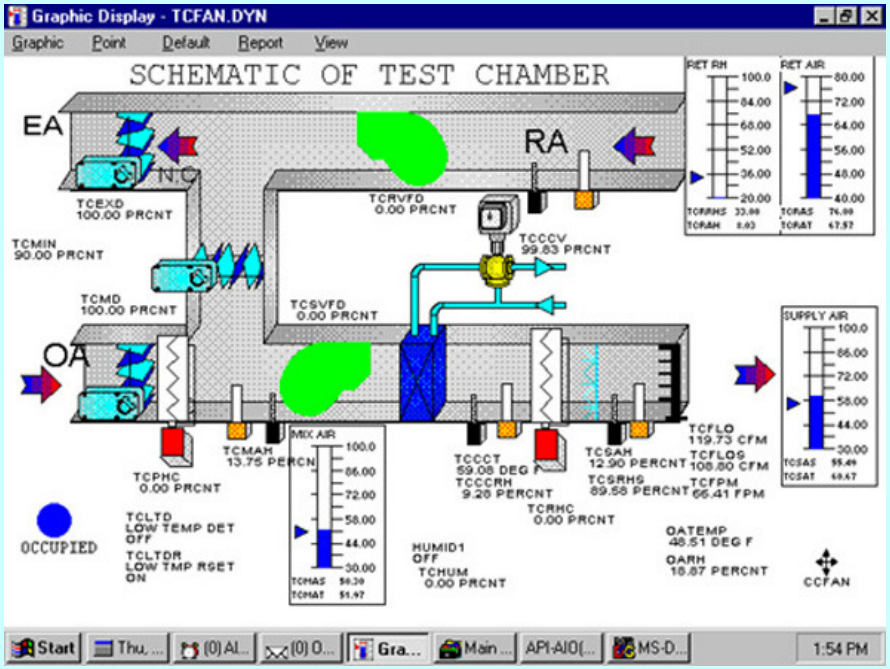
MEBS6006 Environmental Services I

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



Introduction

Dr. Sam C. M. Hui

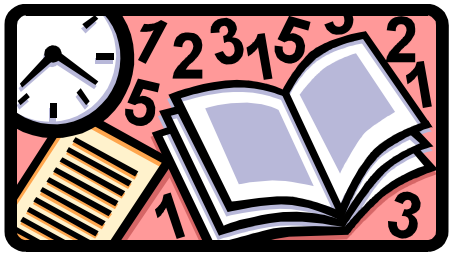
Department of Mechanical Engineering

The University of Hong Kong

E-mail: cmhui@hku.hk

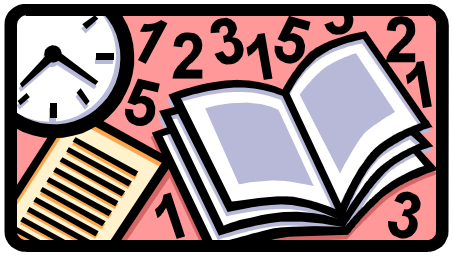
Dec 2015

Course Background



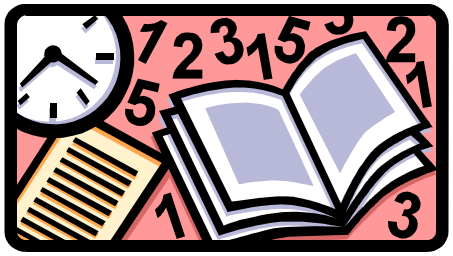
- MEBS6006 Environmental Services I
  - Educational Objectives
    - To enable students to understand the basic principles of design and operation of Heating, Ventilating, Air-Conditioning and Refrigerating (HVAC&R) systems for environmental control of buildings
    - To enable students to design and select proper HVAC&R systems to serve the desired purpose

Course Background

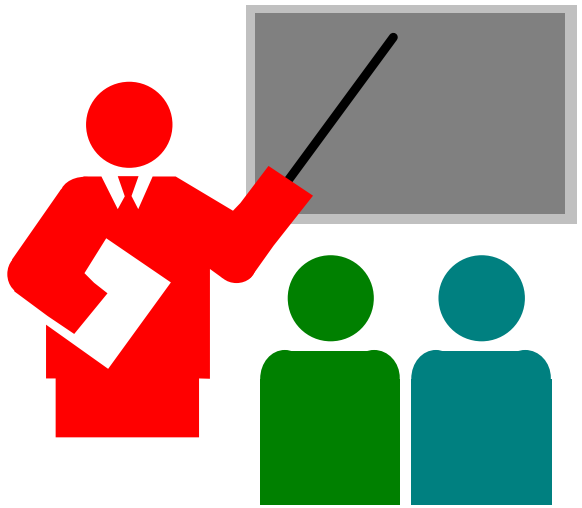


- MEBS6006 Environmental Services I
  - Learning Outcomes:
    - To explain the fundamental principles of HVAC&R systems for environmental control of buildings.
    - To develop skills for design and selection of HVAC&R systems.
  - Assessment:
    - 80% by written examination (2 hours)
    - 20% by continuous assessment (2 nos. assignments)

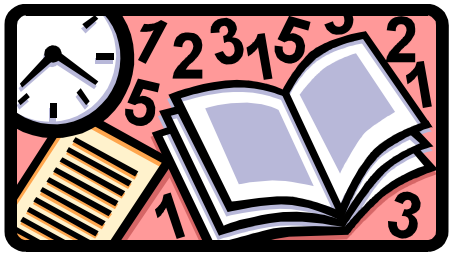
Course Background



- These two courses are related
  - MEBS6006 Environmental services I
    - Basic principles of HVACR
    - Practical design skills
  - MEBS6008 Environmental services II
    - System characteristics and operation
    - Analysis and design strategies



Course Background



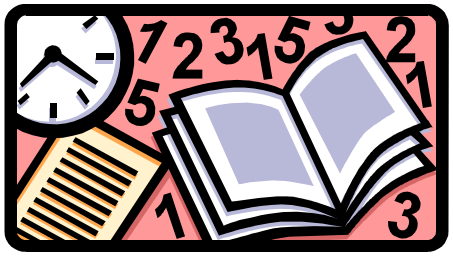
- Study topics of MEBS6006:
  - Introduction
  - Advanced psychrometry
  - Thermal comfort
  - Load estimation
  - Energy calculations

Dr. Sam C M Hui

  - Cooling system
  - Heating and ventilation system
  - Air side system
  - Water side system
  - Refrigeration

Dr. Benjamin P L Ho

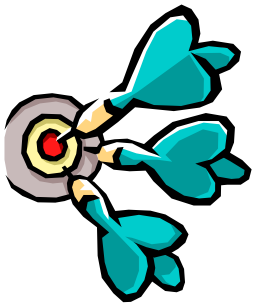
Course Background



- Assumptions
  - You have basic knowledge of thermodynamics and fluid mechanics
  - You are interested in developing your knowledge and skills in HVAC
- Focus of this course
  - From basic principles to intermittent level of HVAC design skills
  - Main focus on cooling design and air conditioning

What is Environmental Services?

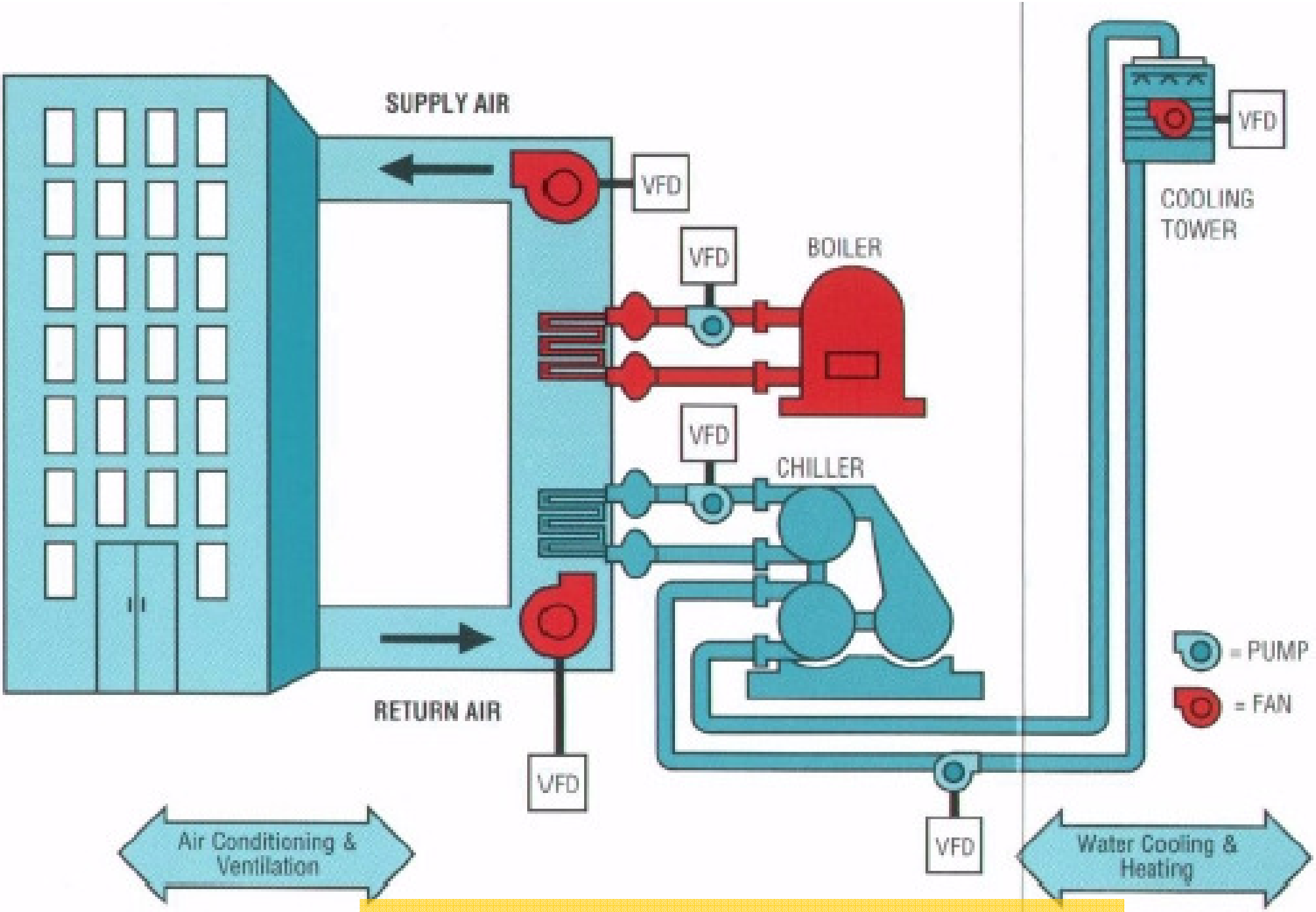
Environmental Services



- They are the engineering systems that help to control and maintain the conditions of indoor built environment
- Also known as:
  - Environmental control systems (ECS)
  - Heating, ventilating, air-conditioning and refrigerating (HVAC&R) systems
  - Heating, ventilating and air-conditioning (HVAC)
  - Mechanical ventilating and air-conditioning (MVAC)
  - Air conditioning and refrigeration (AC&R)

(Video: HVAC Training - Basics of HVAC (10:20) http://www.youtube.com/watch?v=ScVBPAitibQ)

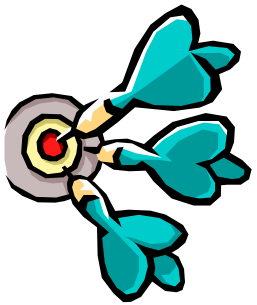
Example of a centralised HVAC system



(Source: http://www.allhvacinfo.com/)

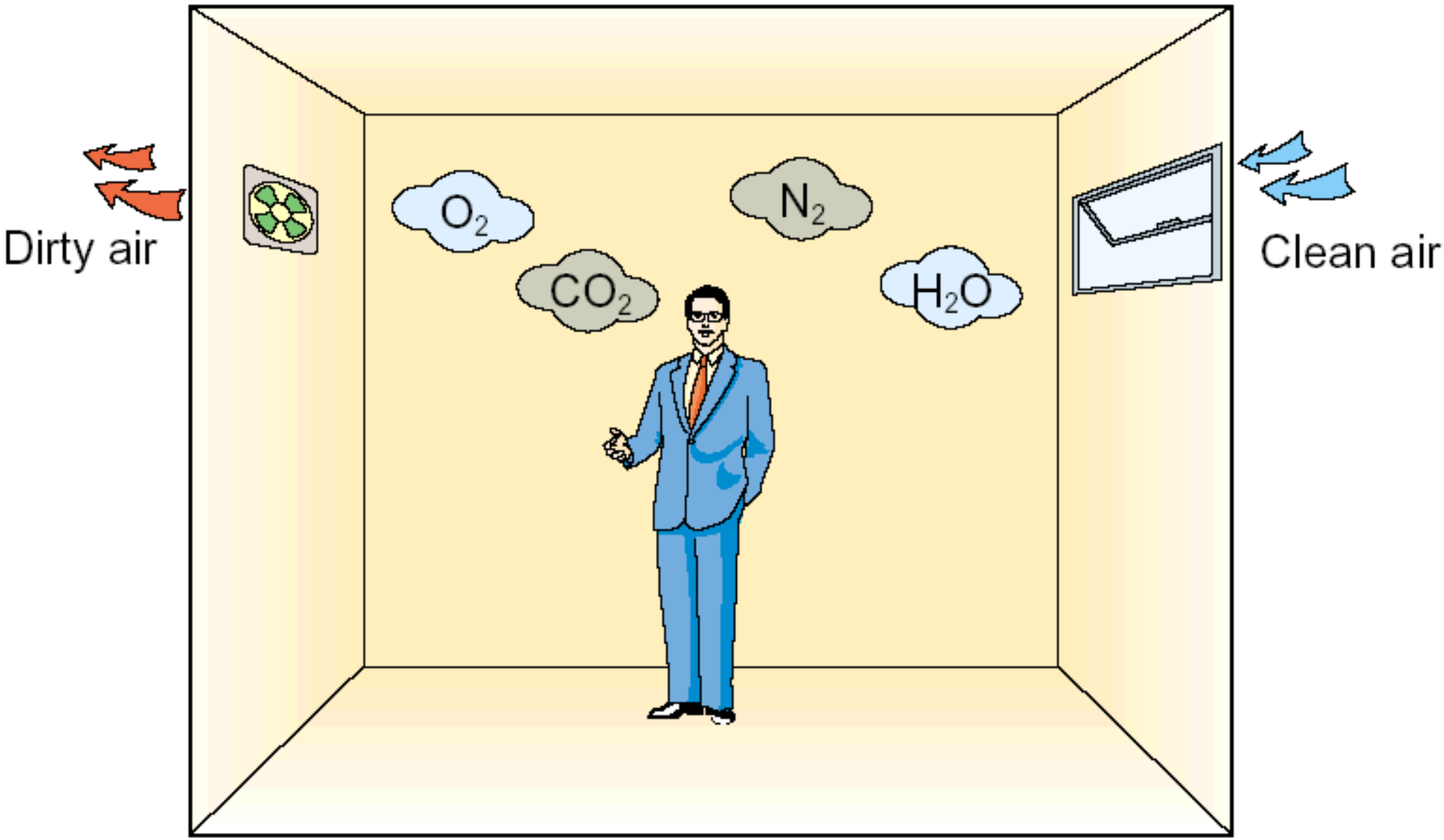
Do you know the HVAC components?

Environmental Services



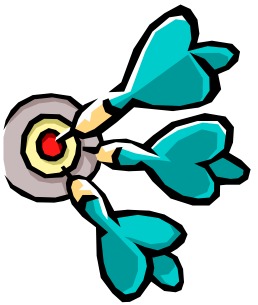
- Understand the purpose of HVAC design
  - To provide adequate indoor air quality by removing and/or diluting indoor pollutants
  - To provide adequate ventilation for processes
  - To remove heat & maintain thermal comfort
  - To control humidity & prevent condensation
- Understand the climate
  - Summer: cooling design & dehumidification
  - Winter: heating design

Simple ventilation design

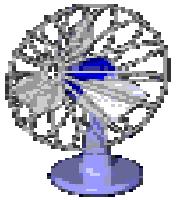


(Source: www.iaq.hk)

Environmental Services



- Common ventilation strategies



  - Natural ventilation
  - Mechanical ventilation
  - Comfort cooling
  - Air conditioning (full control of temp./humidity)
  - Mixed mode or hybrid systems
- If internal heat gains are sufficiently low and the external environment is suitable, natural ventilation can provide a low energy solution

Is it feasible to use
Natural Ventilation?

If situation prevents this,
is it feasible to use
Mechanical Ventilation?

If situation prevents this,
is it feasible to use
Hybrid/Mixed Mode Ventilation?

