HVAC Systems and Efficiencies

Course No. ENRG 55B

HVAC Systems and Efficiencies

Outline

A. INSERT OUTLINE

HVAC Systems and Efficiencies

A. INSERT SECTION OUTLINE

1. SECTION OUTLINE

A. HVAC Fundamentals and Components

- Review of components, equipments, and terminology from ENGR 55A

Overview

- The objective of an HVAC (heating, ventilating, and air-conditioning) system is to control the temperature, humidity, air movement, and air cleanliness, normally with mechanical means, to achieve thermal comfort.
- Centralized HVAC system installations utilize a number of separate components that are assembled to serve the specific needs of an individual building.

B. HVAC SYSTEM TYPES

- There are 4 primary types of heating and cooling systems:
  - Split systems
  - Hybrid heat split systems
  - Duct-free split systems
  - Packaged units

A. Air-Side systems

- As the name implies, in an “all – air” system air is used as the media that transports energy from the conditioned space to the A/C plant. In these systems air is processed in the A/C plant and this processed air is then conveyed to the conditioned space through insulated ducts using blowers and fans. This air extracts (or supplies in case of winter) the required amount of sensible and latent heat from the conditioned space. The return air from the conditioned space is conveyed back to the plant, where it again undergoes the required processing thus completing the cycle. No additional processing of air is required in the conditioned space.
- The system is categorized by the use of air-handling units (AHU) or roof top packages (RTP) to condition air. The conditioned air is sent through ductwork to the occupied space where it will heat or cool the space as required, and return via return air ducts back to the AHU or RTP. Air Handling Units contain a cooling coil (connected to a chiller or condensing unit), a heating coil (connected to boilers or electric heaters), filters, and one or more circulating fans. Roof Top Packages contain a refrigerant cooling cycle, heating coils (connected to boilers or electric heaters), filters, and one or more circulating fans.

1. Package Air Handling Unit (AHU) System Arrangement

- Package AHU:
  - A package unit is factory-assembled, ready for installation either in total or large segments. They can be classified according to their place of installation:
    - Rooftop
    - Indoor Packaged Unit
    - Split-systems
  - This type of unit is self-contained and does not receive hot or cold water from a central plant.
  - It conditions the air, is equipped with heating and cooling sources, and provides movement of the air
  - These units all have an indoor section and an outdoor section.

Roof Top Unit

- A roof-top packaged unit is installed on the roof and is completely weatherproof. Rooftop units can be subdivided into:

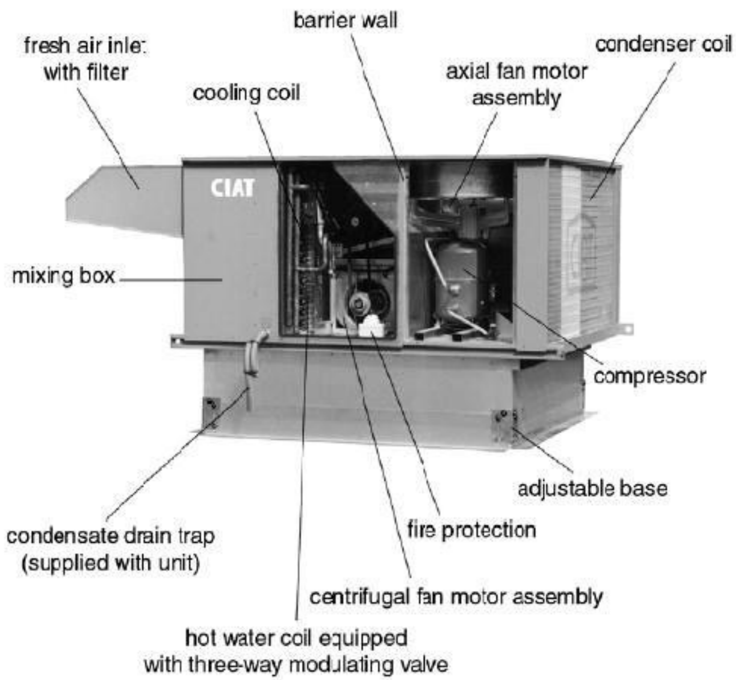
  1- Gas/electric rooftop packaged unit, in which heating is provided by gas furnace and cooling by electric power-driven compressors.

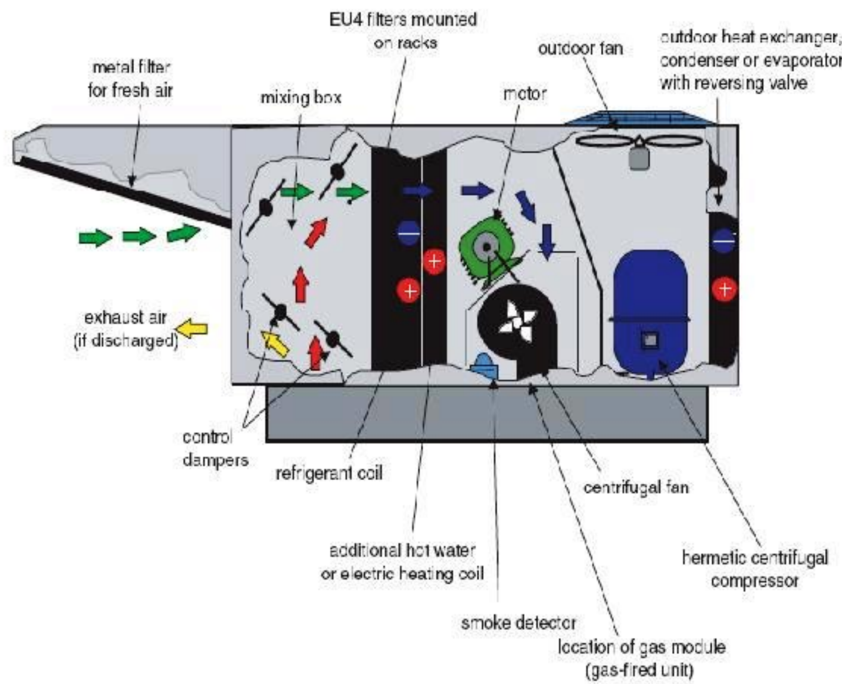
  2- Electric/electric rooftop packaged unit, in which electric heating and electric power-driven compressors provide heating and cooling.

  3- Rooftop packaged heat pump, in which both heating and cooling are provided by the same refrigeration system using a four-way reversing valve (heat pump) in which the refrigeration flow changes when cooling mode is changed to heating mode and vice versa. Auxiliary electric heating is provided if necessary.

Rooftop packaged units are single packaged units. Their cooling capacity may vary from 3 to 220 tons, Rooftop packaged units are the most widely used packaged units.

Rooftop AHU

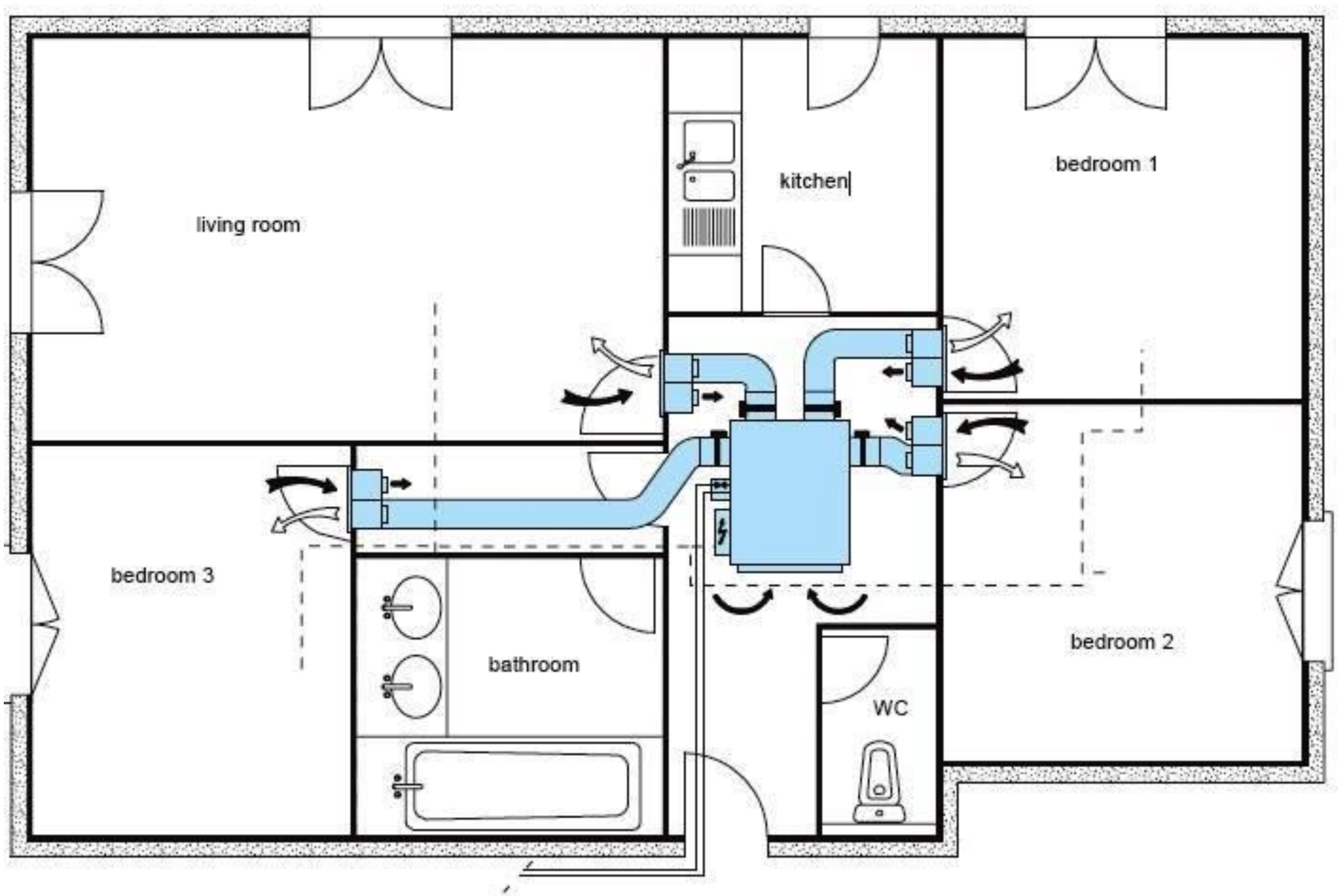

barrier wall
fresh air inlet
with filter
condenser coil
axial fan motor
assembly
cooling coil
CIAT
mixing box
compressor
adjustable base
fire protection
condensate drain trap
(supplied with unit)
centrifugal fan motor assembly
hot water coil equipped
with three-way modulating valve


EU4 filters mounted
on racks
outdoor heat exchanger,
condenser or evaporator
with reversing valve
outdoor fan
metal filter
for fresh air
mixing box
motor
exhaust air
(if discharged)
control
dampers
refrigerant coil
centrifugal fan
additional hot water
or electric heating coil
hermetic centrifugal
compressor
smoke detector
location of gas module
(gas-fired unit)

Indoor AHU

- An indoor packaged unit is also a single packaged and factory-fabricated unit.
- It is usually installed in a fan room or a machinery room.
- A small or medium-sized indoor packaged unit could be floor mounted directly inside the conditioned space with or without ductwork.
- The cooling capacity of an indoor packaged unit may vary from 3 to 100 tons. Indoor packaged unit usually has its compressors located indoors and condensers outdoors.

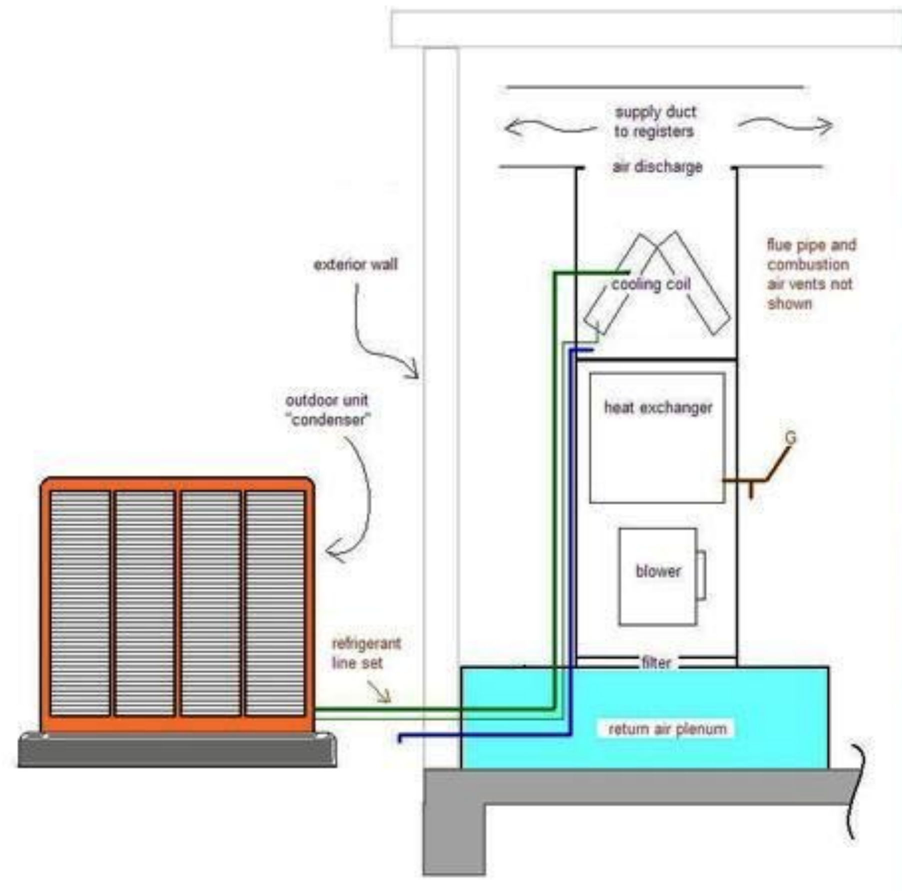
Indoor Package Unit



Split System Packaged Unit

- The split-system packaged unit consists of two separate pieces of equipment:
  - an indoor air handler (often installed in the fan room)
  - an outdoor condensing unit (often installed on a rooftop, or podium, or on the ground)
- A split packaged unit has its compressors and condenser in its outdoor condensing unit, whereas an indoor packaged unit usually has its compressors indoors.
- The two sections are field connected through refrigerant piping and electric wiring.
- The cooling capacity of split packaged units varies from 3 to 75.

Split-System Packaged Unit



1- outdoor unit
2- Air Handler
3- Air Cleaner
4- Thermostat

2. Built-Up AHU (field assembled)

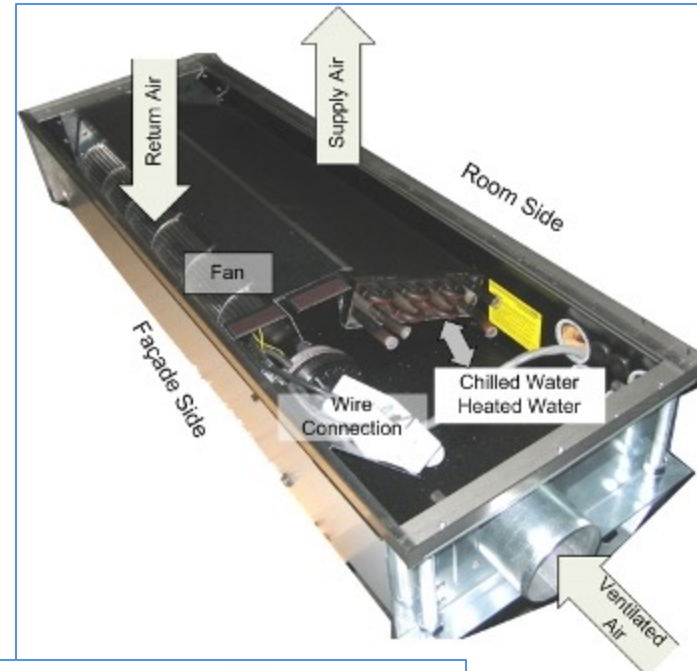
- The built-up AHU is field-assembled from individual components selected by the designer.
- This approach allows the designer complete flexibility of size and arrangement.
- Built-up systems allow choices of styles and performance characteristics in every component. For example:
  - Air intakes and discharges may be roof hoods or wall louvers
  - Dampers may be parallel-blade or opposed-blade, preferably with tight shutoff for outside air and relief air applications
  - Filters may be of any desired style and arrangement for the space allowed.
  - Cooling may utilize any available economically viable service or combination of services, including evaporative cooling , direct-expansion refrigeration, chilled water, etc.
  - Heating may utilize any available viable service including gas-fired devices, oil-fired devices, steam or hot water from a remote plant, geothermal water, solar heated water, etc.
  - Humidification may be by steam injection, air washers, or other wetted media.
  - Fans may be of any design which develops enough static pressure to handle the fan system component and distribution system pres- sure drops.

