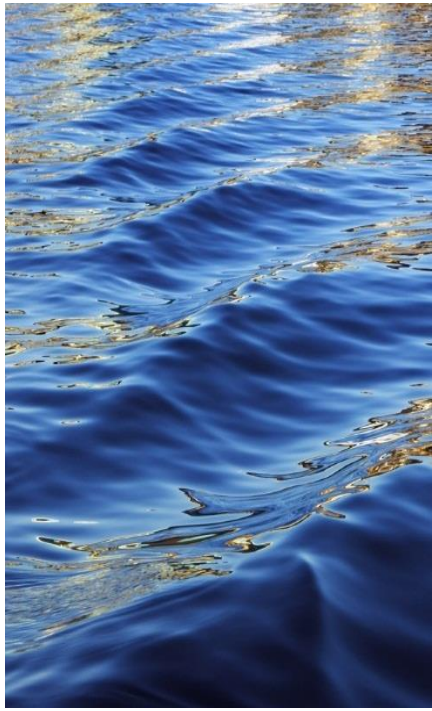
Environmental Thermal Engineering

Lecture Note #11

Professor Min Soo KIM



Introduction

HVAC - Heating

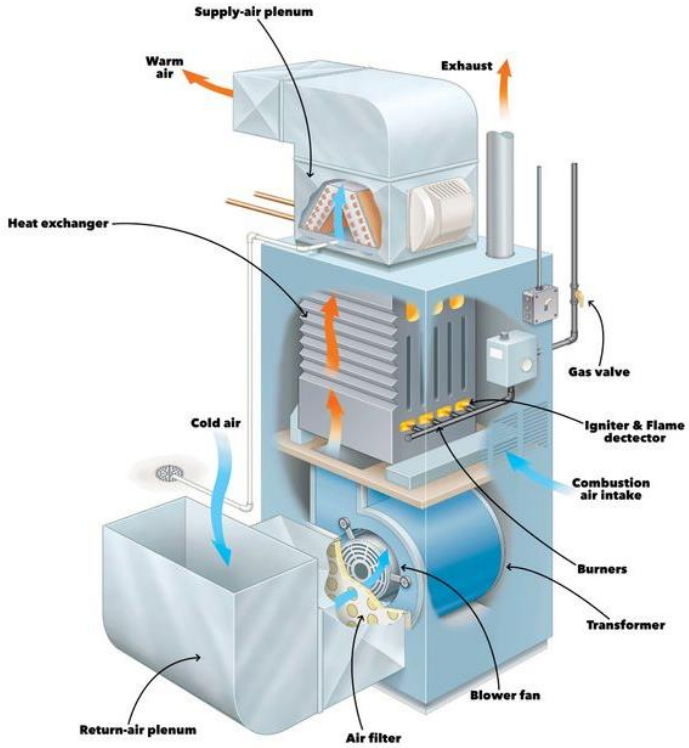
- **Heating - Transfer of energy to a space or to the air in a space**
  - Direct Radiation
  - Free Convection
  - Direct Heating

- **Rate of sensible heat transfer**

$$\dot{q}_s = \dot{m} c_p (t_e - t_i) = \frac{\dot{Q} c_p}{\nu} (t_e - t_i)$$

$\dot{q}_s$: rate of sensible heat transfer [W]
$\dot{m}$: mass rate of air flow [kg/s]
c_p : const. pressure specific heat of air [J/kgK]

$\dot{Q}$: volume flow rate of air flow [m^3/s]
ν : specific volume of air [m^3/kg]
t_e : temperature of air at exit [K]
t_i : temperature of air at inlet [K]



https://www.familyhandyman.com

FIGURE Gas Furnace

HVAC - Ventilation

- **Ventilation : Changing or replacing air in any place to**
  - Control temperature, moisture
  - Remove odors, smoke, dust, airborne bacteria (Inc. COVID-19)
  - Replenish oxygen and remove carbon dioxide

- **Common contaminants**
  - Gases : CO_2, CO, SO_2, NO_2
  - Volatile Organic Compounds
  - Particulate Matter

- **Methods for Ventilation**
  - Mechanical / Forced
  - Natural / Passive

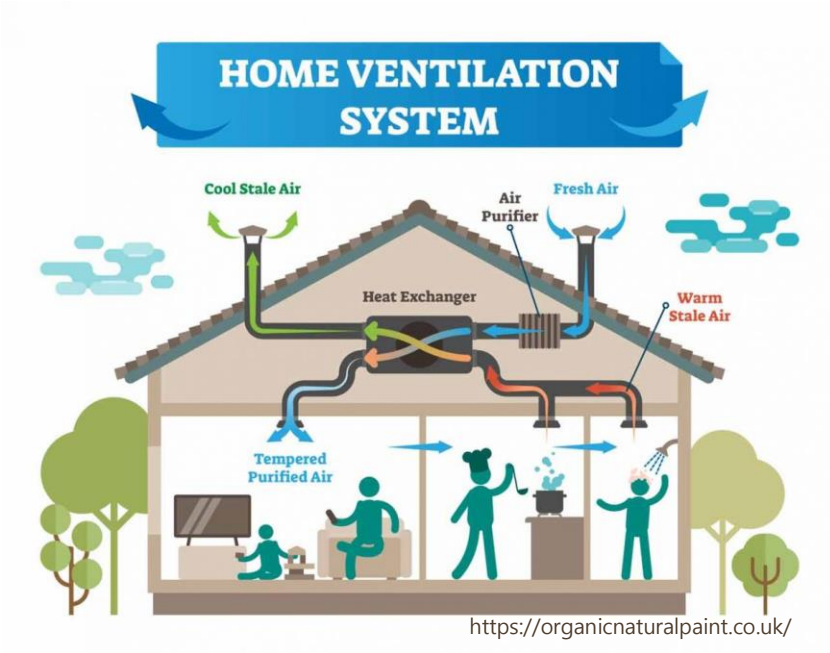


FIGURE Home Ventilation System

HVAC - Air Conditioning

❑ **Air Conditioning : Provides cooling and/or humidity control**

- Refrigeration Cycle
- Free cooling
- Packaged vis-à-vis split system
- Dehumidification
- Humidification

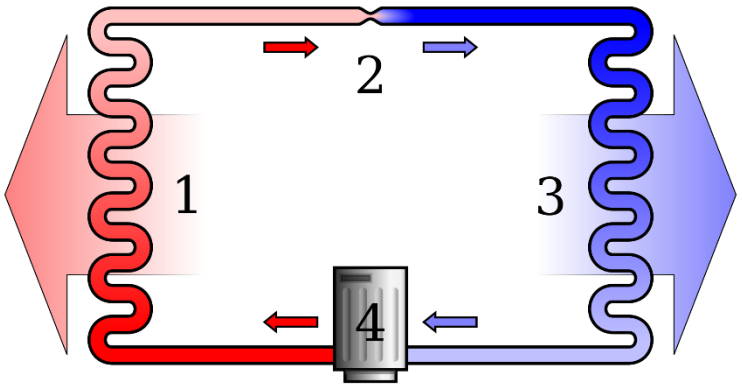


FIGURE Refrigeration cycle

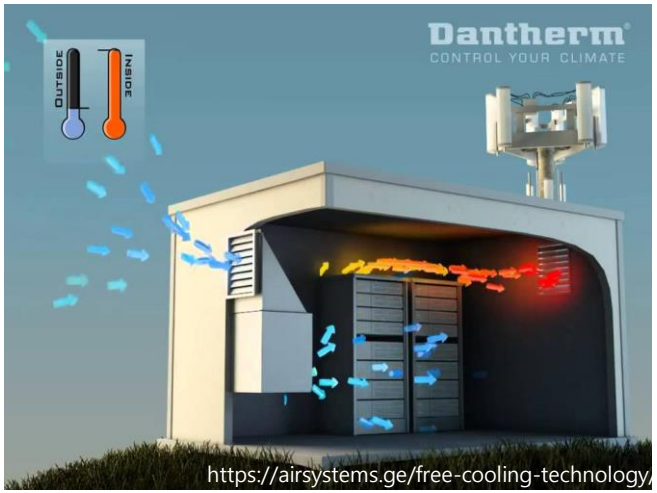


FIGURE Free Cooling

Air-Conditioning and Heating Systems

HVAC Systems - Selection

- **System Constraints**

  Cooling load, zoning requirements, heating and ventilation

- **Architectural Constraints**

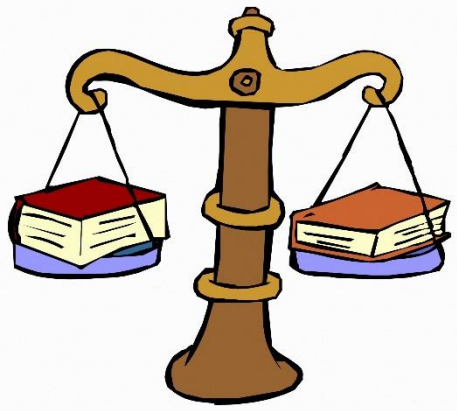
  Spatial requirements, local climate, acoustics and vibration

- **Financial Constraints**

  Capital cost, operating cost, maintenance cost

- **Other Constraints**

  Environmental health and safety design
  (Mold and mildew prevention), serviceability



HVAC Systems - Selection

Criteria	Central system	Decentralized system
Redundancy	• Standby equipment is accommodated for troubleshooting and maintenance	• No backup or standby equipment
Special requirements	• An equipment room is located outside the conditioned area, or adjacent to or remote from the building	• Possible of no equipment room • Equipment may be located on the roof and the adjacent ground
First cost	• High capital cost	• Affordable capital cost
Operating cost	• More significant energy efficient primary equipment • A proposed operating system which saves operating cost	• Less energy efficient primary equipme nt • Various energy peaks due to occupants' preference • Higher operating cost
Maintenance cost	• Accessible to the equipment room for maintenance and saving equipment in excellent condition.	• Accessible to equipment to be located in the basement or the living space.
Reliability	• Long service life	• Service life may be less

https://www.intechopen.com/

All Air Systems

- **An all-air system provides the conditioned space with;**
  - Sensible heating and humidification
  - Sensible and latent cooling

- **All-air systems can be classified into 2 categories;**
  - Single duct system
  - Dual duct system

  or

  - Constant air volume system
  - Variable air volume (VAV) system

All Air Systems

❑ Advantages

- Maintenance is performed in unoccupied areas (centrally located).
- No drain piping or power wiring or compressors in occupied areas.
- Systems can include options such as;
- Air-side economizer, heat recovery, winter humidification
- Simple seasonal changeover
- Simultaneous cooling and heating in various zones.

❑ Disadvantages

- Additional duct space is required.
- Air-balancing may be difficult in large systems.
- Close coordination is needed between designers and installers to assure good accessibility to terminal units.

All Air Systems

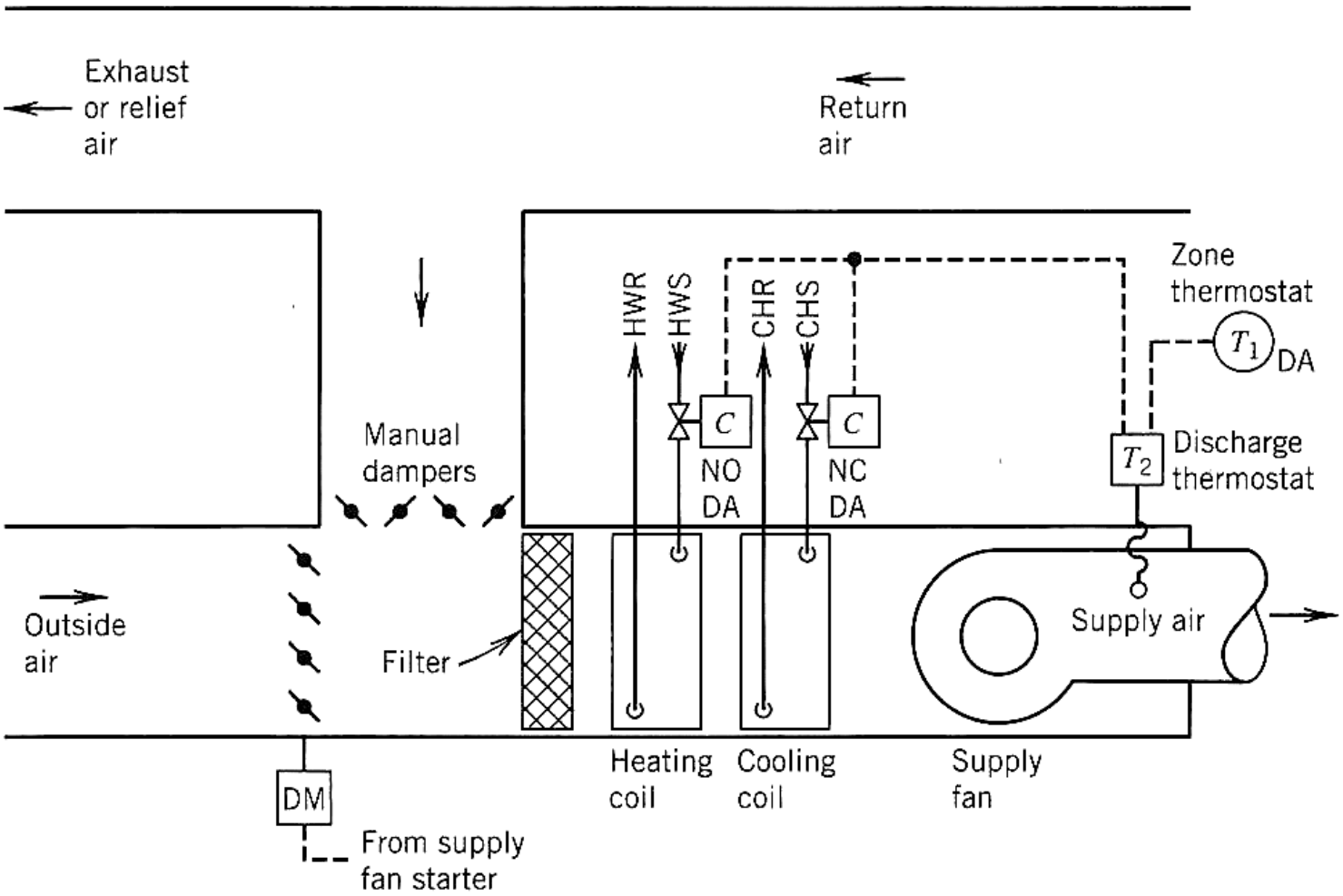
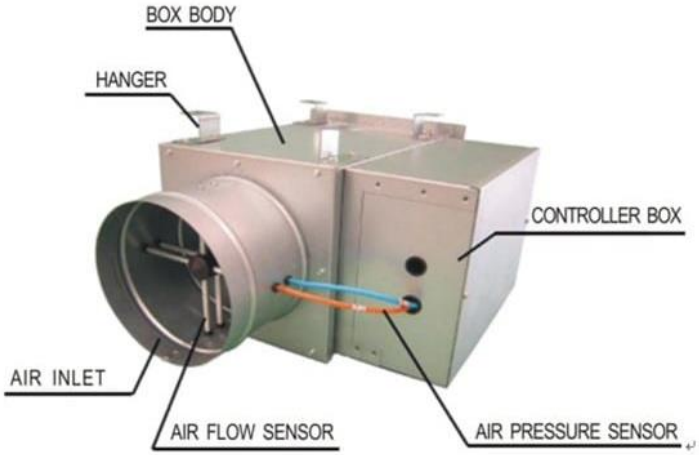


