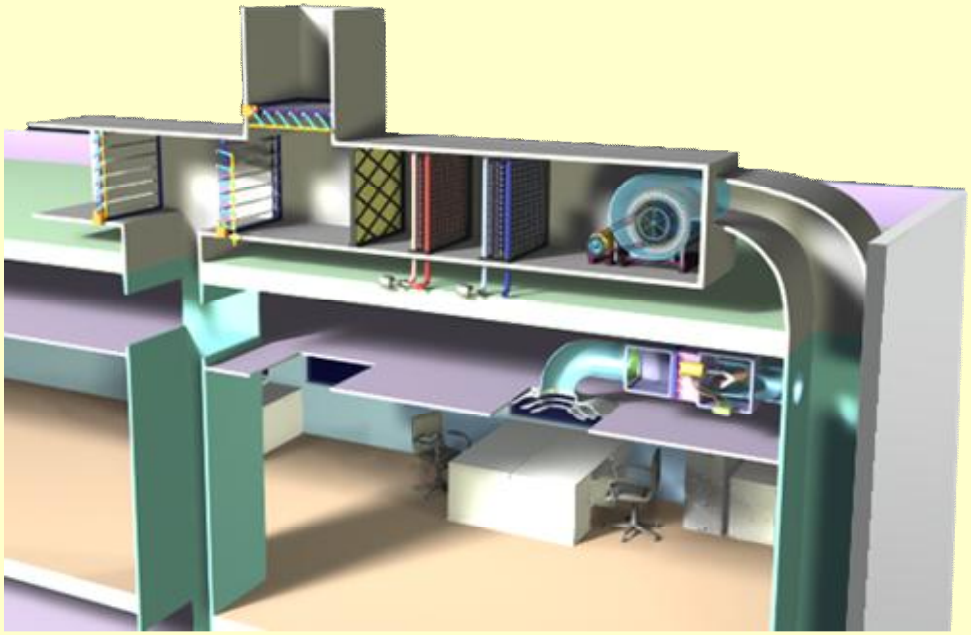
SPD5132 Indoor Environment and HVAC Systems

http://ibse.hk/SPD5132/



Course background

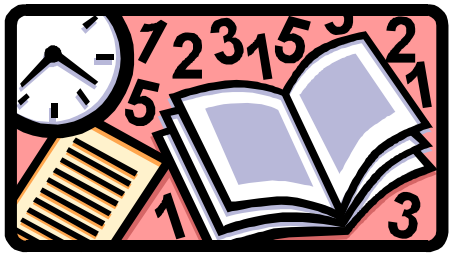
Ir. Dr. Sam C. M. Hui

Faculty of Science and Technology

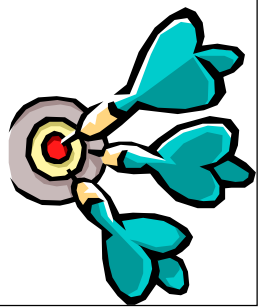
E-mail: cmhui@vtc.edu.hk

Dec 2016

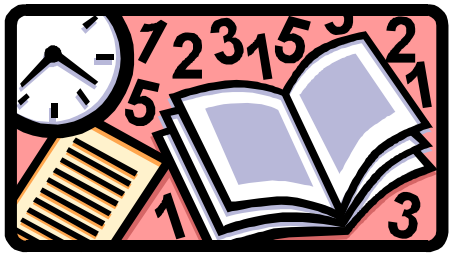
Course background



- Module Aim(s):
  - Provides an integrative view on the design and analysis of indoor air quality (IAQ) and indoor environment by the consideration of different types and functions of various building components in heating, ventilation, air conditioning, refrigeration (HVACR) and energy recovery systems commonly adopted for building services in Hong Kong.

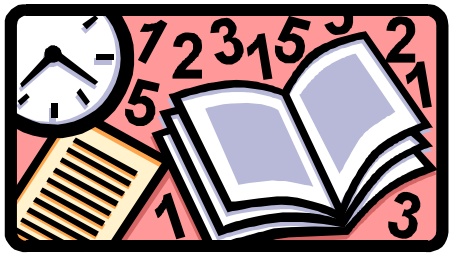


Course background

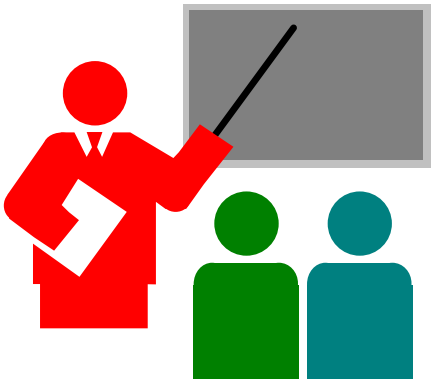


- Learning Outcomes:
  - 1. design various HVACR and energy recovery systems;
  - 2. analyse the processes and performances of various HVACR and energy recovery systems;
  - 3. resolve indoor air quality problems according to the effects of physical, biological and chemical parameters, basic strategy for better IAQ, assessment techniques and the relevant codes and practice; and
  - 4. analyse the problems and development of engineering solutions to resolve indoor acoustical and vibrational problems in association with various HVACR components.

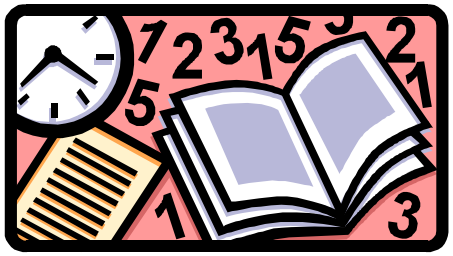
Course background



- Lecturers:
  - Dr. Sam C. M. Hui (cmhui@vtc.edu.hk)
  - Dr. Yimo LUO, Constance (yimo.luo@vtc.edu.hk)
- Assessment Methods:
  - Assignments (20%)
  - Mini Project (40%)
  - Examination (40%) (2 hours)
- Course Website:
  - http://ibse.hk/SPD5132/

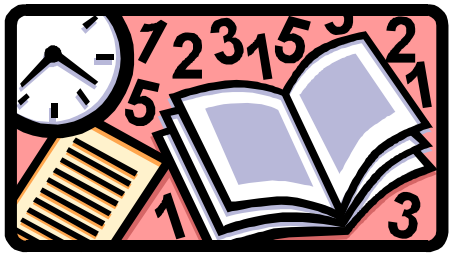


Course background



- Assessment Components:
  - Assignments (20%) – individual
    - Assignment 01 (10%) by Dr. Hui
    - Assignment 02 (10%) by Dr. Luo
  - Mini Project (40%) – group project (3-4 students)
    - Oral presentation and reports are jointly assessed by Dr. Hui and Dr. Luo
  - Examination (40%) (2 hours)
    - Section A by Dr. Hui (2 out of 3 questions @ 25 marks)
    - Section B by Dr. Luo (2 out of 3 questions @ 25 marks)

Course background



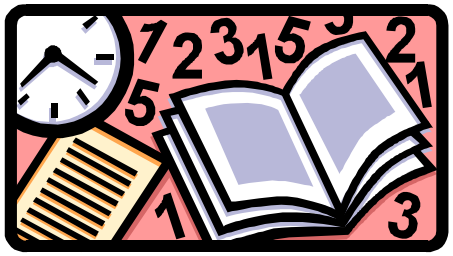
- Study topics:
  - HVAC systems: basic concepts
  - Water-side systems
  - Heat rejection systems
  - Chiller plant control and operation
  - Heating systems
  - Energy recovery systems

Dr. Hui

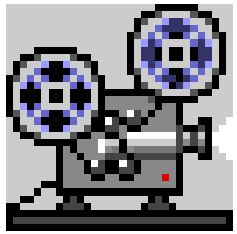
  - HVAC system control
  - Indoor air quality: basic concepts and parameters
  - IAQ management and remediation
  - IAQ assessment
  - Room acoustics
  - Noise assessment and control

Dr. Luo

Course background

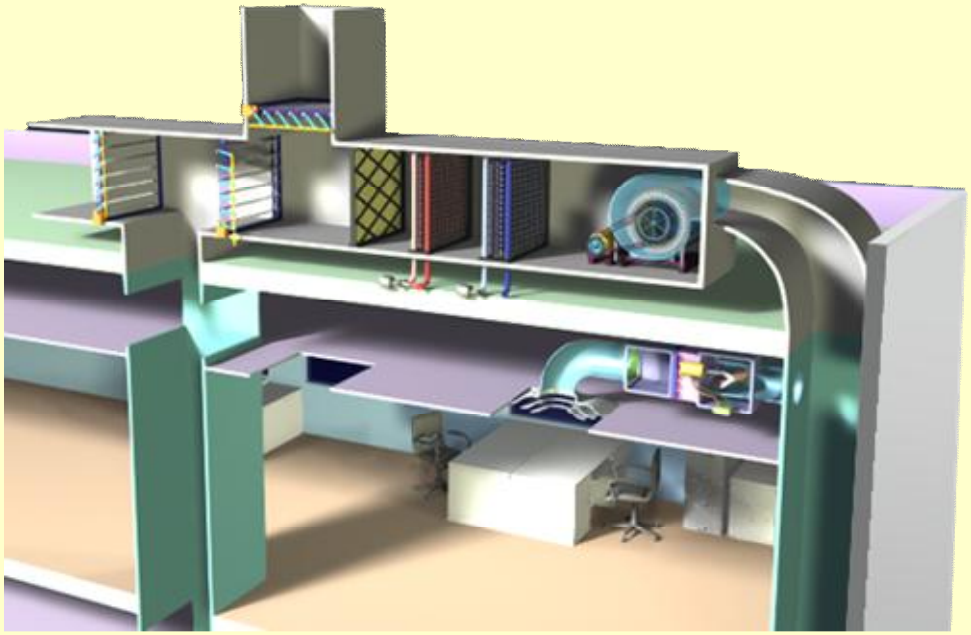


- Learning Methods:
  - Lectures + Further Reading
  - Individual Assignment
  - Discussions
    - During lectures
    - When doing the group project
- Resources:
  - Video presentations
  - Web links + References



SPD5132 Indoor Environment and HVAC Systems

http://ibse.hk/SPD5132/



HVAC systems: basic concepts

Ir. Dr. Sam C. M. Hui
Faculty of Science and Technology
E-mail: cmhui@vtc.edu.hk

Dec 2016

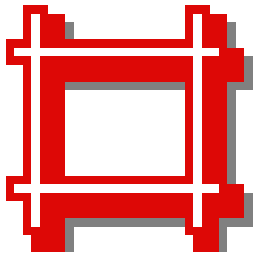
Contents

- HVAC systems
- HVAC system design
- All air systems
- All water systems
- Air-water systems
- Unitary package systems
- VRF systems

HVAC systems

- What is HVAC&R?
  - HVACR is an acronym or abbreviation for the products and services related to the functions of:
  - **H**eating 採暖
  - **V**entilation 通風
  - **A**ir-**C**onditioning 空調
  - **R**efrigeration 製冷

HVAC systems



- Comfort air-conditioning
  - A process of controlling the air temperature, relative humidity, ventilation, air movement and air cleanliness of a given space in order to provide the occupants with a comfortable indoor temperature.
- Air-conditioning (AC) system: consists of a group of components or equipment connected in series to control the environmental parameters

Components of HVAC systems

Air side:

1. Outdoor air intake (screen, louvers, dampers)
2. Preheater
3. Return air intake (dampers)
4. Filter
5. Cooling coil
6. Dehumidifier
7. Heating coil
8. Humidifier
9. Fan
10. Duct system
11. Air outlet
12. Air terminal (with outlet)

Refrigerant side:

1. Refrigeration machine or chiller (compressor, condenser, cooler and refrigerant piping)

Water side:

1. Pumps
2. Water piping

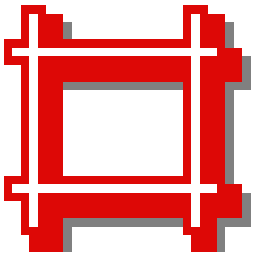
Heat rejection:

1. Cooling tower

Heating side:

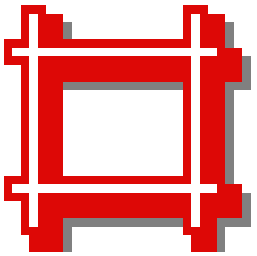
1. Boiler and auxiliaries
2. Piping (hot water or steam)