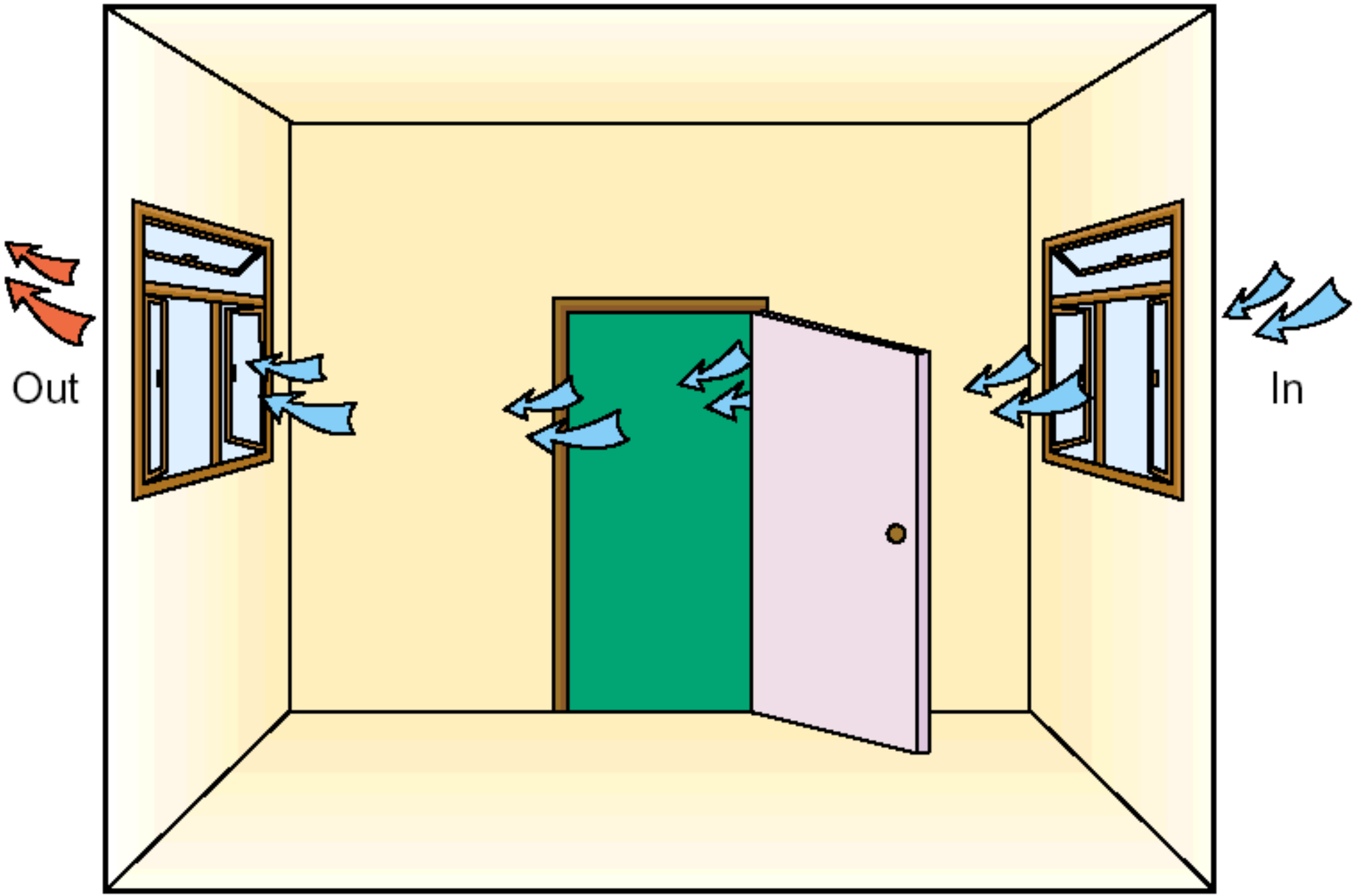
If situation prevents this,
is it feasible to use
Cooling and Heating
(without humidity control)?

If situation prevents this,
is it feasible to use
Full Air Conditioning
(with humidity control)?

Ventilation design hierarchy

Increasing:
- energy consumption
- capital cost
- running costs
- maintenance
- complexity

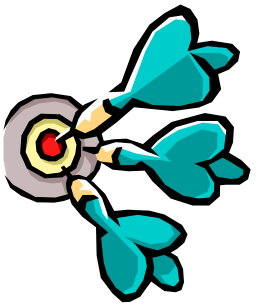
Cross ventilation



(Source: www.iaq.hk)

(Source: www.iaq.hk)

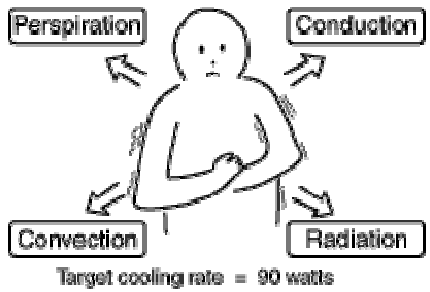
Environmental Services



- Interactions affecting HVAC design
  - Building fabric (architectural design)

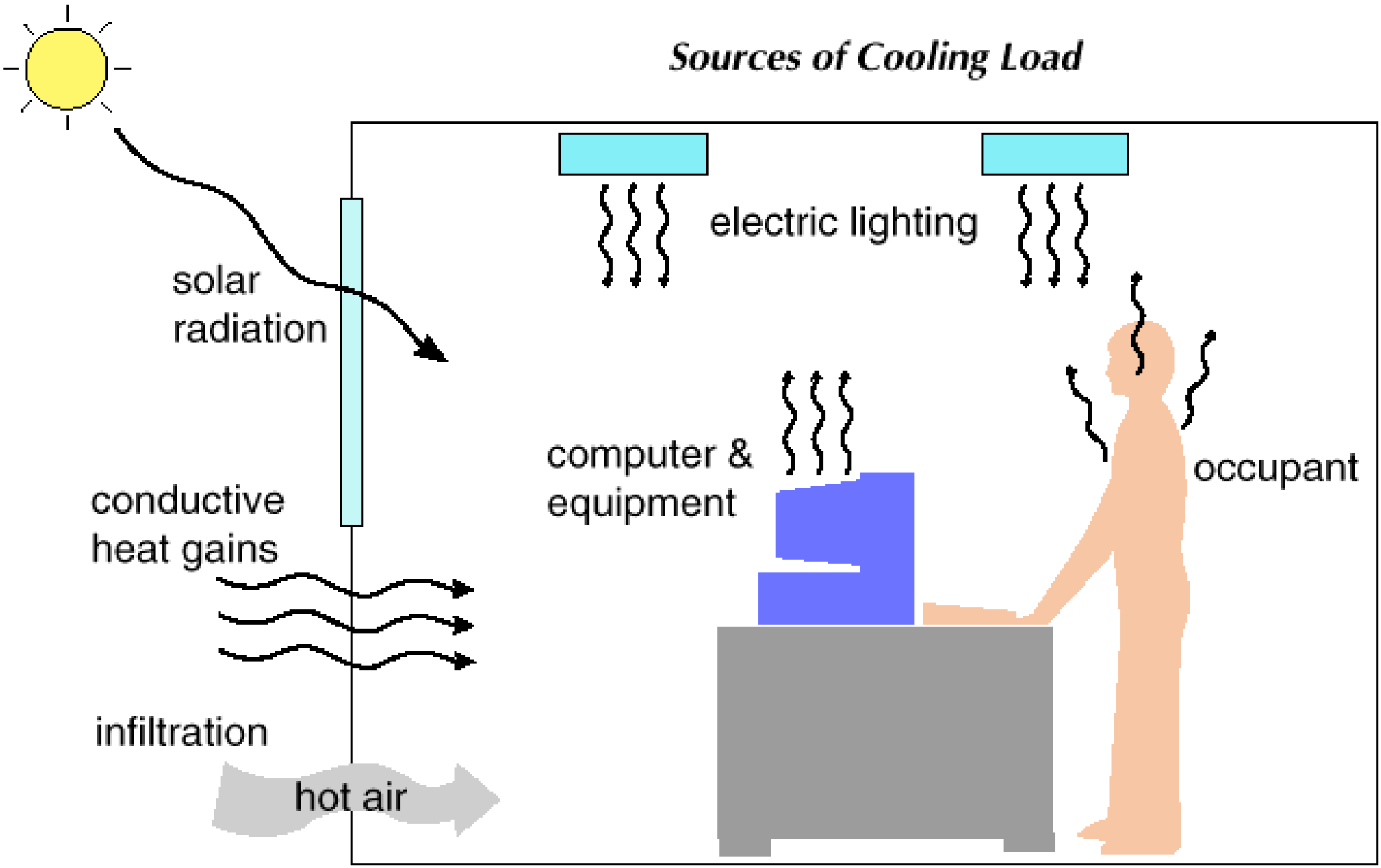
    - Site orientation & conditions
    - Built form, shading, window performance, thermal mass
    - Thermal insulation, reducing infiltration/air leakage
  - Building services elements, e.g.
    - Lighting system & daylighting
    - Small power or equipment loads

  - Occupants' behaviour (human factors)
    - How users behave and react

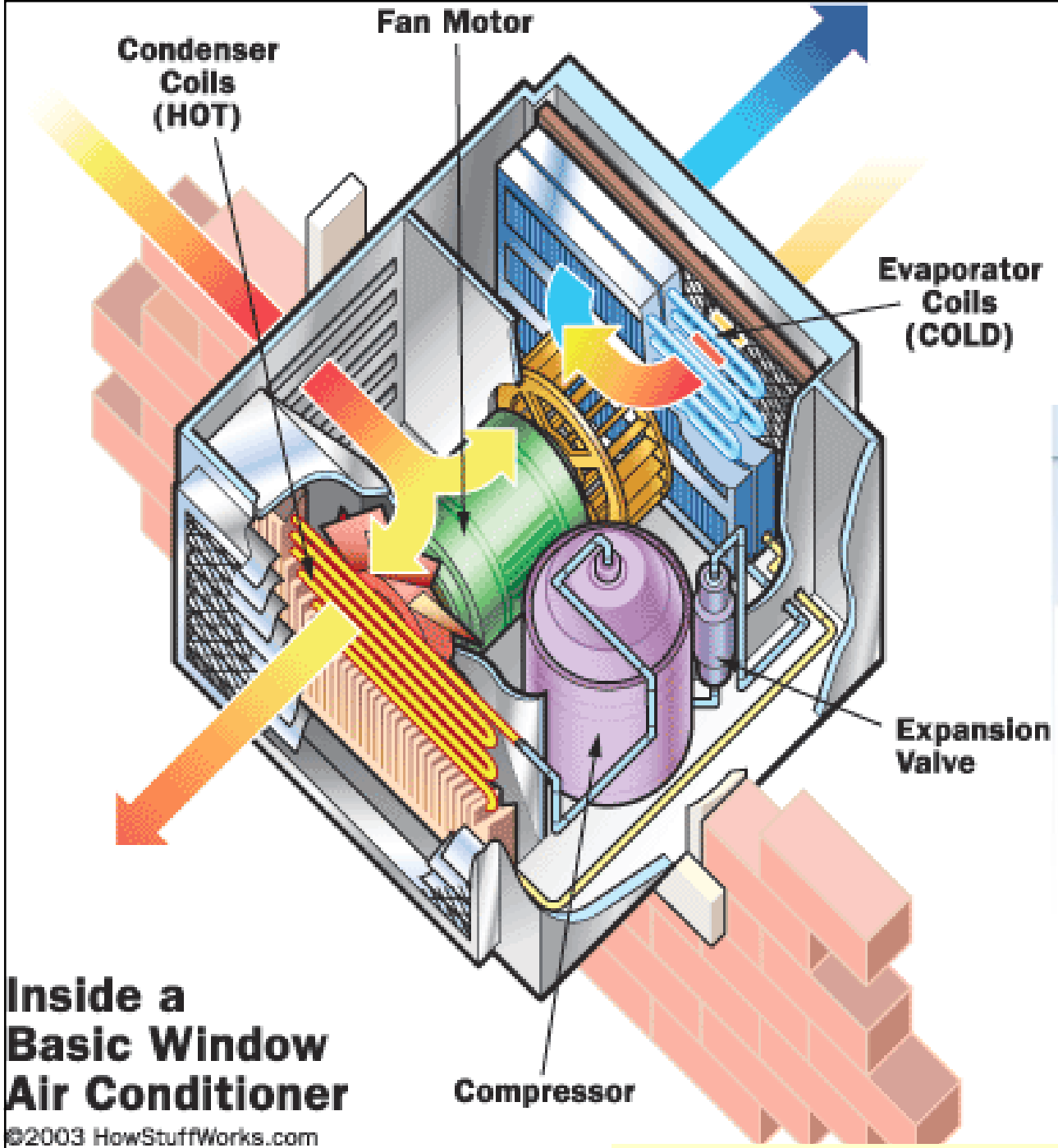


Outdoor weather

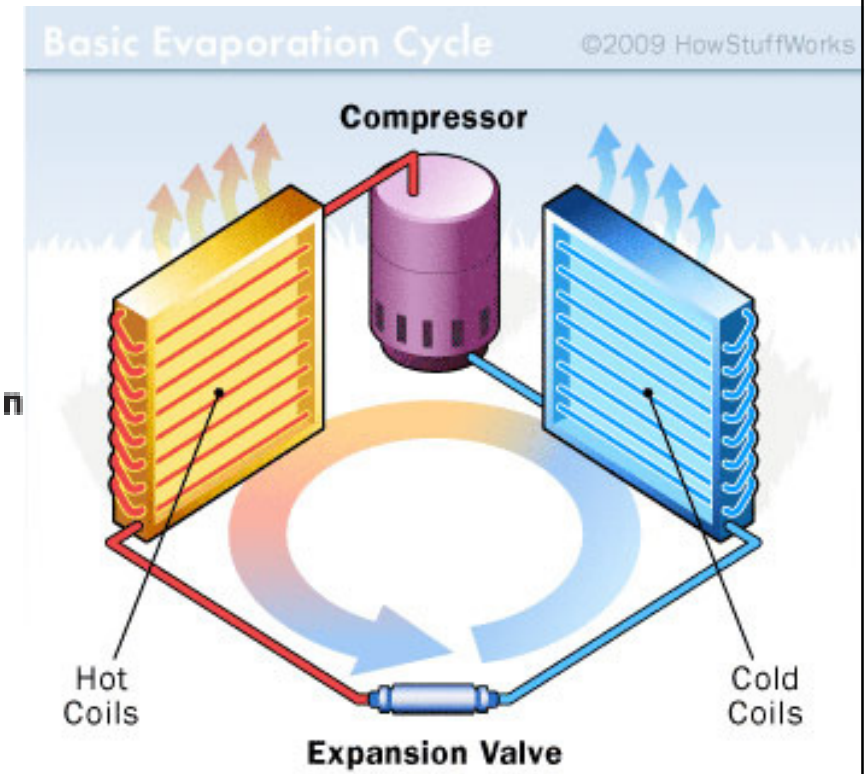
Can you identify all the heat gains?



Indoor conditions and activities



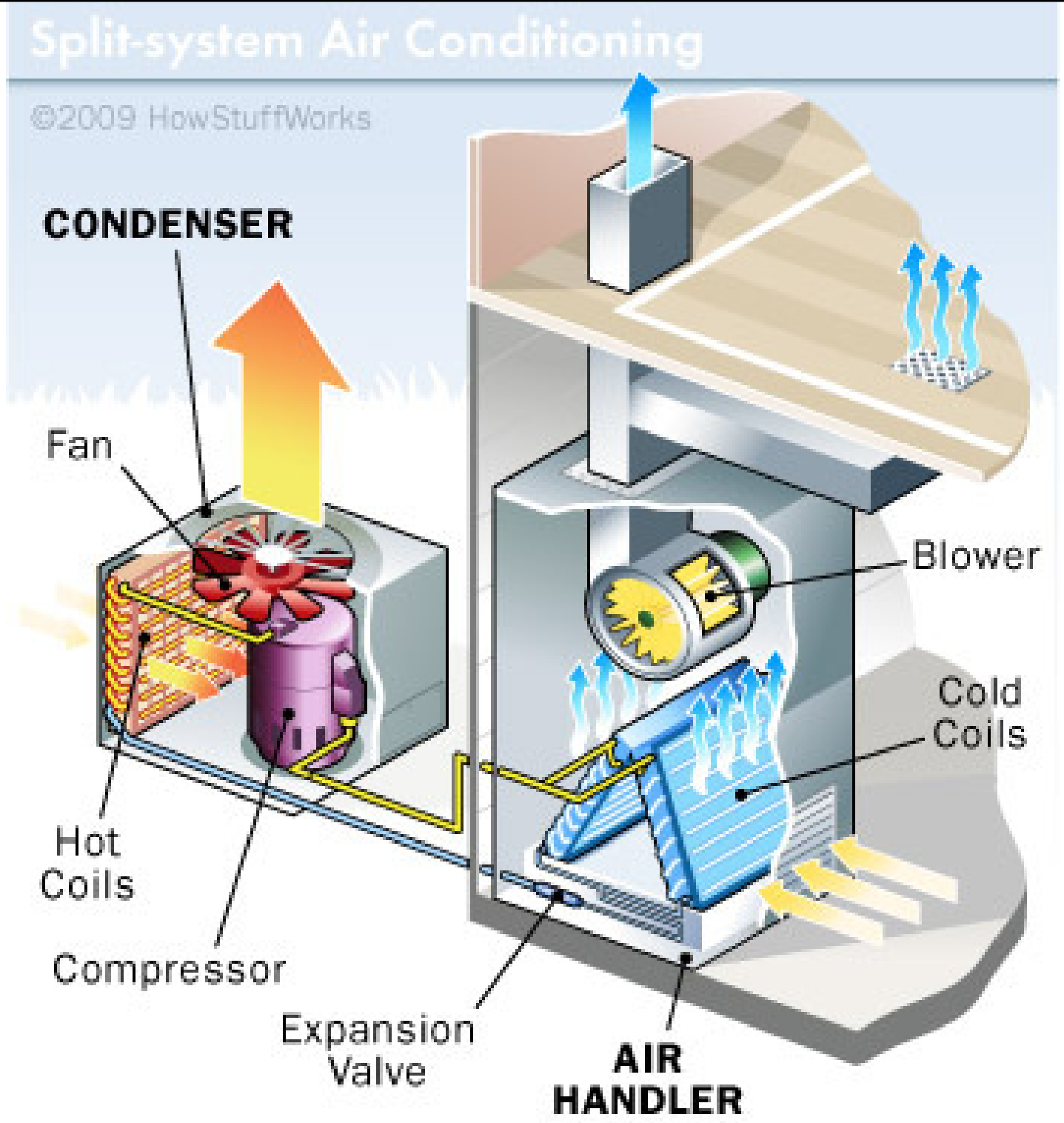
Window-type air conditioner



See also: "How Air Conditioners Work" (1:07)
http://youtu.be/nKZ2DPvvua8

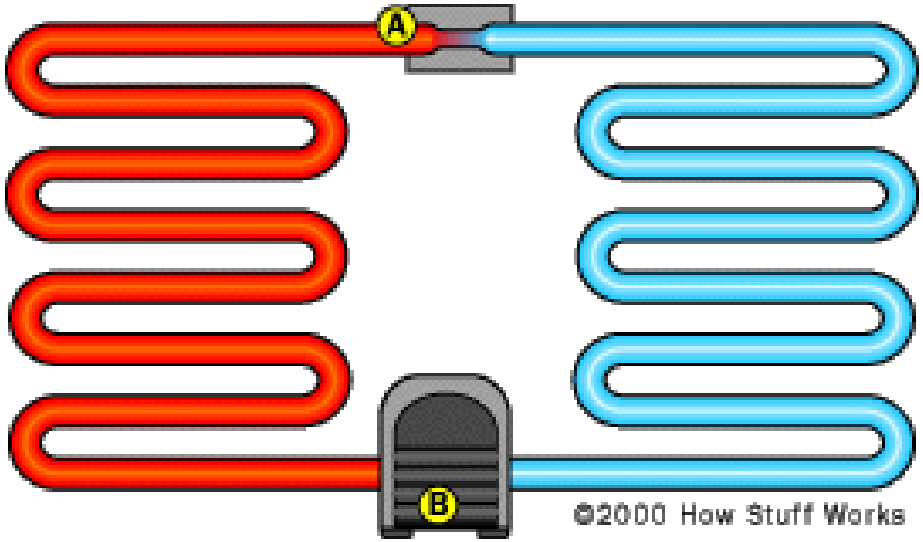
(Source: www.howstuffworks.com/ac.htm)