FIGURE All-Air System (Single duct)

All Air Systems

❑ Variable air volume (VAV) system

- Keep the air temperature constant by vary the air supply volume.
- Easy to control, energy efficient and fairly good room control.
- Poor ventilation under low load conditions
- Difficult humidity control under widely varying latent loads



https://wginc.com

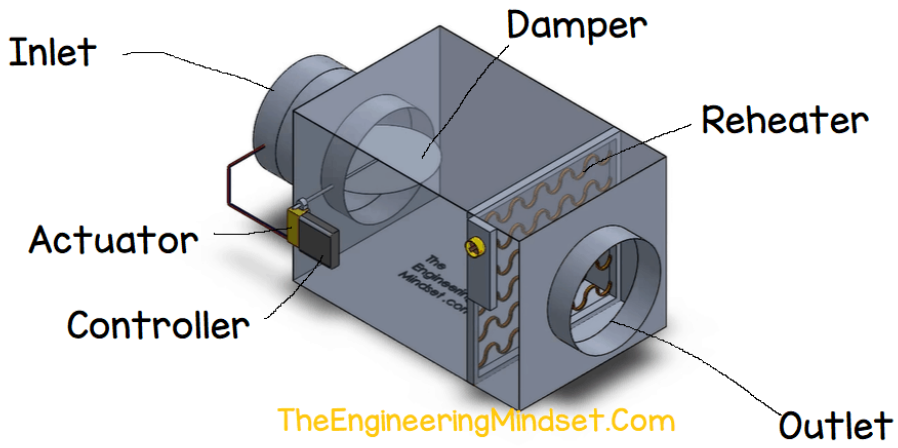


FIGURE Variable air volume box

All Air Systems

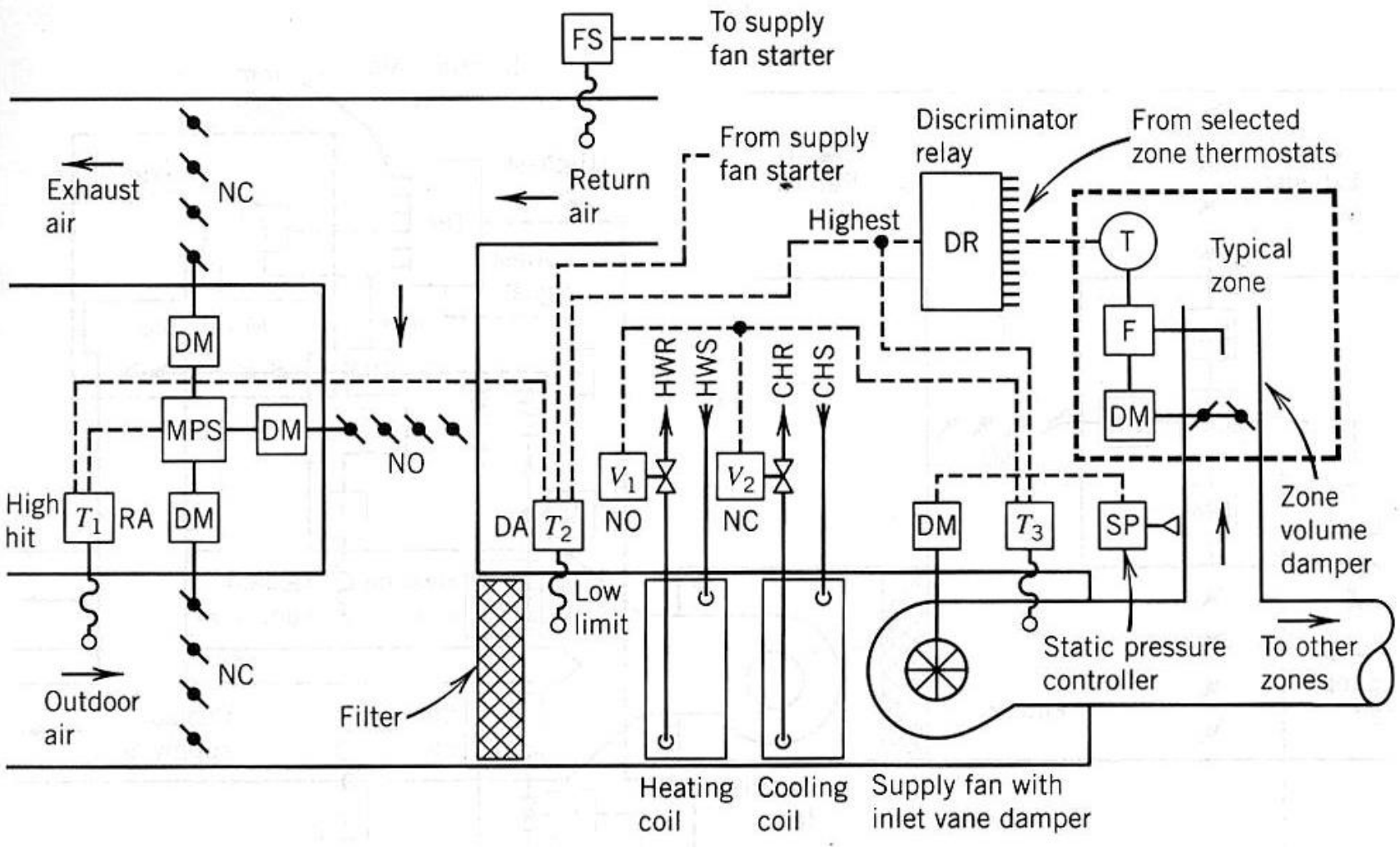


FIGURE Variable air volume (VAV) system

All Air Systems

❑ Dual duct system

employs two air ducts to supply cold air and warm air to a mixing terminal unit which proportions the cold and warm air in response to a thermostat located in the conditioned space

FIGURE Dual duct

- Systems with terminal volume regulation are self-balancing.
- Zoning of central equipment is not required.
- Instant temperature response
- No seasonal changeover is needed
- Higher initial cost
- Does not operate as economically as other systems.

All Air Systems

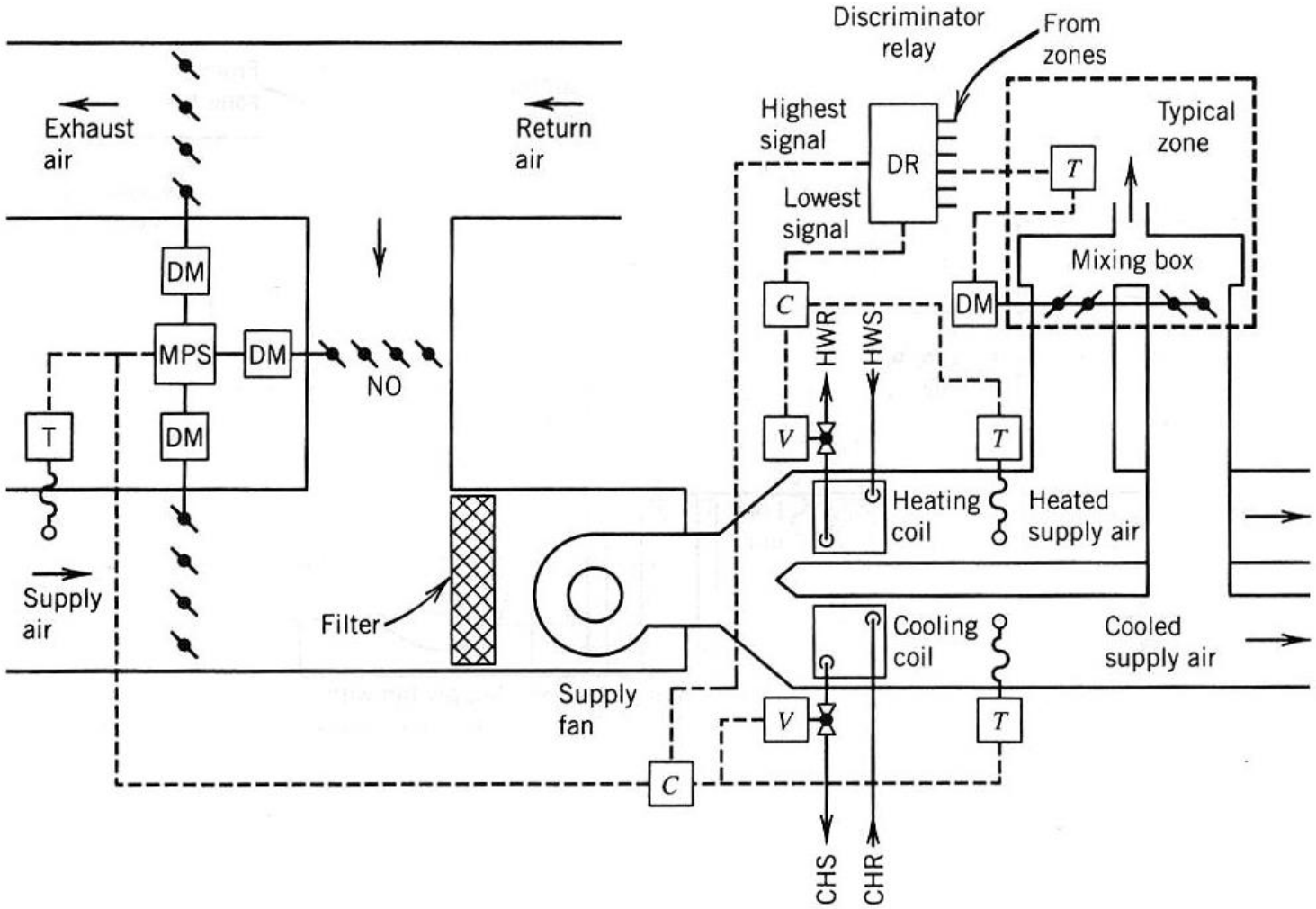


FIGURE Dual duct system

All Air Systems

❑ Reheat system

Reheat system heats the supply air whenever the cooling load is below the maximum.
This is applied where spaces have wide load variations, high latent loads, or where close control of both temperature and humidity is required.

- High operating cost
- Energy inefficient

All Air Systems

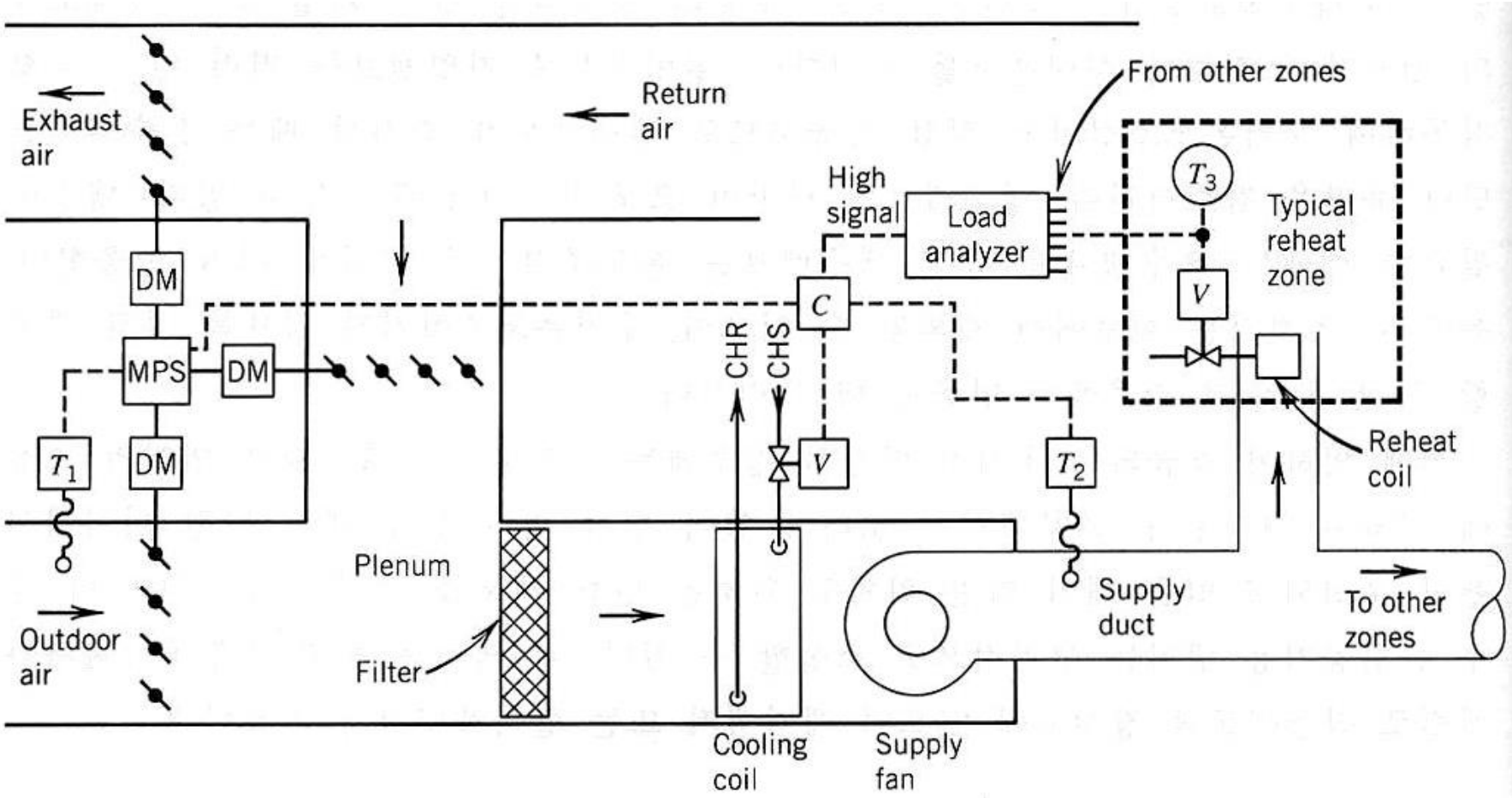


FIGURE Reheat system

All Air Systems

❑ Multizone System (central)

The multi-zone system applies to a relatively small number of zones served by a single, central air-handling unit. Different zone requirements are met by mixing cold and warm air through zone dampers at the central air handler in response to zone thermostats

