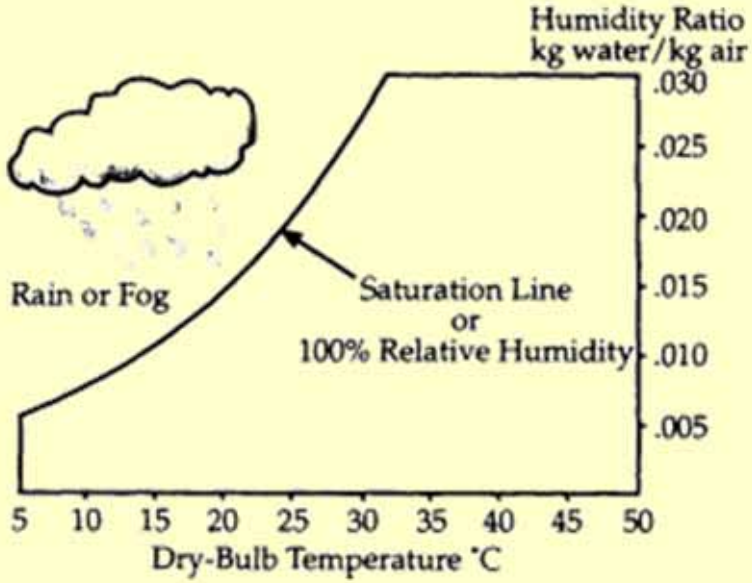
MEBS6006 Environmental Services I

http://me.hku.hk/bse/MEBS6006/



Advanced Psychrometry

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Dec 2013

Contents

- Review of Basic Psychrometry*
  - Introduction to Psychrometry (Handout Chapter 1)
  - Psychrometric Processes (Handout Chapter 2)
- Practical Applications of Psychrometry
  - Characteristics and use of psychrometric charts
  - Software for psychrometric analysis
- Techniques of Psychrometric Analysis
  - Psychrometrics and Bioclimatic Analysis

(* Printed handouts can be downloaded for self study)

Introduction to Psychrometry

- Basics
  - The atmosphere
  - Water vapour
  - Saturated vapour pressure
- Also, Appendix - Thermodynamic Basics
  - Perfect gas laws
  - 1st law of thermodynamics
  - Conservation of energy

Introduction to Psychrometry

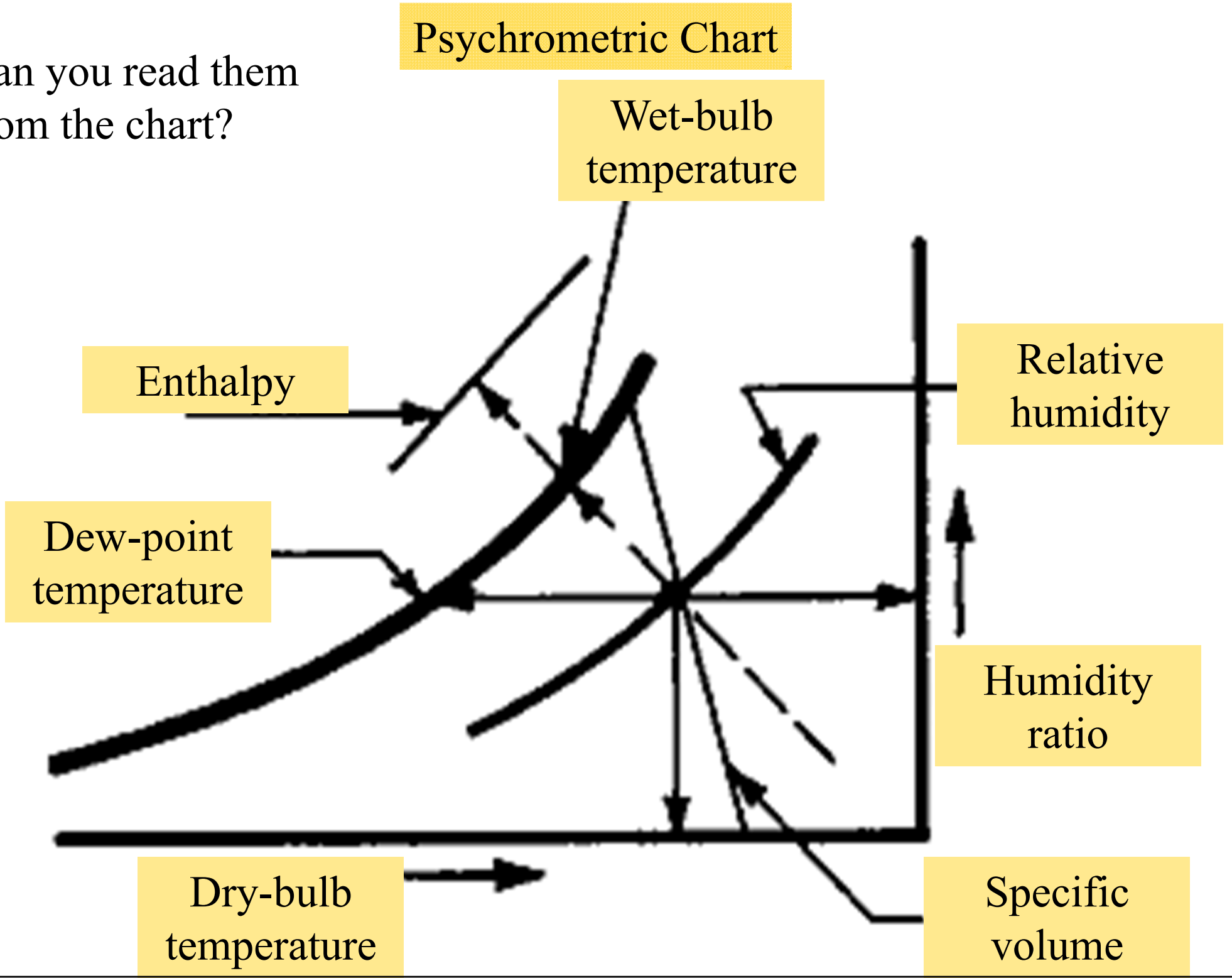
- Psychrometry
  - The study of atmospheric air and its associated water vapour
  - Dry air and moist air
- Dalton's law of partial pressures
- Standard atmospheric pressure = 101.325 kPa
- Saturated vapour pressure
  - Max. pressure of water vapour that can occur at any given temperature

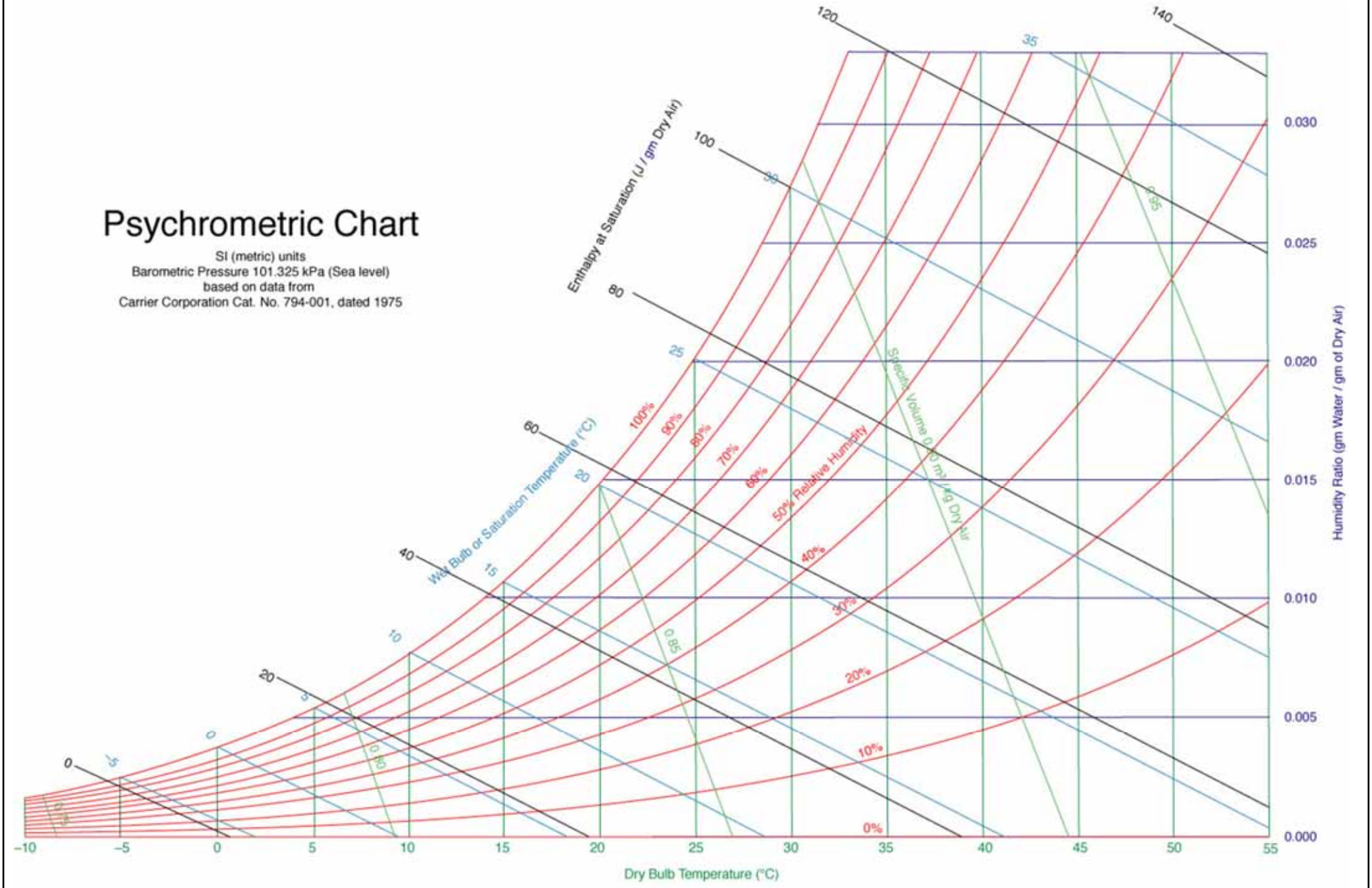
Introduction to Psychrometry

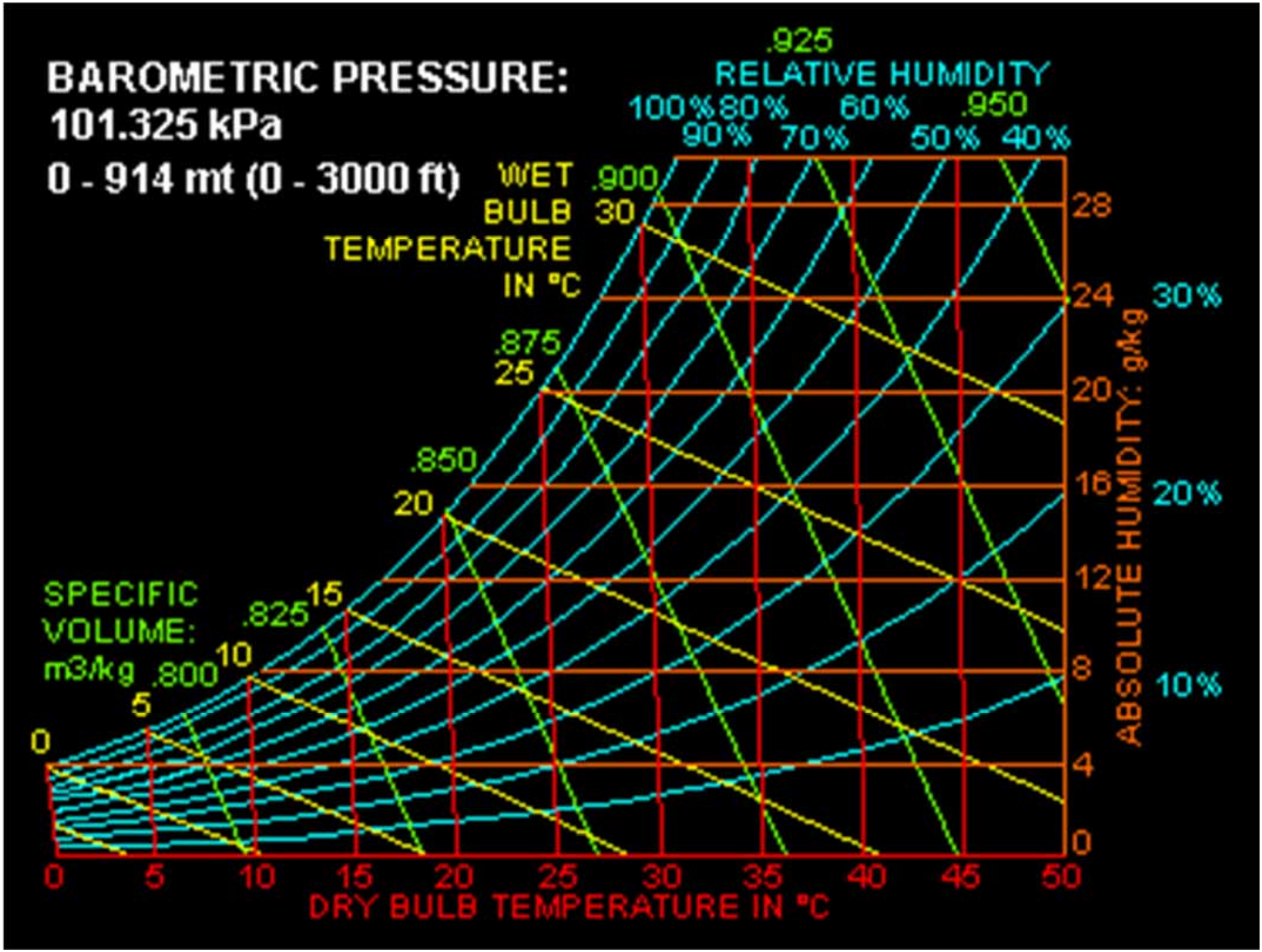
- Psychrometric Chart (Theory)
  - Moisture content (g), or absolute humidity (w)
  - Relative humidity (rh or RH)
  - Percentage saturation (μ)
  - Wet-bulb temperature (t_{wb})
  - Specific volume (v)

- (See the illustration on psychrometric chart)

Can you read them from the chart?




Psychrometric Chart
SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, dated 1975
Enthalpy at Saturation (J / gm Dry Air)
Wet Bulb or Saturation Temperature (°C)
Dry Bulb Temperature (°C)
Humidity Ratio (gm Water / gm of Dry Air)
Specific Volume 0.80 m³/kg Dry Air
0.85
0.90
0.95
50% Relative Humidity
100%
90%
80%
70%
60%
40%
30%
20%
10%
0%
120
140
100
80
60
40
20
0
35
30
25
20
15
10
5
0
-5
-10
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55


BAROMETRIC PRESSURE:
101.325 kPa
0 - 914 mt (0 - 3000 ft)
.925
RELATIVE HUMIDITY
100%
90%
80%
70%
60%
50%
.950
40%
WET BULB TEMPERATURE IN °C
.900
30
.875
25
.850
20
.825
15
.800
10
5
0
SPECIFIC VOLUME: m3/kg
28
24
20
16
12
8
4
0
30%
20%
10%
ABSOLUTE HUMIDITY: g/kg
0
5
10
15
20
25
30
35
40
45
50
DRY BULB TEMPERATURE IN °C

Sling psychrometer

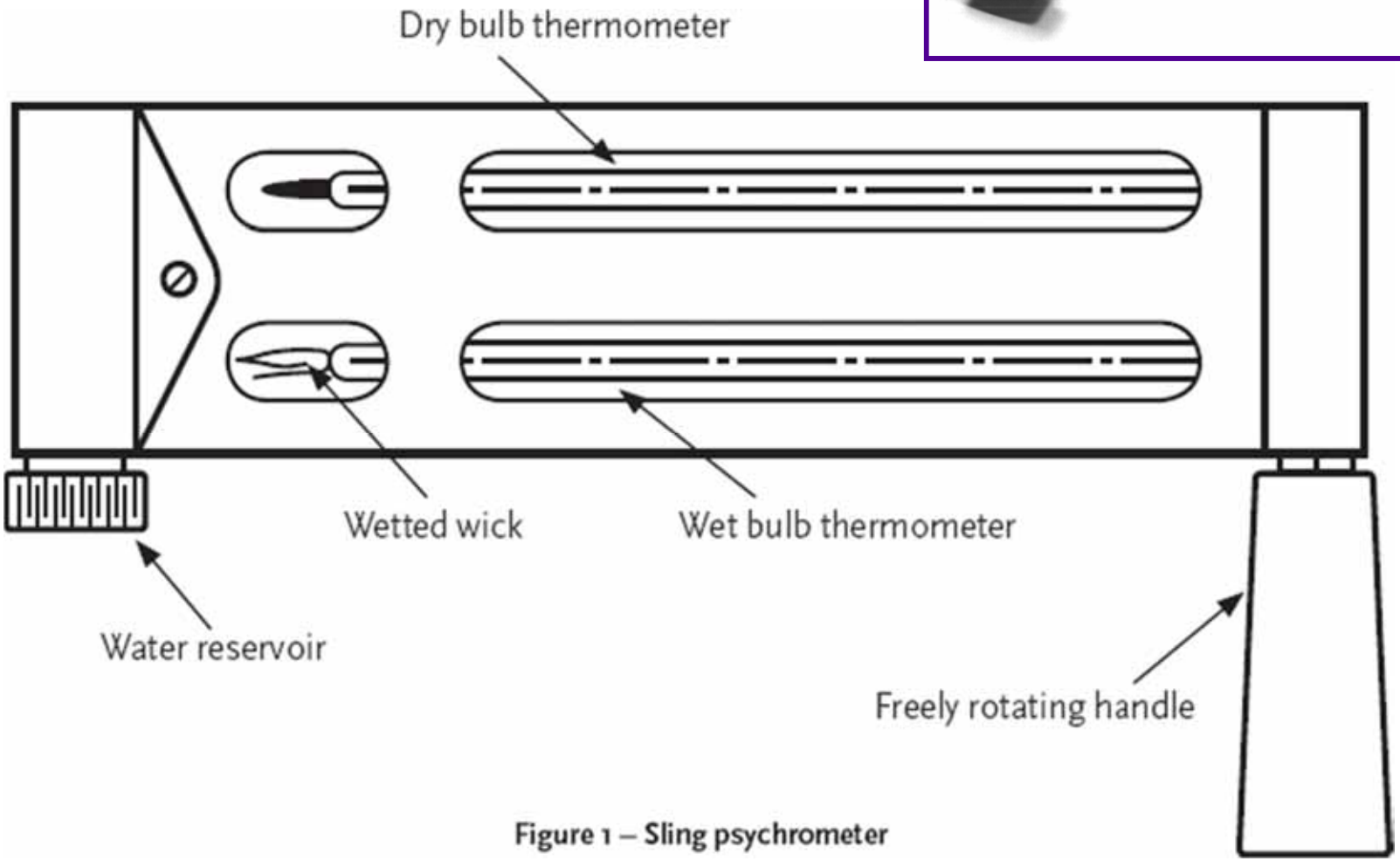


Figure 1 – Sling psychrometer

Introduction to Psychrometry

- The Psychrometric Equation
  - Dew-point temperature (t_{dp})
  - Specific enthalpy (h)
  - Specific volume (v)
  - Density (ρ)
- Do you know how to find out the moist air properties using the psychrometric chart?

