

## Air conditioning processes and cycles

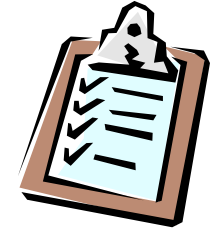


*Ir. Dr. Sam C. M. Hui*

Faculty of Science and Technology

E-mail: [cmhui@vtc.edu.hk](mailto:cmhui@vtc.edu.hk)

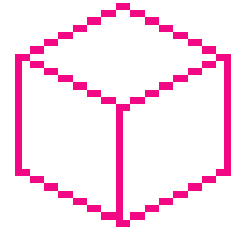
# Contents



- Psychrometric processes\*
  - Common processes
  - Typical devices
  - Calculations
- Psychrometric analysis
  - External climate
  - Design strategies

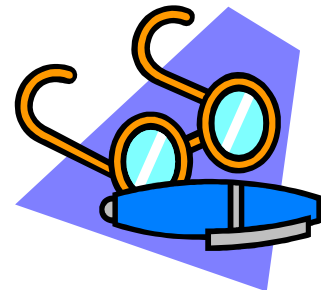
(\* Handouts with details can be downloaded from the course website:  
Chapter 2 – Psychrometric Processes.)

# Overview of the handouts



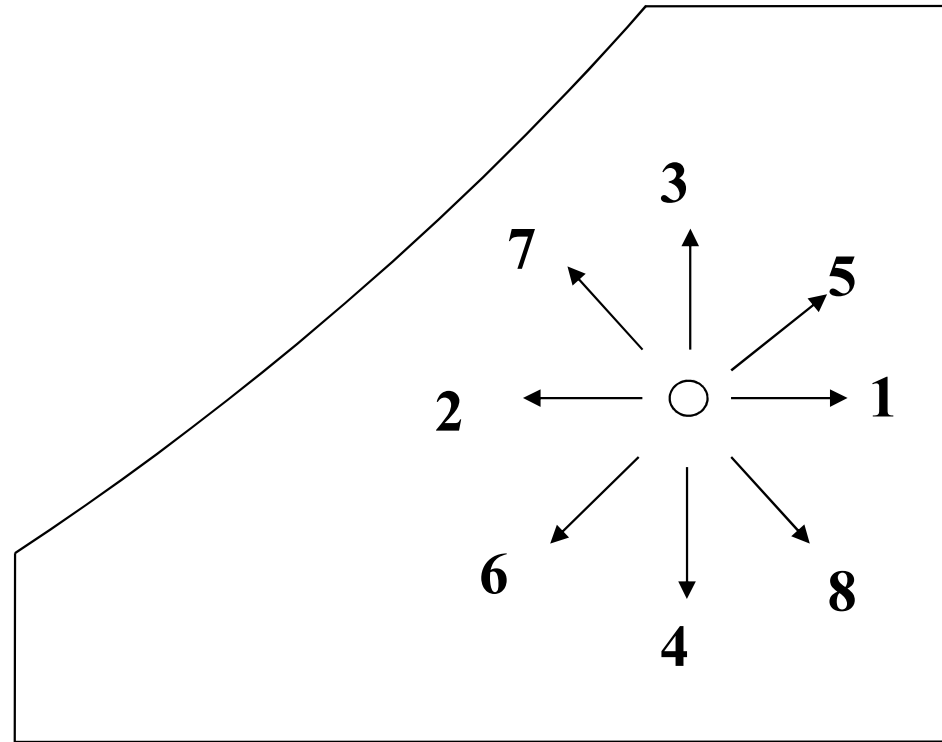
- Chapter 2 – Psychrometric Processes
  - Sensible heating coils
  - Cooling coils
  - Humidifiers
  - Water spray types
  - Steam humidifier
  - Humidifier – psychrometric process
  - Room psychrometric process
  - Mixing air streams
  - Quick revision study guide
  - Chapter notes (footnotes)

