[ATGS 7140] Plant Factory – Theory and Practice
[ANISCI7047] Smart Production of Livestock
[BME5117] 環控農業工程學

濕空氣熱力學
Psychrometrics

the study of moist air and its thermodynamic properties

方煒 Wei FANG
NTU_BME and Global ATGS
National Taiwan University

Moist air

- Moist air: air with water vapor
- Dry air: air without water vapor

- Moist air = dry air + water vapor

- Dry air: mixed gas (N_2: 80%, O_2: 19%, Others including CO_2 400 ppm = 0.04% and else)

物理基礎

- 溼空氣=空氣+水蒸汽
- 特定溫度有最大的水蒸汽分壓(=飽和蒸汽壓)=水平面上水蒸汽與液態水達到平衡時的壓力
- 水蒸汽壓力是溫度的函數

$$Ps(T) = 0.61121 \exp(((18.678 - (T / 234.5)) * (T / (257.14 + T)))$$
, over liquid water, $T > 0\ °C$

$$Ps(T) = 0.61115 \exp(((23.036 - (T / 333.7)) * (T / (279.82 + T)))$$
, over ice, $T < 0\ °C$

Where:

Ps (T) is the equilibrium pressure, also called saturation pressure in kPa

exp is the exponent based on the natural number e = 2.71828

T is the air temperature in degrees Celsius

Functions of moist air

- As the heat source / sink，涉及 熱傳
- As the water source/ sink，涉及質傳
- As the N_2 source / sink ，涉及質傳
- As the O_2 source / sink ，涉及質傳
- As the source / sink of organic particles ，涉及質傳
- As the source / sink of inorganic particles ，涉及質傳
- others

Applications of moist air

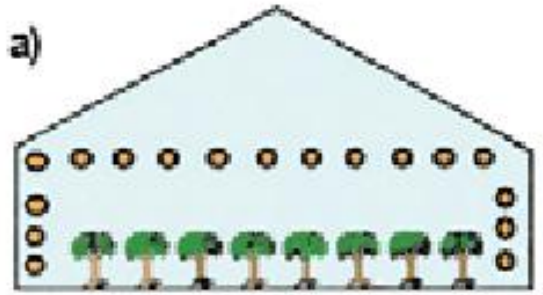
1. HeatingVentilatingAirConditioning
2. Drying
3. (De)humidification
4. Evaporative cooling
   - Pad and Fan
   - Fogging
5. Deodorization
6. ……

Heating

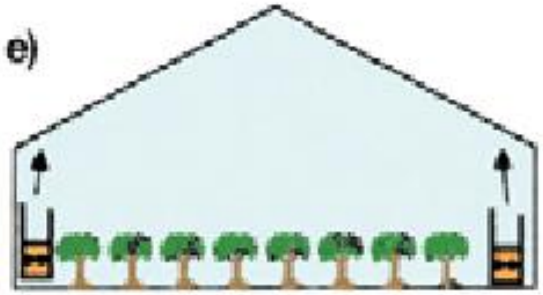
Fan Jet system with heater

多功能系統

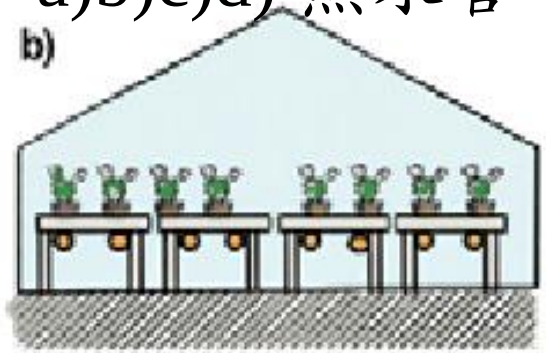
加熱/強制通風/內循環

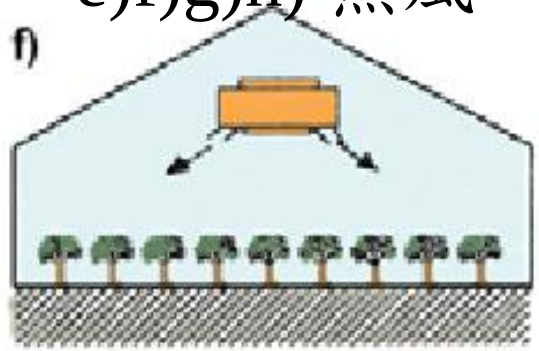


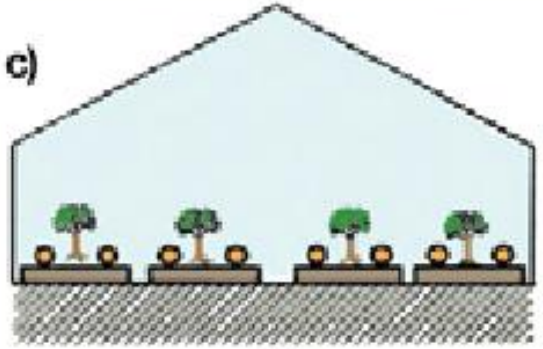
a)b)c)d) 熱水管

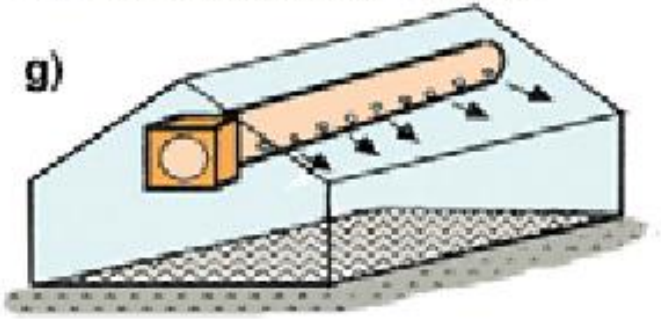


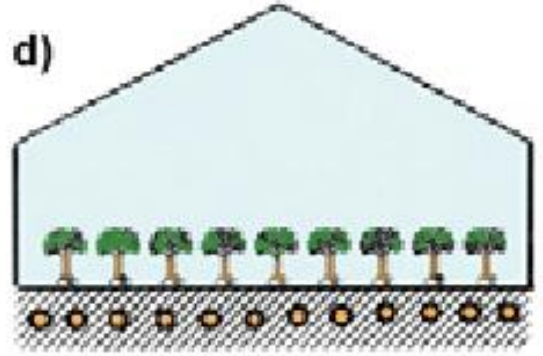
e)f)g)h) 熱風

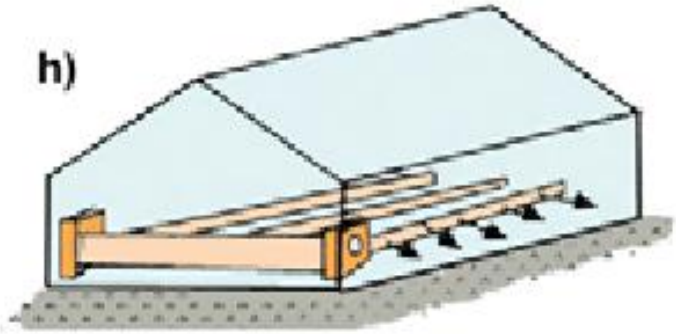




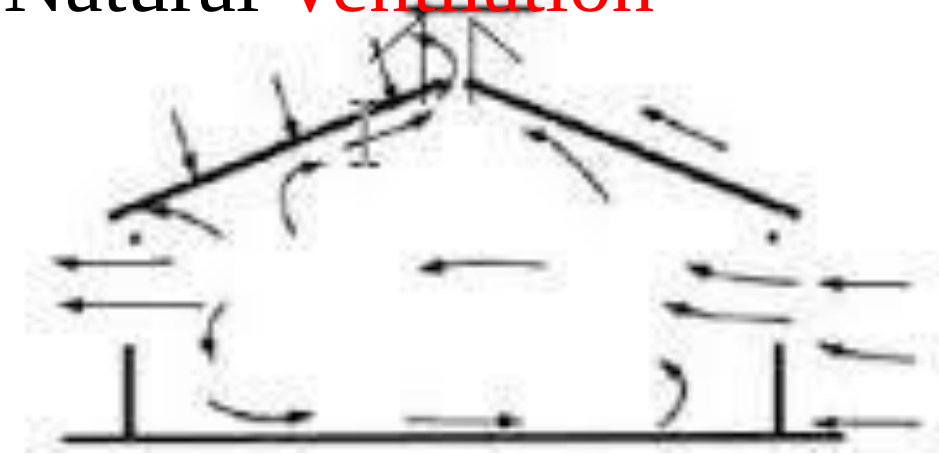




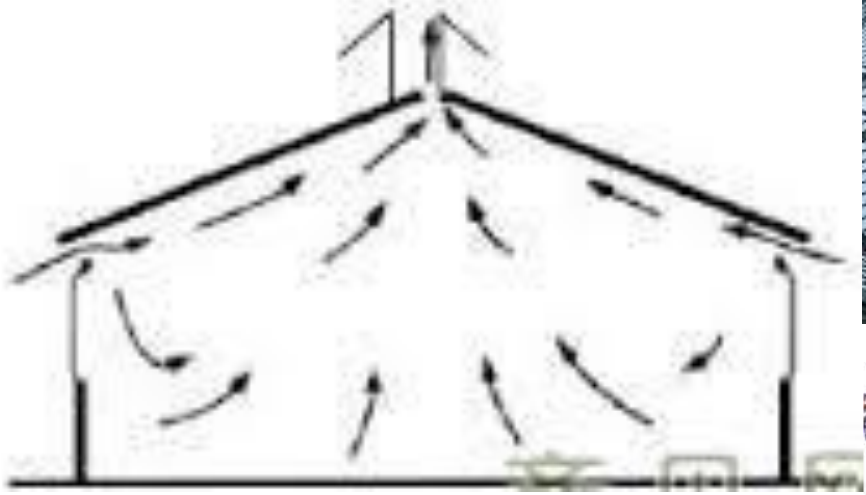




Natural Ventilation



Summer



Winter

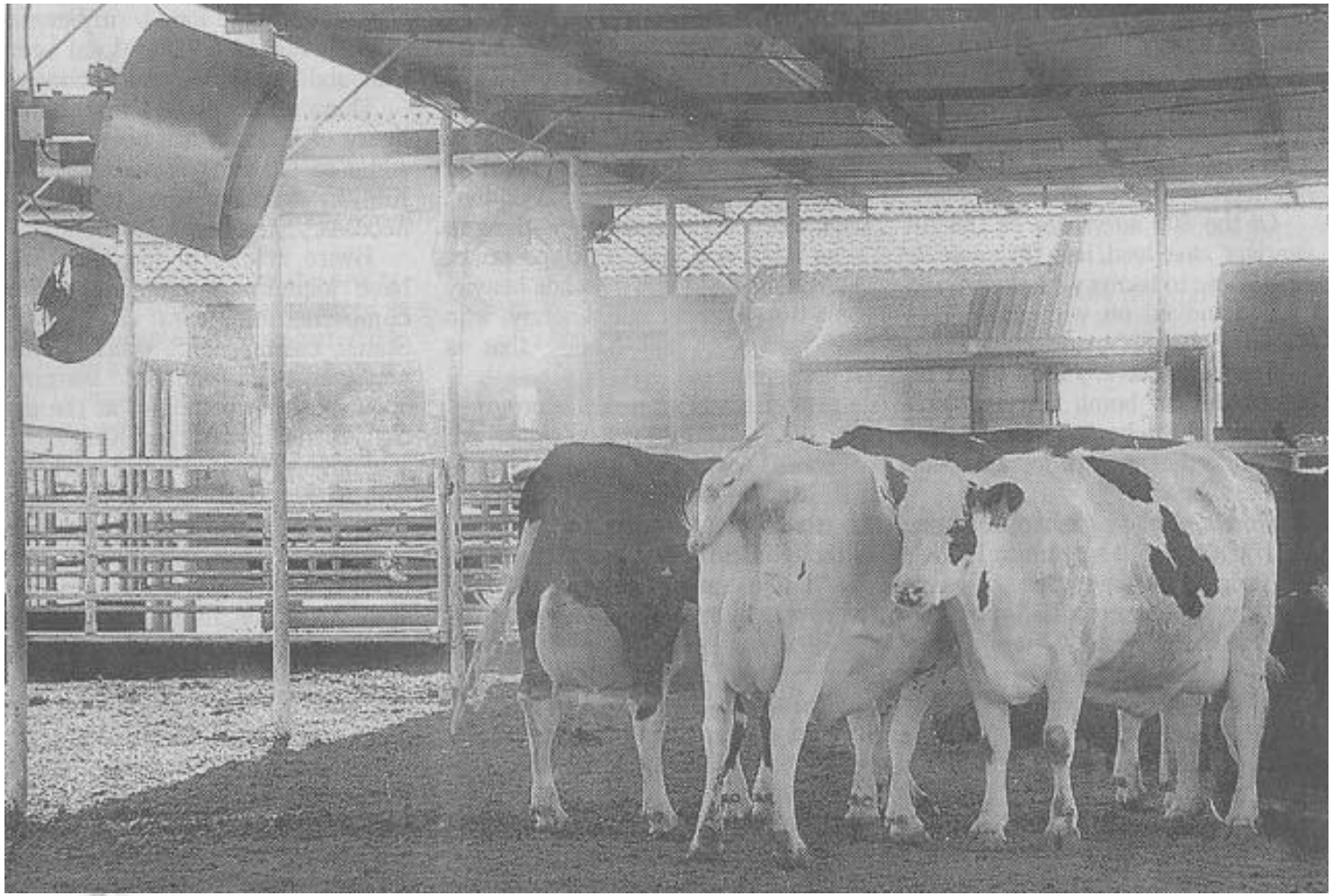
Horizontal airflow fan

Forced Ventilation

Evaporative Cooling: Pad and Fan system

Miss leading information in places other than extremely dry climate zone

Evaporative Cooling: Fogging with fan



Evaporative Cooling

depends on size of water droplet, 3 terms are used:

Fogging
Misting
Spraying

Evaporative Cooling: Fogging for comfort

Temperature affects humidity

- In general, it means Dry bulb Temperature

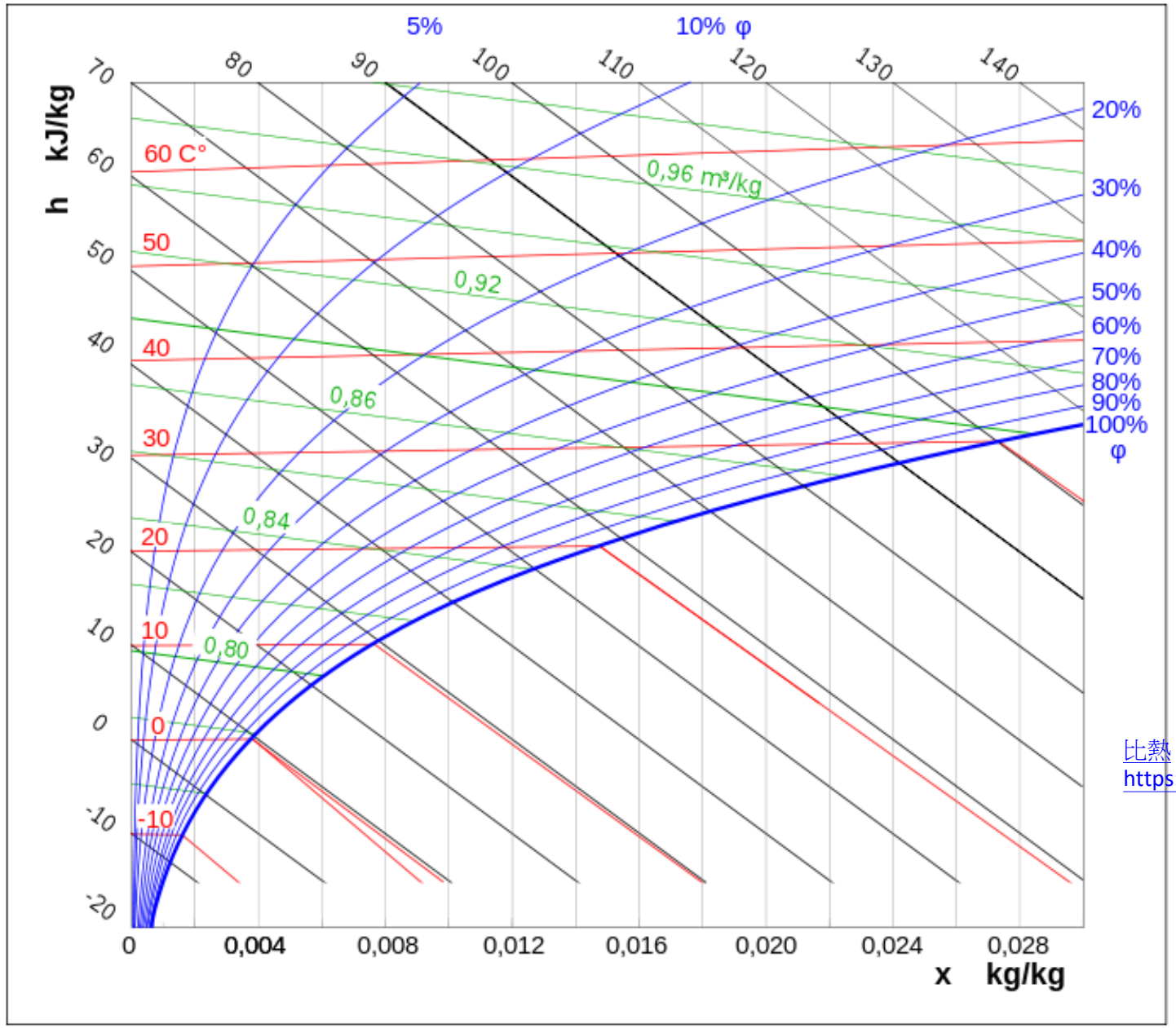
  Affects Relative Humidity

- But there are

  3 types of temperature & 2 types of humidity

The Mollier diagram is a graphic representation of the relationship between air temperature, moisture content and enthalpy.

莫利耳圖



h 熱焓值 (=乾球溫度 when RH=0%)

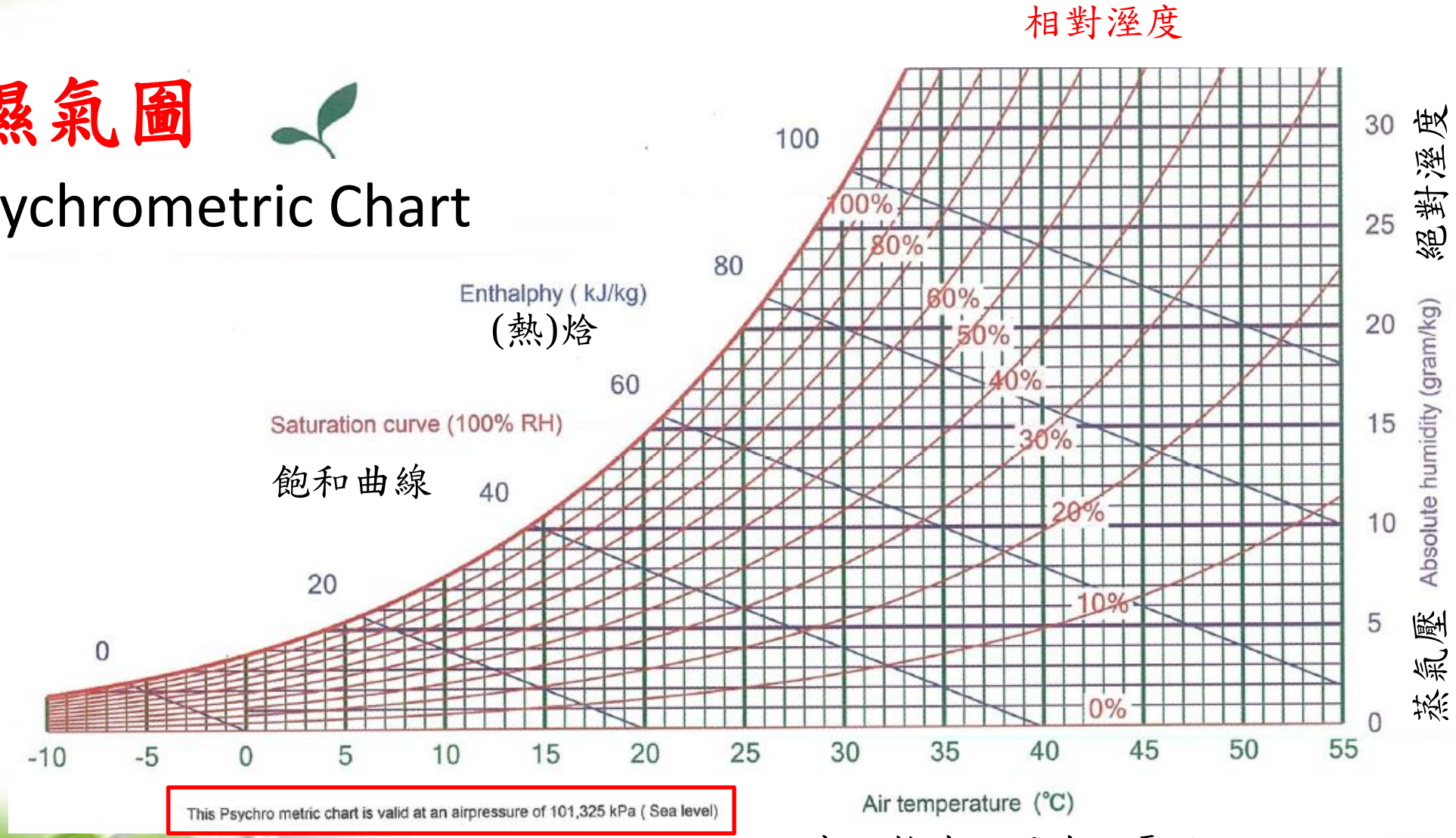
Φ 相對溼度

x 絕對溼度

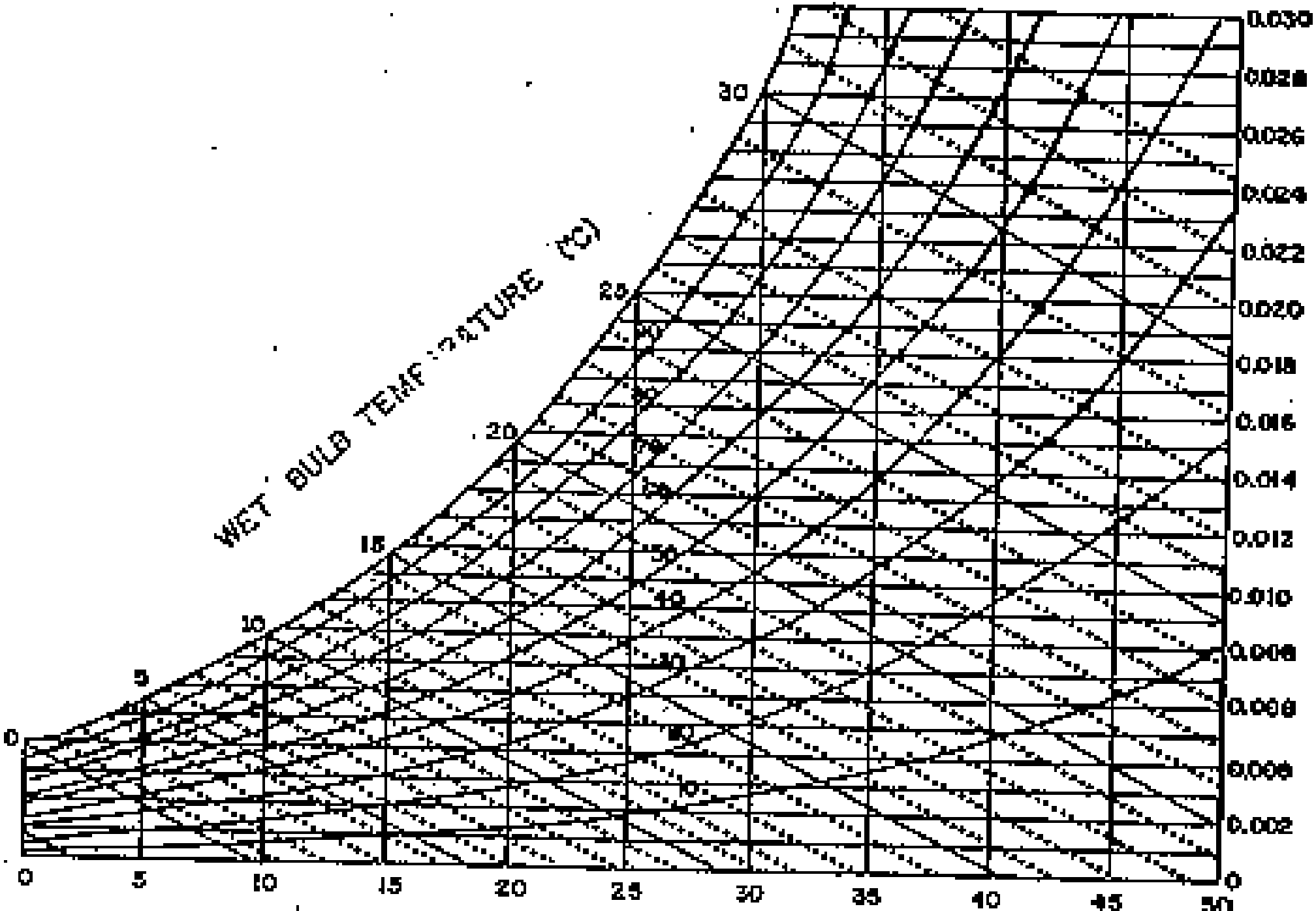
比熱
https://www.engineeringtoolbox.com/air-specific-heat-capacity-d_705.html

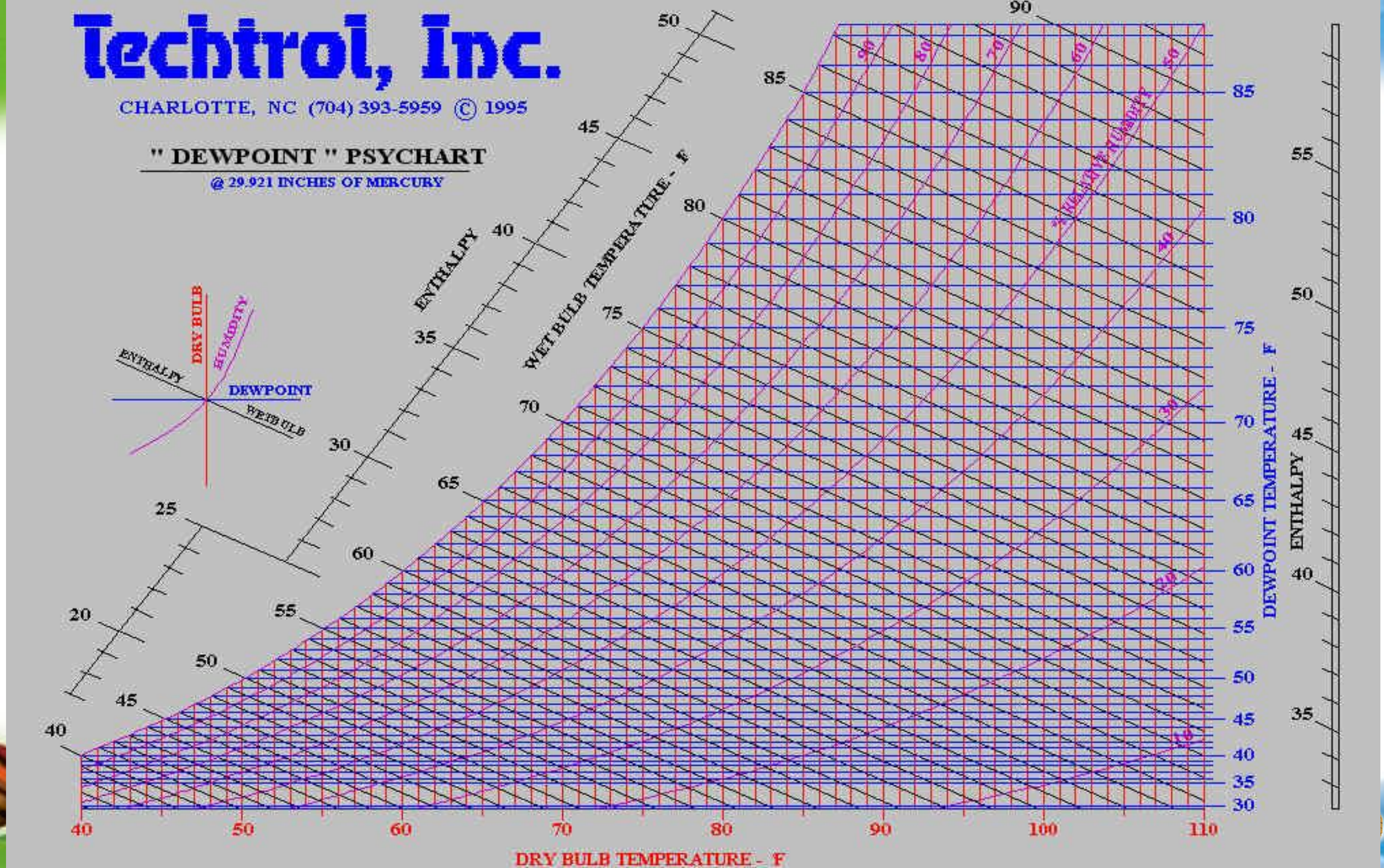
濕氣圖

Psychrometric Chart



溫度：乾球、濕球、露點


WET BULB TEMPERATURE (°C)
0
5
10
15
20
25
30
35
40
45
50
0.030
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0


Techtrol, Inc.
CHARLOTTE, NC (704) 393-5959 © 1995
" DEWPOINT " PSYCHART
@ 29.921 INCHES OF MERCURY
DRY BULB
HUMIDITY
ENTHALPY
DEWPOINT
WETBULB
ENTHALPY
WET BULB TEMPERATURE - F
DEWPOINT TEMPERATURE - F
ENTHALPY
DRY BULB TEMPERATURE - F
40
50
60
70
80
90
100
110

Thermodynamic Properties of moist air

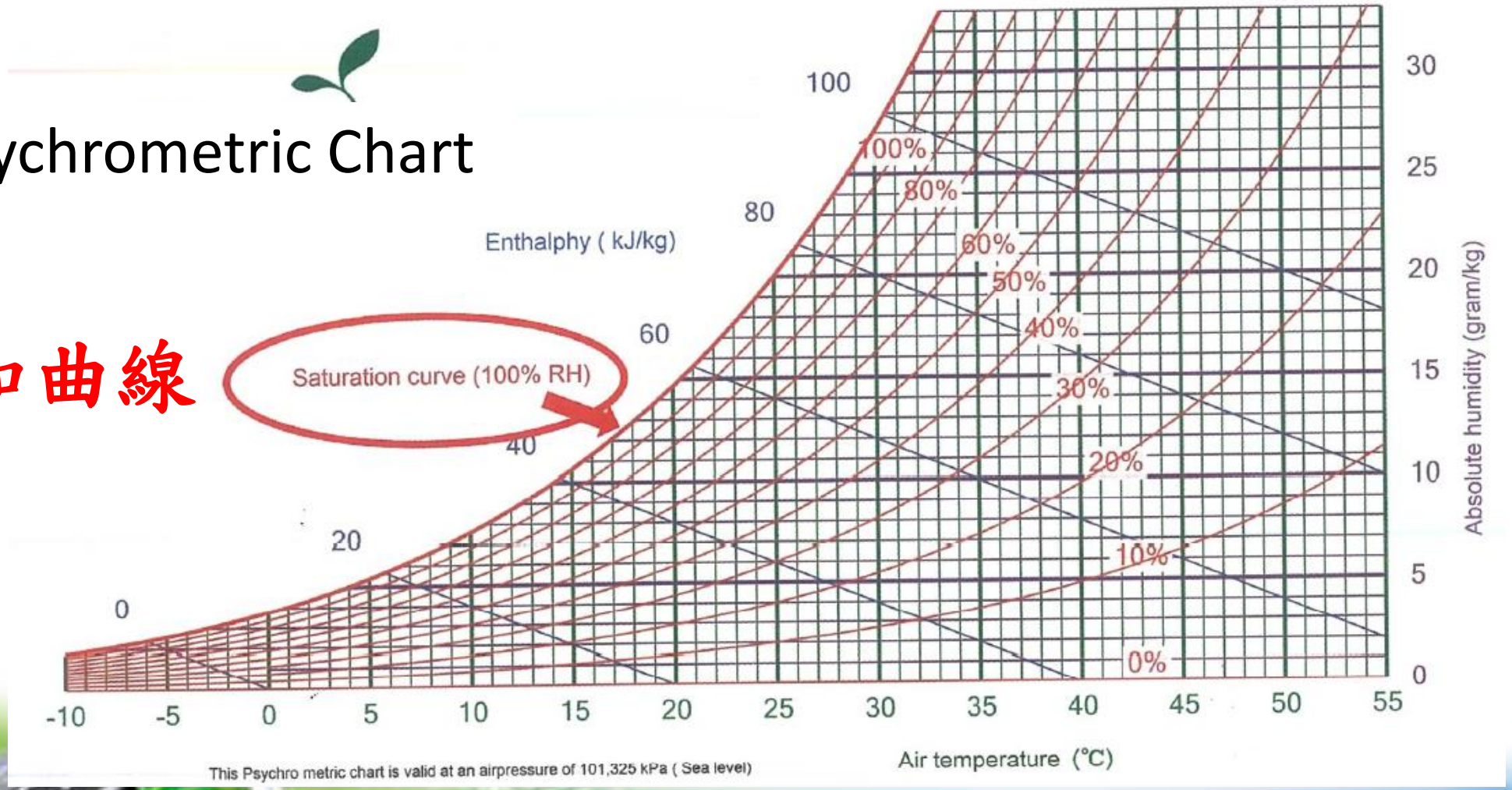
1. 乾球溫度
   dry bulb T
2. 濕球溫度
   wet bulb T
3. 露點溫度
   dew point T
4. 相對溼度
   relative humidity
5. 絕對溼度
   absolute humidity
   (濕度比humidity ratio)
6. 比容 specific volume
7. 熱焓 enthalpy
8. 蒸汽壓vapor pressure
9. 飽和蒸汽壓 saturated vapor pressure

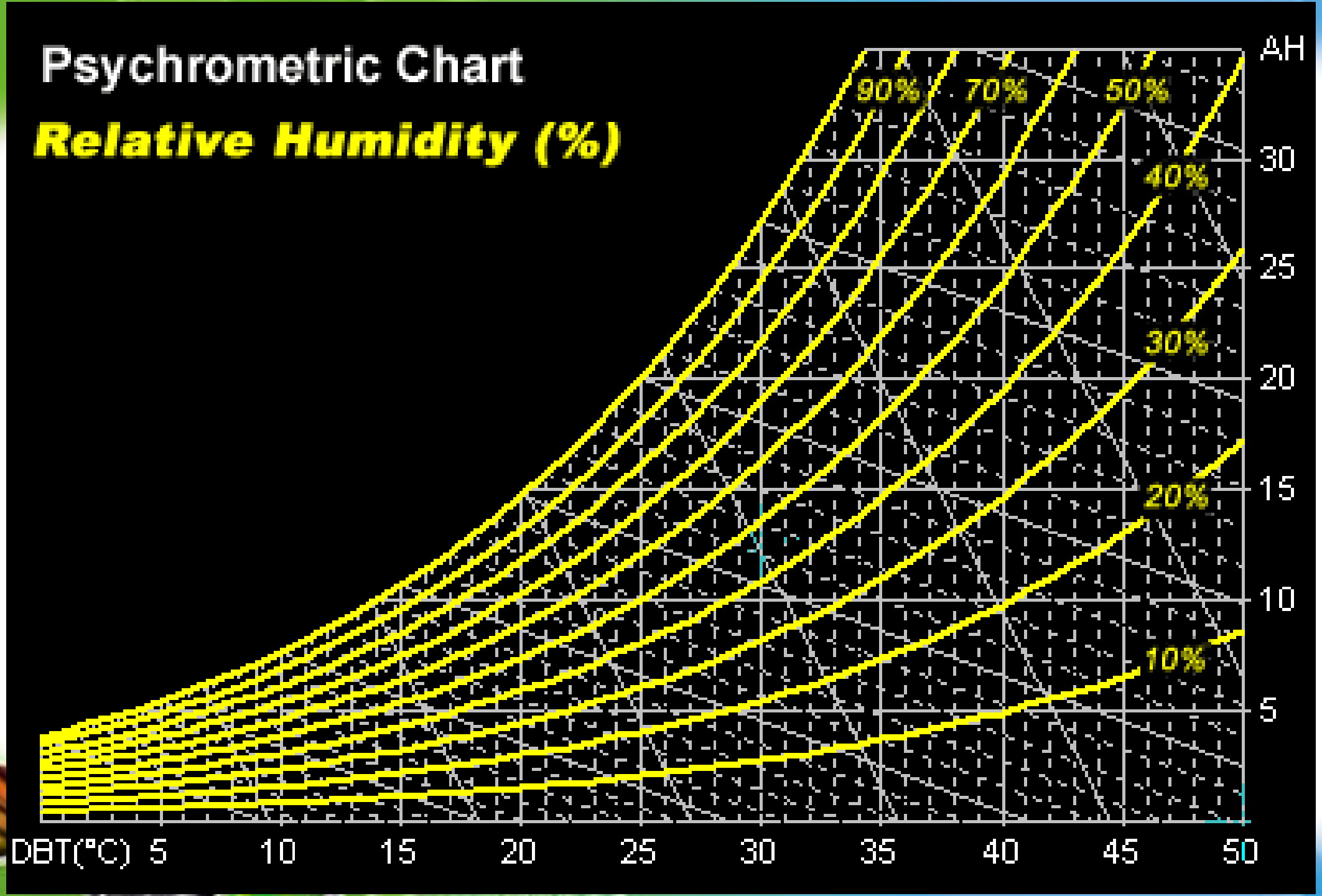
特定溫度之空氣最大水蒸汽含量(=飽和)，單位g/kg。

在飽和點時，空氣是霧狀，當溫度下降，超過飽和點，水蒸汽凝結及降雨。

Psychrometric Chart

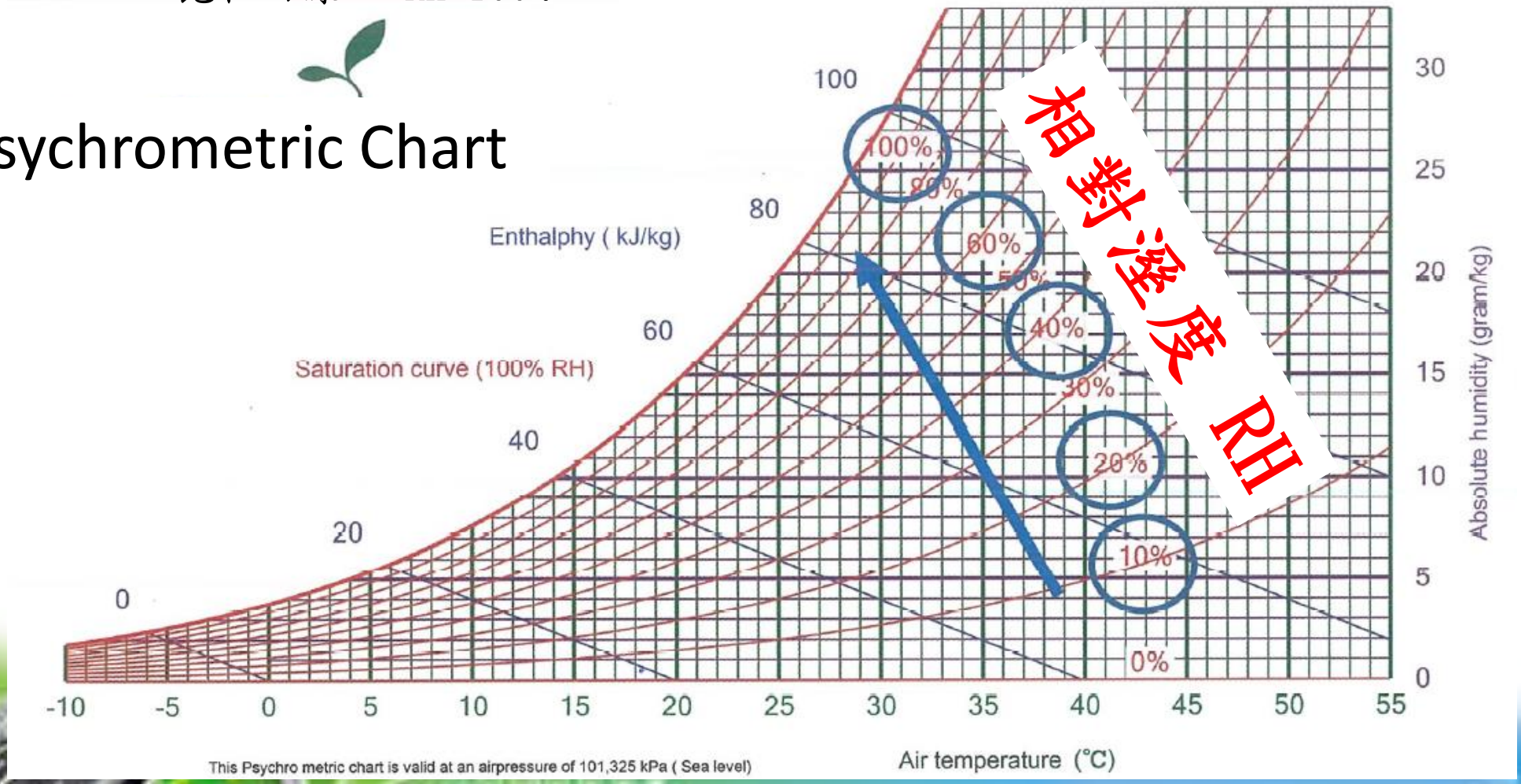
飽和曲線



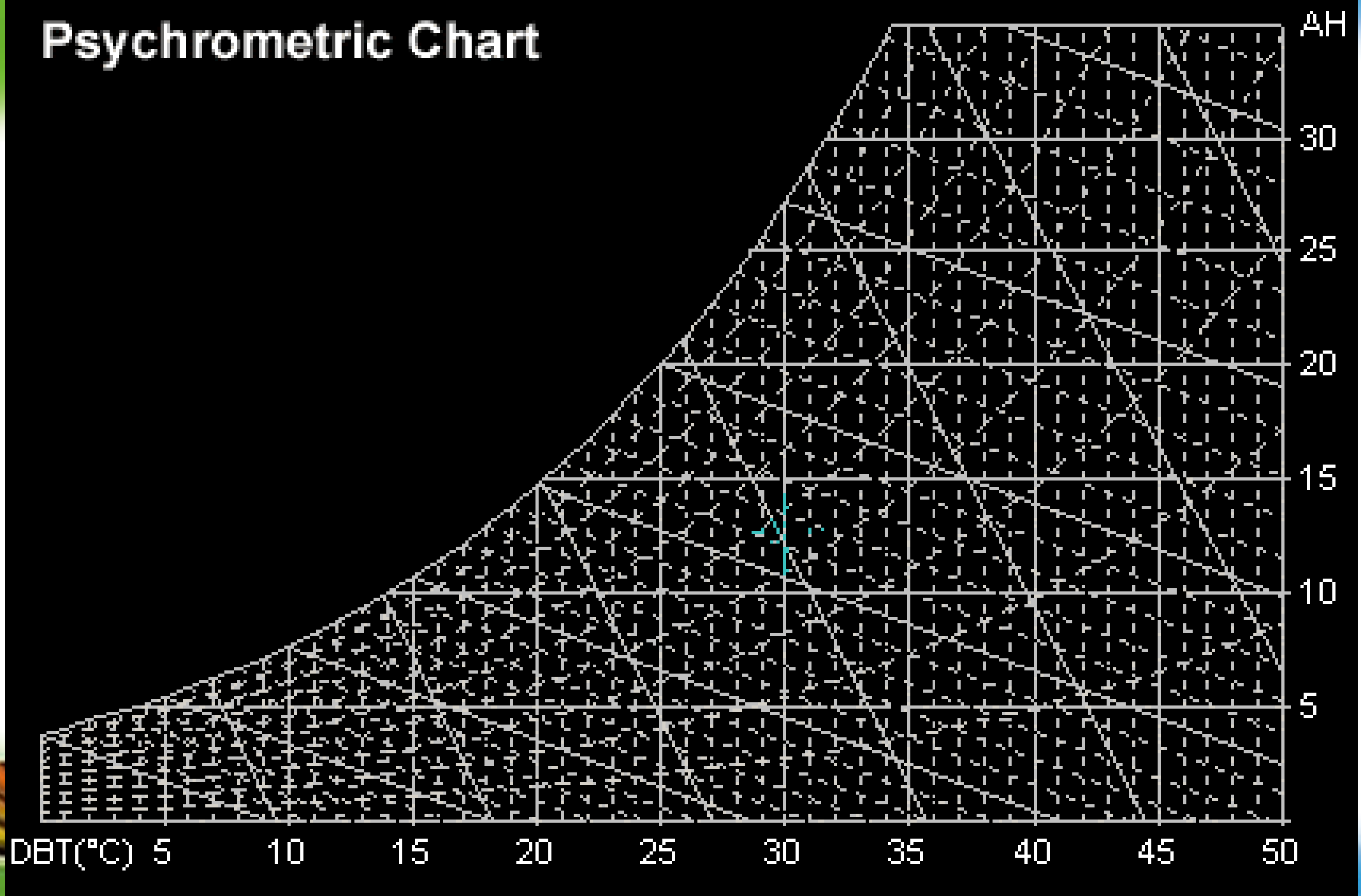

Psychrometric Chart
Relative Humidity (%)
90%
70%
50%
40%
30%
20%
10%
AH
30
25
20
15
10
5
DBT(°C) 5
10
15
20
25
30
35
40
45
50

- 特定溫度下空氣的水蒸汽壓 飽和比例
- 溫度20°C時、AH最大含量14.7g/kg。若真實的AH=10.0g/kg，RH=10.0/14.7 x 100% = 68%
- 飽和曲線 = RH 100%

Psychrometric Chart



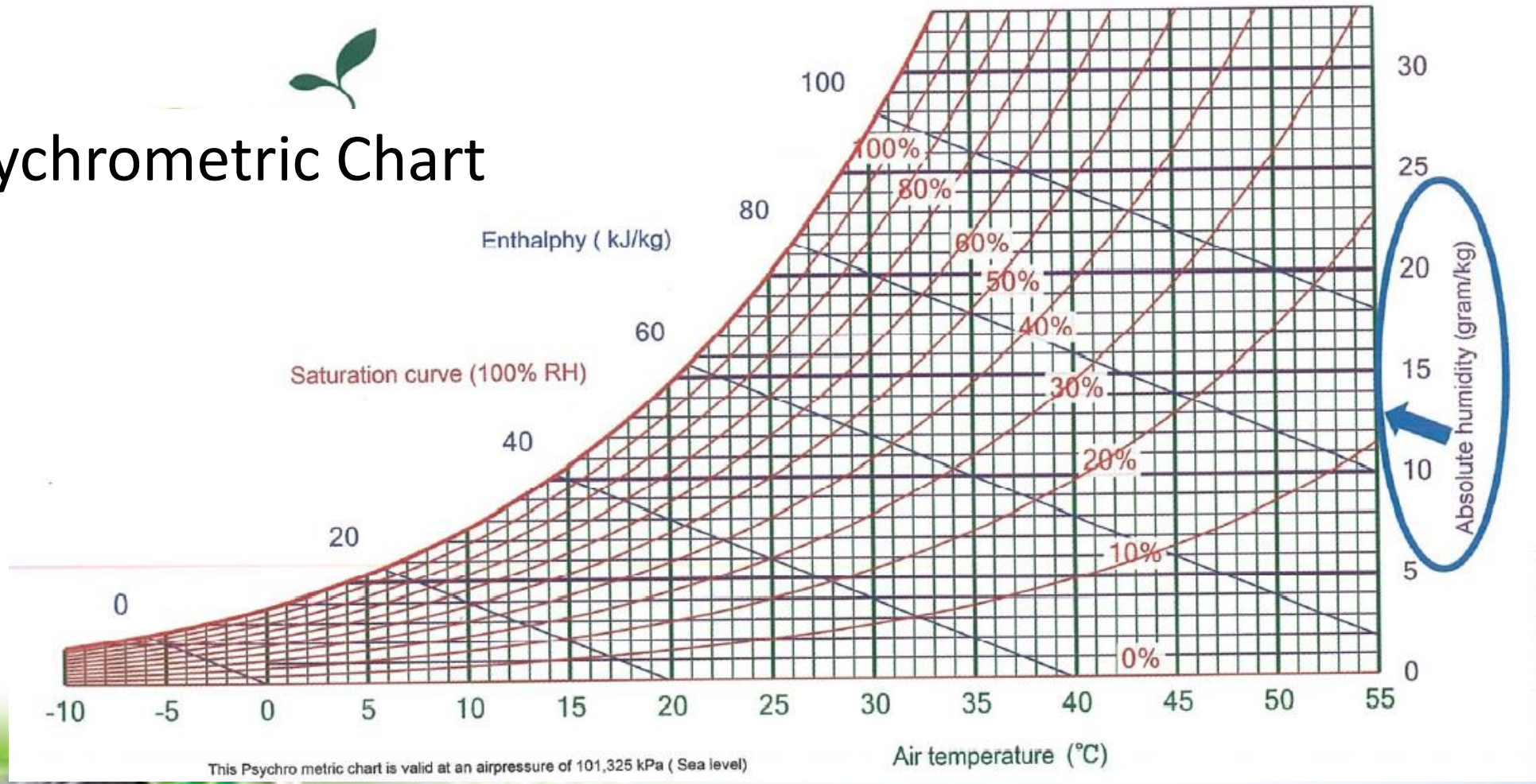
Psychrometric Chart



乾空氣含有的水蒸汽量

單位 g/kg or g/m^3

Psychrometric Chart

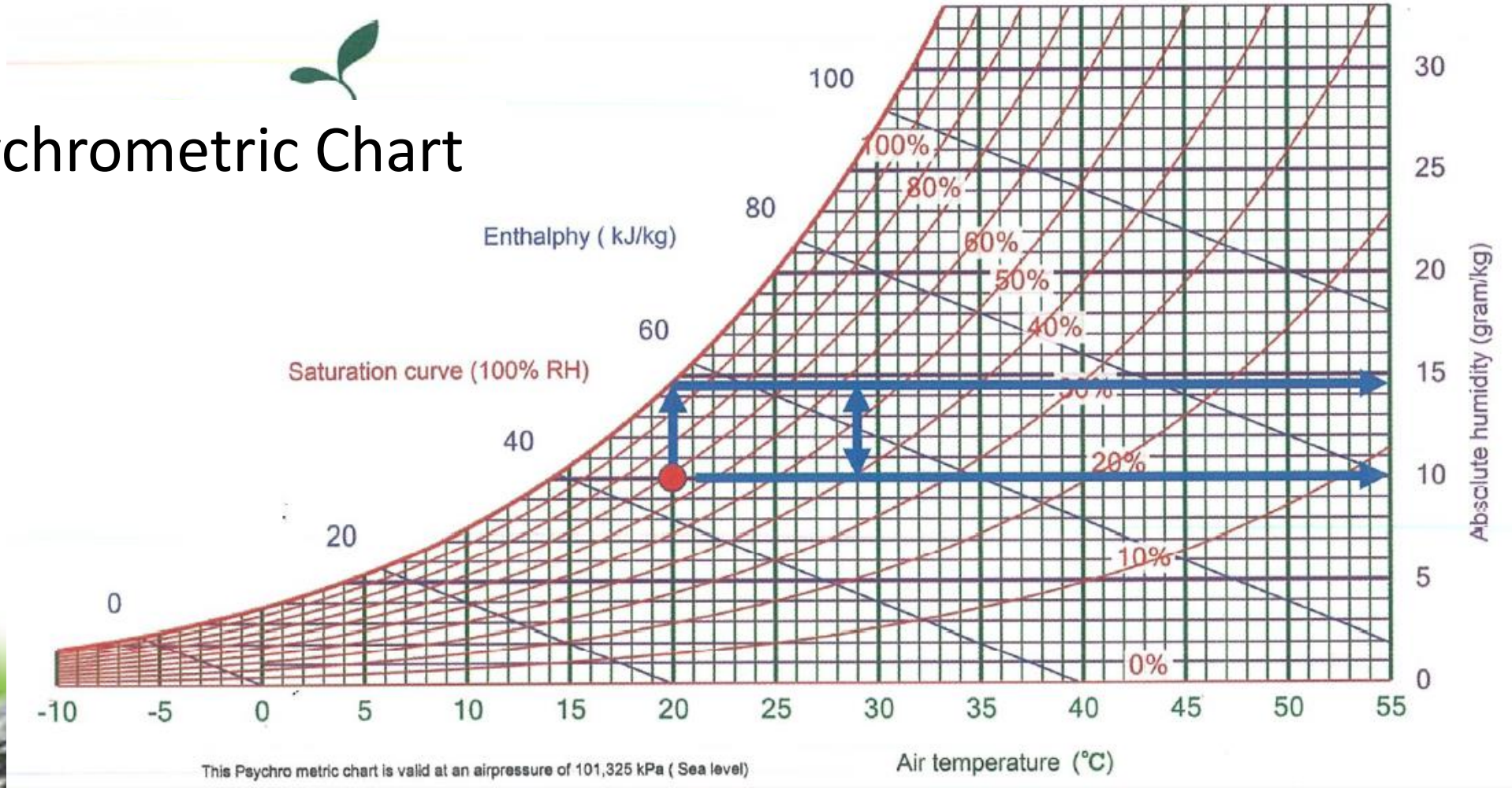


絕對溼度 AH

飽差 HD

- 園藝界常用，用來表達空氣中還可吸收的水蒸汽量，亦即植物可繼續蒸散的空間，單位有 g/m^3 air & g/kg air。
- 溫度20°C時、AH 最大含量14.7 g/kg、真實的 AH=10.0 g/kg，
  HD = 14.7-10.0 = 4.7 g/kg = 5.6 g/m^3

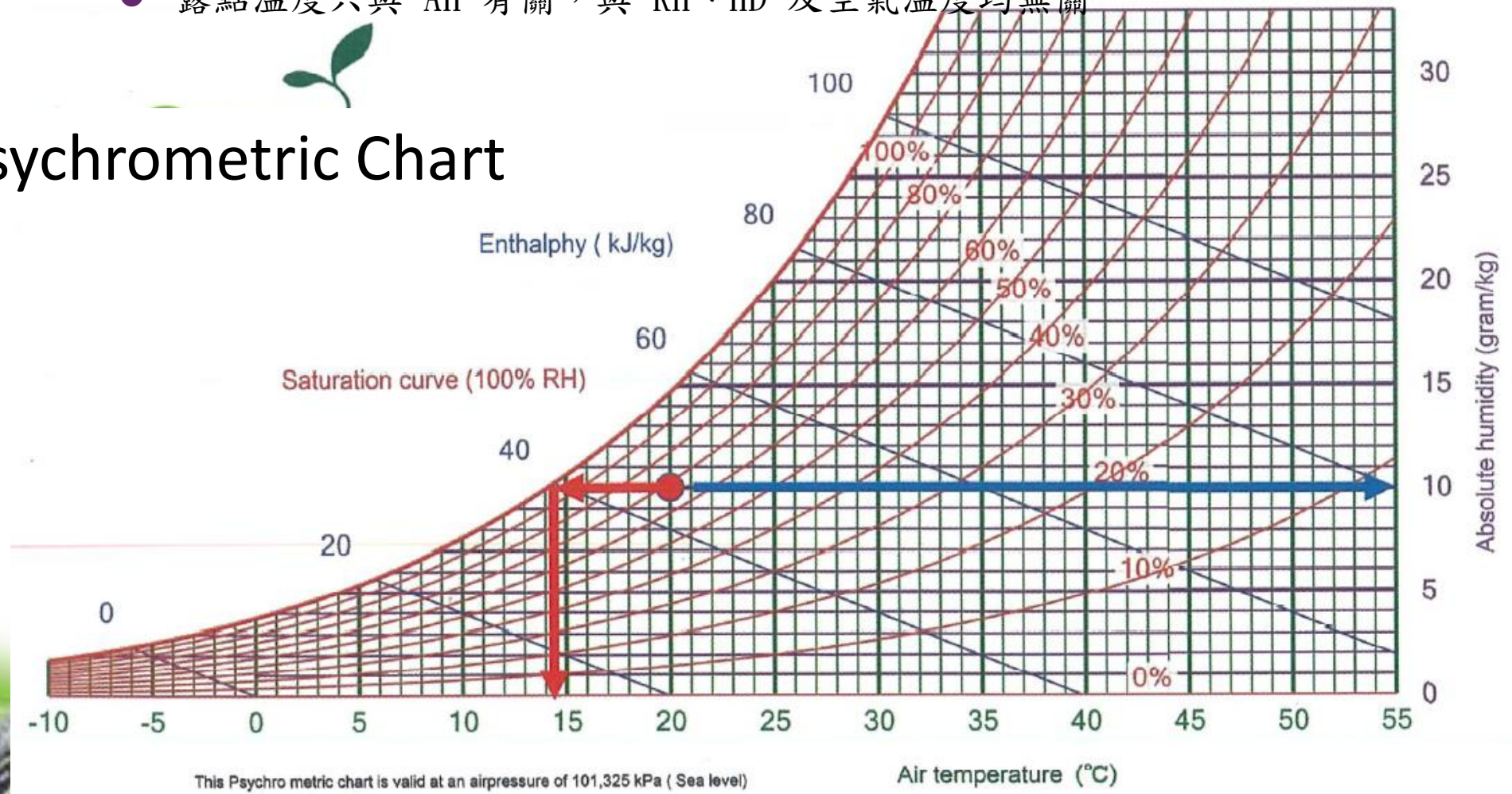
Psychrometric Chart



露點溫度

- 特定的AH下，持續降溫直到飽和時的溫度
- 例如AH = 10.0 g/kg，露點溫度是 14.1°C
- 物體表面開始結露(凝結)的溫度。例如: 淋洗熱水澡時，AH增加、露點溫度也會增加。當露點溫度超過鏡子表面溫度時，就會出現凝結水
- 露點溫度只與 AH 有關，與 RH、HD 及空氣溫度均無關

