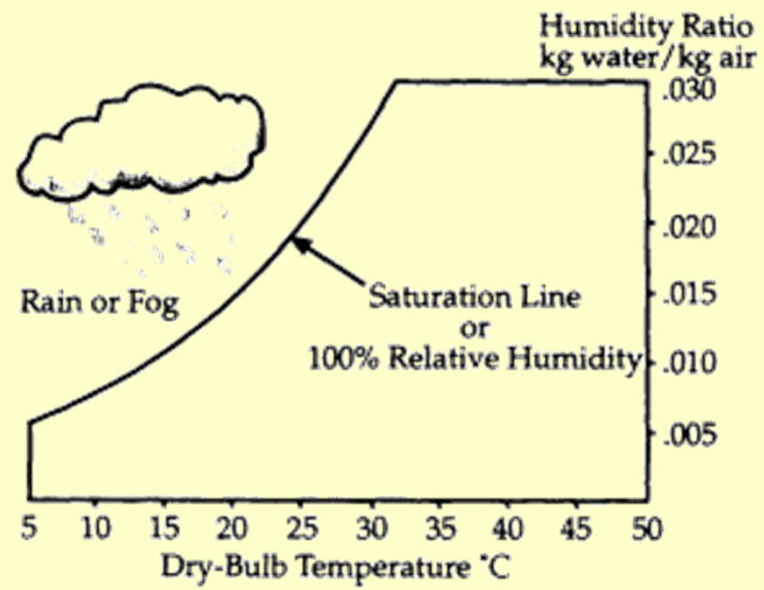
MEBS7012 Air conditioning and refrigeration

http://ibse.hk/MEBS7012/



Advanced Psychrometry

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Contents

- Introduction to Psychrometry
- Psychrometric Processes
- Psychrometric Software
- Psychrometric Analysis

Introduction to Psychrometry

- Chapter 1 – Introduction to Psychrometry
  http://ibse.hk/MEBS7012/DencoCH1.pdf
  - Atmosphere and water vapour
  - Psychrometric chart (theory)
  - The psychrometric equation
  - Psychrometric chart (CIBSE)
  - Quick revision study guide (5 questions) & chapter notes
  - Appendix - Thermodynamic Basics
    - Perfect gas laws
    - 1st law of thermodynamics
    - Conservation of energy

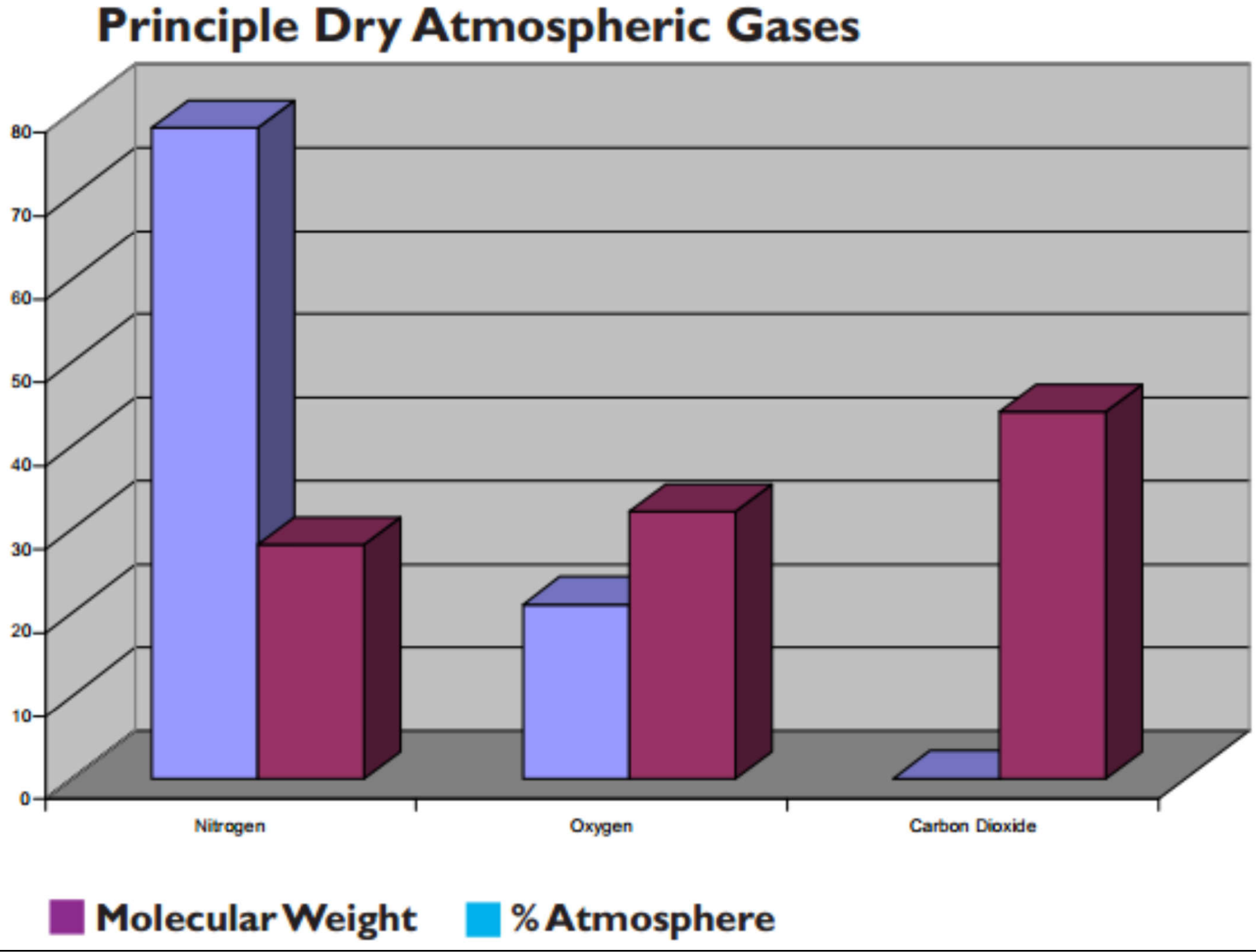
Study notes

Introduction to Psychrometry

- Psychrometry (測濕學)
  - The measurement or study of the thermodynamic properties of moist air (dry air + water vapour)
    - The Greek term psuchron (ψυχρόν) meaning "cold" and metron (μέτρον) meaning "means of measurement"
  - Moist air properties:
    - Ideal gas laws: 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

(See also: Psychrometrics - Wikipedia http://en.wikipedia.org/wiki/Psychrometrics)

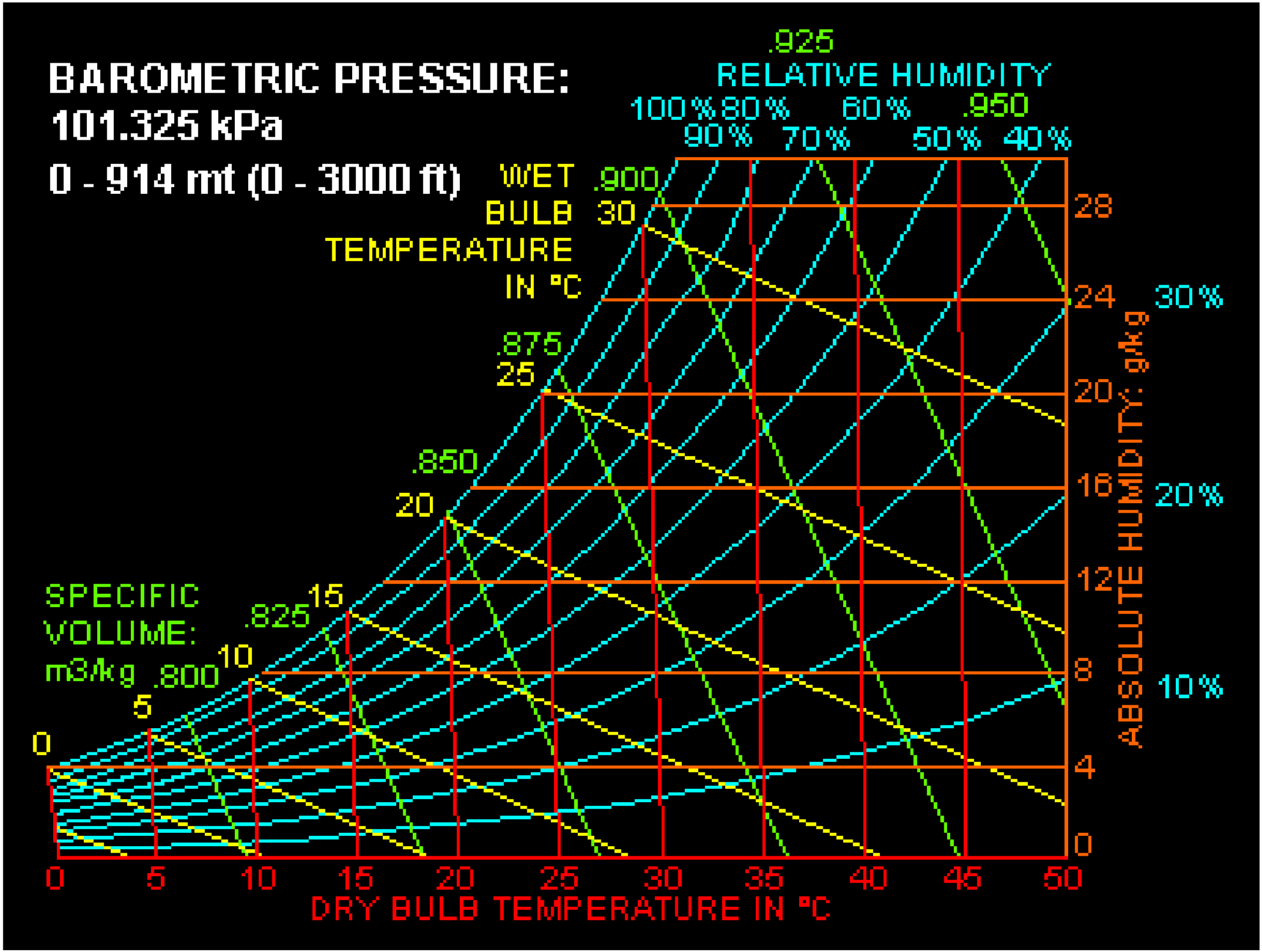
Moist Air = Dry Air + Water Vapour (the gas phase of H_2O)



Introduction to Psychrometry

- Psychrometric chart (空氣濕度線圖)
  - A tool for understanding the relationships between the various parameters of supply air and the relative humidity
    - Can be used to assess the physical and thermodynamic properties of gas-vapour mixtures at a constant pressure
  - Learning to use psychrometric chart
    - Identify parts of the chart
    - Determine moist air properties
    - Use chart to analyse processes involving moist air

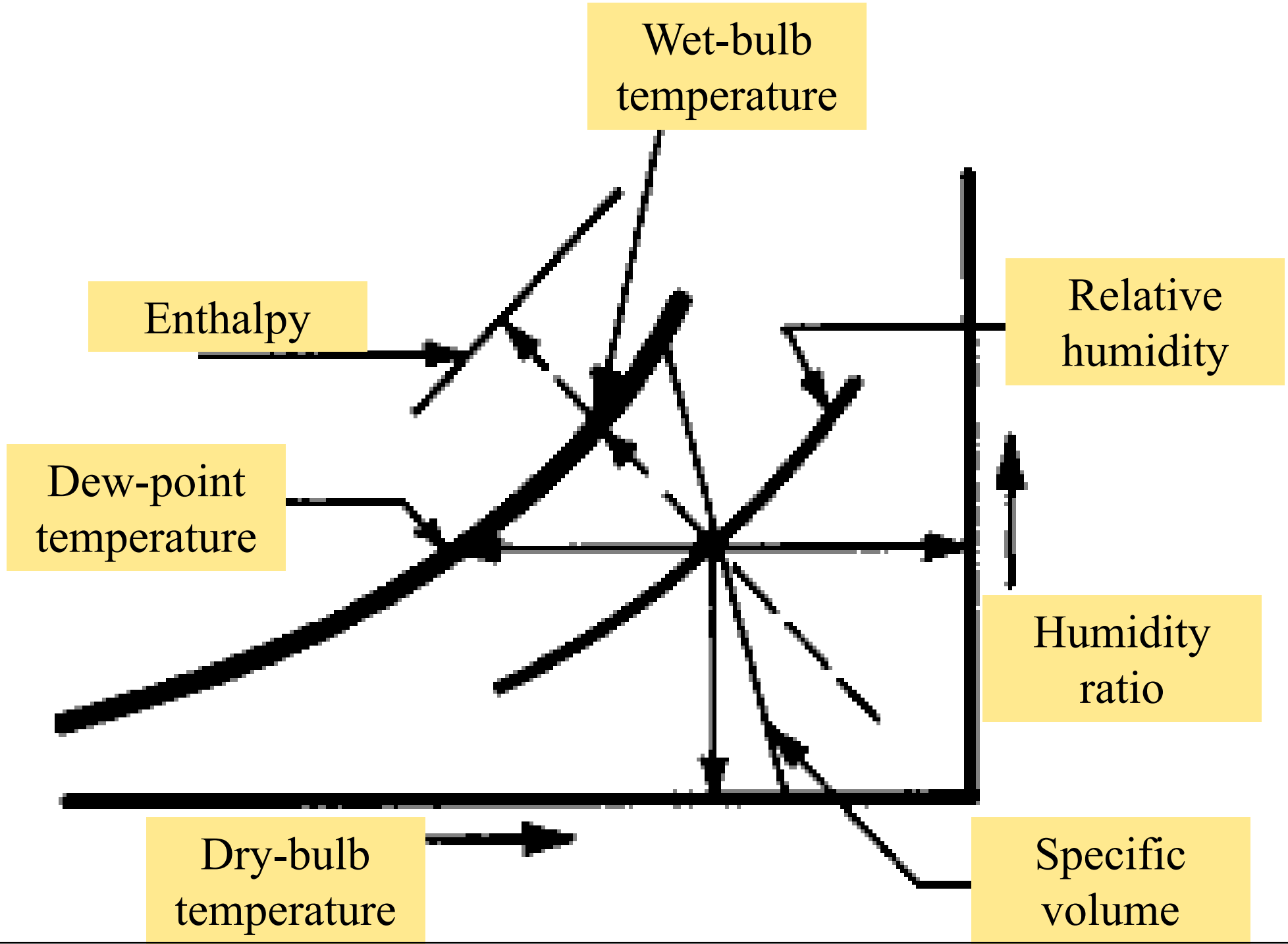
(See also: https://www.designingbuildings.co.uk/wiki/Psychrometric_charts)


BAROMETRIC PRESSURE:
101.325 kPa
0 - 914 mt (0 - 3000 ft)
.825
RELATIVE HUMIDITY
100% 80% 60% .950
90% 70% 50% 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

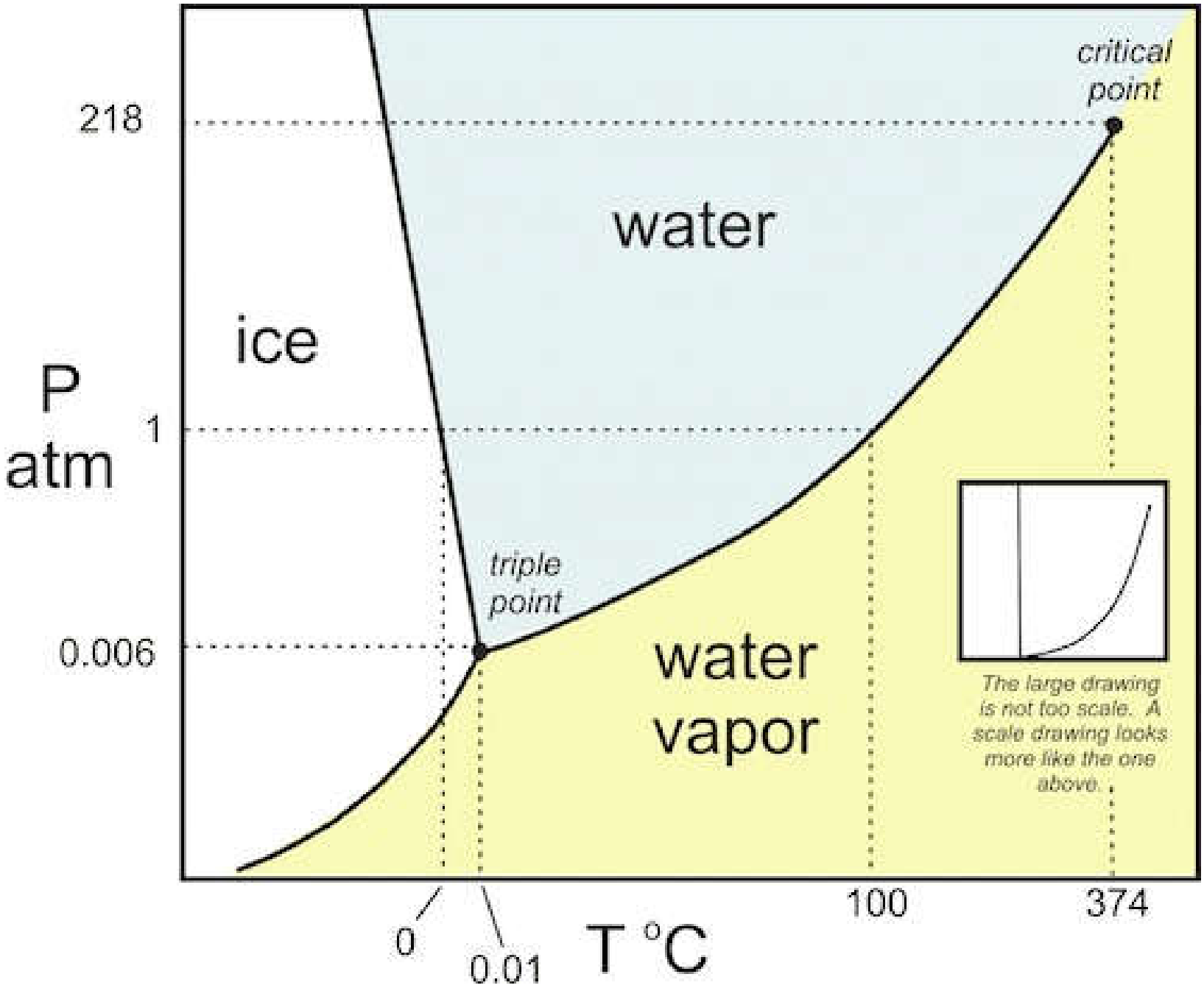
Introduction to Psychrometry

- Major parameters: (see handouts for details)
  - Moisture content (g), or absolute humidity (w)
  - Relative humidity (rh or RH)
  - Percentage saturation (μ)
  - Wet-bulb temperature (t_{wb})
  - Dew-point temperature (t_{dp})
  - Specific enthalpy (h)
  - Specific volume (v)
  - Density (ρ)

Major parameters on a psychrometric chart



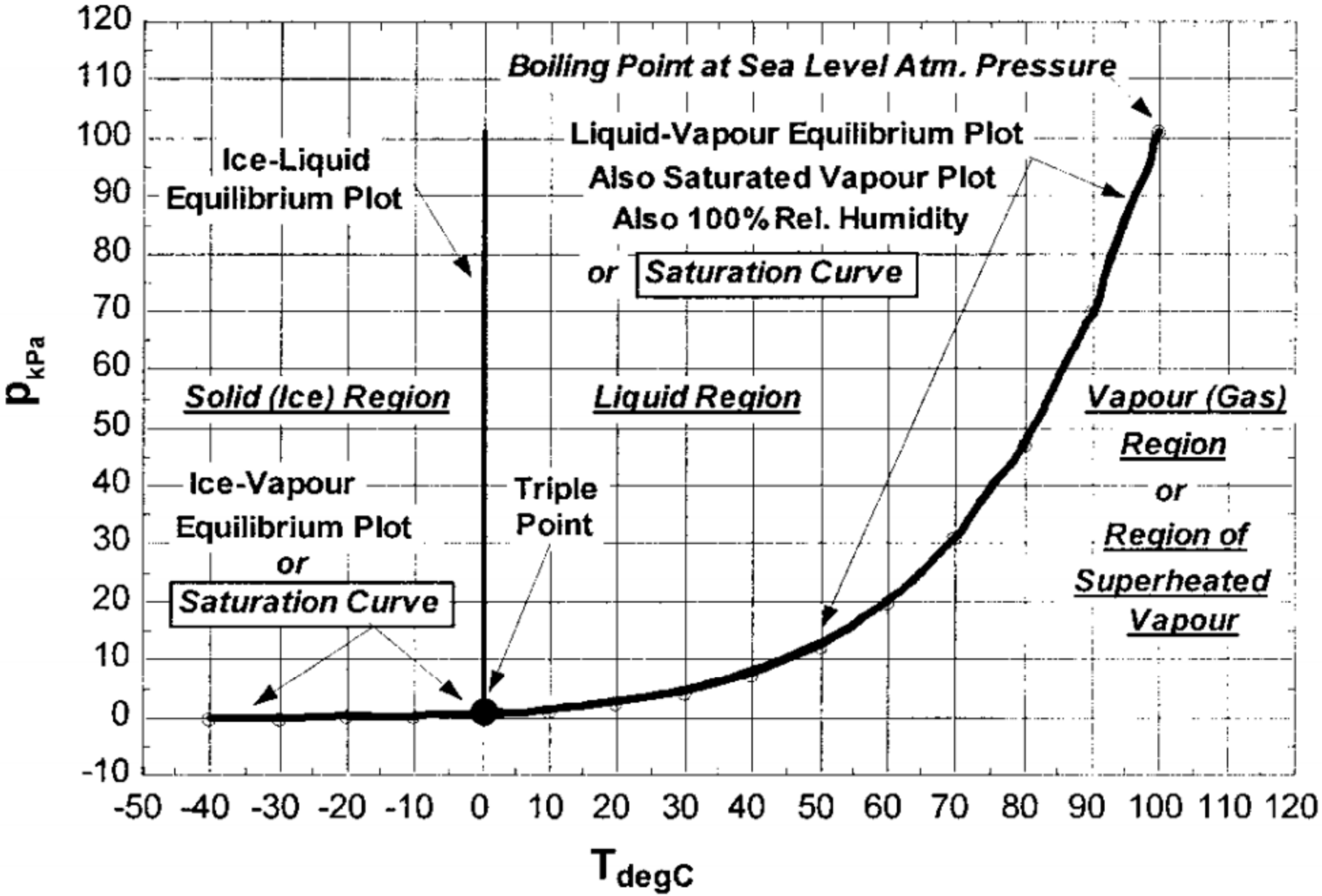
From chemistry to psychrometrics (pressure-temperature diagram for water)



In psychrometrics, we care mainly about the yellow region (the boundary between the vapor phase and the liquid or solid phases)

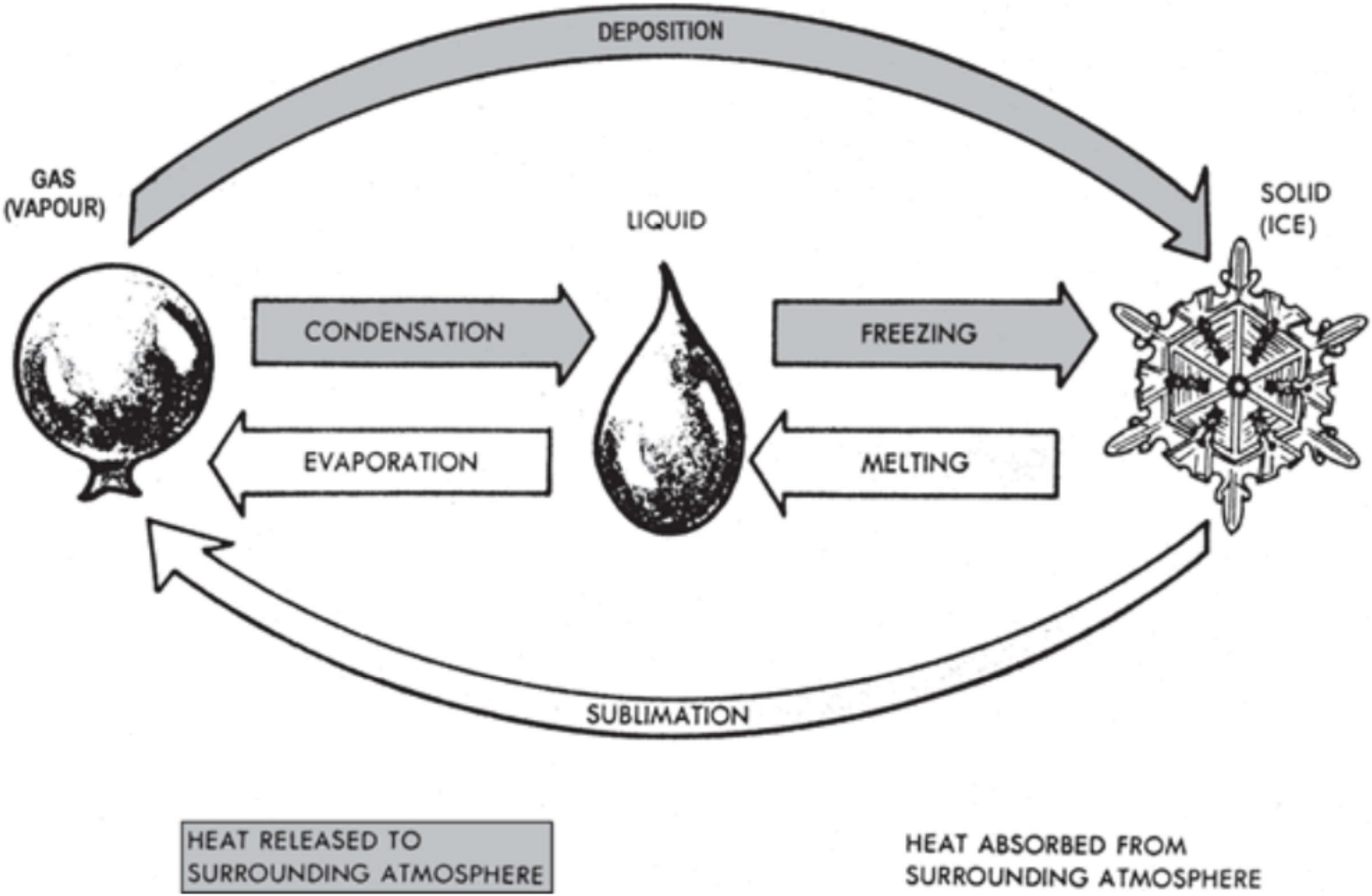
(Source: https://www.energyvanguard.com/blog/78101/Psychrometrics-Impenetrable-Chart-or-Path-to-Understanding)

Pressure vs. temperature diagram for H_2O



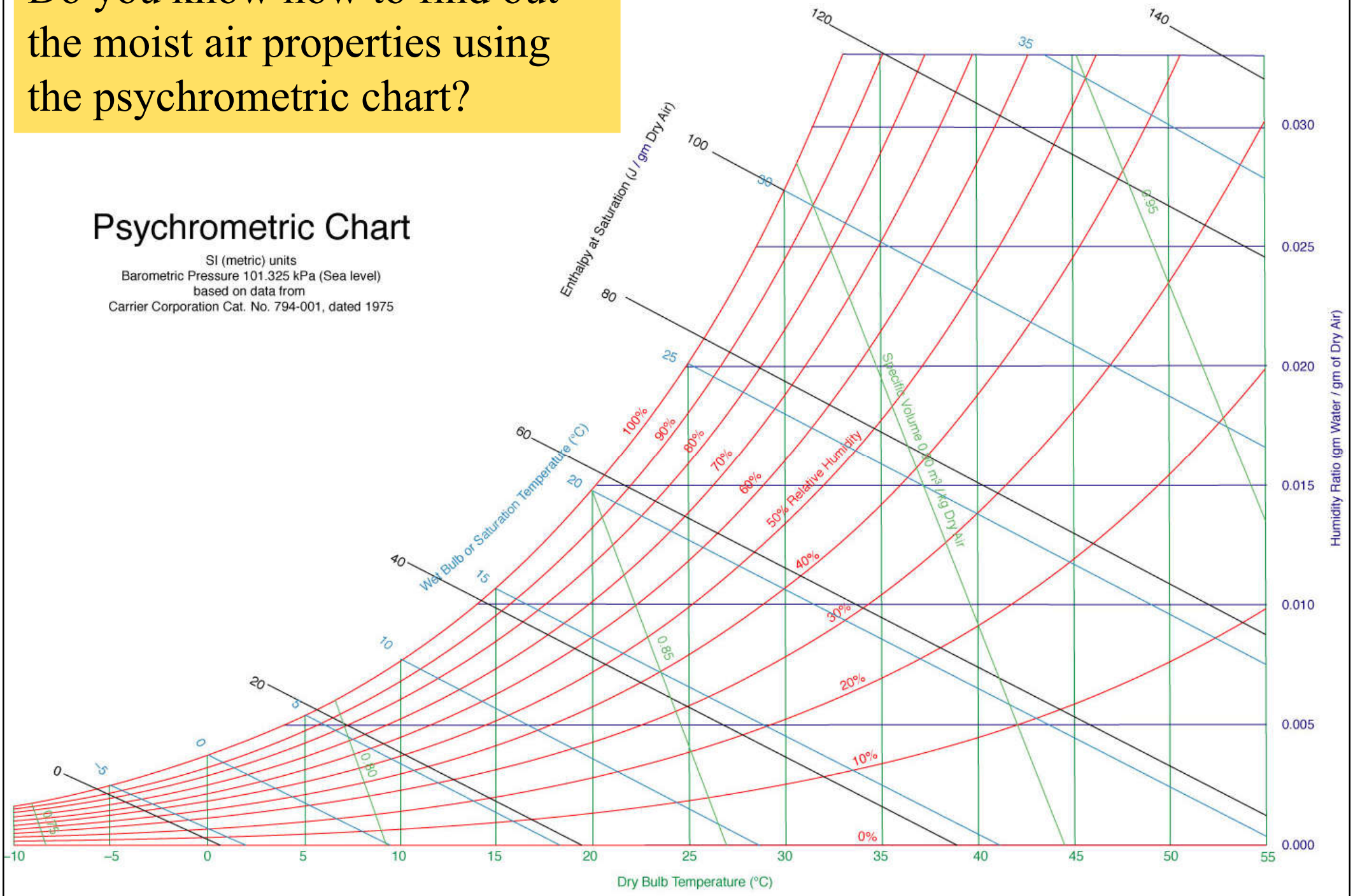
(Source: Gatley, D. P., 2013. *Understanding Psychrometrics*, 3rd ed.)

Phase change processes for H_2O



(Source: Gatley, D. P., 2013. *Understanding Psychrometrics*, 3rd ed.)

Do you know how to find out the moist air properties using the psychrometric chart?