Introduction to Psychrometry

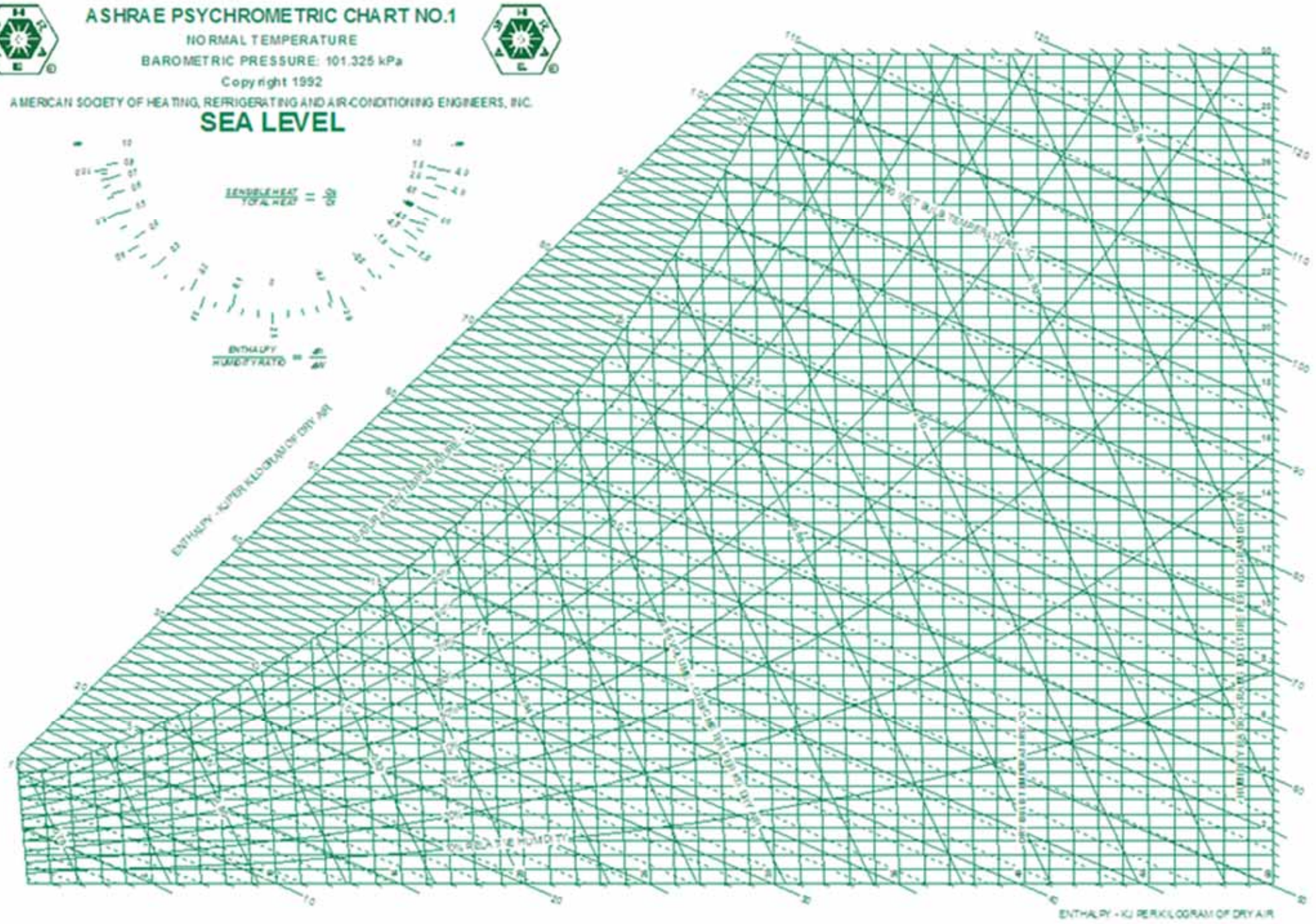
- Commonly used psychrometric charts
  - ASHRAE psychrometric chart
  - CIBSE psychrometric chart
- Why are they slightly different?
- Can you find out the differences?

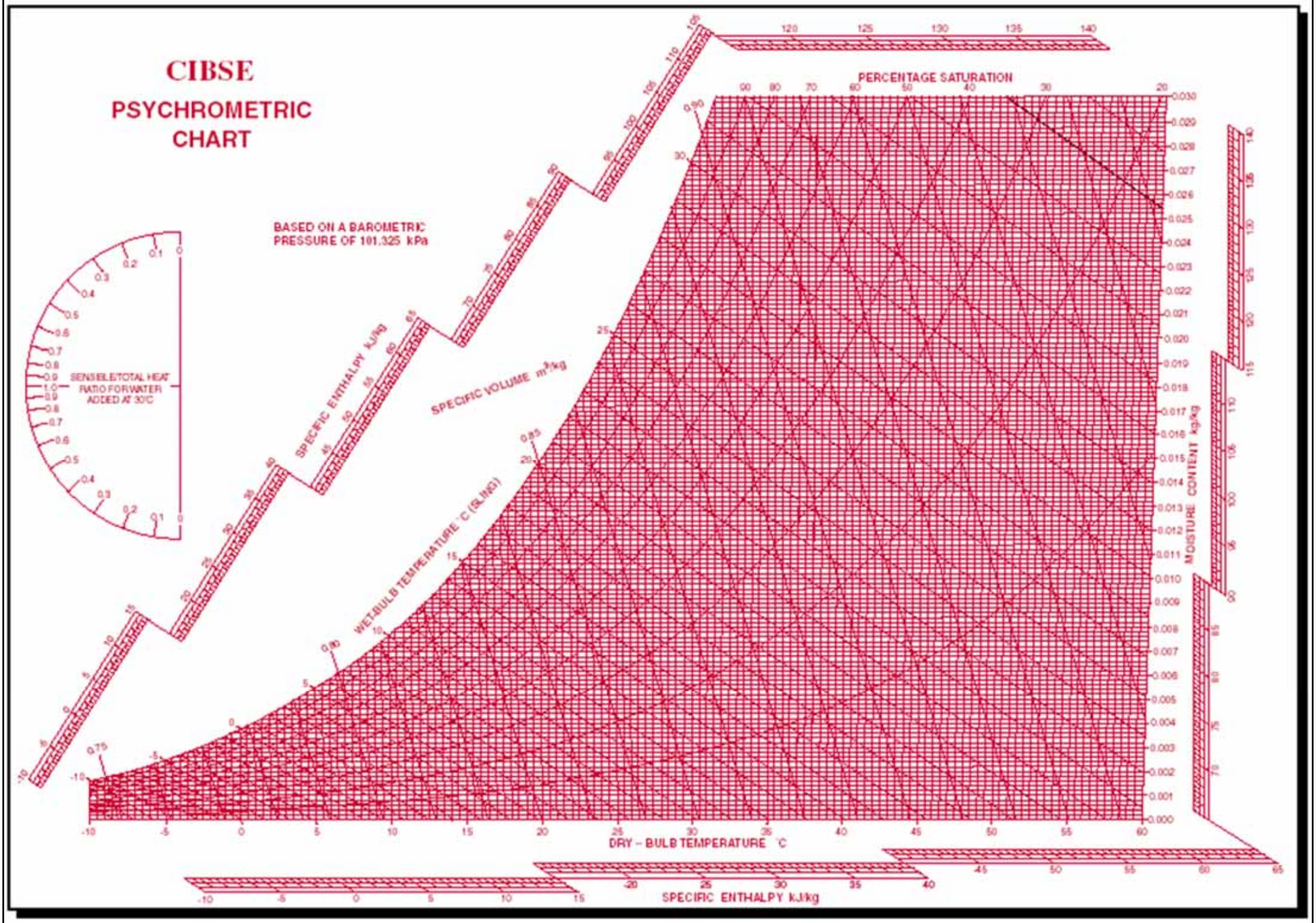
ASHRAE PSYCHROMETRIC CHART NO.1

NORMAL TEMPERATURE

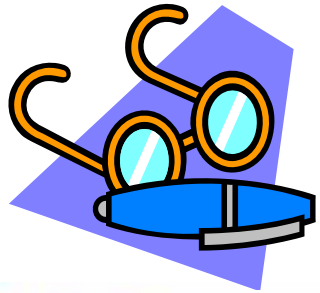
BAROMETRIC PRESSURE: 101.325 kPa

SEA LEVEL



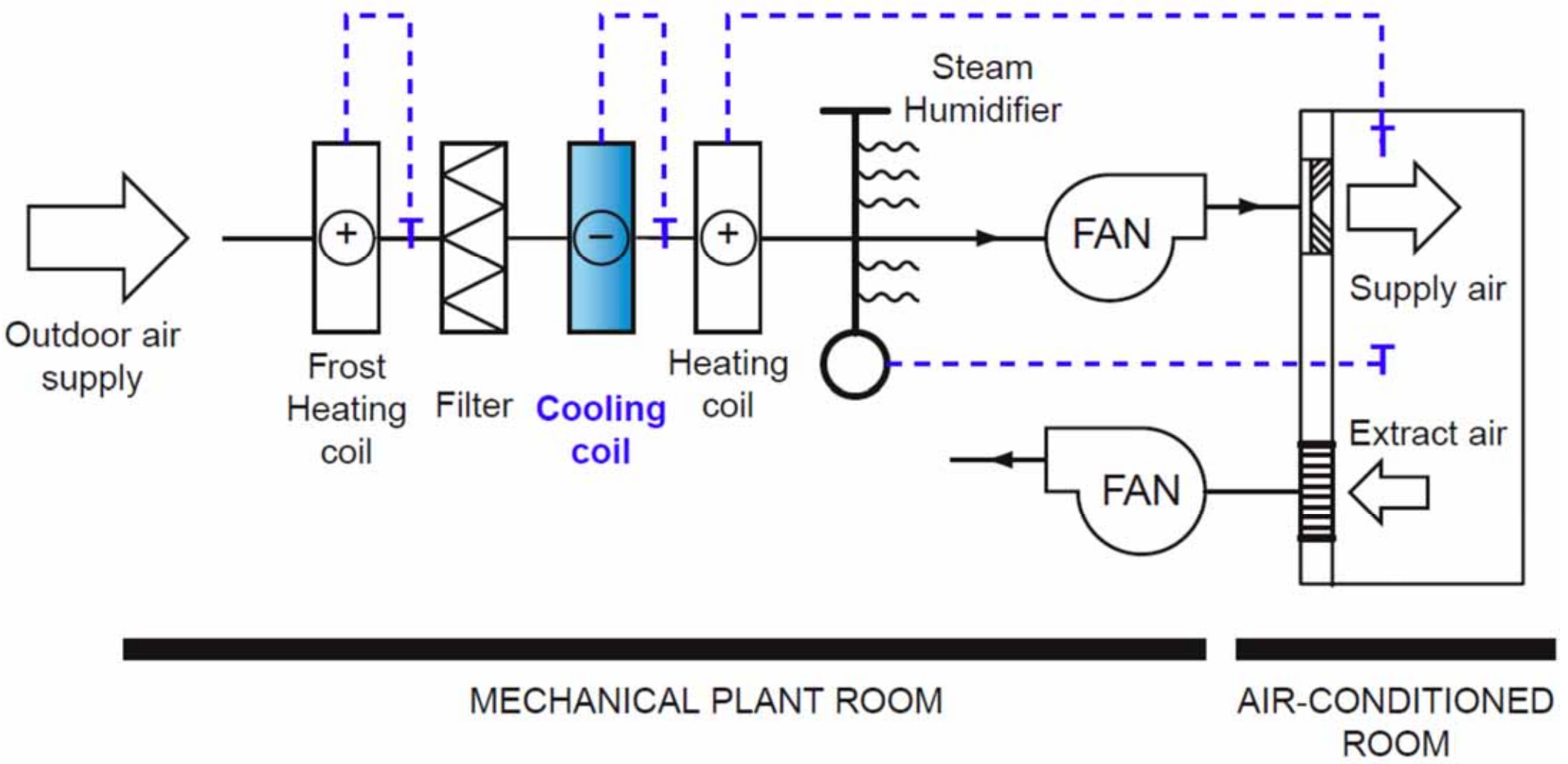

CIBSE
PSYCHROMETRIC
CHART
BASED ON A BAROMETRIC
PRESSURE OF 101.325 kPa
SENSIBLE/TOTAL HEAT
RATIO FOR WATER
ADDED AT 30°C
SPECIFIC ENTHALPY kJ/kg
SPECIFIC VOLUME m³/kg
WET-BULB TEMPERATURE °C (SLING)
PERCENTAGE SATURATION
MOISTURE CONTENT kg/kg
DRY – BULB TEMPERATURE °C
SPECIFIC ENTHALPY kJ/kg

Psychrometric Processes

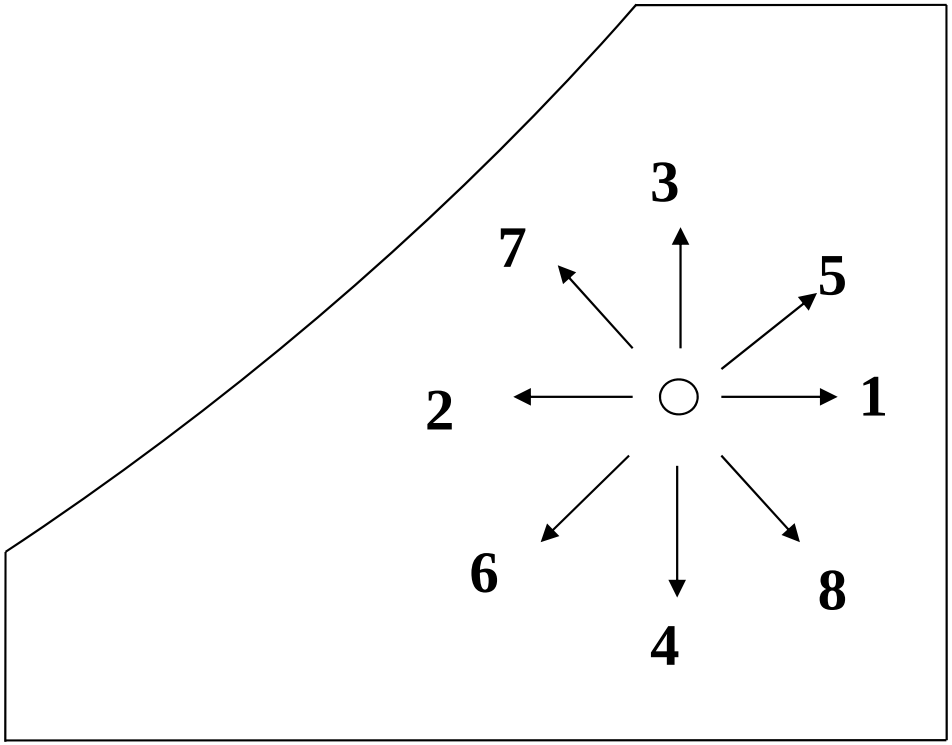


- Common processes:
  - Sensible cooling / sensible heating
  - Cooling and dehumidification / heating and humidification
  - Humidification / dehumidification
  - Evaporative cooling / chemical dehydration
- Typical devices:
  - Cooling/heating coils
  - Humidifiers / dehumifiers

Schematic representation of all fresh-air, constant volume air conditioning system

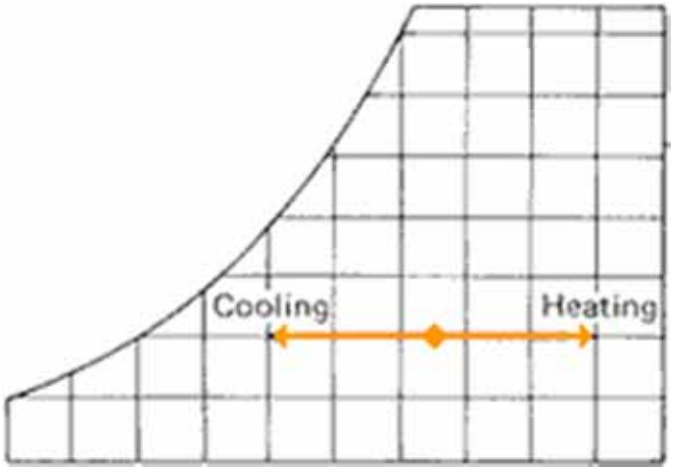


Basic psychrometric processes

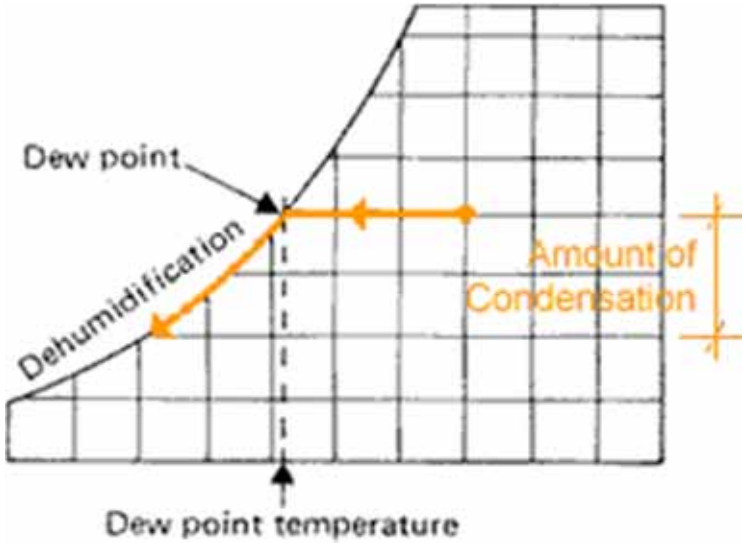


Process 0-1: Sensible heating
Process 0-2: Sensible cooling
Process 0-3: Humidifying
Process 0-4: Dehumidifying
Process 0-5: Heating and humidifying
Process 0-6: Cooling and dehumidifying
Process 0-7: Cooling and humidifying
Process 0-8: Heating and dehumidifying