# 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 / dehumidifiers

# Basic psychrometric processes



Process 0-1: Sensible heating

Process 0-2: Sensible cooling

Process 0-3: Humidifying

Process 0-4: Dehumidifying

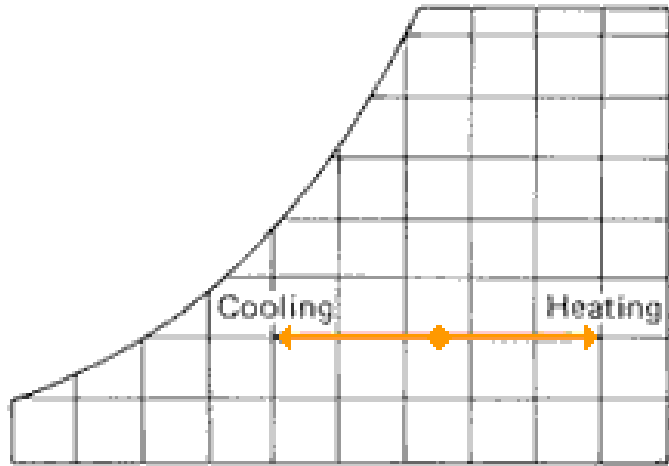
Process 0-5: Heating and humidifying

Process 0-6: Cooling and dehumidifying

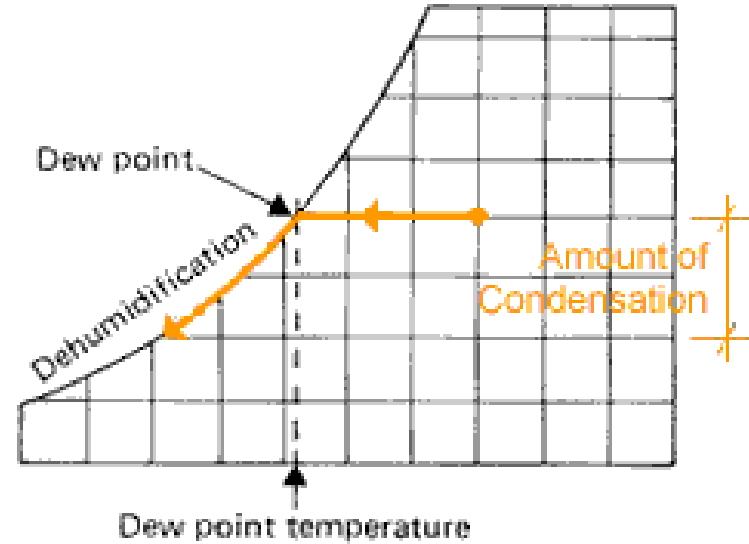
Process 0-7: Cooling and humidifying

Process 0-8: Heating and dehumidifying

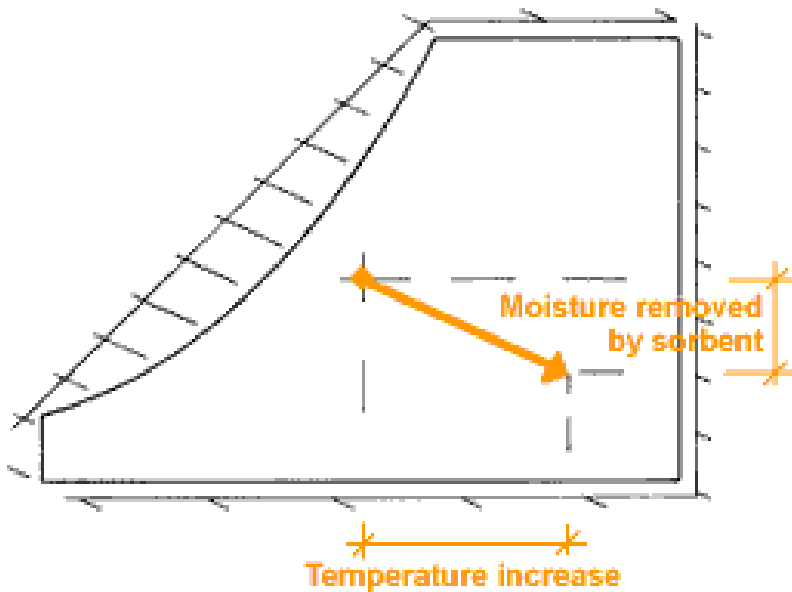
# Psychrometric processes



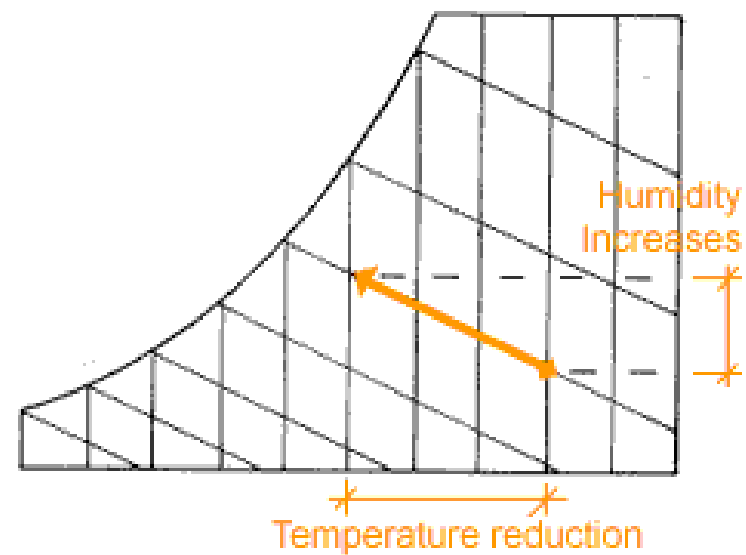
Sensible cooling/heating



Cooling and dehumidification

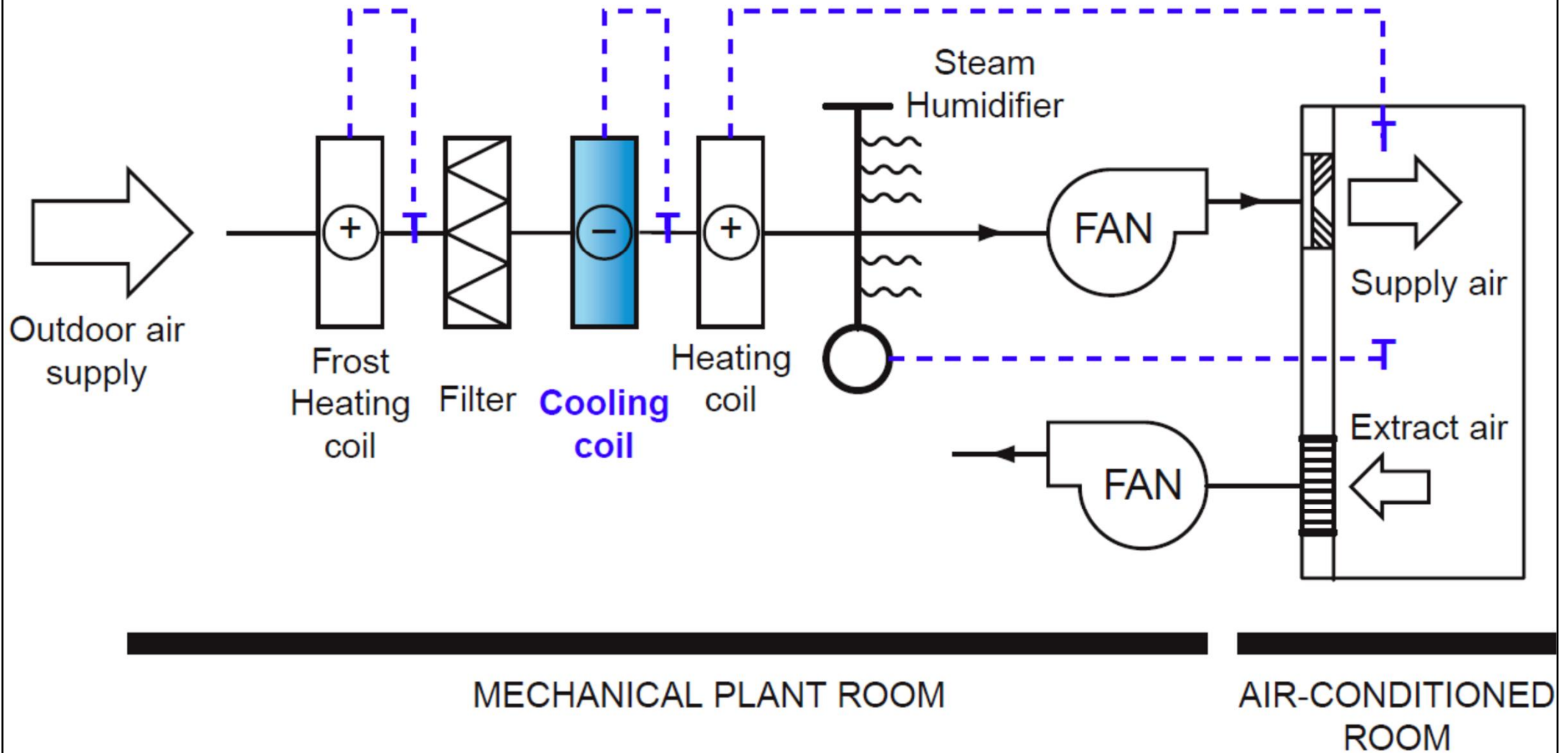


Adiabatic dehumidification



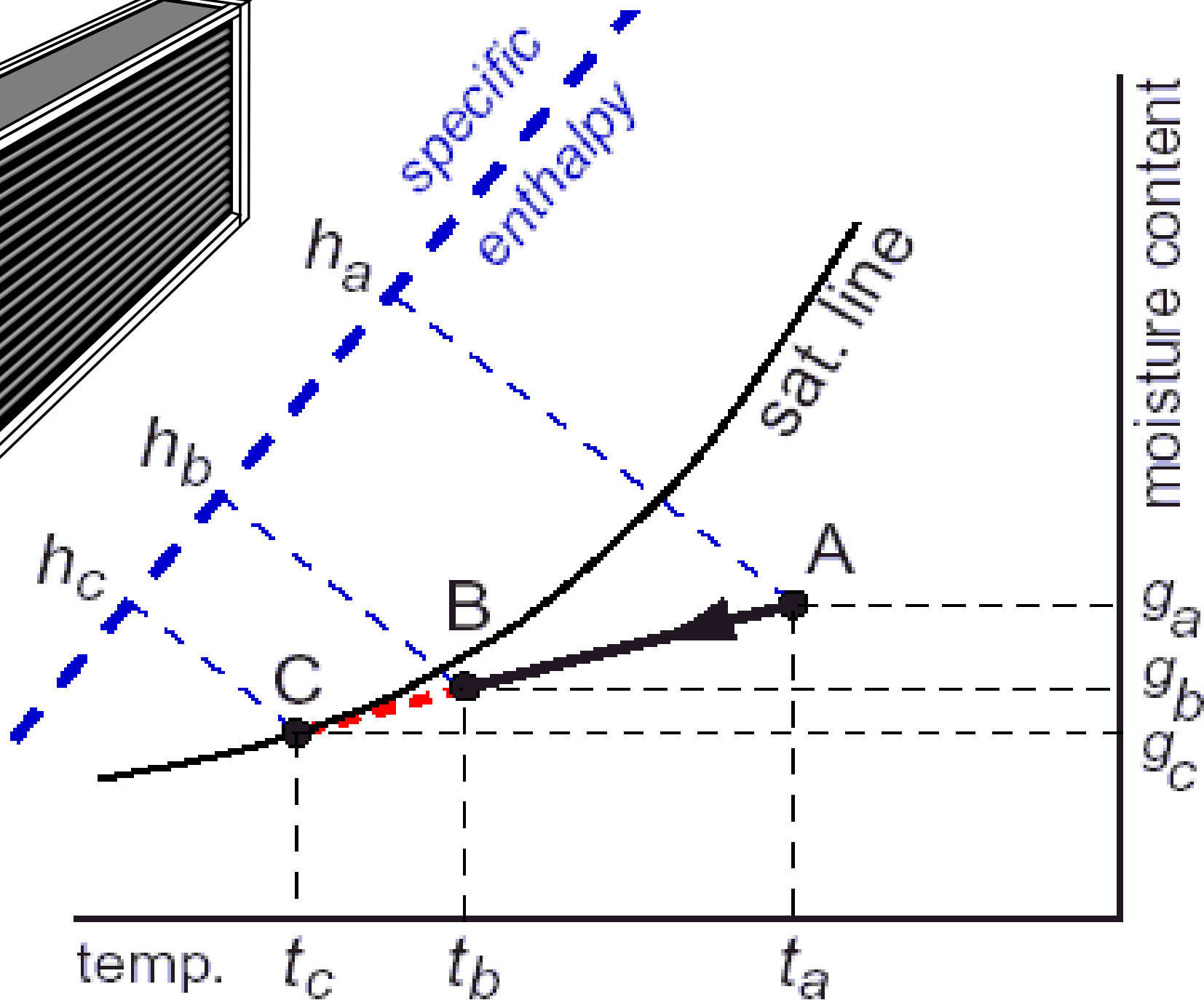
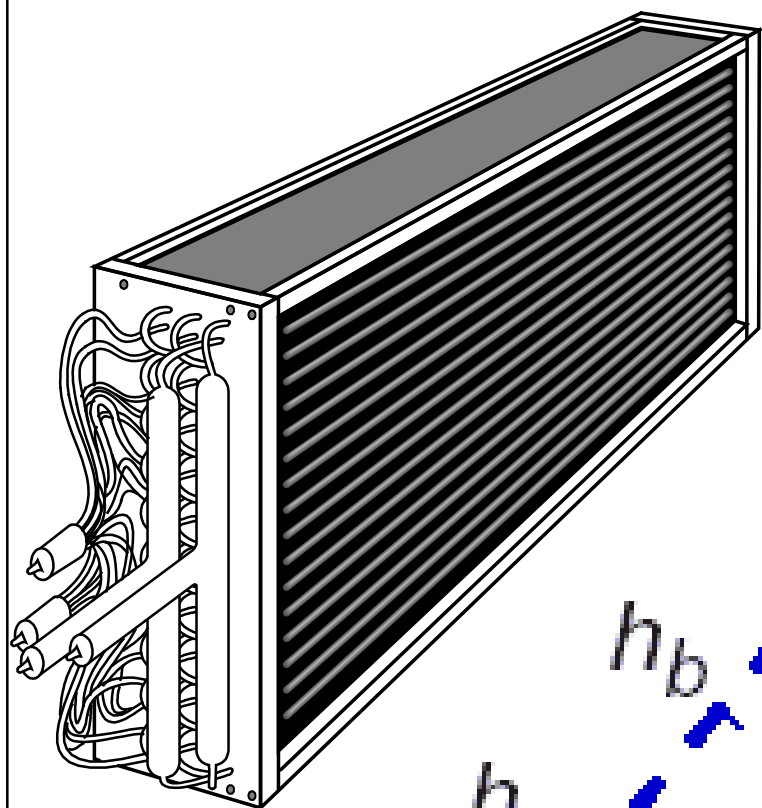
Evaporative cooling

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



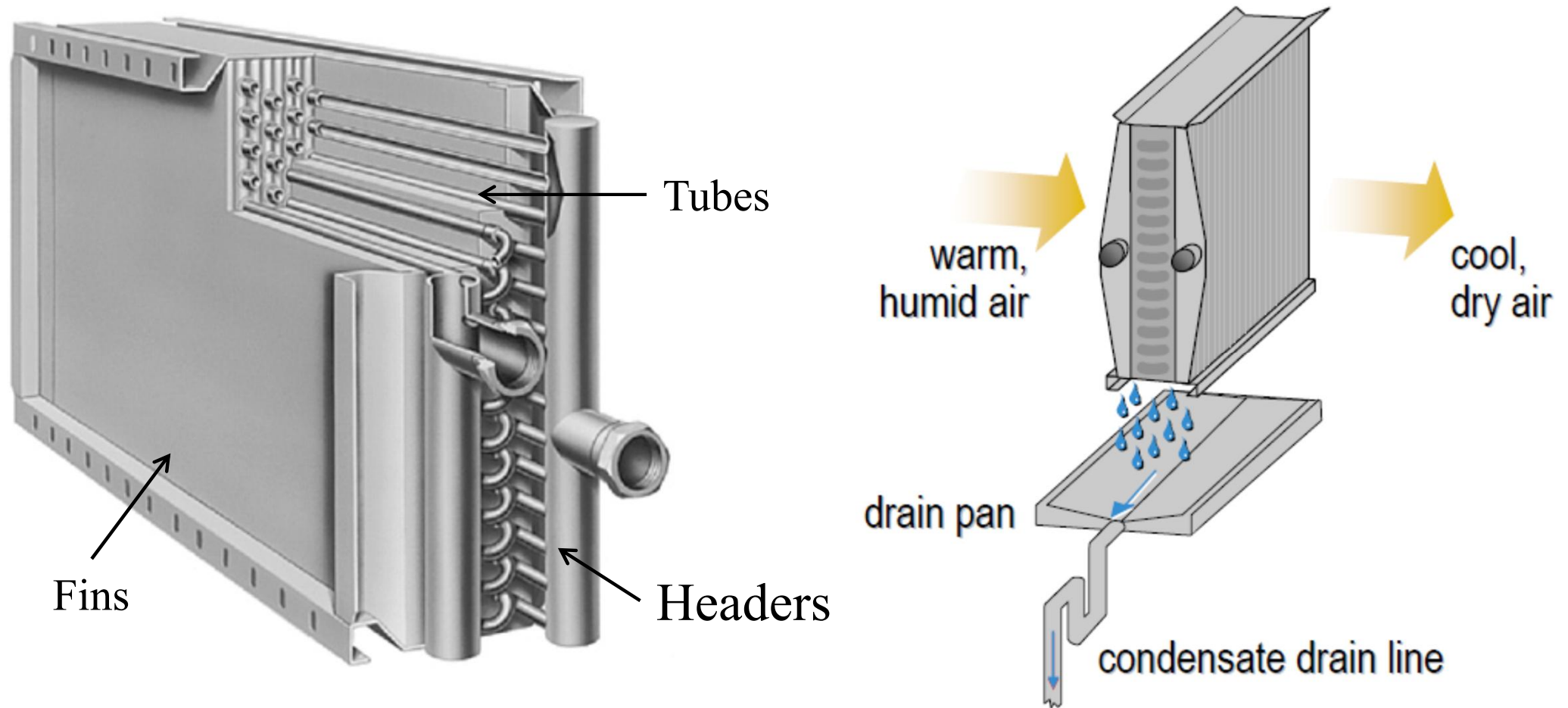
Can you explain the functions of each components?

# Cooling and dehumidification





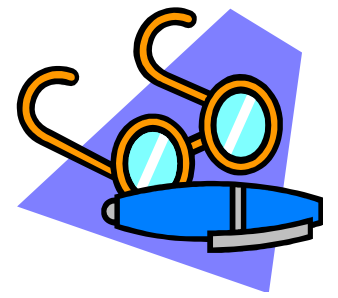
# Chilled water cooling coil (a heat exchanger)



Sensible heat exchange:  $q_S = m_a \times c_p \times (t_b - t_a)$

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

# Psychrometric processes

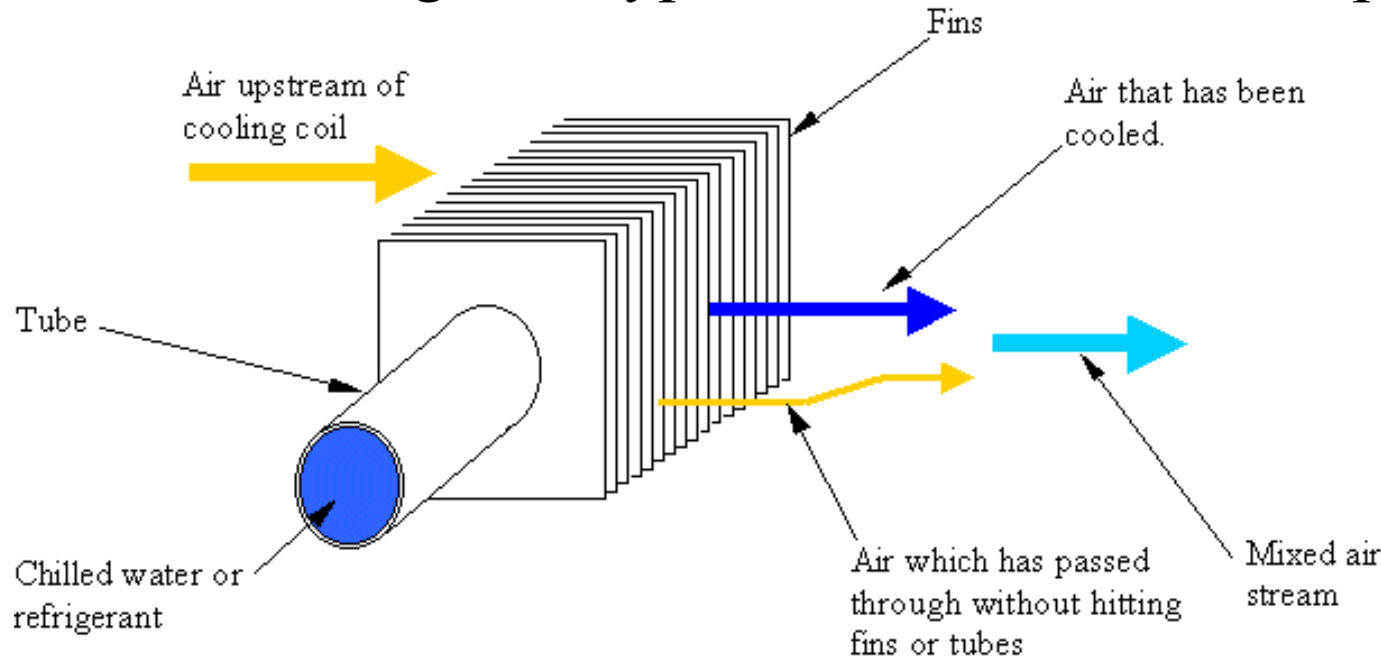


- Specific enthalpy difference:  $q = m \times (h_a - h_b)$
- Sensible heat:  $q_S = m_a \times c_p \times (t_b - t_a)$
- Latent heat:  $q_L = m_a \times h_{fg}$
- Contact factor (cooling coil):

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

- Bypass factor = 1 – Contact factor

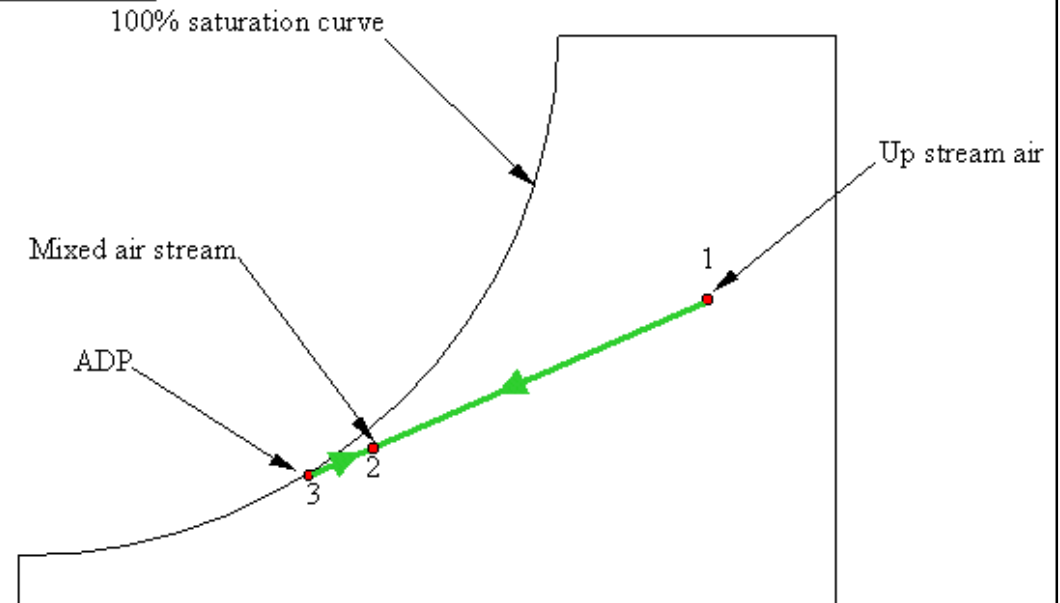
# Cooling coil bypass/contact factor and apparatus dew point