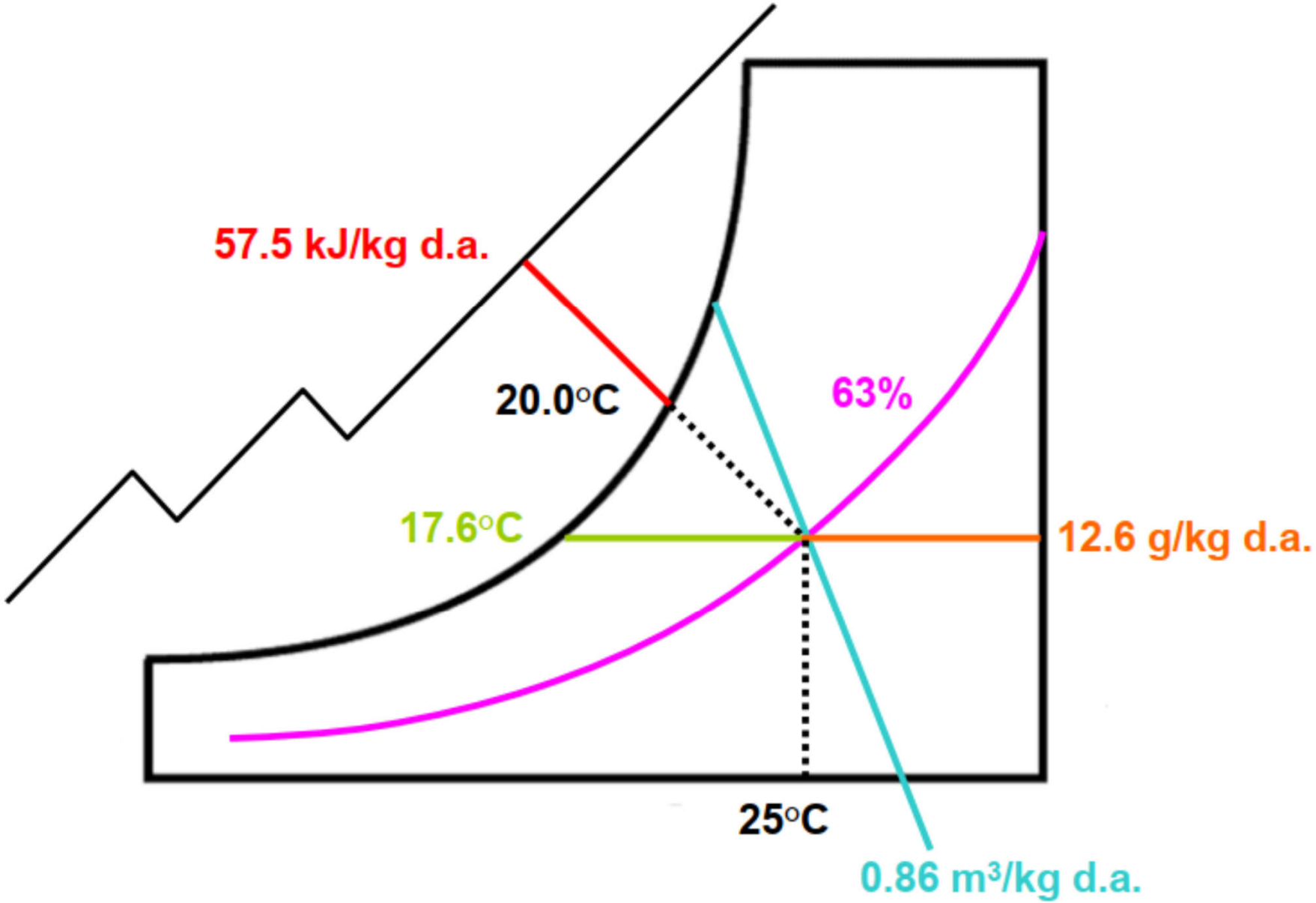


(Source: https://www.designingbuildings.co.uk/wiki/Psychrometric_charts)

Psychrometric chart: Example 1

Given: DBT = 25°C, WBT = 20°C

Find: (a) RH, (b) dew point temp., (c) humidity ratio, (d) specific volume, (e) enthalpy



(Source: Perry Peralta, NC State University)

Measurement of moist air by sling psychrometer

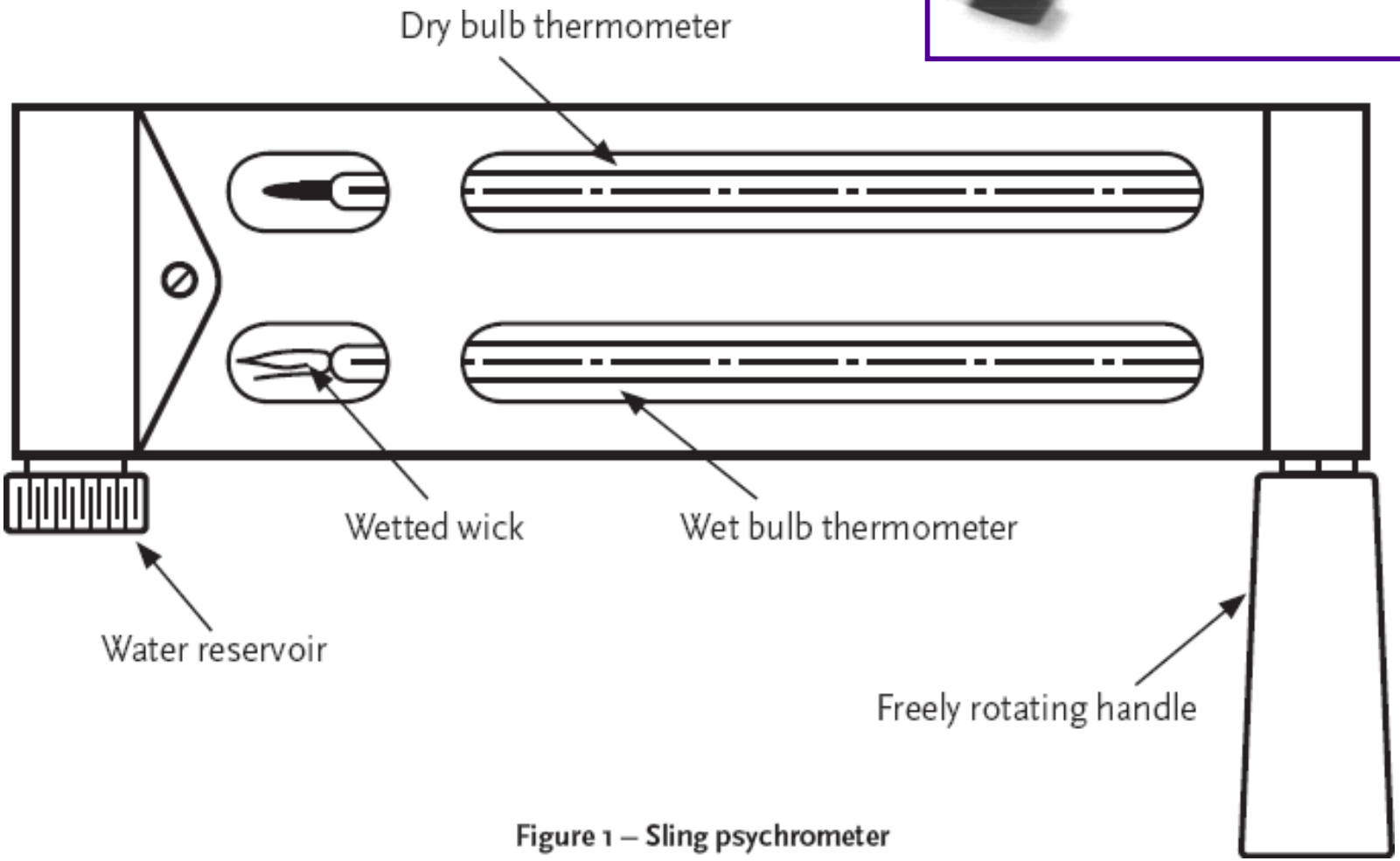


Figure 1 – Sling psychrometer

Introduction to Psychrometry

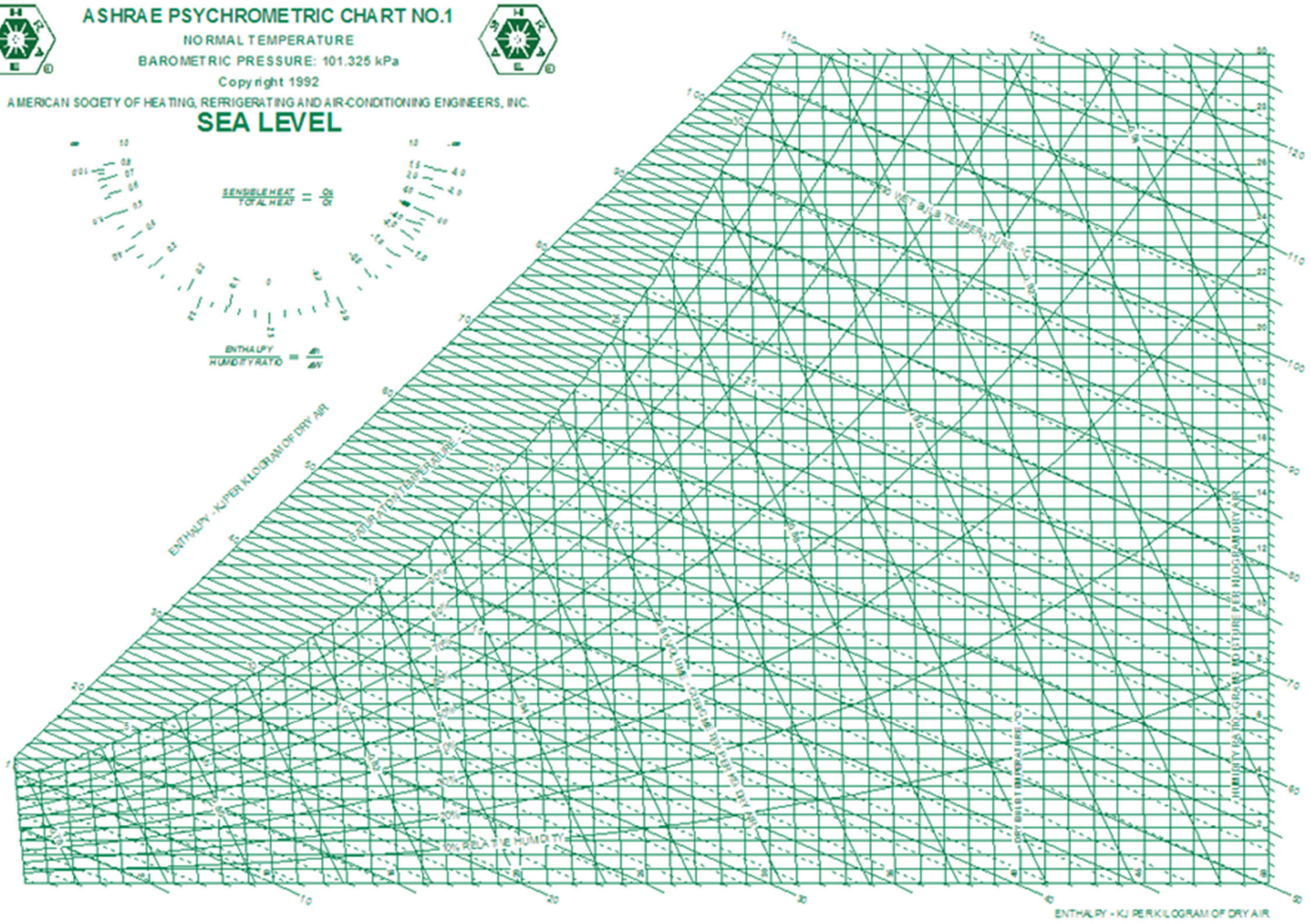
- Commonly used psychrometric charts
  - ASHRAE psychrometric chart
  - CIBSE psychrometric chart
  - Carrier psychrometric chart
  - Trane psychrometric chart
  - Mr. S K Wang (similar to Trane)
  - Mollier chart in Mainland China (濕空氣焓濕圖)
- You should learn how to read and use the psychrometric charts for HVAC design

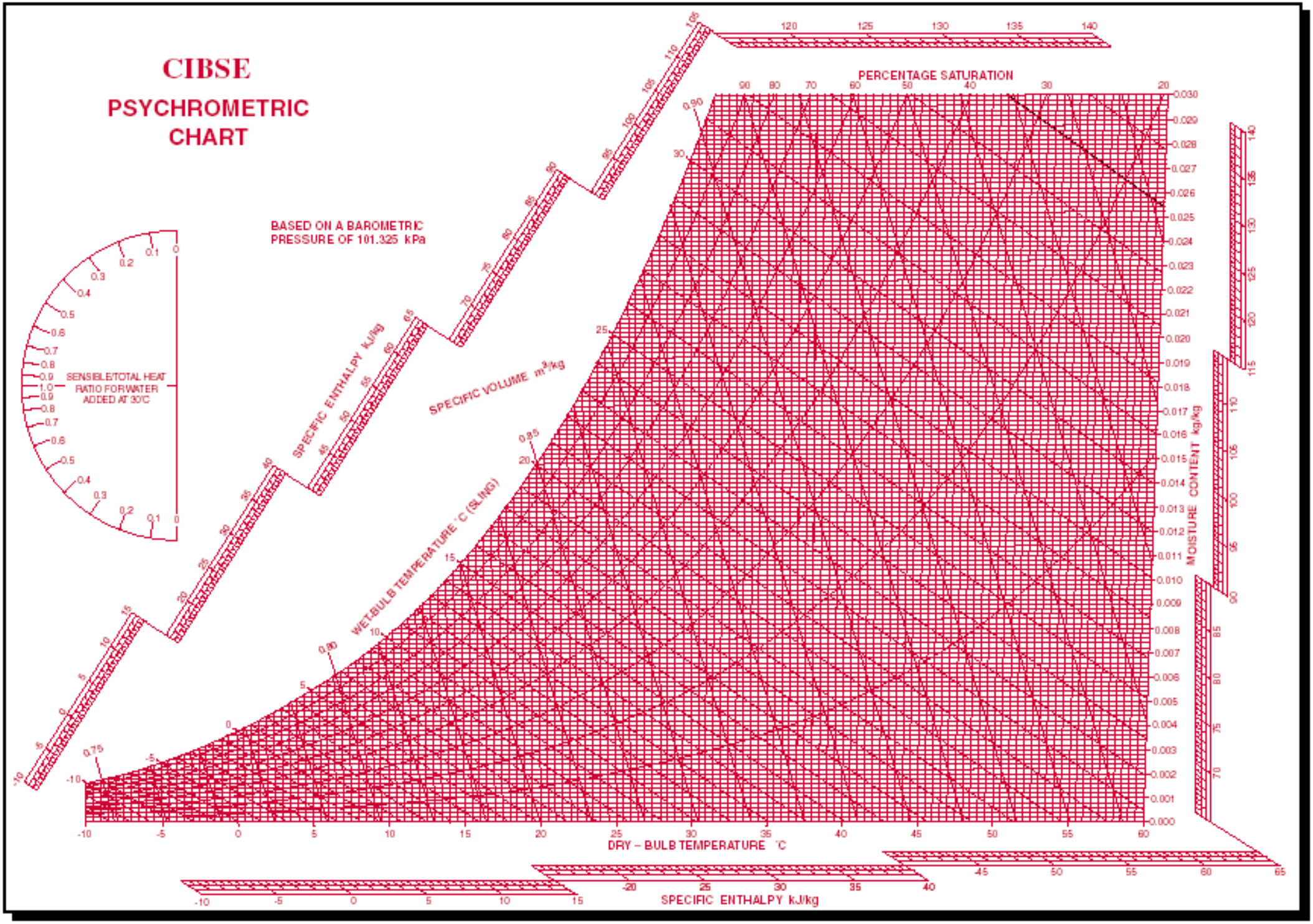
ASHRAE PSYCHROMETRIC CHART NO.1

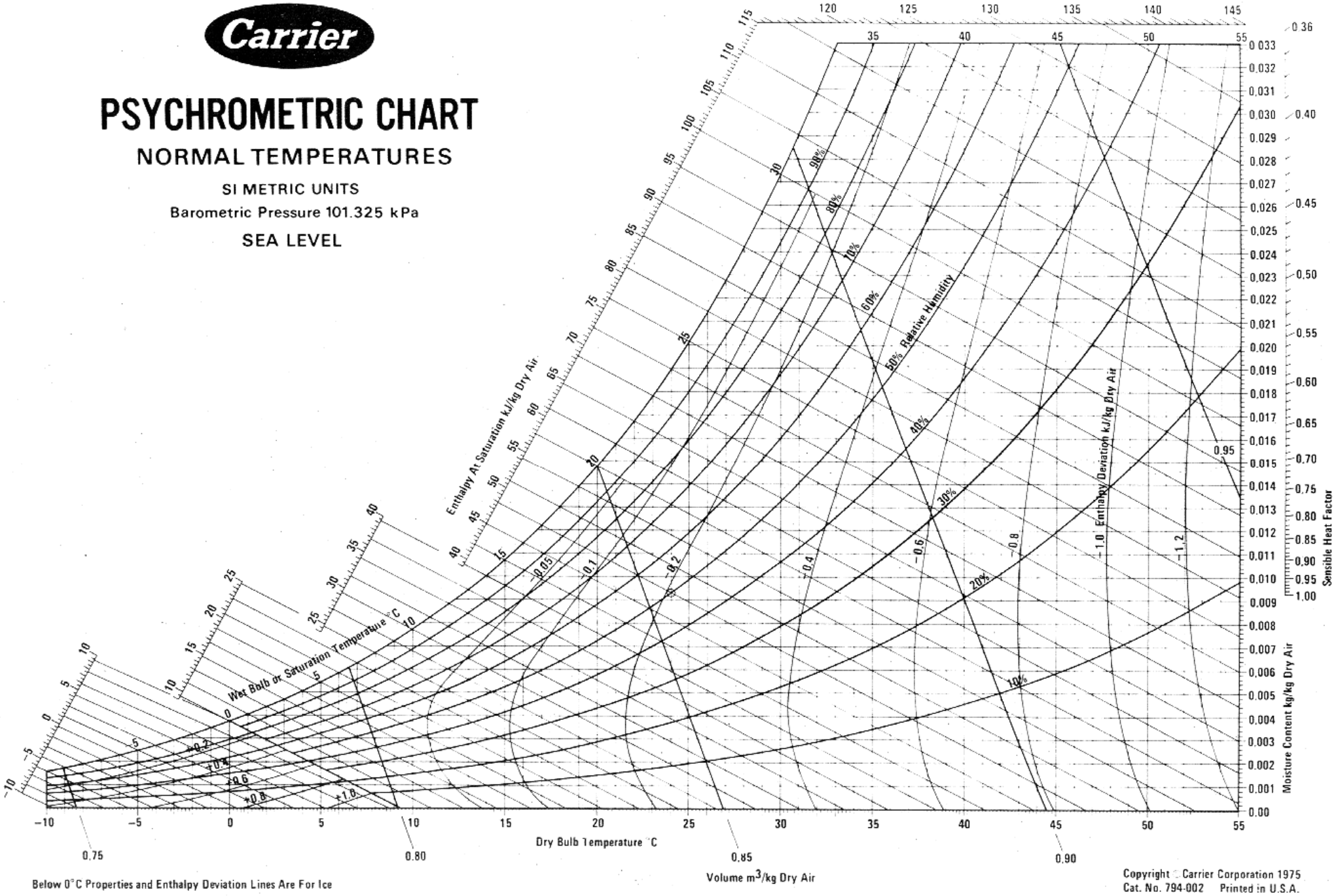
NORMAL TEMPERATURE

BAROMETRIC PRESSURE: 101.325 kPa

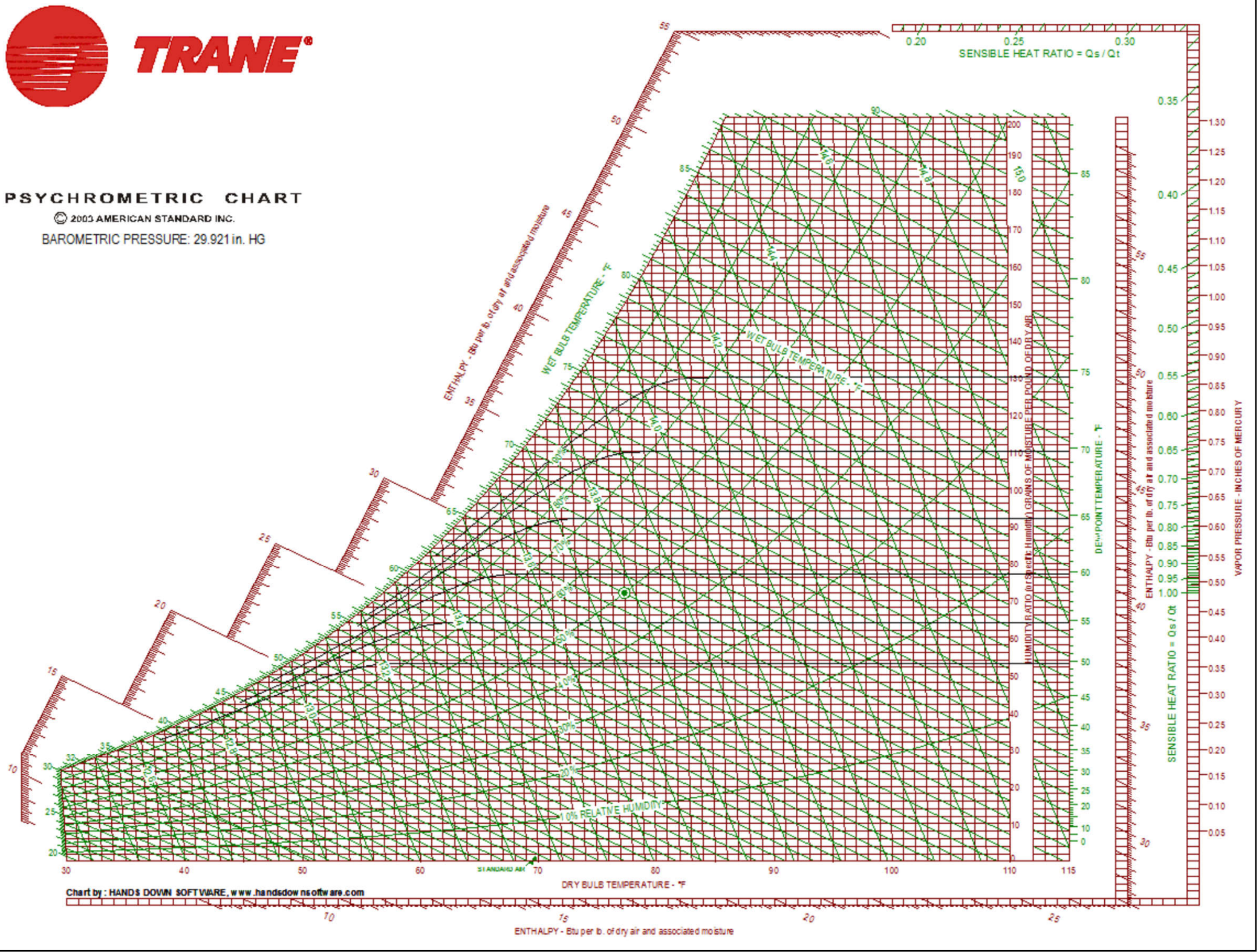
SEA LEVEL




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



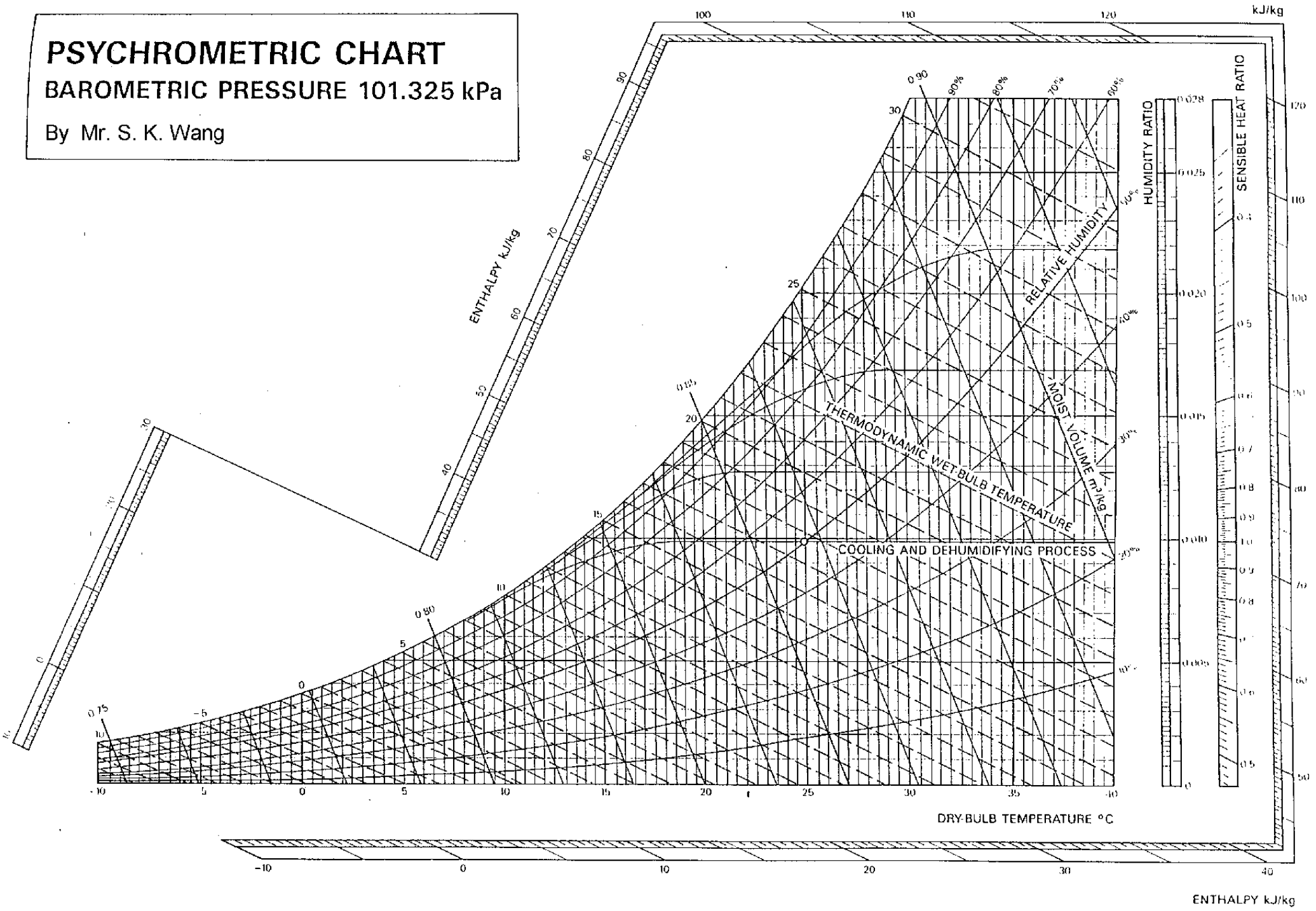
Reproduced courtesy of Carrier Corporation

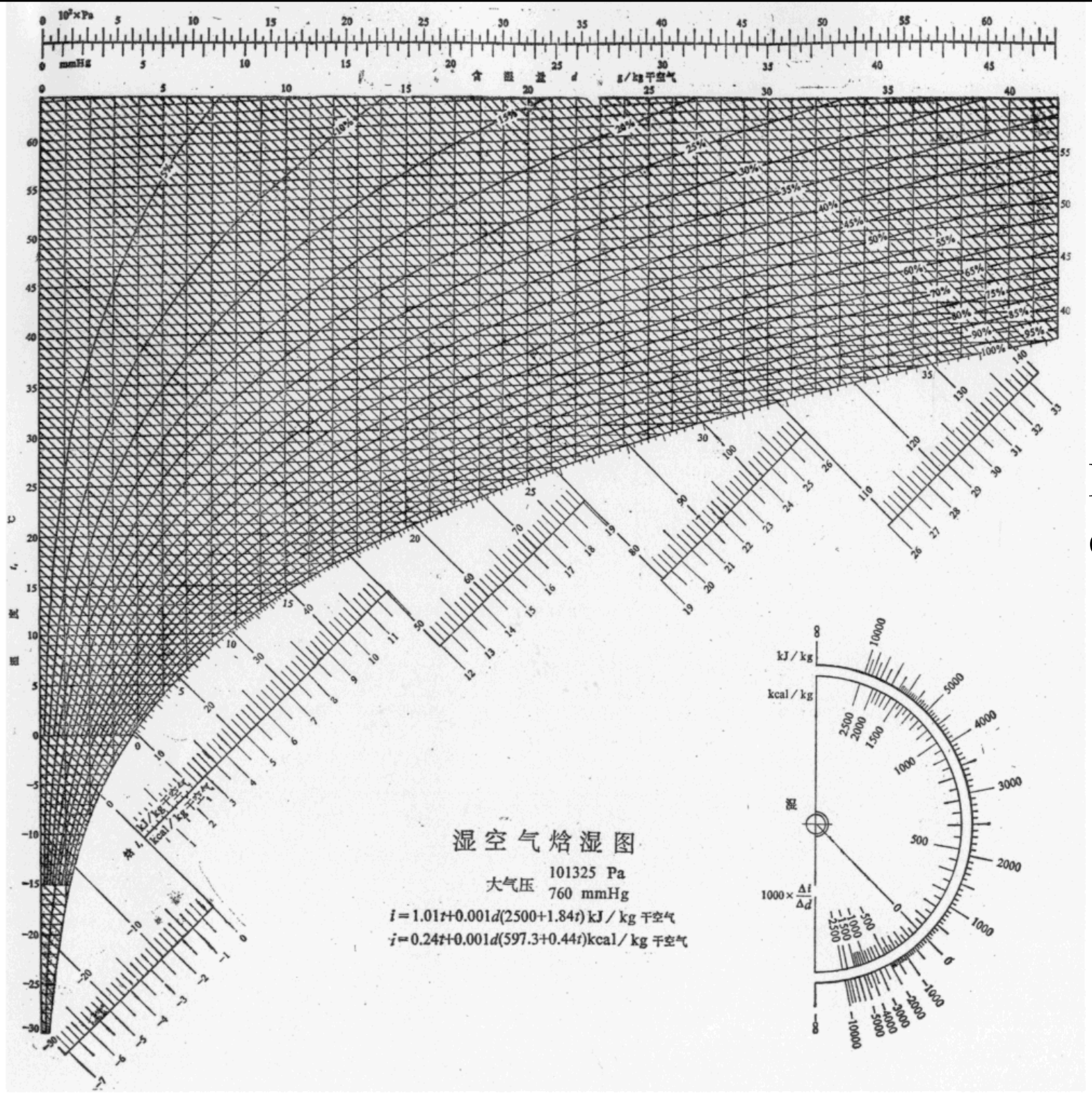

TRANE
PSYCHROMETRIC CHART
© 2003 AMERICAN STANDARD INC.
BAROMETRIC PRESSURE: 29.921 in. HG
SENSIBLE HEAT RATIO = Qs / Qt
ENTHALPY - Btu per lb. of dry air and associated moisture
WET BULB TEMPERATURE - °F
HUMIDITY RATIO (or Specific Humidity) GRAINS OF MOISTURE PER POUND OF DRY AIR
DEW-POINT TEMPERATURE - °F
VAPOR PRESSURE - INCHES OF MERCURY
10% RELATIVE HUMIDITY
STANDARD AIR
DRY BULB TEMPERATURE - °F
Chart by : HANDS DOWN SOFTWARE, www.handsdownsoftware.com

PSYCHROMETRIC CHART

BAROMETRIC PRESSURE 101.325 kPa

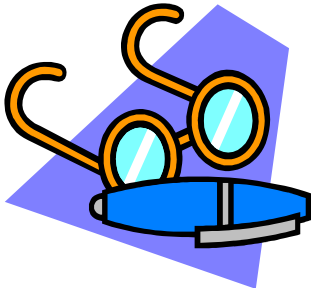
By Mr. S. K. Wang





Mollier chart style

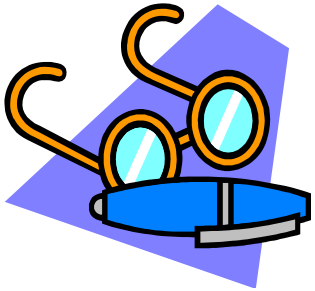
Psychrometric Processes



- Chapter 2 – Psychrometric Processes
  http://ibse.hk/MEBS7012/DencoCH2.pdf
  - Sensible heating coils
  - Cooling coils
  - Humidifiers
  - Water spray types
  - Steam humidifier
  - Humidifier – psychrometric process
  - Room psychrometric process
  - Mixing air streams
  - Quick revision study guide & chapter notes