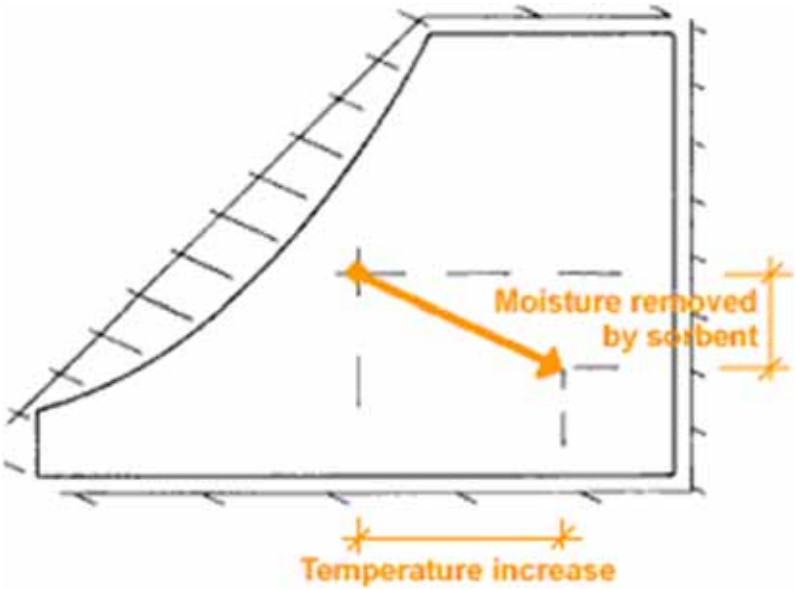
Psychrometric processes



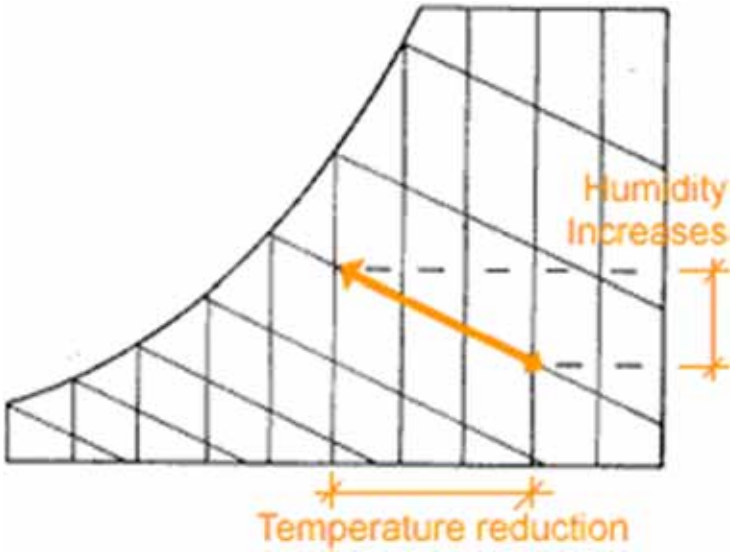
Sensible cooling/heating



Cooling and dehumidification

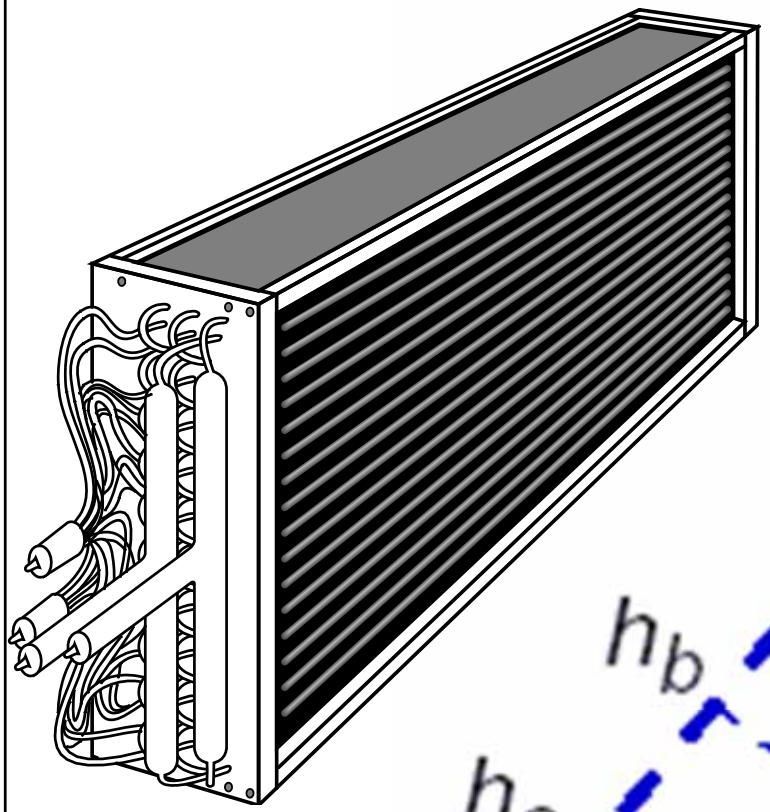


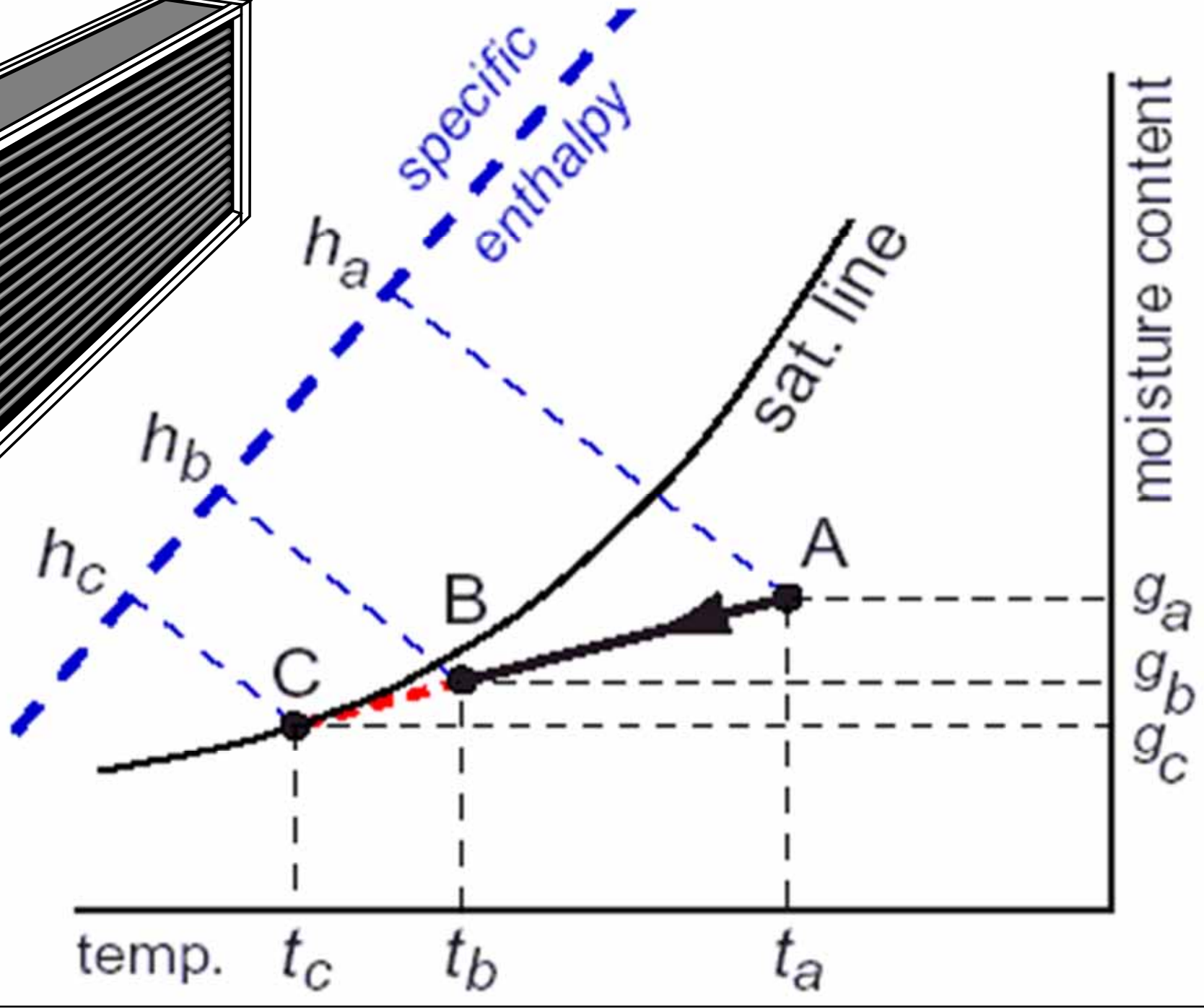
Adiabatic dehumidification



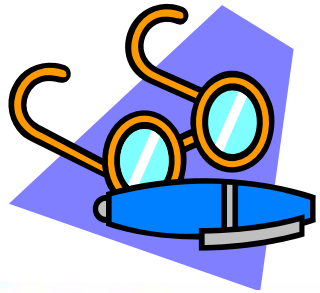
Evaporative cooling

Cooling and dehumidification





Psychrometric Processes

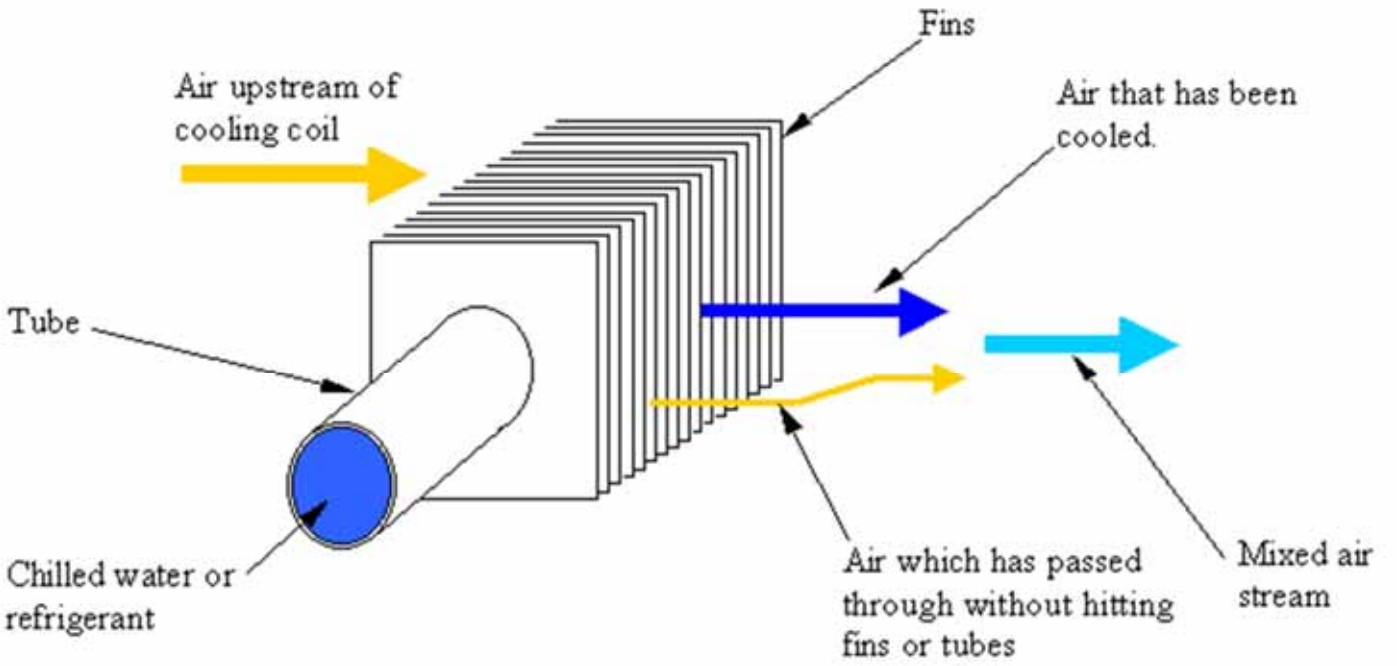


- Specific enthalpy difference: $q = m \text{ x } (h_a - h_b)$
- Sensible heat: $q_S = m_a \text{ x } c_p \text{ x } (t_b - t_a)$
- Latent heat: $q_L = m_a \text{ x } h_{fg}$
- Contact factor (cooling coil):

$$\beta = \frac{g_a - g_b}{g_a - g_c} = \frac{h_a - h_b}{h_a - h_c} = \frac{t_a - t_b}{t_a - t_c}$$