HVAC systems



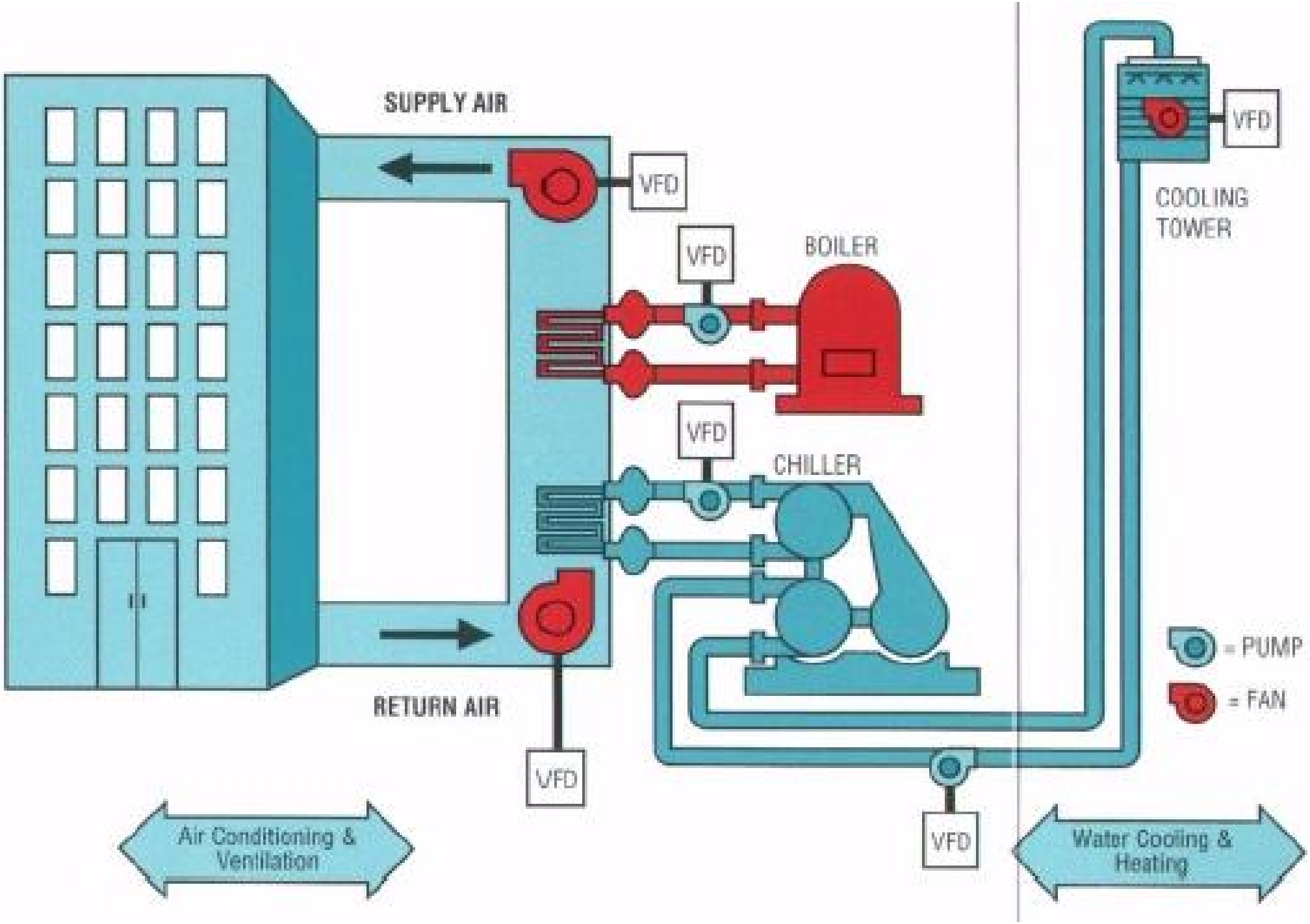
- Classification of AC systems (by scale/size)
  - Individual Systems
    - Use a small, self-contained , factory-made air conditioner to serve one or two rooms (e.g. room/window air conditioner and split-type units), usually with direct expansion (DX) coils
  - Unitary Packaged Systems
    - Similar to individual systems but serve more rooms or even more than one floor, have an air system consisting of fans, coils, filters, ductwork and outlets (e.g. in small restaurants, small shops and small cold storage rooms)

HVAC systems



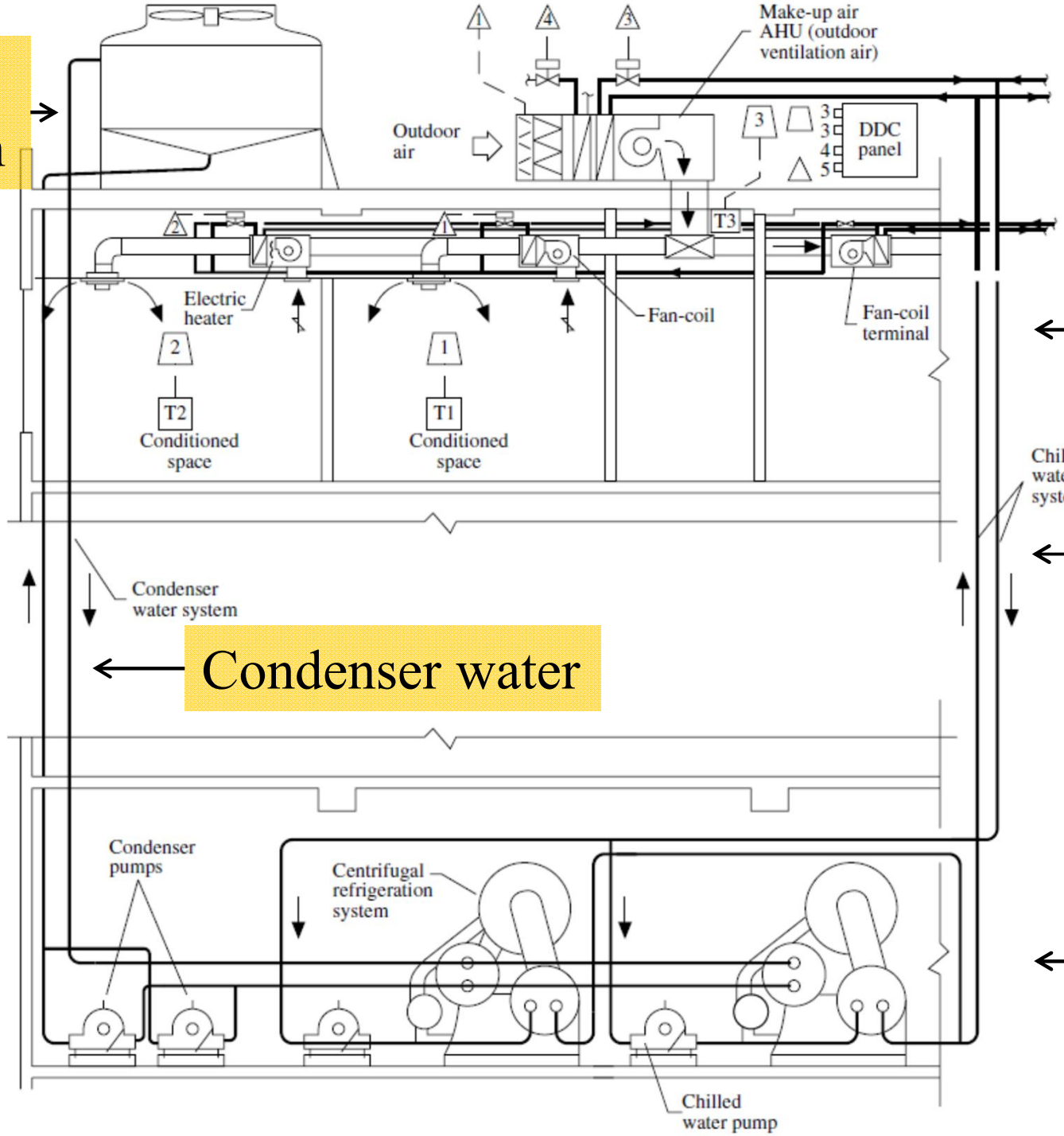
- Classification of AC systems (cont'd)
  - Central (Hydronic) Systems – use chilled water as a cooling medium to cool air indirectly. It basically consists of three major parts:
    - Air system – air handling units (AHU), air distribution (air duct) system and terminals
    - Water system – chilled water system, hot water system, condenser water system
    - Central plant – refrigeration (chiller) plant, boiler plant

Example of a centralised HVAC system



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

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*)

Thermal energy moves from left to right through five loops of heat transfer (i.e. heat pump)

Air side → Chilled water → Refrigeration → Condenser water → Heat rejection

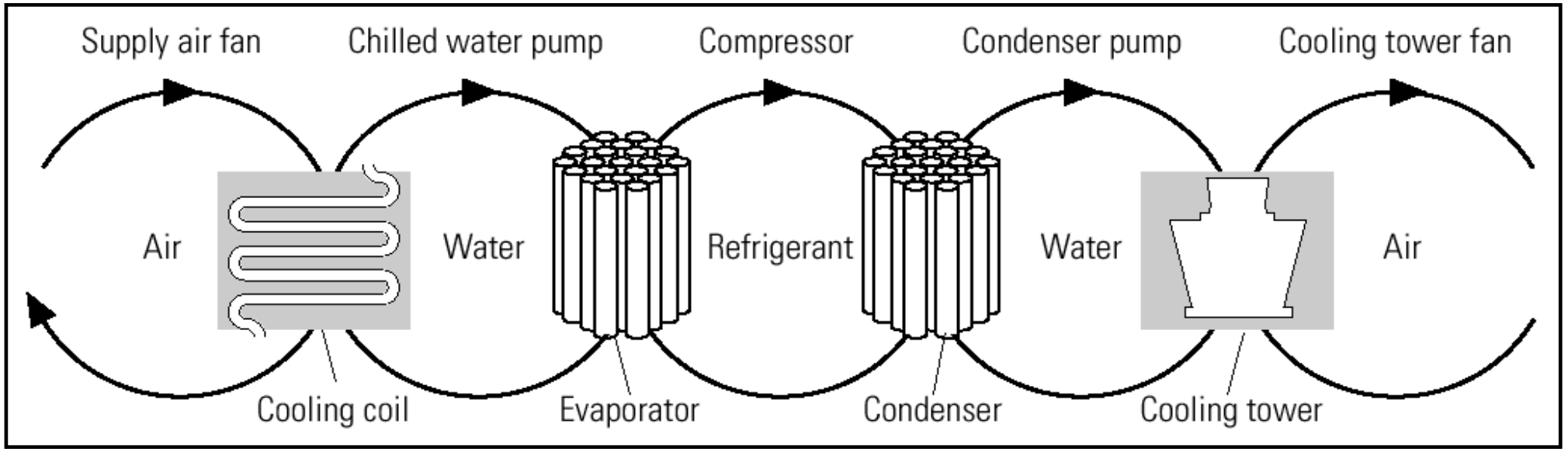
1) Indoor air loop

2) Chilled water loop

3) Refrigerant loop

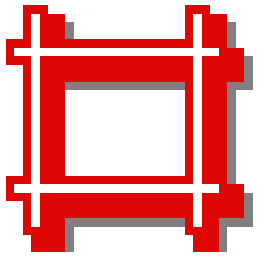
4) Condenser water loop

5) Cooling water loop



(Source: *www.energyefficiencyasia.org*)

HVAC systems



- Air and refrigeration systems designation
  - To describe more clearly the main characteristics of AC systems
  - Specified terminology for an AC system with a designated air system and primary cooling and heating plant, e.g.
    - Air system
    - Refrigeration (method and compressor type)
    - General classification (individual, package, central)
    - Primary heating plant or method

Air and refrigeration systems designation

Air system	Refrigeration	Air conditioning system
• Constant volume • Fan-coil • Single-zone VAV • Perimeter-heating VAV • VAV reheat • Dual-duct VAV • Fan-powered VAV	• Centrifugal • Reciprocating • Screw • Scroll • Absorption • Gas cooling • Desiccant evaporative	• Central system • Rooftop packaged system • Indoor packaged system • Split packaged system • Rooftop heat pump system • Split heat pump system • Water-loop heat pump system • Ice thermal storage system • Chilled water storage system • Heat recovery central system

CAV = constant air volume, VAV = variable air volume

Examples: - VAV reheat screw central system
- Fan-powered VAV, centrifugal, ice thermal storage central system
- Reciprocating water-loop heat pump system

(* If the distinctions between centrifugal, reciprocating, scroll, and screw compression are not important for an AC system, just omit them. In areas where the type of primary heating plant is important, gas heating, electric heating, and oil heating can be added.)

HVAC system design

- The goal of HVAC system design
  - Achieve a highly quality system that functions effectively and is energy-efficient and cost-effective
    - All design criteria are fulfilled, and the requirements of the owner and the user are satisfied
    - A good indoor air quality is provided
    - The system is reliable and safe, e.g. it has adequate fire protection level (like smoke management)

