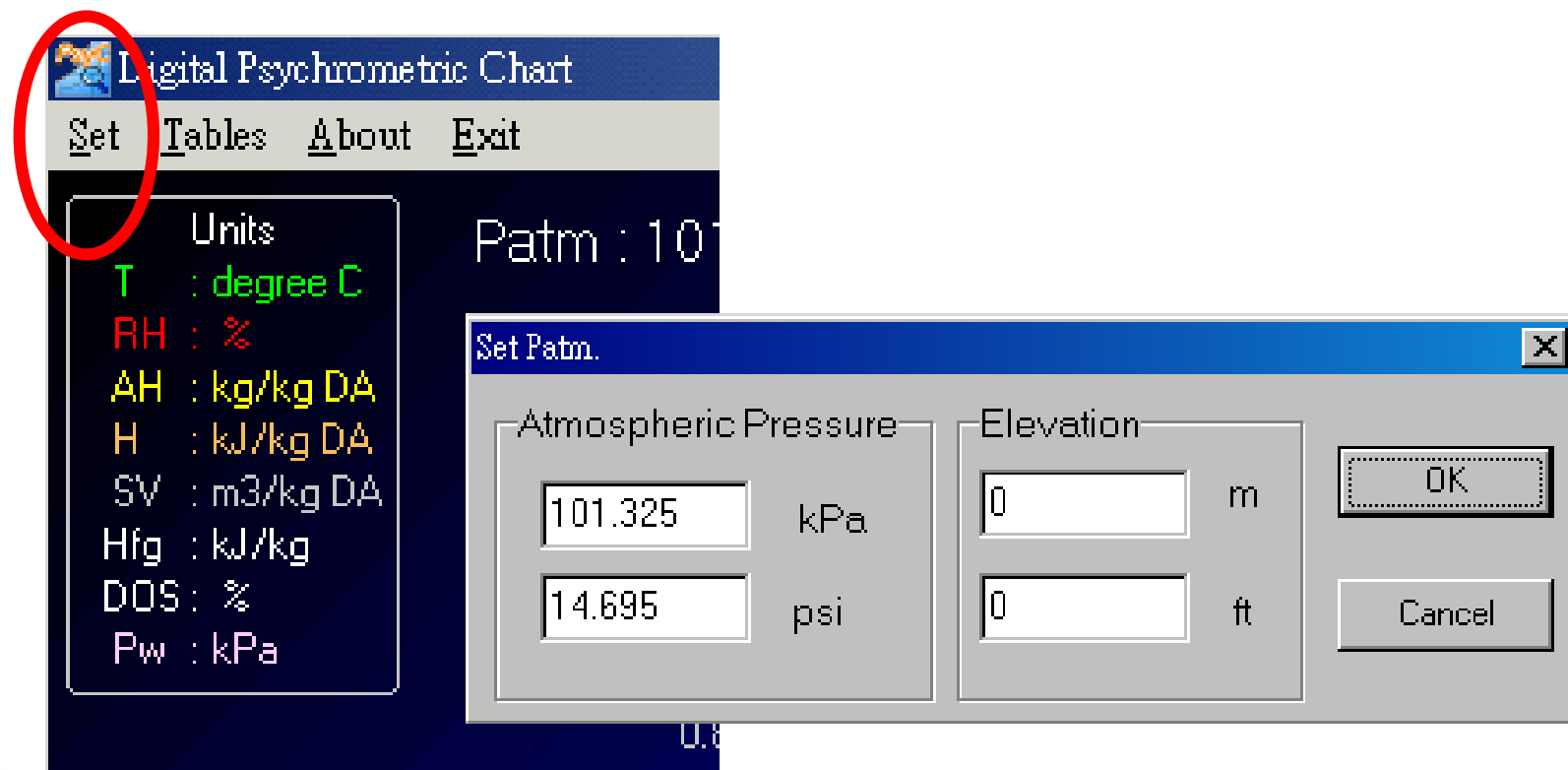
游標所在欄位的進一步說明



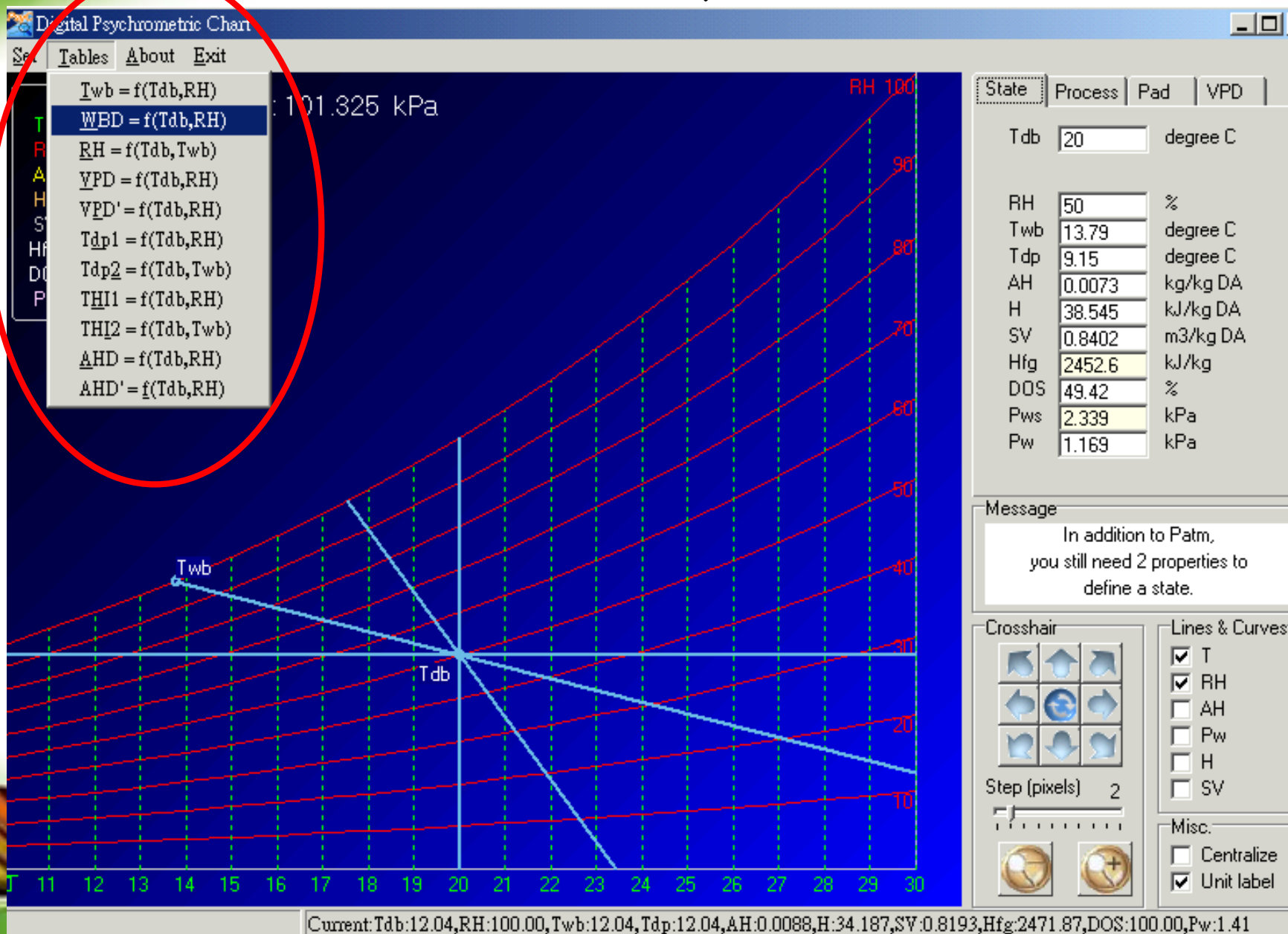
紅色區為濕氣圖範圍



首先要設定大氣壓力值或是海拔高度



好用的表格



共 11 個好用的表格選項

$$\underline{T}_{wb} = f(T_{db}, RH)$$

$$\underline{WBD} = f(T_{db}, RH)$$

$$\underline{RH} = f(T_{db}, T_{wb})$$

$$\underline{VPD} = f(T_{db}, RH)$$

$$\underline{VPD}' = f(T_{db}, RH)$$

$$\underline{T}_{dp1} = f(T_{db}, RH)$$

$$\underline{T}_{dp2} = f(T_{db}, T_{wb})$$

$$\underline{THI1} = f(T_{db}, RH)$$

$$\underline{THI2} = f(T_{db}, T_{wb})$$

$$\underline{AHD} = f(T_{db}, RH)$$

$$\underline{AHD}' = f(T_{db}, RH)$$



User friendly 3-step design in PsyTable

Psytable

Twb = f(Tdb, RH)

Lower Limit Upper Limit Interval Units

Col.: Tdb 20 40 1 degree C

Row: RH 50 100 5 %

Twb WBD RH VPD VPD' Tdp1 Tdp2 THI1 T

Table

1. Define the ranges

2. Set the intervals

3. List the values

Psytable

Patm : 101.325 kPa

Message

Twb:

Wet Bulb Temperature
(in degree C)

Twb WBD RH VPD VPD' Tdp1 Tdp2 THI1 T

Twb Table

	20	21	22	23	24	25	26	27	28	29	30	31	32
50	13.79	14.59	15.39	16.2	17	17.8	18.61	19.41	20.22	21.03	21.84	22.65	23.46
55	14.47	15.3	16.12	16.95	17.77	18.6	19.43	20.26	21.08	21.91	22.75	23.58	24.42
60	15.15	15.99	16.84	17.68	18.53	19.38	20.23	21.07	21.93	22.78	23.63	24.49	25.34
65	15.81	16.67	17.54	18.4	19.27	20.14	21.01	21.87	22.75	23.62	24.49	25.37	26.25
70	16.45	17.34	18.22	19.11	19.99	20.88	21.77	22.66	23.55	24.44	25.33	26.23	27.13
75	17.09	17.99	18.9	19.8	20.7	21.61	22.51	23.42	24.33	25.24	26.15	27.07	27.99
80	17.71	18.63	19.56	20.48	21.4	22.32	23.25	24.17	25.1	26.03	26.96	27.89	28.82
85	18.33	19.27	20.2	21.14	22.08	23.02	23.96	24.91	25.85	26.8	27.74	28.69	29.64
90	18.93	19.89	20.84	21.8	22.75	23.71	24.67	25.63	26.59	27.55	28.51	29.48	30.45
95	19.53	20.5	21.47	22.44	23.41	24.38	25.36	26.33	27.31	28.29	29.27	30.25	31.24
100	20	21	22	23	24	25	26	27	28	29	30	31	32

Table 1: $T_{wb} = f(T_{db}, RH)$

	20	22	24	26	28	30	32	34	36	38	40	42	44
50	13.79	15.39	17.00	18.61	20.22	21.84	23.46	25.08	26.70	28.32	30.04	31.7	33.38
55	14.47	16.12	17.77	19.43	21.08	22.75	24.42	26.09	27.78	29.47	31.18	32.89	34.62
60	15.15	16.84	18.53	20.23	21.93	23.63	25.34	27.06	28.79	30.53	32.28	34.04	35.81
65	15.81	17.54	19.27	21.01	22.75	24.49	26.25	28.01	29.78	31.56	33.35	35.16	36.97
70	16.45	18.22	19.99	21.77	23.55	25.33	27.11	28.93	30.74	32.56	34.39	36.24	38.09
75	17.09	18.9	20.7	22.51	24.33	26.15	27.99	29.83	31.67	33.53	35.4	37.28	39.17
80	17.71	19.56	21.4	23.25	25.1	26.96	28.82	30.7	32.59	34.48	36.39	38.3	40.23
85	18.33	20.2	22.08	23.96	25.85	27.74	29.64	31.56	33.48	35.41	37.35	39.3	41.26
90	18.93	20.84	22.75	24.67	26.59	28.51	30.45	32.39	34.35	36.31	38.28	40.27	42.26
95	19.53	21.47	23.41	25.36	27.31	29.27	31.24	33.21	35.2	37.19	39.2	41.21	43.24
100	20	22	24	26	28	30	32	34	36	38	40	42	44

RH (50 – 100%) and T_{db} (20 – 44 °C)

Table 2: $WBD = f(T_{db}, RH)$

	20	22	24	26	28	30	32	34	36	38	40	42	44
50	6.21	6.61	7.01	7.39	7.78	8.16	8.54	8.91	9.27	9.62	9.96	10.3	10.62
55	5.53	5.88	6.23	6.57	6.92	7.25	7.58	7.91	8.22	8.53	8.82	9.11	9.38
60	4.85	5.16	5.47	5.77	6.07	6.37	6.66	6.94	7.21	7.47	7.72	7.96	8.19
65	4.19	4.46	4.73	4.99	5.25	5.51	5.75	5.99	6.22	6.44	6.65	6.84	7.03
70	3.55	3.78	4.01	4.23	4.45	4.67	4.87	5.07	5.26	5.44	5.61	5.76	5.91
75	2.91	3.1	3.3	3.49	3.67	3.85	4.01	4.17	4.33	4.47	4.6	4.72	4.83
80	2.29	2.44	2.6	2.75	2.9	3.04	3.18	3.3	3.41	3.52	3.61	3.7	3.77
85	1.67	1.8	1.92	2.04	2.15	2.26	2.36	2.44	2.52	2.59	2.65	2.7	2.74
90	1.07	1.16	1.25	1.33	1.41	1.49	1.55	1.61	1.65	1.69	1.72	1.73	1.74
95	0.47	0.53	0.59	0.64	0.69	0.73	0.76	0.79	0.8	0.81	0.8	0.79	0.76
100	0	0	0	0	0	0	0	0	0	0	0	0	0

Wet Bulb Depression is the limit of evaporative cooling methods.



Table 3: $RH = f(T_{db}, T_{wb})$

	20	22	24	26	28	30	32	34	36	38	40	42	44
20	100	82.63	69.02	57.61	48.01	39.89	33	27.14	22.14	17.89	14.26	11.17	8.55
22	N/A	100	83.49	70.48	59.48	50.13	42.16	35.35	29.52	24.52	20.24	16.57	13.42
24	N/A	N/A	100	84.34	71.84	61.18	52.06	44.23	37.49	31.69	26.69	22.38	18.67
26	N/A	N/A	N/A	100	85.17	73.11	62.75	53.83	46.12	39.45	33.68	28.67	24.34
28	N/A	N/A	N/A	N/A	100	85.98	74.3	64.21	55.45	47.85	41.24	35.49	30.48
30	N/A	N/A	N/A	N/A	N/A	100	86.78	75.43	65.56	56.95	49.44	42.88	37.13
32	N/A	N/A	N/A	N/A	N/A	N/A	100	87.56	76.49	66.81	58.33	50.89	44.36
34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	88.32	77.49	67.96	59.58	52.19
36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	89.03	78.39	68.99	60.68
38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	89.67	79.18	69.87
40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	90.19	79.82
42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	90.57
44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100

RH

T_{wb} (20 – 44 °C) and T_{db} (20 – 44 °C)

Table 4: VPD of air

[illegible]

$$VPD = P_{ws}@T_{db} - P_w@T_{db}$$

$$AHD = \text{Sat. AH}@T_{db} - \text{Sat. AH}@T_{dp}$$

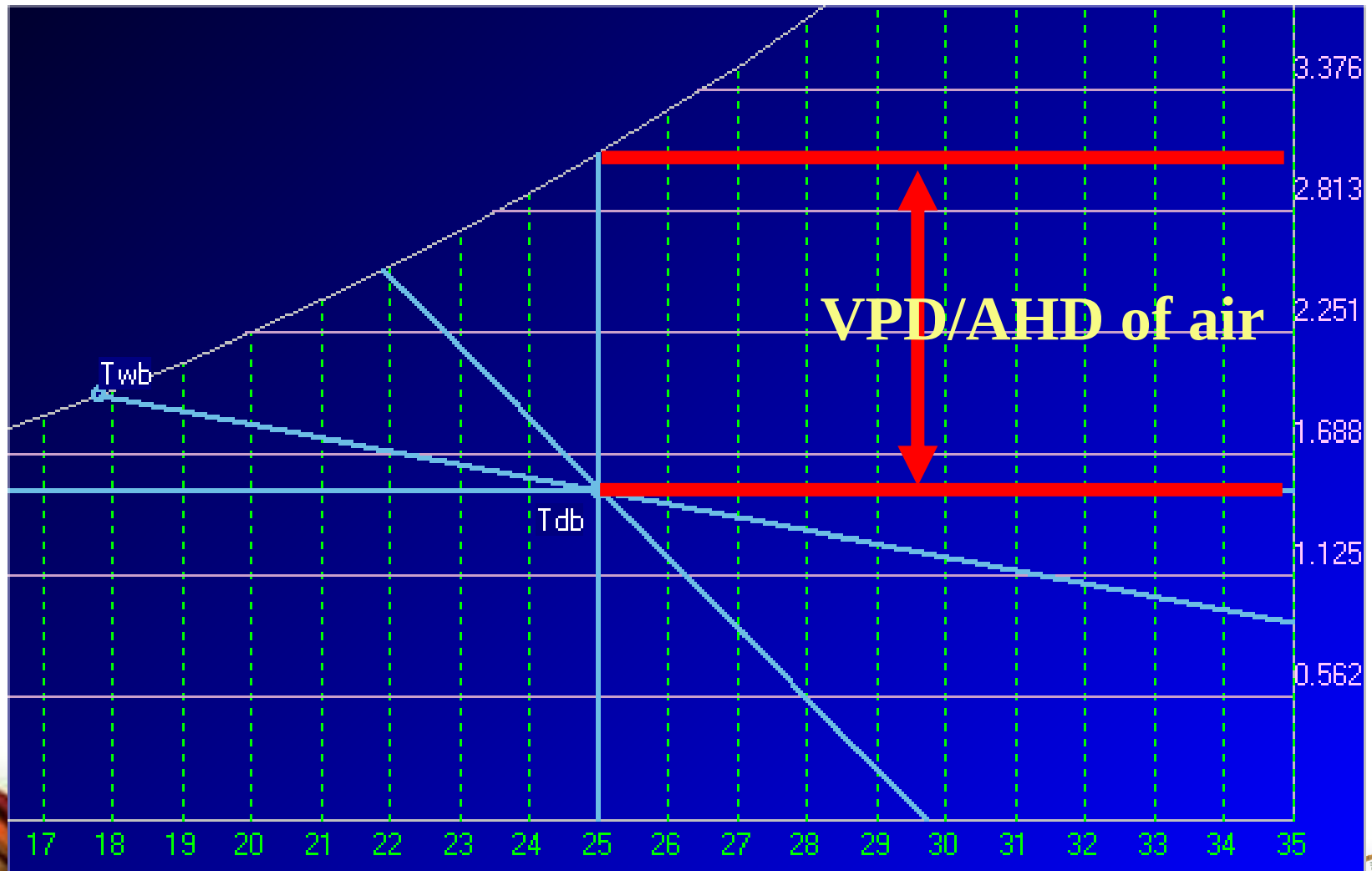
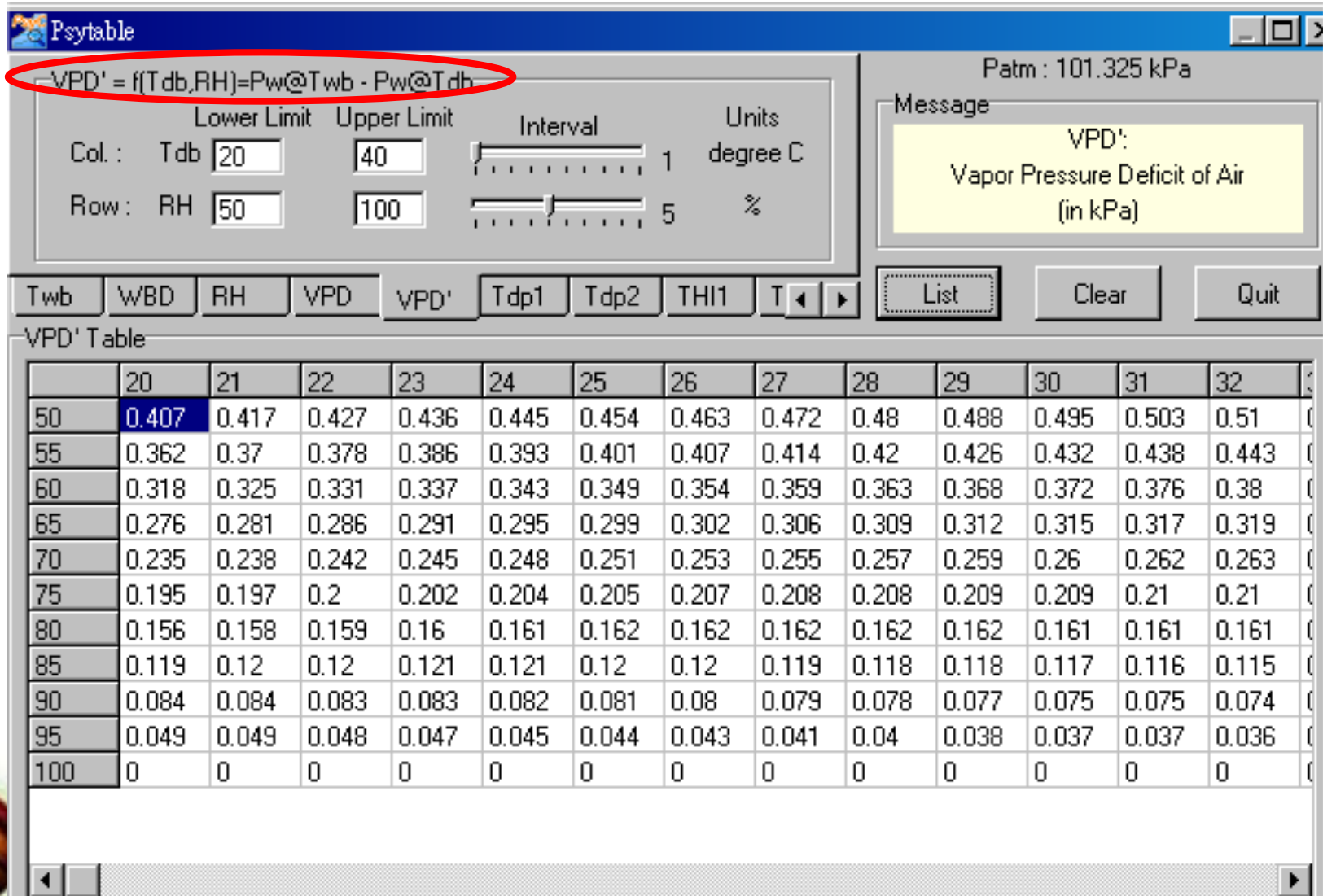
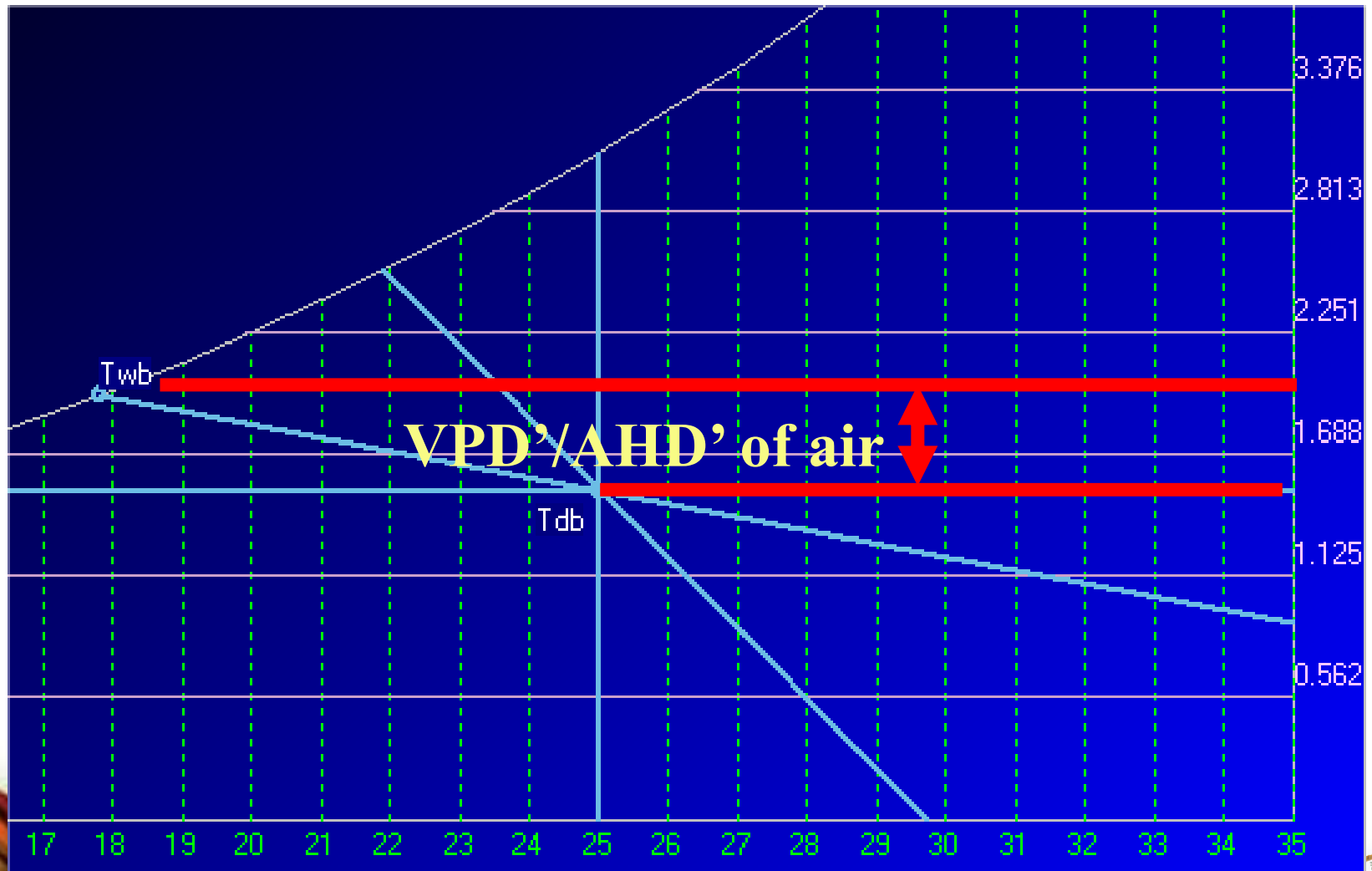


Table 5: VPD' of air



$$VPD' = P_w @ T_{wb} - P_w @ T_{db}$$

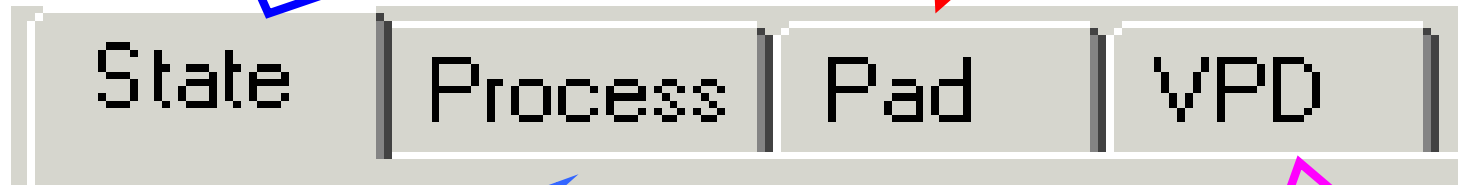
$$AHD' = \text{Sat. AH} @ T_{wb} - \text{Sat. AH} @ T_{db}$$



Psychcharts

Besides atmospheric pressure, values of 2 independent states are required to derive others

Evaporative cooling process calculation

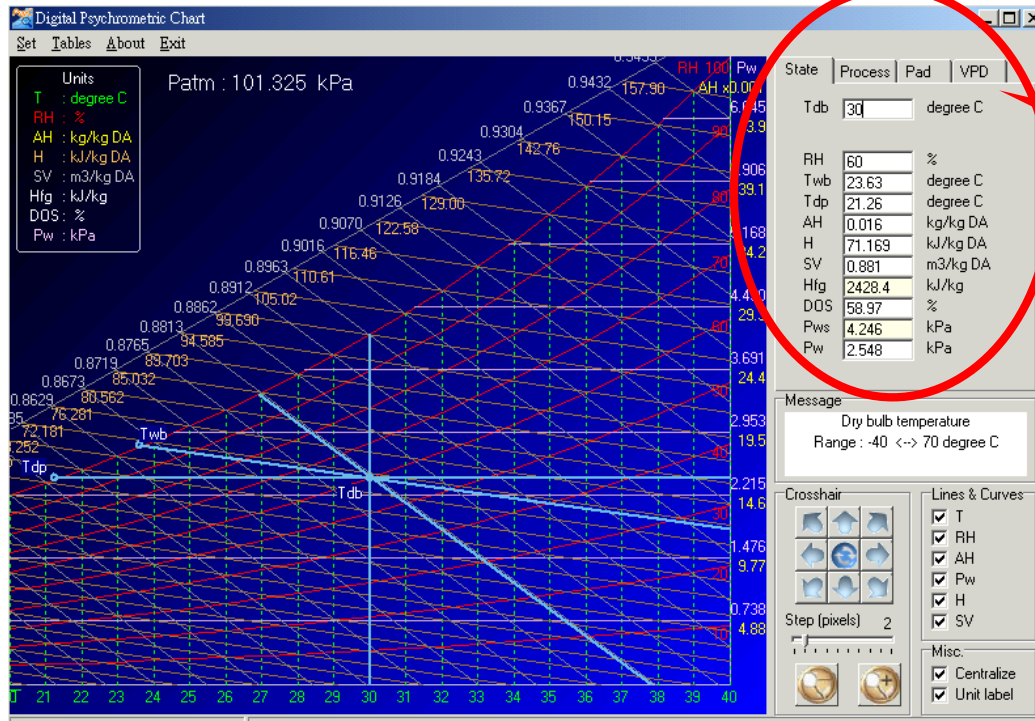


find differences between 2 states

Vapor pressure deficit on leaf



State Calculation



State Process Pad VPD

Tdb 30 degree C

RH 60 %

Twb 23.63 degree C

Tdp 21.26 degree C

AH 0.016 kg/kg DA

H 71.169 kJ/kg DA

SV 0.881 m3/kg DA

Hfg 2428.4 kJ/kg

DOS 58.97 %

Pws 4.246 kPa

Pw 2.548 kPa



Independent Properties (IP)