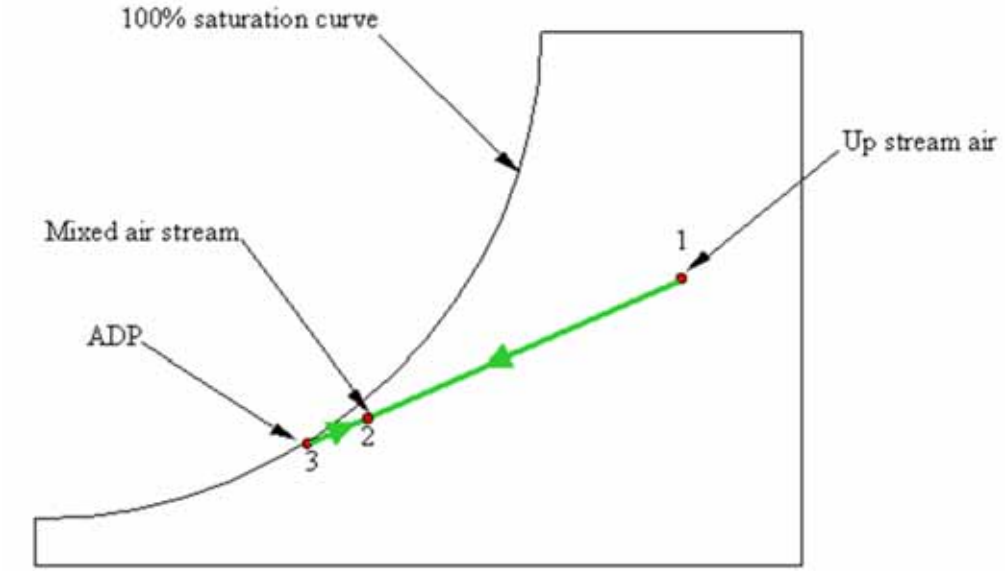
- Bypass factor = 1 – Contact factor

Cooling coil contact factor



A SECTION OF COOLING COIL SHOWING AIR STREAMS

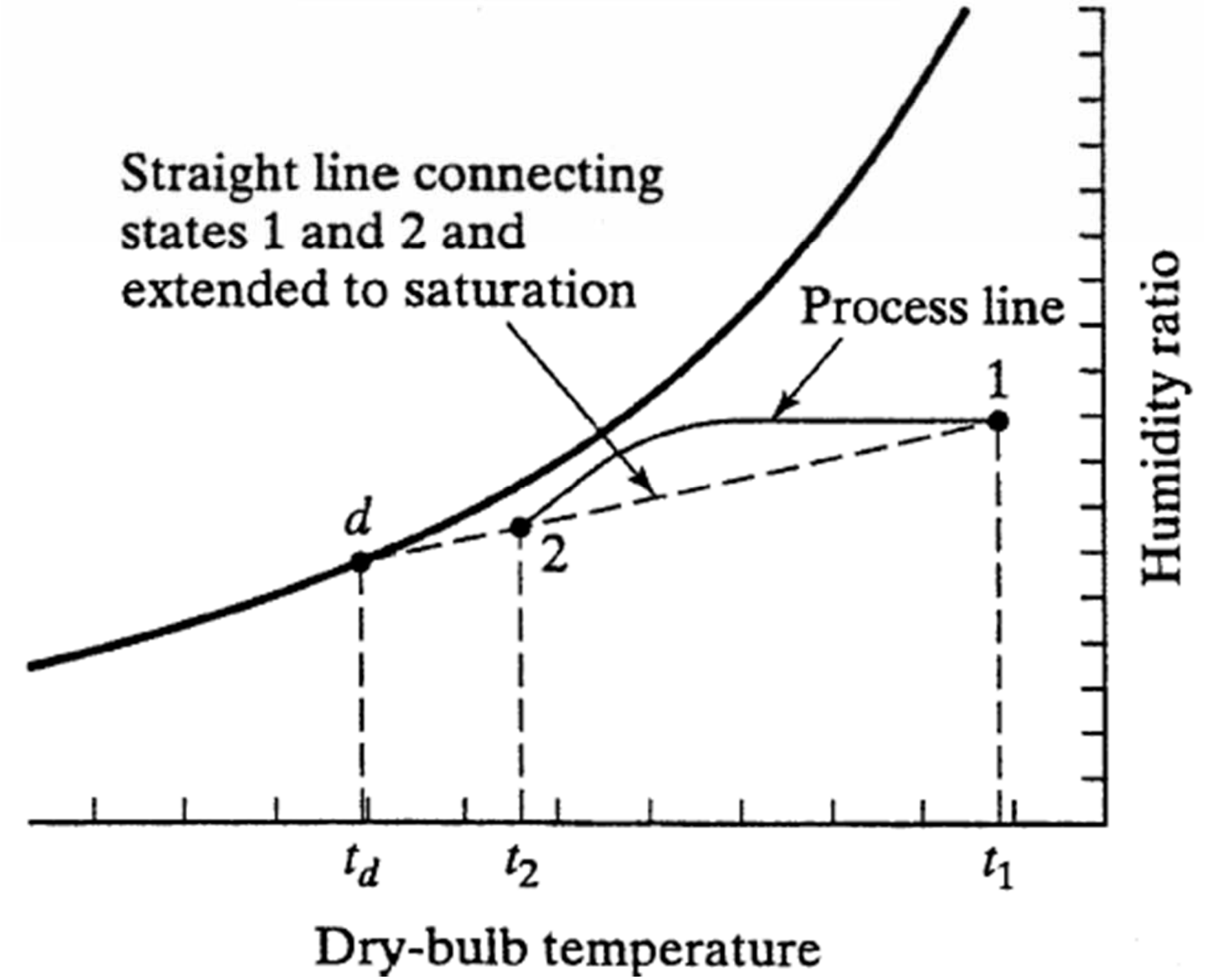
ADP = apparatus dew point



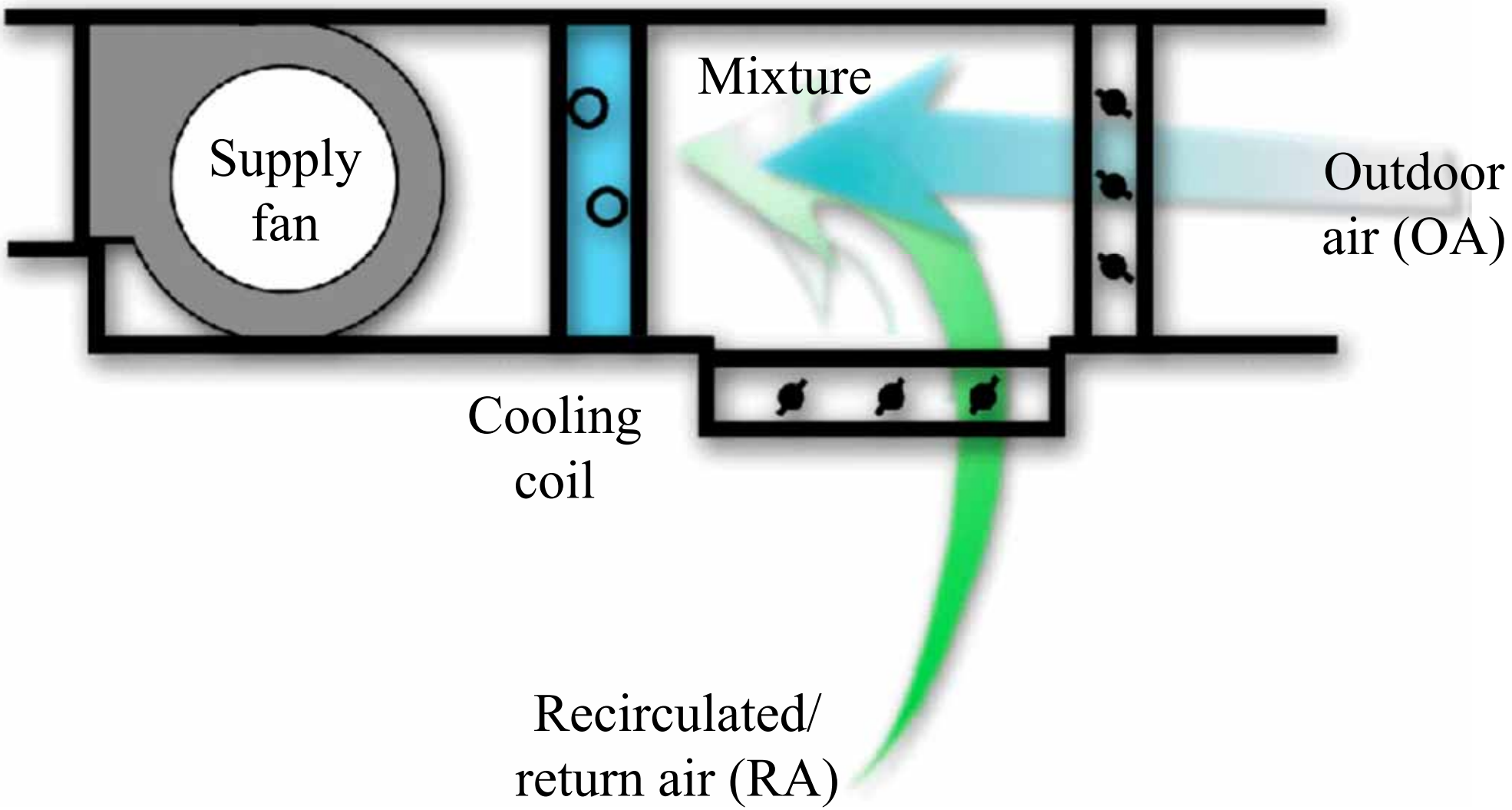
PSYCHROMETRIC CHART SHOWING COOLING COIL CONTACT FACTOR

(Source: http://www.arca53.dsl.pipex.com/index_files/psy9.htm)

Cooling and dehumidification

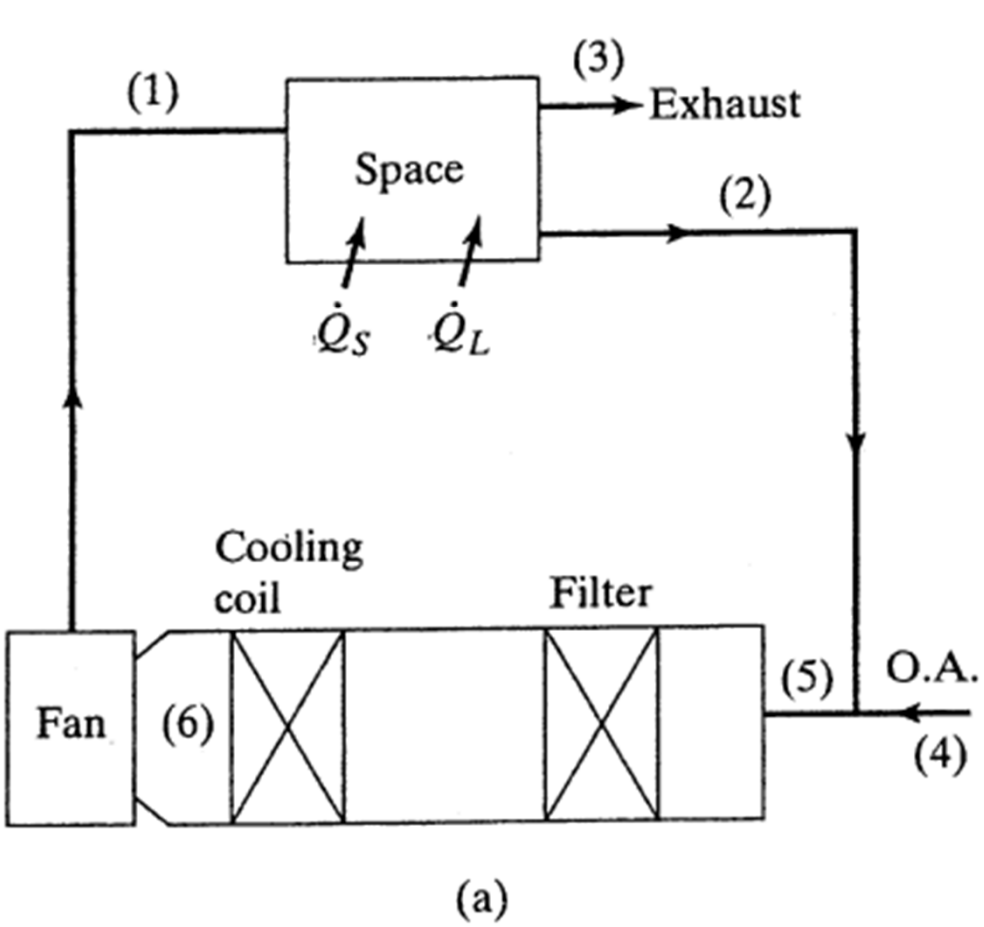


Determining entering air conditions

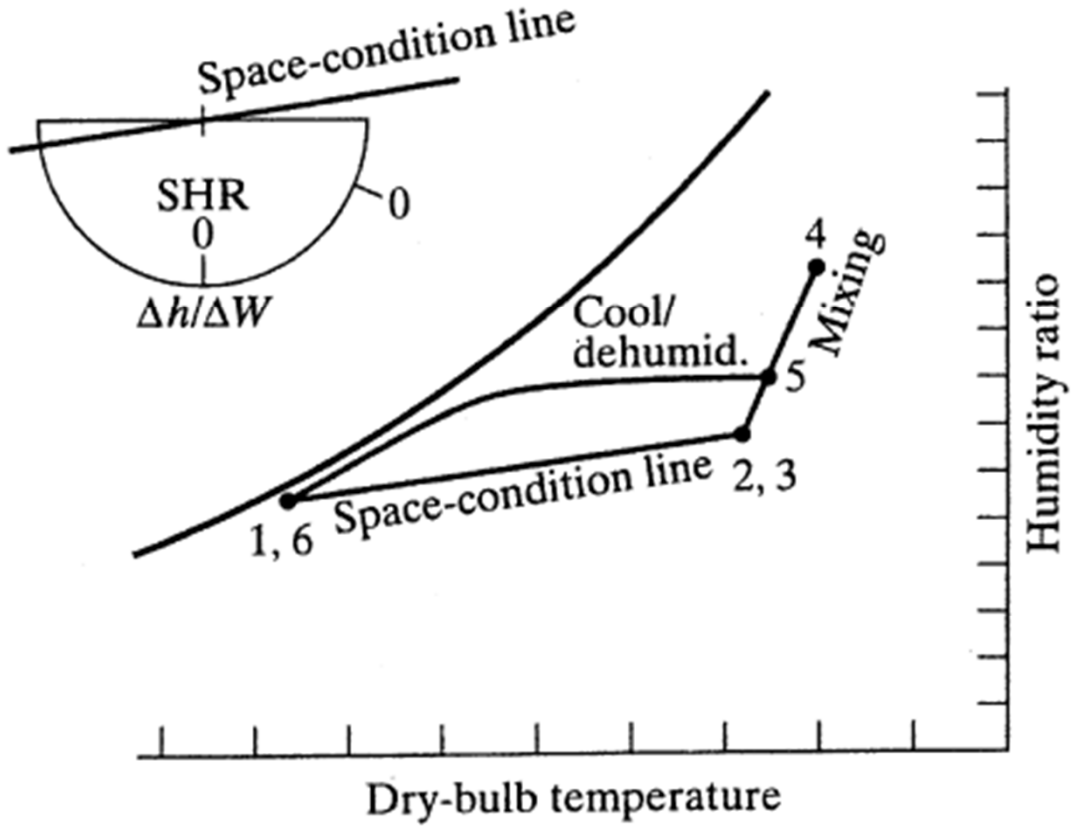


(Source: Trane)

Simple air conditioning cycle



(a)

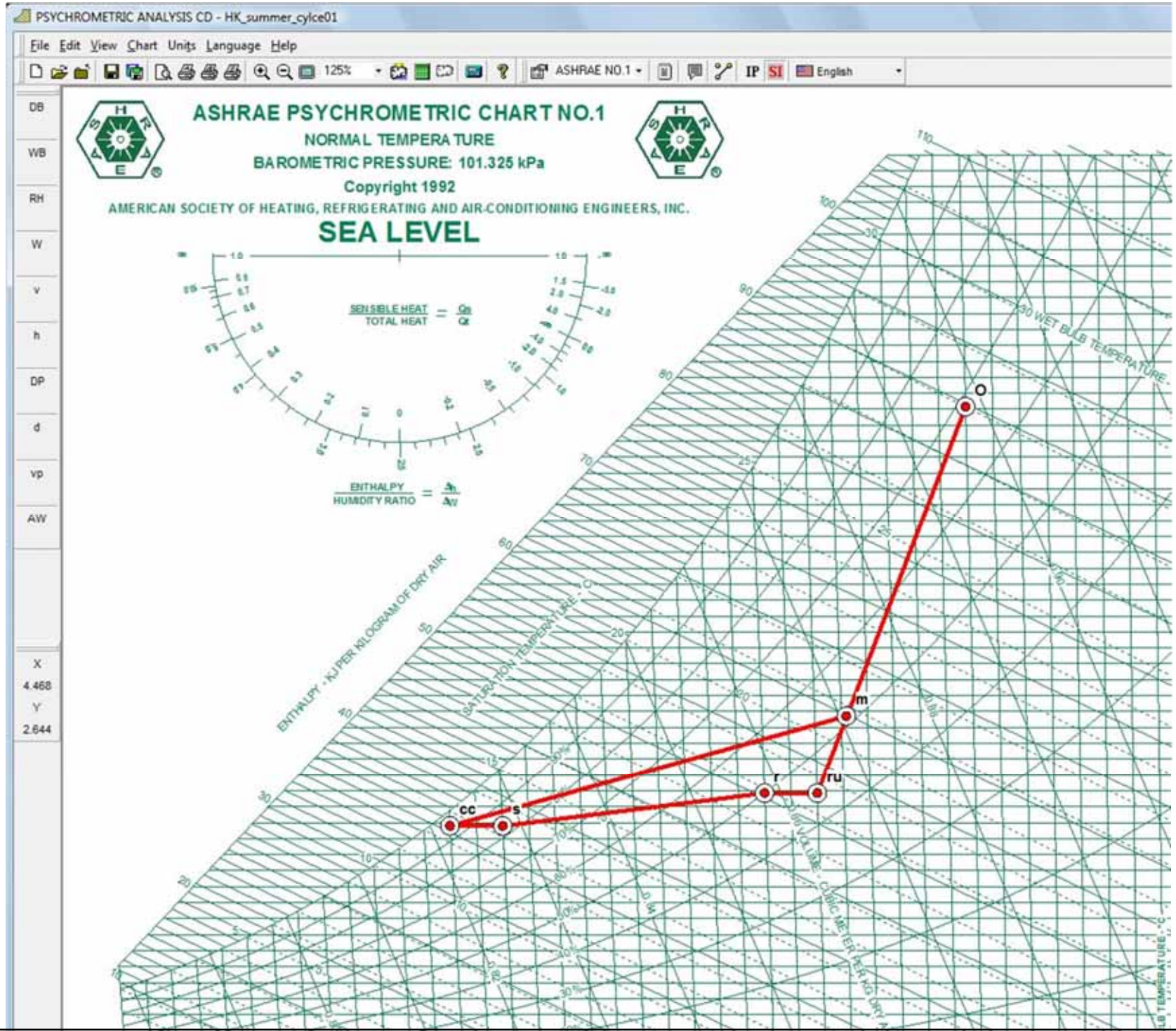


(b)

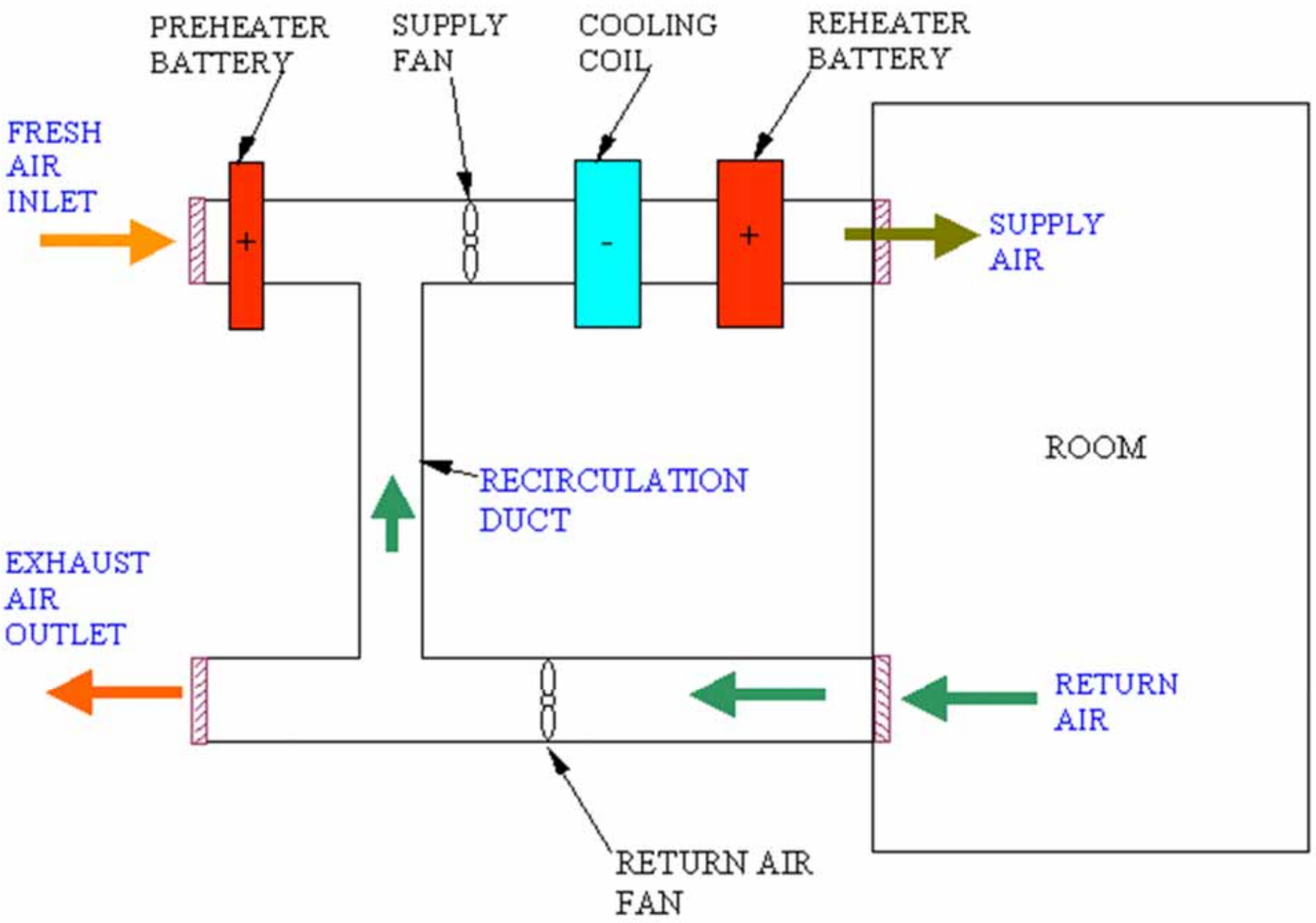
Can you draw such a cycle for Hong Kong summer conditions?