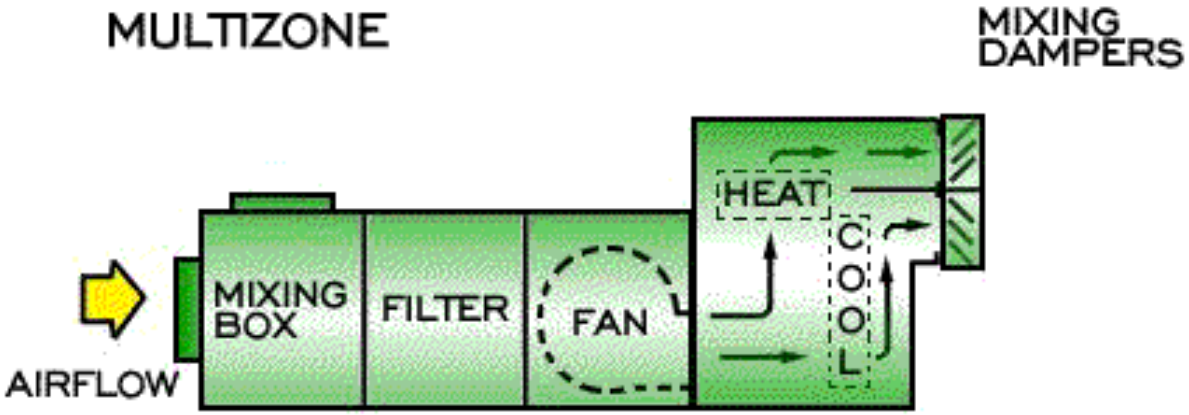


FIGURE Multizone System

All Air Systems

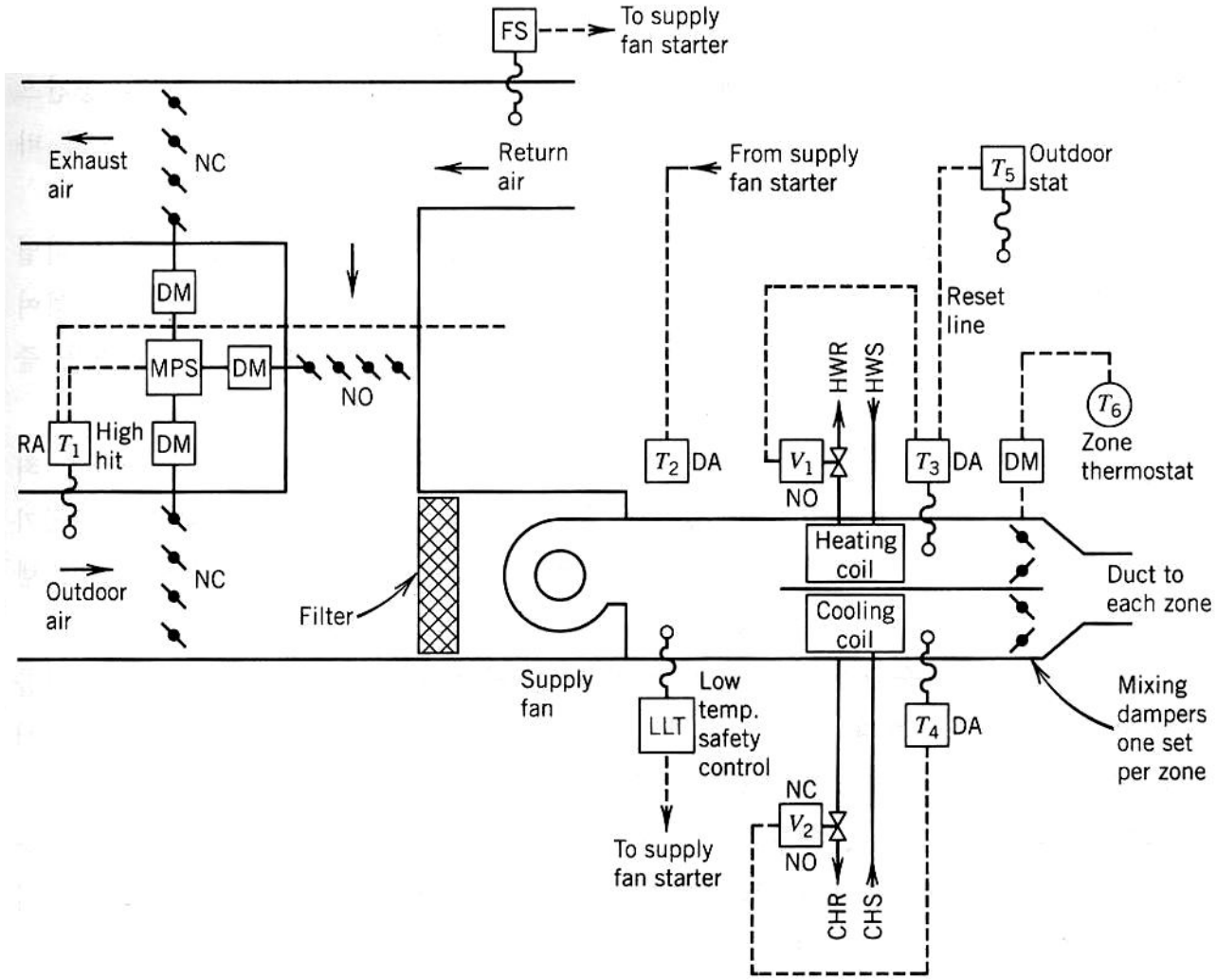


FIGURE Multizone System

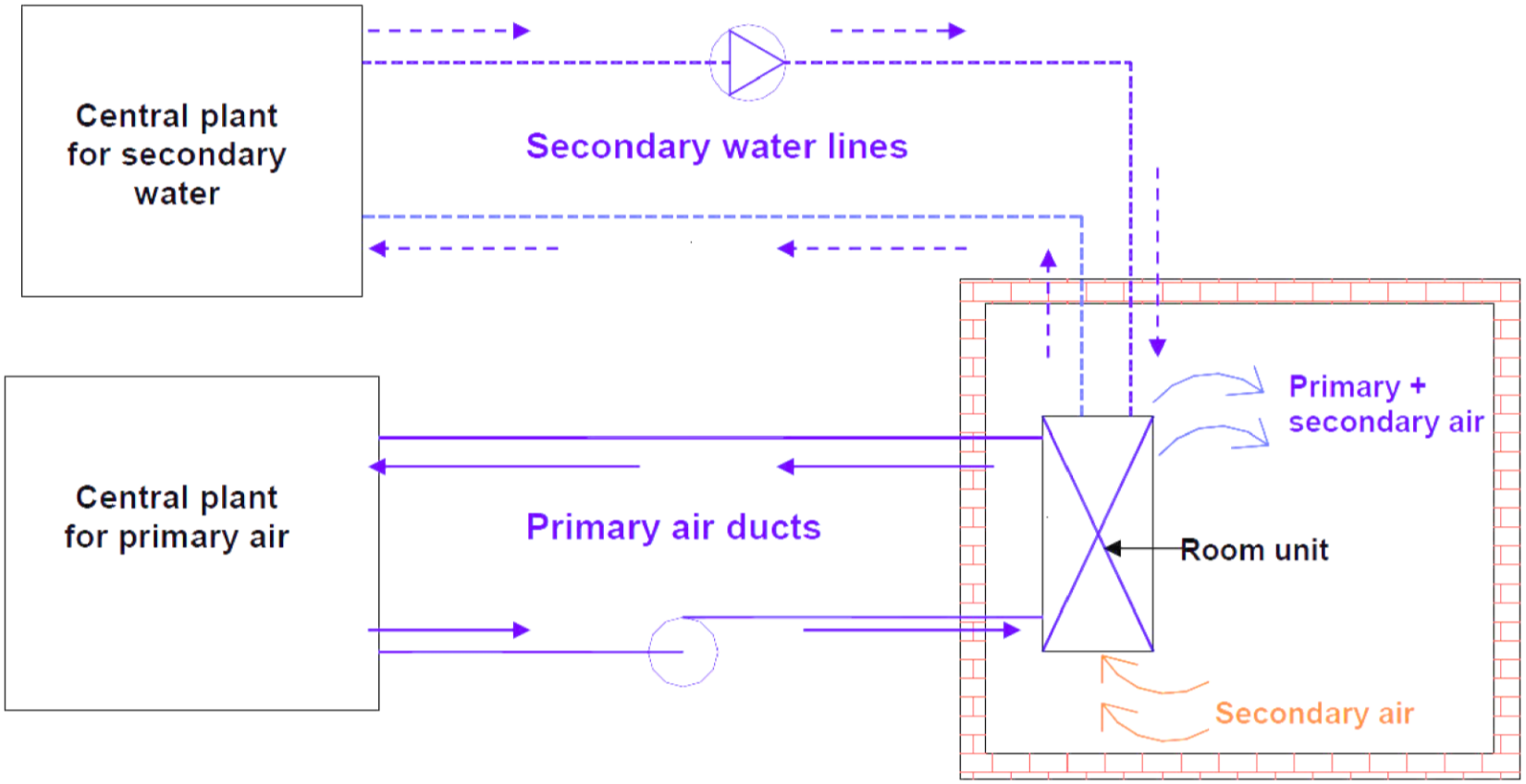
Air and Water Central Systems

❑ Air-water Central System

These systems distribute both air and hot/cold water to terminal units in the conditioned spaces. The air and water is cooled and heated in a central mechanical room.

- The use of water greatly reduces the size of the air ducts.
- The air-handling system is also much smaller.
- Provides positive ventilation
- All zones can be individually controlled.
- Zone cooling and heating needs are satisfied independently.
- High operating cost
- Design for the intermediate season operation is critical
- Changeover is complicated and requires trained operators
- Controls are more complicated than for all-air systems
- Terminal units require frequent in-space maintenance
- Humidity cannot be tightly controlled.

Air and Water Central Systems



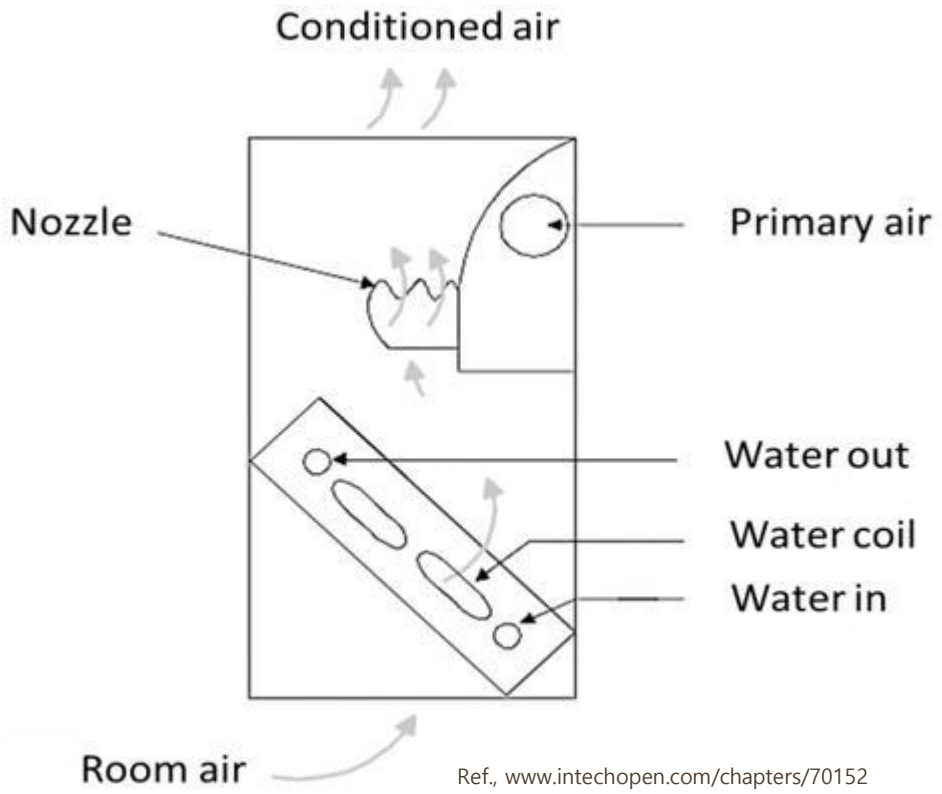
Ref., www.learnpick.in/prime/documents/ppts/details/1209/all-air-systems-all-water-systems-air-water-systems-direct-refrigerant-systems

Air and Water Central Systems

❑ **The room terminals**

- Induction unit
- Room fan-coil units

  : usually used
- Radiant panels



Ref., www.intechopen.com/chapters/70152

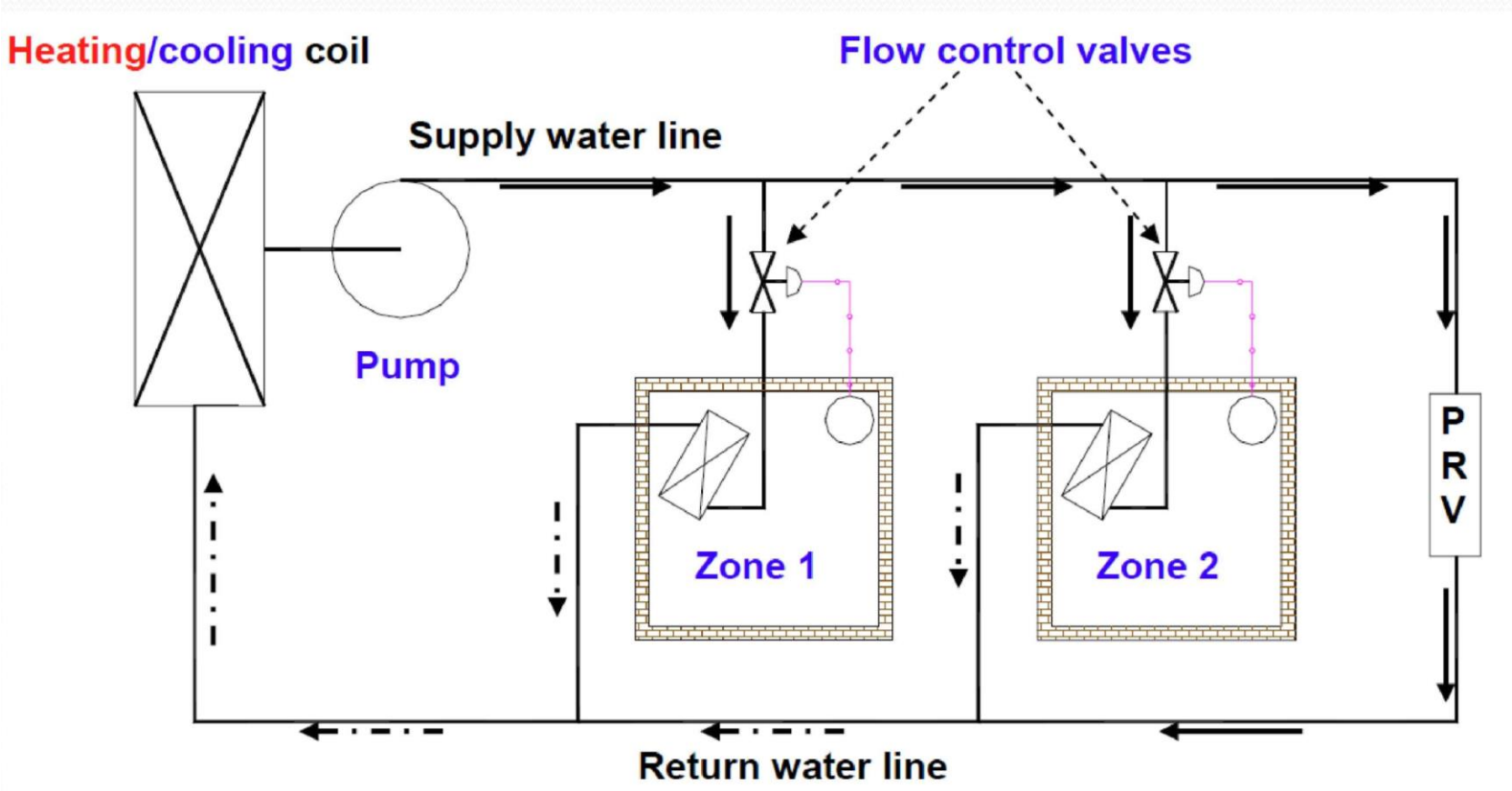
All Water Central Systems

❑ All Water Central System

The space cooling is performed by chilled water circulated from a central plant to air handling or terminal units. Heating water is supplied through the same or a separate piping system.