3. Individual Room AHUs

- Individual room AHUs are used extensively in hotels, motels, and apartments.
- The principal advantages are economy and convenience
  - if the room is not occupied, the unit can be shut off
  - the occupant can select heating, cooling, or nothing to suit
- Room AHUs include:
  - fan-coil units
  - unit ventilators
  - self-contained heat pumps
  - water-to-air heat pumps

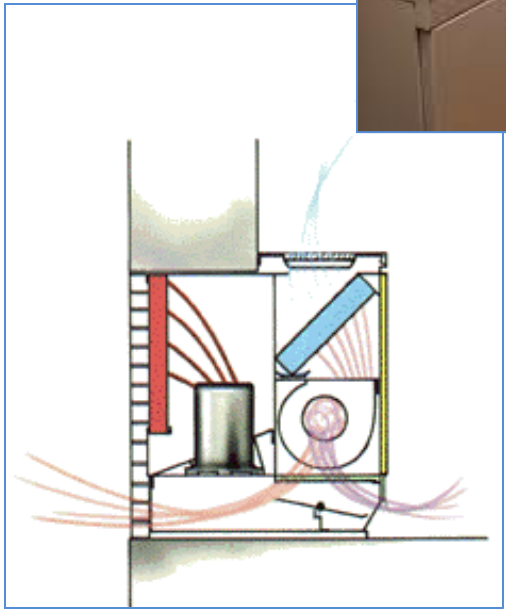
Fan Coil Unit

- A fan-coil unit includes a fan, a heating and/or cooling coil, a filter, and sometimes an outside air connection with a manual damper, all in a sheet-metal casing with supply and return connections (for concealed units) or grilles (for exposed units).
- Ceiling or floor-mounted arrangements are typical
- The coil may have one set of connections for both heating and cooling or may be split, with separate sections for heating and cooling
- A fan-coil unit depends on an outside source for its thermal energy
- Common sizes range from 100 to 1200 cfm, and some manufacturers offer ceiling-mounted units up to 2000 cfm.



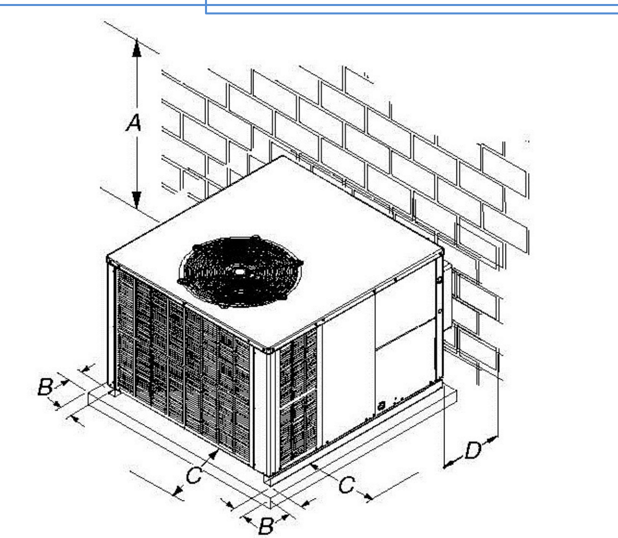
Unit Ventilators

- A unit ventilator is a larger fan-coil with an outside air connection which allows it to provide up to 100 percent outside air for ventilation and natural cooling .
- The unit ventilator is used primarily in schoolrooms and similar spaces where high ventilation rates are needed.
- Controls are included with the unit.
- The typical control cycle provides for opening the outside air damper to minimum position when the fan is started, and increasing the outside air amount to 100 percent as the room temperature approaches the heating set point. Only minimal outside air is used when refrigerated cooling is required.
- Many unit-ventilator system designs ignore the need for relief air when the units are in full ventilation mode. The consequence is a pressurized room or building. Failure of the outside air damper to close tightly may result in freezing of water coils in cold climates.



Self Contained Heat Pumps

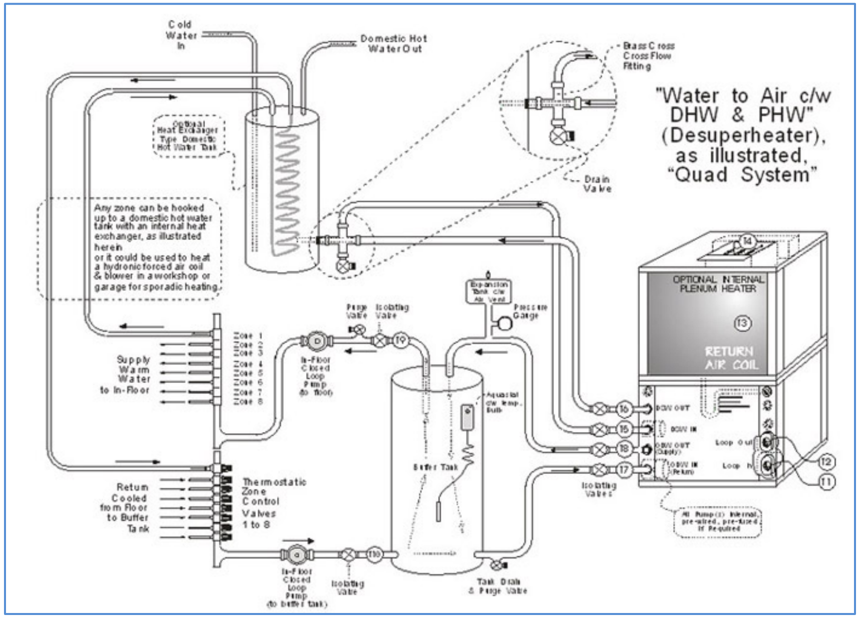
- These are through-the-wall units, with an outside coil, an inside coil, and an auxiliary heating coil all in a single package.
- It has the lowest first cost of any individual AHU system.
- It is the noisiest and typically least comfortable of all the systems discussed.
- These units are often found in hotel/motel applications; guard shacks, vending kiosks and similar applications.



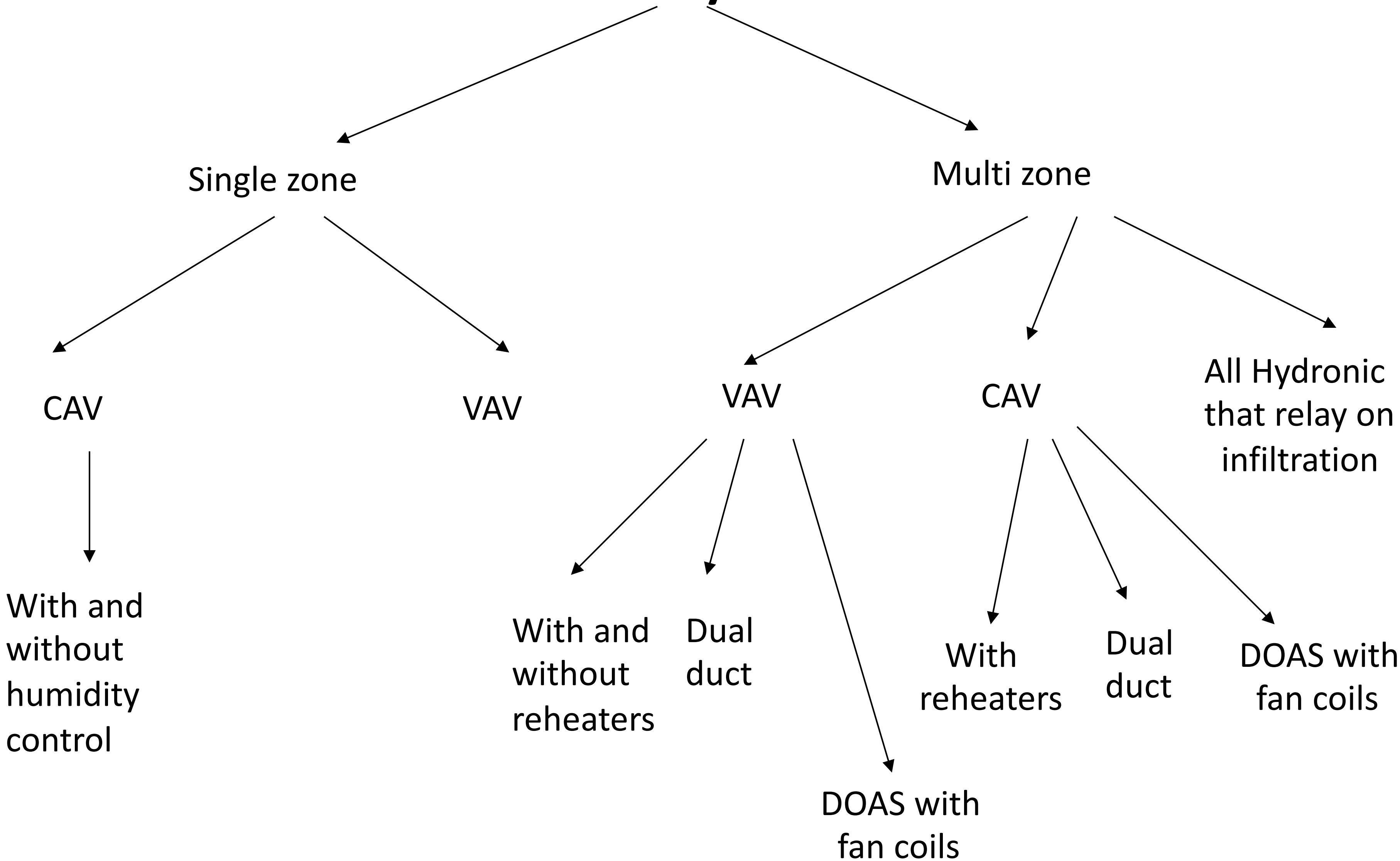
A. 48" (121.9 m) minimum B. 12" (30.5 cm) minimum C. 36" (91.4 cm) minimum service clearance D. 4" (10.2 cm) minimum

Water to Air Heat Pump

- This system provides a small individual heat pump for each zone or room, with a central source of water at an intermediate temperature which allows each heat pump to provide either heating or cooling, as desired by the occupant.
- Depending on the occupancy schedule, the central circulating pump has to run whenever any of the heat pumps is in operation.
- Operating costs for these systems may be higher than average.



HVAC Systems



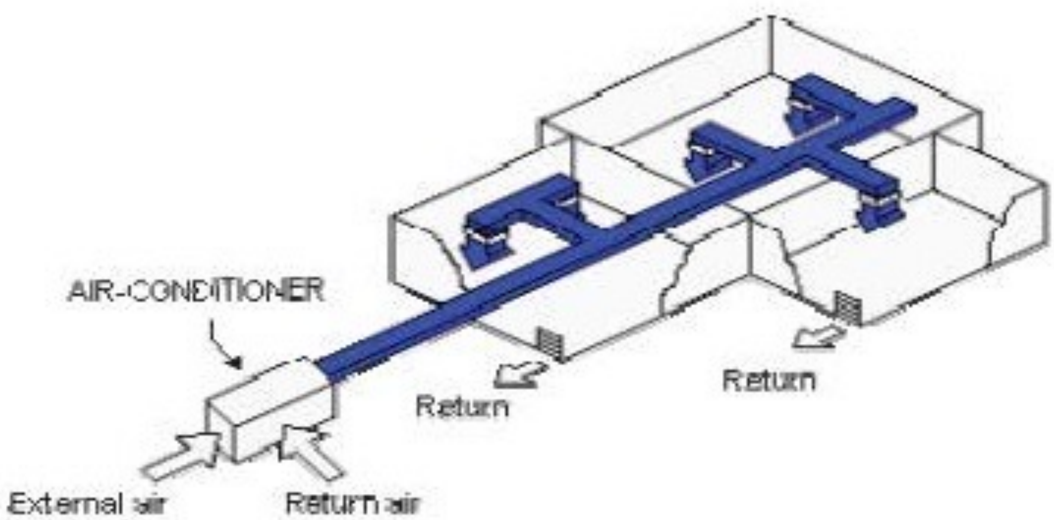
This is not the complete list !

B. Single-Duct System

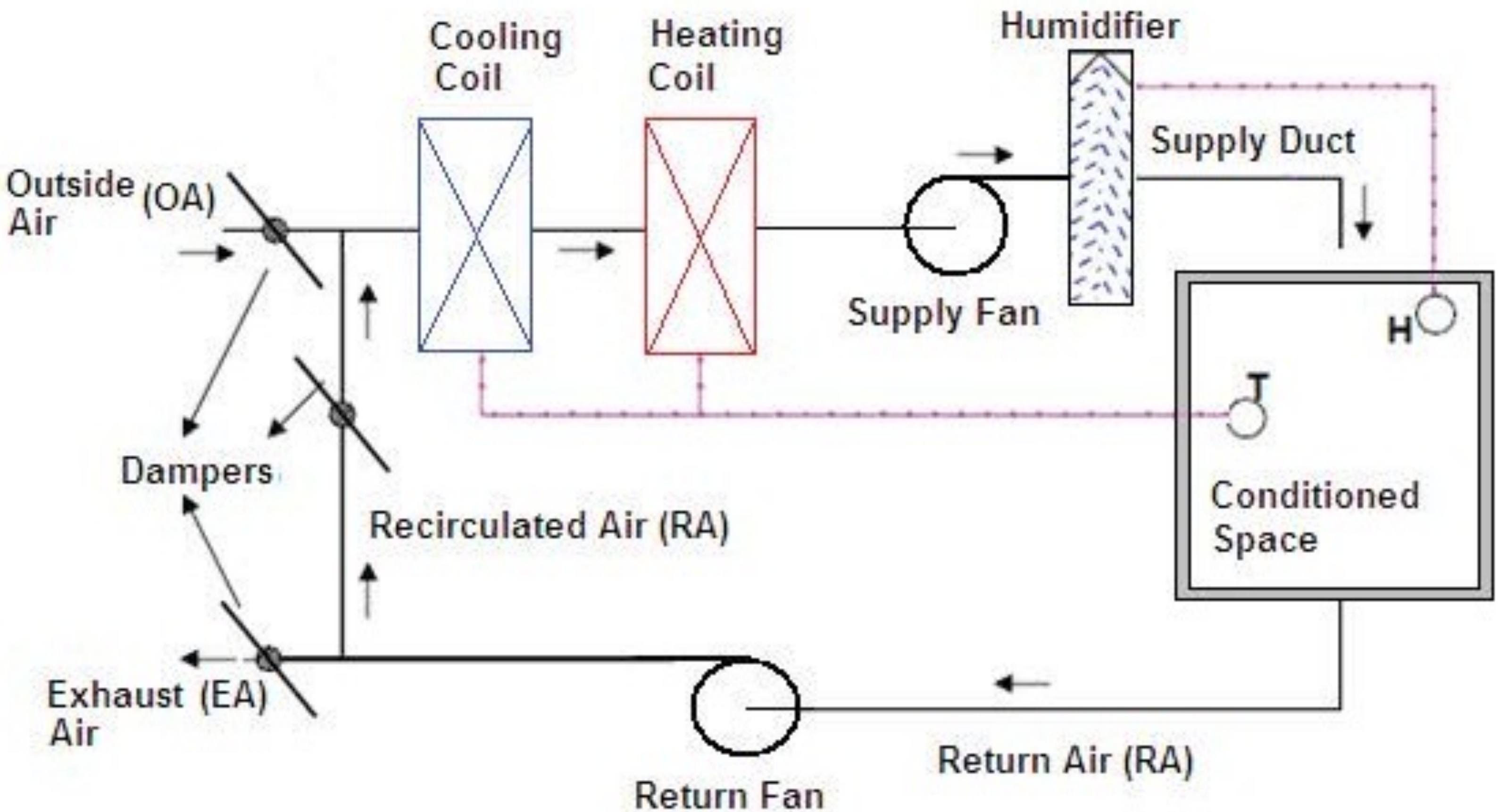
- A single duct system is an “all-air” system in which dehumidified air at an appropriate temperature is circulated throughout a building in a single branching duct
- The air is supplied from a central plant
- The single duct systems can provide either cooling or heating using the same duct, but not both heating and cooling simultaneously. These systems can be further classified as:
  - Single duct, constant volume, single zone system;
  - Single duct, constant volume, multiple zone system with terminal reheat;
  - Variable air volume system

1. Constant volume

- The simplest and most common of the "All-Air" central systems is a single duct, constant volume, single zone system.
- It is called "single duct" because there is only one supply duct, through which either hot air or cold air flows, but not both simultaneously.
- It is called as a constant volume system as the volumetric flow rate of supply air is always maintained constant.
- It is a single zone system as the control is based on temperature and humidity ratio measured at a single point.
- A single zone system consists of an air-handling unit, a heat source, cooling source, distribution ductwork, and appropriate delivery devices.