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

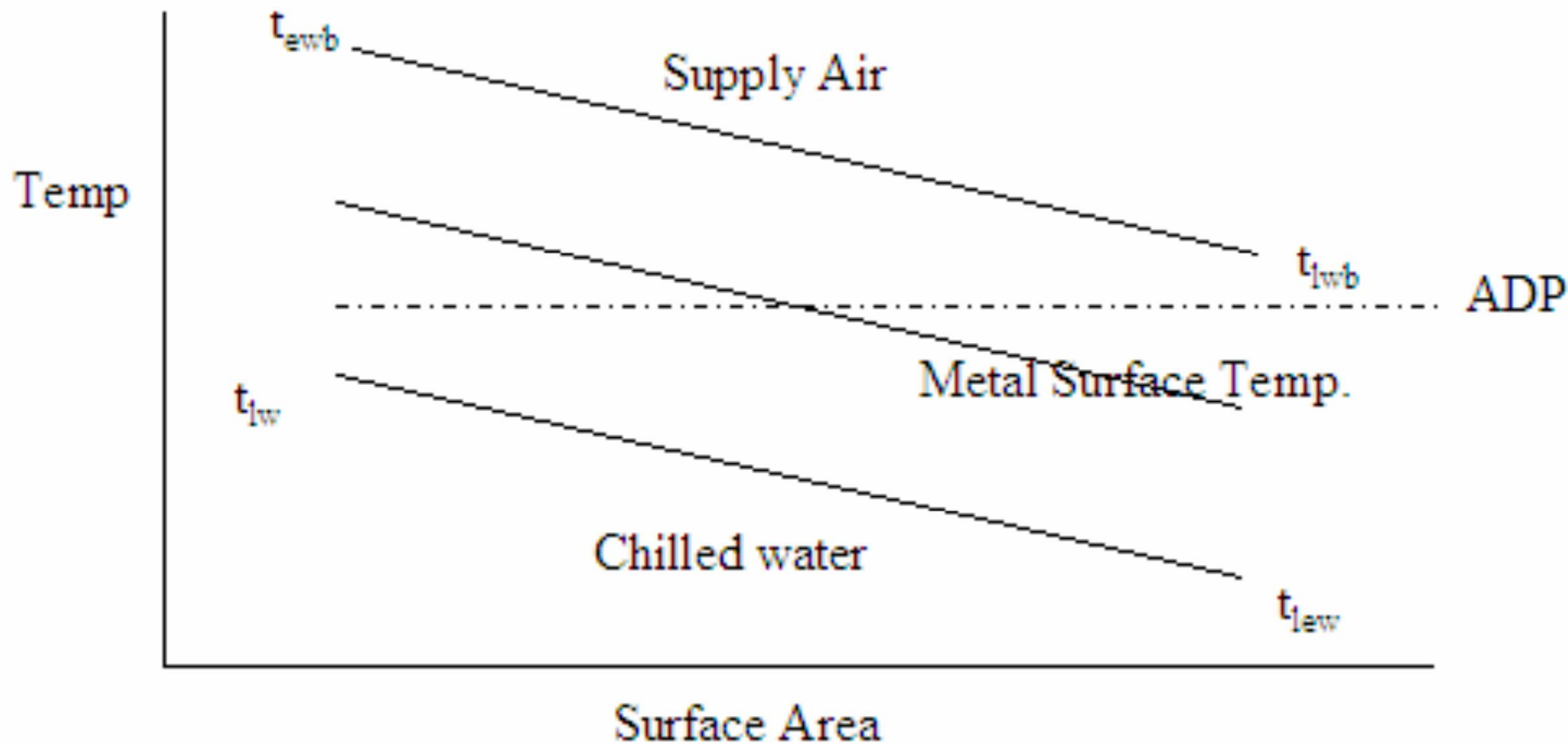
A SECTION OF COOLING COIL SHOWING AIR STREAMS

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

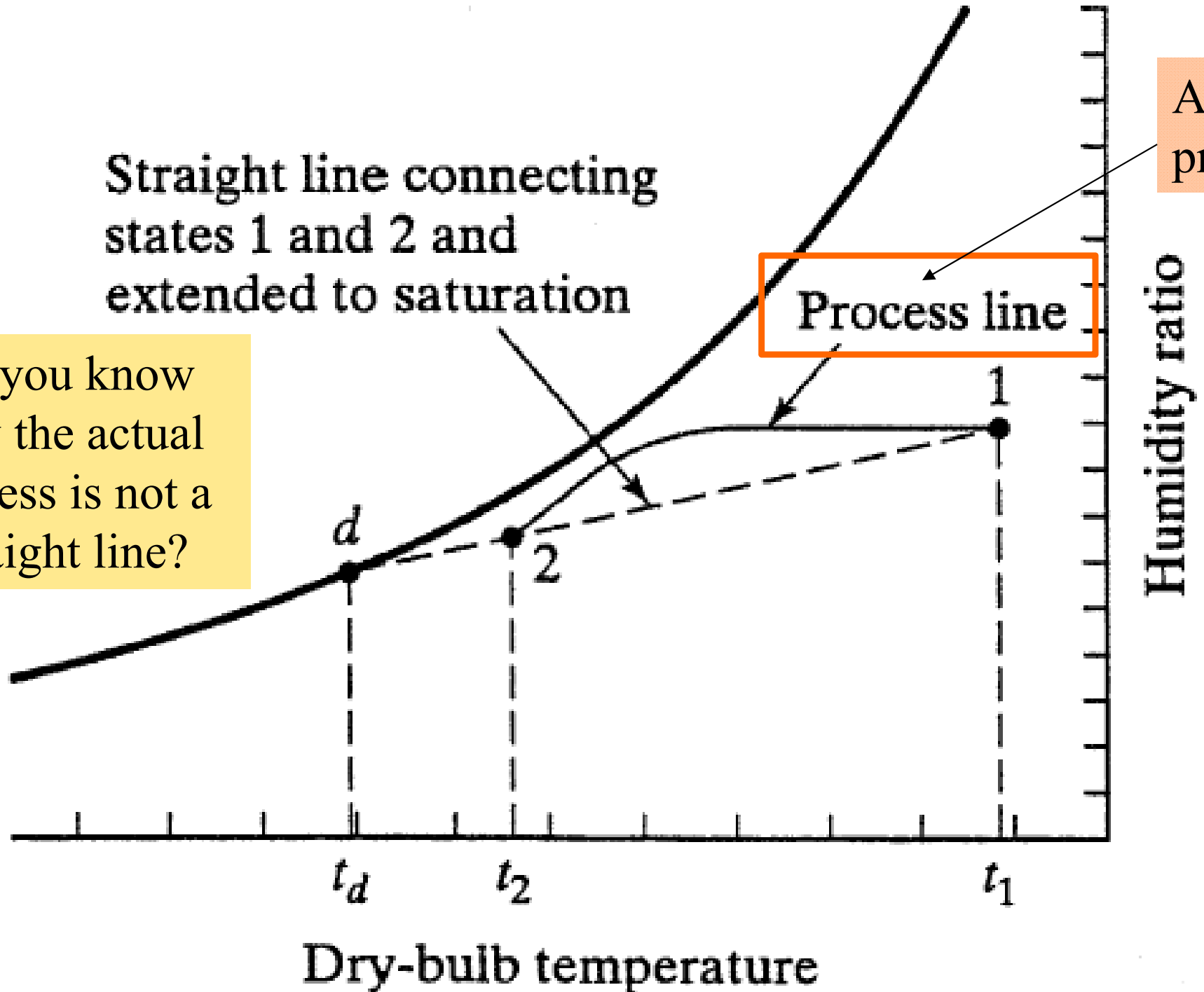
# Relationship of apparatus dew point (ADP) to supply air and chilled water temperatures



# Cooling and dehumidification

Straight line connecting states 1 and 2 and extended to saturation

Do you know why the actual process is not a straight line?