	Twb	RH	Tdp	AH	SV	H	hfg	DOS	Pws	Pw
Tdb	IP	IP	IP	IP	IP	IP		IP		IP

State

Process

Pad

VPD

Tdb

30

degree C

RH

60

%

Twb

23.63

degree C

Tdp

21.26

degree C

AH

0.016

kg/kg DA

H

71.169

kJ/kg DA

SV

0.881

m³/kg DA

Hfg

2428.4

kJ/kg

DOS

58.97

%

Pws

4.246

kPa

Pw

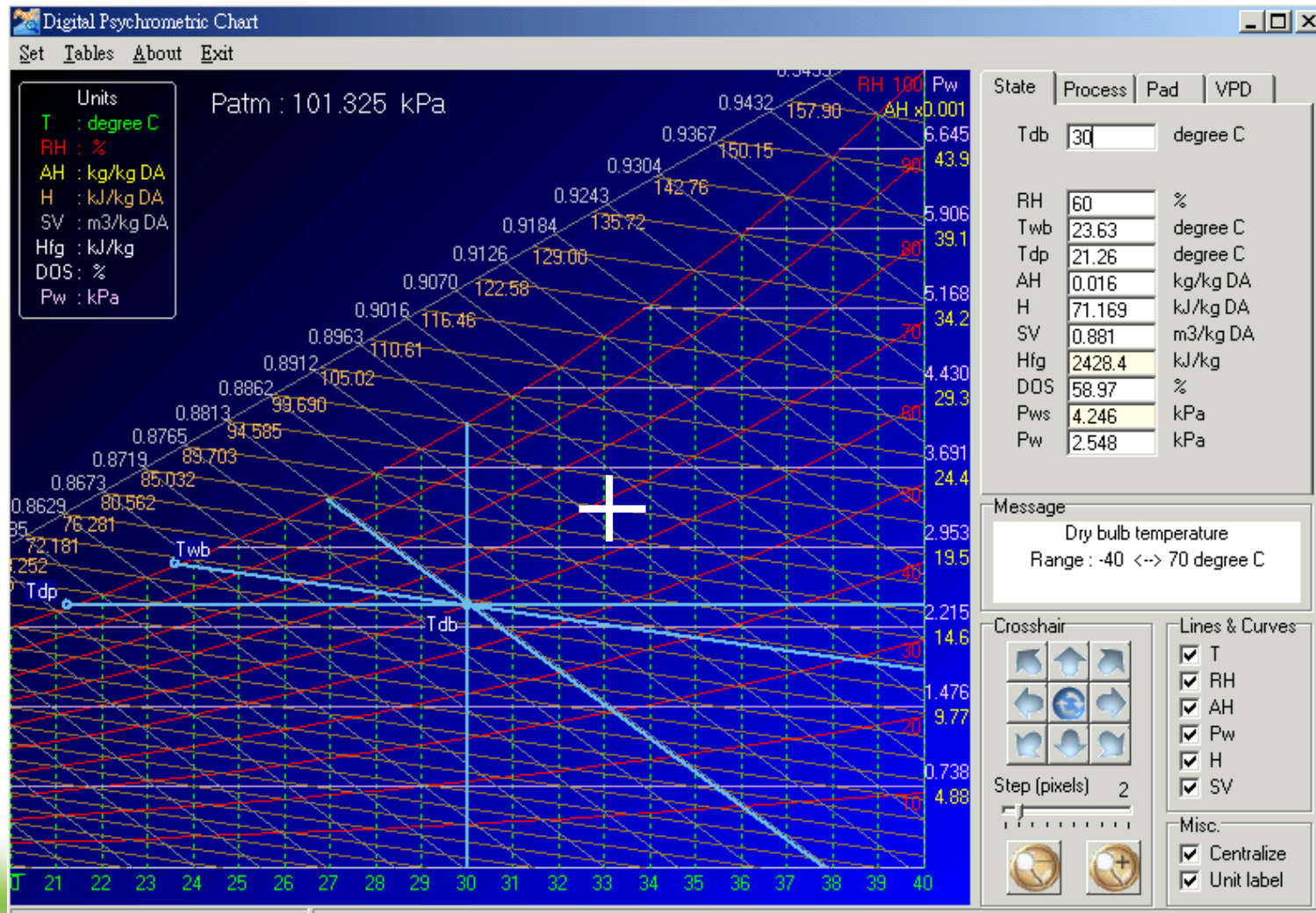
2.548

kPa

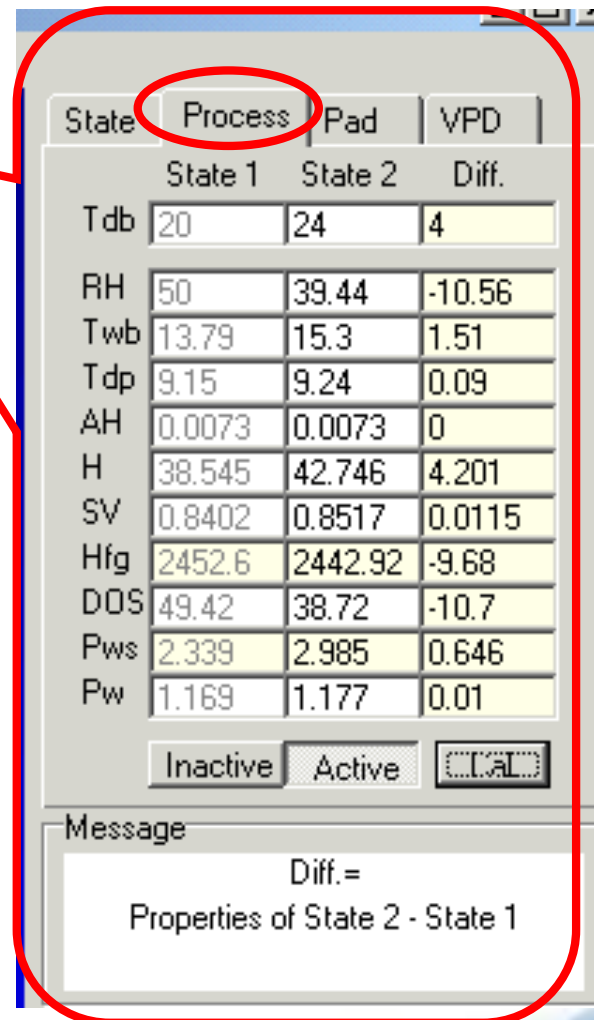
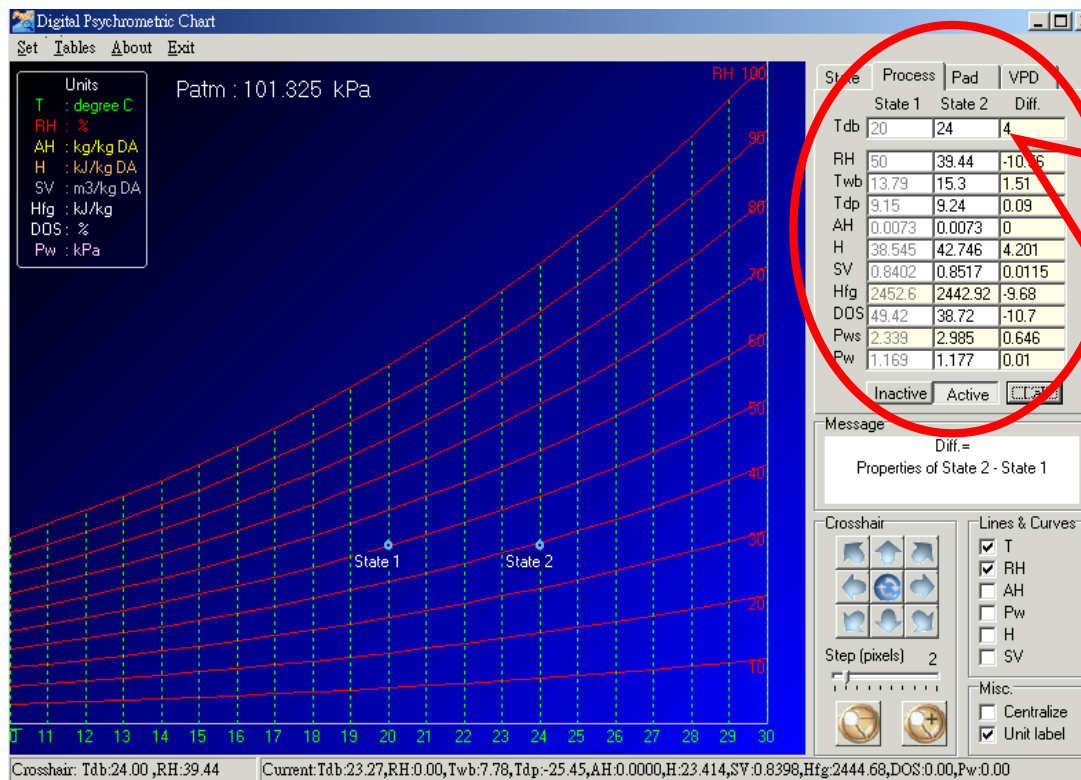
Any pair of IP can be the given values to derive others.



One click in Psychchart window using left button of the mouse can define a state



Process Calculation



Use mouse to define 2 states

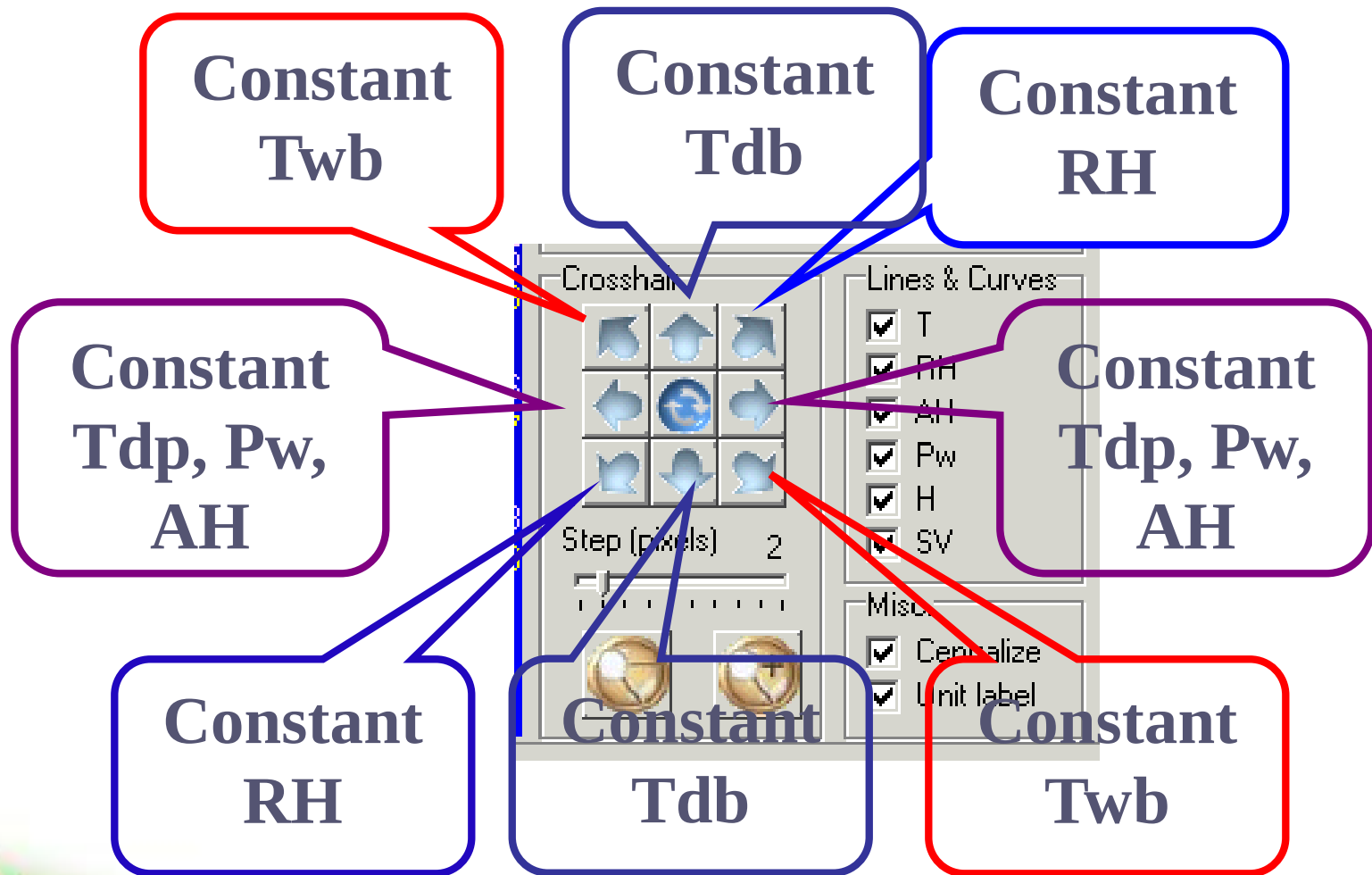
State	Process	Pad	VPD
	State 1	State 2	Diff.
Tdb	20.98		
RH	60.76		
Twb	16.08		
Tdp	12.96		
AH	0.0094		
H	44.994		
SV	0.8459		
Hfg	2450.22		
DOS	60.17		
Pws	2.485		
Pw	1.51		
<input checked="" type="button" value="Active"/> Inactive Cal.			

1. To define 2nd state, change from 'Inactive' to 'Active' first.
2. Click in the Psychart window at the selected state or click on the crosshair region to move along constant lines or curves.
3. Click on 'Cal.' to calculate the difference.

Inactive	<input checked="" type="button" value="Active"/>	Cal.
---	--	-------------------------------------

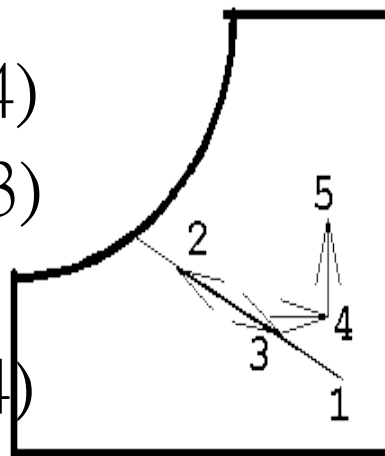


Move along prefix lines or Curves

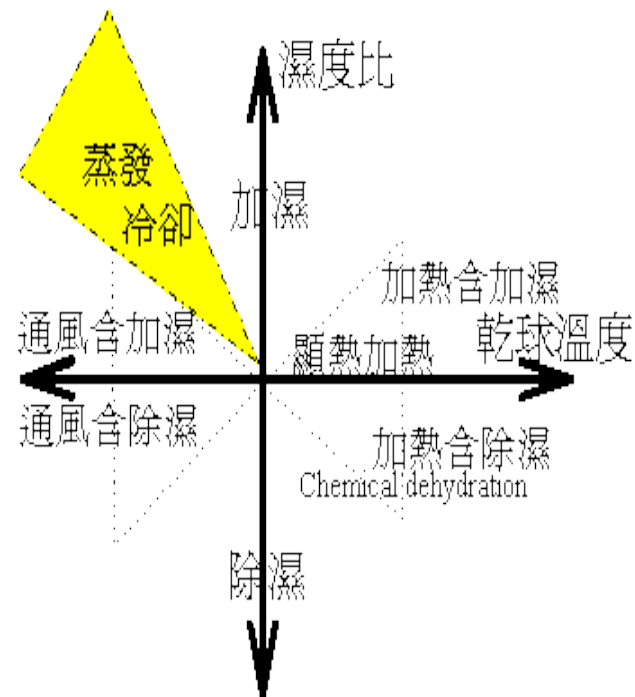


過程：由一個狀態到另一個狀態

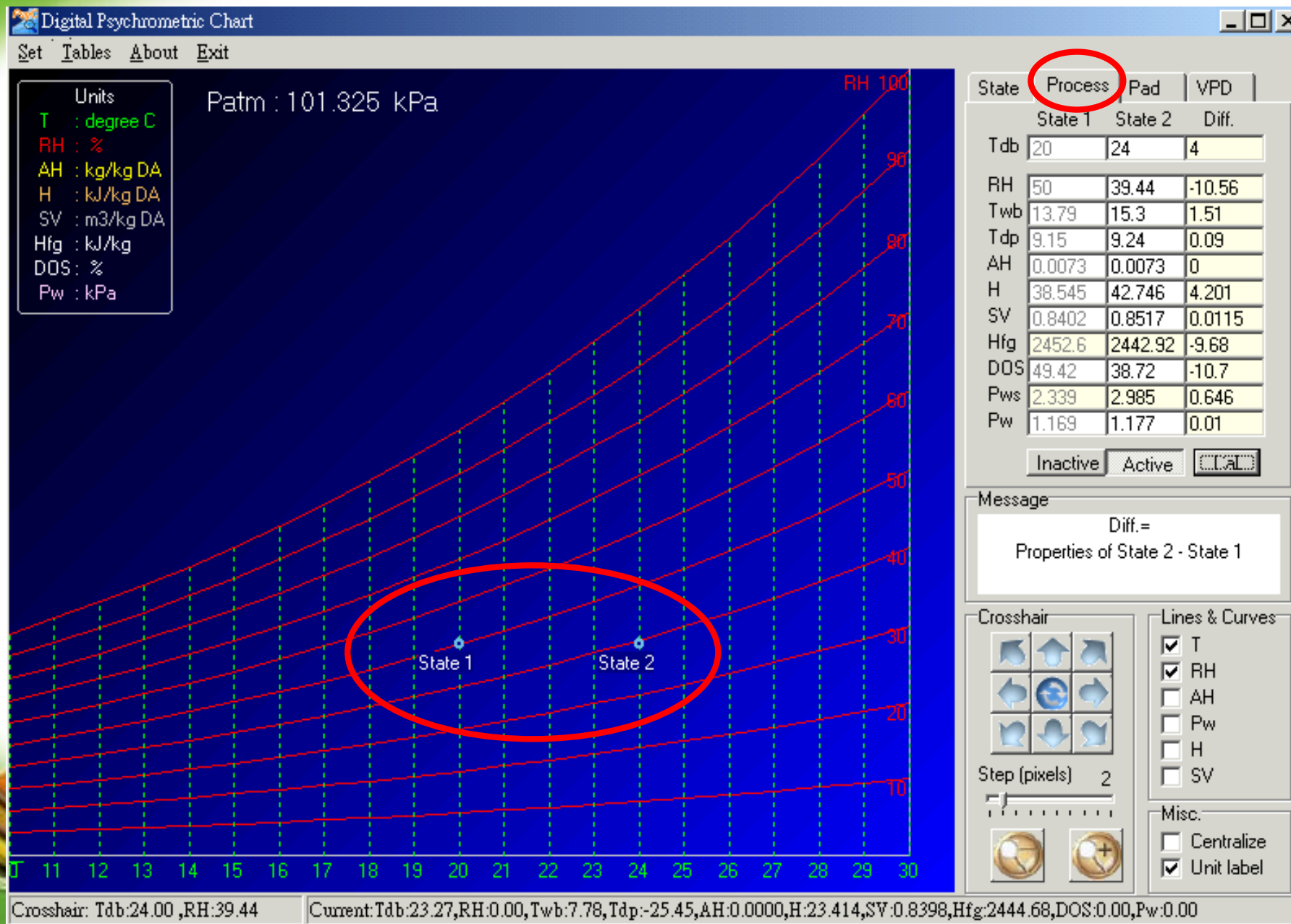
- Sensible Heating (3->4)
- Sensible Cooling (4->3)
- Humidification (4->5)
- Dehumidification (5->4)
- Heating (3->5, 3->1)
- Cooling (5->3, 1->3)
- Air Mixing (1, 2->3)
- Evaporative Cooling, Drying (1->2, 1->3)
- Combination of above (1->2->3->4->5)



蒸發冷卻 (1-2)
 + 空氣混合 (2-3)
 + 顯熱加熱 (3-4)
 + 加濕 (4-5)



加熱（顯熱） Sensible heat gain



蒸發冷卻法

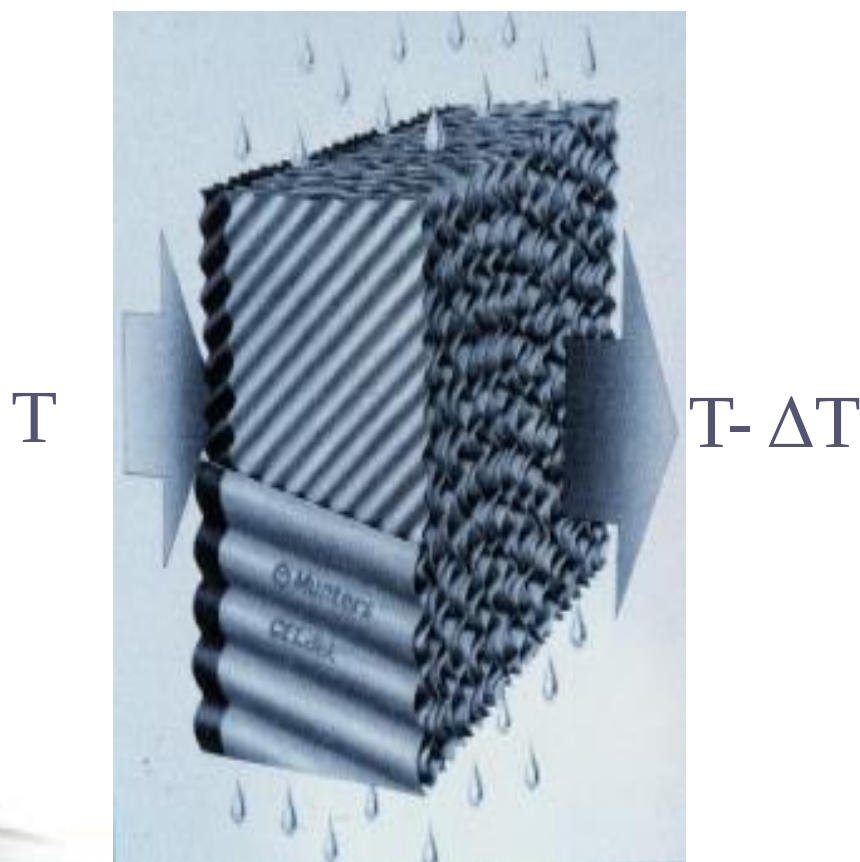
Evaporative cooling Methods

- 降溫極限為室外的濕球溫度
 - Pad and Fan system 風扇+水簾系統
 - Multi-Net Fogging and Fan system 風扇+多層網噴霧
- 降溫極限為室內的濕球溫度
 - Spraying 灑水
 - Misting 低壓噴霧 / 細霧
 - Fogging 高壓噴霧 / 微霧



經過濕簾後溫度降低 ΔT

$\Delta T = \text{室外的 WBD} \times \text{濕簾的效率}$



蒸發冷卻過程

State	Process	Pad	VPD
	Outdoor	AfterPad	Eff.
Tdb	26	19.41	80
RH	45	85.65	
Twb	17.77	17.86	
Tdp	13	16.79	
AH	0.0094	0.0121	
H	50.185	50.185	
SV	0.8603	0.8449	
Hfg	2438.08	2454.02	
DOS	44.17	0.85	
Pws	3.363	2.255	
Pw	1.513	1.932	

Message: Either AfterPad or Eff. can be the unknown

Crosshair: Step (pixels) 2

Lines & Curves: ☒ T, ☒ RH, ☐ AH, ☐ Pw, ☐ H, ☐ SV

Misc.: ☐ Centralize, ☒ Unit label

State	Process	Pad	VPD
	Outdoor	AfterPad	Eff.
Tdb	26	19.41	80
RH	45	85.65	
Twb	17.77	17.86	
Tdp	13	16.79	
AH	0.0094	0.0121	
H	50.185	50.185	
SV	0.8603	0.8449	
Hfg	2438.08	2454.02	
DOS	44.17	0.85	
Pws	3.363	2.255	
Pw	1.513	1.932	

Message: Either AfterPad or Eff. can be the unknown

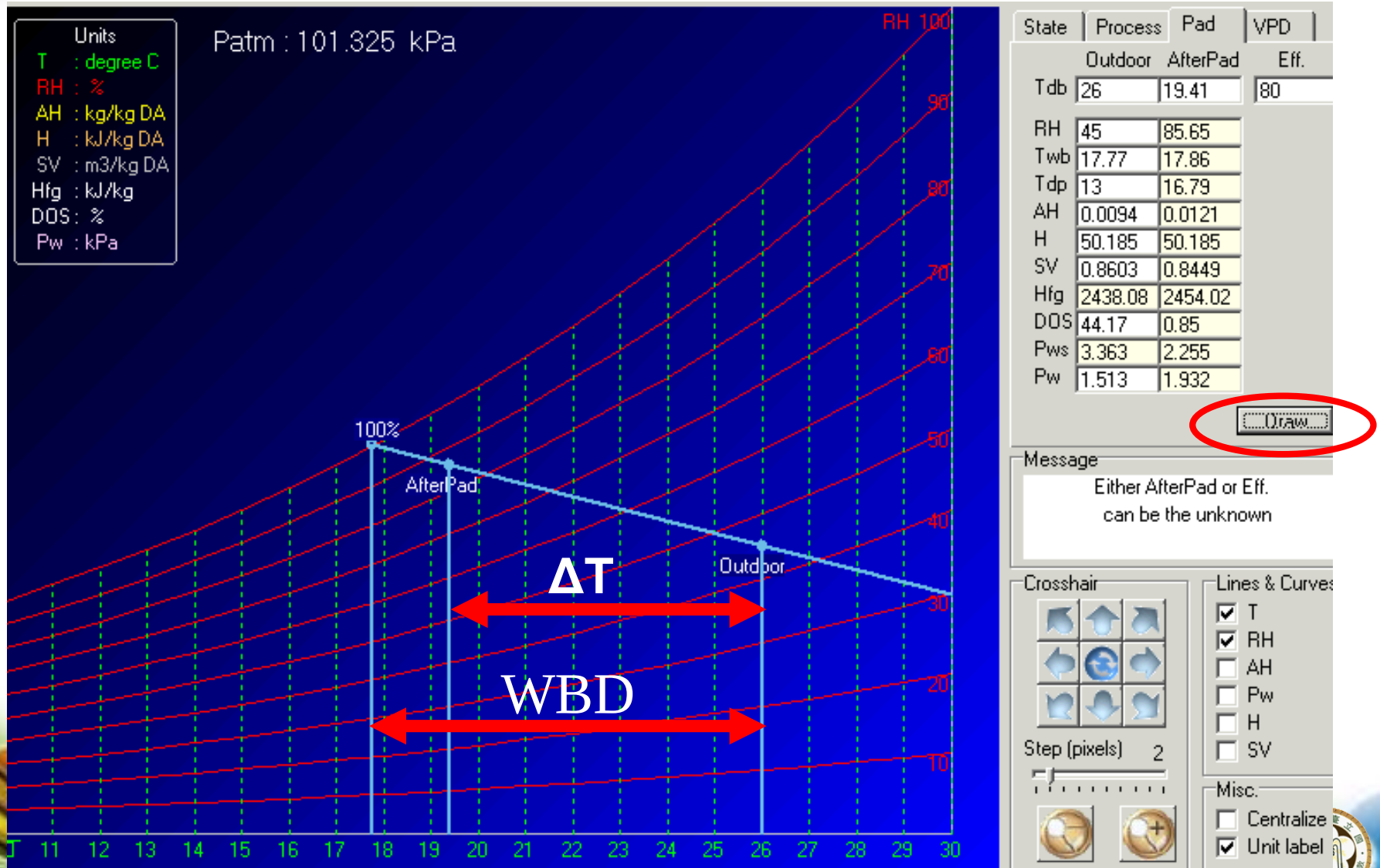
Crosshair: Step (pixels) 2

Lines & Curves: ☒ T, ☒ RH, ☐ AH, ☐ Pw, ☐ H, ☐ SV

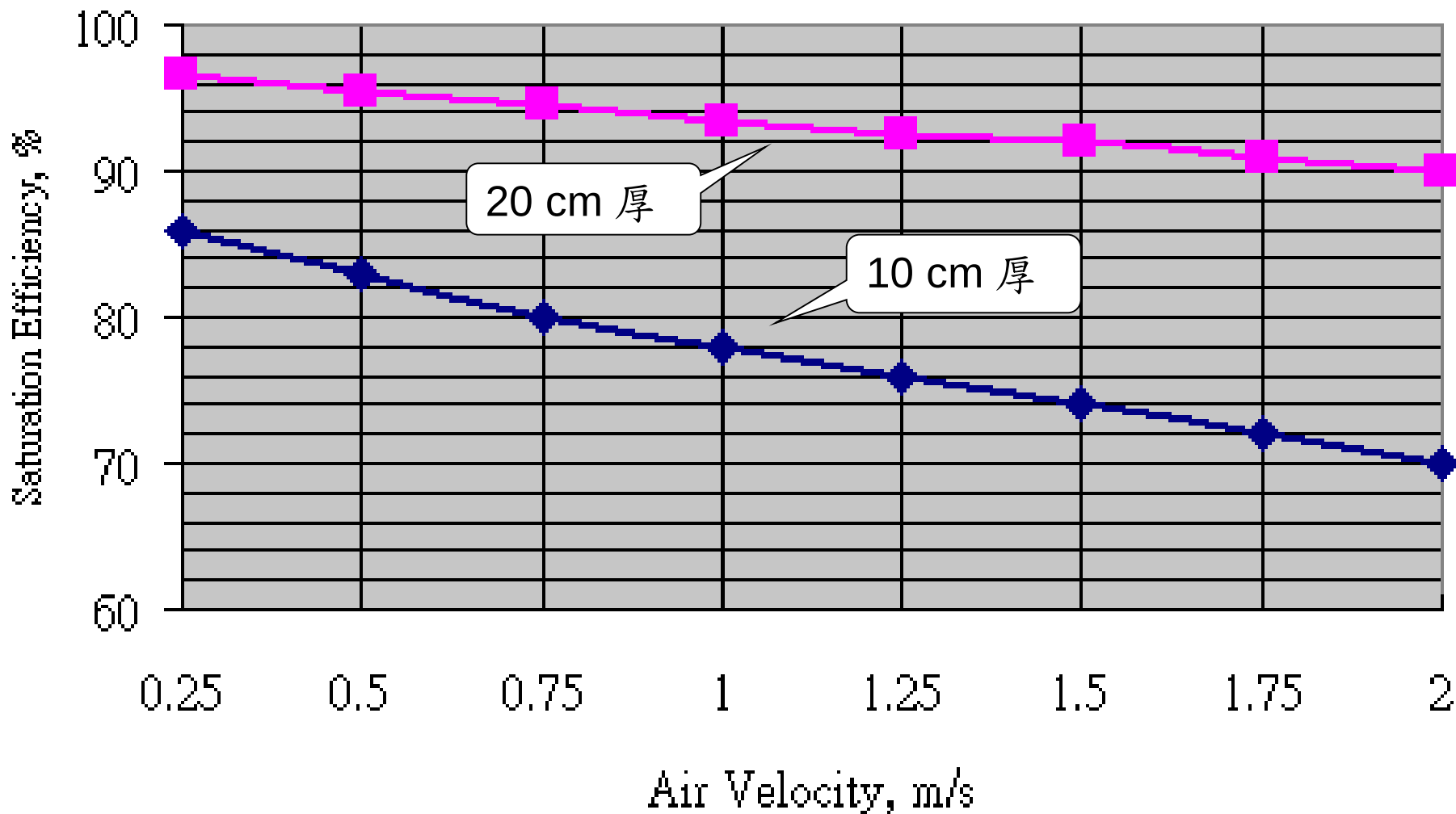
Misc.: ☐ Centralize, ☒ Unit label

1. 先輸入室外的空氣狀態
 2. 再輸入濕簾的降溫效率
 3. 來求出通過濕簾後的溫度與其他熱力性質
-
2. 也可輸入通過濕簾後的溫度
 3. 來求出空氣的其他熱力性質與濕簾的降溫效率