Single Duct, Constant Volume, Single Zone System



Single Duct, Constant Volume, Single Zone System

Advantages

- The primary advantage of a single zone central system is simplicity of design;
- Single zone systems are the most basic and least complex of central all-air systems;
- Low first cost among all types of systems;
- Easiest to maintain.

Disadvantages

- It can effectively condition only one zone. This is only a disadvantage when improperly applied.
- Because control is achieved at the air-handling unit, single zone systems are not easily modified to serve multiple zones, should building usage change with time.

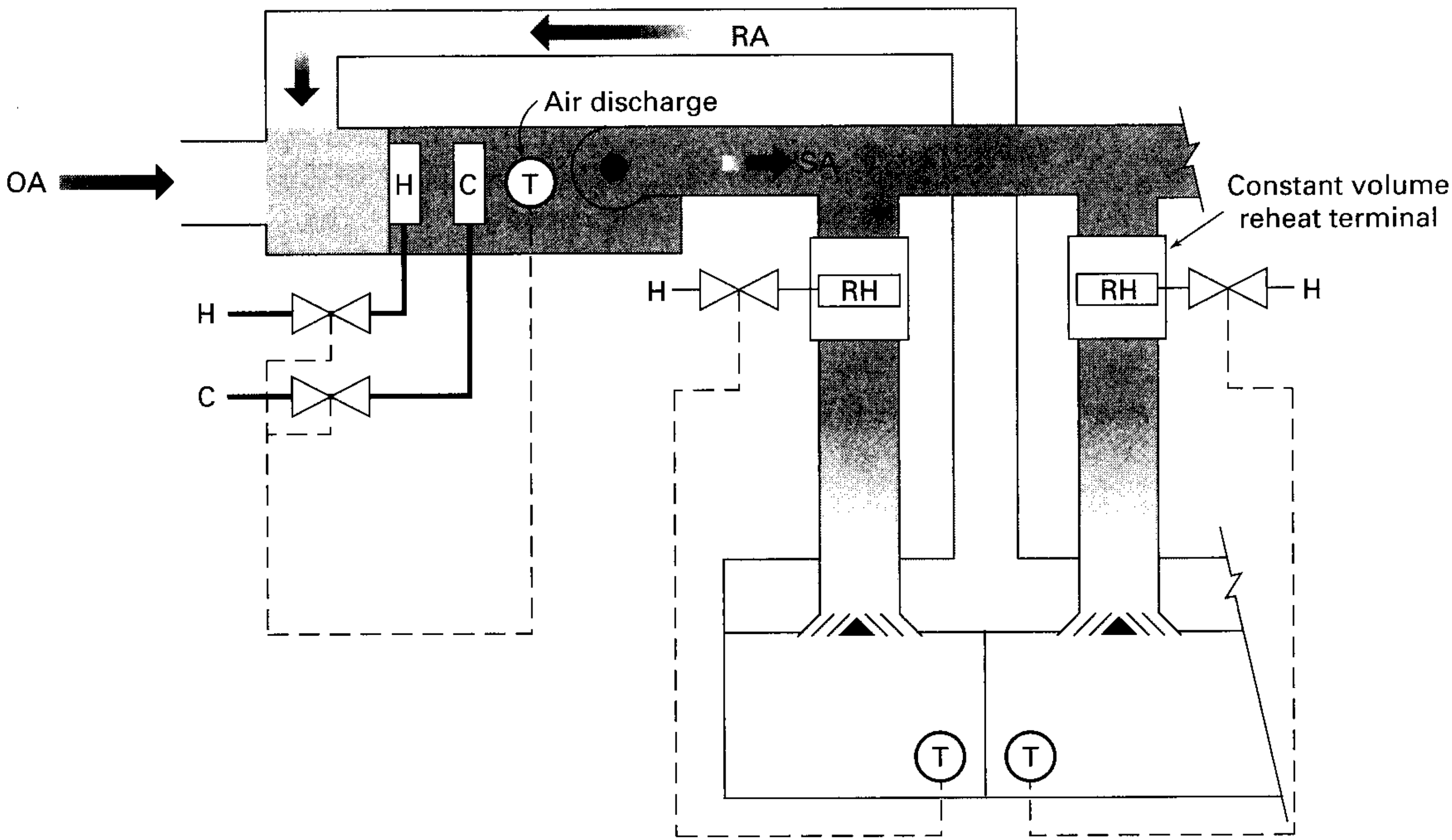
Applications of Single Duct, Single Zone, Constant Volume Systems:

- The all-air single-zone air conditioning system is the basic central system, which can supply a constant air volume or a variable air volume at low, medium, or high pressure.
- Single zone systems find many applications because of simplicity.
- Many large single-story buildings such as supermarkets, discount stores, and the like, can be effectively conditioned by a series of single zone systems with each system serving a loosely defined region of the building.
- Typically applications of single duct, constant volume, single zone systems include:
  - Space with uniform loads such as large open areas with small external loads e.g. theatres, auditoria, departmental stores;
  - Small spaces requiring precision control such as laboratories;
  - Multiple single zone systems for large areas.

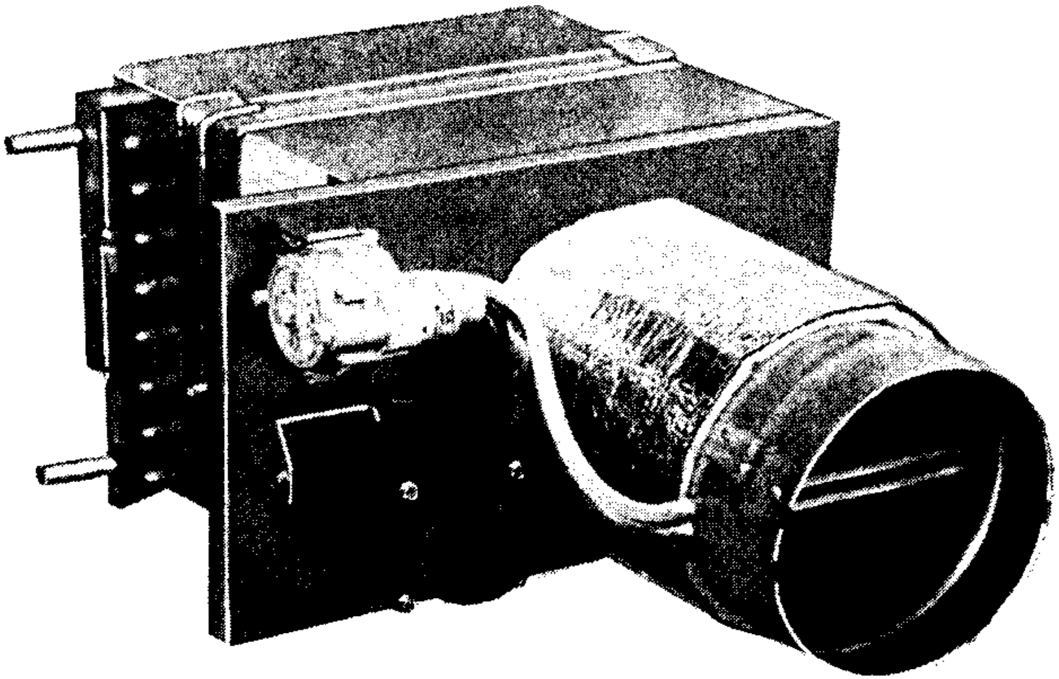
Single Duct, Constant Volume, **Multiple Zone System** with Reheat

- The Multi-zone AHU provides both hot and cold air and allows simultaneous heating and cooling in contiguous zones.
- The traditional multi-zone unit had only two ducts—hot and cold—and was therefore a reheat system
- Multi-zone systems are normally limited to a small number of zones with short runs of ductwork

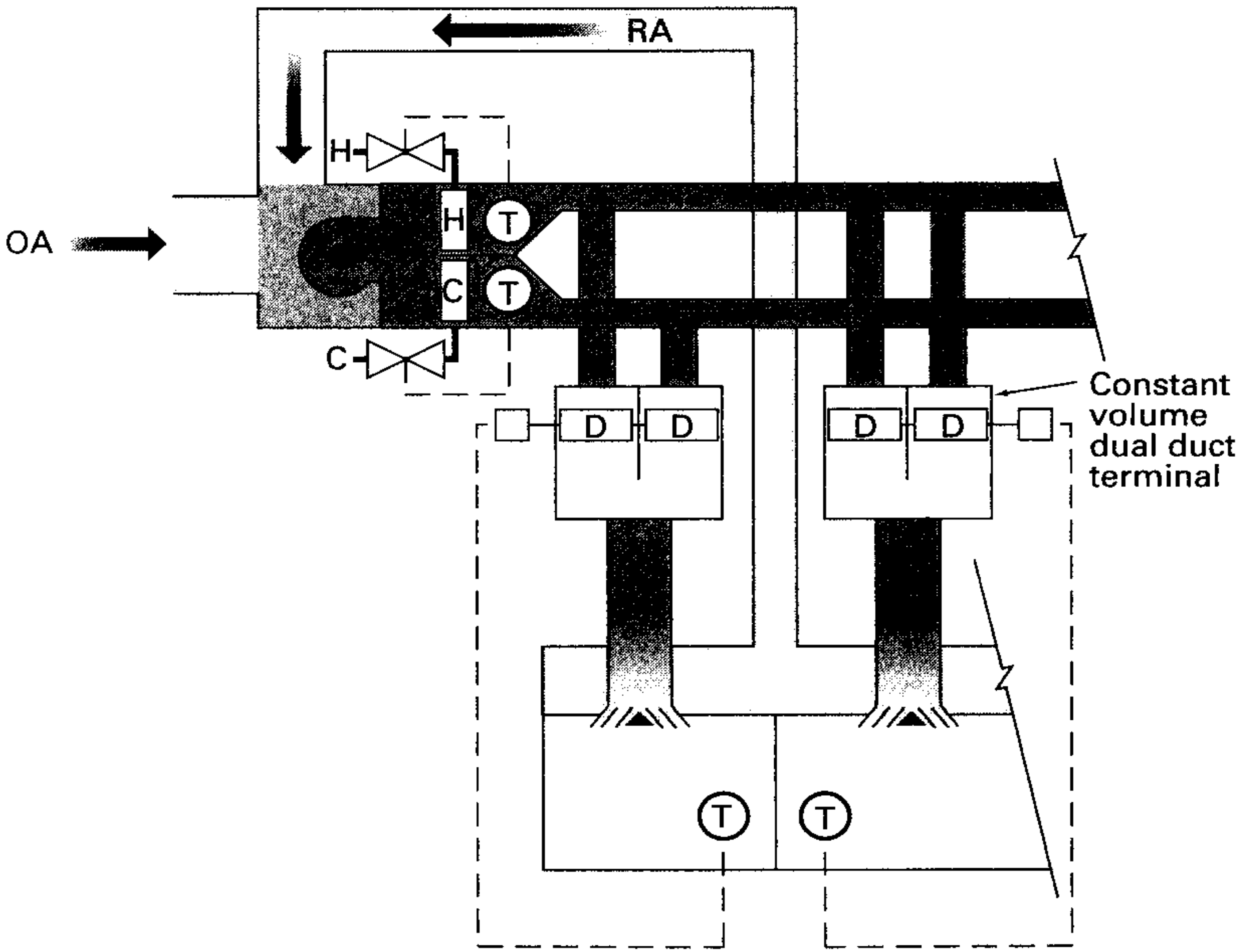
Single Duct, Constant Volume, **Multiple Zone System** with Reheat



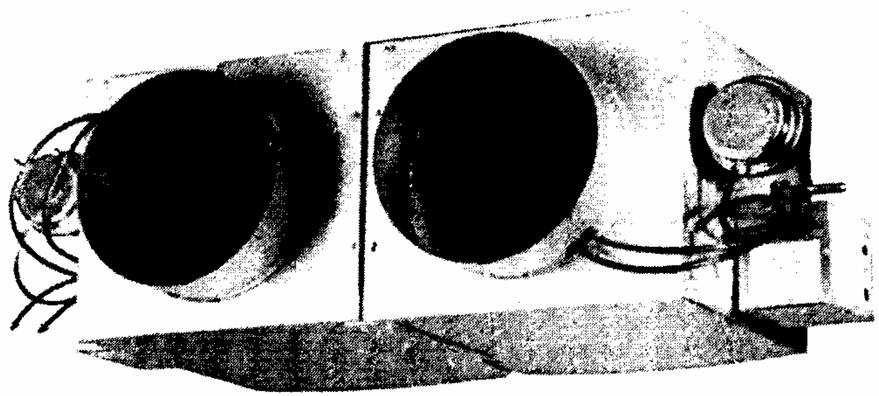
Duct reheat unit

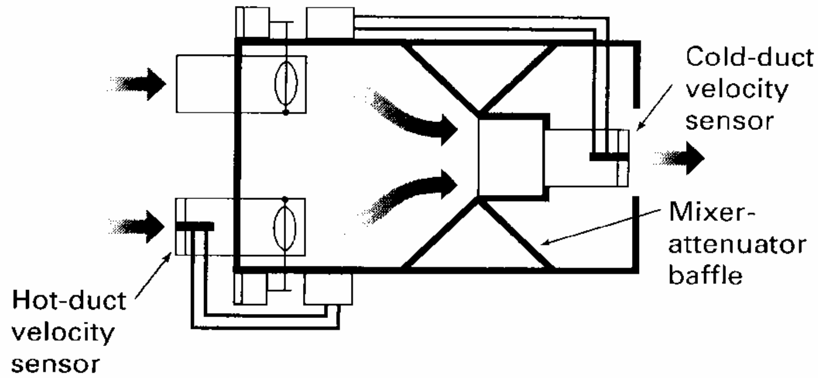


Multizone CAV Dual Duct System



Dual duct terminal (Mixing box)