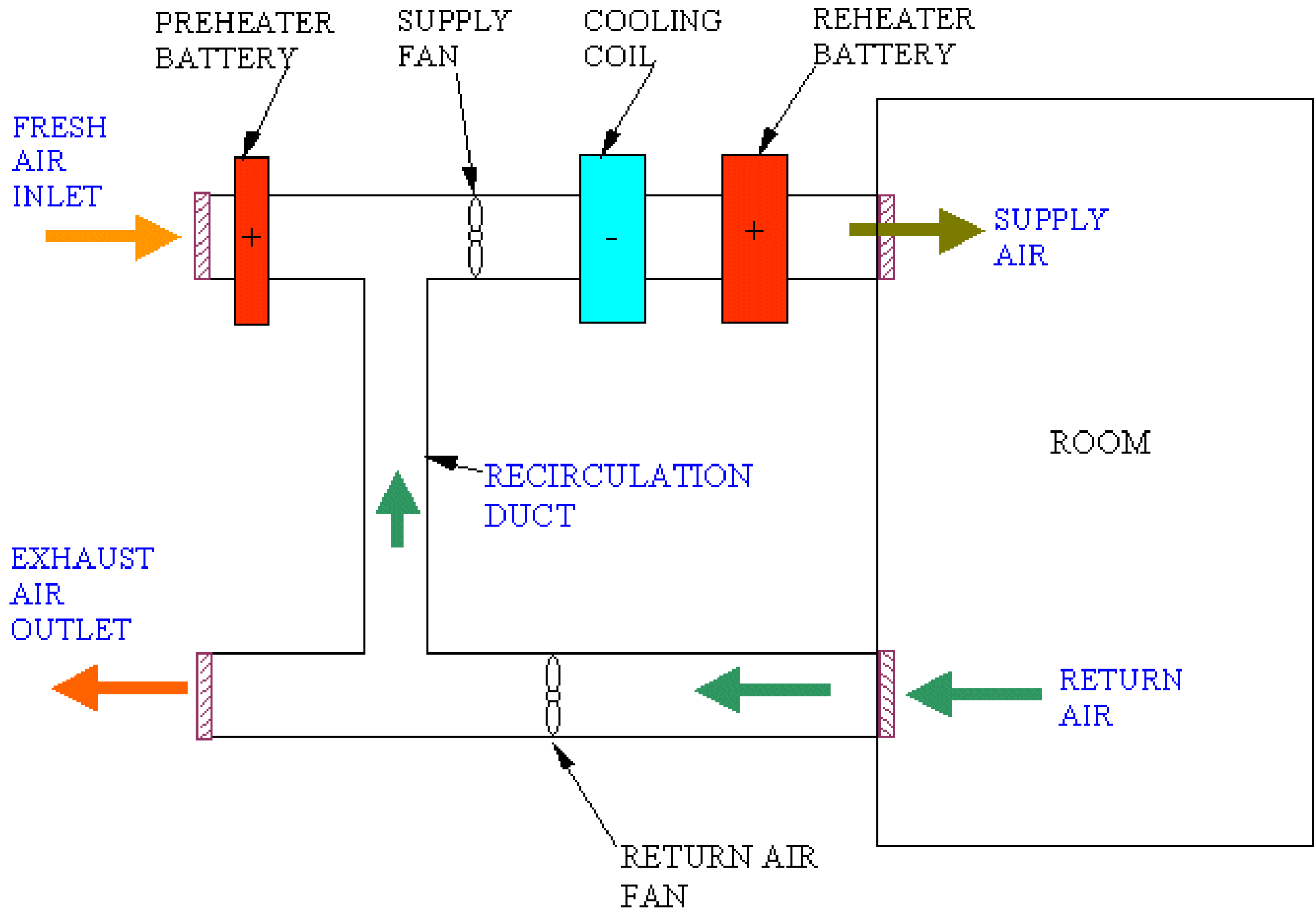
Actual process

Process line

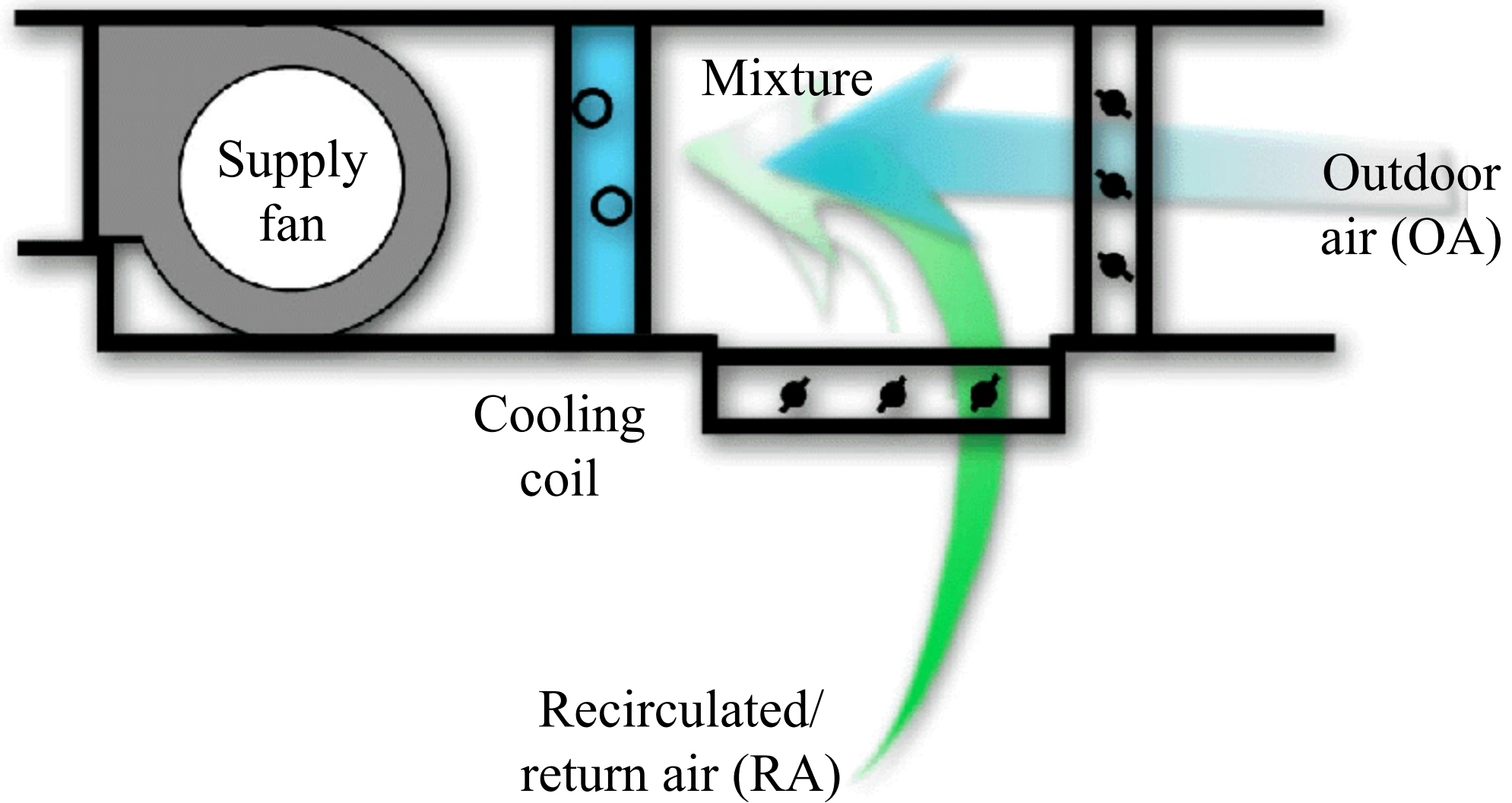
Humidity ratio

Dry-bulb temperature

# Major components of the HVAC air-side system

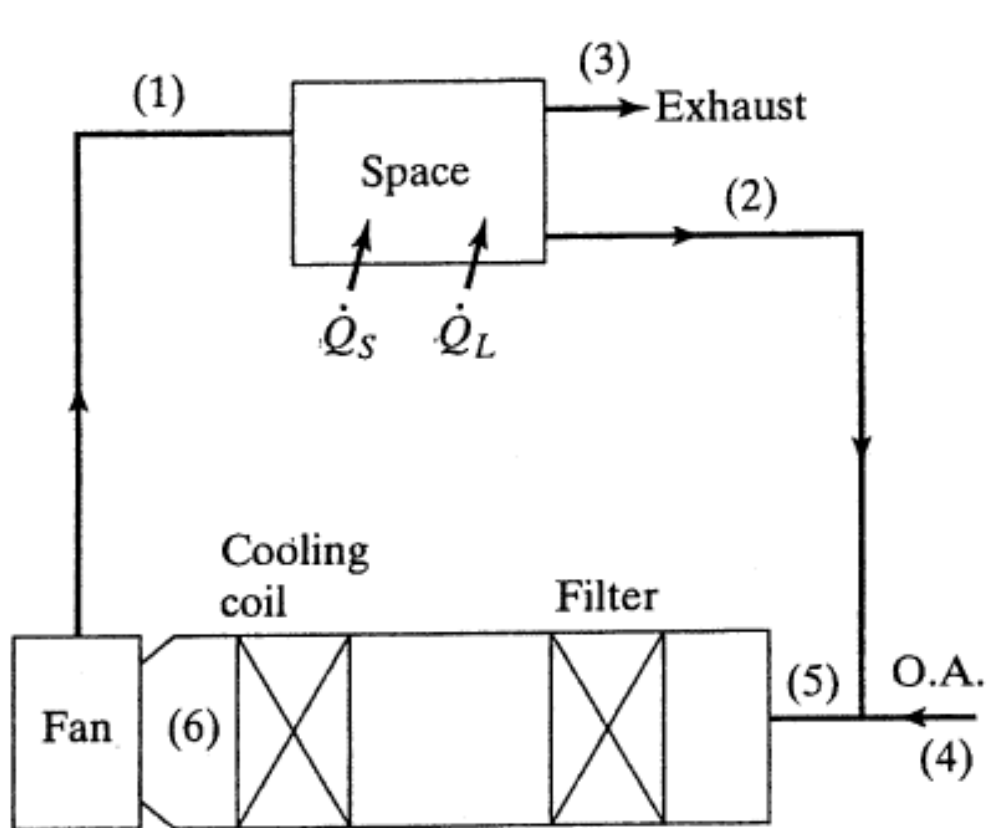


# Determining entering air conditions

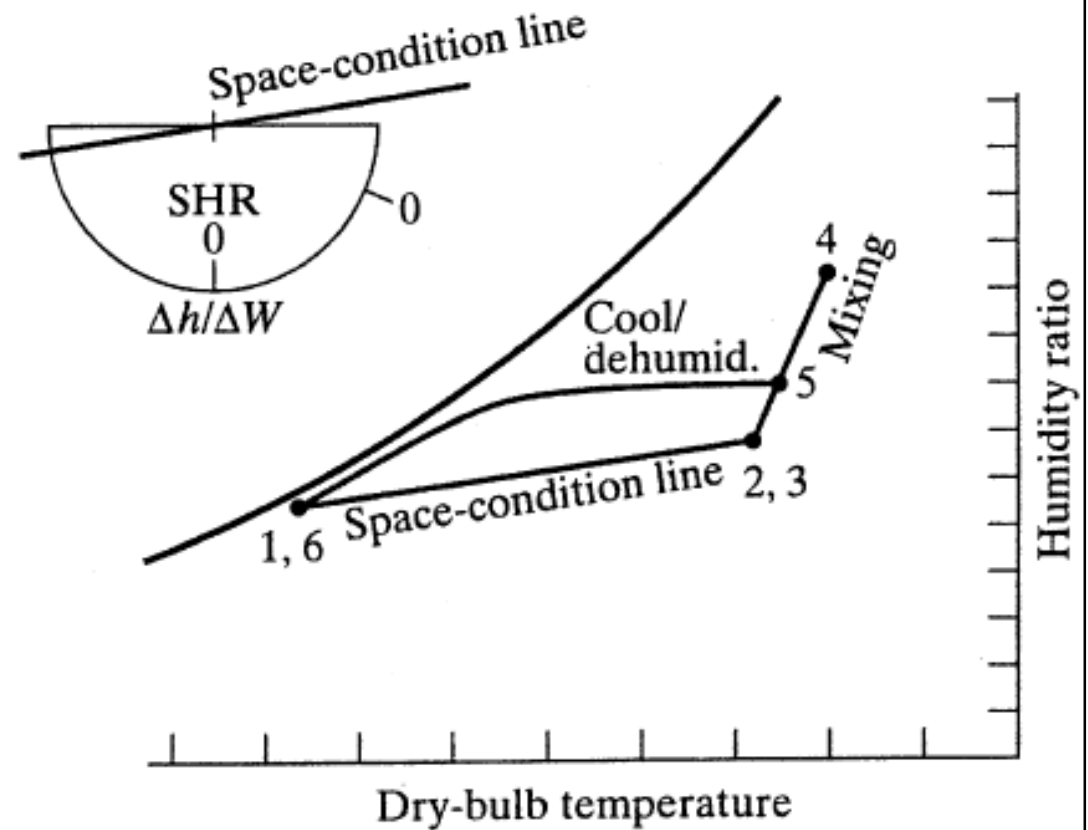


(Source: Trane)

## Simple air conditioning cycle



(a)



(b)

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

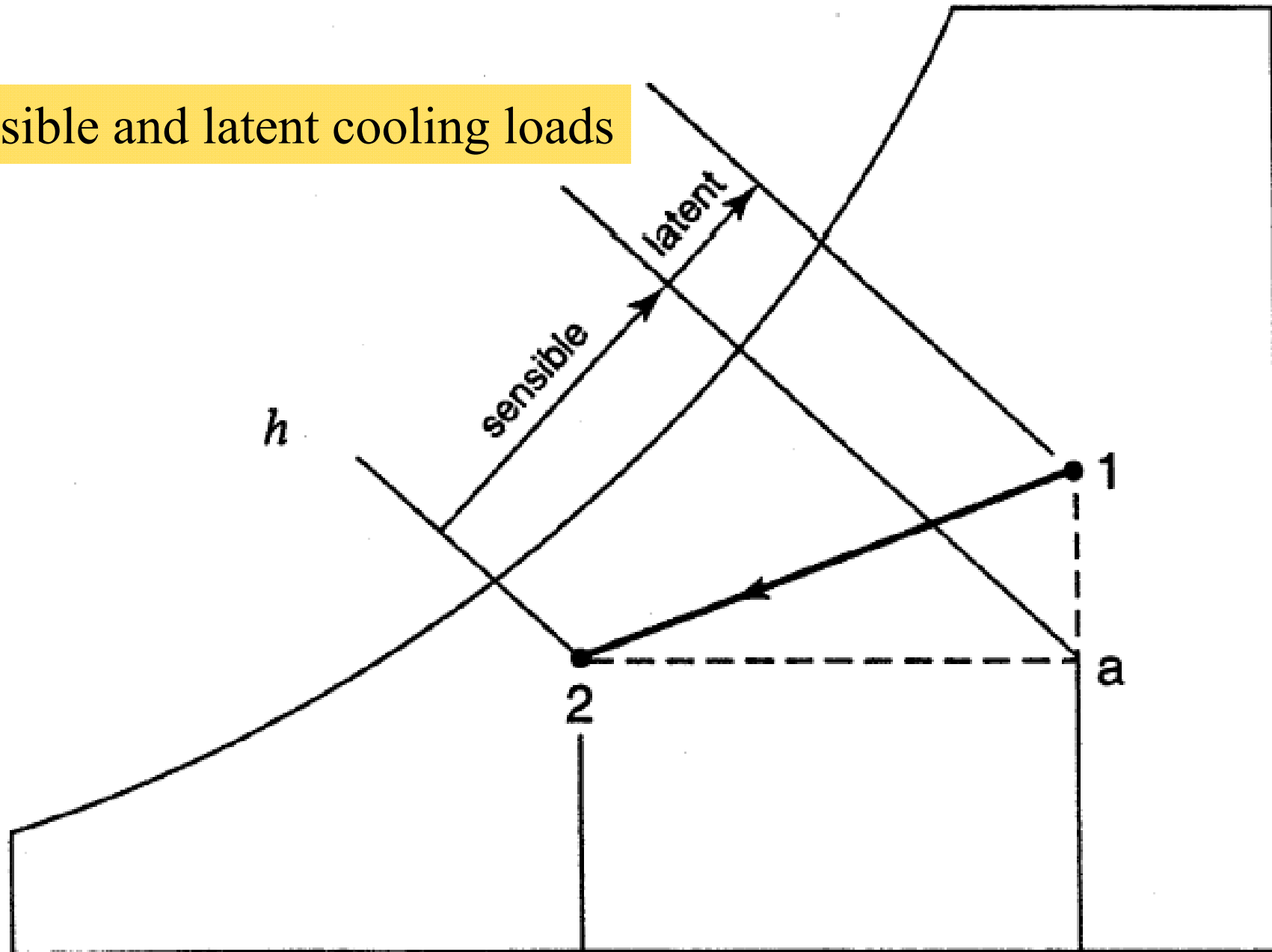
- Outdoor: DBT = 33 °C; WBT = 28 °C; flow = 20% of supply air
- Indoor: DBT = 25 °C; %RH = 50%
- Air leaving cooling coil: DBT = 13 °C; %RH = 95%