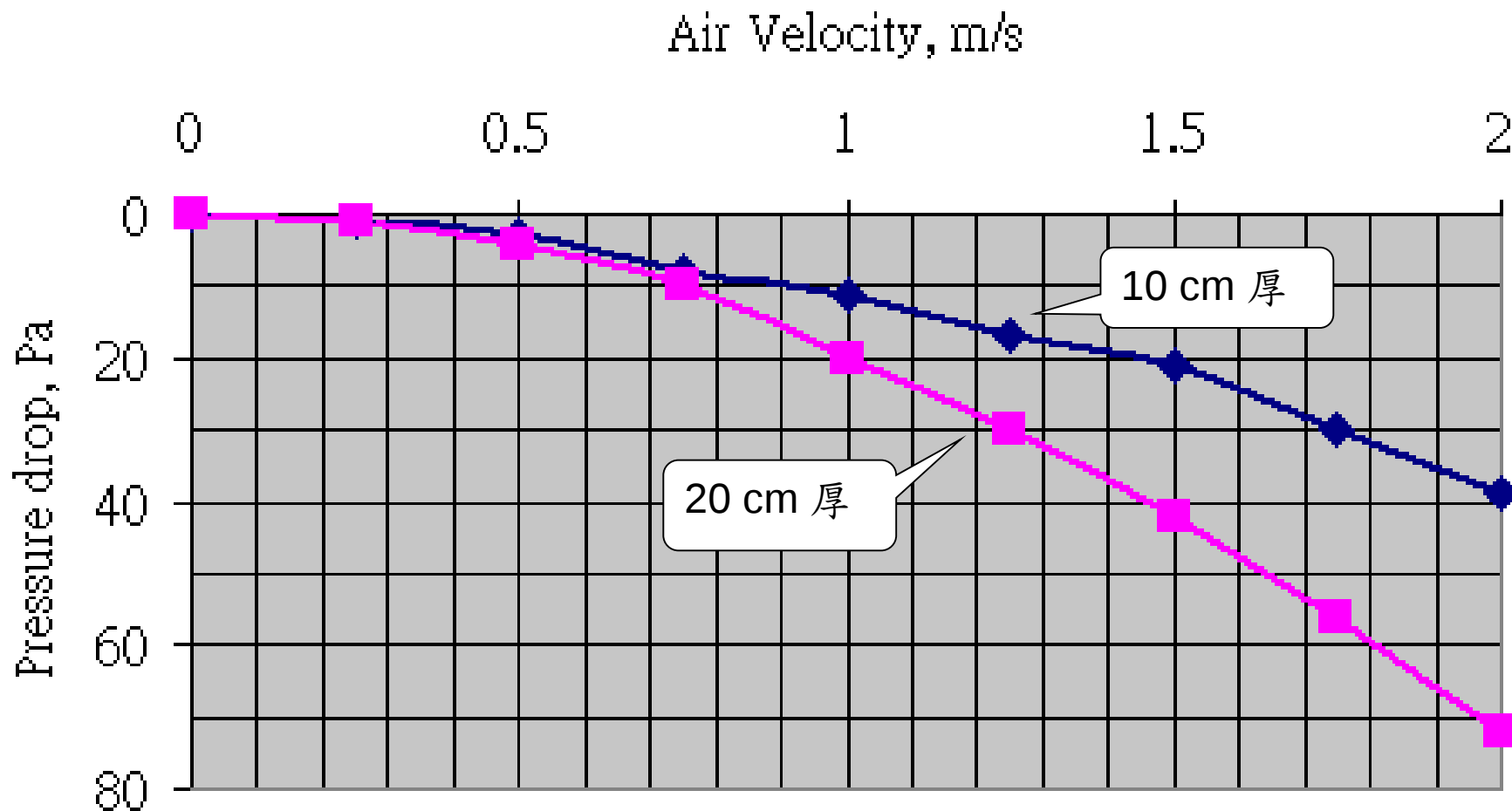
點選 Draw 來繪出 此過程在濕氣圖上的位置與相關解說



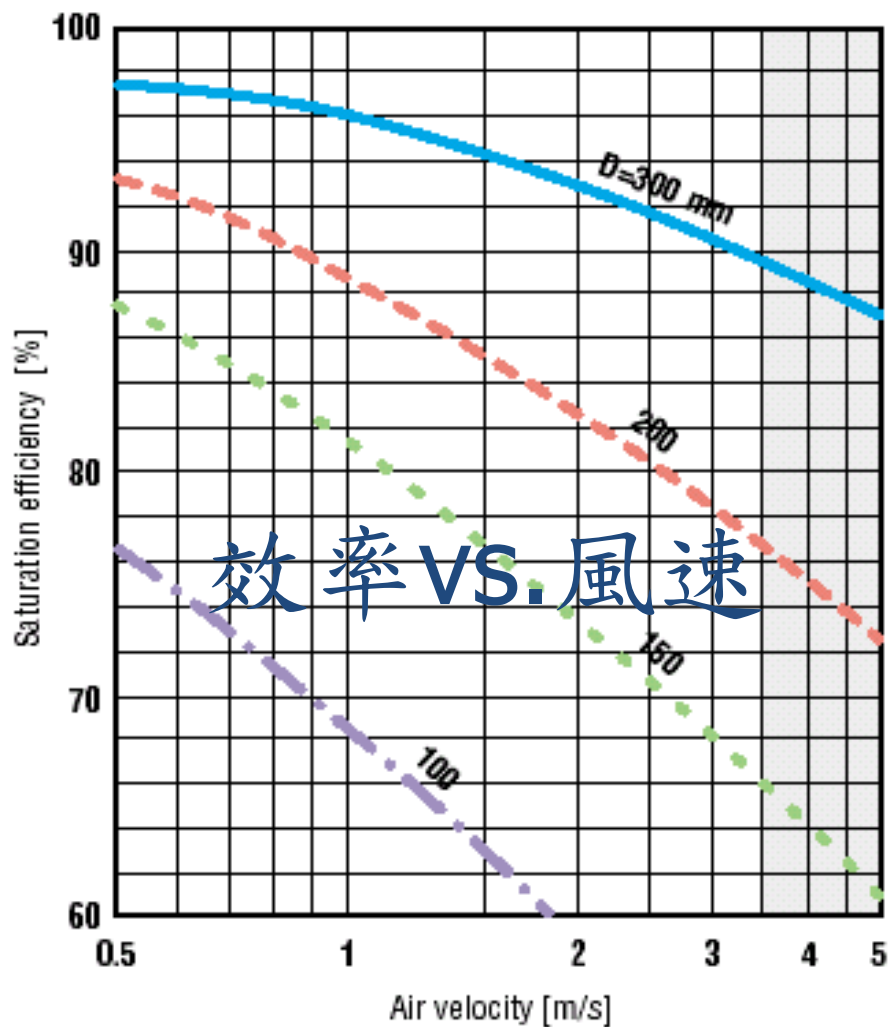
不同厚度的水簾在不同風速下的系統效率



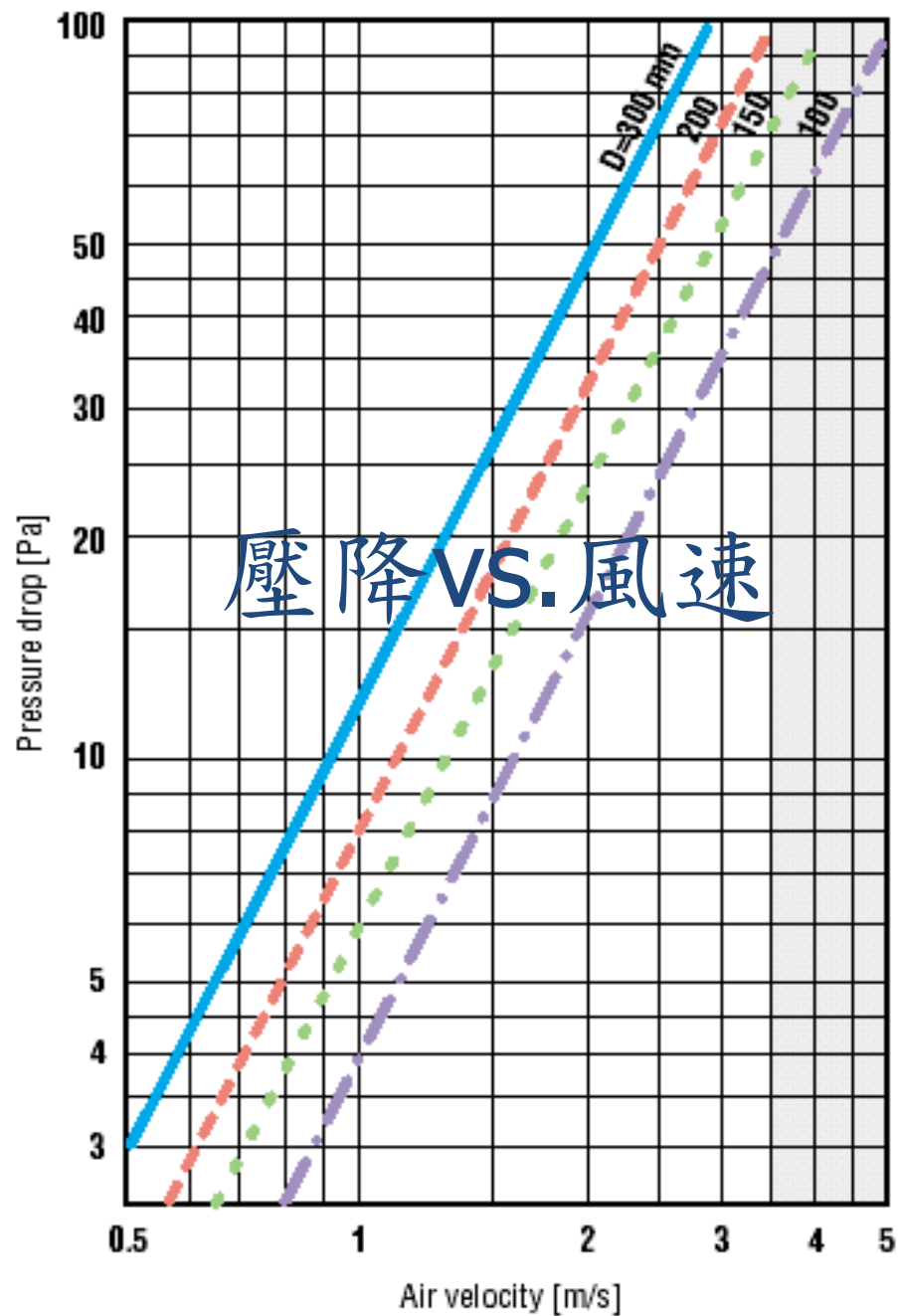
不同厚度的水簾在不同風速下的 壓力降 (壓損)



Saturation efficiency CELdek 7060-15

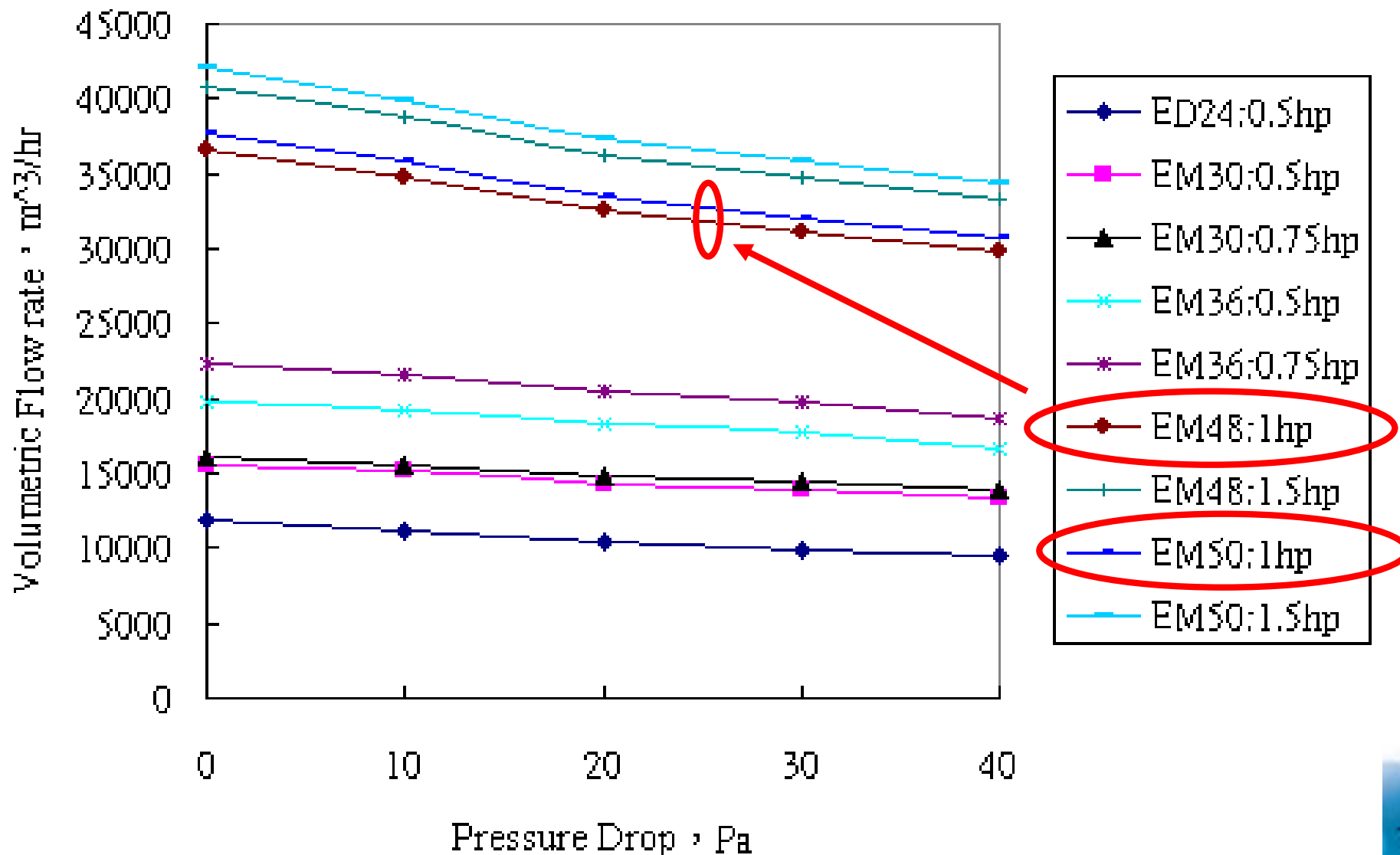


Pressure drop CELdek 7060-15



不同風機的風機曲線（不同壓力降下的風機所能提供的風量）

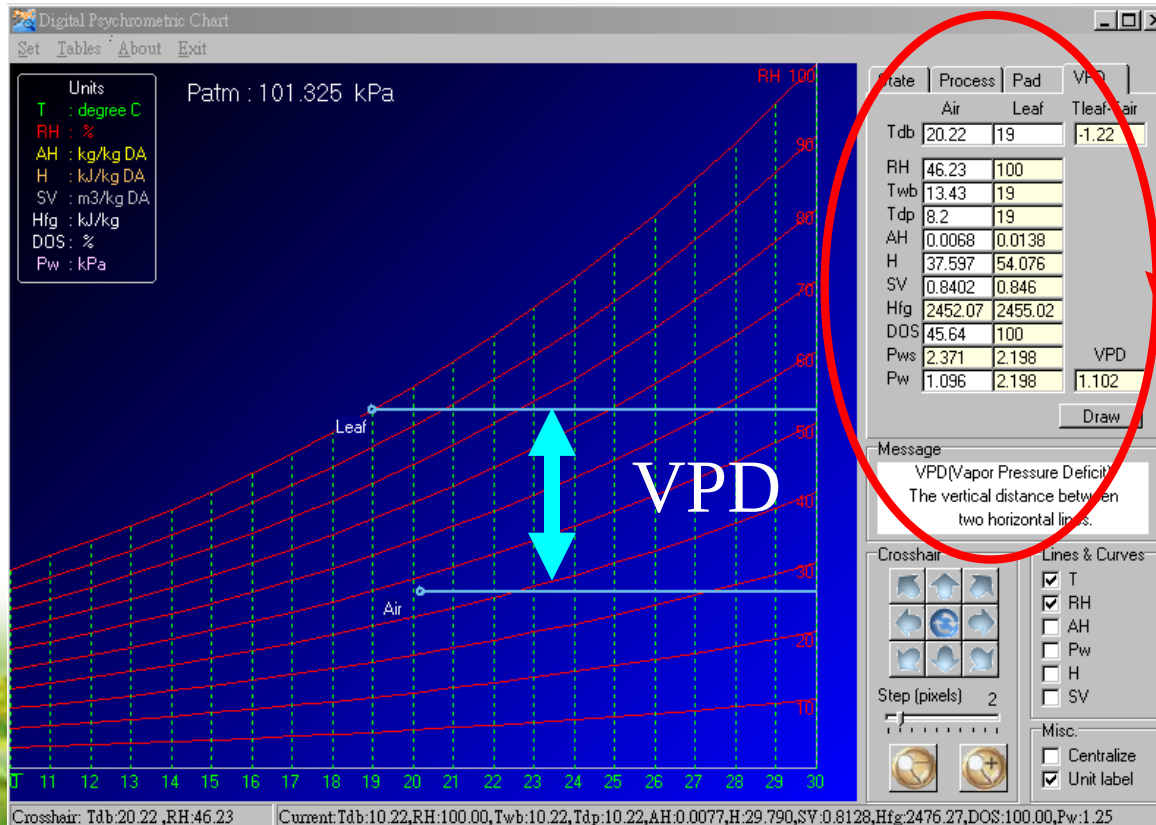
Euroemme Fans



葉片內外的蒸汽壓差

Vapor pressure deficit (VPD) of leaf

Enter Leaf temperature,
then click on Draw icon.



State	Process	Pad	VPD
Air		Leaf	Leaf-Air
Tdb	20.22	19	-1.22
RH	46.23	100	
Twb	13.43	19	
Tdp	8.2	19	
AH	0.0068	0.0138	
H	37.597	54.076	
SV	0.8402	0.846	
Hfg	2452.07	2455.02	
DOS	45.64	100	
Pws	2.371	2.198	
Pw	1.096	2.198	1.102

VPD

Draw

Message

VPD(Vapor Pressure Deficit)
The vertical distance between two horizontal lines.



溫濕度指標 THI

Psytable

THI1 = $f(T_{db}, RH) = T_{db} + 0.36 \times T_{dp} + 41.2$

Col: Tdb Interval Units degree C

Row: RH %

Patm: 101.325 kPa

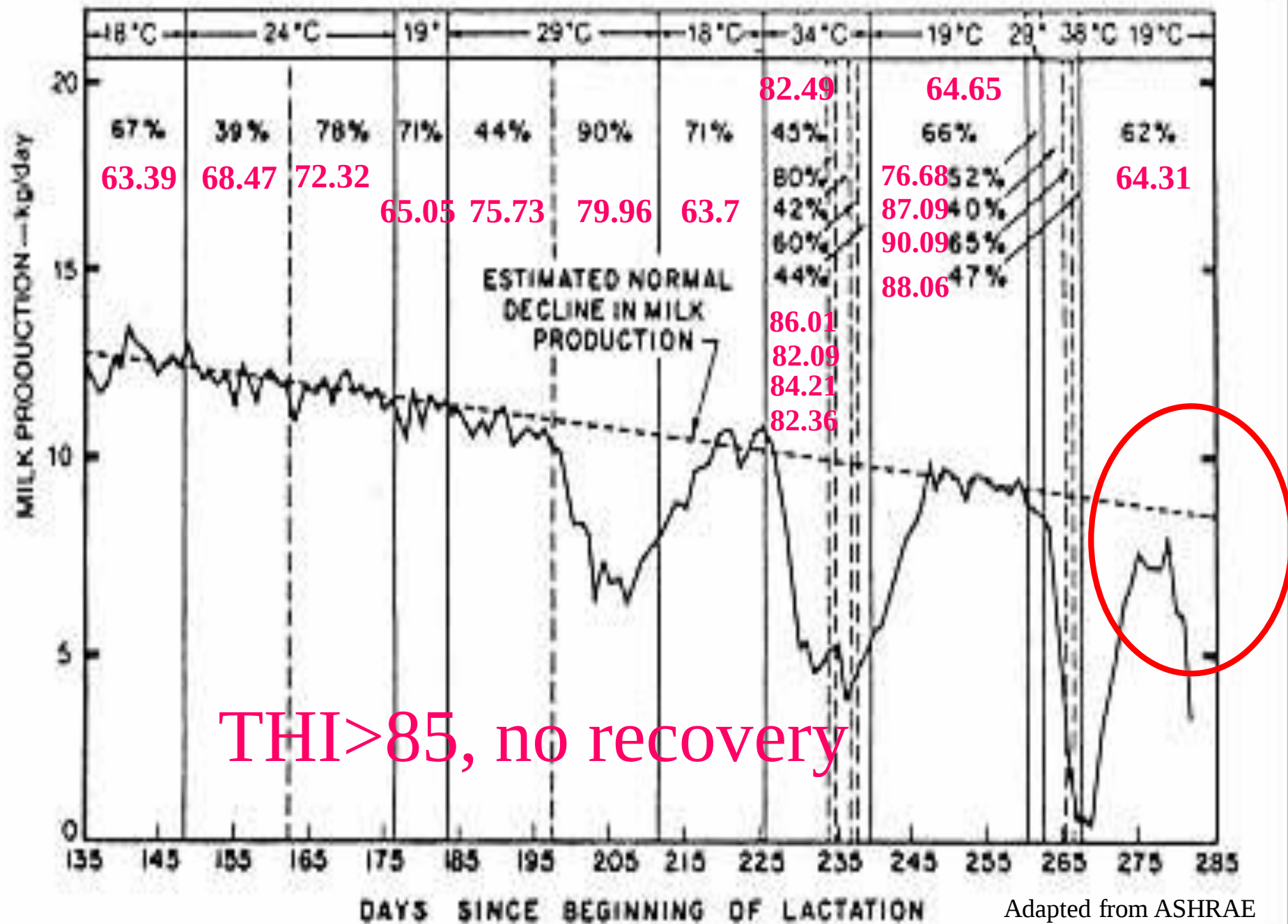
Message: THI: Temperature Humidity Index (in degree C)

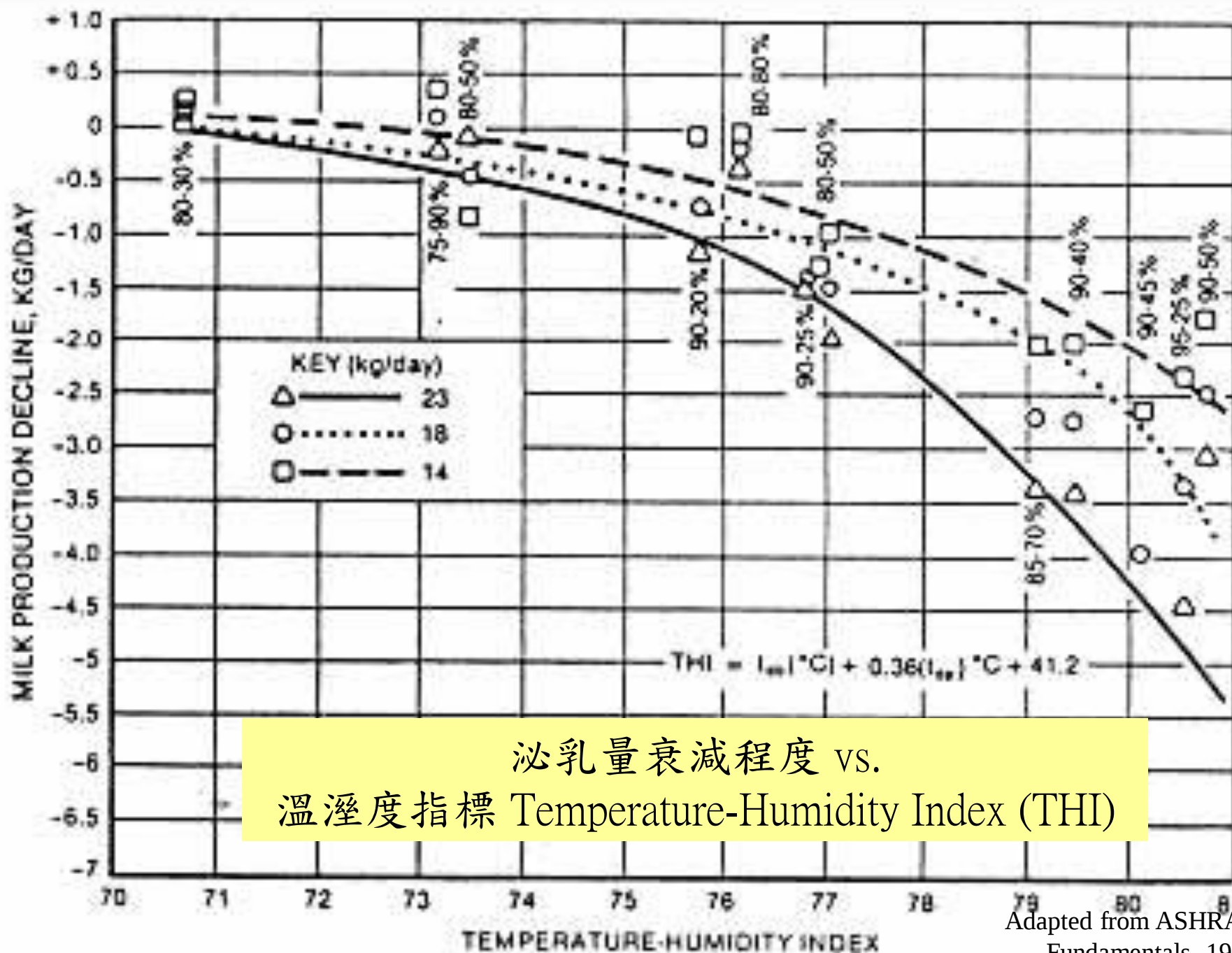
WBD RH VPD VPD' Tdp1 Tdp2 THI1 THI2 A ◀ ▶ List Clear Quit

THI1 Table

	16	18	20	22	24	26	28	30	32	34	36	38	40
35	57.44	60.05	62.67	65.28	67.9	70.53	73.15	75.78	78.41	81.04	83.67	86.3	88.94
40	58.08	60.71	63.34	65.97	68.6	71.24	73.88	76.52	79.16	81.8	84.45	87.09	89.74
45	58.66	61.3	63.94	66.59	69.23	71.88	74.53	77.18	79.84	82.49	85.14	87.8	90.46
50	59.19	61.84	64.49	67.15	69.8	72.46	75.12	77.79	80.45	83.11	85.78	88.44	91.11
55	59.68	62.34	65	67.66	70.33	73	75.67	78.34	81.01	83.69	86.36	89.03	91.71
60	60.13	62.8	65.47	68.14	70.82	73.49	76.17	78.85	81.53	84.21	86.9	89.58	92.26
65	60.55	63.23	65.9	68.59	71.27	73.96	76.64	79.33	82.02	84.71	87.4	90.09	92.77
70	60.94	63.63	66.31	69	71.69	74.39	77.08	79.78	82.47	85.17	87.86	90.56	93.26
75	61.31	64.01	66.7	69.4	72.09	74.79	77.49	80.2	82.9	85.6	88.3	91.01	93.71
80	61.66	64.36	67.06	69.77	72.47	75.18	77.88	80.59	83.3	86.01	88.72	91.43	94.13
85	62	64.7	67.41	70.12	72.83	75.54	78.25	80.97	83.68	86.4	89.11	91.82	94.54
90	62.31	65.02	67.74	70.45	73.17	75.89	78.61	81.32	84.04	86.76	89.48	92.2	94.92
95	62.61	65.33	68.05	70.77	73.49	76.22	78.94	81.66	84.39	87.11	89.84	92.56	95.29
100	62.9	65.62	68.35	71.07	73.8	76.53	79.26	81.99	84.72	87.44	90.16	92.88	95.6







泌乳量衰減程度 vs.
溫溼度指標 Temperature-Humidity Index (THI)

$$\text{泌乳量} = f(\text{HD74}, \text{HA80S})$$

$$\text{MP} = 21.48 - 0.051 * \text{HD74} - 0.0099 * \text{HA80S}$$

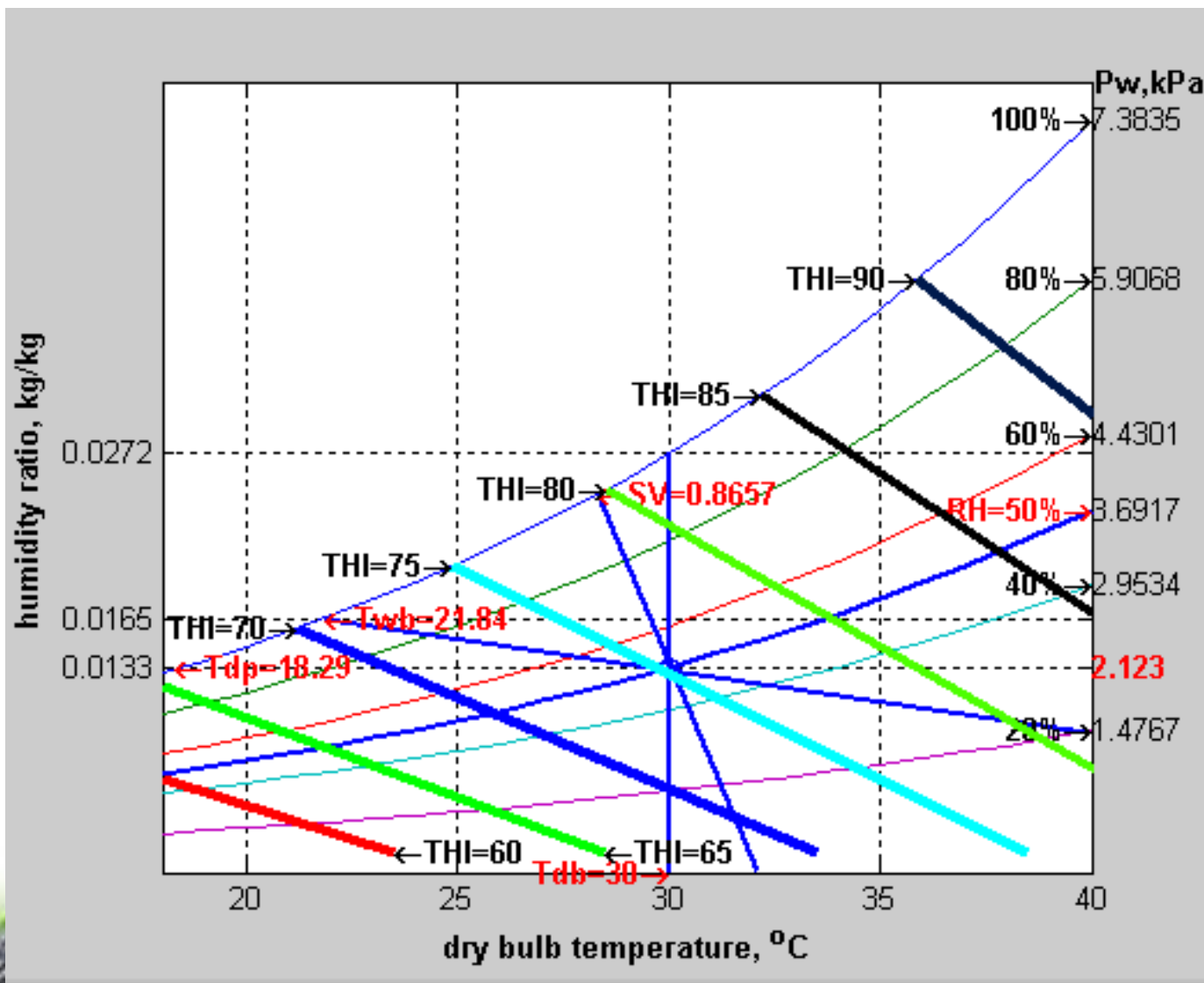
其中，

- MP: 每日每頭乳牛的泌乳量 (in kg/day/cow)
- 21.48: 正常天候下乳牛的每日泌乳量 (in kg)
- HD74: 前四天中THI > 74 的總小時數
- HA80S: 前一天中THI > 80的總小時數的平方