- Outdoor: DBT = 33 ºC; WBT = 28 ºC; flow = 20% of supply air
- Indoor: DBT = 25 ºC; %RH = 50%
- Air leaving cooling coil: DBT = 13 ºC; %RH = 95%

An example of Hong Kong summer air-conditioning cycle

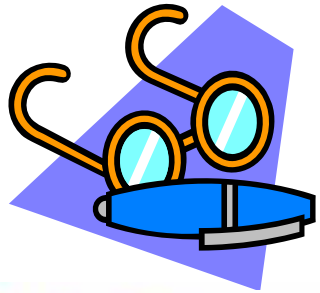


Components of the air-side system



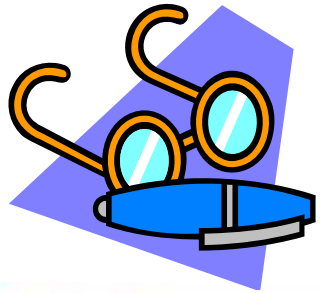
(Source: http://www.arca53.dsl.pipex.com/index_files/psy1.htm)

Psychrometric Processes



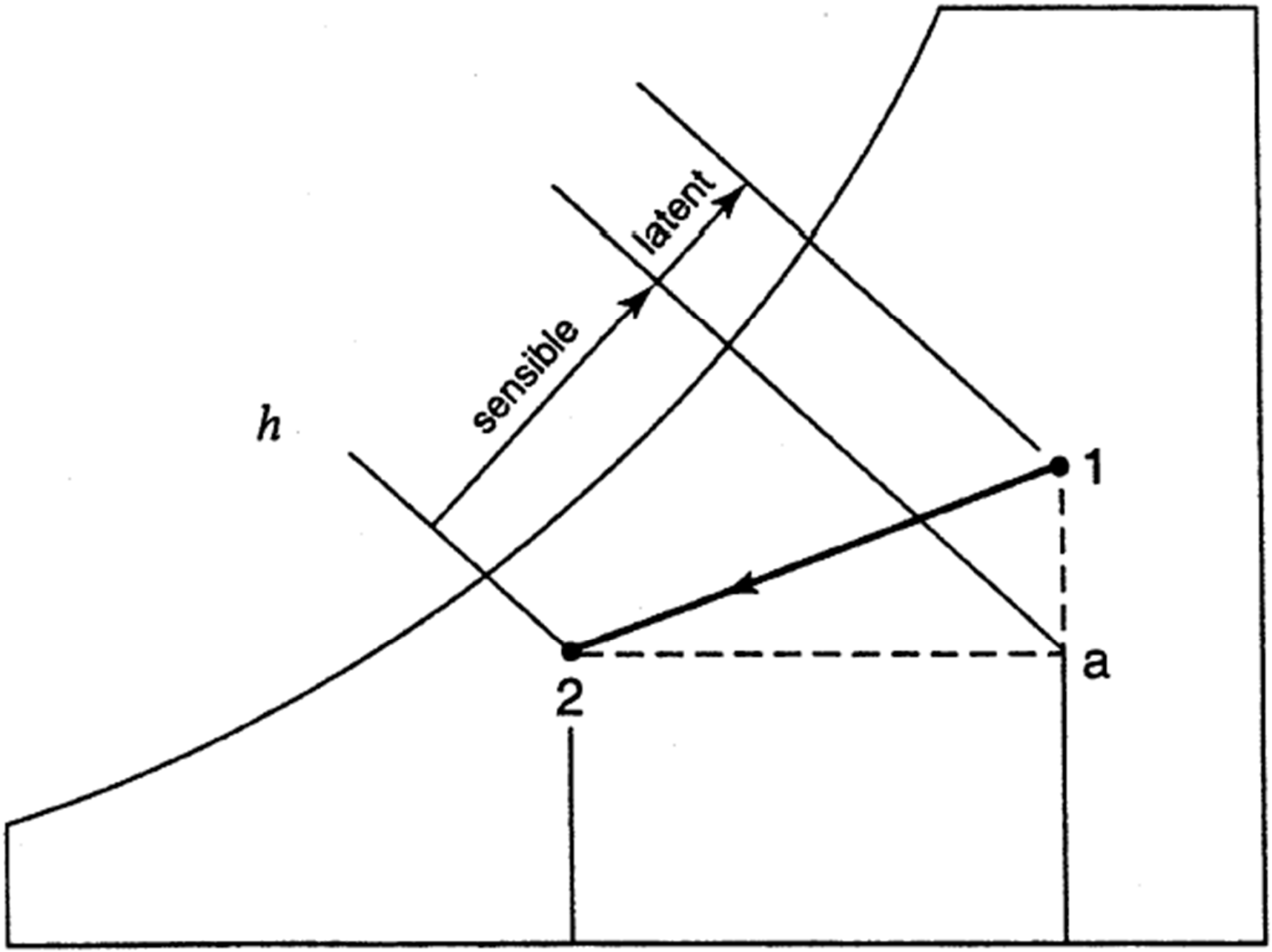
- Sensible heating coils
- Cooling coils
- Humidifiers
- Water spray types
- Steam humidifier
- Room psychrometric process
- Mixing air streams

Psychrometric Processes

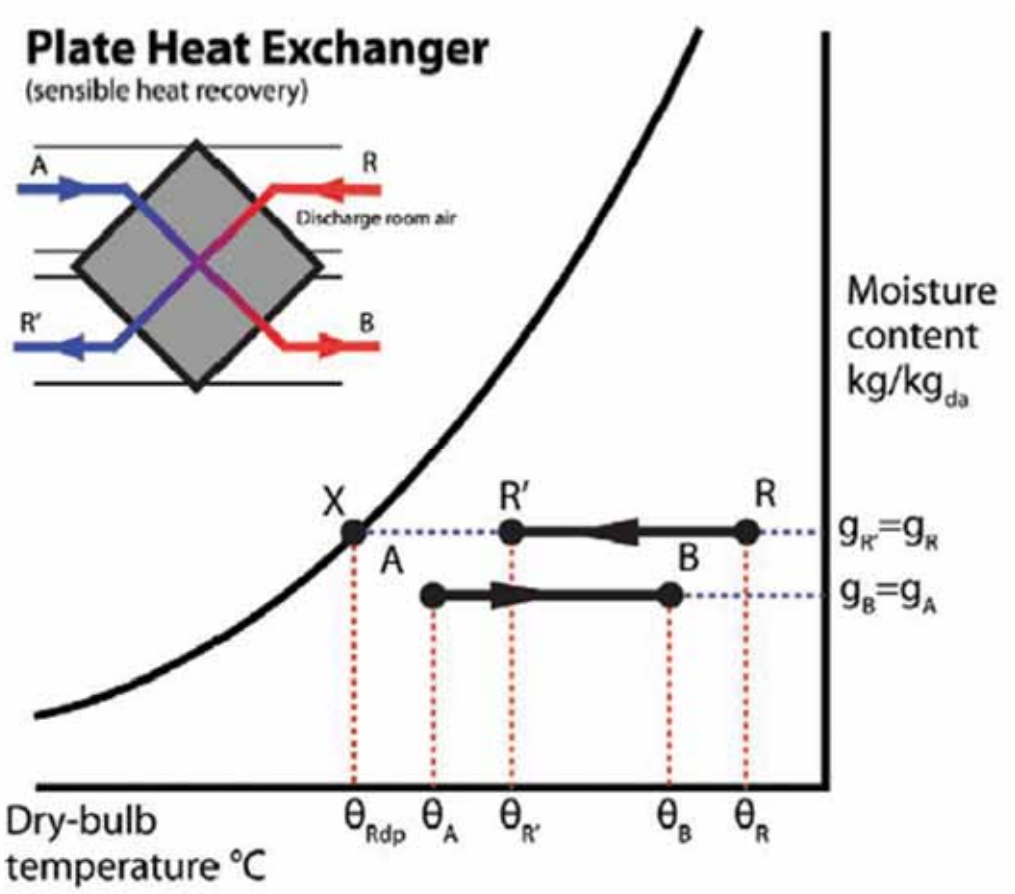


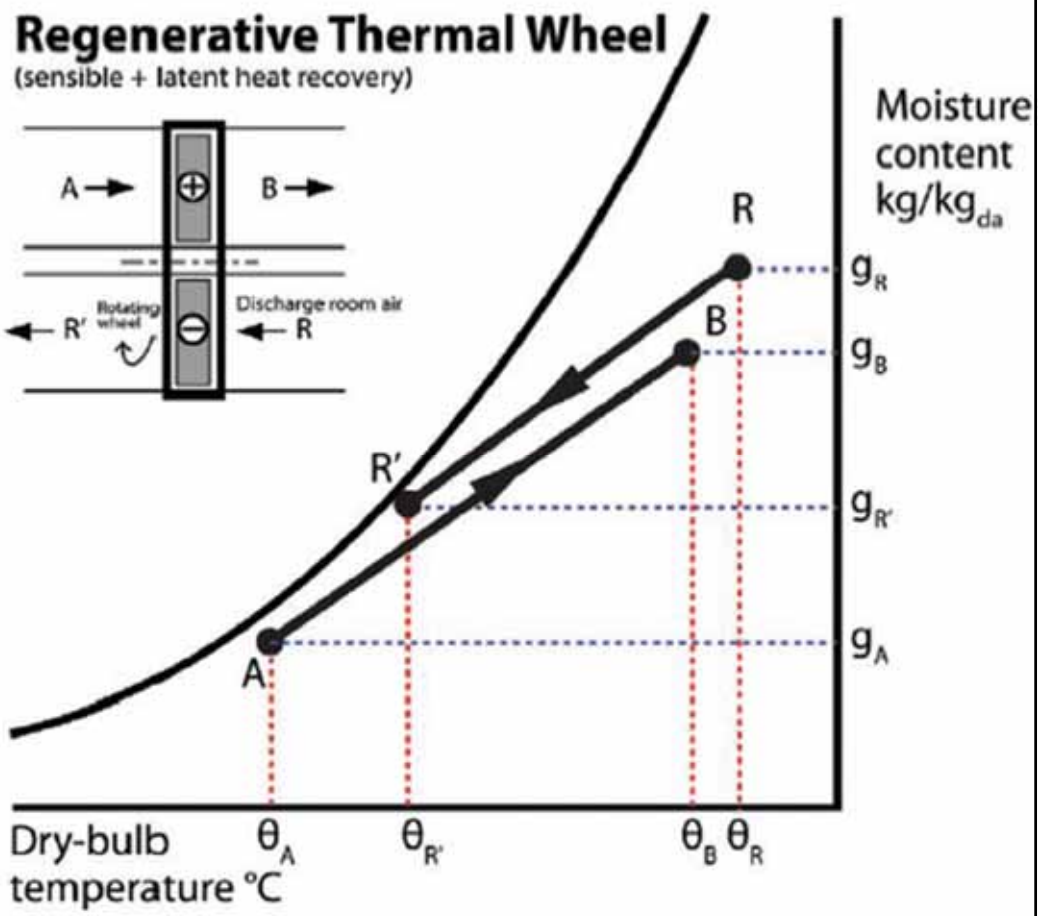
- Calculations:
  - 1. Sensible heat ratio (SHR)
  - 2. Space cooling load
  - 3. Cooling coil's load/capacity
  - 4. Humidification capacity
  - 5. Mixing processes
    - Principles of heat balance & conservation of mass

Sensible and latent cooling loads



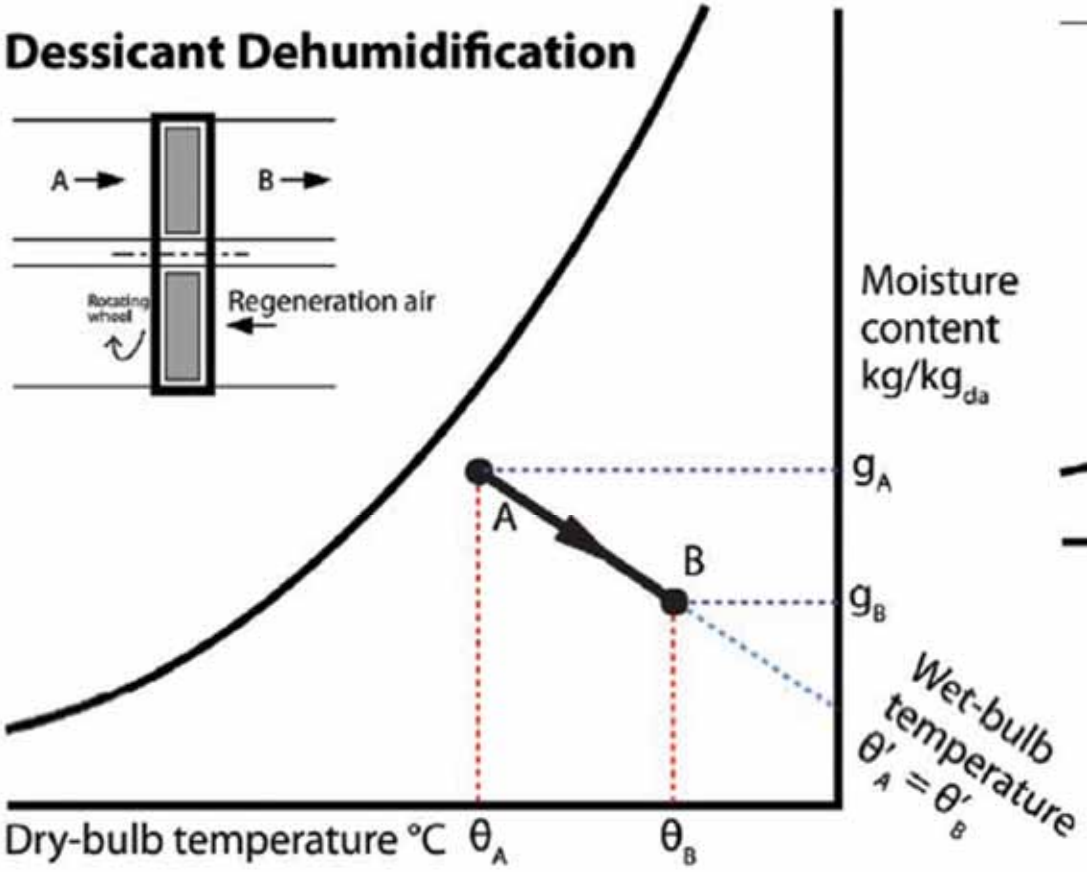
The psychrometrics of HVAC sub-systems

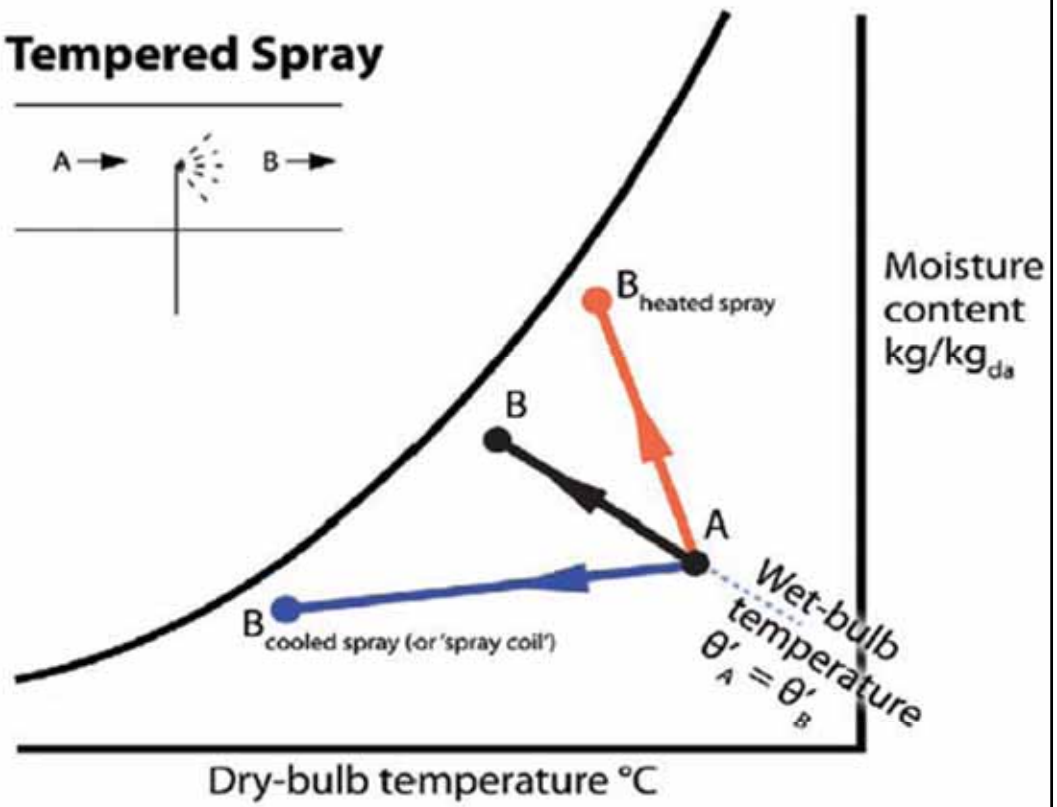




(Source: CIBSE Journal CPD Programme: The psychrometrics of HVAC sub-systems (Dec 2009))

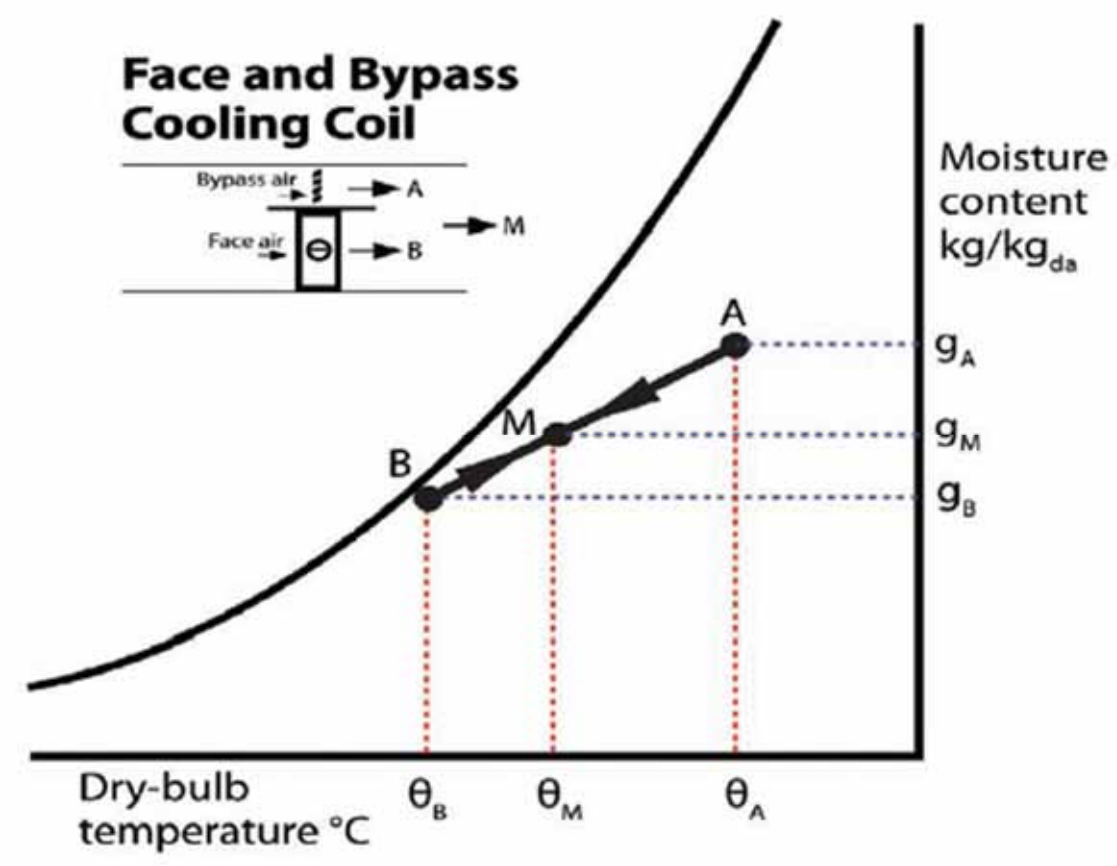
The psychrometrics of HVAC sub-systems (cont'd)





(Source: CIBSE Journal CPD Programme: The psychrometrics of HVAC sub-systems (Dec 2009))

The psychrometrics of HVAC sub-systems (cont'd)



(Source: CIBSE Journal CPD Programme: The psychrometrics of HVAC sub-systems (Dec 2009))

Practical Use of Psych. Chart

- Examples of psychrometric charts
  - ASHRAE
  - CIBSE
  - Carrier
  - Mr. S K Wang (similar to Trane)
  - The chart used in Mainland China (upside down)

- Do you know how to construct these charts?