Psychrometric Chart



空氣焓值（空氣含有的熱量）

- 單位:kJ/kg。包含顯熱及潛熱兩部分

- 顯熱: 1kg空氣從0°C加熱至真實溫度所需要的熱量

  空氣的比熱 Cp = 1 kJ/kg.K

  比熱
  https://www.engineeringtoolbox.com/air-specific-heat-capacity-d_705.html

- 潛熱: 液體水蒸發變成水蒸汽所需要的熱量

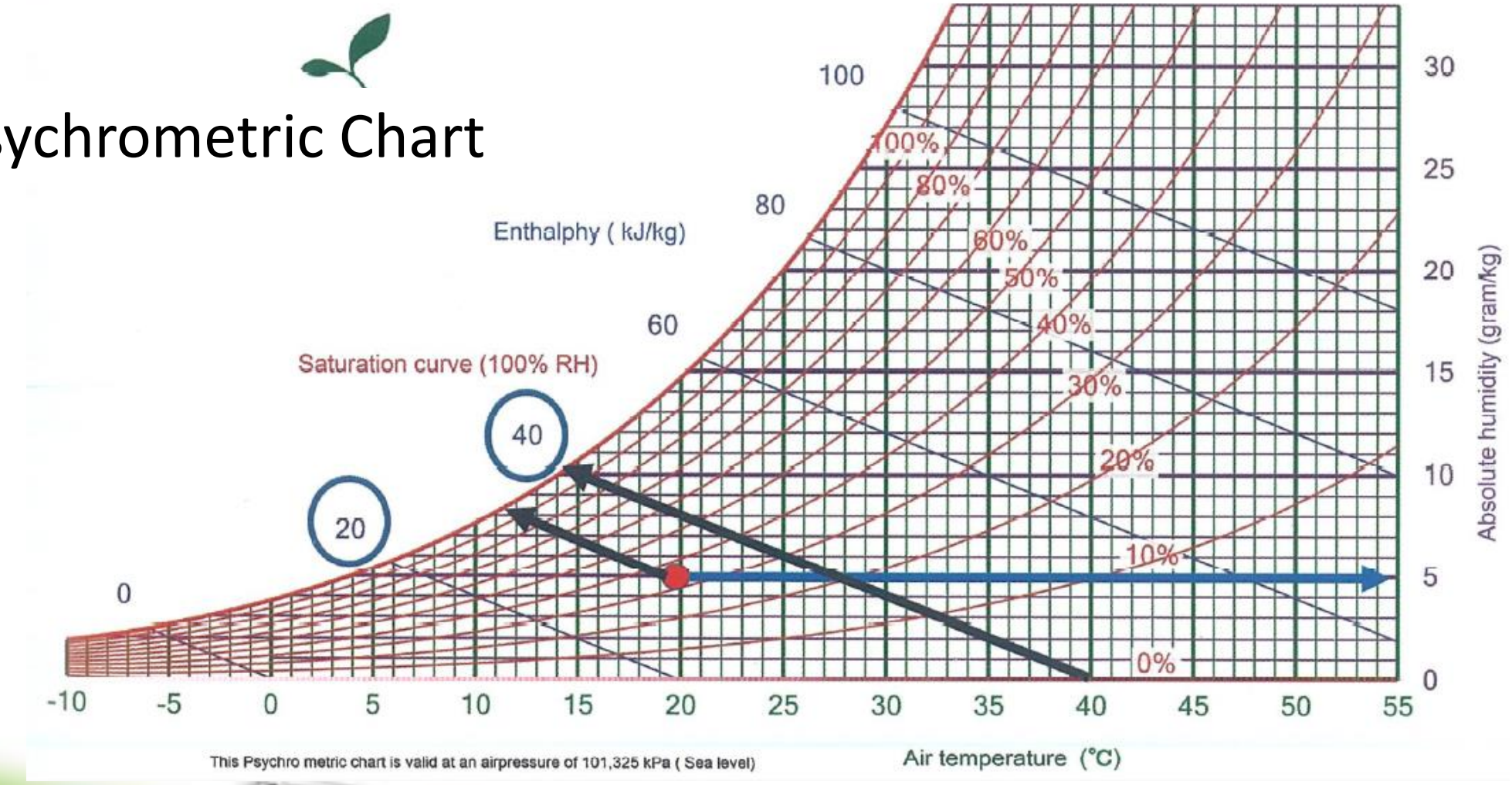
  水的蒸發潛熱約為2500 kJ/kg

- 焓值計算: 20°C 1 kg 空氣含有 5 g 水蒸汽

  空氣焓值 = (20 x 1) + (0.005 x 2500) = 32.5 kJ/kg

熱焓值

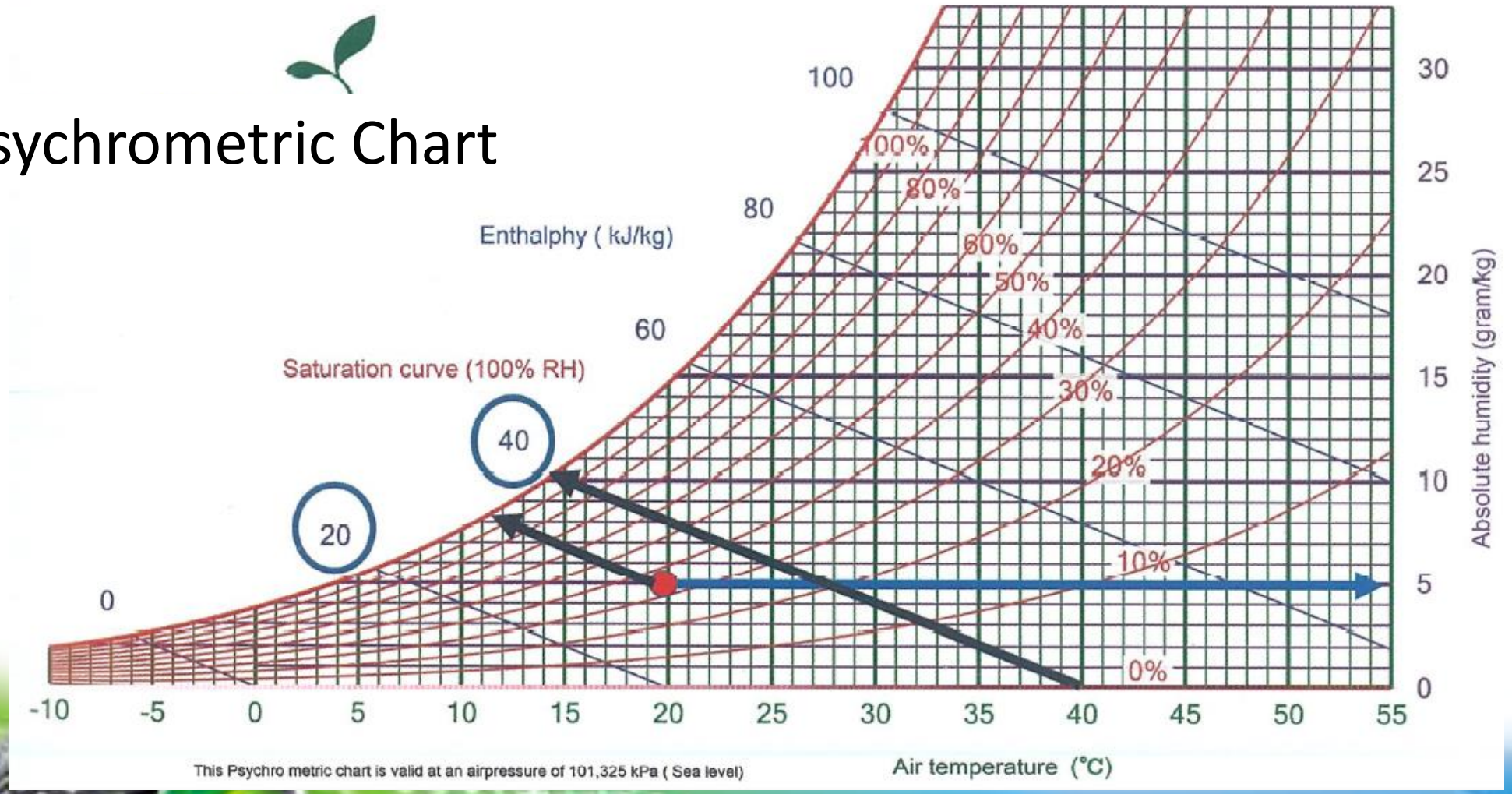
Psychrometric Chart



Adiabatic line（絕熱）（希臘語：adiábatos，不可通行）

- 將空氣溫度及水蒸汽加總後有相同的焓值
- 如 40 kJ/kg = 40°C, 0 g/kg 到 15°C, 10 g/kg 都有相同的總焓值

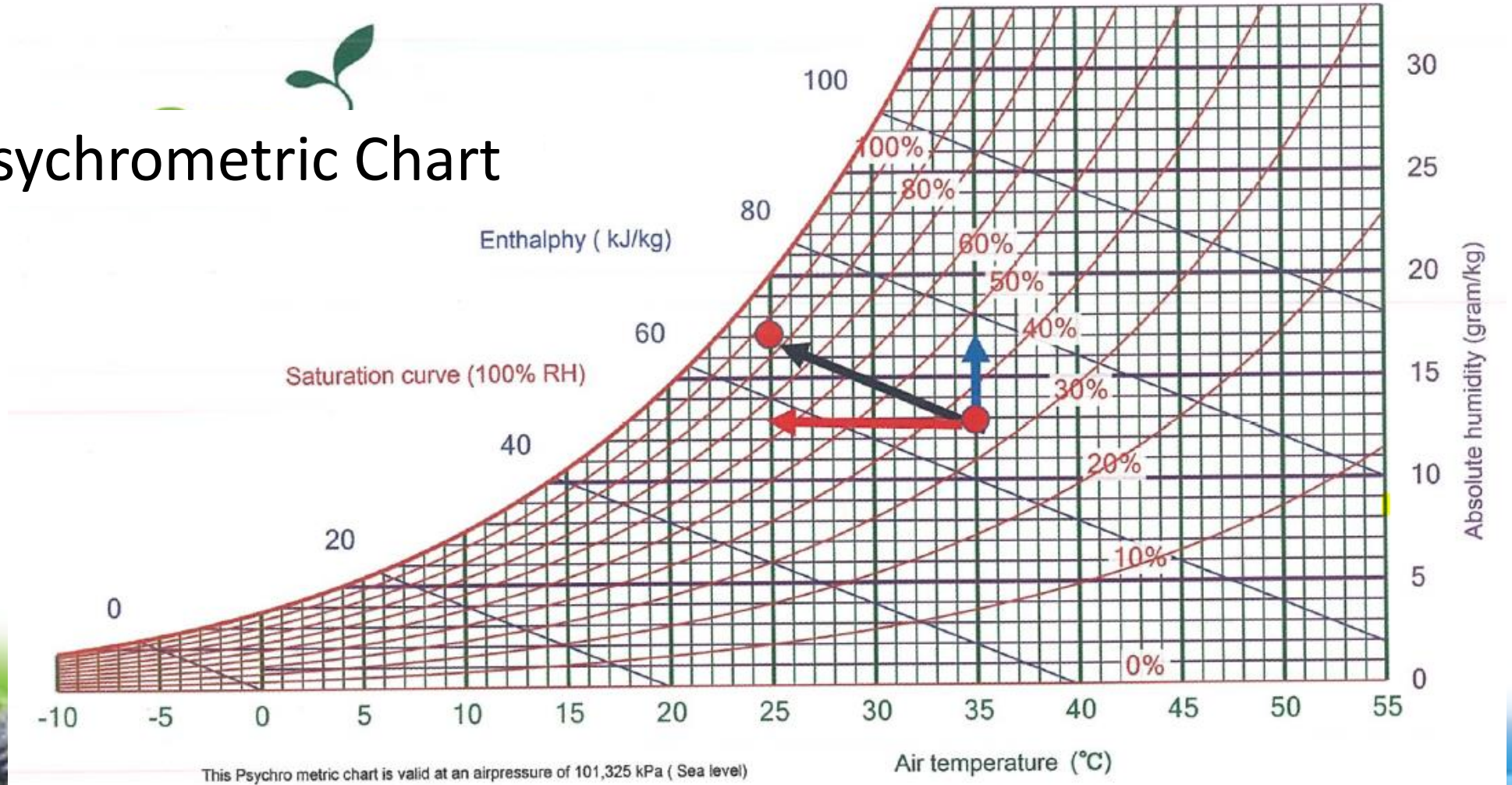
Psychrometric Chart



絕熱冷卻 (Adiabatic cooling)/蒸發冷卻 (Evaporative cooling)

- 噴霧可以降溫，過程中液態水會蒸發成水蒸汽，並增加空氣中的潛熱。空氣中的熱量會被吸收，因此顯熱會減少相同的熱量。這過程叫做絕熱冷卻，因為總焓值是沒有改變的。這也是能量守恆。
- 1 kg 空氣噴 4 g 霧，假設完全蒸發，溫度 35°C可降溫至25°C。
  顯熱的減少量 = (35-25) x 1 = 10 kJ = 0.004 kg x 2500 kJ/kg = 增加的潛熱量

Psychrometric Chart



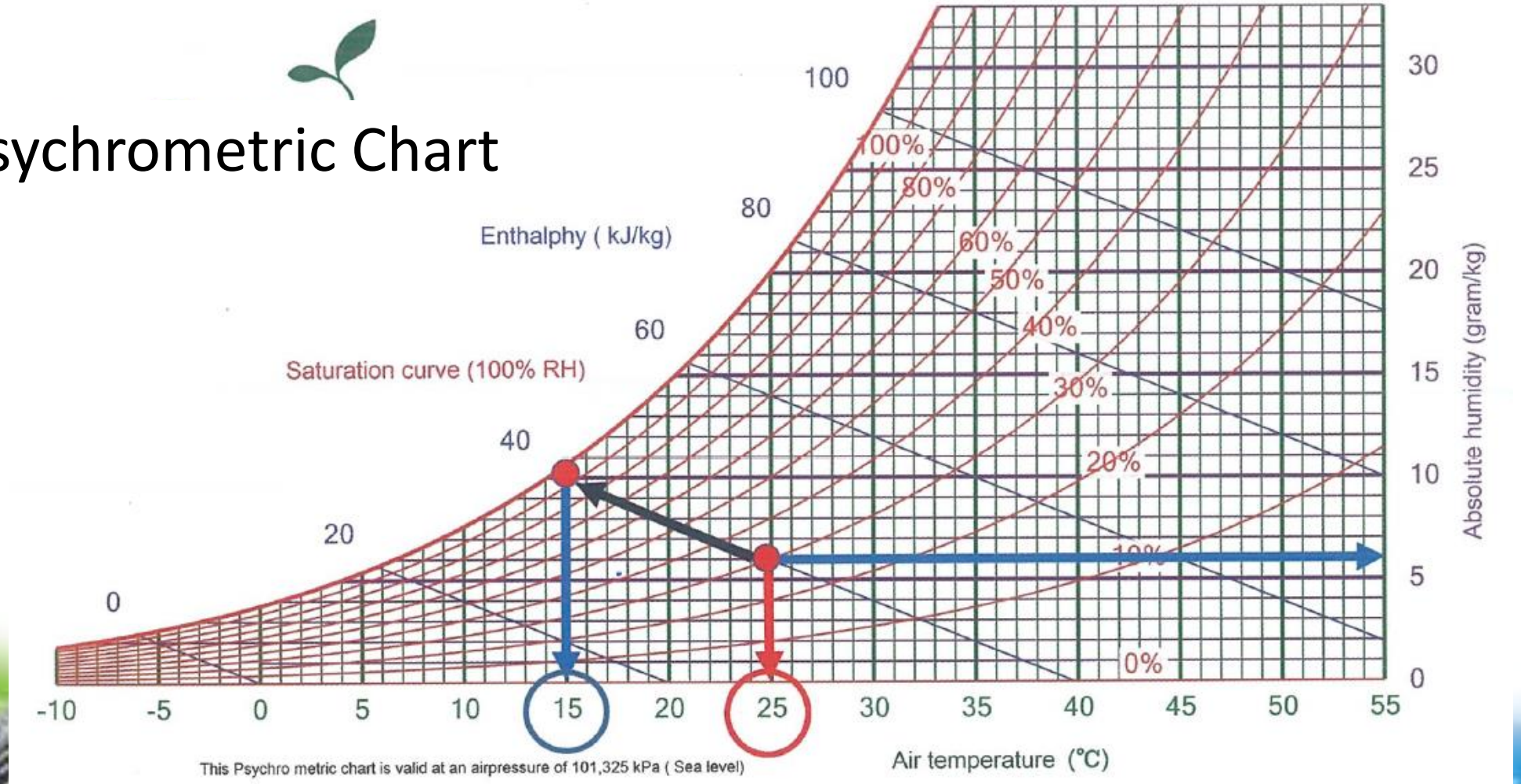
- 日照強烈時、植物蒸散作用對維持溫室低溫是非常重要的

- 假設戶外日照強度1000 W/m^2，進入溫室內光線是800 W/m^2 = $J/m^2.s$，所以一小時的熱量有800 x 60 x 60 /1000 = 2520 $kJ/m^2.h$.

- 2520 $kJ/m^2.h$.熱量，會讓溫室溫度上升至無法接受的溫度，但只要植物蒸散及土壤蒸發 1 $kg/m^2.h$的水，即可平衡此溫度

溼球溫度

- 透過蒸發方式空氣溫度可以下降，直到飽和點。這個點也是飽和曲線與絕熱線的交會點，亦即溼球溫度。
- 例如: 25°C 空氣中有 6 g/kg 水蒸汽，在達到絕熱線與飽和曲線交叉點前，可容納 4 g/kg 水，查表 X 軸溫度 15°C，即是溼球溫度。



大氣壓力 & 比質量（比重）

- 溫度及大氣壓力決定了空氣的比重，因此濕氣圖的值也會與大氣壓力有關

- 一般濕氣圖顯示的是海平面位置大氣壓力的狀態 (一大氣壓) 0.101 MPa, 101.325 kPa or 1013.25 hPa (百帕)，後者通常使用於氣象。1 hPa = 1 millibar。
  但也有濕氣圖會標出海拔，如 500, 750,1000 m。

乾空氣和濕空氣的比質量(比重)

- 冷空氣會比熱空氣重。當空氣加熱時，會膨脹及密度變輕，因此溫暖空氣會向上移動。很多人以為水比空氣重，所以濕空氣比乾空氣重，聽起來合理，但這是錯的理解。
  - ✓ 水蒸汽H_2O分子量=18 g/mol
  - ✓ 乾燥空氣分子量=28.8 g/mol（20% O_2分子量=32 g/mol + 80% N_2分子量 = 28 g/mol）

- 如果乾燥空氣中添加水蒸汽，比較輕的 H_2O 分子會取代質量較重的 O_2 & N_2 分子，因此空氣與水蒸汽的混合物比重會變輕。這也是為什麼烏雲在天空中會浮在更高位置，而不是沉降。

- 因此，除了風之外，溫度與濕度對空氣比重的交互影響，也會促進溫室空氣經由通風口與戶外空氣的氣體交換。

Vapor pressure difference vs. vapor pressure deficit

- 雖然濕氣圖並未顯示水蒸汽的分壓，但 VPD 因為涉及植物蒸散作用及氣孔行為是很重要的概念，所以在這個部分來討論會比較方便。

- 因為空氣中的水蒸汽被視為與氧氣&氮氣一樣的氣體，因此分壓單位是 kPa。
  1 Pascal= 1 Newton per m^2 (N/m^2)

- 水蒸汽分壓與空氣中的水分子濃度成正比，可用 mol/m^3表達，也會與 AH (g/m^3) 成正比。

- 結果，依據濕氣圖飽和曲線，空氣溫度決定了水蒸汽分壓最大值。

例如，30°C，空氣中水蒸汽達到飽和時，分壓最大值是4.25 kPa，此時 AH = 27.15 g/kg，RH = 100%。（海平面大氣壓力是101.325 kPa）

- VPD有兩種不同意義，容易混淆:

1. Vapor Pressure Difference: 葉片內的水蒸汽分壓與溫室空氣水蒸汽分壓的差異
   。VPD 只能透過量測葉片溫度來計算，葉片(氣孔的空間內) RH會假設是100%

For example: if plant leaf temperature is 25 °C, then VP inside the leaves (RH = 100 %) equals 3.17 kPa.

Let air temperature be 24 °C and RH = 70 %, then VP is 2.09 kPa.
Thus VPD (difference) = 3.17 – 2.09 = 1.08 kPa.

因此 VPD 是水蒸汽透過氣孔從葉片蒸散至空氣中的結果

2. Vapor Pressure Deficit: 溫室空氣中相同溫度下最大的水蒸汽分壓 (RH = 100%) 與實際水蒸汽分壓的差異

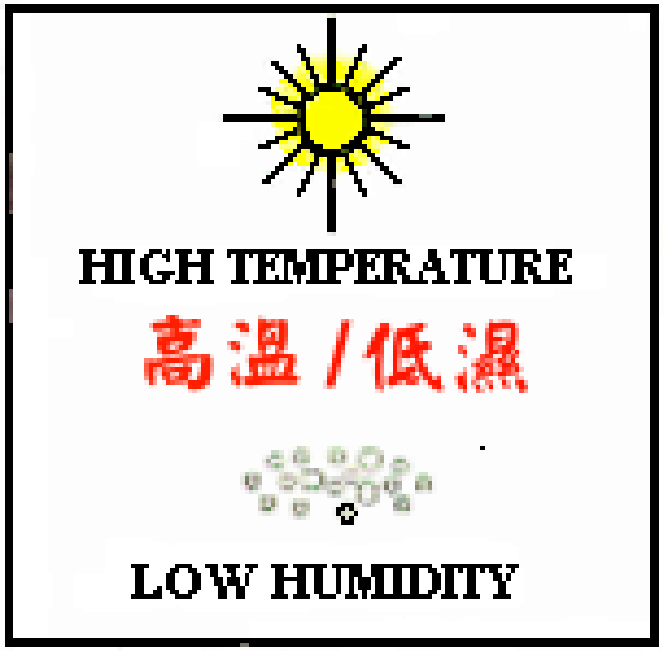
For example: if air temperature = 30 °C and RH = 70 % then actual VP = 2.97 kPa. If RH were 100 % at the same temperature VP max = 4.25 kPa
So VPD (deficit) equals 4.25 – 2.97 = 1.28 kPa.

- VP difference = VP deficit，當葉溫 = 氣溫
  但大多數情況下，葉溫≠氣溫

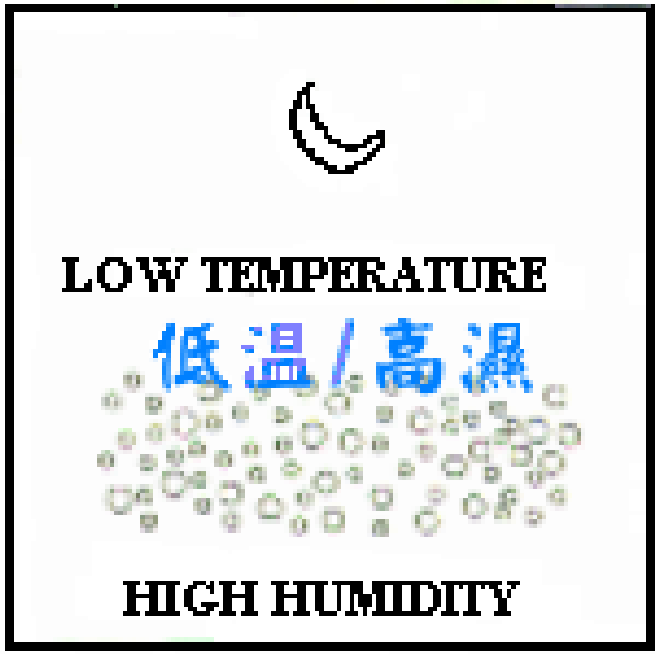
- 為了避免誤解，有時候將量測葉片溫度計算出的 VP difference 用 VPD-plant來表示。

- 或是以 VPD_{air} & $VPD_{leaf\text{-}air}$ 來區分

Daily variation of T and RH

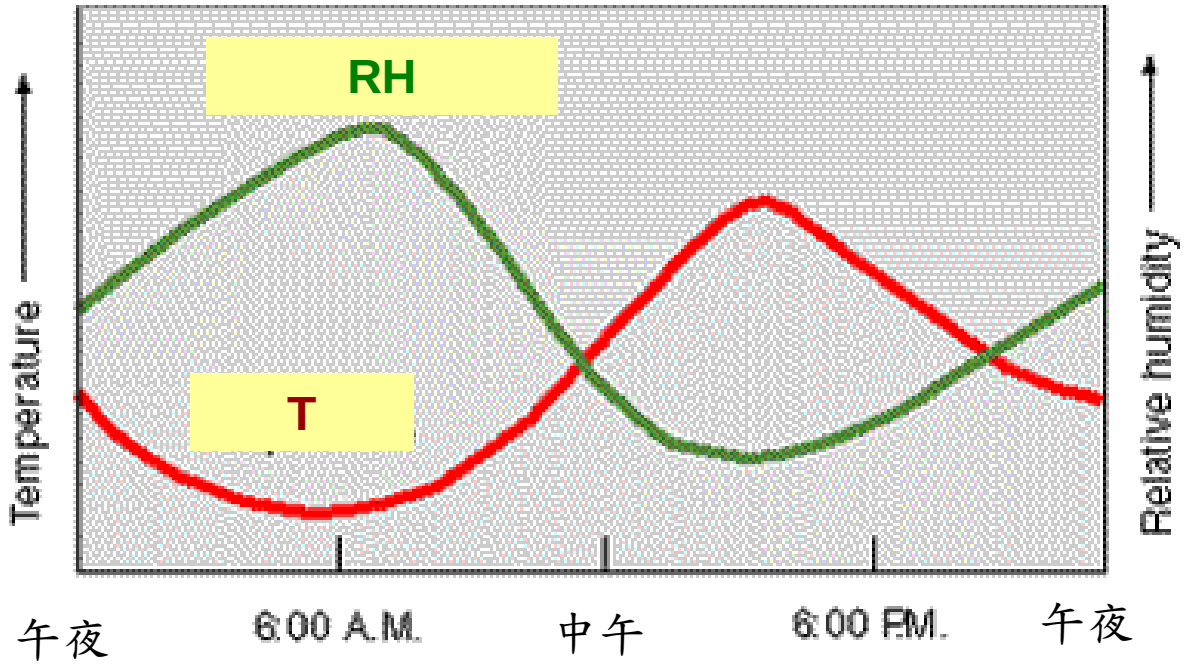


白 DAY 天



夜 NIGHT 晚

High T Low RH occurs at the same time



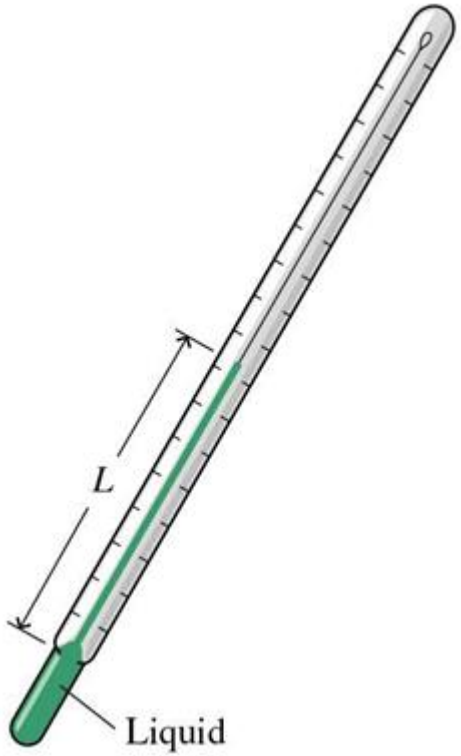
Which one is wrong

Low T
High RH

High T, high RH

High T
Low RH

Dry bulb Temperature, T_{db}



Relative Humidity, RH

- Ratio of the vapor pressure (VP) of the moist air vs. saturated VP of the moist air at the same T_{db}. in %
- Saturated moist air means moist air at 100% RH

- Air at higher temperature can absorb more water vapor
- Moist air at same temperature, one with higher RH has less capacity left to absorb water vapor.

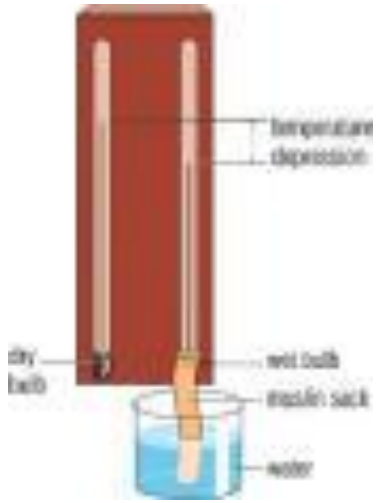
Wet Bulb Temperature, T_{wb}

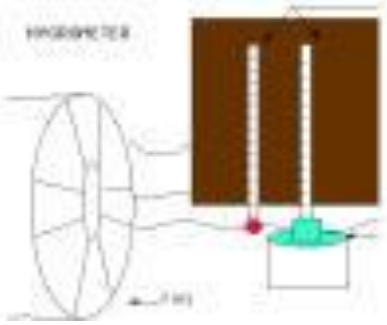
Require device to measure RH

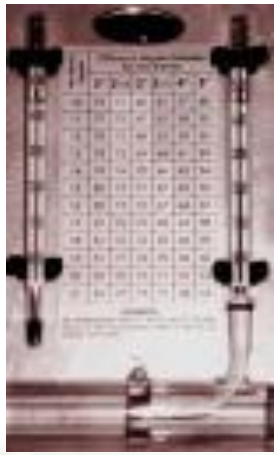
Without device,

RH can be derived from given T_{db} and T_{wb}

Dry and Wet Bulb Temperature

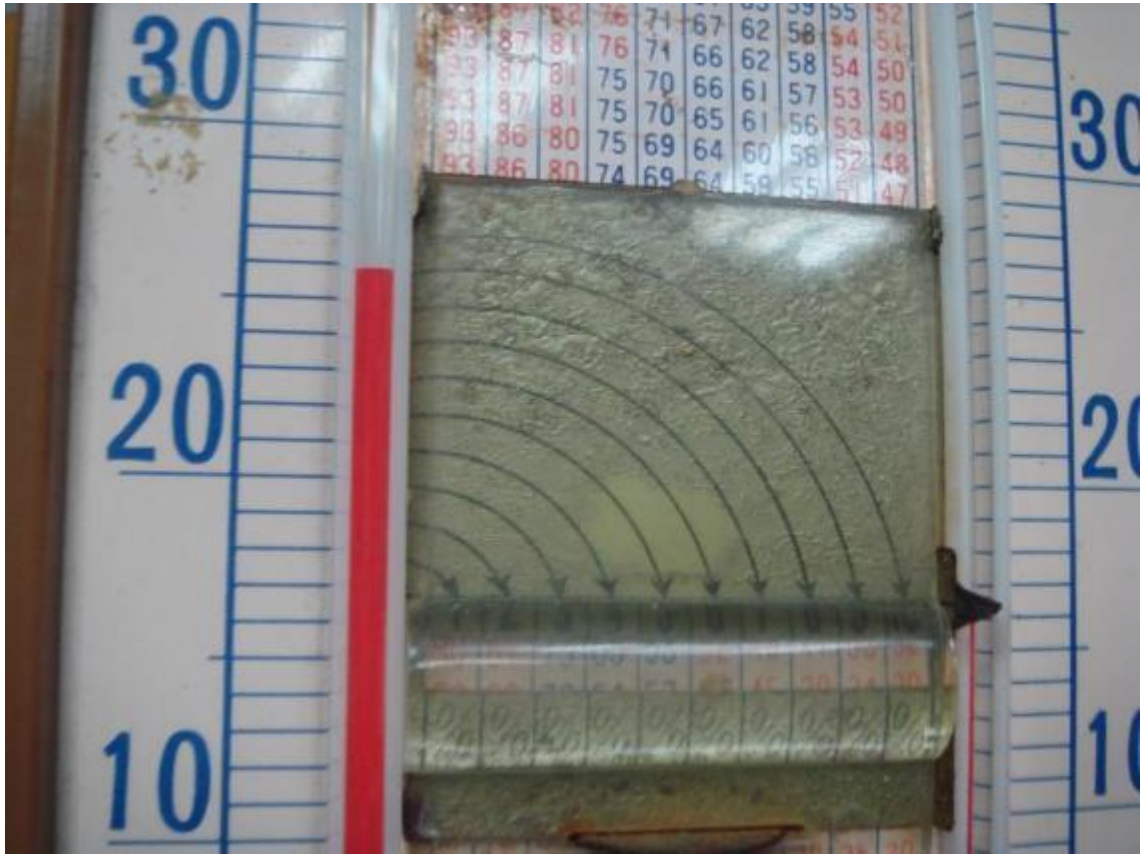


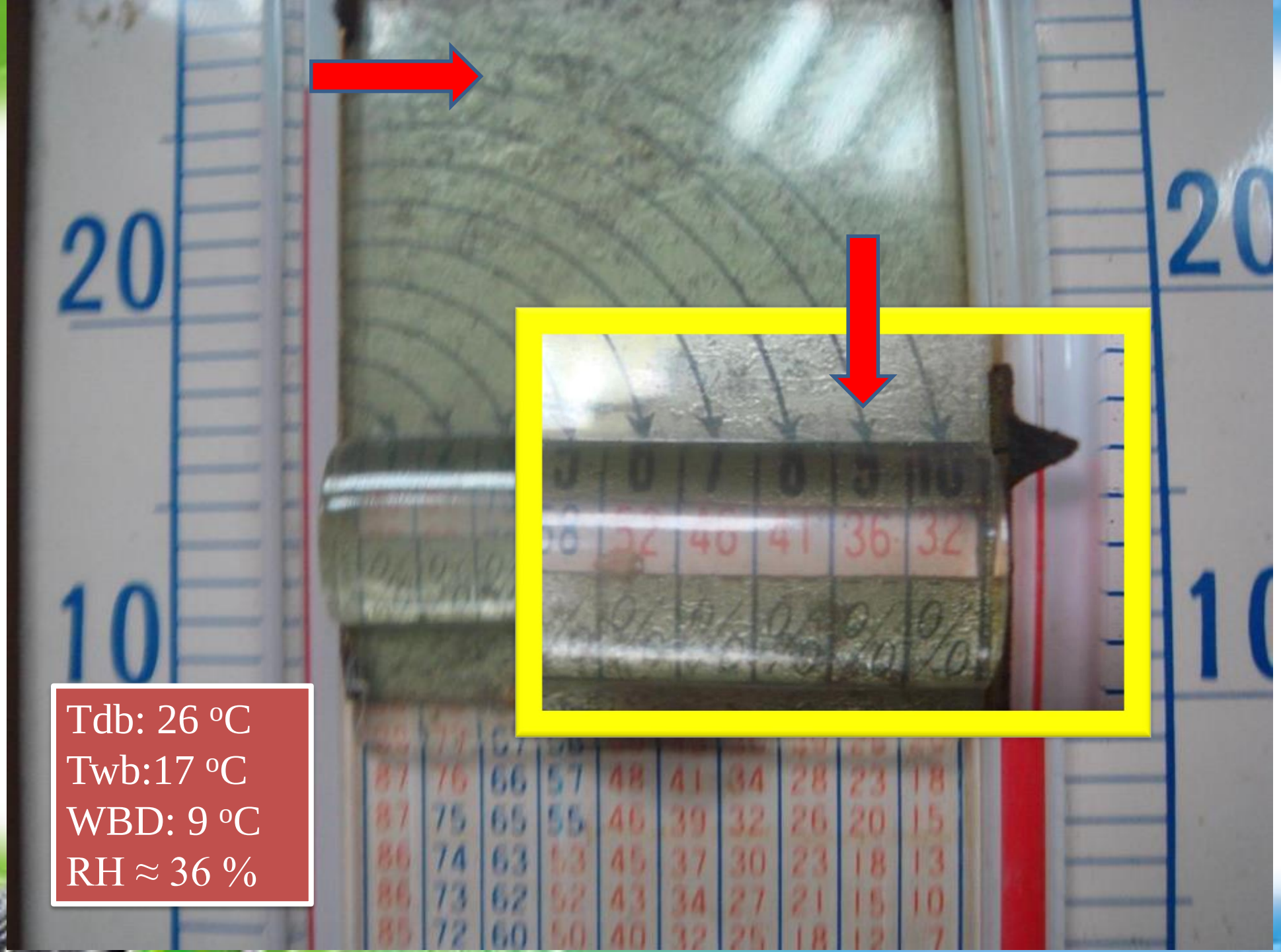





°C 乾濕度表 %
乾球示度
乾濕球溫差
1 2 3 4 5 6
35 93 87 80 74 68 63
34 93 86 80 74 68 62
33 93 86 80 73 67 61
32 93 86 79 73 67 61
31 93 86 79 72 66 60
30 93 85 78 72 65 59
29 92 85 78 71 65 58
28 92 85 77 70 64 57
27 92 84 77 70 63 56
26 92 84 76 69 62 55
25 92 84 76 68 61 54
24 91 83 75 68 60 53
23 91 83 75 67 59 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
0
0
20
30
40
50

T_{db} and T_{wb}




20
10
Tdb: 26 °C
Twb:17 °C
WBD: 9 °C
RH ≈ 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

$RH = f(T_{db} \text{ and } T_{wb})$

	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

$P_{atm} = 101.325 \text{ kPa} = 1013.25 \text{ hPa}$

RH = f(T_{db} and 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

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

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

Wet bulb depression, WBD

$$WBD = Tdb - Twb$$

Limit of the degree of temperature drop of the Evaporative cooling system

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

	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

Psychrometric properties

- At given latitude (given P_{atm}) and
  2 independent properties, others can be derived.

- T_{db}、T_{wb} → RH
- T_{db}、RH → T_{wb}
- T_{wb}、RH → T_{db}

Psychrometric properties

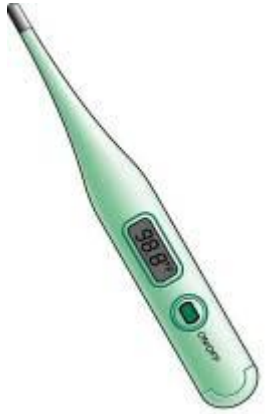
- 3+1 T, 2 H and 2 P properties

  - Tdb $\geq$ Twb $\geq$ Tdp (Dew point temperature)
  - T_{sat}: Saturated T (T_{db} at RH=100%)
  - Relative Humidity (RH), Absolute Humidity (AH)
  - Water vapor pressure (P_w)
  - Saturated water vapor pressure (P_{ws}, P_w at T_{sat})

3+1 T

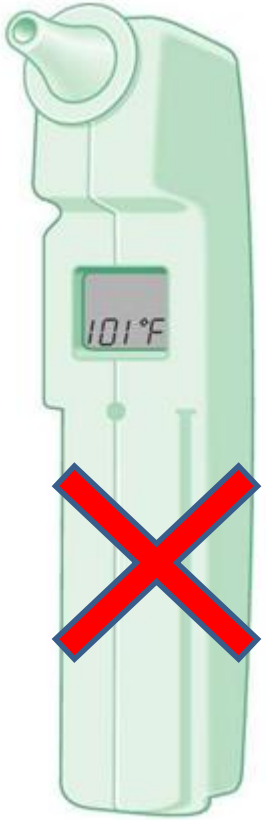
- T_{db} T_{sat}
- T_{wb}
- T_{dp}: lowest temperature with no condensation occurred
  - When surface T is lower than T_{dp} of the moist air, condensation will be occurred on the surface such as the eyeglass, cup, flower, leaves, etc.

Portable digital T, RH measuring device



Infra-red Dry Bulb Temperature
Measuring only the surface T

Need to know the emissivity of the surface of interest to correctly measure the surface temperature.



Not for surface T measurement

Emissivity 輻射率

Emissivity is a measure of a material's radiating efficiency. An emissivity of 1.00 implies that the material is 100% efficient at radiating energy. An emissivity of 0.20 implies that the material radiates only 20% of that which it is capable of radiating. Black body $\varepsilon = 1$, Grey body $\varepsilon < 1$

Tables of emissivity values are only approximated values for real materials. A range of emissivity values is usually given for many materials whose emissivity can be affected by surface roughness or finish. Additionally, thin sheets of material such as plastics may be semi-transparent in the infrared and therefore have reduced emissivity

Thermal Imager

http://us.fluke.com/usen/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

2 H

Relative humidity (RH) in %

Ratio of vapor pressure (mass) of moist air vs. saturated vapor pressure (mass) at same T_{db}

is called Relative Humidity (Degree of Saturation, DOS)

Absolute humidity (AH) in g/kg or kg/kg or g/m^3 or kg/m^3

Mass (g or kg) of water vapor per kg or m^3 of dry air

AH

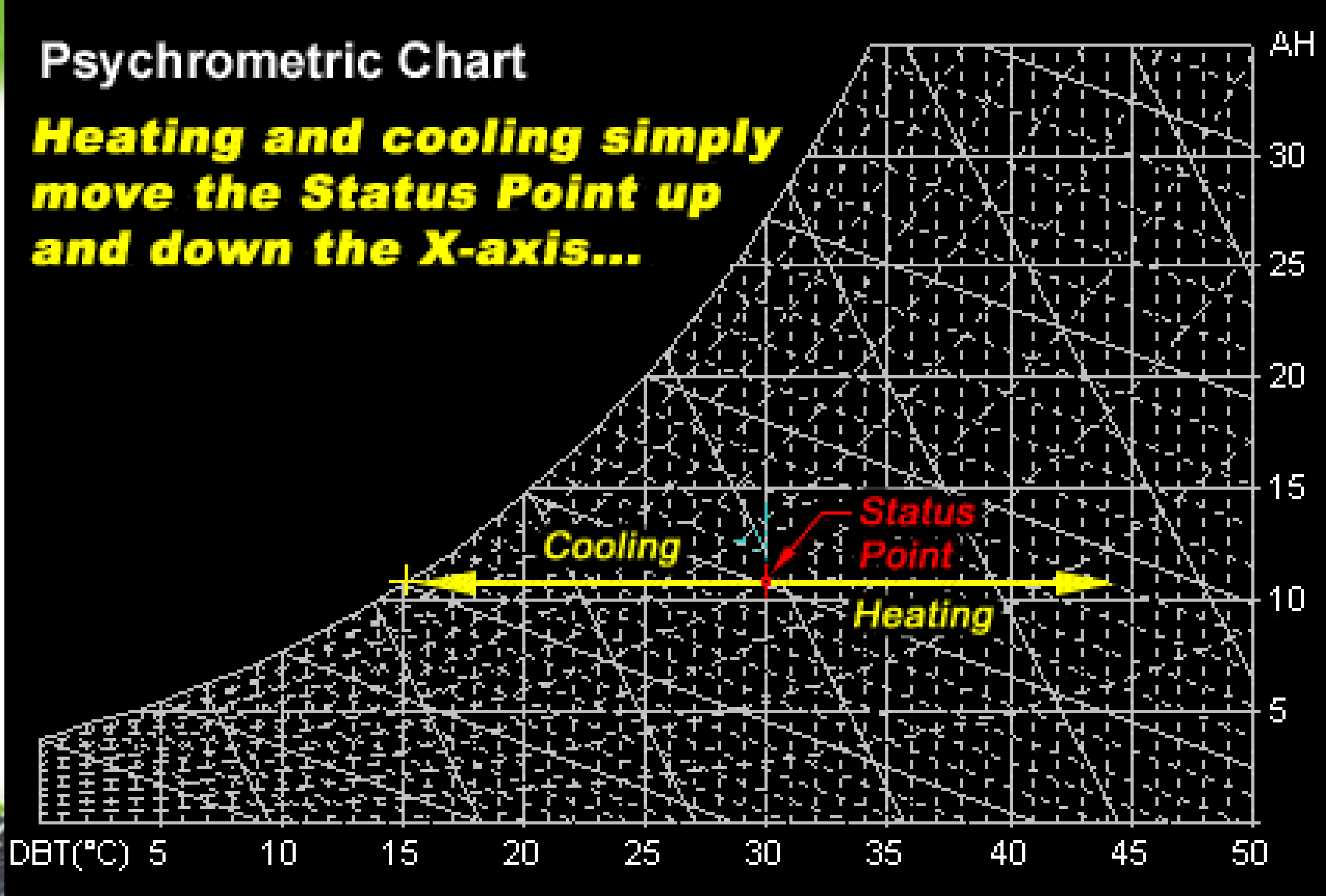
- AH in g or kg/kg Dry Air (DA) divided by specific volume (SV) of DA is the AH in g or kg/m^3 DA.
- SV (m^3/kg) is the inverse of air density (kg/m^3)
- At normal temperature range, mass of water vapor per 1 kg of dry air is 0 ~ 30 g

- At same T_{db}, air with higher RH has higher AH
- At same RH, air with higher T_{db} has higher AH

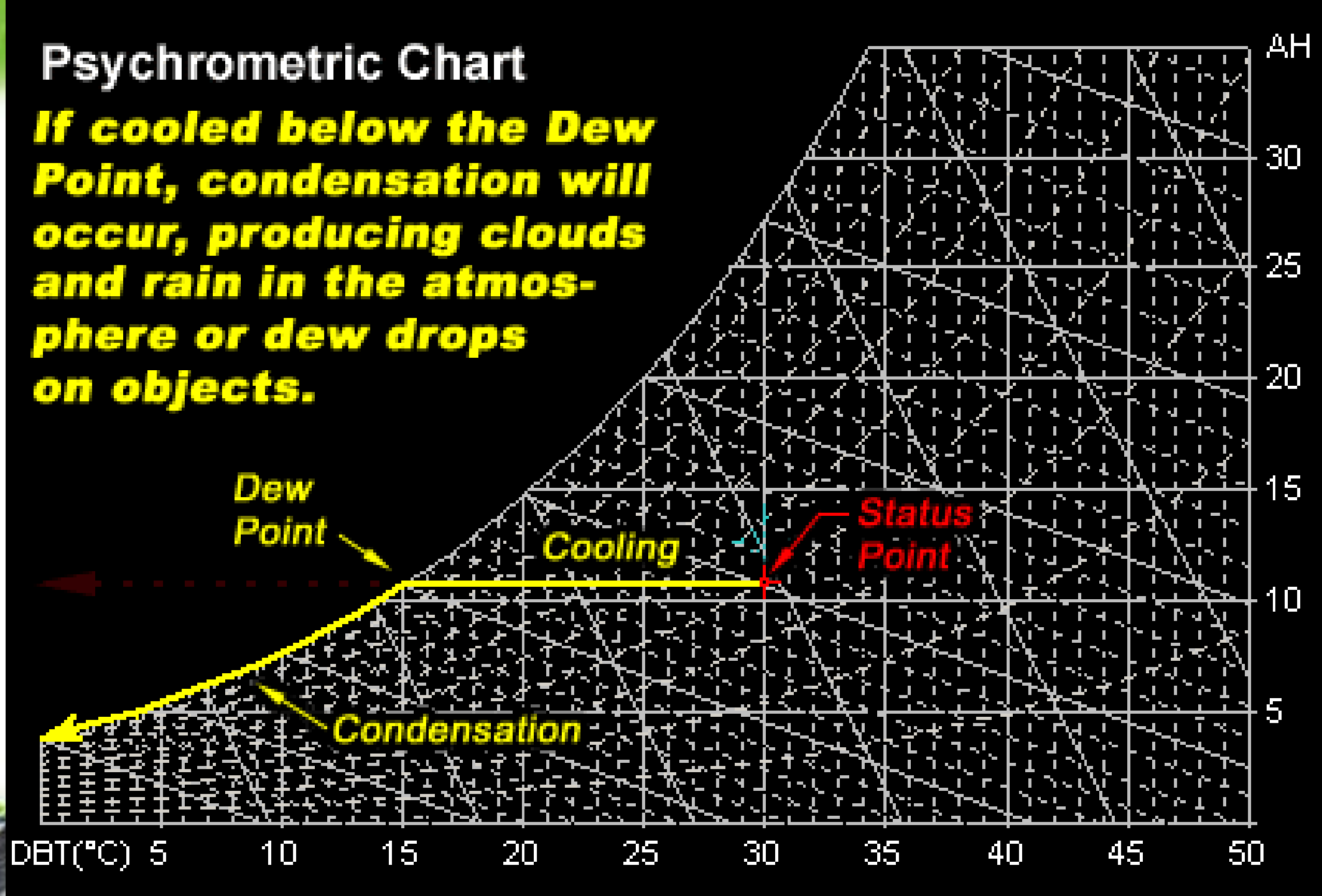
How many PSY. related terms you have learned so far?