Linville and Pardue (1992)



在濕氣圖上繪製 溫溼度指標 (THI) 之等值線



AHD

Psytable

AHD = $f(T_{db}, RH) = \text{SaturatedAH@T}_{db} - \text{SaturatedAH@T}_{dp}$

Lower Limit Upper Limit Interval Units

Col : Tdb 16 40 2 degree C

Row : RH 35 100 5 %

Patm : 101.325 kPa

Message

AHD:
Absolute Humidity Deficit
(x0.001 kg/kg DA)

VPD VPD' Tdp1 Tdp2 THI1 THI2 AHD AHD' List Clear Quit

AHD Table

	16	18	20	22	24	26	28	30	32	34	36	38	40
35	7.402	8.455	9.636	10.96	12.444	14.106	15.964	18.042	20.365	22.961	25.863	29.108	32.738
40	6.857	7.832	8.927	10.154	11.528	13.067	14.788	16.713	18.864	21.27	23.959	26.968	30.335
45	6.308	7.206	8.213	9.342	10.606	12.021	13.603	15.373	17.351	19.563	22.037	24.806	27.906
50	5.757	6.577	7.496	8.525	9.678	10.968	12.41	14.022	15.826	17.842	20.098	22.624	25.454
55	5.203	5.944	6.774	7.704	8.744	9.908	11.208	12.663	14.289	16.108	18.143	20.422	22.978
60	4.647	5.309	6.049	6.878	7.805	8.841	10	11.294	12.741	14.36	16.172	18.202	20.48
65	4.089	4.67	5.321	6.048	6.861	7.769	8.783	9.916	11.183	12.6	14.186	15.964	17.959
70	3.528	4.029	4.589	5.214	5.912	6.691	7.56	8.53	9.615	10.827	12.185	13.708	15.417
75	2.965	3.385	3.854	4.376	4.958	5.607	6.329	7.136	8.036	9.043	10.17	11.434	12.854
80	2.4	2.739	3.116	3.534	4	4.517	5.092	5.733	6.448	7.247	8.14	9.143	10.27
85	1.832	2.09	2.374	2.689	3.037	3.422	3.849	4.323	4.851	5.439	6.097	6.834	7.664
90	1.263	1.438	1.63	1.839	2.069	2.322	2.599	2.905	3.244	3.62	4.039	4.509	5.038
95	0.692	0.784	0.882	0.987	1.098	1.216	1.343	1.48	1.628	1.79	1.968	2.167	2.392
100	0	0	0	0	0	0	0	0	0	0	0	0	0



AHD'

Psytable

AHD' = f(Tdb,RH)=SaturatedAH@Twb - SaturatedAH@Tdp

Lower Limit Upper Limit Interval Units

Col : Tdb 16 40 2 degree C

Row : RH 35 100 5 %

Patm : 101.325 kPa

Message

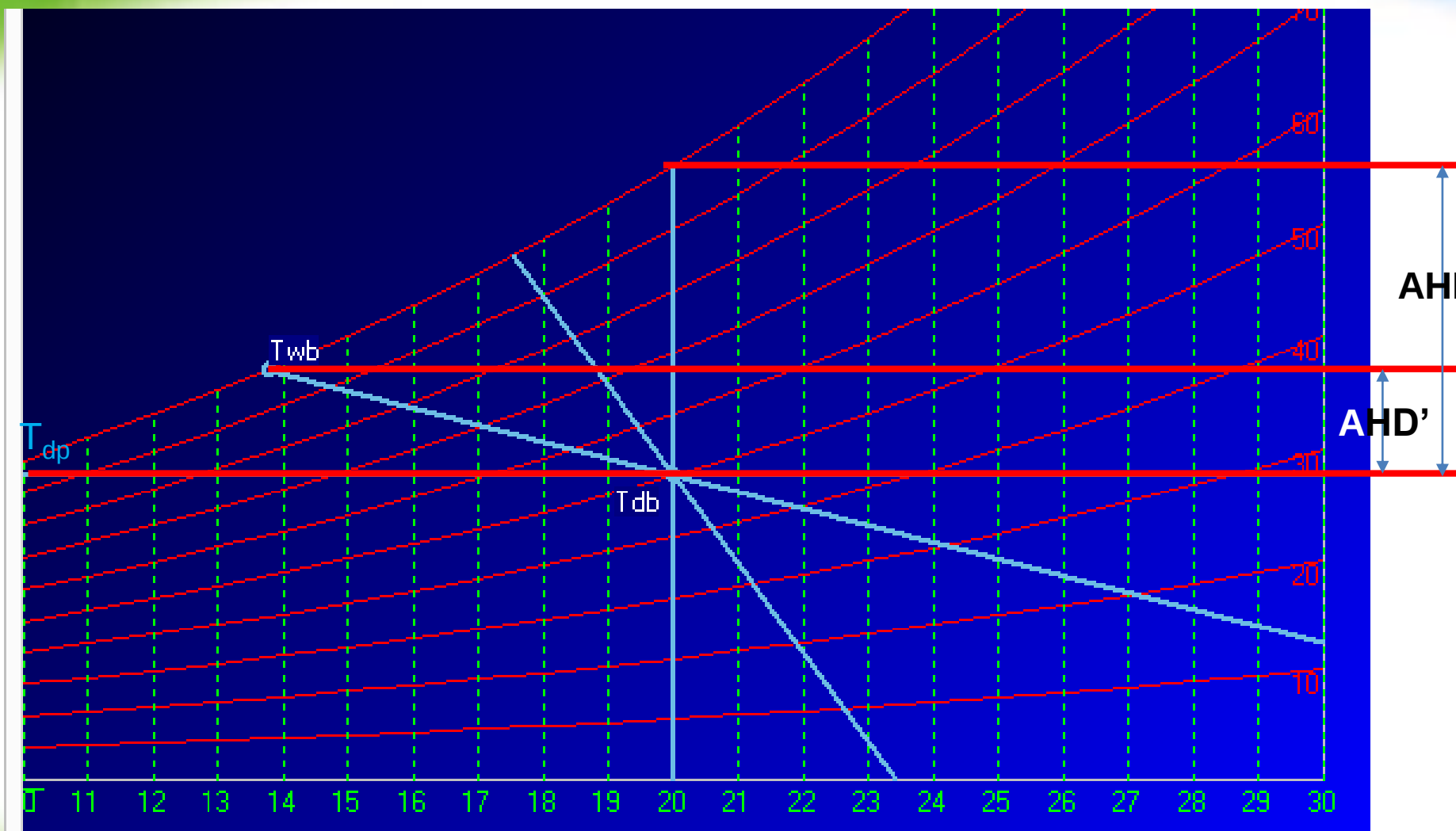
AHD':
Absolute Humidity Deficit
(x0.001 kg/kg DA)

VPD VPD' Tdp1 Tdp2 THI1 THI2 AHD AHD' List Clear Quit

AHD' Table

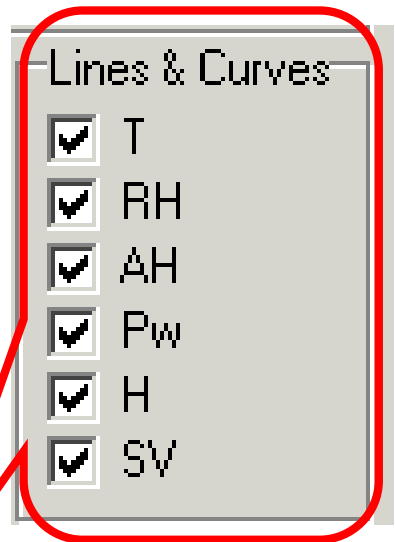
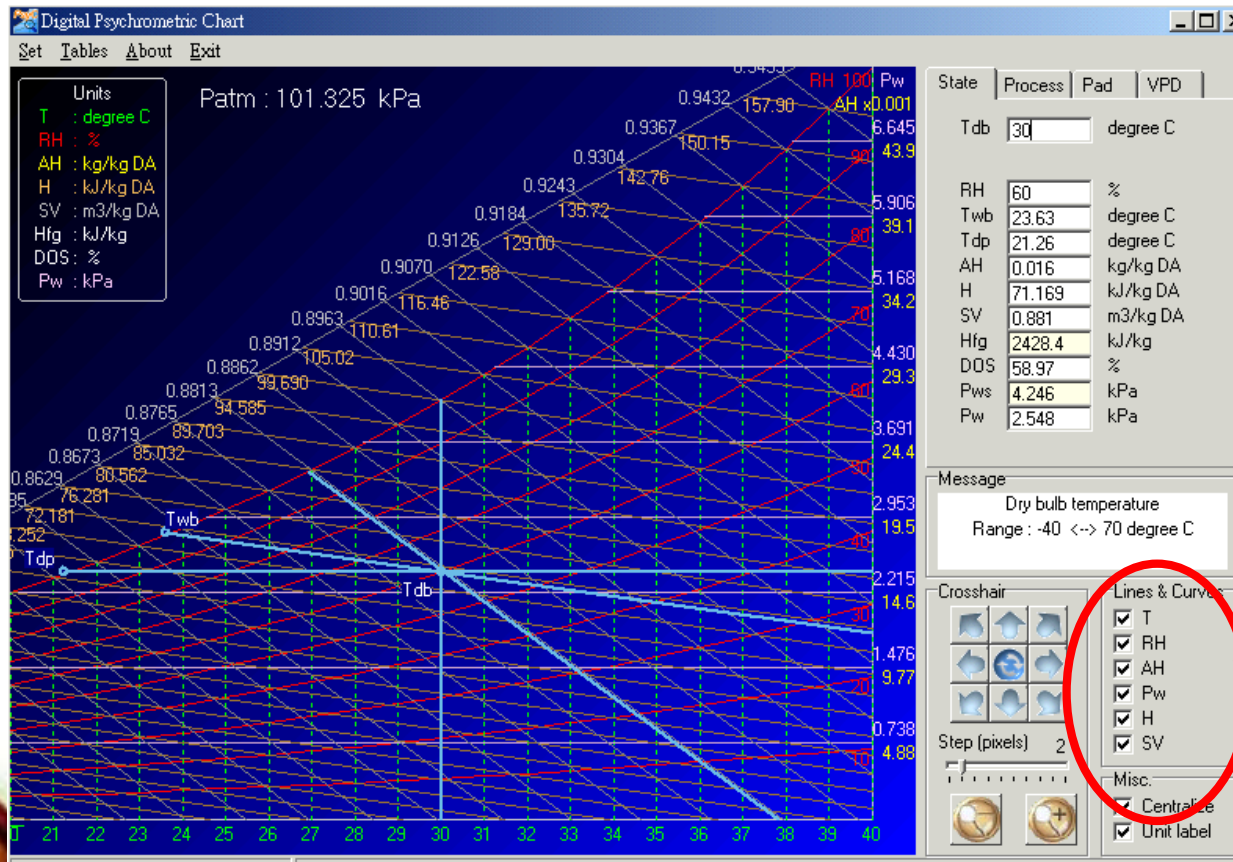
	16	18	20	22	24	26	28	30	32	34	36	38	40
35	3.011	3.234	3.457	3.681	3.904	4.126	4.347	4.566	4.783	4.998	5.212	5.423	5.631
40	2.776	2.977	3.178	3.376	3.573	3.766	3.955	4.141	4.322	4.5	4.673	4.843	5.008
45	2.544	2.724	2.902	3.077	3.246	3.411	3.571	3.724	3.872	4.014	4.15	4.281	4.406
50	2.315	2.475	2.631	2.782	2.926	3.064	3.195	3.318	3.434	3.543	3.645	3.74	3.83
55	2.09	2.23	2.365	2.493	2.613	2.726	2.829	2.924	3.011	3.089	3.16	3.223	3.282
60	1.868	1.99	2.104	2.21	2.308	2.396	2.474	2.543	2.602	2.653	2.696	2.733	2.765
65	1.65	1.753	1.849	1.934	2.01	2.076	2.131	2.176	2.211	2.237	2.256	2.27	2.281
70	1.436	1.522	1.599	1.666	1.722	1.767	1.8	1.824	1.837	1.843	1.842	1.837	1.833
75	1.226	1.296	1.356	1.404	1.442	1.468	1.483	1.487	1.482	1.47	1.454	1.436	1.422
80	1.02	1.075	1.119	1.151	1.172	1.181	1.179	1.167	1.147	1.121	1.094	1.068	1.05
85	0.819	0.859	0.888	0.906	0.911	0.906	0.889	0.864	0.832	0.797	0.763	0.734	0.719
90	0.622	0.649	0.665	0.669	0.661	0.643	0.615	0.579	0.539	0.498	0.462	0.436	0.43
95	0.43	0.445	0.449	0.441	0.422	0.393	0.355	0.312	0.267	0.225	0.192	0.176	0.186
100	0	0	0	0	0	0	0	0	0	0	0	0	0





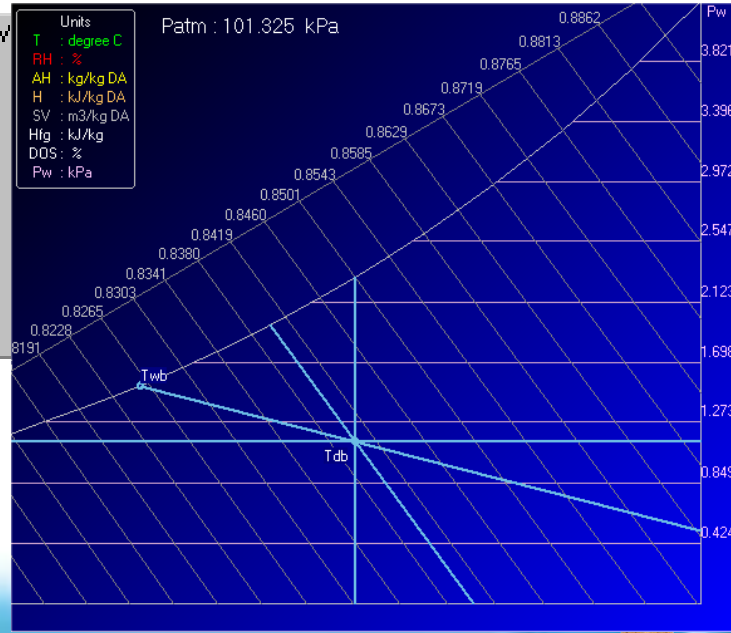
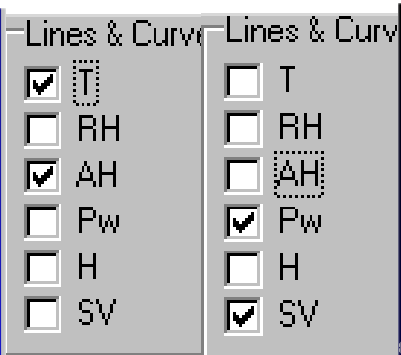
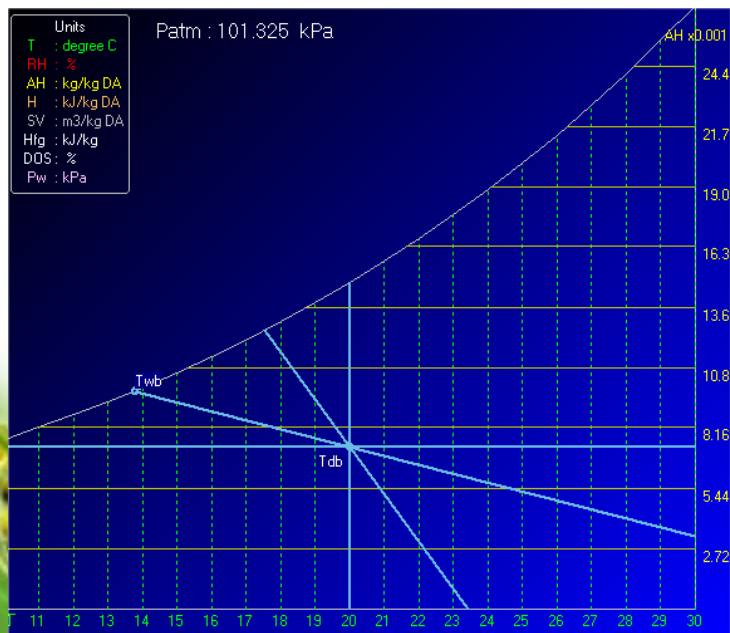
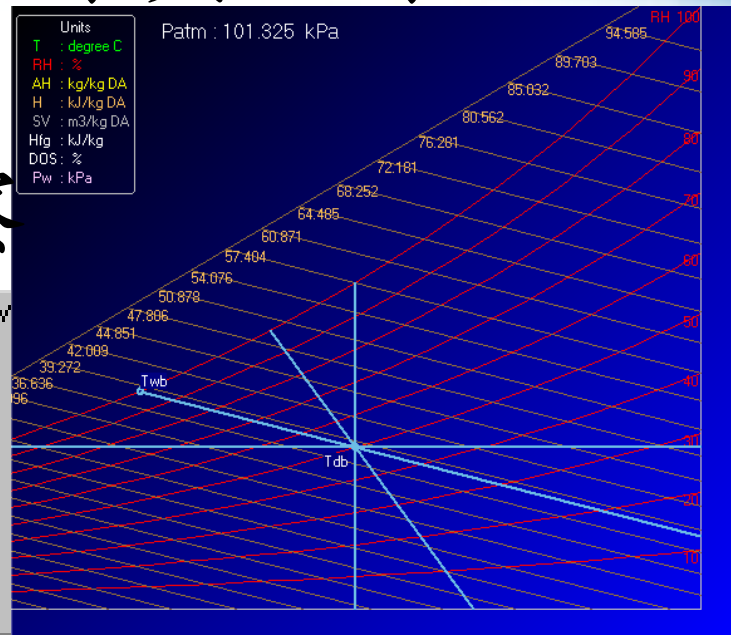
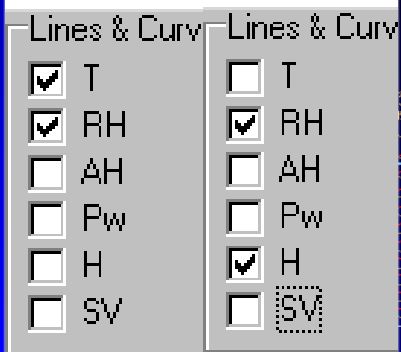
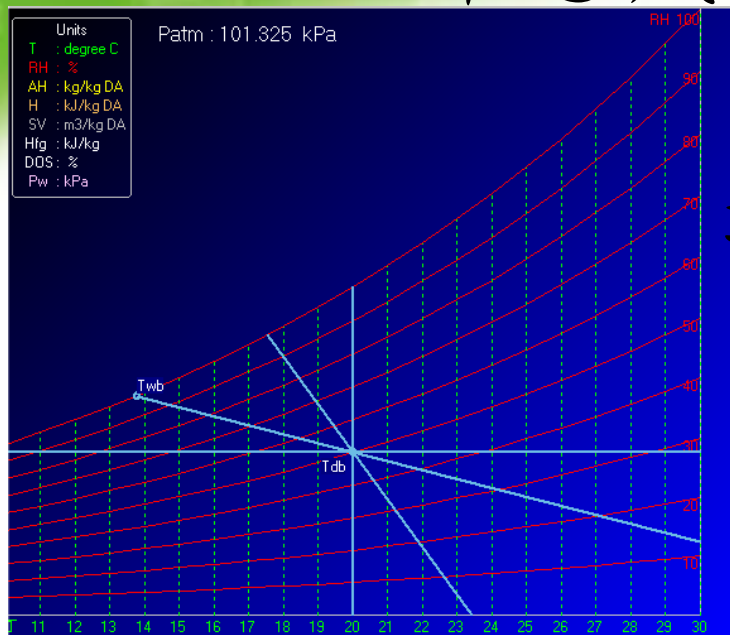
其他好用功能

取消右下角選項的點選
可隱藏該選項相關的直線或曲線



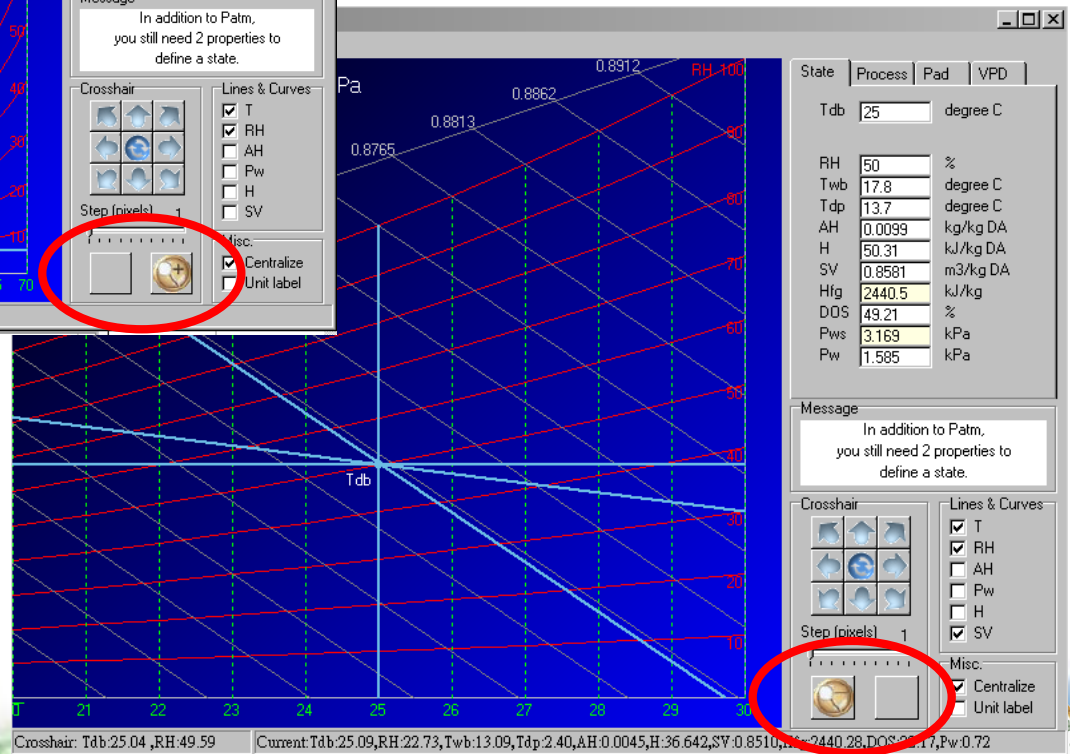
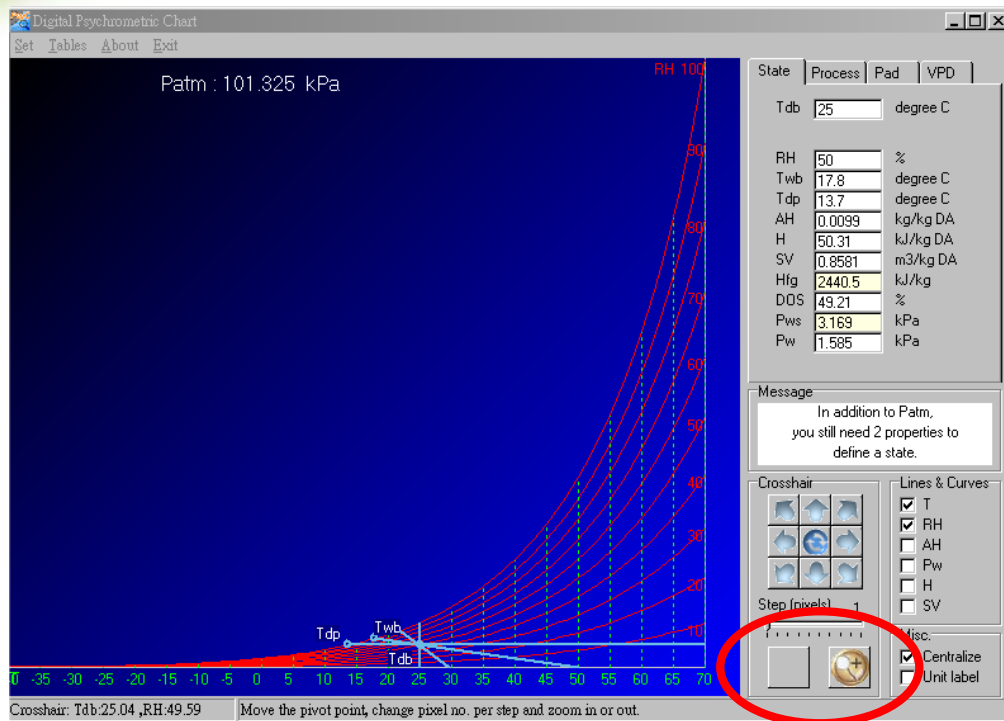
允許隱藏部分的直線與曲線