Split-type air conditioner



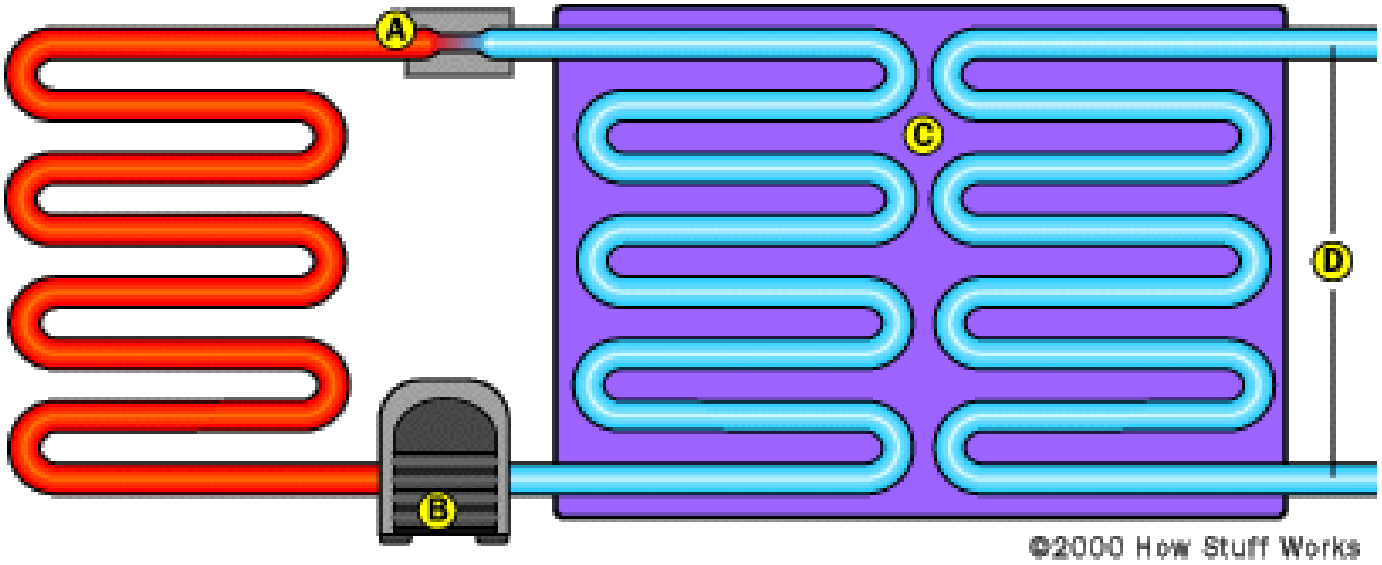
(Source: www.howstuffworks.com/ac.htm)

Refrigerant cycle



What are the major components?

A typical air conditioner

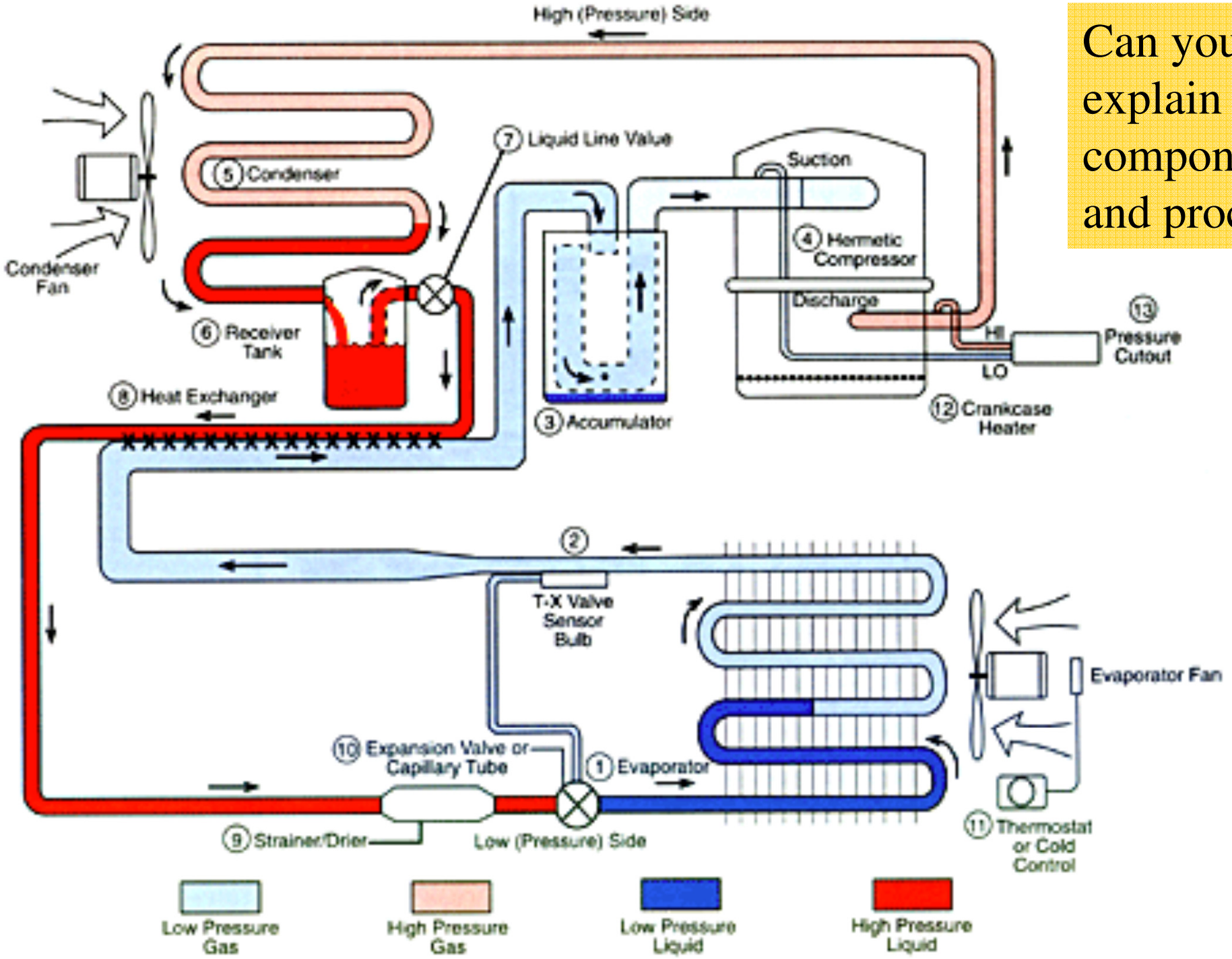


Chilled water system

Air conditioning with a chilled water system

(Source: www.howstuffworks.com/ac.htm)

Basic refrigeration cycle

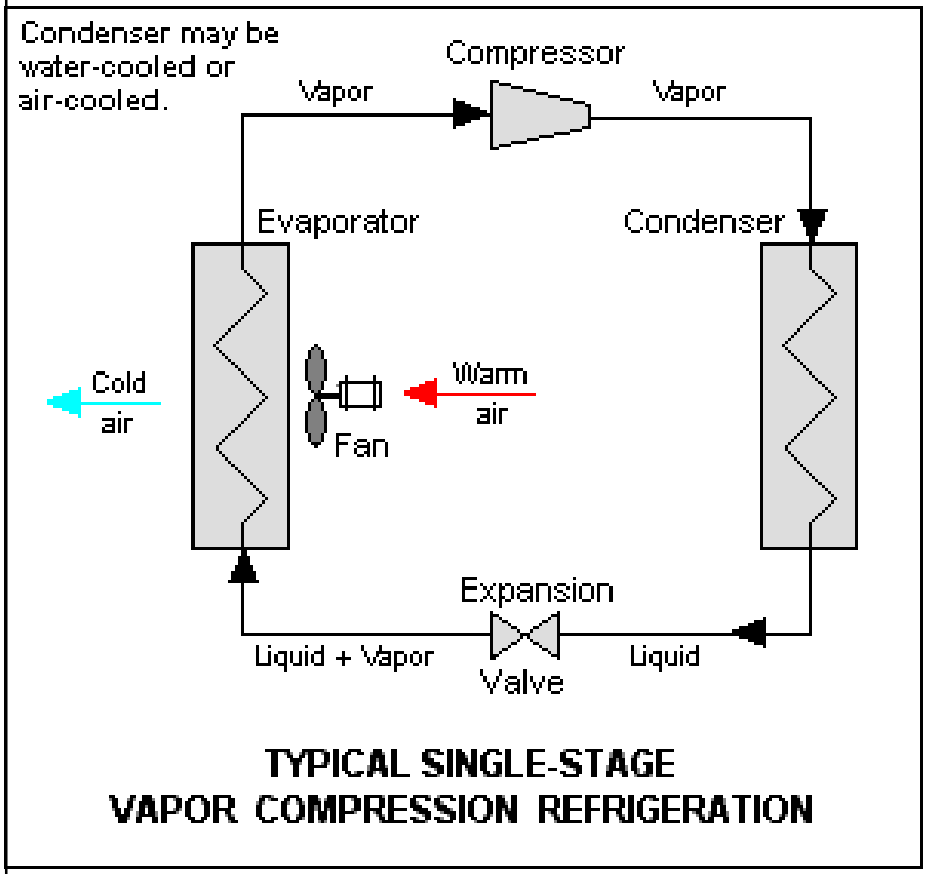


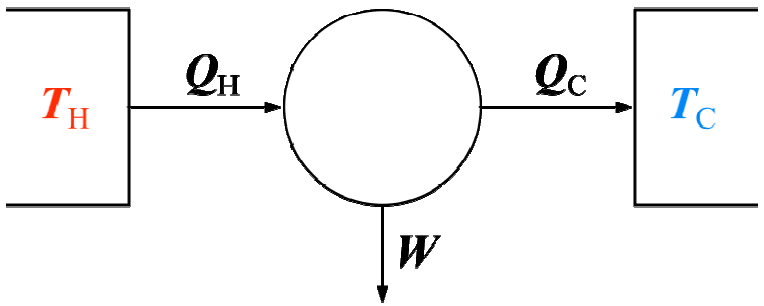
Can you explain the components and process?

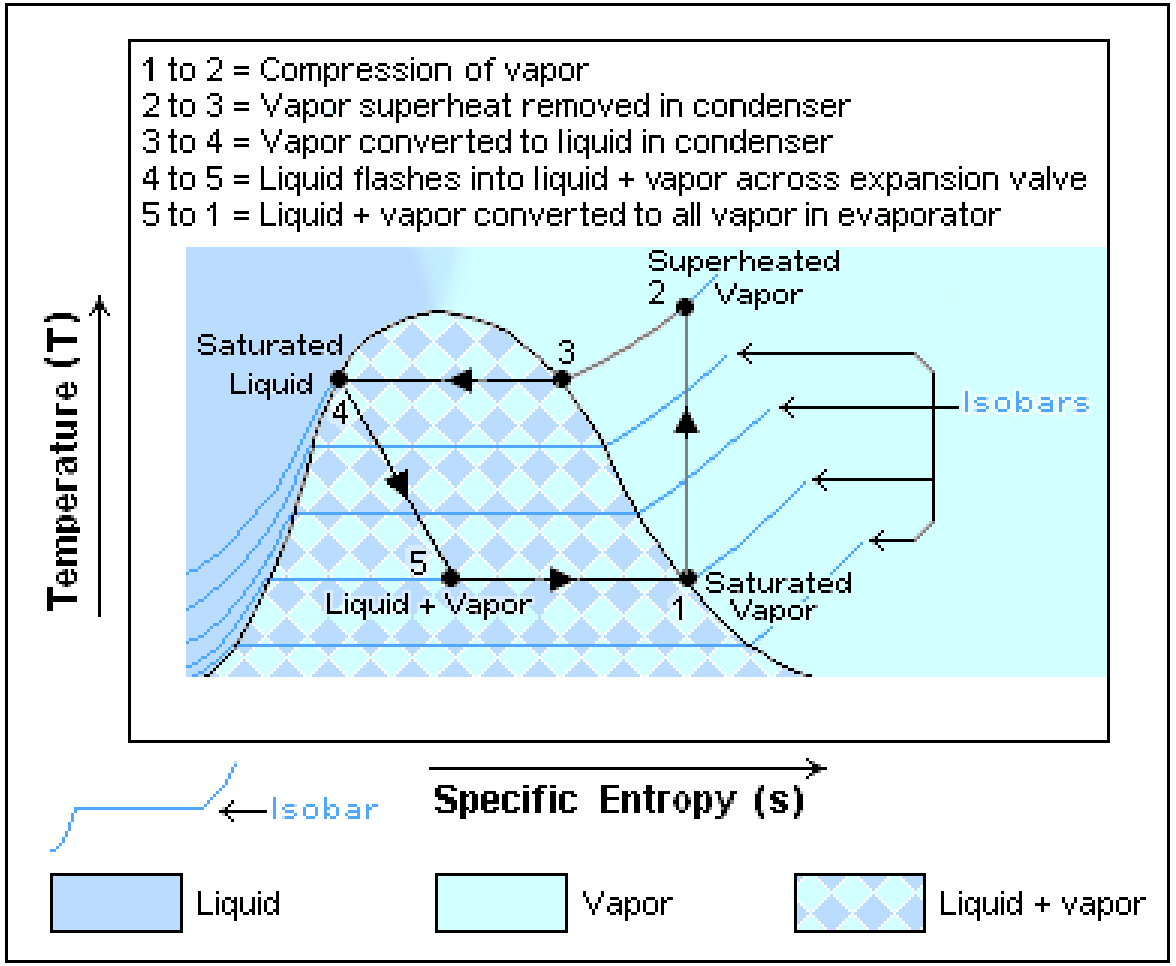
(See also: www.swtc.edu/ag_power/air_conditioning/lecture/basic_cycle.htm)

Vapour compression refrigeration

Can you explain the principles?