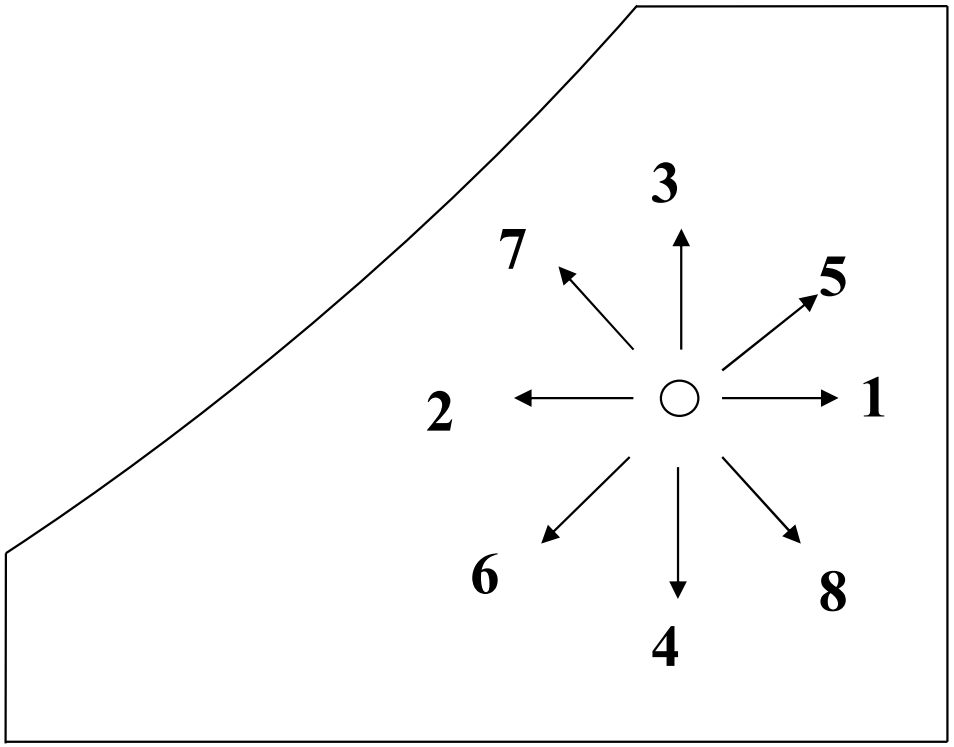
Study notes

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

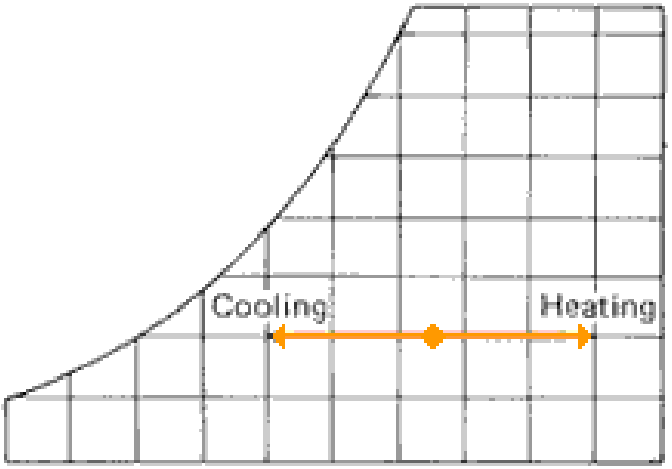
Basic psychrometric processes



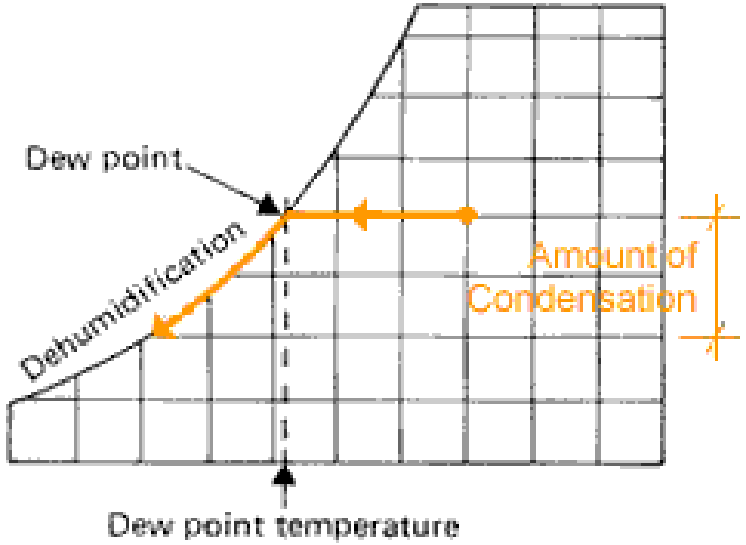
Process 0-1: Sensible heating
Process 0-2: Sensible cooling
Process 0-3: Humidifying
Process 0-4: Dehumidifying
Process 0-5: Heating and humidifying
Process 0-6: Cooling and dehumidifying
Process 0-7: Cooling and humidifying
Process 0-8: Heating and dehumidifying

(Video: Psychrometric Chart - air conditioning processes (3:00) https://youtu.be/C93mWf3rr30)

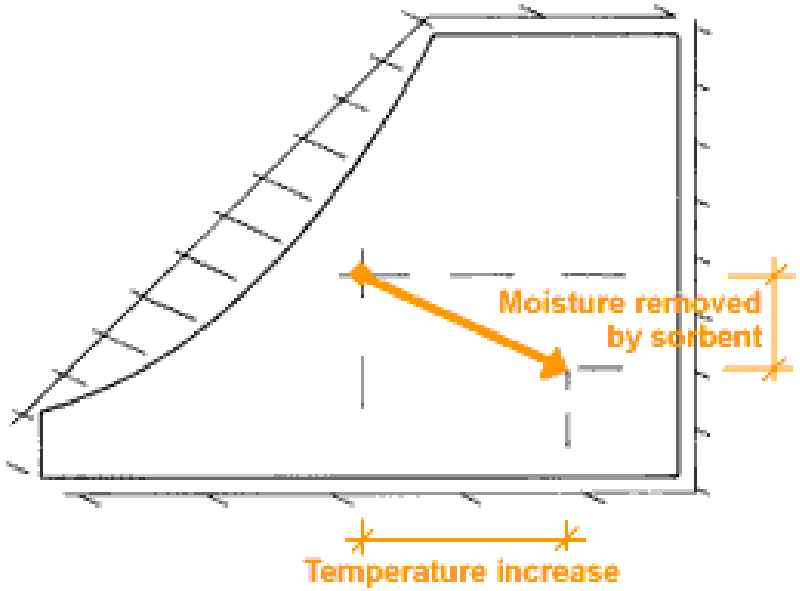
Psychrometric processes



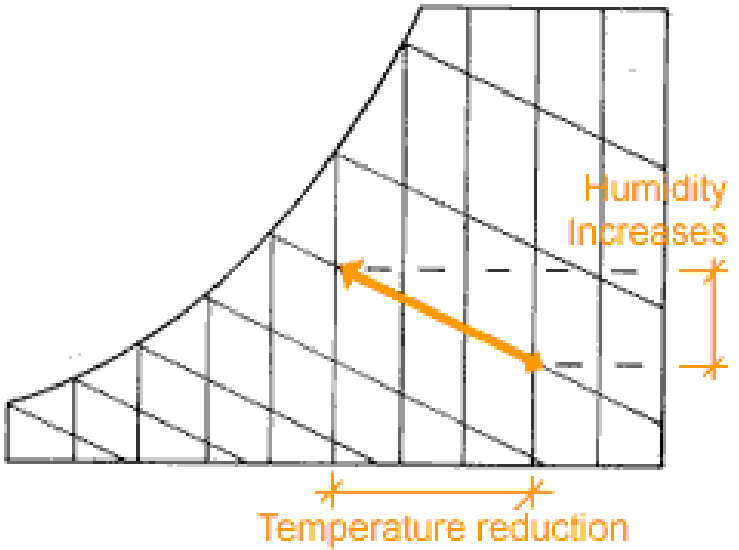
Sensible cooling/heating



Cooling and dehumidification

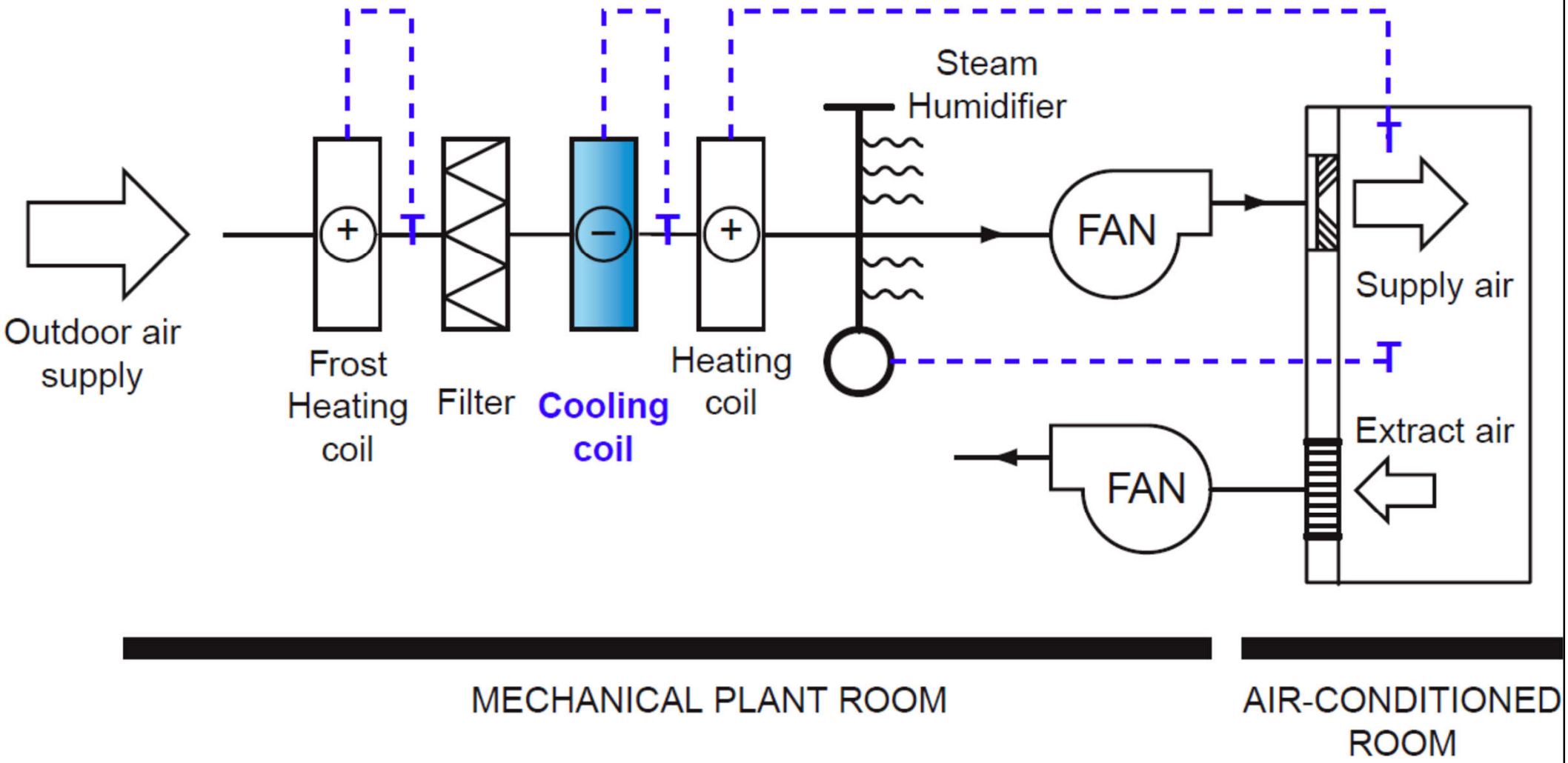


Adiabatic dehumidification



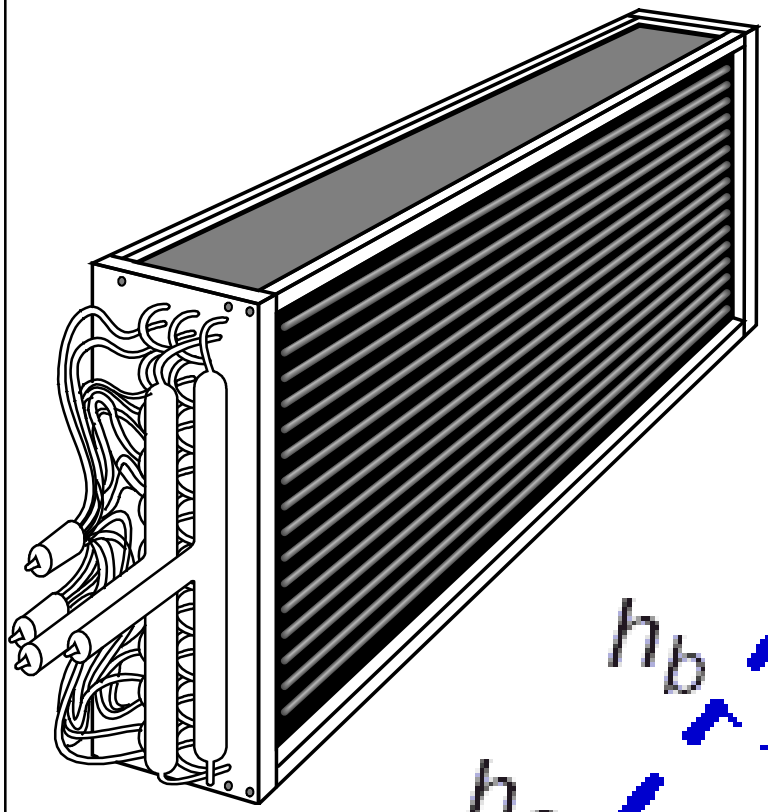
Evaporative cooling

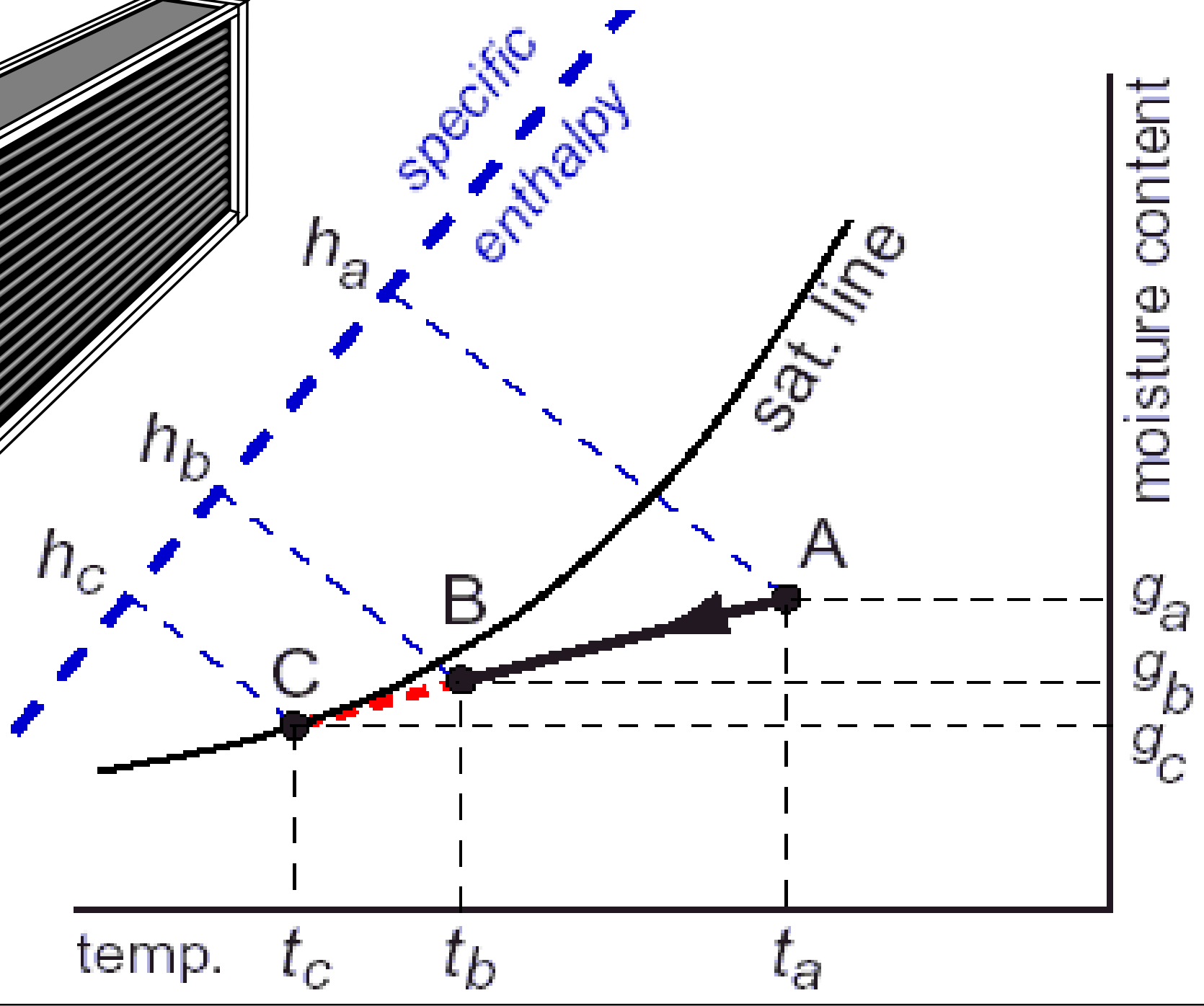
Schematic representation of all fresh-air, constant volume air conditioning system



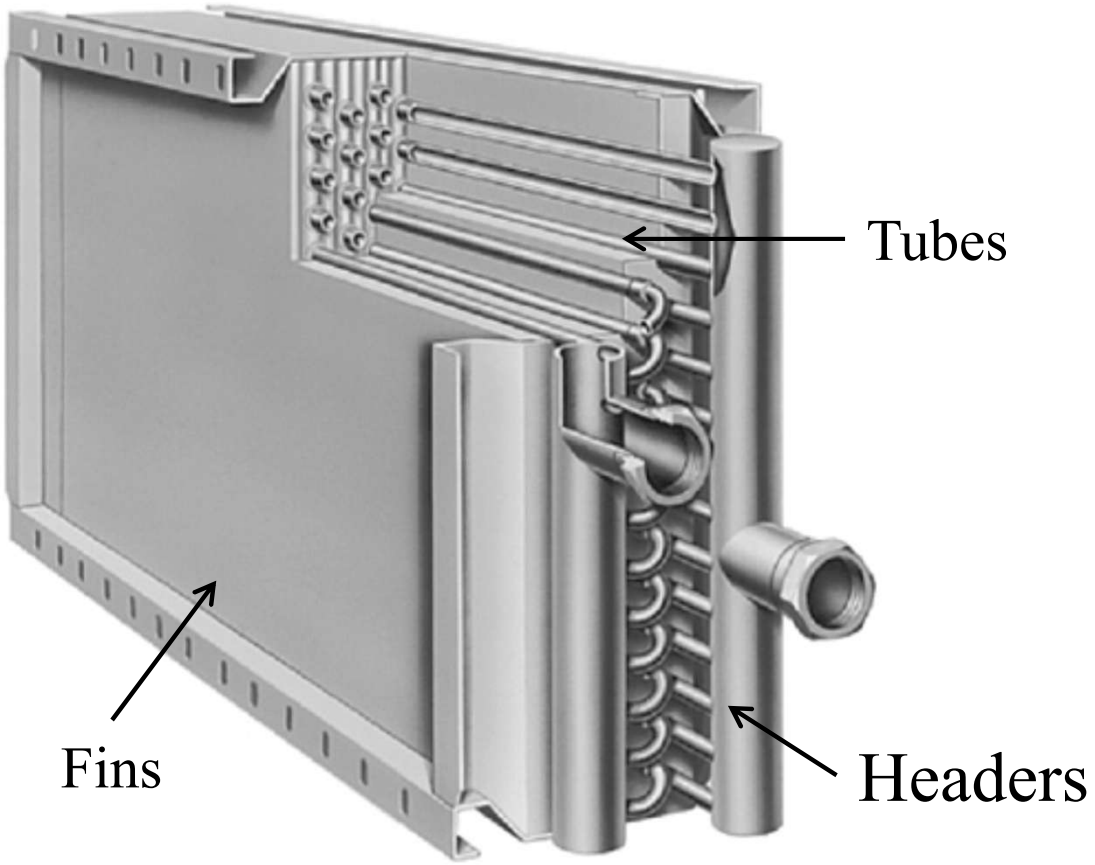
Can you explain the functions of each components?

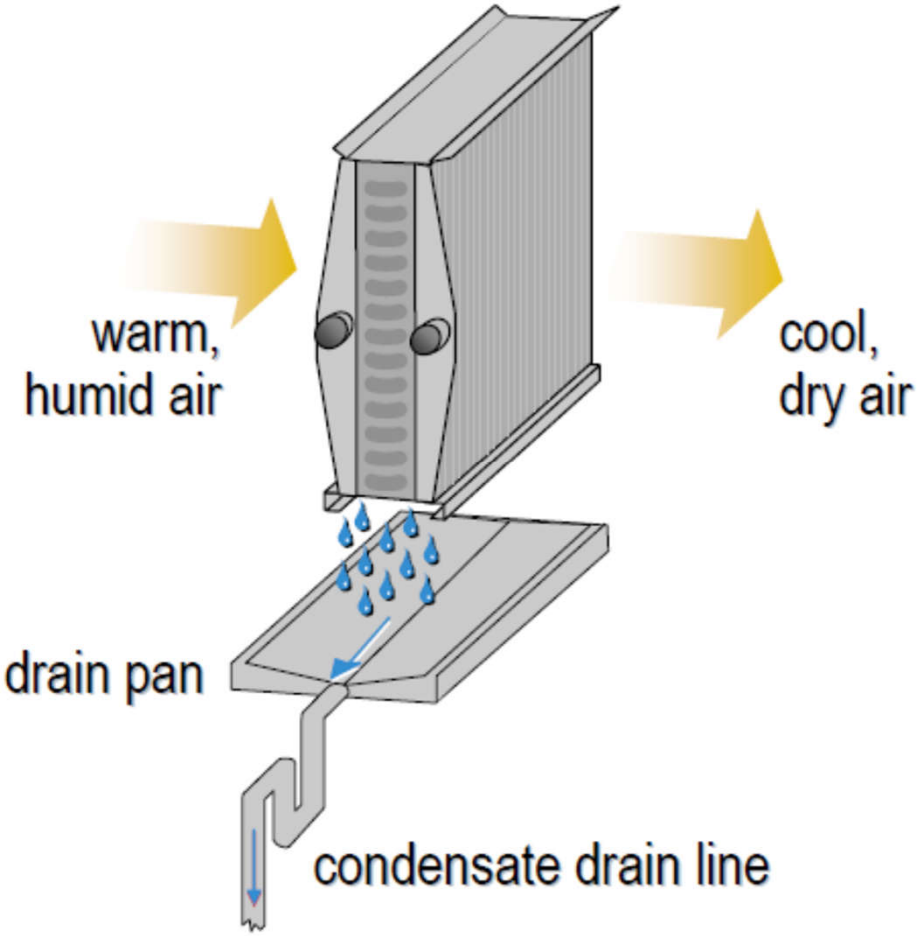
Cooling and dehumidification process at the cooling coil





Chilled water cooling coil (a heat exchanger)



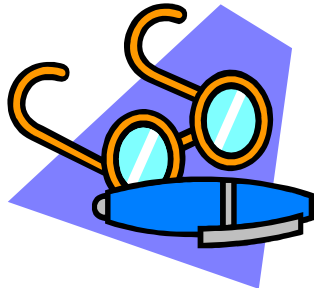


Sensible heat exchange: $q_S = m_a \text{ x } c_p \text{ x } (t_b - t_a)$

Latent heat exchange: $q_L = m_a \text{ x } h_{fg}$

(Source: Trane)

Psychrometric Processes

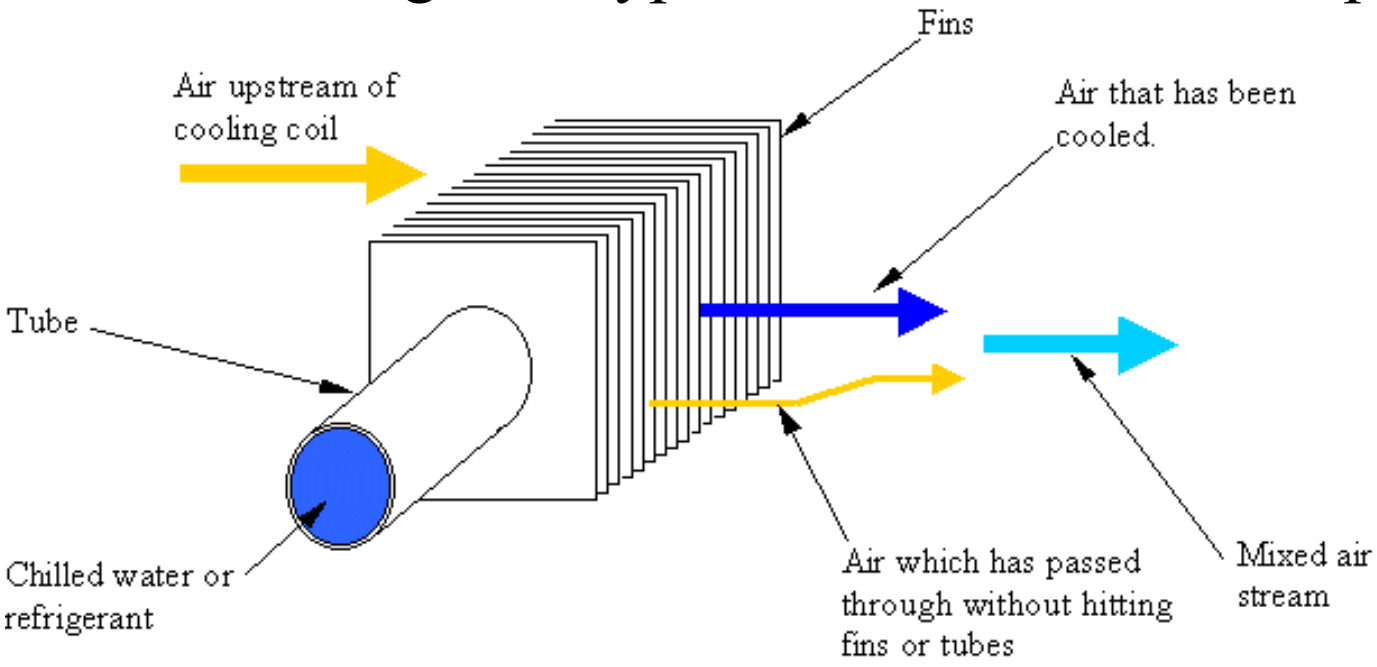


- Specific enthalpy difference: $q = m \text{ x } (h_a - h_b)$
- Sensible heat: $q_S = m_a \text{ x } c_p \text{ x } (t_b - t_a)$
- Latent heat: $q_L = m_a \text{ x } h_{fg}$
- Contact factor (cooling coil):

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

- Bypass factor = 1 – Contact factor

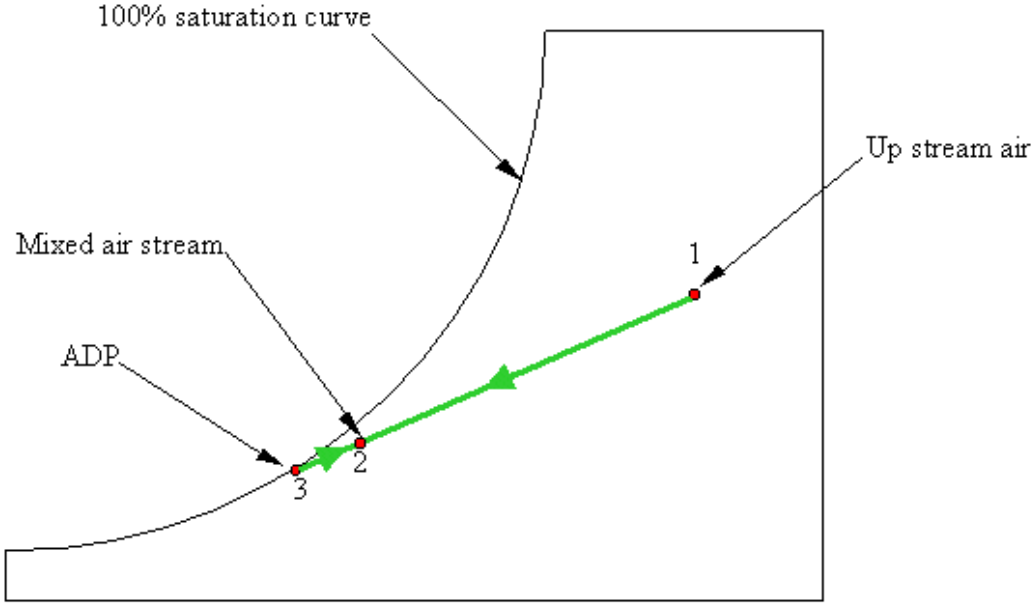
Cooling coil bypass/contact factor and apparatus dew point



A SECTION OF COOLING COIL SHOWING AIR STREAMS

The percentage of air that passes through the coil unchanged is called the bypass factor.