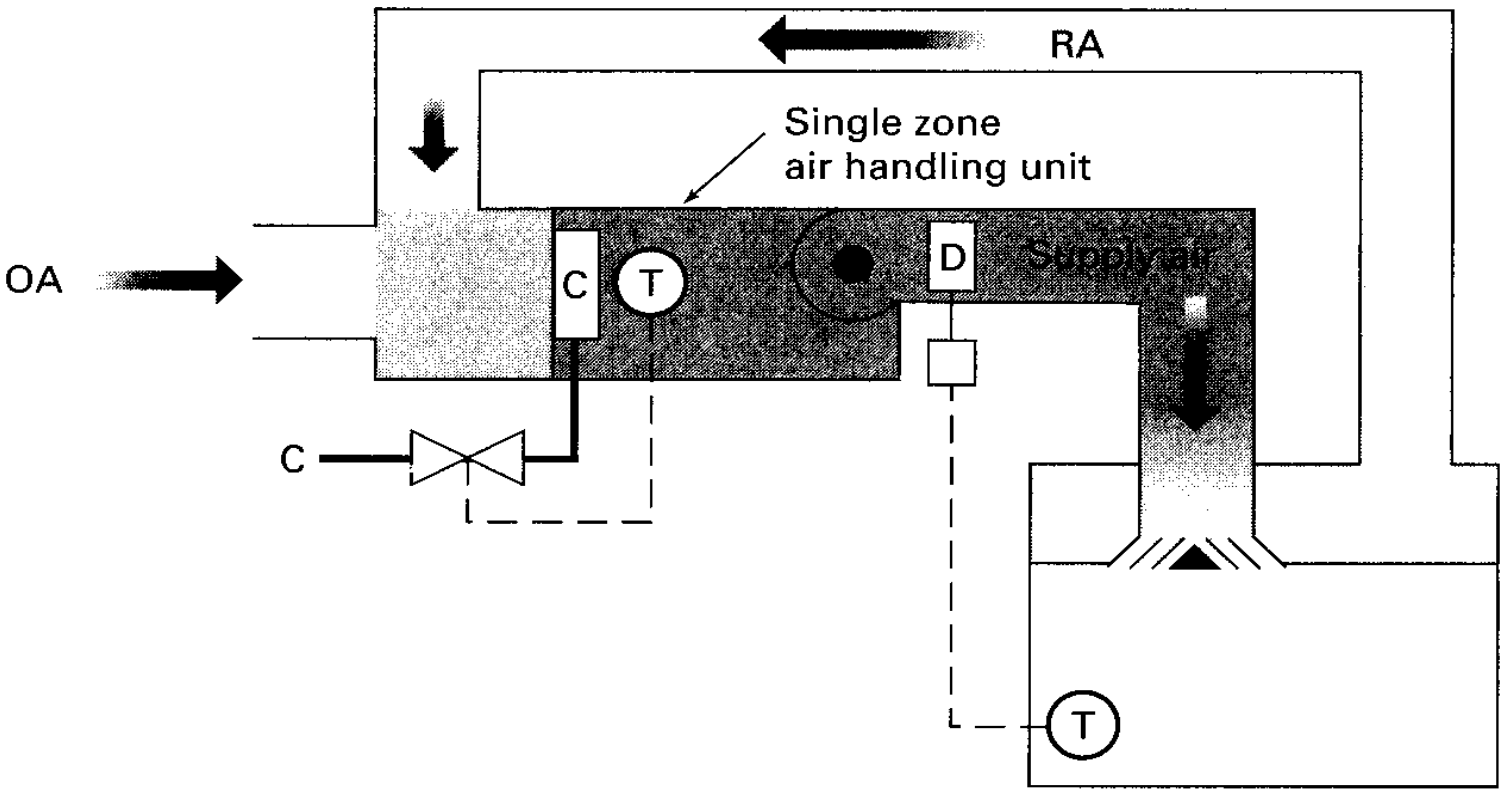




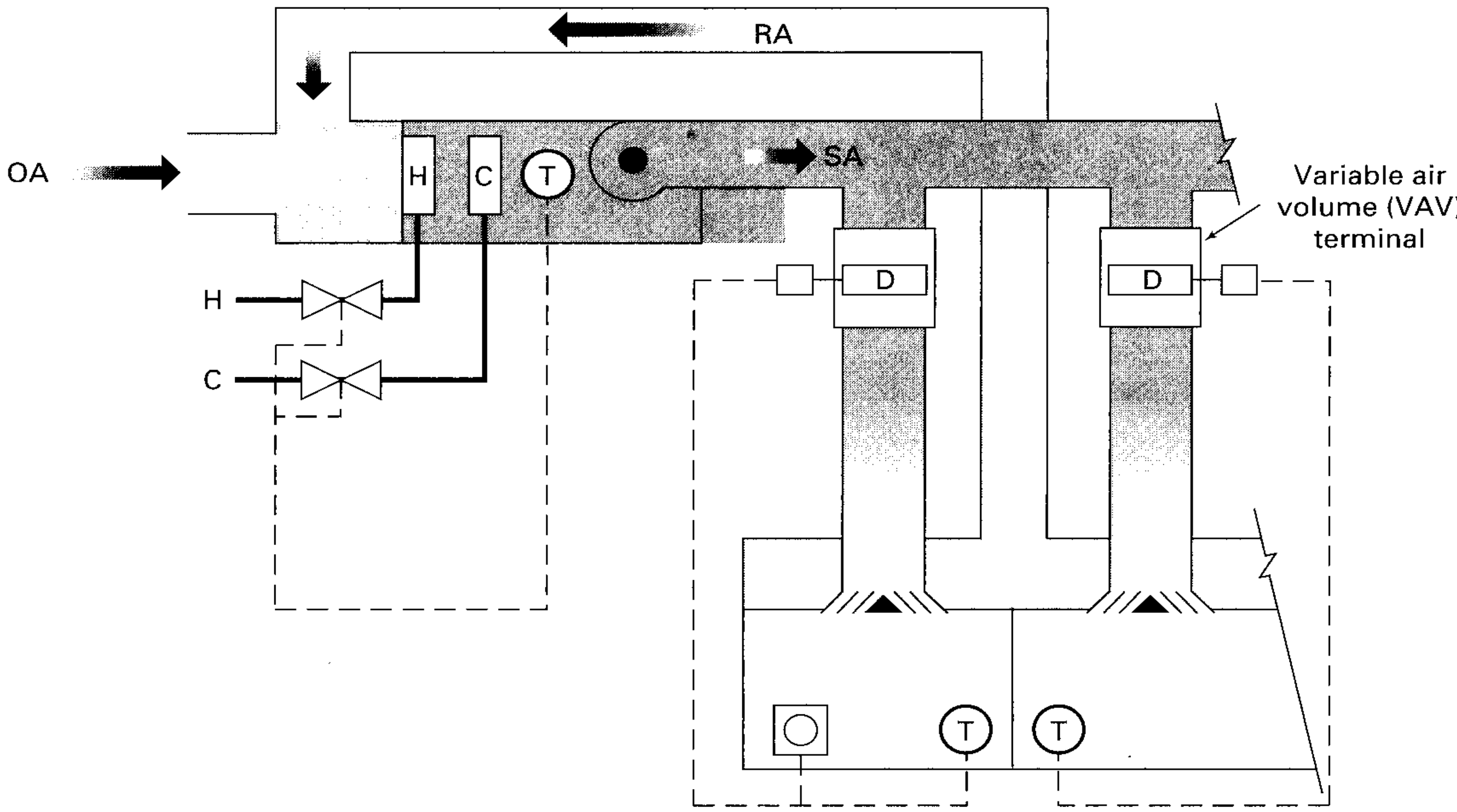
Variable Air Volume (VAV)

- The VAV system is based on the principle of matching the load by varying the air volume supplied to each zone rather than varying the temperature
- The intent is to save fan work energy as compared with a CAV system
- VAV boxes modulate in response to zone demands

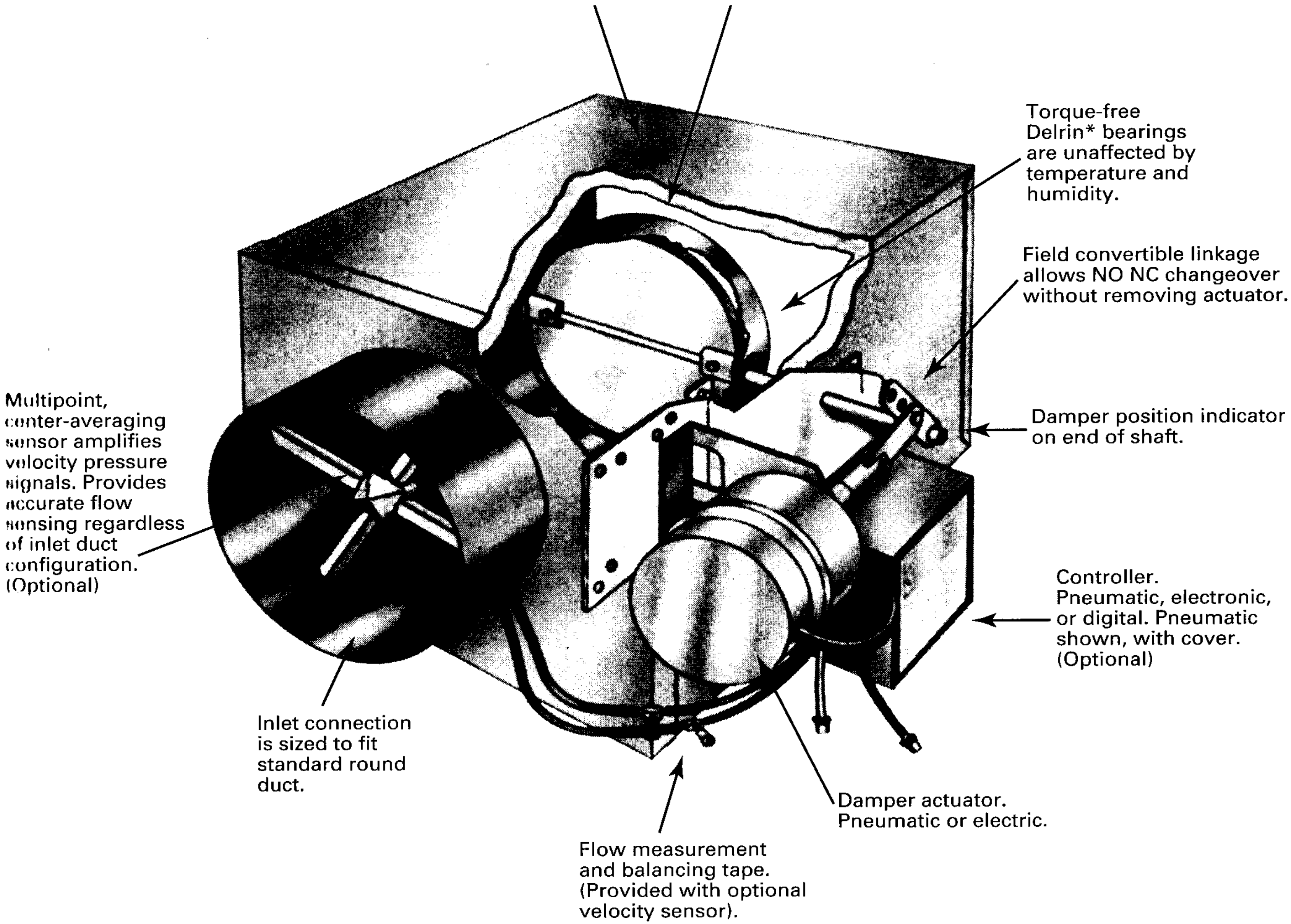
Single zone VAV



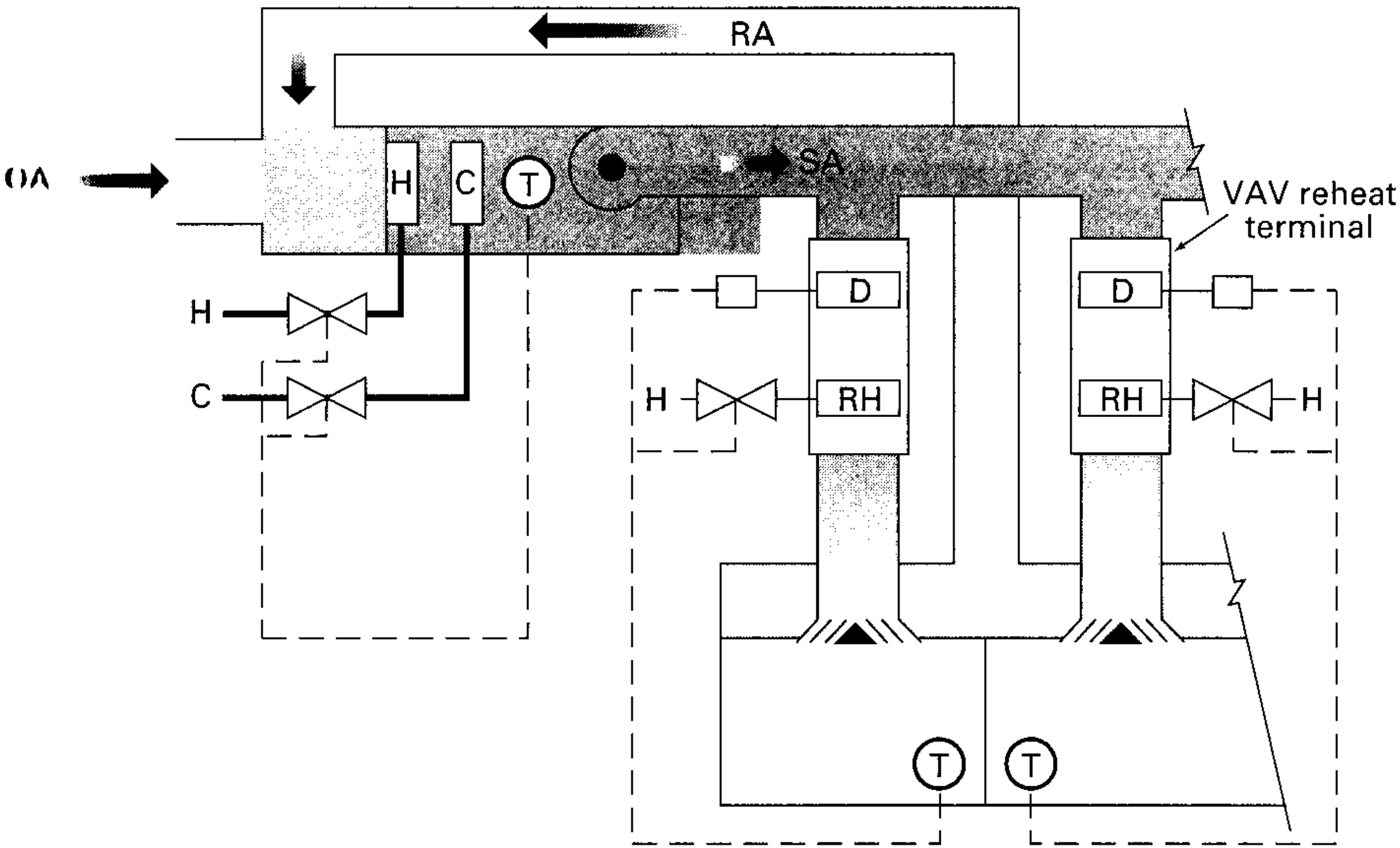
Multi zone VAV



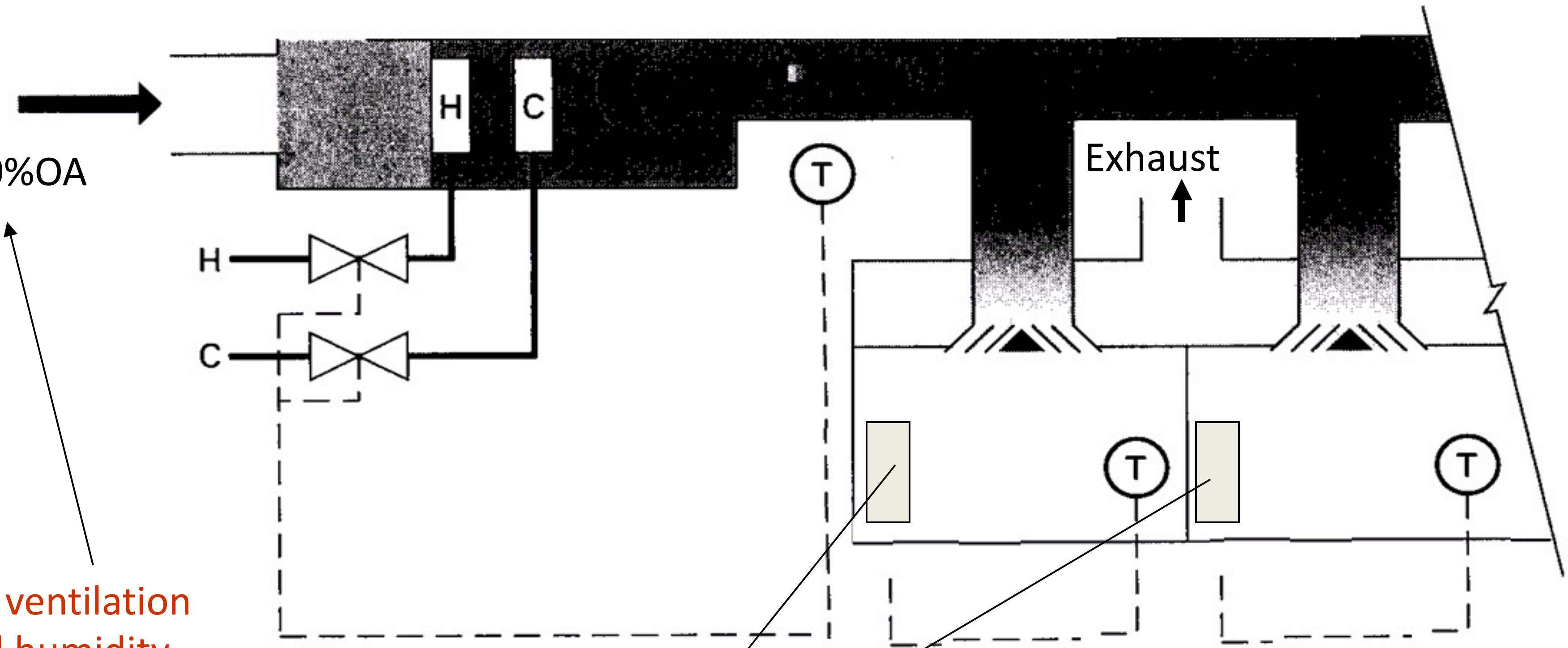
VAV box


Torque-free Delrin* bearings are unaffected by temperature and humidity.
Field convertible linkage allows NO NC changeover without removing actuator.
Damper position indicator on end of shaft.
Multipoint, center-averaging sensor amplifies velocity pressure signals. Provides accurate flow sensing regardless of inlet duct configuration. (Optional)
Controller. Pneumatic, electronic, or digital. Pneumatic shown, with cover. (Optional)
Inlet connection is sized to fit standard round duct.
Damper actuator. Pneumatic or electric.
Flow measurement and balancing tape. (Provided with optional velocity sensor).