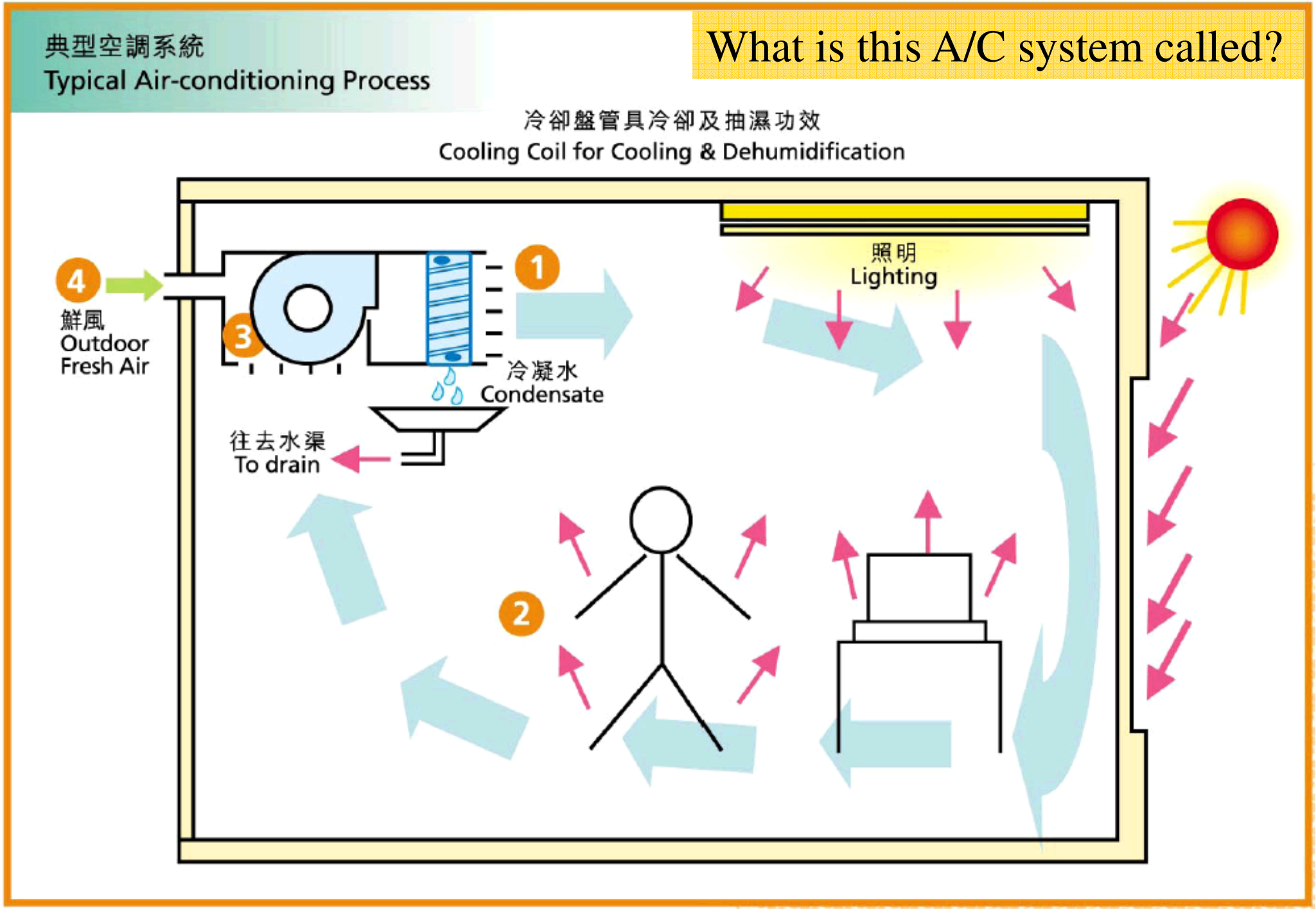


COP of a refrigerator = Cooling Effect/Work Input = $Q_L/W_{net,in}$

COP of a heat pump = Heating Effect/Work Input = $Q_H/W_{net,in}$

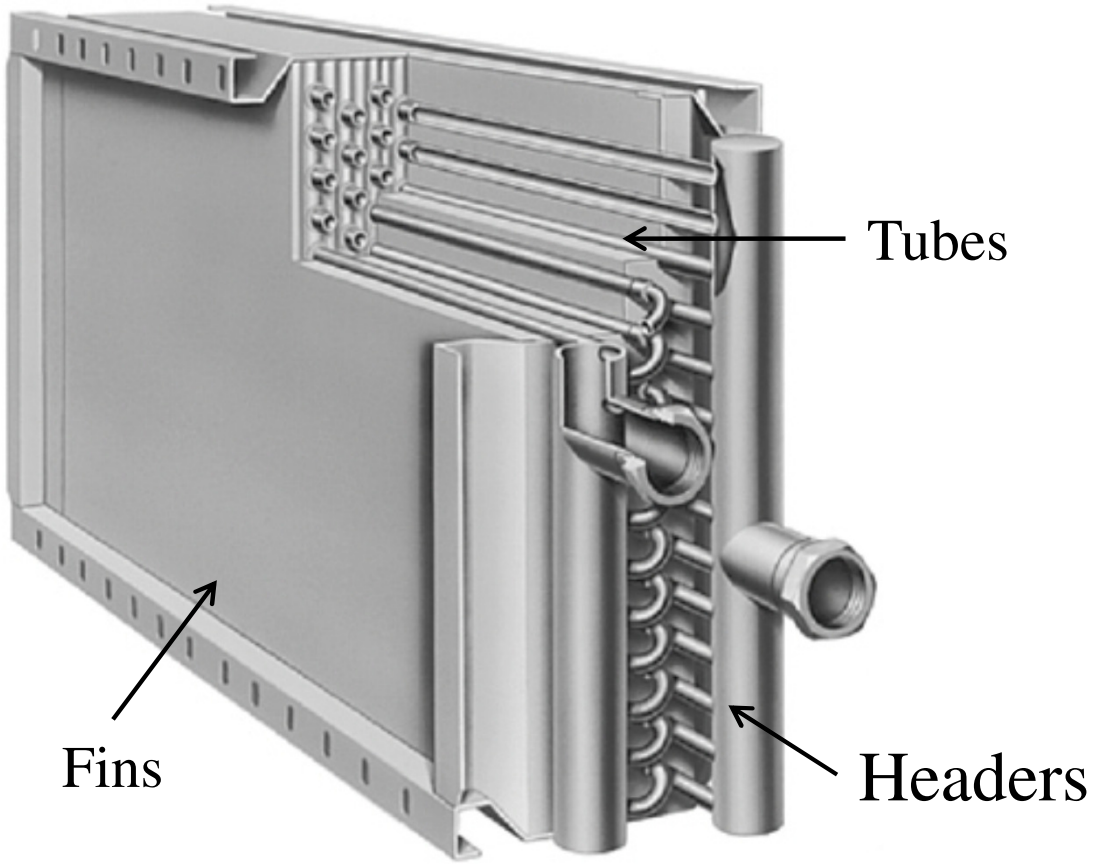
(Source: http://en.wikipedia.org/wiki/Heat_pump_and_refrigeration_cycle)

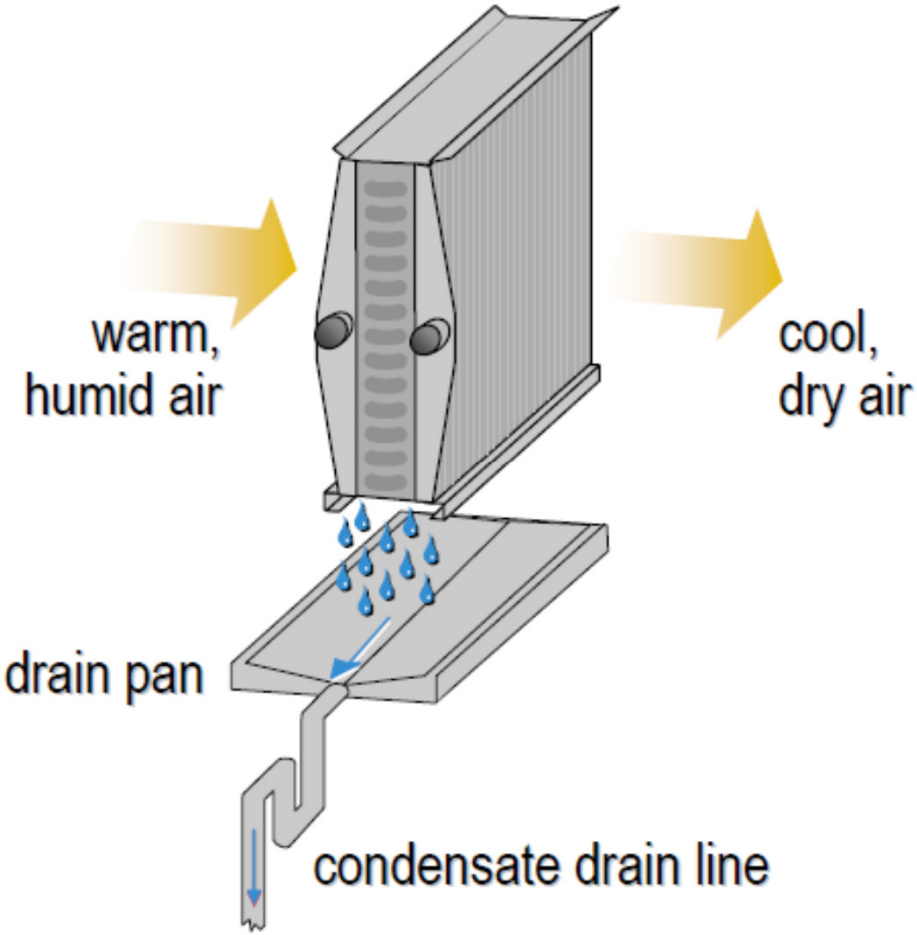
What is this A/C system called?



(Source: EnergyWitts newsletter, EMSD)

Chilled water cooling coil (a heat exchanger)



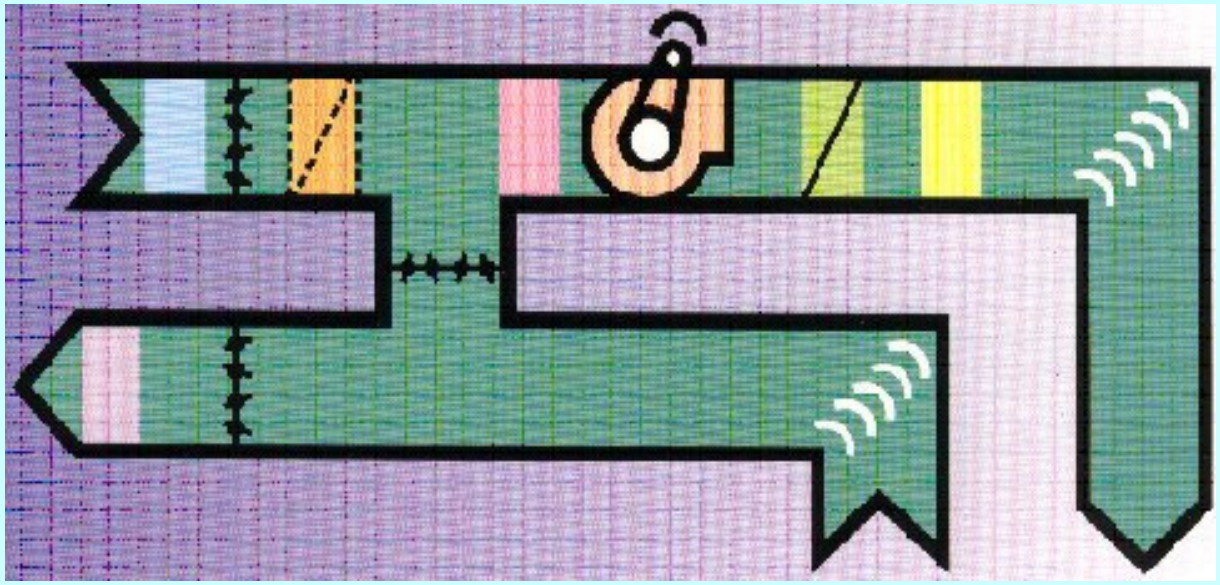


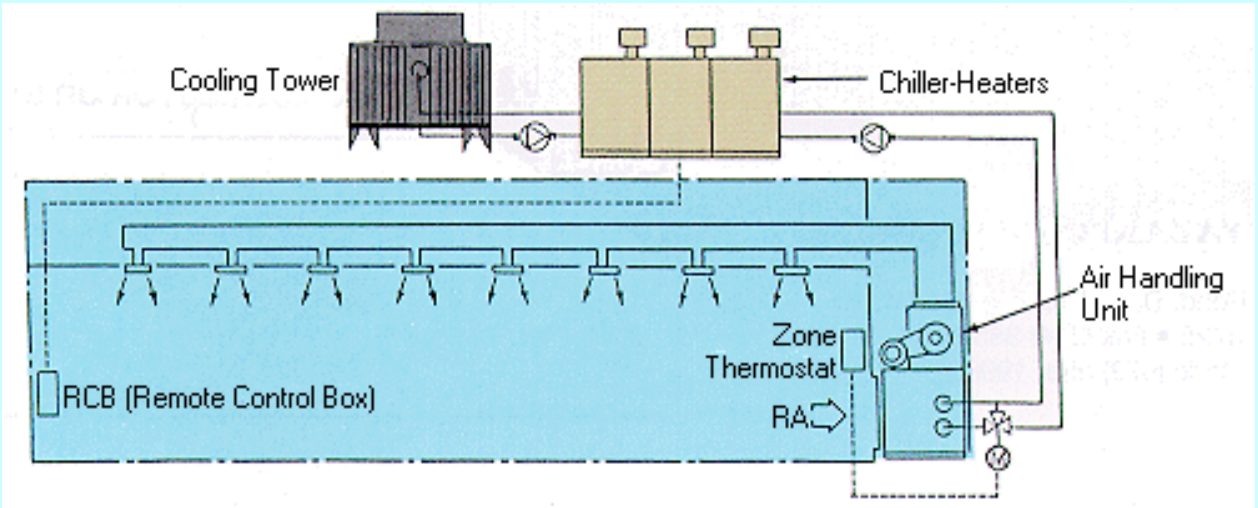
Sensible heat exchange: $q_S = m_a \text{ x } c_p \text{ x } (t_b - t_a)$

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

(Source: Trane)

Air Conditioning





Air Conditioning

- The term “air conditioning” has gradually changed, from meaning just cooling to the total control of:
  - Temperature
  - Moisture in the air (humidity)
  - Supply of outside air for ventilation
  - Filtration of airborne particles
  - Air movement in the occupied space

“冷氣”

▼

“空氣調節”

“空調”

Air Conditioning

- Definition (from ASHRAE*)
  - Air conditioning is the process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.
    - Basic processes: Cooling and Heating
- Comfort cooling (air conditioning)
  - To meet comfort requirements of occupants

(*ASHRAE = American Society of Heating, Refrigerating & Air-conditioning Engineers, Inc.)

Air Conditioning

- Seven main air-conditioning processes:
  - 1. Heating (adding thermal energy)
  - 2. Cooling (removing thermal energy)
  - 3. Humidifying (adding moisture)
  - 4. Dehumidifying (removing moisture)
  - 5. Cleaning (removing particulates/contaminants)
  - 6. Ventilating (exchanging air between the outdoors and the conditioned space)
  - 7. Air Movement (circulating and mixing air)

History of refrigeration and air conditioning

Seasonal harvesting of snow and ice has begun earlier than 1000 B.C. (Store ice in winter for summer use), e.g. ice cellars of ancient Chinese

(Source: 5 Smart Ways to Keep Cool of Ancient Chinese http://www.chinawhisper.com/5-smart-ways-to-keep-cool-of-ancient-chinese/)

Do you know ways to keep cool of ancient Chinese?

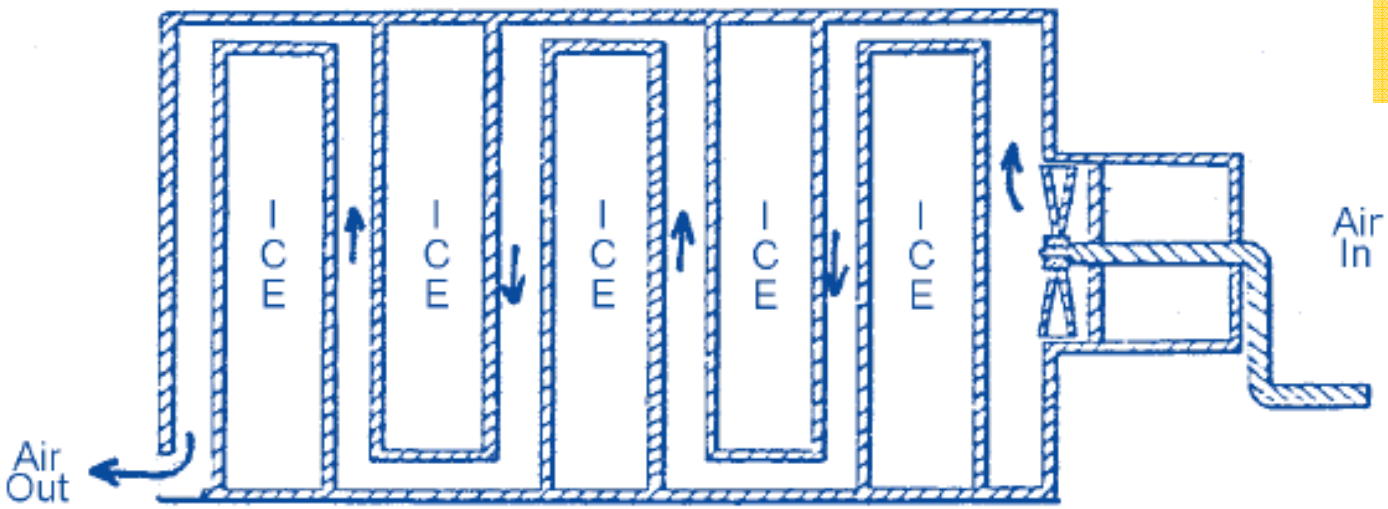


Figure 1: Shaler's patented cooler for ventilating air, 1865.