Carrier

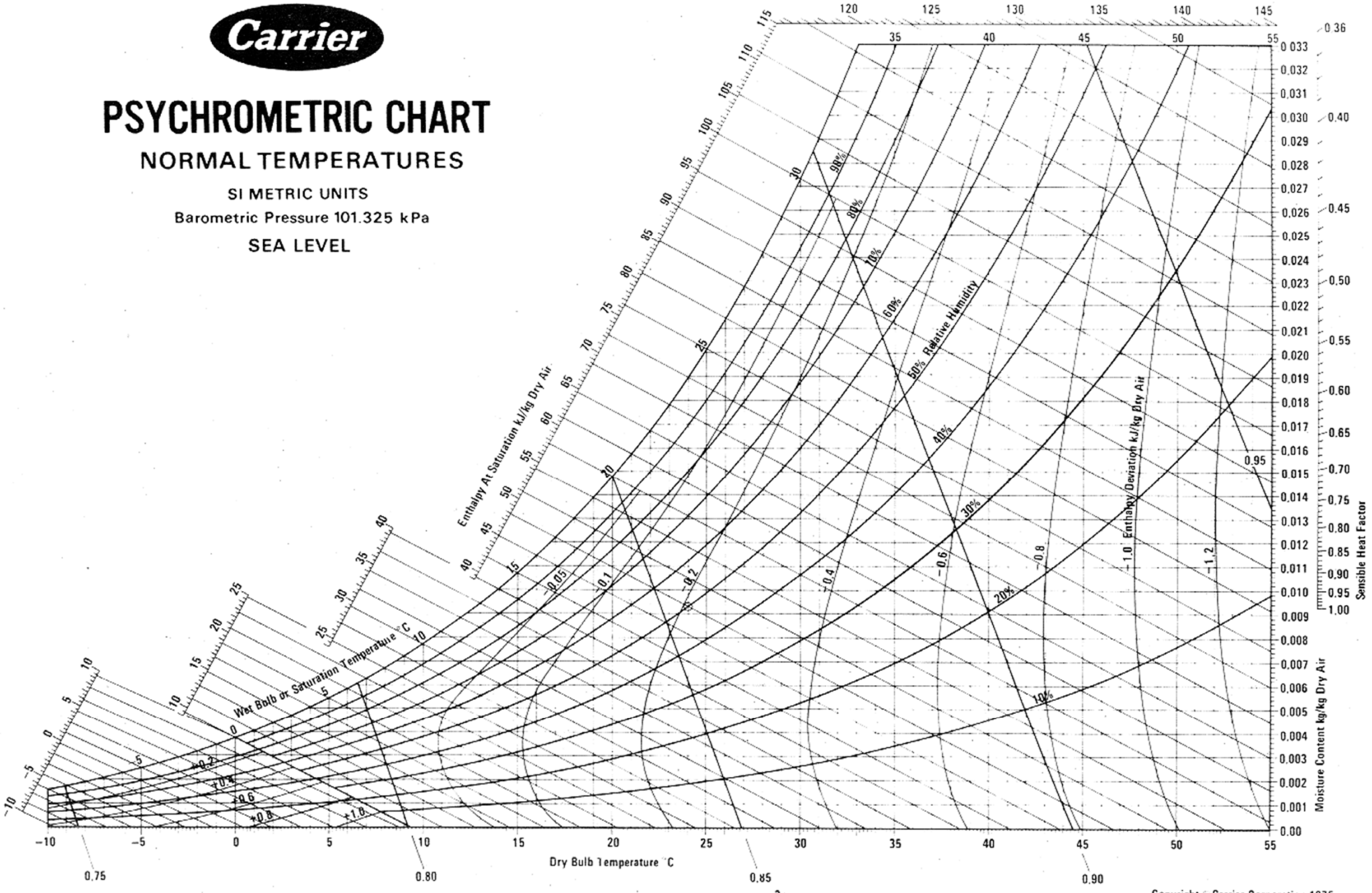
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL



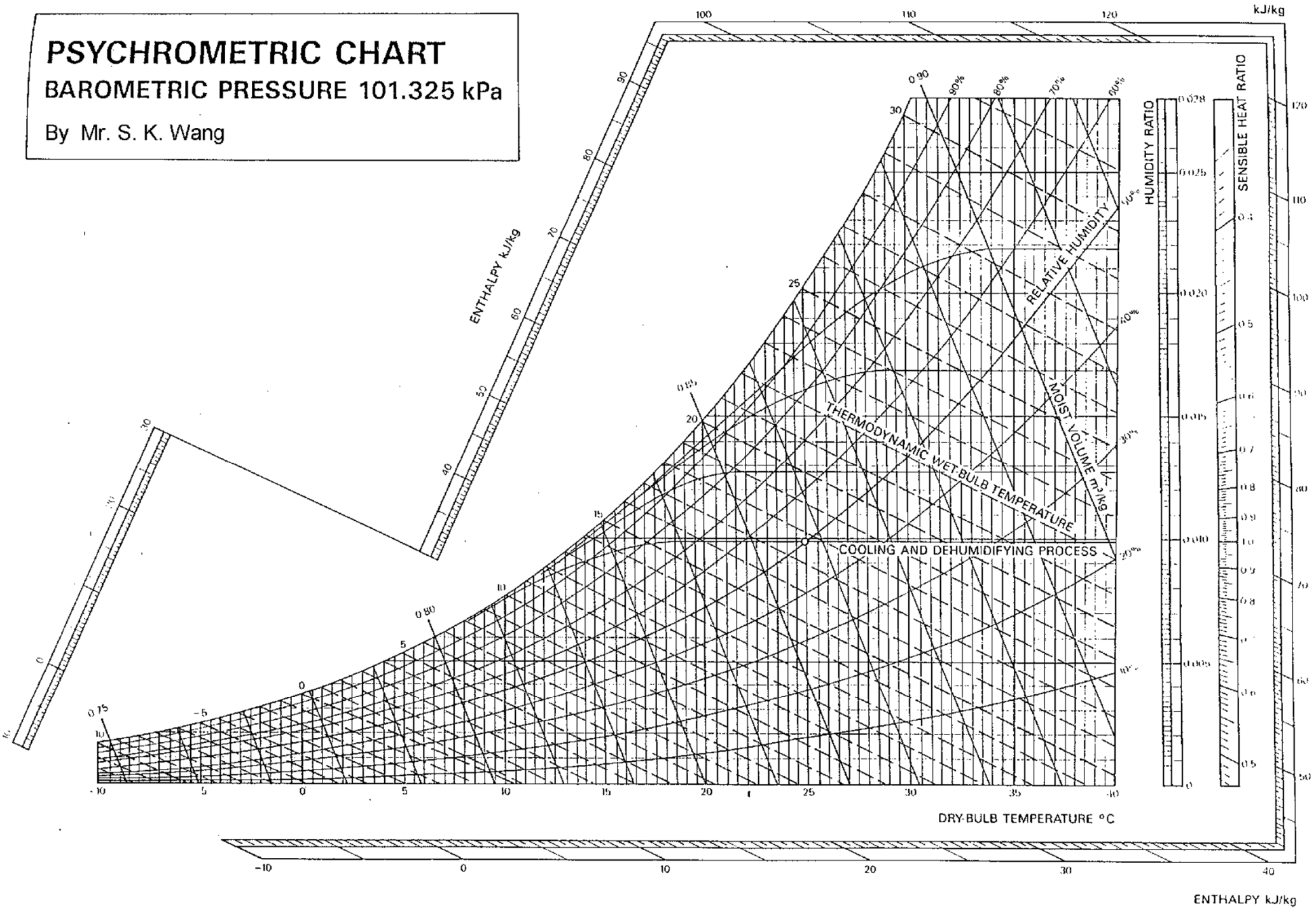
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice

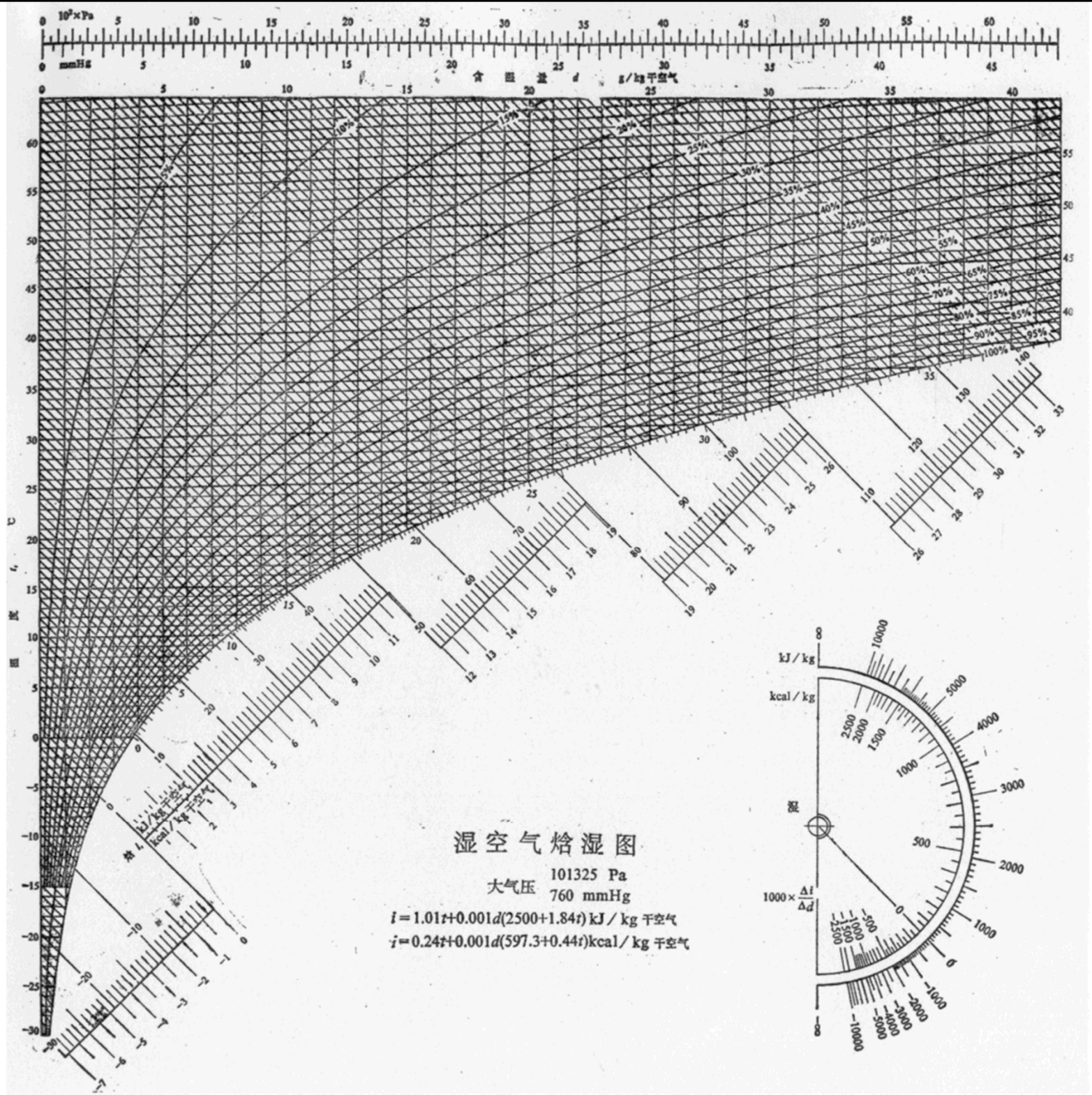
Reproduced courtesy of Carrier Corporation

PSYCHROMETRIC CHART

BAROMETRIC PRESSURE 101.325 kPa

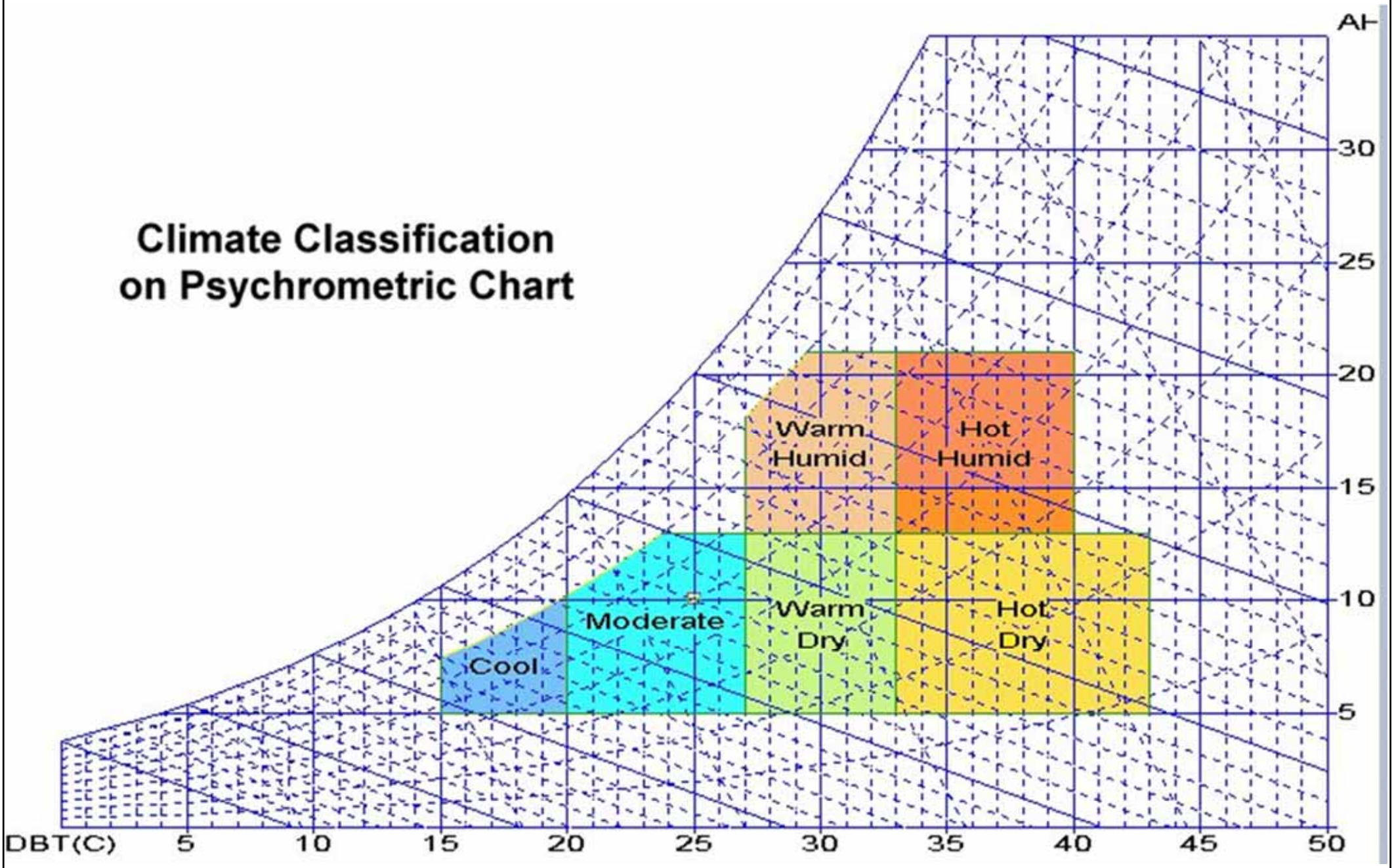
By Mr. S. K. Wang




湿空气焓湿图
大气压 101325 Pa
760 mmHg
$i = 1.01t + 0.001d(2500 + 1.84t)$ kJ / kg 干空气
$i = 0.24t + 0.001d(597.3 + 0.44t)$ kcal / kg 干空气
含湿量 d g/kg干空气
焓 i kJ/kg干空气 kcal/kg干空气
干球温度 t
kJ / kg
kcal / kg
$1000 \times \frac{\Delta i}{\Delta d}$