有利於
逐一觀察



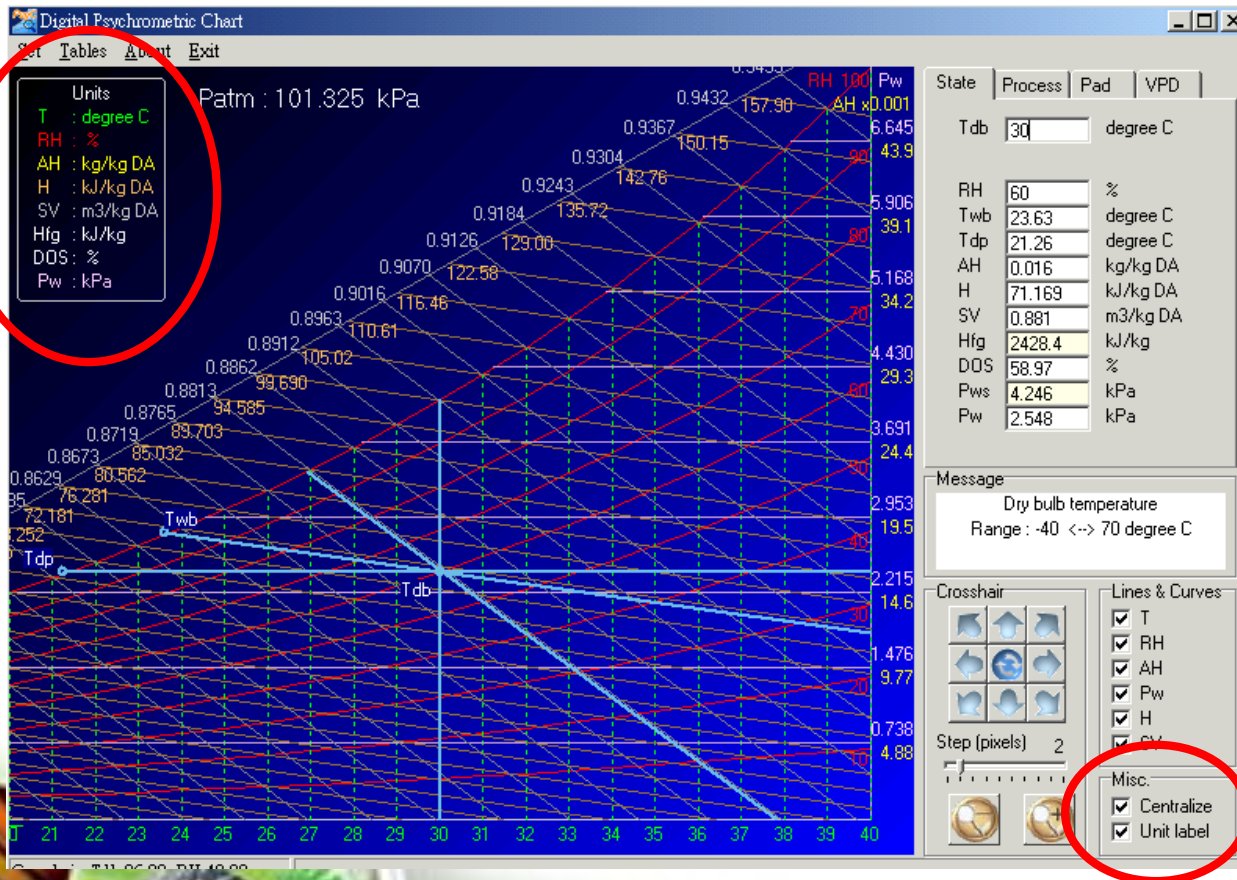
其他好用的功能

顯示範圍的
縮小與放大



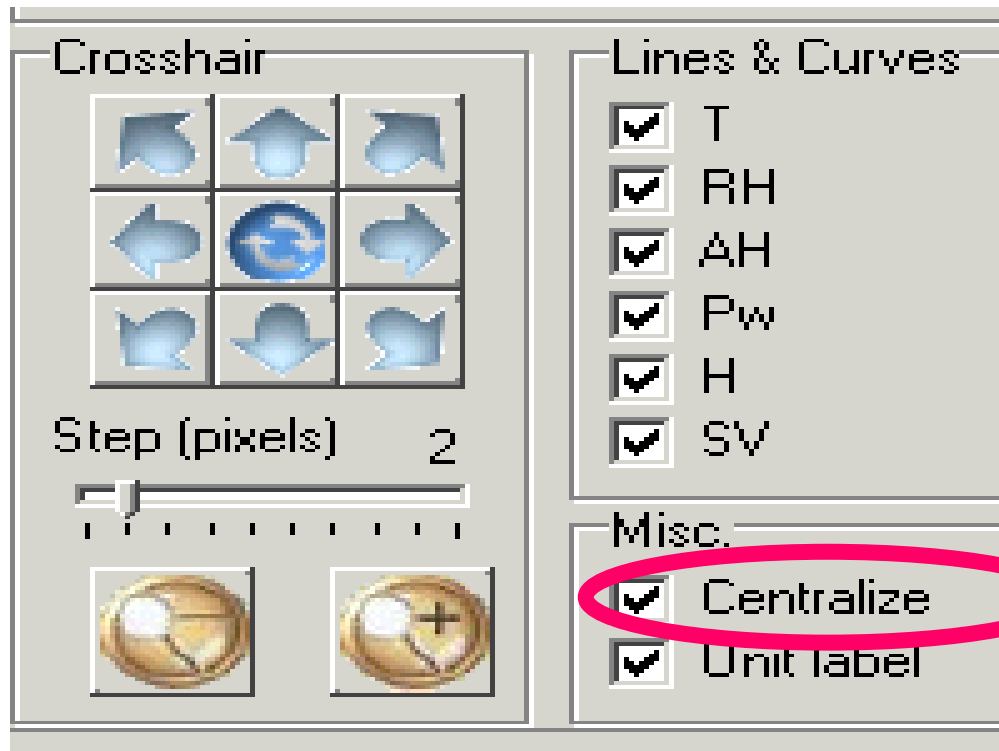
其他好用的功能

取消右下角選項的點選
可以隱藏左上角的單位方塊



其他好用的功能

點選此選項可讓每次在濕氣圖上游標或滑鼠的點選位置落於顯示範圍的中央



使用Psychart 軟體 做相關計算

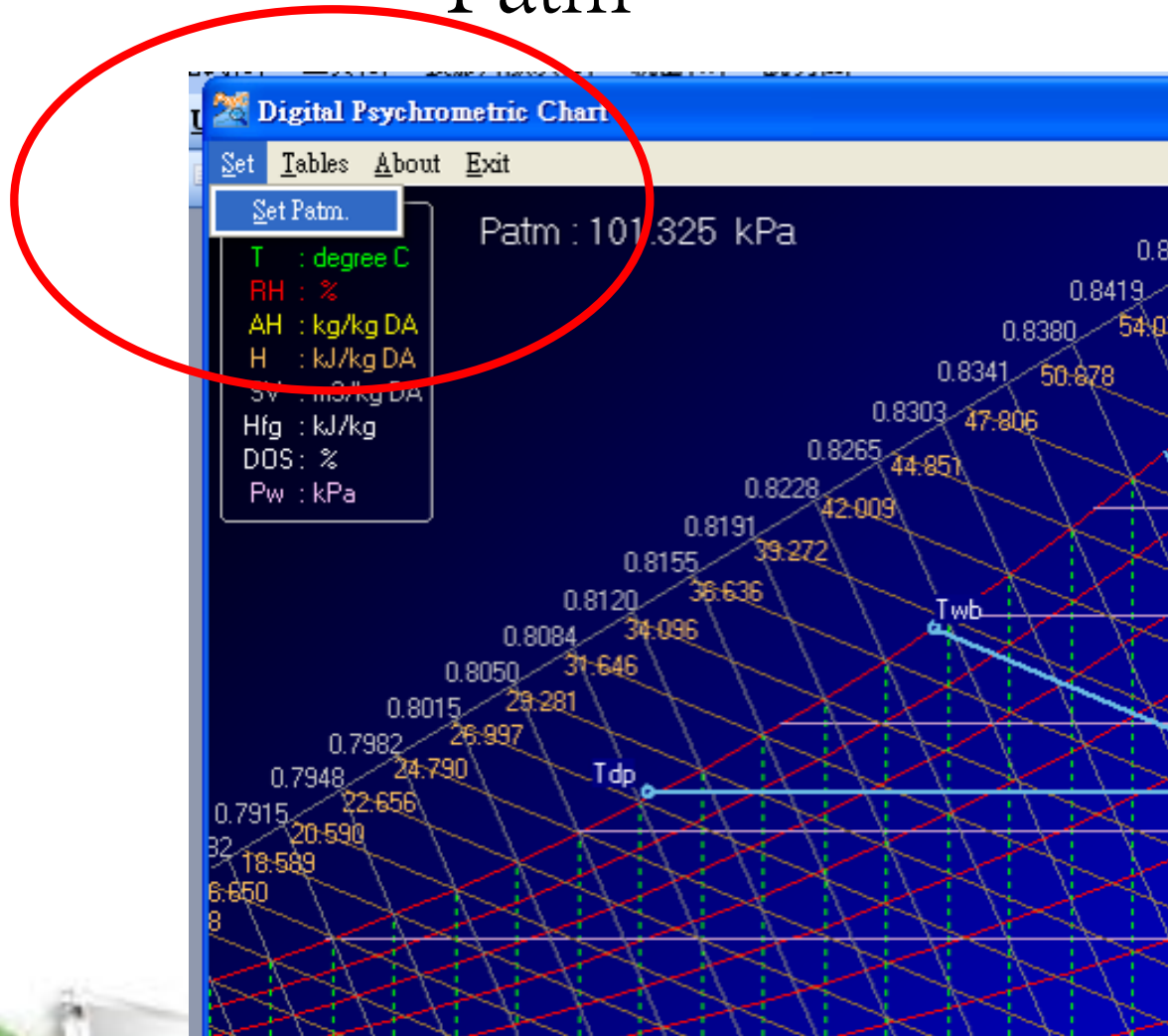


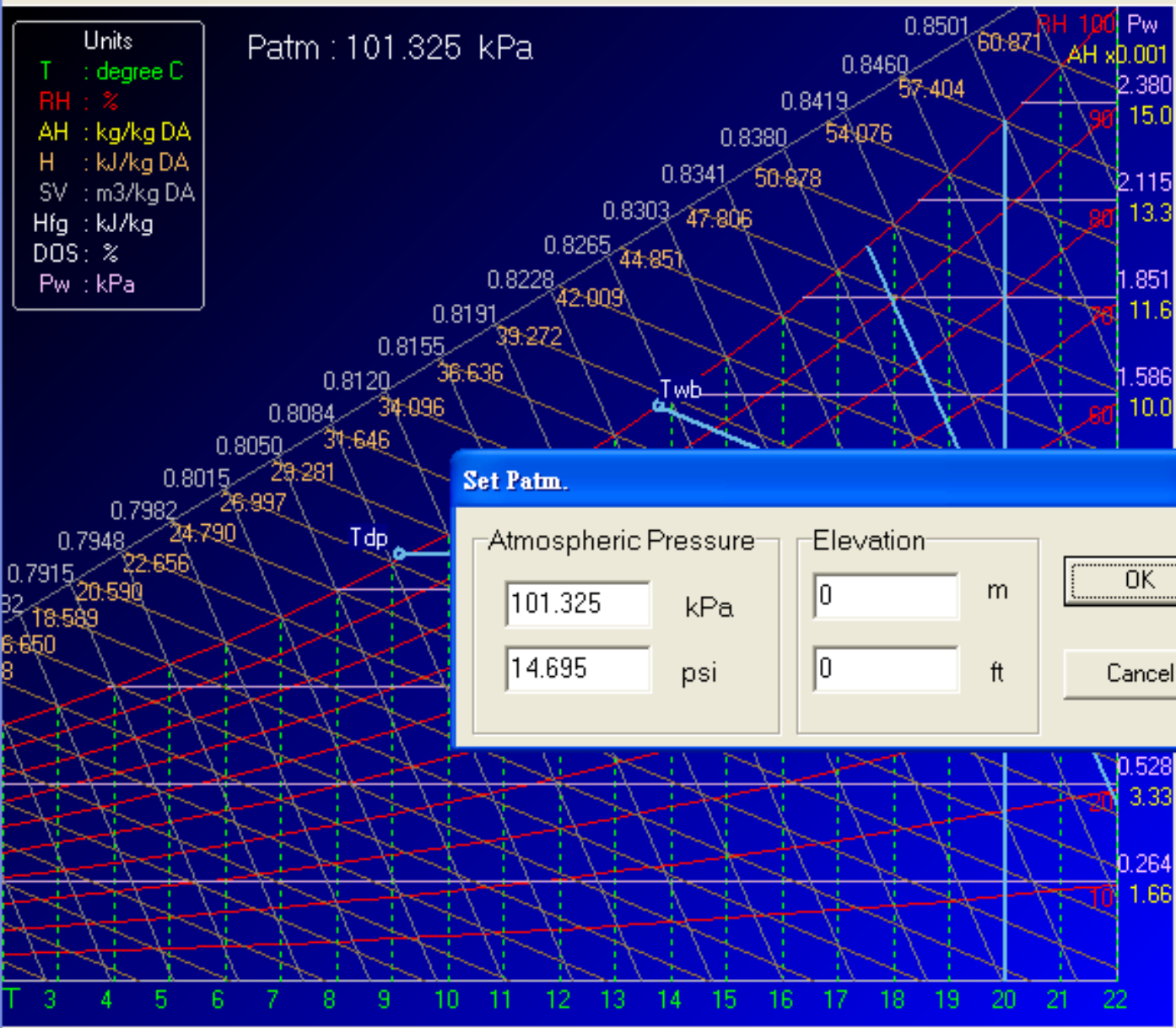
濕空氣熱力性質的計算

1. 在一大氣壓下，濕空氣的乾球溫度 (T_{db}) 為 20 度C，相對溼度 (RH) 為 50 %，請問 humidity ratio (absolute humidity, AH), degree of saturation (DOS), dew point temperature (T_{dp}), enthalpy (h), and wet bulb temperature (T_{wb}) 各為何？



Set the atmospheric pressure P_{atm}





- Units
- T : degree C
 - RH : %
 - AH : kg/kg DA
 - H : kJ/kg DA
 - SV : m3/kg DA
 - Hfg : kJ/kg
 - DOS : %
 - Pw : kPa

Patm : 101.325 kPa

State	Process	Pad	VPD
Tdb	20	degree C	
RH	50	%	
Twb	13.79	degree C	
Tdp	9.15	degree C	
AH	0.0073	kg/kg DA	
H	38.545	kJ/kg DA	
SV	0.8402	m3/kg DA	
Hfg	2452.6	kJ/kg	
DOS	49.42	%	
Pws	2.339	kPa	
Pw	1.169	kPa	

Set Patm.

Atmospheric Pressure		Elevation	
101.325	kPa	0	m
14.695	psi	0	ft

OK Cancel

In addition to Patm, you still need 2 properties to define a state.

Step (pixels) 2

Lines & Curves

- ☒ T
- ☒ RH
- ☒ AH
- ☒ Pw
- ☒ H
- ☒ SV

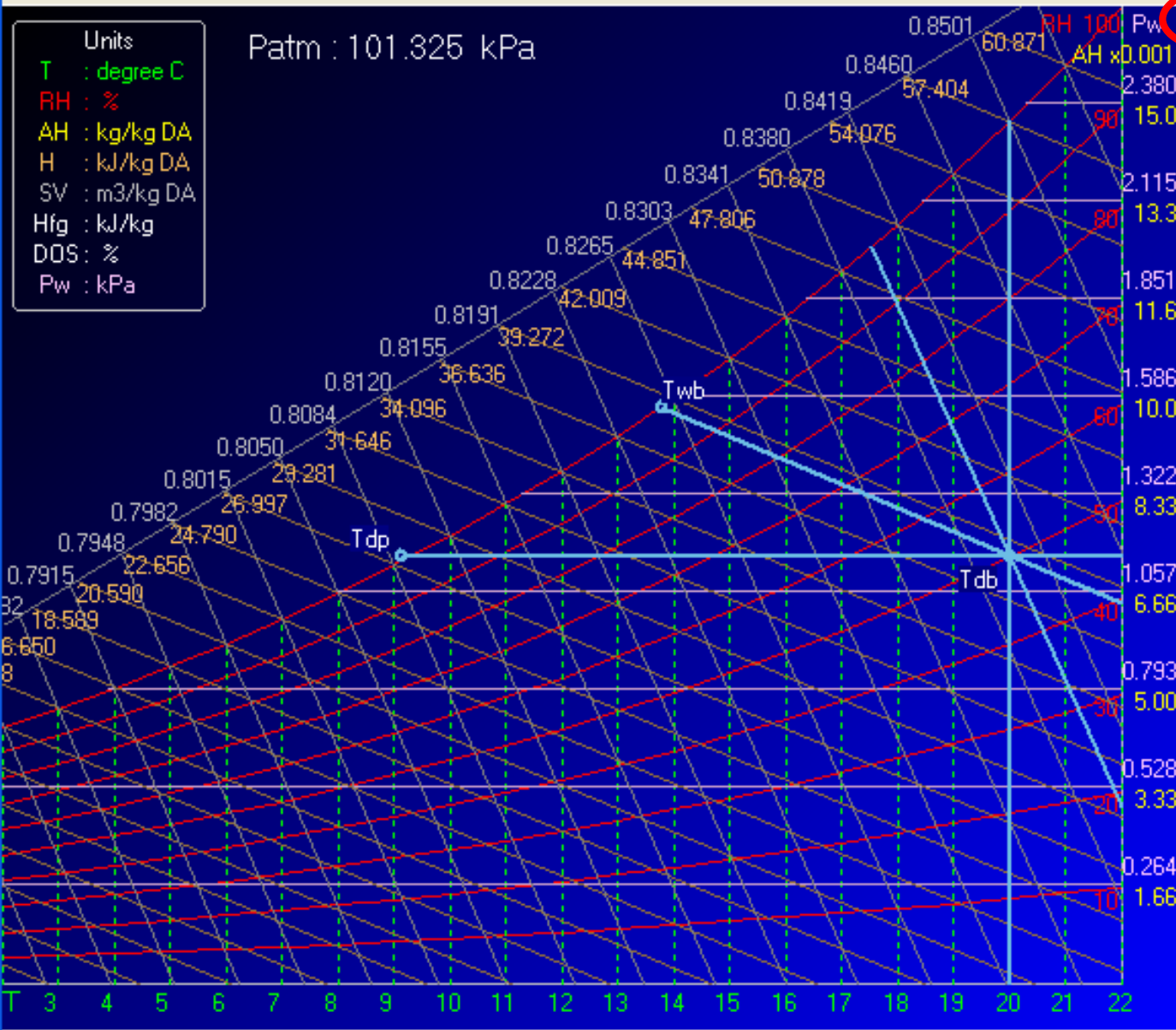
Misc.

- ☐ Centralize
- ☒ Unit label



Digital Psychrometric Chart

Set Tables About Exit



Crosshair: Tdb:29.87 ,RH:51.80

State Process Pad VPD

Tdb	20	degree C
RH	50	%
Twb	13.79	degree C
Tdp	9.15	degree C
AH	0.0073	kg/kg DA
H	38.545	kJ/kg DA
SV	0.8402	m3/kg DA
Hfg	2452.6	kJ/kg
DOS	49.42	%
Pws	2.339	kPa
Pw	1.169	kPa

Message
In addition to Patm,
you still need 2 properties to
define a state.

Crosshair	Lines & Curves
	☒ T ☒ RH ☒ AH ☒ Pw ☒ H ☒ SV
Step (pixels) 2	Misc.
	☐ Centralize ☒ Unit label



濕空氣熱力性質的計算

2. 續上題，濕球降 wet bulb depression (WBD) 與蒸汽壓差 vapor pressure deficit (VPD) 各為何？





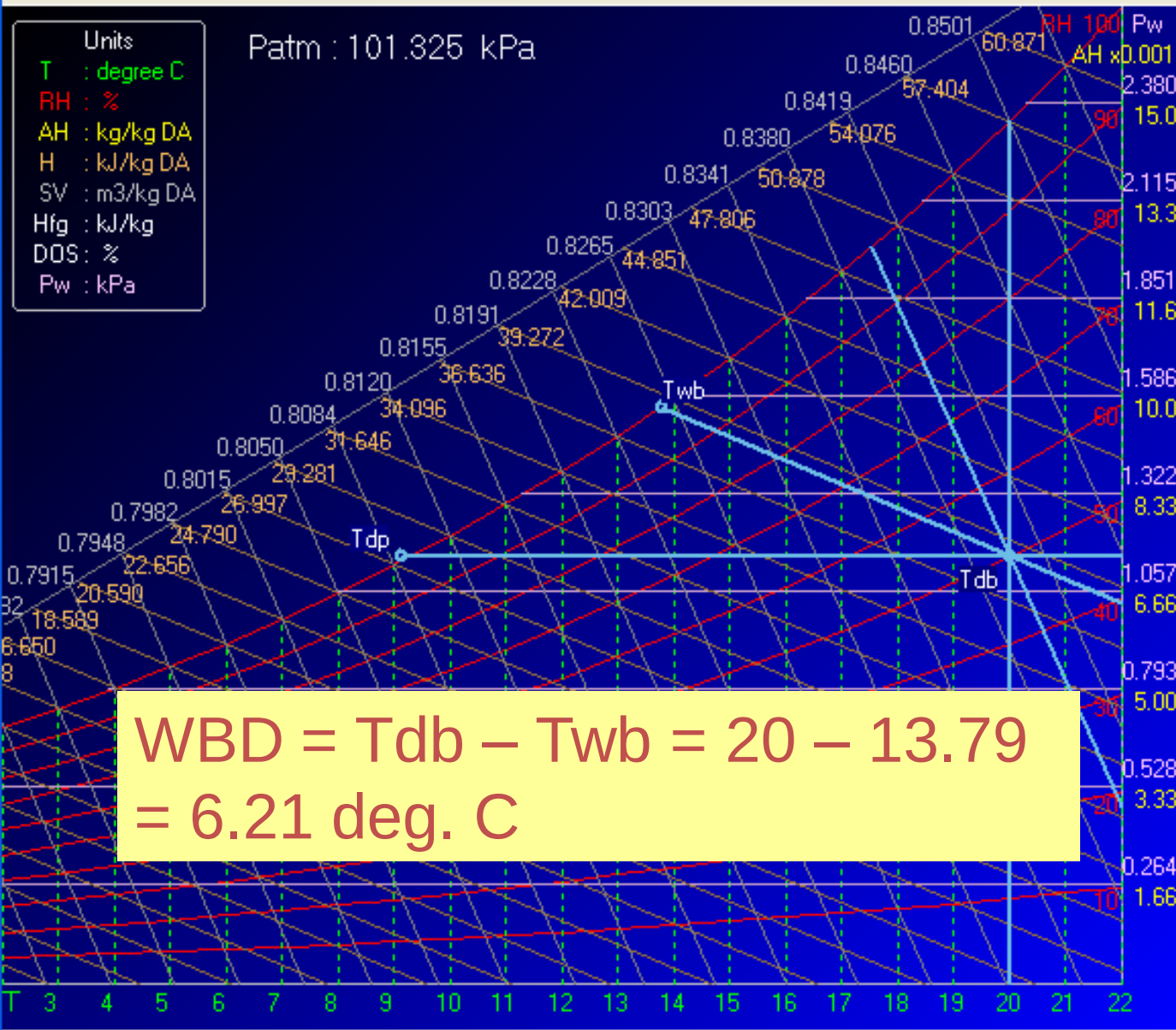
Digital Psychrometric Chart



Set Tables About Exit

- Units
- T : degree C
 - RH : %
 - AH : kg/kg DA
 - H : kJ/kg DA
 - SV : m3/kg DA
 - Hfg : kJ/kg
 - DOS : %
 - Pw : kPa

Patm : 101.325 kPa



State	Process	Pad	VPD
Tdb	20	degree C	
RH	50	%	
Twb	13.79	degree C	
Tdp	9.15	degree C	
AH	0.0073	kg/kg DA	
H	38.545	kJ/kg DA	
SV	0.8402	m3/kg DA	
Hfg	2452.6	kJ/kg	
DOS	49.42	%	
Pws	2.339	kPa	
Pw	1.169	kPa	

Message

In addition to Patm, you still need 2 properties to define a state.

Crosshair

Lines & Curves

- ☒ T
- ☒ RH
- ☒ AH
- ☒ Pw
- ☒ H
- ☒ SV

Misc.

- ☐ Centralize
- ☒ Unit label

$$\begin{aligned} \text{WBD} &= T_{db} - T_{wb} = 20 - 13.79 \\ &= 6.21 \text{ deg. C} \end{aligned}$$

Crosshair: Tdb:29.87 ,RH:51.80

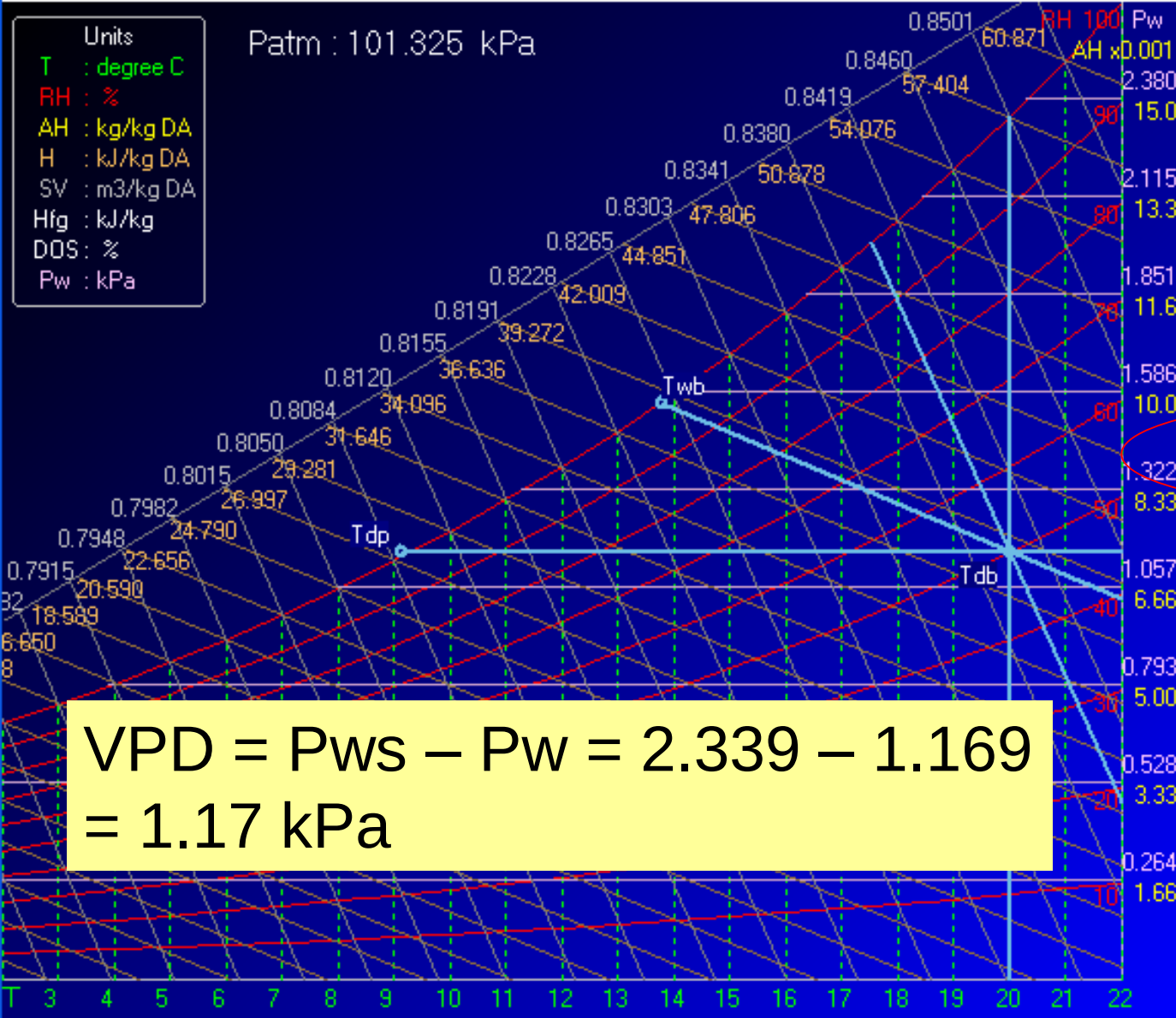


Digital Psychrometric Chart

Set Tables About Exit

- Units
- T : degree C
 - RH : %
 - AH : kg/kg DA
 - H : kJ/kg DA
 - SV : m3/kg DA
 - Hfg : kJ/kg
 - DOS : %
 - Pw : kPa

Patm : 101.325 kPa



State	Process	Pad	VPD
Tdb	20	degree C	
RH	50	%	
Twb	13.79	degree C	
Tdp	9.15	degree C	
AH	0.0073	kg/kg DA	
H	38.545	kJ/kg DA	
SV	0.8402	m3/kg DA	
Hfg	2452.6	kJ/kg	
DOS	49.42	%	
Pws	2.339	kPa	
Pw	1.169	kPa	

Message

In addition to Patm, you still need 2 properties to define a state.

Crosshair

Lines & Curves

- ☒ T
- ☒ RH
- ☒ AH
- ☒ Pw
- ☒ H
- ☒ SV

Misc.

- ☐ Centralize
- ☒ Unit label

Crosshair: Tdb:29.87, RH:51.80

濕空氣熱力性質的計算

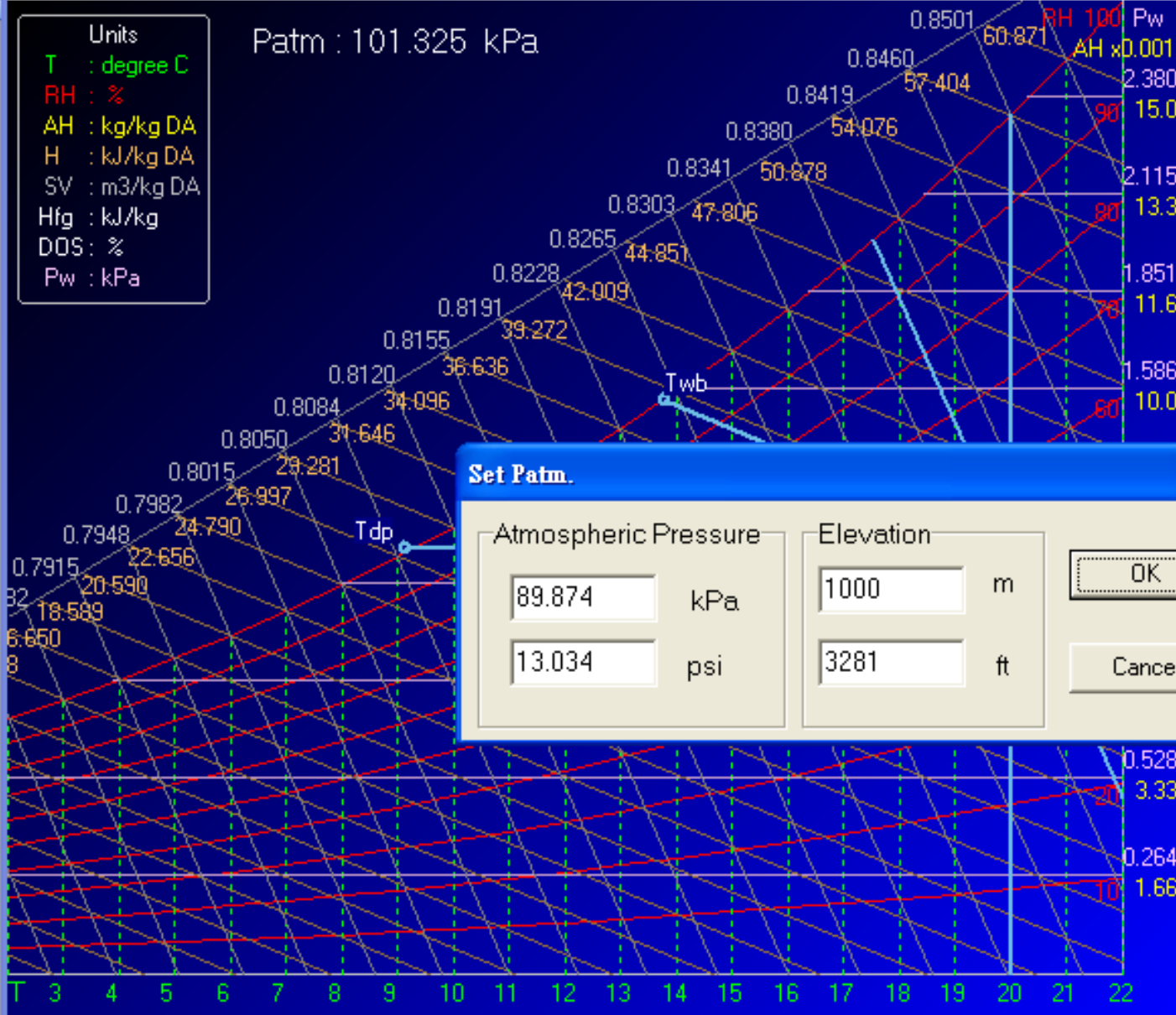
3. 完成下表

	#1	#2	#3	#4
Atmospheric pressure, kPa	101.325	101.325	101.325	89.874
Dry-bulb T, deg.C	20	20	-10	20
Relative humidity, %	50	80	50	50
Humidity ratio, kg/kg				
Dew point T, deg.C				
Wet bulb T, deg.C				
Specific volume, m ³ /kg				



- Units
- T : degree C
 - RH : %
 - AH : kg/kg DA
 - H : kJ/kg DA
 - SV : m3/kg DA
 - Hfg : kJ/kg
 - DOS : %
 - Pw : kPa

Patm : 101.325 kPa



State	Process	Pad	VPD
Tdb	20	degree C	
RH	50	%	
Twb	13.79	degree C	
Tdp	9.15	degree C	
AH	0.0073	kg/kg DA	
H	38.545	kJ/kg DA	
SV	0.8402	m3/kg DA	
Hfg	2452.6	kJ/kg	
DOS	49.42	%	
Pws	2.339	kPa	
Pw	1.169	kPa	

Set Patm.

Atmospheric Pressure		Elevation	
89.874	kPa	1000	m
13.034	psi	3281	ft

OK Cancel

In addition to Patm, you still need 2 properties to define a state.