Multi zone VAV with Reheater



CAV Dedicated Outdoor Air System (DOAS) with Fan Coil Units



100%OA

For ventilation and humidity control

Fan coil units for heating and cooling

Fan Coil Units

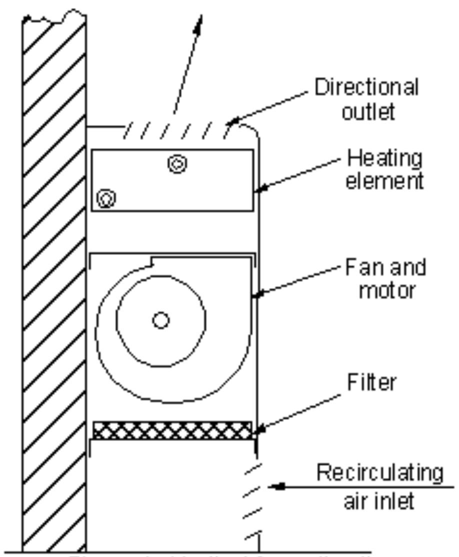
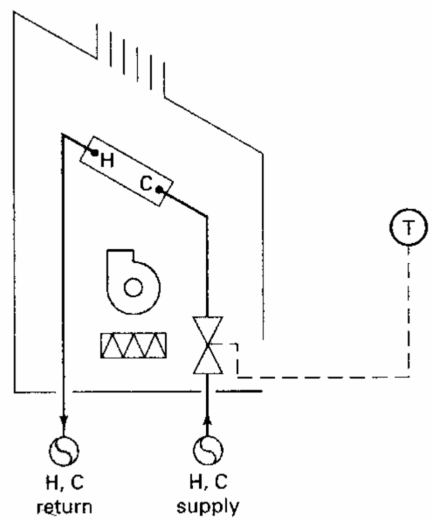
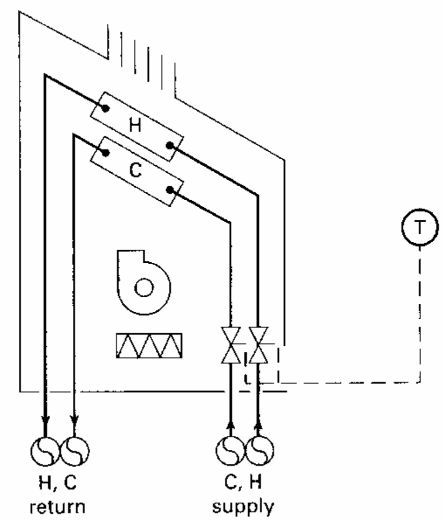


Figure 4. Vertical fan coil unit (Bloomquist, 1987).



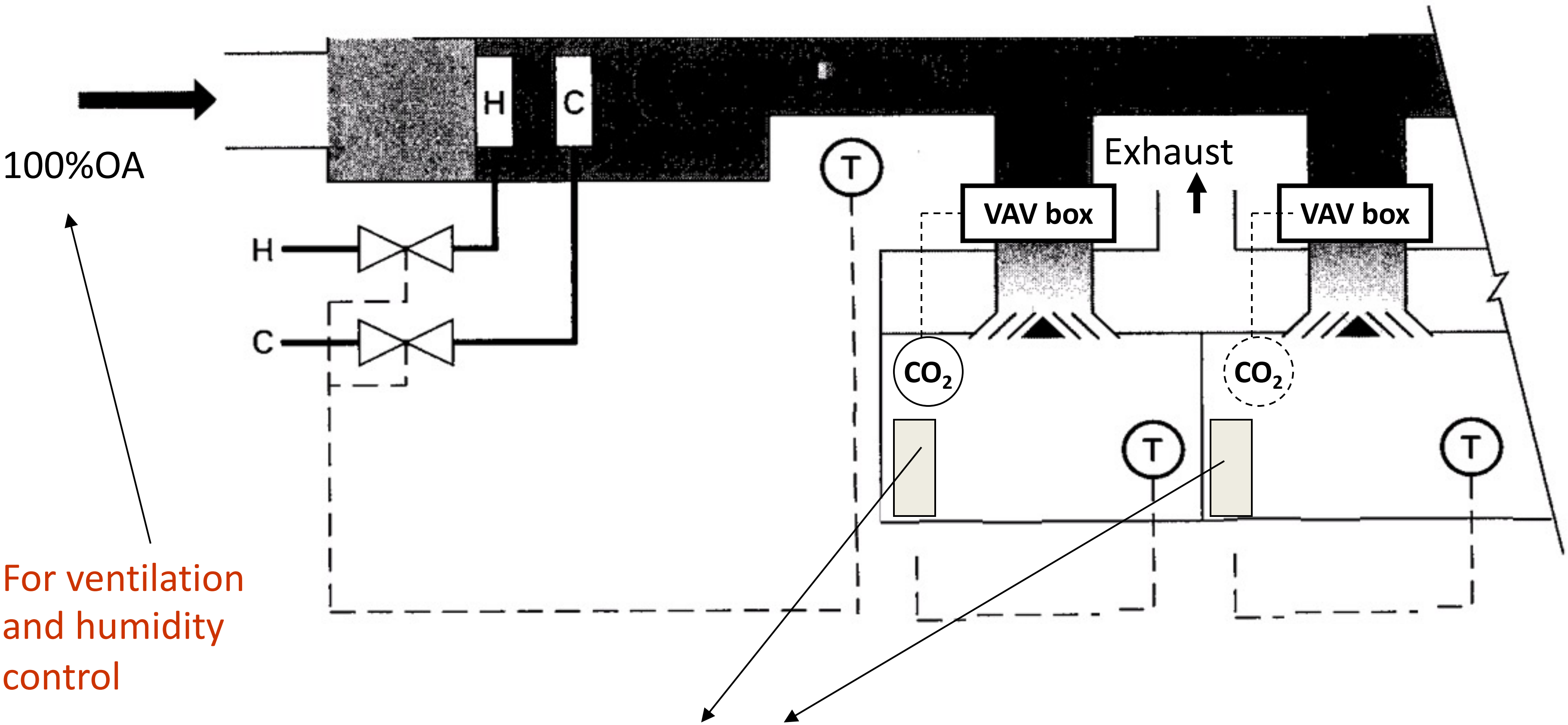
Two-pipe system



Four-pipe system

Fan coil Units can be combined with mechanical ventilation or rely on infiltration

VAV Dedicated Outdoor Air System (DOAS) with occupancy sensors



For ventilation and humidity control

Fan coil units for heating and cooling

f. Terminal Units

- A terminal unit is a part of a larger air-handling system —double-duct, VAV, or CAV
- The terminal unit is installed in or near to the zone which it serves and provides final control of the air temperature and / or air volume in that zone.
- Included in this category are mixing boxes, VAV boxes, terminal reheat coils, and induction units.

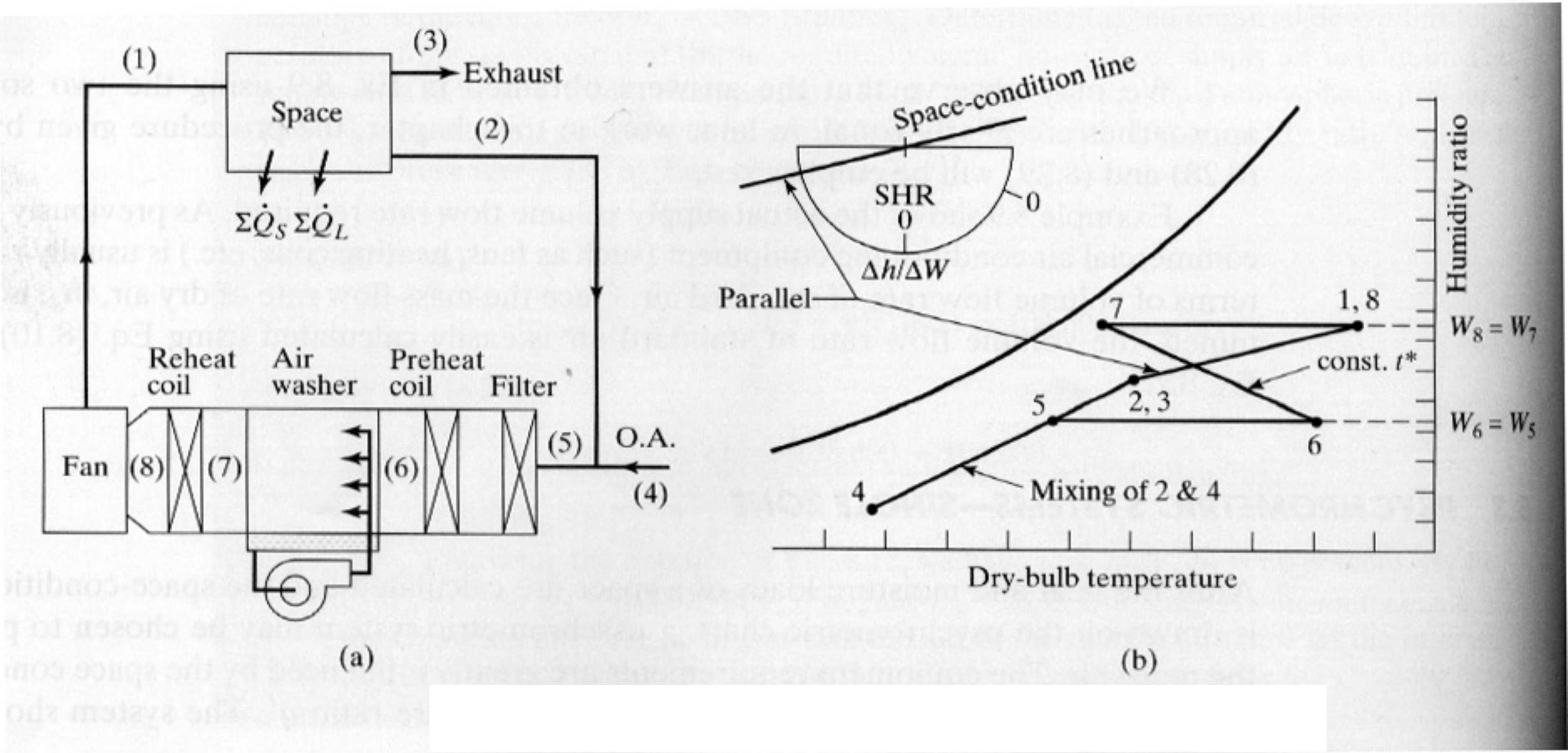
Mixing Boxes

- A mixing box is the section of an air handling unit used to mix the return air flow with the outside air flow.
- It consists of three sets of dampers whose operation is coordinated to control the fraction of the outside air in the supply air while maintaining the supply airflow rate approximately constant.

g. Psychrometrics of HVAC Systems

Single-Zone Systems

- Zone – any space with a thermostat



Air conditioning

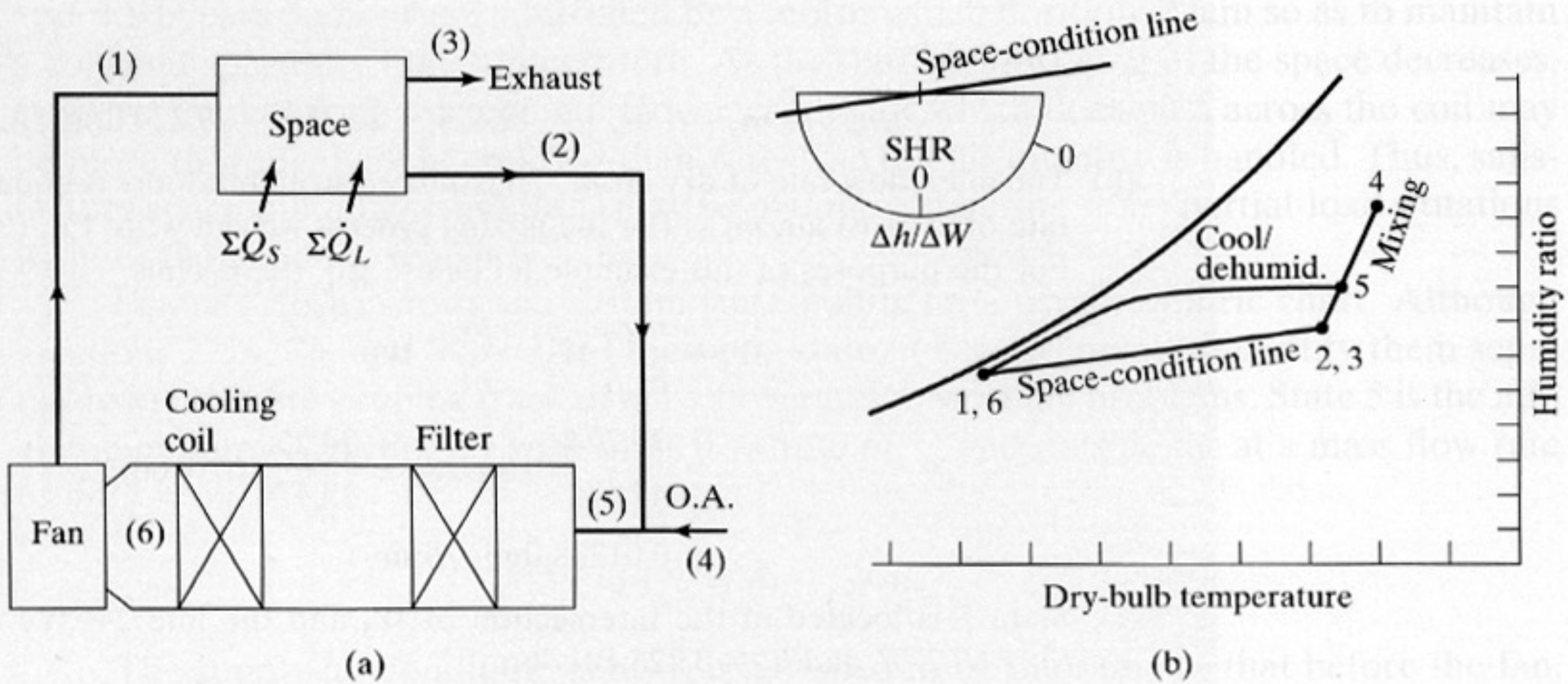


Figure 8.15 Schematic elementary summer air conditioning system.