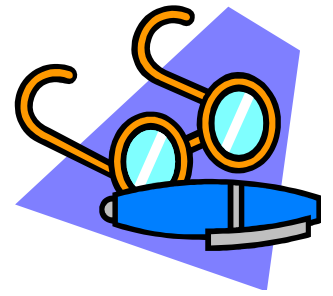


# Using psychrometric chart to represent different HVAC systems

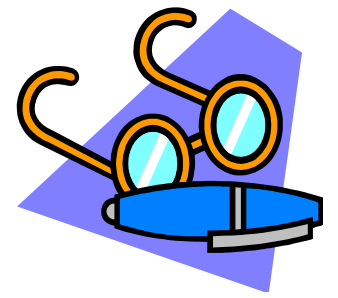
Sensible and latent cooling loads



# Psychrometric processes



- 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>

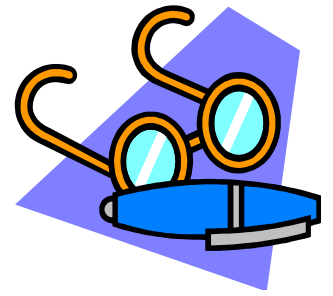


# Psychrometric processes

---

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

# Psychrometric processes

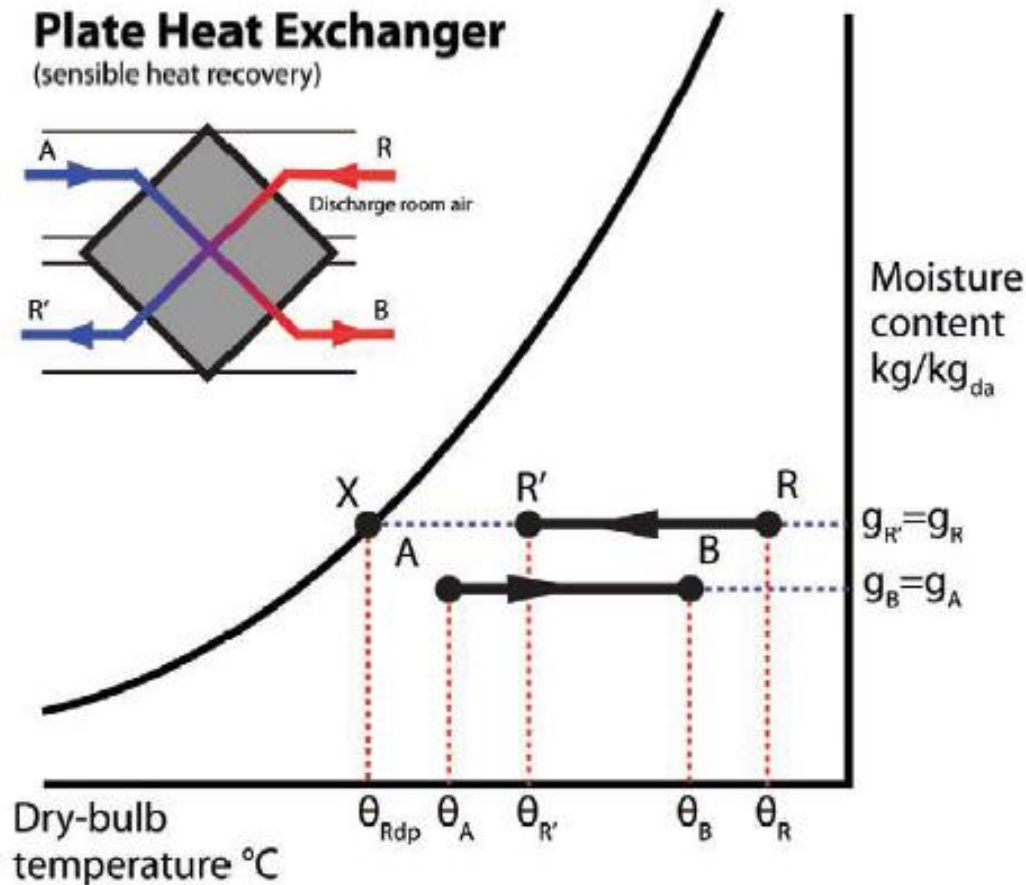
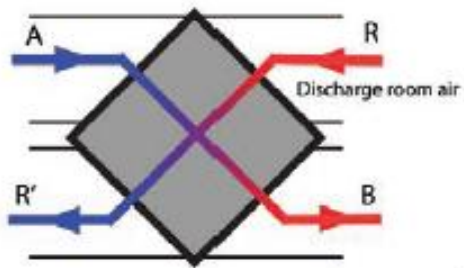


- Calculations:
  - 1. Sensible heat ratio (SHR)
    - SHR is the ratio of sensible heat load to total heat load
  - 2. Space cooling load
  - 3. Cooling coil's load/capacity
  - 4. Humidification capacity
  - 5. Mixing processes
    - Principles of heat balance & conservation of mass

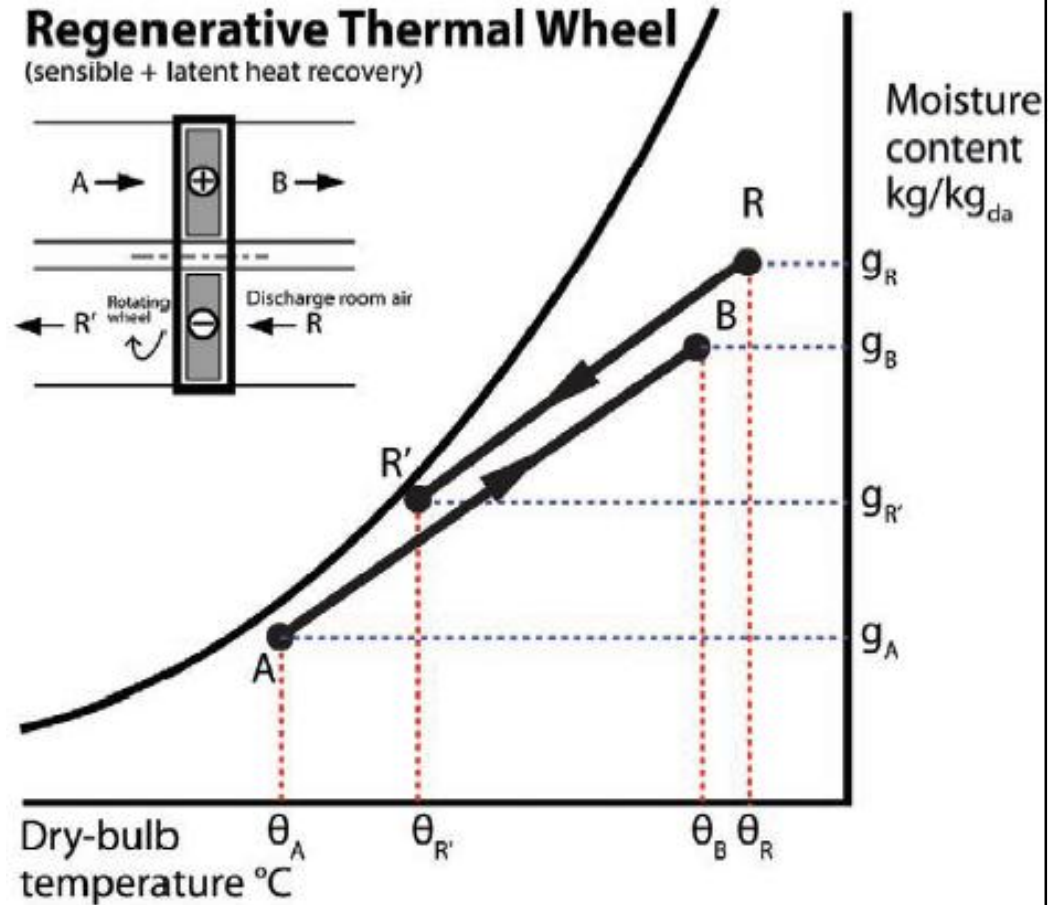
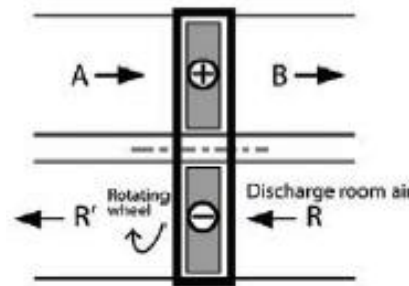


# The psychrometrics of HVAC sub-systems

## Plate Heat Exchanger (sensible heat recovery)



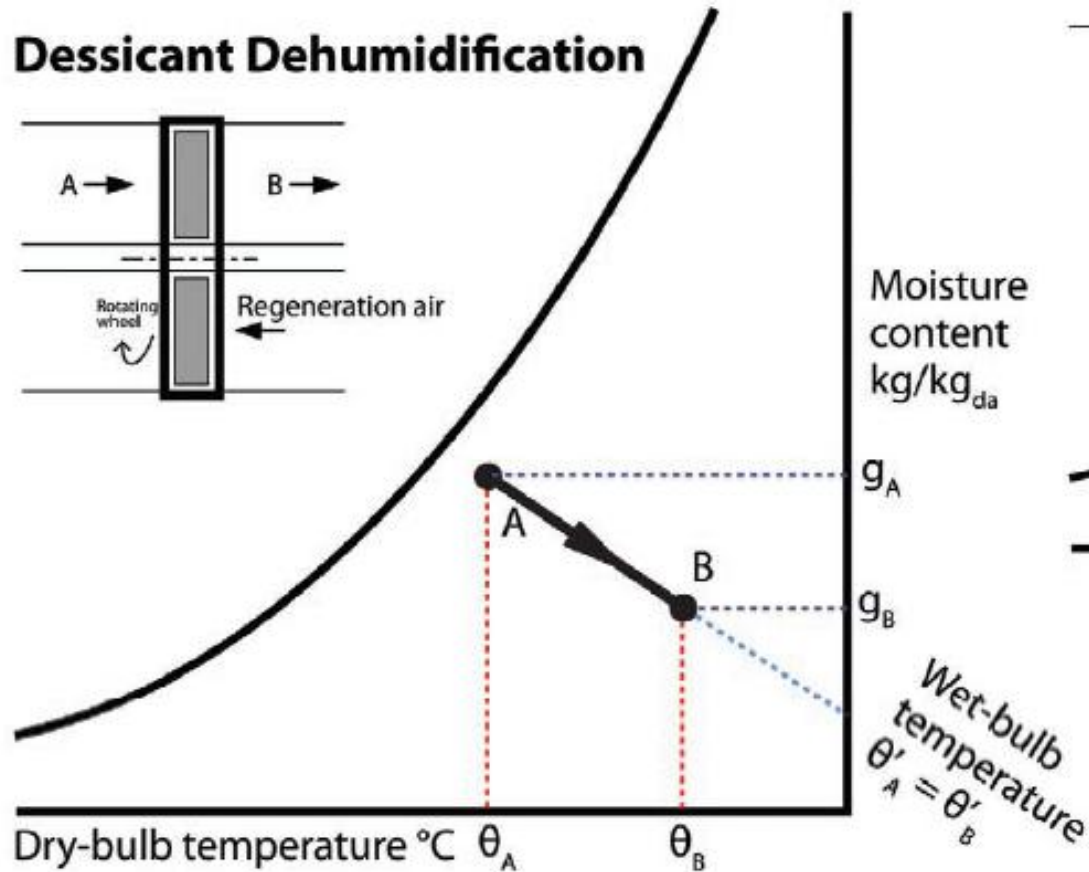
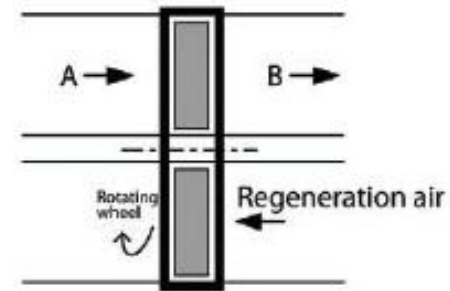
## Regenerative Thermal Wheel (sensible + latent heat recovery)



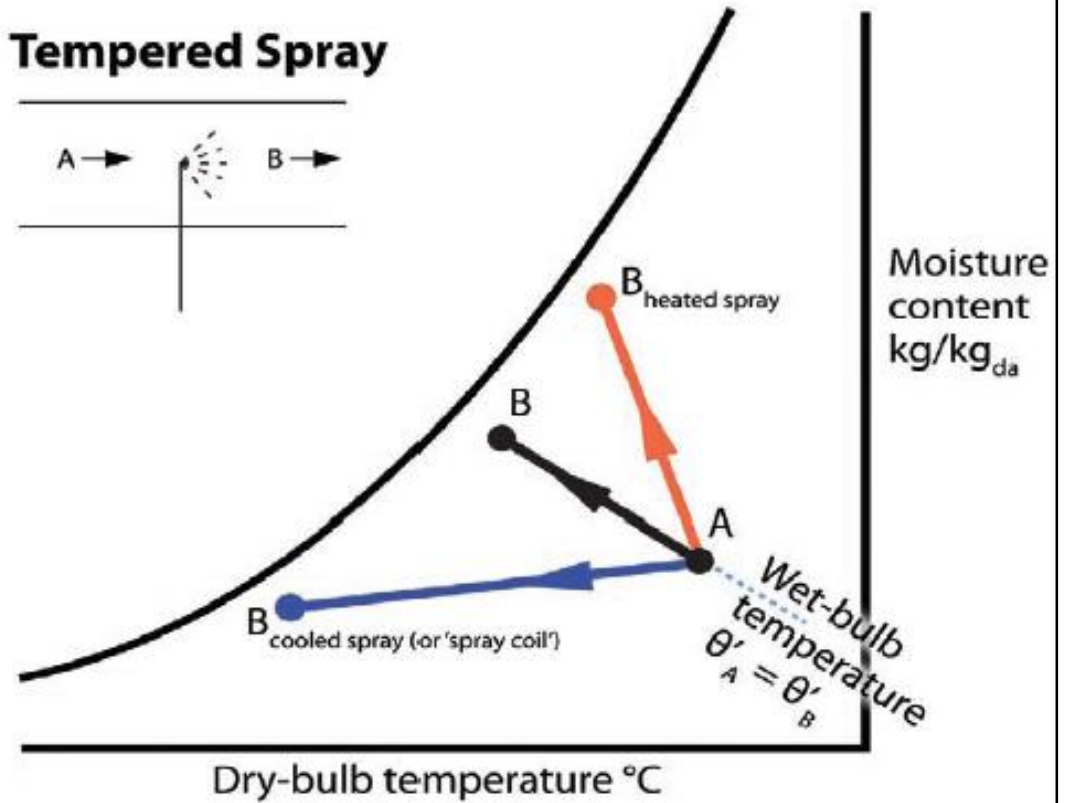
Do you know how to represent the processes of different HVAC sub-systems on the psychrometric chart?