- Water is a more energy and space efficient method.
- Recirculation of air is unnecessary.
- First cost is often less than for other central systems
- Individual zone temperature control
- Some maintenance must be performed in occupied areas.
- No humidification is provided.
- Seasonal change over is required
- No positive ventilation is provided unless wall openings are used

All Water Central Systems

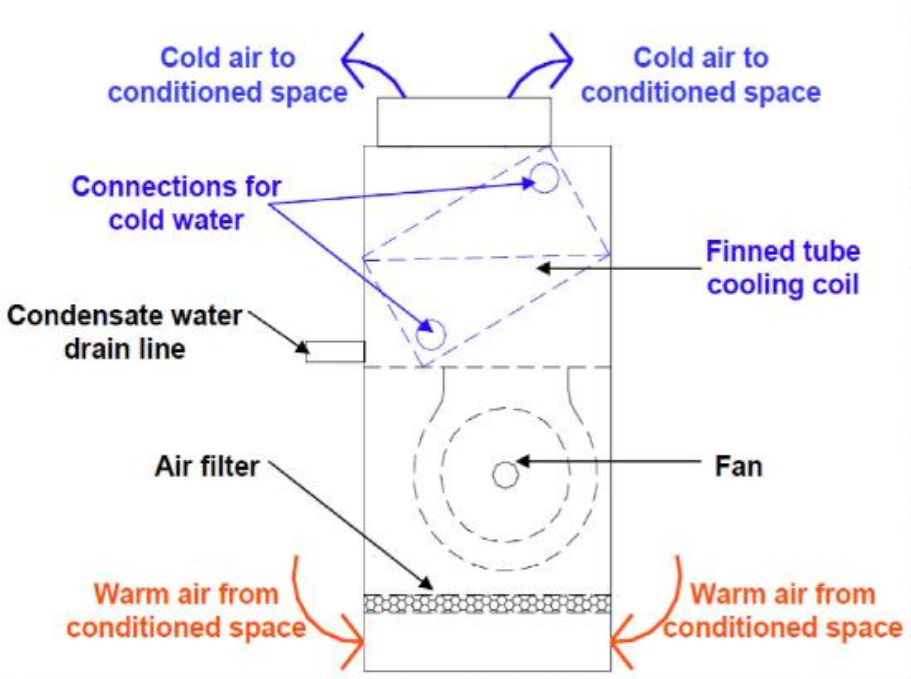


Ref., www.learnpick.in/prime/documents/ppts/details/1209/all-air-systems-all-water-systems-air-water-systems-direct-refrigerant-systems

All Water Central Systems

❑ The Room Terminals

- Fan-coil unit
- Consists of finned tube coil, filter, and fan section
- Fan recirculates air continuously



Ref., www.learnpick.in/prime/documents/ppts/details/1209/all-air-systems-all-water-systems-air-water-systems-direct-refrigerant-systems

HVAC Applications

Comfort Applications

- Residences
- Retail Facilities
- Commercial and public Buildings
- Places of Assembly
- Domiciliary Facility
- Educational Facilities
- Health Care Facilities
- Surface Transportation
- Aircraft
- Ships

Industrial Applications

- Industrial Air Conditioning
- Enclosed Vehicular Facilities
- Laboratory Systems
- Engine Test Facilities
- Clean Spaces
- Data Processing System Areas
- Printing Plants
- Textile Processing
- Photographic Materials
- Environmental Control for Animals and Plants
- Drying and Storing Farm Crops
- Air Conditioning of Wood and Paper Products Facilities
- Nuclear Facilities
- Ventilation of the Industrial Environment
- Mine Air Conditioning and Ventilation
- Industrial Exhaust Systems

Residences

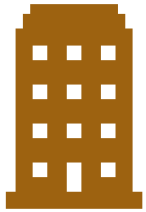
❑ Single-Family Residences

- Heating
  - Heat Pumps
  - Furnaces
  - Hydronic Heating Systems (Boilers)
- Air Conditioners
  - Unitary Air Conditioners
  - Evaporative Coolers
- Humidifiers
- Air Filters

❑ Multifamily Residences

- Central Forced-air Systems
- Hydronic Central Systems
- Through-the-wall units
- Water-Loop Heat Pump Systems

vs.

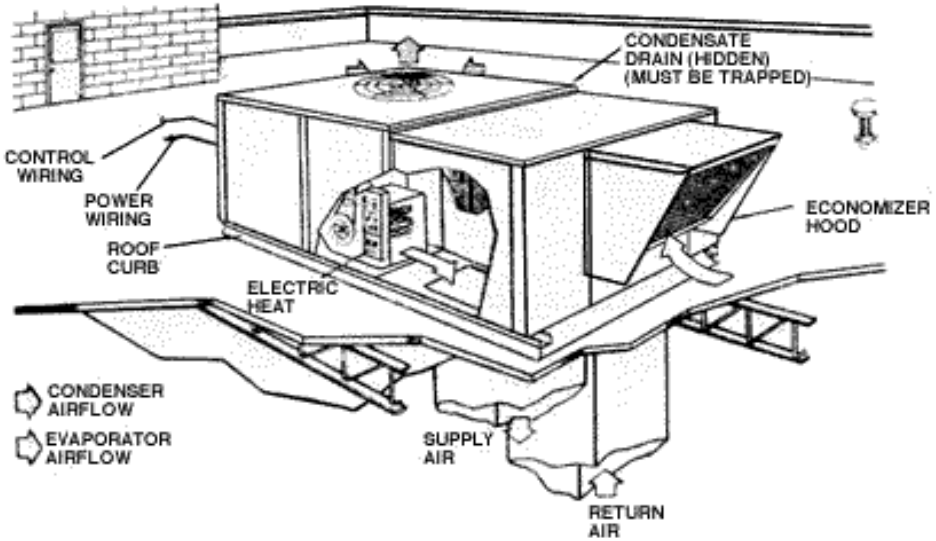


Residential Heating & Cooling Systems

	Forced Air	Hydronic	Zonal
Most Common Energy Sources	Gas Oil Electricity Resistance Heat Pump	Gas Oil Electricity Resistance Heat Pump	Gas Electricity Resistance Heat Pump
Heat Distribution Medium	Air	Water Steam	Air Water Refrigerant
Heat Distribution System	Ducting	Piping	Ducting Piping or None
Terminal Devices	Diffusers Registers Grilles	Radiators Radiant panels Fan-coil units	Included with product

Retail Facilities

- Even small stores often have large frontal glass areas which could result in high peak solar effects. High heat loss can also occur on cold, cloudy days.



ROOFTOP HEATING/COOLING

- Single-package rooftop units are most commonly used on 1 and 2 story buildings for heating and cooling service.

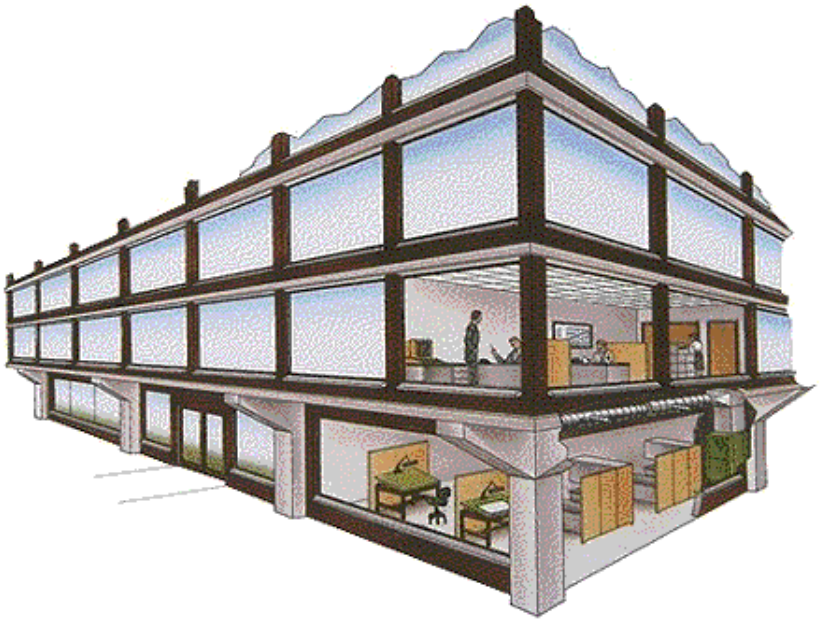
Retail Facilities

❑ Duct System

- Duct velocities should be kept low (800 to 1,200 fpm) to minimize any noise. Lights, displays and other ceiling-suspended obstacles require attention as they can interfere with air distribution
- An ample outside air intake duct should also be provided and dampers installed for proper air balance and ventilation

Office Buildings

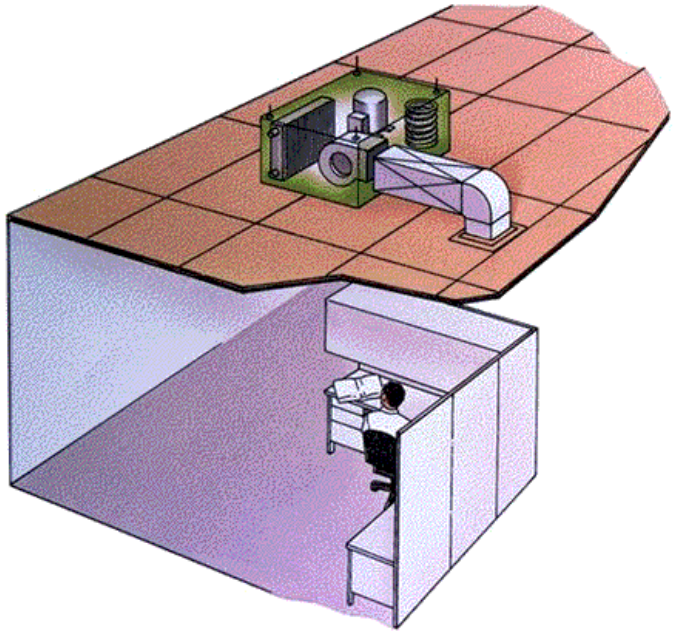
- Weather, occupancy, lighting, and floor loads (computers, printers, copiers, and other office machinery) are the big energy users.
- Building shape, design, and orientation can also have a major effect on energy use.

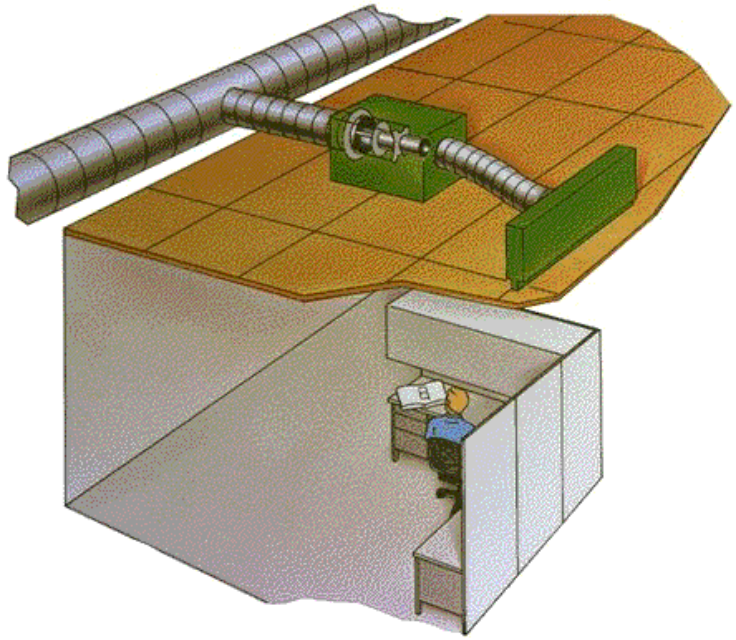


Office Buildings

❑ Systems

- Rooftop cooling unit
- Heat pumps
- Separate VAV unit
- Central condenser water loop, etc…

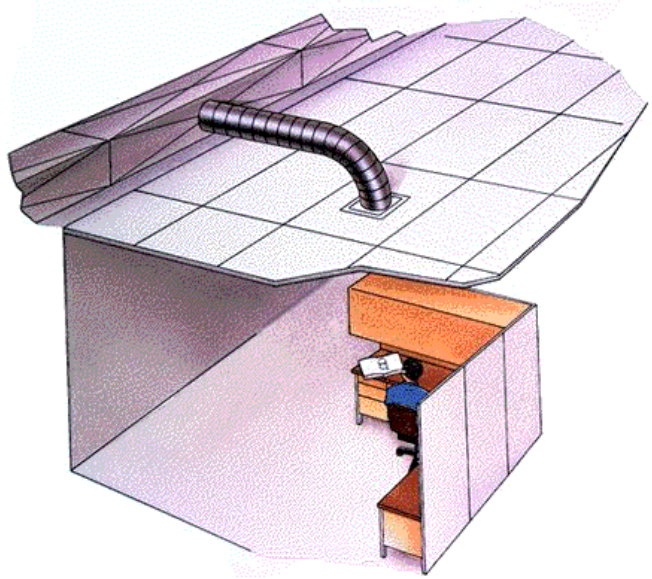




Office Buildings

❑ Ducts

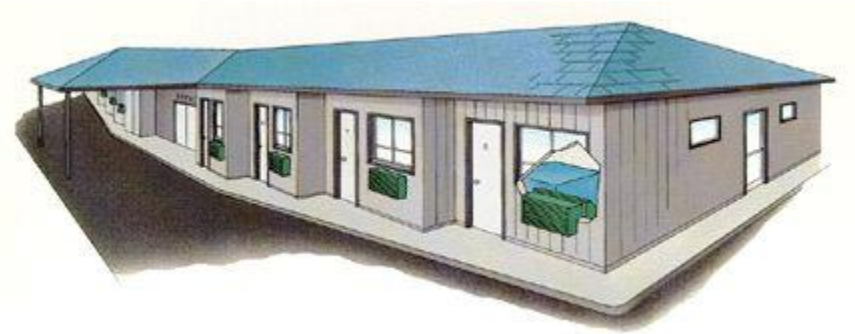
- The outdoor air quantities are needed for suitable indoor air quality.
- However, a constant minimum volume of ventilation air is needed for VAV units depending upon occupant requirements.