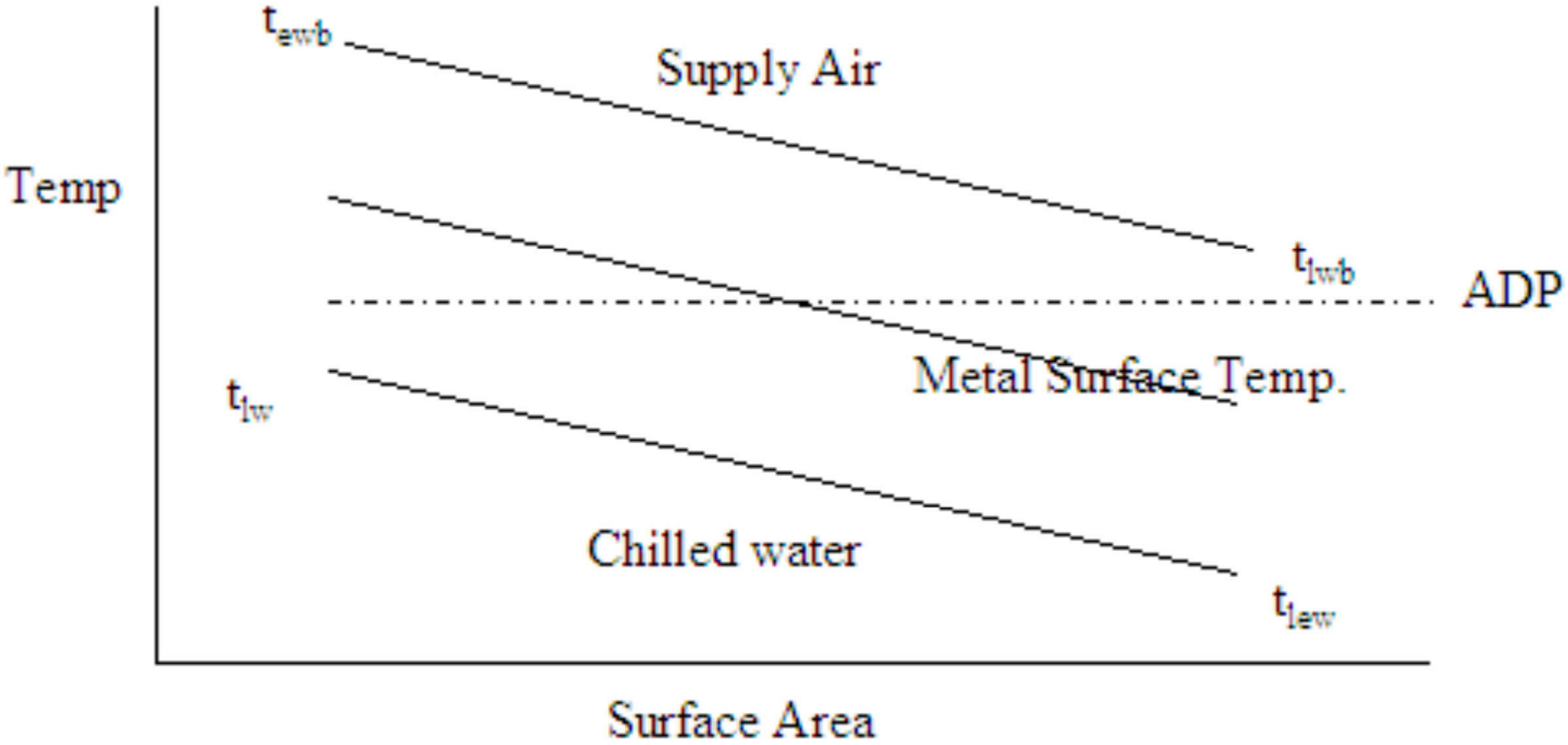
ADP = apparatus dew point
It is the coil surface dew point temperature required to accomplish a cooling/dehumidifying process.



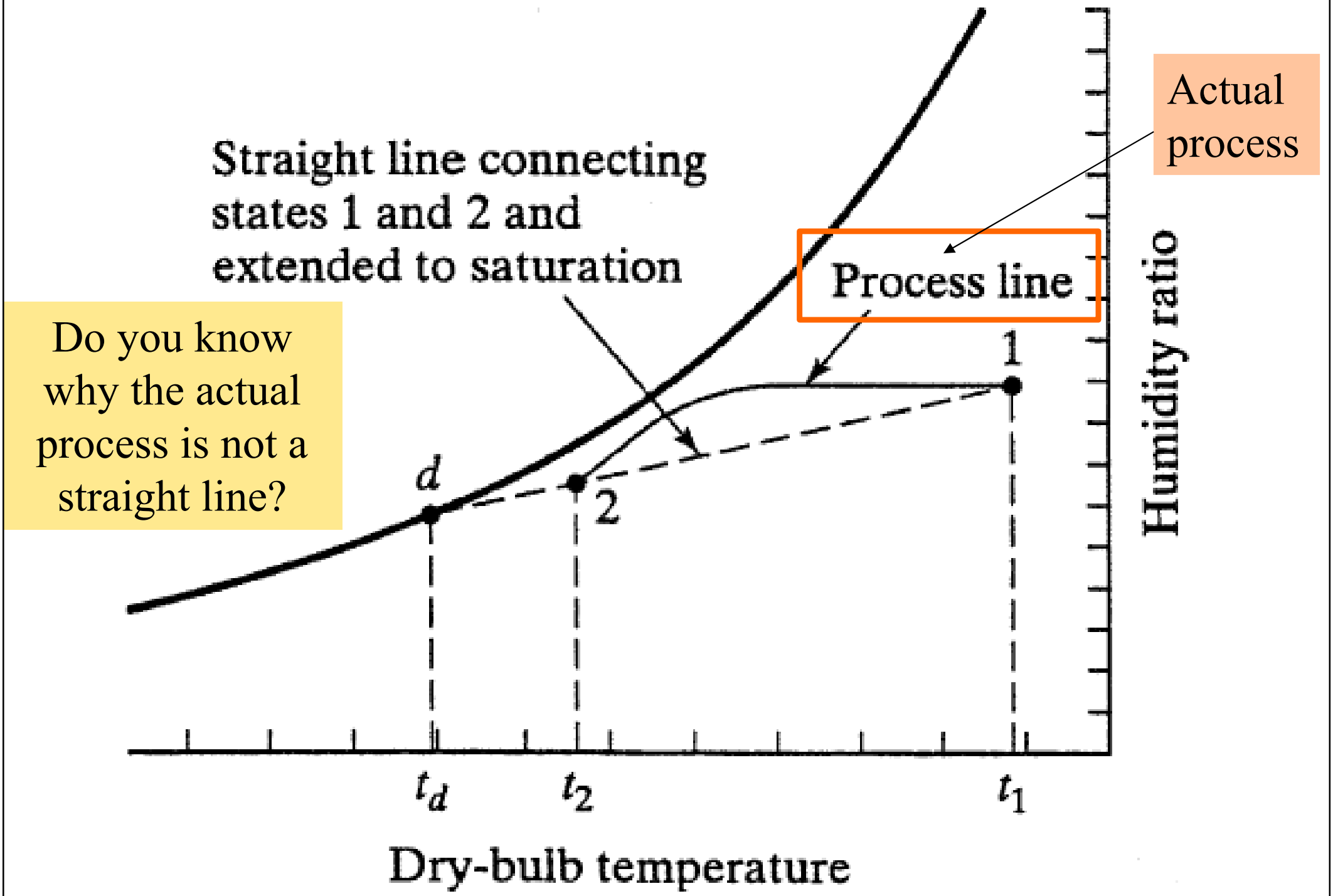
PSYCHROMETRIC CHART SHOWING COOLING COIL CONTACT FACTOR

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

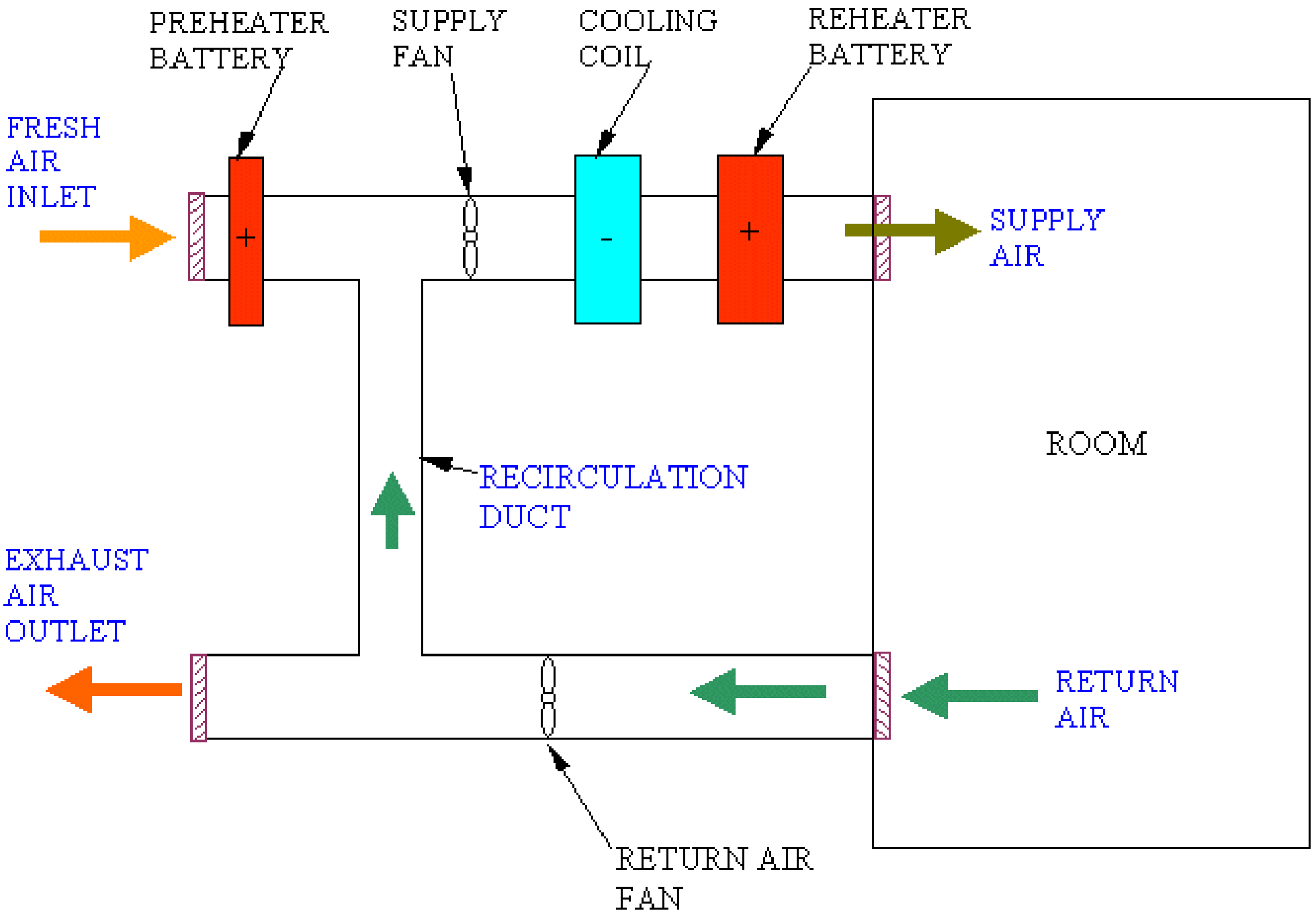
Relationship of apparatus dew point (ADP) to supply air and chilled water temperatures



Cooling and dehumidification process line

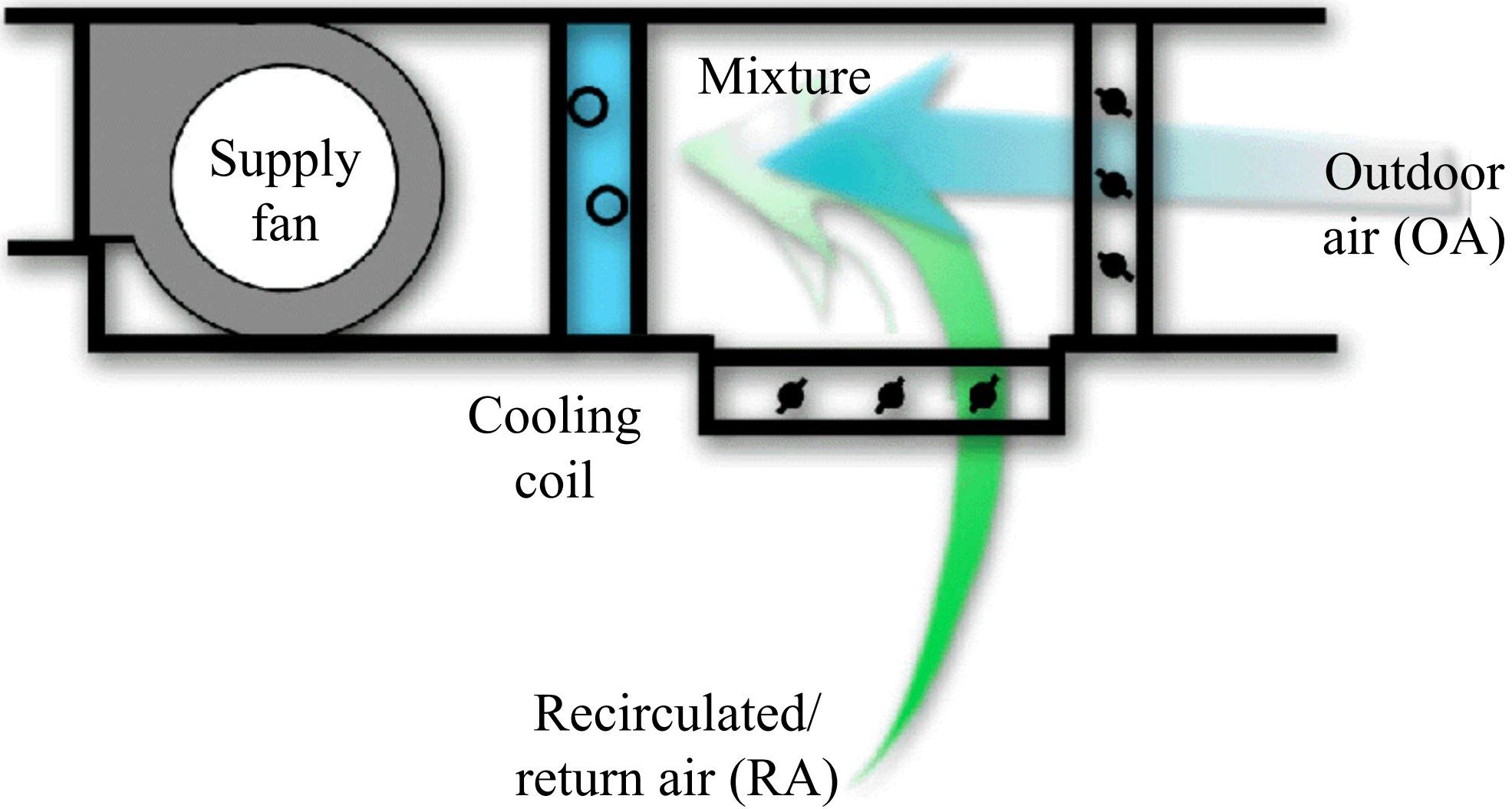


Major components of the HVAC air-side system



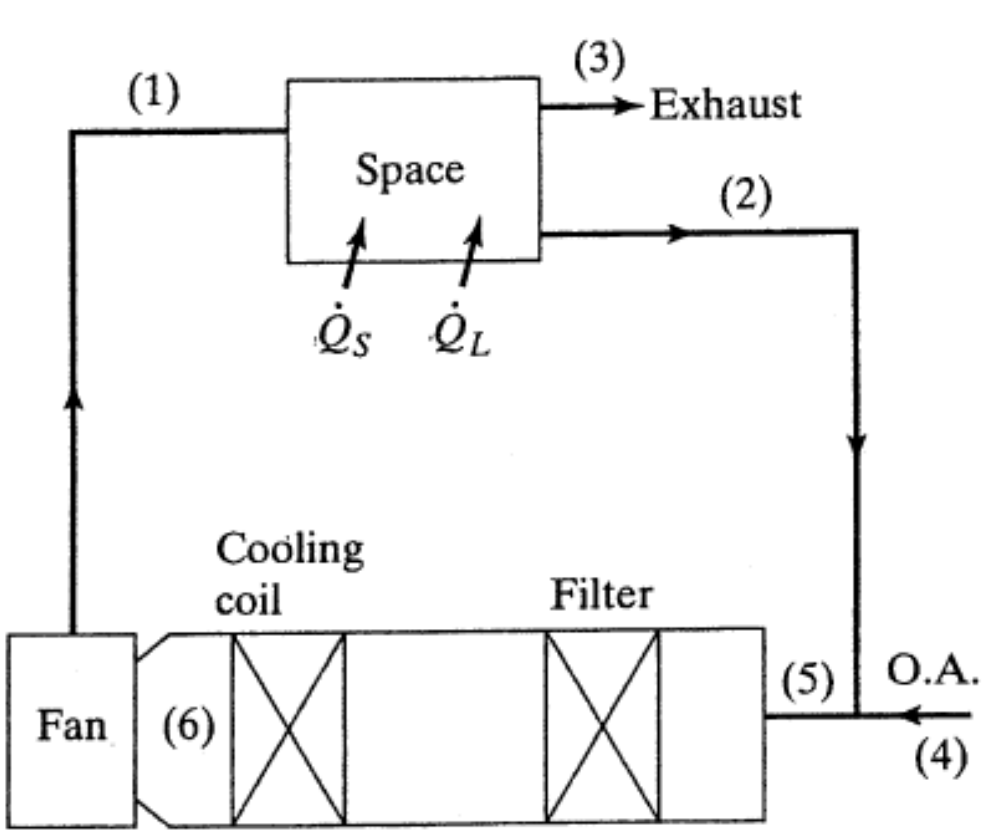
(Source: http://www.arca53.dsl.pipex.com/index_files/psy1.htm)

Determining entering air conditions

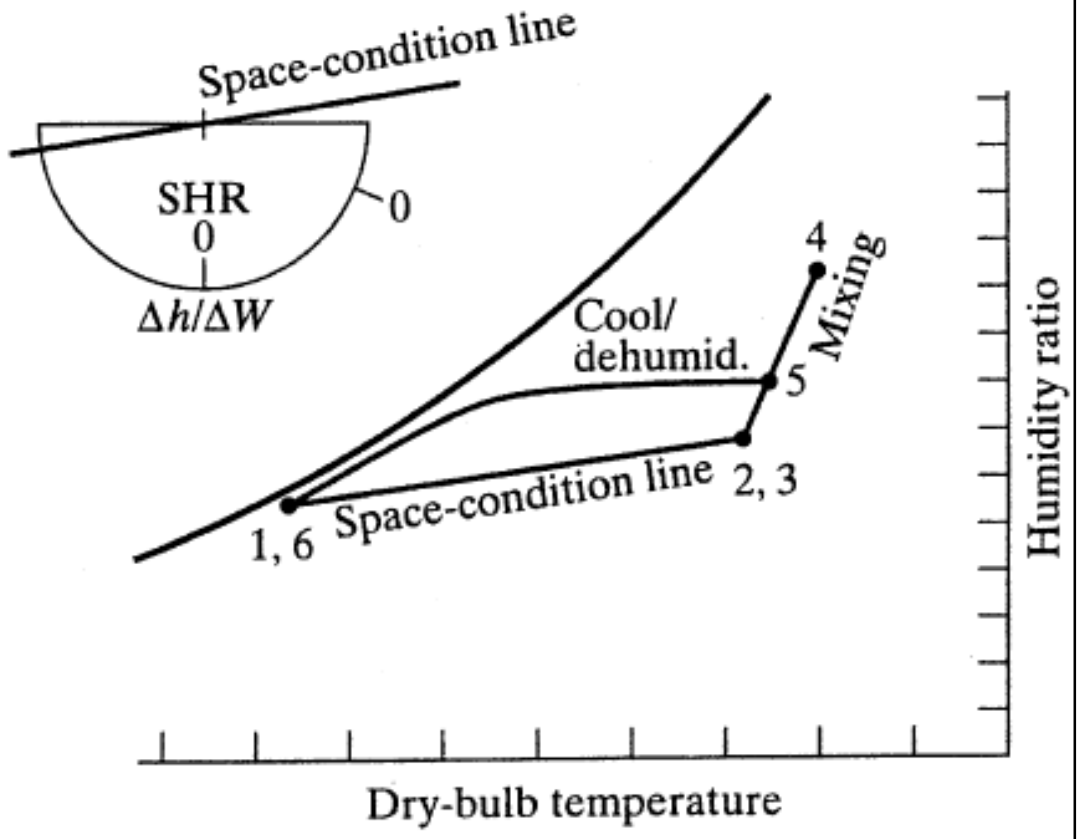


(Source: Trane)

Simple air conditioning cycle



(a)

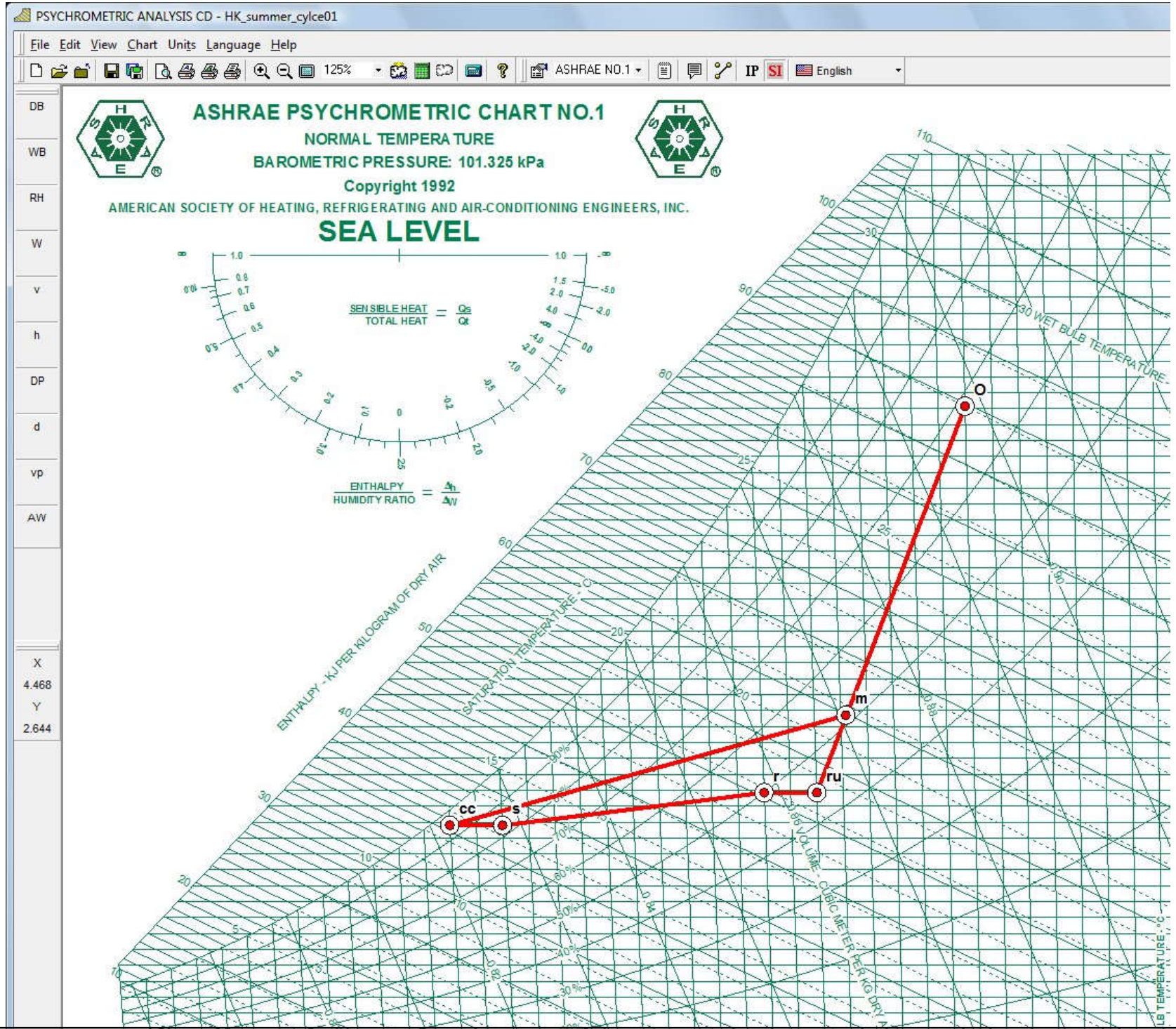


(b)

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

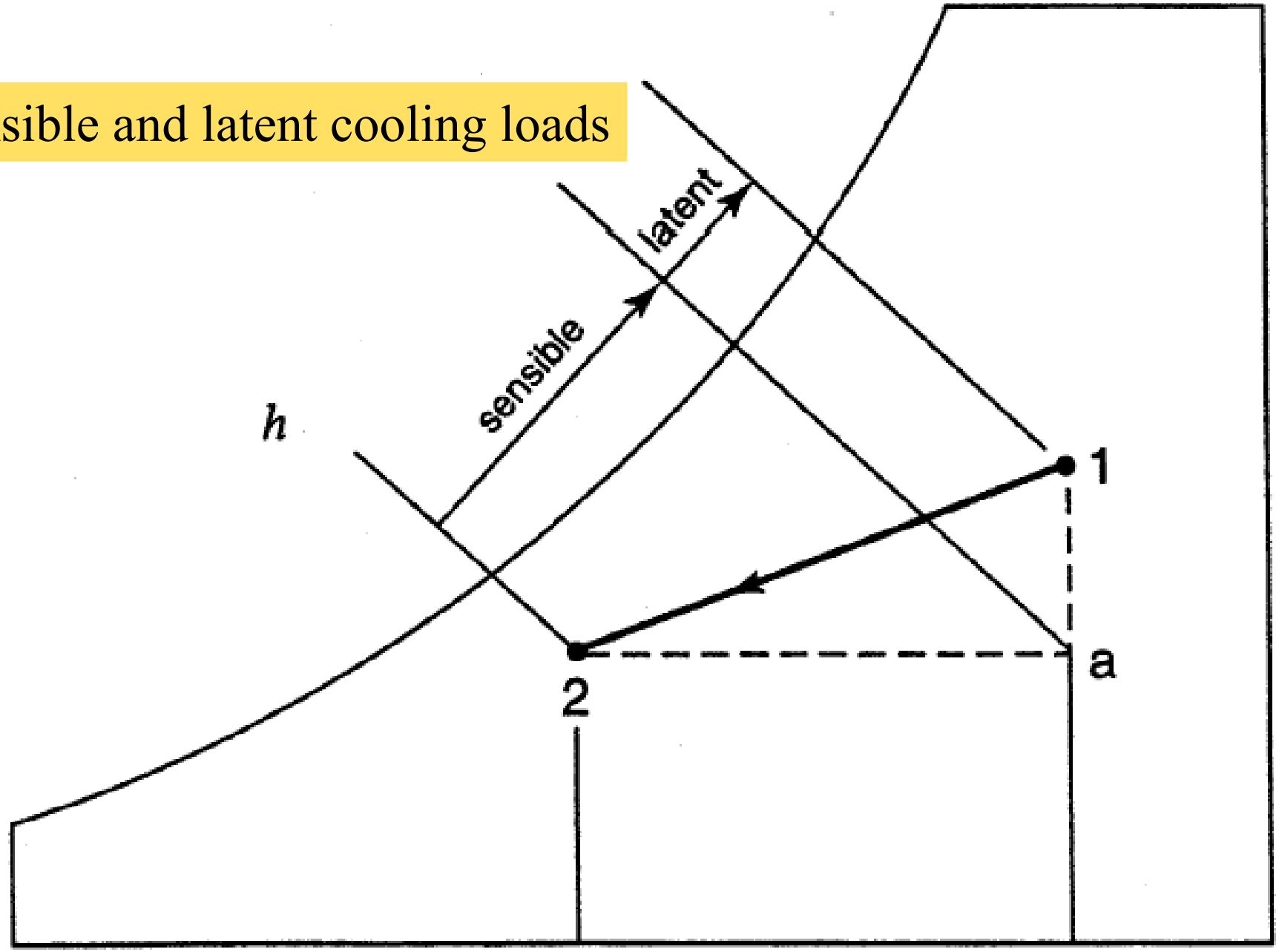
- Outdoor: DBT = 33 ºC; WBT = 28 ºC; flow = 20% of supply air
- Indoor: DBT = 25 ºC; %RH = 50%
- Air leaving cooling coil: DBT = 13 ºC; %RH = 95%

An example of Hong Kong summer air-conditioning cycle

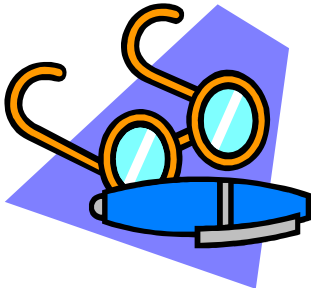


Using psychrometric chart to represent different HVAC systems (provide a visualization of the processes of air-conditioning cycles)

Sensible and latent cooling loads



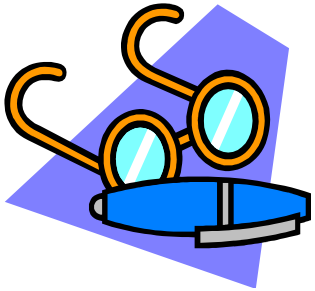
Psychrometric Processes



- Video demonstration examples of calculations using the psychrometric chart

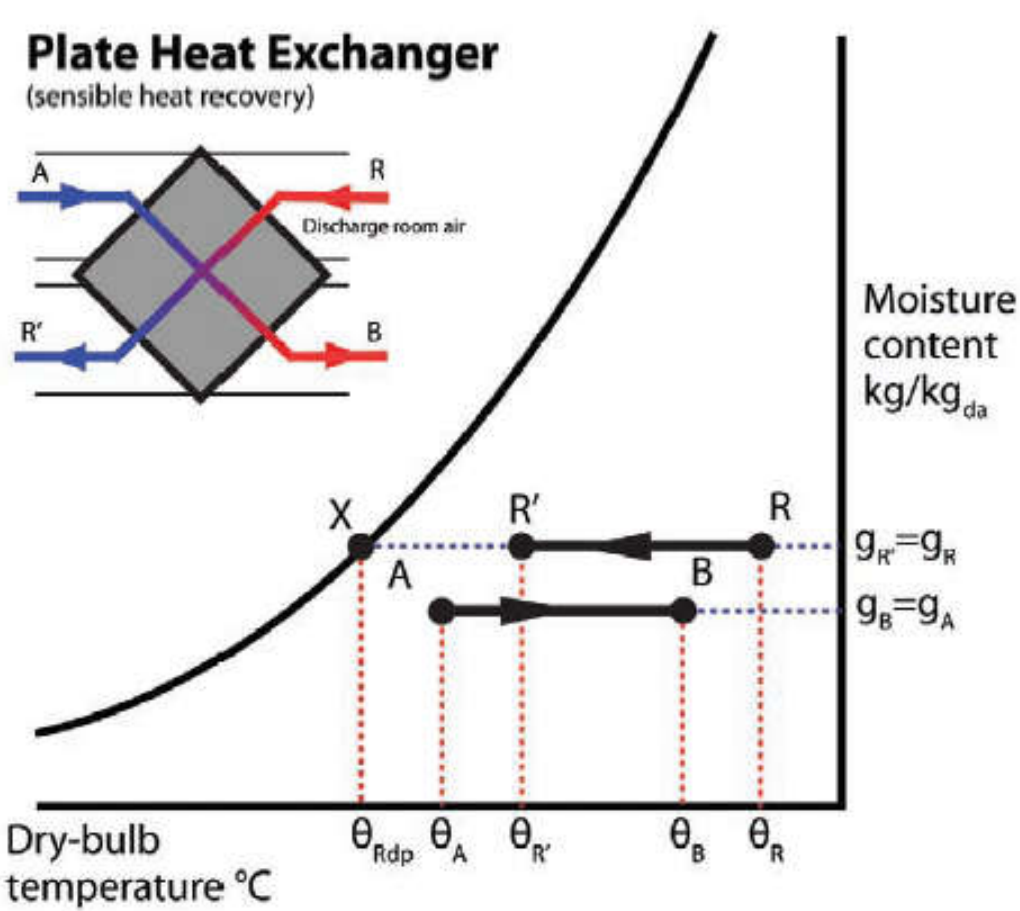
  - An Example Using the Psychrometric Chart (6:25) http://youtu.be/xzT9y0QZz20
  - Use Psychrometric chart for cooling moist air (9:45) http://youtu.be/A6PVsARawvs
- Exercises on Advanced Psychrometry (worked examples)
  - http://ibse.hk/MEBS7012/advanced_psychrometery_exercise.pdf