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

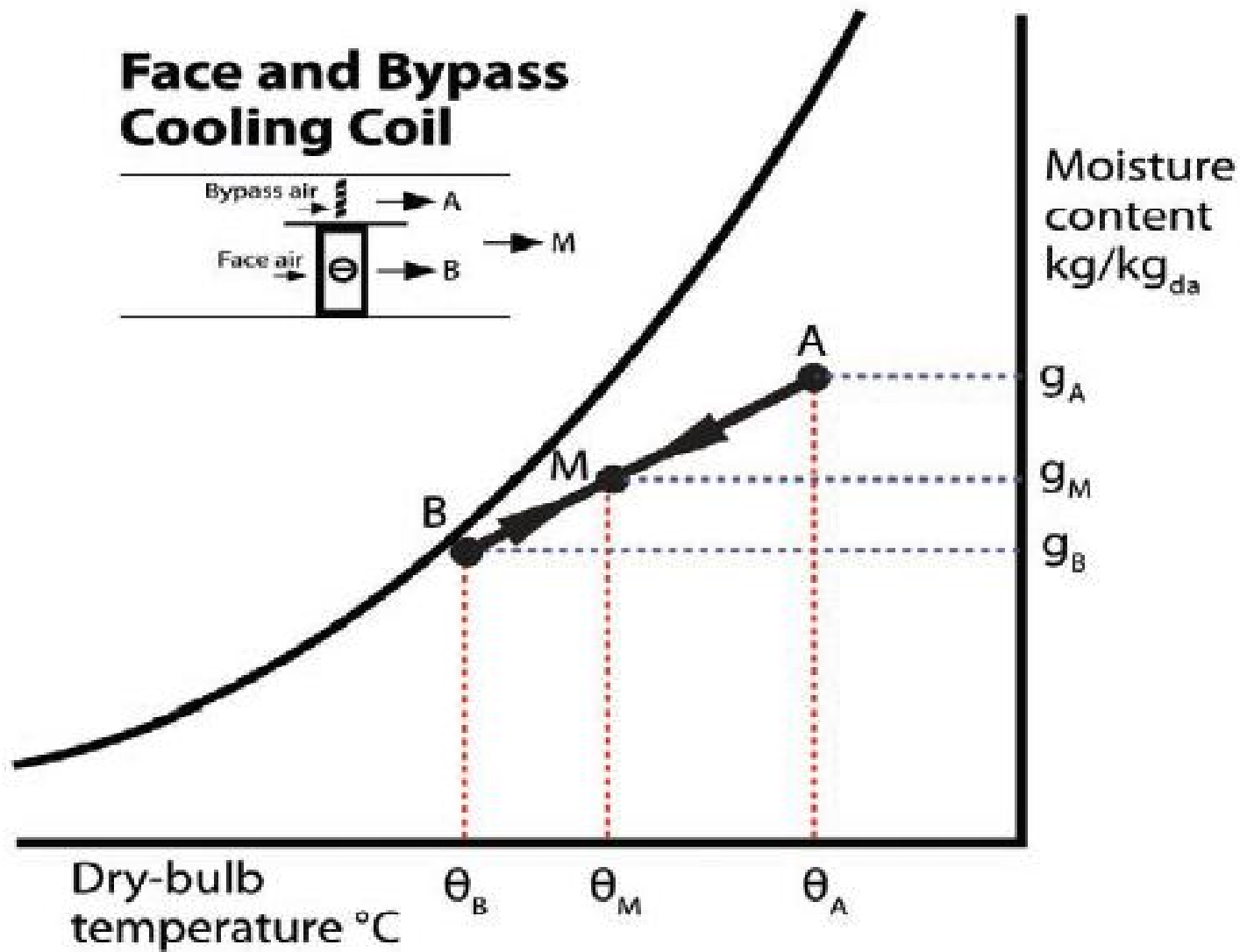
## Dessicant Dehumidification



## Tempered Spray



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

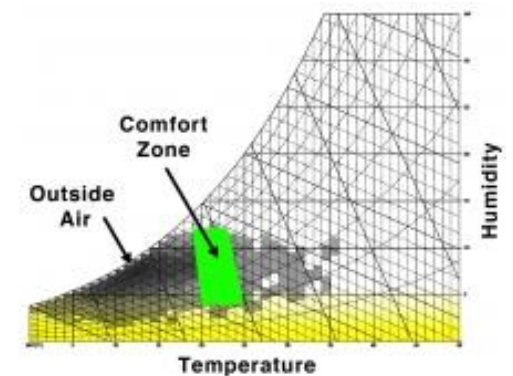
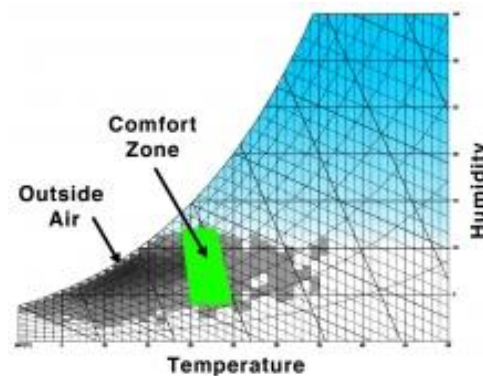
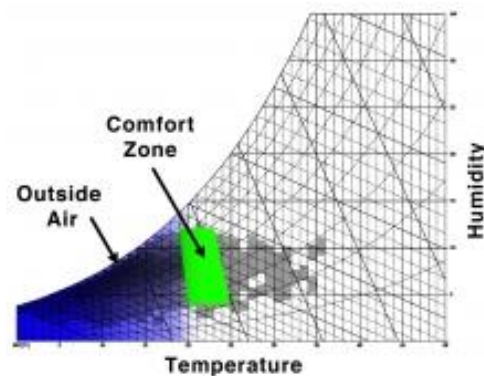
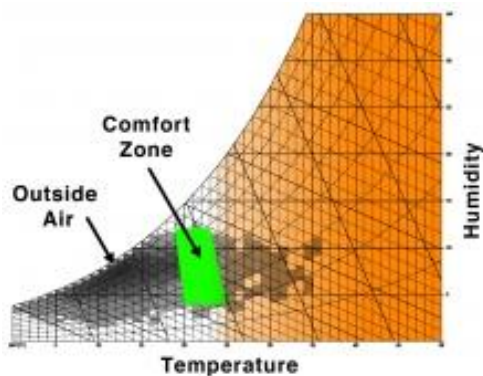




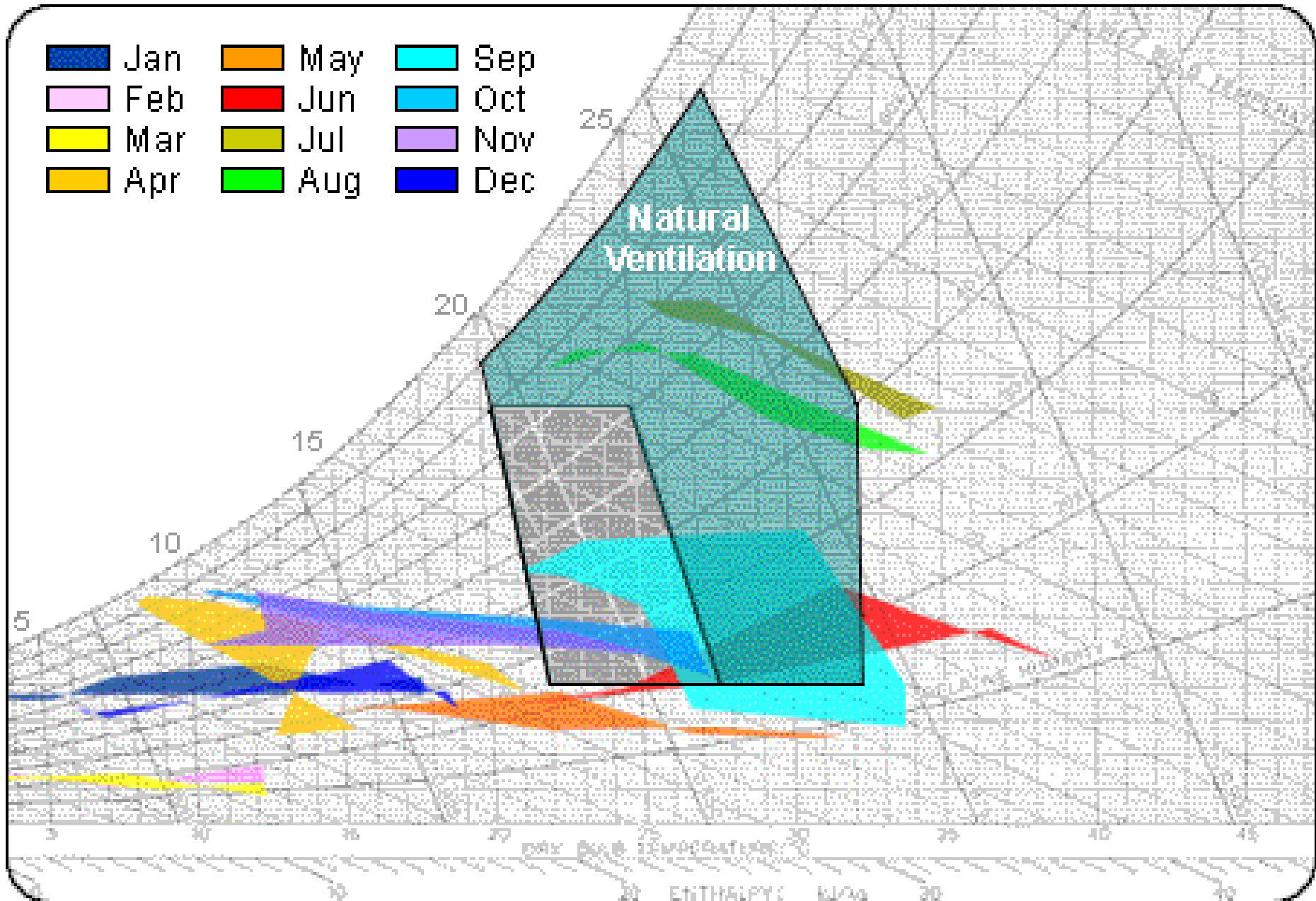


# Psychrometric analysis

- Psychrometric Charts [Autodesk Sustainability W/S]
  - <http://sustainabilityworkshop.autodesk.com/buildings/psychrometric-charts>
  - What is a Psychrometric Chart ?
  - Anatomy of the Psychrometric Chart
  - Interpreting the Psychrometric Chart
  - Design Strategies and the Psychrometric Chart



# Analysis of external climate



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

## PSYCHROMETRIC CHART ASHRAE Standard 55

LOCATION: Climate Zone 3, CA, USA  
 Latitude/Longitude: 37.7° North, 122.2° West, Time Zone from Greenwich -8  
 Data Source: WYEC2-C-00003 724930 WMO Station Number. Elevation 6 ft

### LEGEND

COMFORT INDOORS  
 100% ■ COMFORTABLE  
 0% ■ NOT COMFORTABLE

### DESIGN STRATEGIES: JANUARY through DECEMBER

9.5%	1 Comfort(829 hrs)
2.9%	2 Sun Shading of Windows(256 hrs)
0.7%	3 High Thermal Mass(61 hrs)
	4 High Thermal Mass Night Flush(0 hrs)
	5 Direct Evaporative Cooling(0 hrs)
	6 Two-Stage Evaporative Cooling(0 hrs)
	7 Natural Ventilation Cooling(0 hrs)
	8 Fan-Forced Ventilation Cooling(0 hrs)
50.2%	9 Internal Heat Gain(4400 hrs)
	10 Passive Solar Direct Gain Low Mass(0 hrs)
19.2%	11 Passive Solar Direct Gain High Mass(1680 hrs)
0.1%	12 Wind Protection of Outdoor Spaces(11 hrs)
	13 Humidification Only(0 hrs)
0.6%	14 Dehumidification Only(56 hrs)
0.3%	15 Cooling, add Dehumidification if needed(22 hrs)
30.4%	16 Heating, add Humidification if needed(2662 hrs)

100.0% Comfortable Hours using Selected Strategies  
 (8760 out of 8760 hrs)

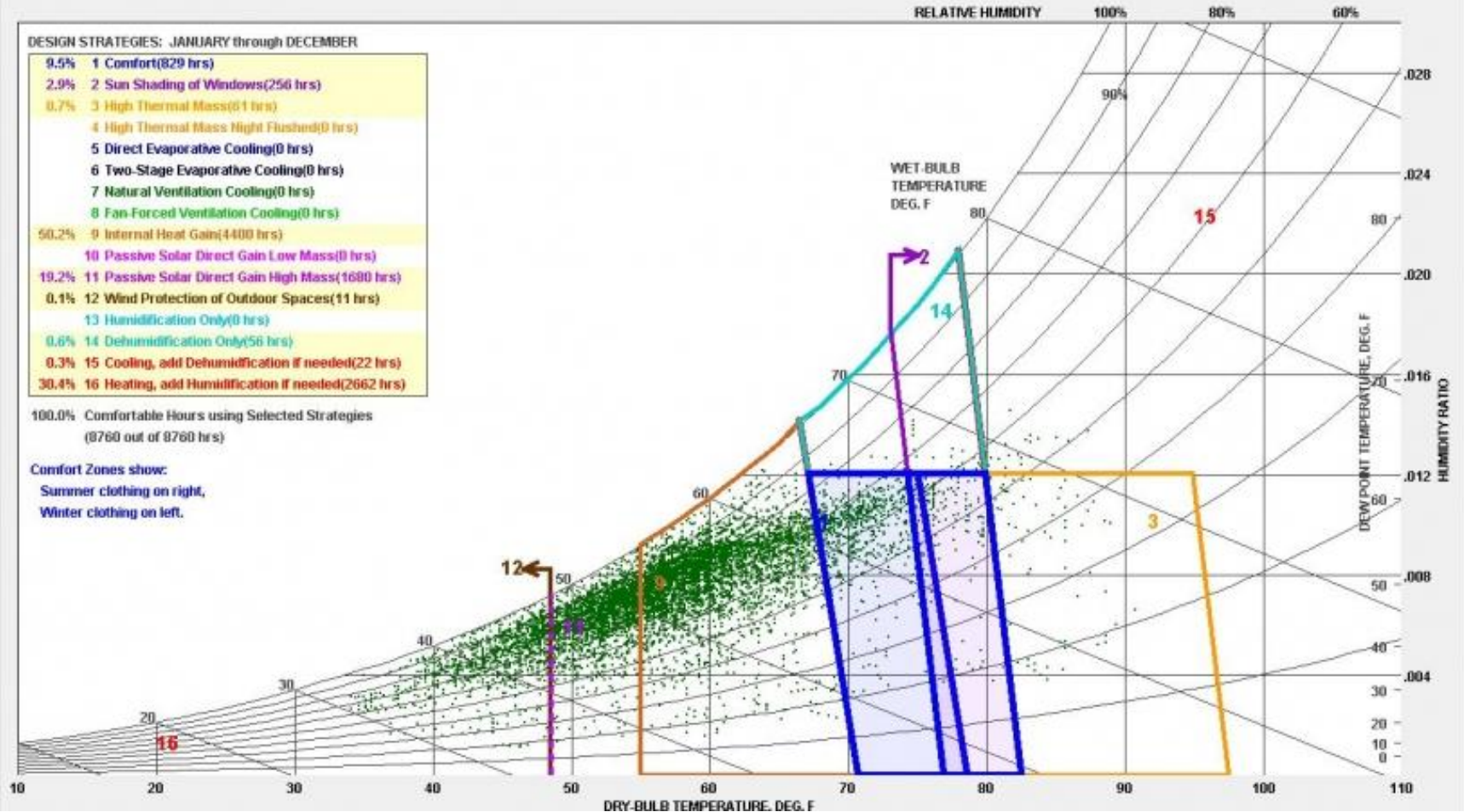
Comfort Zones show:  
 Summer clothing on right,  
 Winter clothing on left.