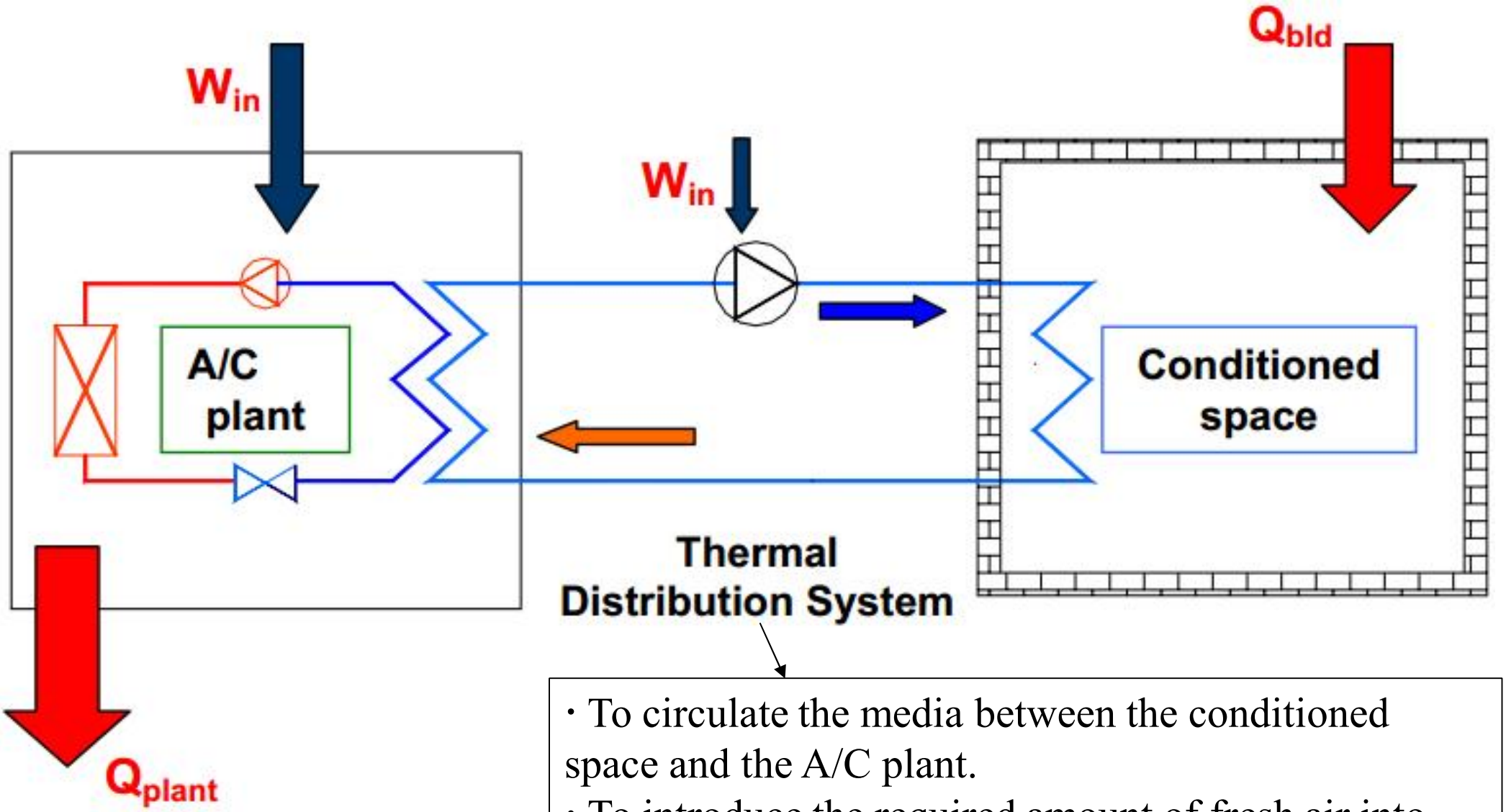
HVAC system design

- HVAC system selection
  - The designer must understand the building and the client's requirements and evaluate the factors
    - Building location, surrounding environment and external climate
    - Uses and functional requirements of the building
    - Client's budget, investment policy, expected quality of service, and sustainability issues
  - Should consider various system options and recommend one or several that will be likely to perform as desired

HVAC system design

- HVAC system selection criteria
  - Performance requirements – on comfort, noise, control options, flexibility and meeting requirements of local regulations/codes
  - Capacity requirements – range of capacity, multiple units, zoning, etc.
  - Spatial requirement – plant room space, space for ducting and piping (vertical shafts), space for terminal equipment
  - Costs – initial cost, operating cost and maintenance cost
  - Energy consumption – for both economic and environment reasons
  - System qualities – e.g. aesthetics, lifetime, reliability, flexibility and maintainability

Schematic of an air conditioning system with the thermal distribution system



- To circulate the media between the conditioned space and the A/C plant.
- To introduce the required amount of fresh air into the conditioned space so that the required Indoor Air Quality (IAQ) can be maintained.

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

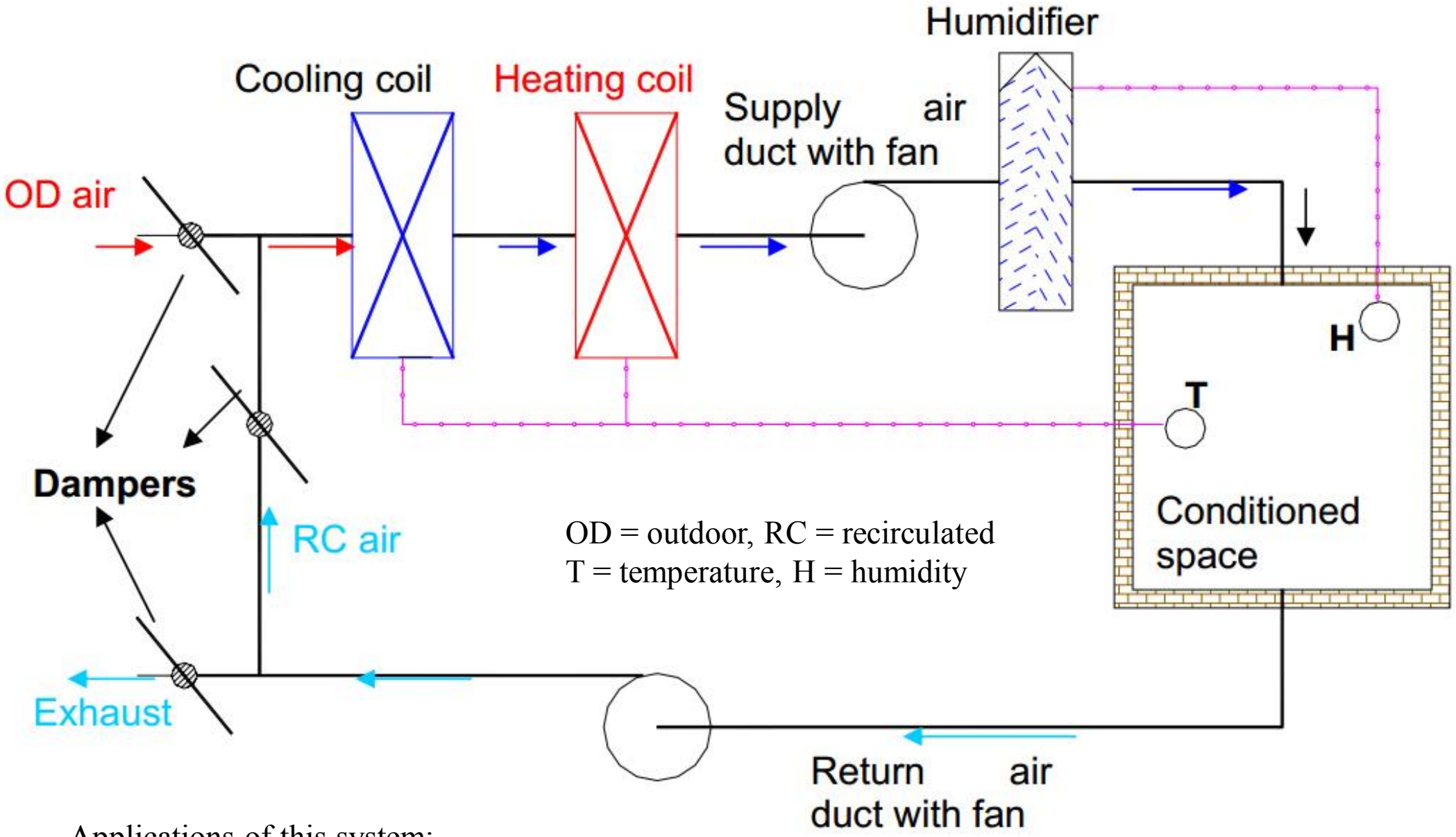
HVAC system design

- Four generic types of AC systems:
  - 1. All air systems
    - Air is used as the media that transports energy from the conditioned space to the A/C plant
  - 2. All water systems
    - Water is used as the media for thermal distribution
  - 3. Air- water systems
    - Both air and water are used for thermal distribution in the conditioned space
  - 4. Unitary refrigerant based systems

All air systems

- All air systems
  - Single duct systems (provide either cooling or heating using the same duct)
    - 1. Constant volume, single zone systems
    - 2. Constant volume, multiple zone systems
    - 3. Variable volume systems
  - Dual duct systems (two supply air ducts to provide both cooling and heating simultaneously)
    - 1. Dual duct, constant volume systems
    - 2. Dual duct variable volume systems

Constant volume, single duct, single zone system



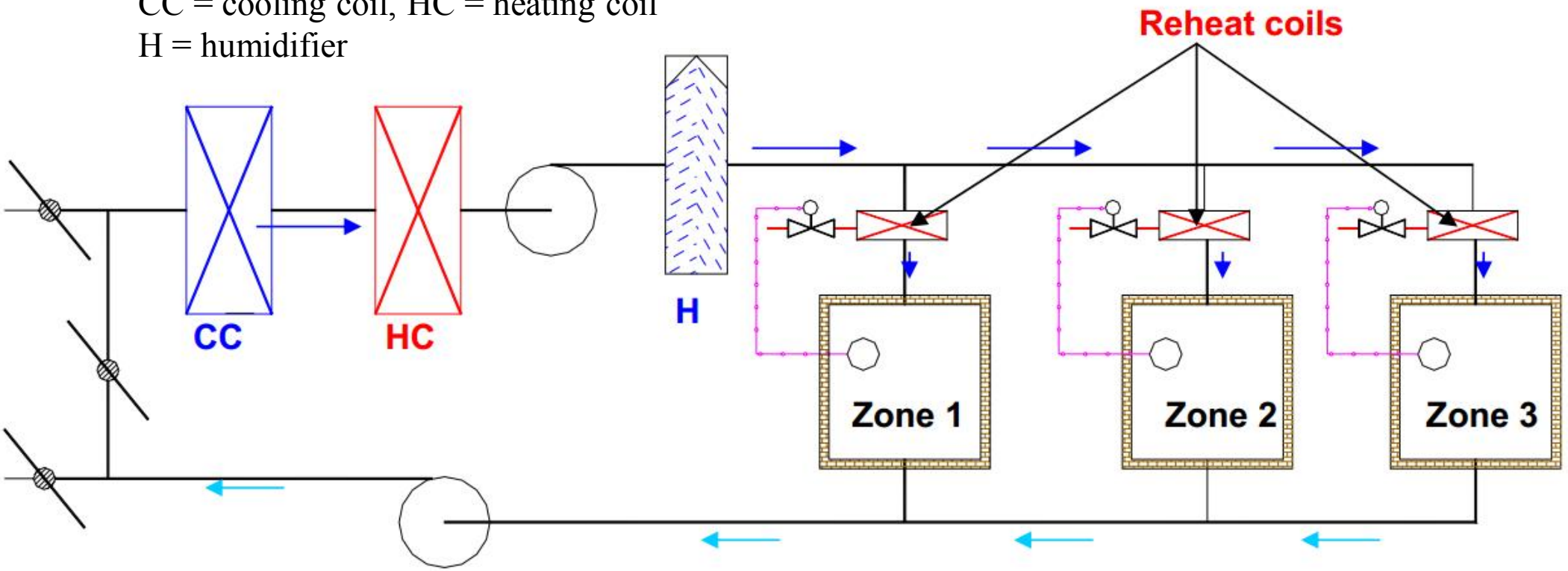
Applications of this system:

1. Spaces with uniform loads, e.g. large open areas with small external loads e.g. theatres, auditoria, departmental stores.
2. Spaces requiring precision control e.g. laboratories

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

Single duct, constant volume system with multiple zones and reheat coils

CC = cooling coil, HC = heating coil
H = humidifier



Advantages of this system:

a) Relatively small space requirement

b) Excellent temperature and humidity control over a wide range of zone loads

c) Proper ventilation and air quality in each zone is maintained as the supply air amount is kept constant under all conditions

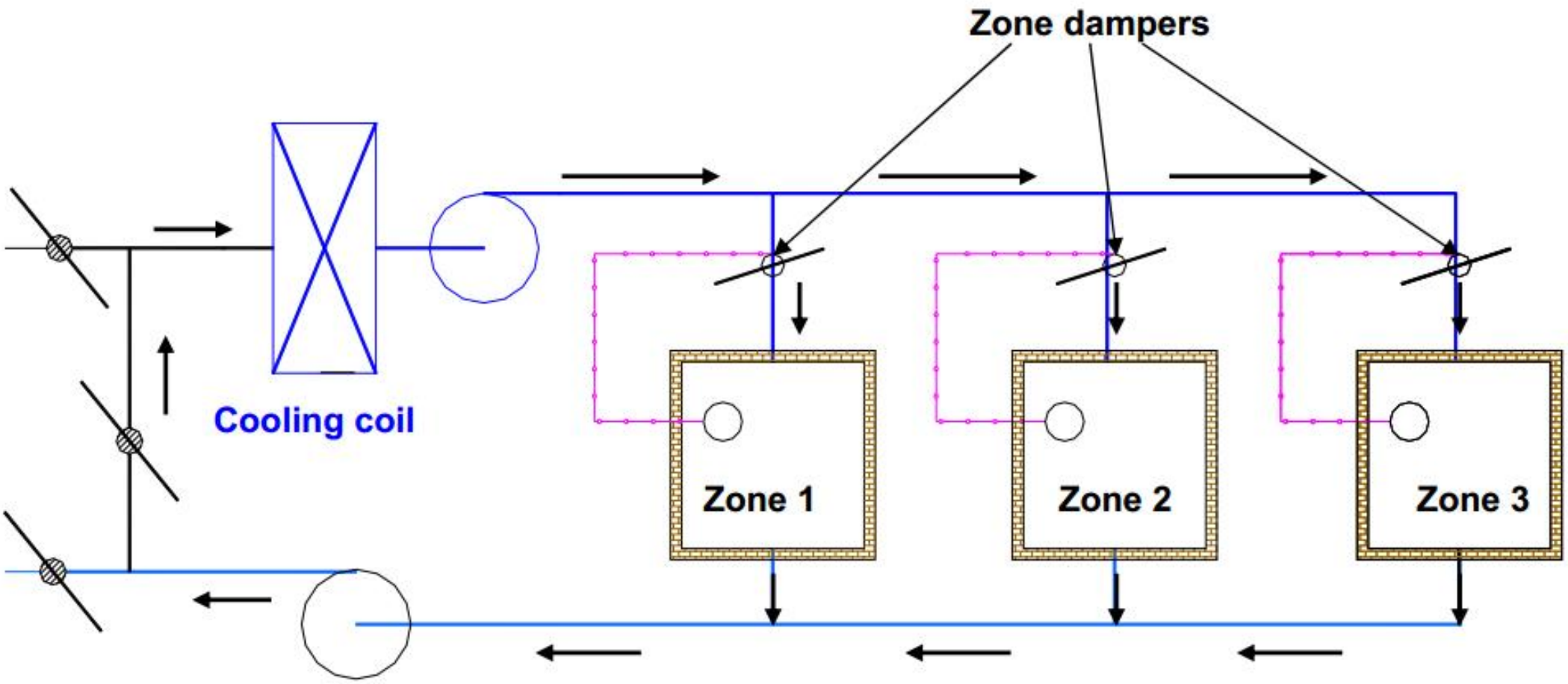
Disadvantages of this system:

a) High energy consumption for cooling (cooling + reheat)

b) Simultaneous cooling and heating is not possible

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

Single duct, multiple zone, variable air volume system



Advantages of this system:

a) Lower cooling energy consumption as air is not cooled to very low temperatures and then reheated as in constant volume systems

b) Lower fan power input due to lower flow rate, when the load is low.