(Source: ASHRAE Journal, Feb 1999, https://www.ashrae.org/File%20Library/docLib/Public/200362710047_326.pdf)

- Ice cooling
- Evaporative cooling
- Ventilation (air flow)
- Porcelain pillows
- Salt solution cooling

Air Conditioning

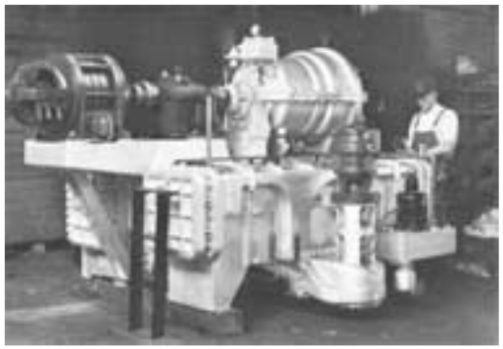
- The History of Air Conditioning
  - http://www.air-conditioners-and-heaters.com/air_conditioning_history.html
    - 1830: Dr. John Gorrie (ice for cooling hospital rooms)
    - 1881: James Garfield (device w/ melted ice water)
    - Late 19th century: "manufactured air" (controlling humidity in textile mills)
    - Early 1900s': Willis Carrier (designed modern A/C systems for offices, apartments, hotels, hospitals)
    - 1917-1930: movie theatres were kept cool by A/C

(Video: Air Conditioning History (1:09) http://www.youtube.com/watch?v=6NFmsU3Am7c)

Air Conditioning

- The Father of Modern Air Conditioning
  - Dr. Willis Haviland Carrier (1875-1950)

- Formed Carrier Air Conditioning Company (1907)
- Published a paper on rational psychrometric formulae in 1911
- Invented and patented many HVAC equipment
- Wrote a well-known air conditioning textbook



(Video: Air Conditioning History (5:31) http://www.youtube.com/watch?v=rf5okqLX-Uo)

Air Conditioning

- Applications of air conditioning:
  - Industrial sector
    - e.g. textile mills, electronics, pharmaceutical
  - Commercial sector
    - e.g. offices, hotels, retails
  - Residential sector
    - e.g. apartments, houses
  - Transport sector
    - e.g. aircrafts, buses, private cars, trains

Air Conditioning

- Significance of air conditioning and refrigeration
  - No. 10 on the list of the [Greatest Engineering Achievements of the 20th Century]
  - http://www.greatachievements.org
    - These cooling technologies have altered some of our most fundamental patterns of living
    - Buildings are climate-controlled & comfortable
    - Fresh foods & milk are kept in refrigerators/freezers
    - Building designs are changed completely
    - Environment for industrial processes are controlled

Air Conditioning

- Importance of air conditioning for buildings
  - Change building designs & human adaptation
  - Affect occupant satisfaction, productivity, health and safety
  - Contribute to effective building performance
  - Often form a major part of building construction costs and running costs
  - Affect energy consumption & environmental performance of a building

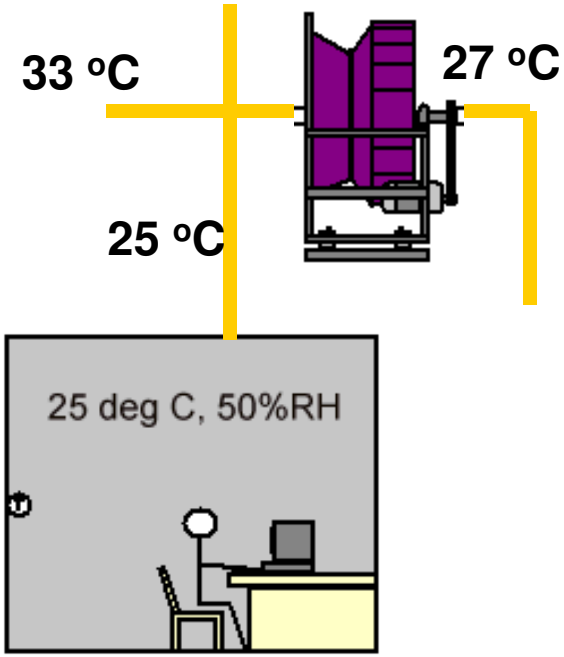
Air Conditioning

- Key issues of modern HVAC design:
  - Indoor air quality (IAQ)
    - Affect our health, productivity, and even safety
  - Energy conservation
    - Reduce energy consumption in new and existing buildings w/o compromising comfort and IAQ
  - Greenhouse gas (GHG) emissions
    - Ozone layer destruction
    - Use of low polluting materials, e.g. refrigerants

Air Conditioning

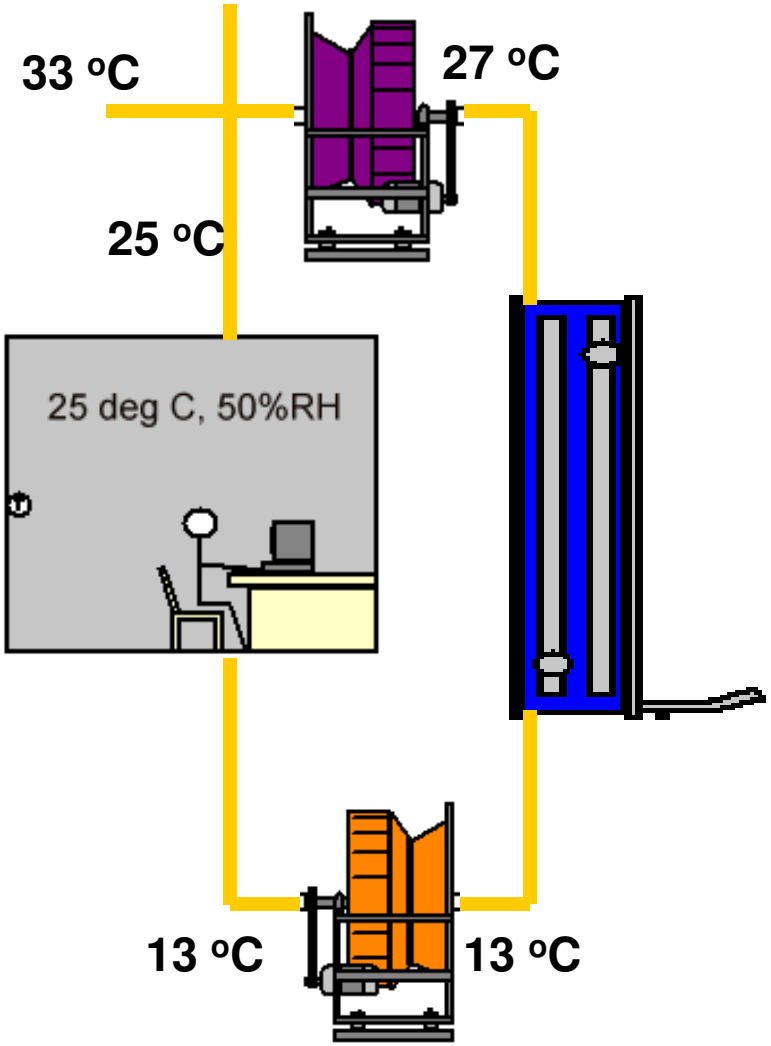
- To understand better, air conditioning system can be divided into five subsystems or loops:
  - 1. Air-side
  - 2. Chilled water
  - 3. Refrigeration equipment
  - 4. Heat rejection
  - 5. Controls