PLOT: COMFORT\_INDOORS

Hourly     Daily Min/Max  
 All Hours     Selected Hours  
 1 a.m. through midnight  
 All Months     Selected Months  
 JAN through DEC  
 One Month JAN Next Month  
 One Day 1 Next Day  
 One Hour 1 a.m. Next Hour

TEMPERATURE RANGE:  
 10 to 110 °F     Fit to Data

Display Design Strategies  
 Show Best set of Design Strategies



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

# Psychrometric analysis



- Psychrometrics and Bioclimatic Analysis for Hong Kong

<http://www.ad.arch.hku.hk/~cmhui/teach/65156-7e.htm>

- Cooling strategies
- Thermal comfort zones
- Frequency distribution on psychrometric charts

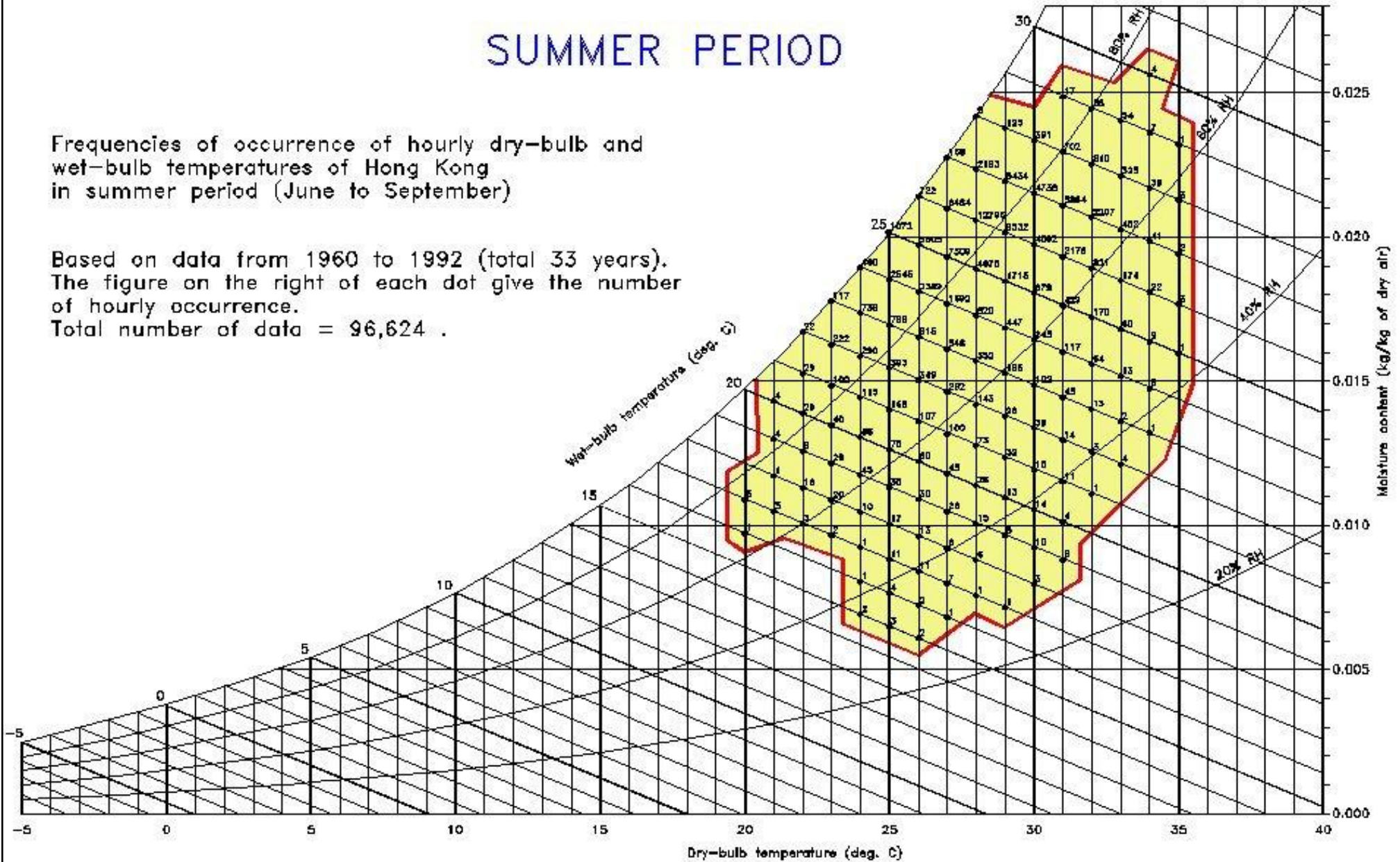


# Analysis of weather conditions in Hong Kong

## SUMMER PERIOD

Frequencies of occurrence of hourly dry-bulb and wet-bulb temperatures of Hong Kong in summer period (June to September)

Based on data from 1960 to 1992 (total 33 years).  
The figure on the right of each dot give the number of hourly occurrence.  
Total number of data = 96,624 .

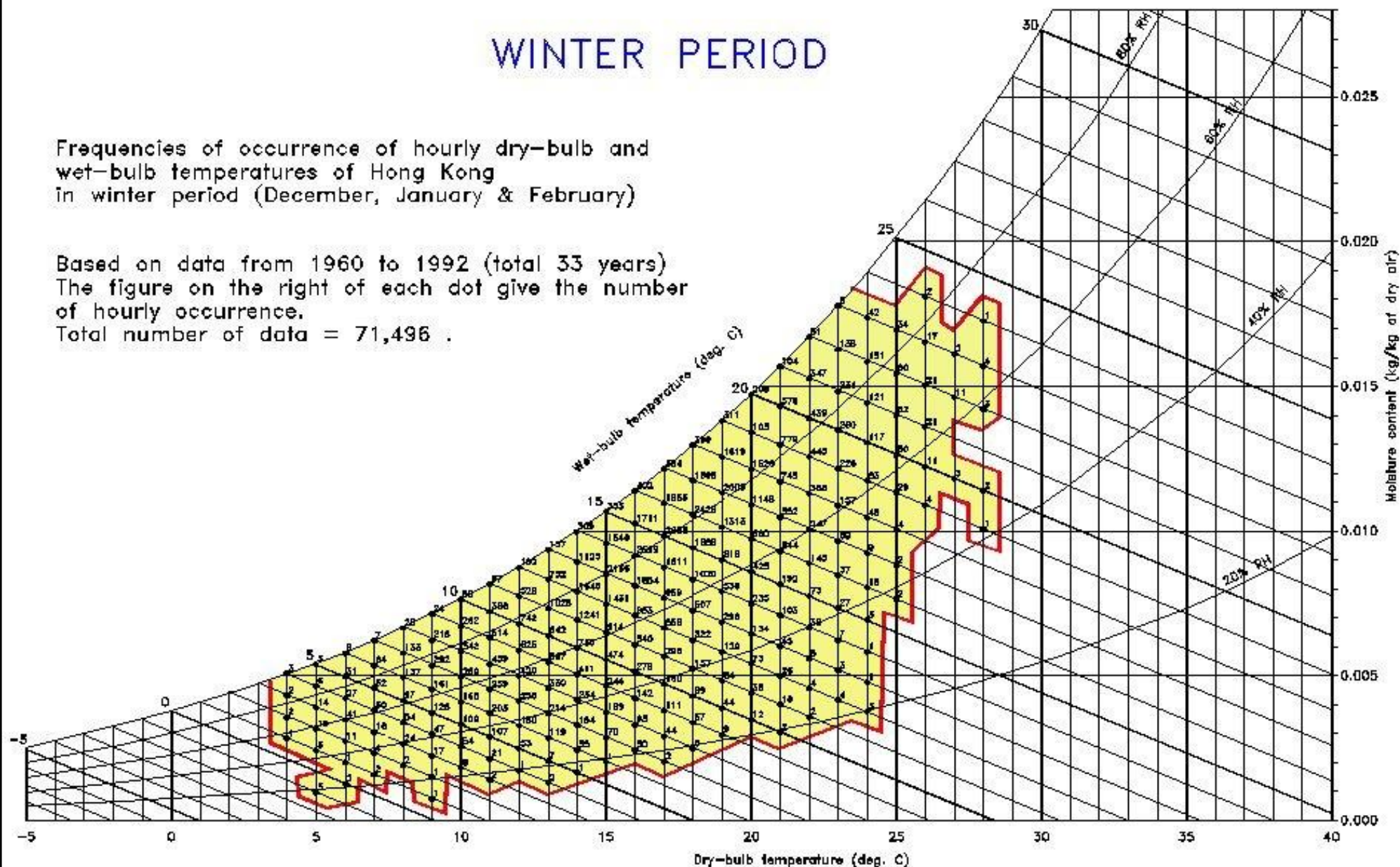


# Analysis of weather conditions in Hong Kong

## WINTER PERIOD

Frequencies of occurrence of hourly dry-bulb and wet-bulb temperatures of Hong Kong in winter period (December, January & February)

Based on data from 1960 to 1992 (total 33 years)  
The figure on the right of each dot give the number of hourly occurrence.  
Total number of data = 71,496 .



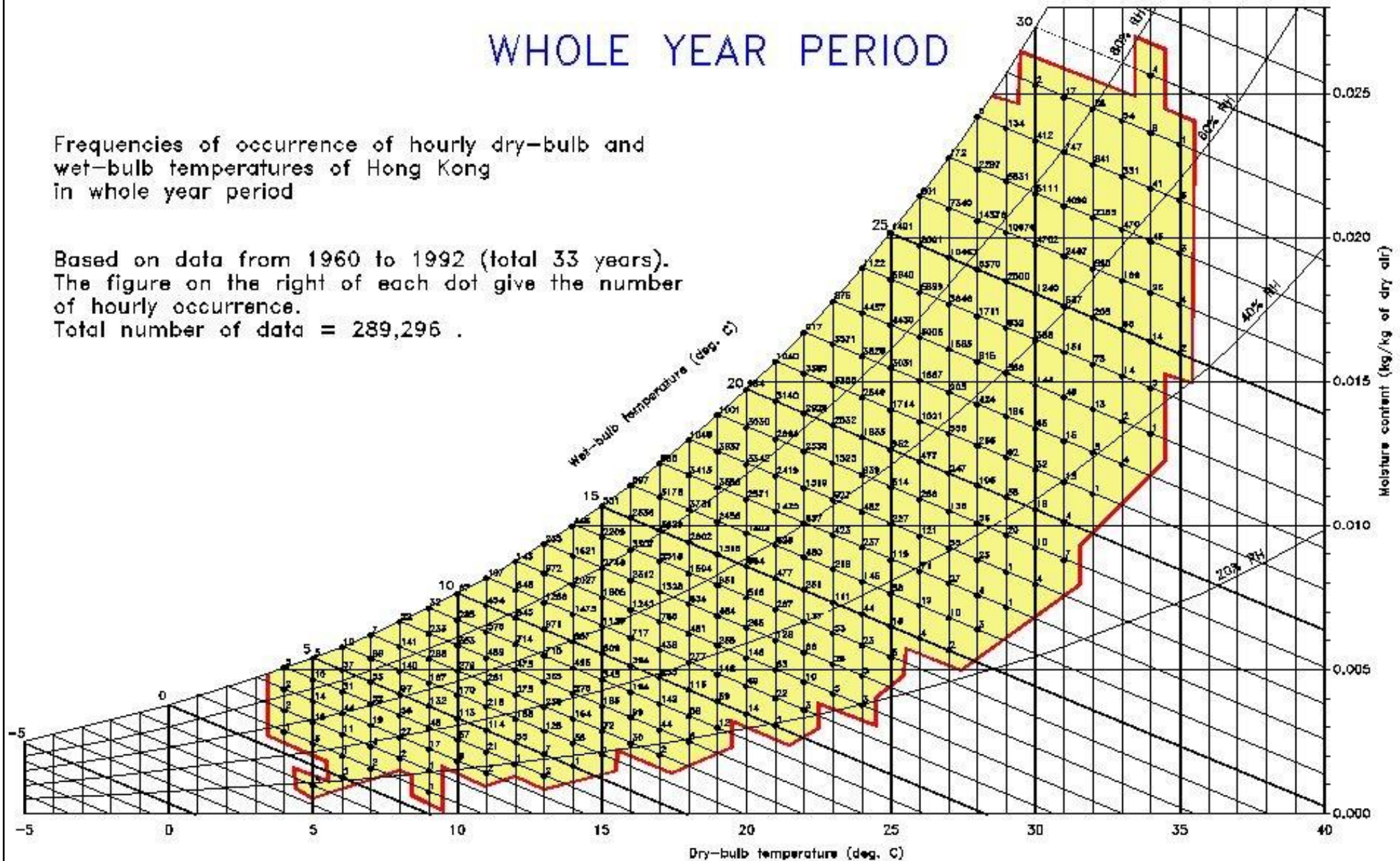


# Analysis of weather conditions in Hong Kong

## WHOLE YEAR PERIOD

Frequencies of occurrence of hourly dry-bulb and wet-bulb temperatures of Hong Kong in whole year period

Based on data from 1960 to 1992 (total 33 years).  
The figure on the right of each dot give the number of hourly occurrence.  
Total number of data = 289,296 .