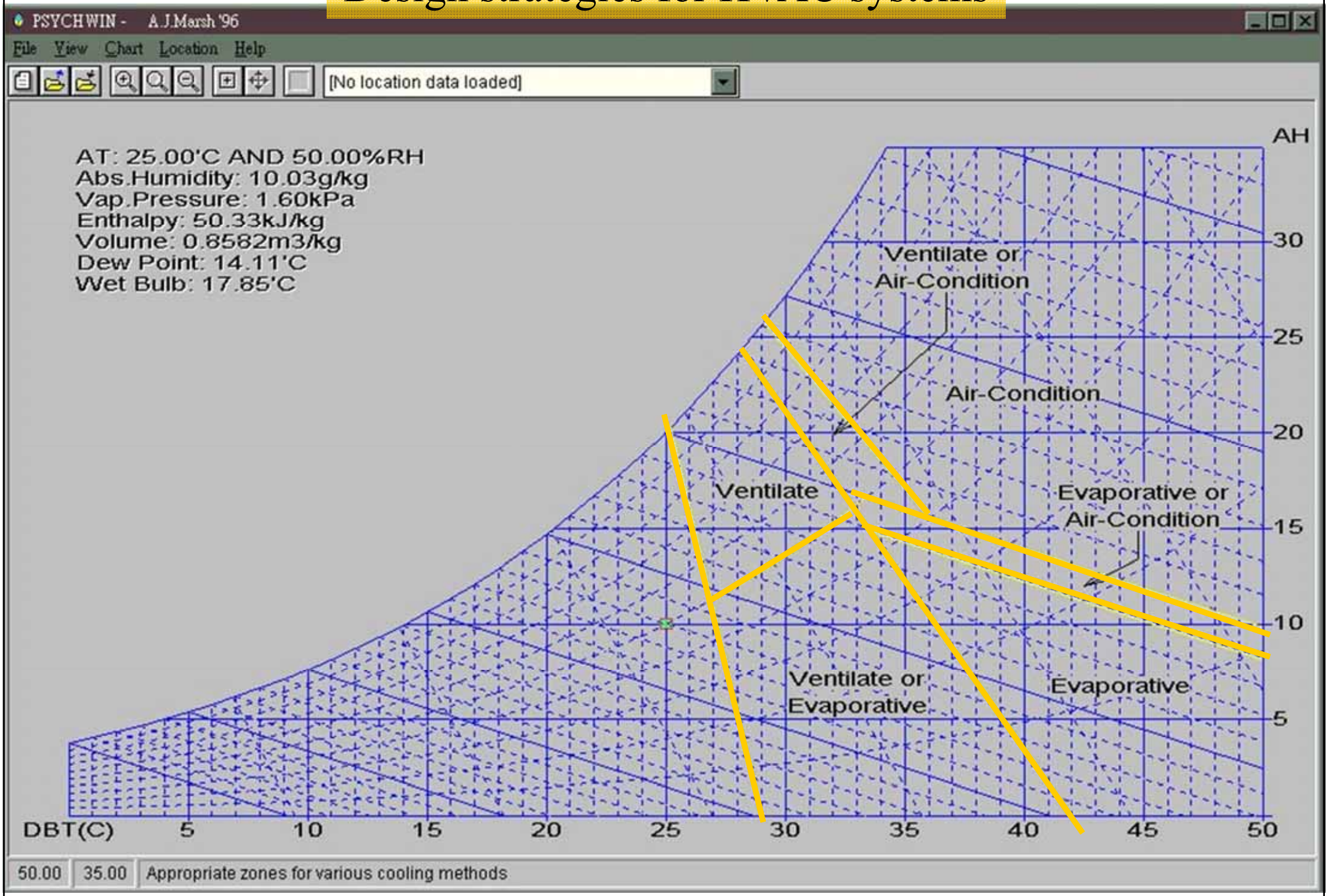
Psychrometric Software

- ASHRAE Psychrometric Analysis CD-ROM (2012, 2007, 2002) [AV 697 P97]
- ArchiSci Software - PSYCHWIN (an evaluation version can be downloaded)
- Psychrometric Chart (PSY) software (Free for download)
- Daikin's Free Psychrometrics tool



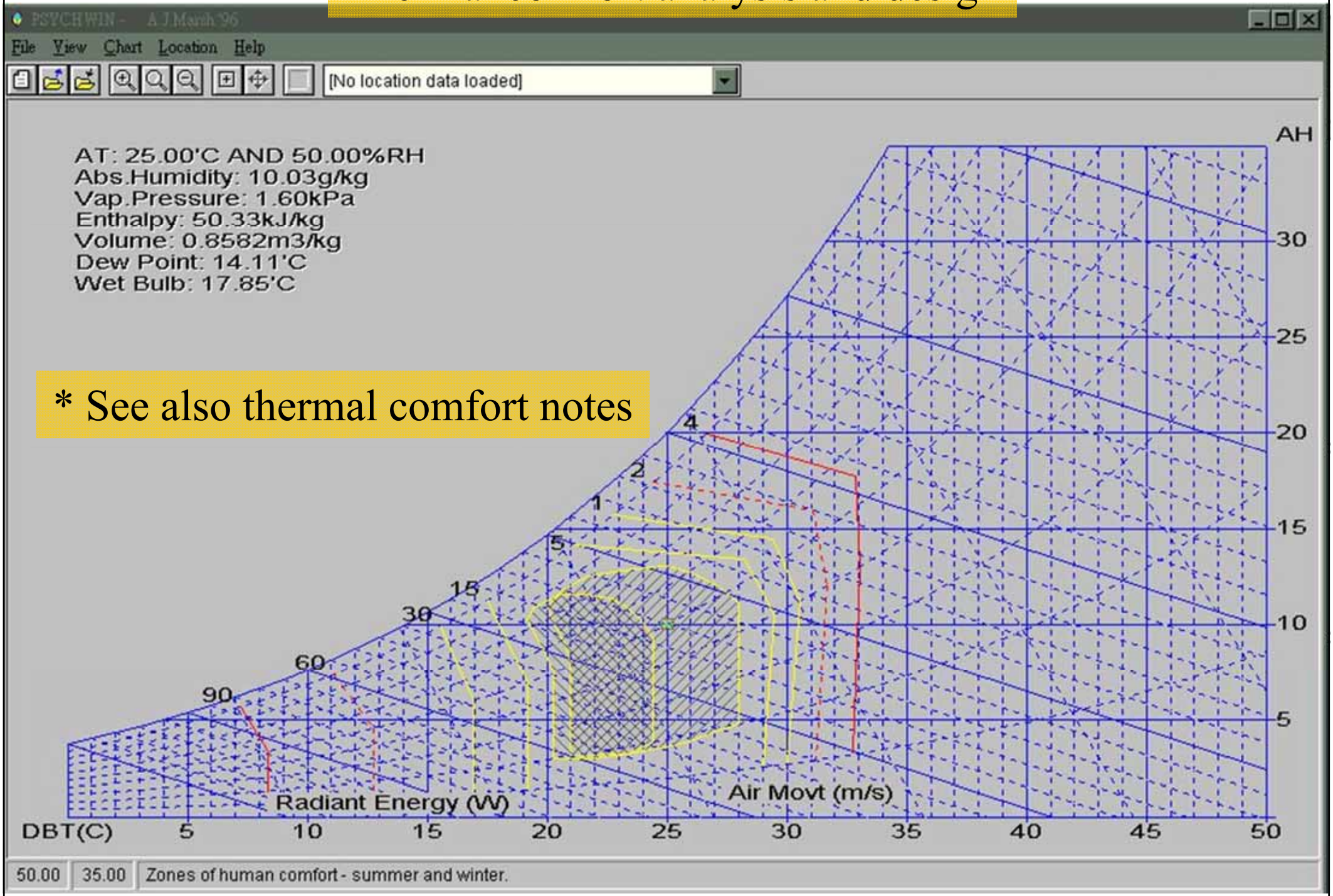
(Source: ArchiSci Software - PSYCHWIN)

Design strategies for HVAC systems



(Source: ArchiSci Software - PSYCHWIN)

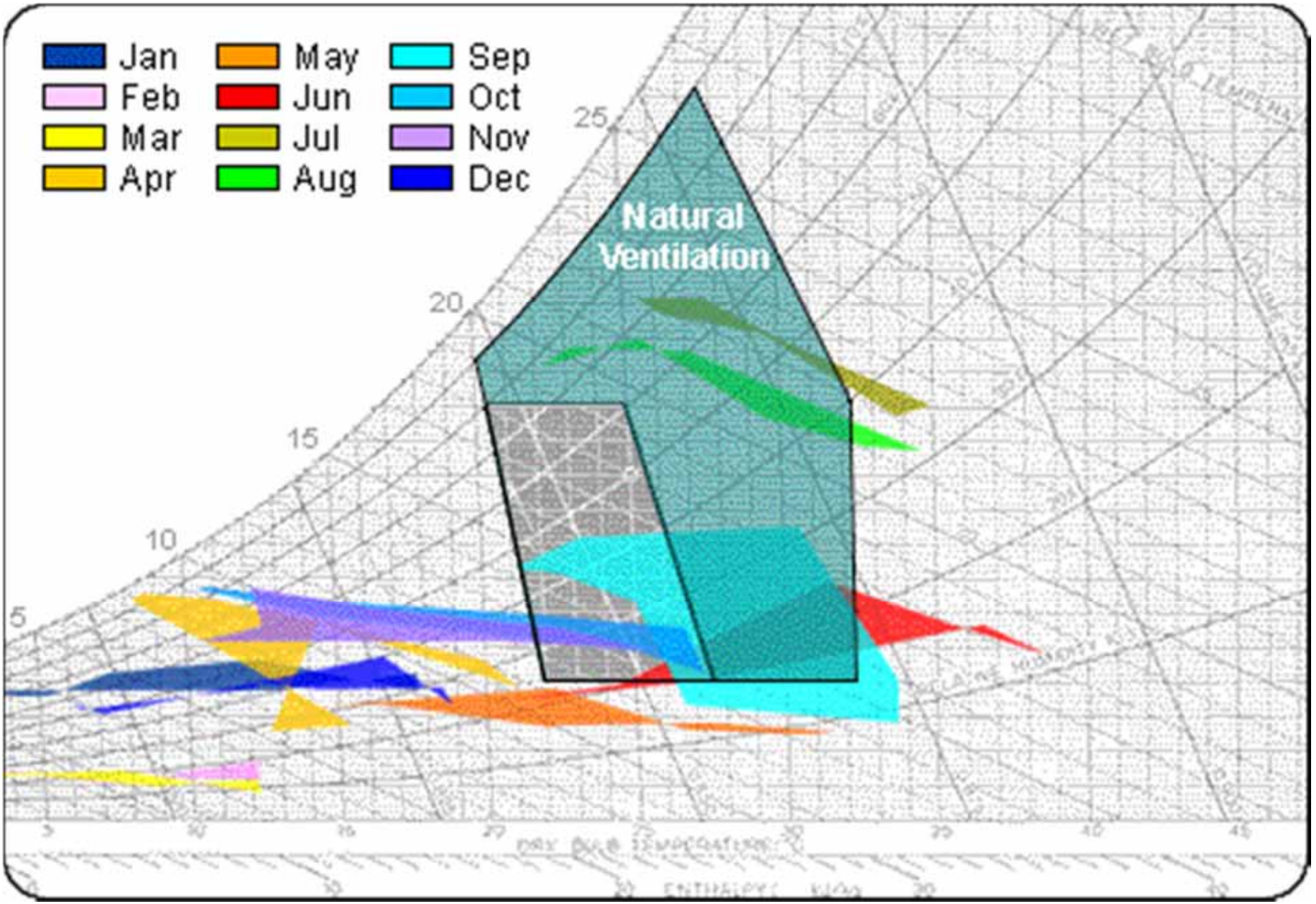
Thermal comfort analysis and design



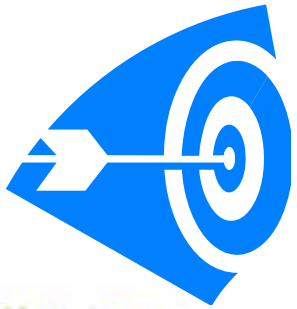
* See also thermal comfort notes

(Source: ArchiSci Software - PSYCHWIN)

Analysis of external climate

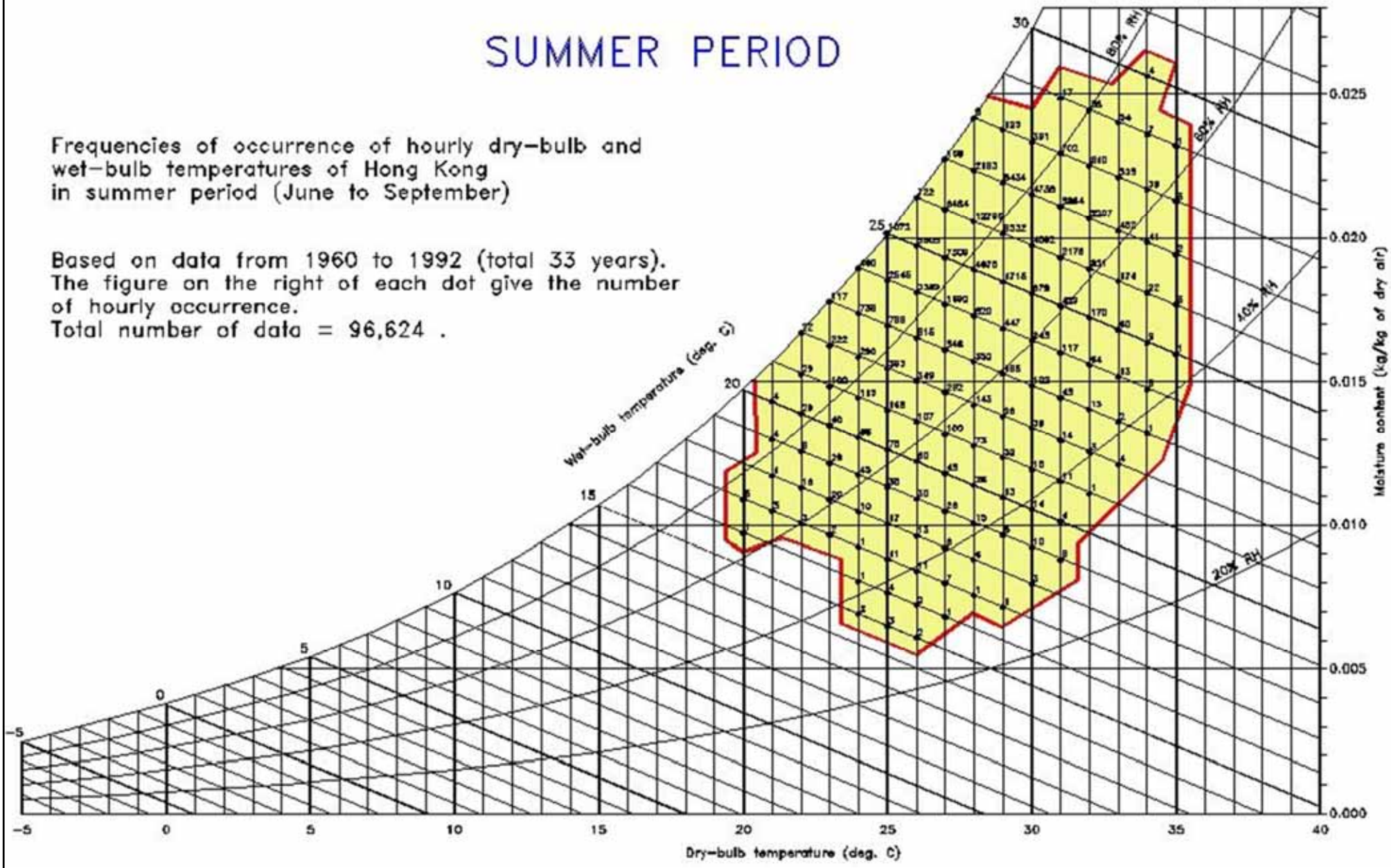


Psychrometric Analysis

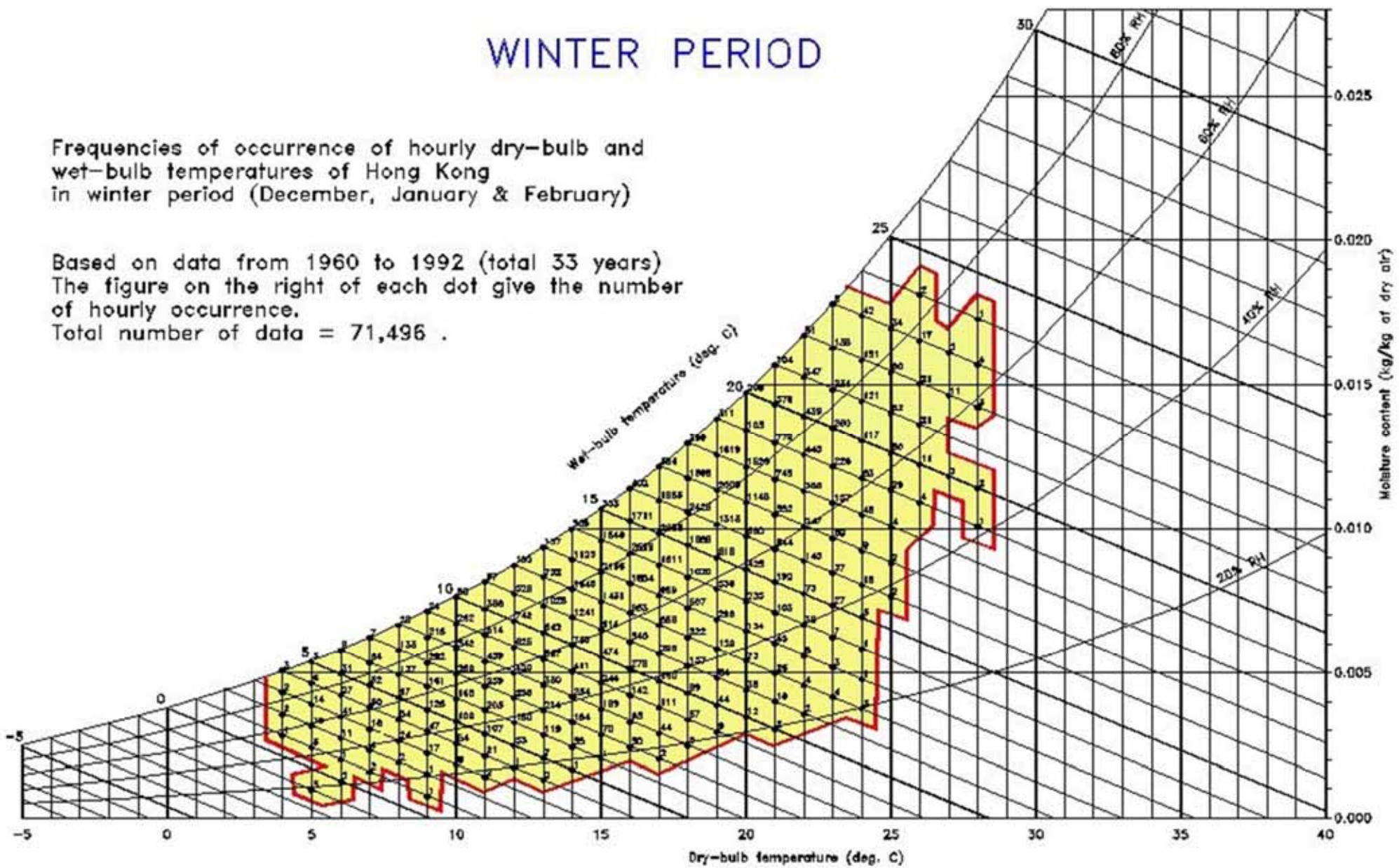


- Psychrometrics and Bioclimatic Analysis for Hong Kong
  http://arch.hku.hk/~cmhui/teach/65156-7e.htm
  - Cooling strategies
  - Thermal comfort zones
  - Frequency distribution on psychrometric charts