Step (pixels) 2

Lines & Curves

- ☒ T
- ☒ RH
- ☒ AH
- ☒ Pw
- ☒ H
- ☒ SV

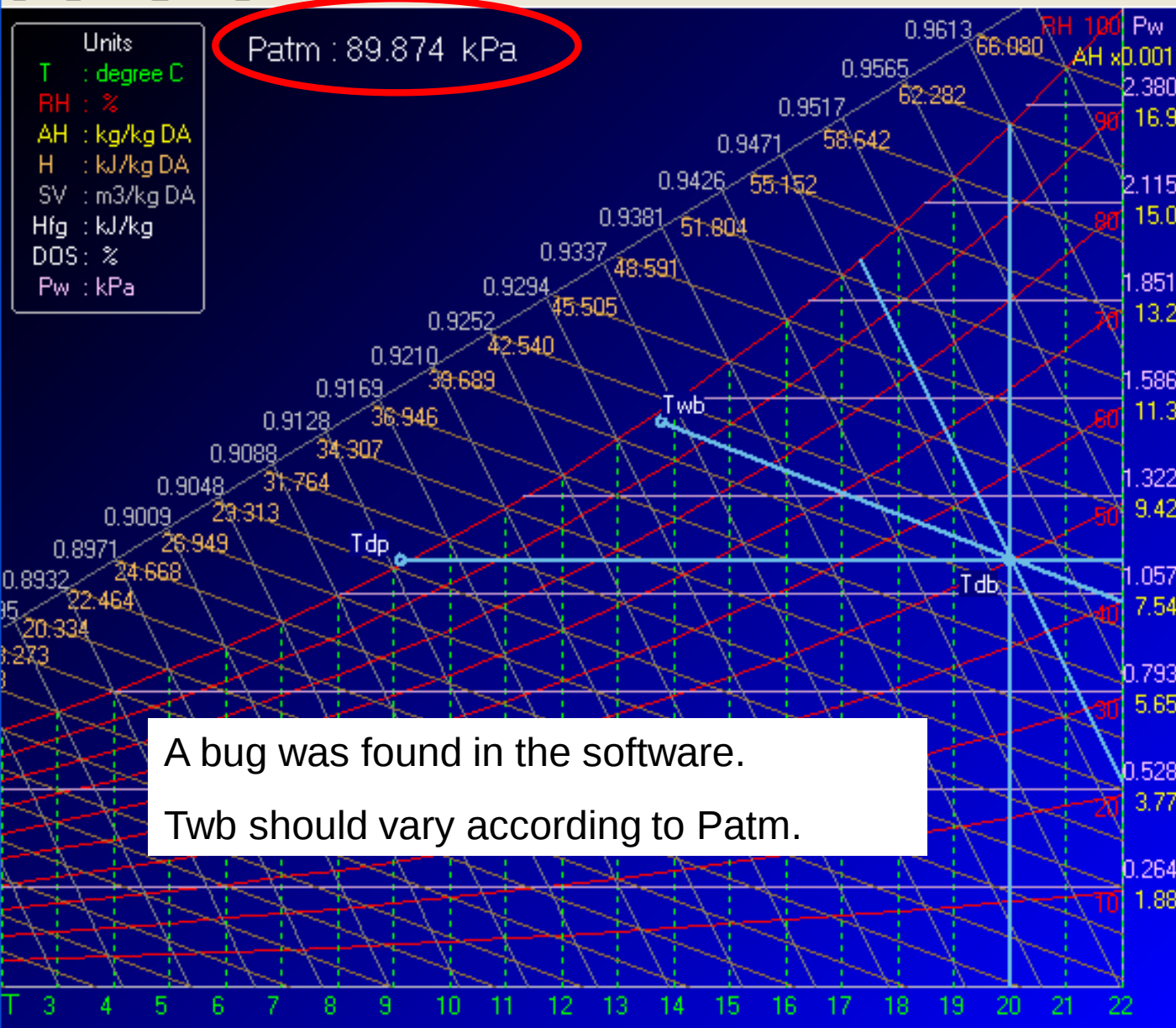
Misc.

- ☐ Centralize
- ☒ Unit label

Units

T : degree C
 RH : %
 AH : kg/kg DA
 H : kJ/kg DA
 SV : m3/kg DA
 Hfg : kJ/kg
 DOS : %
 Pw : kPa

Patm : 89.874 kPa



State Process Pad VPD

Tdb 20 degree C

RH 50 %

Twb 13.79 degree C

Tdp 9.15 degree C

AH 0.0082 kg/kg DA

H 40.923 kJ/kg DA

SV 0.9487 m3/kg DA

Hfg 2452.6 kJ/kg

DOS 49.34 %

Pws 2.339 kPa

Pw 1.169 kPa

Message

Enthalpy

Range : 20.120 <--> 62.282 kJ/kg
 Based on current Tdb.

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☒ AH
☒ Pw
☒ H
☒ SV

Misc.

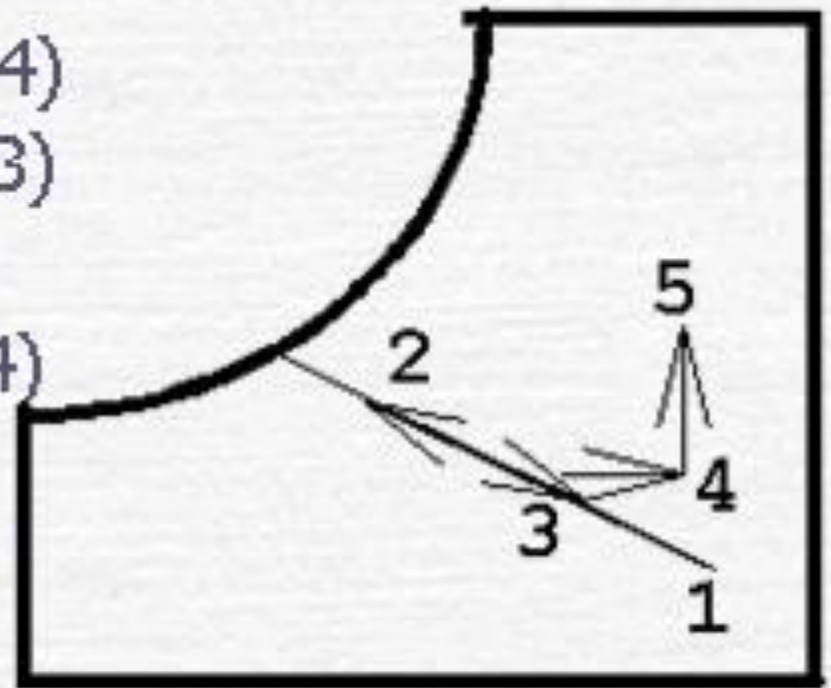
☐ Centralize
☒ Unit label

A bug was found in the software.

Twb should vary according to Patm.

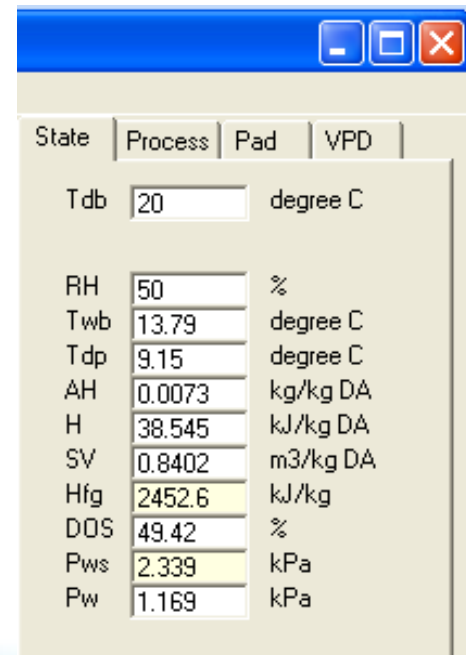
由一個狀態 (state) 到另一個狀態稱為過程 (process)

- ✓ Sensible Heating (3->4)
- ✓ Sensible Cooling (4->3)
- ✓ Humidification (4->5)
- ✓ Dehumidification (5->4)
- ✓ Heating (3->5, 3->1)
- ✓ Cooling (5->3, 1->3)
- ✓ Air Mixing (1, 2->3)
- ✓ Evaporative Cooling , Drying (1->2, 1->3)
- ✓ Combination of above (1->2->3->4->5)



濕空氣熱力性質的變化過程

4. Determine the final state of moist air originally at 20 deg.C and 50 % relative humidity if **10 kJ** are removed from 1.2 kg of the air.



A screenshot of a psychrometric chart software window. The window has a blue title bar with standard Windows controls. Below the title bar is a tabbed interface with four tabs: 'State', 'Process', 'Pad', and 'VPD'. The 'State' tab is selected. The main area displays various air properties in a two-column list. The first column contains the property name, and the second column contains the value and unit. The values are: Tdb (20 degree C), RH (50 %), Twb (13.79 degree C), Tdp (9.15 degree C), AH (0.0073 kg/kg DA), H (38.545 kJ/kg DA), SV (0.8402 m3/kg DA), Hfg (2452.6 kJ/kg), DOS (49.42 %), Pws (2.339 kPa), and Pw (1.169 kPa). The values for Hfg, DOS, Pws, and Pw are highlighted in yellow.

State	Process	Pad	VPD
Tdb	20		degree C
RH	50		%
Twb	13.79		degree C
Tdp	9.15		degree C
AH	0.0073		kg/kg DA
H	38.545		kJ/kg DA
SV	0.8402		m3/kg DA
Hfg	2452.6		kJ/kg
DOS	49.42		%
Pws	2.339		kPa
Pw	1.169		kPa



問題 4 的解答

- $\Delta T = q/(Ma \cdot C_p) = (-10 \text{ kJ})/(1.2 \text{ kg} \cdot 1.006 \text{ kJ/kg.K}) = -8.28 \text{ K}$
- The final dry bulb T will be $20 - 8.28 = 11.72 \text{ deg.C}$ if this is a sensible heating process.
- The dew point T of moist air at initial state = 9.15 deg.C
- The final dry bulb T > the dew point T of initial state, this is a **sensible cooling process**.
- $\Delta h = q/Ma = (-10 \text{ kJ})/(1.2 \text{ kg}) = -8.333 \text{ kJ/kg}$
- The initial $h = 38.5 \text{ kJ/kg}$
- The final $h = 38.545 - 8.333 = 30.212 \text{ kJ/kg}$
- The initial dew point T = final dew point T.
- Final state can be found based on final Tdb and Tdp, or Tdb and h, or Tdp and h





Digital Psychrometric Chart



Set Tables About Exit

Units

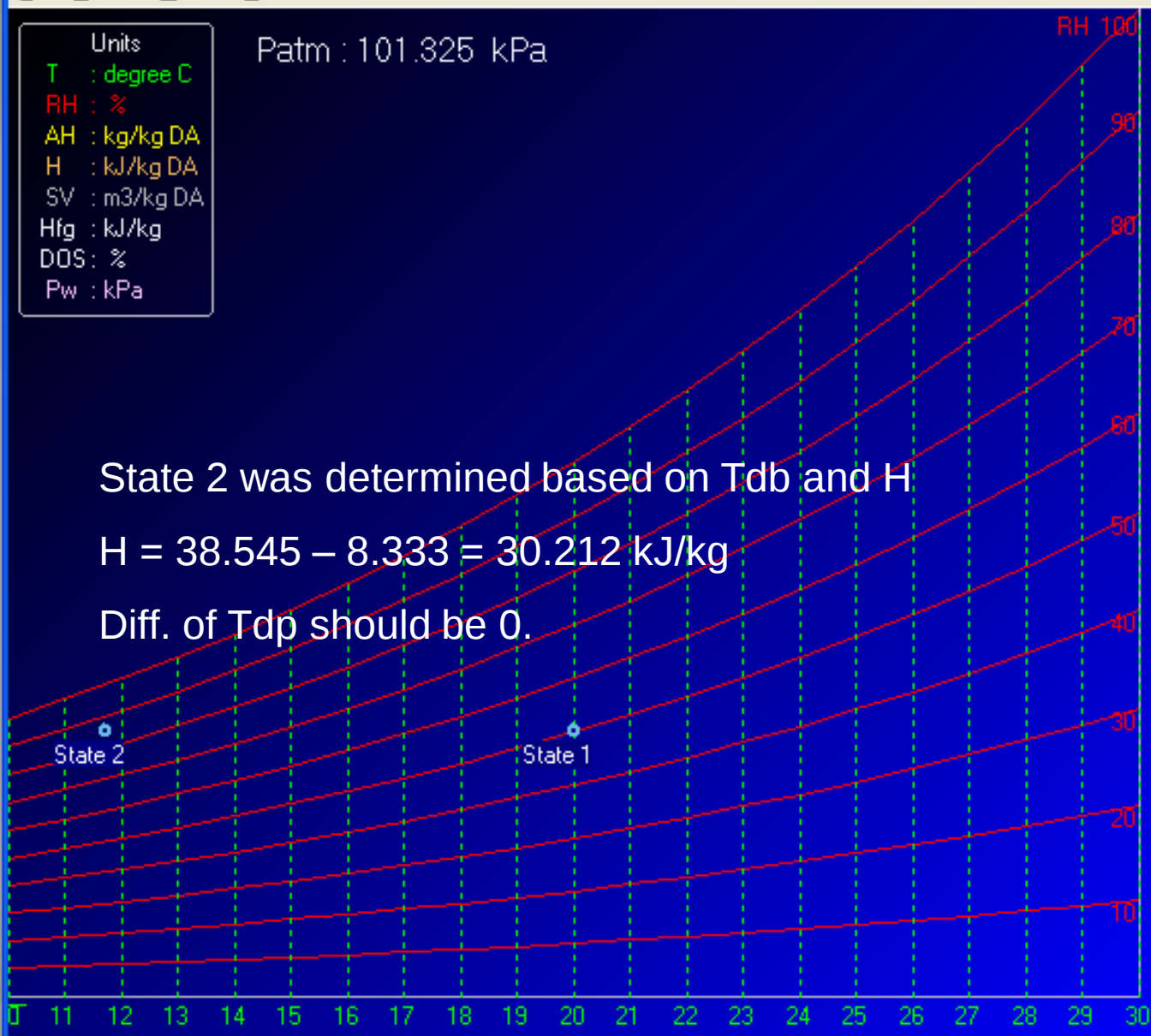
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa

State 2 was determined based on Tdb and H

$$H = 38.545 - 8.333 = 30.212 \text{ kJ/kg}$$

Diff. of Tdp should be 0.



State	Process	Pad	VPD
State 1 State 2 Diff.			
Tdb	20	11.72	-8.28
RH	50	85.41	35.41
Twb	13.79	10.57	-3.22
Tdp	9.15	9.23	0.08
AH	0.0073	0.0073	0
H	38.54	30.212	-8.333
SV	0.8402	0.8165	-0.0237
Hfg	2452.6	2472.64	20.04
DOS	49.42	85.24	35.82
Pws	2.339	1.377	-0.962
Pw	1.169	1.176	0.01

Inactive Active ☐

Message

Diff. =
Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

- ☒ T
- ☒ RH
- ☐ AH
- ☐ Pw
- ☐ H
- ☐ SV

Misc.

- ☐ Centralize
- ☒ Unit label



Set Tables About Exit

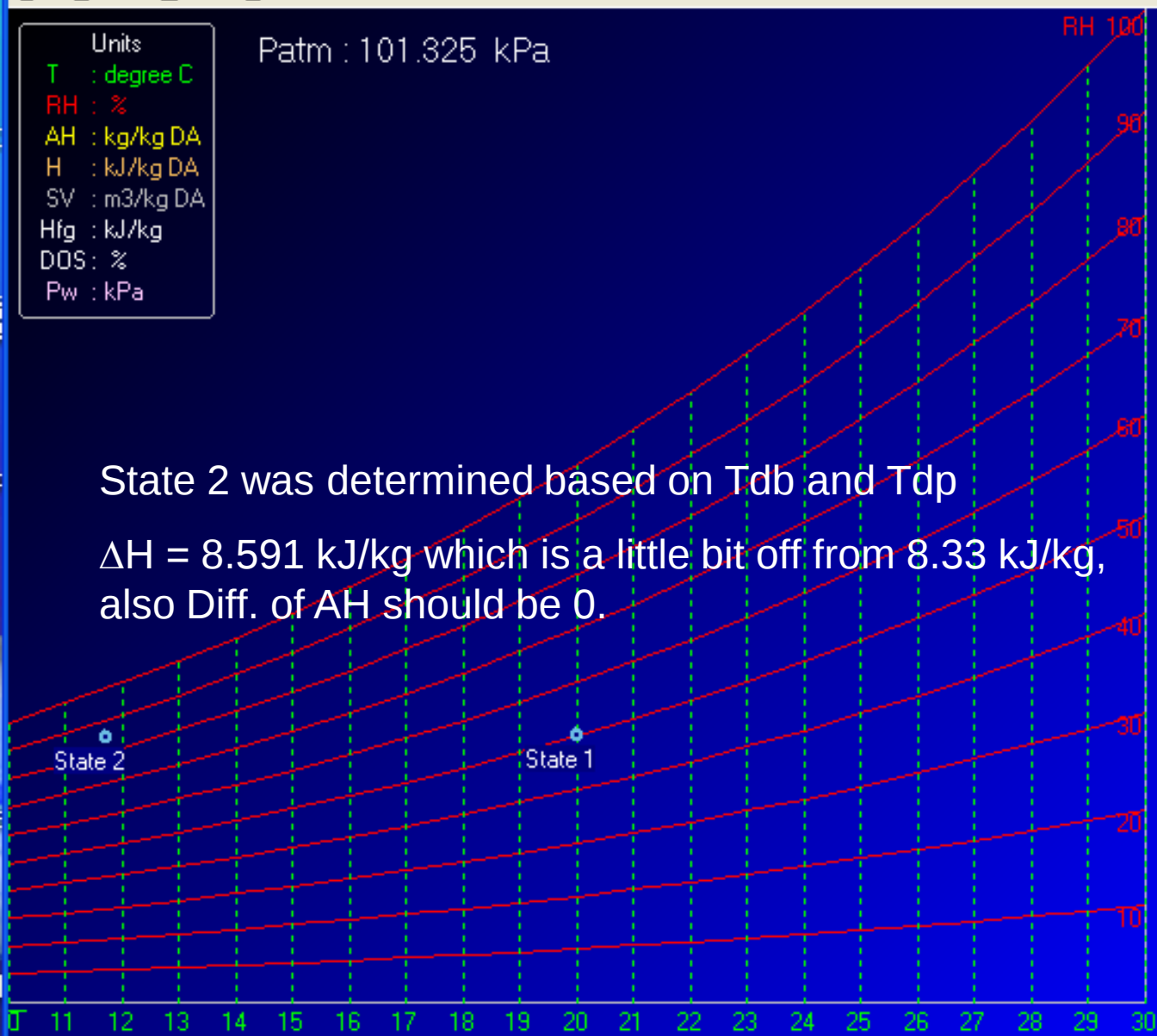
Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m³/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa

State 2 was determined based on Tdb and Tdp

$\Delta H = 8.591$ kJ/kg which is a little bit off from 8.33 kJ/kg,
also Diff. of AH should be 0.



State	Process	Pad	VPD
State 1 State 2 Diff.			
Tdb	20	11.72	-8.28
RH	50	84.23	34.23
Twb	13.79	10.52	-3.27
Tdp	9.15	9.15	0
AH	0.0073	0.0072	-0.0001
H	38.545	29.954	-8.591
SV	0.8402	0.8164	-0.0238
Hfg	2452.6	2472.64	20.04
DOS	49.42	84.05	34.63
Pws	2.339	1.377	-0.962
Pw	1.169	1.16	-0.01

Inactive Active ☐

Message

Diff. =
Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

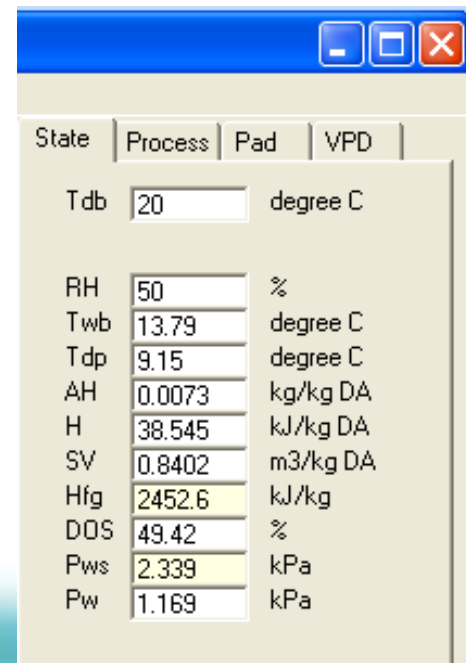
☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

濕空氣熱力性質的變化過程

5. Determine the final state of moist air originally at 20 deg.C and 50 % relative humidity if **20 kJ** are removed from 1.2 kg of the air.



The screenshot shows a software window with a blue title bar and standard Windows window controls. It contains a tabbed interface with 'State', 'Process', 'Pad', and 'VPD' tabs. The 'State' tab is active, displaying a list of psychrometric properties for moist air. The input values are 20 degree C for dry-bulb temperature (Tdb) and 50% for relative humidity (RH). The software has calculated various other properties, including wet-bulb temperature (Twb), dew-point temperature (Tdp), humidity ratio (AH), enthalpy (H), specific volume (SV), latent heat of vaporization (Hfg), density of saturated vapor (DOS), partial pressure of water vapor (Pws), and total pressure (Pw).

Property	Value	Unit
Tdb	20	degree C
RH	50	%
Twb	13.79	degree C
Tdp	9.15	degree C
AH	0.0073	kg/kg DA
H	38.545	kJ/kg DA
SV	0.8402	m3/kg DA
Hfg	2452.6	kJ/kg
DOS	49.42	%
Pws	2.339	kPa
Pw	1.169	kPa

問題 5 的解答

- $\Delta T = q/(Ma \cdot C_p) = (-20 \text{ kJ}) / (1.2 \text{ kg} \cdot 1.006 \text{ kJ/kg} \cdot \text{K}) = -16.56 \text{ K}$
- The final T will be $20 - 16.56 = 3.44 \text{ deg.C}$ if this is a sensible heating process.
- The dew point T of moist air at initial state = 9.1 deg.C
- The final dry bulb T < dew point at initial state, this is a **cooling with condensation/dehumidification** process.
- The final relative humidity is 100 %.

- $\Delta h = q/Ma = (-20 \text{ kJ}) / (1.2 \text{ kg}) = -16.66 \text{ kJ/kg}$
- The initial h = 38.545 kJ/kg
- The final h = $38.545 - 16.66 = 21.885 \text{ kJ/kg}$

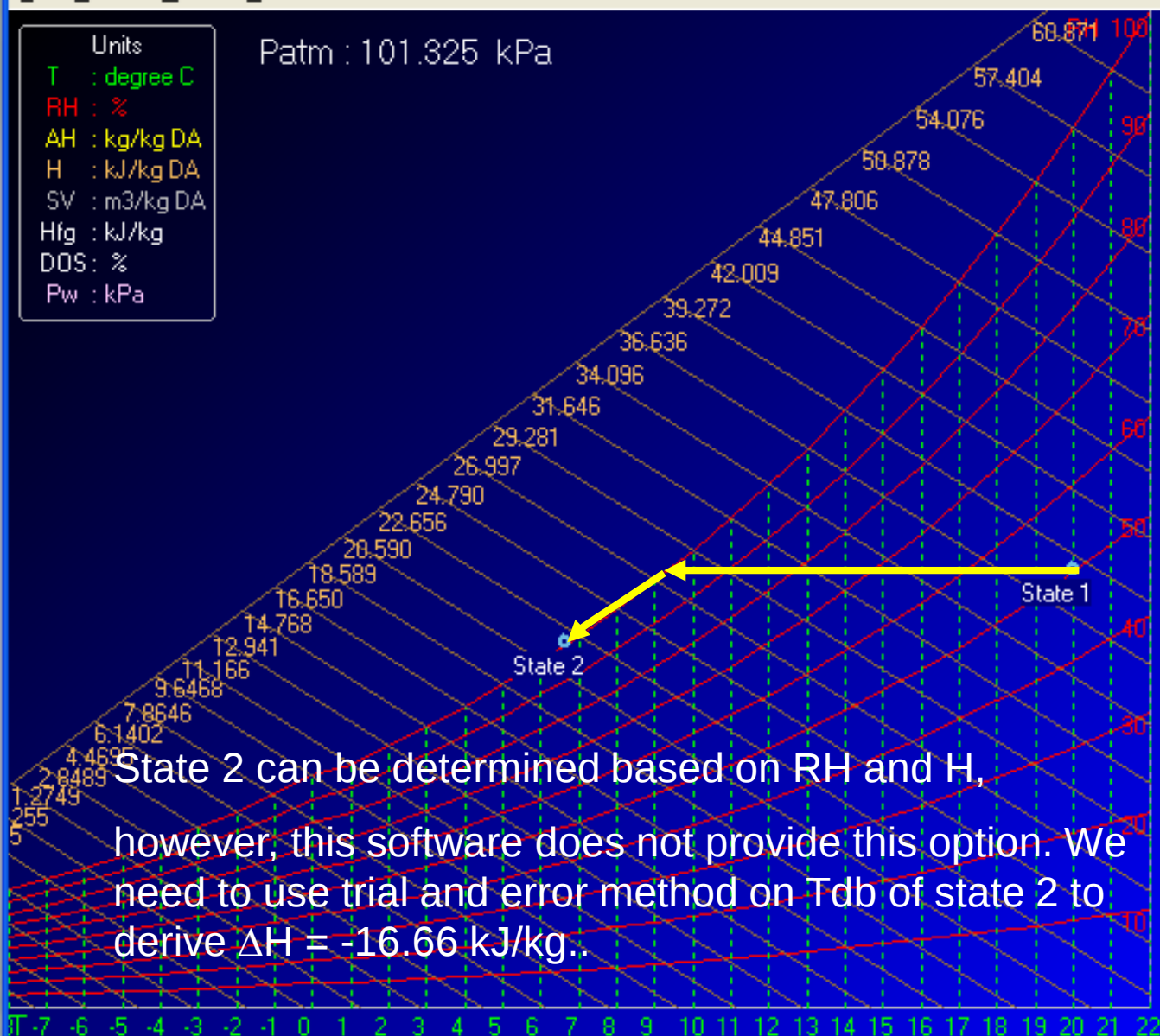




Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa



State	Process	Pad	VPD
State 1 State 2 Diff.			
Tdb	20	6.63	-13.37
RH	50	100	50
Twb	13.79	6.63	-7.16
Tdp	9.15	6.55	-2.6
AH	0.0073	0.0061	-0.0012
H	38.545	21.884	-16.661
SV	0.8402	0.8003	-0.0399
Hfg	2452.6	2484.96	32.36
DOS	49.42	100	50.58
Pws	2.339	0.977	-1.362
Pw	1.169	0.977	-0.19

Inactive Active ☐

Message

Diff. =
Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

- ☒ T
- ☒ RH
- ☐ AH
- ☐ Pw
- ☒ H
- ☐ SV

Misc.

- ☐ Centralize
- ☒ Unit label



濕空氣熱力性質的變化過程

6. Greenhouse in tropical and subtropical regions often encounter high humidity problem. For some floral industries, dehumidifier is used in the greenhouses. Assuming the night time T_{db} and RH in a 3 m height 1000 m² greenhouse before turn on the dehumidifier is 18 degree C, 91 % respectively. After turn on the dehumidifier for a while, the T_{db} remain the same and RH drop to 80 %. How much water was removed from the moist air inside this greenhouse ?

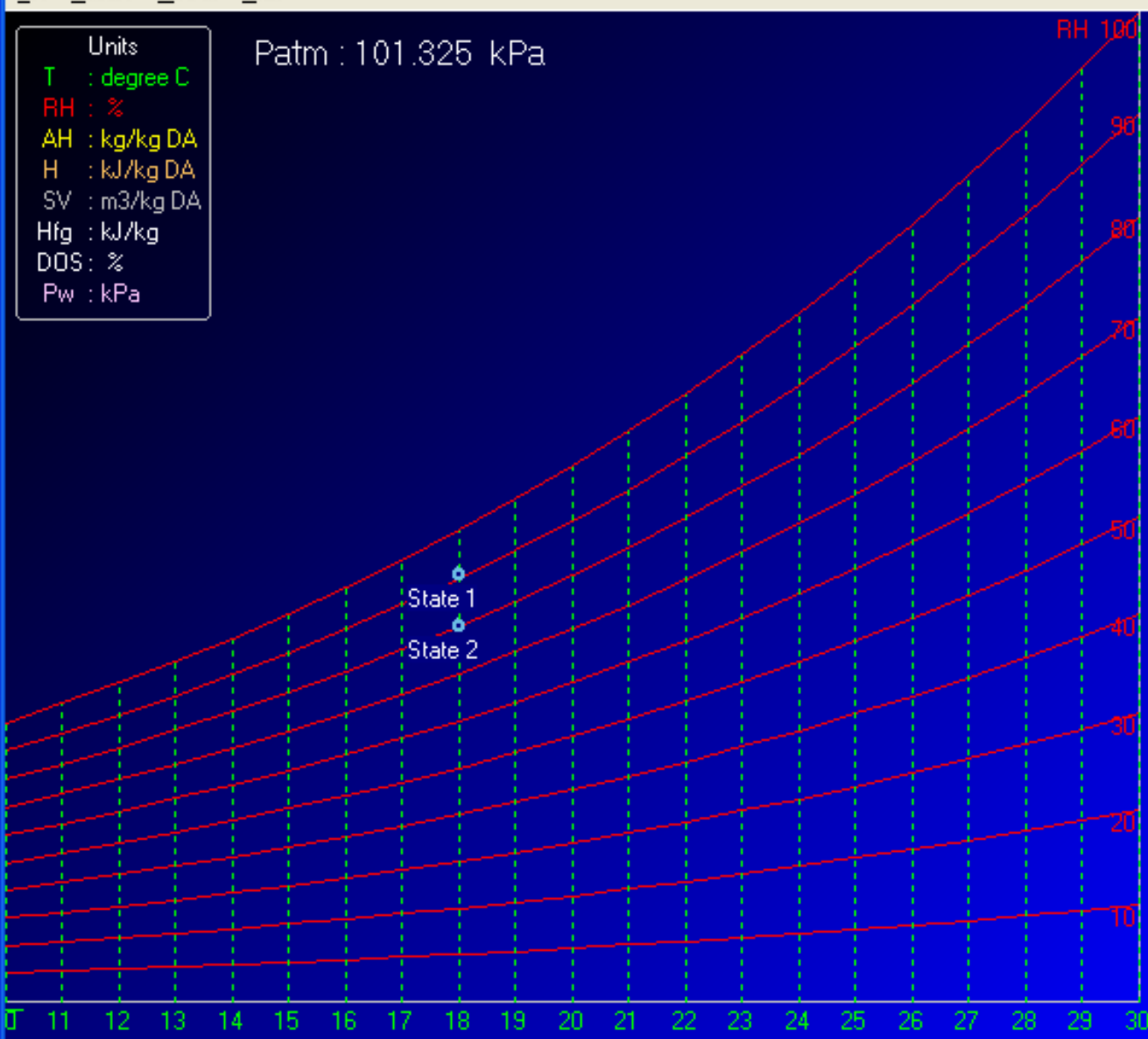


Digital Psychrometric Chart

Set Tables About Exit

Patm : 101.325 kPa

Units
 T : degree C
 RH : %
 AH : kg/kg DA
 H : kJ/kg DA
 SV : m3/kg DA
 Hfg : kJ/kg
 DOS : %
 Pw : kPa



State	Process	Pad	VPD
State 1	State 2	Diff.	
Tdb	18	18	0
RH	91	80	-11
Twb	17.14	15.87	-1.27
Tdp	16.35	14.34	-2.01
AH	0.0117	0.0103	-0.0014
H	47.874	44.216	-3.658
SV	0.8404	0.8385	-0.0019
Hfg	2457.44	2457.44	0
DOS	90.83	79.67	-11.16
Pws	2.064	2.064	0
Pw	1.879	1.651	-0.23

Inactive Active ☒

Message

Diff. =
 Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

問題 6 的解答

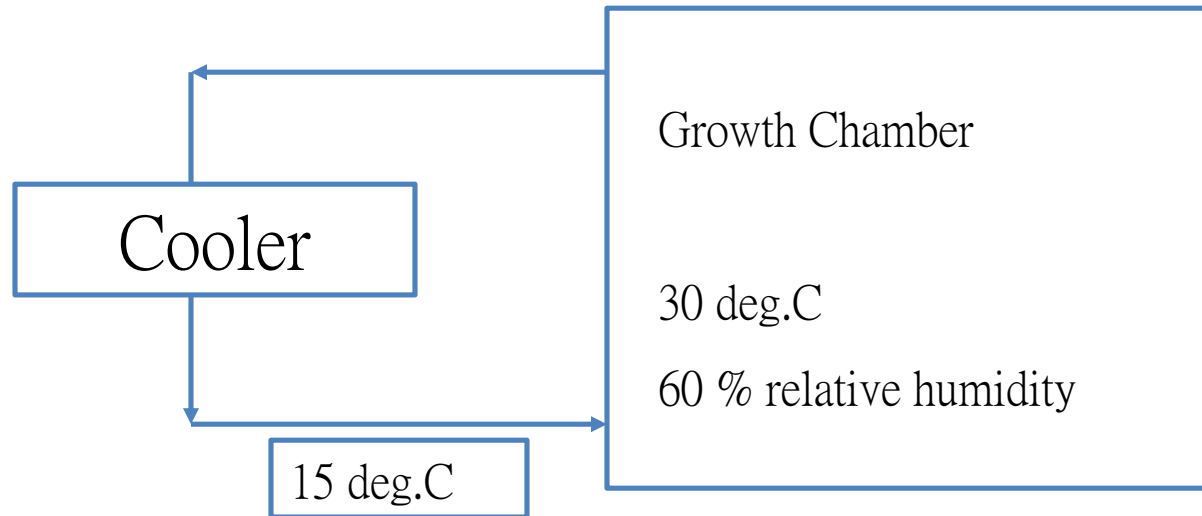
- Before use
 - Specific volume = $0.8404 \text{ m}^3/\text{kg}$
 - AH = $0.0117 \text{ kg vapor/kg dry air}$
- After use
 - AH = $0.0103 \text{ kg vapor/kg dry air}$
- Difference in AH
 - $AH_1 - AH_2 = 0.0014 \text{ kg vapor/kg dry air}$
 - Air volume $1000 \times 3 = 3000 \text{ m}^3$
 - Air weight = $3000 / 0.8404 = 3569.7 \text{ kg}$
 - Total water condensed = $3569.7 * 0.0014 = 4.997 \text{ kg}$



濕空氣熱力性質的變化過程

7. Air at 30 deg.C and 60% relative humidity in a growth chamber is cycled past the cooling coils and is returned back to the chamber at a temperature of 15 deg.C. Determine the psychrometric properties of the air after it is cooled, the sensible and latent heat removed, and the water vapor condensed per kg of dry air moved past the coils.