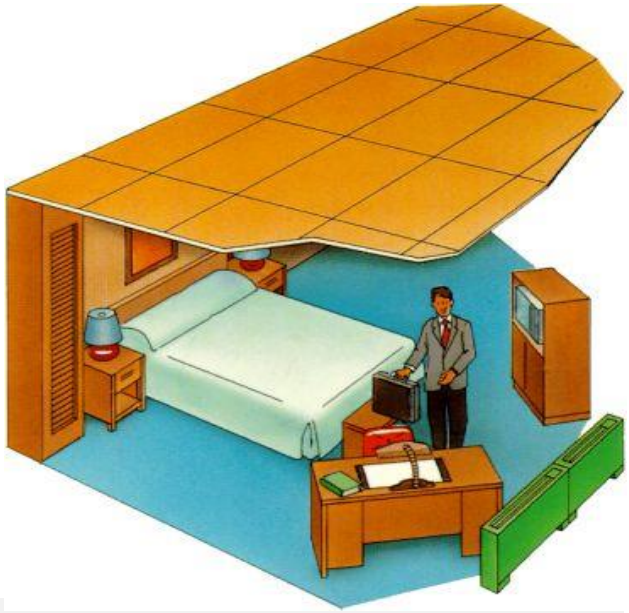


Domiciliary Facility

❑ Systems

- Constantly operational, but not necessarily occupied at all times.
  - ➢ Individual room control of the HVAC system.
- Relatively high domestic hot water use over short periods of time, several times a day.
- Load characteristics are well defined at design stages, without need for future expansion.





Libraries and Museums

❑ Systems

- HVAC systems run year-round (cooling systems can easily run up to 5,000 hours a year or more).
  - ➢ Heavy-duty long-life equipment required
- All equipment should be vibration and sound isolated
  - ➢ Mechanical rooms should be located as remotely as possible to minimize the cost of acoustic and vibration isolation

Equipment of Air Conditioning System

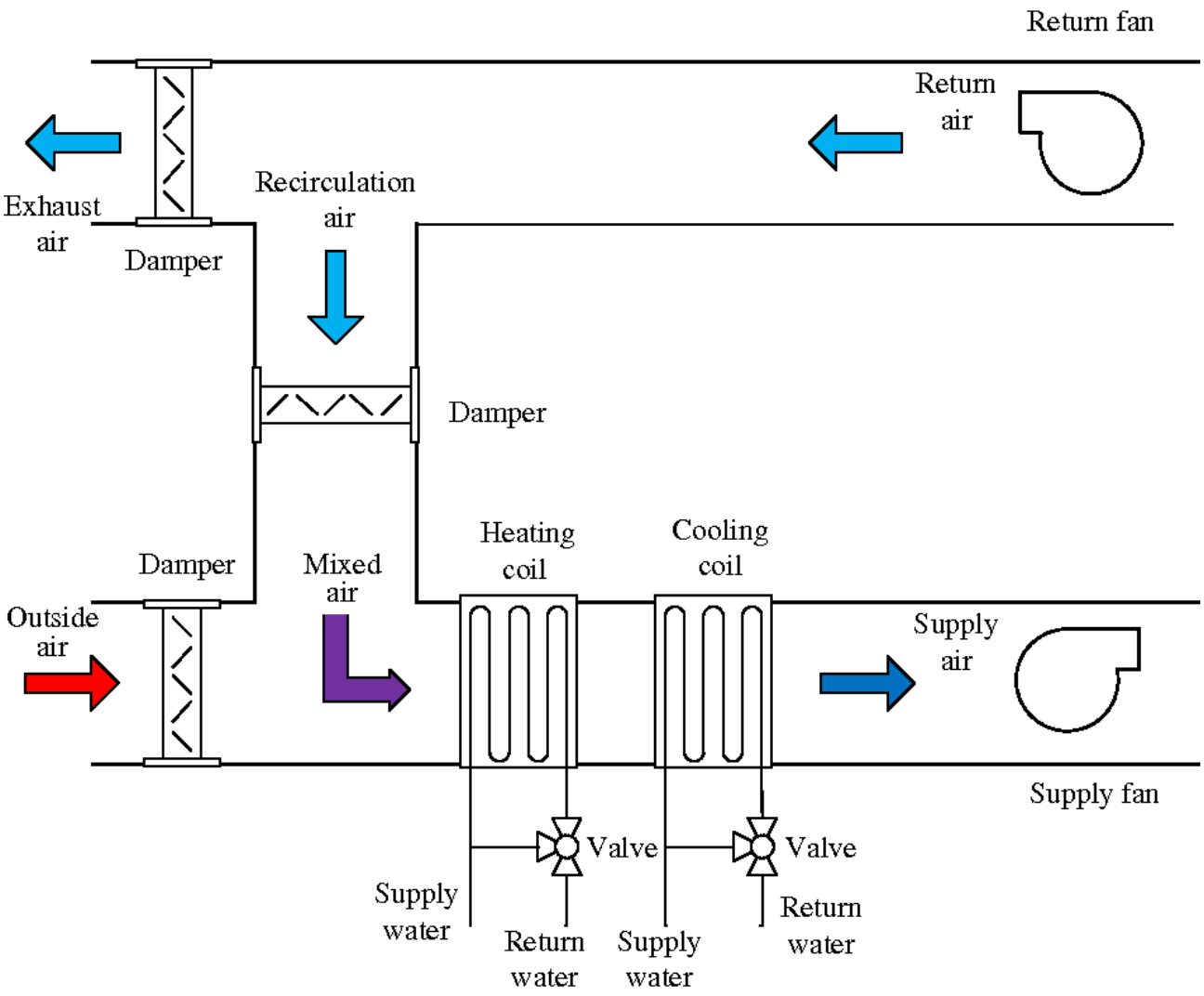
Primary Equipment of HVAC

- **Air-Handling Equipment**
- **Heating Equipment**
- **Refrigeration Equipment**
- **Other Energy Saving Equipment**
  - Thermal storage
  - Energy recovery
  - Solar energy
  - Geothermal

Air Handling Equipment

- Duct Construction
- Air-Diffusing Equipment
- Fans
- Evaporative Air Cooling Equipment
- Humidifiers
- Air-Cooling and Dehumidifying Coils
- Desiccant Dehumidification

Air Handling Equipment



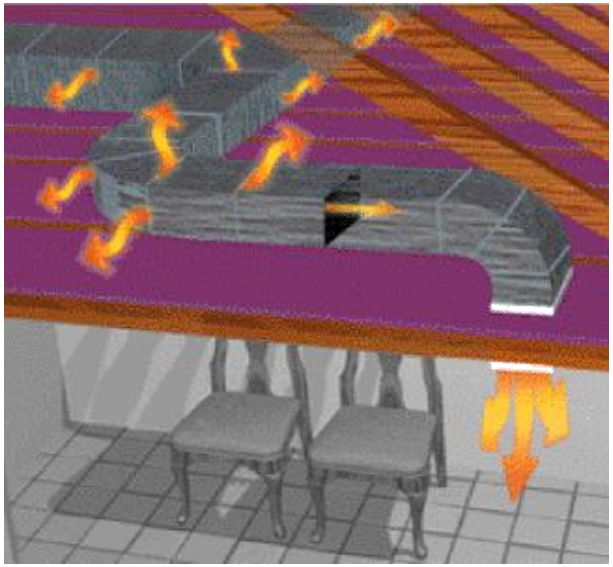
Ref., Kusiak, Andrew and Mingyang Li. "Cooling output optimization of an air handling unit." *Applied Energy* 87 (2010): 901-909.

Duct Construction

Duct system delivers a specific amount of air to each diffuser in the conditioned space at a specified total pressure.

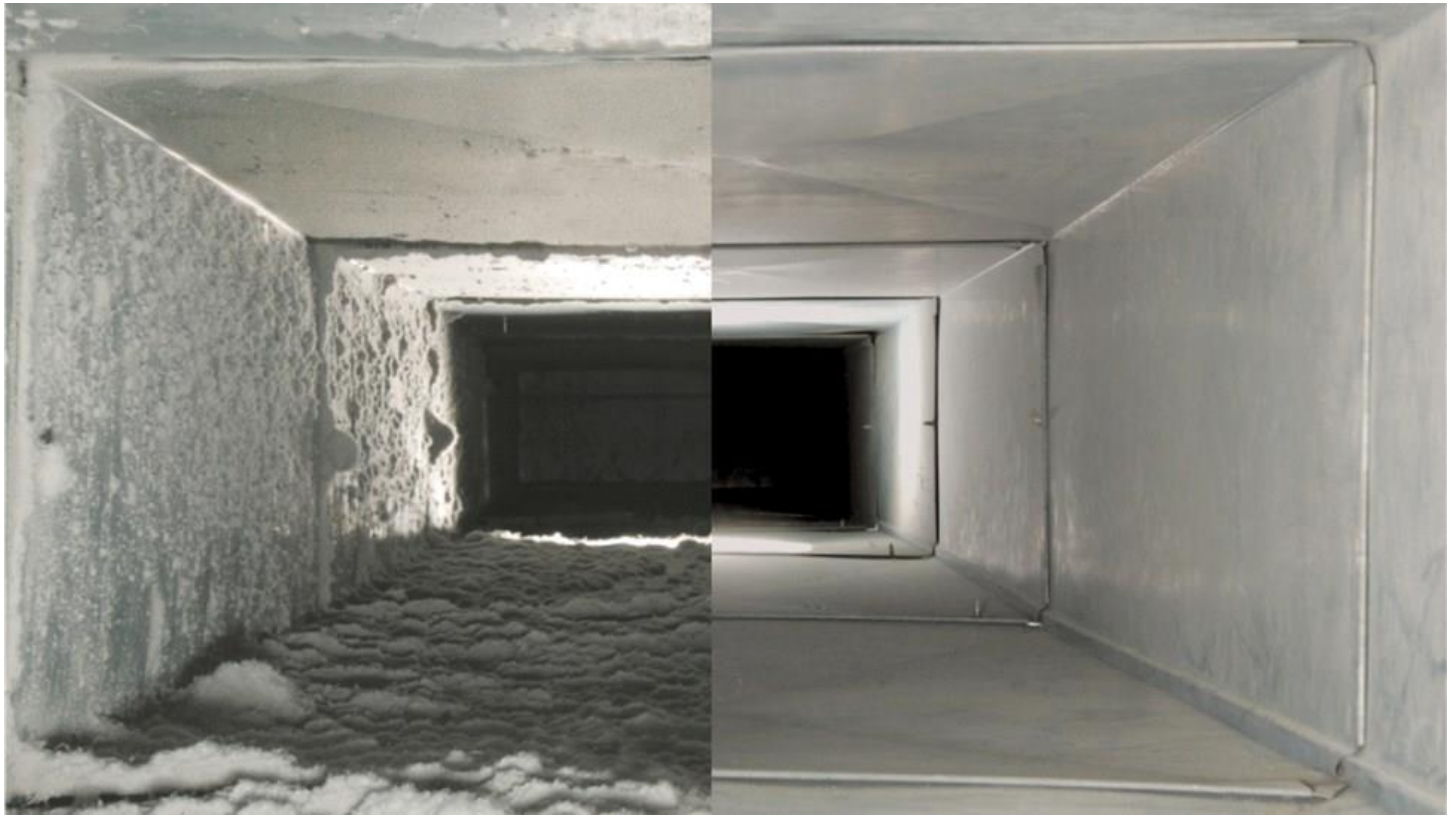
Duct construction is classified by application and pressure ;

- Residences ±125 Pa, ±250 Pa
- Commercial Systems ±125 Pa ~ ±2500 Pa
- Industrial Systems Any pressure



Duct Construction - Cleaning

- Ducts should be designed, constructed, and maintained to minimize the opportunity for growth and dissemination of microorganisms.