- 4 T, 2 H, 2 P
- DOS
- WBD
- SV, Density

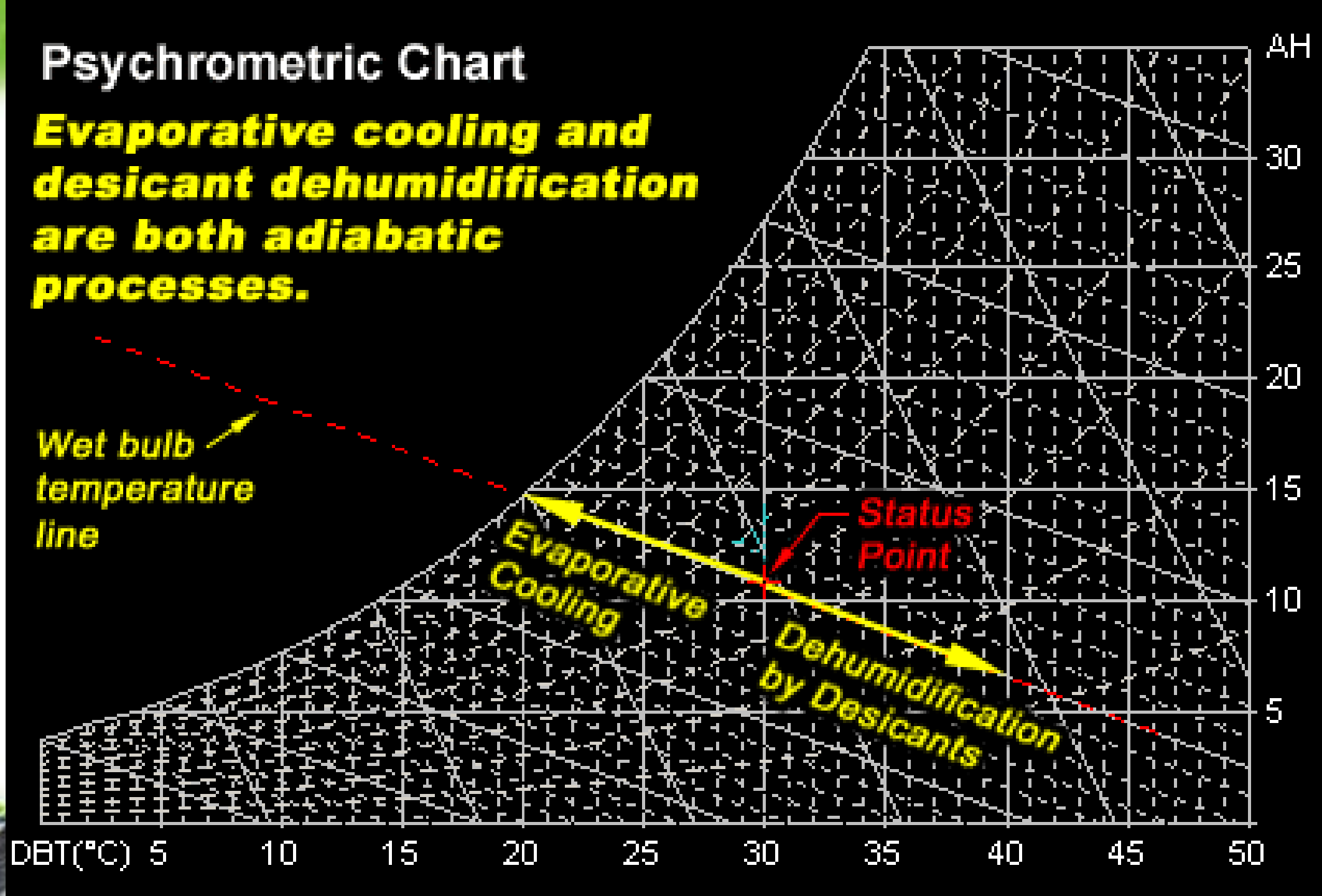
Process: from one state to another



Process: from one state to another



Process: from one state to another



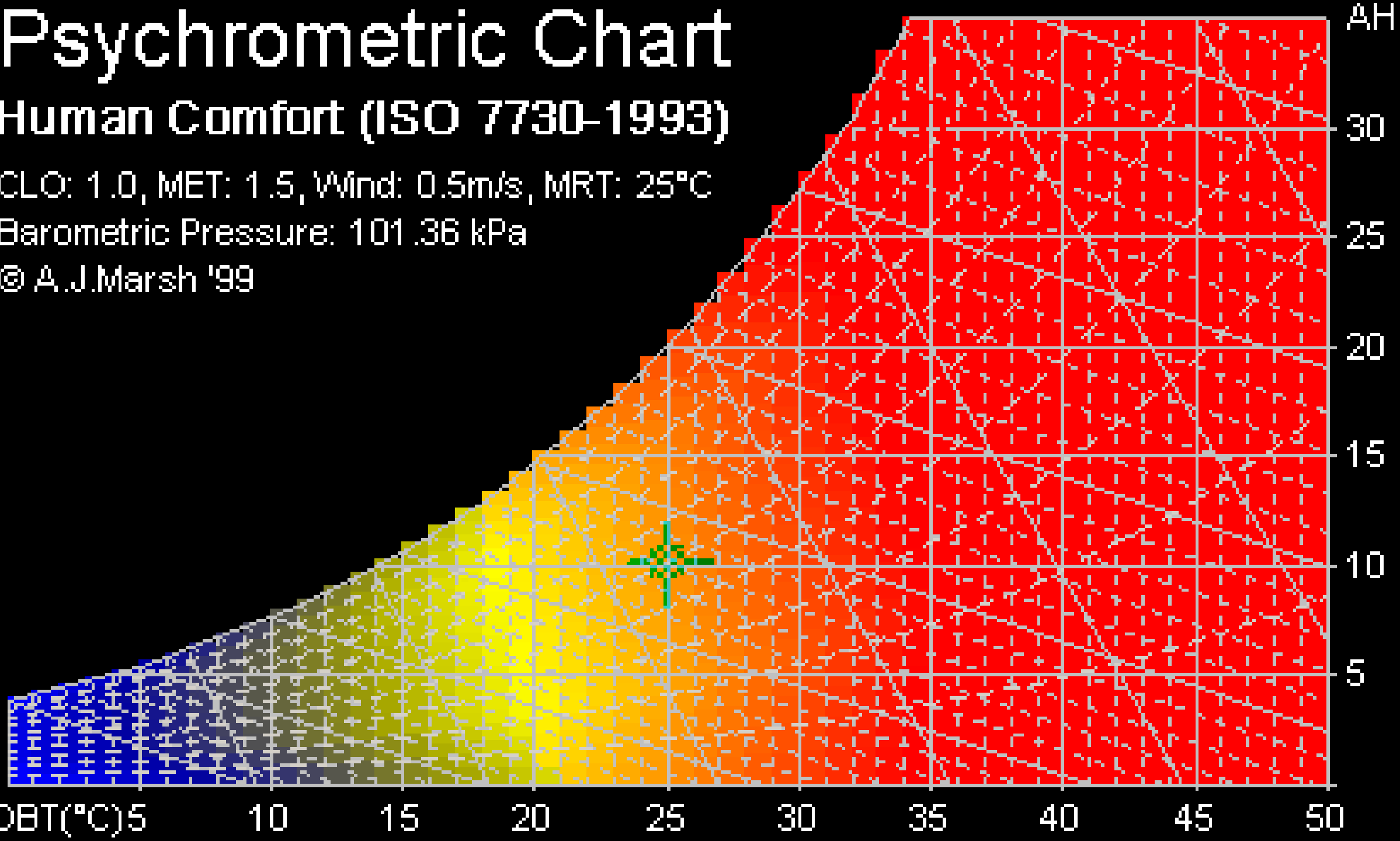
Psychrometric Chart

Human Comfort (ISO 7730-1993)

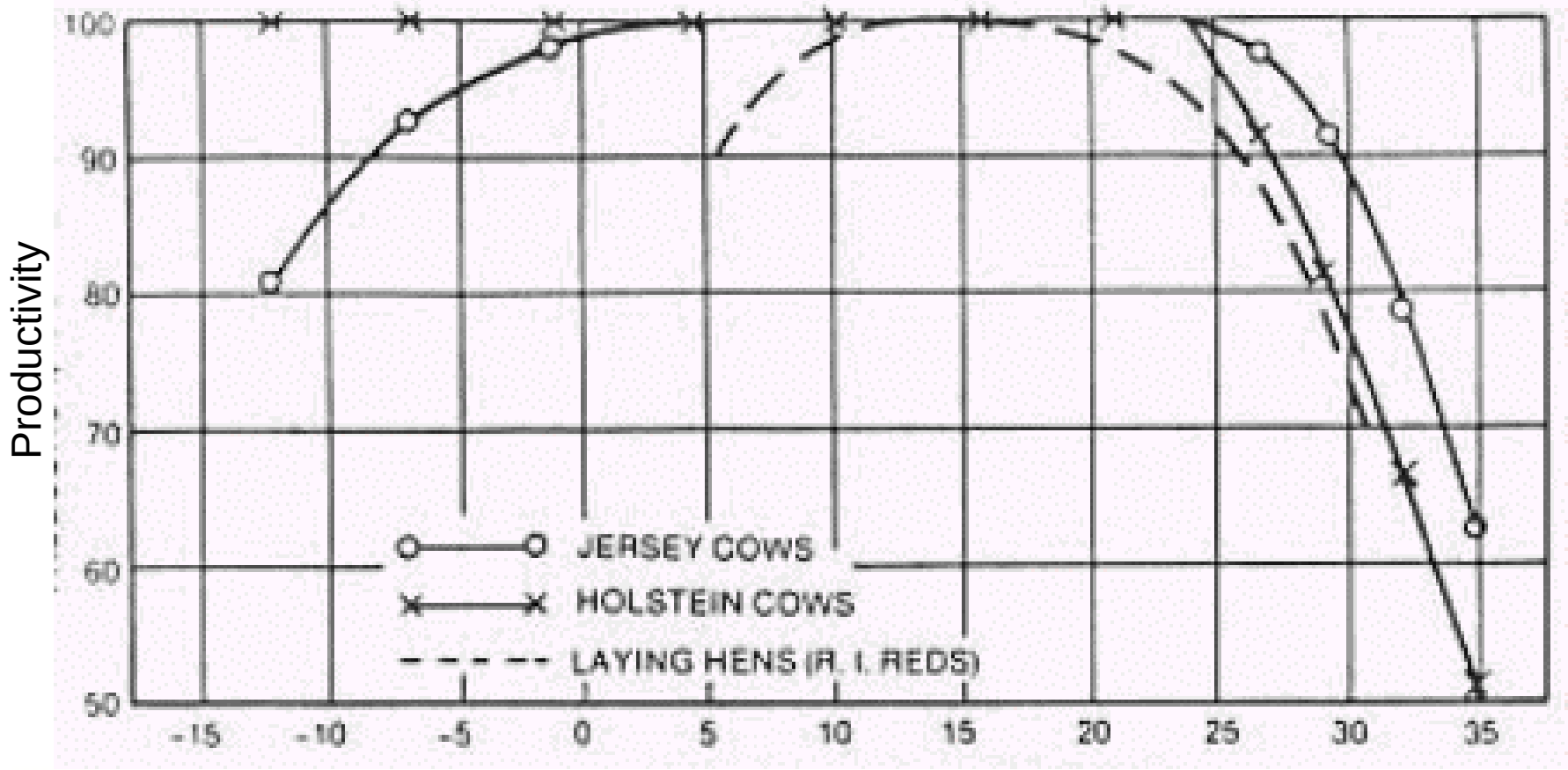
CLO: 1.0, MET: 1.5, VWind: 0.5m/s, MRT: 25°C

Barometric Pressure: 101.36 kPa

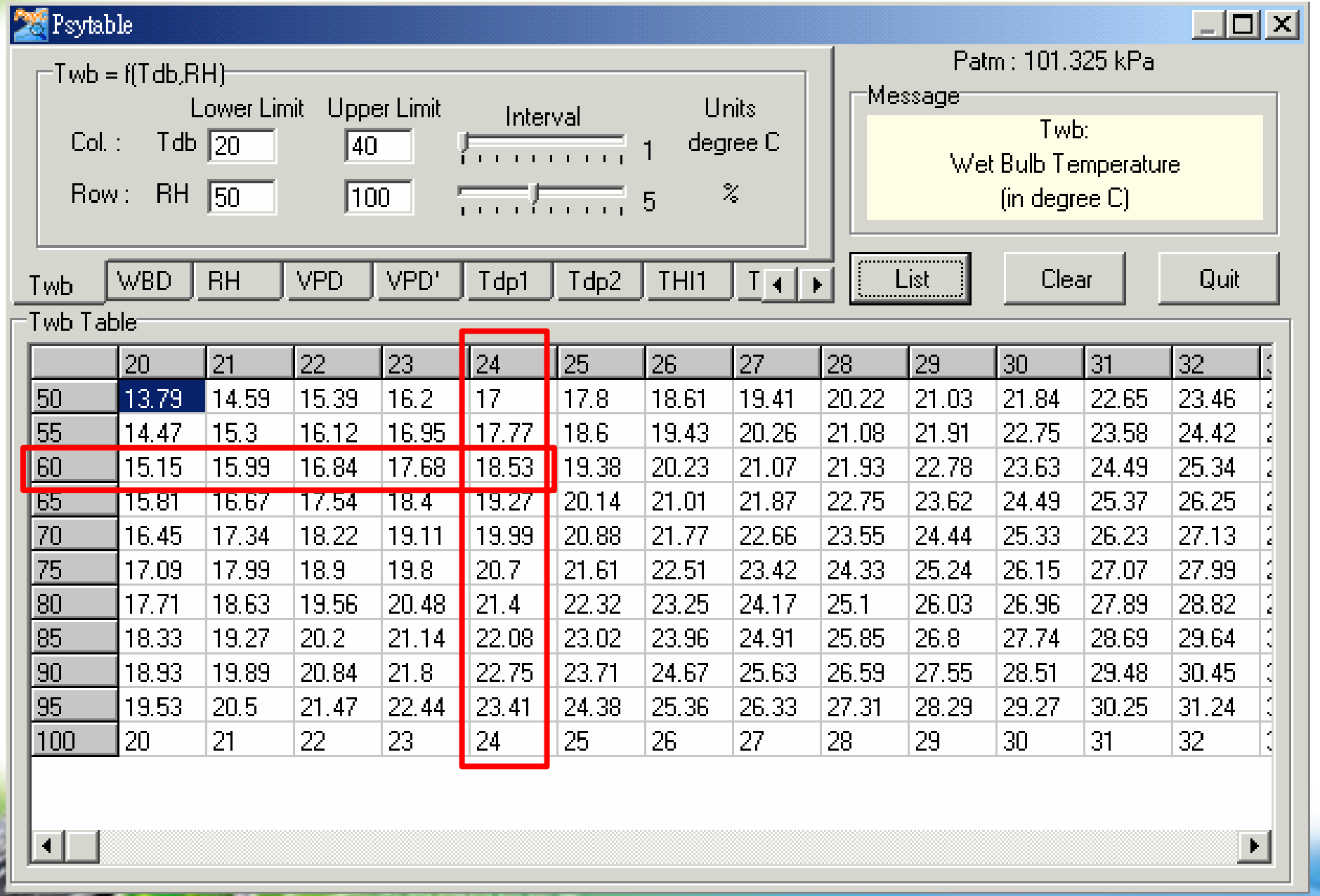
人體的溫溼度舒適帶



Comfort zone of 3 animals



Psychart software



	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

RH = f(Tdb, Twb)

	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

WBD= Tdb – Twb = f(Tdb, 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

RH range for plant growth

Tdb, ^{o}C	RH too low (humidification required)	Proper RH	RH too high (dehumidification required)
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		相對濕度													
°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

unit conversion
millibar to others

Your value (millibar): 1 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/cm²)	0.00102
kilogram per square meter (kgf/m²)	10.2
newton per square meter (N/m²)	100
kilonewton per square meter (kN/m²)	0.1
meganewton per square meter (MN/m²)	0.0001
newton per square centimeter (N/cm²)	0.01
newton per square millimeter (N/mm²)	0.0001

British and U.S. (Imperial system)

ounce per square inch (osi, oz/in²)	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.

VPD

1 millibar = 0.1 kPa

VPD too big (humidification or cooling required)	**Proper VPD**	**VPD too small (dehumidification or heating required)**
1.25 kPa	**0.85 kPa**	**< 0.45 kPa (Suitable for bacterial to survive)** **< 0.2 kPa (suitable for bacterial invasion)**

VPD = f(Tdb, 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

RH range for plant growth

Tdb, °C	RH too low (humidification required)	Proper RH	RH too high (dehumidification required)
15	-	50 %	73
20	46	64	80
25	60	73	86
30	70	80	89

VPD

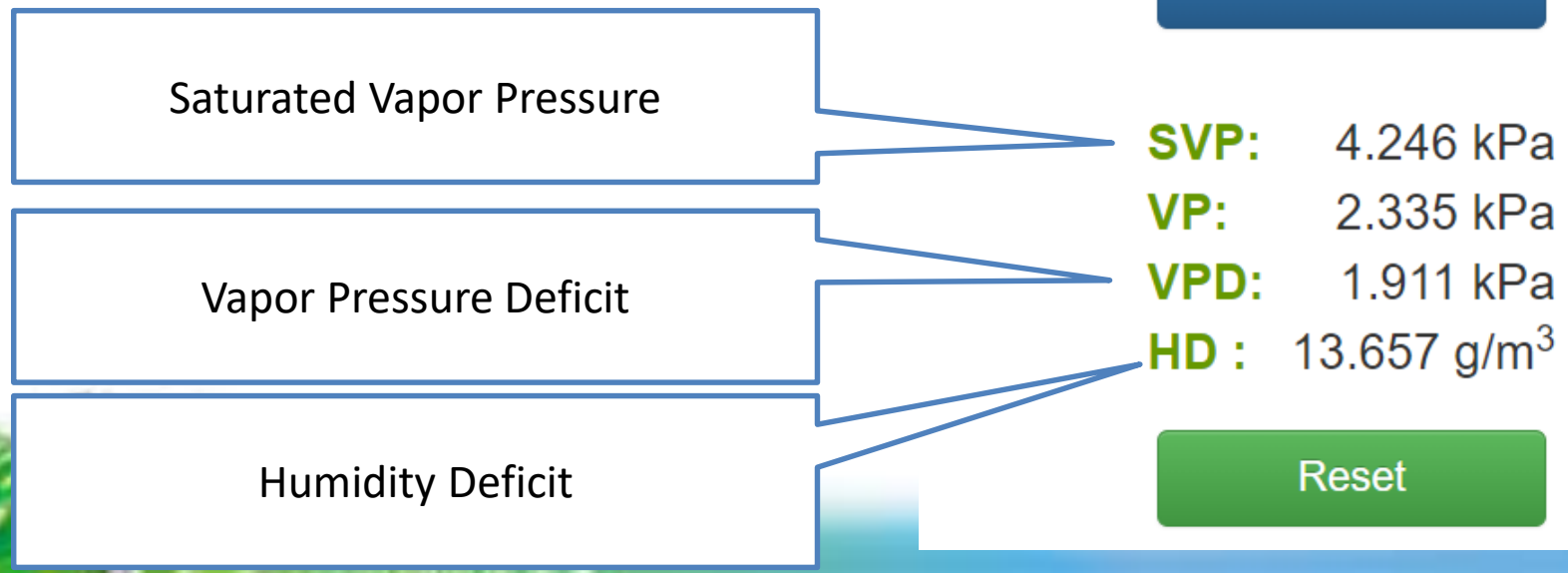
1 millibar = 0.1 kPa

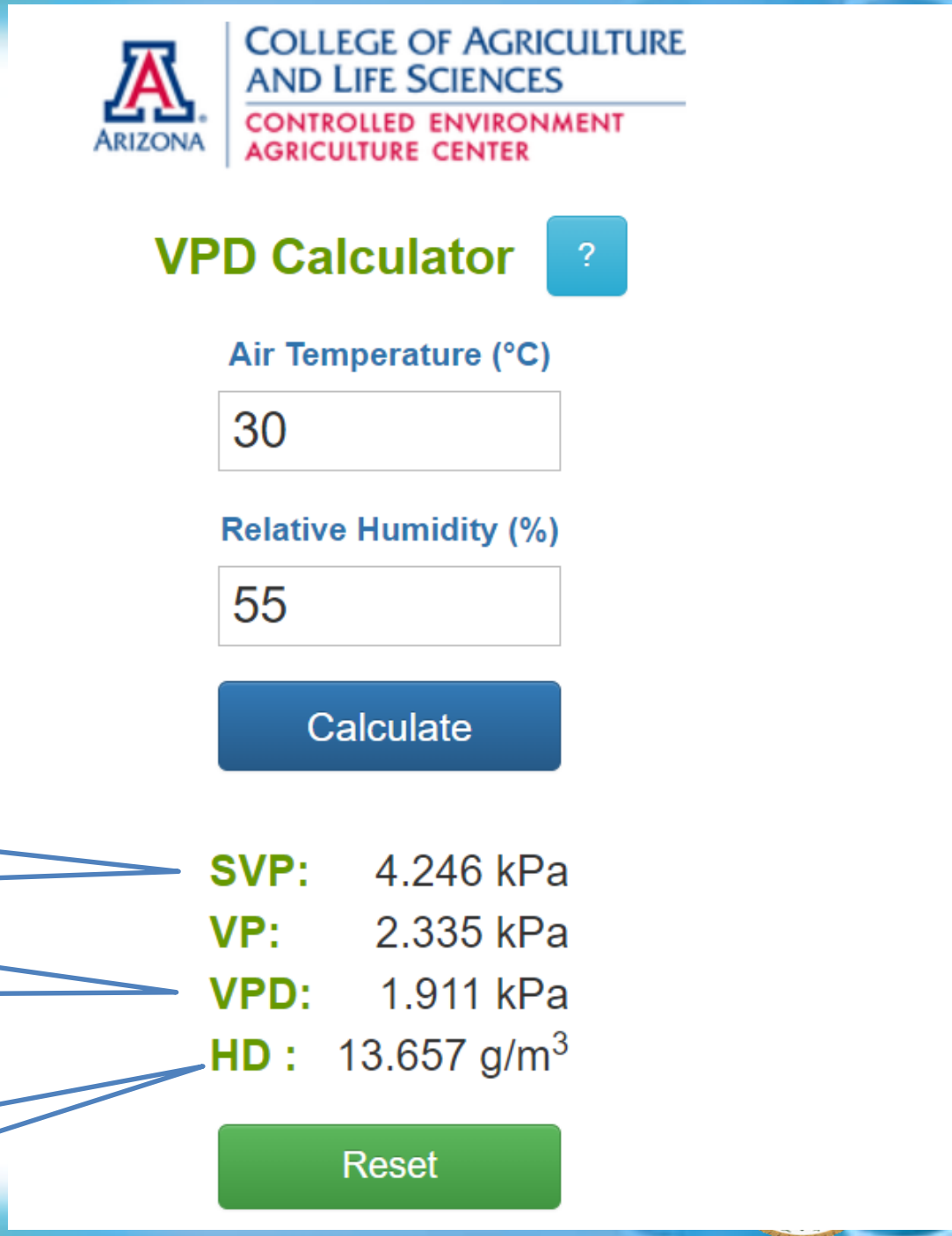
VPD too big (humidification or cooling required)	Proper VPD	VPD too small (dehumidification or heating required)
1.25 kPa	0.85 kPa	< 0.45 kPa (Suitable for bacterial to survive) < 0.2 kPa (suitable for bacterial invasion)

VPD is a better index for humidity control

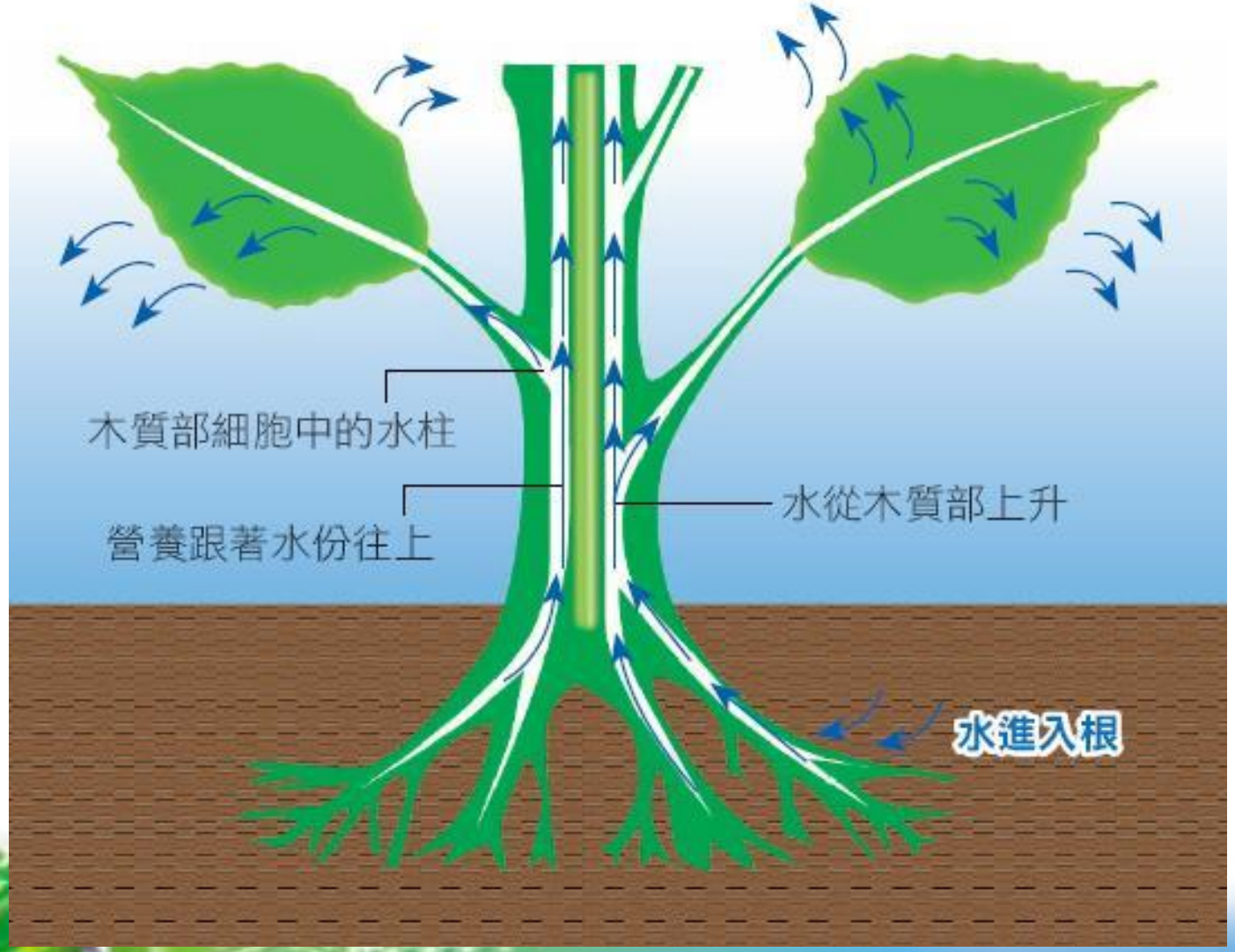
Vapor Pressure Deficit

https://cals.Arizona.edu/vpdcalc/

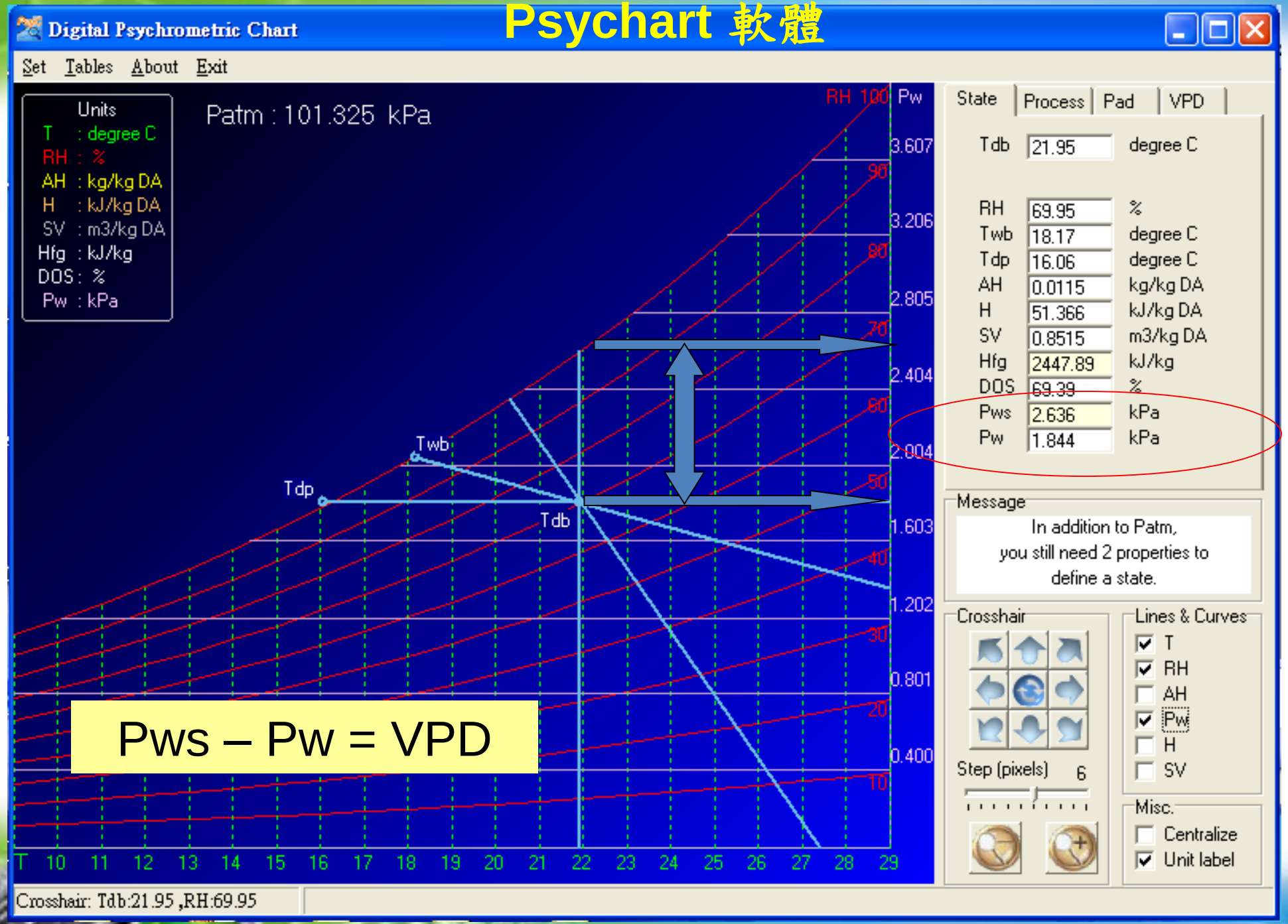




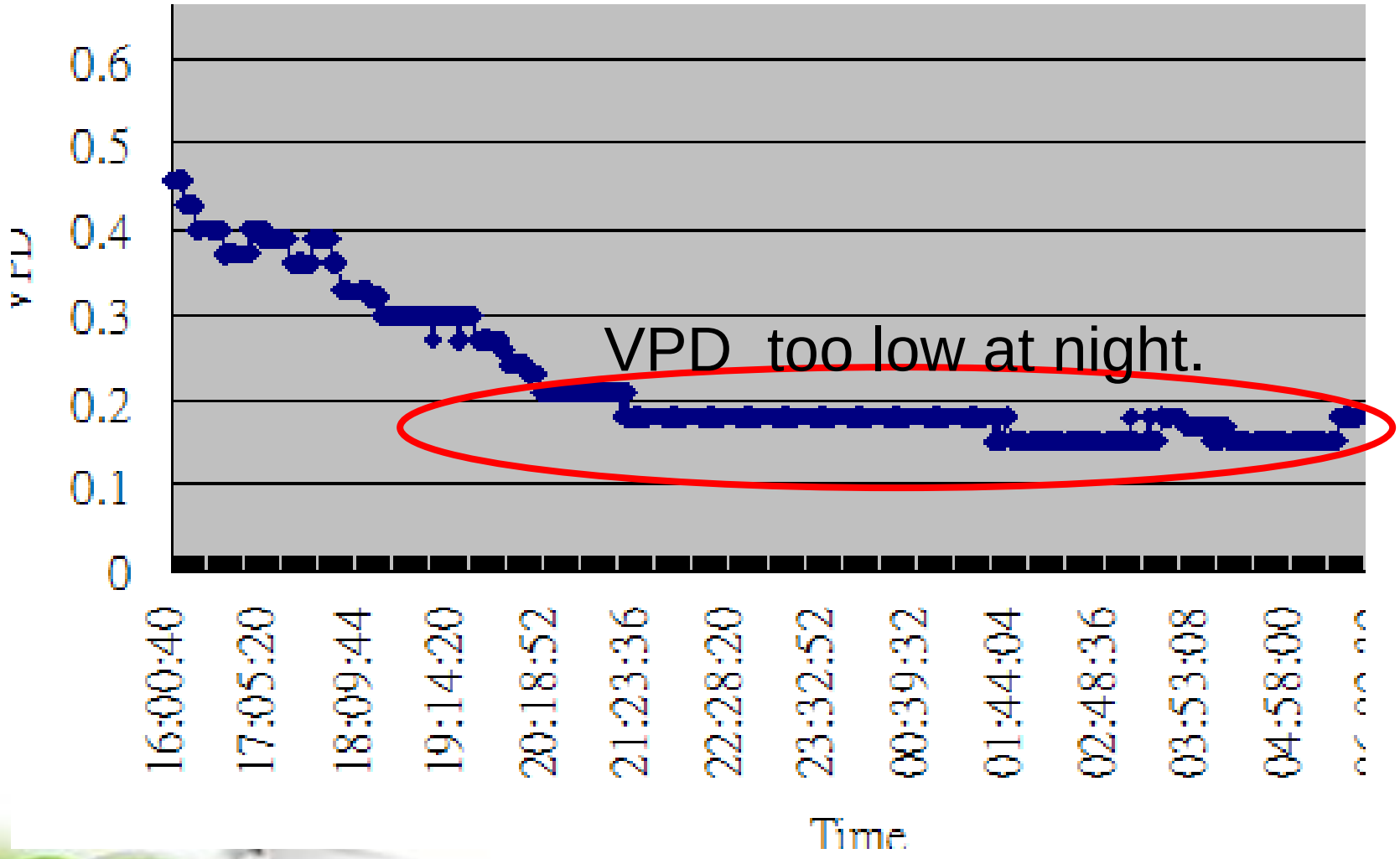
VPD is the driving force for the transpiration to occur.
Proper VPD leads to proper transpiration, proper water/nutrient uptake and proper growth.
VPD too high, stomata tends to close, no CO_2 intake and no water/nutrient uptake.
VPD too low, less transpiration occur, leads to less water/nutrients uptake, slow growth.



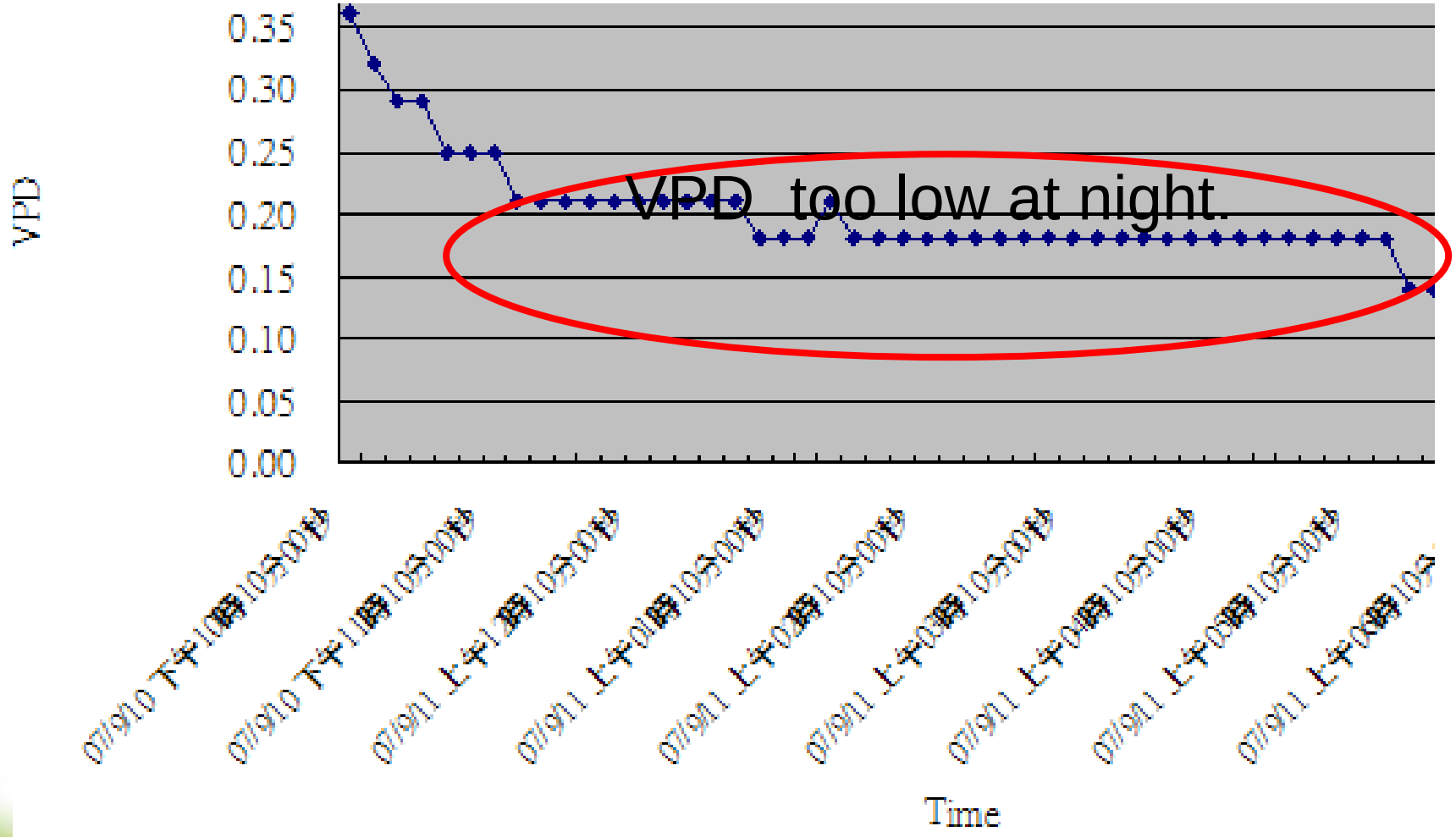
Psychart 軟體


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
RH 100
90
80
70
60
50
40
30
20
10
Pw
3.607
3.206
2.805
2.404
2.004
1.603
1.202
0.801
0.400
Twb
Tdp
Tdb
T 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Pws – Pw = VPD
State
Process
Pad
VPD
Tdb 21.95 degree C
RH 69.95 %
Twb 18.17 degree C
Tdp 16.06 degree C
AH 0.0115 kg/kg DA
H 51.366 kJ/kg DA
SV 0.8515 m3/kg DA
Hfg 2447.89 kJ/kg
DOS 69.39 %
Pws 2.636 kPa
Pw 1.844 kPa
Message
In addition to Patm, you still need 2 properties to define a state.
Crosshair
Step (pixels) 6
Lines & Curves
T
RH
AH
Pw
H
SV
Misc.
Centralize
Unit label
Crosshair: Tdb:21.95 ,RH:69.95

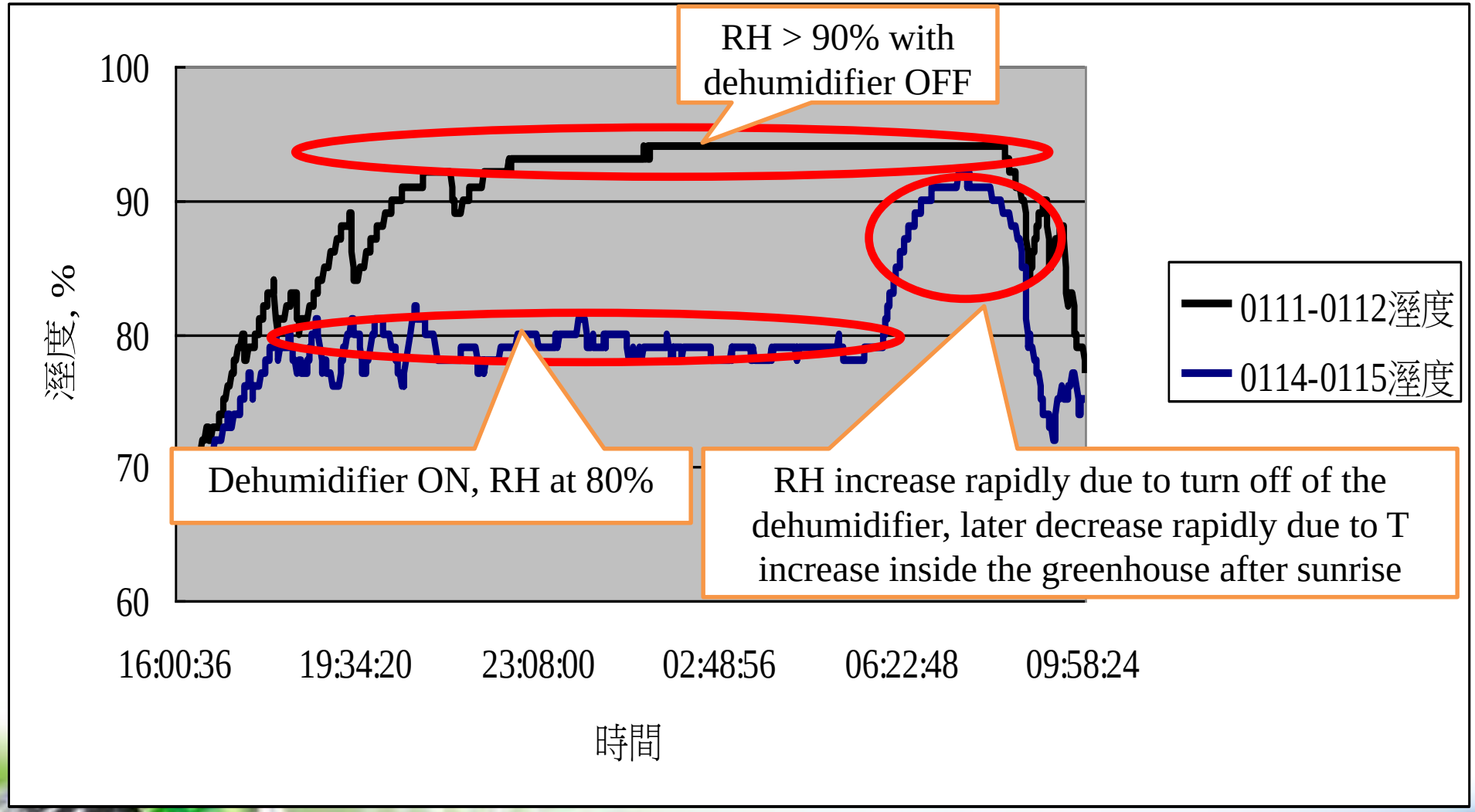
VPD of GH_A during the night time



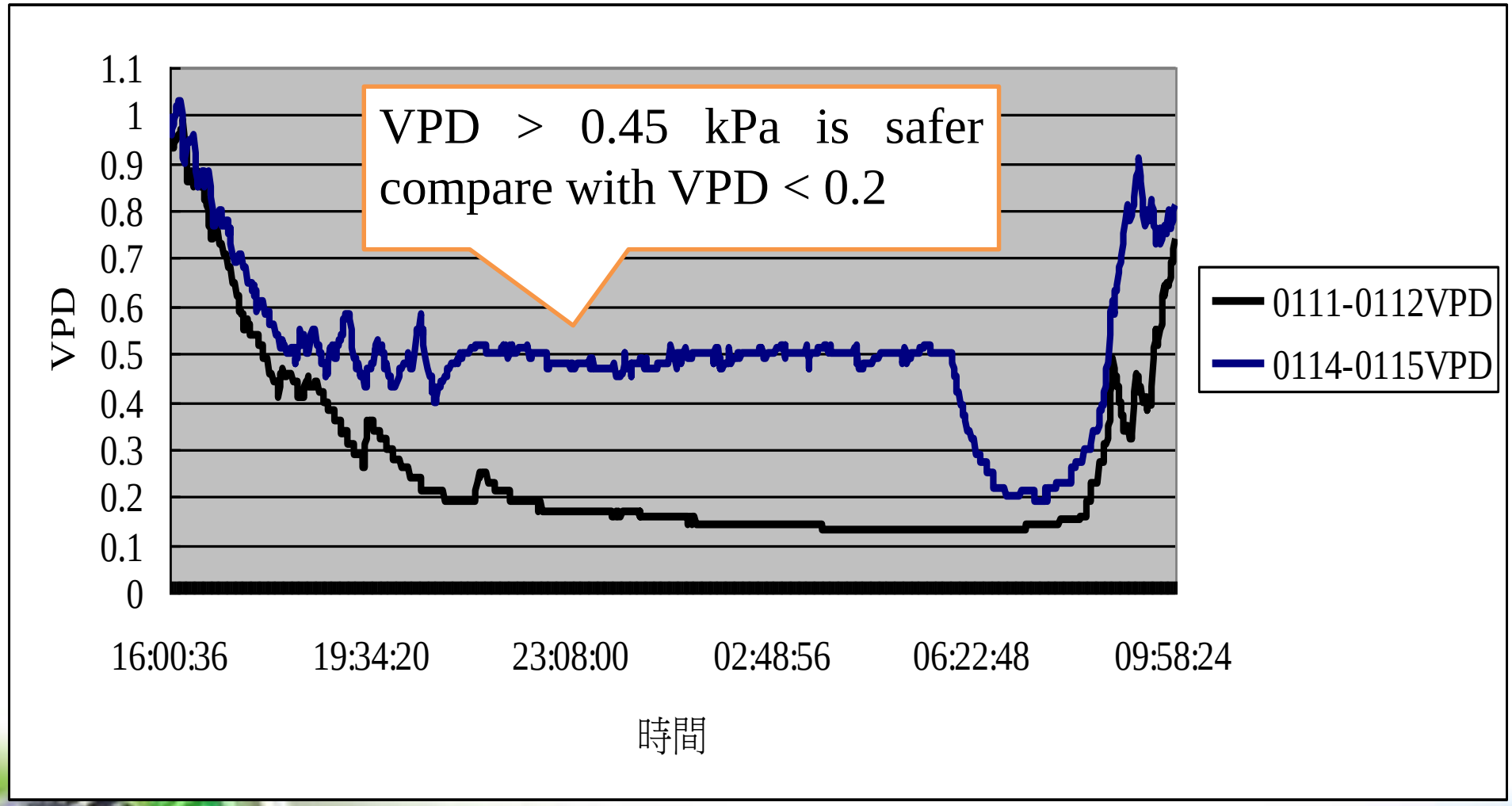
VPD of GH_B during the night time



Dehumidifier ON from 6 pm to 6 am

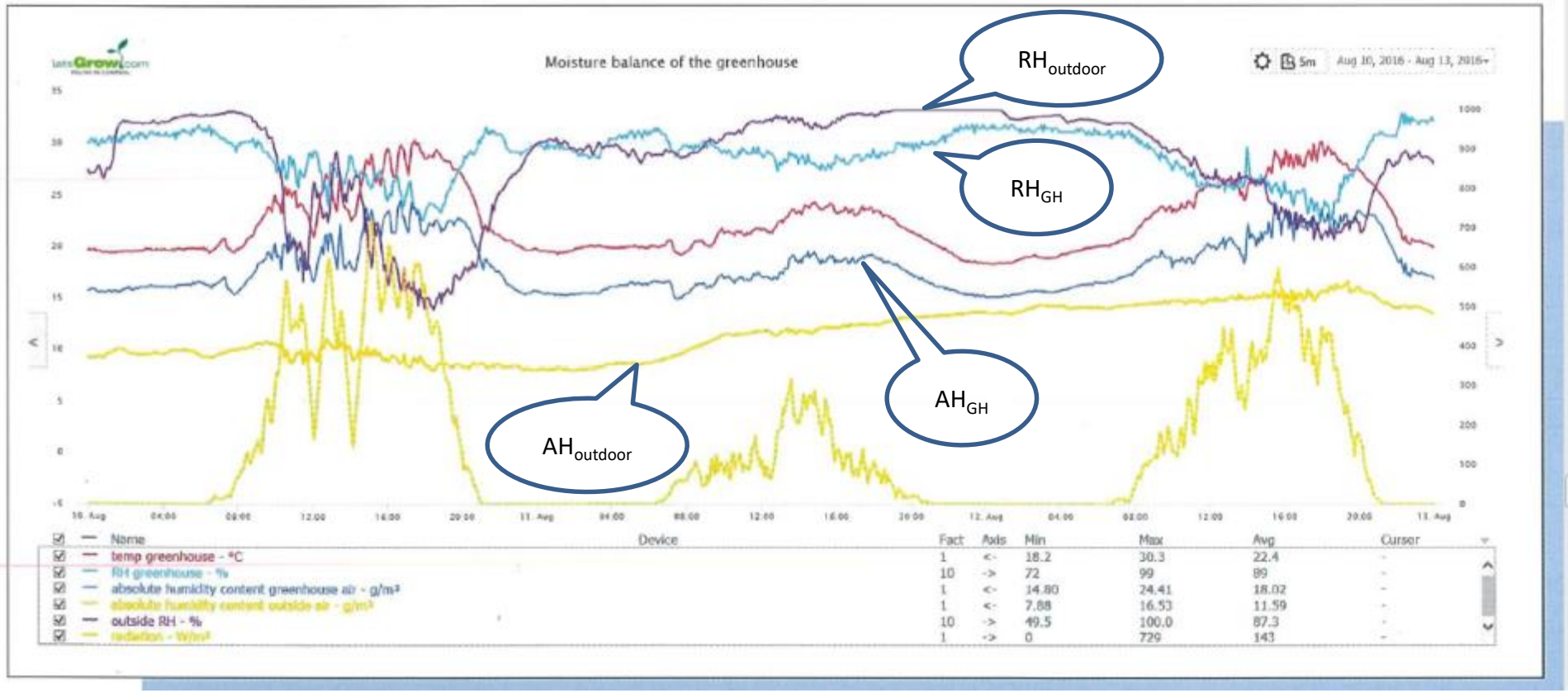


VPD difference due to ON/OFF of the dehumidifier



When outdoor RH is higher than indoor, ventilation can still be used to reduce the water content inside the greenhouse.

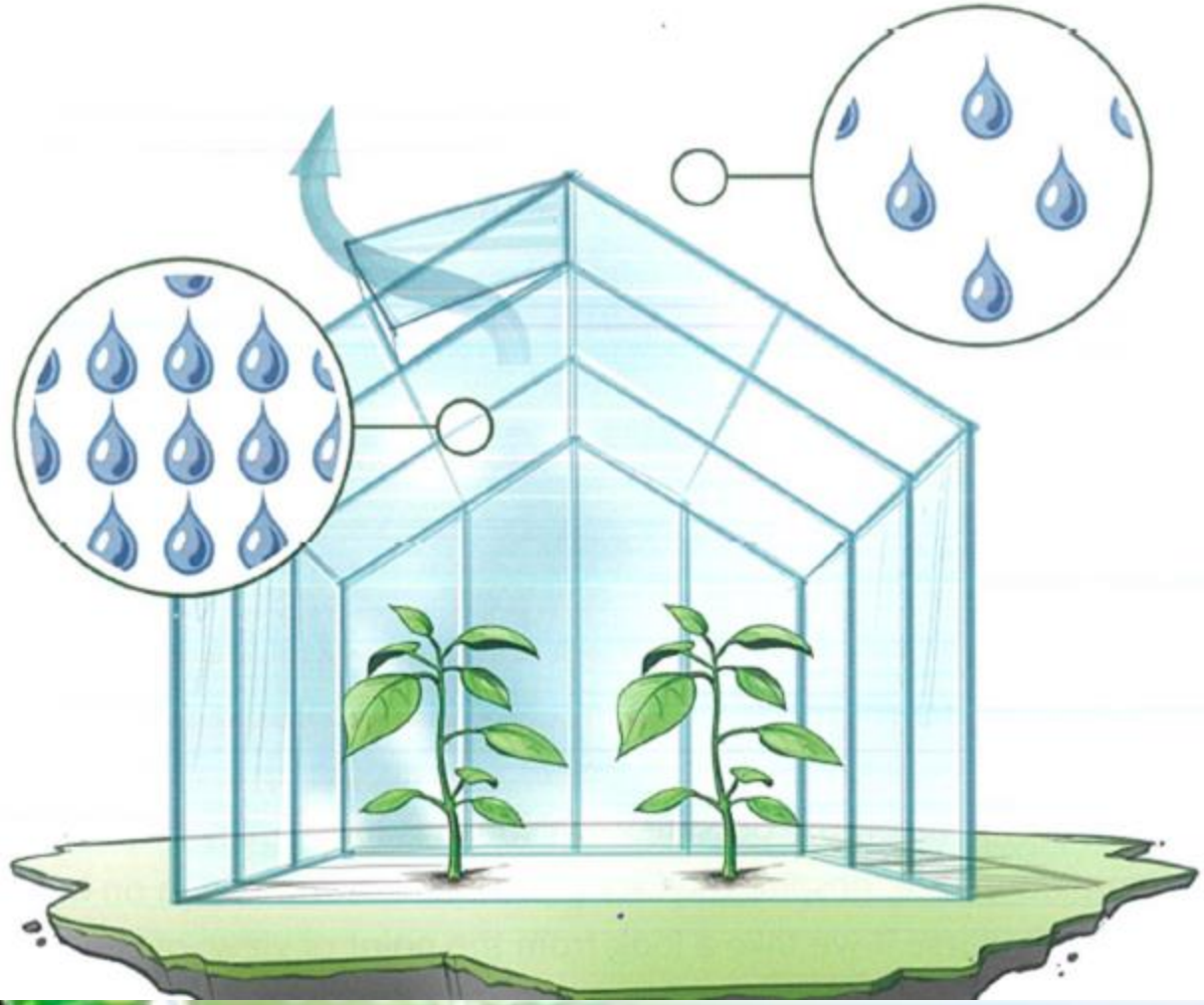
Figure 4.3.6-2 Graph to assess the moisture balance of the greenhouse and ventilation



Between August 11th and 12th the RH outside (purple) is higher than RH inside (light blue). However, moisture can still be expelled through the vents. The reason is that AH in the greenhouse (dark blue) is higher than AH outside (dark yellow).

Natural ventilation can also remove indoor water vapor when indoor AH is higher than outdoor AH

Figure 4.3.6-1 Moisture transport by ventilation



Moisture exchange through the ventilation windows is proportional with the difference between AH inside and AH outside multiplied by the ventilation rate.

How many PSY. related terms you have learned so far?

- 4 T, 2 H, 2 P
- DOS, WBD
- SV, Density
- VPD_{air}, $VPD_{airTdbwb}$, VPD_{air_leaf}
- HD_{air}, $HD_{airTdbwb}$, $HD_{indoor\_outdoor}$

Tutorial for Psyc0226

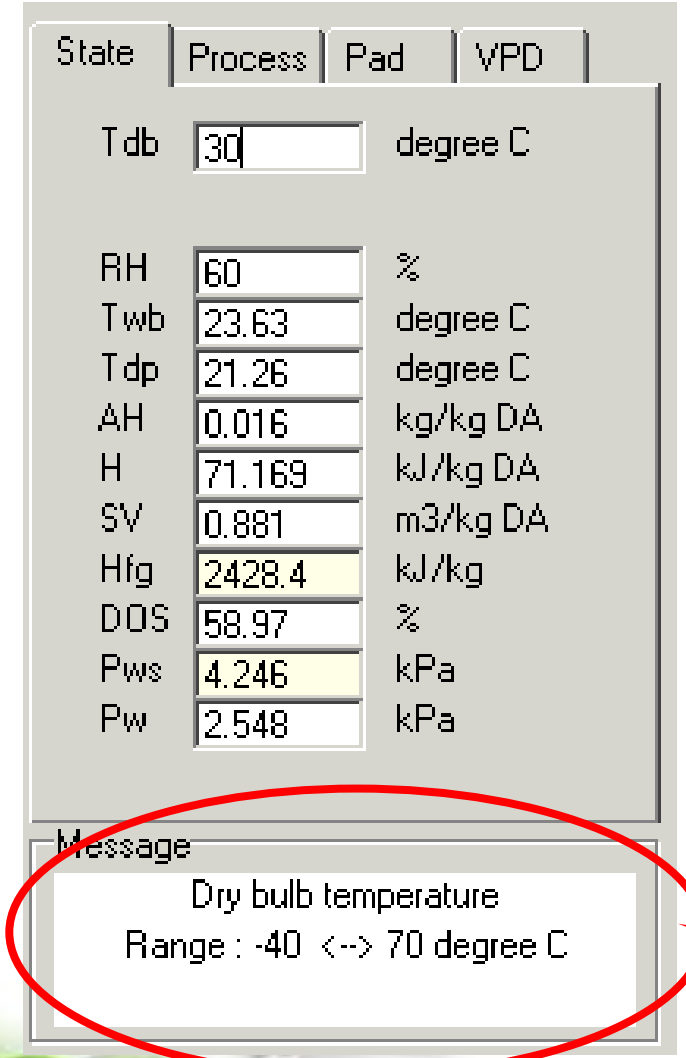
Wei Fang, Ph.D., Professor
Dept. of Bio-Industrial Mechatronics Engineering
National Taiwan University

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

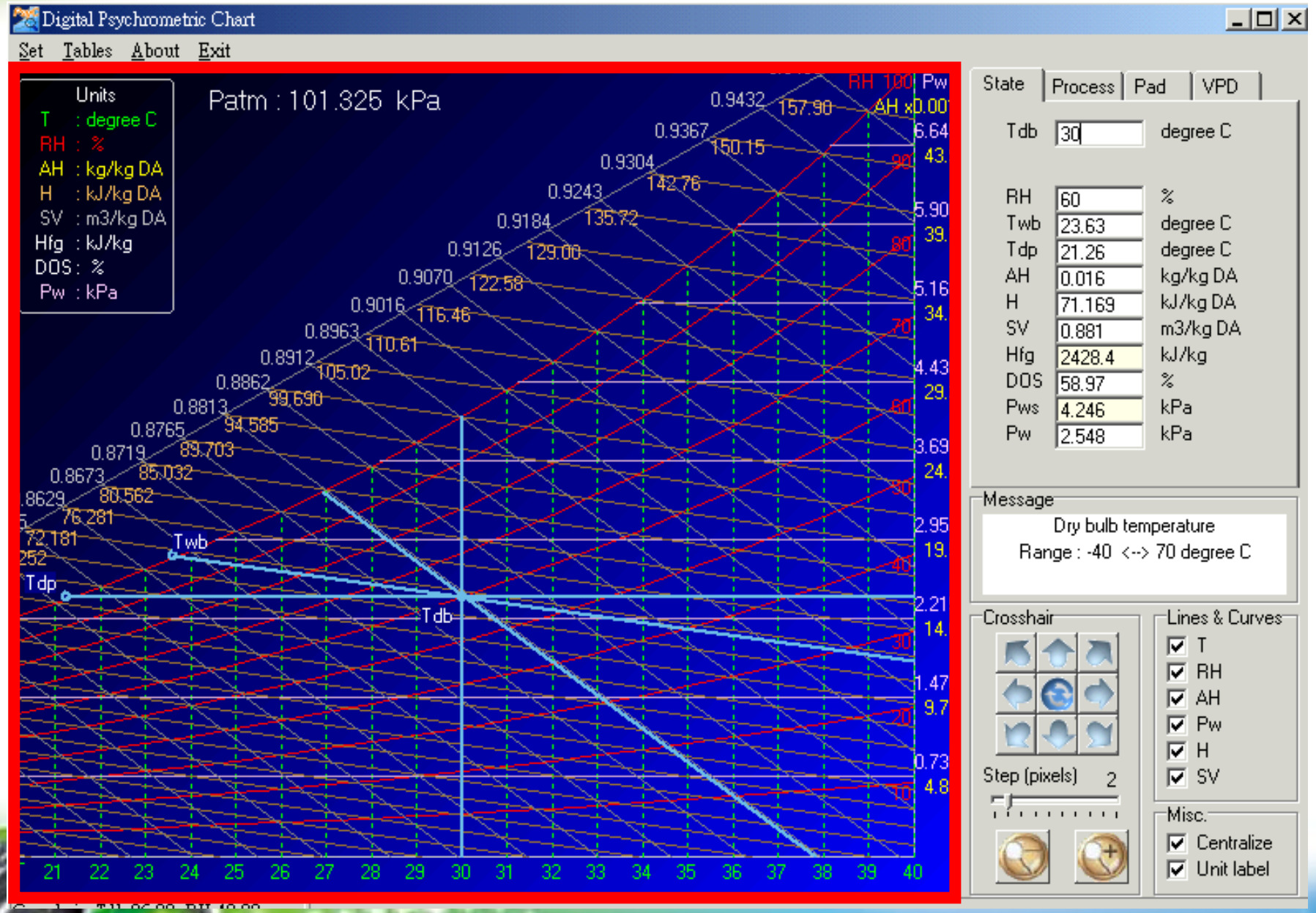
Psyc0226 software



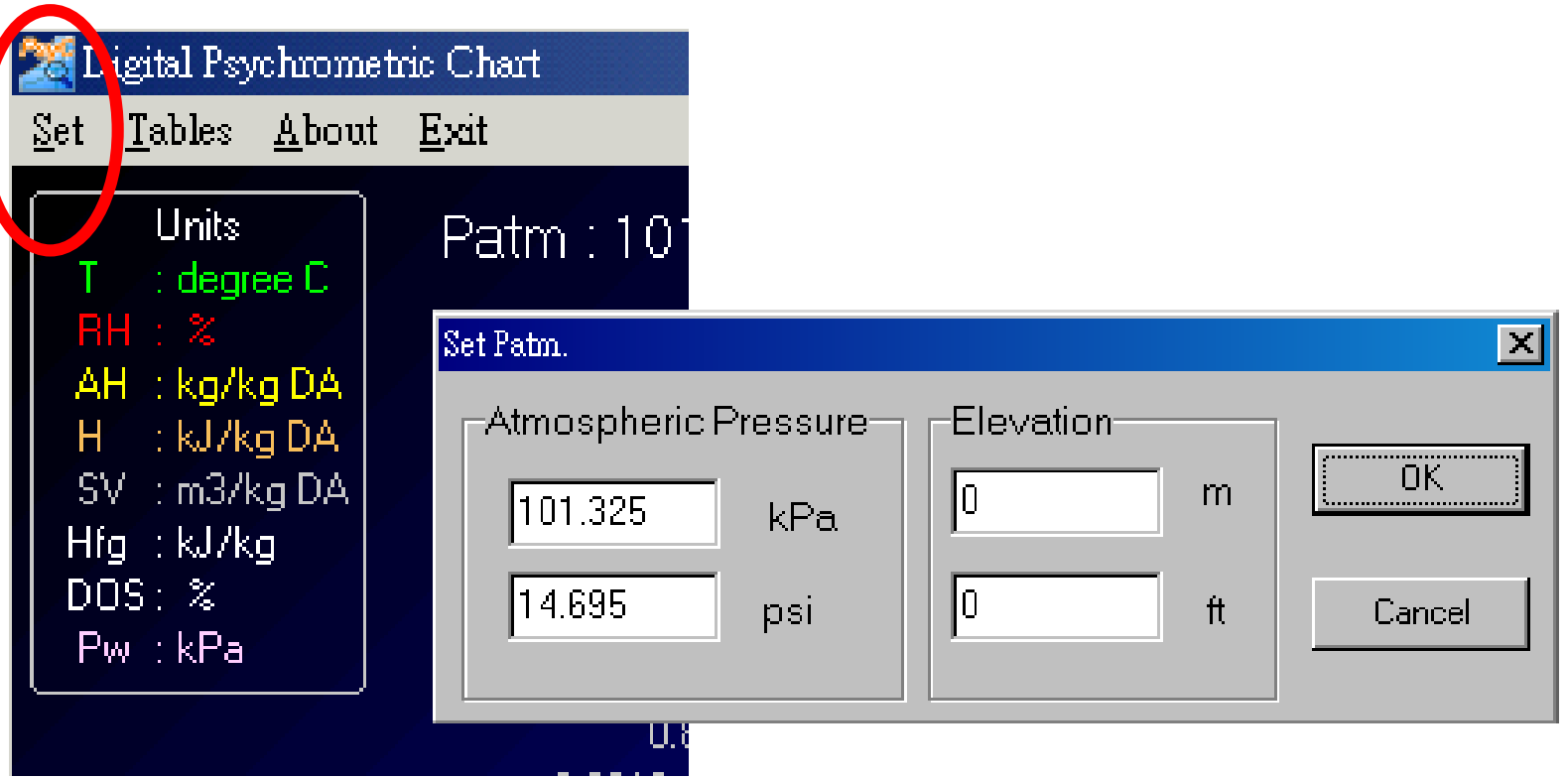
1. Tdb: dry bulb Temp.
2. RH : relative humidity
3. Twb: wet bulb Temp.
4. Tdp: dew point Temp.
5. AH : absolute humidity
6. H: enthalpy
7. SV : specific volume
8. Hfg: evaporated latent heat
9. DOS: degree of saturation
10. Pws: saturated water vapor pressure
11. Pw: water vapor pressure

Further illustration of the cell

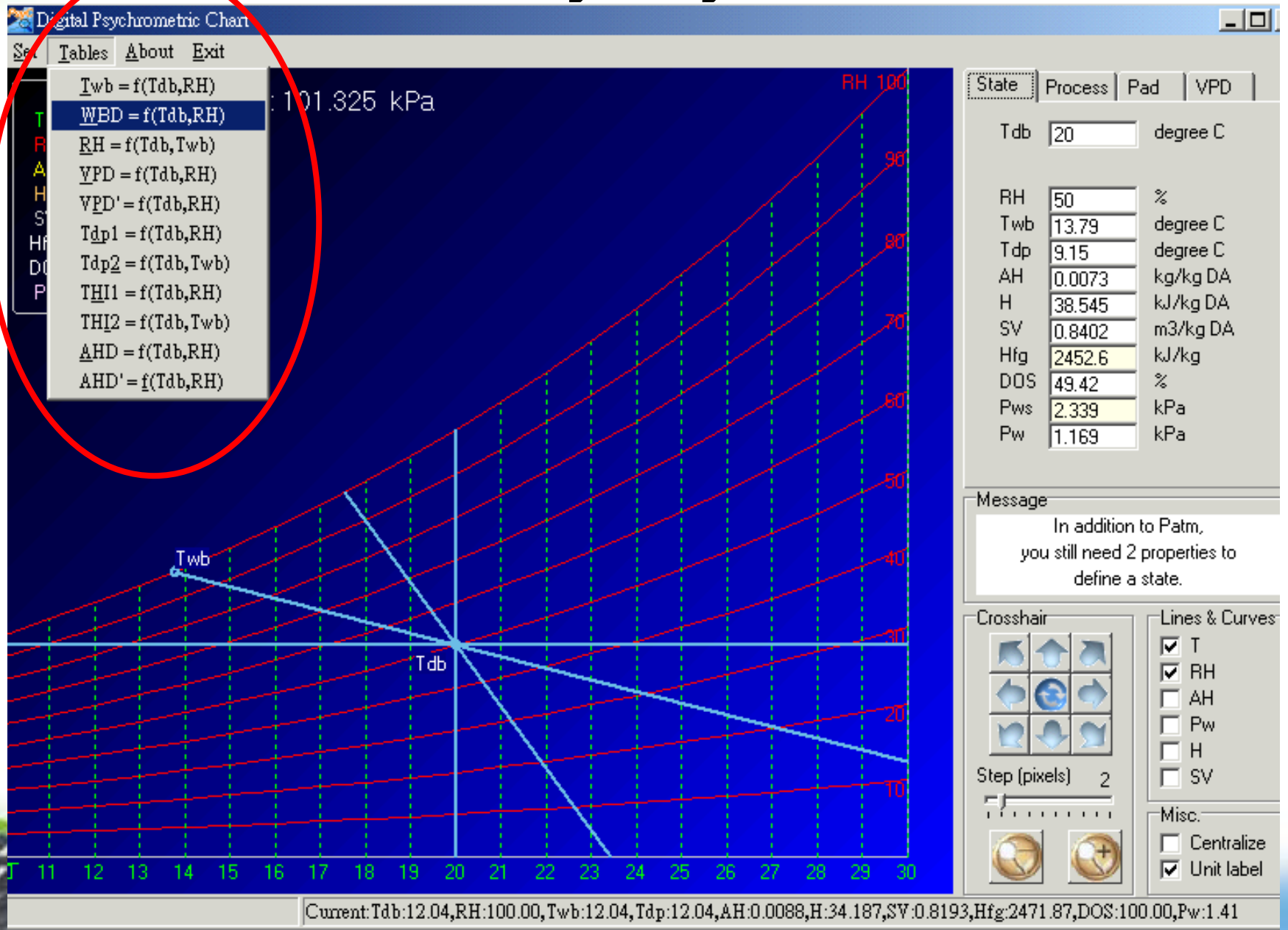
Red zone is the chart



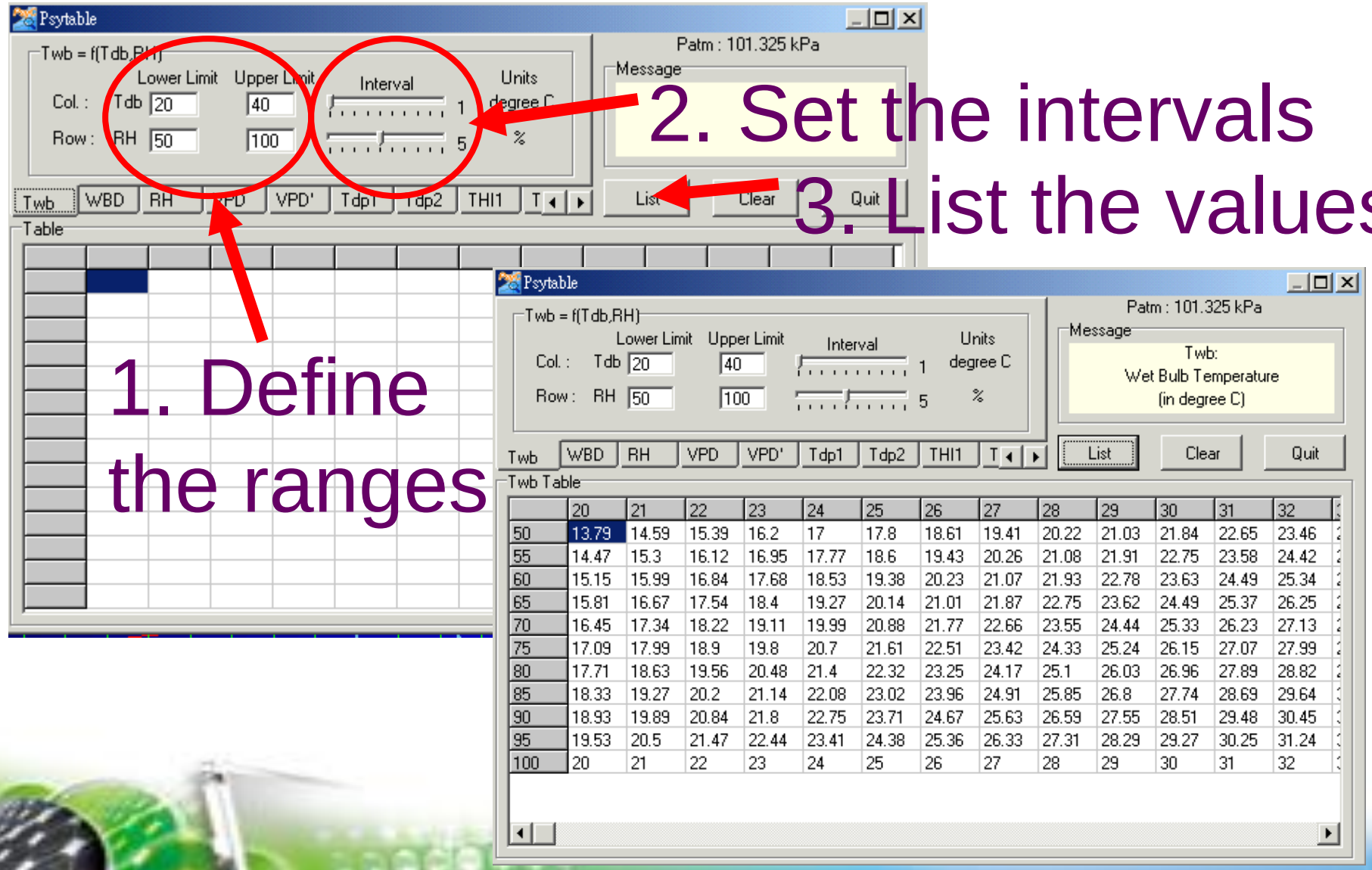
Two ways to set the atmospheric pressure



11 handy PsyTables



User friendly 3-step design in PsyTable



	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: Twb = f(Tdb, RH)

	20	22	24	26	28	30	32	34	36	38	40	42	44
50	13.79	15.39	17	18.61	20.22	21.84	23.46	25.09	26.73	28.38	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	27.13	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

Twb

RH (50 – 100%)and Tdb (20 – 44 ºC)

Table 2: WBD = f(Tdb,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

WBD

Wet **B**ulb **D**epression is the limit of evaporative cooling methods.