33 °C, 28 °C



Conditioned space

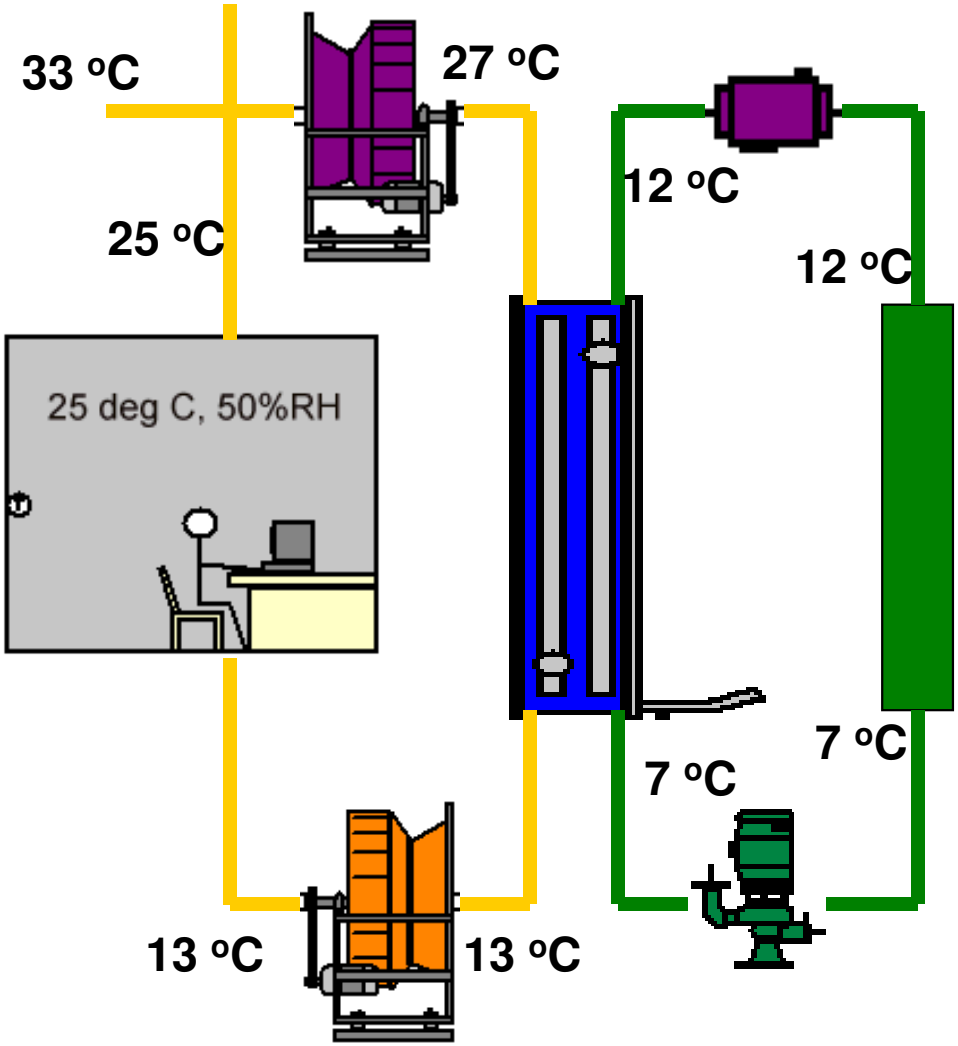
33 °C, 28 °C



Air side system

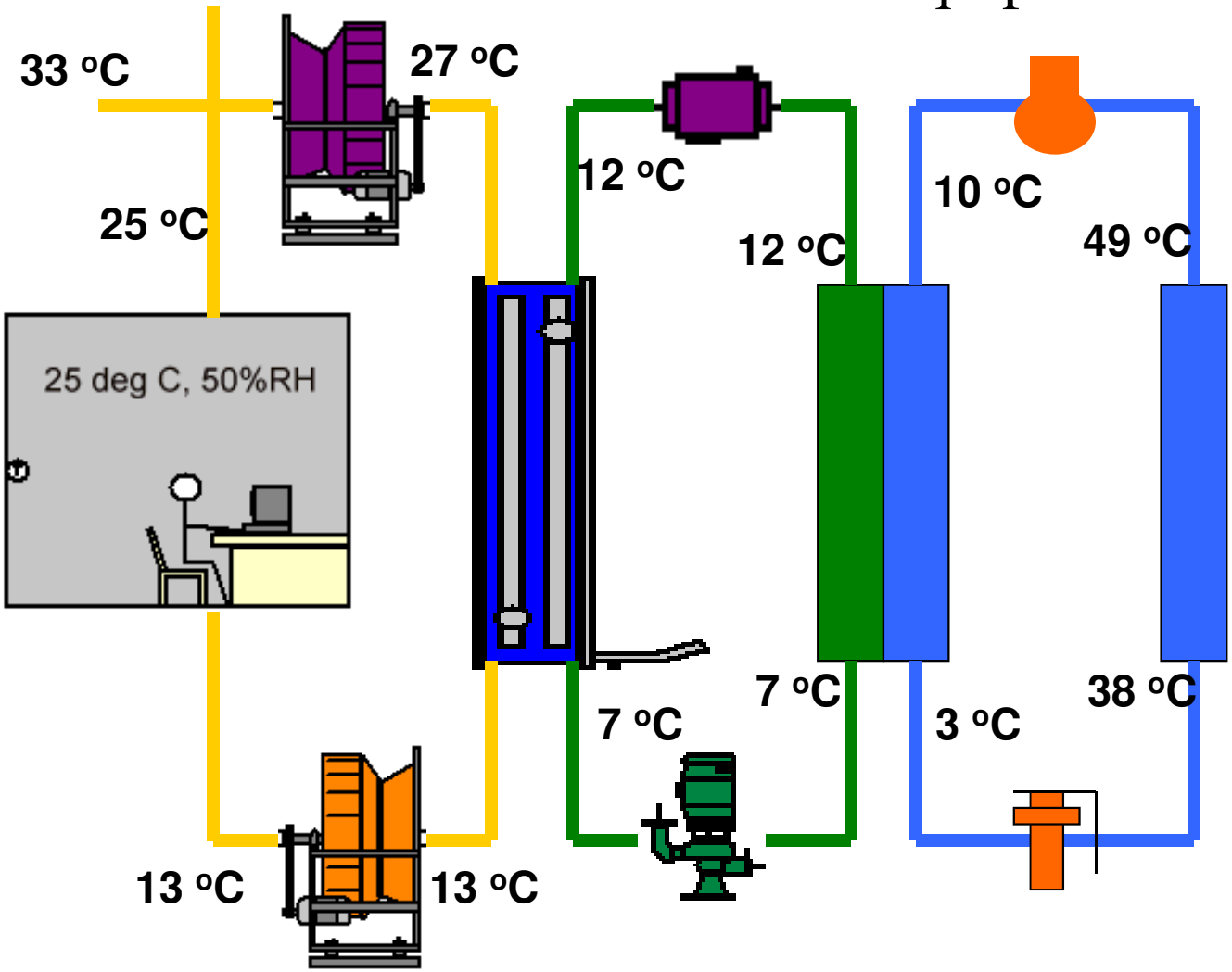
33 °C, 28 °C

Chilled water system



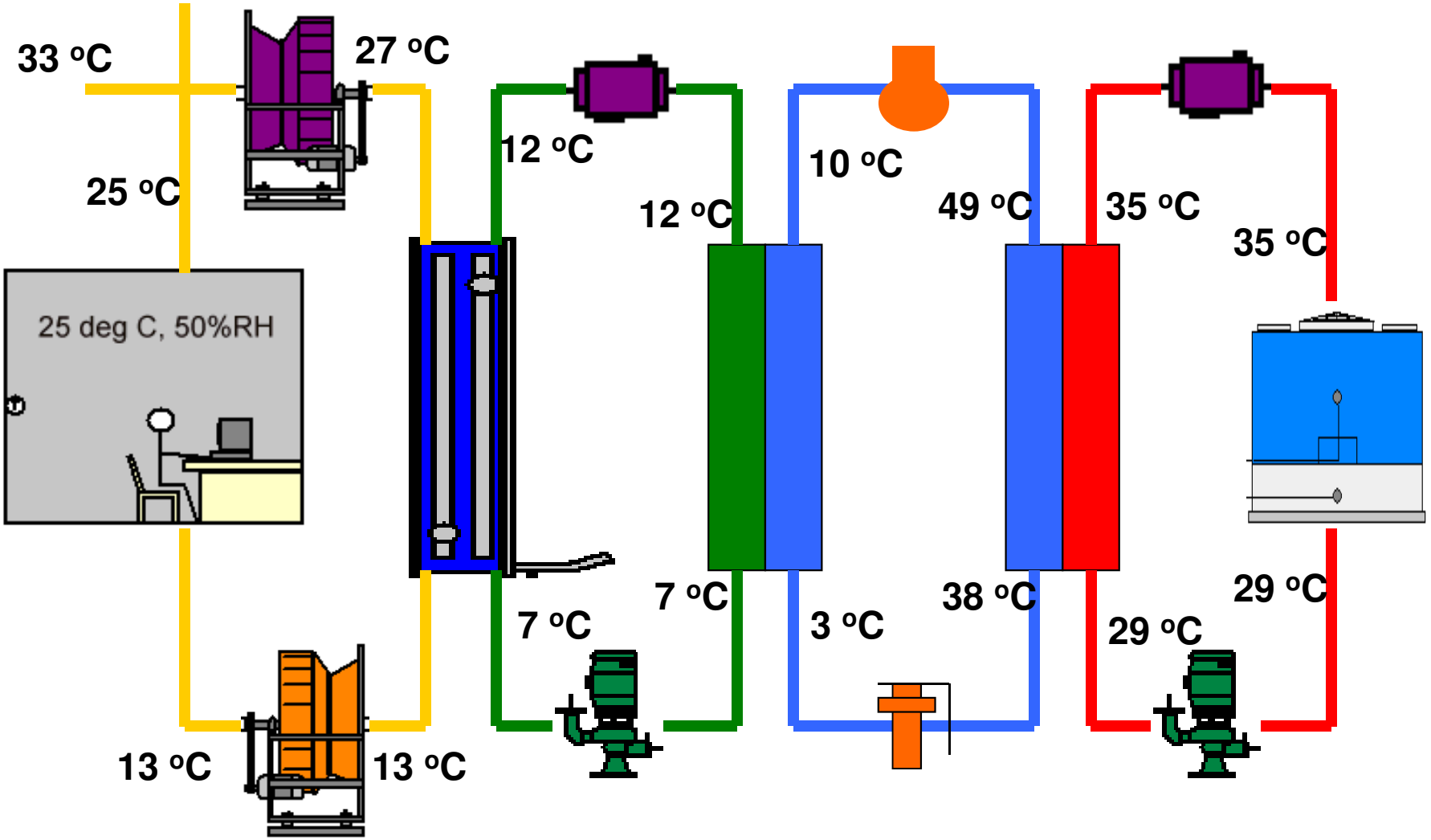
33 °C, 28 °C

Refrigeration equipment



33 °C, 28 °C

Heat rejection



33 °C, 28 °C

Control Loop

33 °C

27 °C

25 °C

25 deg C, 50%RH

Airside System

13 °C

13 °C

12 °C

7 °C

Chilled Water System

12 °C

7 °C

10 °C

3 °C

Refrigeration System

49 °C

38 °C

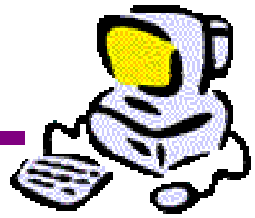
35 °C

29 °C

Heat rejection

35 °C

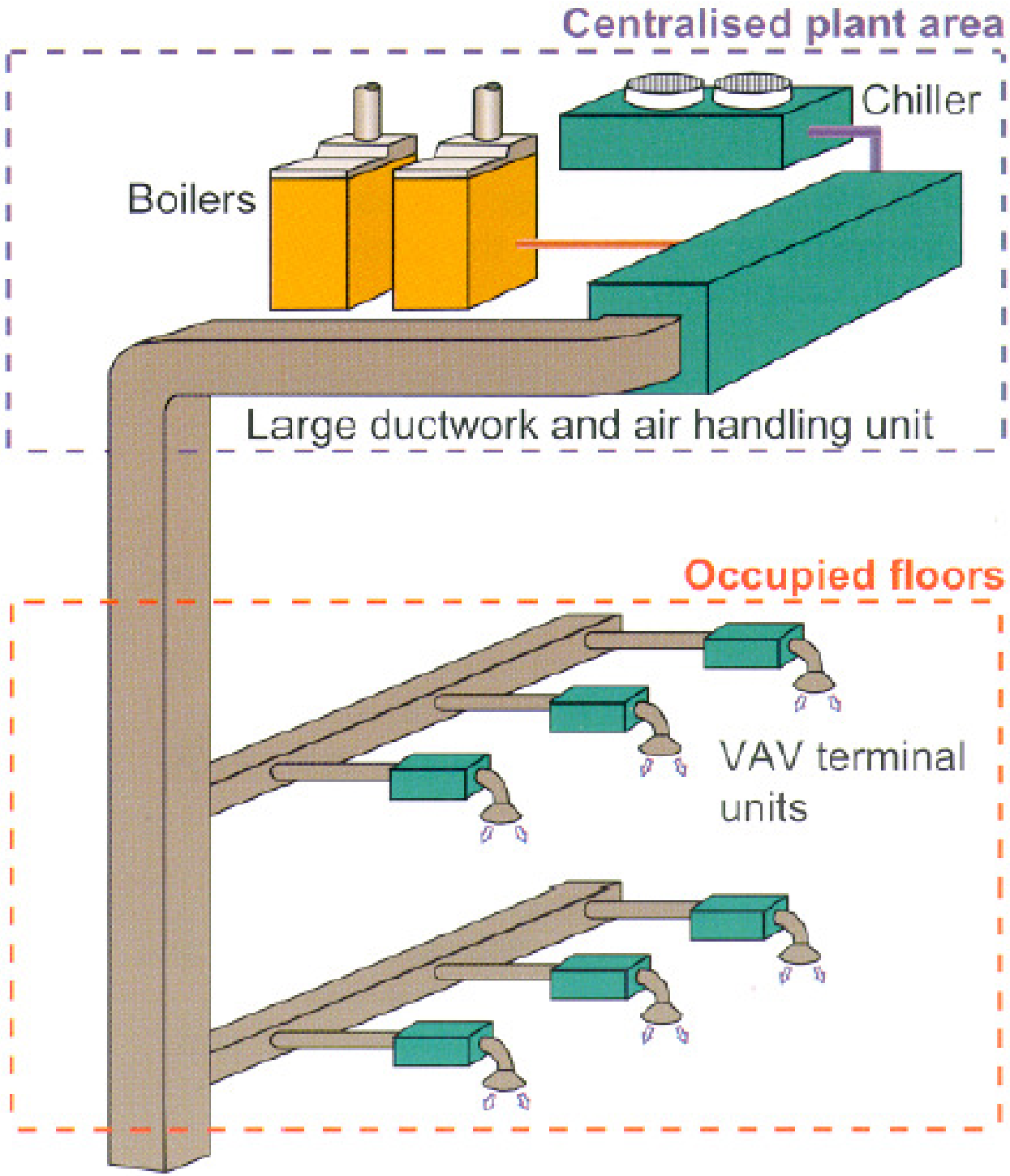
29 °C



Air Conditioning

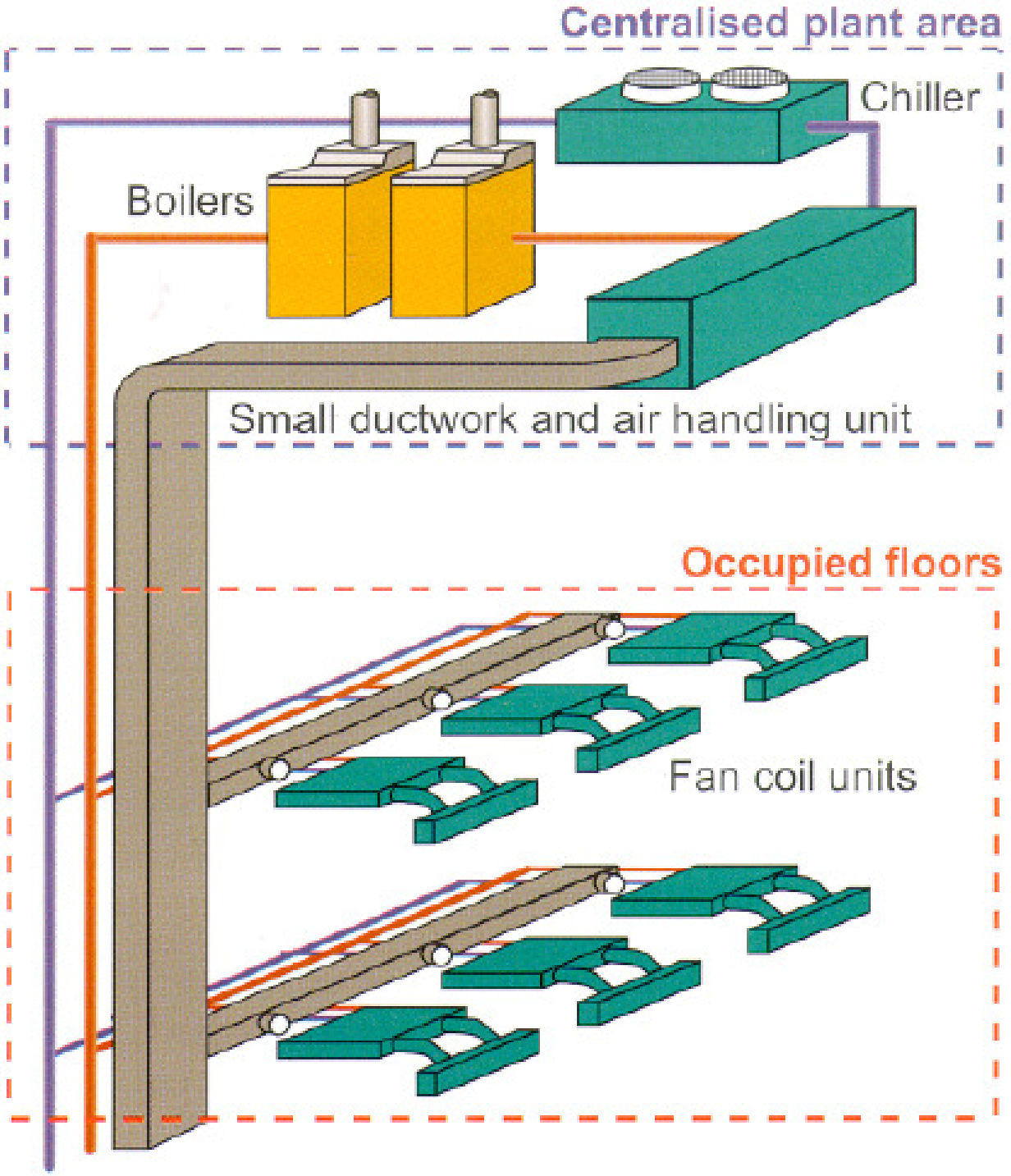
- Classification of HVAC systems -- three generic types of systems:
  - Centralised all air systems
    - Such as CAV (constant air volume), VAV (variable air volume), dual duct, multizone
  - Partially centralised air/water systems
    - Such as FCU (fan coil unit), induction units
  - Local systems (mainly direct expansion systems)
    - Such as window-type units, split-type systems, VRF (variable refrigerant flow)(?)

Centralised air system *(VAV example)*

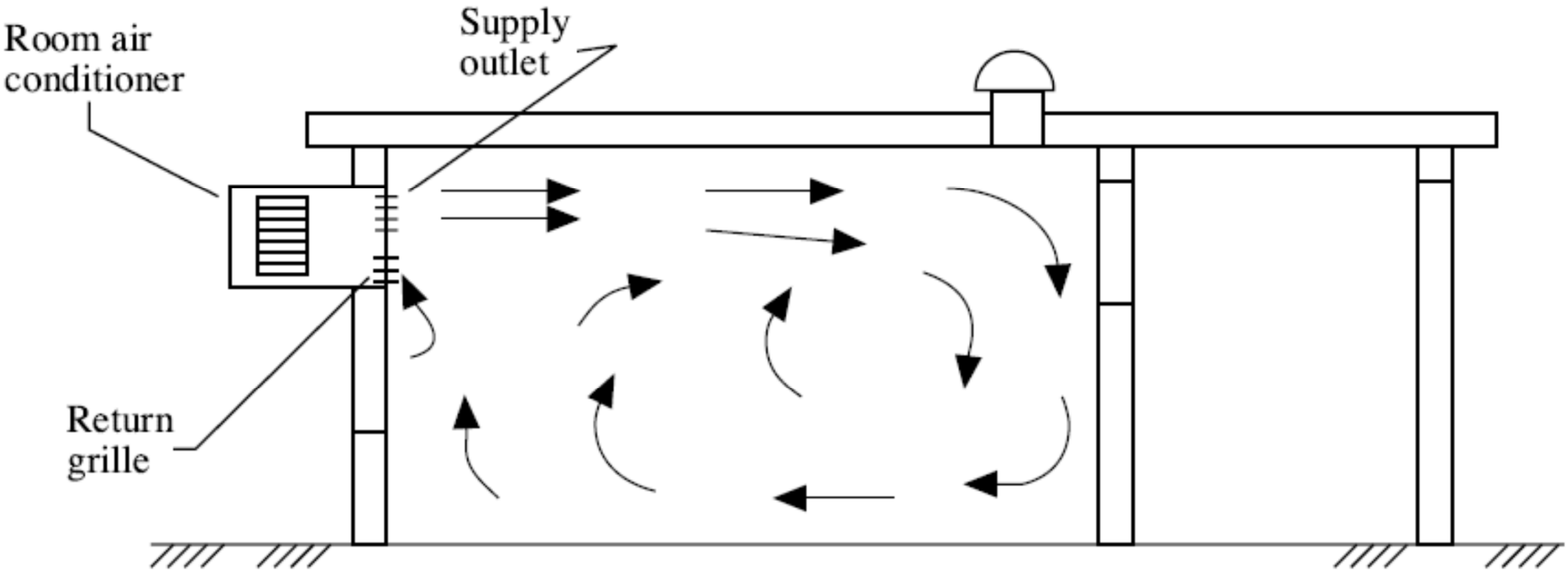


Partially centralised air/water system

(Fan coil example)

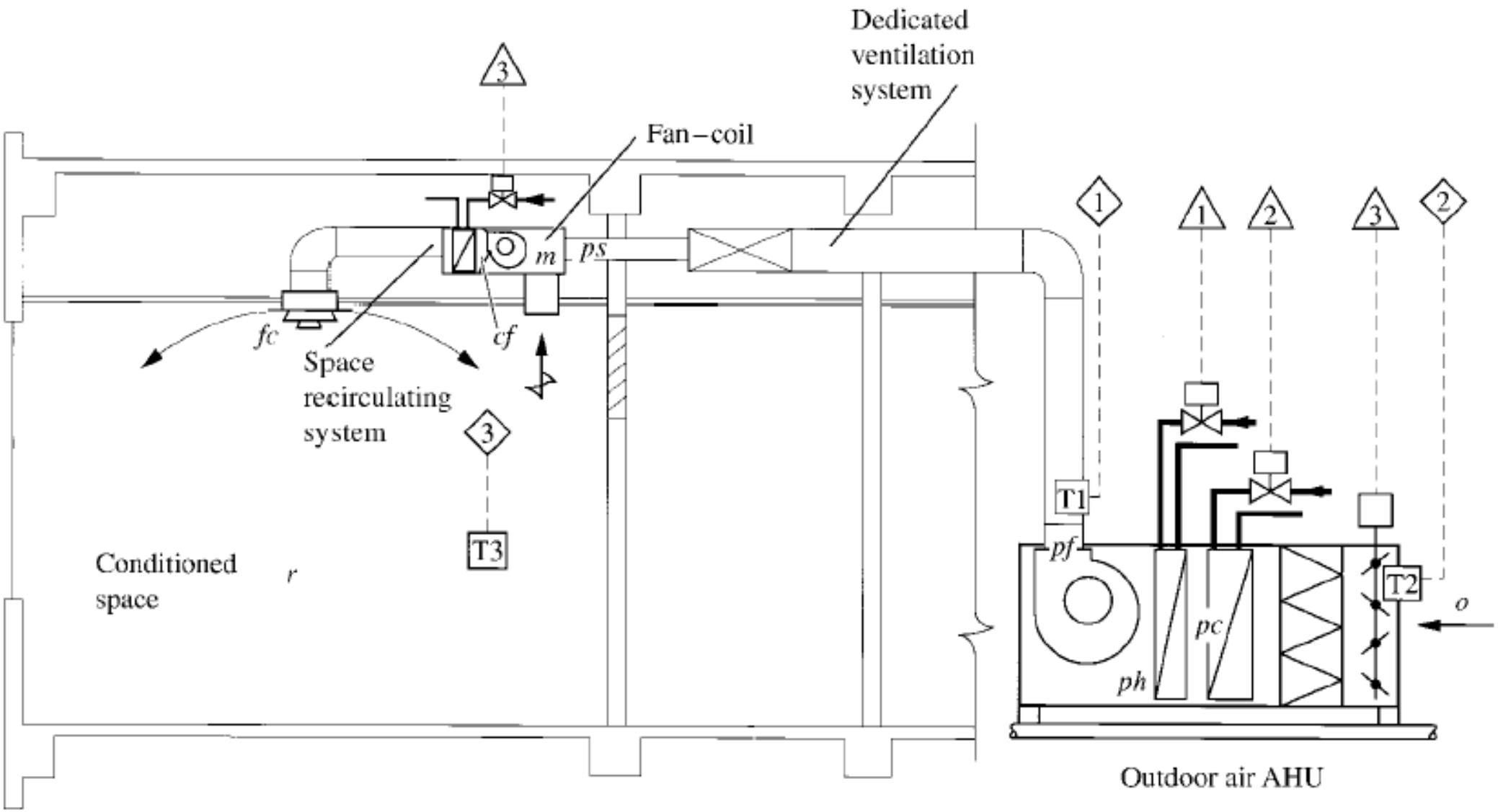


An individual room air-conditioning system



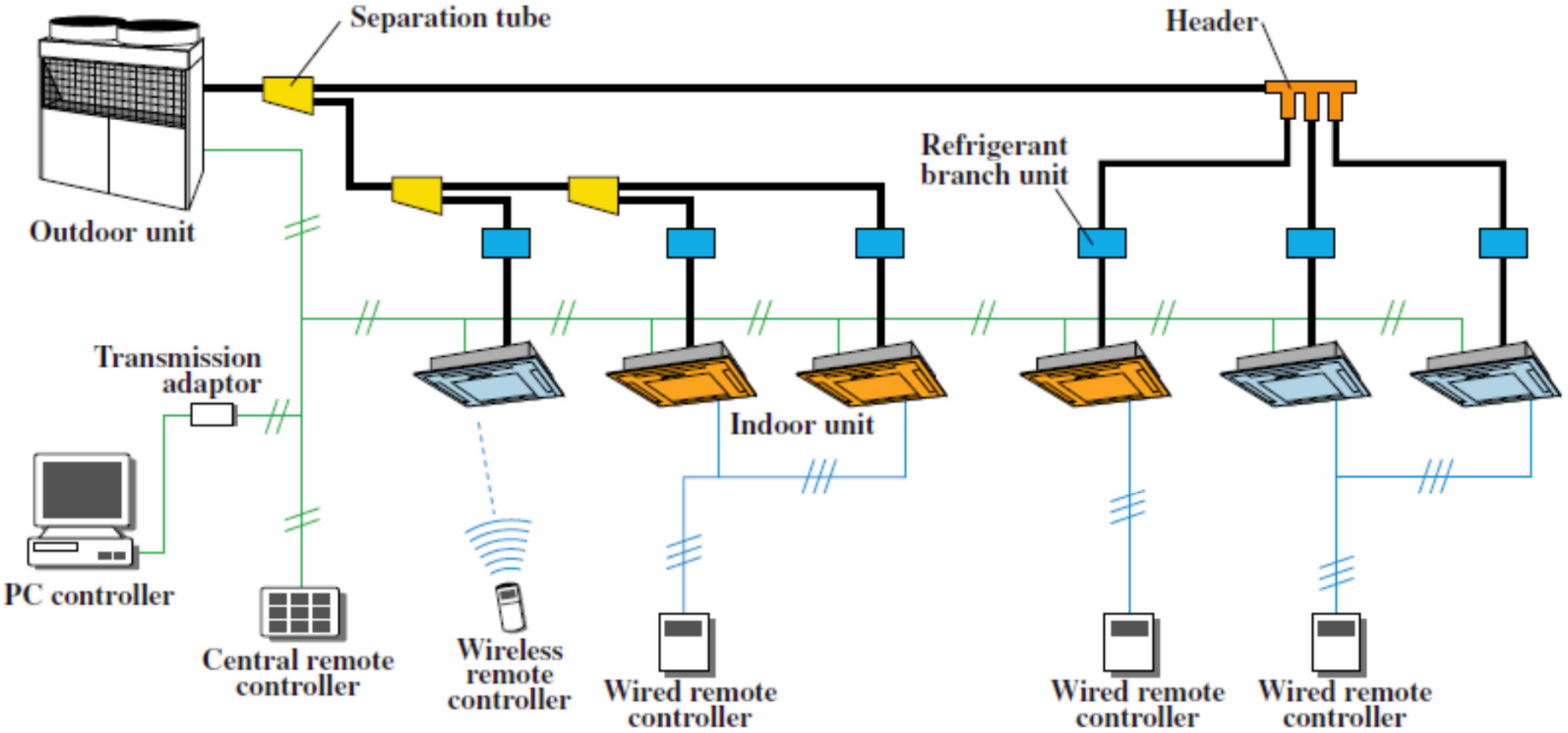
(Source: Wang, S. K., Lavan, Z. and Norton, P., 2000. *Air Conditioning and Refrigeration Engineering*)