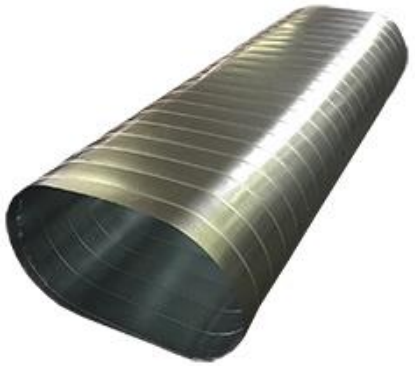


Ref., www.fourseasonsheatingcooling.com/air-quality/duct-cleaning

Duct Construction

❑ Types of Ducts

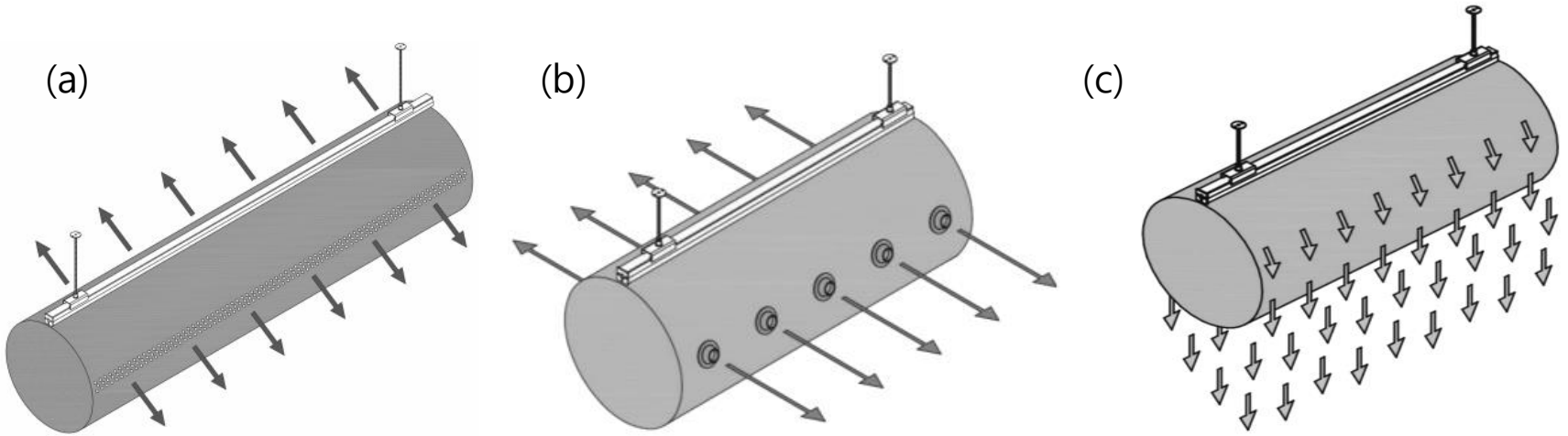
- Round Ducts
- Flat Oval Ducts
- Rectangular Ducts
- Fibrous Glass Duct
- Flexible Ducts



Duct Construction

❑ Air dispersion systems

- Linear vent outlets
- Orifice and nozzle outlets
- Porous-duct-surface air distribution



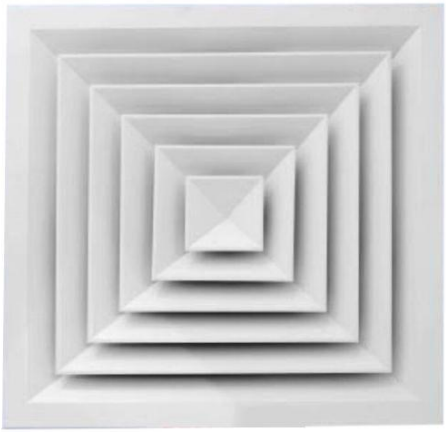
Ref., 2020 ASHRAE Handbook – HVAC Systems and Equipment

FIGURE Fabric ducts with (a) linear vent outlet, (b) nozzle outlet, (c) porous material

Air Diffusing Equipment

❑ Requirements of air distribution;

- The flow rate must compensate for the net heat loss or gain in the space
- The velocity must not be higher than 0.25 m/s in the occupied regions of the room
- There should be some motion of air to breakup temperature gradients in the room (warm air at the ceiling and cold air at the floors)



Air Diffusing Equipment

❑ Types of Supply Air Outlets

- Grilles and Register Outlets
- Linear Slot Outlets
- Ceiling Diffuser Outlets

Linear bar grill

Linear Slot diffuser

Ceiling Diffuser Outlets

Perforated diffuser

Air Diffusing Equipment

TABLE Typical Applications for Supply Air outlets

Outlet Types	Fully Mixed			Fully Stratified		Partially Mixed		
	Ceiling Mounted	Wall Mounted	Floor/Sill	Wall Mounted	Floor/Sill	Ceiling Mounted	Wall Mounted	Floor/Sill
Grilles								
Adjustable blade	◉	●	⊗	⊗	⊗	⊗	⊙	⊙
Fixed blade	⊙	◉	⊗	◉	⊙	⊗	⊙	⊗
Linear bar	⊗	●	●	◉	◉	⊗	⊙	●
Nozzle and drum louver	◉	●	⊗	⊗	⊗	⊗	⊗	⊗
Diffusers								
Round	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Square	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Perforated face	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Louvered face	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Plaque face	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Hemispherical	◉	⊗	⊗	⊗	⊗	◉	⊗	⊗
Laminar flow	◉	⊗	⊗	⊗	⊗	◉	⊗	⊗
Linear slot	●	●	⊗	⊗	⊗	⊗	⊗	⊗
T-bar slot	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Light troffer	●	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Swirl	●	⊗	⊗	⊗	◉	⊗	⊙	●
Displacement	⊗	⊗	⊗	●	●	◉	⊗	⊗
Air dispersion duct	●	◉	⊗	⊗	⊗	◉	◉	⊗

● = often used ◉ = sometimes used ⊙ = seldom used ⊗ = not recommended

Ref., 2020 ASHRAE Handbook – HVAC Systems and Equipment

Fans

- Fan is an air pump that creates a pressure difference and causes airflow

- Types of Fans
  - Centrifugal Fan
  - Axial Fan

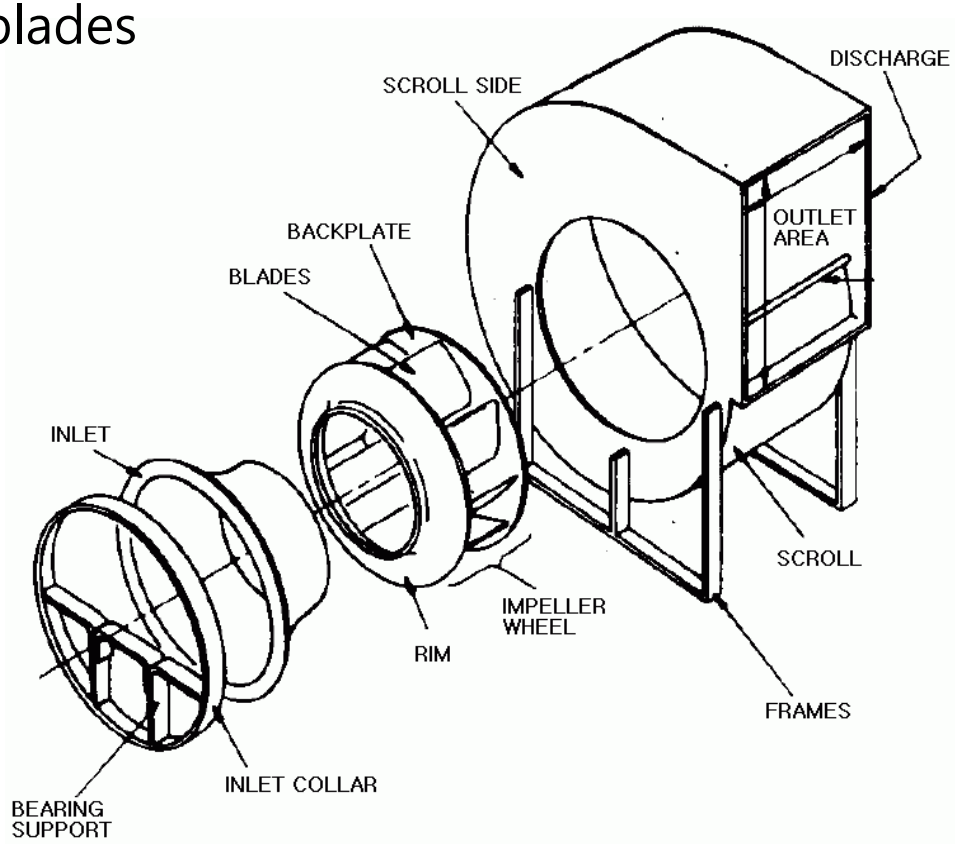
Centrifugal Fans

❑ Air enters the fan

- Turns and moves into the blades
- Enters the scroll

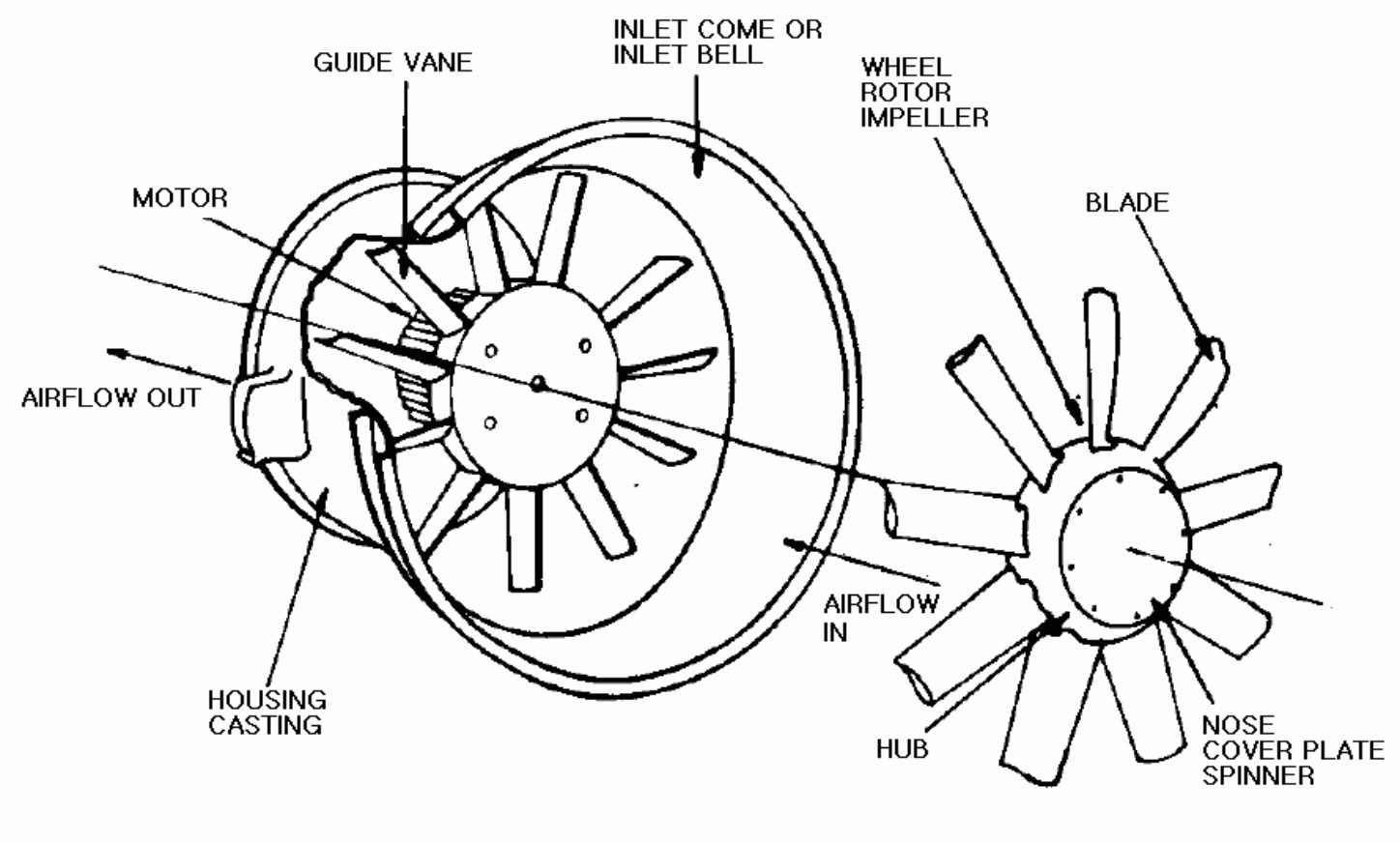
❑ Produce pressure from;

- Centrifugal force created by rotating the air
- Kinetic energy imparted to the air



Axial Fans

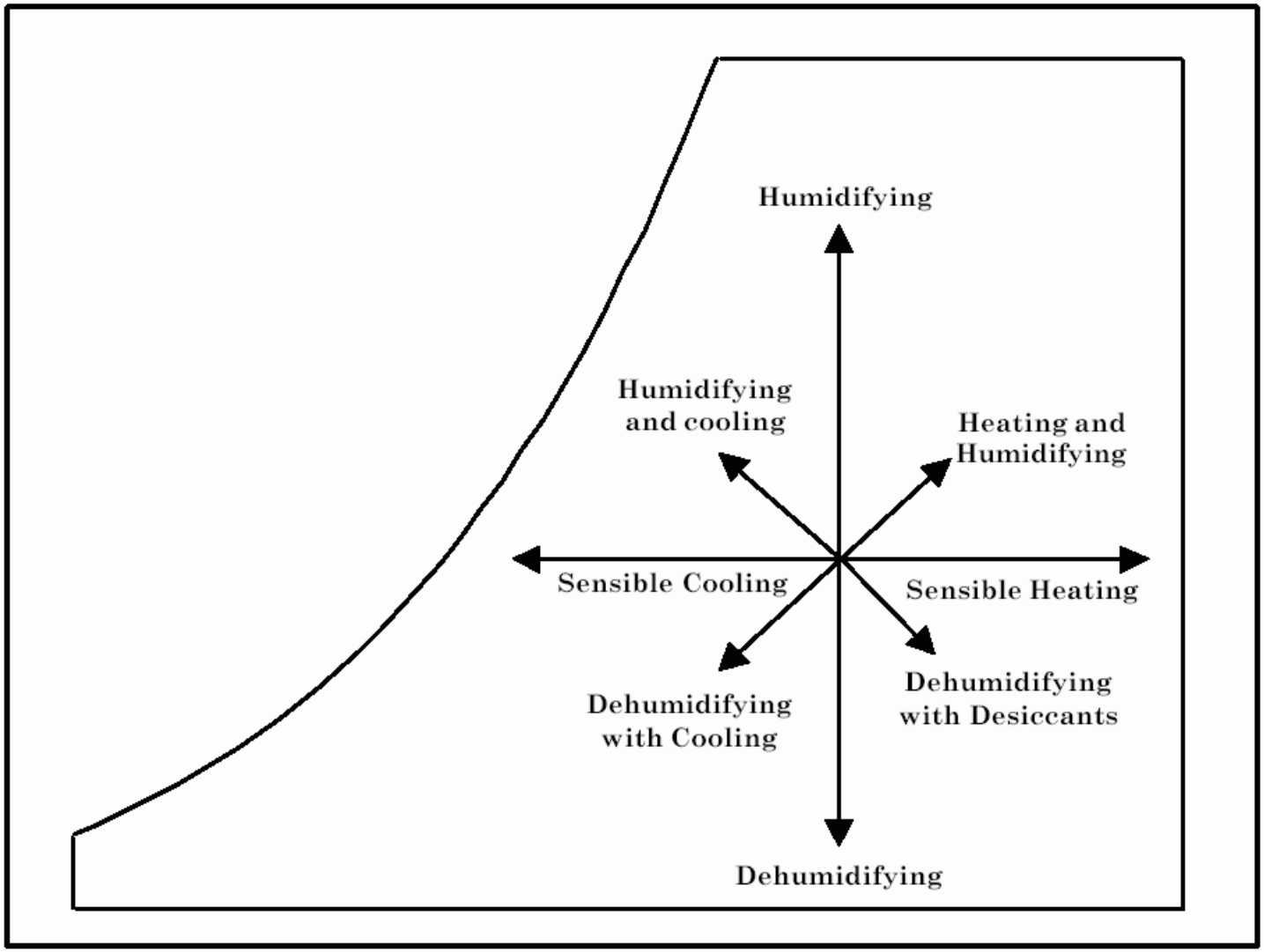
- **Produce pressure from the change in velocity passing through the impeller**