Precautions of this system:

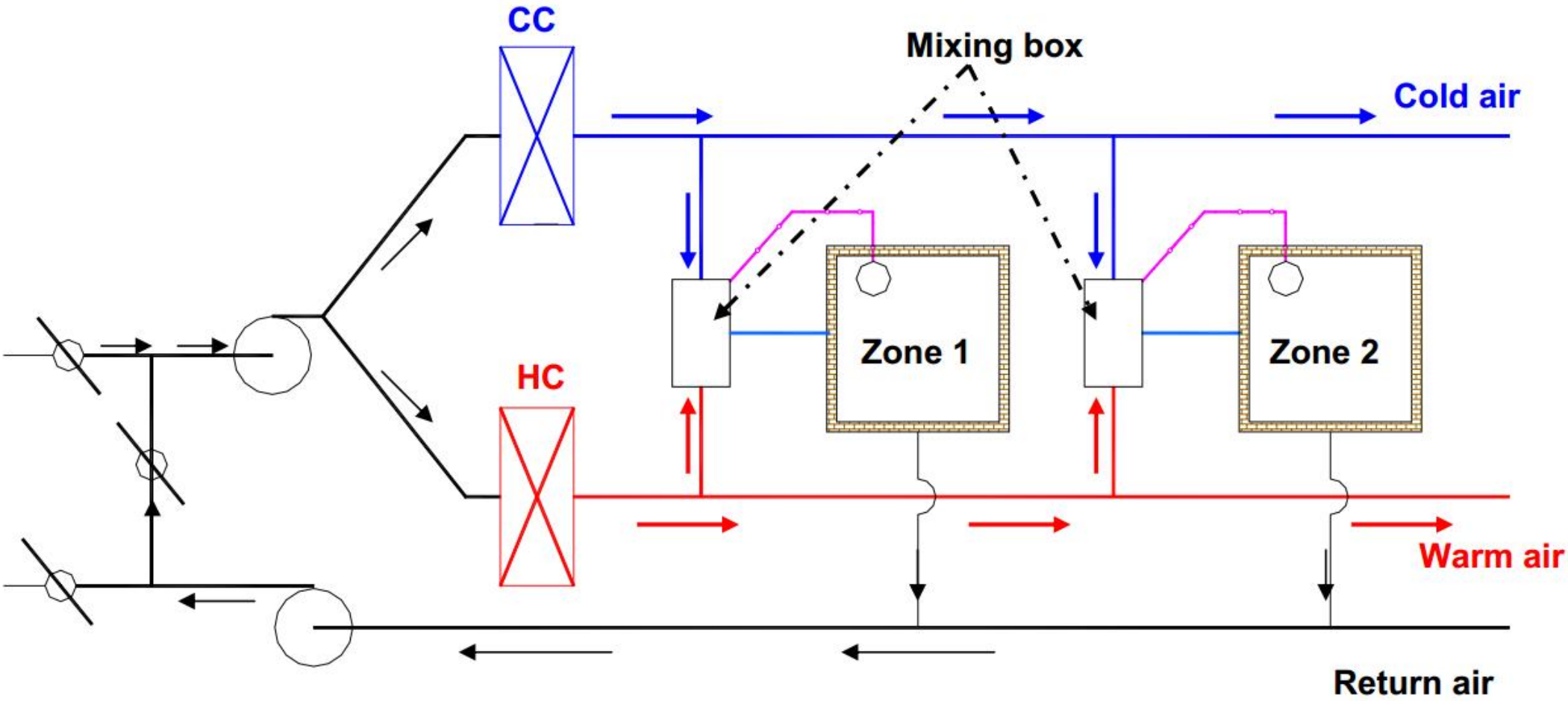
a) Problems with ventilation, IAQ and room air distribution when the zone loads are very low

b) Difficult to control humidity precisely

c) Balancing of dampers could be difficult if the airflow rate varies widely

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

Dual duct, constant volume system



Advantages of this system:

a) With constant airflow rate, it is possible to maintain proper IAQ and room air distribution

b) Cooling in some zones and heating in other zones can be achieved simultaneously

c) System is very responsive to variations in the zone load, thus it is possible to maintain required conditions precisely

Disadvantages of this system:

a) Occupies more space as both cold air and hot air ducts have to be sized to handle all the air flow rate

b) Not very energy efficient due to the need for simultaneous cooling and heating of the air streams

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

All air systems

- All air systems – Advantages
  - 1. Energy saving potential by utilizing the outdoor air effectively.
  - 2. By using high-quality controls it is possible to maintain the temperature and relative humidity of the conditioned space within ± 0.15˚C (DBT) and ± 0.5%, respectively.
  - 3. Using dual duct systems, it is possible to provide simultaneous cooling and heating.
  - 4. It is possible to provide good room air distribution and ventilation under all conditions of load.
  - 5. Building pressurization can be achieved easily.
  - 6. The complete air conditioning plant including the supply and return air fans can be located away from the conditioned space. Due to this it is possible to use a wide variety of air filters and avoid noise in the conditioned space.

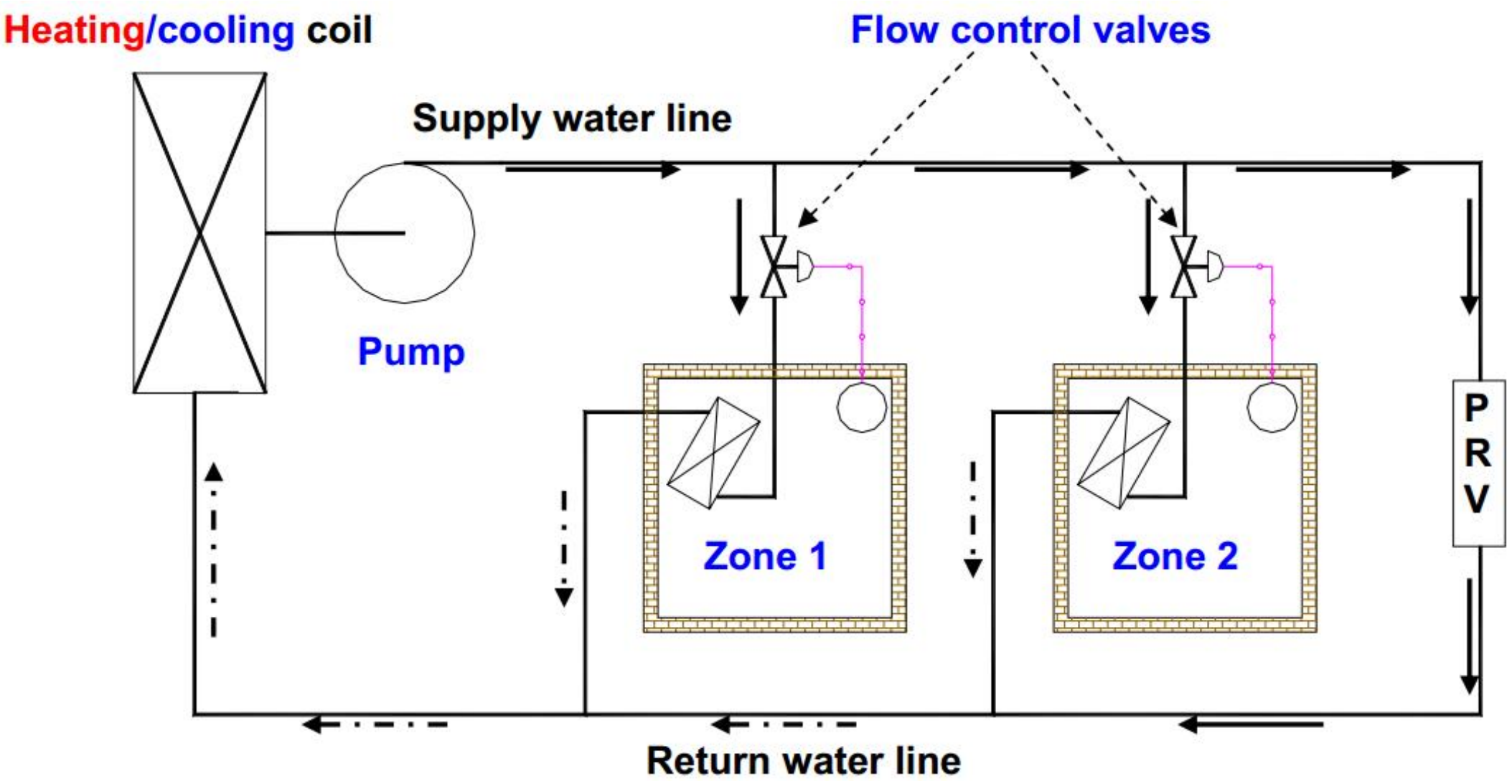
All air systems

- All air systems – Disadvantages
  - 1. They occupy more space and thus reduce the available floor space in the buildings.
  - 2. Retrofitting may not always be possible due to the space requirement.
  - 3. Balancing of air in large and particularly with variable air volume systems could be difficult.
- Applications of all air systems
  - They are especially suited to buildings that require individual control of multiple zones, e.g. office buildings, classrooms, laboratories, hospitals, hotels, ships etc.
  - They are also used extensively in applications that require very close control of the conditions in the conditioned space e.g. clean rooms, computer rooms, operation theatres, research facilities etc.

All water systems

- All water systems
  - Water (cold or hot) transports energy between the conditioned space and the air conditioning plant
    - 2-pipe system: one for supply of cold/hot water to the conditioned space and the other for the return water
    - 4-pipe system: two supply pipelines – one for cold water and one for hot water, two return water pipelines
  - Provision must be made for supplying required amount of treated, outdoor air to the conditioned space for ventilation purposes

A two-pipe, all water system



PRV = pressure relief valve

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

All water systems

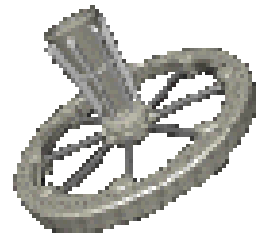
- All water systems – Advantages
  - 1. Requires less space in conditioned floor compared to all air systems. Also the plant size will be small due to the absence of large supply air fans.
  - 2. Individual room control is possible, and at the same time the system offers all the benefits of a large central system.
  - 3. Since the temperature of hot water required for space heating is small, it is possible to use solar or waste heat for winter heating.
  - 4. It can be used for new as well existing buildings (retrofitting).
  - 5. Simultaneous cooling and heating is possible with 4-pipe systems.

All water systems

- All water systems – Disadvantages
  - 1. Requires higher maintenance compared to all air systems, particularly in the conditioned space.
  - 2. Draining of condensate water can be messy and may also create health problems if water stagnates in the drain tray.
  - 3. If ventilation is provided by opening windows or wall apertures, then, it is difficult to ensure positive ventilation under all circumstances, as this depends on wind and stack effects.
  - 4. Control of humidity, particularly during summer is difficult using chilled water control valves.

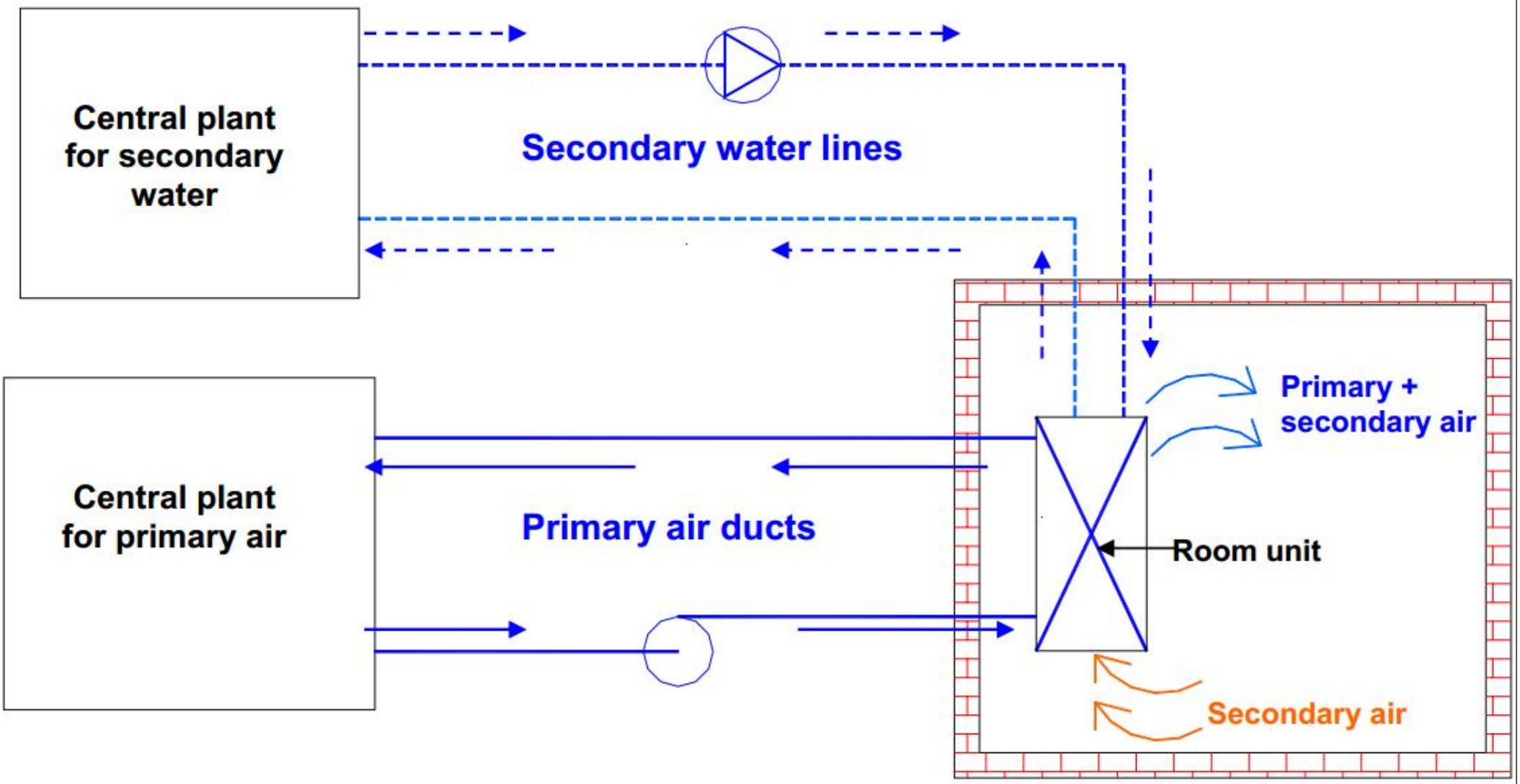
*All water systems using fan coil units are most suitable in buildings requiring individual room control, e.g. hotels, apartment buildings and office buildings.