Recirculation

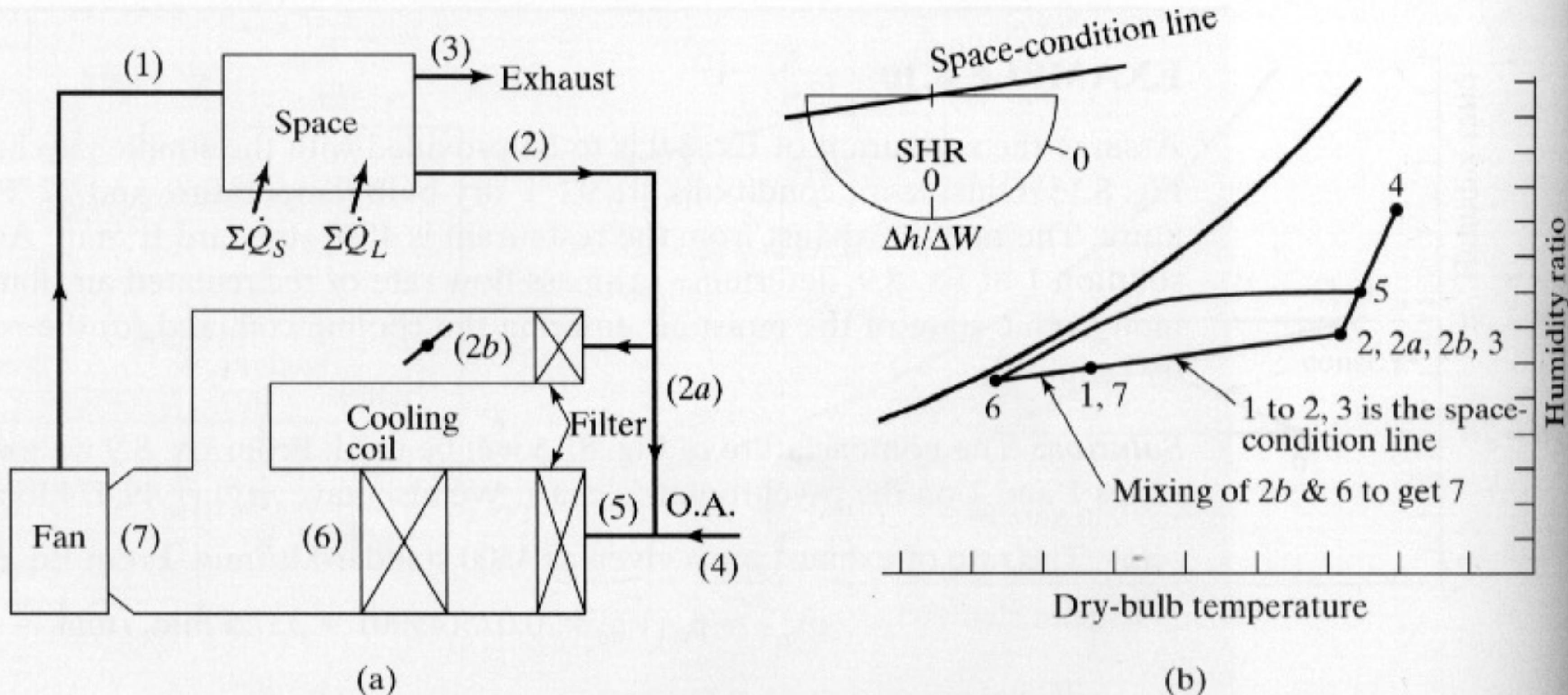


Figure 8.16 Schematic elementary summer air conditioning system with bypass of recirculated air.

Reheat

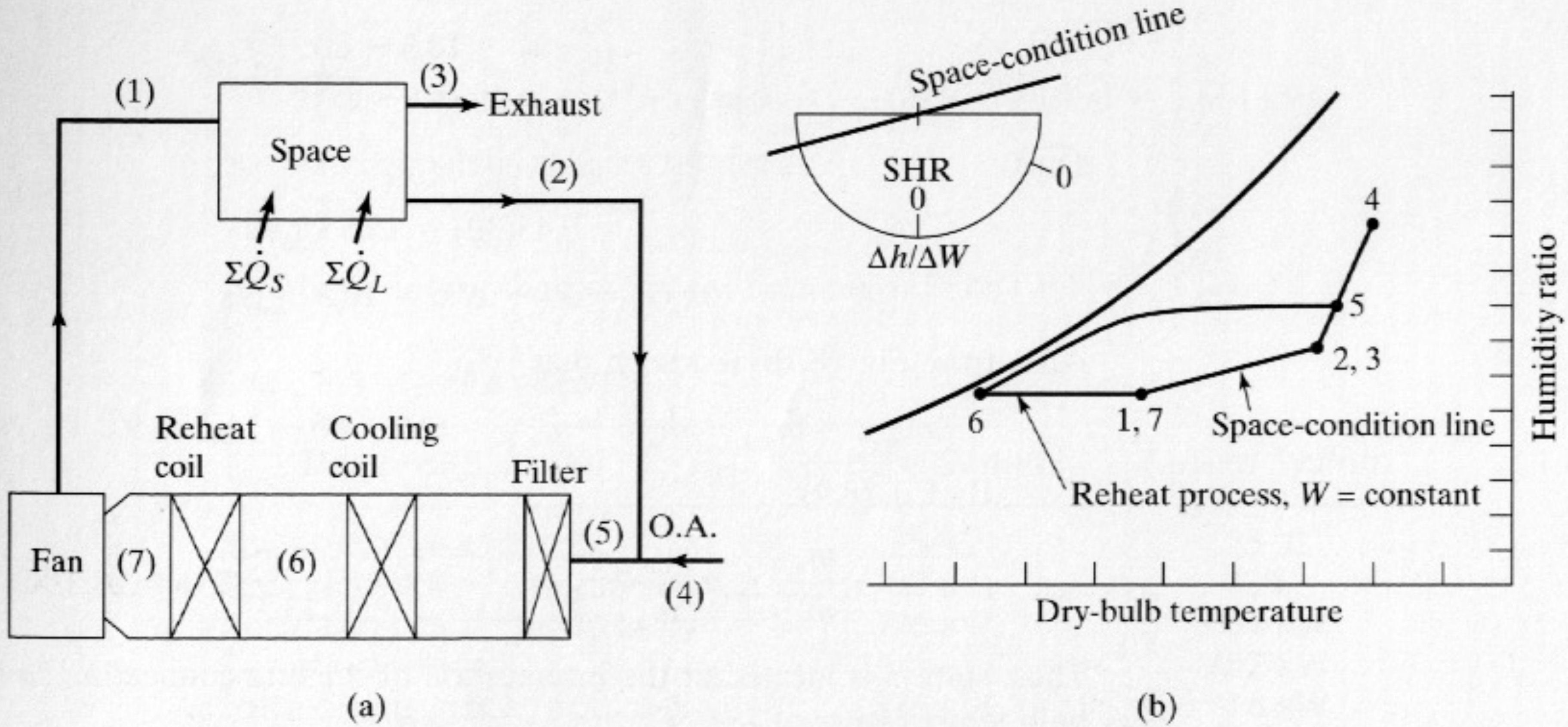


Figure 8.17 Schematic summer air conditioning system with reheat.

Evaporative Cooler

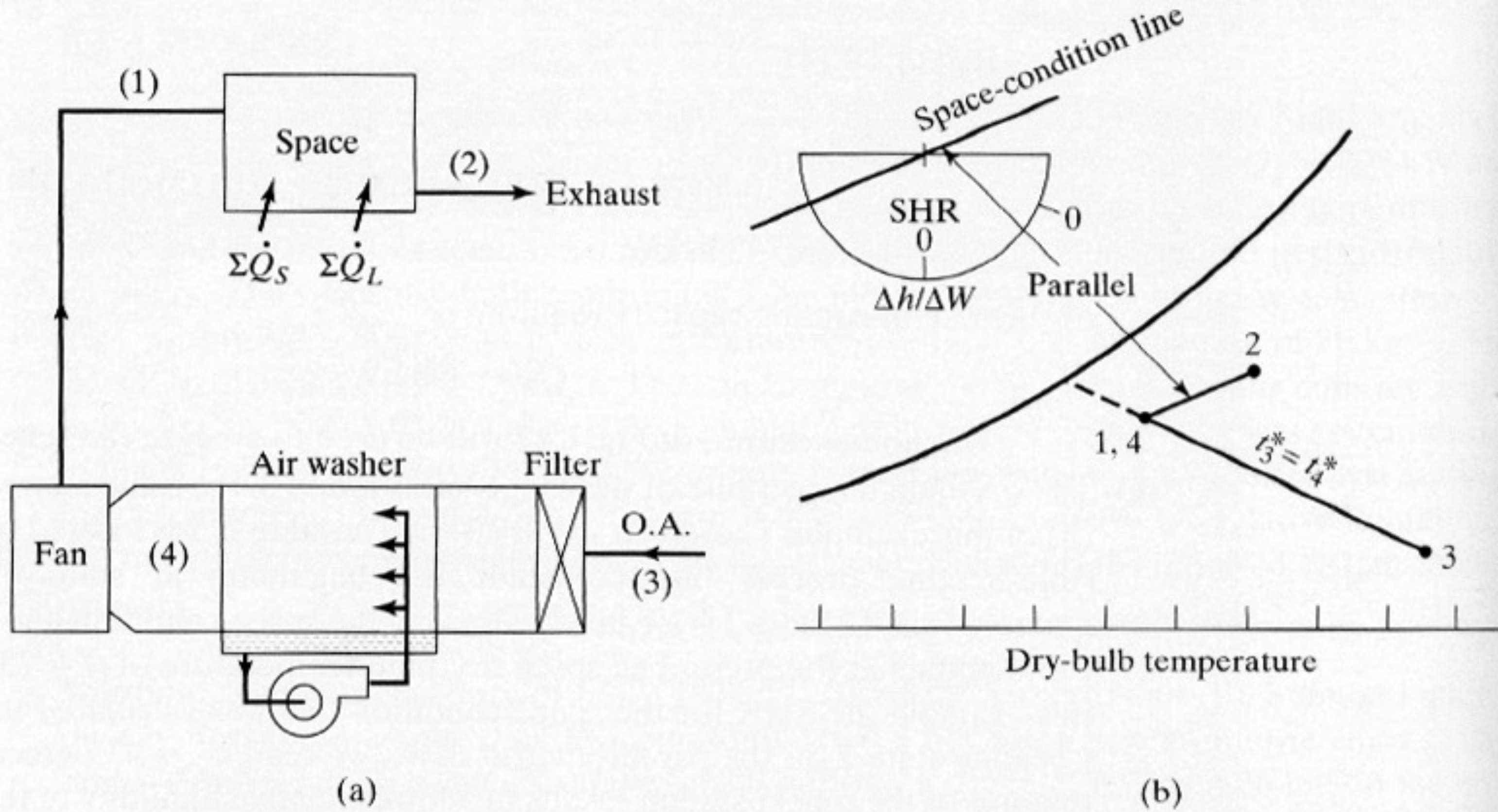


Figure 8.18 Schematic elementary evaporative-cooling system.

Air-to-air heat exchanger

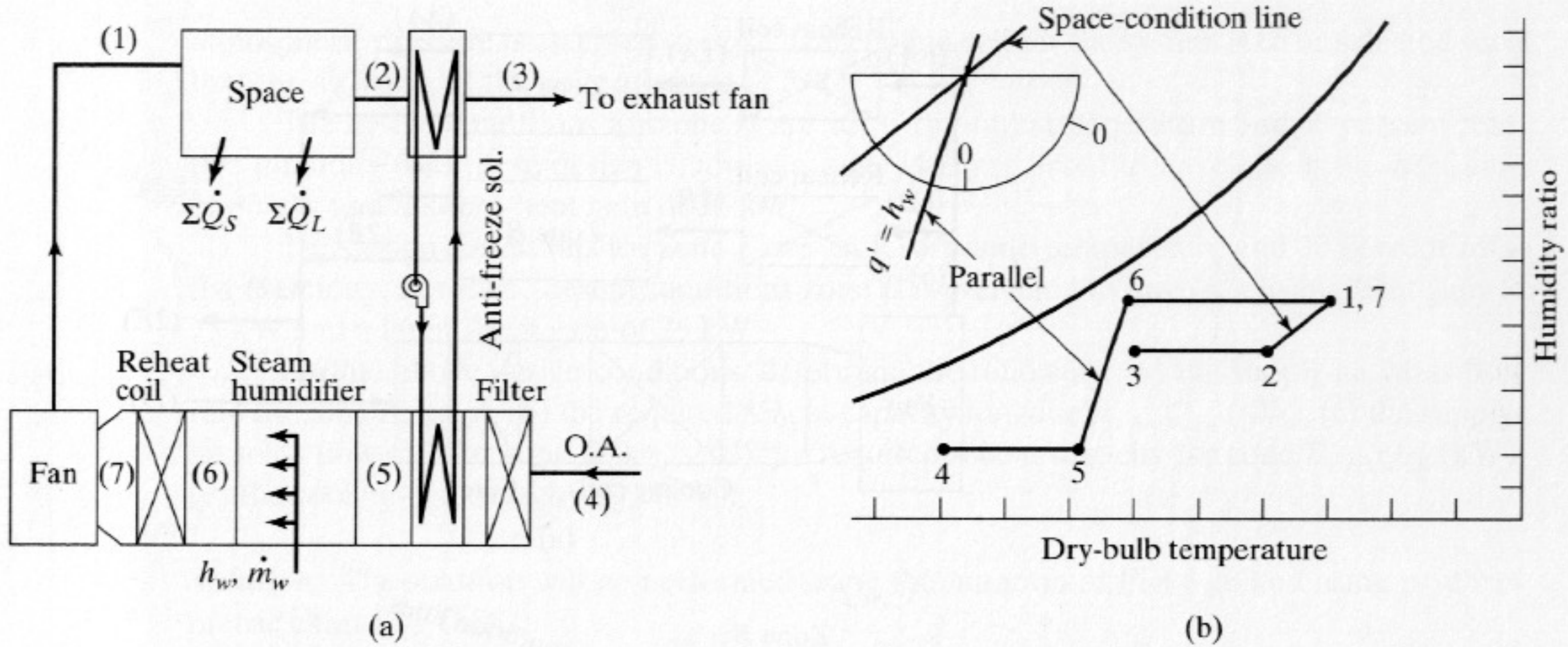


Figure 8.19 Schematic winter air conditioning system using 100 percent outdoor air with preheating by waste heat from the exhaust air.