Centrifugal Fans vs. Axial Fans

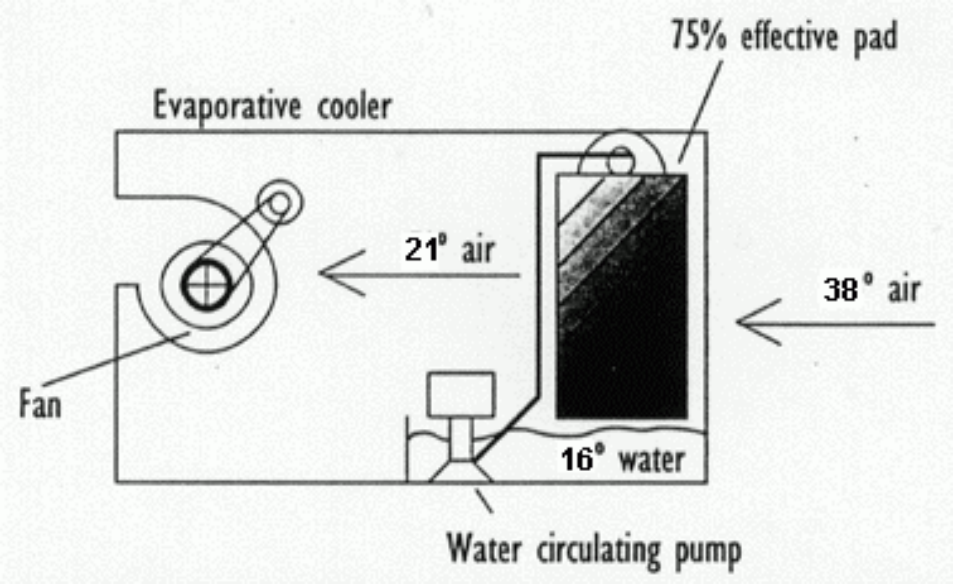
	Axial Fans	Centrifugal Fans
Applications	• Air-cooled heat exchanger units. • HVAC operations and package cooling tower operations.	• Industrial ventilation as hot air exhausts • Air conveyor systems • Secondary fluid transfer equipment for air turbine
Operating Speed	• Higher than centrifugal fans.	• Comparatively lesser than axial fans.
Power Consumption	• Less power for operation	• More power for operation
Air-Pressure and Volume	• Low-Pressure with higher air volume	• High-pressure with lower air volume
Size	• Typically smaller, lighter	• Considerably bulky
others	• Higher dynamic pressure • Less expensive	• More durable and resistant • Less likely to overload • Can be equipped with self-cleaning characteristics

Cooling and Humidification



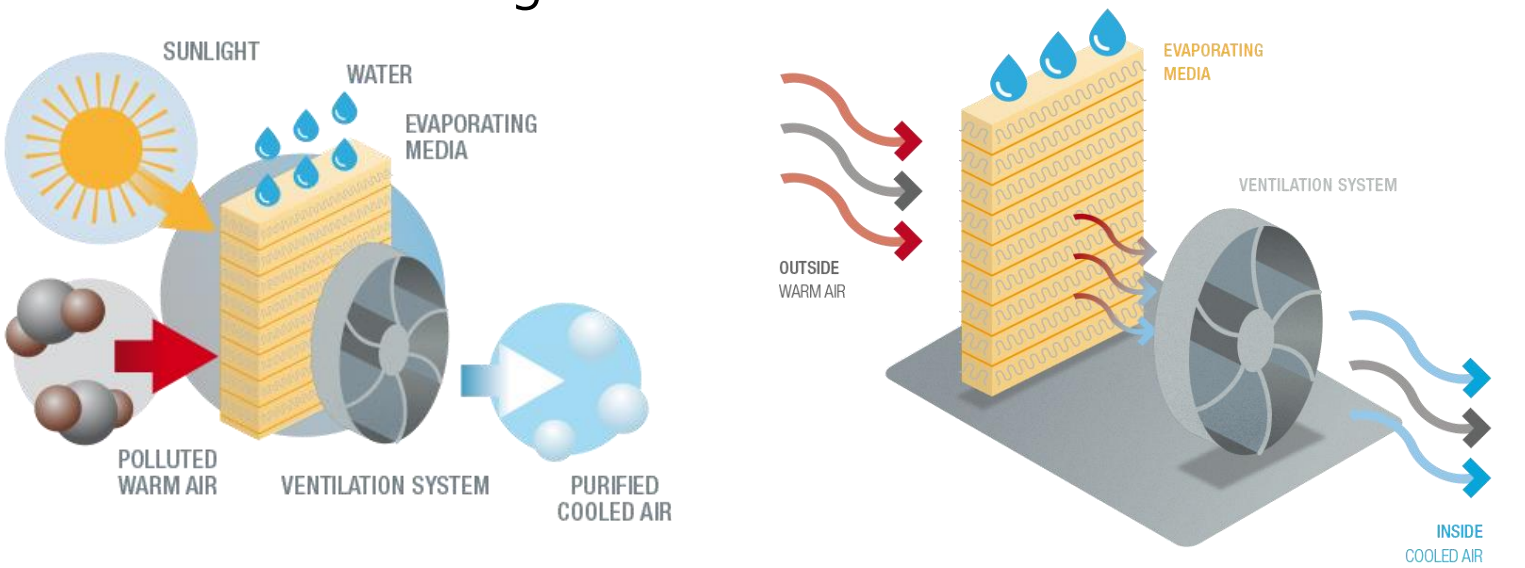
Evaporative Air Cooling Equipment

- An evaporative cooler produces effective cooling by combining a natural process - water evaporation - with a simple, reliable air-moving system.
- Fresh outside air is filtered through the saturated evaporative media, cooled by evaporation, and circulated by a blower wheel.



Evaporative Air Cooling Equipment

- Substantial energy & cost savings
- Reduced peak power demand
- Improved indoor air quality
- Life cycle cost effectiveness
- Easily integrated into built-up systems
- Environmental benign

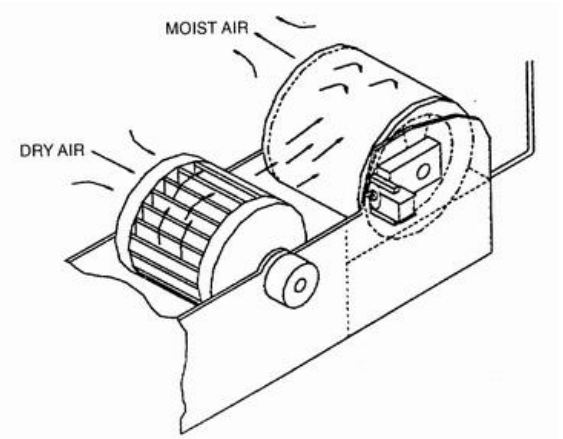


Ref., www.impresind.com

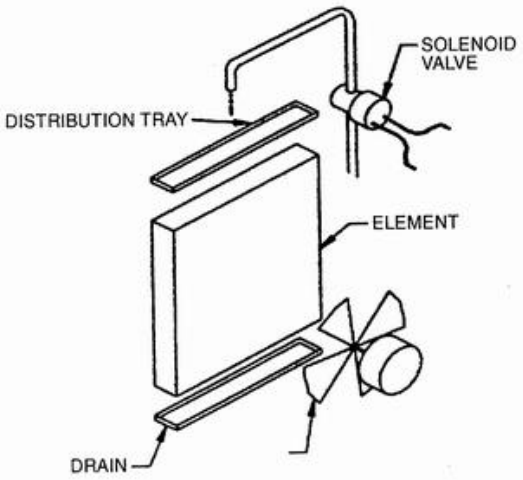
FIGURE Evaporative Cooling

Humidifiers

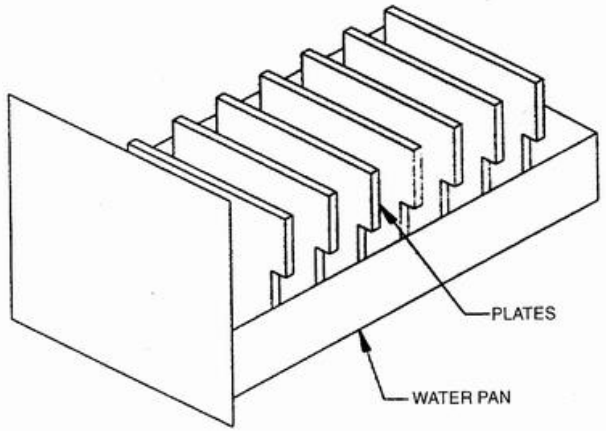
❑ Residential Humidifiers



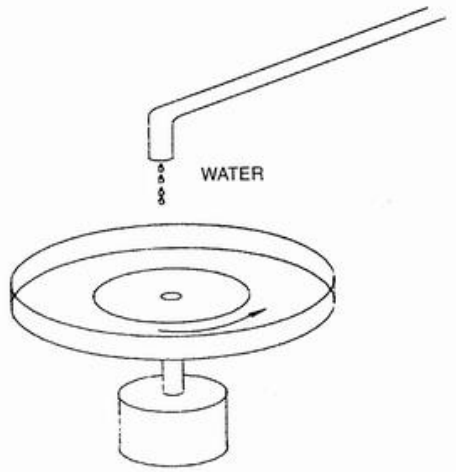
Wetted-Drum Humidifier



Power Wetted-Element Humidifier



Pan Humidifier



Atomizing Humidifier

Humidifiers

❑ Load calculation

- For ventilation systems having natural infiltration

$$H = \rho VR(W_i - W_o) - S + L$$

- For mechanical ventilation systems having a fixed quantity of outside air

$$H = \rho Q_o (W_i - W_o) - S + L$$

H = humidification load, kg/h

V = volume of space to be humidified, m^3

R = infiltration rate, air changes per hour

Q_o = volumetric flow rate of outside air, kg/h

W_i = humidity ratio at indoor design conditions, kg(water)/kg(dry air)

W_o = humidity ratio at outdoor design conditions, kg(water)/kg(dry air)

S = contribution of internal moisture sources, kg/h

L = other moisture losses, kg/h

P = density of air at sea level, 1.2 kg/m^3

Air-Cooling and Dehumidifying Coils

- **Fluid inside the coil**
  - Water and Aqueous Glycol Coils
  - Direct-Expansion Coils (refrigerant inside)
- **Coil design: Extended surface (finned) cooling coil**
  - Most popular and practical

Ref., www.hawco.co.uk

Desiccant Dehumidification

- **The use of chemical (or physical) absorption of water vapor to dehumidify air and reduce the latent cooling load in a building HVAC system**

- **Advantage**
  - Reduces cost of cooling
  - Improves product quality for companies with moisture sensitive products
  - Improves occupant comfort
  - Increases overall cooling capacity of existing cooling equipment
  - Reduces the amount of conventional cooling and elective demand
  - Improves indoor quality by reducing airborne bacteria and fungus

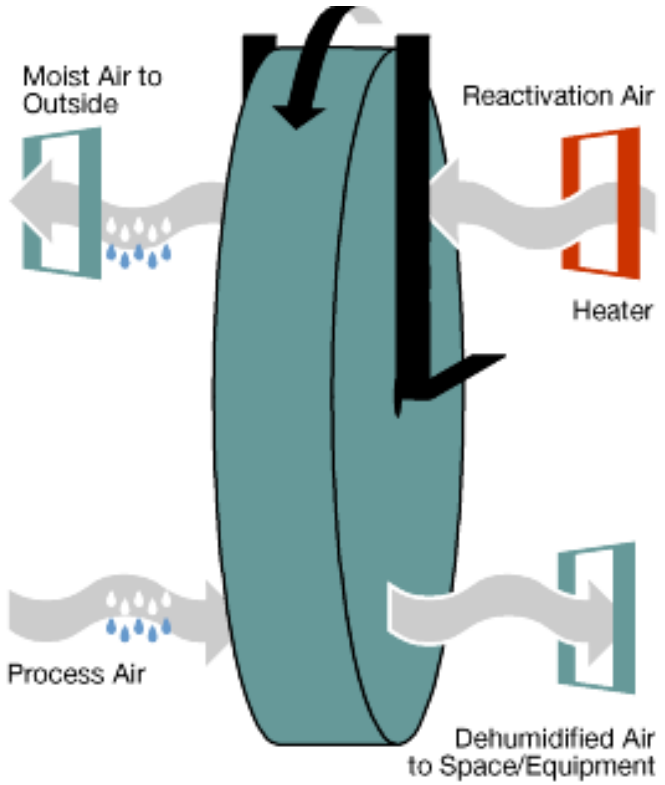
Desiccant Dehumidification

❑ Traditional System

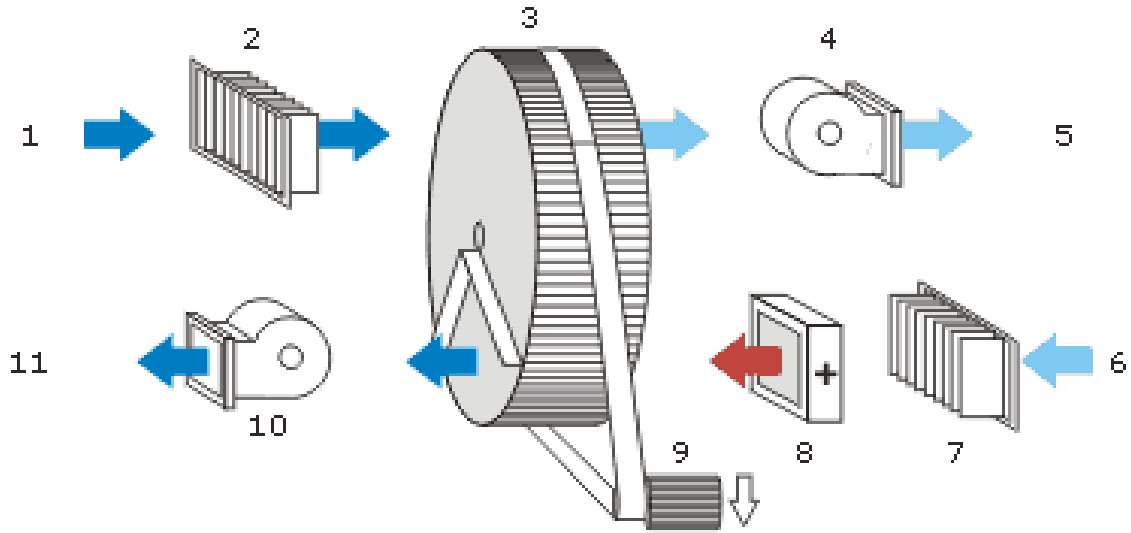
- Dehumidification was achieved by lowering the temperature of the air.
- Large energy required because air is over-cooled.