Air-water systems



- Air-water systems
  - The air supplied to the conditioned space from the central plant is called as primary air, while the water supplied from the plant is called as secondary water. The system consists of:
    - A central plant for cooling or heating of water and air
    - Ducting system with fans for conveying air
    - Water pipelines and pumps for conveying water
    - A room terminal (e.g. a fan coil unit, an induction unit or a radiation panel)

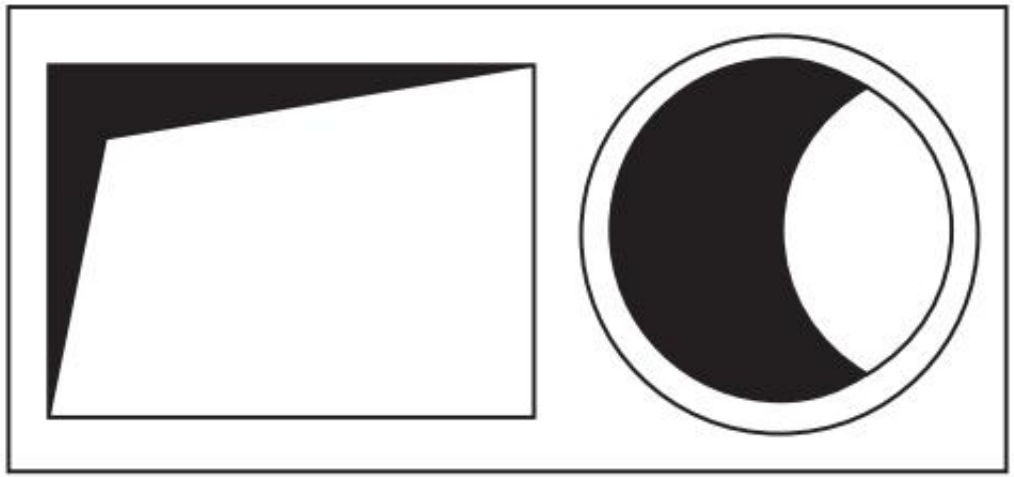
A basic air-water system



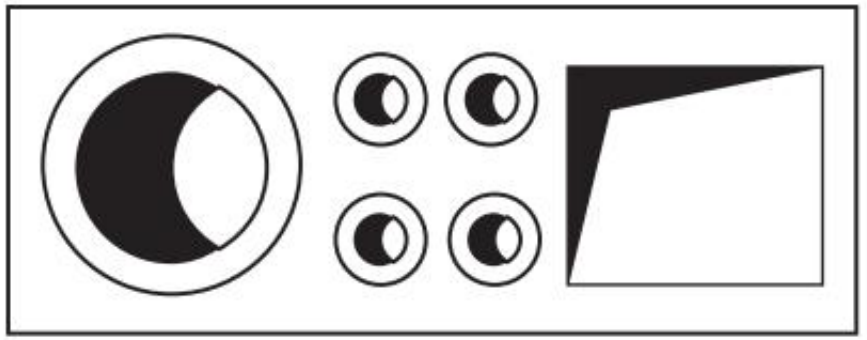
* The primary air supplied at medium to high pressure to the room unit, induces flow of secondary air from the conditioned space. The secondary air is sensibly cooled or heated as it flows through the cooling/heating coil. The primary and secondary air are mixed and supplied to the conditioned space.

(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

Space requirements for all-air and air-water distribution arrangements



All-air
(supply and extract)

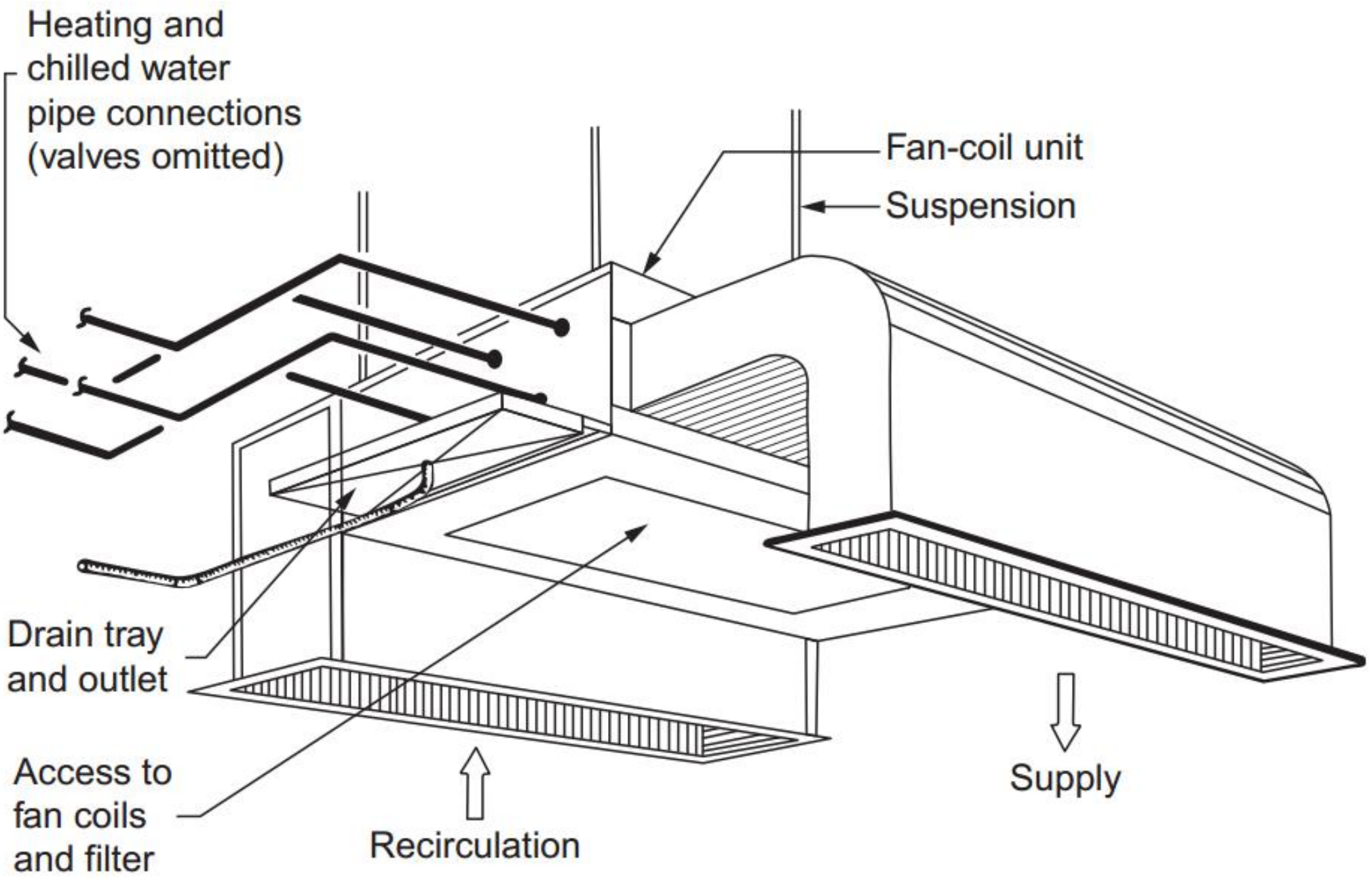


Area ratio = 3:2

Air–water
(Supply, extract, heating and chilled water)

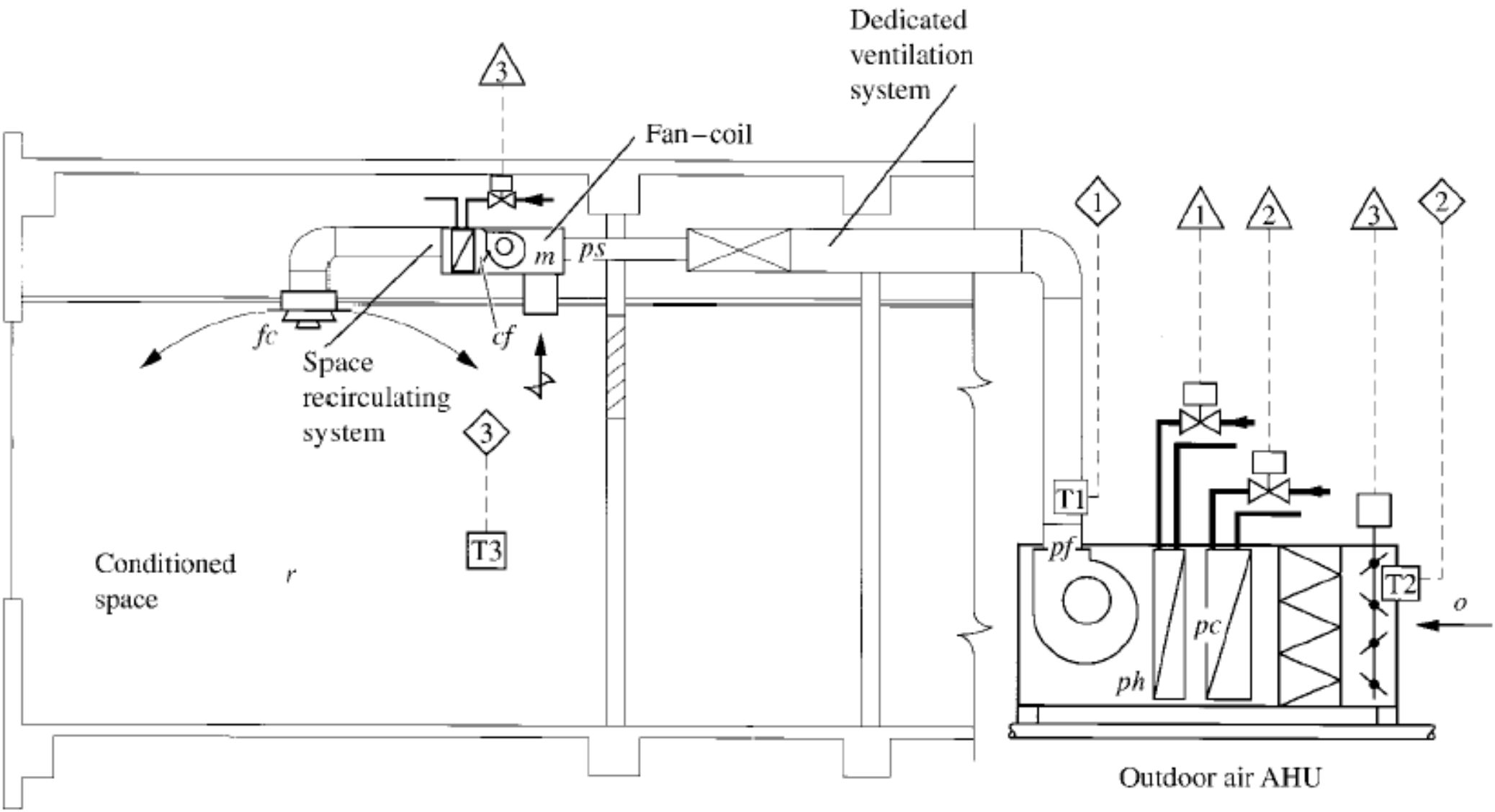
(Source: Oughton, D. and wilson, A., 2015. *Faber and Kell's Heating and Air-conditioning of Buildings*, 11th edition)

Fan coil unit fitted above a suspended ceiling



(Source: Oughton, D. and wilson, A., 2015. *Faber and Kell's Heating and Air-conditioning of Buildings*, 11th edition)

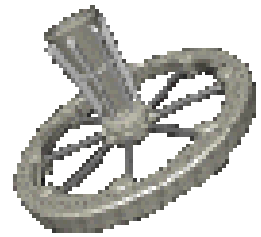
Primary air fan coil unit (PA-FCU) system



Why the PA-FCU is so popular in hotel and office buildings?