Primary air fan coil unit (PA-FCU) system



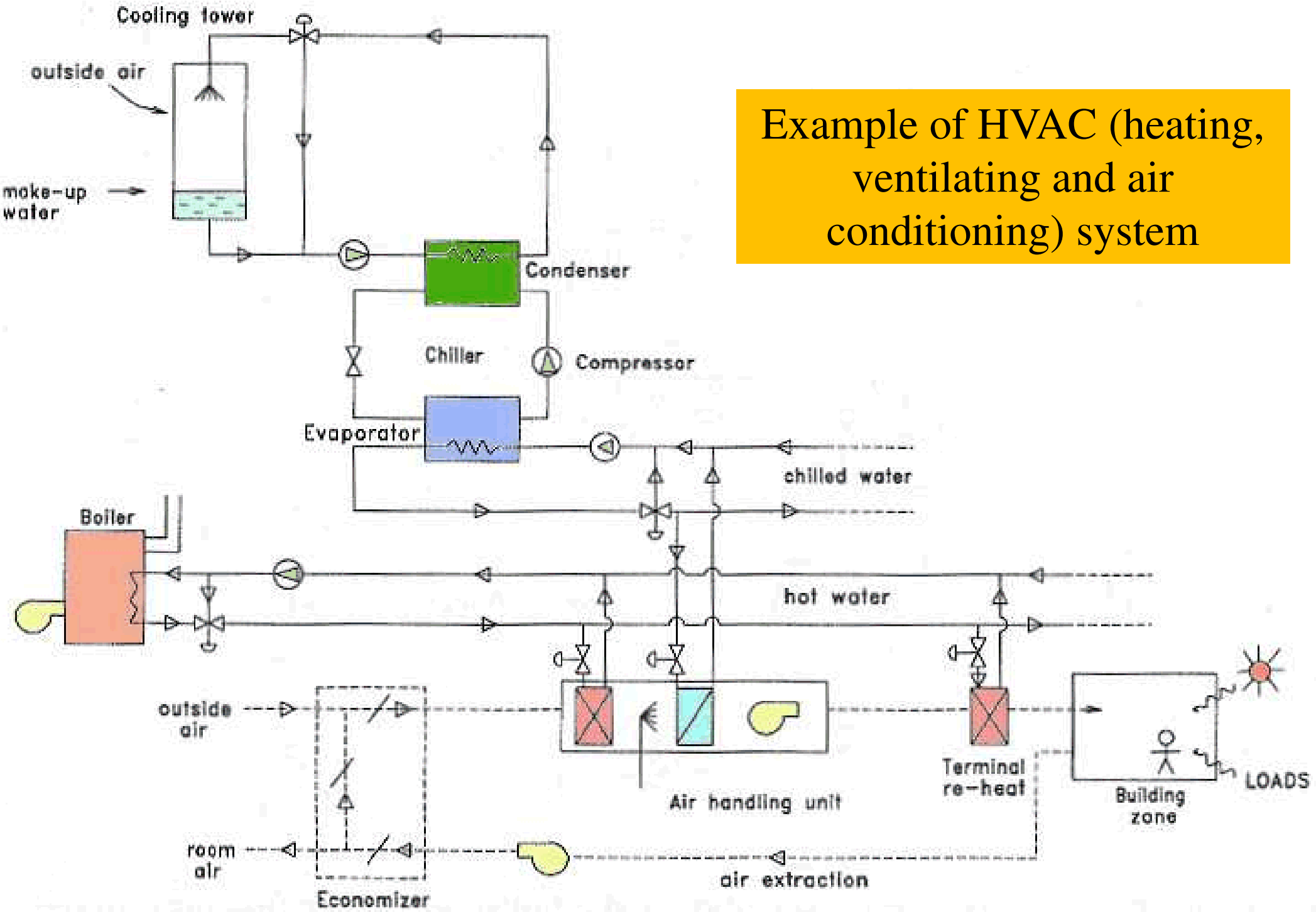
(Source: Wang, S. K., 2001. *Handbook of Air Conditioning and Refrigeration*, 2nd ed.)

Variable refrigerant flow (VRF) system

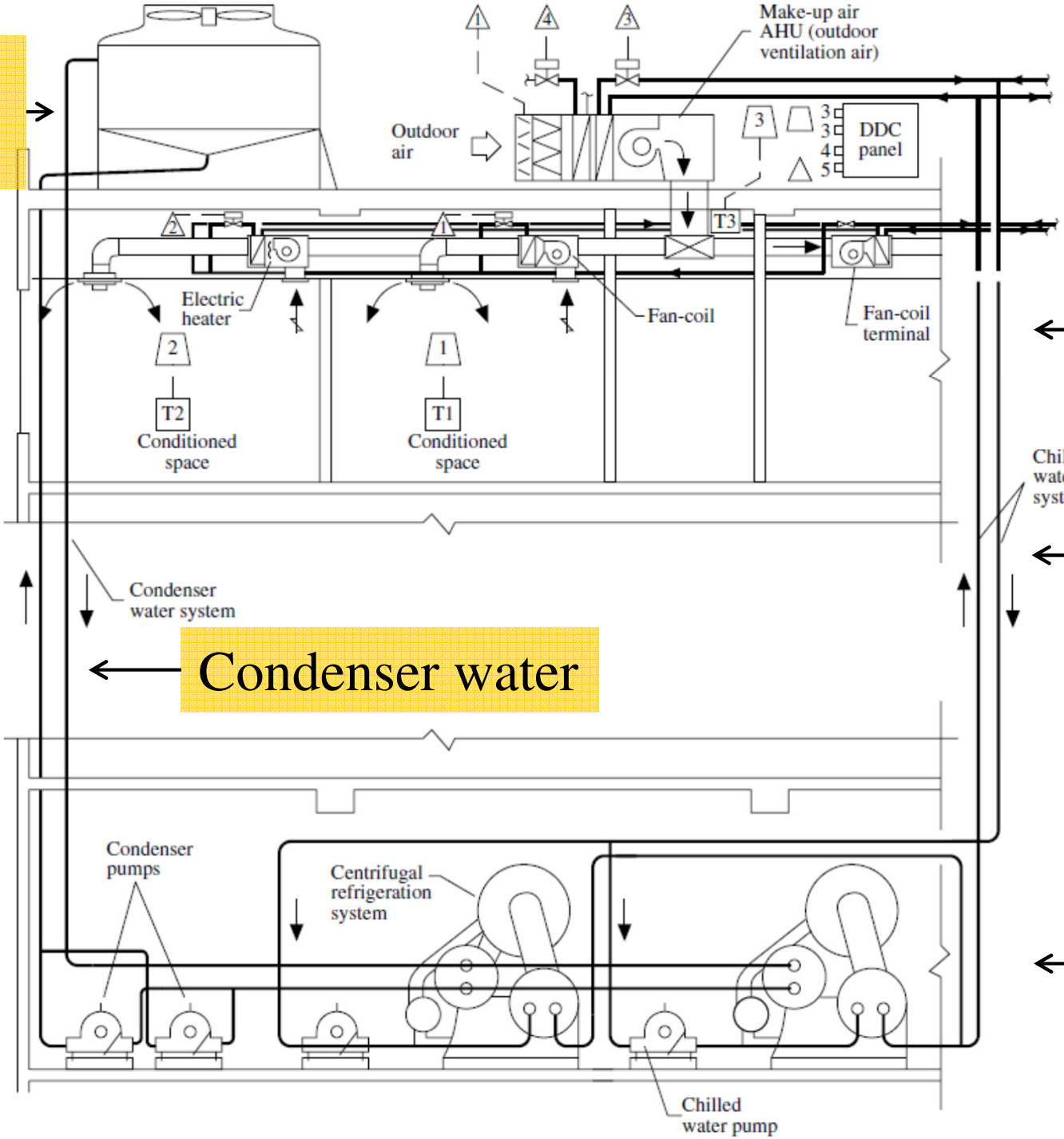


(Source: Fujitsu) (See also: http://en.wikipedia.org/wiki/Variable_refrigerant_flow)

Example of HVAC (heating, ventilating and air conditioning) system



A space-conditioning air-conditioning system (fan-coil system)



Heat rejection

Air side

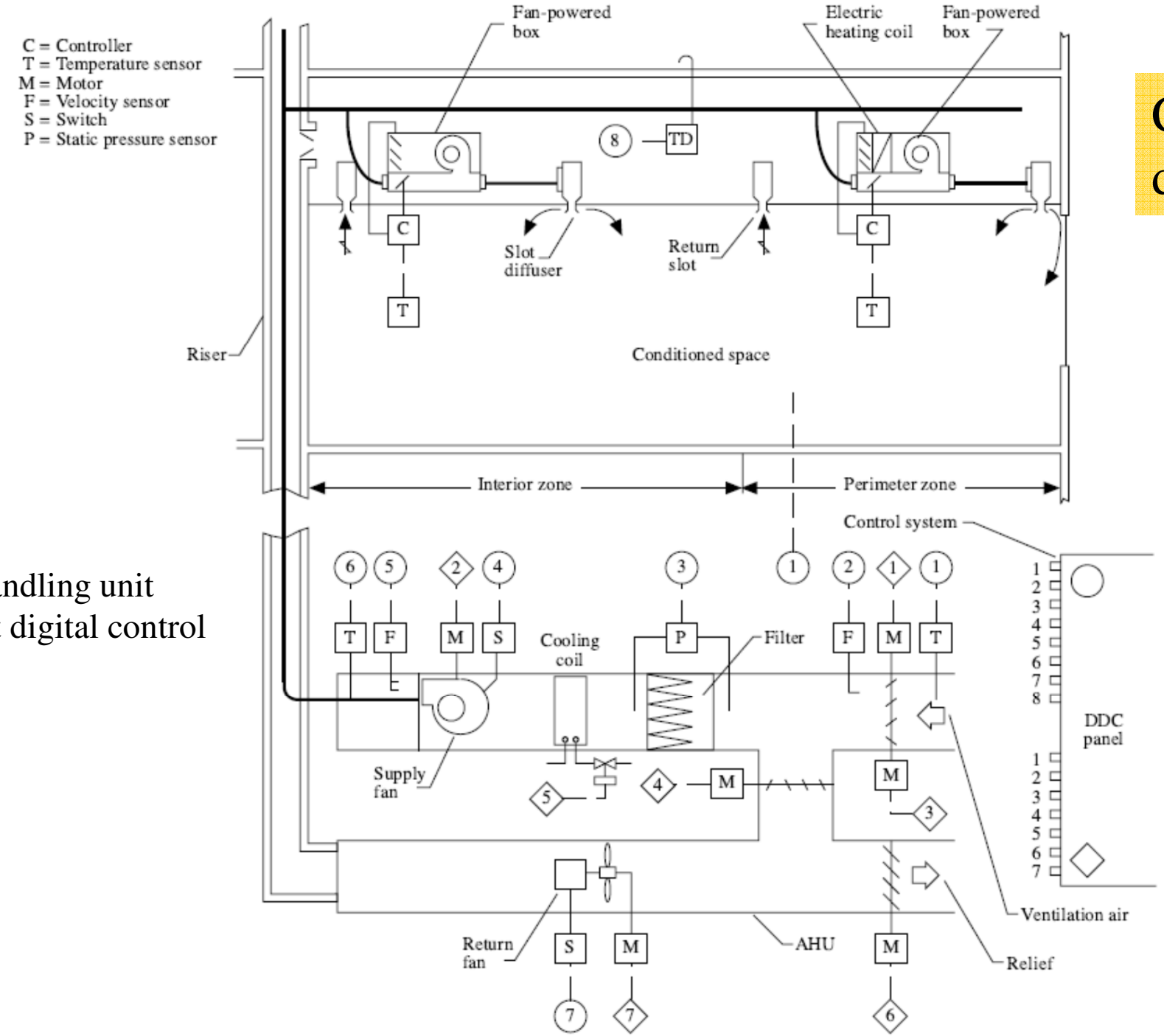
Chilled water

Condenser water

Refrigeration

(Source: Wang, S. K., Lavan, Z. and Norton, P., 2000. *Air Conditioning and Refrigeration Engineering*)

Air-side and control systems for a typical floor of a central system

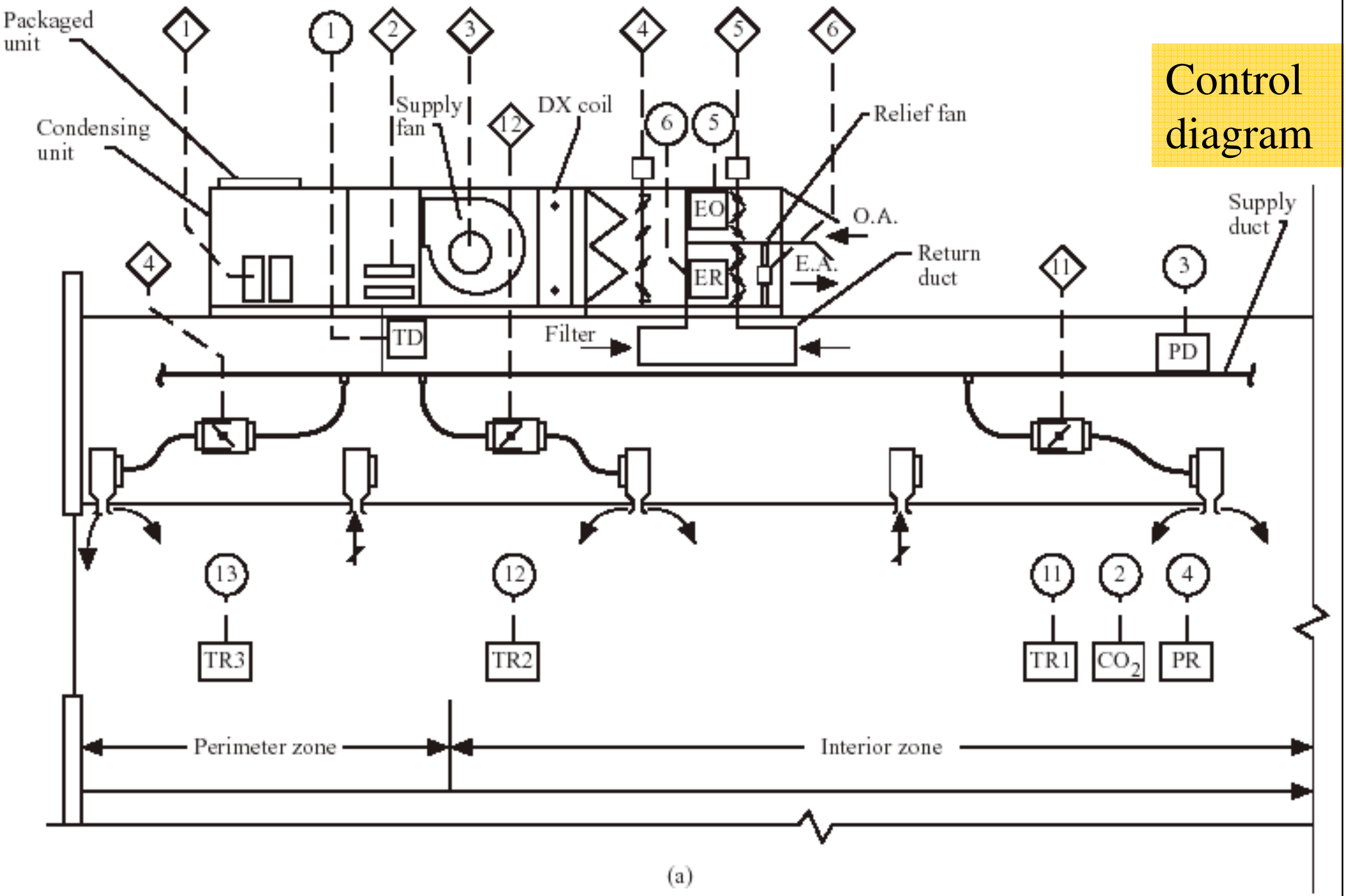


Control diagram

AHU = air handling unit
DDC = direct digital control

(Source: Wang, S. K., Lavan, Z. and Norton, P., 2000. *Air Conditioning and Refrigeration Engineering*)

Variable-air volume (VAV) package system (rooftop unit)

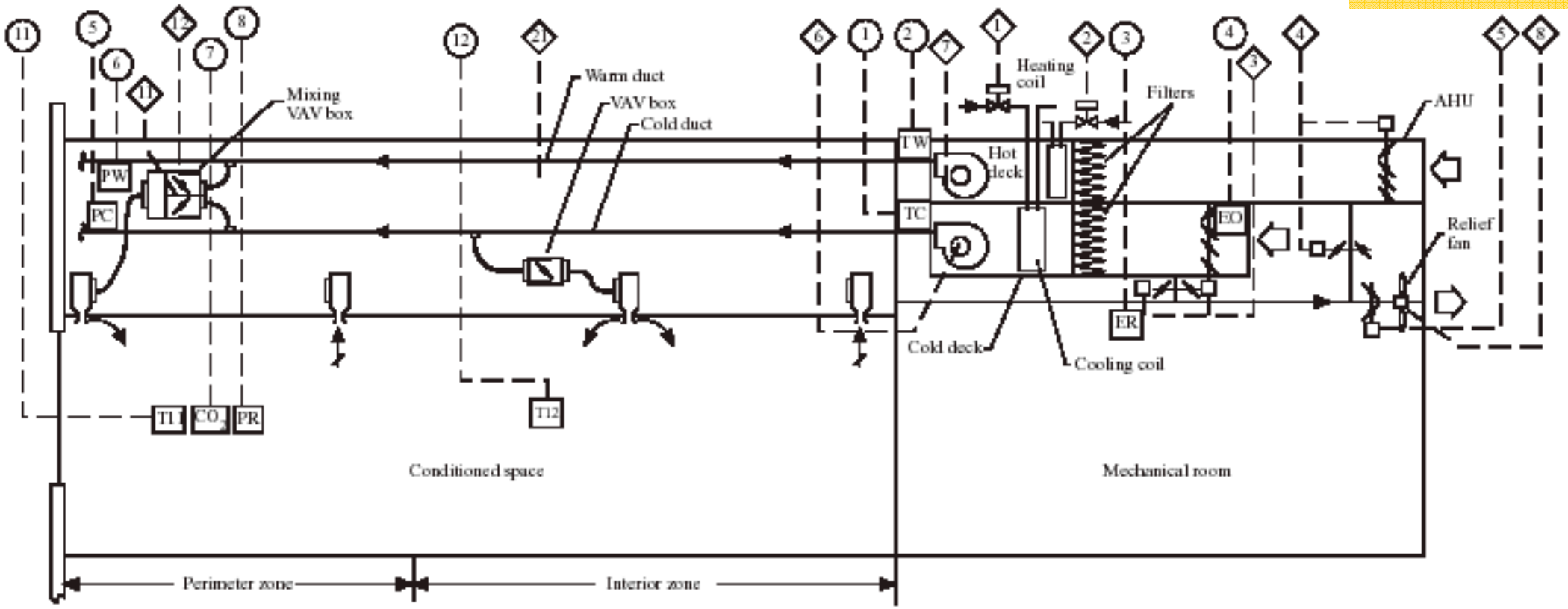


Control diagram

(Source: Wang, S. K., 2001. *Handbook of Air Conditioning and Refrigeration*, 2nd ed.)