❑ Rotary Dehumidification Unit

- Desiccant dehumidification flows air from the building over a porous material that attracts moisture.
- The porous material attracts moisture until it is saturated and can hold no more. Warm air is then passed over the desiccant and the moisture is released and exhausted to the outside



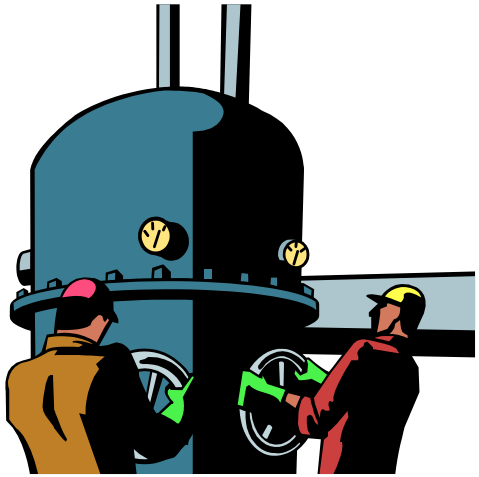
Desiccant Dehumidification



1: Process air "ON"
2: Filter
3: Rotor
4: Process air fan
5: Process air "OFF" (Dry air)
6: Regeneration air "ON"
7: Filter
8: Heating elements
9: Drive motor
10: Regeneration air fan
11: Regeneration air "OFF" (Wet air)

Heating Equipment

- Boiler
- Furnace
- Residential In-Space Heating Equipment



Boilers

❑ Basic Classification of Boilers

- **Working pressure and temperature**

Medium & High-Pressure Boiler

Low-Pressure Boiler

Pressure : 100 ~ 200 kPa (Water)
1,100 kPa (Steam)
Temperature : 120°C

❑ Steam Boilers / Water Boilers

Boilers

❑ Other Classifications:

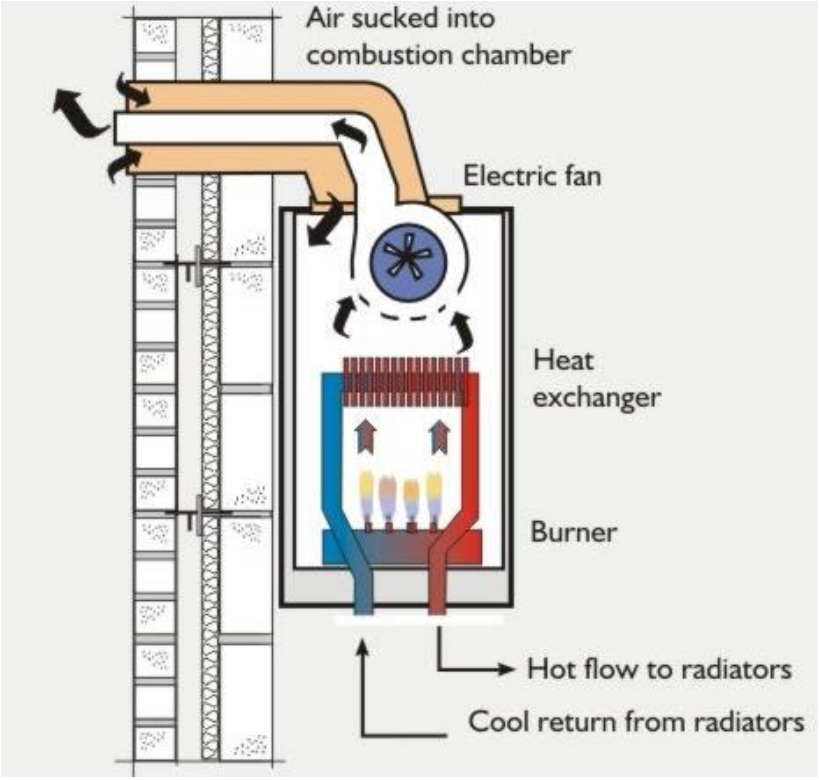
- **Fuel Used: coal, fuel oil, gas / electricity**
- **Construction Material:**
  - ➢ Cast-iron, steel, copper, stainless steel, etc.…
- **Condensing/Non-condensing Boilers:**
  - ➢ Condensing fuel gas in the boiler
- **Etc.**

Boiler classifications are important to the engineers because they affect performance, first cost and space requirements.

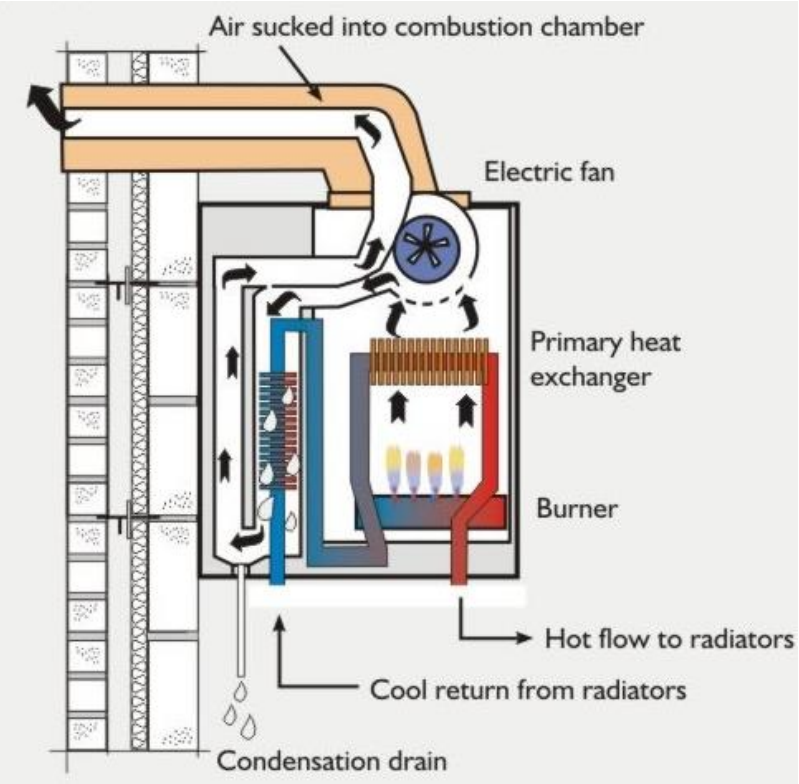
Boilers

❑ Condensing Boilers

Hot exhaust gases condense and lose much of their energy to pre-heat the water in the boiler system



Non-condensing Boiler

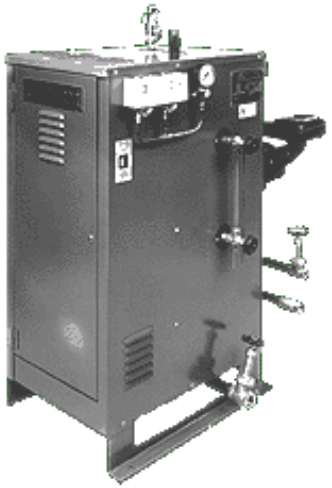


Condensing Boiler

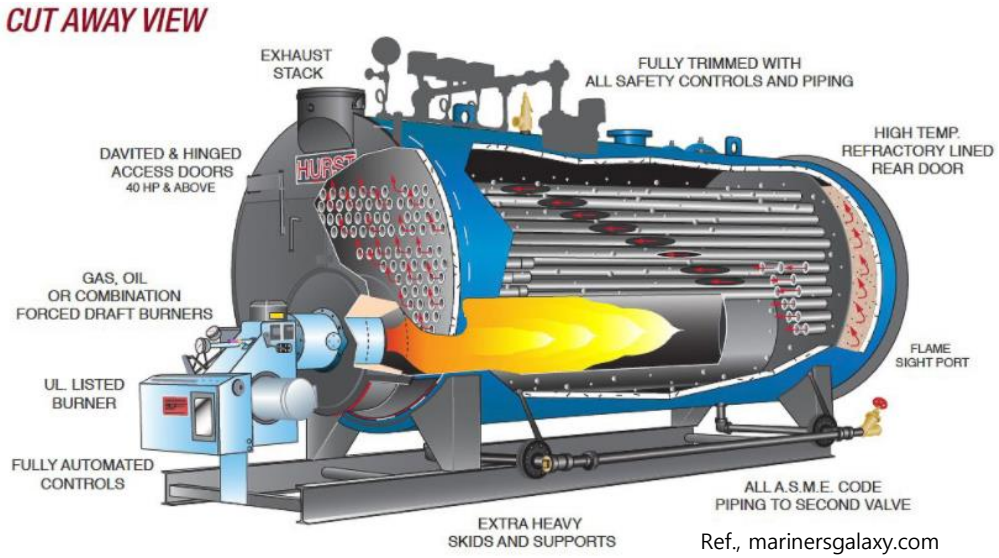
Boilers

❑ Electric Boiler

- No Combustion
- electrode is immersed in the boiler water



❑ Packaged Fire-Tube Boiler



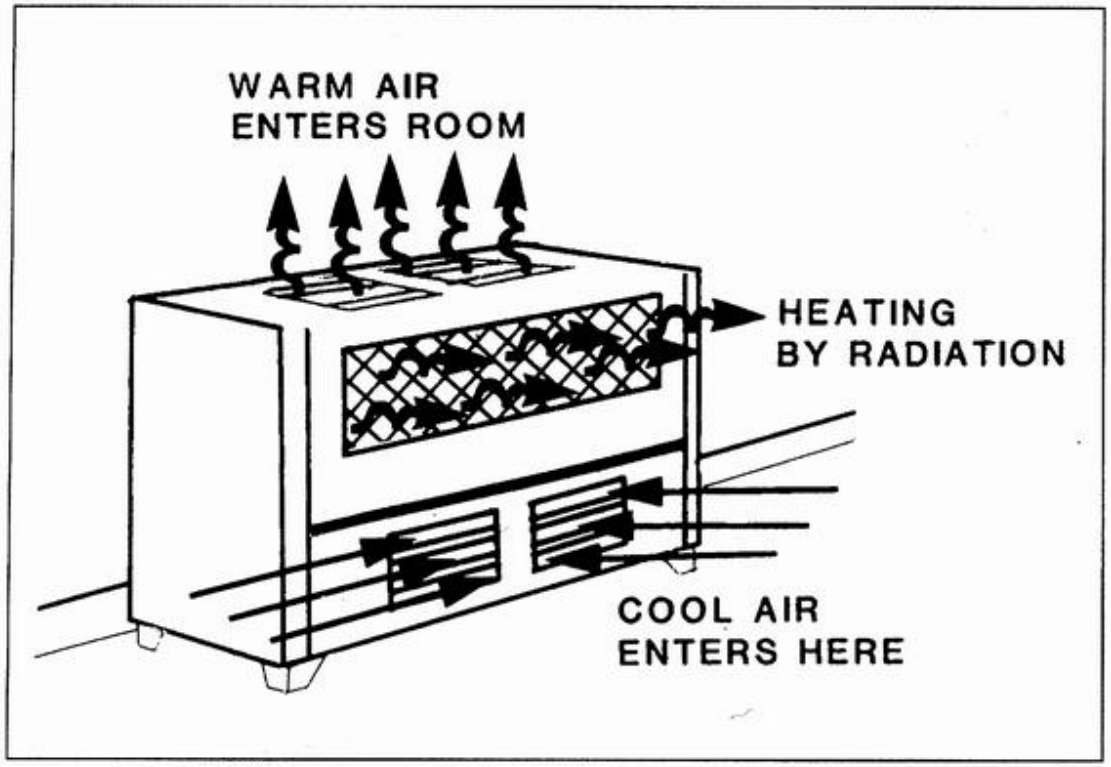
Ref., marinersgalaxy.com

Ref., CleaverBrooks.com

In-Space Heating Equipment

❑ Room Heater

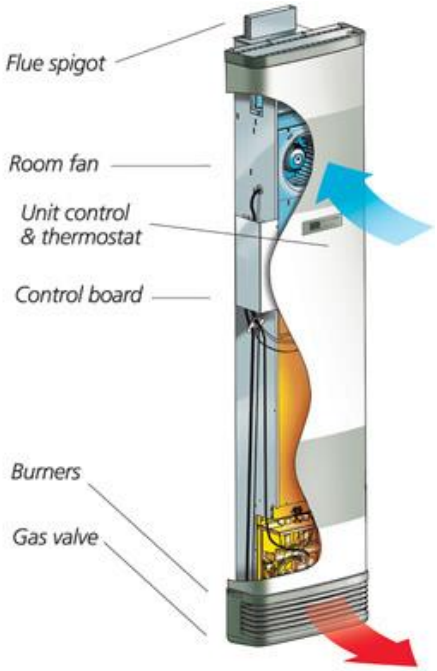
- Not for the central heating system

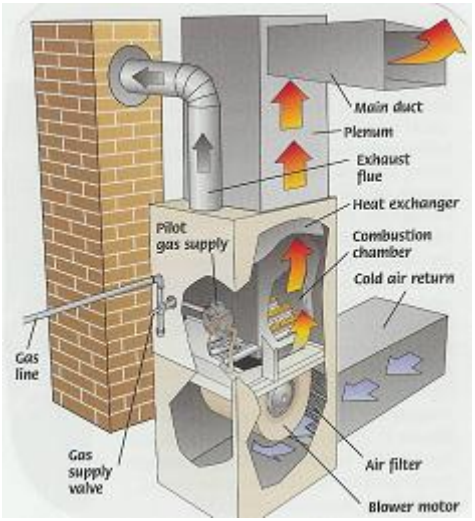


Furnace

❑ Wall Furnace

- Part of the structure of building
- Supplying heated air by natural/forced convection





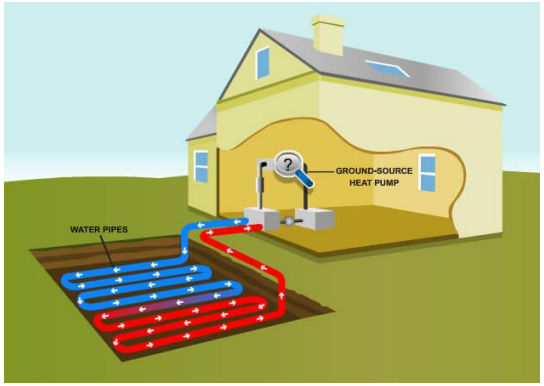
❑ Heating Furnace

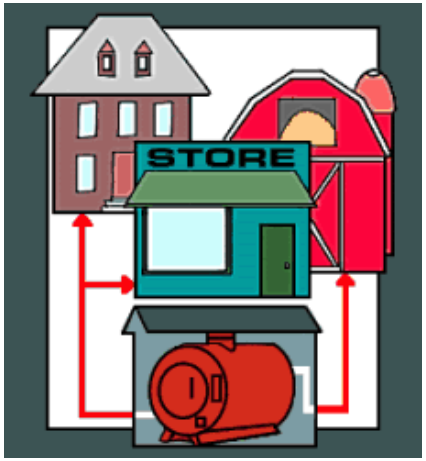
- Air is heated directly by the hot gas of combustion

Other Energy Saving Equipment

- ❑ Thermal storage
- ❑ Energy recovery
- ❑ Solar energy
- ❑ Geothermal energy

Thermal Storage facility





Question and Answer Session