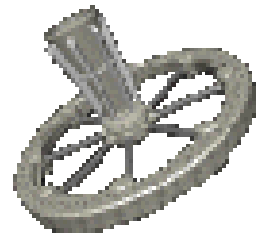
(Source: Wang, S. K., 2001. *Handbook of Air Conditioning and Refrigeration*, 2nd ed.)

Air-water systems



- Air-water systems – Advantages
  - 1. Individual zone control is possible in an economic manner.
  - 2. Can provide simultaneous cooling and heating.
  - 3. Space requirement is reduced, as the amount of primary supplied is less than that of an all air systems.
  - 4. Positive ventilation can be ensured under all conditions.
  - 5. No latent heat transfer in the cooling coil; the coil is dry to increase its life and avoid odours or fungal growth problems.
  - 6. The space can be heated with the help of the heating coil and secondary air, thus avoiding supply of primary air during winter.
  - 7. Service of indoor units is relatively simpler compared to all water systems.

Air-water systems

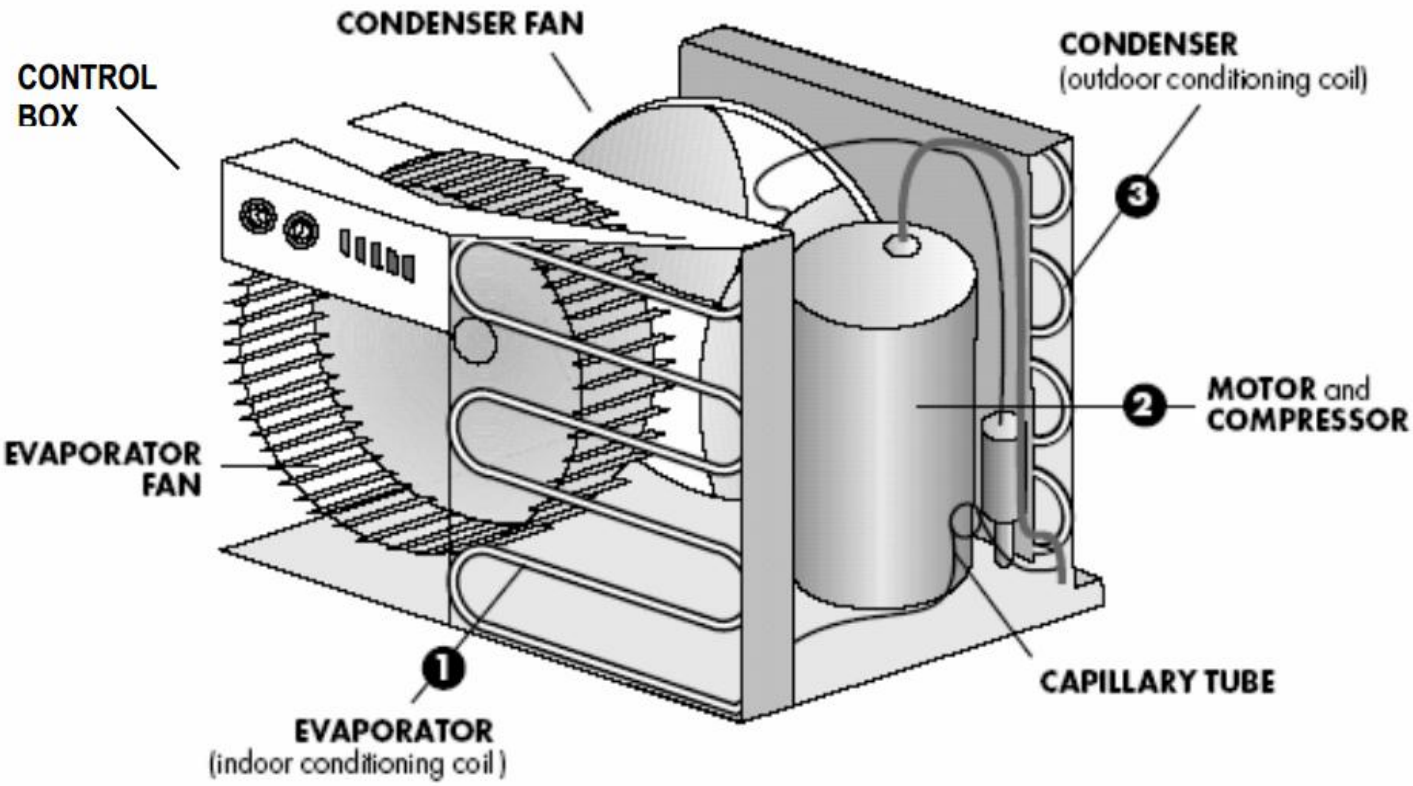


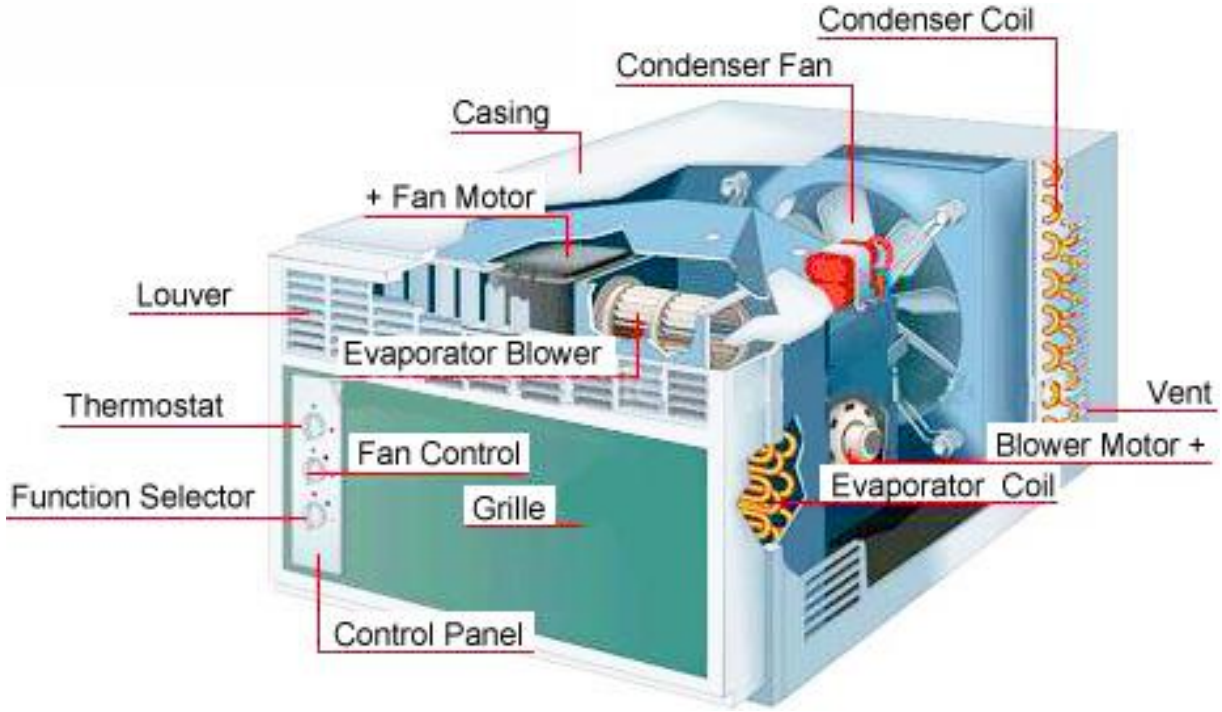
- Air-water systems – Disadvantages
  - 1. Operation and control are complicated due to the need for handling and controlling both primary air and secondary water.
  - 2. In general these systems are limited to perimeter zones.
  - 3. The secondary water coils in the conditioned space can become dirty if the quality of room filters is not good.
  - 4. Since a constant amount of primary air is supplied to conditioned space, shutting down the supply of primary air to unoccupied spaces is not possible.
  - 5. If there is abnormally high latent load on the building, then condensation may take place on the cooling coil.
  - 6. Initial cost could be high compared to all air systems.

Unitary package systems

- Unitary refrigerant based systems
  - Consist of several separate AC units with individual refrigeration systems
  - Factory assembled and tested as per standard specifications, as package units
    - Each package consists of refrigeration and/or heating units with fans, filters, controls etc
    - Available in the form of window air conditioners, split air conditioners, heat pumps, ductable systems with air cooled or water cooled condensing units etc

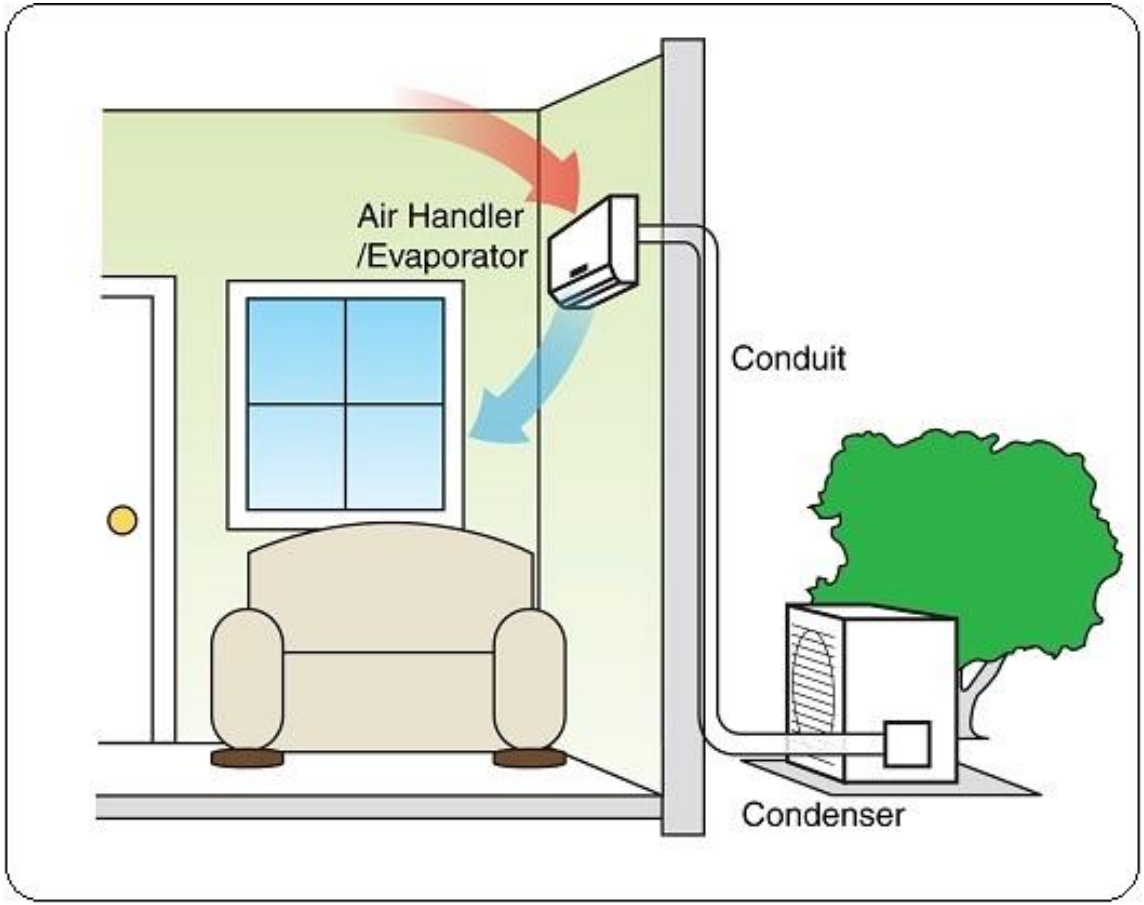
A typical window type room air conditioner





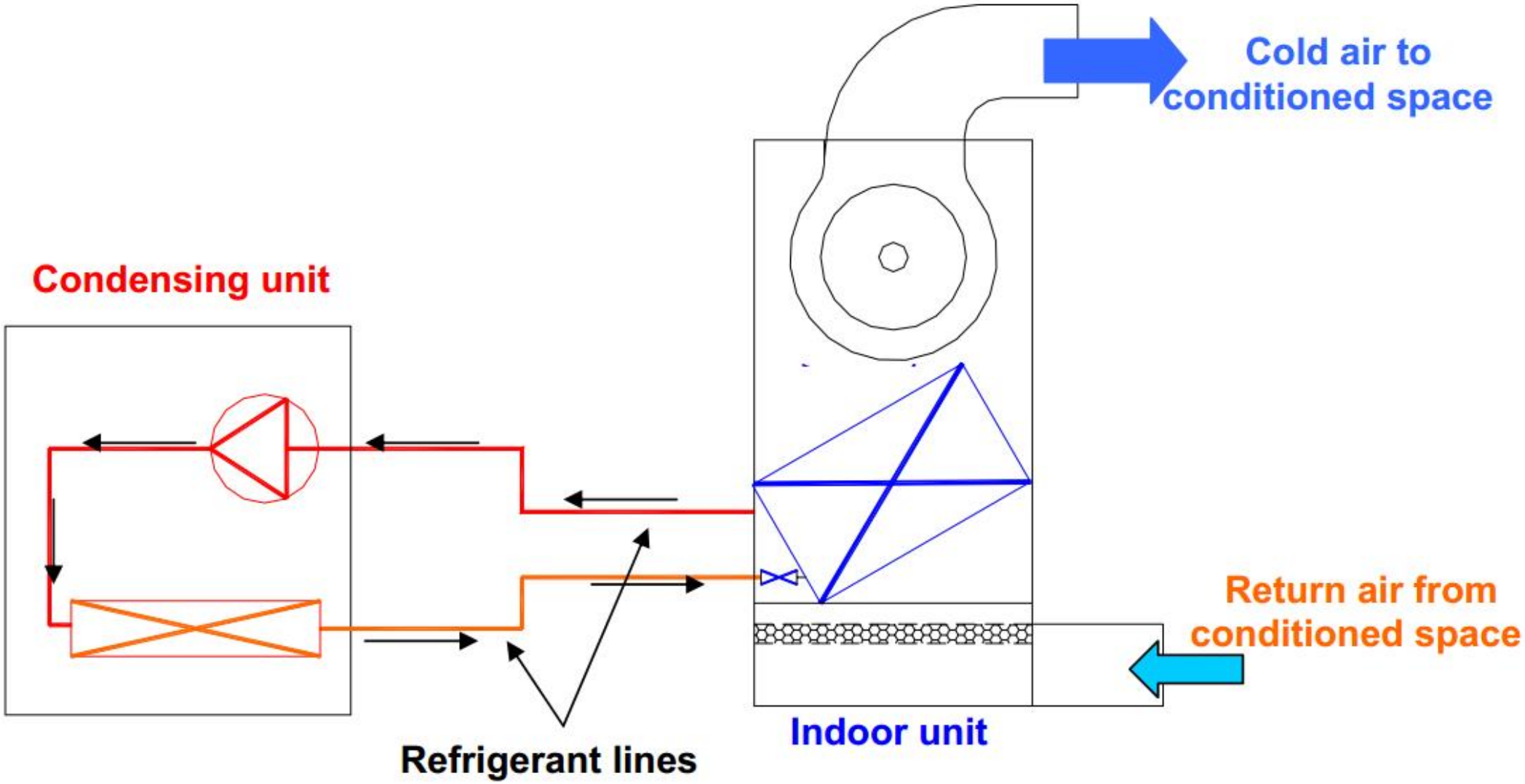
(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