# Analysis of weather conditions in Hong Kong



ASHRAE PSYCHROMETRIC CHART NO.1

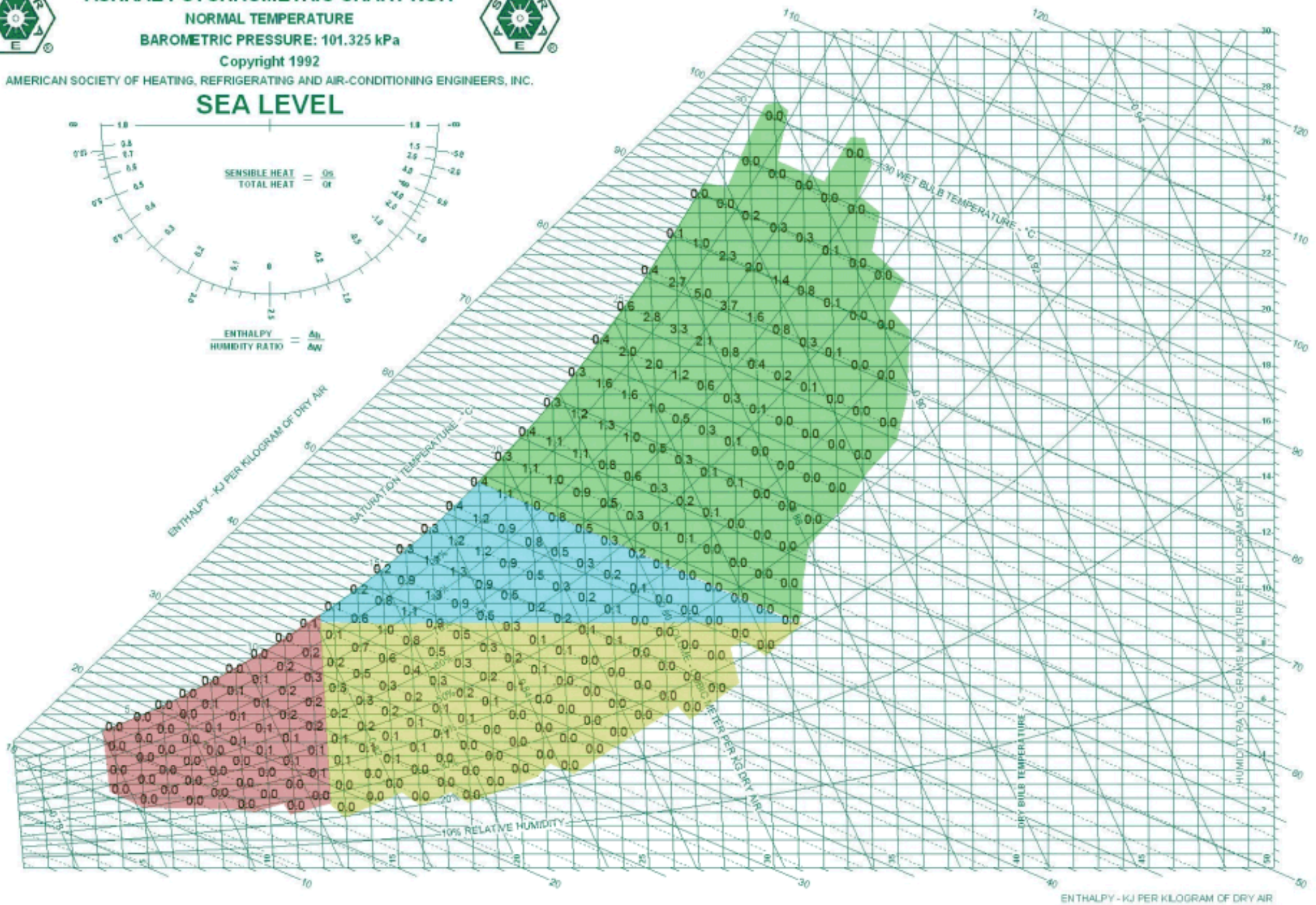
NORMAL TEMPERATURE

BAROMETRIC PRESSURE: 101.325 kPa

Copyright 1992

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.

SEA LEVEL



\* The number represents the possibility of occurrence.



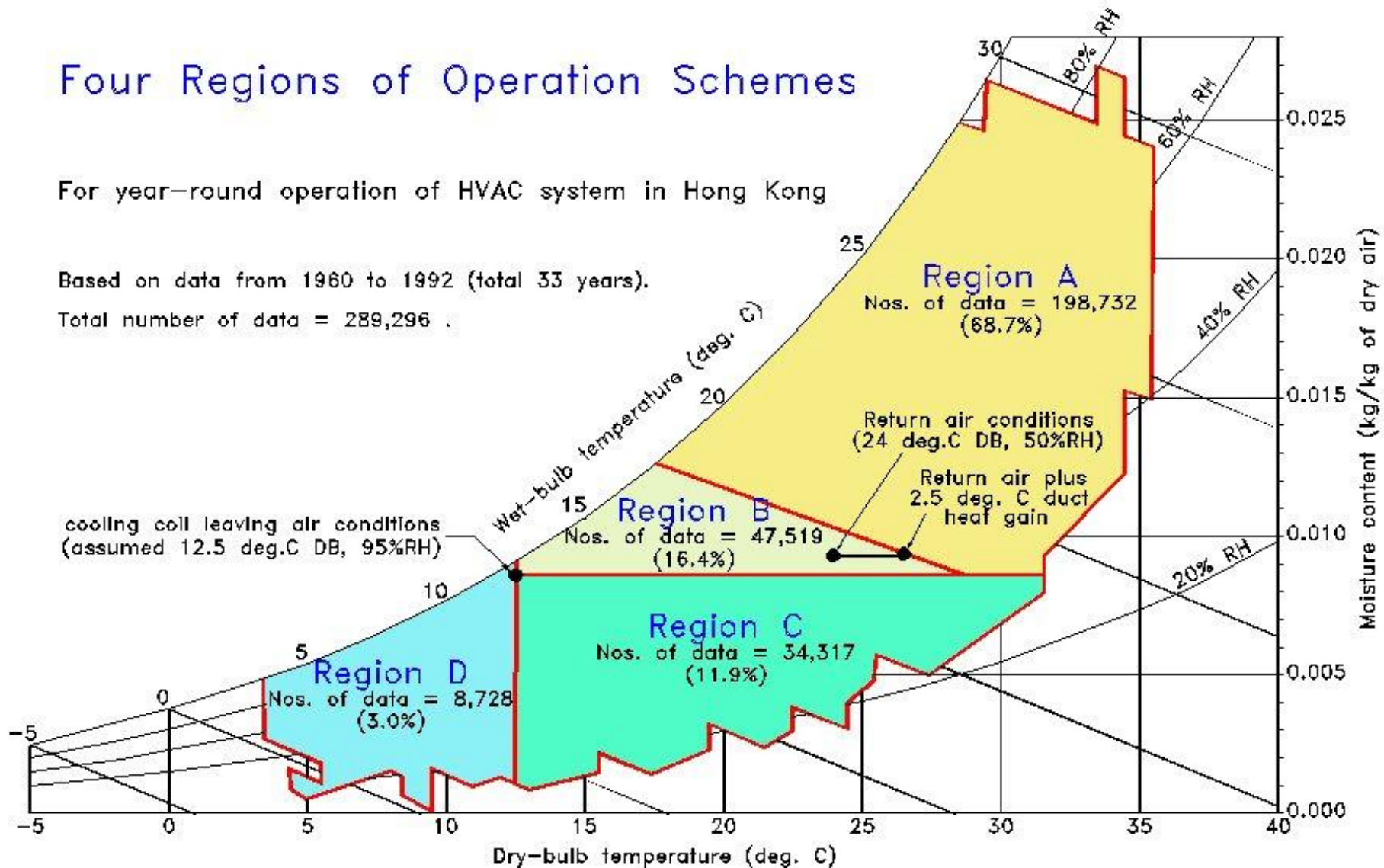
# Analysis of HVAC operation strategy

## Four Regions of Operation Schemes

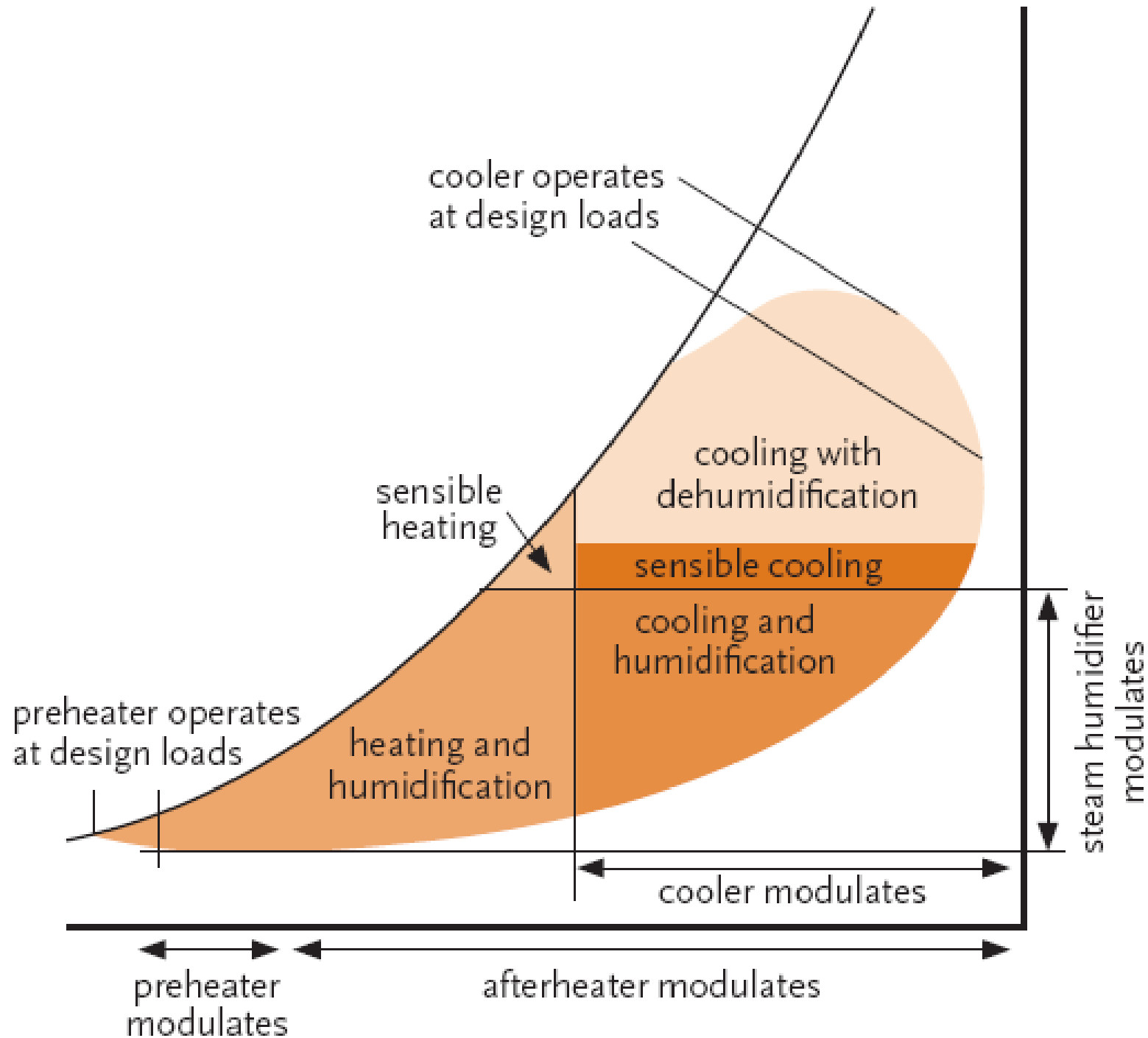
For year-round operation of HVAC system in Hong Kong

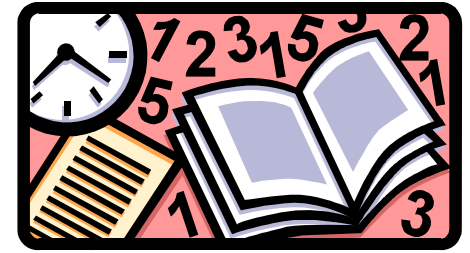
Based on data from 1960 to 1992 (total 33 years).

Total number of data = 289,296 .



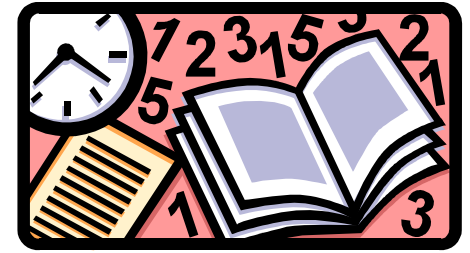
# All-year-round operating regime based on outdoor conditions





# Further Reading

- Air Conditioning: Psychrometrics (pages 5 to 20)
  - [http://www.arca53.dsl.pipex.com/index\\_files/psy1.htm](http://www.arca53.dsl.pipex.com/index_files/psy1.htm)
- CIBSE Journal CPD Programme:
  - <http://www.cibsejournal.com/cpd/>
  - 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)



# References

- NPTEL E-learning course -- Refrigeration and Air Conditioning <http://nptel.ac.in/courses/112105129/>
  - Lesson 28 Psychrometric Processes <http://nptel.ac.in/courses/112105129/28>
  - Lesson 30 Psychrometry Of Air Conditioning Systems <http://nptel.ac.in/courses/112105129/30>
- Gatley, D. P., 2005. *Understanding Psychrometrics*, 2nd ed., American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
- Sherif, S. A., 2002. Overview of psychrometrics, *ASHRAE Journal*, 44 (7): 33-39. [[PDF](#)]