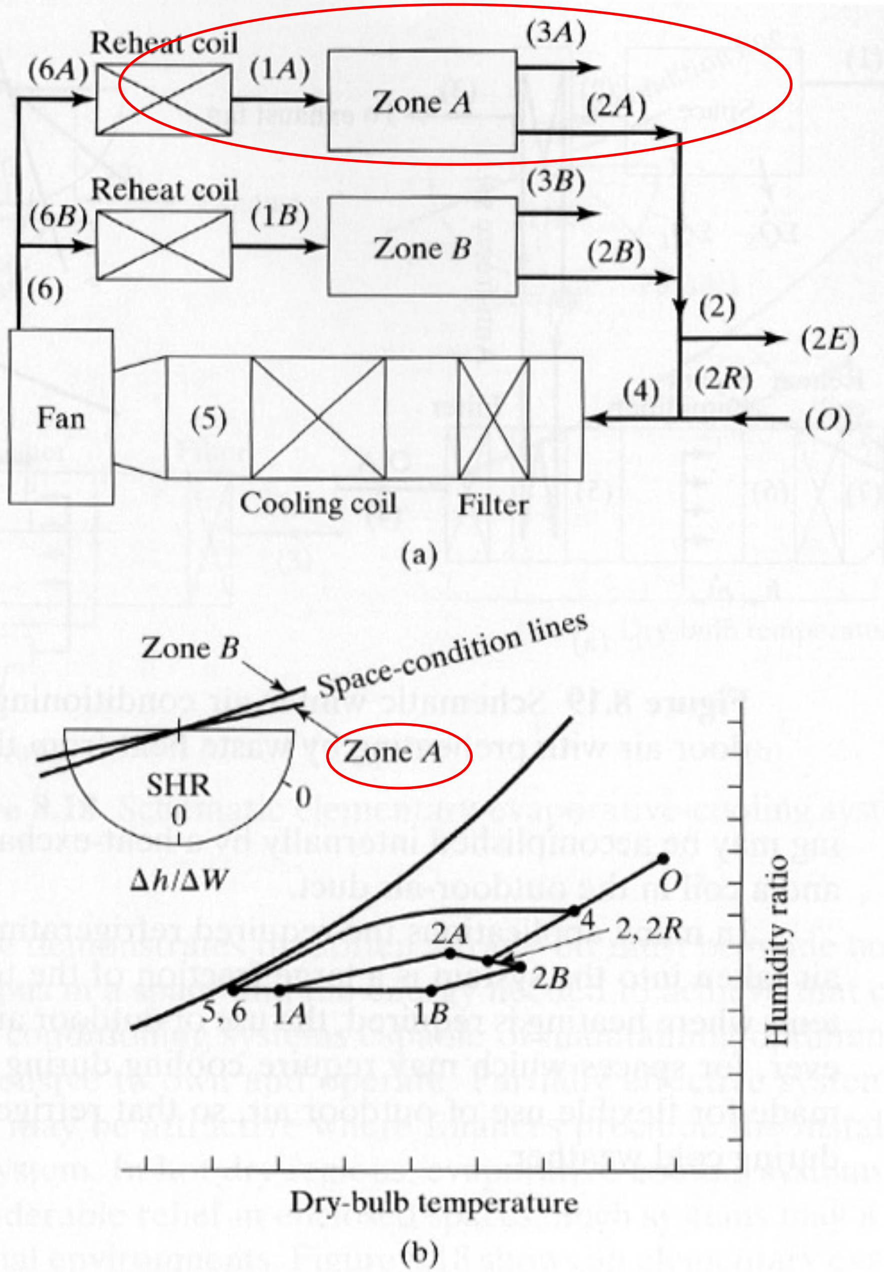


Figure 8.20 Schematic of a two-zone reheat system.

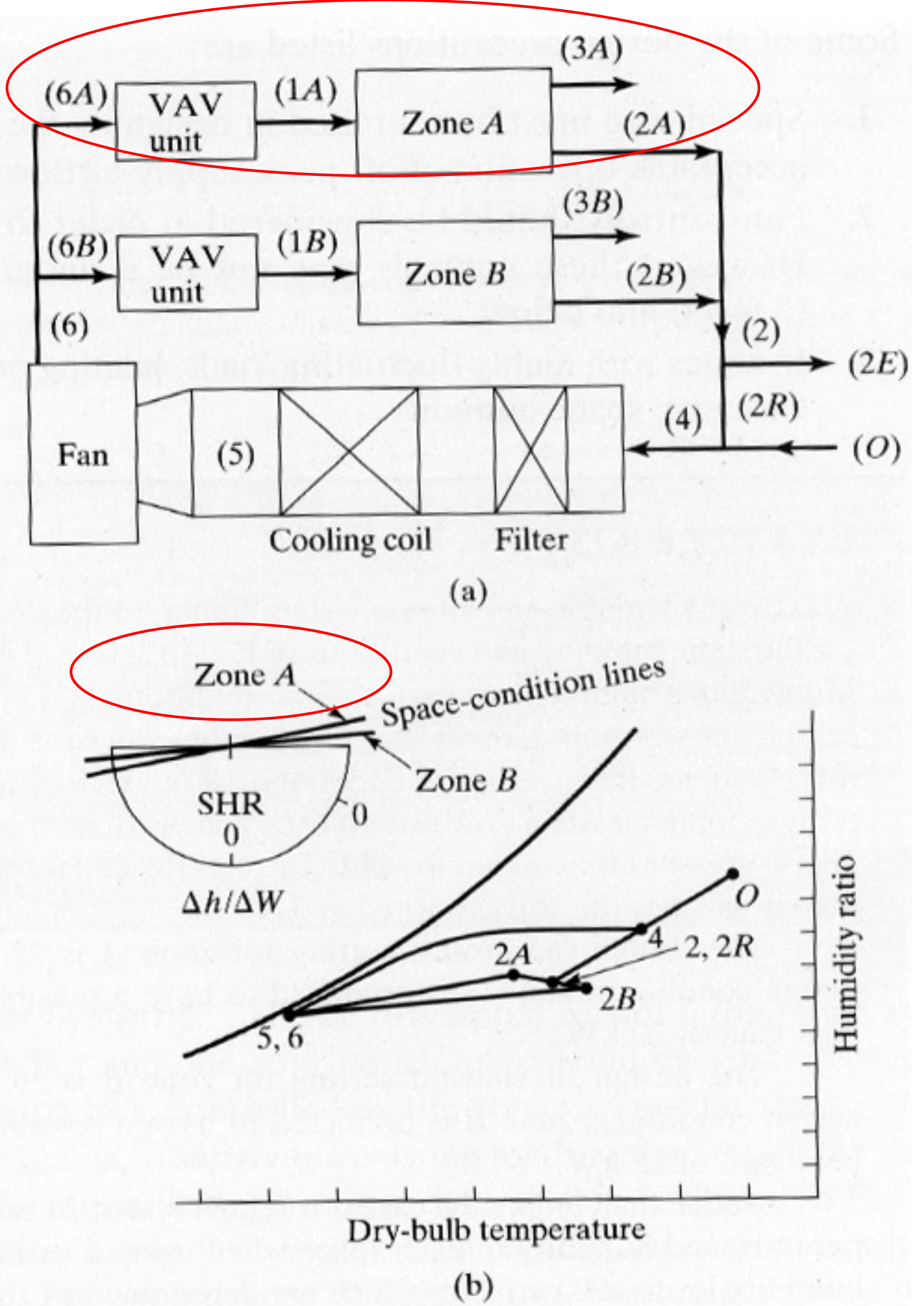


Figure 8.21 Schematic of a two-zone variable-air-volume system.

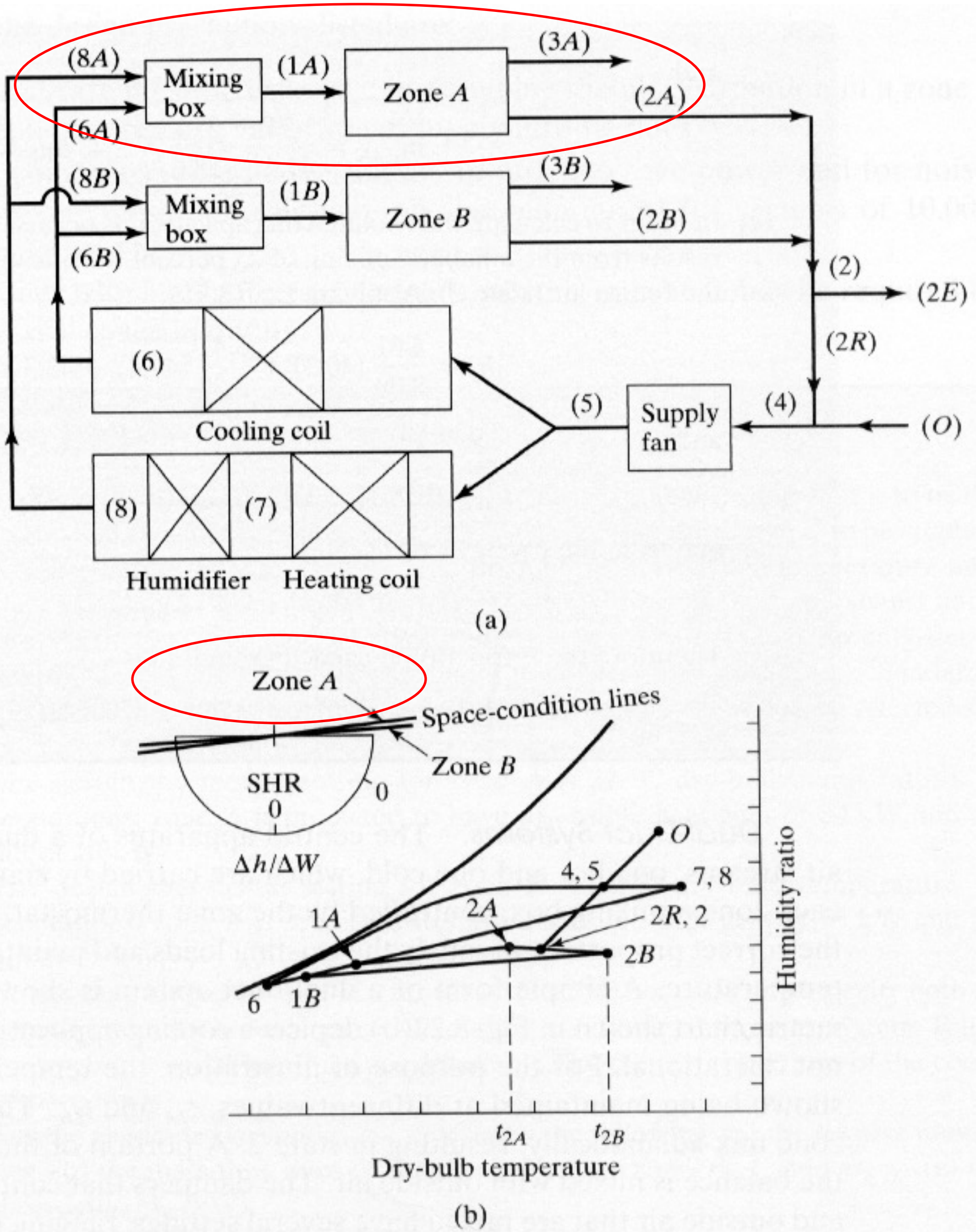


Figure 8.22 Schematic of a two-zone dual-duct system.

Heat recovery by
Air-to-air and air-water-air heat exchanger

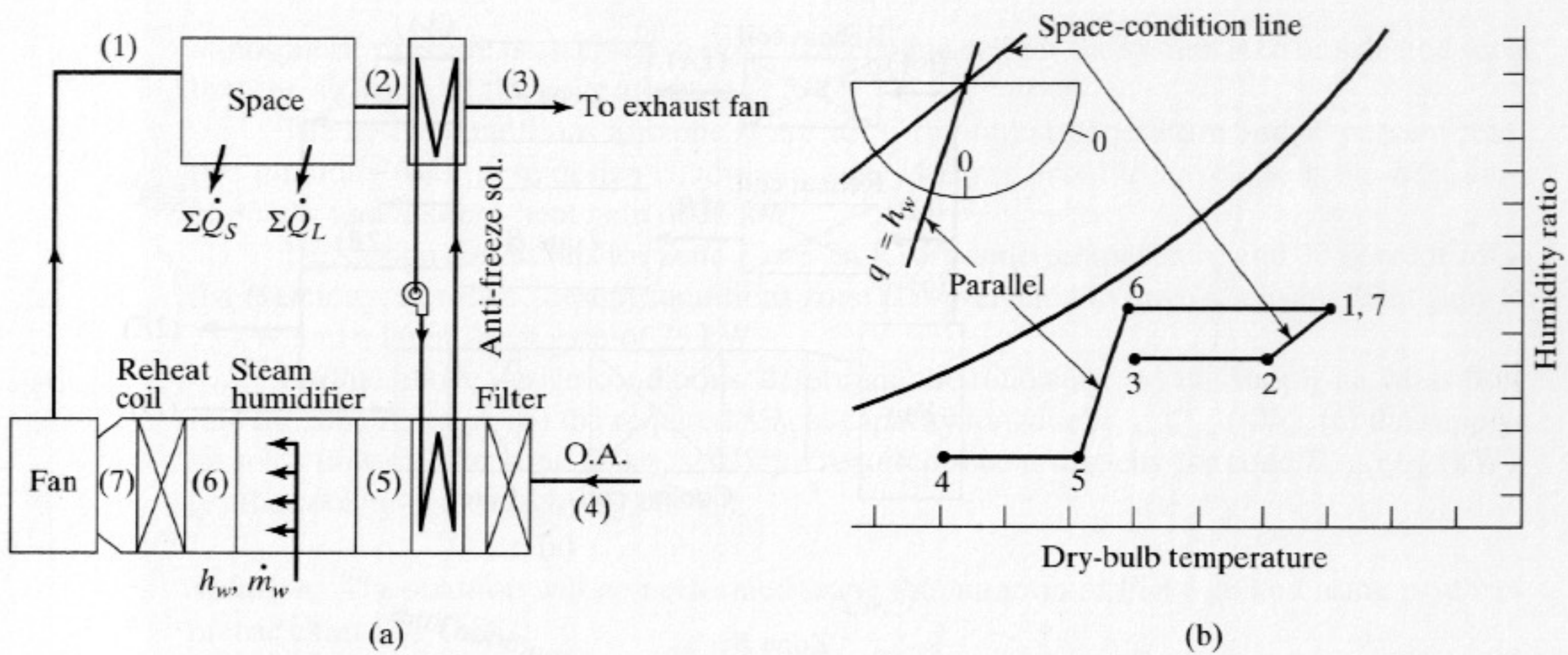


Figure 8.19 Schematic winter air conditioning system using 100 percent outdoor air with preheating by waste heat from the exhaust air.

2. Water Side HVAC Systems

a. Steam Systems
b. Condenser Water Systems
c. Variable Refrigerant Flow (VRF) System
d. Hydronic System
e. HVAC System Types
    a. Cooling Source
    b. Heating Source

Introduction

- Most air-handling units and terminal units require a *source* of heating and/or cooling energy.
- This *source* is called a Central Plant
- The means by which thermal energy is transferred is by fluid conveyed through a piping system.
- Fluids used in HVAC practice are steam, hot or cold water, refrigerant, brine, or a combination of these

a. Steam Systems

- Stream is water in vapor form
- Steam conveys heat very efficiently
- Steam has many performance advantages for the delivery of energy:
  - Low toxicity
  - Ease of transportability
  - High heat capacity
  - Heat content of steam is stored as latent heat and that means that heat can be transferred efficiently at a constant temperature

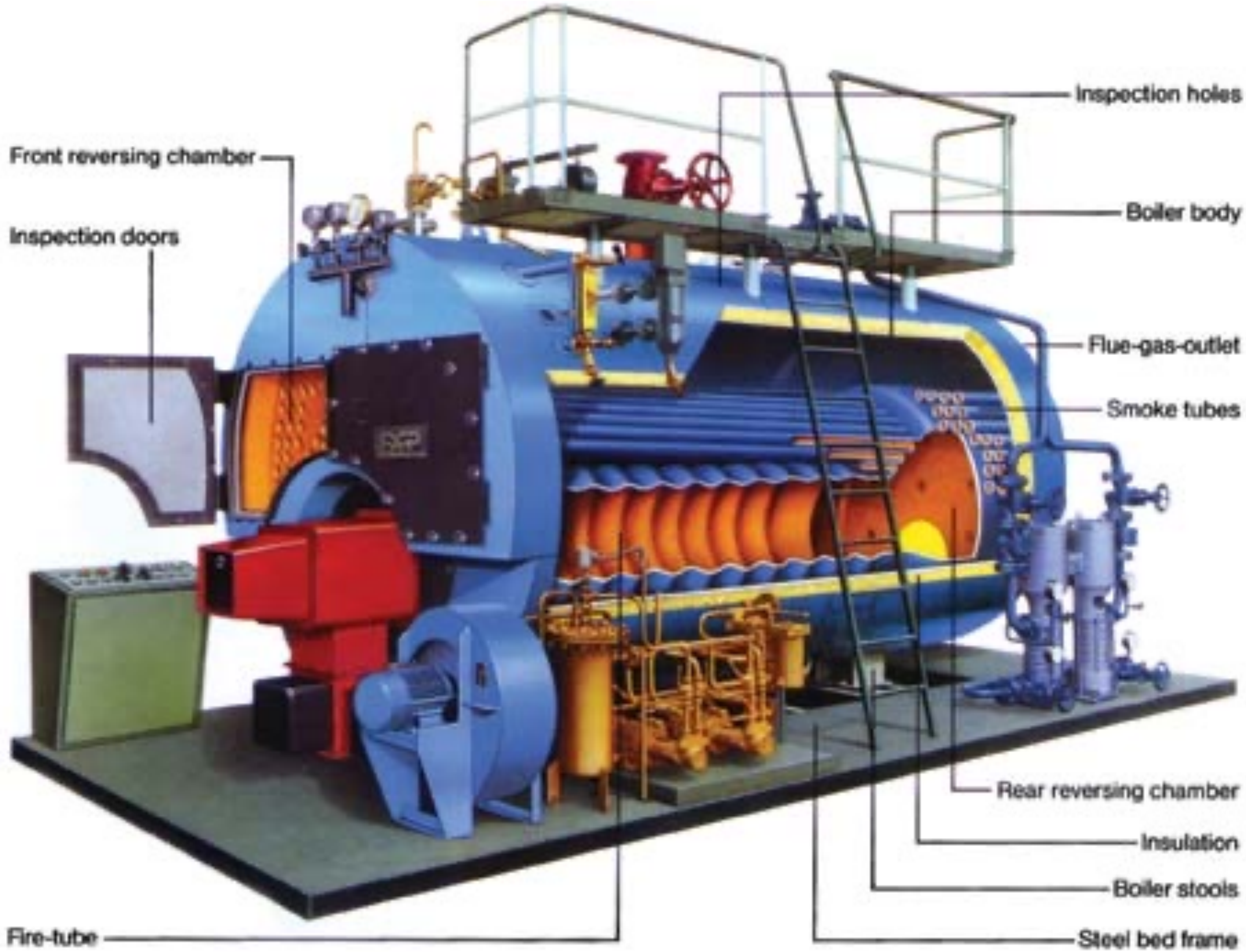
Steam Source: Generation

- Steam is typically generated in a boiler by transferring the heat of combustion gases to water
- When water absorbs enough heat, it changes phases from liquid to steam
- Under pressure, the steam flows from the boiler into the distribution system