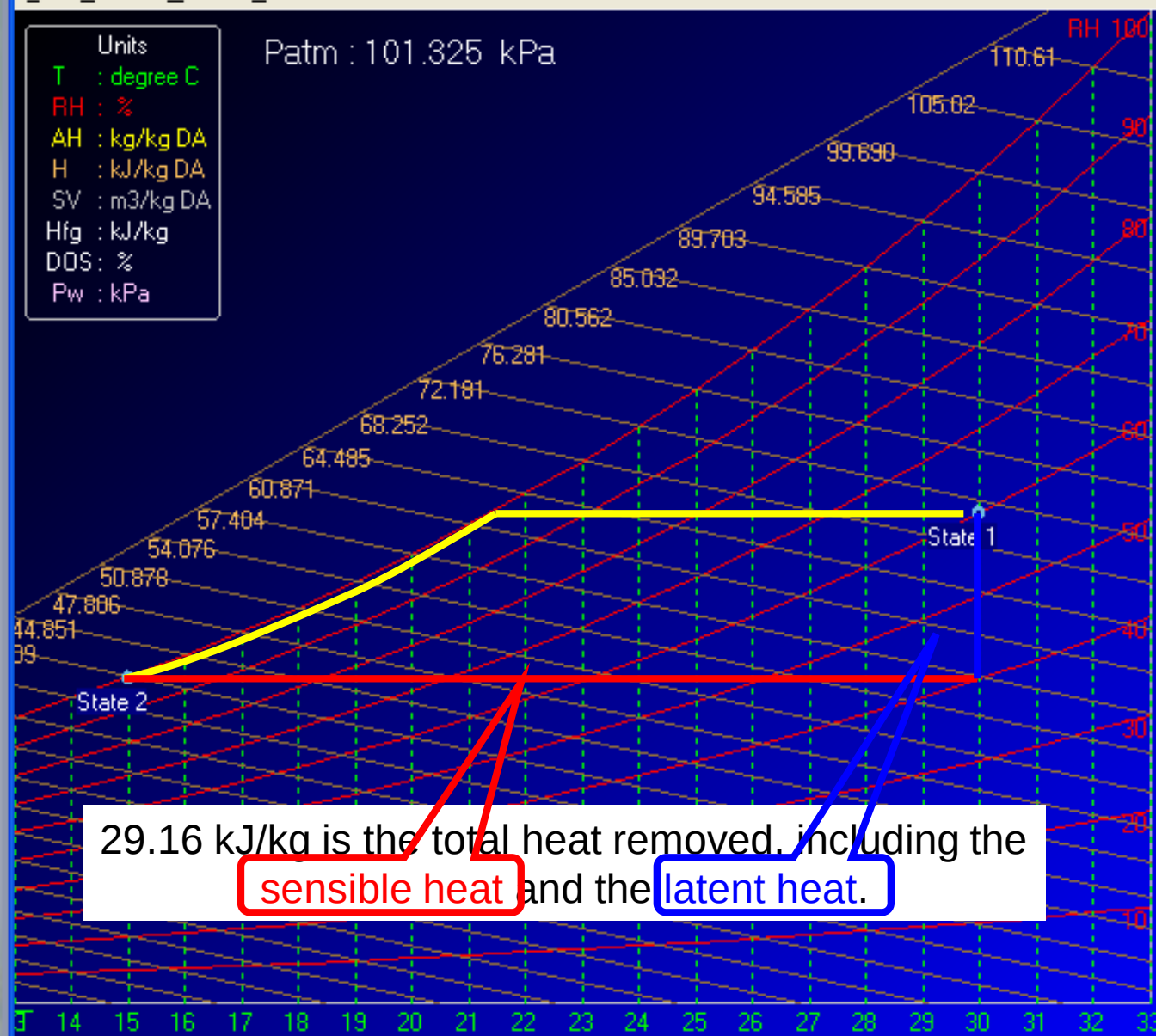


Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa



State	Process	Pad	VPD
State 1	State 2	Diff.	
Tdb	30	15	-15
RH	60	100	40
Twb	23.63	15	-8.63
Tdp	21.26	15	-6.26
AH	0.016	0.0106	-0.0054
H	71.169	42.009	-29.16
SV	0.881	0.8303	-0.0507
Hfg	2428.4	2464.7	36.3
DOS	58.97	100	41.03
Pws	4.246	1.705	-2.541
Pw	2.548	1.705	-0.84

Active Inactive Cal.

Message

Diff. =
Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☒ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

Crosshair: Tdb:23.25 ,RH:55.25





Digital Psychrometric Chart

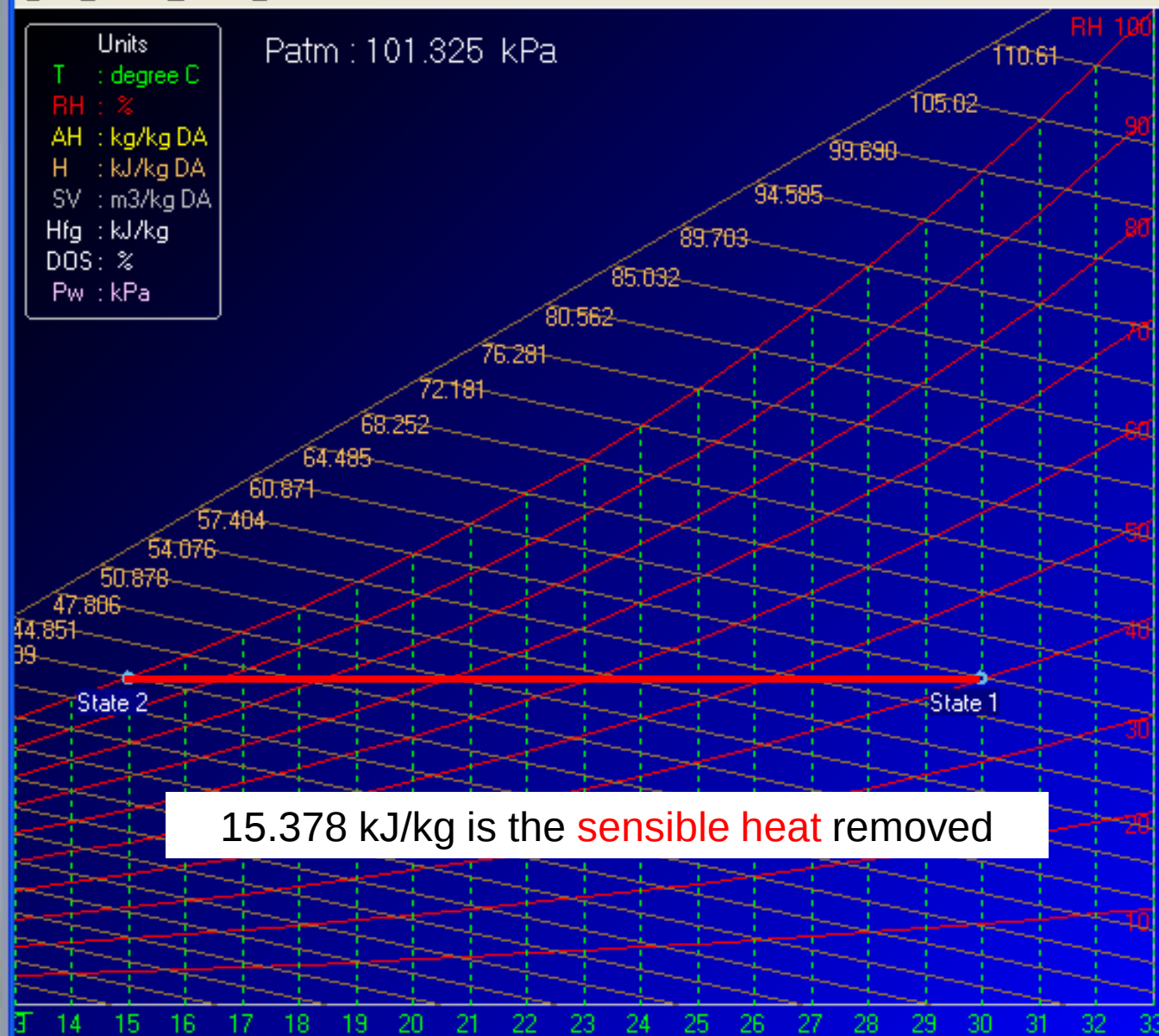


Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa



15.378 kJ/kg is the **sensible heat** removed

State	Process	Pad	VPD
State 1 State 2 Diff.			
Tdb	30	15	-15
RH	40.17	100	59.83
Twb	20.05	15	-5.05
Tdp	15	15	0
AH	0.0106	0.0106	0
H	57.387	42.009	-15.378
SV	0.8735	0.8303	-0.0432
Hfg	2428.4	2464.7	36.3
DOS	39.14	100	60.86
Pws	4.246	1.705	-2.541
Pw	1.705	1.705	0

Active Inactive CAL

Message

Diff. =
Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☒ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

Crosshair: Tdb:23.25 ,RH:55.25





Set Tables About Exit

Units

T : degree C

RH : %

AH : kJ/kg

H : kJ/kg

SV : m³/kg DA

Hfg : kJ/kg

DOS : %

Pw : kPa

Patm : 101.325 kPa

13.782 kJ/kg is the latent heat removed

0.0054 kg/kg dry air is the amount of water removed

$13.782 / 2428.4 = 0.00567$ kg/kg dry air is the amount of water removed based on H_{fg} .

State	Process	Pad	VPD
State 1 State 2 Diff.			
Tdb	30	30	0
RH	60	40.17	-19.83
Twb	23.63	20.05	-3.58
Tdp	21.26	15	-6.26
AH	0.016	0.0106	-0.0054
H	71.169	57.387	-13.782
SV	0.881	0.8735	-0.0075
Hfg	2428.4	2428.4	0
DOS	58.97	39.14	-19.83
Pws	4.246	4.246	0
Pw	2.548	1.705	-0.84
Active Inactive Cal.			

Message

Diff. =
Properties of State 2 - State 1

Crosshair



Step (pixels) 2



Lines & Curves

- ☒ T
- ☒ RH
- ☒ AH
- ☐ Pw
- ☒ H
- ☐ SV

Misc.

- ☐ Centralize
- ☒ Unit label

Crosshair: Tdb:23.25 ,RH:55.25

Plot family curves of selected Properties.



濕空氣熱力性質的變化過程

8. When ambient conditions are 35 deg.C and 25 % relative humidity, (a). determine the dry bulb temperature to which ventilation air could be cooled if drawn through an evaporative cooler with an efficiency of 75%. (b). Calculate how much water must be added to each cubic meter of the air drawn through the cooler. (c). Redo problem 7(a) with the ambient conditions at 35 deg.C and 80 % relative humidity.



問題 8a 的解答

(a). At the given condition:

- $T_{db} = 35 \text{ deg.C}$
- $RH = 25 \% \text{ (Very dry weather)}$

Answer

- $T_{wb} = 20.15 \text{ deg.C}$
- $WBD = 35 - 20.15 = 14.85 \text{ deg.C}$
- $\Delta T = 0.75 * WBD = 11.13 \text{ deg.C}$
- $\text{Final } T = 35 - 11.13 = 23.87 \text{ deg.C}$





Digital Psychrometric Chart

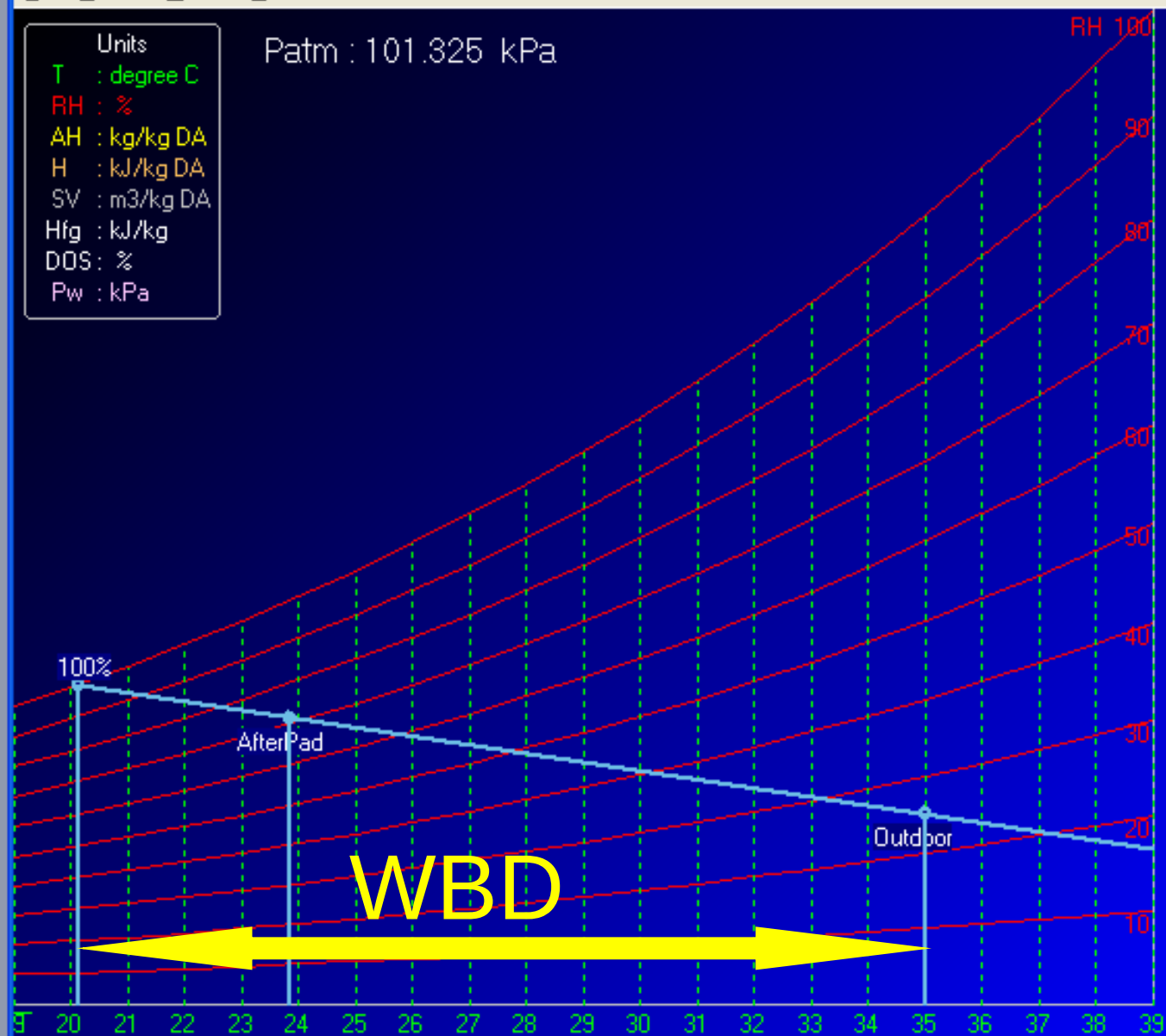


Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa



State Process Pad VPD

	Outdoor	AfterPad	Eff.
Tdb	35	23.87	75
RH	25	71.27	
Twb	20.15	20.06	
Tdp	11.89	18.2	
AH	0.0088	0.0132	
H	57.667	57.667	
SV	0.8853	0.8593	
Hfg	2416.3	2443.24	
DOS	23.94	0.71	
Pws	5.628	2.961	
Pw	1.407	2.11	

Draw

Message

Either AfterPad or Eff.
can be the unknown

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

Crosshair: Tdb:29.87 ,RH:51.80



問題 8c 的解答

(c). At the given condition:

- $T_{db} = 35 \text{ deg.C}$
- $RH=80 \%$ (Regular humid weather)

Answer

- $T_{wb} = 31.64 \text{ deg.C}$
- $WBD = 35 - 31.64 = 3.36$
- $\Delta T = 0.75 * WBD = 2.52 \text{ deg.C}$
- $\text{Final } T = 35 - 2.52 = 32.48 \text{ deg.C}$





Digital Psychrometric Chart

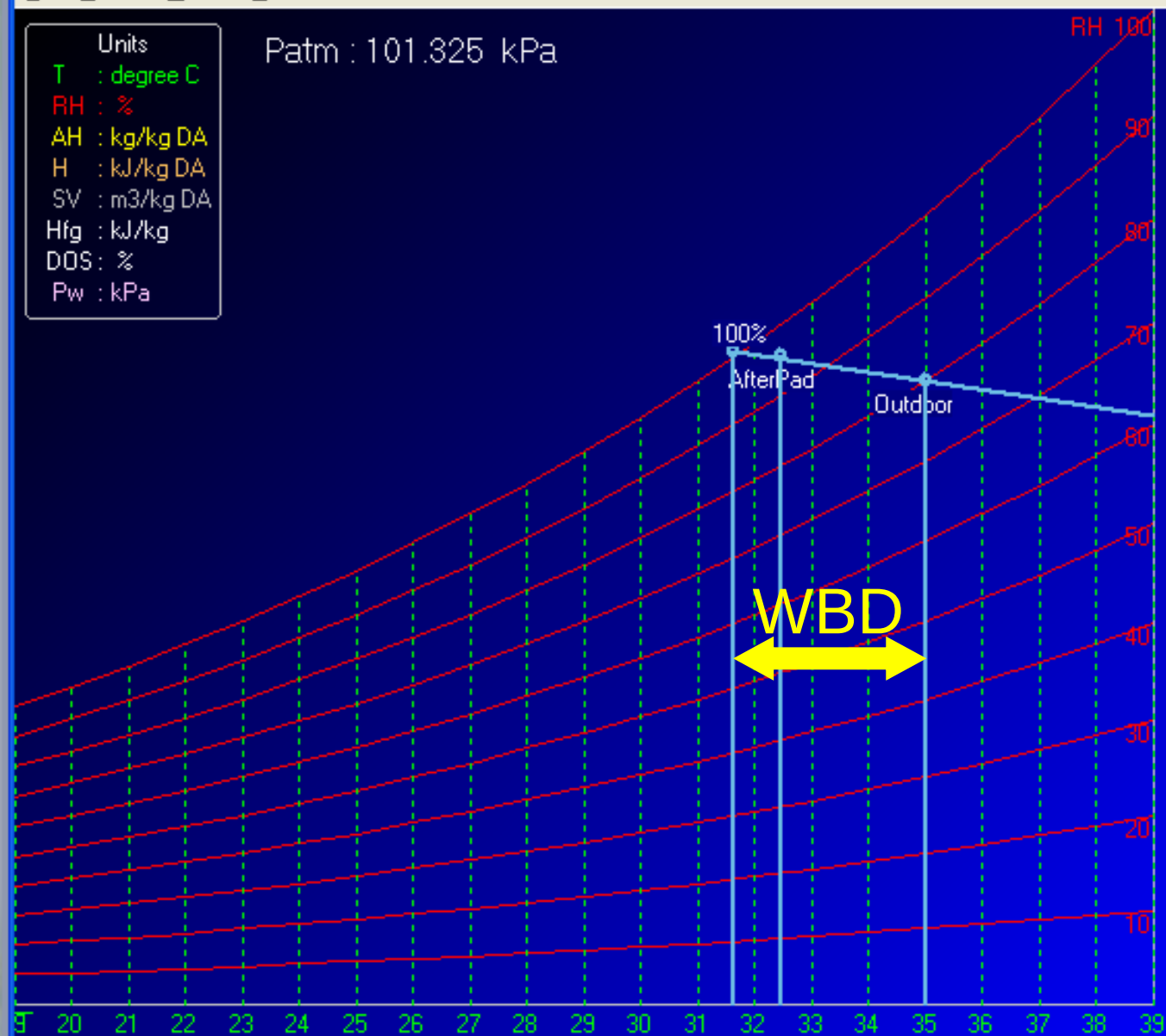


Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa



State Process Pad VPD

	Outdoor	AfterPad	Eff.
Tdb	35	32.48	75
RH	80	95.24	
Twb	31.64	31.75	
Tdp	31.01	31.61	
AH	0.0289	0.03	
H	109.371	109.371	
SV	0.9136	0.9076	
Hfg	2416.3	2422.4	
DOS	79.07	0.95	
Pws	5.628	4.89	
Pw	4.502	4.657	

Draw

Message

Either AfterPad or Eff.
can be the unknown

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

Crosshair: Tdb:29.87 ,RH:51.80



問題 8b 的解答

(b). At initial conditions,

- $T_{db} = 35 \text{ deg.C}$
- $RH = 25 \%$

Answer

- the specific volume is $0.8853 \text{ m}^3/\text{kg}$, humidity ratio is 0.0088 kg/kg of dry air.
- At wet bulb of 20.15 and dry bulb of 23.87 , the humidity ratio is 0.0132 kg/kg of dry air.
- A cubic meter of air will contain $1 \text{ m}^3 / 0.8853 \text{ m}^3/\text{kg} = 1.13 \text{ kg}$.
- The change of humidity ratio is $0.0132 - 0.0088 = 0.0044 \text{ kg/kg}$ dry air.
- Thus, the total water gained by each cubic meter of outdoor air will be $1.13 \text{ kg} * 0.0044 \text{ kg/kg} = 0.005 \text{ kg}$.





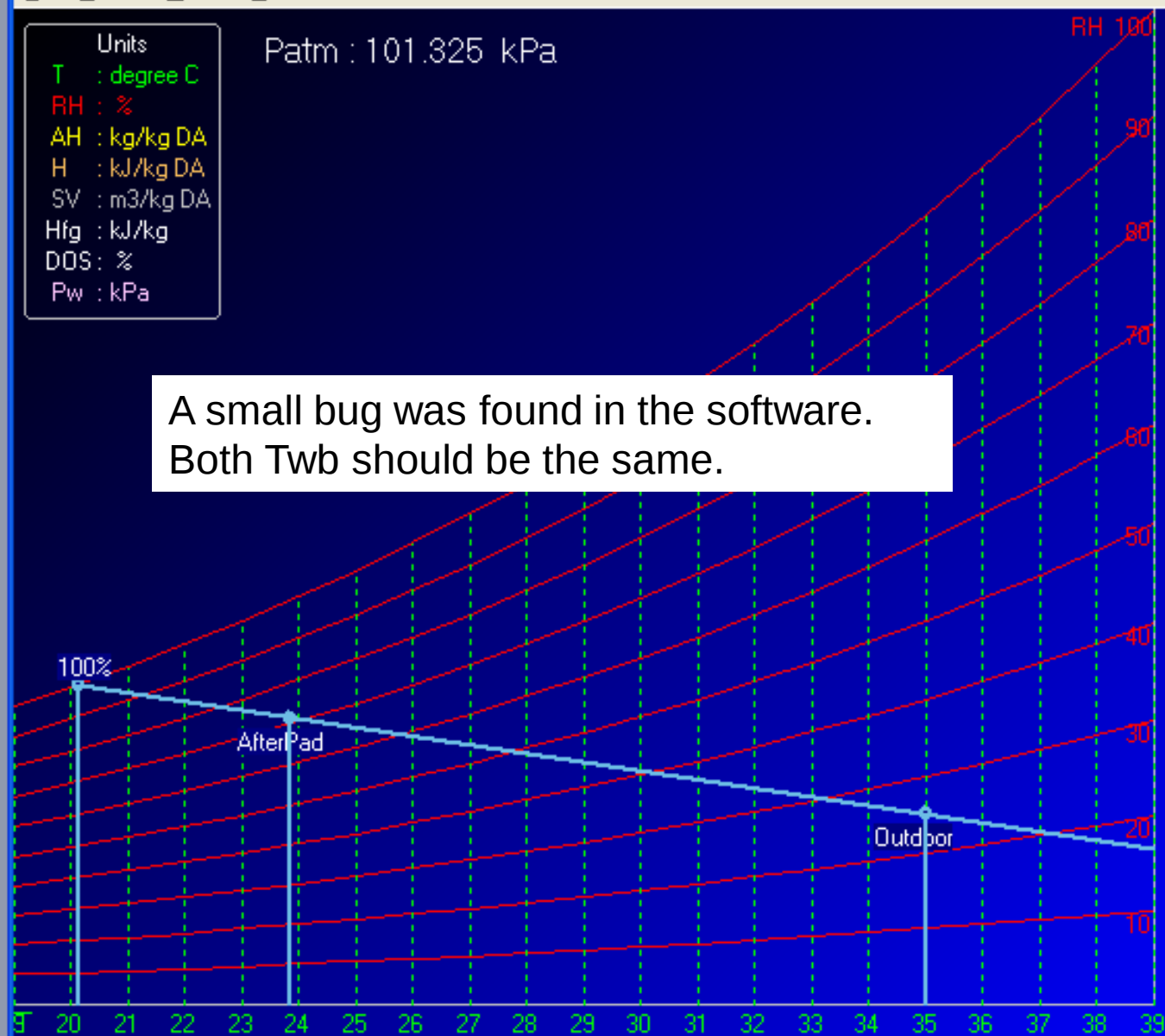
Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa

A small bug was found in the software.
Both Twb should be the same.



State	Process	Pad	VPD
	Outdoor	AfterPad	Eff.
Tdb	35	23.87	75
RH	25	71.27	
Twb	20.15	20.06	
Tdp	11.89	18.2	
AH	0.0088	0.0132	
H	57.667	57.667	
SV	0.8853	0.8593	
Hfg	2416.3	2443.24	
DOS	23.94	0.71	
Pws	5.628	2.961	
Pw	1.407	2.11	

Draw

Message

Either AfterPad or Eff.
can be the unknown

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

Misc.

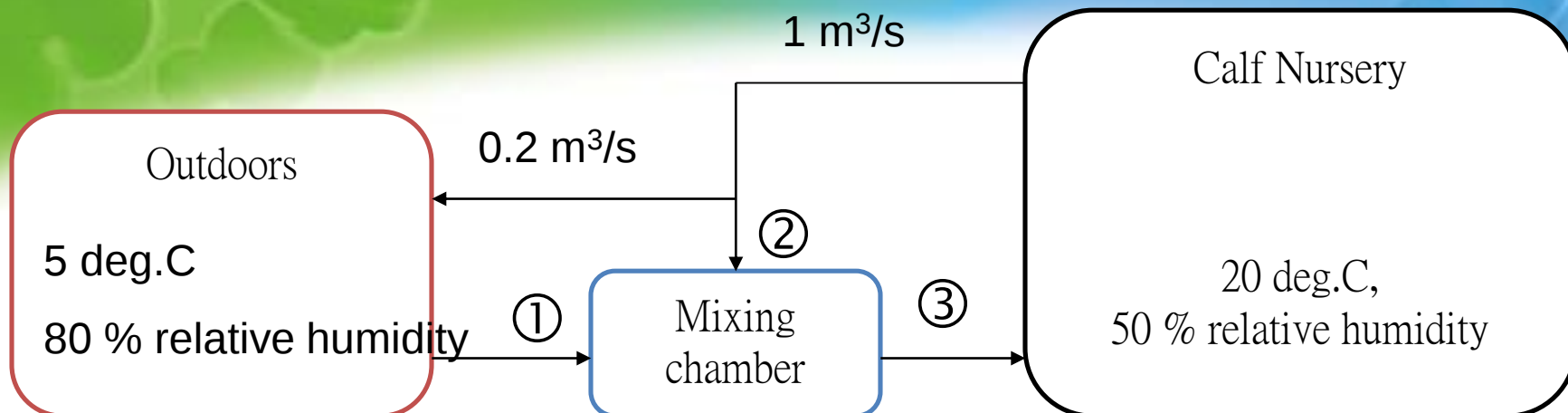
☐ Centralize
☒ Unit label

Crosshair: Tdb:29.87 ,RH:51.80

濕空氣熱力性質的變化過程

9. A ventilation system for a calf nursery draws $1 \text{ m}^3/\text{s}$ of air from the nursery, exhausts $0.2 \text{ m}^3/\text{s}$ of the air to the outside, and replaces the exhausted air with fresh air. Air in the nursery is at 20 deg.C and 50% relative humidity, and outdoor air is at 5 deg.C and 80% relative humidity. Determine properties of the mixed air when it is returned to the nursery.