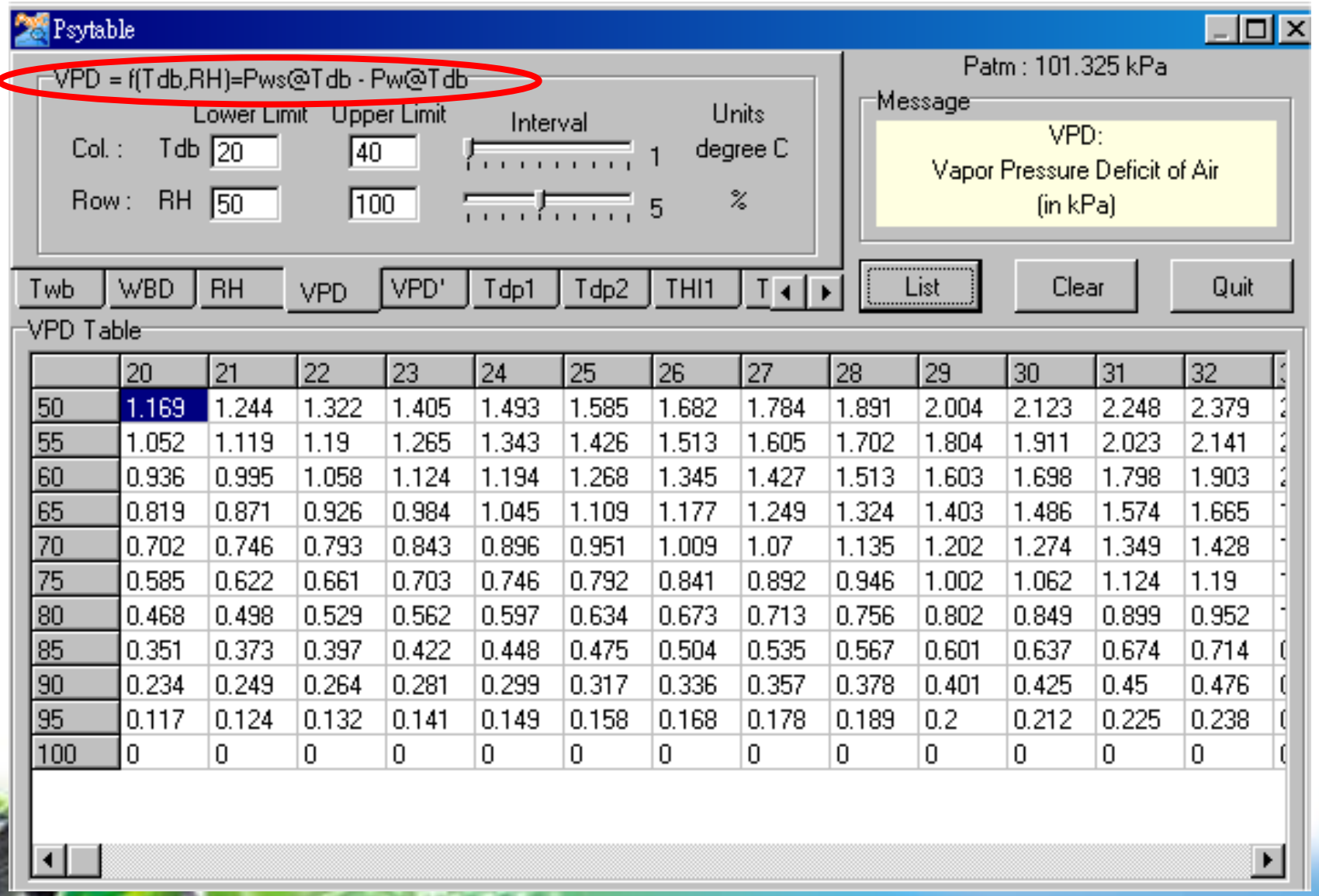
Table 3: RH = f(Tdb,Twb)

	20	22	24	26	28	30	32	34	36	38	40	42	44
20	100	82.63	65.02	57.61	49.01	39.99	33	27.14	22.11	17.69	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

Twb (20 – 44 °C) and Tdb (20 – 44 °C)

Table 4: VPD of air, Table 10: AHD



	20	21	22	23	24	25	26	27	28	29	30	31	32
50	1.169	1.244	1.322	1.405	1.493	1.585	1.682	1.784	1.891	2.004	2.123	2.248	2.379
55	1.052	1.119	1.19	1.265	1.343	1.426	1.513	1.605	1.702	1.804	1.911	2.023	2.141
60	0.936	0.995	1.058	1.124	1.194	1.268	1.345	1.427	1.513	1.603	1.698	1.798	1.903
65	0.819	0.871	0.926	0.984	1.045	1.109	1.177	1.249	1.324	1.403	1.486	1.574	1.665
70	0.702	0.746	0.793	0.843	0.896	0.951	1.009	1.07	1.135	1.202	1.274	1.349	1.428
75	0.585	0.622	0.661	0.703	0.746	0.792	0.841	0.892	0.946	1.002	1.062	1.124	1.19
80	0.468	0.498	0.529	0.562	0.597	0.634	0.673	0.713	0.756	0.802	0.849	0.899	0.952
85	0.351	0.373	0.397	0.422	0.448	0.475	0.504	0.535	0.567	0.601	0.637	0.674	0.714
90	0.234	0.249	0.264	0.281	0.299	0.317	0.336	0.357	0.378	0.401	0.425	0.45	0.476
95	0.117	0.124	0.132	0.141	0.149	0.158	0.168	0.178	0.189	0.2	0.212	0.225	0.238
100	0	0	0	0	0	0	0	0	0	0	0	0	0

VPD=Pws@Tdb – Pw@Tdb

AHD=Sat.AH@Tdb – Sat.AH@Tdp

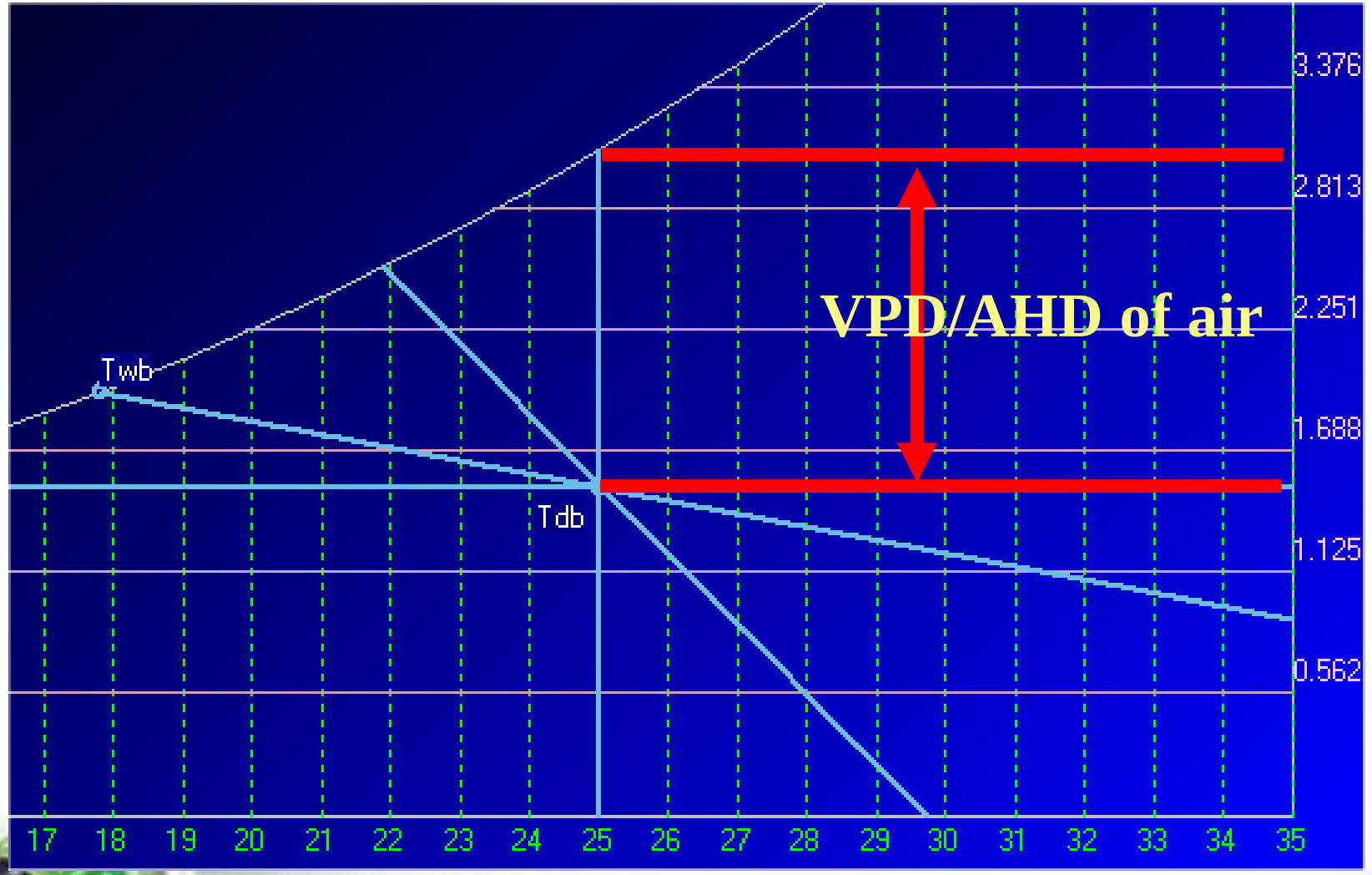
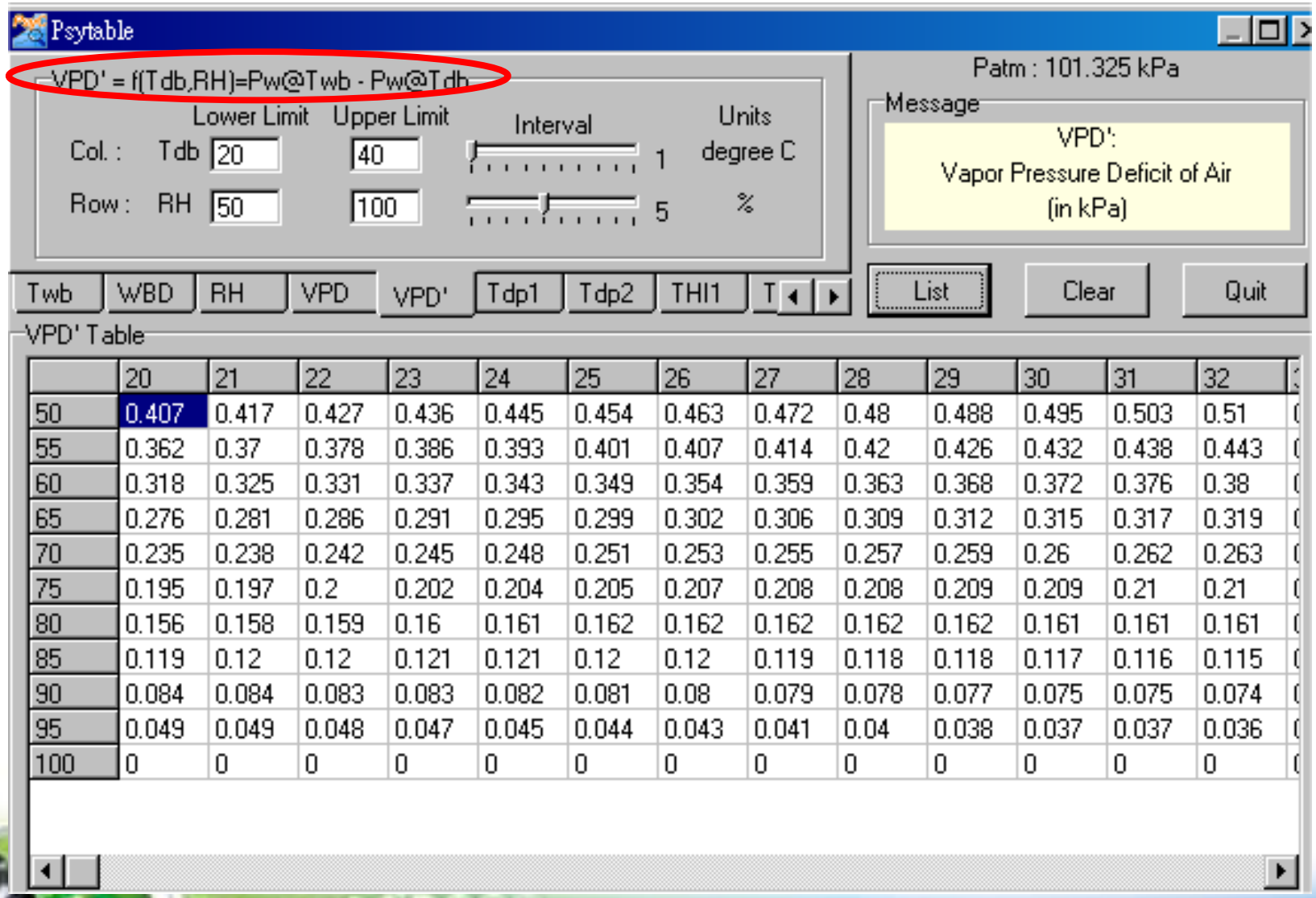


Table 5: VPD’ of air, Table 11: AHD’



	20	21	22	23	24	25	26	27	28	29	30	31	32
50	0.407	0.417	0.427	0.436	0.445	0.454	0.463	0.472	0.48	0.488	0.495	0.503	0.51
55	0.362	0.37	0.378	0.386	0.393	0.401	0.407	0.414	0.42	0.426	0.432	0.438	0.443
60	0.318	0.325	0.331	0.337	0.343	0.349	0.354	0.359	0.363	0.368	0.372	0.376	0.38
65	0.276	0.281	0.286	0.291	0.295	0.299	0.302	0.306	0.309	0.312	0.315	0.317	0.319
70	0.235	0.238	0.242	0.245	0.248	0.251	0.253	0.255	0.257	0.259	0.26	0.262	0.263
75	0.195	0.197	0.2	0.202	0.204	0.205	0.207	0.208	0.208	0.209	0.209	0.21	0.21
80	0.156	0.158	0.159	0.16	0.161	0.162	0.162	0.162	0.162	0.162	0.161	0.161	0.161
85	0.119	0.12	0.12	0.121	0.121	0.12	0.12	0.119	0.118	0.118	0.117	0.116	0.115
90	0.084	0.084	0.083	0.083	0.082	0.081	0.08	0.079	0.078	0.077	0.075	0.075	0.074
95	0.049	0.049	0.048	0.047	0.045	0.044	0.043	0.041	0.04	0.038	0.037	0.037	0.036
100	0	0	0	0	0	0	0	0	0	0	0	0	0

VPD’=Pw@Twb – Pw@Tdb

AHD’=Sat.AH@Twb – Sat.AH@Tdp

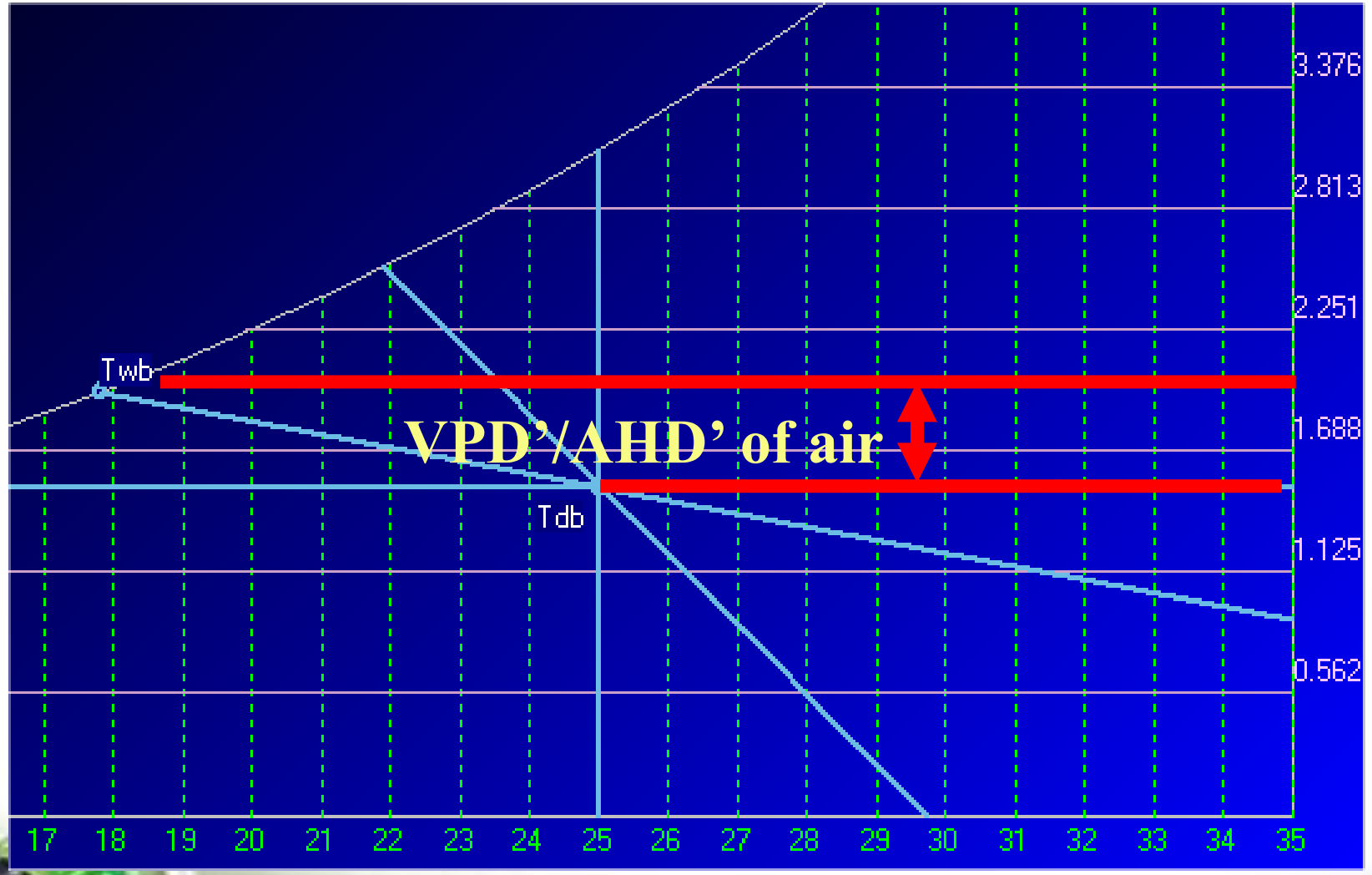


Table 6: Tdp

Psytable

Tdp1 = f(Tdb,RH)

		Lower Limit	Upper Limit	Interval	Units
Col. :	Tdb	20	40	2	degree C
Row :	RH	50	100	5	%

Patm : 101.32

Message

Tdp:
Dew Point Tem
(in degree

Twb | WBD | RH | VPD | VPD' | Tdp1 | Tdp2 | THI1 | T | List | Clear

Tdp1 Table

	20	22	24	26	28	30	32	34	36	38	40
50	9.15	10.96	12.79	14.62	16.45	18.29	20.14	21.98	23.83	25.68	27.52
55	10.55	12.4	14.25	16.11	17.97	19.83	21.7	23.57	25.44	27.31	29.19
60	11.86	13.73	15.6	17.48	19.37	21.26	23.15	25.04	26.93	28.83	30.72
65	13.07	14.96	16.86	18.76	20.67	22.58	24.49	26.41	28.32	30.24	32.15
70	14.21	16.12	18.04	19.96	21.89	23.82	25.75	27.69	29.62	31.56	33.49
75	15.28	17.21	19.15	21.09	23.04	24.99	26.94	28.89	30.84	32.79	34.74
80	16.29	18.24	20.2	22.16	24.12	26.09	28.06	30.03	31.99	33.96	35.93
85	17.25	19.22	21.19	23.17	25.15	27.13	29.12	31.1	33.08	35.07	37.05
90	18.16	20.14	22.13	24.13	26.13	28.12	30.12	32.12	34.12	36.12	38.11
95	19.03	21.03	23.03	25.04	27.06	29.07	31.08	33.1	35.11	37.12	39.13
100	20	22	24	26	28	30	32	34	36	38	40

6 Tdp1 = f(Tdb,RH)

7 Tdp2 = f(Tdb,Twb)

THI1 = f(Tdb,RH)

THI2 = f(Tdb,Twb)

AHD = f(Tdb,RH)

AHD' = f(Tdb,RH)

Table 7: Tdp

Psytable

Tdp2 = f(Tdb,Twb)

		Lower Limit	Upper Limit	Interval	Units
Col. :	Tdb	20	40	2	degree C
Row :	Twb	20	40	2	degree C

Patm : 101.32

Message

Tdp:
Dew Point Tem
(in degree

Twb | WBD | RH | VPD | VPD' | Tdp1 | Tdp2 | THI1 | T | List | Clear

Tdp2 Table

	20	22	24	26	28	30	32	34	36	38	40
20	20	18.76	17.81	16.84	15.82	14.73	13.56	12.3	10.9	9.36	7.62
22	N/A	22	20.9	20.08	19.23	18.34	17.39	16.38	15.29	14.1	12.81
24	N/A	N/A	24	23.04	22.32	21.58	20.8	19.97	19.08	18.13	17.11
26	N/A	N/A	N/A	26	25.18	24.56	23.9	23.21	22.48	21.69	20.86
28	N/A	N/A	N/A	N/A	28	27.33	26.78	26.2	25.58	24.93	24.23
30	N/A	N/A	N/A	N/A	N/A	30	29.48	28.99	28.47	27.92	27.33
32	N/A	N/A	N/A	N/A	N/A	N/A	32	31.63	31.19	30.73	30.22
34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	34	33.78	33.38	32.95
36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	36	35.92	35.55
38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	38	38.04
100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	40

Table 8, 9: THI, Temperature Humidity Index

Psytable

THI1 = f(Tdb,RH)=Tdb+0.36*Tdp+41.2

		Lower Limit	Upper Limit	Interval	Units
Col. :	Tdb	16	40	2	degree C
Row :	RH	35	100	5	%

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

Psytable

THI2 = f(Tdb,Twb)=Tdb+0.36*Tdp+41.2

		Lower Limit	Upper Limit	Interval	Units
Col. :	Tdb	20	40	2	degree C
Row :	Twb	20	40	2	degree C

Patm : 101.32

Message: THI: Temperature Hu (in degre

WBD | RH | VPD | VPD' | Tdp1 | Tdp2 | THI1 | THI2 | A | List | Clea

THI2 Table

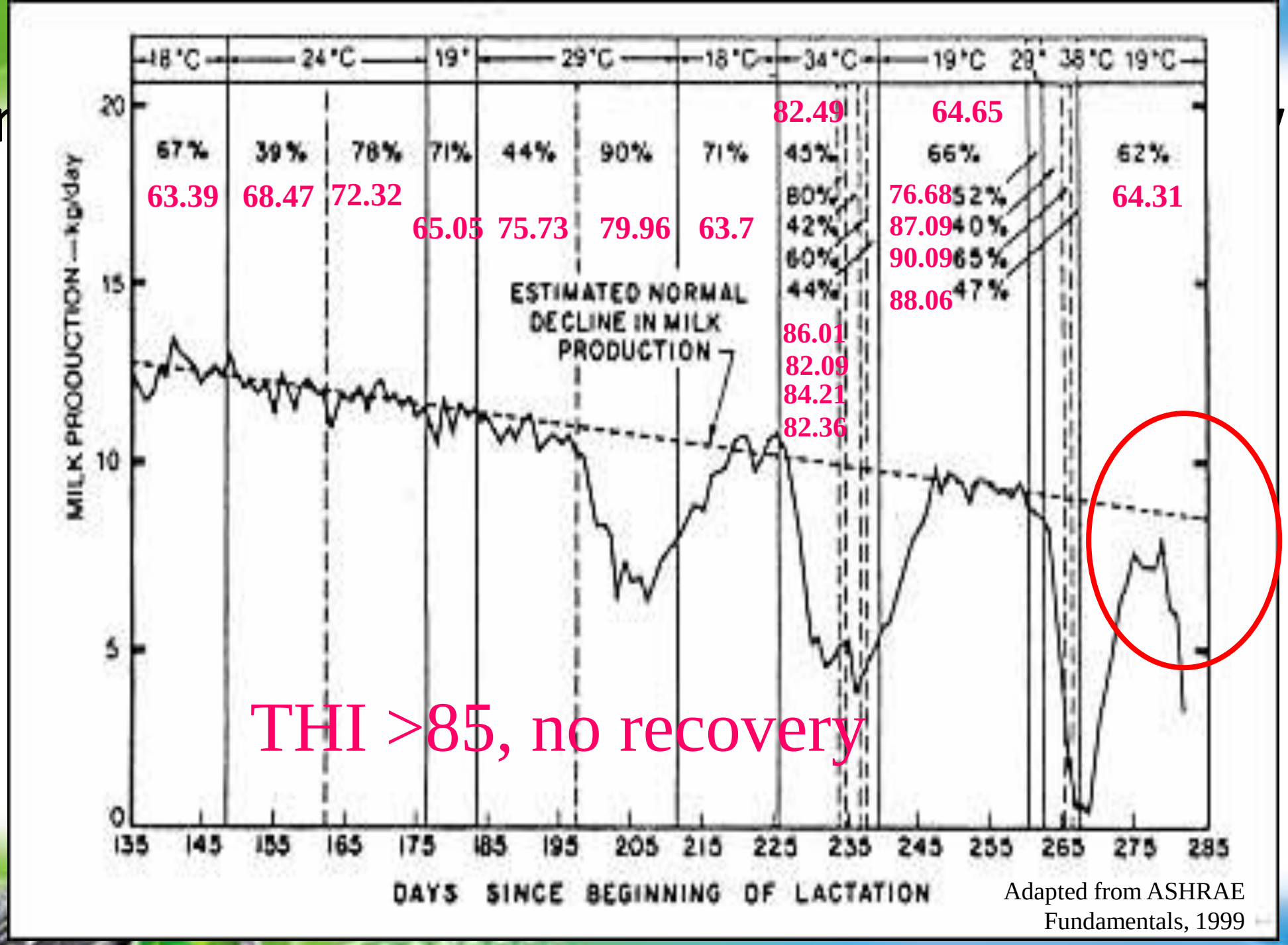
	20	22	24	26	28	30	32	34	36	38	40
20	68.35	69.95	71.61	73.26	74.89	76.5	78.08	79.63	81.12	82.57	83.94
22	N/A	71.07	72.72	74.43	76.12	77.8	79.46	81.1	82.7	84.28	85.81
24	N/A	N/A	73.8	75.49	77.24	78.97	80.69	82.39	84.07	85.73	87.36
26	N/A	N/A	N/A	76.53	78.27	80.04	81.8	83.56	85.29	87.01	88.71
28	N/A	N/A	N/A	N/A	79.26	81.04	82.84	84.63	86.41	88.17	89.92
30	N/A	N/A	N/A	N/A	N/A	81.99	83.81	85.64	87.45	89.25	91.04
32	N/A	N/A	N/A	N/A	N/A	N/A	84.72	86.59	88.43	90.26	92.08
34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	87.44	89.36	91.22	93.06
36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	90.16	92.13	94
38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	92.88	94.9
40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	95.6

8 THI1 = f(Tdb,RH)

9 THI2 = f(Tdb,Twb)

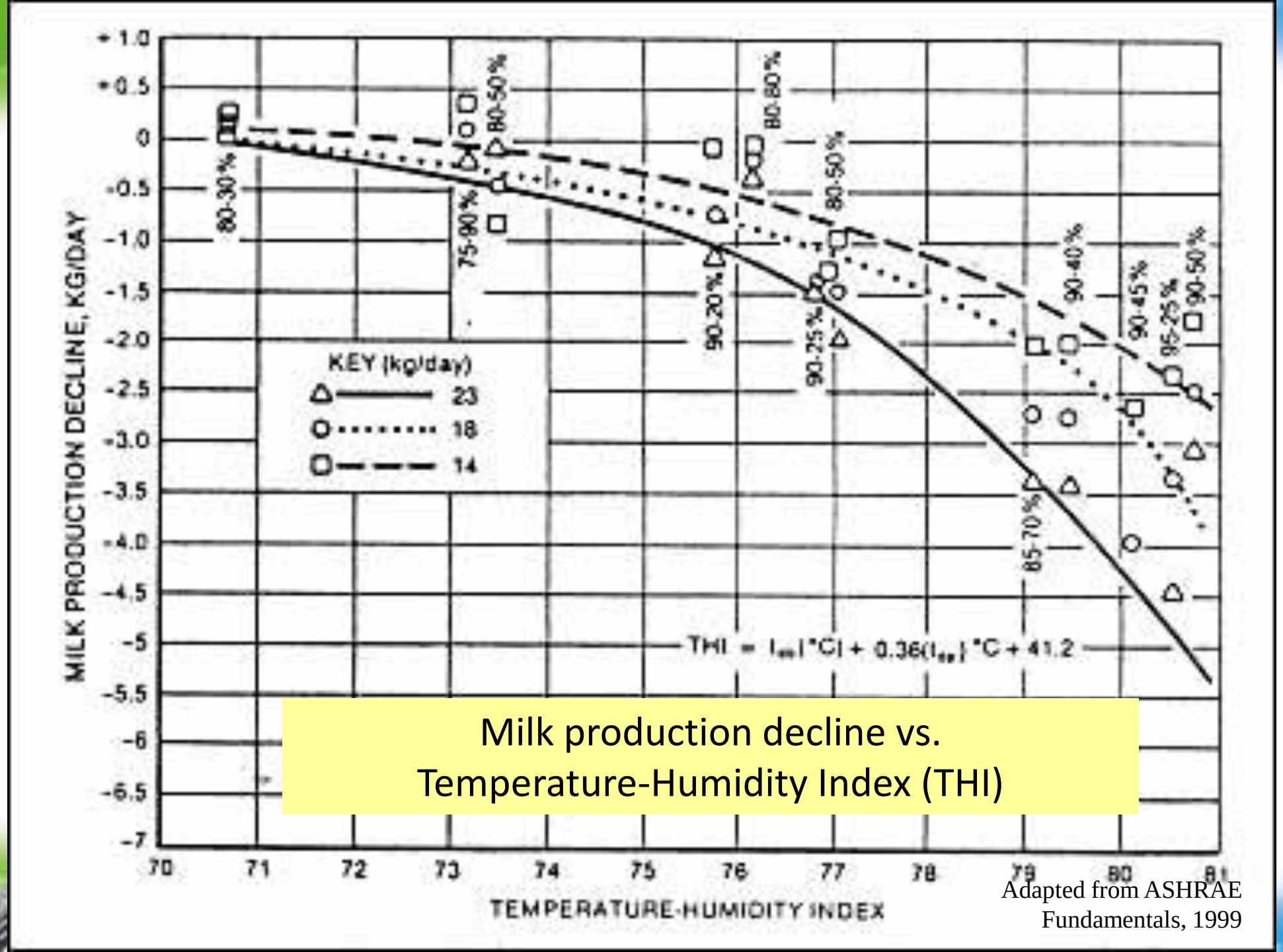
AHD = f(Tdb,RH)

AHD' = f(Tdb,RH)



THI >85, no recovery

Adapted from ASHRAE Fundamentals, 1999



Milk production decline vs.
Temperature-Humidity Index (THI)

Adapted from ASHRAE Fundamentals, 1999

MP = f(HD74, HA80S)

$$MP = 21.48 - 0.051 * HD74 - 0.0099 * HA80S$$

where,

MP: milk production per cow per day (in kg/day/cow)

21.48: regular MP amount (in kg)

HD74: total hours of THI > 74 for previous 4 days

HA80S: square of total hours of THI > 80 for previous day

Linvill and Pardue (1992)

Iso-THI lines

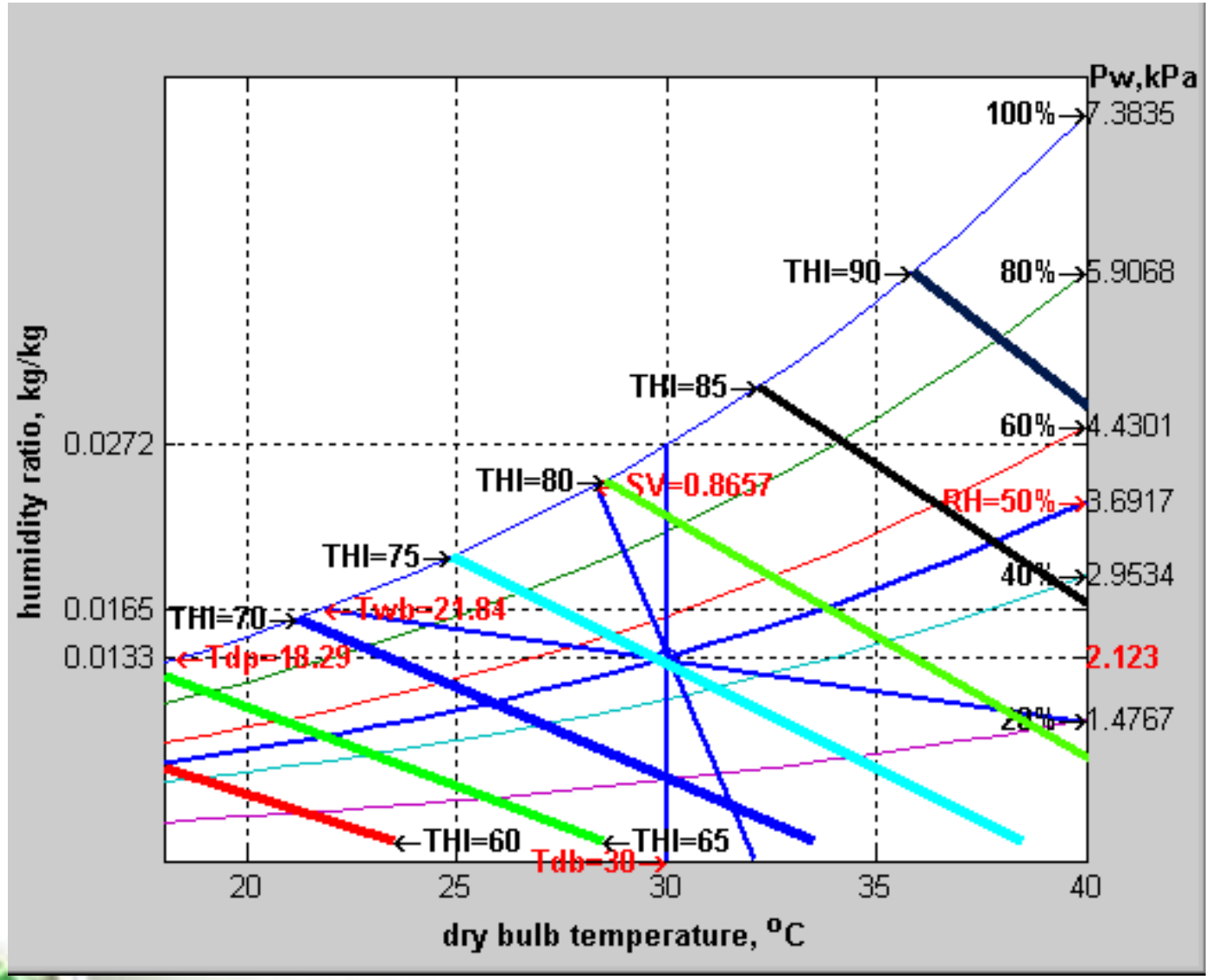
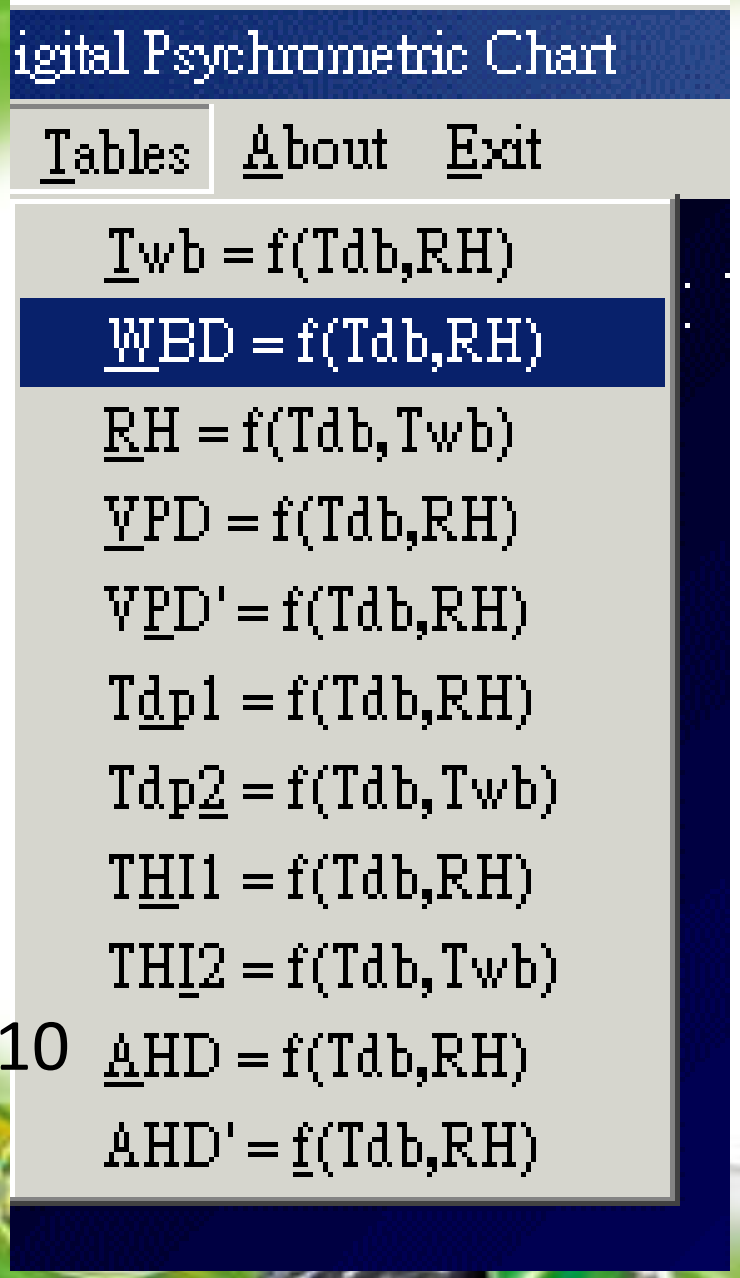


Table 10: AHD or HD



10

Psytable

AHD = f(Tdb,RH)=SaturatedAH@Tdb - 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

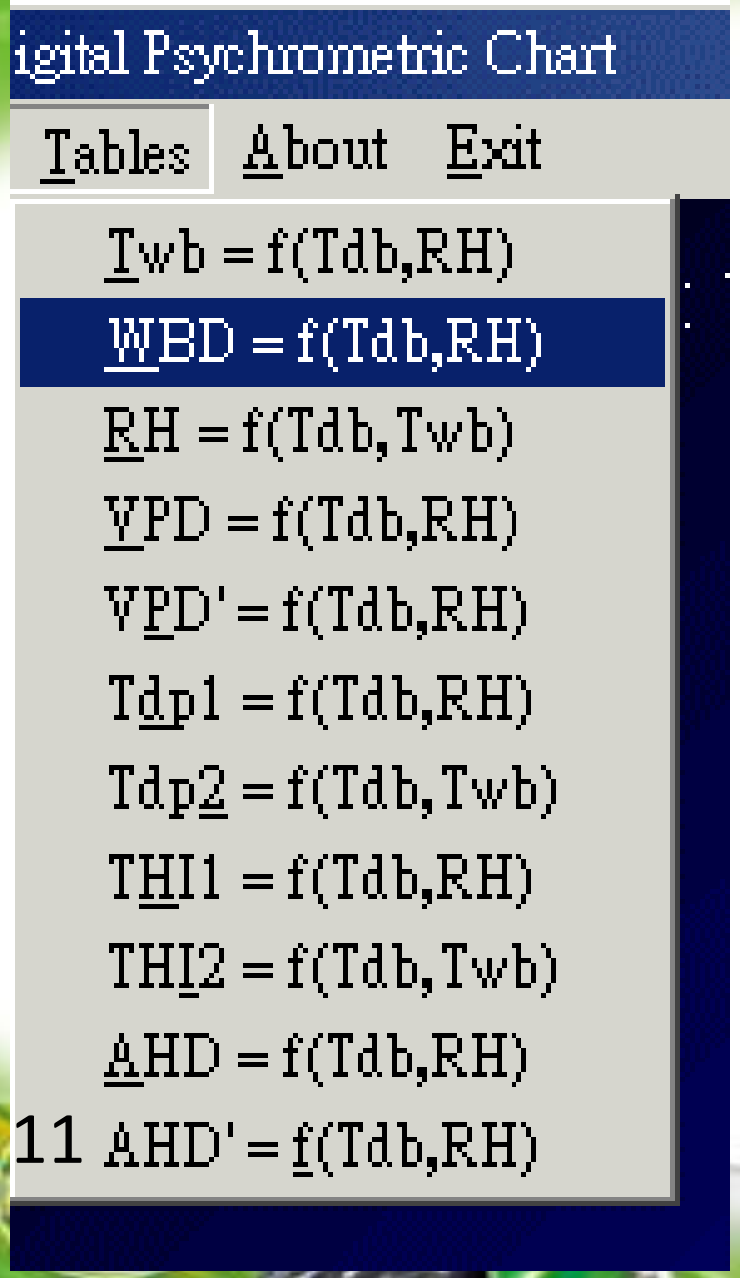
AHD:
Absolute Humidity Deficit
(x0.001 kg/kg DA)

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	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

Table 11: AHD’ or HD’



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	%

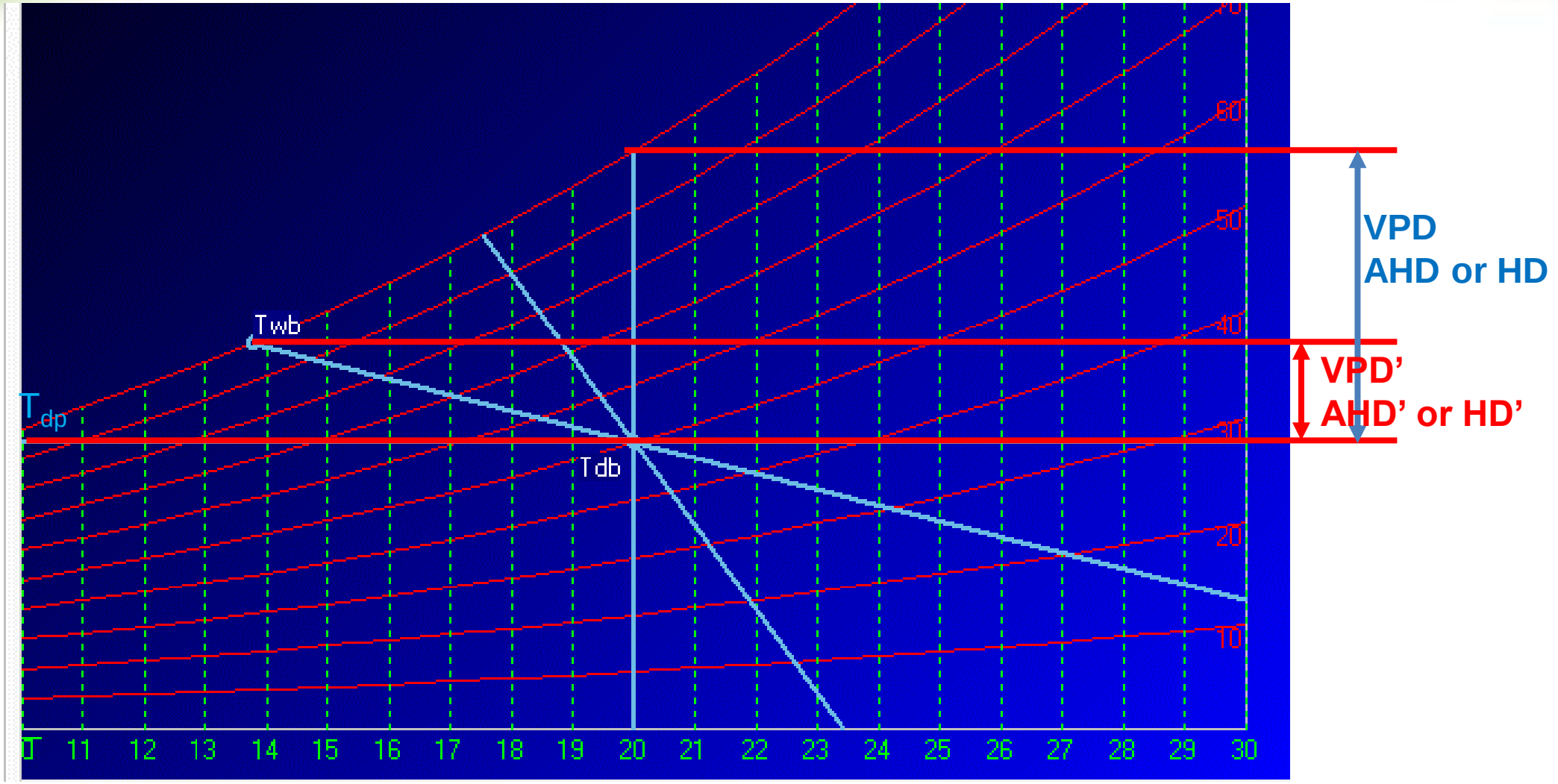
Patm : 101.325 kPa

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

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

AHD' Table

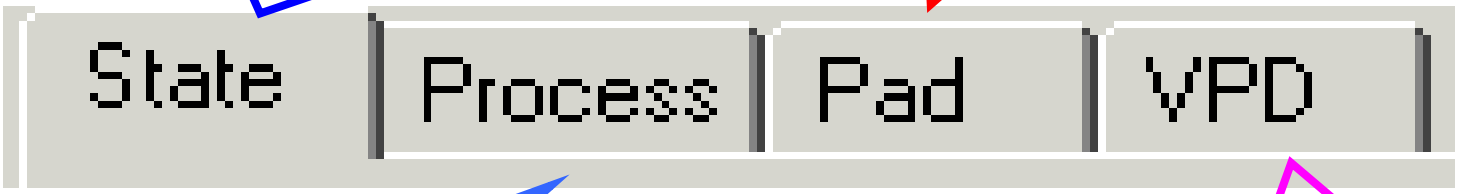
	16	18	20	22	24	26	28	30	32	34	36	38	40
35	3.011	3.234	3.457	3.681	3.904	4.126	4.347	4.566	4.783	4.998	5.212	5.423	5.631
40	2.776	2.977	3.178	3.376	3.573	3.766	3.955	4.141	4.322	4.5	4.673	4.843	5.008
45	2.544	2.724	2.902	3.077	3.246	3.411	3.571	3.724	3.872	4.014	4.15	4.281	4.406
50	2.315	2.475	2.631	2.782	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


Twb
Tdp
Tdb
60
50
40
30
20
10
0
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
VPD
AHD or HD
VPD'
AHD' or HD'