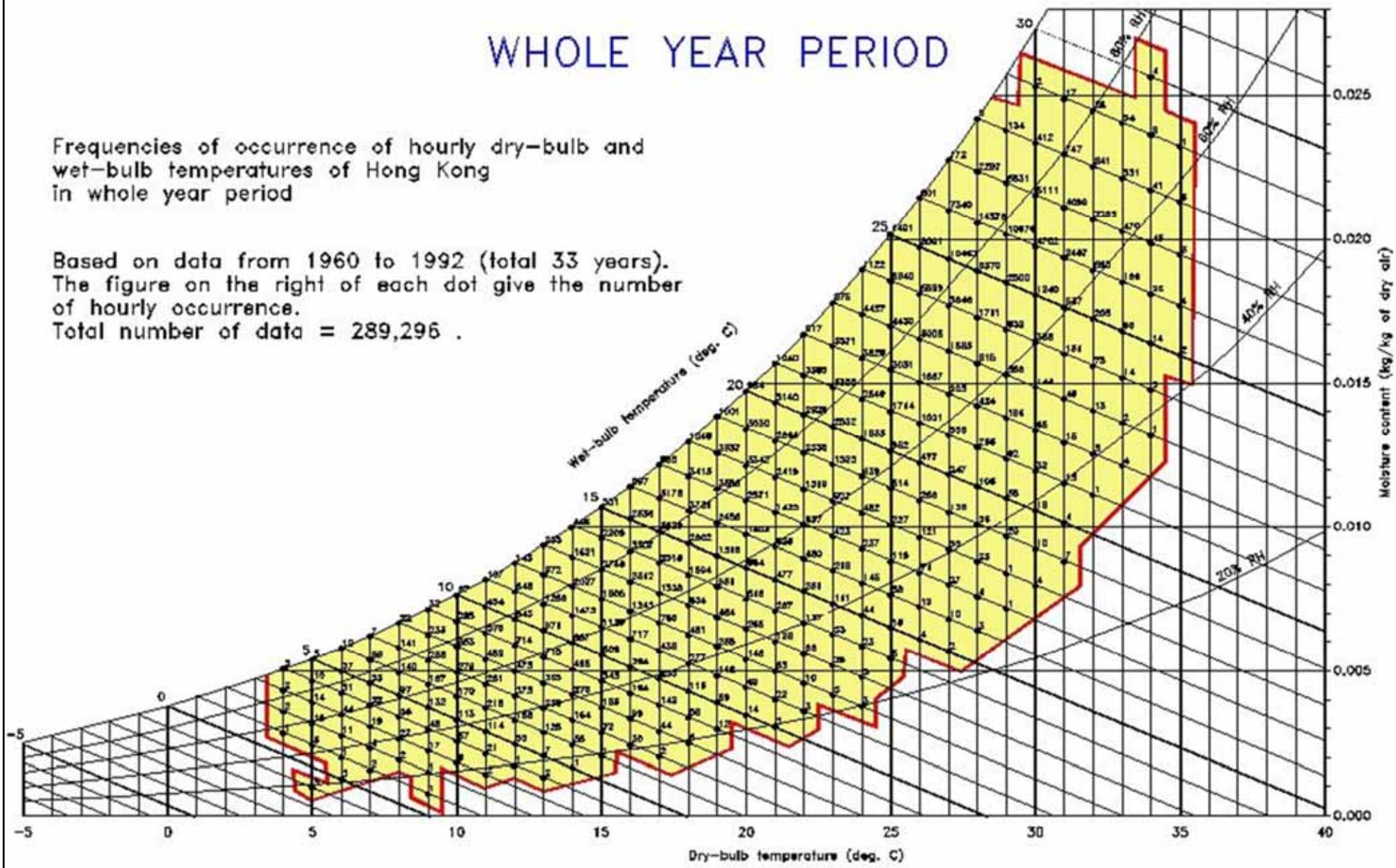
Analysis of weather conditions in Hong Kong



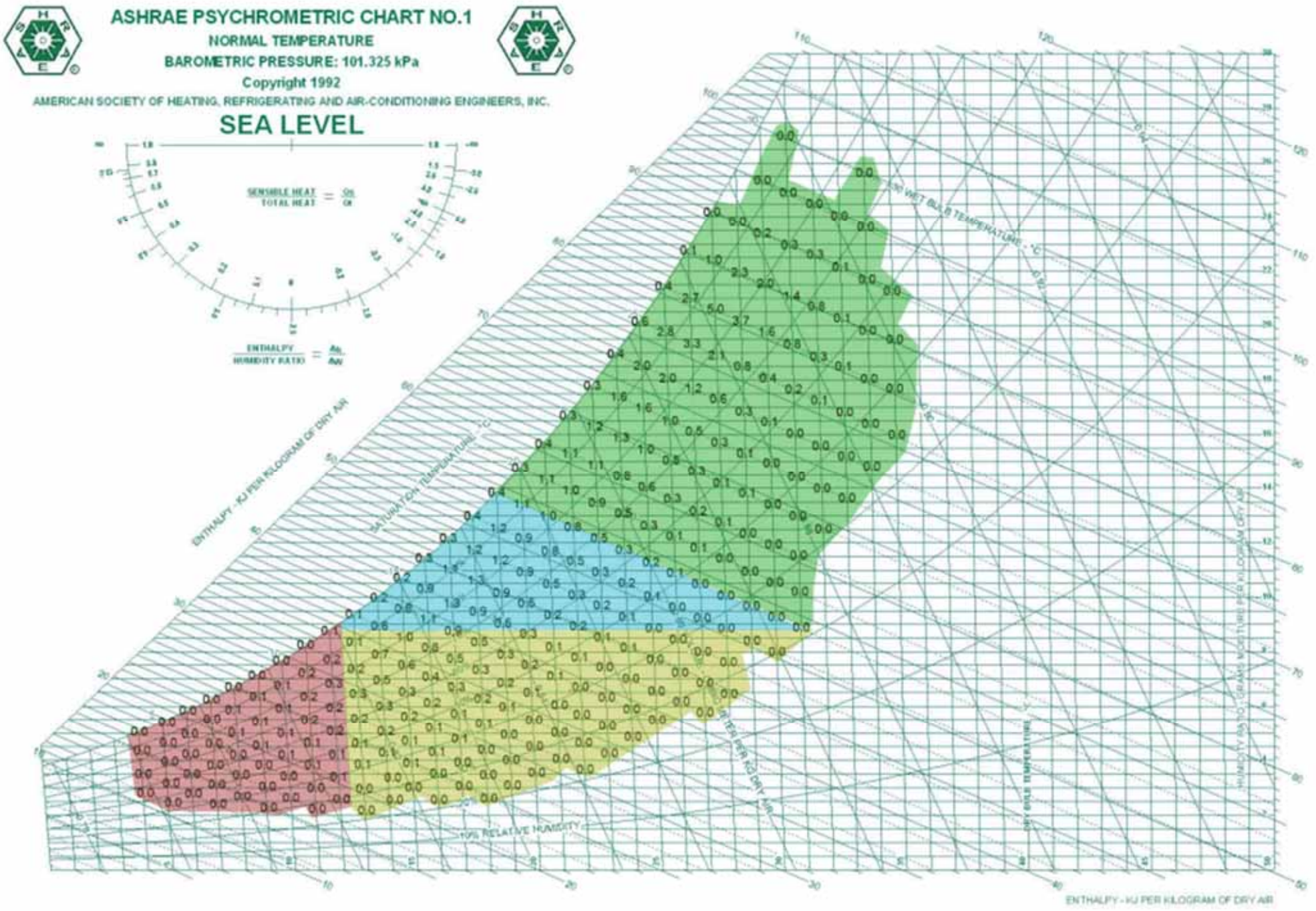
Analysis of weather conditions in Hong Kong



Analysis of weather conditions in Hong Kong

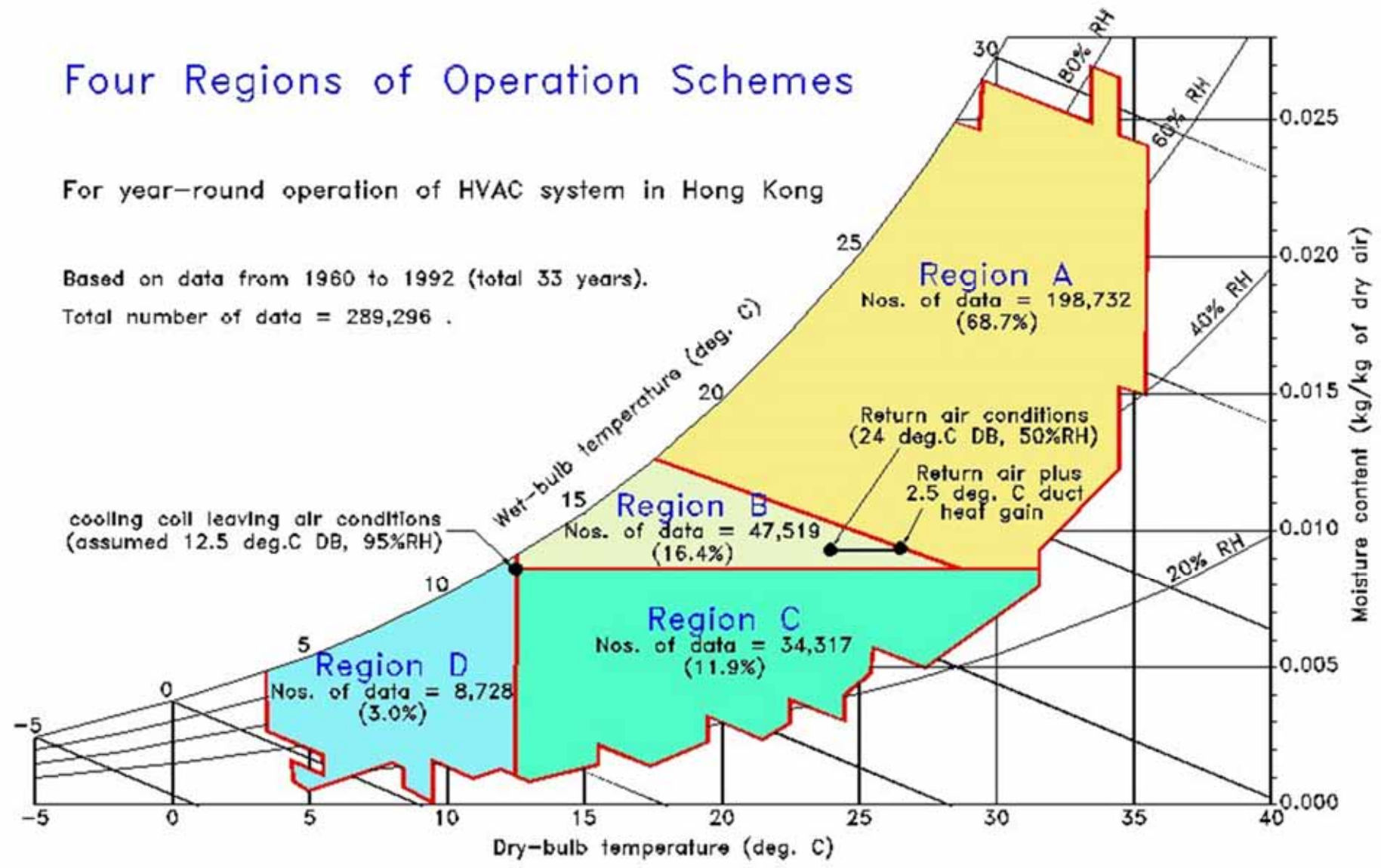


Analysis of weather conditions in Hong Kong

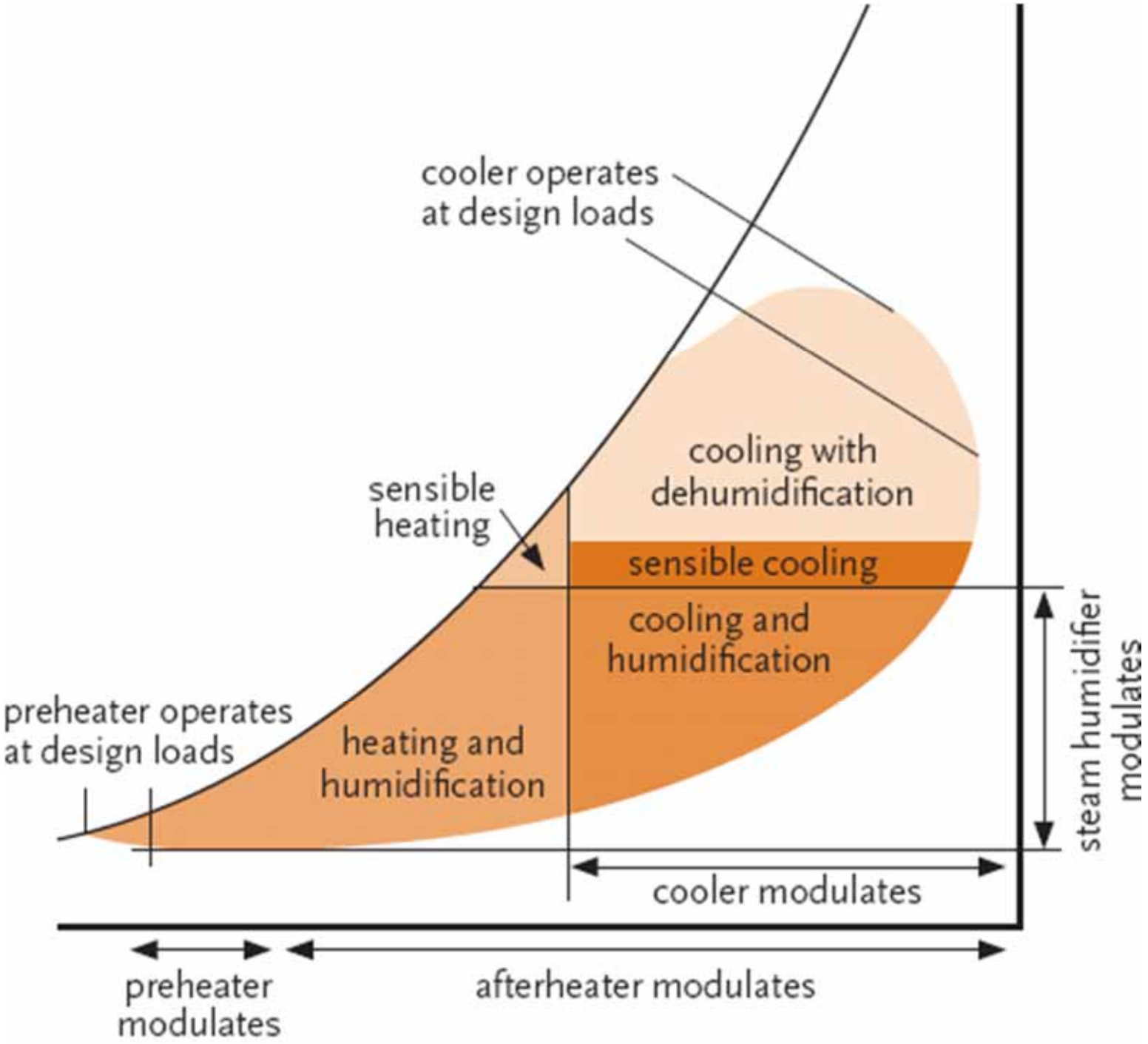


* The number represents the possibility of occurrence.

Analysis of HVAC operation strategy

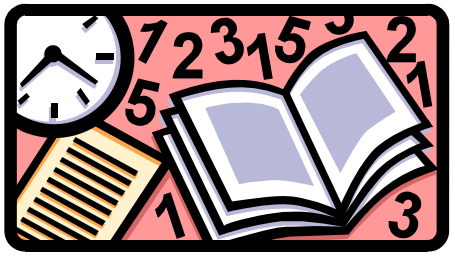


All-year-round operating regime based on outdoor conditions



(Source: CIBSE Journal CPD Programme: The psychrometrics of air conditioning systems (Mar 2010))

Further Reading



- Air Conditioning: Psychrometrics [www.bsenotes.com]
  - http://www.arca53.dsl.pipex.com/index_files/psy1.htm
- CIBSE Journal CPD Programme:
  - The properties of air (Apr 2009)
  - Applying the psychrometric relationships (Aug 2009)
  - The Basic Psychrometric Processes (Oct 2009)
  - The psychrometrics of HVAC sub-systems (Dec 2009)
  - The psychrometrics of air conditioning systems (Mar 2010)
  - Travelling into time with psychrometry (Dec 2010)