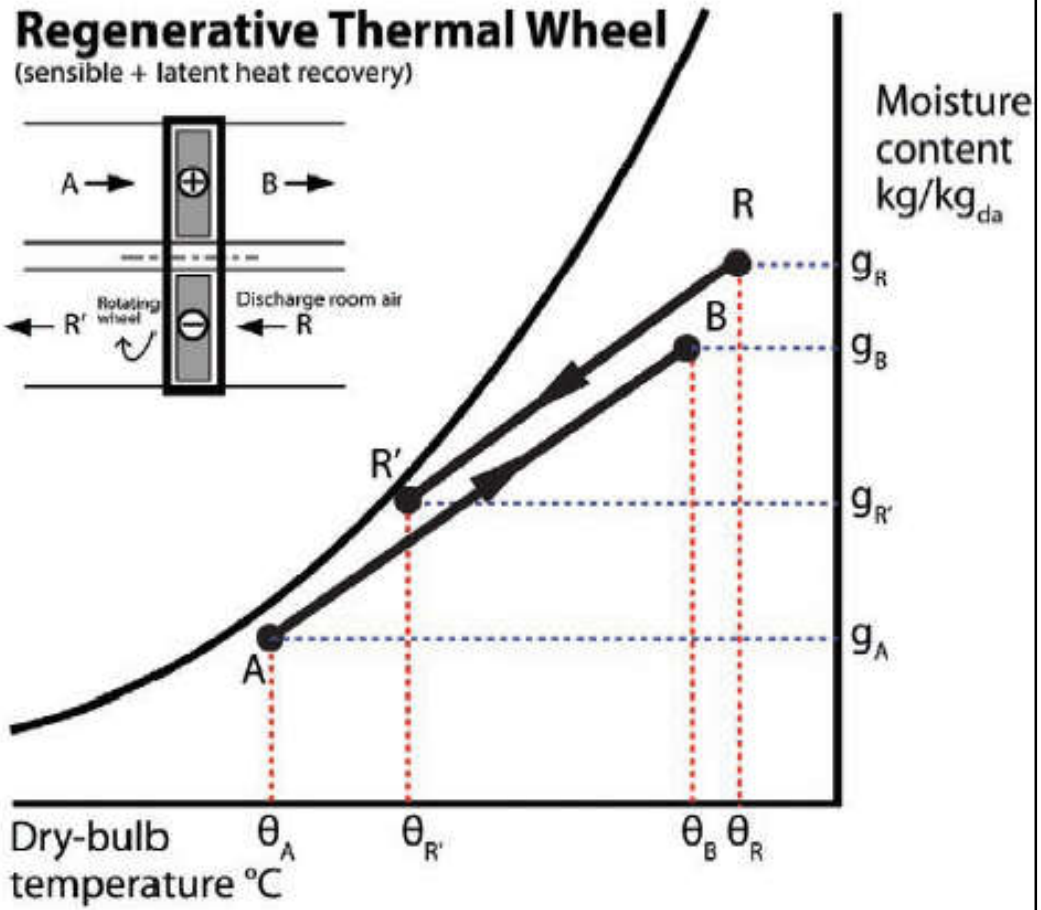
Psychrometric Processes



- Typical calculations:
  - 1. Sensible heat ratio (SHR)
    - SHR is the ratio of sensible heat load to total heat load
  - 2. Space cooling load
  - 3. Cooling coil's load/capacity
  - 4. Humidification capacity
  - 5. Mixing processes
    - Using principles of heat balance & conservation of mass

The psychrometrics of HVAC sub-systems

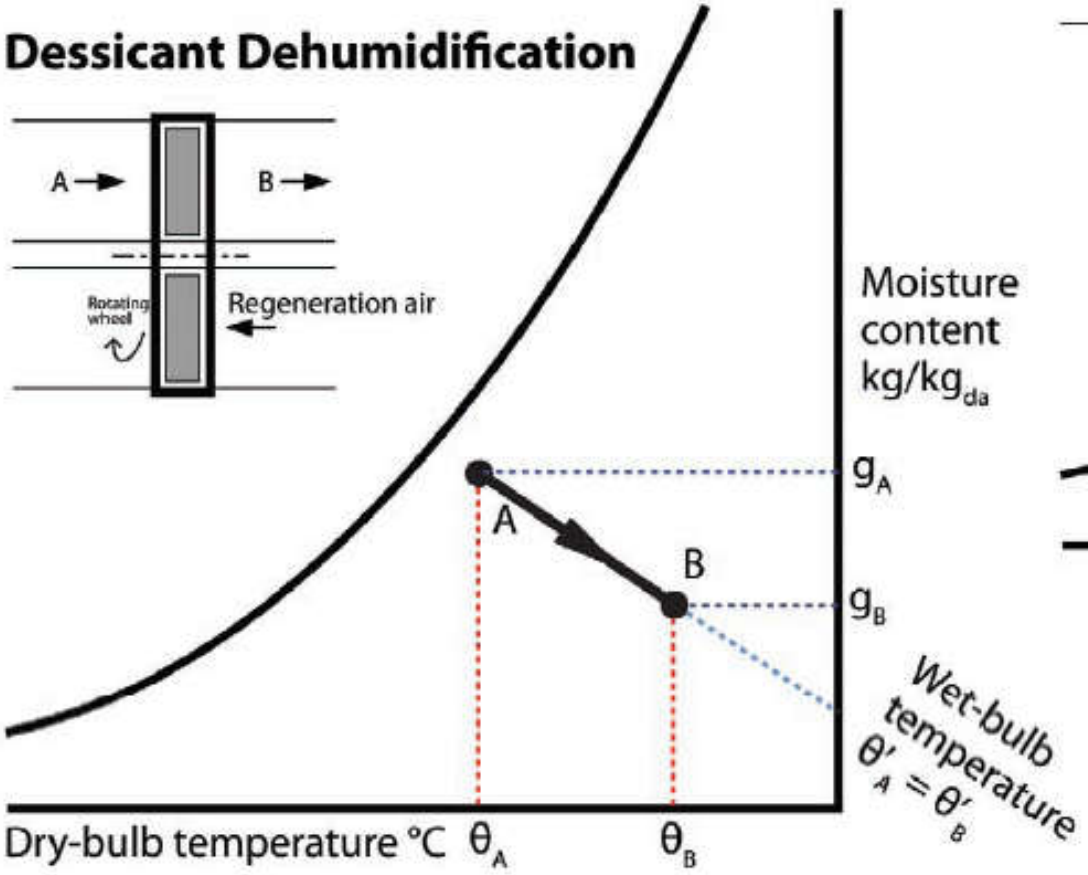


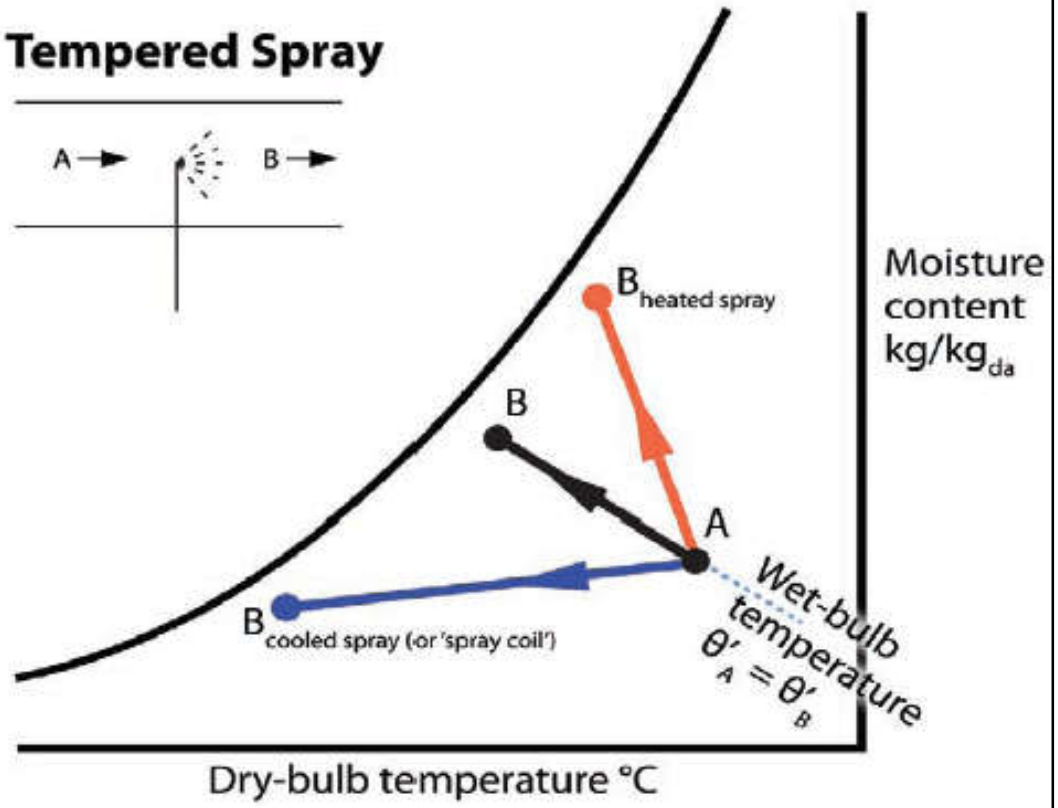


Do you know how to represent the processes of different HVAC sub-systems on the psychrometric chart?

(Source: CIBSE Journal CPD Module 11: The psychrometrics of HVAC sub-systems https://www.cibsejournal.com/cpd/modules/2009-12/)

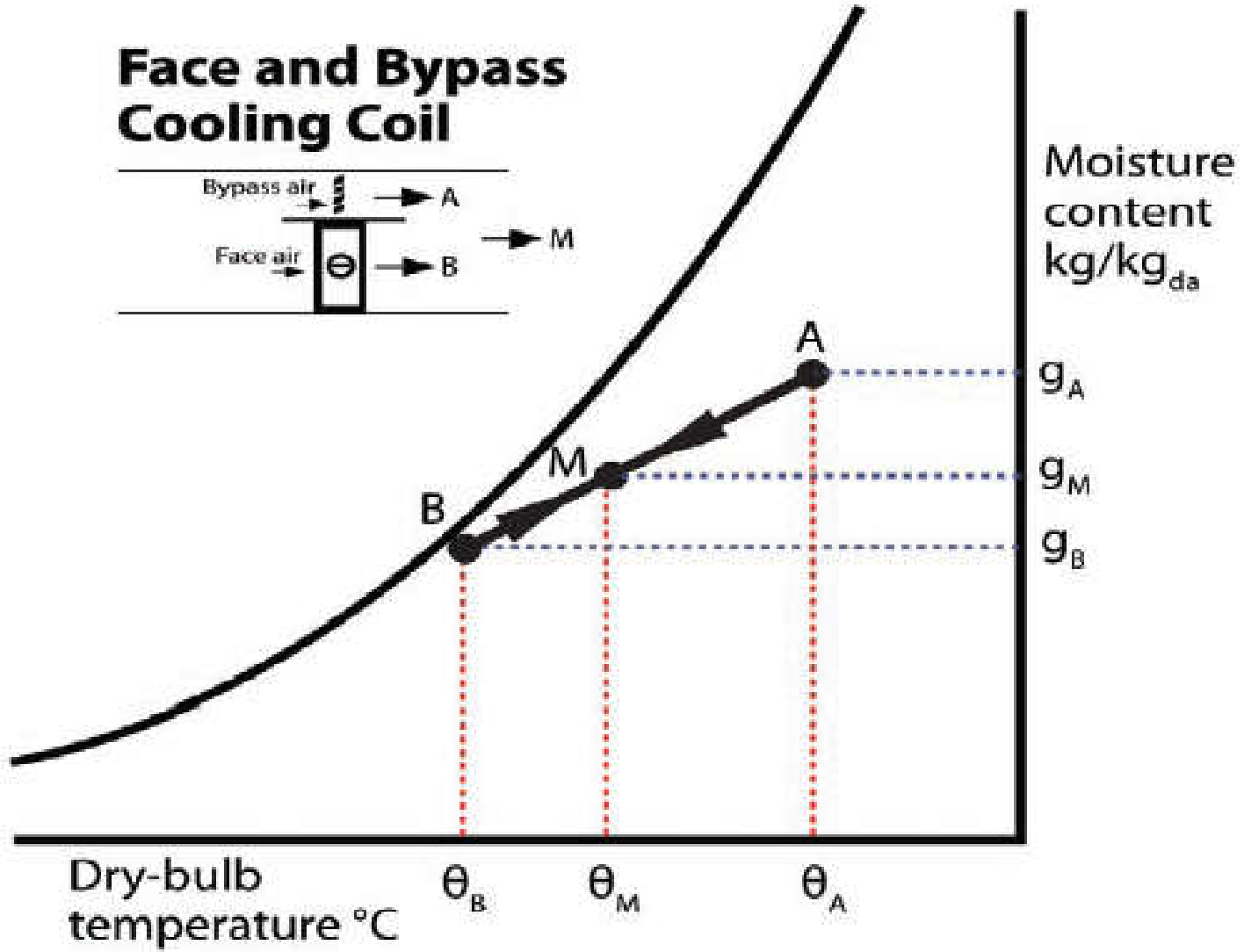
The psychrometrics of HVAC sub-systems (cont'd)





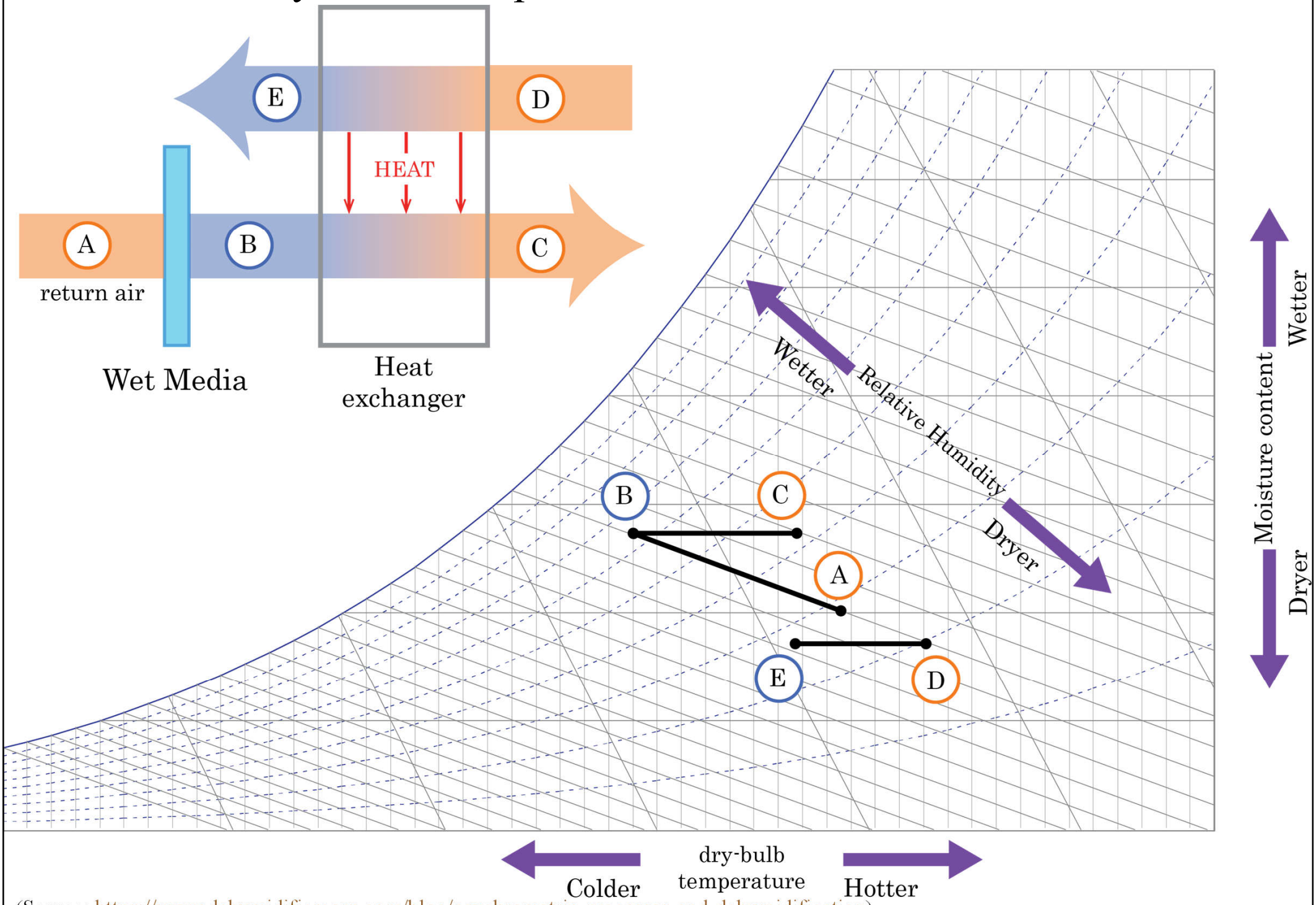
(Source: CIBSE Journal CPD Module 11: The psychrometrics of HVAC sub-systems https://www.cibsejournal.com/cpd/modules/2009-12/)

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



(Source: CIBSE Journal CPD Module 11: The psychrometrics of HVAC sub-systems https://www.cibsejournal.com/cpd/modules/2009-12/)

Psychrometric processes and dehumidification



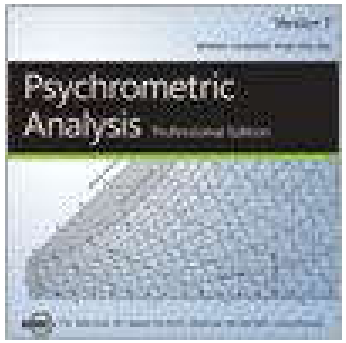
(Source: https://www.dehumidifiercorp.com/blog/psychrometric-processes-and-dehumidification)

Psychrometric Software

- Latest trends:
  - Apply computer software & mobile apps for psychrometric chart and calculations
  - Online psychrometric charts and calculators
  - Use of psychrometric chart analysis for climatic data, thermal comfort, system design & operation of HVAC or drying systems (e.g. for food, medicine & agriculture)

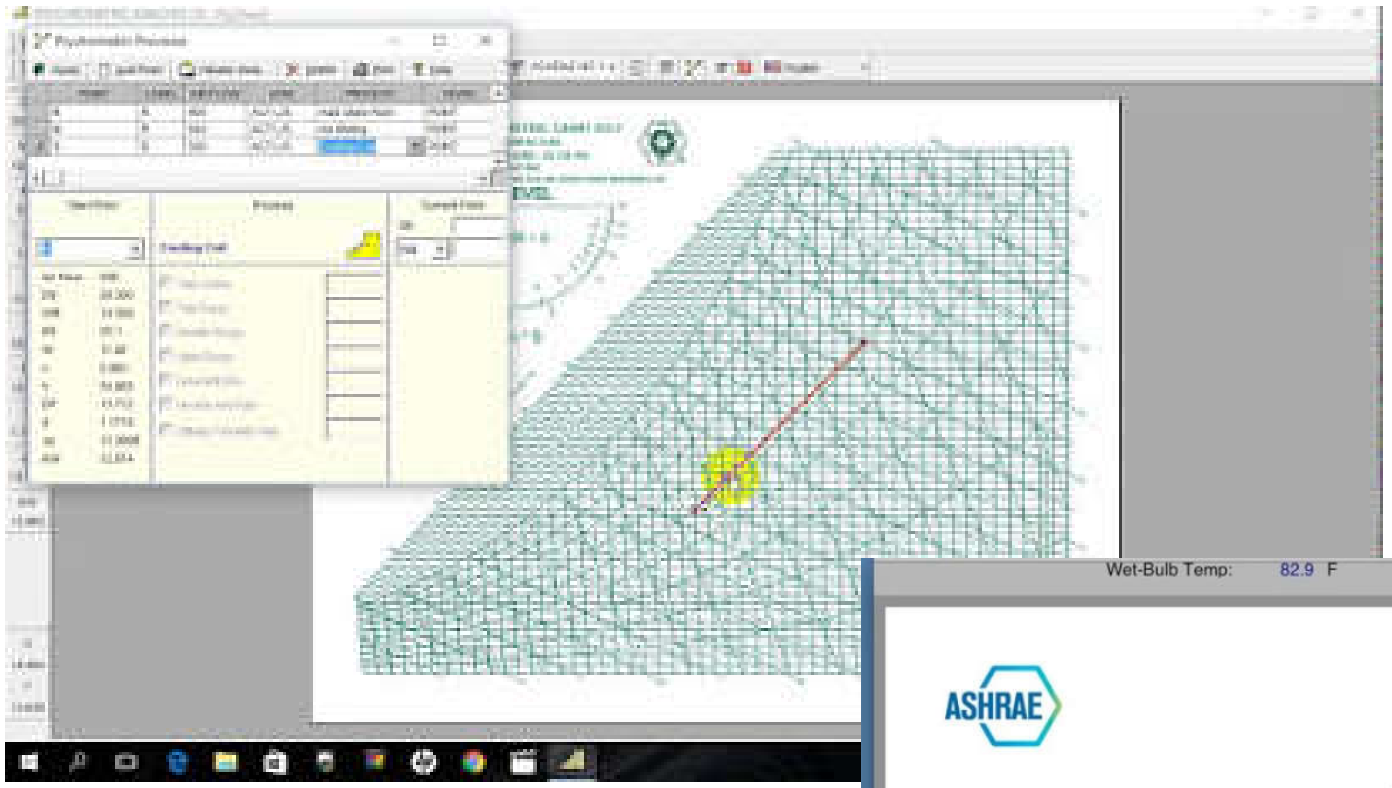
Psychrometric Software

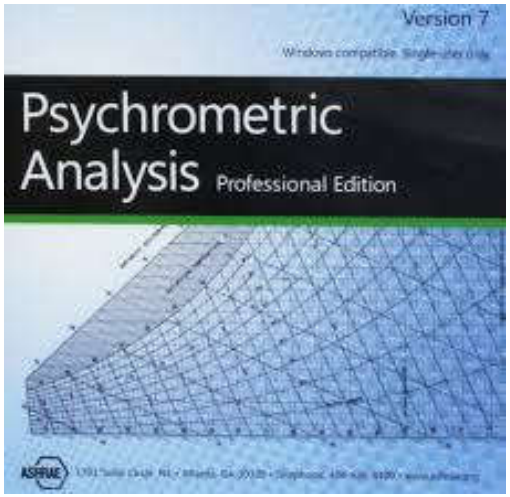
- ASHRAE Psychrometric Analysis CD-ROM (2012, 2007, 2002) [AV 697 P97]
  - The program allows the user to plot typical psychrometric processes and perform the corresponding energy calculations
    - The program produces near-exact replications of the charts and can output a listing of points and processes in a tabular report with calculated properties and energy values for each. It includes a presentation of the ASHRAE climate data presented in the 2009 ASHRAE Handbook - Fundamentals

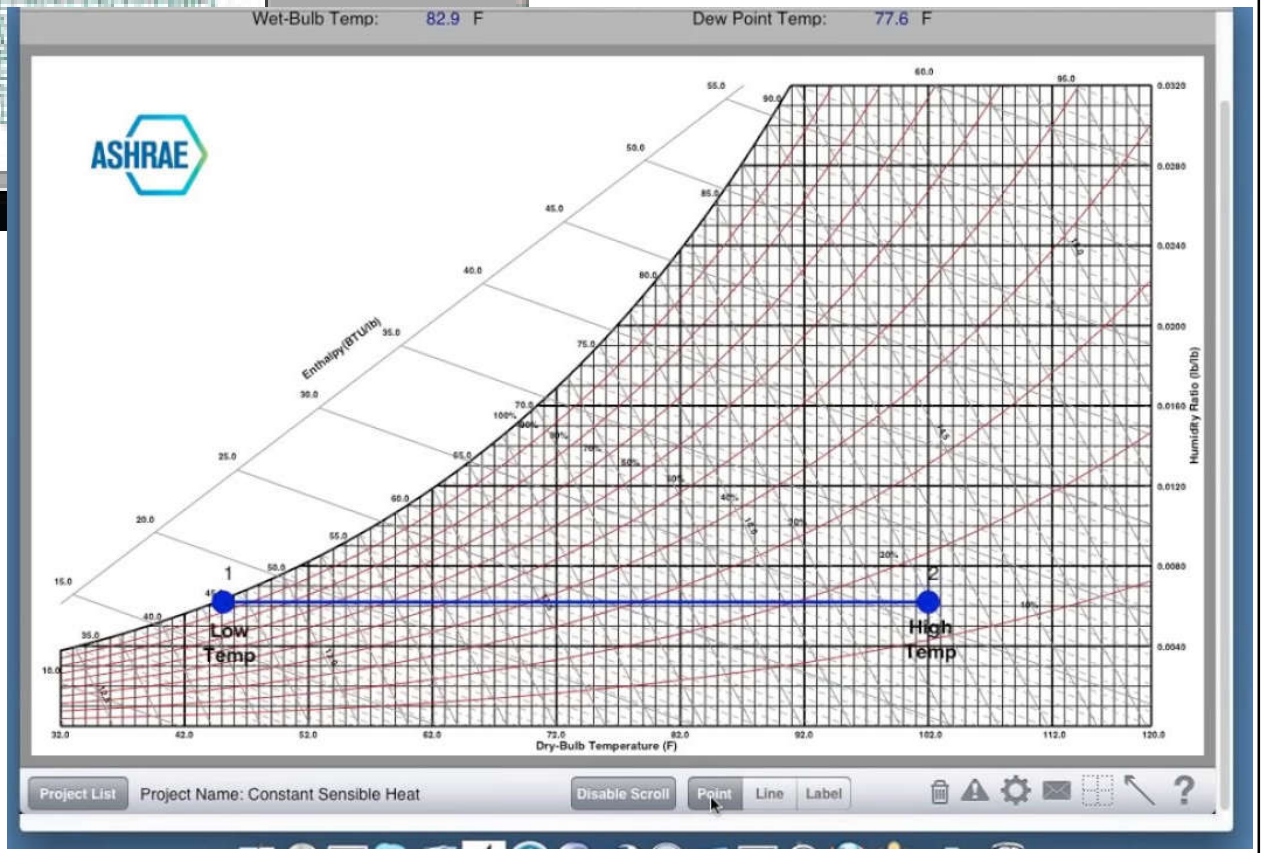


(More info & the ASHRAE Psychrometric Chart App: https://www.ashrae.org/technical-resources/bookstore/psychrometrics)

ASHRAE Psychrometric Analysis Software and Mobile App



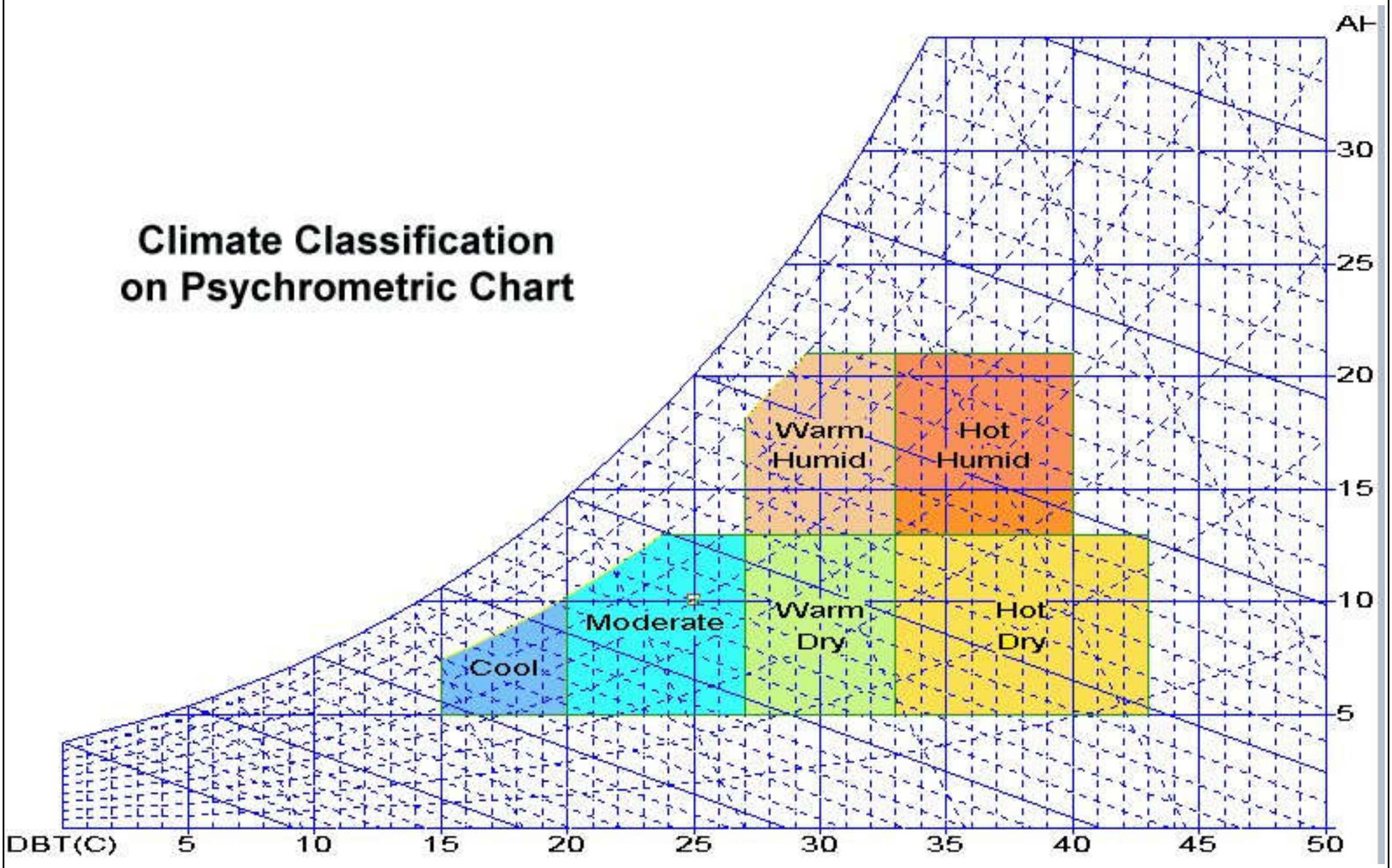




(Source: https://www.ashrae.org/technical-resources/bookstore/psychrometrics)