Psycharts

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

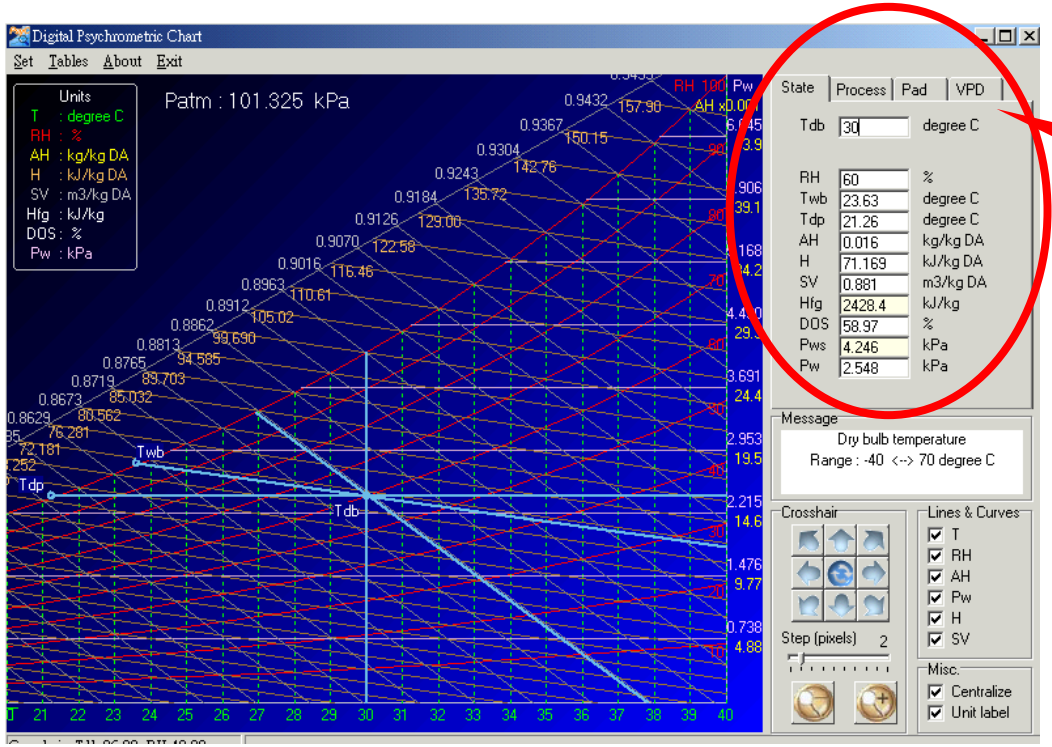
Evaporative cooling process calculation

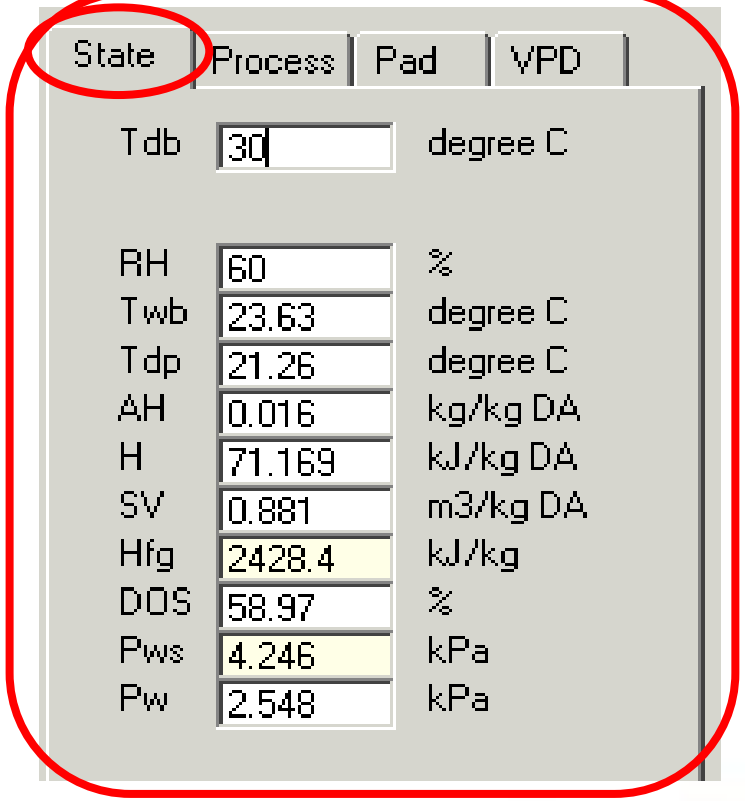


find differences between 2 states

Vapor pressure deficit on leaf

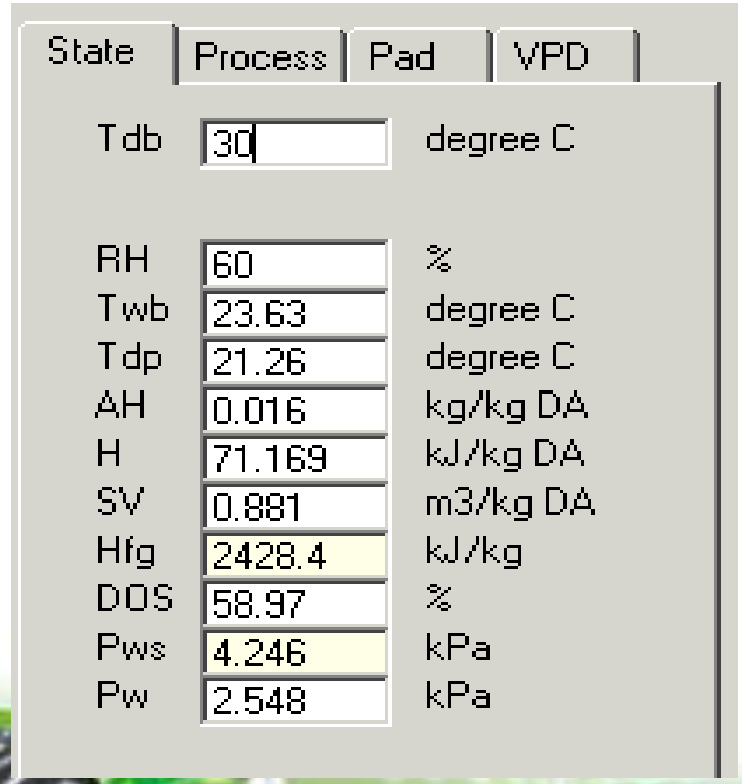
State Calculation





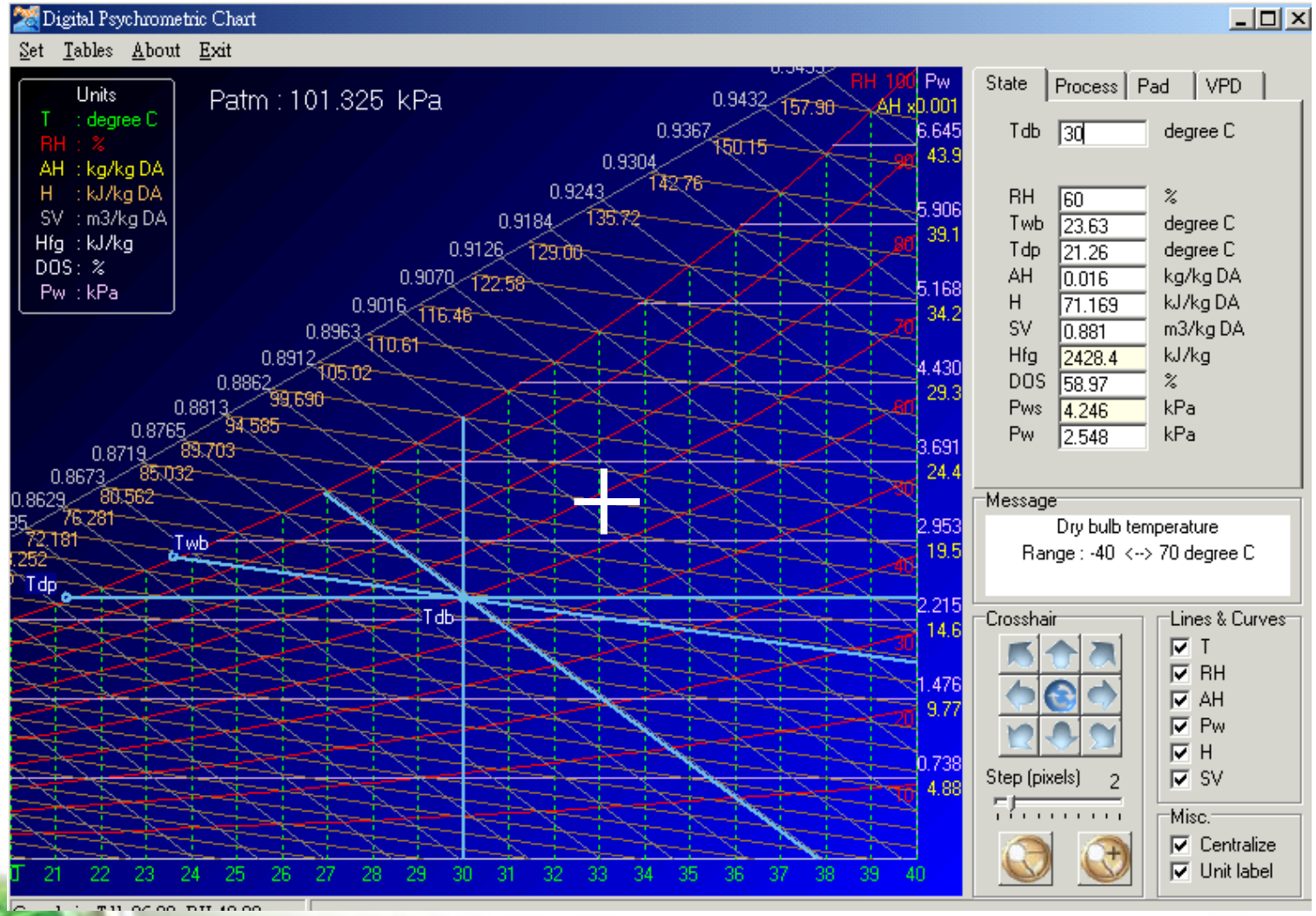
Independent Properties (IP)

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

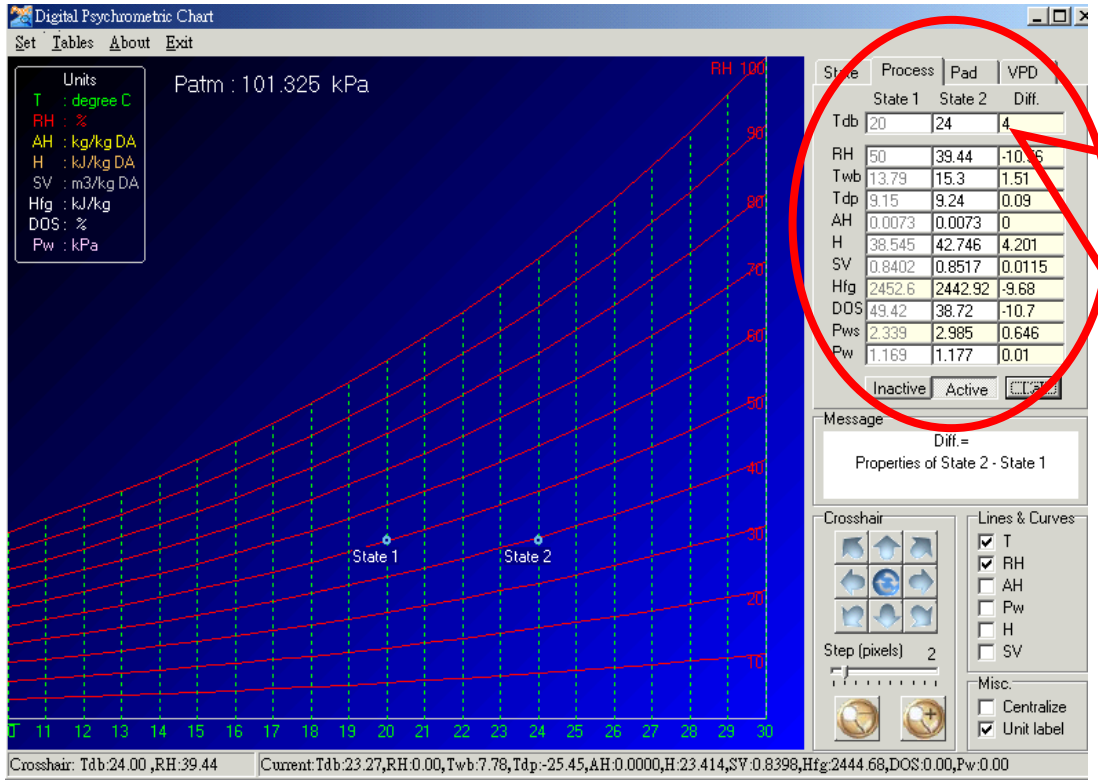


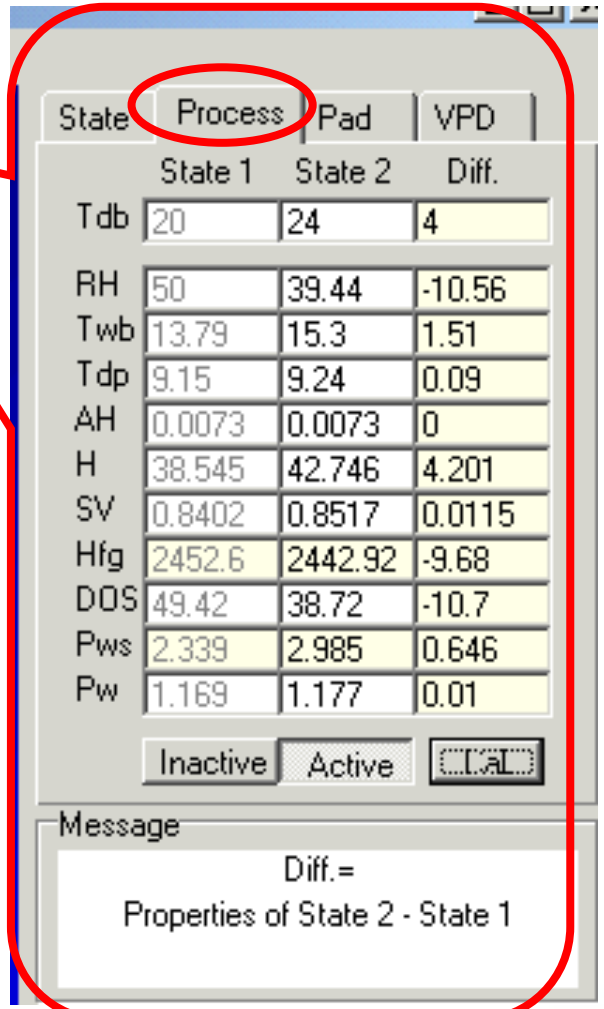
Any pair of IP can be the given values to derive others.

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

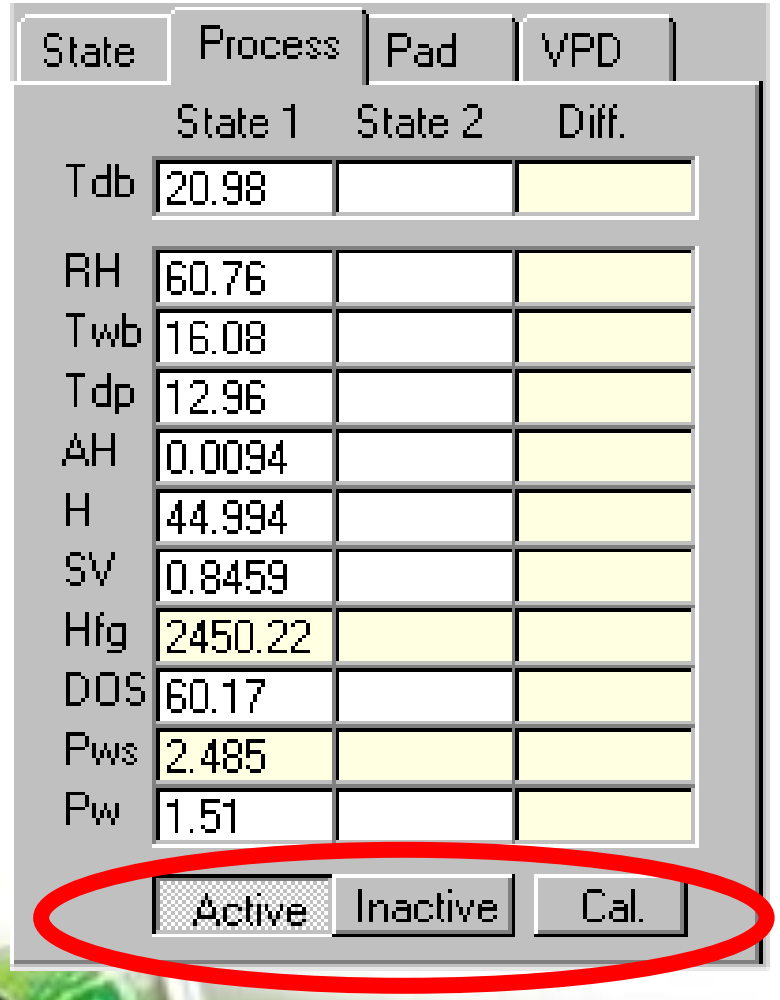


Process Calculation



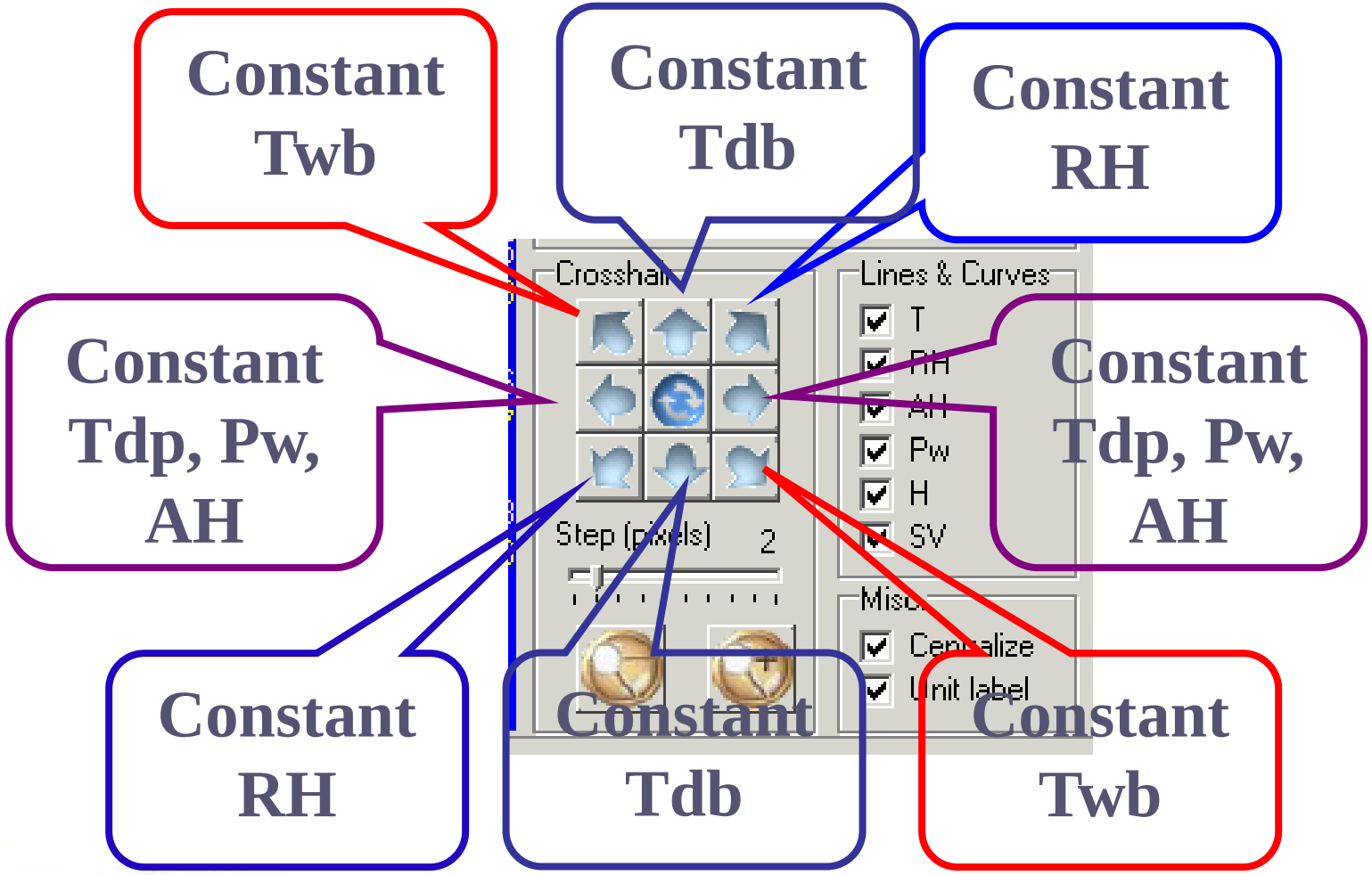


Use mouse to define 2 states



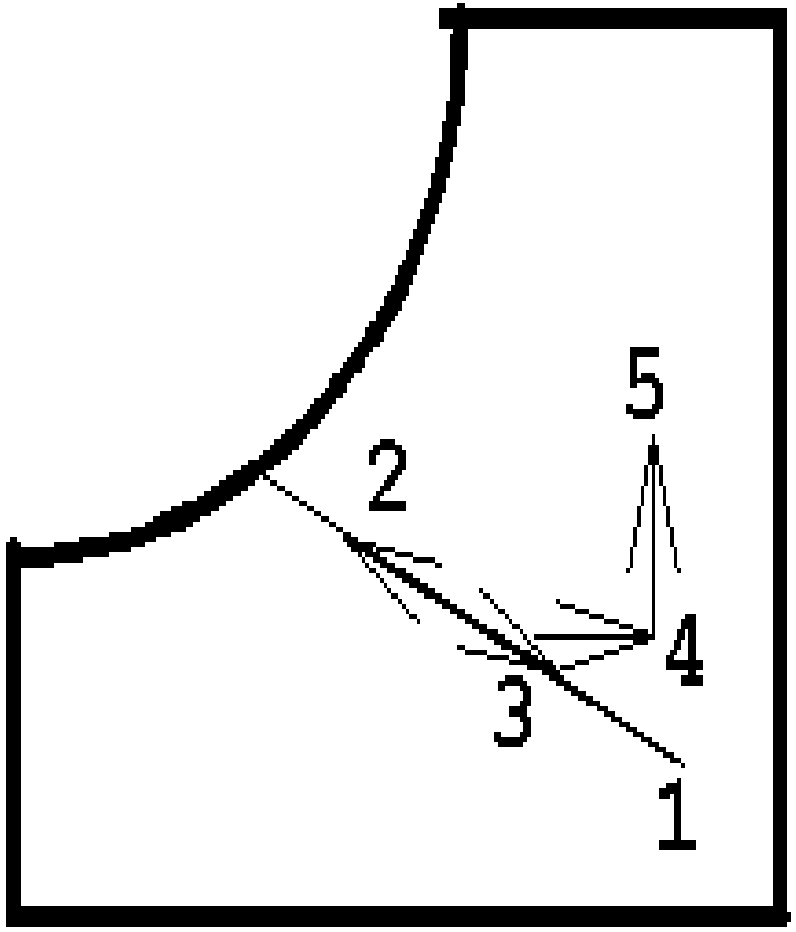
1. **To define 2nd state, change from 'Inactive' to 'Active' first.**
2. **Click in the Psychart window at the selected state or click on the crosshair region to move along constant lines or curves.**
3. **Click on 'Cal.' to calculate the difference.**

Move along prefix lines or Curves

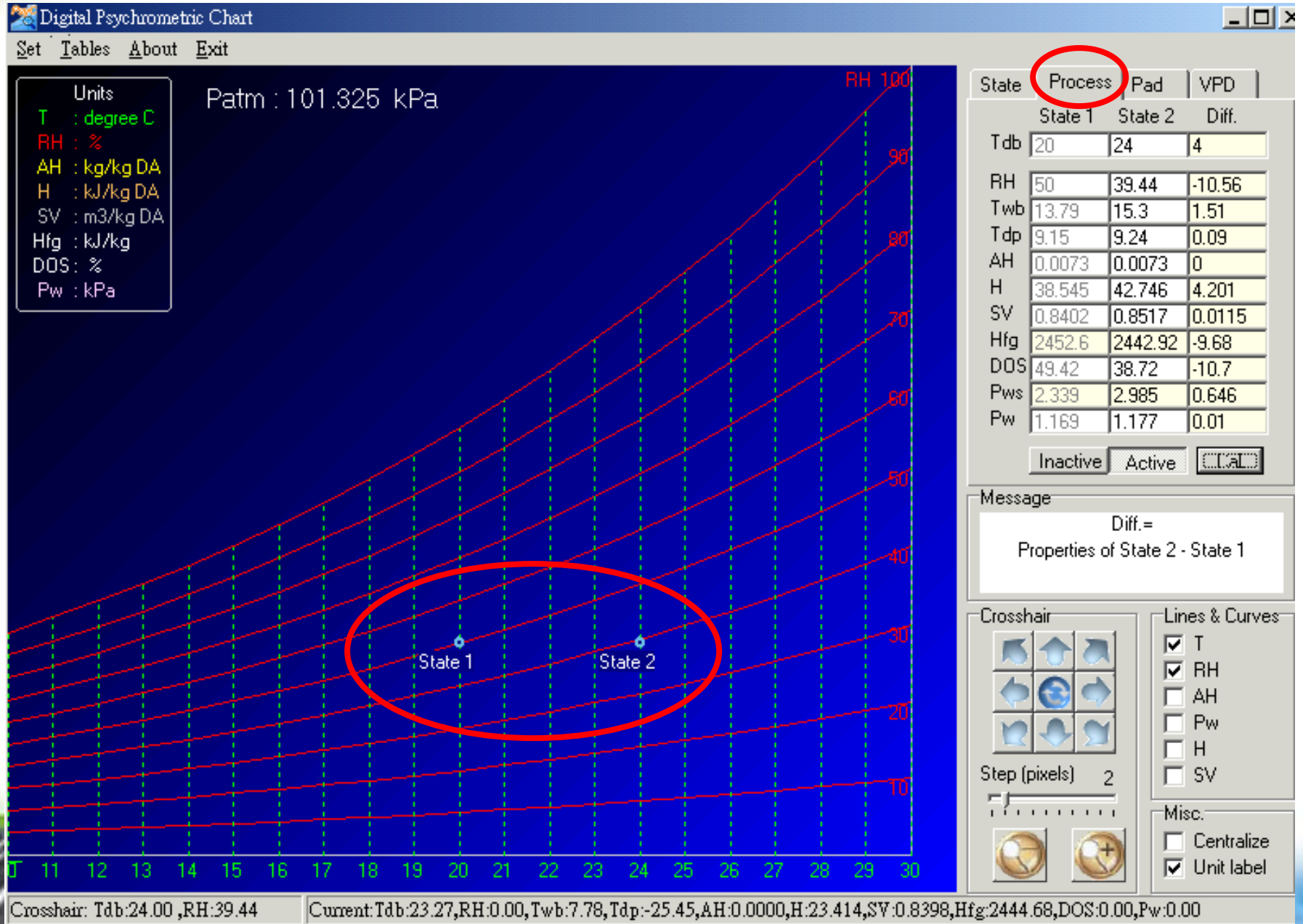


Process: Move from 1 state to another

- 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)



Sensible heat gain



Evaporative cooling

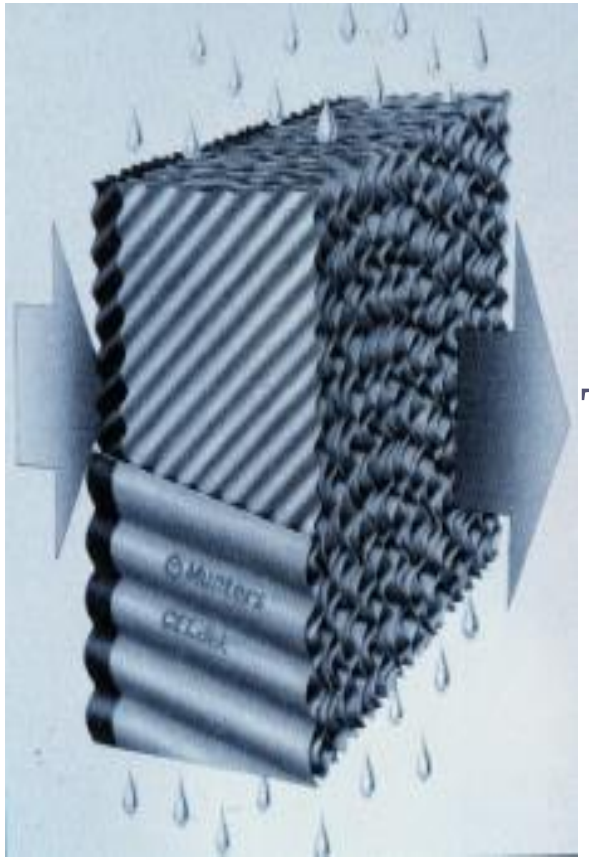
- Limit: Outdoor WB Temperature
  - Pad and Fan system
  - Misting/Fogging with nozzle at one side of the wall

- Limit: INDOOR WB Temperature
  - Indoor Spraying/Misting/Fogging

How to derive ΔT

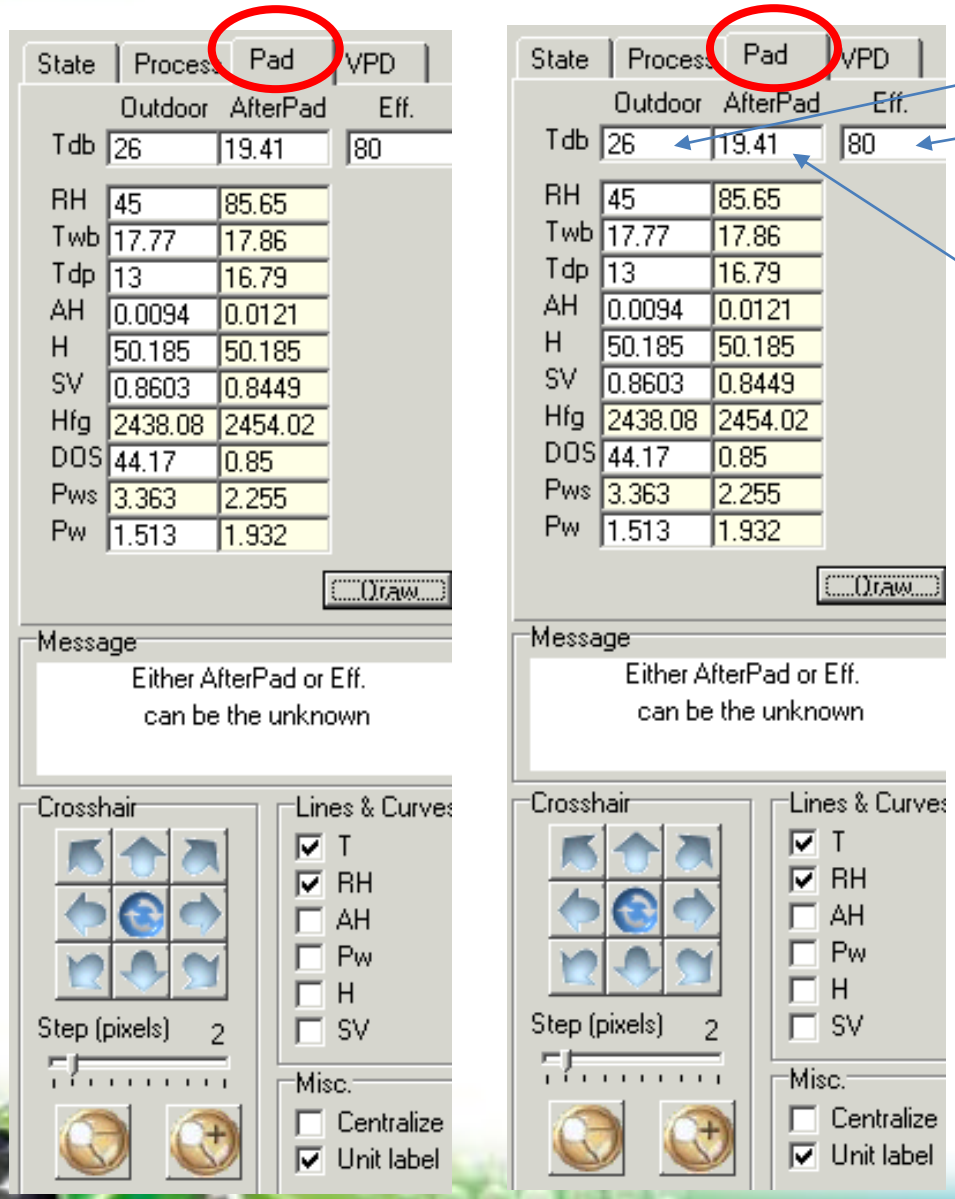
ΔT = WBD of outdoor air x Pad Efficiency

T



T- ΔT

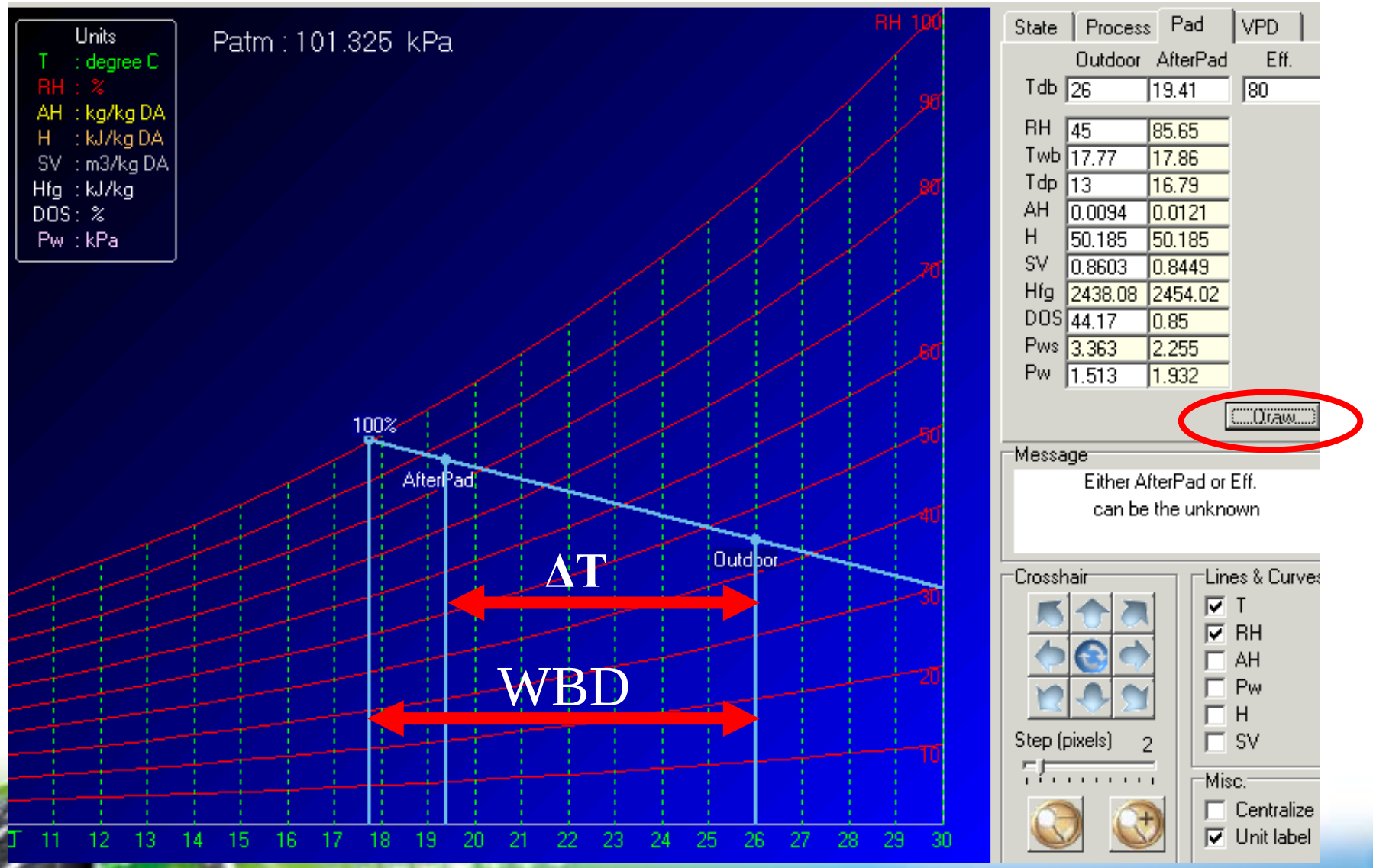
Evaporative cooling of a pad



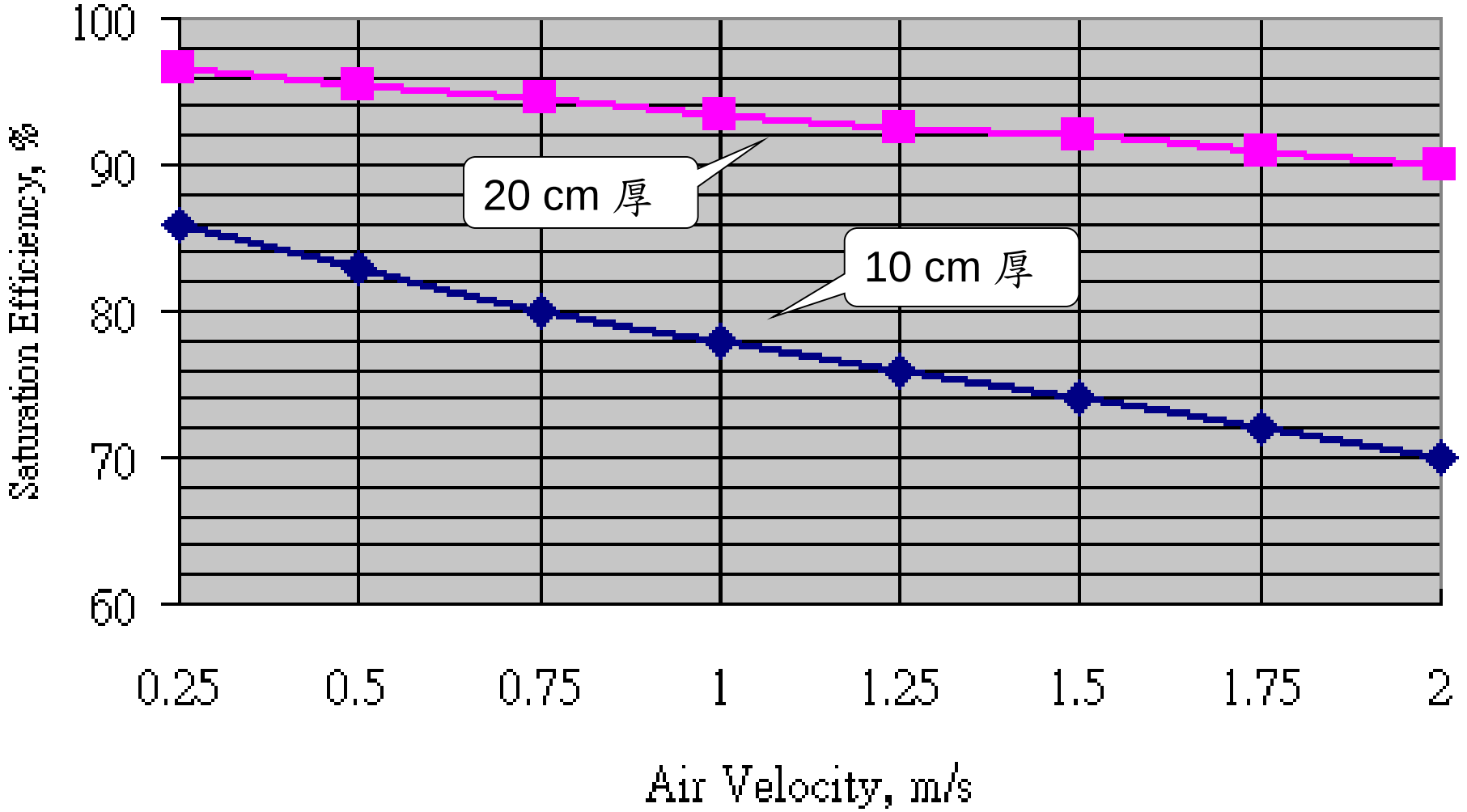
1. Enter T outdoor
2. Enter Pad efficiency
3. Derive others

2. Enter T after Pad
3. Derive others

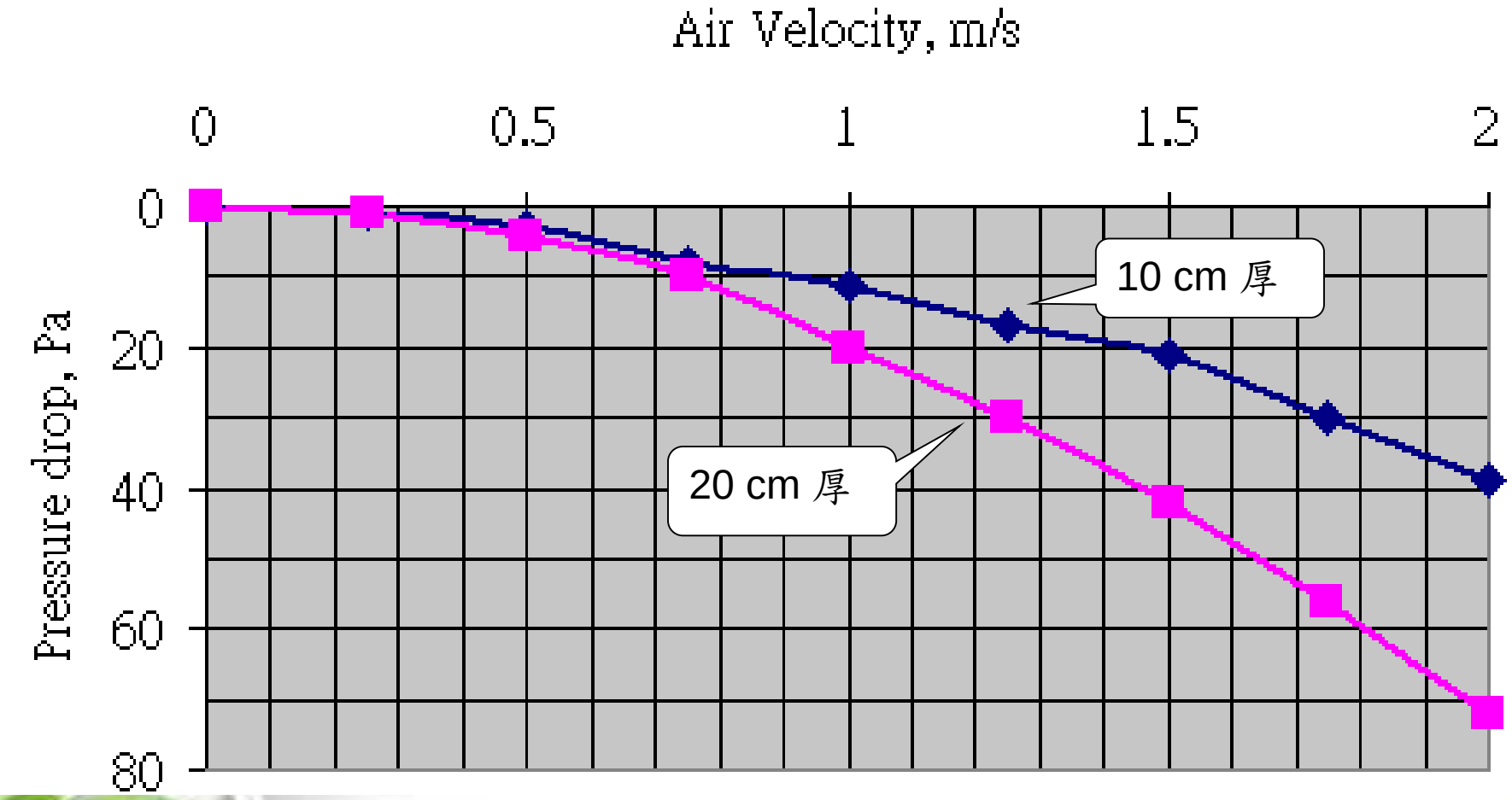
Click on “Draw” icon to visually see the outcome

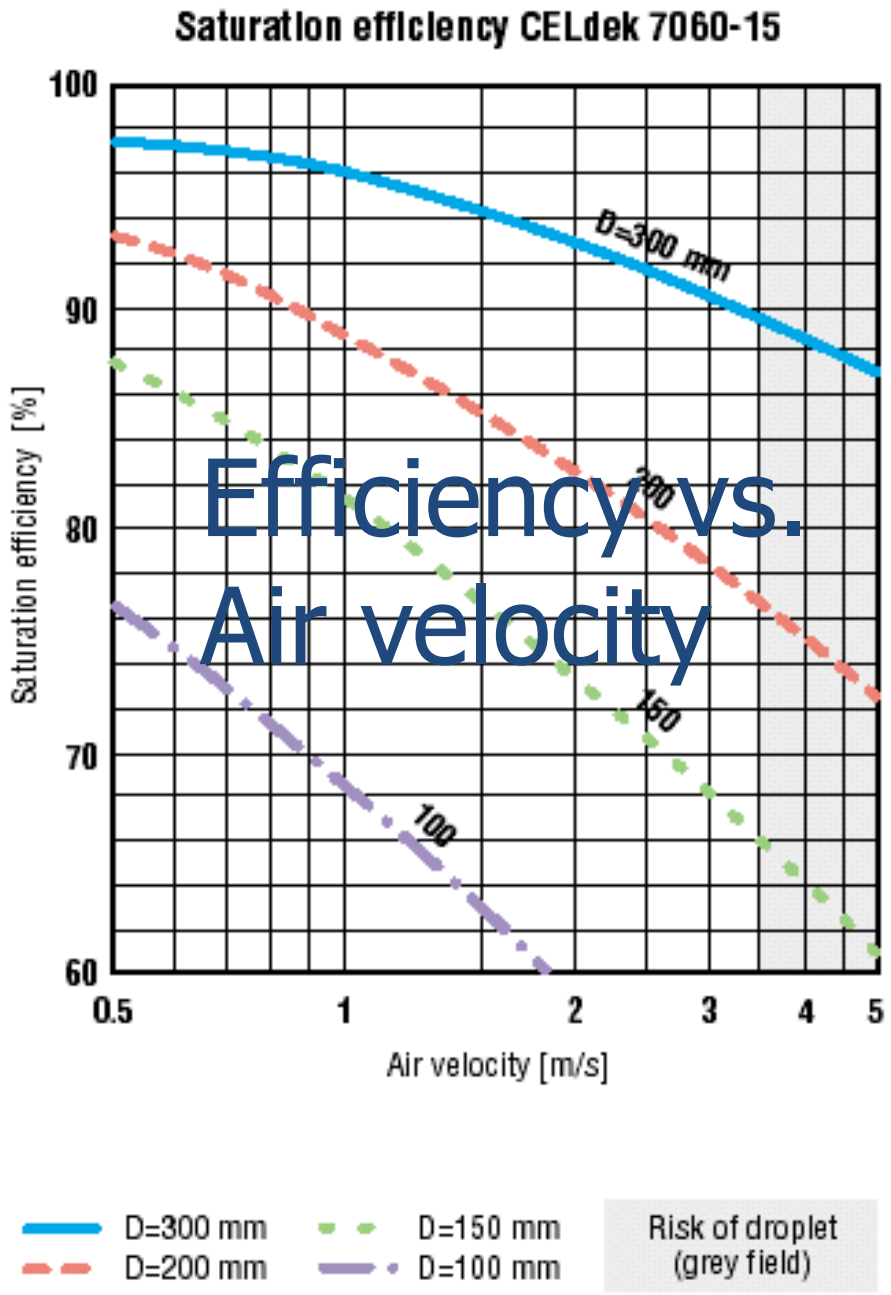


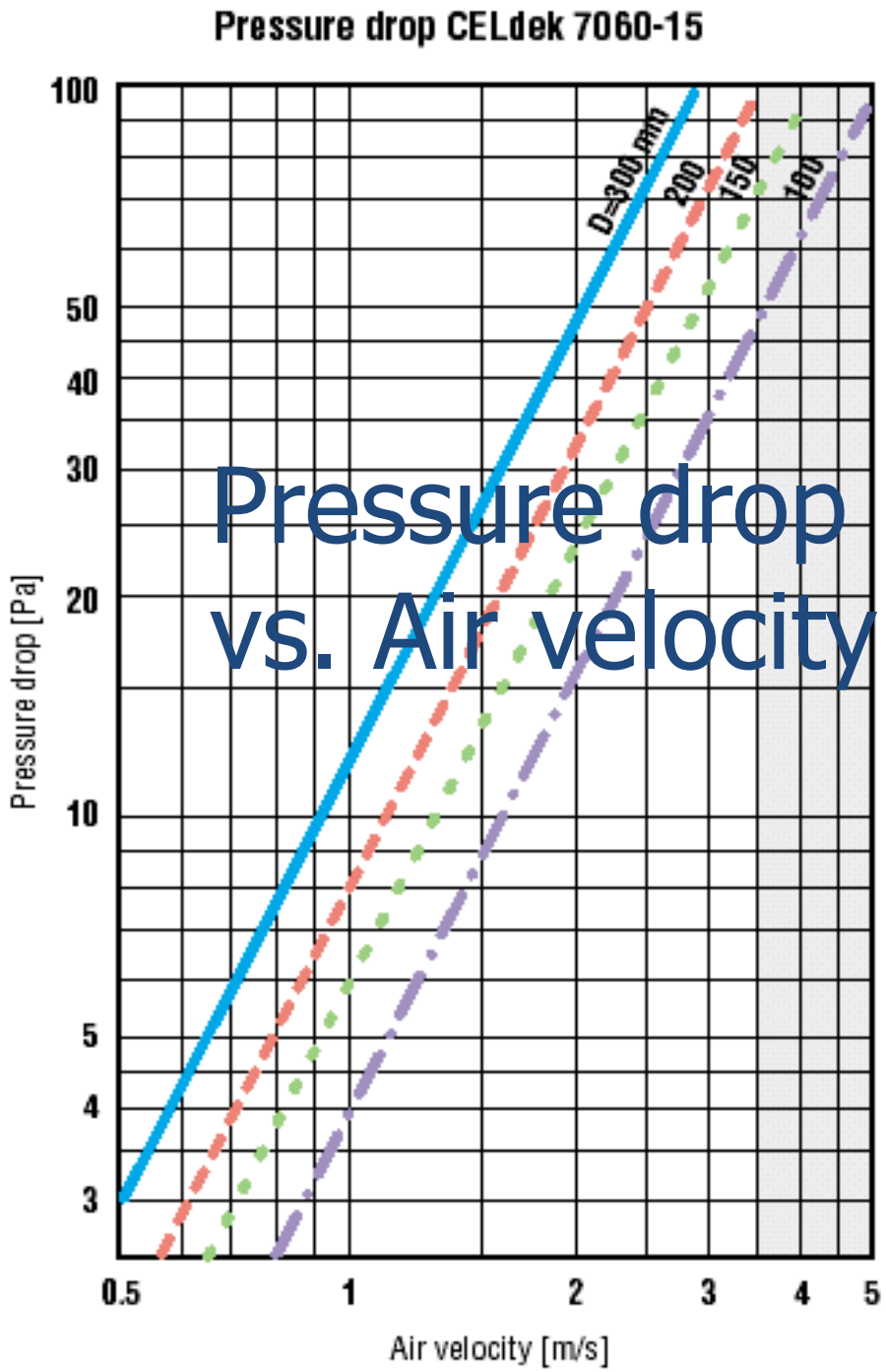
Pad Efficiency vs. Air velocity (2 thickness of pad)



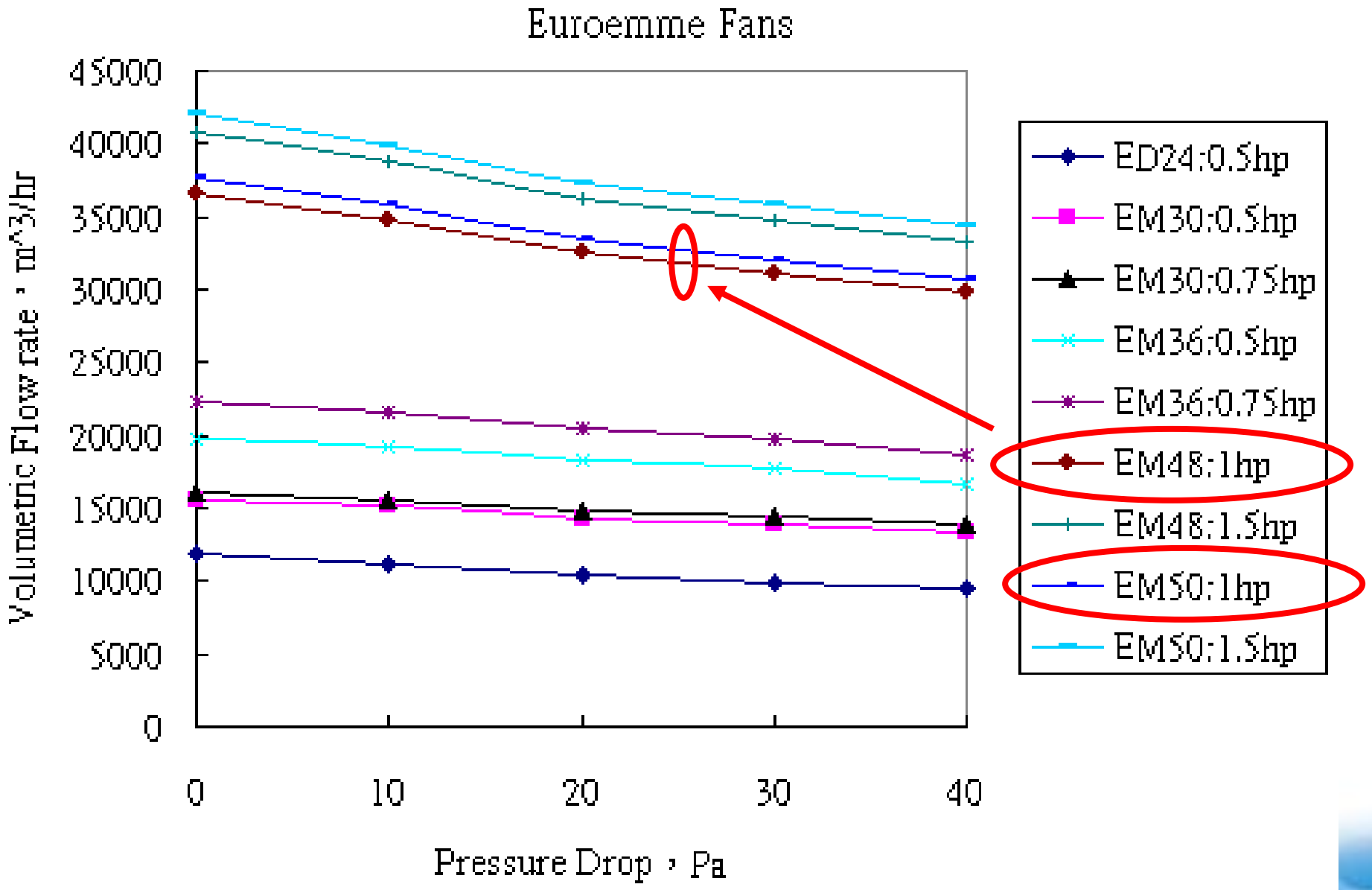
ΔP vs. Air velocity (2 thickness of pad)




Saturation efficiency CELdek 7060-15
Saturation efficiency [%]
100
90
80
70
60
0.5
1
2
3
4
5
Air velocity [m/s]
D=300 mm
200
150
100
Efficiency vs. Air velocity
D=300 mm
D=200 mm
D=150 mm
D=100 mm
Risk of droplet (grey field)

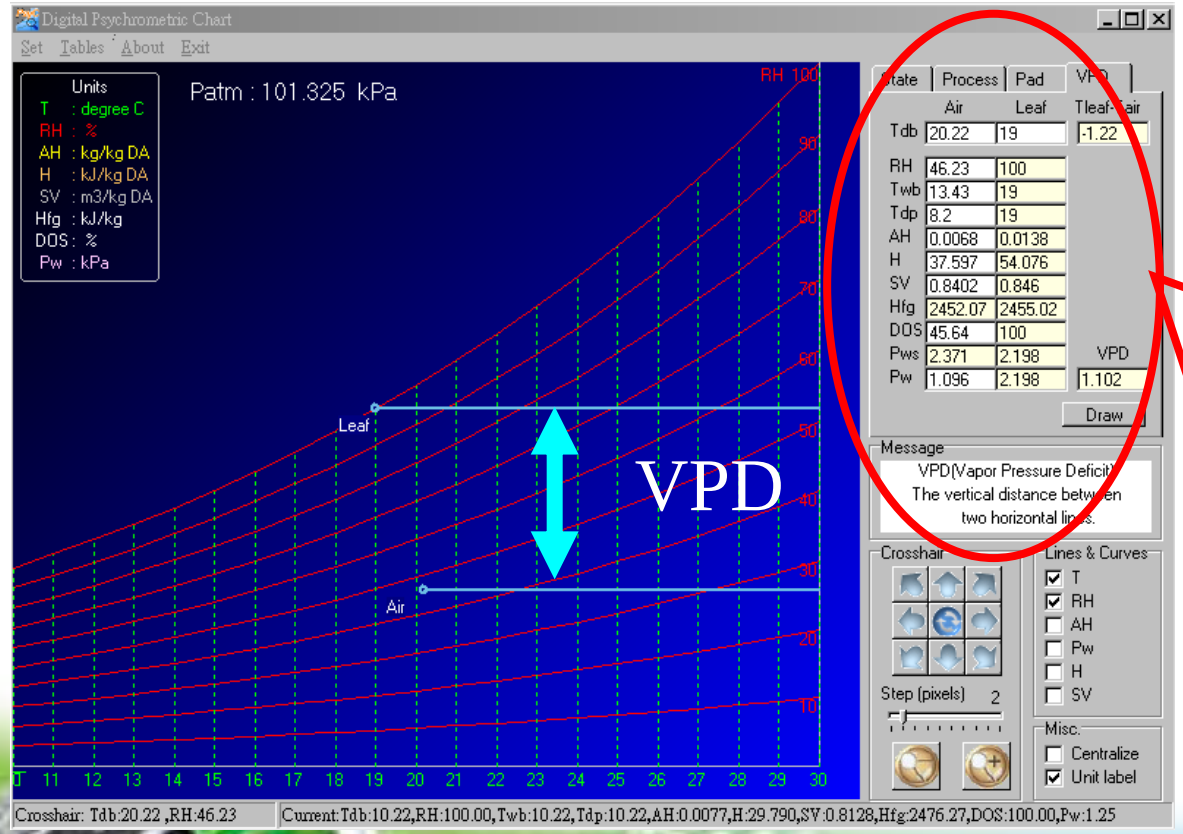

Pressure drop CELdek 7060-15
Pressure drop [Pa]
100
50
40
30
20
10
5
4
3
0.5
1
2
3
4
5
Air velocity [m/s]
D=300 mm
200
150
100
Pressure drop vs. Air velocity

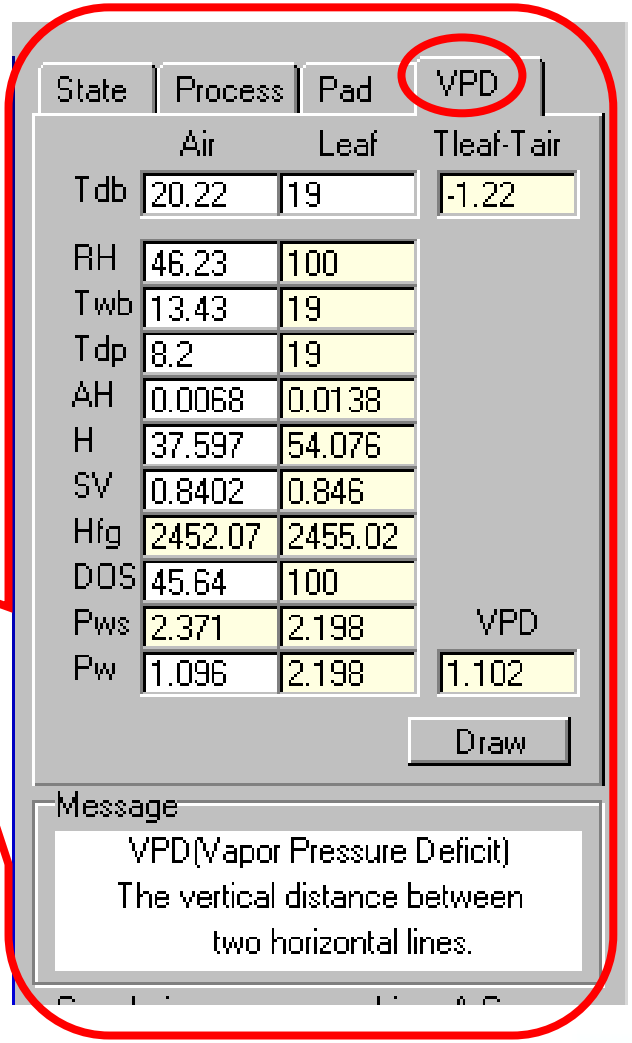
Fan curves


Euroemme Fans
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Volumetric Flow rate，m^3/hr
0
10
20
30
40
Pressure Drop，Pa
ED24:0.5hp
EM30:0.5hp
EM30:0.75hp
EM36:0.5hp
EM36:0.75hp
EM48:1hp
EM48:1.5hp
EM50:1hp
EM50:1.5hp

Vapor pressure deficit (VPD) of leaf

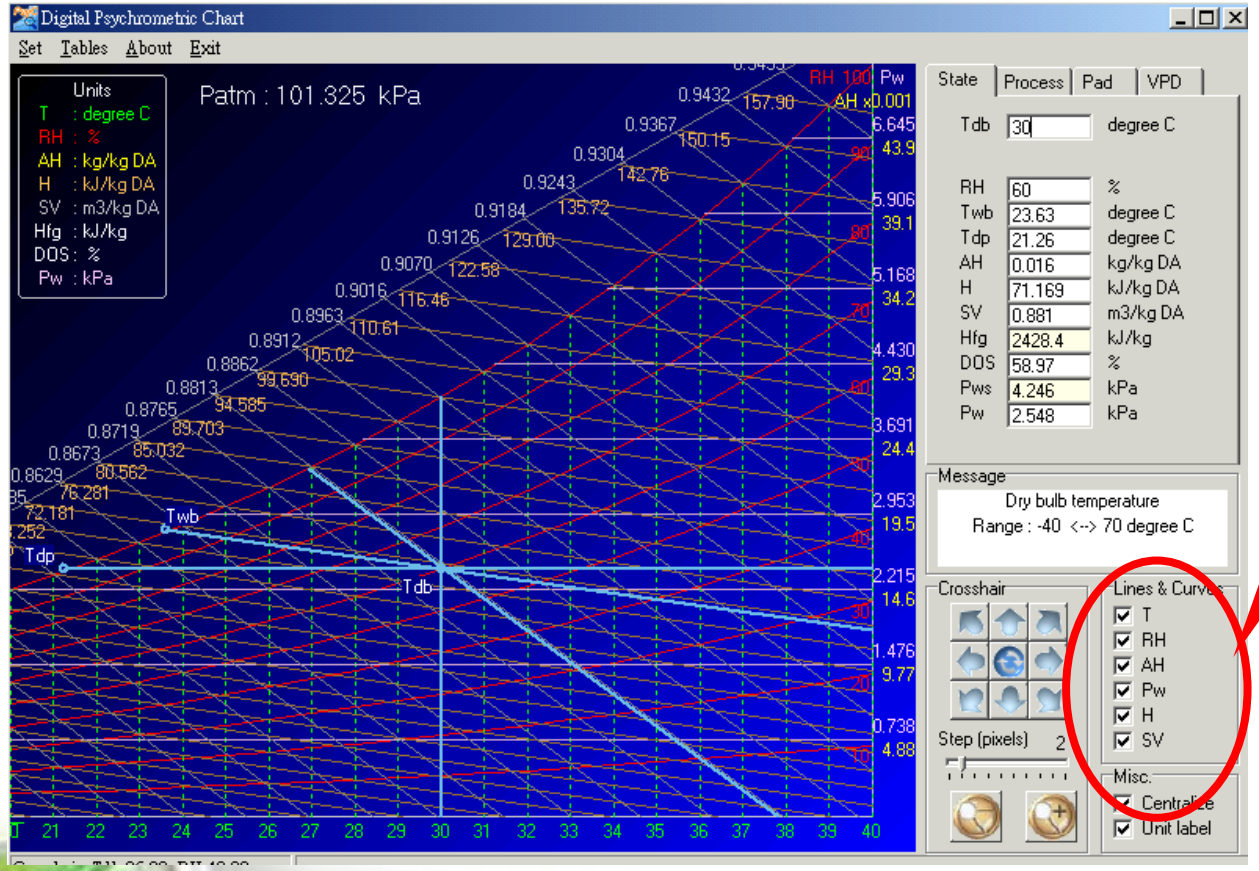
Enter Leaf temperature,
then click on Draw icon.