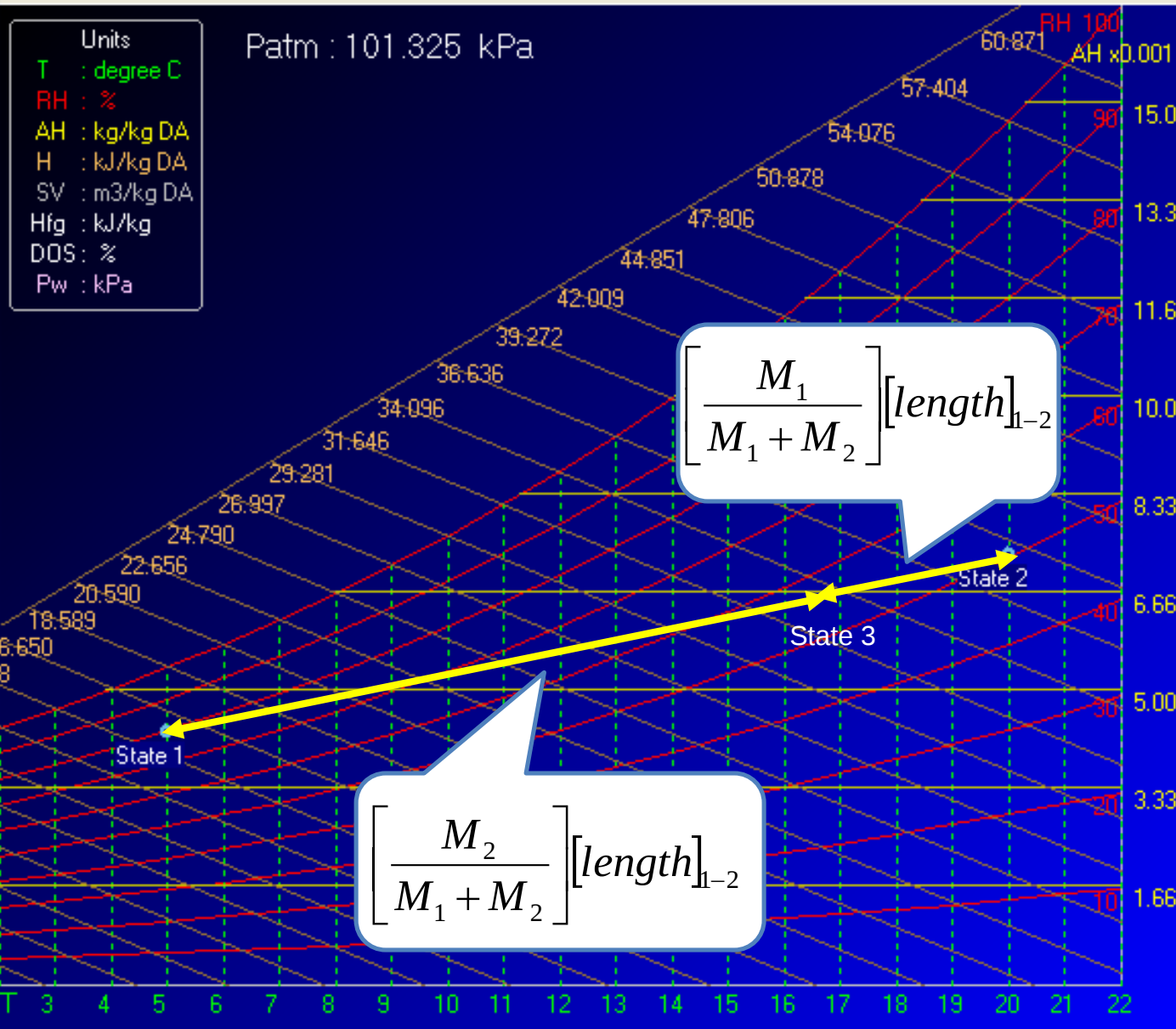
	#1	#2	#3
T, deg.C	5	20	16.86 (cal.)
RH, %	80	50	53.37 (psychart)
V, m3/s	0.2	0.8	0.999
v, m3/kg	0.7935	0.8402	0.83
M, kg/s	0.252	0.952	1.204
W, kg/kg	0.0043	0.0073	0.0066 (cal.) / 0.0064 (psychart)
h, kJ/kg	15.859	38.545	33.796 (cal.) / 33.054 (psychart)

$$W_3 = (M_1 \cdot W_1 + M_2 \cdot W_2) / (M_1 + M_2)$$

$$T_3 = (M_1 \cdot T_1 + M_2 \cdot T_2) / (M_1 + M_2)$$

$$h_3 = (M_1 \cdot h_1 + M_2 \cdot h_2) / (M_1 + M_2)$$





Crosshair: Tdb:29.87 ,RH:51.80

State	Process	Pad	VPD
State 1	State 2	Diff.	
Tdb	5	20	15
RH	80	50	-30
Twb	3.72	13.79	10.07
Tdp	1.9	9.15	7.25
AH	0.0043	0.0073	0.003
H	15.859	38.545	22.686
SV	0.7935	0.8402	0.0467
Hfg	2488.9	2452.6	-36.3
DOS	79.86	49.42	-30.44
Pws	0.872	2.339	1.467
Pw	0.698	1.169	0.47

Inactive Active Cal.

Message

Diff. =
Properties of State 2 - State 1

Crosshair

Lines & Curves

- ☒ T
- ☒ RH
- ☒ AH
- ☐ Pw
- ☒ H
- ☐ SV

Misc.

- ☐ Centralize
- ☒ Unit label



Digital Psychrometric Chart

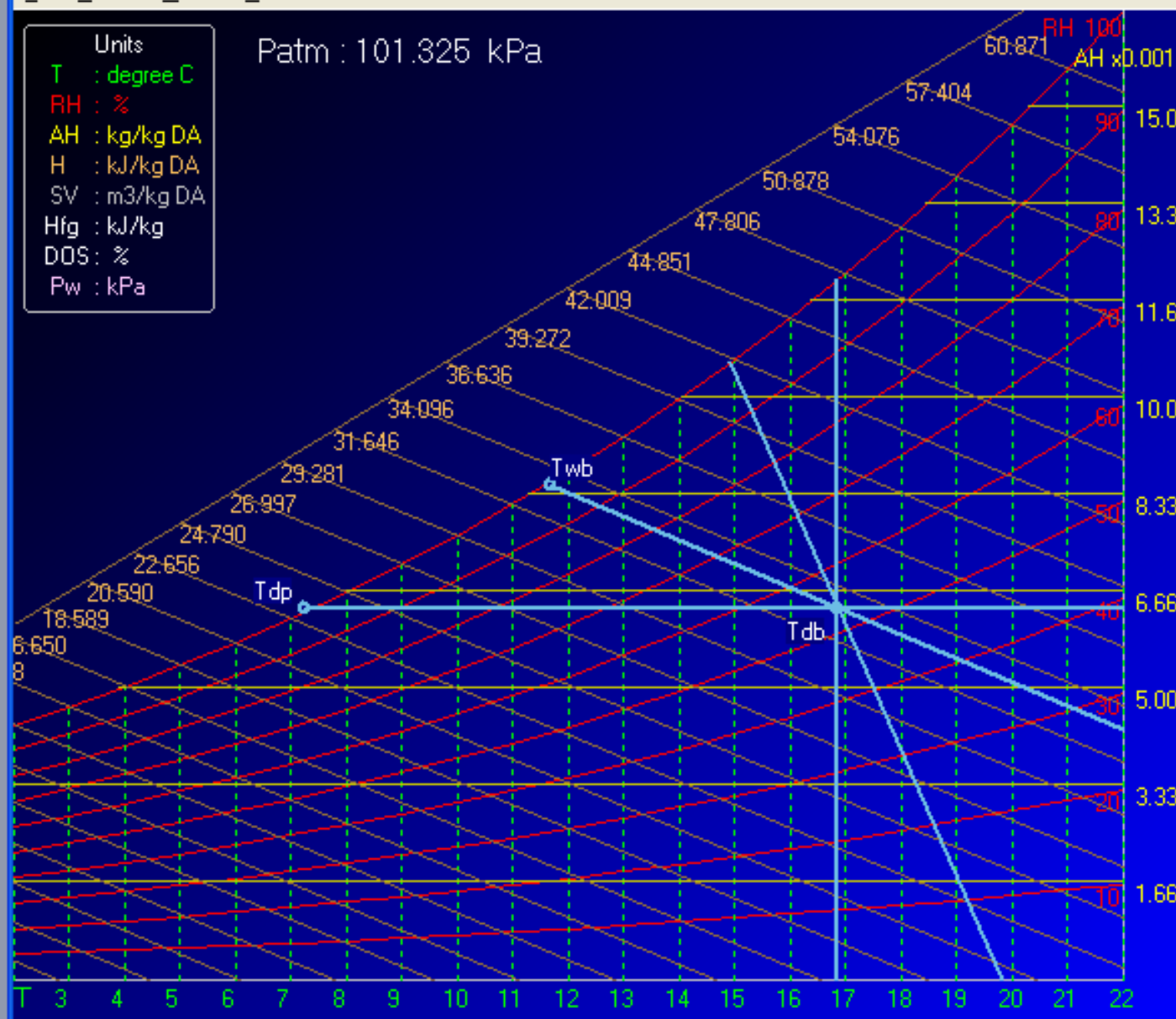


Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa



State Process Pad VPD

Tdb 16.86 degree C

RH 53.37 %

Twb 11.67 degree C

Tdp 7.24 degree C

AH 0.0064 kg/kg DA

H 33.054 kJ/kg DA

SV 0.83 m3/kg DA

Hfg 2460.2 kJ/kg

DOS 52.89 %

Pws 1.921 kPa

Pw 1.025 kPa

Message

Relative Humidity
Range : 0 % <--> 100 %

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☒ AH
☐ Pw
☒ H
☐ SV

Misc.

☐ Centralize
☒ Unit label

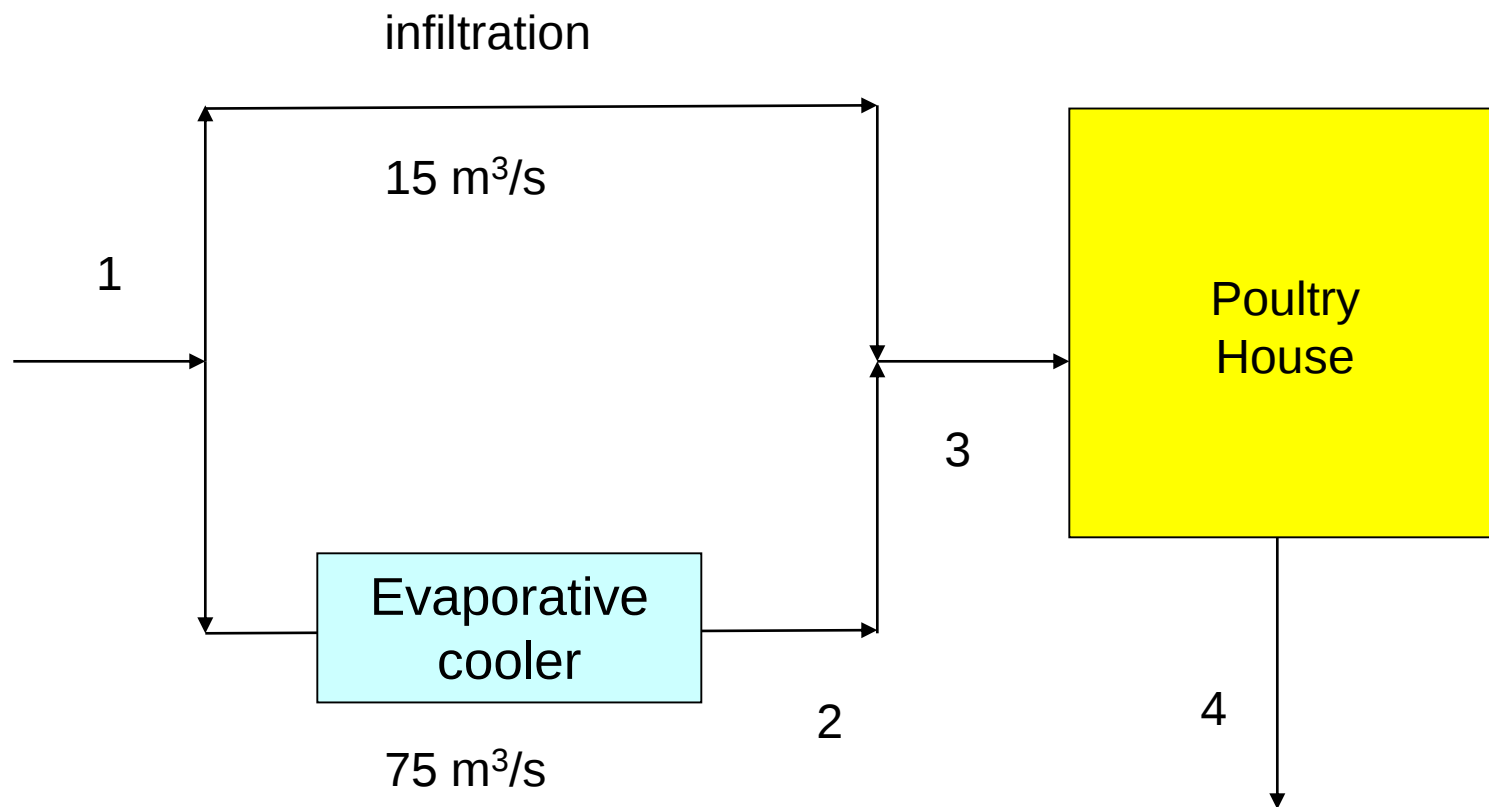
Crosshair: Tdb:29.87 ,RH:51.80



濕空氣熱力性質的變化過程

10. You are designing an evaporative cooling system to ventilate a controlled environment, totally enclosed, poultry house in a hot and dry climate.
- Summer design weather conditions for your location are 40 degree C Tdb and 20 % RH.
 - 75 m³/s of outdoor air will be drawn by the evaporative cooling system (75% efficiency) and 15 m³/s of outdoor air will be drawn into the house through infiltration.
 - The birds in the house are expected to produce 250 kW of total heat of which 40% is latent heat. Determine
 - a) the psychrometric properties of the air mixed by air through evaporative cooling pad and air through infiltration.
 - b) the psychrometric properties of the exhausted air.
 - c) the volumetric flow rate of air exhausted from the house.
 - d) the rate (L/s) at which water must be supplied to the evaporative cooling pads by a water pump. When a (water flow/evaporation rate) ratio of 3 is desire.





Set Tables About Exit

Units

T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa

Patm : 101.325 kPa

$$\dot{M}_1 = 16.66, \dot{M}_2 = 86.3, \dot{M}_3 = 102.96 \text{ kg/s}$$

$$T_3 = (\dot{M}_1 * T_1 + \dot{M}_2 * T_2) / \dot{M}_3 = 28.69 \text{ deg. C}$$

$$W_3 = (\dot{M}_1 * W_1 + \dot{M}_2 * W_2) / \dot{M}_3 = 0.0137 \text{ kg/kg}$$

State 3

State 2

After Pad

Outdoor

State 1

Zoom out

State Process Pad VPD

	Outdoor	AfterPad	Eff.
Tdb	40	26.51	75
RH	20	67.1	
Twb	22.01	21.77	
Tdp	12.63	19.77	
AH	0.0092	0.0146	
H	63.91	63.91	
SV	0.9003	0.8689	
Hfg	2404.2	2436.85	
DOS	18.82	0.66	
Pws	7.383	3.466	
Pw	1.477	2.326	

Draw

Message

Either AfterPad or Eff.
can be the unknown

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

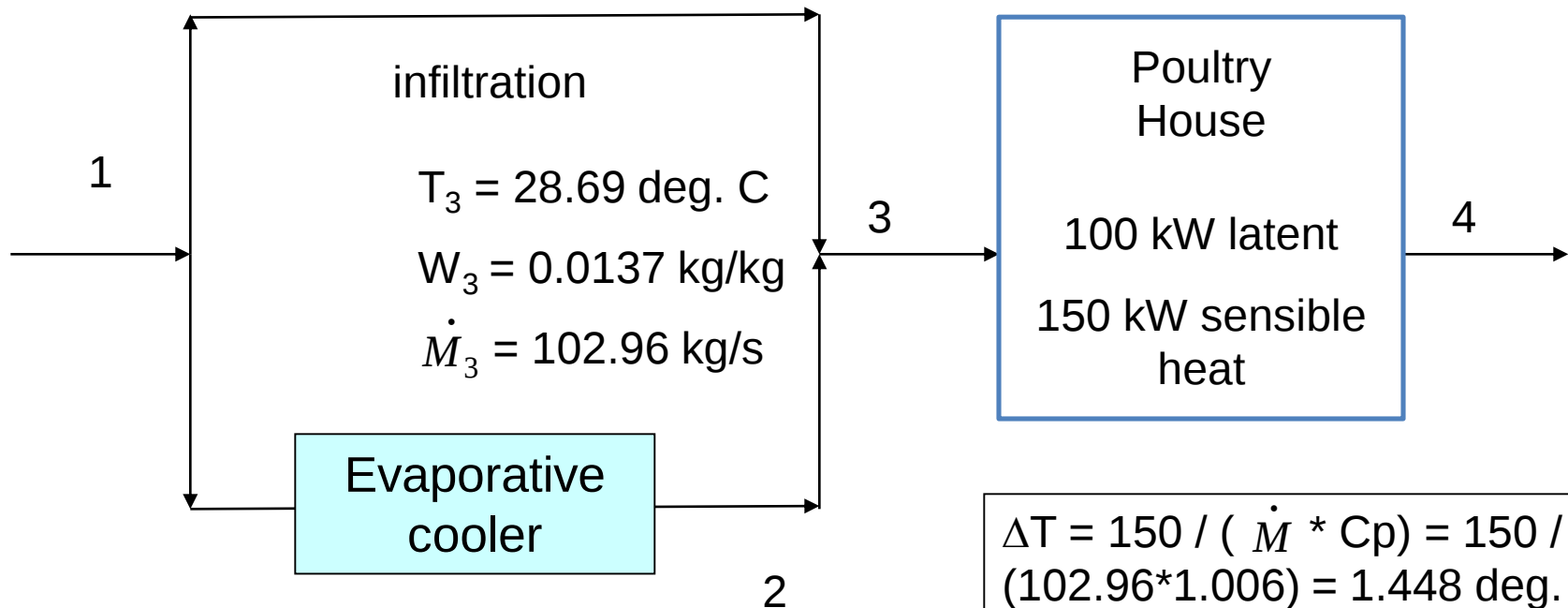
Misc.

☐ Centralize
☒ Unit label

Plot family curves of selected Properties.

$\dot{V}_1 = 15 \text{ m}^3/\text{s}$	$T_1 = 40 \text{ deg. C}$
$v_1 = 0.9003 \text{ m}^3/\text{kg}$	$RH_1 = 20 \%$
$\dot{M}_1 = 16.66 \text{ kg/s}$	$W_1 = 0.0092 \text{ kg/kg}$

$T_4 = T_3 + \Delta T = 28.69 + 1.448$ $= 30.138 \text{ deg. C}$
$W_4 = W_3 + \Delta W = 0.0137 +$ $0.0004 = 0.0141 \text{ kg/kg}$



$\dot{V}_2 = 75 \text{ m}^3/\text{s}$	$T_2 = 26.51 \text{ deg. C}$
$v_2 = 0.8689 \text{ m}^3/\text{kg}$	$RH_2 = 67.1 \%$
$\dot{M}_2 = 86.3 \text{ kg/s}$	$W_2 = 0.0146 \text{ kg/kg}$

$\Delta T = 150 / (\dot{M} * C_p) = 150 /$ $(102.96 * 1.006) = 1.448 \text{ deg. C}$
$h_{fg} = 2501 - 2.42 * (28.69 + 1.448)$ $= 2428 \text{ kJ/kg}$
$\Delta W = 100 / (\dot{M} * h_{fg}) = 100 /$ $(102.96 * 2428) = 0.0004 \text{ kg/kg}$





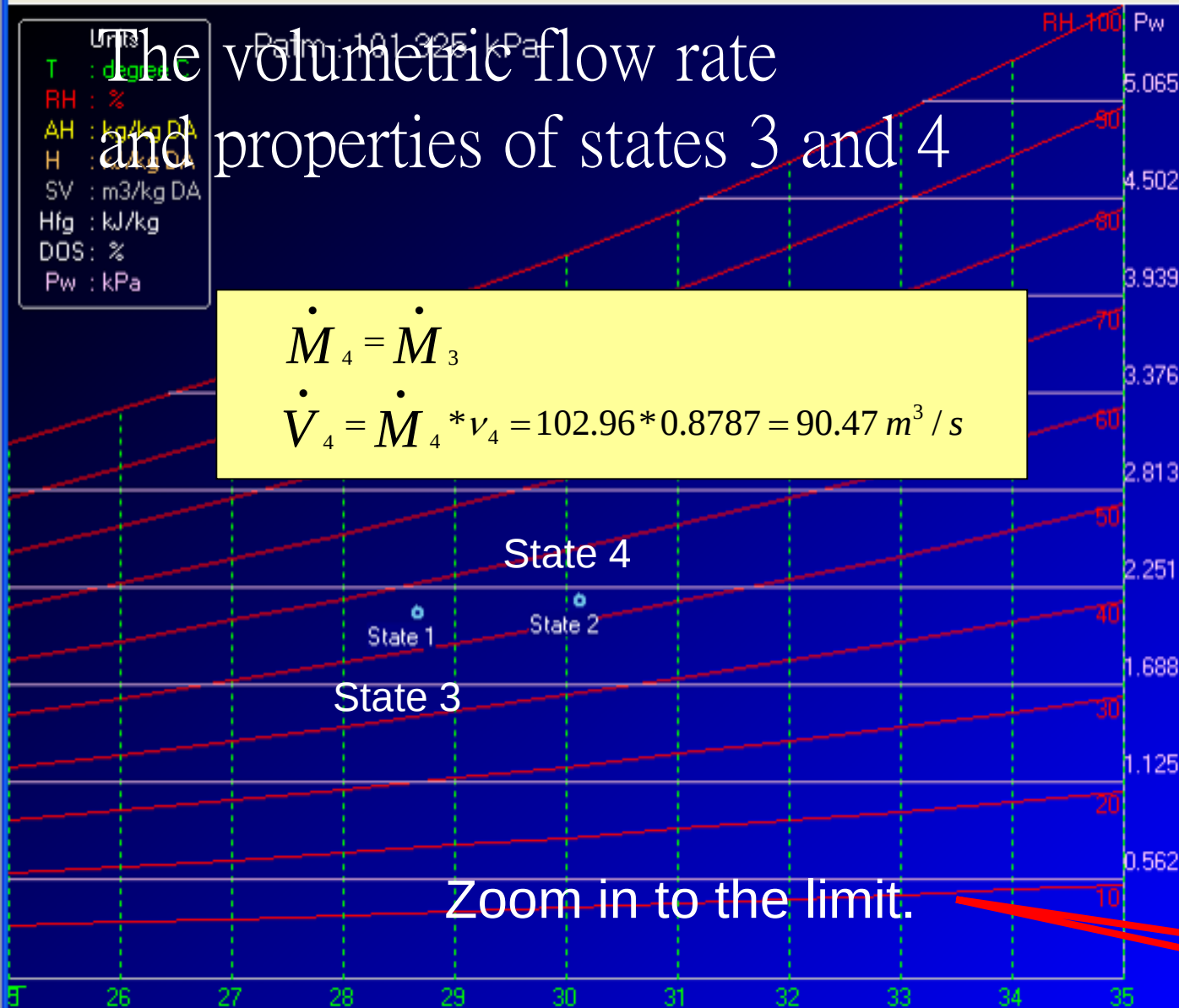
Set Tables About Exit

Units
 T : degree C
 RH : %
 AH : kg/kg DA
 H : kJ/kg DA
 SV : m3/kg DA
 Hfg : kJ/kg
 DOS : %
 Pw : kPa

The volumetric flow rate and properties of states 3 and 4

$$\dot{M}_4 = \dot{M}_3$$

$$\dot{V}_4 = \dot{M}_4 * v_4 = 102.96 * 0.8787 = 90.47 \text{ m}^3 / \text{s}$$



State	Process	Pad	VPD
State 1	State 2	Diff.	
Tdb	28.69	30.14	1.45
RH	55.47	52.48	-2.99
Twb	21.74	22.4	0.66
Tdp	18.75	19.2	0.45
AH	0.0137	0.0141	0.0004
H	63.835	66.35	2.515
SV	0.874	0.8787	0.0047
Hfg	2431.57	2428.07	-3.5
DOS	54.49	51.4	-3.09
Pws	3.937	4.28	0.343
Pw	2.184	2.246	0.06

Inactive Active Cal.

Message

Diff. =
Properties of State 2 - State 1

Crosshair

Step (pixels) 2

Lines & Curves

☒ T
☒ RH
☐ AH
☒ Pw
☐ H
☐ SV

Misc.

☒ Centralize
☒ Unit label



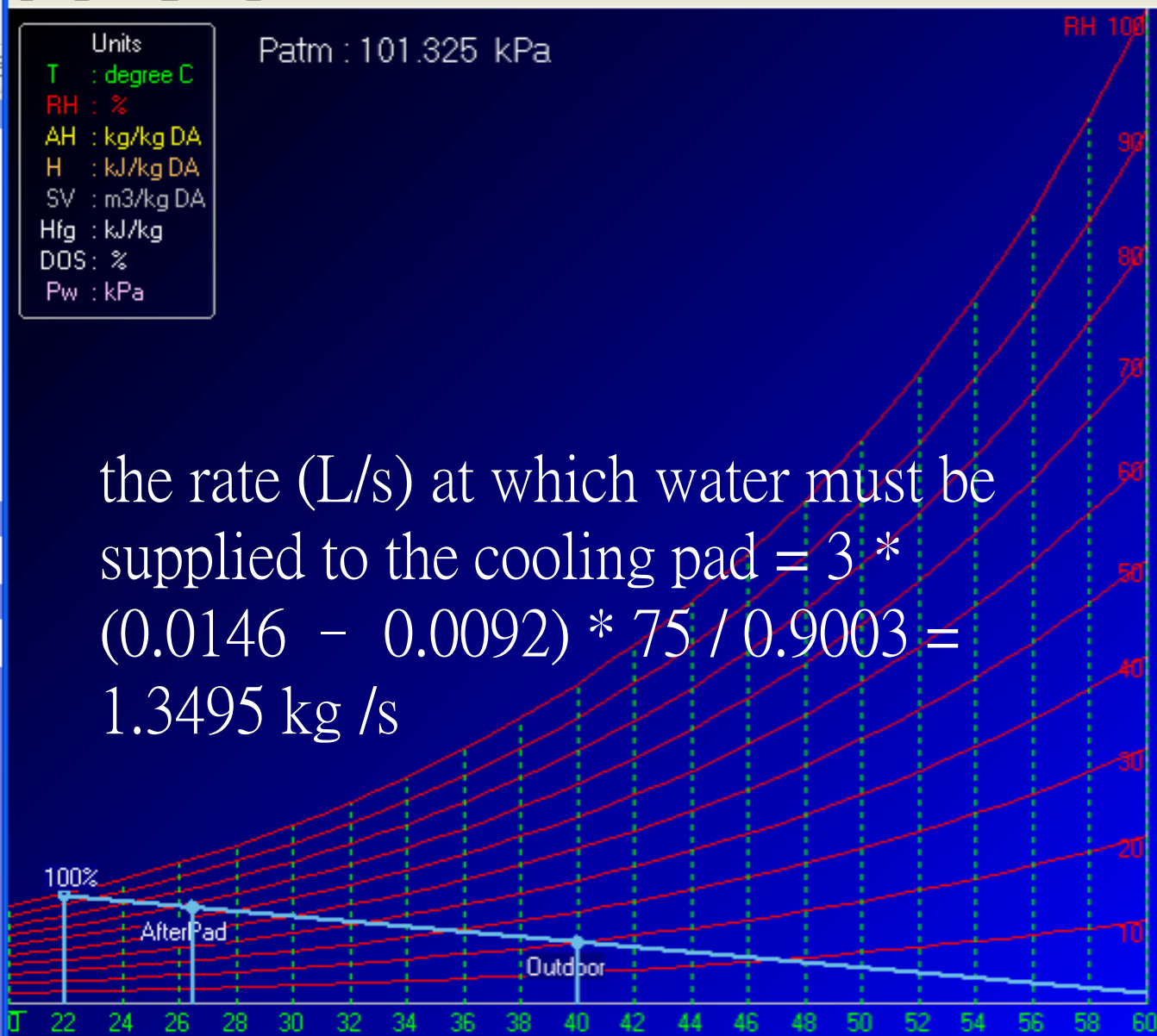
Set Tables About Exit

Units

T : degree C
 RH : %
 AH : kg/kg DA
 H : kJ/kg DA
 SV : m3/kg DA
 Hfg : kJ/kg
 DOS : %
 Pw : kPa

Patm : 101.325 kPa

the rate (L/s) at which water must be supplied to the cooling pad = $3 * (0.0146 - 0.0092) * 75 / 0.9003 = 1.3495 \text{ kg /s}$



Plot family curves of selected Properties.

State	Process	Pad	VPD
	Outdoor	AfterPad	Eff.
Tdb	40	26.51	75
RH	20	67.1	
Twb	22.01	21.77	
Tdp	12.63	19.77	
AH	0.0092	0.0146	
H	63.91	63.91	
SV	0.9003	0.8689	
Hfg	2404.2	2436.85	
DOS	18.82	0.66	
Pws	7.383	3.466	
Pw	1.477	2.326	

Draw

Message

Either AfterPad or Eff.
 can be the unknown

Crosshair



Step (pixels) 2



Lines & Curves

☒ T
☒ RH
☐ AH
☐ Pw
☐ H
☐ SV

Misc.

☐ Centralize
☒ Unit label



計算範例之參考文獻

Albright, L.D. 1990. Chapter 2 – Psychrometrics.
Environment Control for Animals and Plants. An
ASAE Textbook. ASAE, St. Joseph, MI, USA.

如果您對 Psychart 軟體有興趣
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