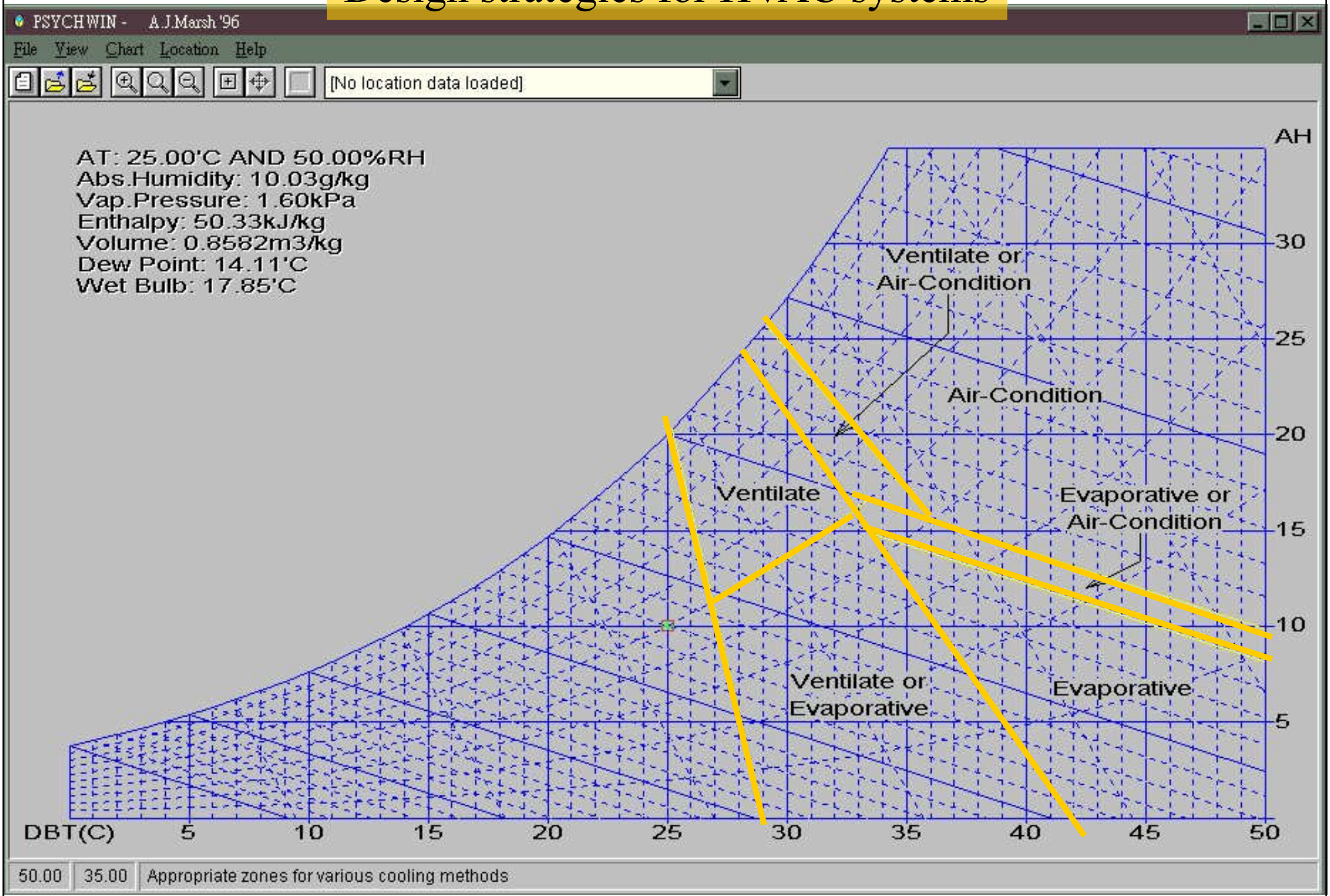
Psychrometric Software

- Other examples of psychrometric software:
  - ArchiSci Software – PSYCHWIN
    - http://ibse.hk/archisci.zip
  - Daikin's Psychrometrics tool
    - https://www.daikin.eu/en_us/customers/software-downloads/daikin-psychometrics-diagram-viewer.html
  - HDPsyChart (Hands Down Software) http://www.handsdownsoftware.com/Downloads.htm
  - Psychrometric Chart (PSY) software
    - http://www.vector.co.jp/soft/win95/business/se288946.html



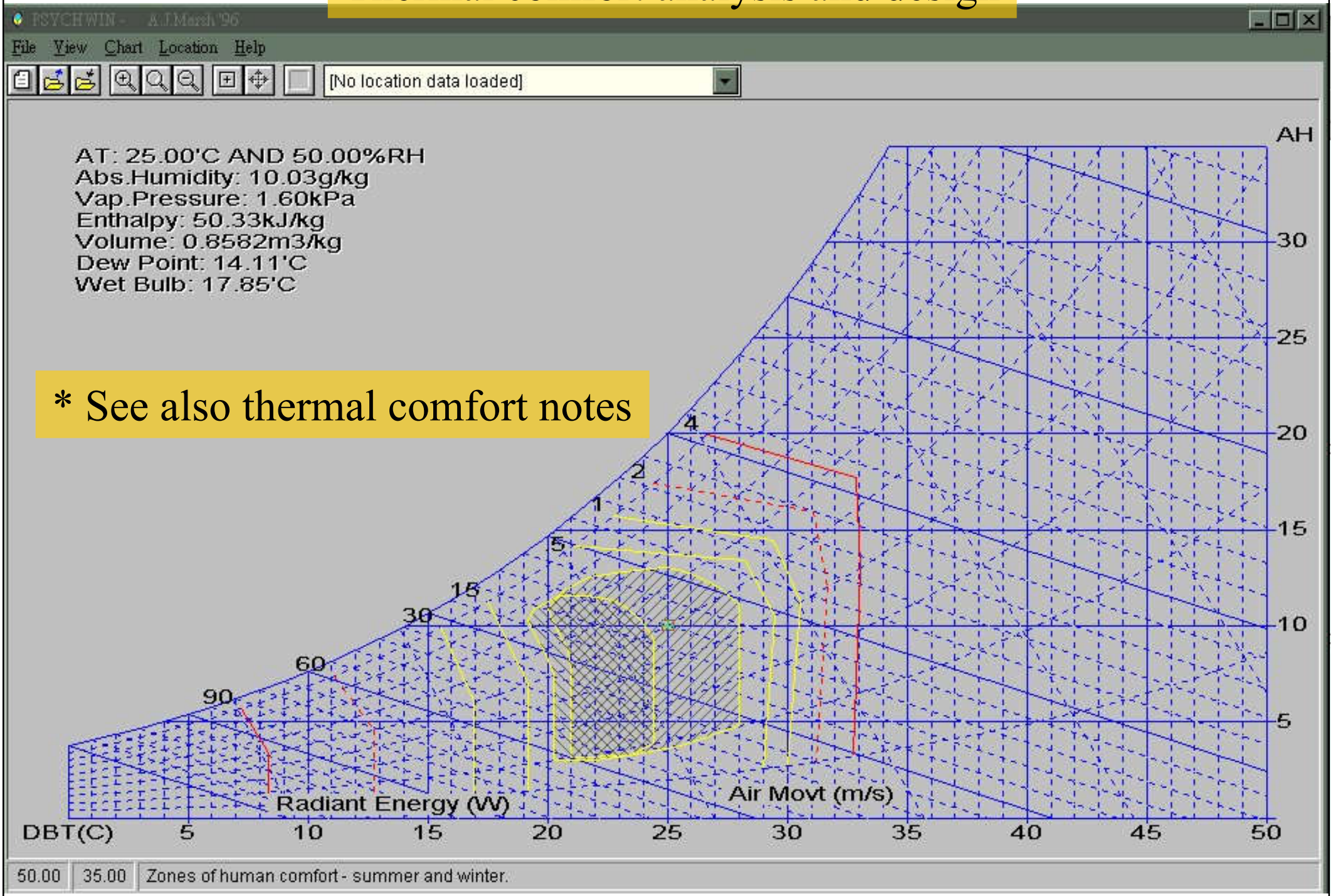
(Source: ArchiSci Software - PSYCHWIN)

Design strategies for HVAC systems



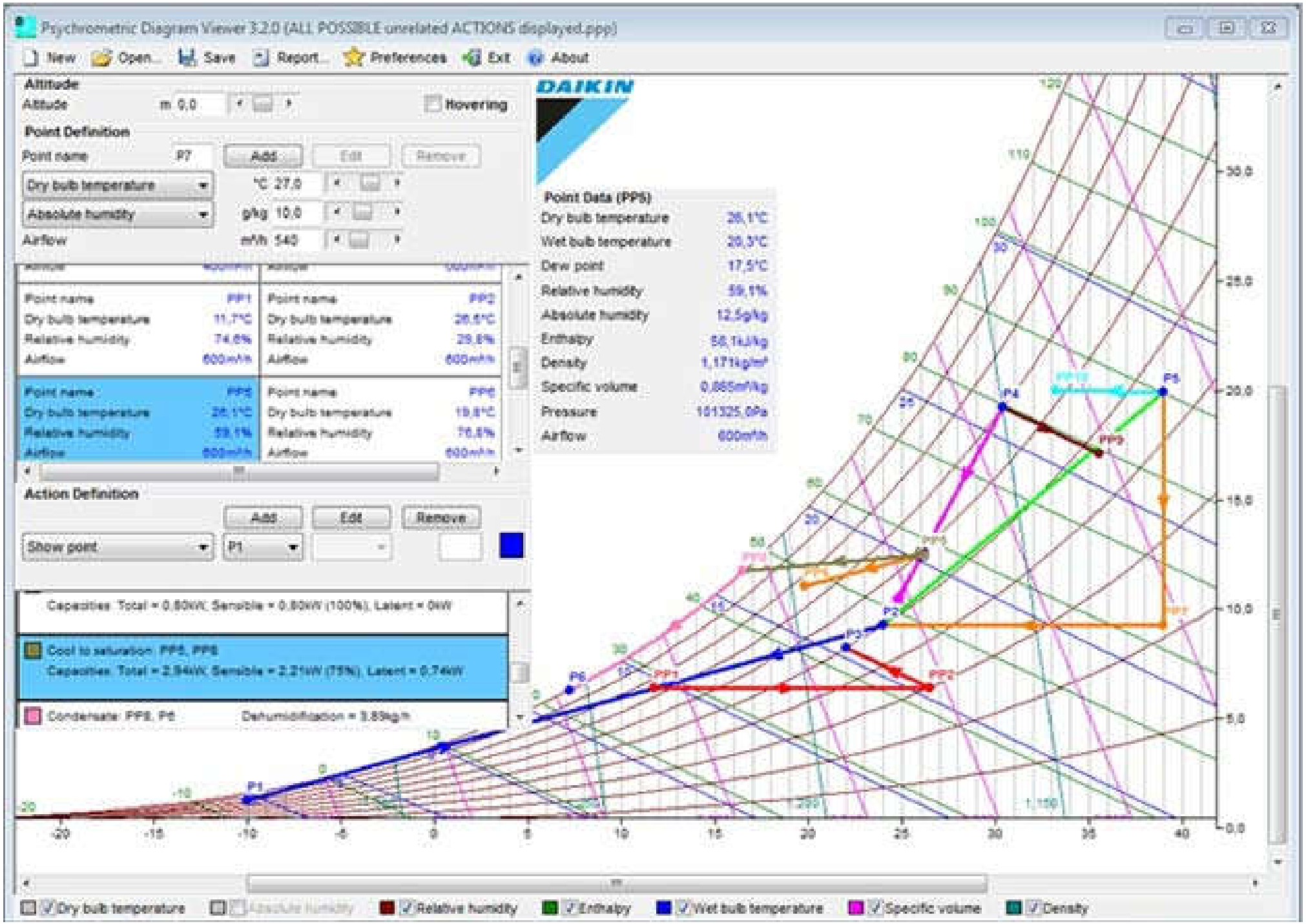
(Source: ArchiSci Software - PSYCHWIN)

Thermal comfort analysis and design



(Source: ArchiSci Software - PSYCHWIN)

Daikin psychrometric diagram viewer software

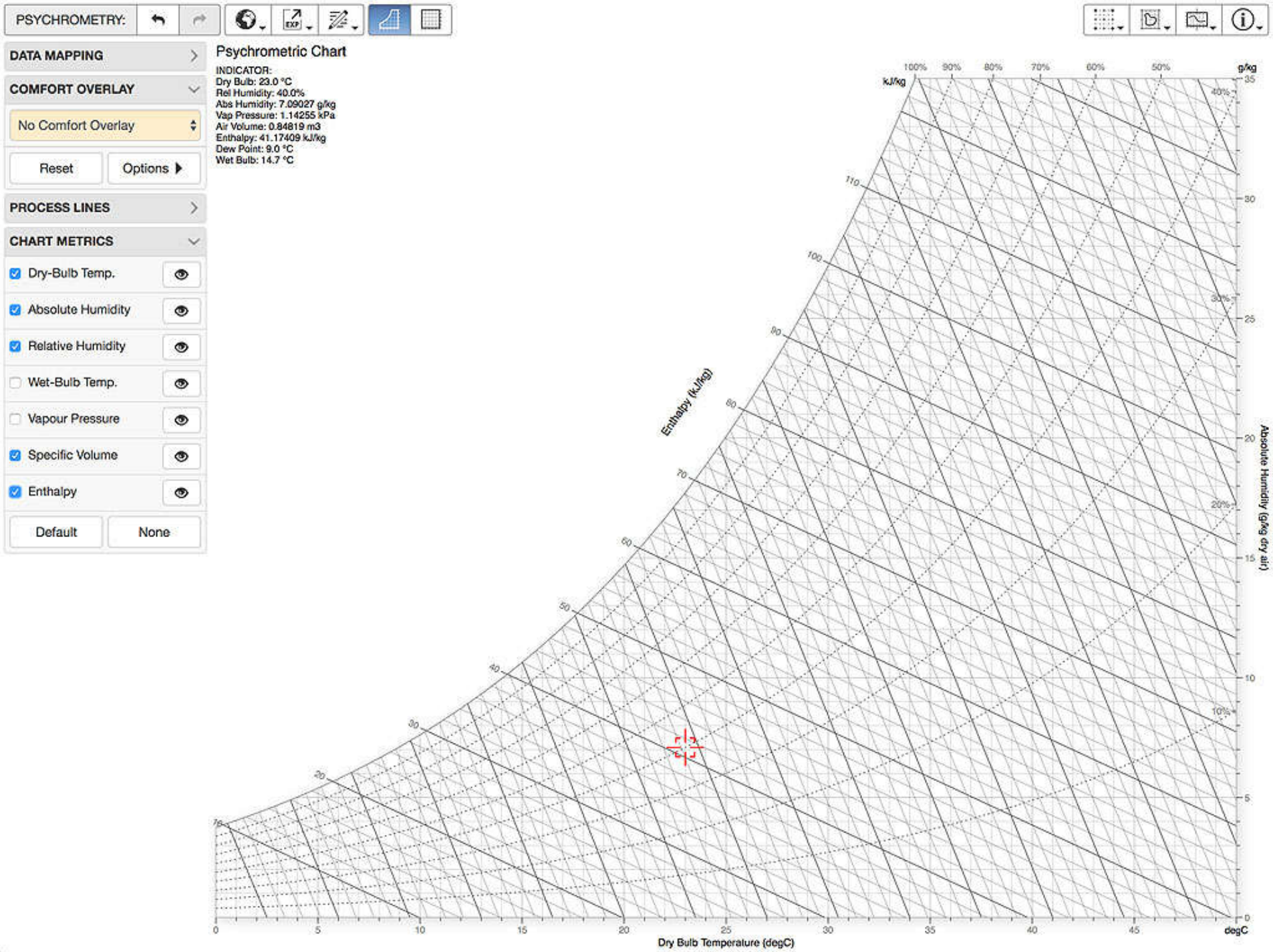


(Source: https://www.coolingpost.com/products/daikin-upgrades-psychrometric-software/)

Psychrometric Software

- Online psychrometric chart (examples)
  - Psychrometric Chart (from Dr. Andrew Marsh)
    - http://andrewmarsh.com/software/psychro-chart-web/
    - https://drajmarsh.bitbucket.io/psychro-chart2d.html
  - PsyOnline (by FlyCarpet) (English & Chinese)
    - http://www.flycarpet.net/en/PsyOnline
  - Online psychrometric chart and calculator
    - https://www.herramientasingenieria.com/onlinecalc/psychrometrics/psychrometrics.html

Psychrometric Chart (from Dr. Andrew Marsh)



(Source: http://andrewmarsh.com/software/psychro-chart-web/)

PsyOnline (by FlyCarpet)

www.flycarpet.net/en/PsyOnline

Home About Projects Contact

Free Online Psychrometric Chart World's first online, and only! A convenient, precise and powerful psychrometric chart & calculator tool for HVAC engineers.

Basic Process Cycle 1 Cycle 2 Setting Display 简体中文

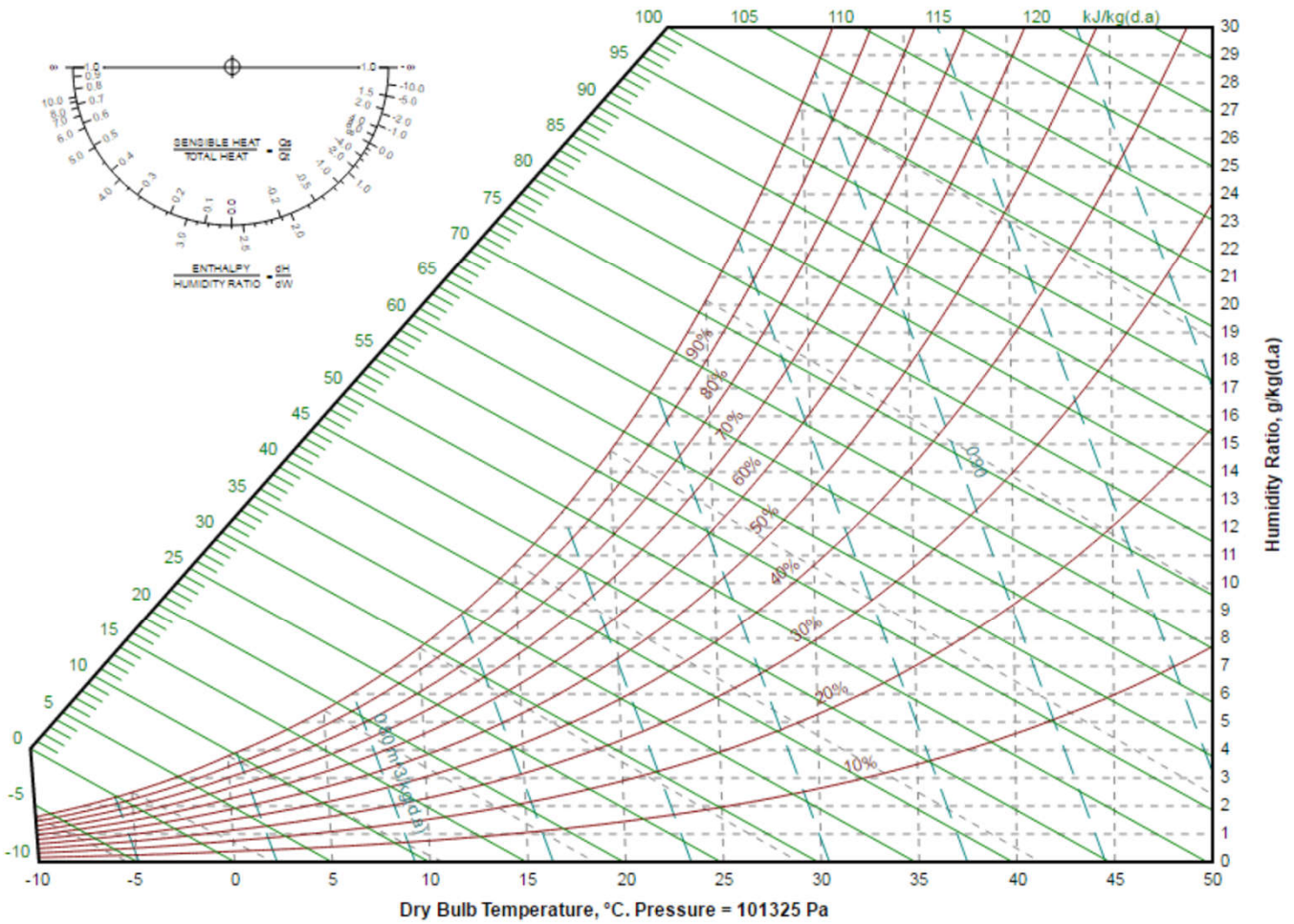
Click on chart for air properties

Or input data for air properties

T.Dry, °C	25
Rel.Humid, %	50

Quantity	Value	Units
P.Ambient		Pa
T.Dry.Bulb		°C
Humid.Ratio		g/kg(d.a)
Rel.Humid		%
T.Wet.Bulb		°C
T.Dew		°C
T.Saturation		°C
Enthalpy		kJ/kg(d.a)
P.Vapour		Pa
P.Sat.Vapour		Pa
Spec.Heat		kJ/(kg.K)

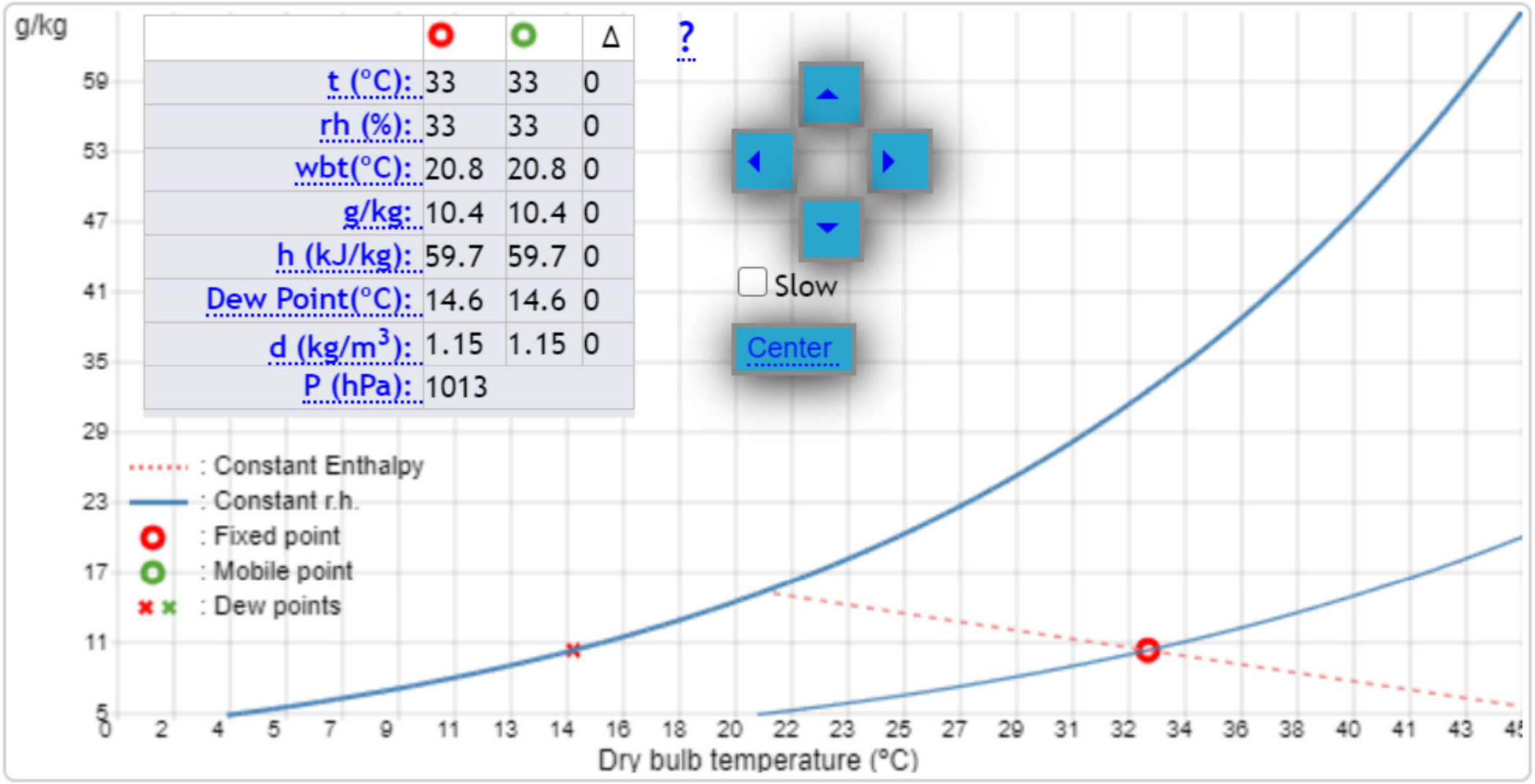
Stop and Play. We have a free small game for you: Survive Broken. Click to start play.



(Source: http://www.flycarpet.net/en/PsyOnline)

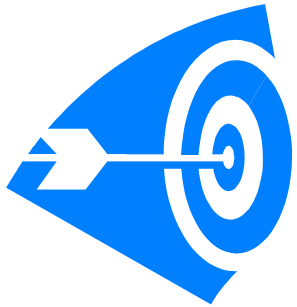
Online psychrometric chart and calculator

Interactive Psychrometric Diagram.



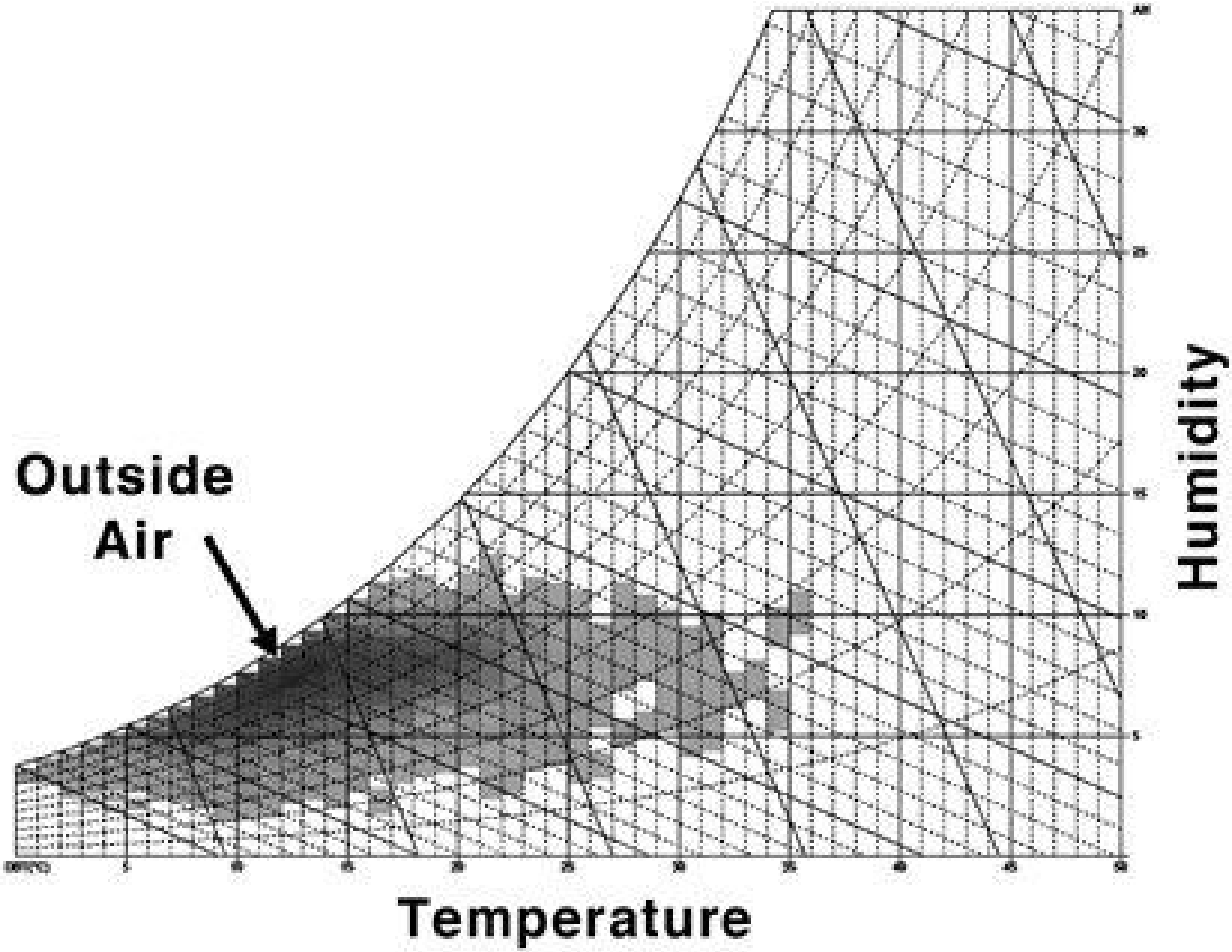
(Source: https://www.herramientasingenieria.com/onlinecalc/psychrometrics/psychrometrics.html)

Psychrometric Analysis



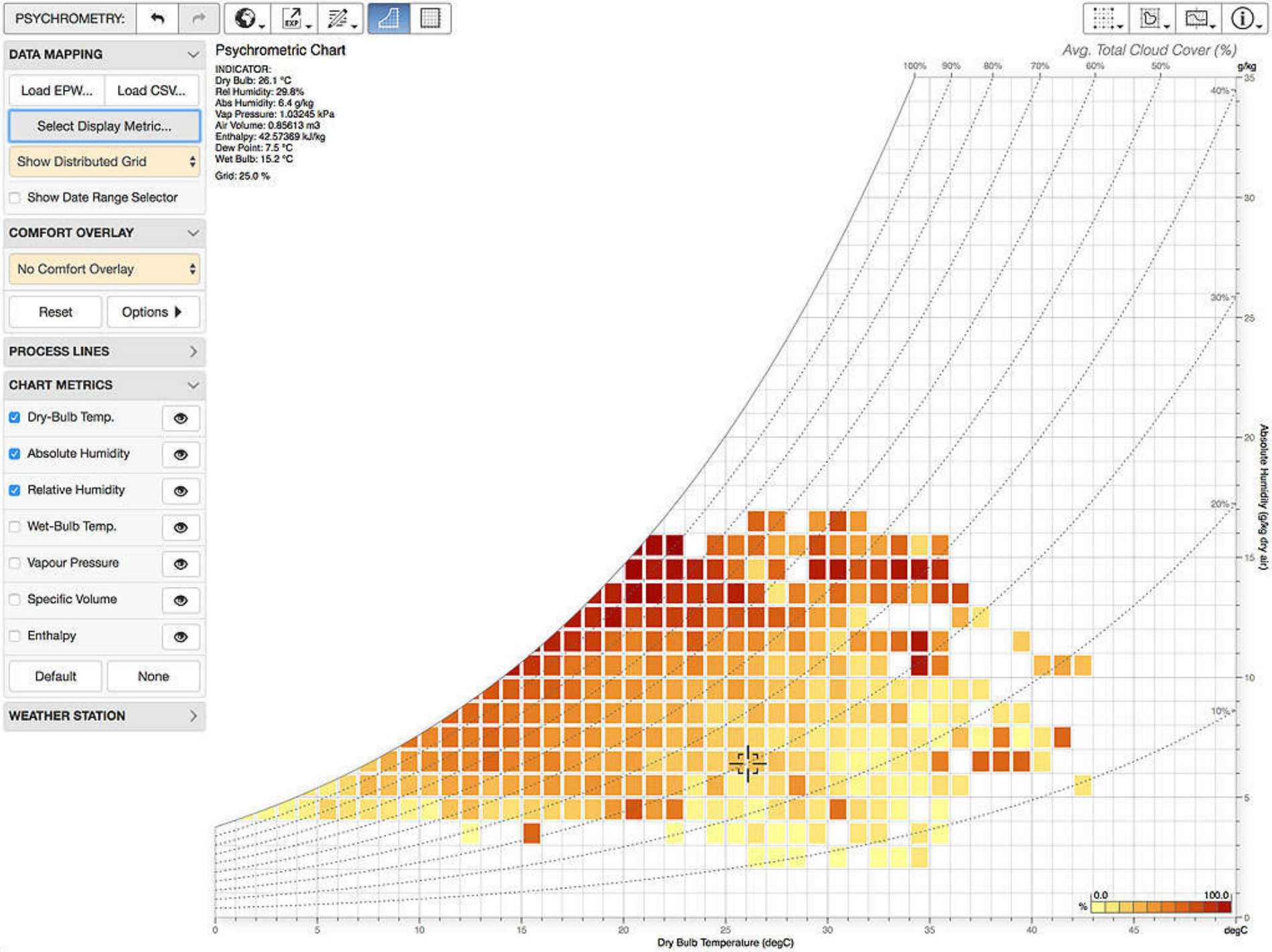
- Using psychrometric chart to analyse moist air
  - Climate analysis
    - Frequency distribution of annual weather data on psychrometric charts
  - Thermal comfort analysis
    - Bioclimatic analysis (such as Givoni bioclimatic chart)
    - Thermal comfort zones & index
      - ASHRAE Standard 55 (https://comfort.cbe.berkeley.edu/)
  - Cooling & ventilation strategies
    - Natural ventilation & passive cooling design