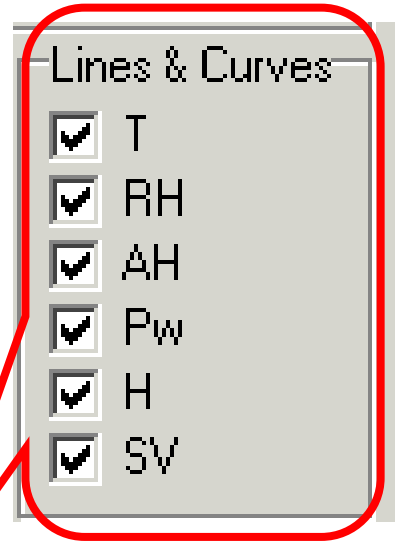




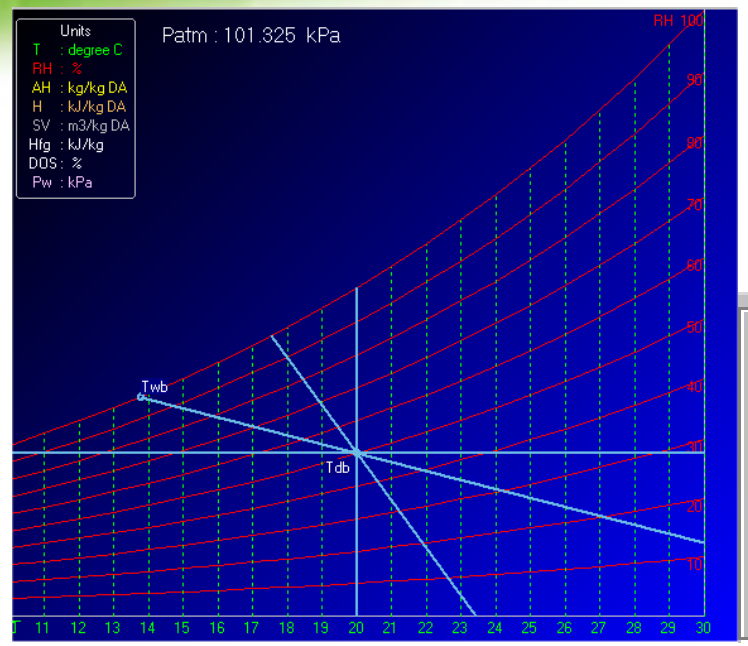
Other handy features

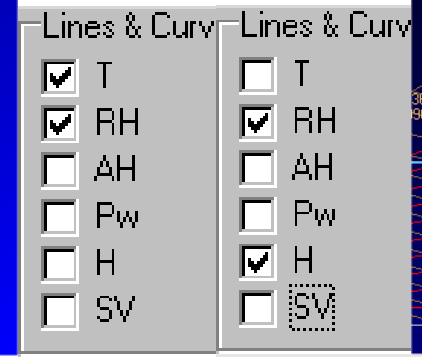
Shows the line/curves of the selected properties

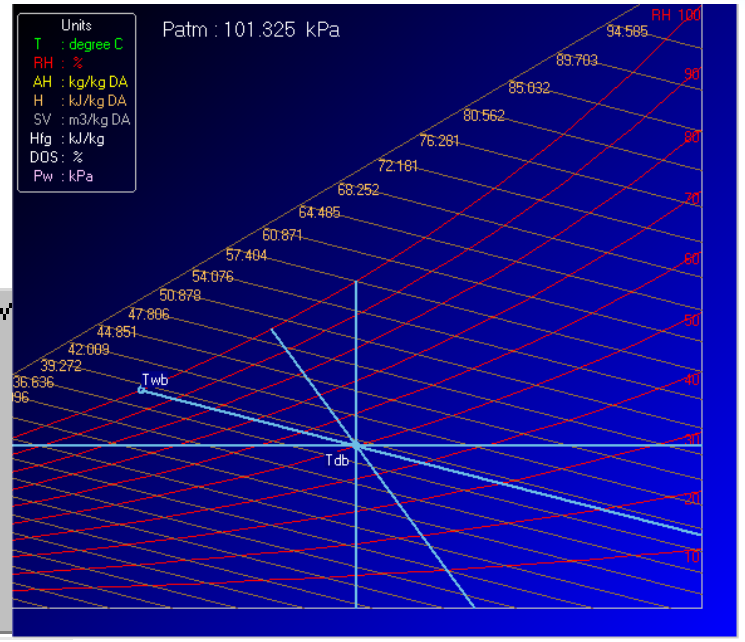


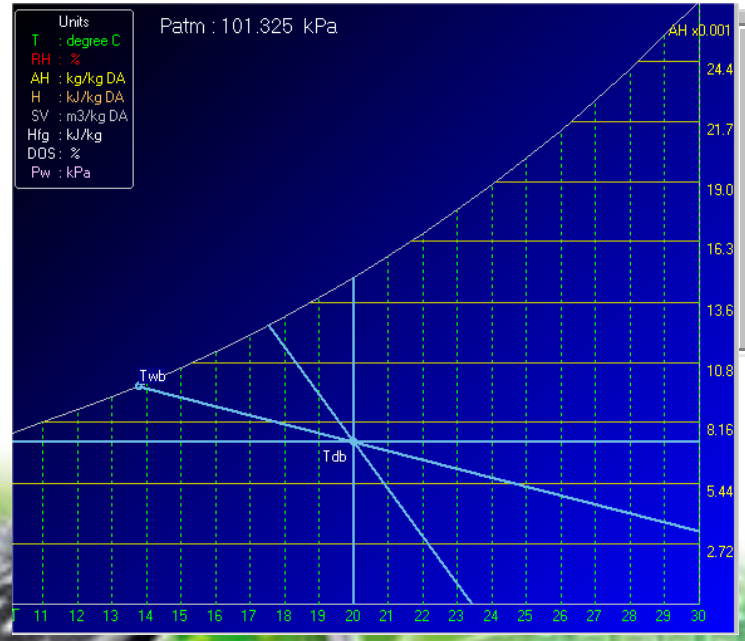


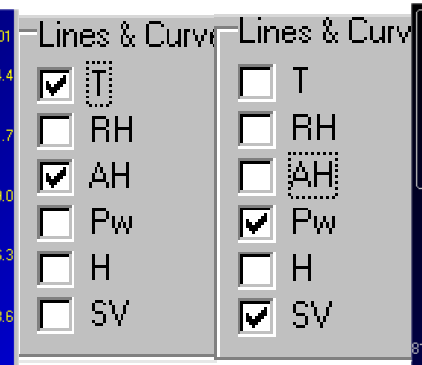
Shows the line/curves of the selected properties

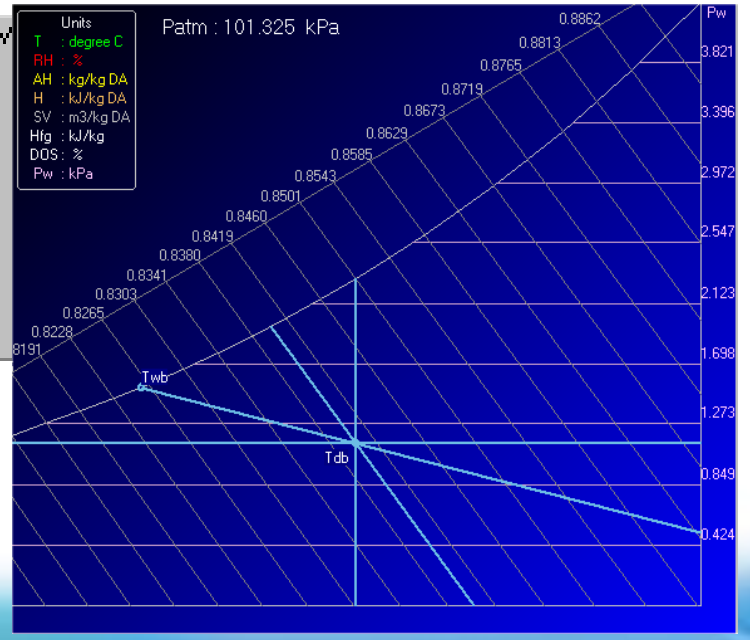




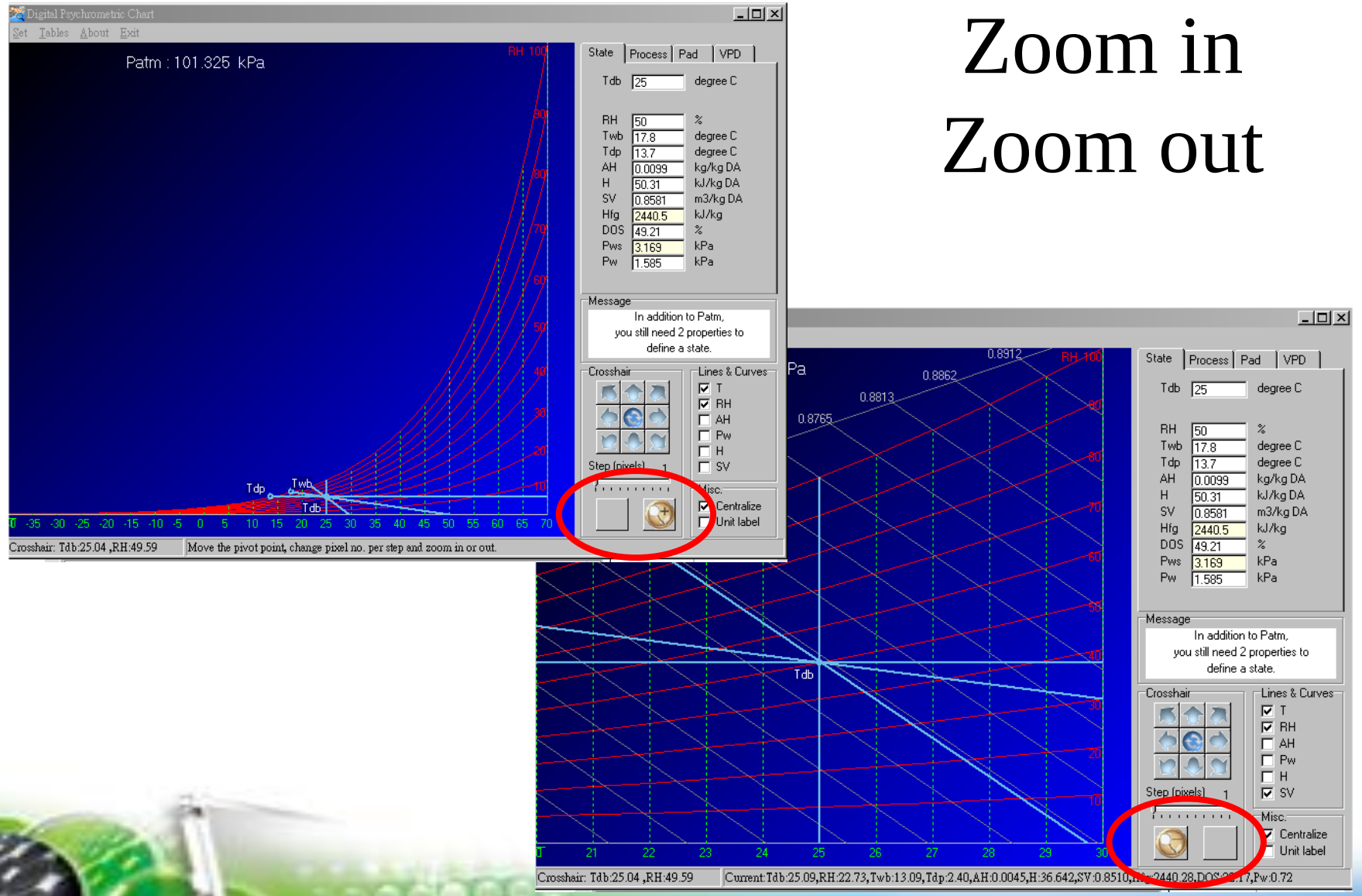








Other handy features

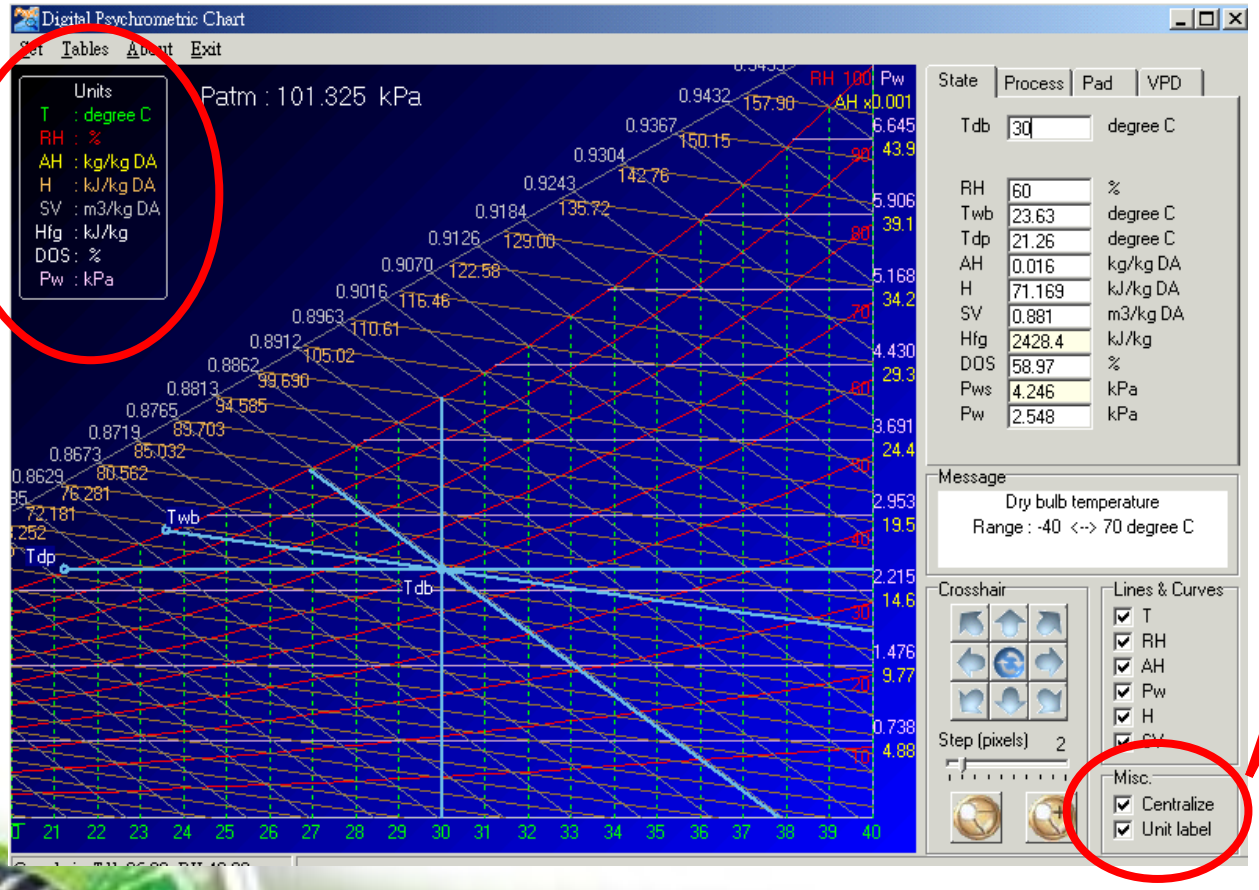


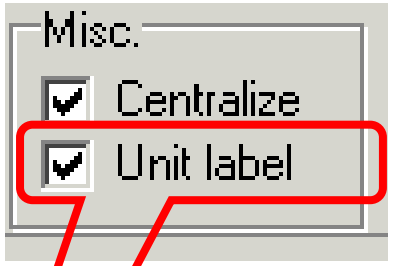
Zoom in

Zoom out

Other handy features

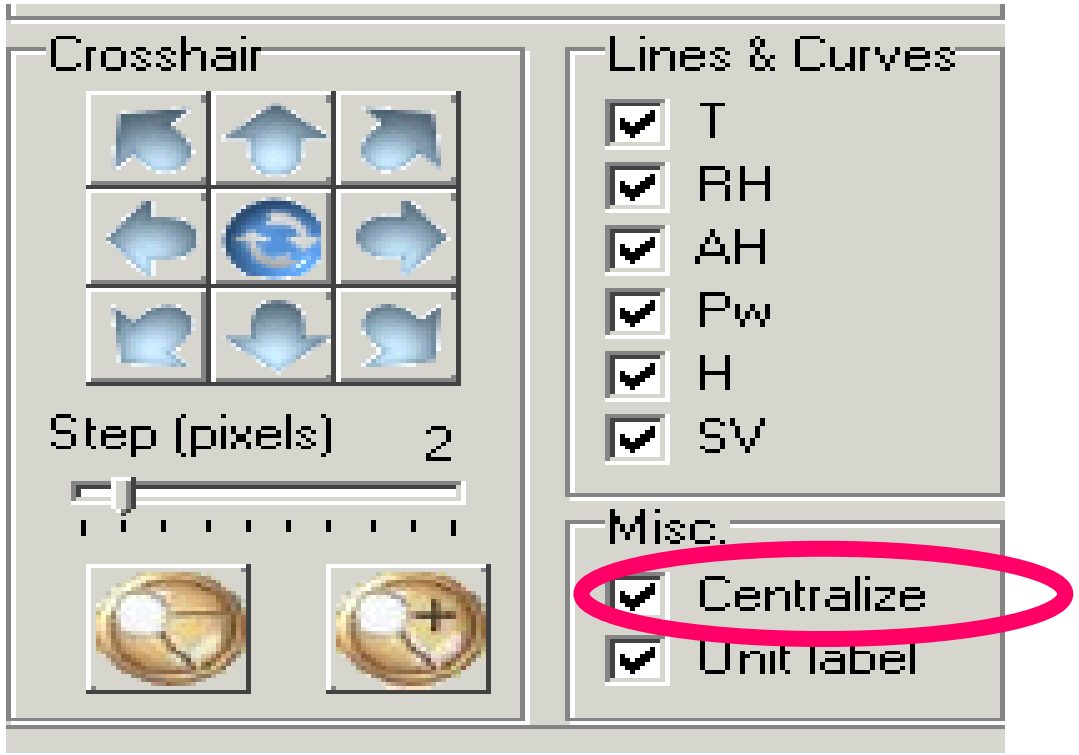
Unit label: to hide or not to hide the labels





Other handy features

Centralize: allow the state that user chose to appear at the center of the chart



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[ANISCI7047] Smart Production of Livestock

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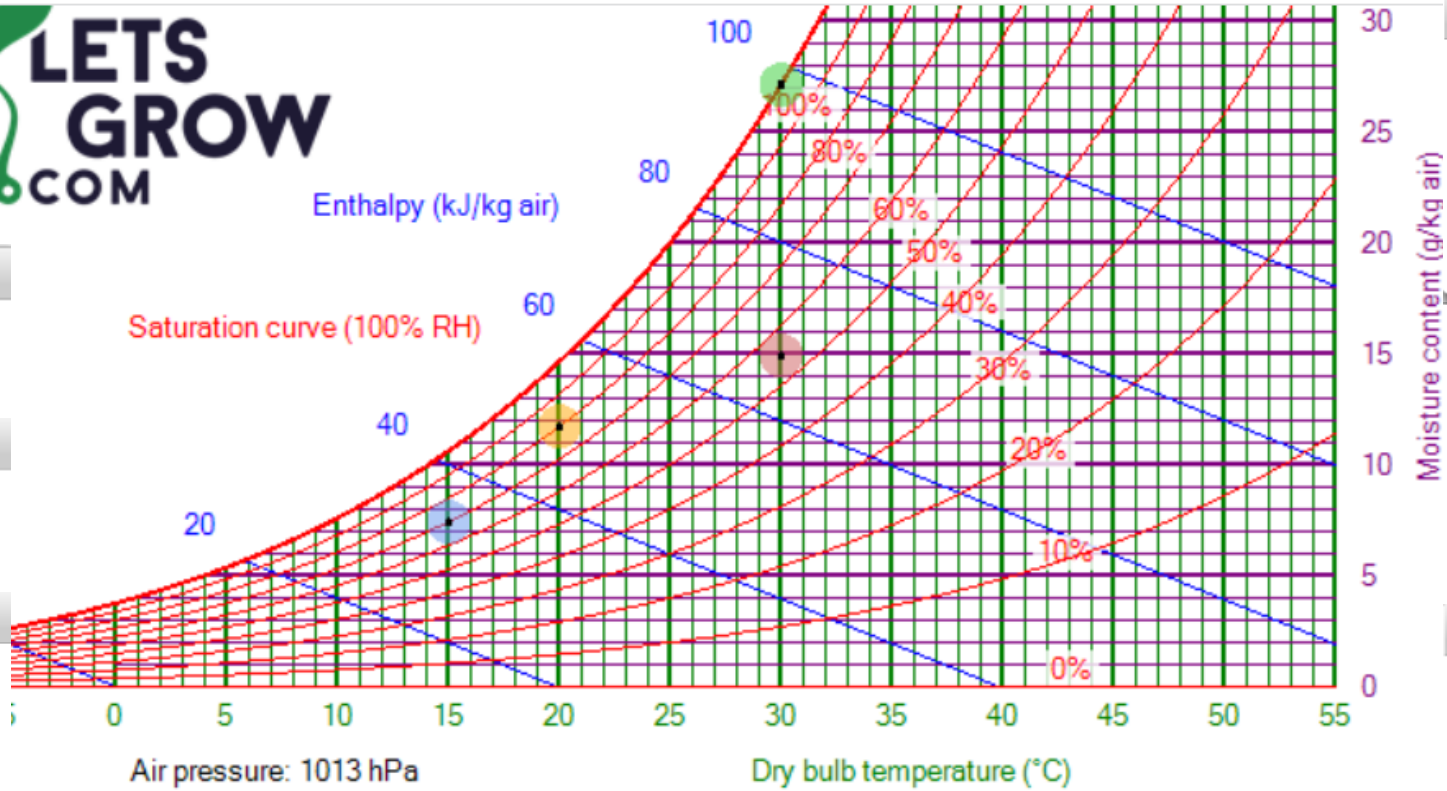
Wei FANG
NTU_BME and Global ATGS
National Taiwan University



Absolute Humidity AH (g/kg) or (g/m3)

The Absolute Humidity AH is the number of grams of watervapour that is actual present per kilo of air or per m3 of air.

Humidity Deficit HD (g/kg) or (g/m3)

Humidity Deficit is the amount of water vapour in grams that is needed to achieve full saturation of 1 kilo of air or 1 m3 of air at the current temperature.

Enthalpy (kJ/kg) or (kJ/m3)

The Enthalpy in kJ/kg is the energy content of 1 kilo of air in kiloJoule: the energy that is needed to heat up 1 kilo of air to the current temperature (sensible heat) plus the energy that is needed to evaporate the present watercontent (latent heat). The enthalpy in kJ/m3 is the energy content of 1 cubic meter of air in kiloJoule.

VPD Vapour Pressure Deficit (kPa)

Vapour Pressure Deficit is the difference between the maximum possible vapour pressure VPsat at the current temperature and the actual vapour pressure VP in kilo Pascal (kPa).
Note that VPD can also mean: Vapour Pressure Difference between the Plant and the Inside air. This Vapor Pressure Difference is shown in the column "Difference" between the VP value "Inside" and VP value "Plant".

Dewpoint temperature (°C)

The Dewpoint temperature of the air is that temperature at which the actual moisture content equals the maximum possible moisture content. If air is beeing cooled down below dewpoint condensation will occur.

sychro diagram | More info

Air pressure 1013 hP

Outside		Difference	Above screen		Difference	Inside		Difference	Plant		
Temp	15 °C	5.00	Temp	20 °C	10.00	Temp	30 °C	--	Temp	30 °C	
RH	70 %	10.00	RH	80 %	-25.00	RH	55 %	--	RH	100 %	
Absolute Humidity AH	7.44 g/kg	-3.95	Absolute Humidity AH	11.73 g/kg	3.20	Absolute Humidity AH	14.93 g/kg	--	Absolute Humidity AH	27.15 g/kg	
Humidity Deficit HD	3.19 g/kg	-2.32	Humidity Deficit HD	2.93 g/kg	9.28	Humidity Deficit HD	12.22 g/kg	--	Humidity Deficit HD	0.00 g/kg	
Enthalpy	33.63 kJ/kg	-22.91	Enthalpy	49.33 kJ/kg	17.95	Enthalpy	67.29 kJ/kg	--	Enthalpy	97.67 kJ/kg	
VPD	0.51 kPa	-0.37	VPD	0.47 kPa	1.44	VPD	1.91 kPa	--	VPD	0.00 kPa	
VP	1.19 kPa	-0.63	VP	1.87 kPa	0.46	VP	2.33 kPa	--	VP	4.25 kPa	
VPsat	1.71 kPa	-1.00	VPsat	2.34 kPa	1.91	VPsat	4.25 kPa	--	VPsat	4.25 kPa	
Dewpoint	9.6 °C	-10.7	Dewpoint	16.4 °C	3.5	Dewpoint	20.0 °C	--	Dewpoint	30.0 °C	

Air pressure 1013 hPa　1個大氣壓＝海平面，海拔0 m

Inside		Difference	Plant	
Temp	30 °C	--	Temp	30 °C
RH	55 %	--	RH	100 %
			假設氣孔內相對濕度為100%	
Absolute Humidity AH	14.93 g/kg	12.22	Absolute Humidity AH	27.15 g/kg
Absolute Humidity AH	17.19 g/m³	13.84	Absolute Humidity AH	31.02 g/m³
Humidity Deficit HD	12.22 g/kg	-12.22	Humidity Deficit HD	0.00 g/kg
Humidity Deficit HD	14.06 g/		Deficit HD	0.00 g/m³
Enthalpy	67.29 kJ/kg		Enthalpy	97.67 kJ/kg
Enthalpy	77.45 kJ/m		py	111.61 kJ/m³
VPD	1.91 kPa	-1.91	VPD	0.00 kPa
VP	2.33 kPa	1.91	VP	4.25 kPa
VPsat	4.25 kPa	0.00	VPsat	4.25 kPa
Dewpoint	20.0 °C	10.0	Dewpoint	30.0 °C

此值>0 確保水汽
也由氣孔出來

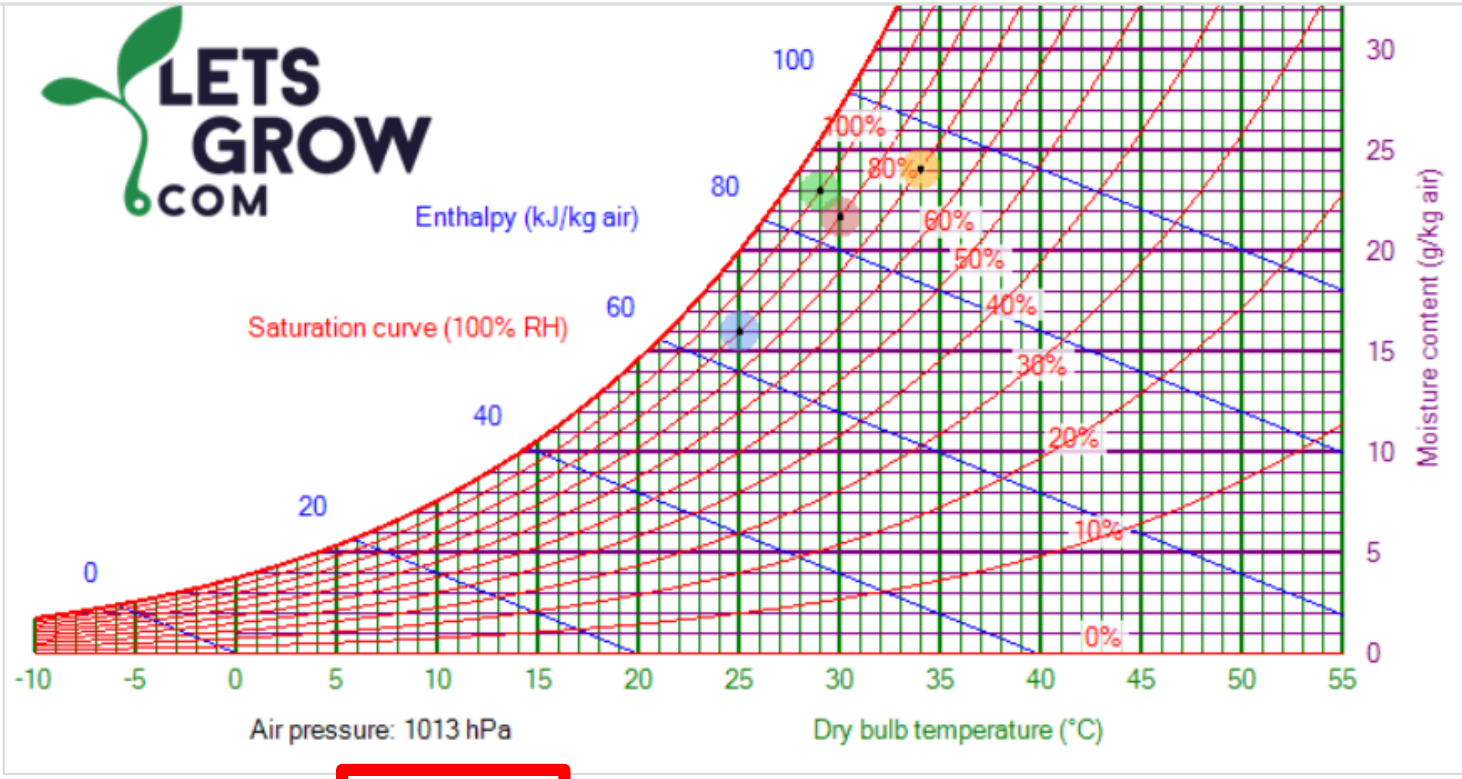
作物範圍內微氣候

Inside		Difference	Plant	
Temp	30 °C	-1.00	Temp	29 °C
RH	80 %	10.00	RH	90 %
Absolute Humidity AH	21.72 g/kg	1.29	Absolute Humidity AH	23.01 g/kg
Absolute Humidity AH	24.90 g/m³	1.55	Absolute Humidity AH	26.44 g/m³
Humidity Deficit HD	5.4		ity Deficit HD	2.56 g/kg
Humidity Deficit HD	6.2		Deficit HD	2.94 g/m³
Enthalpy	84.1			86.38 kJ/kg
Enthalpy	96.49 kJ/m³	2.79	Enthalpy	99.28 kJ/m³
VPD = VPsat - VP	0.85 kPa	-0.45	VPD	0.40 kPa
VP	3.40 kPa	0.21	VP	3.61 kPa
VPsat	4.25 kPa	-0.24	VPsat	4.01 kPa
Dewpoint	26.2 °C	1.0	Dewpoint	27.2 °C

此值>0 確保水汽

也散逸到溫室上方

詳細版本

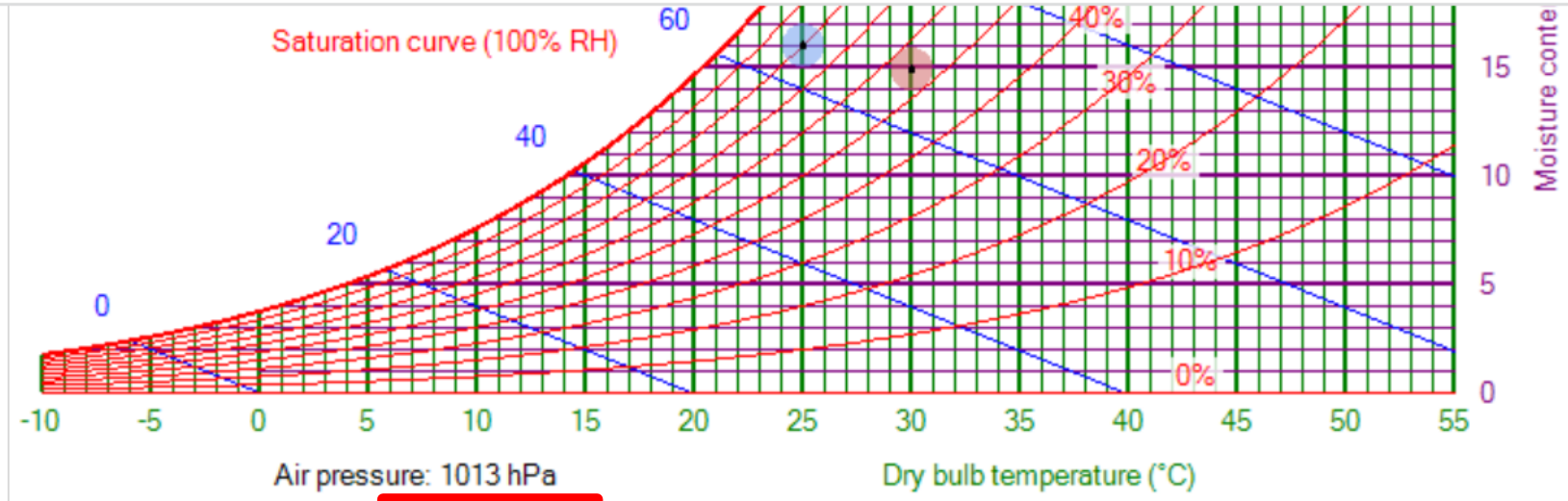


Hide Psychro diagram | More info

Air pressure 1013 hPa

Outside		Difference	Above screen		Difference	Inside		Difference	Plant		
Temp	25 °C	9.00	Temp	34 °C	-4.00	Temp	30 °C	-1.00	Temp	29 °C	
RH	80 %	-10.00	RH	70 %	10.00	RH	80 %	10.00	RH	90 %	
Absolute Humidity AH	16.03 g/kg	8.06	Absolute Humidity AH	24.10 g/kg	-2.38	Absolute Humidity AH	21.72 g/kg	1.29	Absolute Humidity AH	23.01 g/kg	
Absolute Humidity AH	18.75 g/m³	8.47	Absolute Humidity AH	27.23 g/m³	-2.33	Absolute Humidity AH	24.90 g/m³	1.55	Absolute Humidity AH	26.44 g/m³	
Humidity Deficit HD	4.01 g/kg	6.32	Humidity Deficit HD	10.33 g/kg	-4.90	Humidity Deficit HD	5.43 g/kg	-2.87	Humidity Deficit HD	2.56 g/kg	
Humidity Deficit HD	4.69 g/m³	6.98	Humidity Deficit HD	11.67 g/m³	-5.44	Humidity Deficit HD	6.22 g/m³	-3.29	Humidity Deficit HD	2.94 g/m³	
Enthalpy	65.04 kJ/kg	29.02	Enthalpy	94.05 kJ/kg	-9.89	Enthalpy	84.16 kJ/kg	2.21	Enthalpy	86.38 kJ/kg	
Enthalpy	76.07 kJ/m³	30.20	Enthalpy	106.27 kJ/m³	-9.78	Enthalpy	96.49 kJ/m³	2.79	Enthalpy	99.28 kJ/m³	
VPD	0.63 kPa	0.96	VPD	1.60 kPa	-0.75	VPD	0.85 kPa	-0.45	VPD	0.40 kPa	
VP	2.53 kPa	1.19	VP	3.73 kPa	-0.33	VP	3.40 kPa	0.21	VP	3.61 kPa	
VPsat	3.17 kPa	2.15	VPsat	5.32 kPa	-1.08	VPsat	4.25 kPa	-0.24	VPsat	4.01 kPa	
Dewpoint	21.3 °C	6.4	Dewpoint	27.8 °C	-1.6	Dewpoint	26.2 °C	1.0	Dewpoint	27.2 °C	

精簡版本

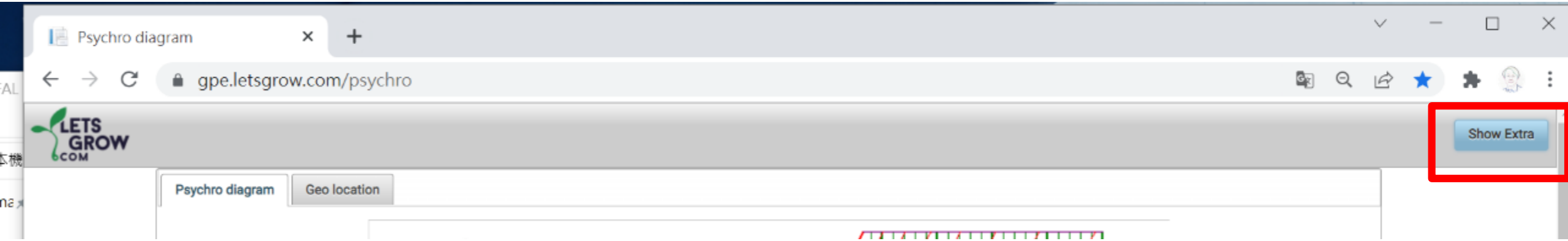


Hide Psychro diagram | More info

Air pressure 1013 hPa

Outside		Difference	Above screen		Difference	Inside		Difference	Plant		
Temp	25 °C	9.00	Temp	34 °C	-4.00	Temp	30 °C	0.00	Temp	30 °C	
RH	80 %	-10.00	RH	70 %	-15.00	RH	55 %	45.00	RH	100 %	
Absolute Humidity AH	16.03 g/kg	8.06	Absolute Humidity AH	24.10 g/kg	-9.16	Absolute Humidity AH	14.93 g/kg	12.22	Absolute Humidity AH	27.15 g/kg	
Humidity Deficit HD	4.01 g/kg	6.32	Humidity Deficit HD	10.33 g/kg	1.89	Humidity Deficit HD	12.22 g/kg	-12.22	Humidity Deficit HD	0.00 g/kg	
Enthalpy	65.04 kJ/kg	29.02	Enthalpy	94.05 kJ/kg	-26.77	Enthalpy	67.29 kJ/kg	30.38	Enthalpy	97.67 kJ/kg	
VPD	0.63 kPa	0.96	VPD	1.60 kPa	0.31	VPD	1.91 kPa	-1.91	VPD	0.00 kPa	
VP	2.53 kPa	1.19	VP	3.73 kPa	-1.39	VP	2.33 kPa	1.91	VP	4.25 kPa	
VPsat	3.17 kPa	2.15	VPsat	5.32 kPa	-1.08	VPsat	4.25 kPa	0.00	VPsat	4.25 kPa	
Dewpoint	21.3 °C	6.4	Dewpoint	27.8 °C	-7.8	Dewpoint	20.0 °C	10.0	Dewpoint	30.0 °C	

更多分析


Psychro diagram
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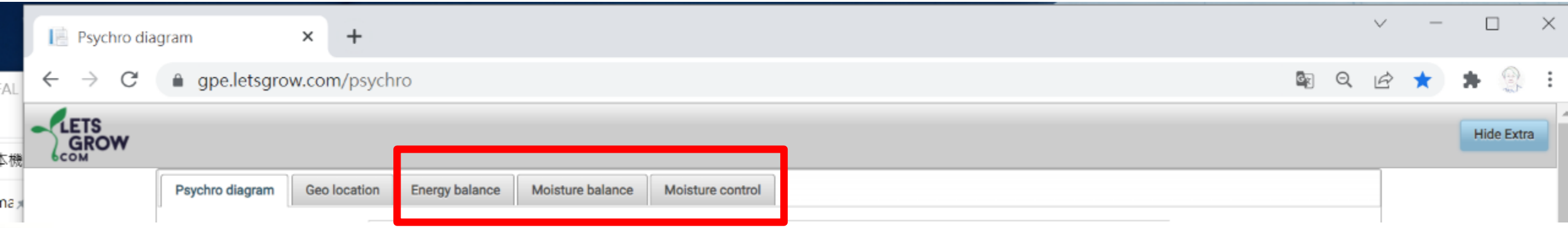
Show Extra
Psychro diagram
Geo location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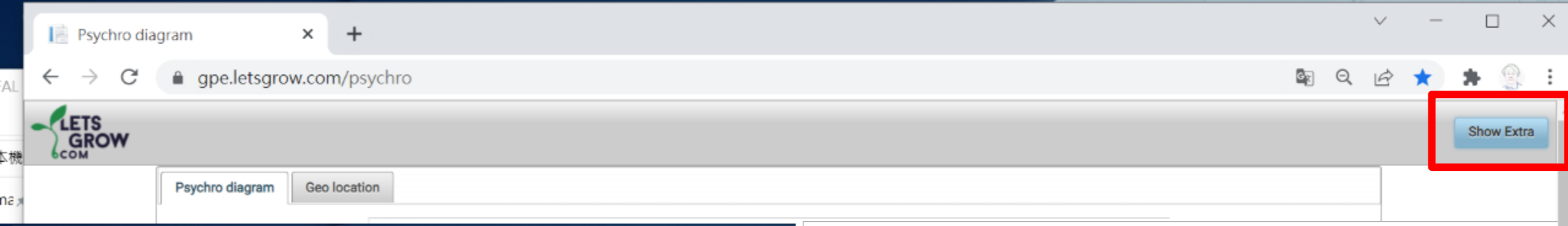
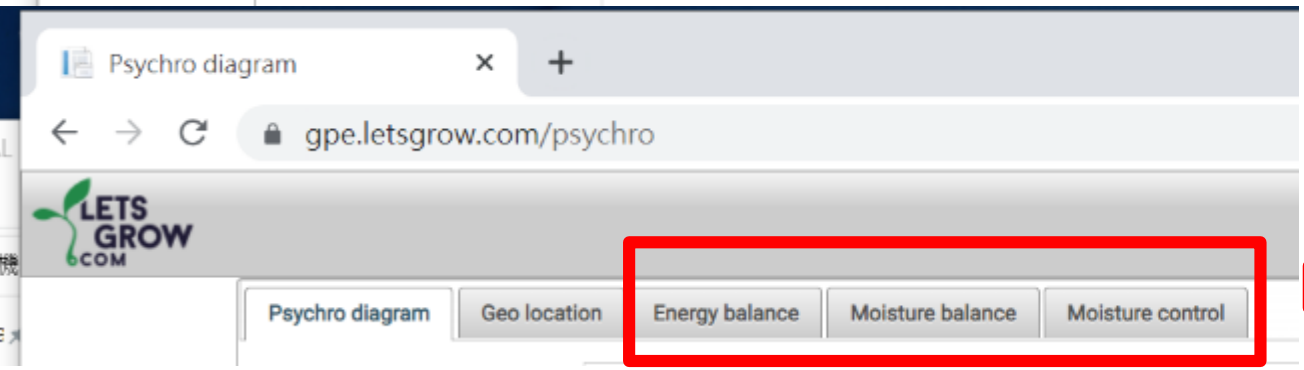
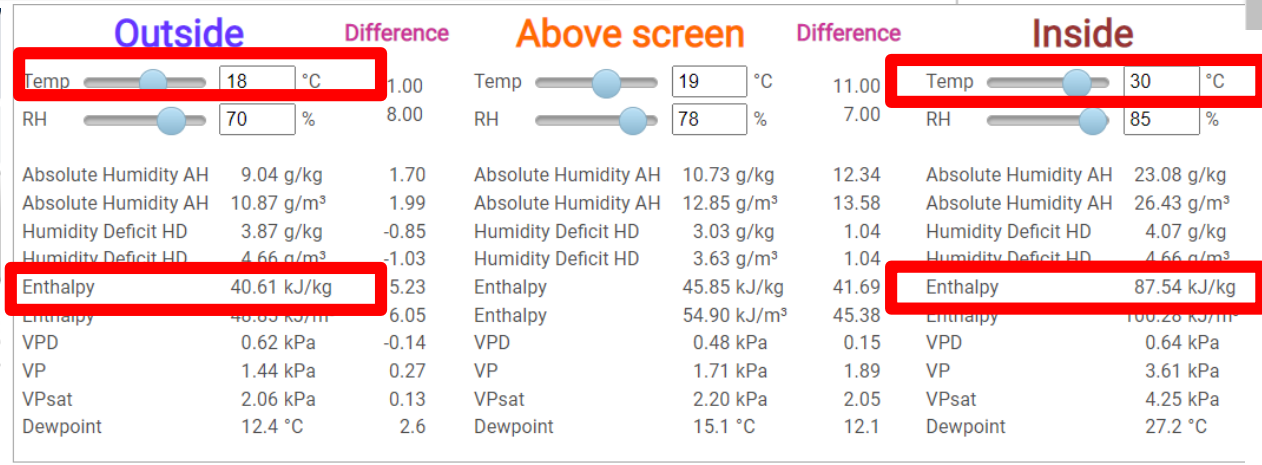
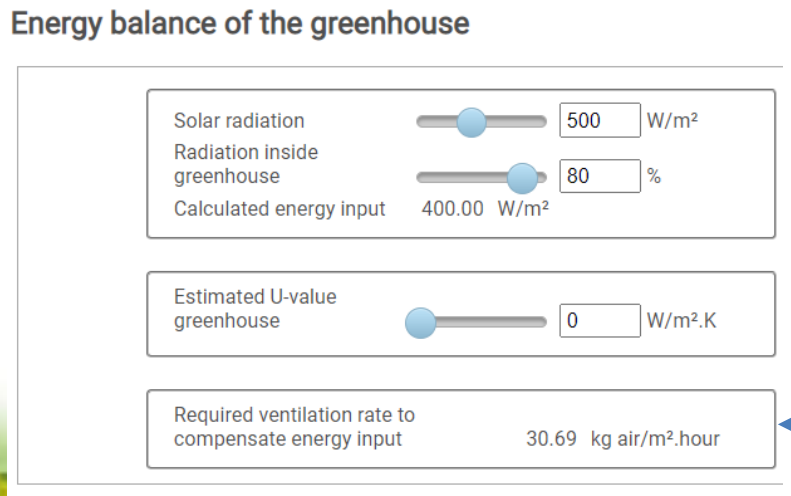
LETS GROW COM
Hide Extra
Psychro diagram
Geo location
Energy balance
Moisture balance
Moisture control





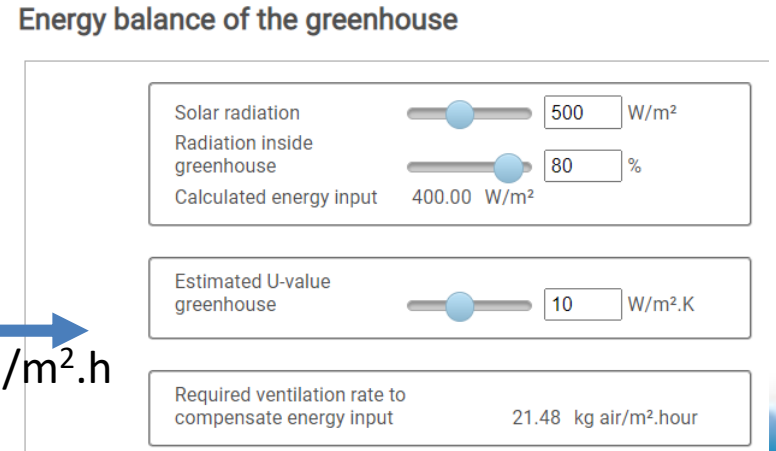


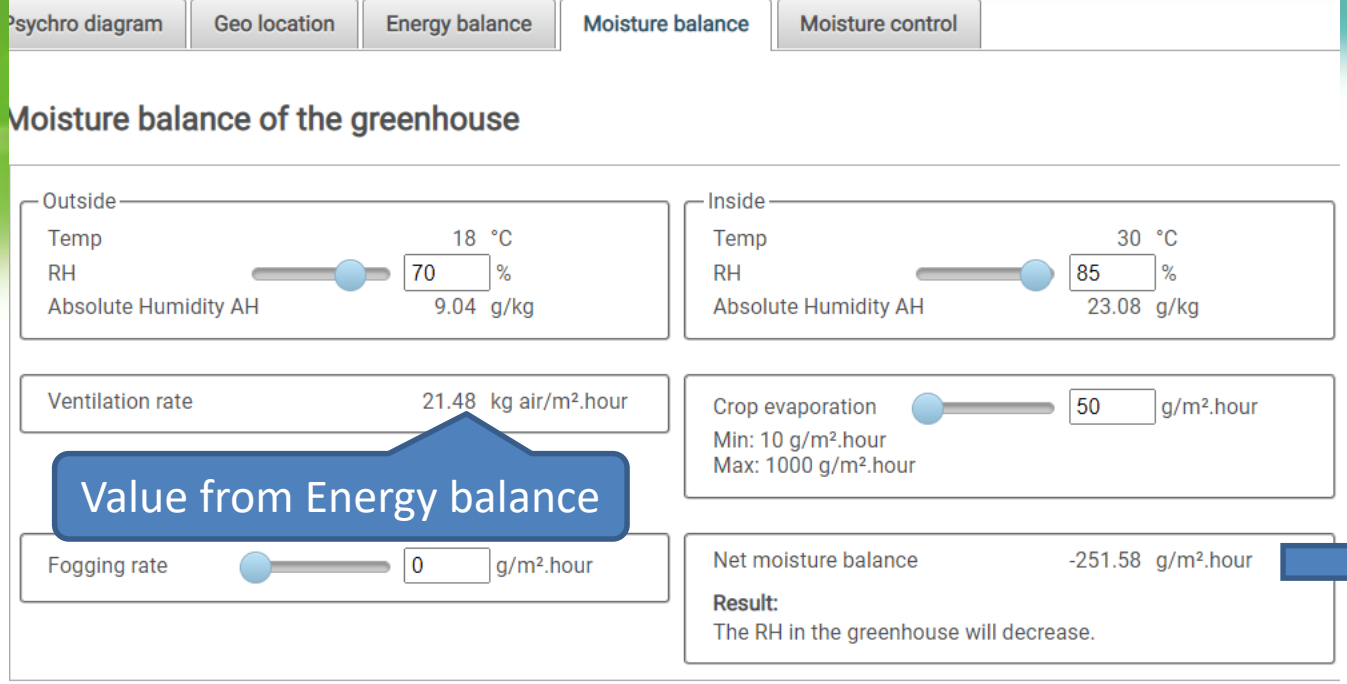
	Outside	Difference	Above screen	Difference	Inside
Temp	18 °C	1.00	19 °C	11.00	30 °C
RH	70 %	8.00	78 %	7.00	85 %
Absolute Humidity AH	9.04 g/kg	1.70	10.73 g/kg	12.34	23.08 g/kg
Absolute Humidity AH	10.87 g/m³	1.99	12.85 g/m³	13.58	26.43 g/m³
Humidity Deficit HD	3.87 g/kg	-0.85	3.03 g/kg	1.04	4.07 g/kg
Humidity Deficit HD	4.66 g/m³	-1.03	3.63 g/m³	1.04	4.66 g/m³
Enthalpy	40.61 kJ/kg	5.23	45.85 kJ/kg	41.69	87.54 kJ/kg
Enthalpy	46.65 kJ/m³	6.05	54.90 kJ/m³	45.38	100.28 kJ/m³
VPD	0.62 kPa	-0.14	0.48 kPa	0.15	0.64 kPa
VP	1.44 kPa	0.27	1.71 kPa	1.89	3.61 kPa
VPsat	2.06 kPa	0.13	2.20 kPa	2.05	4.25 kPa
Dewpoint	12.4 °C	2.6	15.1 °C	12.1	27.2 °C