A dual-duct VAV central system

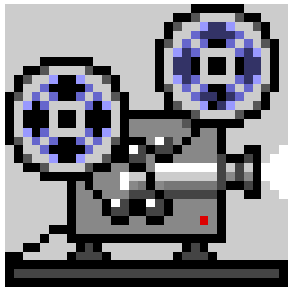
Control diagram



(Source: Wang, S. K., 2001. *Handbook of Air Conditioning and Refrigeration*, 2nd ed.)

Air Conditioning

- Videos: (Introduction to air conditioning)
  - Air Conditioning 1 - Introduction (0:47), http://youtu.be/rUJjj6Fnhz4
  - Air Conditioning 2 - Air Cycle (1:46), http://youtu.be/nDUrjUgjADE
  - Air Conditioning 3 - Chilled and Condenser Water Cycles (1:51), http://youtu.be/IIzv1TJPyYQ
  - Air Conditioning 4 - Constant Air Volume (CAV) System (3:12), http://youtu.be/ZJBSDTpwUpY
  - Air Conditioning 5 - Variable Air Volume (VAV) System (1:50), http://youtu.be/YCogTVa3XOw
  - Air Conditioning 6 - Fan Coil Unit (FCU) (1:58), http://youtu.be/QI0O5xZ3liI
  - Air Conditioning 8 - Air Conditioning Design (1:32), http://youtu.be/do6TnHuZn5A



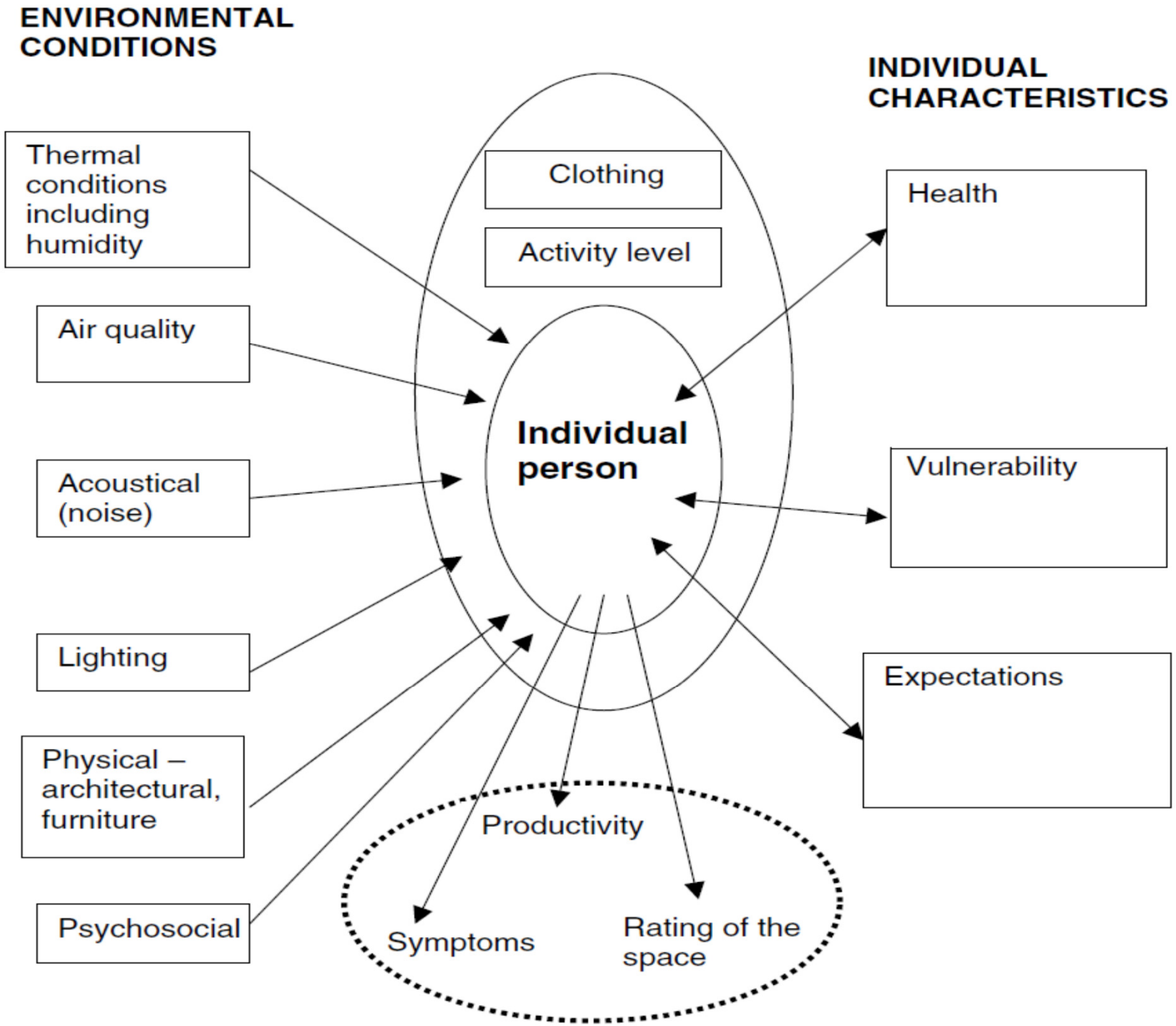
Air Conditioning

- Design of an HVAC system includes:
  - 1. Calculation of the maximum cooling and heating loads for the spaces to be served
  - 2. Selection of the type of system to be used
  - 3. Calculation of piping and/or duct sizes
  - 4. Selection of the type and size of equipment (chillers, boilers, fans, air handling units, heat exchangers, etc.)
  - 5. A layout of the system and schematic diagrams

Air Conditioning

- Establish key performance requirements, e.g.
  - Demands of building occupants & activities
  - Spatial requirements
  - Reliability, adaptability & flexibility
  - Maintenance requirements
  - Control quality & complexity
  - Aesthetics, time constraints & security
  - Investment criteria & whole life cycle costs
  - Energy/environmental targets
  - Indoor environmental standards

Three main groups of factors that affect human comfort



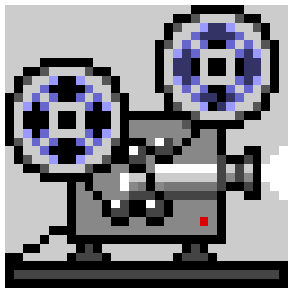
(Source: Mcdowall, R., 2007. *Fundamentals of HVAC Systems*)

Air Conditioning

- Practical design strategy: integrated approach
  - AIM to meet the requirements of the people & processes without being excessive & wasteful
    - Energy efficiency, technically & economically sound
  - LINK with the design of building fabric (architecture) to maximise passive design potential
  - BASED on clear understanding of the building, client and end-user needs
  - FOLLOWED by effective commissioning, handover and building management

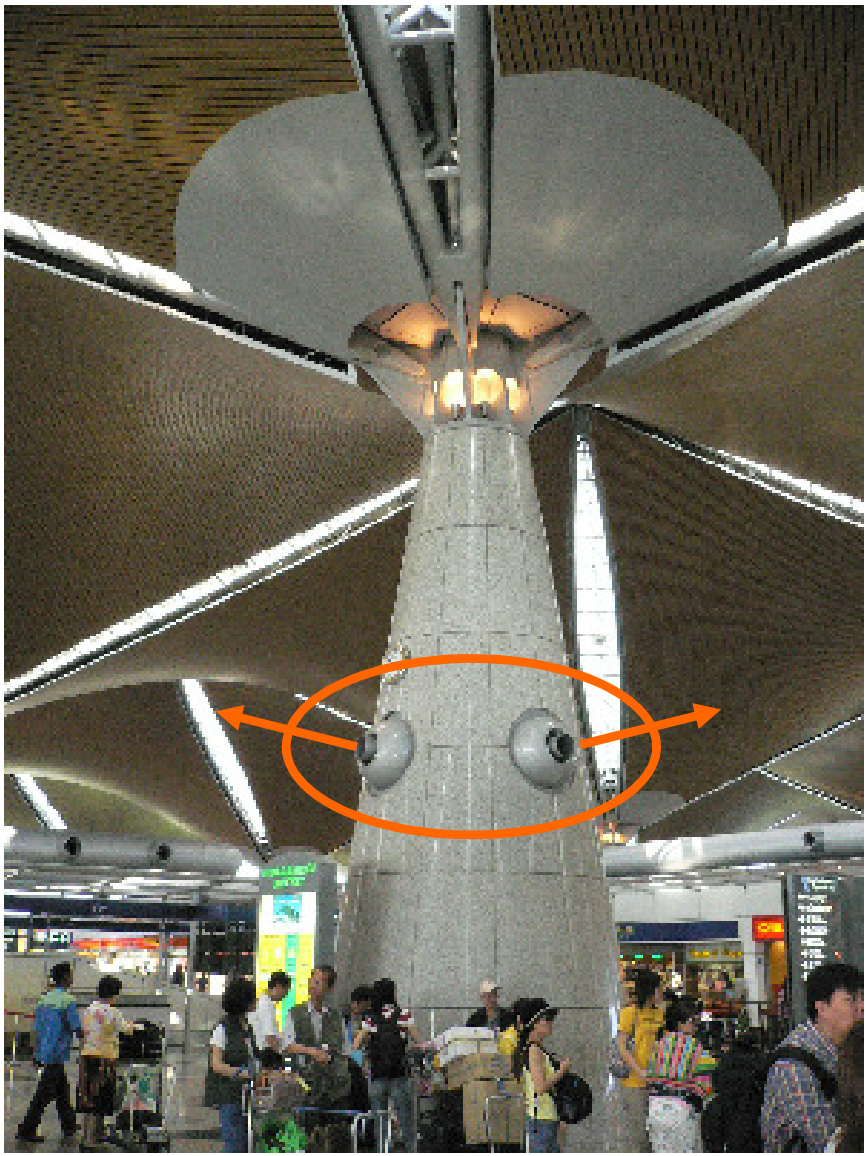
Air Conditioning

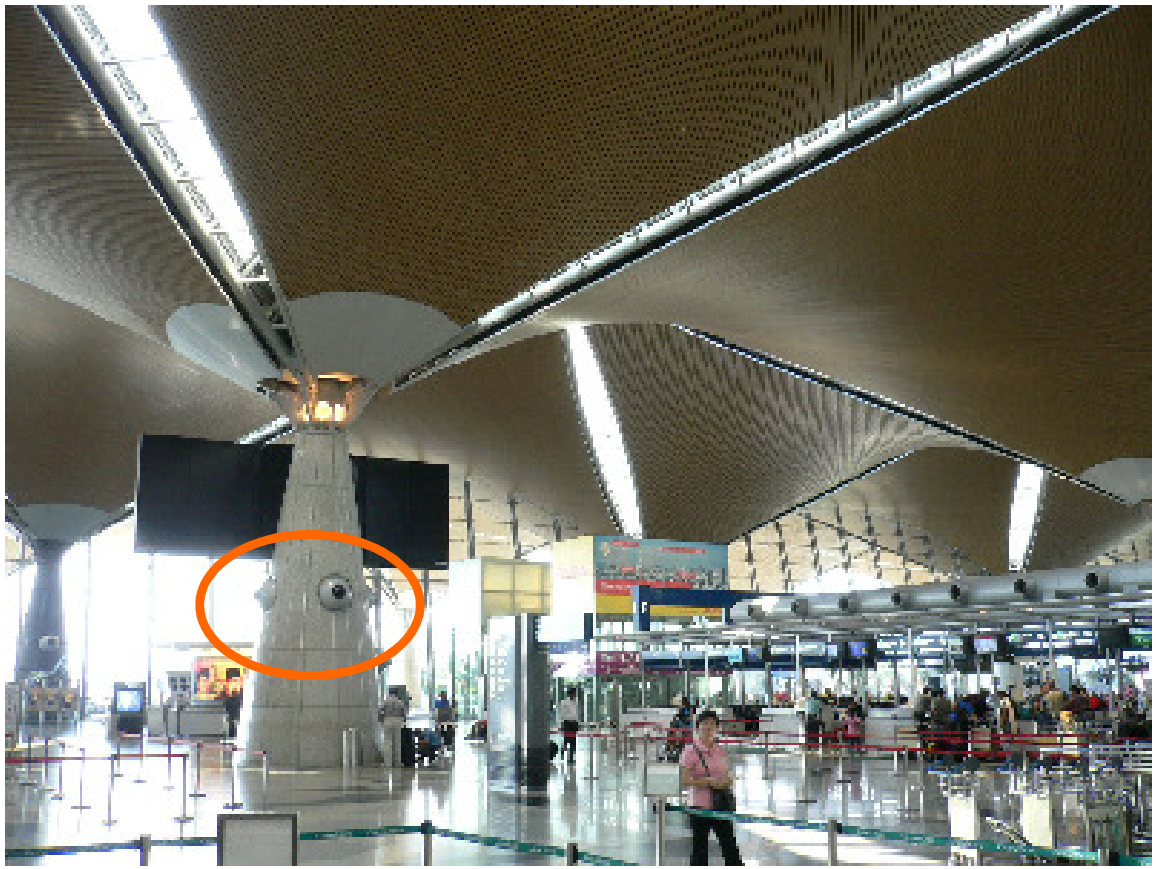
- Video: Fundamentals of Air Conditioning (24 min.) (available in HKU Library)
  - HVAC at Heathrow Airport Terminal 4, London
  - Basic psychrometric principles
  - HVAC equipment and components
  - Design factors:
    - Building
    - System
    - Climate
    - Economic



Hong Kong International Airport

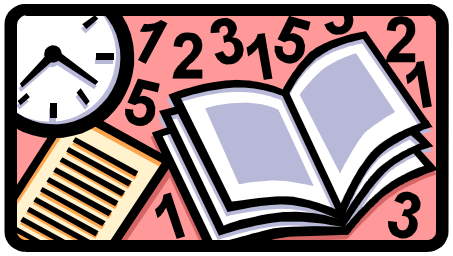
Stansted Airport, UK





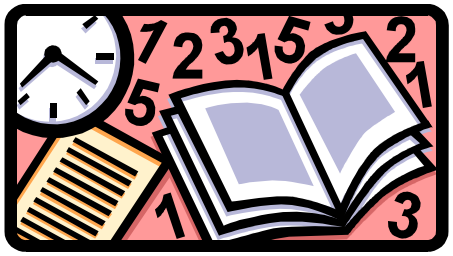
KL International Airport, Malaysia

Further Reading



- Introduction to Air Conditioning
  - www.arca53.dsl.pipex.com/index_files/ac1.htm
- Howell, R. H., Coad, W. J. and Sauer, H. J., 2013. *Principles of Heating, Ventilating, and Air Conditioning*, 7th ed., Chp. 1, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.
- Kreith, F. and Goswami, D. Y. (eds.), 2005. *The CRC Handbook of Mechanical Engineering*, 2nd ed., CRC Press, Boca Raton, FL. [621 C9][ebook via ENGnetBASE]
  - Chapter 9. Air-Conditioning and Refrigeration (by Herbert A. Ingley, Shan K. Wang, Ari Rabl, Peter S. Curtiss, Zalman Lavan) OR
  - Wang, S. K., Lavan, Z. and Norton, P., 2000. Air *Conditioning and Refrigeration Engineering*, Chp. 1, CRC Press, Boca Raton. [697.93 W246 a]

References



- Useful references: (with ebooks)
  - ASHRAE, 2013. *ASHRAE Handbook Fundamentals 2013*, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, GA.
  - Grondzik, W. (ed.), 2007. *Air-conditioning Systems Design Manual*, Second Edition, Butterworth-Heinemann, Burlington, MA.
  - Jones, W. P., 2001. *Air Conditioning Engineering*, 5th ed., Butterworth-Heinemann, Oxford & Boston.

ASHRAE

American Society of Heating Refrigerating & Air-conditioning Engineers

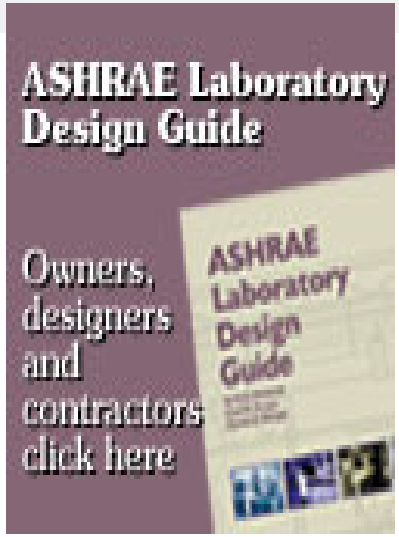
>> You are welcomed to join ASHRAE. www.ashrae.org/join

ASHRAE Publications

- Handbooks
  - Fundamentals
  - Systems & Equipment
  - Applications
  - Refrigeration
- Journal
- E-newsletters
- Design guides
- Books

Handbook

Journal



Guidelines

(Source: www.ashrae.org)