Analysis of outside air (climatic) conditions using a psychrometric chart



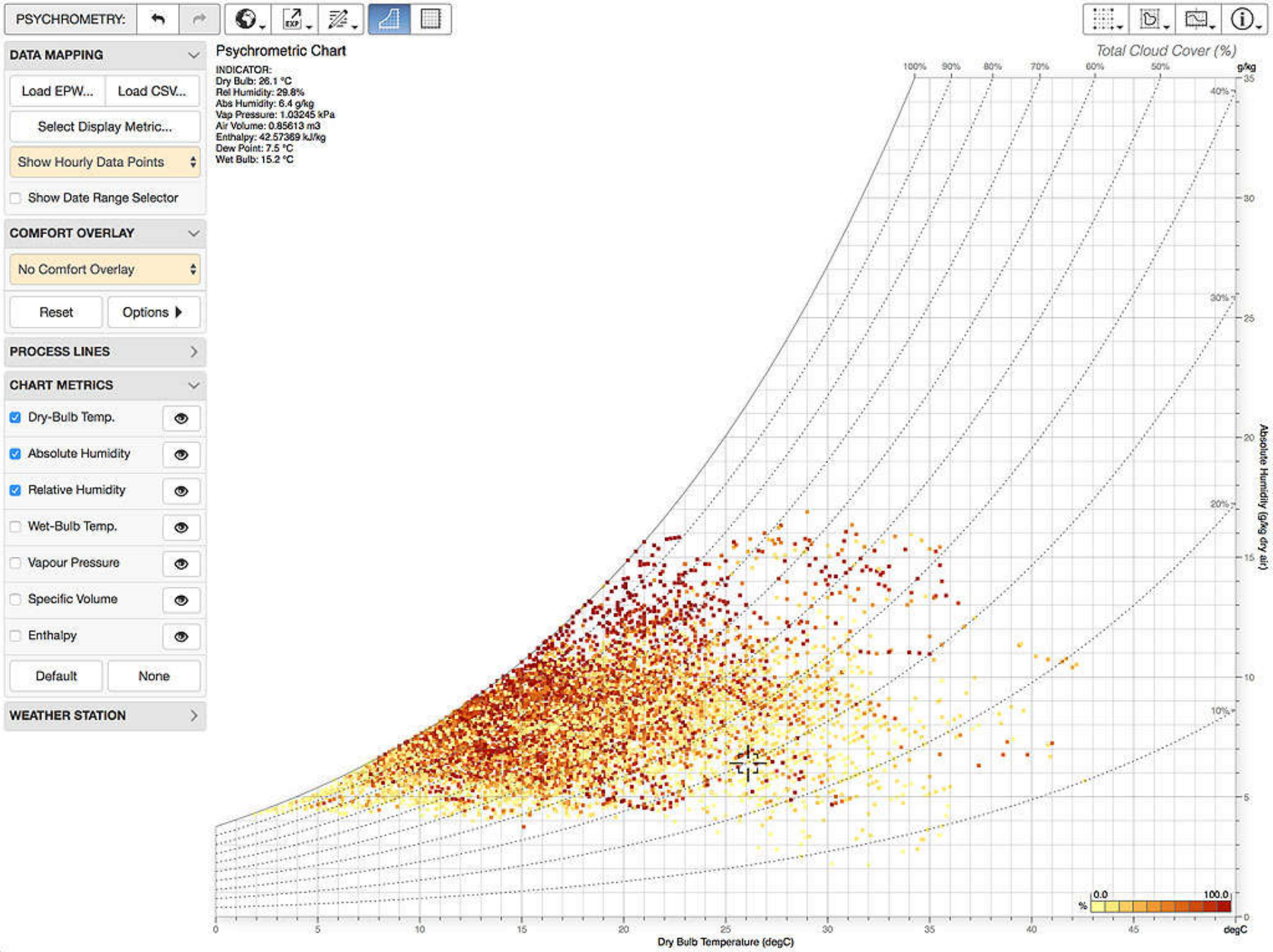
(Source: https://knowledge.autodesk.com/support/revit-products/getting-started/caas/simplecontent/content/psychrometric-charts-part-1.html)

Hourly climatic data as a distributed grid



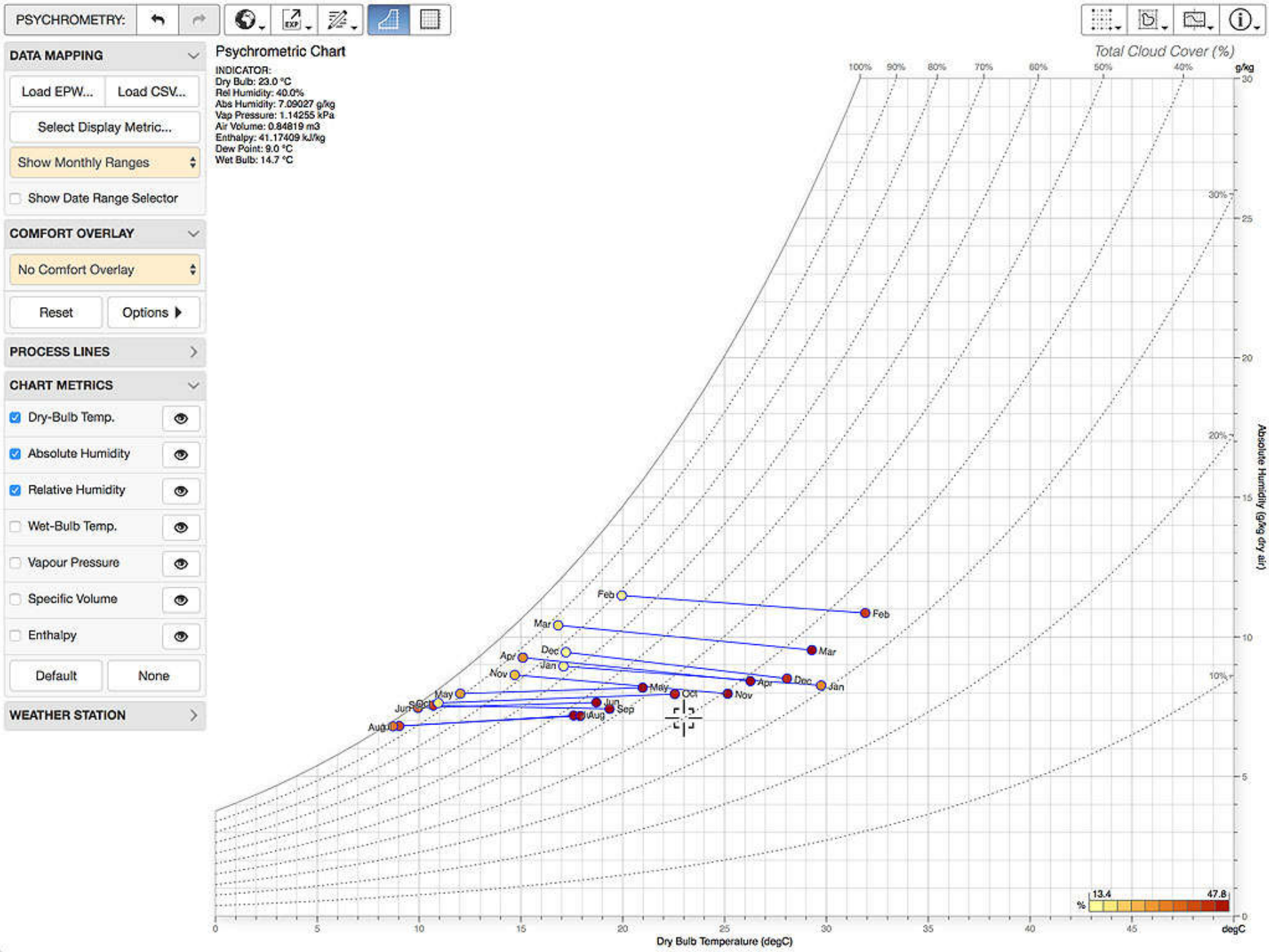
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Climatic data as individual hourly data points



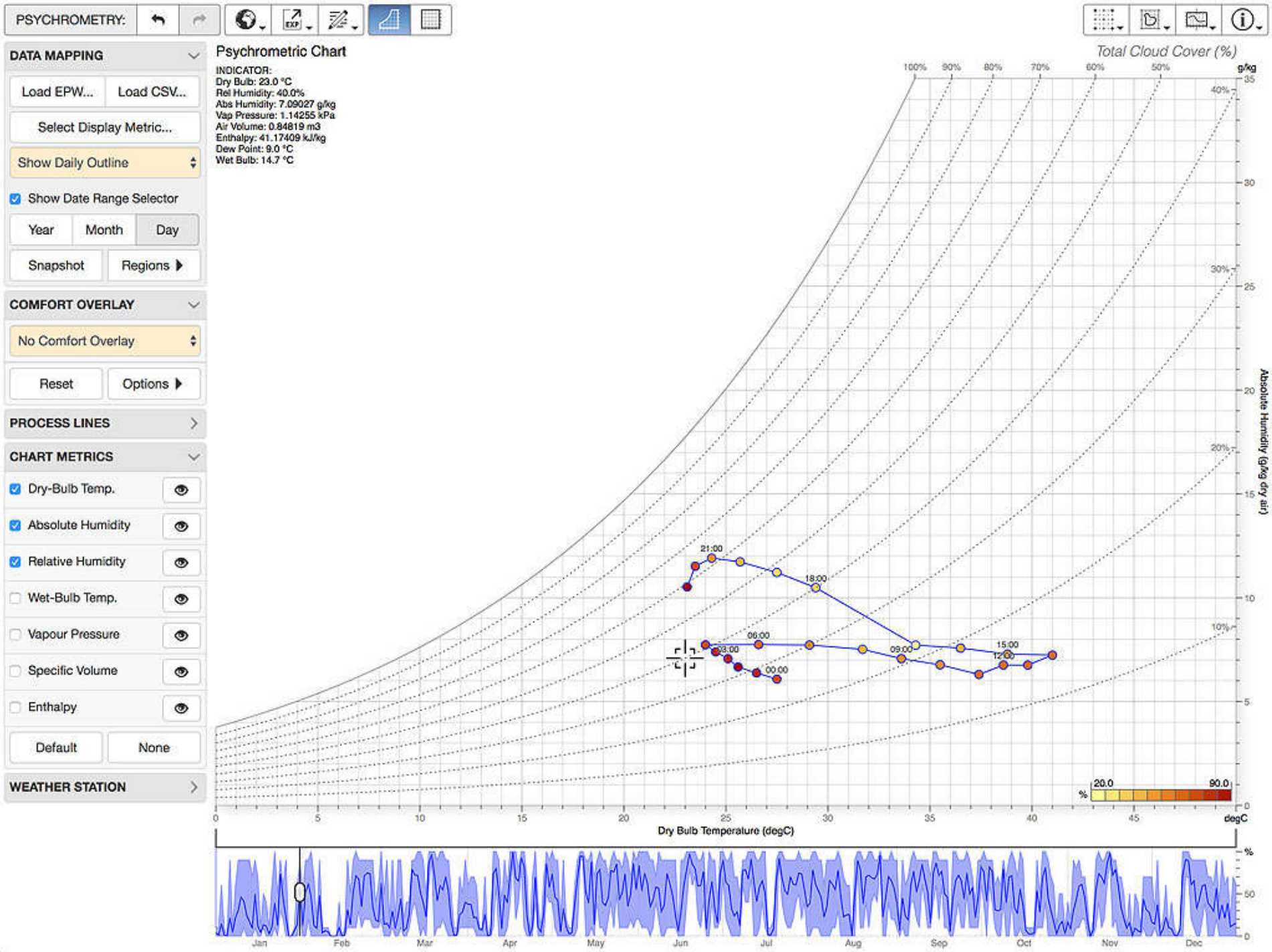
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Climatic data as monthly mean average min/max lines



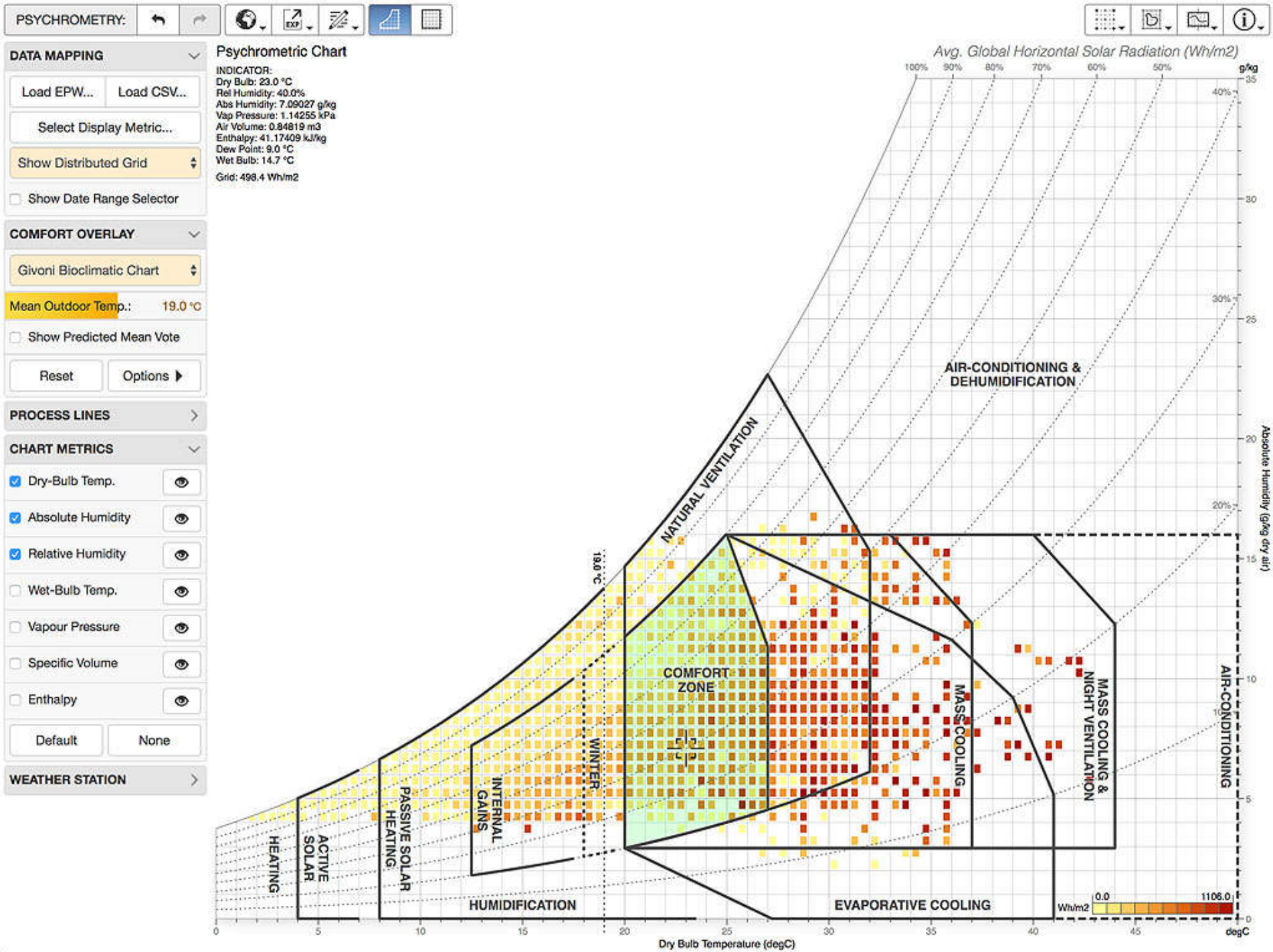
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Climatic data as track conditions over the course of a day



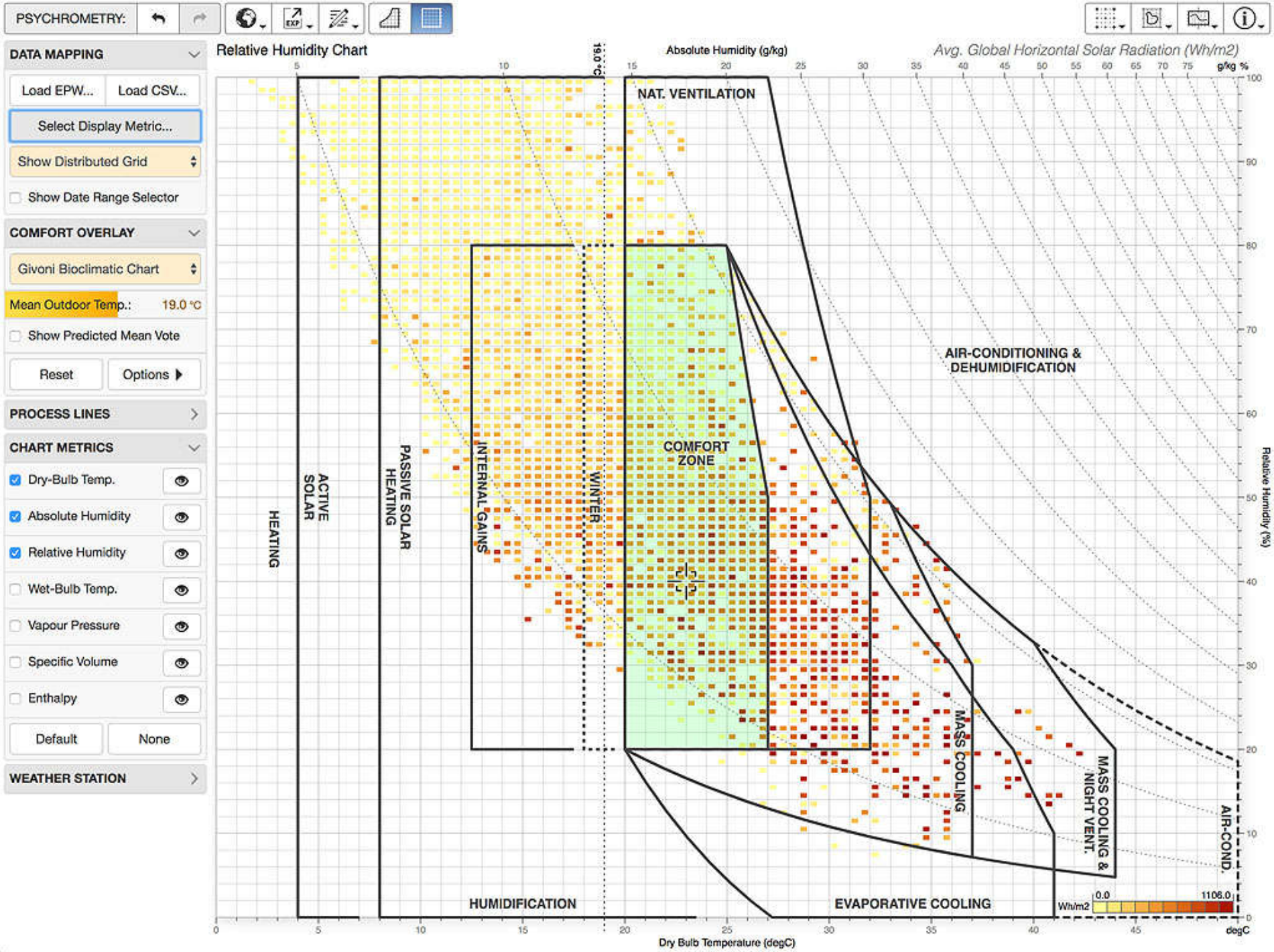
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Bioclimatic analysis using a psychrometric chart



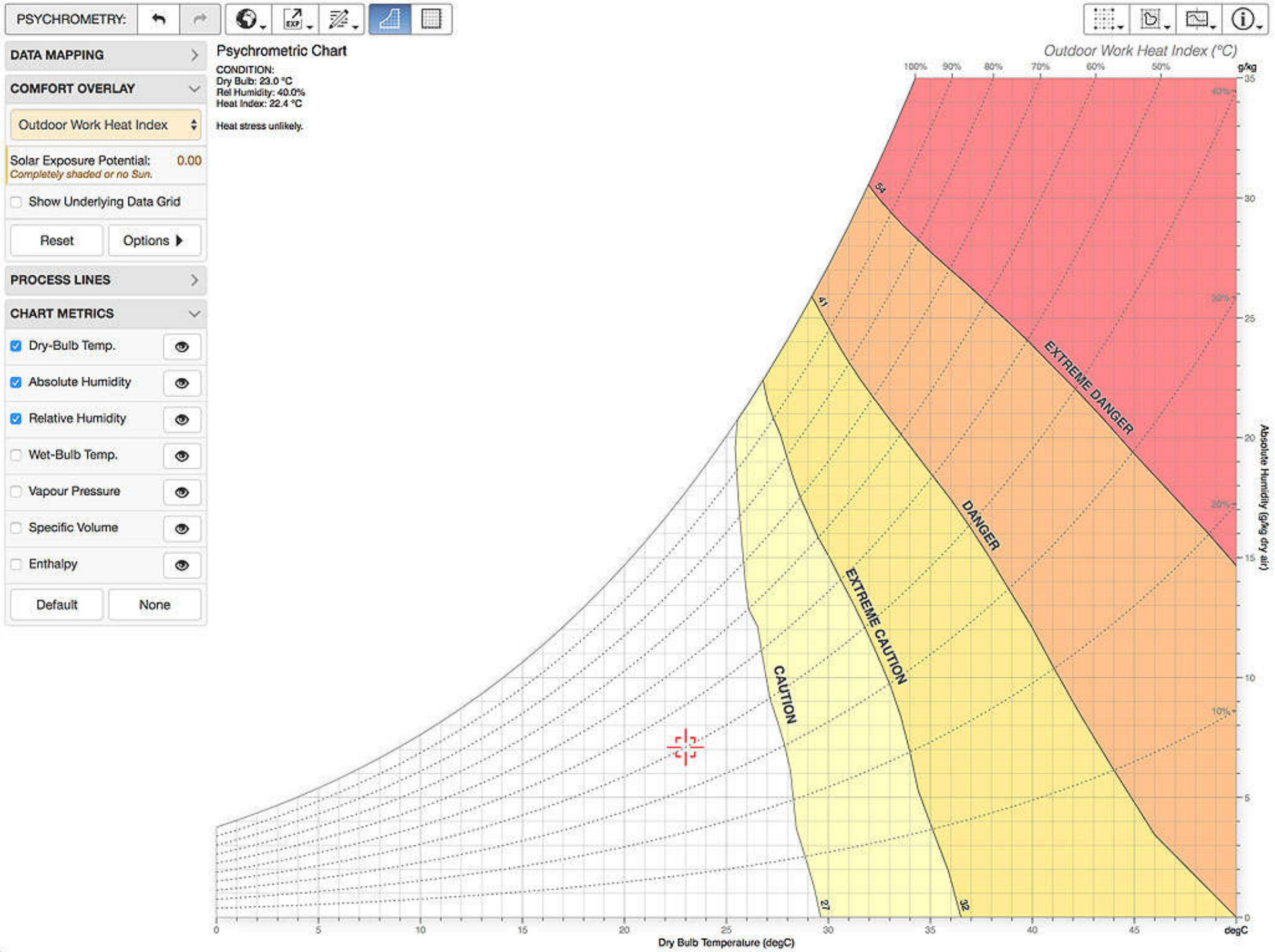
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Bioclimatic analysis using a relative humidity chart



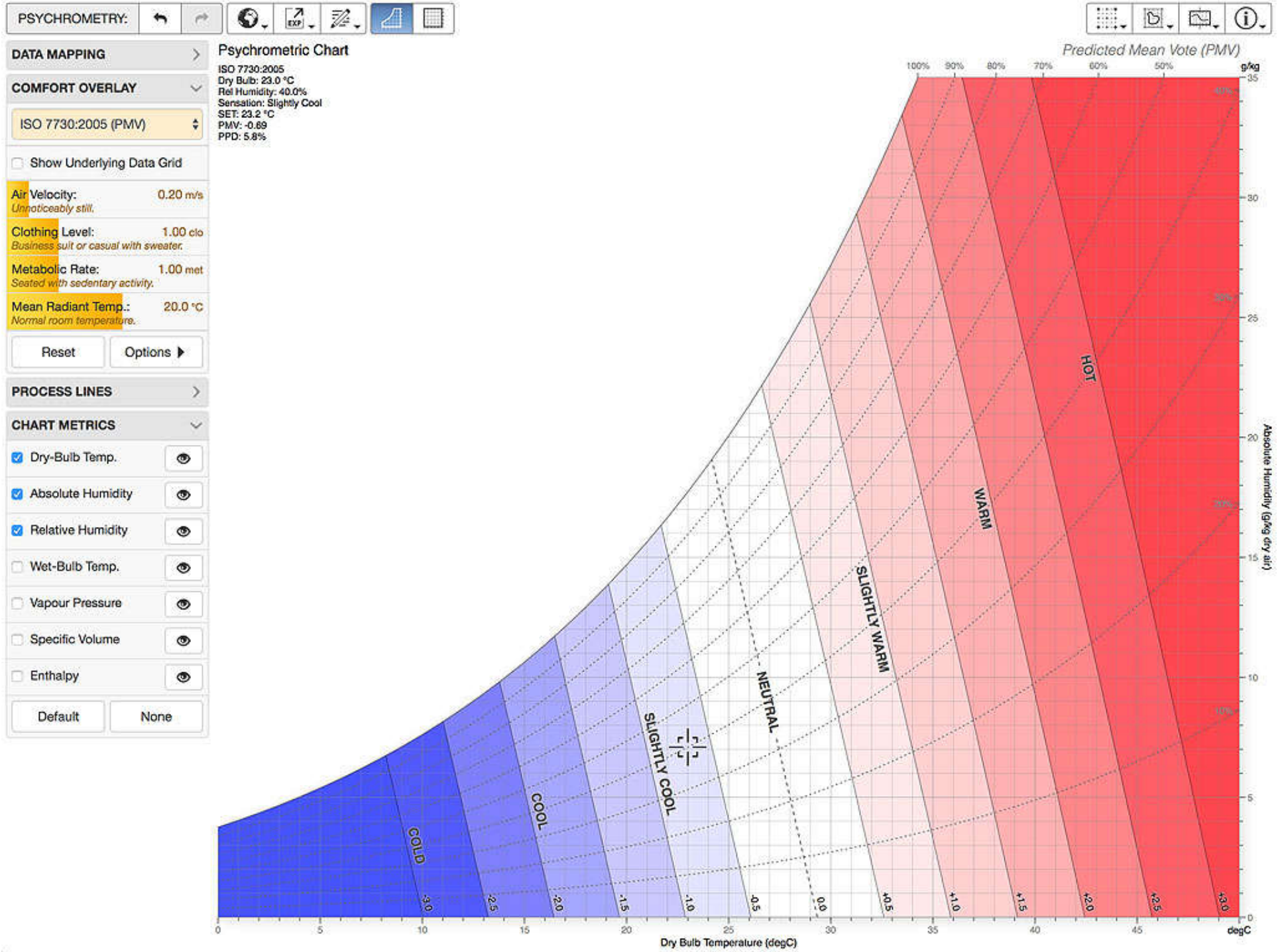
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Heat index contours mapped over the psychrometric chart



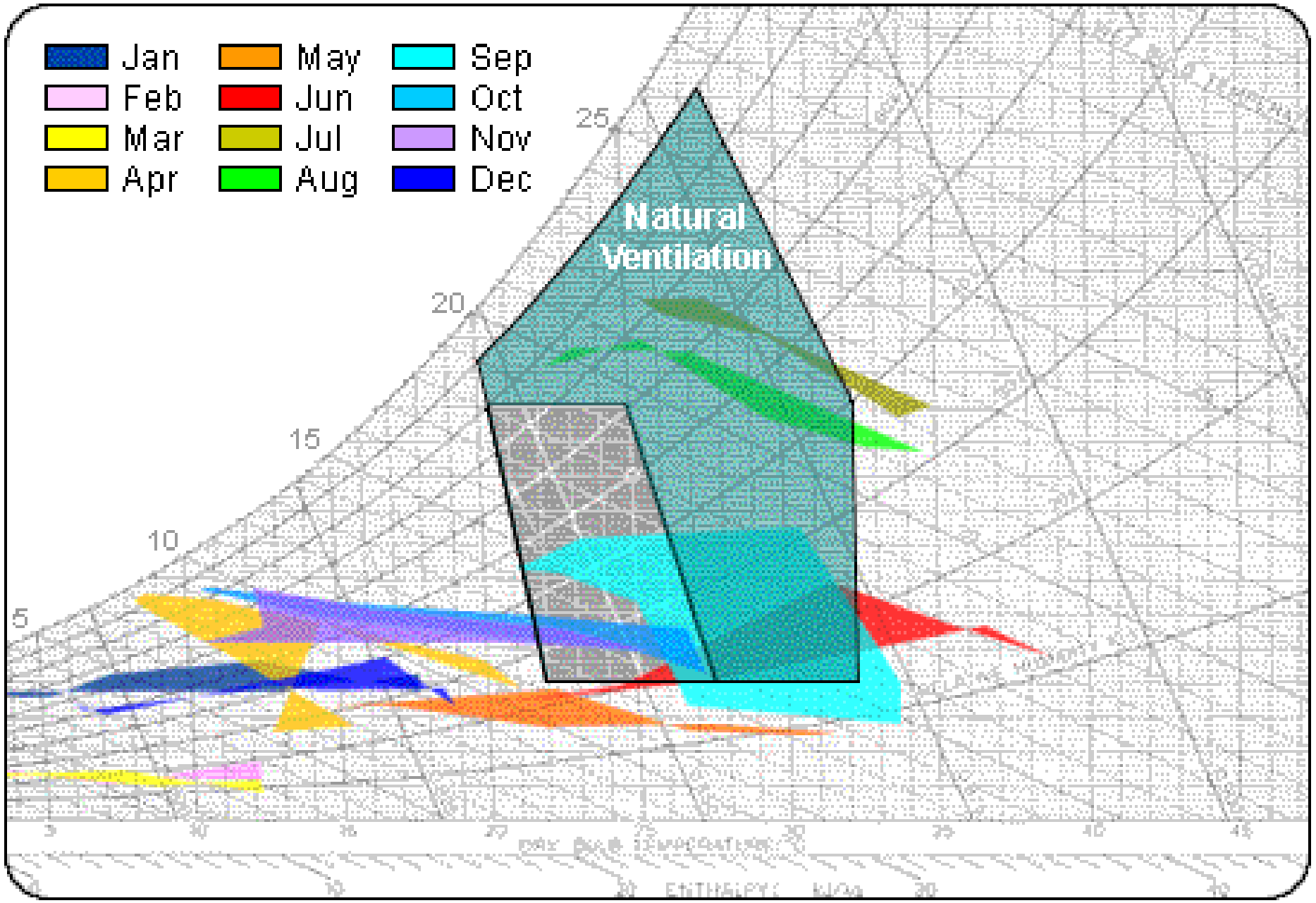
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Thermal comfort predicted mean vote (PMV) contours