ExtraHeat = (Radiation*穿透率) – (U*dT)
=[500*0.8 - **0*(30-18)**]*3600/1000 kJ/m^2.h
ΔEnthalpy=87.54-40.61=46.93 kJ/kg
Ventilation=ExtraHeat/ΔEnthalpy
=400*3.6/46.93=30.69 kg/m^2.h

ExtraHeat=[500*0.8 - **10*(30-18)**]*3600/1000 kJ/m^2.h
ΔEnthalpy=87.54-40.61=46.93 kJ/kg
Ventilation=ExtraHeat/ΔEnthalpy=(400-**120**)/46.93=21.48



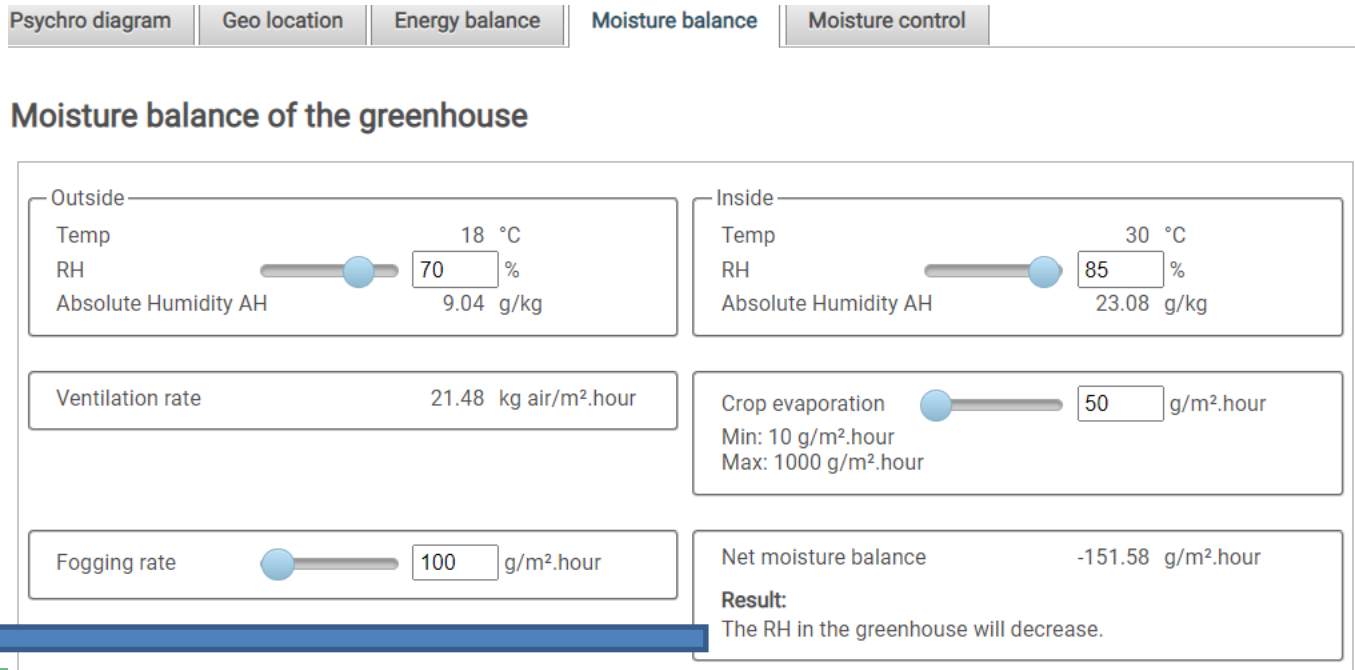


Net Moisture balance = Moisture removed – Crop evaporation – fogging rate = 301.58 – 50 - 0 = 251.58 g/ m^2.h

AHD = 23.08 - 9.04 = 14.04 g/kg air

Moisture removed=

21.48 * 14.04 = 301.58 g/m^2.h



Net Moisture balance = Moisture removed – Crop evaporation – fogging rate = 301.58 – 50 - 100 = 151.58 g/ m^2.h

Moisture control by injection of outdoor air

Outside

Temp	18	°C
RH	70	%
Absolute Humidity AH	9.04	g/kg

Inside

Temp	30	°C
RH	85	%
Absolute Humidity AH	23.08	g/kg

Fan outside air

Greenhouse area	100	m²
Capacity	10	m3/m².hour
Total flow	1000.00	m3/hour
Electrical power		
Pressure difference duct	1000	Pascal
Efficiency	100	%
Fan power	277.78	W

Moisture exhaust

Moisture exhaust	160.8	g/m².hour

Air conditions in the crop

Temp	30	°C
RH	90	%
Absolute Humidity AH	24.43	g/kg

Heat exchanger

Power	38.21	W/m²
Electrical consumption	13.76	MJ/hour

Moisture transport through crop

Crop height	1	m
Diffusion	0.332	g/m².hour
Air movement	0.28	cm/sec
Total moisture transport	279.99	g/m².hour

Fan power = dP x 0.27778 / Efficiency
= 1000 x 0.27778 / 1 = 277.78 W

Elec. Consumption =
Power * Area = 38.21*100 =
3821 W = 3821*3600/10^6
MJ/h = 3.821*3.6
= 13.7556 MJ/h

Moisture exhaust= AHD x Fan capacity x $Density_{insideAir}$
= (23.08 – 9.04) x 10 x (26.43/23.08) = 160.778 g/m².h

Inside

Temp	30	°C
RH	85	%
Absolute Humidity AH	23.08	g/kg
Absolute Humidity AH	26.43	g/m³
Humidity Deficit HD	4.07	g/kg
Humidity Deficit HD	4.66	g/m³

Air density
= (26.43/23.08) = 1.1451473

= (4.66/4.07) = 1.144963

Moisture control by injection of outdoor air

Outside

Temp	18	°C
RH	70	%
Absolute Humidity AH	9.04	g/kg

Inside

Temp	30	°C
RH	85	%
Absolute Humidity AH	23.08	g/kg

Fan outside air

Greenhouse area	100	m²
Capacity	10	m3/m².hour
Total flow	1000.00	m3/hour
Electrical power		
Pressure difference duct	100	Pascal
Efficiency	40	%
Fan power	69.44	W

Moisture exhaust

Moisture exhaust	160.8	g/m².hour

Air conditions in the crop

Temp	30	°C
RH	90	%
Absolute Humidity AH	24.43	g/kg

Heat exchanger

Power	38.21	W/m²
Electrical consumption	13.76	MJ/hour

Moisture transport through crop

Crop height	1	m
Diffusion	0.332	g/m².hour
Air movement	0.28	cm/sec
Total moisture transport	279.99	g/m².hour

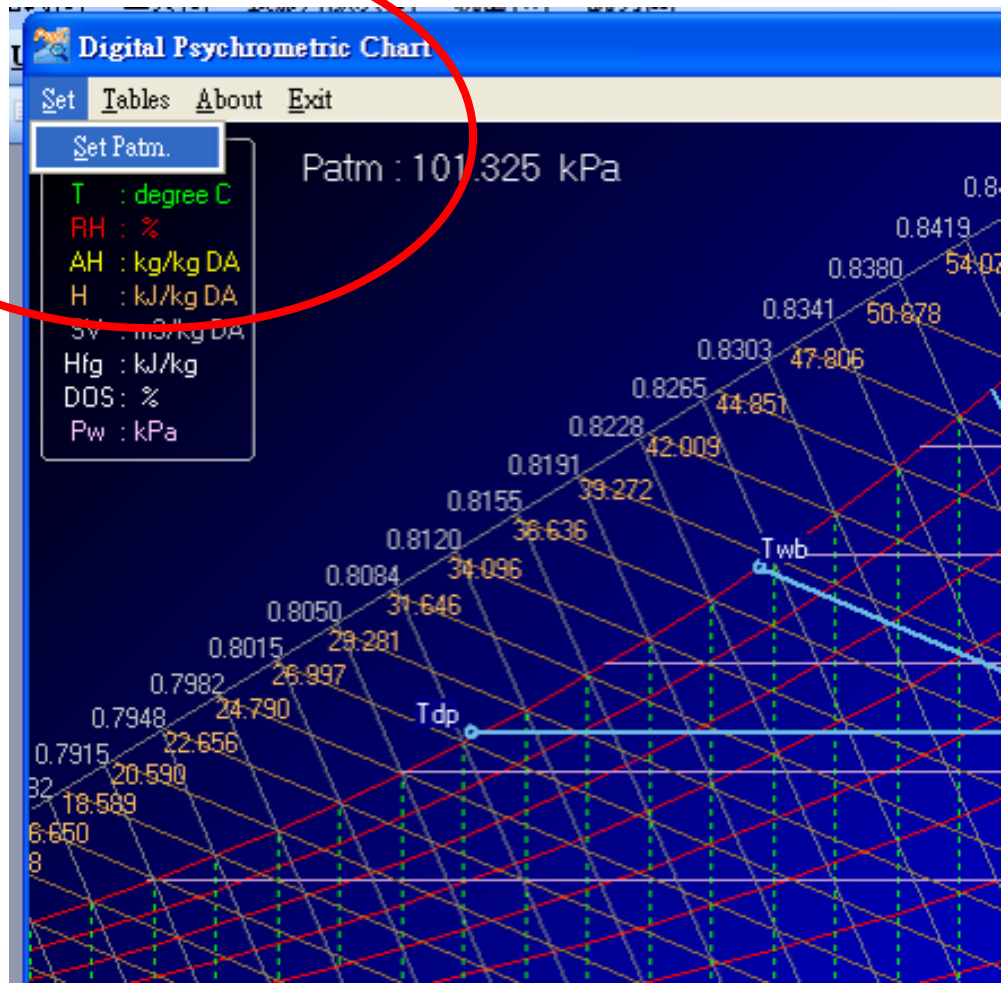
Fan power = dP x 0.27778 / Efficiency
= 100 x 0.27778 / 0.4 = 69.445 W

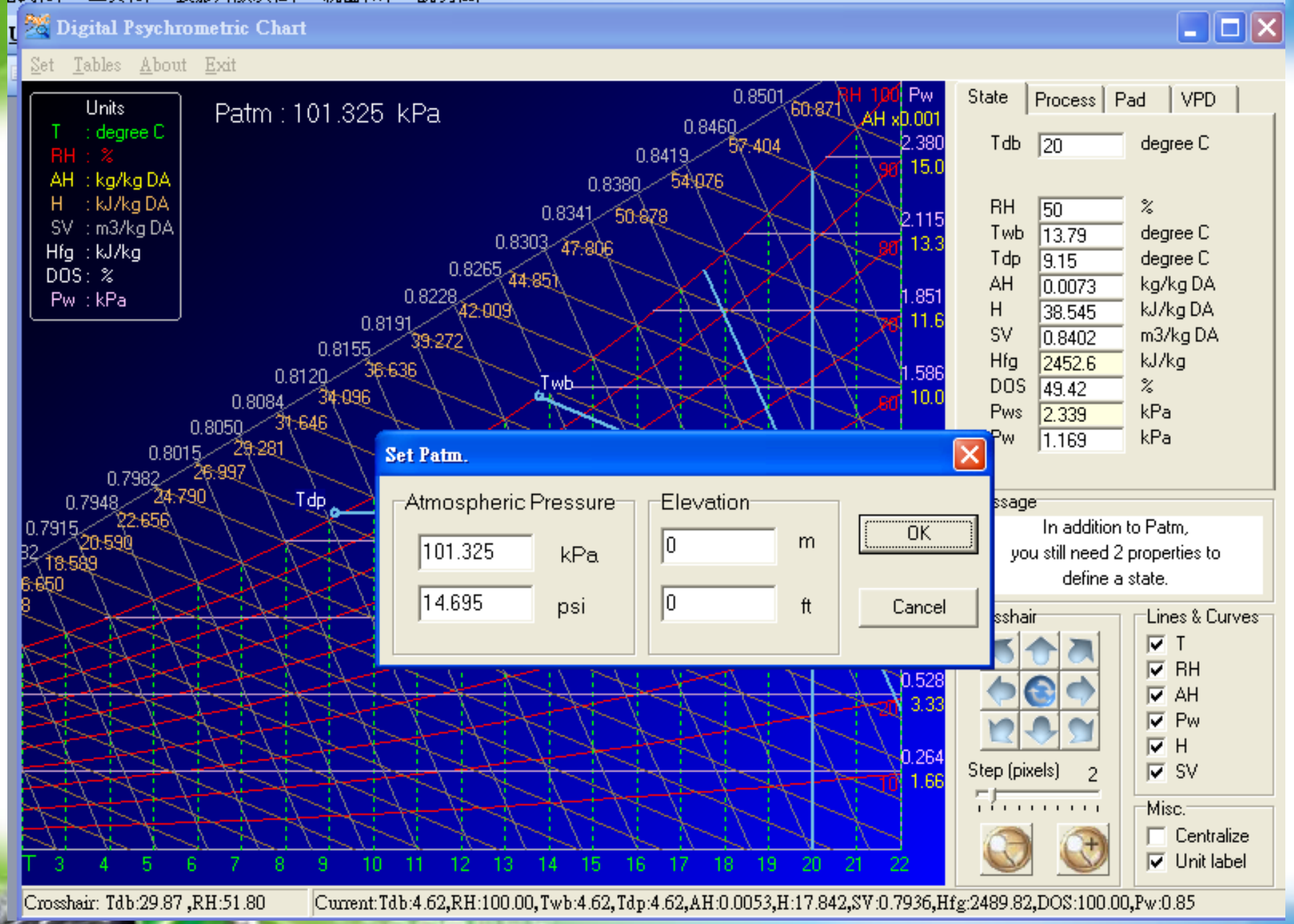
Examples of using Psychart

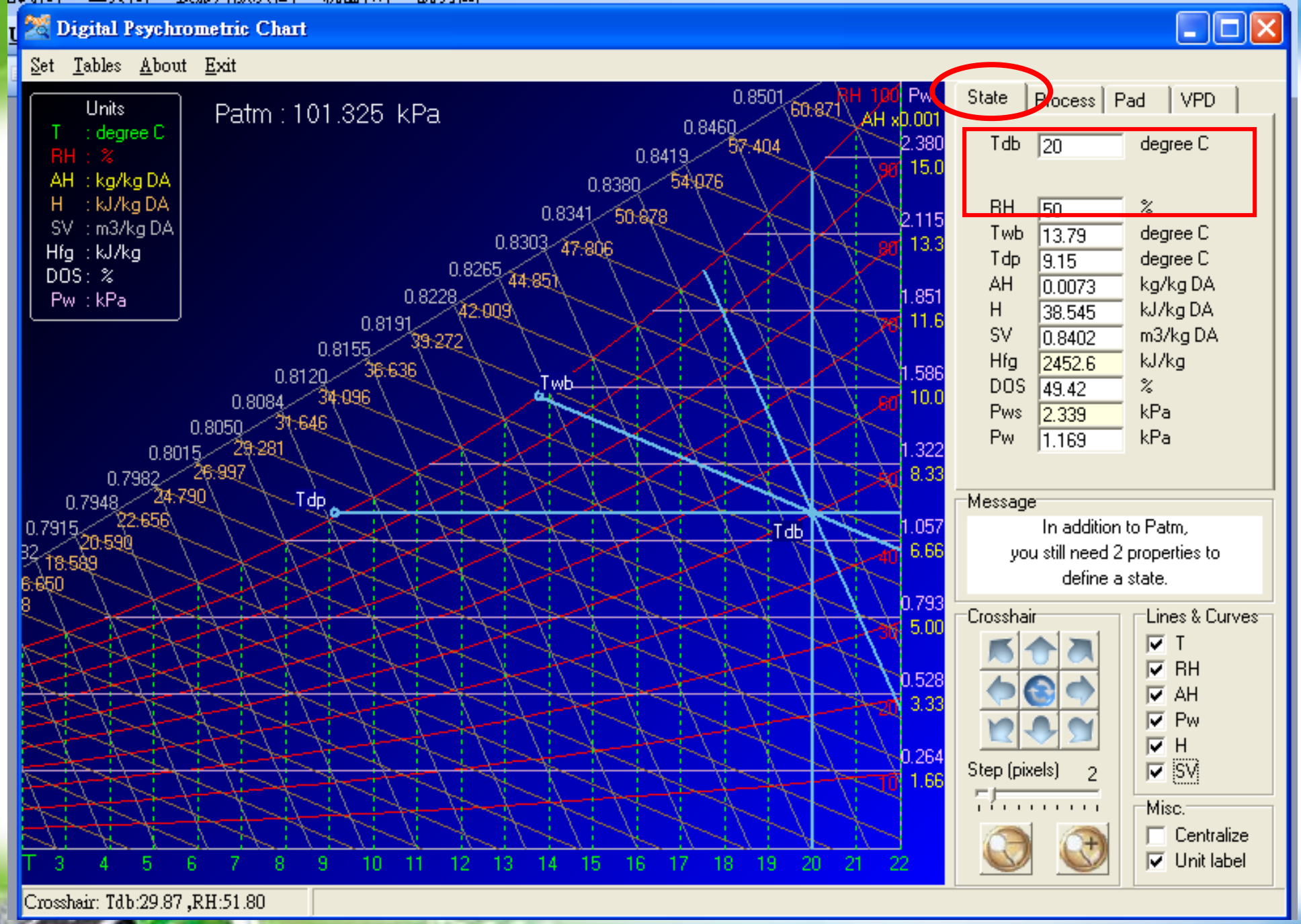
Properties

1. Under 1 ATM, the Tdb of moist air is 20 ^{o}C，RH is 50 %，what is the humidity ratio (absolute humidity, AH), degree of saturation (DOS), dew point temperature (Tdp), enthalpy (h), and wet bulb temperature (Twb)?

Set the atmospheric pressure Patm

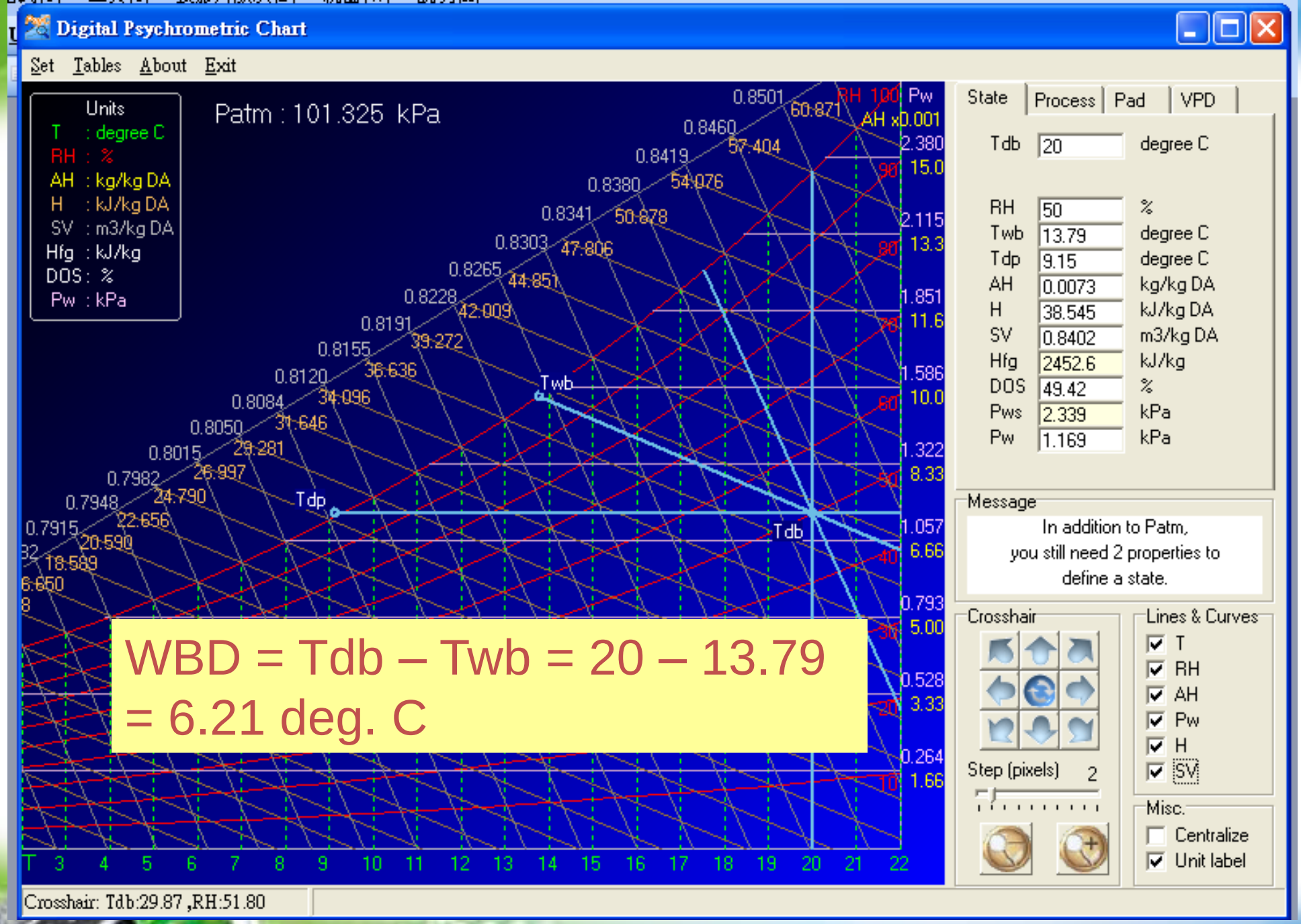



Digital Psychrometric Chart
Set
Tables
About
Exit
Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa
Patm : 101.325 kPa
Twb
Tdp
Set Patm.
Atmospheric Pressure
101.325
kPa
14.695
psi
Elevation
0
m
0
ft
OK
Cancel
State
Process
Pad
VPD
Tdb 20 degree C
RH 50 %
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
In addition to Patm, you still need 2 properties to define a state.
Lines & Curves
T
RH
AH
Pw
H
SV
Step (pixels) 2
Misc.
Centralize
Unit label
Crosshair: Tdb:29.87 ,RH:51.80
Current:Tdb:4.62,RH:100.00,Twb:4.62,Tdp:4.62,AH:0.0053,H:17.842,SV:0.7936,Hfg:2489.82,DOS:100.00,Pw:0.85

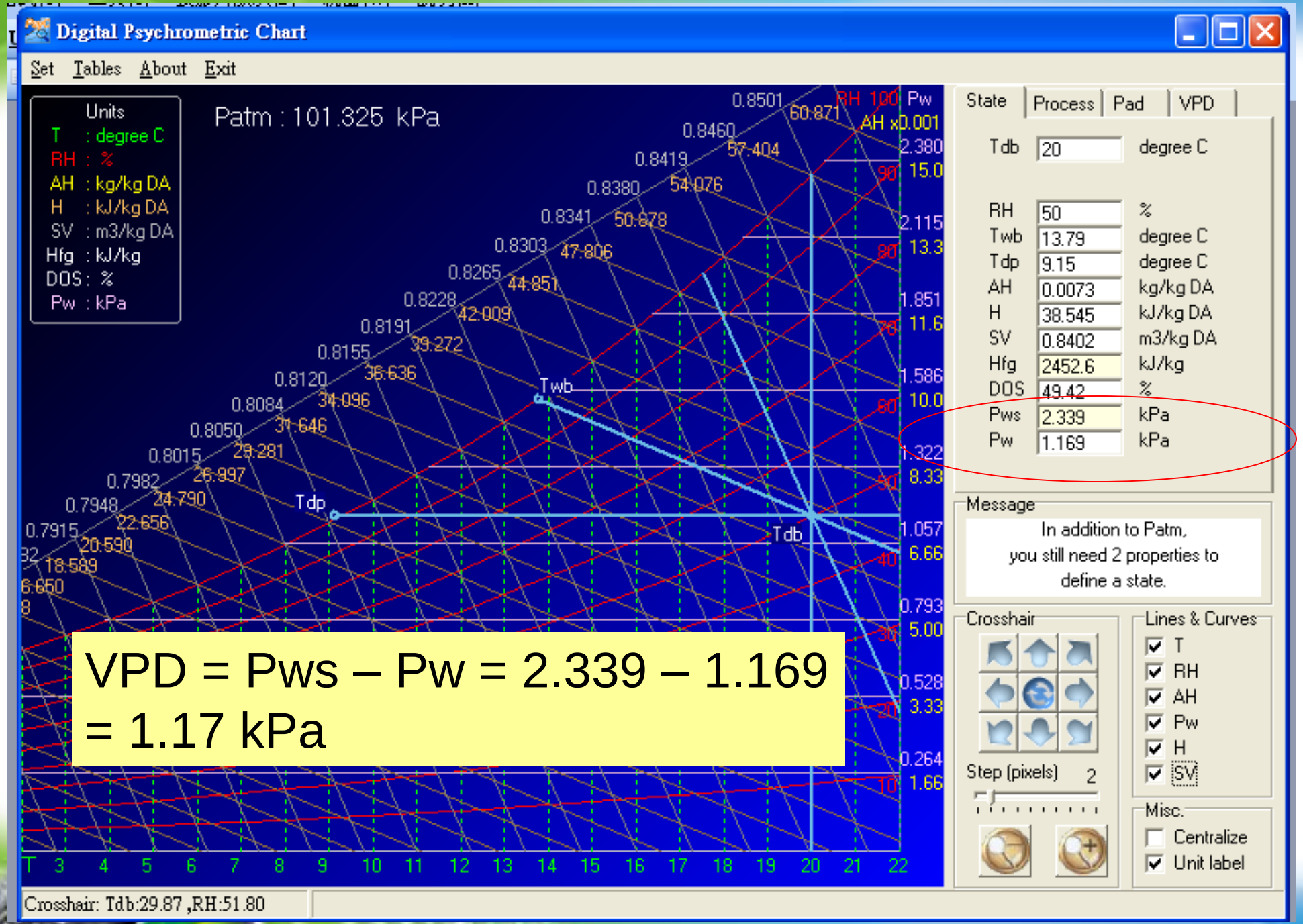

Digital Psychrometric Chart
Set
Tables
About
Exit
Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa
Patm : 101.325 kPa
Twb
Tdp
Tdb
State
Process
Pad
VPD
Tdb 20 degree C
RH 50 %
Twb 13.79 degree C
Tdp 9.15 degree C
AH 0.0073 kg/kg DA
H 38.545 kJ/kg DA
SV 0.8402 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
Step (pixels) 2
Lines & Curves
T
RH
AH
Pw
H
SV
Misc.
Centralize
Unit label
Crosshair: Tdb:29.87 ,RH:51.80

Properties

2. Continue, What is the wet bulb depression (WBD) and vapor pressure deficit (VPD) ?



WBD = Tdb – Twb = 20 – 13.79
= 6.21 deg. C

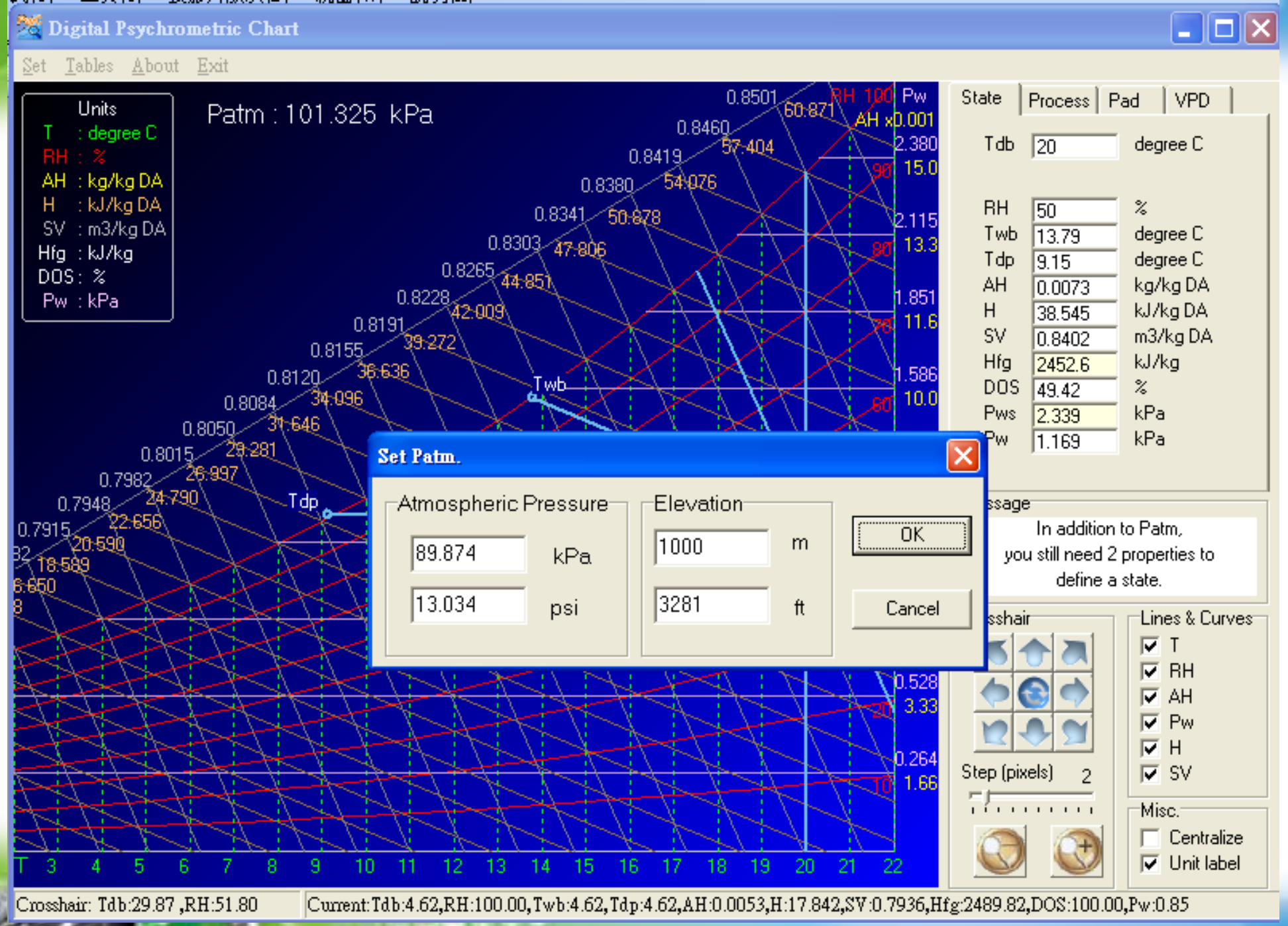


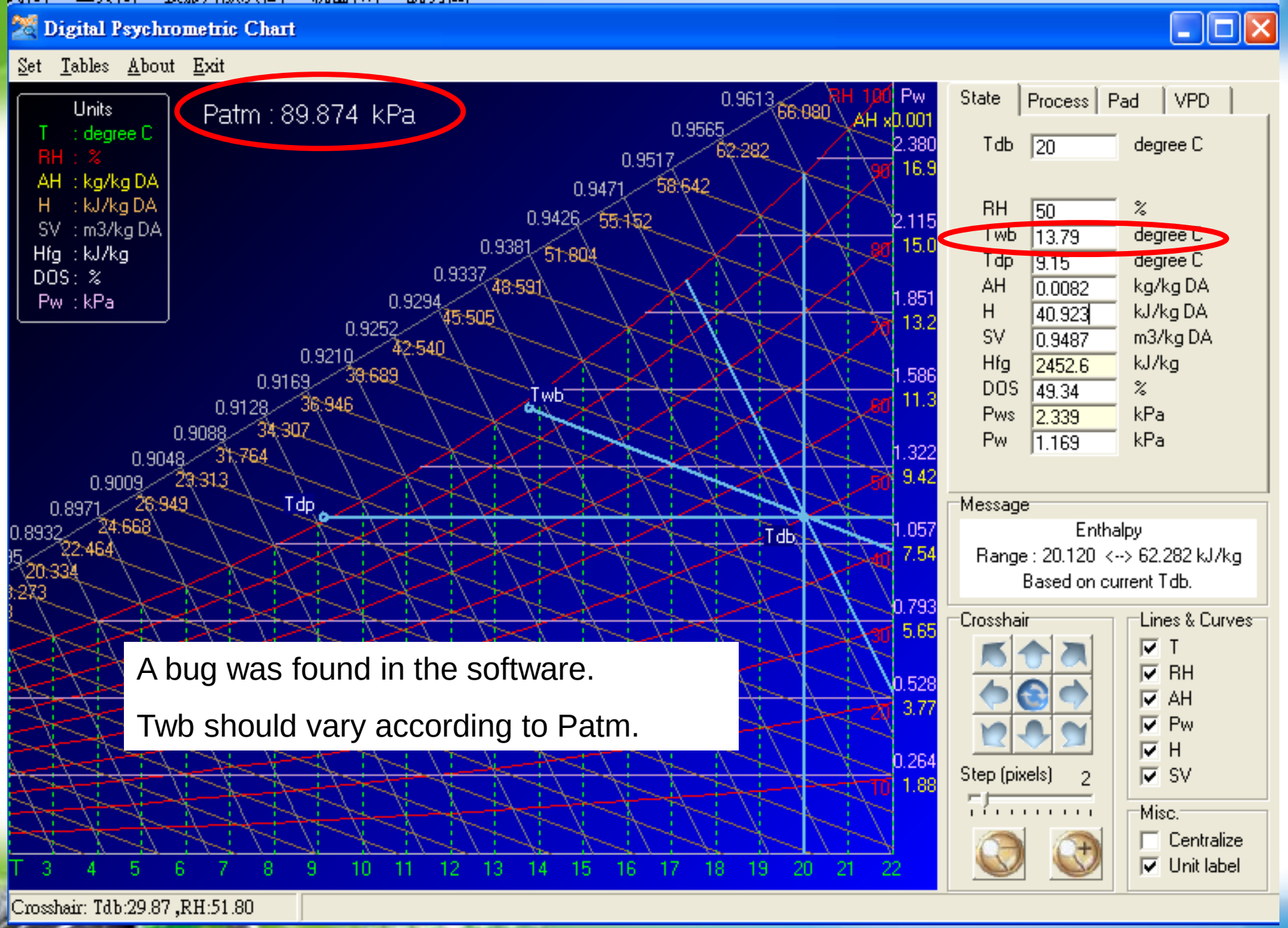
VPD = Pws – Pw = 2.339 – 1.169 = 1.17 kPa

Properties

3. Complete the following Tables

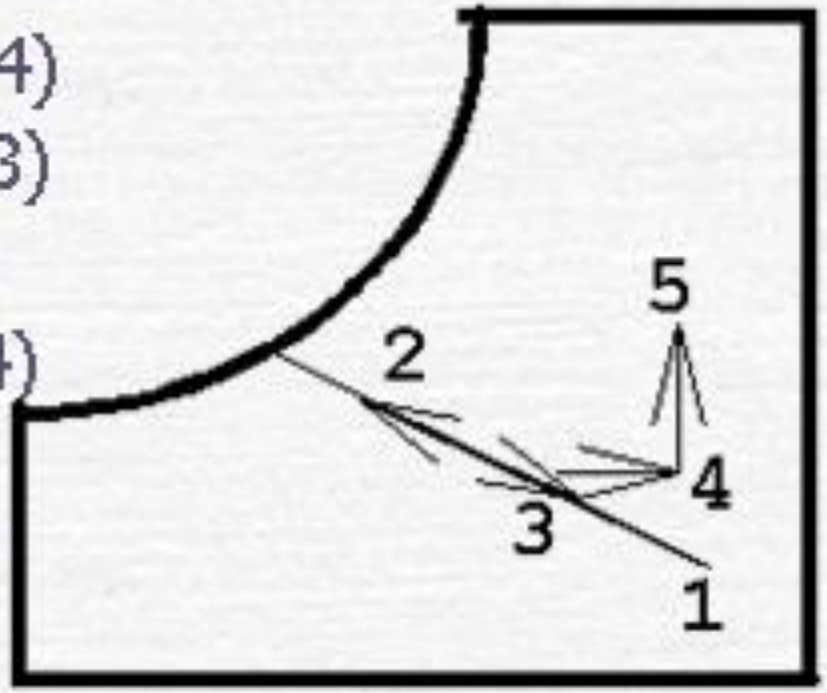
	#1	#2	#3	#4
Atmospheric pressure, kPa	101.325	101.325	101.325	89.874
Dry-bulb T, deg.C	20	20	-10	20
Relative humidity, %	50	80	50	50
Humidity ratio, kg/kg				
Dew point T, deg.C				
Wet bulb T, deg.C				
Specific volume, m^3/kg				


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
Twb
Tdp
Set Patm.
Atmospheric Pressure
89.874
kPa
13.034
psi
Elevation
1000
m
3281
ft
OK
Cancel
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
In addition to Patm, you still need 2 properties to define a state.
Lines & Curves
T
RH
AH
Pw
H
SV
Step (pixels) 2
Misc.
Centralize
Unit label
Crosshair: Tdb:29.87 ,RH:51.80
Current:Tdb:4.62,RH:100.00,Twb:4.62,Tdp:4.62,AH:0.0053,H:17.842,SV:0.7936,Hfg:2489.82,DOS:100.00,Pw:0.85


Digital Psychrometric Chart
Set
Tables
About
Exit
Patm : 89.874 kPa
Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa
Twb
Tdp
Tdb
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.
Crosshair: Tdb:29.87 ,RH:51.80

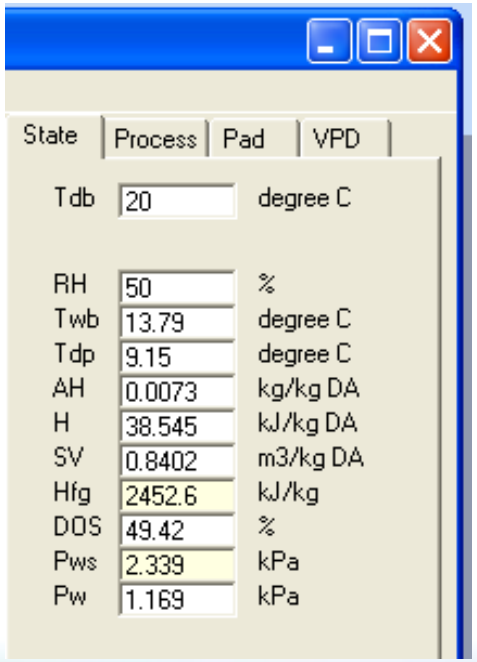
From one state to another state is called process

- 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)



Process

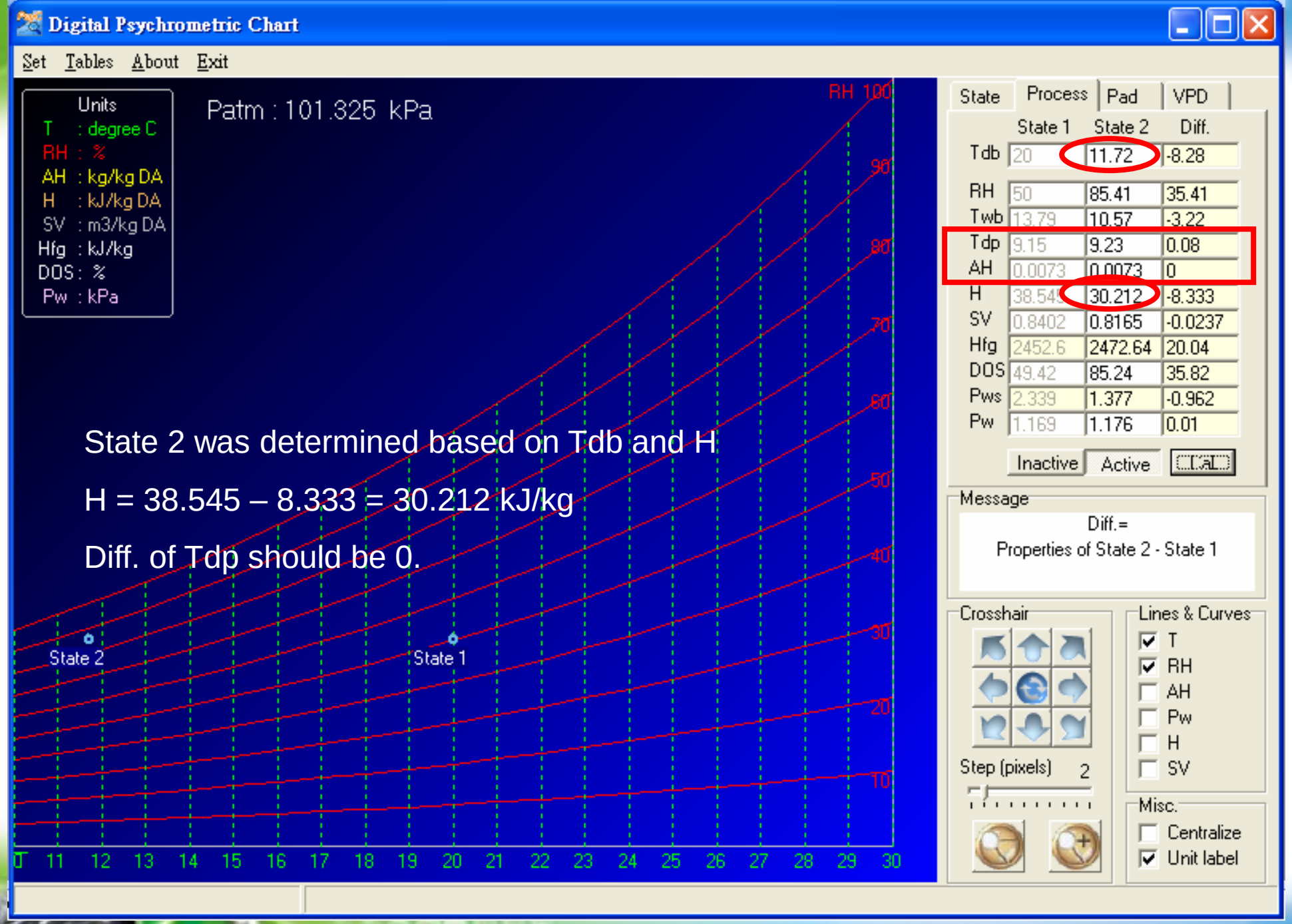
4. Determine the final state of moist air originally at 20 deg.C and 50 % relative humidity if 10 kJ are removed from 1.2 kg of the air.

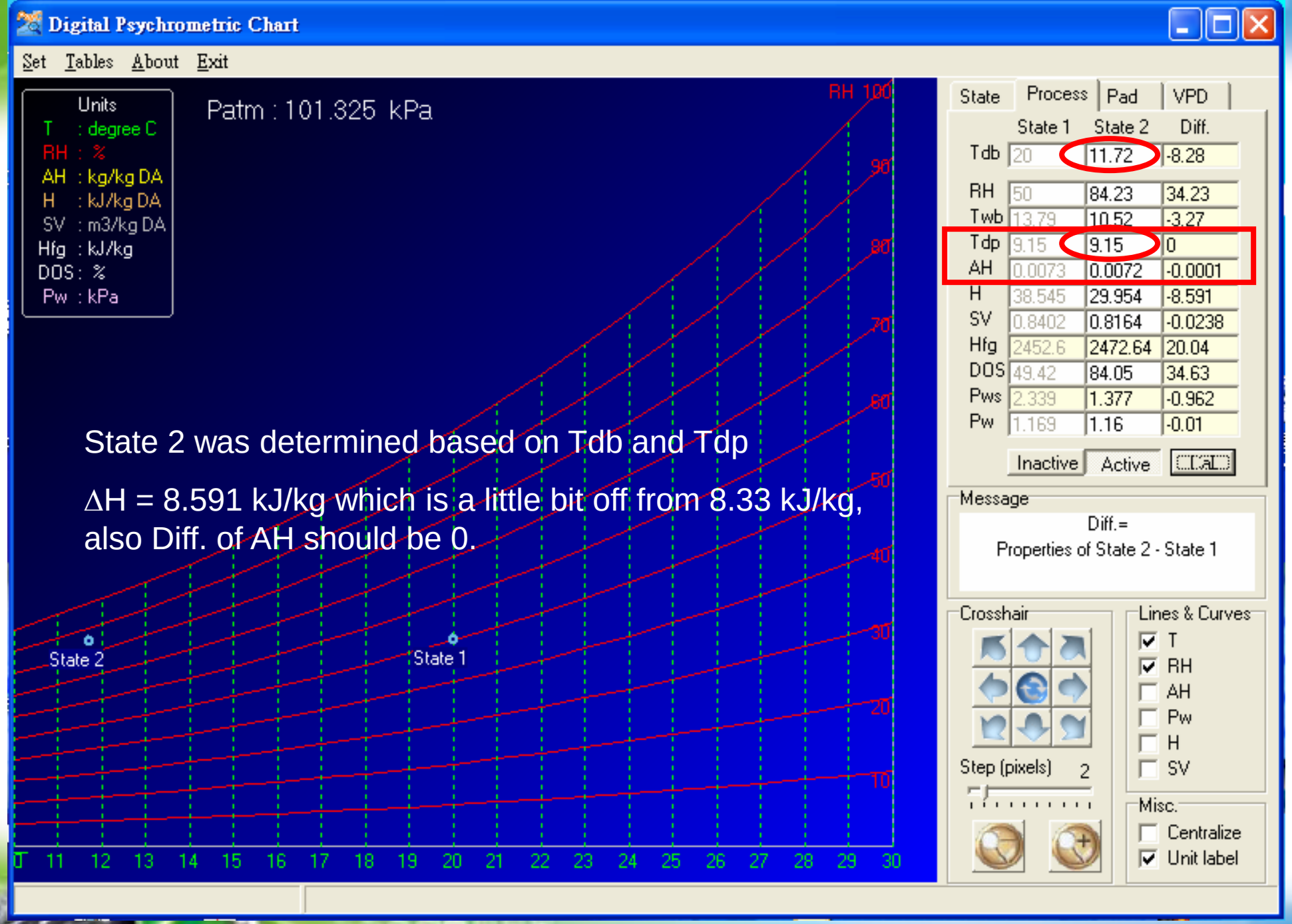


Answer to Q4

- $\Delta T = q/(Ma*Cp)=(-10\ kJ)/(1.2\ kg*1.006\ kJ/kg.K)= -8.28\ K$
- The final dry bulb T will be 20 – 8.28 = 11.72 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.

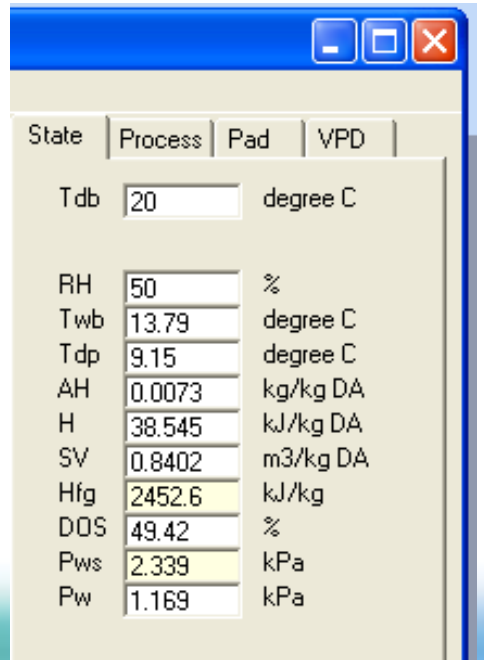
- $\Delta h = q/Ma = (-10\ kJ)/(1.2\ kg) = -8.333\ kJ/kg$
- The initial h = 38.5 kJ/kg
- The final h = 38.545 – 8.333 = 30.212 kJ/kg
- The initial dew point T = final dew point T.
- Final state can be found based on final Tdb and Tdp, or Tdb and h, or Tdp and h


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 kJ/kg
Diff. of Tdp should be 0.
State 2
State 1
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 38.545 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


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
State 1
State 2 was determined based on Tdb and Tdp
ΔH = 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

Process

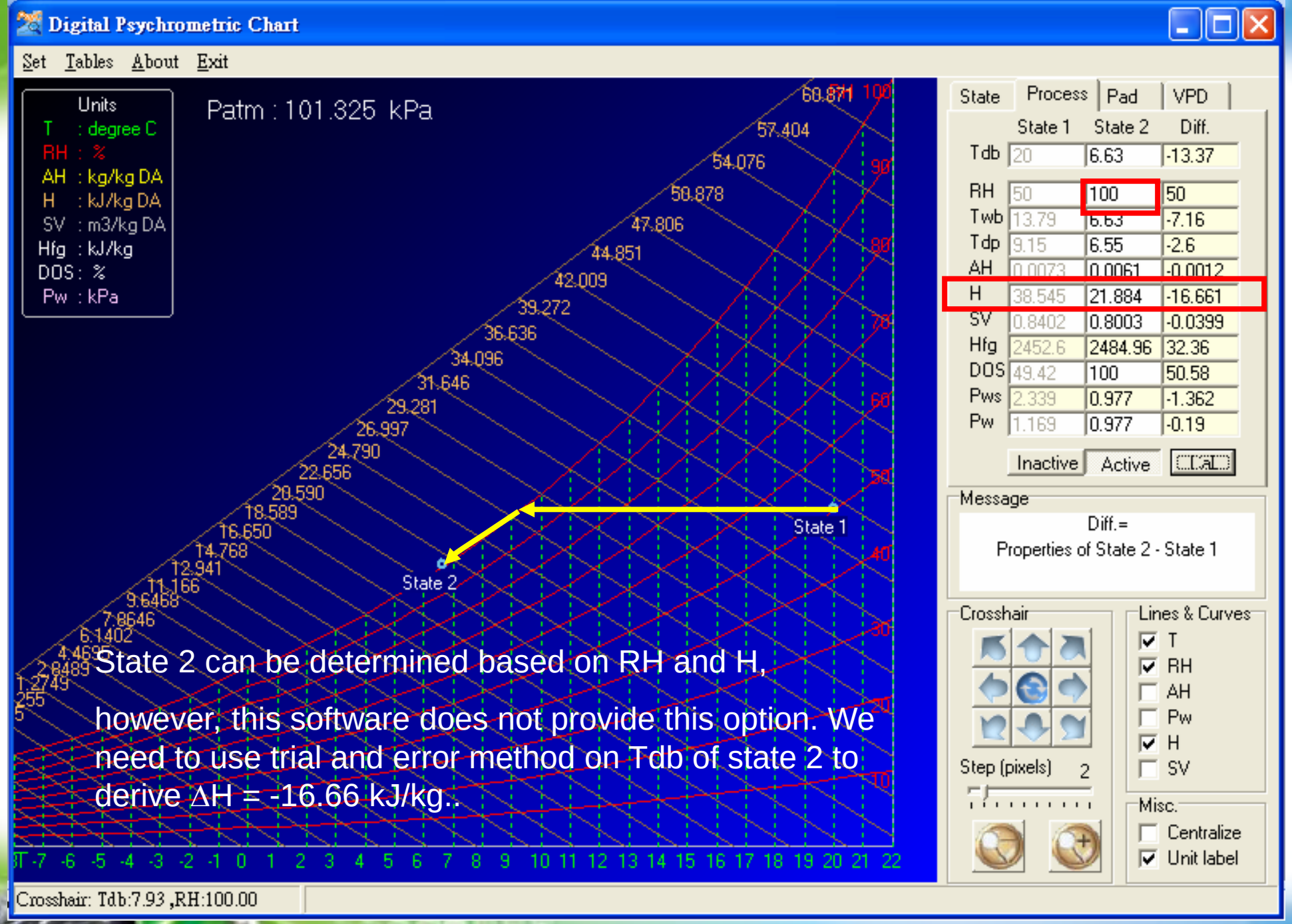
5. Determine the final state of moist air originally at 20 deg.C and 50 % relative humidity if 20 kJ are removed from 1.2 kg of the air.



Answer to Q5

- $\Delta T = q/(Ma*Cp)=(-20kJ)/(1.2kg*1.006kJ/kg.K)= -16.56$ K
- The final T will be 20 – 16.56 = 3.44 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 %.

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

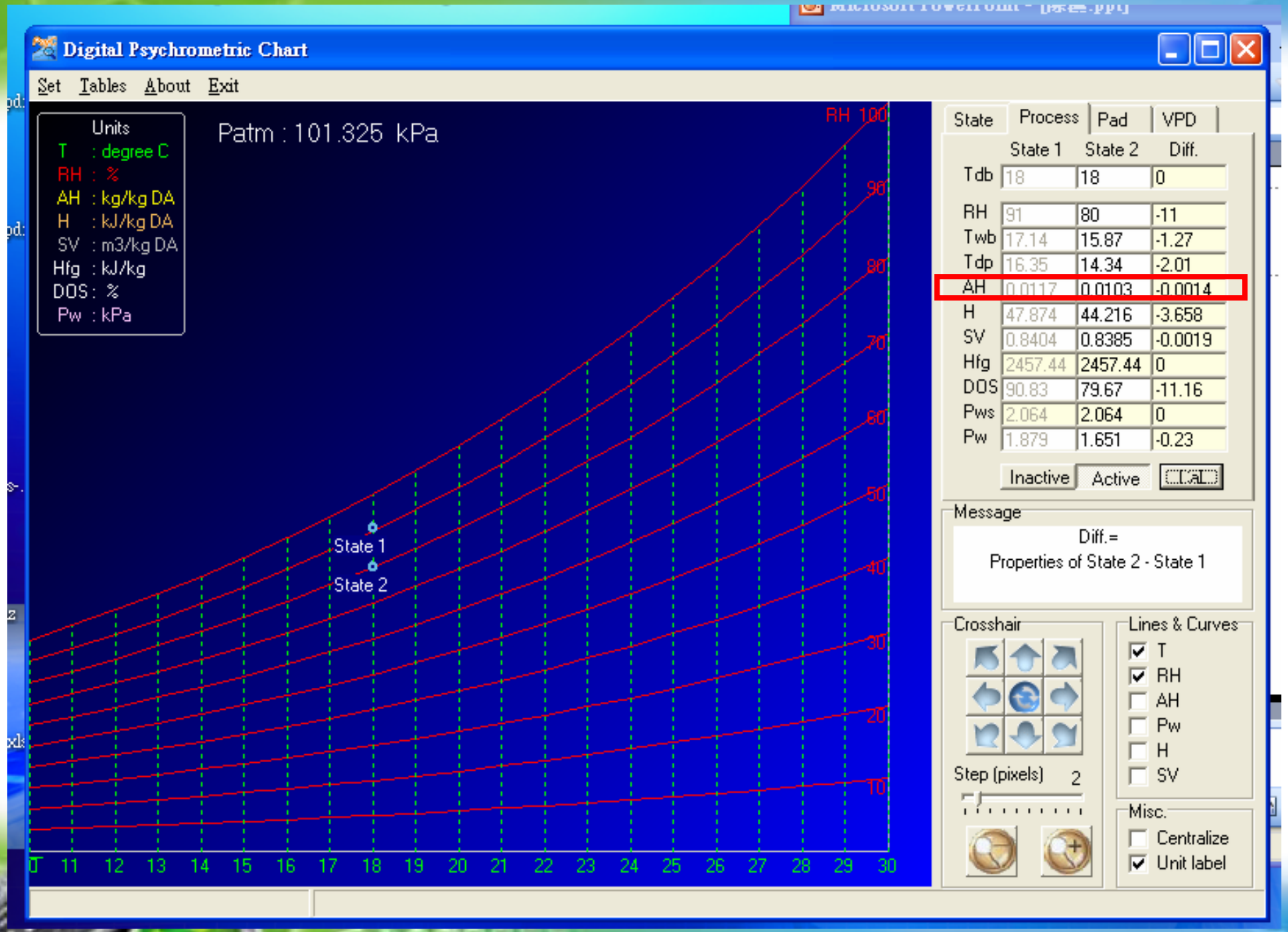


State 2 can be determined based on RH and H,

however, this software does not provide this option. We need to use trial and error method on Tdb of state 2 to derive ΔH = -16.66 kJ/kg..

Process

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 Tdb and RH in a 3 m height 1000 m^2 greenhouse before turn on the dehumidifier is 18 degree C, 91 % respectively. After turn on the dehumidifier for a while, the Tdb remain the same and RH drop to 80 %. How much water was removed from the moist air inside this greenhouse ?