Split type air conditioning system



(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36
http://www.energyland.emsd.gov.hk/en/building/district_cooling_sys/conventional.html)

A typical package unit with remote condensing unit



(Source: Lesson 36 Selection Of Air Conditioning Systems http://nptel.ac.in/courses/112105129/36)

Unitary package systems

- Unitary refrig. based systems – Advantages
  - 1. Individual room control is simple and inexpensive.
  - 2. Each conditioned space has individual air distribution with simple adjustment by the occupants.
  - 3. Performance of the system is guaranteed by the manufacturer.
  - 4. System installation is simple and takes very less time.
  - 5. Operation of the system is simple and there is no need for a trained operator.
  - 6. Initial cost is normally low compared to central systems.
  - 7. Retrofitting is easy as the required floor space is small.

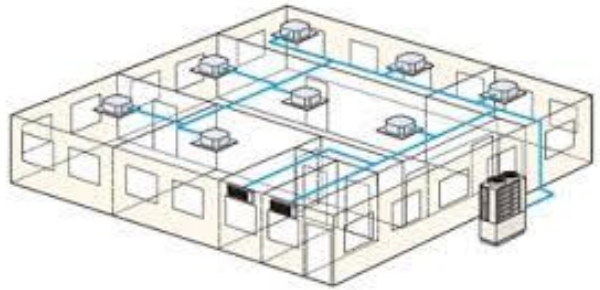
Unitary package systems

- Unitary refrig. based systems – Disadvantages
  - 1. As components are set by the manufacturer, the system is less flexible in terms of air flow rate, condenser and evaporator sizes.
  - 2. Power consumption per ton of refrigeration (TR) could be higher compared to central systems.
  - 3. Close control of space humidity is generally difficult.
  - 4. Noise level in the conditioned space could be higher.
  - 5. Limited ventilation capabilities.
  - 6. Systems are generally designed to meet the appliance standards, rather than the building standards.
  - 7. May not be appealing aesthetically.

Unitary package systems

- Unitary refrig. based systems – Disadvantages (cont'd)
  - 8. The space temperature may experience a swing if on-off control is used as in room air conditioners.
  - 9. Limited options for controlling room air distribution.
  - 10. Equipment life is relatively short.
- Applications of unitary refrigerant based systems
  - These systems are used where stringent control of conditioned space temperature and humidity is not required and where the initial cost should be low with a small lead time

VRF systems



- Variable refrigerant flow (VRF) systems
  - Direct expansion (DX), similar to multi-split systems; widely used in Japan and Europe
  - Able to control the amount of refrigerant flowing to the multiple evaporators (indoor units), enabling the use of many evaporators of differing capacities and configurations connected to a single condensing (outdoor) unit
  - Provides an individualized comfort control, and simultaneous heating & cooling in different zones

(Video: Variable Refrigerant Flow System - VRF System (5:21) http://www.youtube.com/watch?v=Ujv3k59XISo)

Variable refrigerant flow (VRF) global history

- VRF world first's

1982 — VRF is launched globally

1987 — World's first VRF system is developed

1990 — First globally available heat recovery VRF

1991 — Worlds inverter driven VRF

1998 — Worlds first R410A VRF

2003 — World's first R407C VRF system is developed

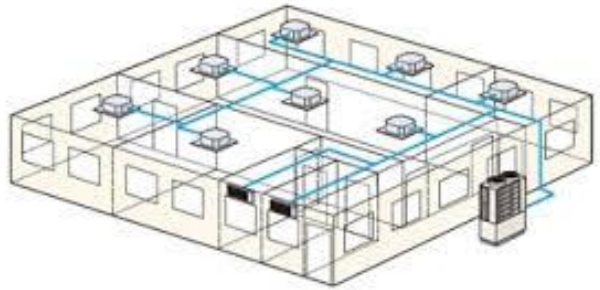
2005 — Industry changing piping and defrost technology

2007 — First water cooled VRF system is launch in the USA

2008 — World's first CO 2 VRF system is developed

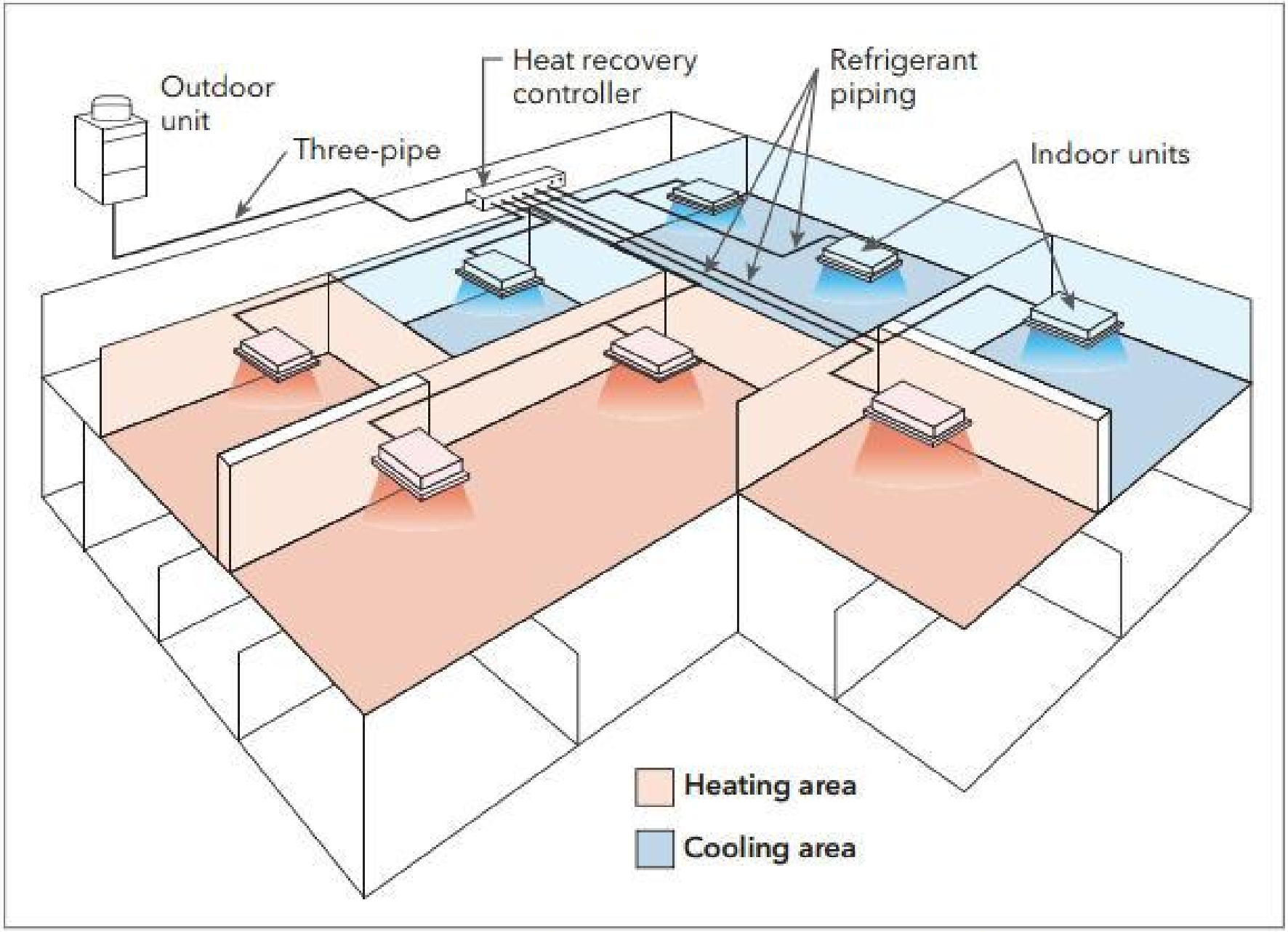
(Source: ASHRAE NM Chapter)

VRF systems



- Three basic types of VRF systems:
  - 1. Cooling only
  - 2. Heat pump
  - 3. Heat recovery (simultaneous heating+cooling)
- Major components
  - Outdoor unit (variable speed fan, inverter-driven compressor)
  - Refrigerant piping
  - Indoor unit (multi-speed fan, electronic expansion valve)
  - System communications network

Variable refrigerant flow (VRF) system

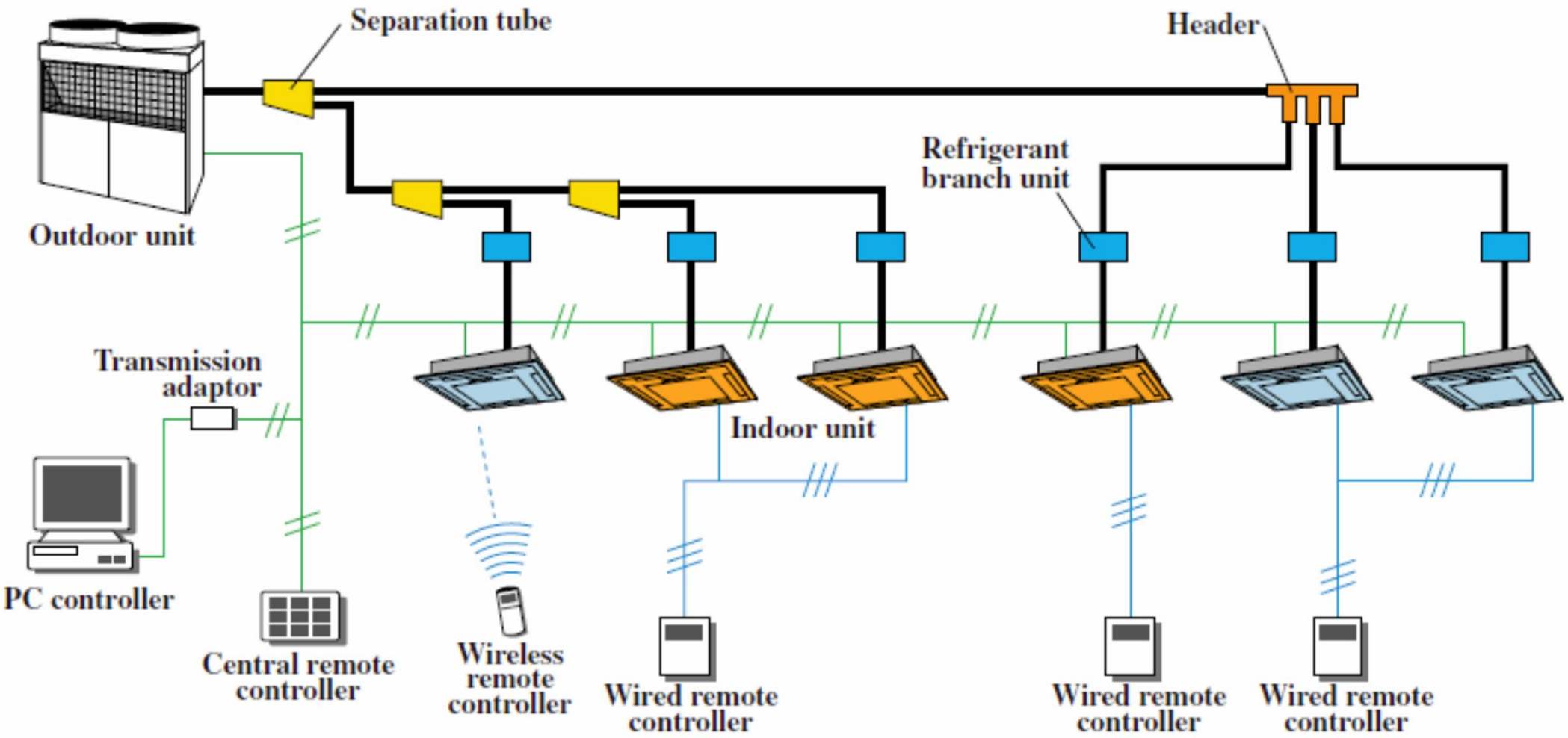


Variable refrigerant flow systems can deliver cooling to some zones and heating to others, with no reheat needed (an air-source system is shown here).