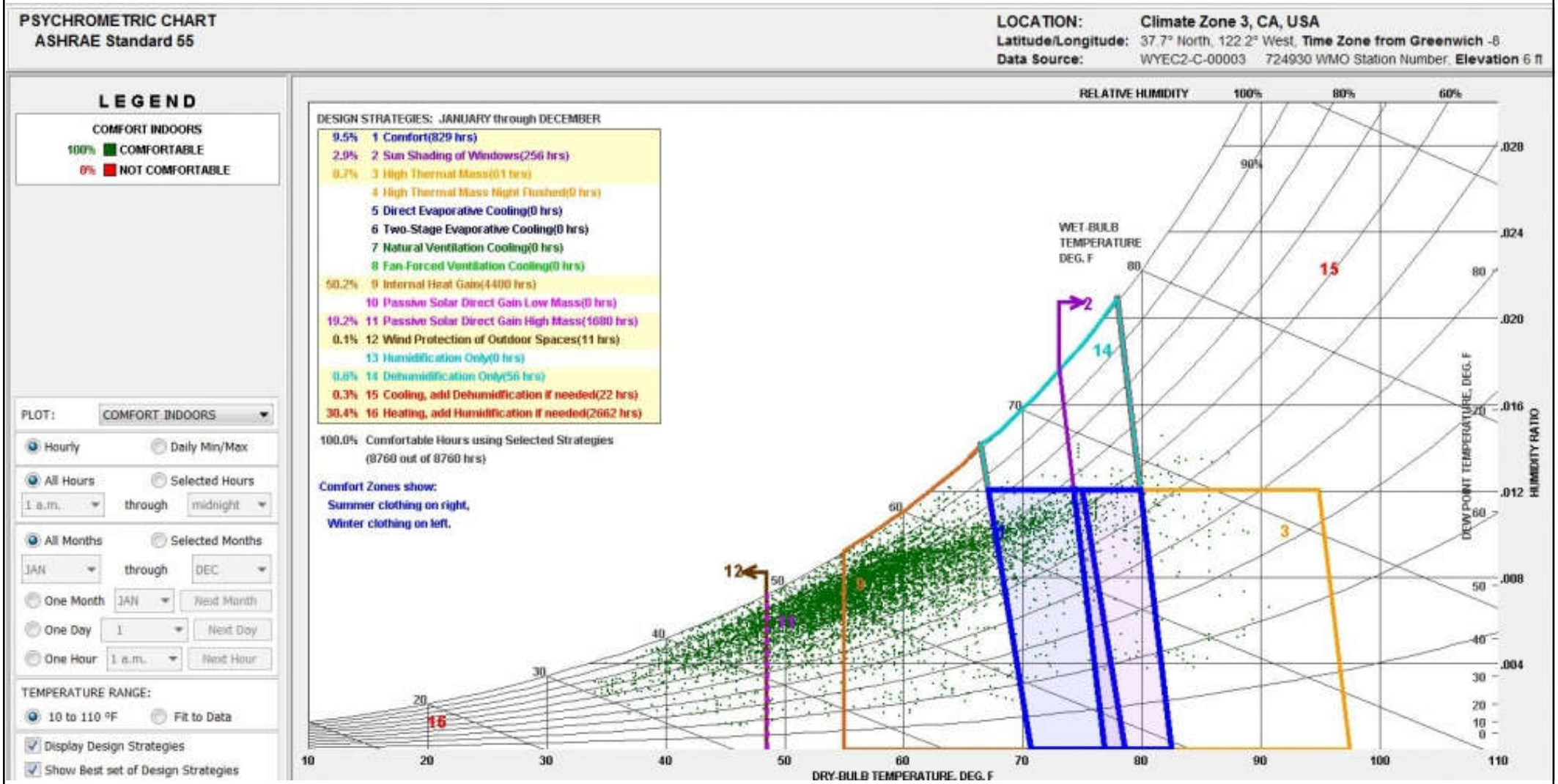
(Source: http://andrewmarsh.com/software/psychro-chart-web/)

Analysis of external climate on cooling & ventilation strategies



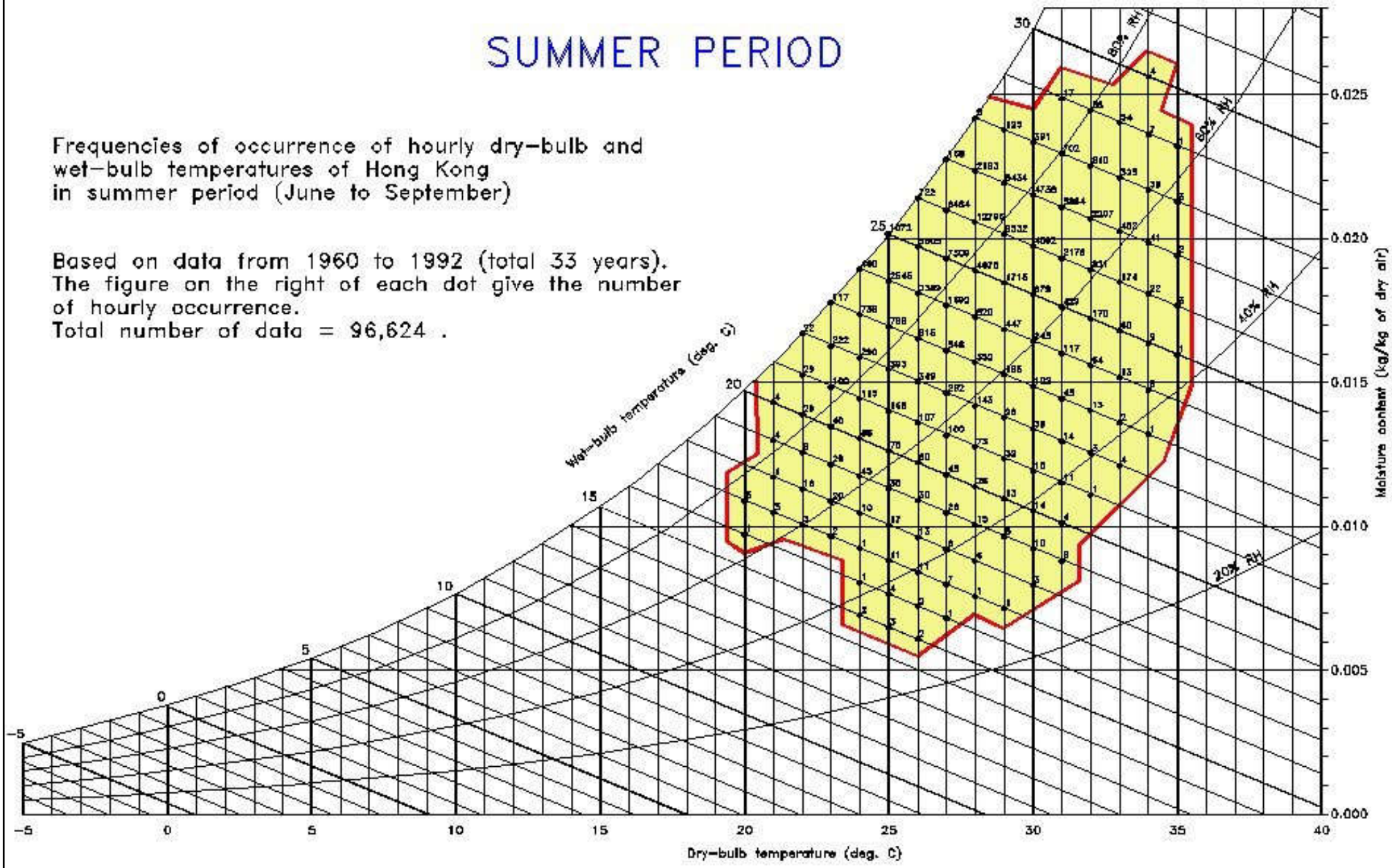
(Video: Using Psychrometric Charts for Building Design (5:25) https://youtu.be/ZVXynRFeZQY)

Example of how plotted data on a psychrometric chart can be studied, and related to passive design (using Climate Consultant*)



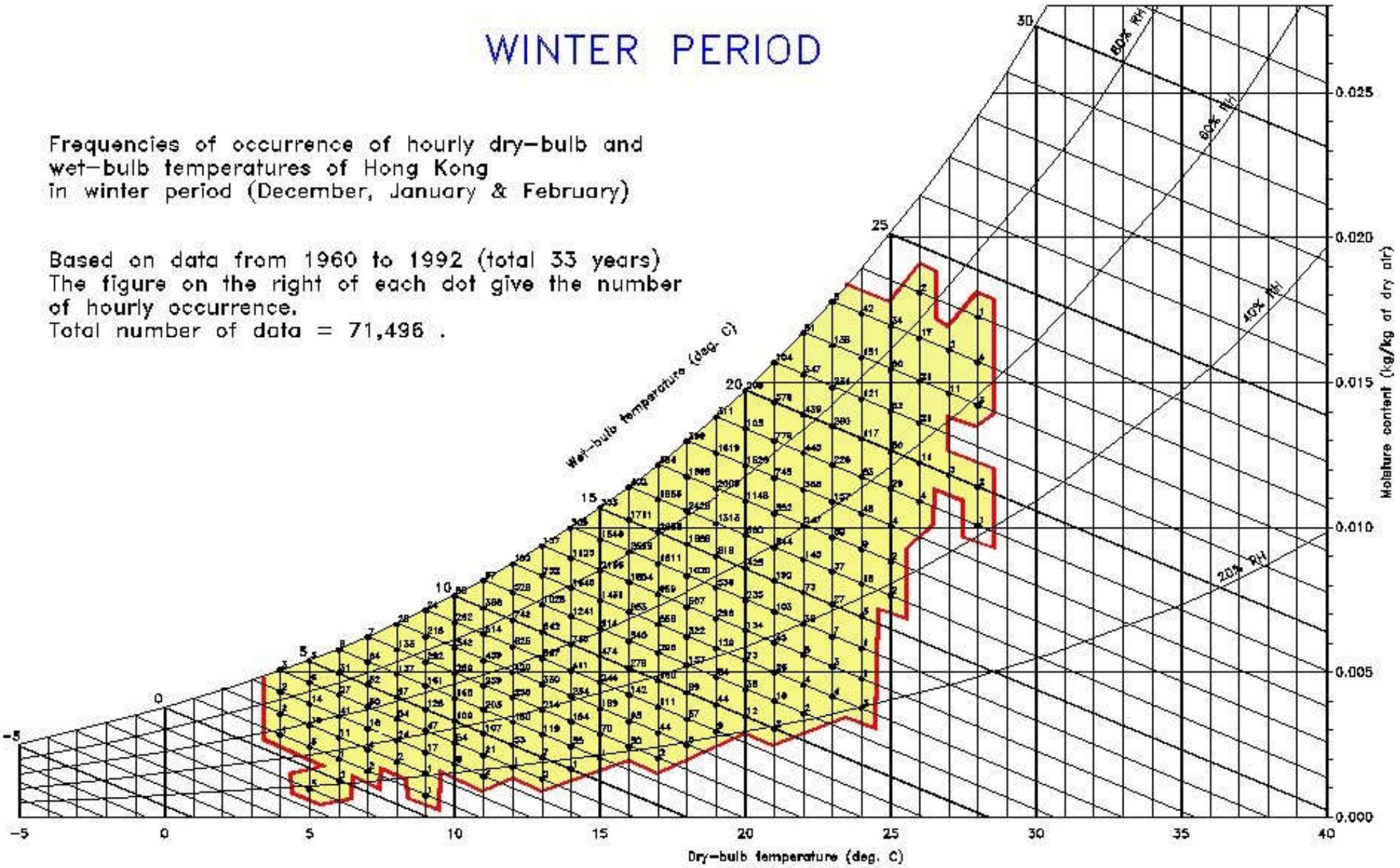
(*Climate Consultant http://www.energy-design-tools.aud.ucla.edu/)

Analysis of weather conditions in Hong Kong



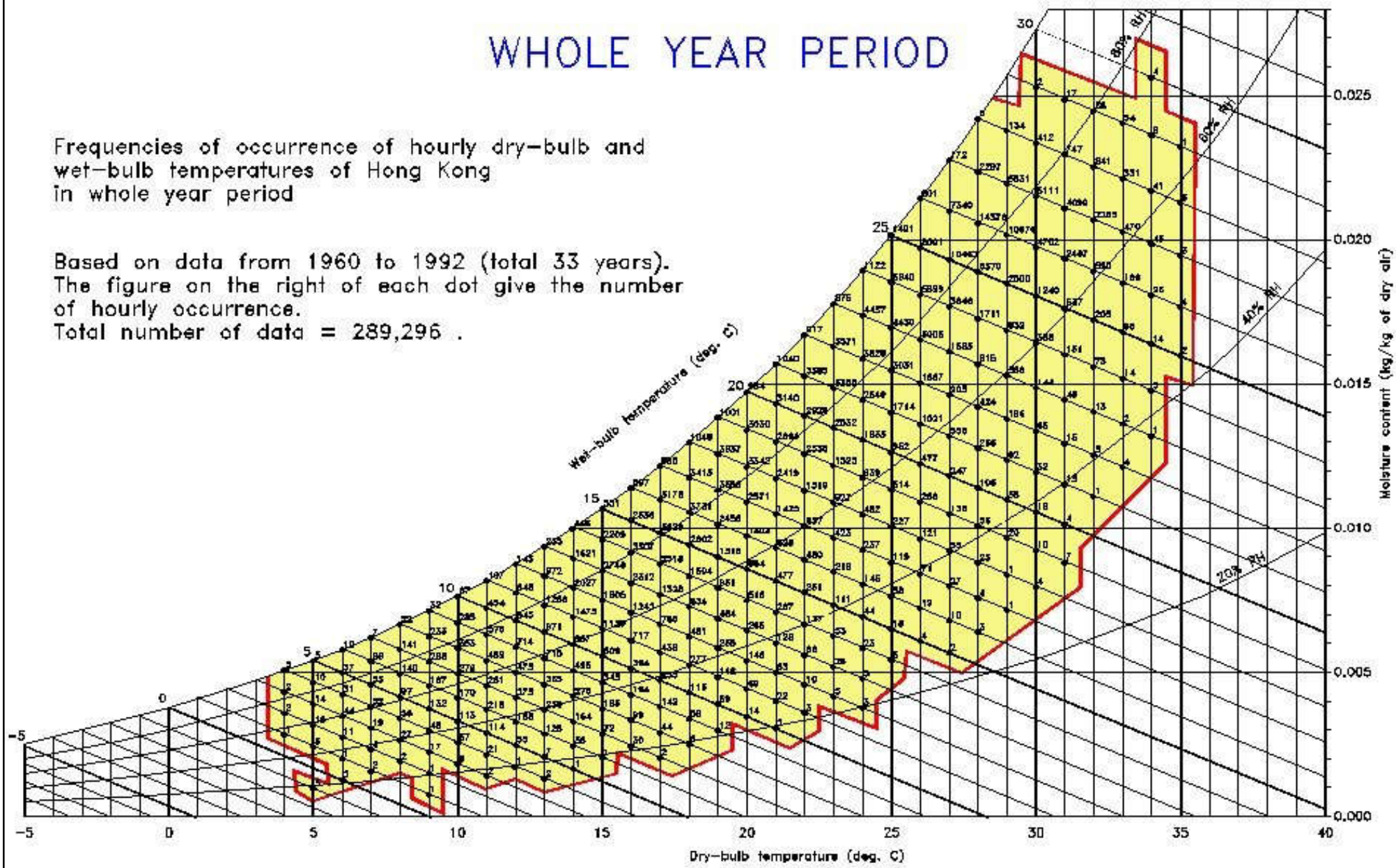
(Source: Dr. Sam C M Hui)

Analysis of weather conditions in Hong Kong



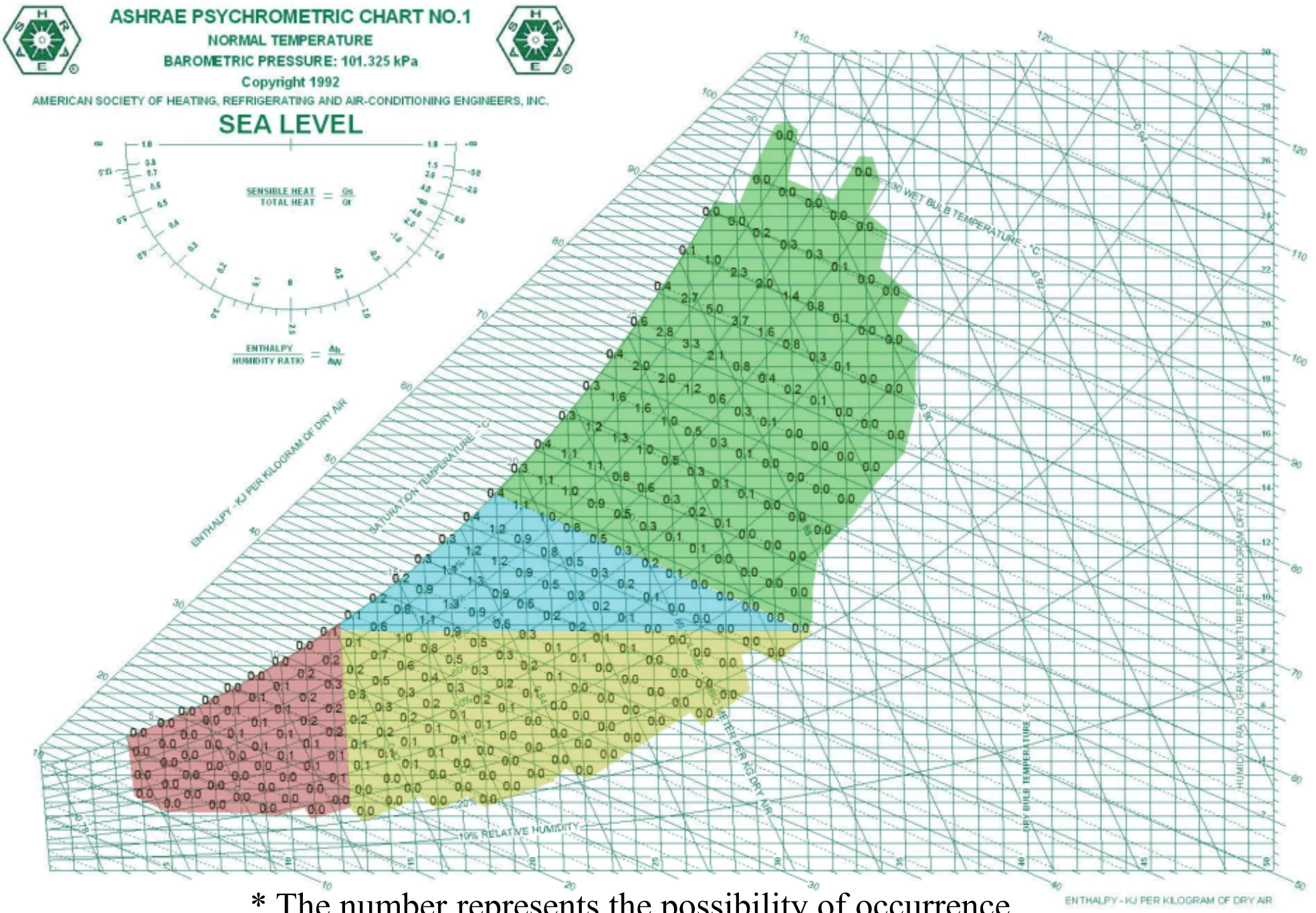
(Source: Dr. Sam C M Hui)

Analysis of weather conditions in Hong Kong



(Source: Dr. Sam C M Hui)

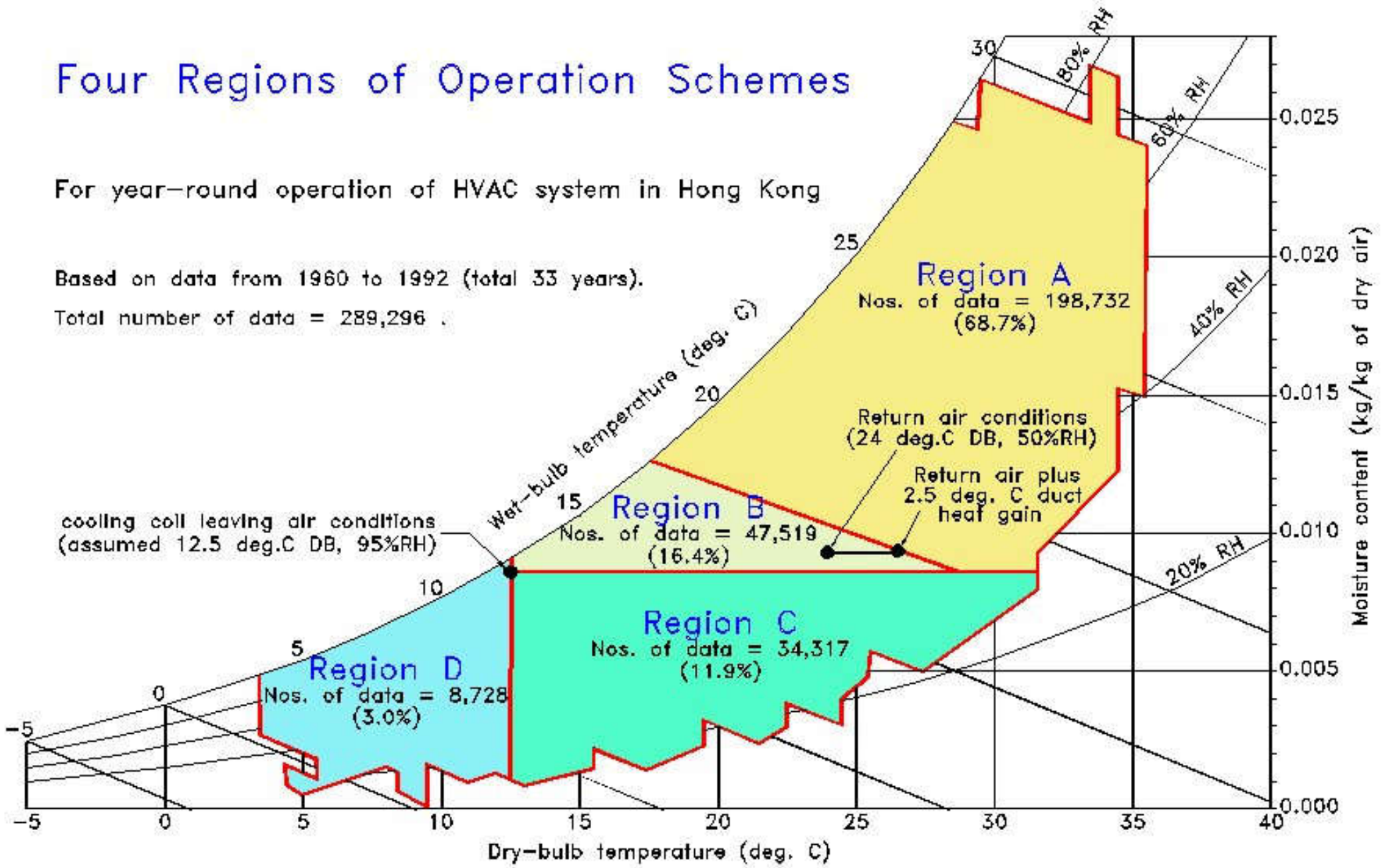
Analysis of weather conditions in Hong Kong



* The number represents the possibility of occurrence.

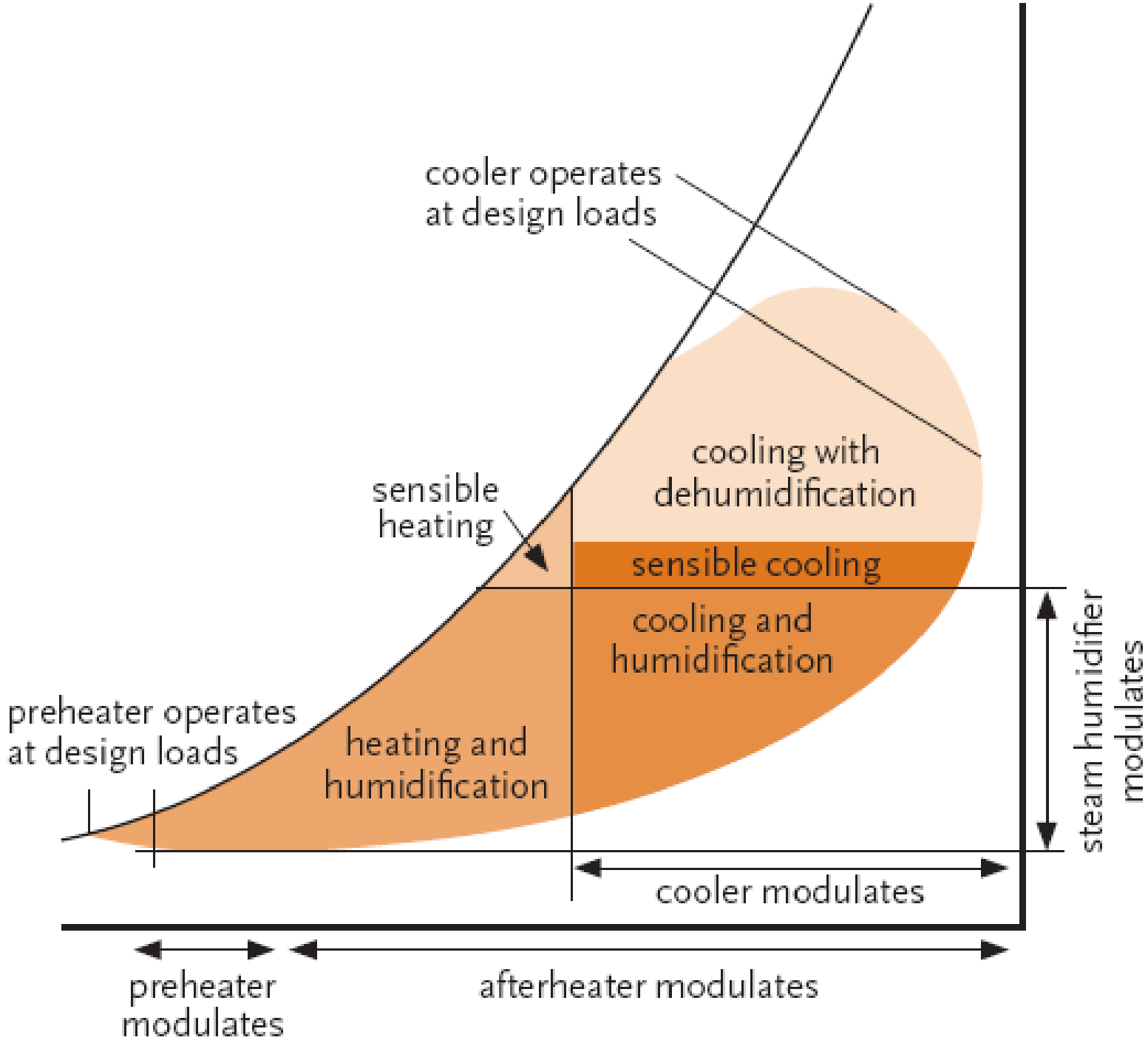
(Source: Dr. Sam C M Hui)

Analysis of HVAC operation strategy



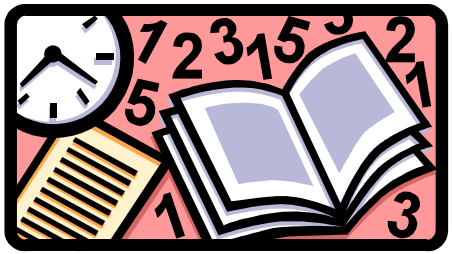
(Source: Dr. Sam C M Hui)

All-year-round operating regime based on outdoor conditions



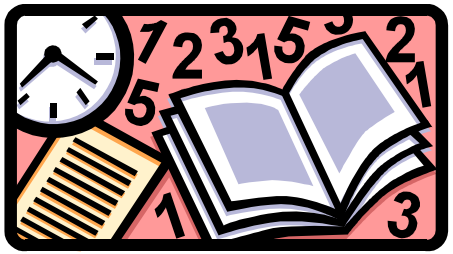
(Source: CIBSE Journal CPD Module 14: The psychrometrics of air conditioning systems https://www.cibsejournal.com/cpd/modules/2010-03/)

Further Reading

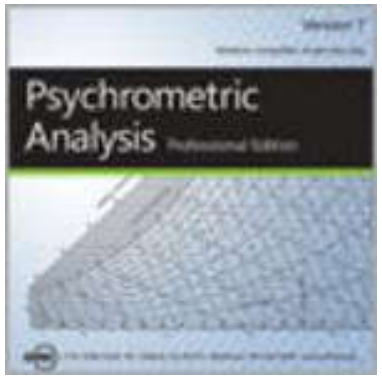


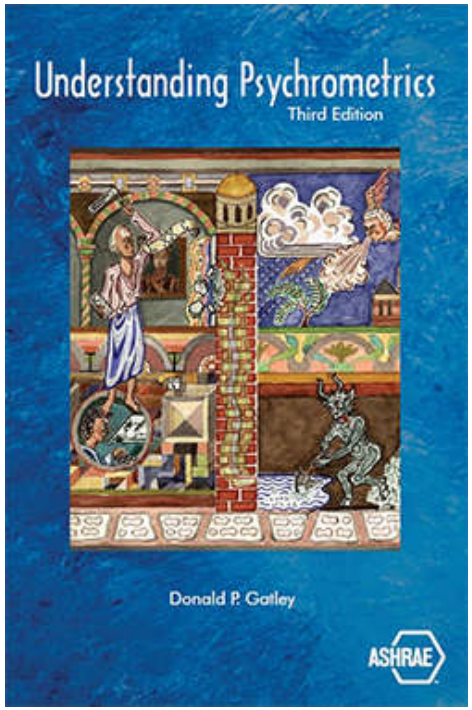
- Why Learn Psychrometrics? (by Donald P. Gatley)
  - https://www.ashrae.org/news/ashraejournal/why-learn-psychrometrics
- CIBSE Journal CPD modules: http://www.cibsejournal.com/cpd/
  - Module 3: The properties of air
    https://www.cibsejournal.com/cpd/modules/2009-04/
  - Module 7: Applying the psychrometric relationships
    https://www.cibsejournal.com/cpd/modules/2009-08/
  - Module 9: The basic psychrometric processes
    https://www.cibsejournal.com/cpd/modules/2009-10/
  - Module 11: The psychrometrics of HVAC sub-systems
    https://www.cibsejournal.com/cpd/modules/2009-12/
  - Module 14: The psychrometrics of air conditioning systems
    https://www.cibsejournal.com/cpd/modules/2010-03/
  - Module 23: Travelling into time with psychrometry
    https://www.cibsejournal.com/cpd/modules/2010-12/

References

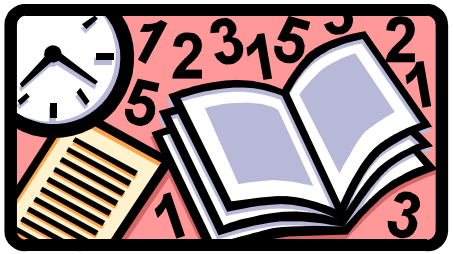


- ASHRAE Psychrometrics Tools
  - www.ashrae.org/resources--publications/bookstore/psychrometrics
  - Psychrometric Chart Mobile App (on iPad)
    - Video: ASHRAE HVAC Psychrometric Chart App (8:11) https://youtu.be/VFFqkBHDqPk
  - Psychrometric Analysis CD, Version 7 (2012)
  - Understanding Psychrometrics, 3rd ed. (2013)



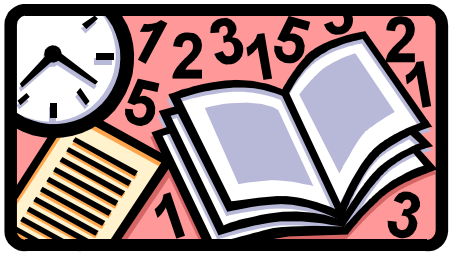


References



- Understanding Psychrometrics, 3rd ed. (2013)
  - Supplemental Files http://www.ashrae.org/UP3
    - 25 ASHRAE psychrometric charts and three 0˚C to 400˚C 0-1.0 humidity ratio charts for 5.53, 101.325, and 2000 kPa
    - LibHuAirProp Add-In Demo
    - HW.exe (to generate a table of 1983 Hyland-Wexler psychrometric properties)

References



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