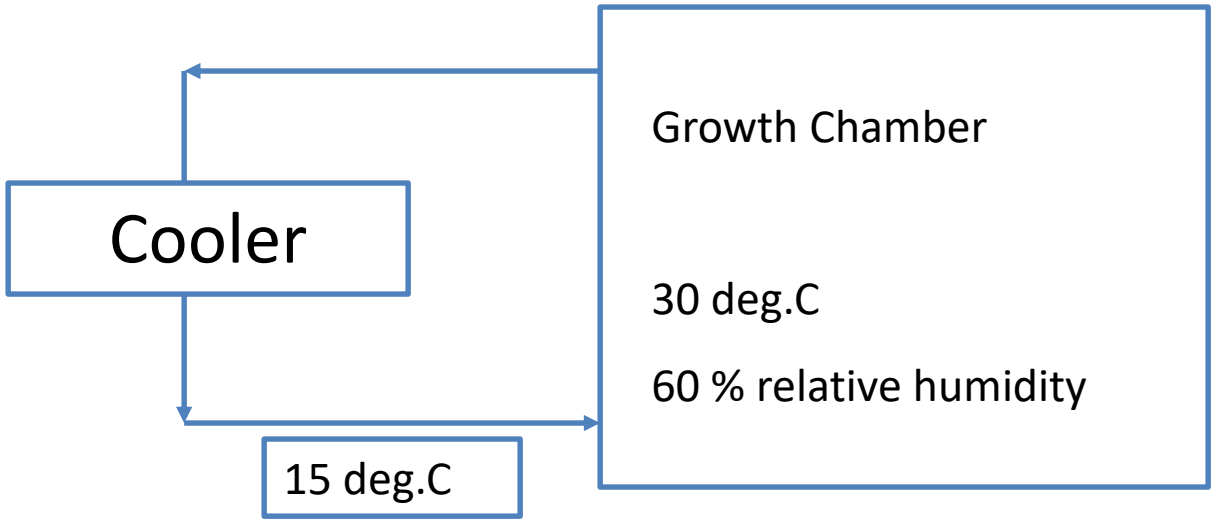

Digital Psychrometric Chart
Set
Tables
About
Exit
Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa
Patm : 101.325 kPa
RH 100
90
80
70
60
50
40
30
20
10
State 1
State 2
T 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
State
Process
Pad
VPD
State 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
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

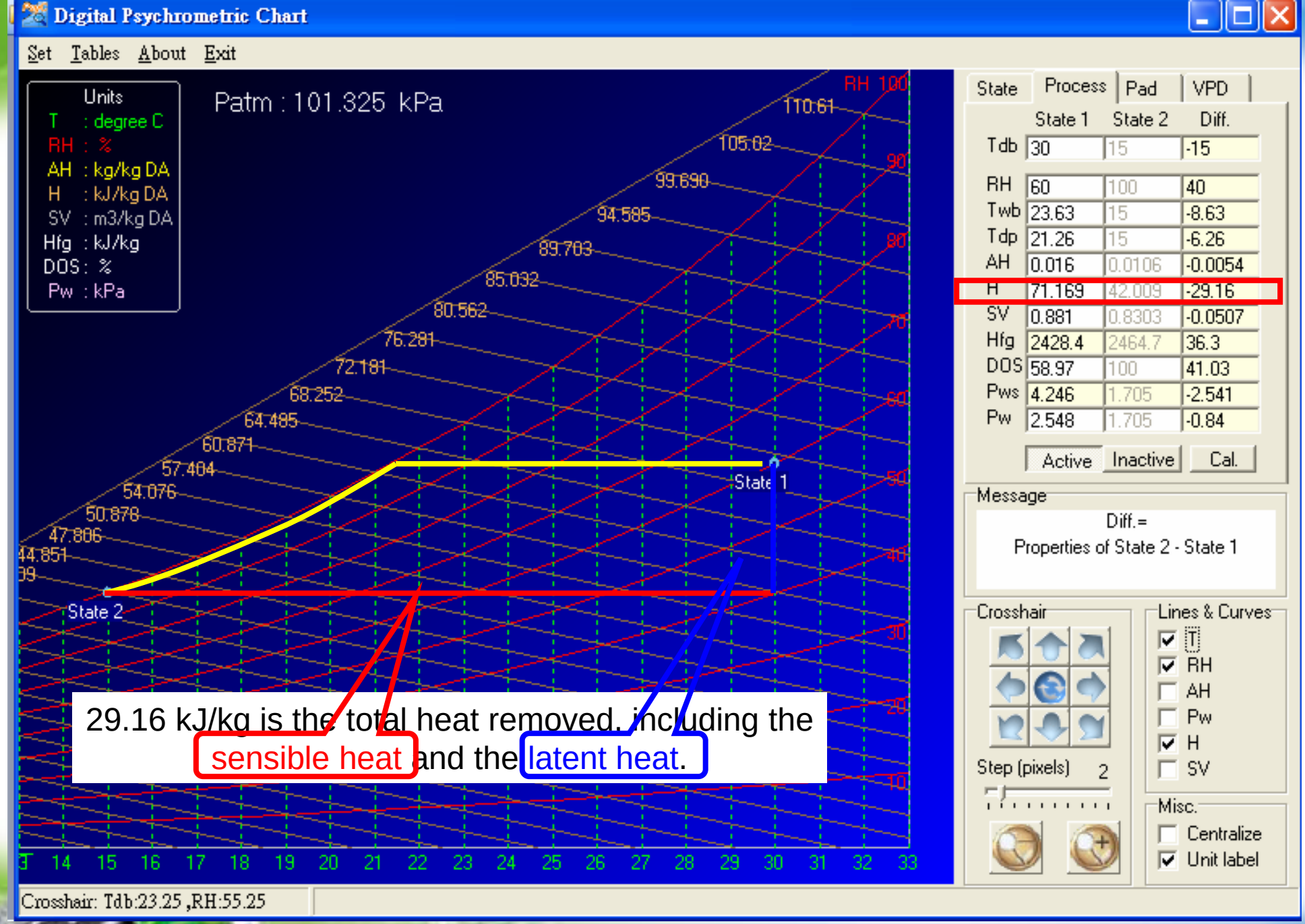
Answer to Q6

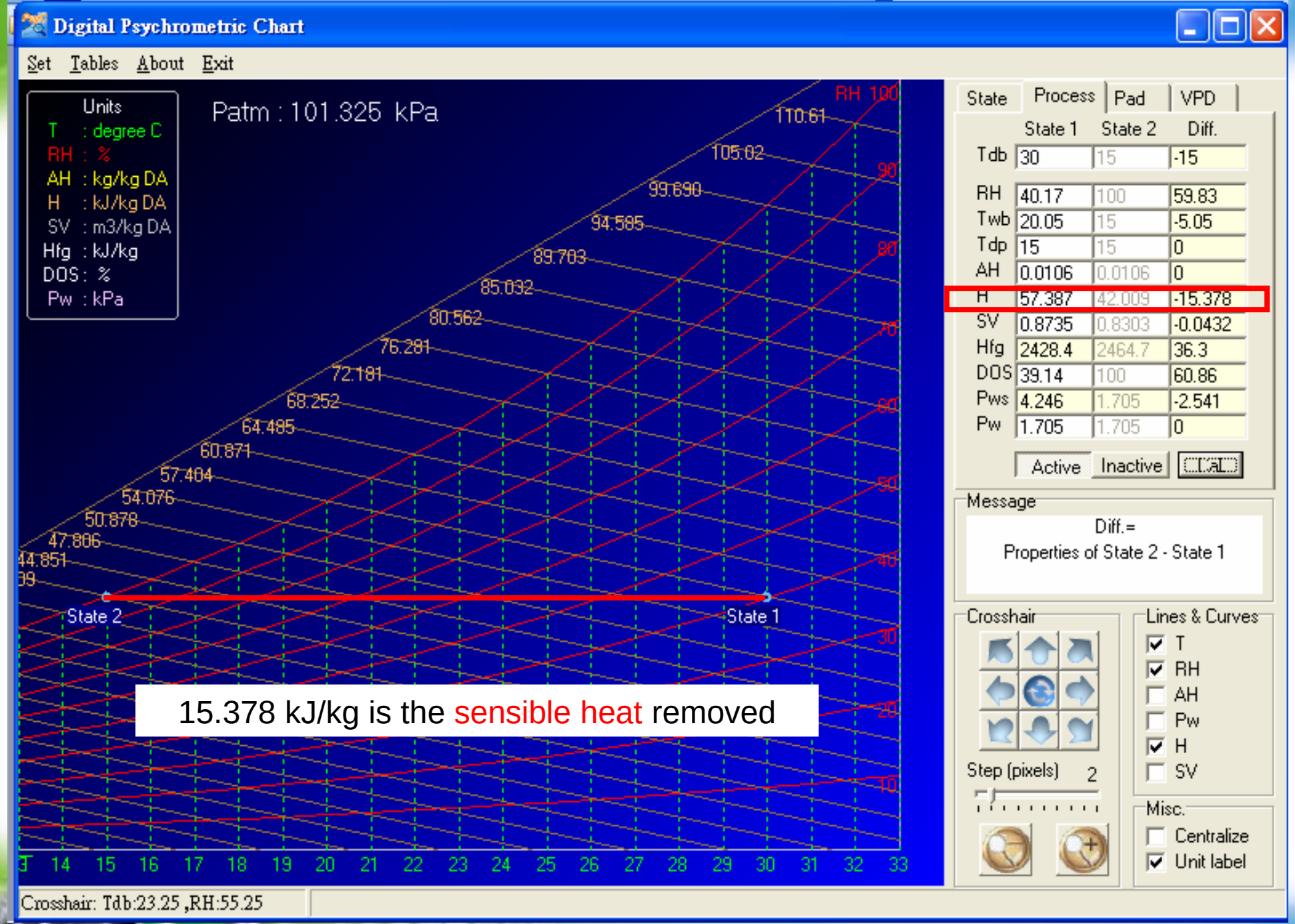
- Before use
  - Specific volume = 0.8404 m^3/kg
  - AH = 0.0117 kg vapor/kg dry air
- After use
  - AH = 0.0103 kg vapor/kg dry air
- Difference in AH
  - $AH_1 - AH_2$ = 0.0014 kg vapor/kg dry air
  - Air volume 1000 x 3 = 3000 m^3
  - Air weight = 3000 / 0.8404 = 3569.7 kg
  - Total water condensed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

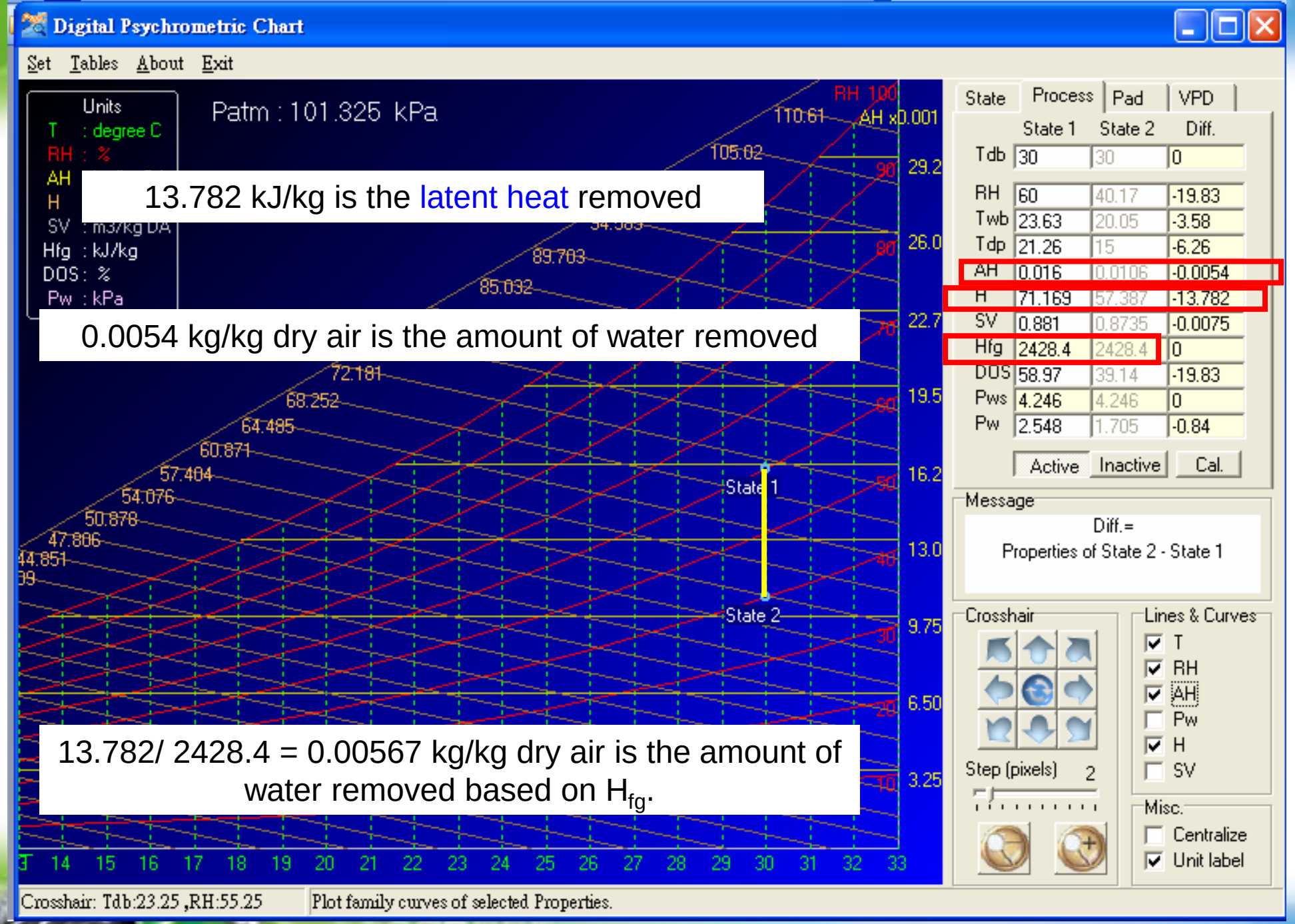
Process

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.


Growth Chamber
30 deg.C
60 % relative humidity
Cooler
15 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
RH 100
110.61
105.02
99.690
94.585
89.703
85.032
80.562
76.281
72.181
68.252
64.485
60.871
57.404
54.076
50.878
47.806
44.851
State 1
State 2
29.16 kJ/kg is the total heat removed, including the sensible heat and the latent heat.
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
RH 100
110.61
105.02
99.690
94.585
89.703
85.032
80.562
76.281
72.181
68.252
64.485
60.871
57.404
54.076
50.878
47.806
State 2
State 1
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
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
H
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 1
State 2
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.

Process

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.

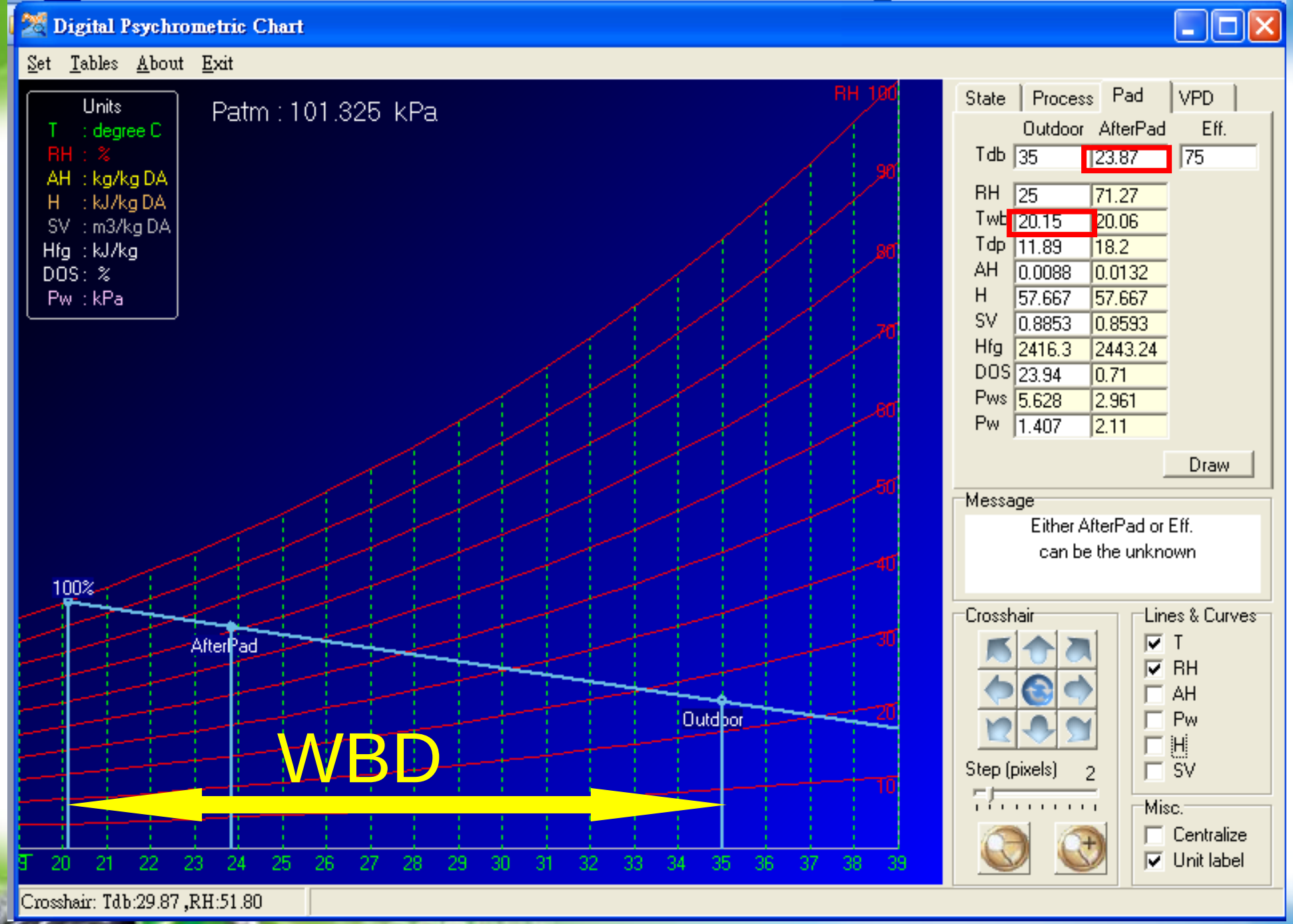
Answer to 8a

(a). At the given condition:

- Tdb = 35 deg.C
- RH = 25 % (Very dry weather)

Answer

- Twb = 20.15 deg.C
- WBD = 35 – 20.15 = 14.85 deg.C
- ΔT = 0.75 * WBD = 11.13 deg.C
- Final T = 35 – 11.13 = 23.87 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
RH 100
90
80
70
60
50
40
30
20
10
100%
AfterPad
Outdoor
WBD
9 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
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

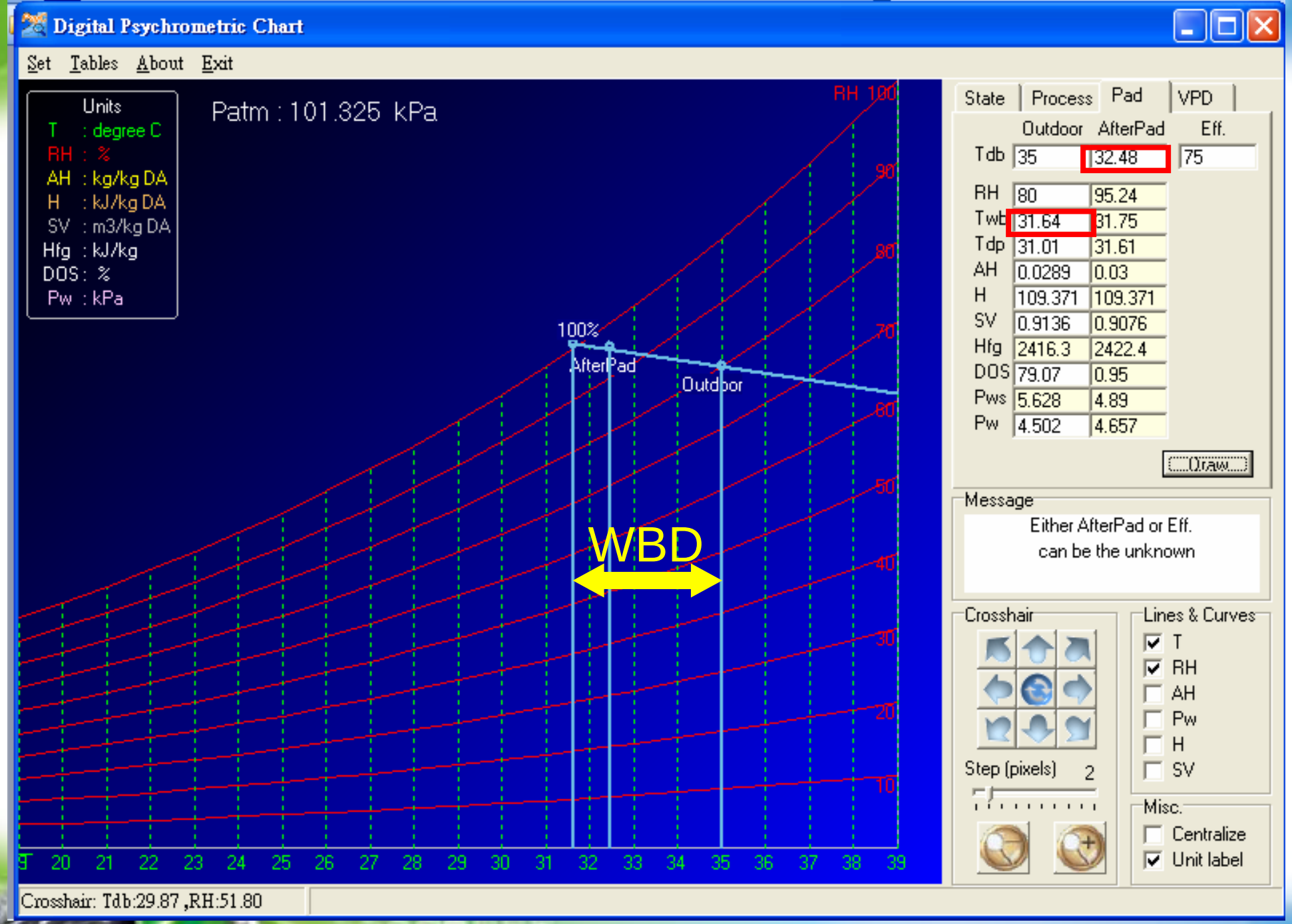
Answer to 8c

(c). At the given condition:

- Tdb = 35 deg.C
- RH=80 % (Regular humid weather)

Answer

- Twb = 31.64 deg.C
- WBD = 35 – 31.64 = 3.36
- ΔT = 0.75 * WBD = 2.52 deg.C
- Final T = 35 – 2.52 = 32.48 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
RH 100
90
80
70
60
50
40
30
20
10
100%
AfterPad
Outdoor
WBD
19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
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

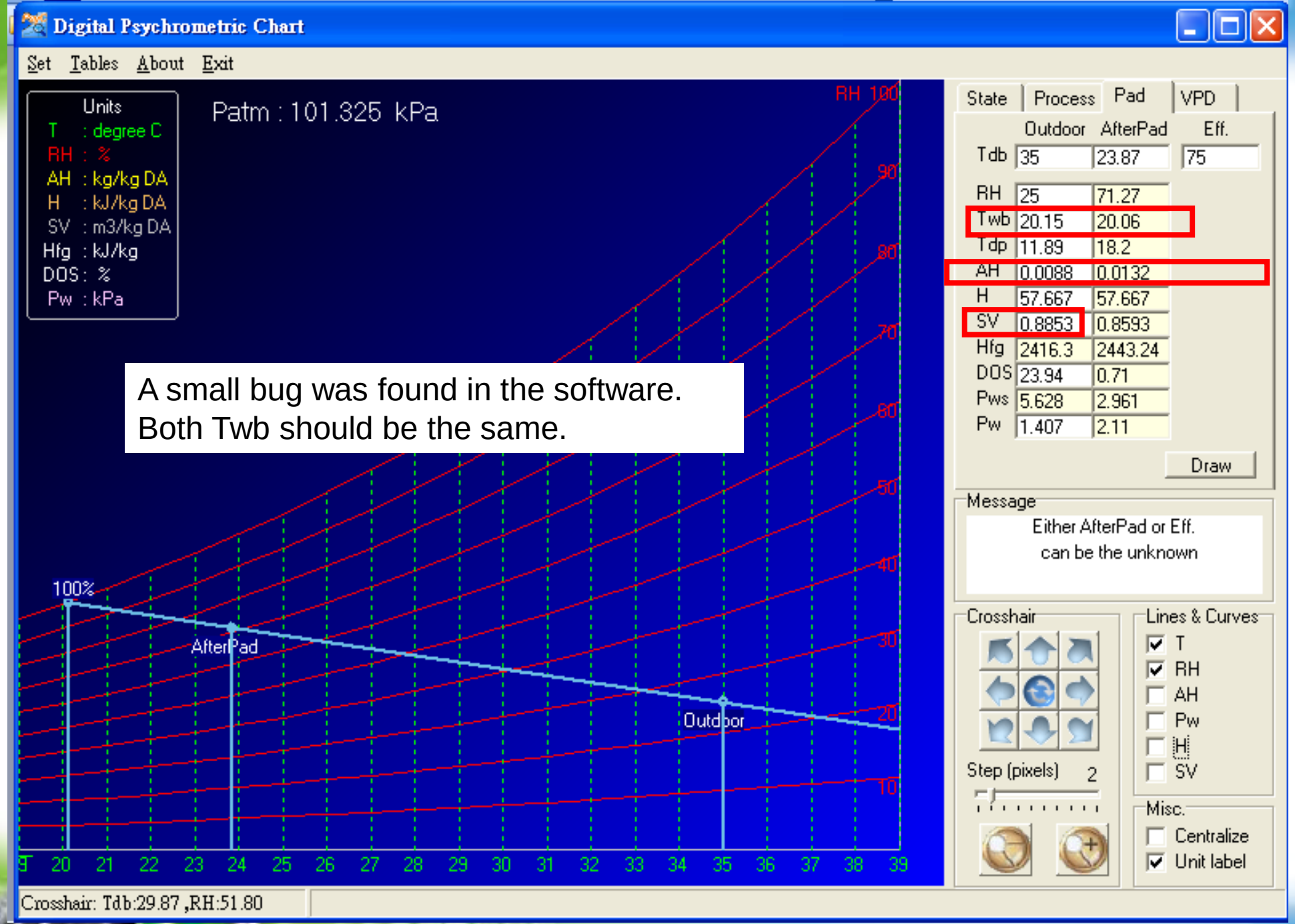
Answer to 8b

(b). At initial conditions,

- Tdb = 35 deg.C
- RH = 25 %

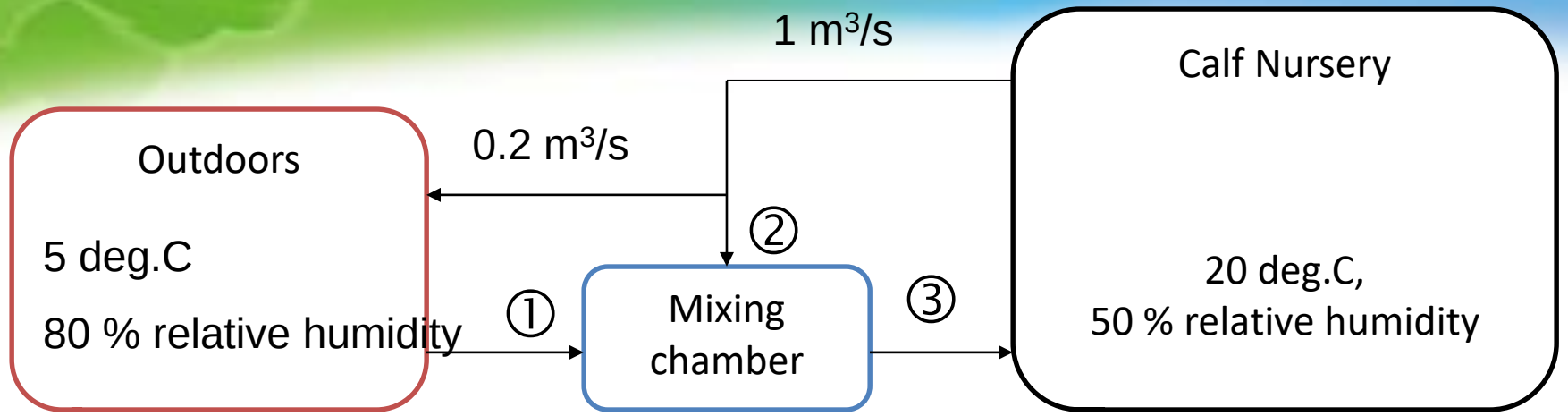
Answer

- the specific volume is 0.8853 m^3/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 m^3/0.8853 m^3/kg = 1.13 kg.
- The change of humidity ratio is 0.0132 – 0.0088 = 0.0044 kg/kg dry air.
- Thus, the total water gained by each cubic meter of outdoor air will be 1.13 kg * 0.0044 kg/kg = 0.005 kg.


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
A small bug was found in the software.
Both Twb should be the same.
100%
AfterPad
Outdoor
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

Process

9. A ventilation system for a calf nursery draws 1 m^3/s of air from the nursery, exhausts 0.2 m^3/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.

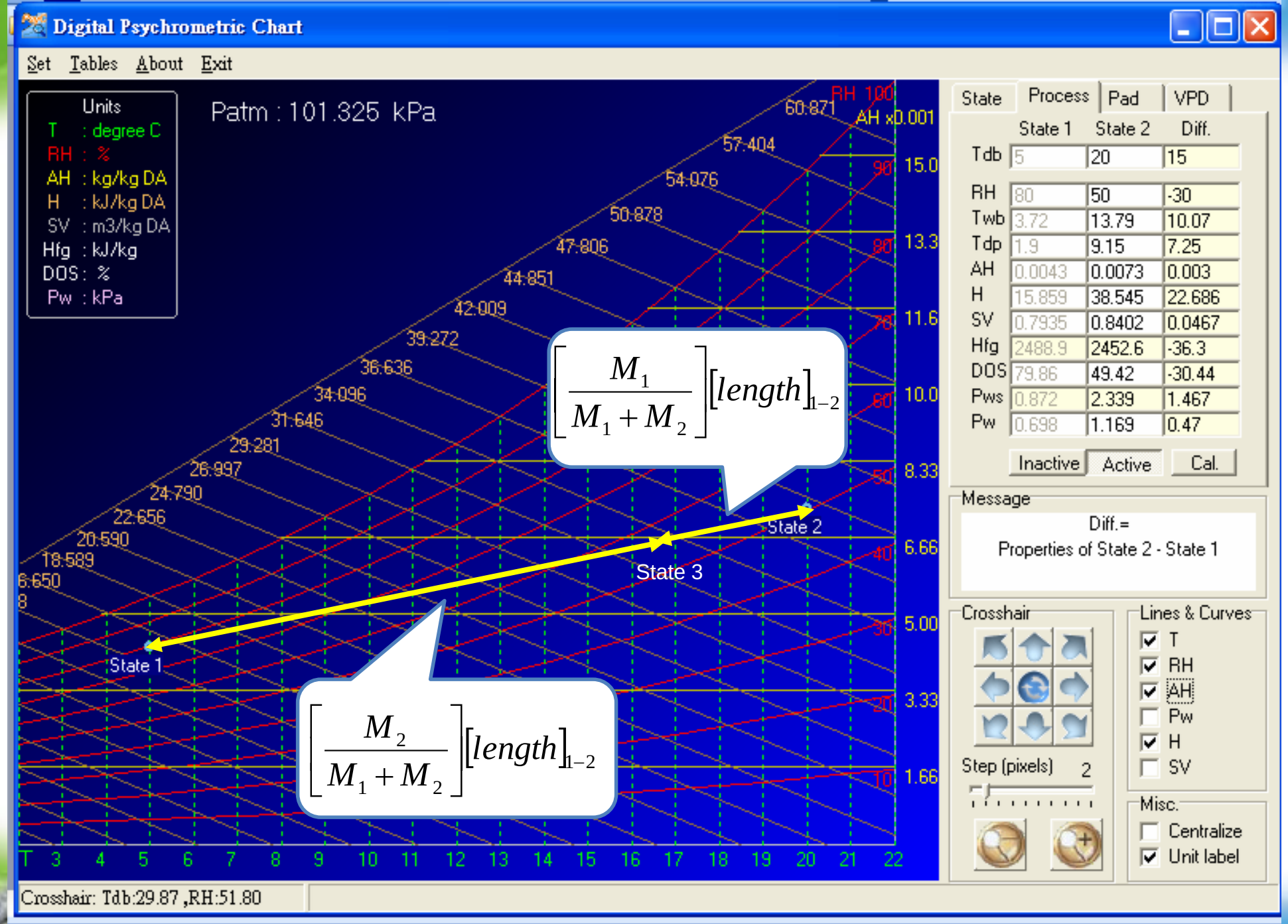


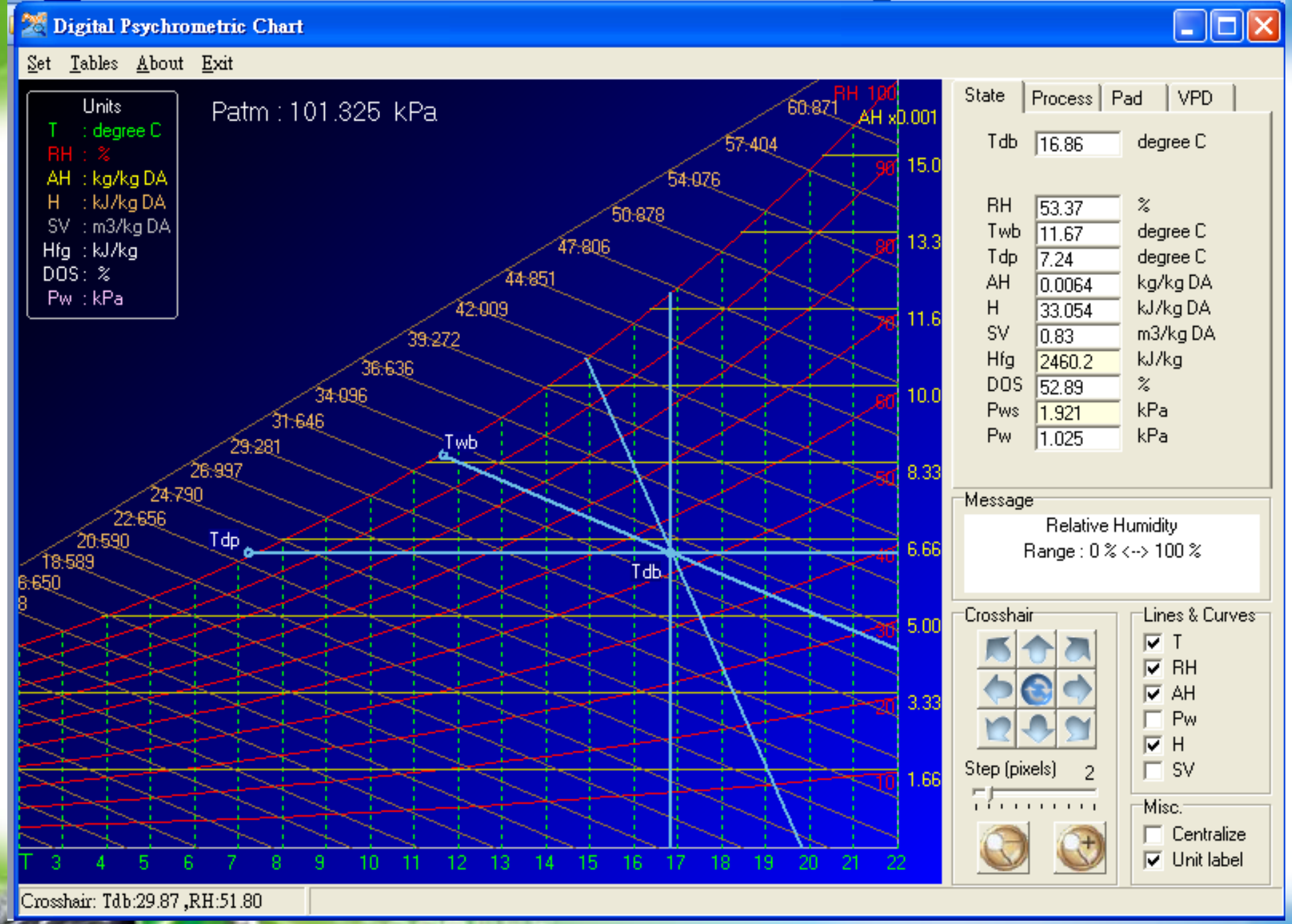
	#1	#2	#3
T, deg.C	5	20	16.86 (cal.)
RH, %	80	50	53.37 (psychart)
V, m3/s	0.2	0.8	0.999
ν, m3/kg	0.7935	0.8402	0.83
M, kg/s	0.252	0.952	1.204
W, kg/kg	0.0043	0.0073	0.0066 (cal.) / 0.0064 (psychart)
h, kJ/kg	15.859	38.545	33.796 (cal.) / 33.054 (psychart)

$W_3 = (M_1*W_1+M_2*W_2)/(M_1+M_2)$

$T_3 = (M_1*T_1+M_2*T_2)/(M_1+M_2)$

$h_3 = (M_1*h_1+M_2*h_2)/(M_1+M_2)$

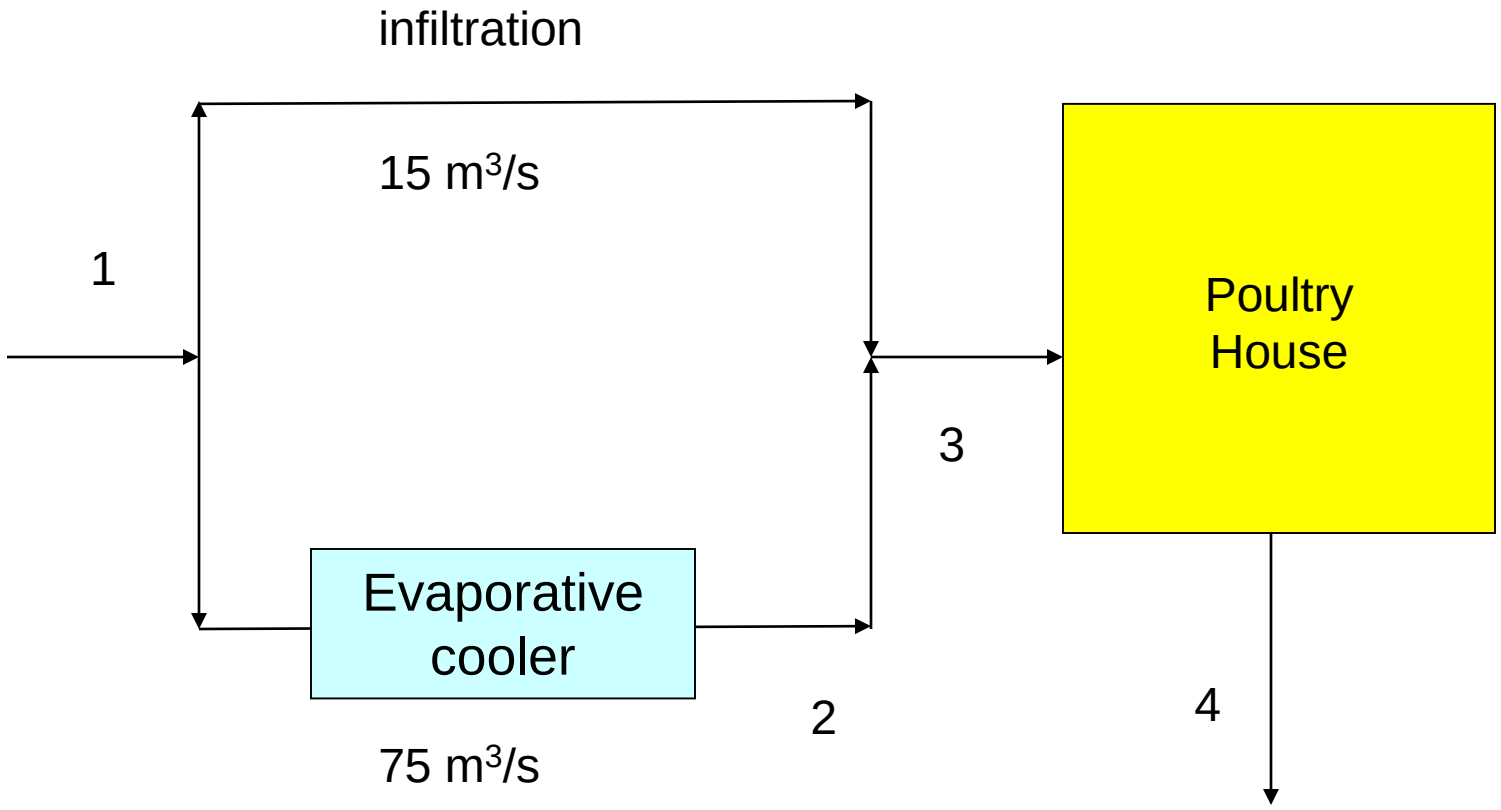

Digital Psychrometric Chart
Set
Tables
About
Exit
Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa
Patm : 101.325 kPa
RH 100
AH x0.001
60.871
57.404
54.076
50.878
47.806
44.851
42.009
39.272
36.636
34.096
31.646
29.281
26.997
24.790
22.656
20.590
18.589
6.650
8
15.0
13.3
11.6
10.0
8.33
6.66
5.00
3.33
1.66
$\left[\frac{M_1}{M_1+M_2}\right][length]_{1-2}$
$\left[\frac{M_2}{M_1+M_2}\right][length]_{1-2}$
State 1
State 2
State 3
T 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
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
Step (pixels) 2
Lines & Curves
T
RH
AH
Pw
H
SV
Misc.
Centralize
Unit label

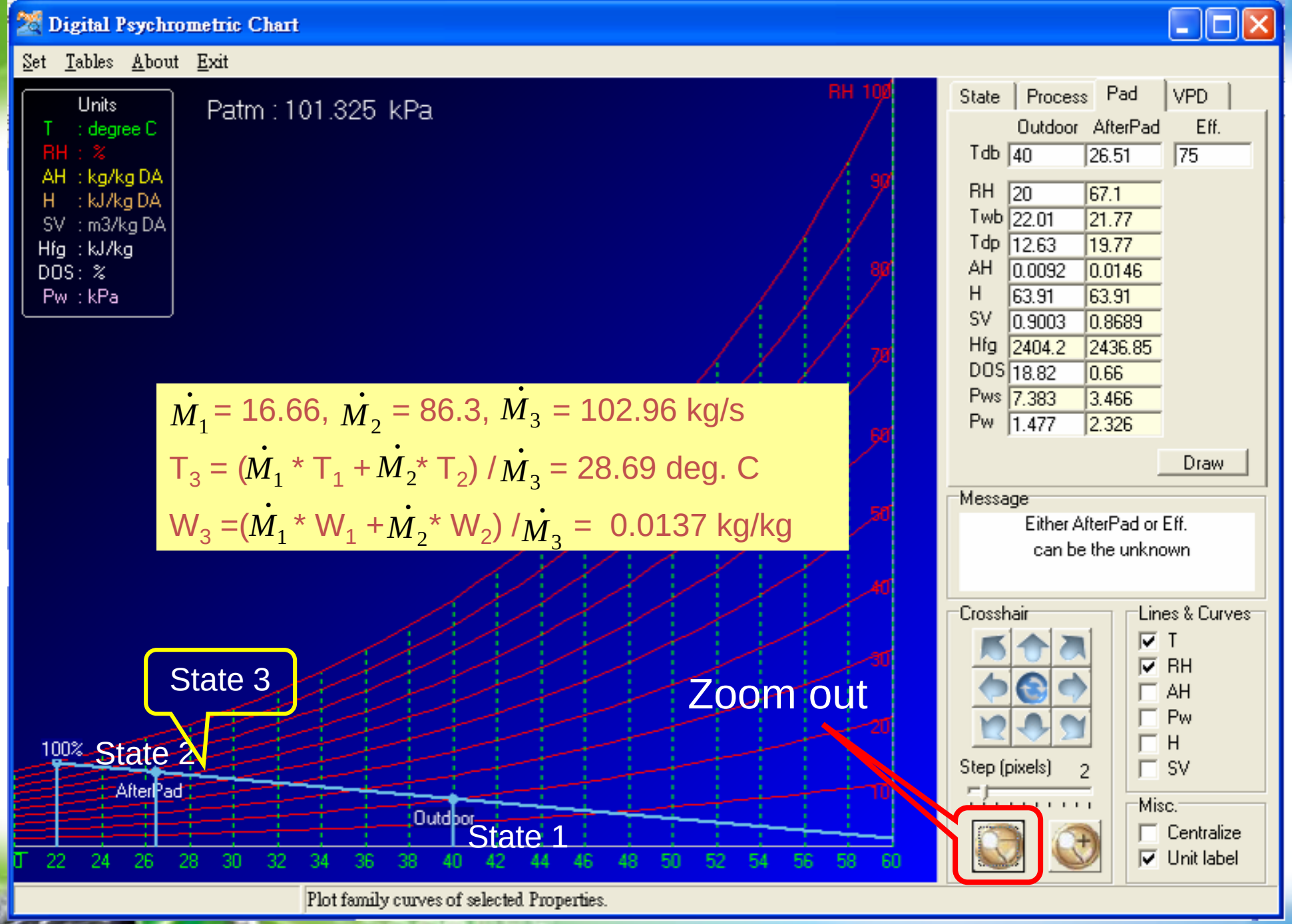

Digital Psychrometric Chart
Set
Tables
About
Exit
Units
T : degree C
RH : %
AH : kg/kg DA
H : kJ/kg DA
SV : m3/kg DA
Hfg : kJ/kg
DOS : %
Pw : kPa
Patm : 101.325 kPa
RH 100
AH x0.001
60.871
57.404
54.076
50.878
47.806
44.851
42.009
39.272
36.636
34.096
31.646
29.281
26.997
24.790
22.656
20.590
18.589
6.650
8
15.0
13.3
11.6
10.0
8.33
6.66
5.00
3.33
1.66
90
80
70
60
50
40
30
20
10
Twb
Tdp
Tdb
T 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
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

Process

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 m^3/s of outdoor air will be drawn by the evaporative cooling system (75% efficiency) and 15 m^3/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.

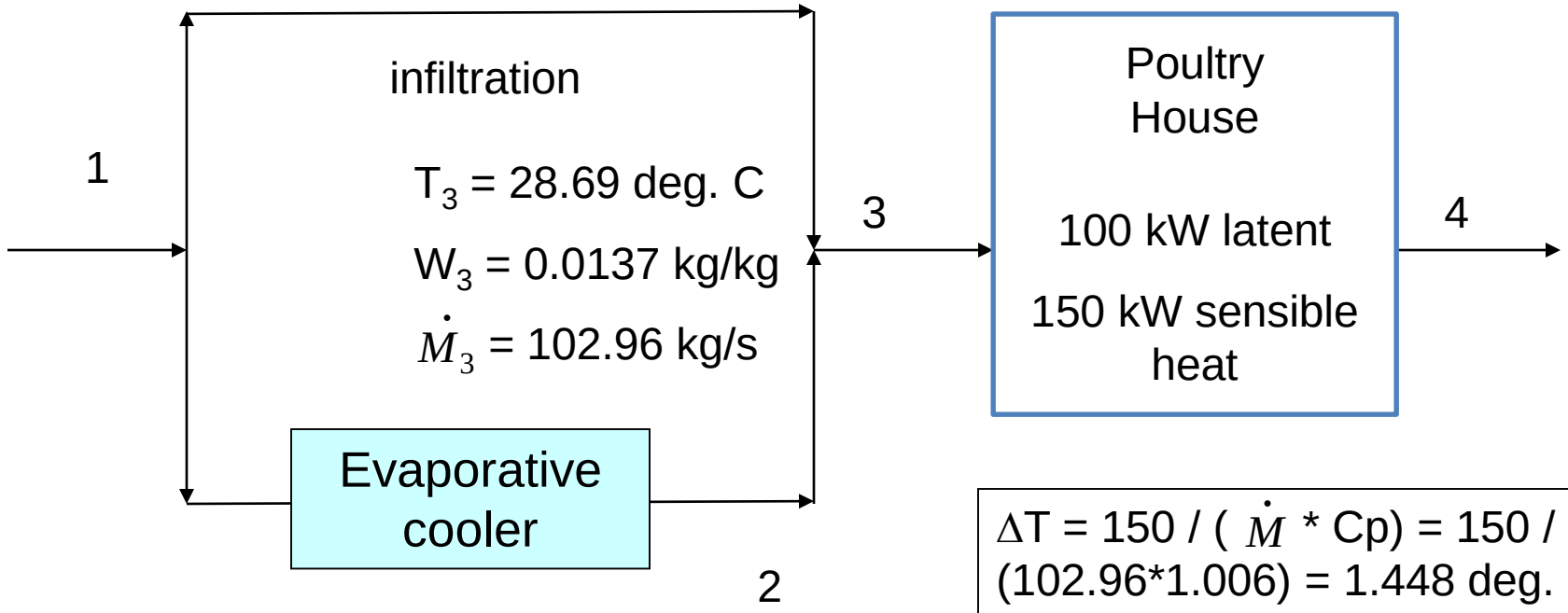

infiltration
15 m3/s
1
Poultry
House
3
Evaporative
cooler
2
4
75 m3/s


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
$\dot{M}_1$ = 16.66, $\dot{M}_2$ = 86.3, $\dot{M}_3$ = 102.96 kg/s
$T_3 = (\dot{M}_1 * T_1 + \dot{M}_2 * T_2) / \dot{M}_3$ = 28.69 deg. C
$W_3 = (\dot{M}_1 * W_1 + \dot{M}_2 * W_2) / \dot{M}_3$ = 0.0137 kg/kg
State 3
100%
State 2
AfterPad
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 m^3/s	T_1 = 40 deg. C
ν_1 = 0. 9003 m^3/kg	RH_1 = 20 %
$\dot{M}_1$ = 16.66 kg/s	W_1 = 0.0092 kg/kg

$T_4 = T_3 + \Delta T = 28.69 + 1.448 = 30.138$ deg. C

$W_4 = W_3 + \Delta W = 0.0137 + 0.0004 = 0.0141$ kg/kg

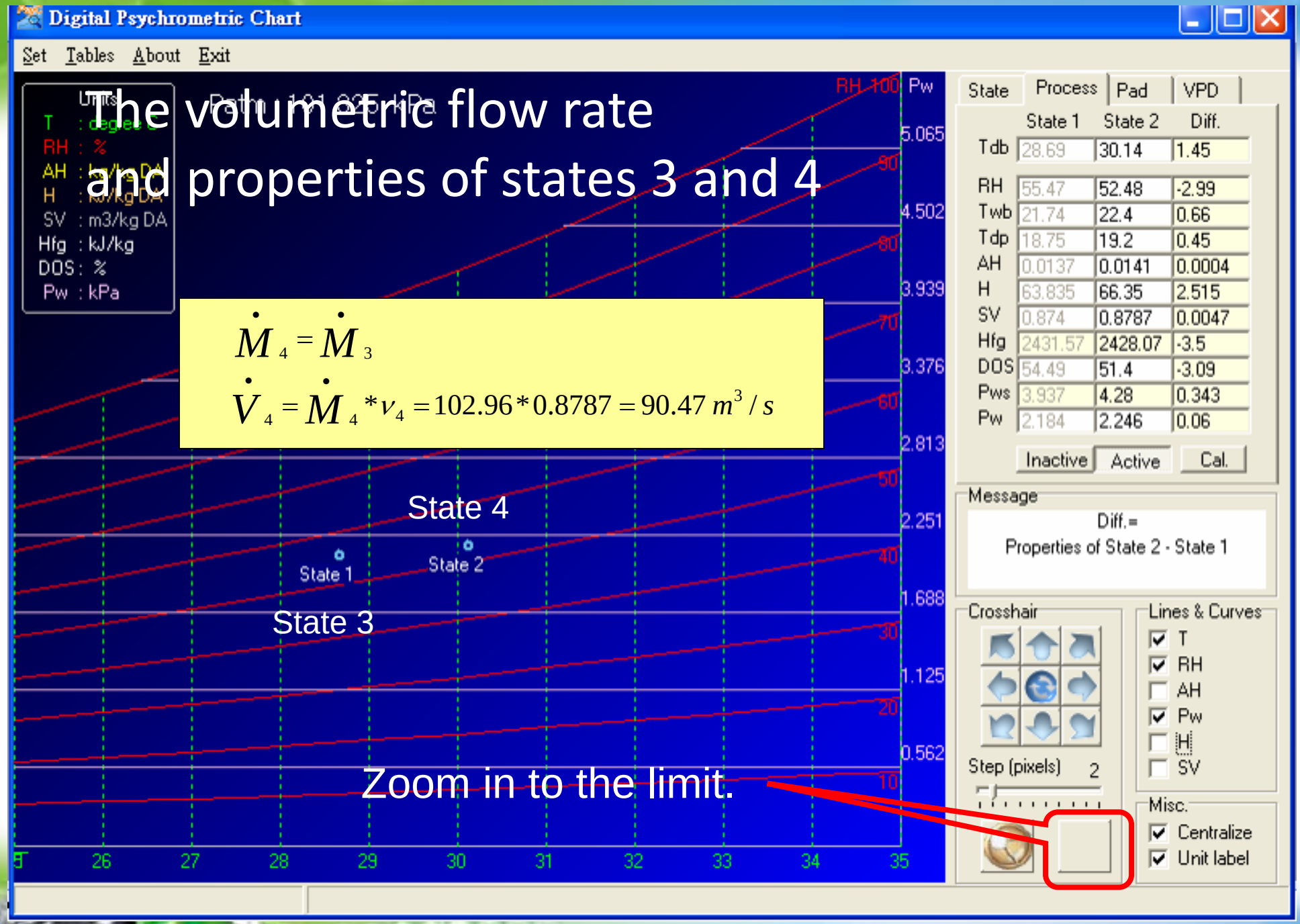


$\dot{V}_2$ = 75 m^3/s	T_2 = 26.51 deg. C
ν_2 = 0.8689 m^3/kg	RH_2 = 67.1 %
$\dot{M}_2$ = 86.3 kg/s	W_2 = 0.0146 kg/kg

$\Delta T = 150 / (\dot{M} * Cp) = 150 / (102.96*1.006) = 1.448$ deg. C

$h_{fg} = 2501 - 2.42 * (28.69+1.448) = 2428$ kJ/kg

$\Delta W = 100 / (\dot{M} * h_{fg}) = 100 / (102.96 * 2428) = 0.0004$ kg/kg

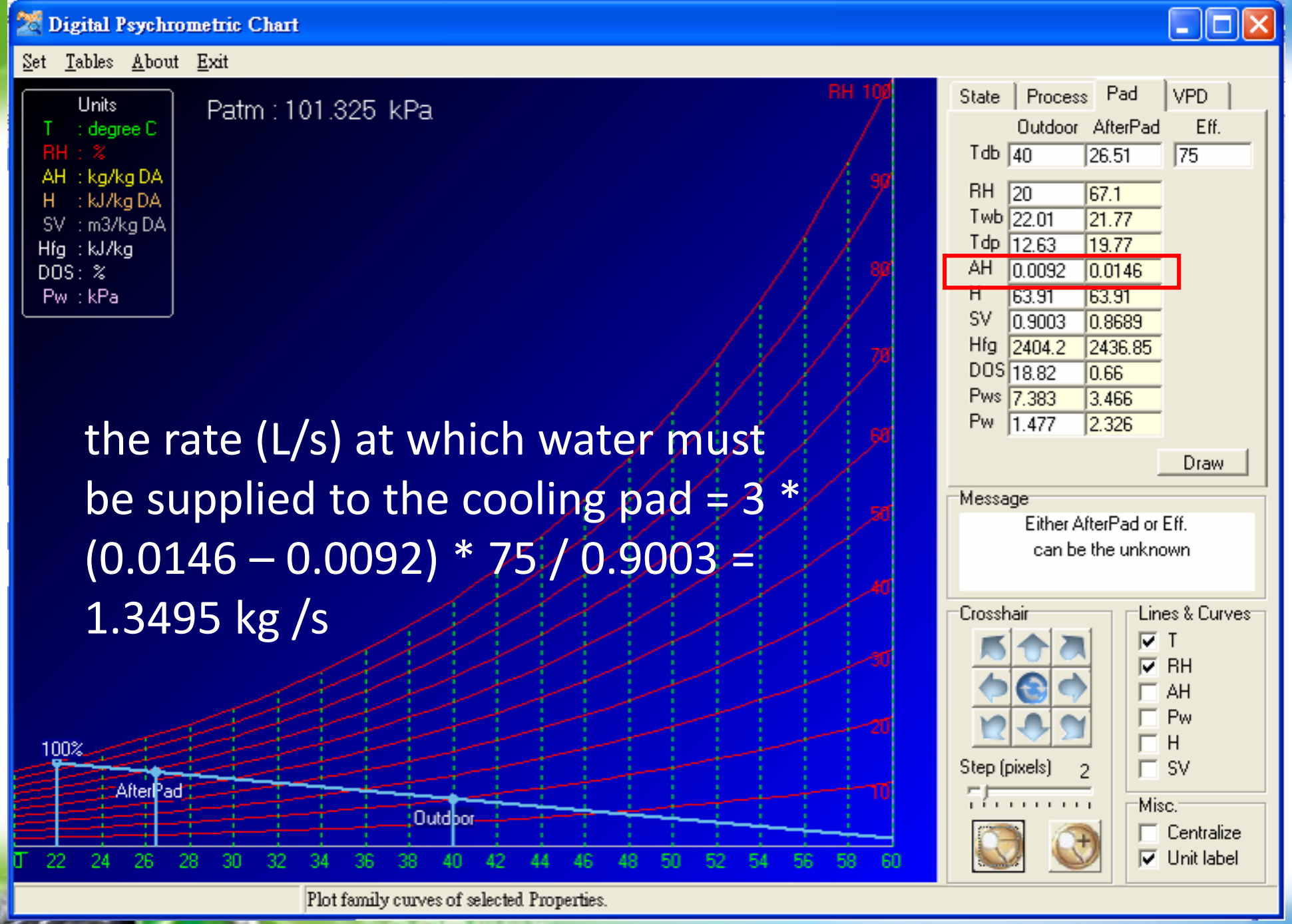


The volumetric flow rate and properties of states 3 and 4

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

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

Zoom in to the limit.



the rate (L/s) at which water must be supplied to the cooling pad = 3 * (0.0146 – 0.0092) * 75 / 0.9003 = 1.3495 kg /s

Reference on Psy. Examples

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