(Source: Variable refrigerant flow (VRF) http://www.seventhwave.org/new-technologies/variable-refrigerant-flow-vrf)

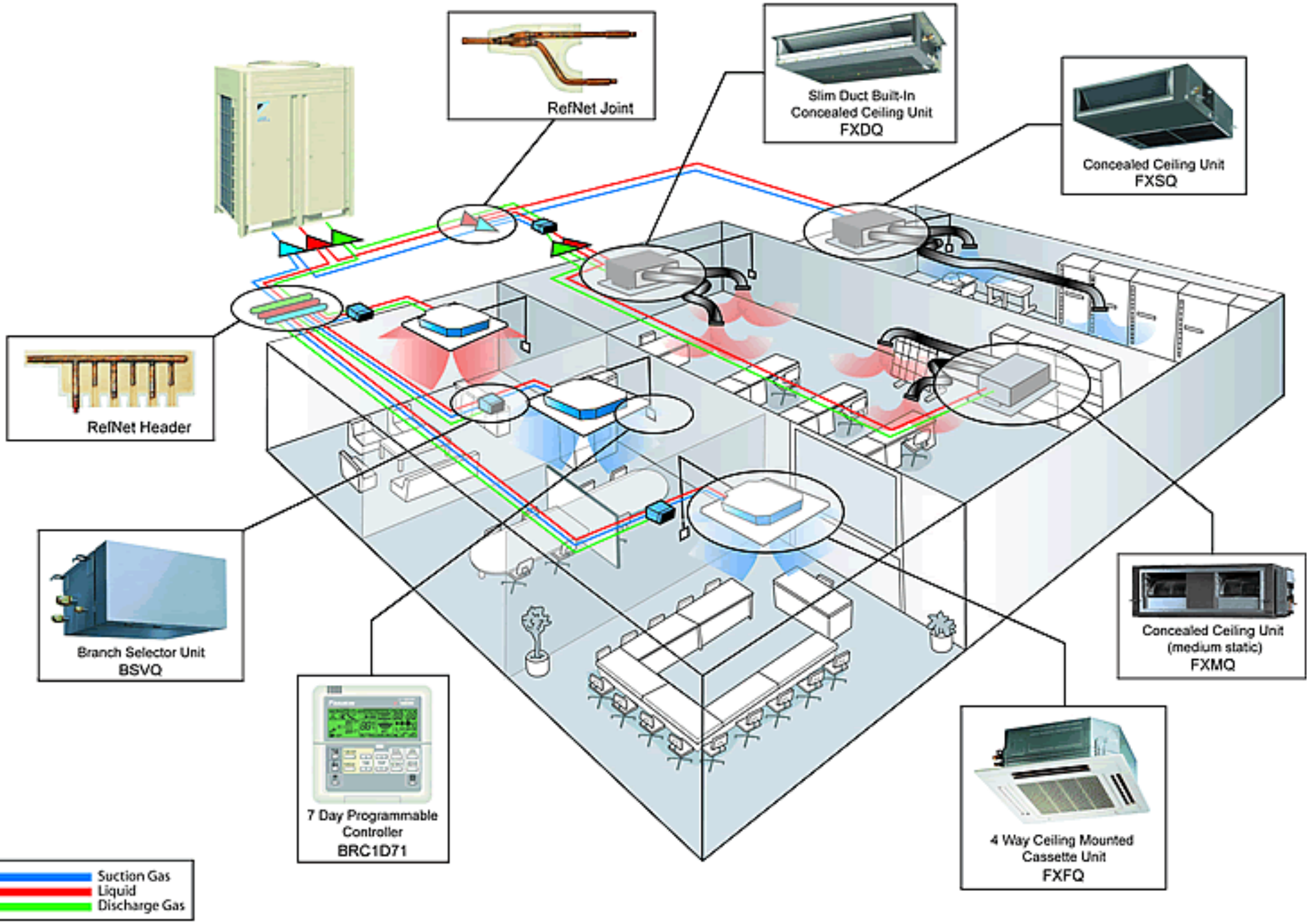
Variable refrigerant flow (VRF) system

An engineered direct expansion (DX) multi-split system incorporating at least one variable capacity compressor distributing refrigerant through a piping network to multiple indoor fan coil units each capable of individual zone temperature control, through a zone temperature control devices and common communications network.



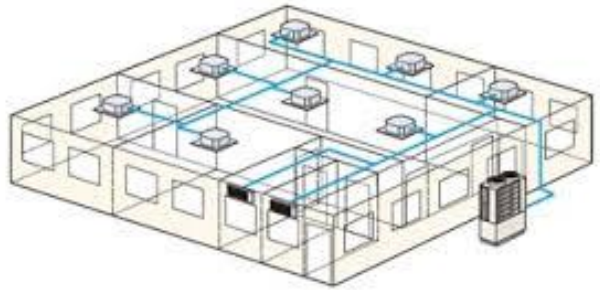
(Source: Fujitsu) (See also: http://en.wikipedia.org/wiki/Variable_refrigerant_flow)

Components of variable refrigerant flow (VRF) systems



(Source: Daikin)

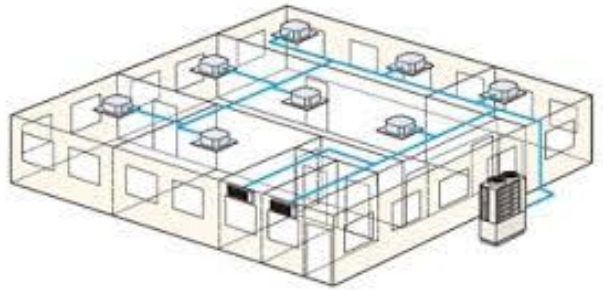
VRF systems



- Energy performance of VRF systems
  - Linear step control in conjunction with inverter and constant speed compressor combination
    - Adjust compressor speed to its optimal energy usage
  - Allows more precise control of the necessary refrigerant circulation amount required according to the system load (smooth capacity control)
    - High part-load and seasonal efficiency
  - Minimizes or eliminates ductwork completely
    - Reduce duct losses and fan energy

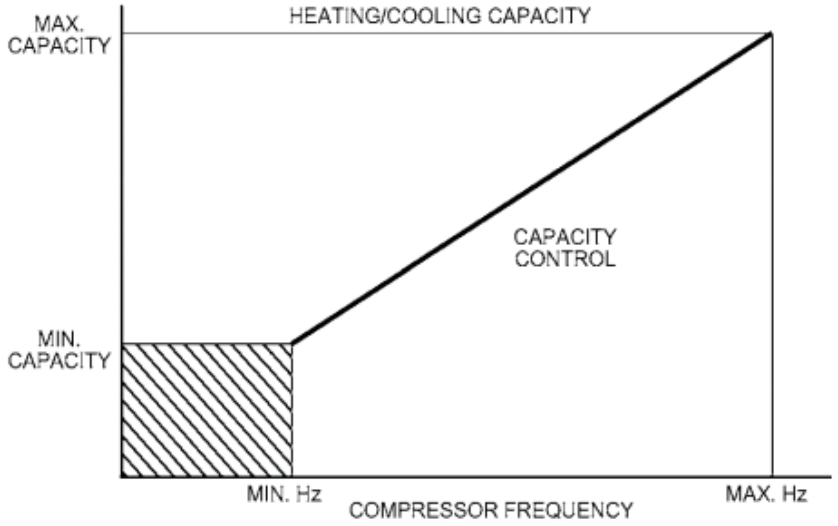
(*See also: Variable Refrigerant Flow (US GSA) http://www.gsa.gov/portal/content/163491)

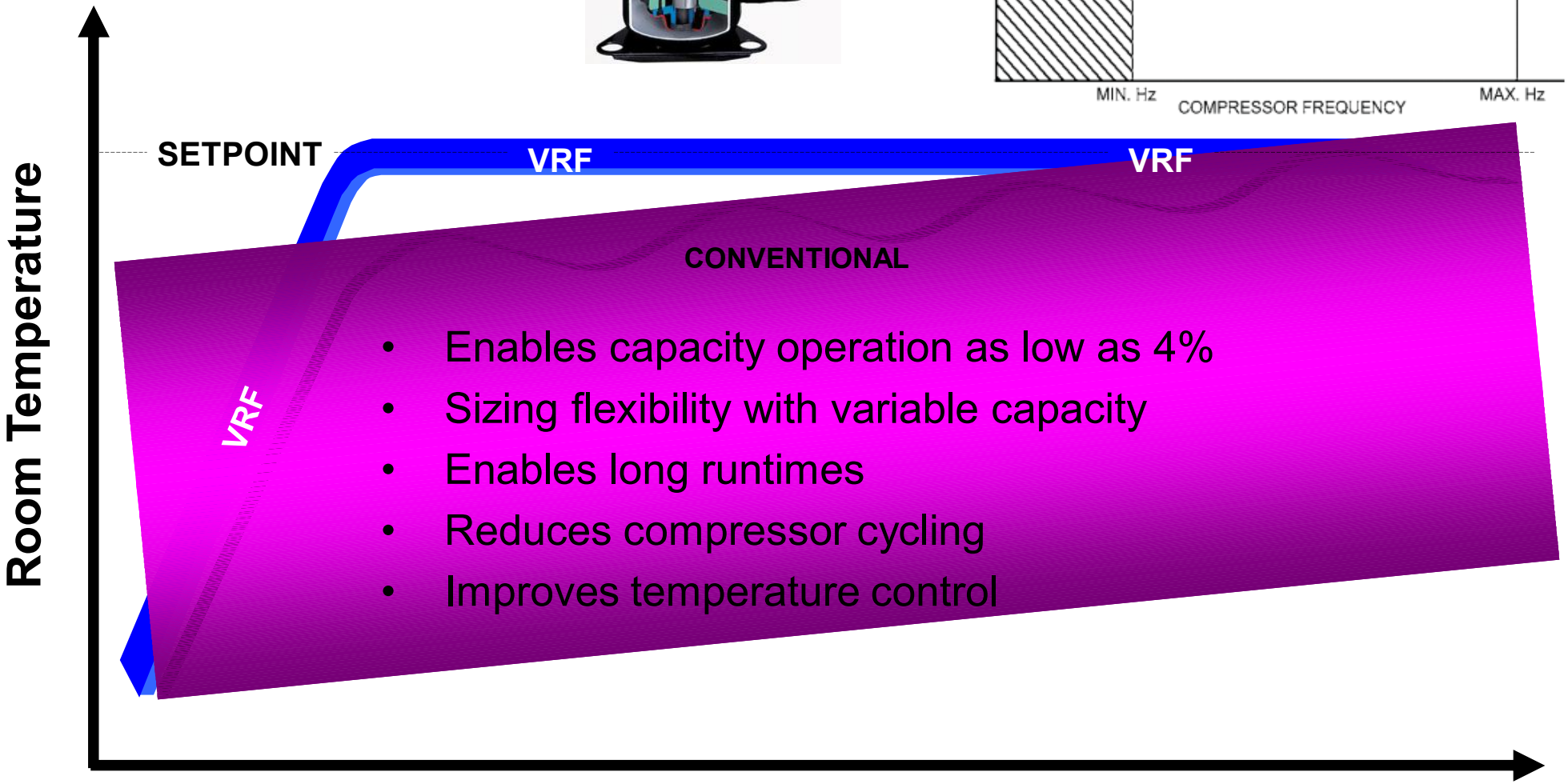
VRF systems



- Other benefits of VRF systems
  - Can bring rooms to desired temperature quickly and keep temperature fluctuations to minimum
  - Modular design and zoning flexibility
  - With heat recovery from one zone to another
  - Energy sub-metering is relatively simple
  - Commissioning/maintenance are not complicated
- Limitations of VRF:
  - Piping distance, oil management, fresh air intake

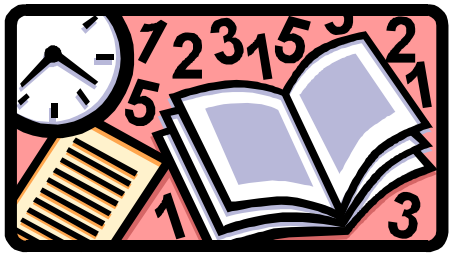
Inverter-driven compressor control in VRF systems



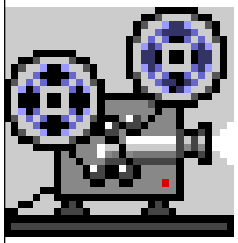


(Source: Mitsubishi)

Further Reading

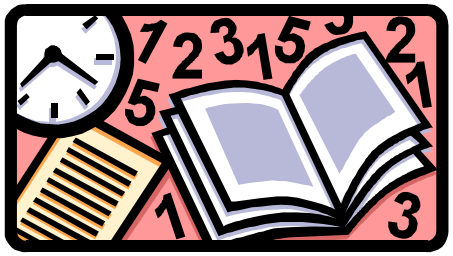


- Videos:



  - 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 6 - Unitary System (0:39) http://youtu.be/B6U2pginbH4
  - Air Conditioning 8 - Air Conditioning Design (1:32) http://youtu.be/do6TnHuZn5A
  - HKHA優質工序系列 - Chapter 30 - 空調系統 - 30.1 空調系統功能 (4:04) http://www.youtube.com/watch?v=uf57Iy0agMw

Further Reading



- Brief Notes on Air Conditioning System Design
  - http://ibse.hk/SPD5132/design-hvac.pdf
- Lesson 36 Selection Of Air Conditioning Systems
  - http://nptel.ac.in/courses/112105129/36

- Useful reference on VRF systems:
  - 2016 ASHRAE Handbook HVAC Systems and Equipment, Chapter 18. Variable Refrigerant Flow
  - (* Available in E-Database: Construction Information Service (CIS))