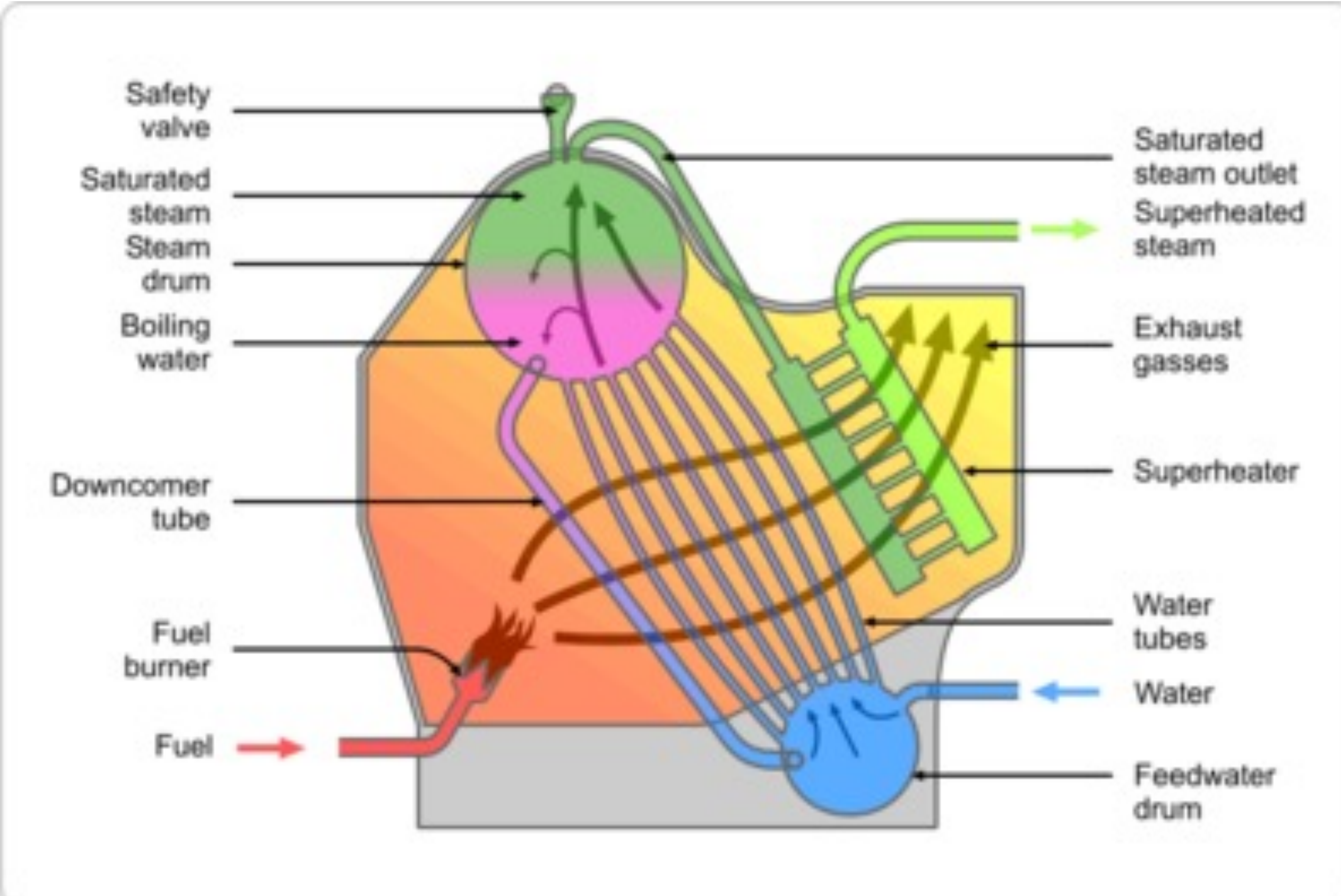
Boilers

- There are two basic types of boilers: Firetube and Watertube
- The basic difference is which side of the boiler tubes contains the combustion gases or the boiler water/steam
  - Firetube: combustion gases pass inside the boiler tubes and heat is transferred to water on the shell side
  - Watertube: boiler water passes through the tubes while the exhaust gases remain in the shell side passing over tube surfaces

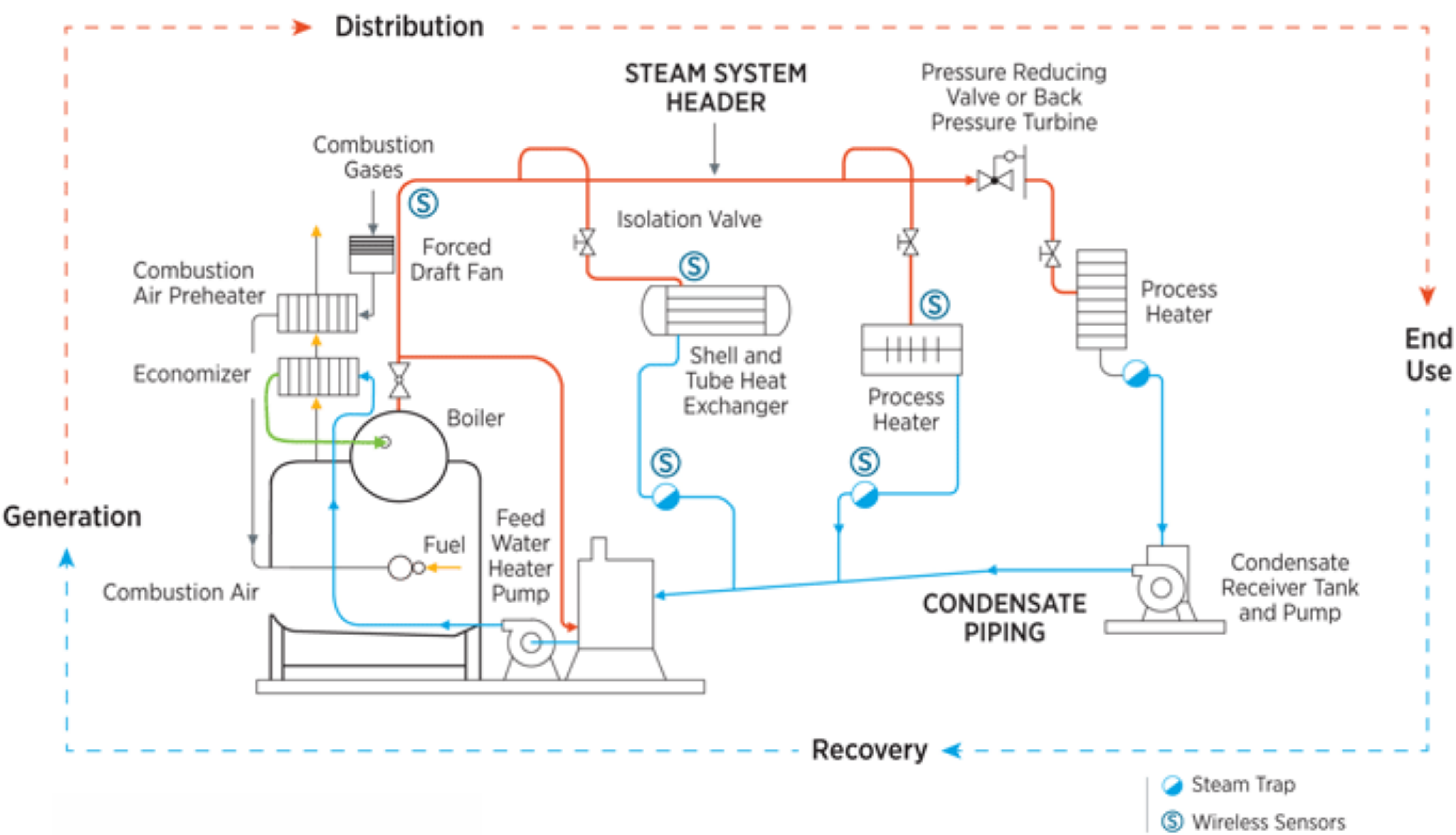
Firetube Boiler



Watertube Boiler



Steam System Schematic



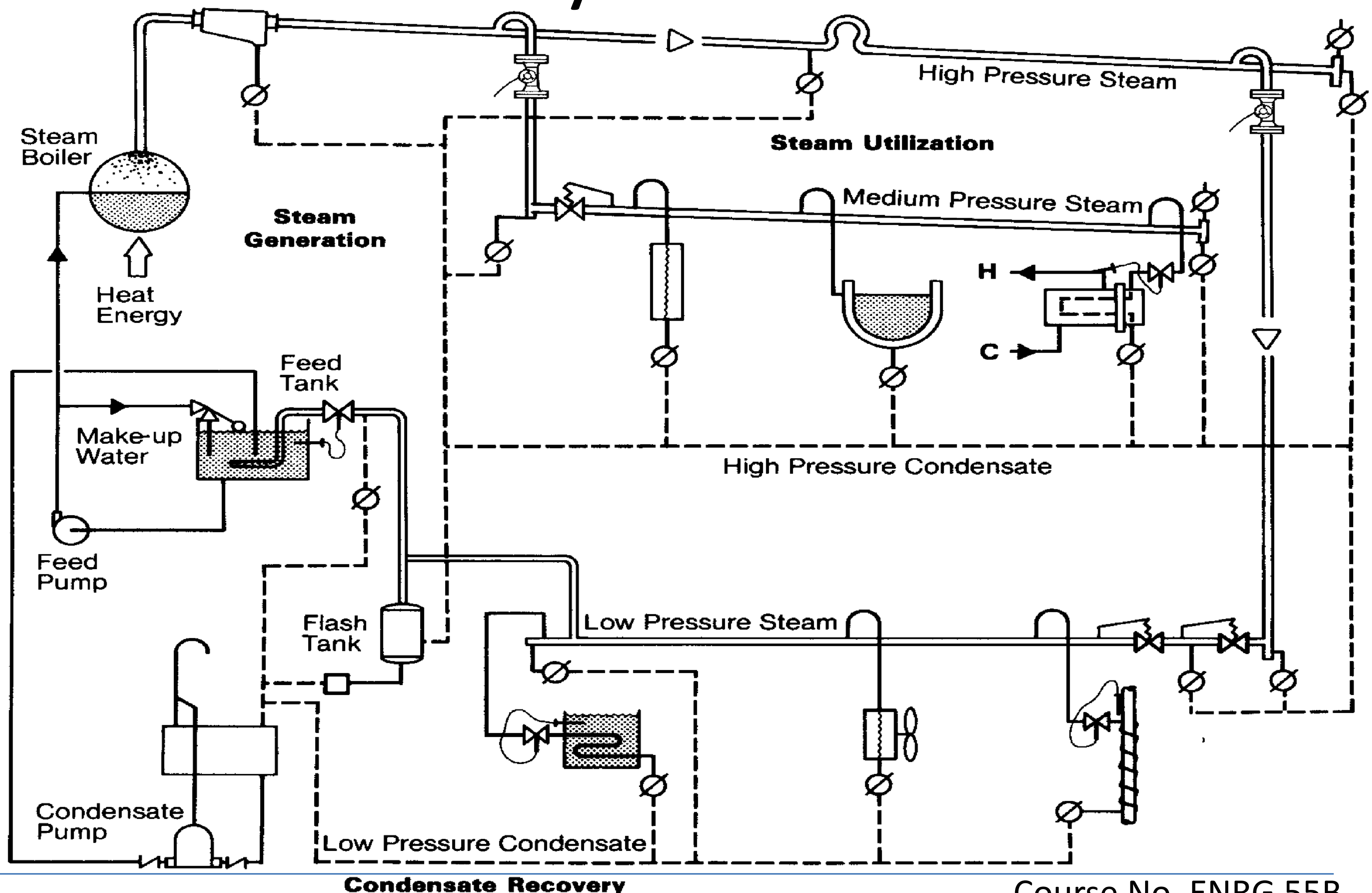
Steam Distribution

- Distribution system carries steam from the boiler to the points of end use
- Many distribution systems have several take-off lines that operate at different pressures
  - These distribution lines are separated by various types of isolation valves, pressure-regulating valves, and, sometimes, backpressure turbines
- A properly performing distribution system delivers sufficient quantities of high quality steam at the right pressures and temperatures to the end uses
- Effective distribution system performance requires proper steam pressure balance, good condensate drainage, adequate insulation, and pressure regulation

Steam Distribution

- Proper performance of distribution system requires careful design practice
  - Piping needs to be properly sized, supported, insulated, and configured
  - Pressure-regulating devices, like valves, should be configured for proper balance
  - System should be configured to allow adequate condensate drainage
- There are three types of distribution systems:
  - Buried pipe, above ground, and building sections

Basic Steam System Connections



Boiler Connection Components

- Piping transports the steam from boiler to end-use services.
- Thermal insulation provides safety, energy saving, and performance benefits
- Valves isolate equipment and regulate flow to prevent over pressurization
  - Types of valves: gate, globe, swing check, pressure relief
- Steam separators remove water droplets
- Steam traps allow air and large quantities of condensate to escape

Steam System: End Uses

- Steam system end-use equipment transfers steam energy into other forms of useful energy
- Common end-use equipment includes heat exchange devised to transfer thermal energy and turbines to recover mechanical energy
- A sample list of steam-supplied end-use equipment is provided below

Equipment	Process Application	Industry
Condenser	Steam turbine operation	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Distillation tower	Distillation, fractionation	Chemical Manufacturing, Petroleum Refining
Dryer	Drying	Forest Products
Evaporator	Evaporation/concentration	Chemical Manufacturing, Forest Products Petroleum Refining
Process heat exchanger	Alkylation, Process air heating, Process water heating, Gas recovery/Light ends distillation, Isomerization, Storage tank heating Visbreaking/Coking	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Reboiler	Fractionation	Petroleum Refining
Reformer	Hydrogen generation	Chemical Manufacturing, Petroleum Refining
Separator	Component separation	Chemical Manufacturing, Forest Products, Petroleum Refining
Steam ejector	Condenser operation, Vacuum distillation	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Steam injector	Agitation/blending, Heating	Chemical Manufacturing, Forest Products, Petroleum Refining
Steam turbine	Power generation, Compressor mechanical drive, Hydrocracking, Naphtha reforming, Pump mechanical drive, Feed pump mechanical drive	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Stripper	Distillation (crude and vacuum units), Catalytic cracking, Asphalt processing, Catalytic reforming, Component removal, Component separation, Fractionation, Hydrogen treatment, Lube oil processing	Chemical Manufacturing, Petroleum Refining
Thermocompressor	Drying, Steam pressure amplification	Forest Products

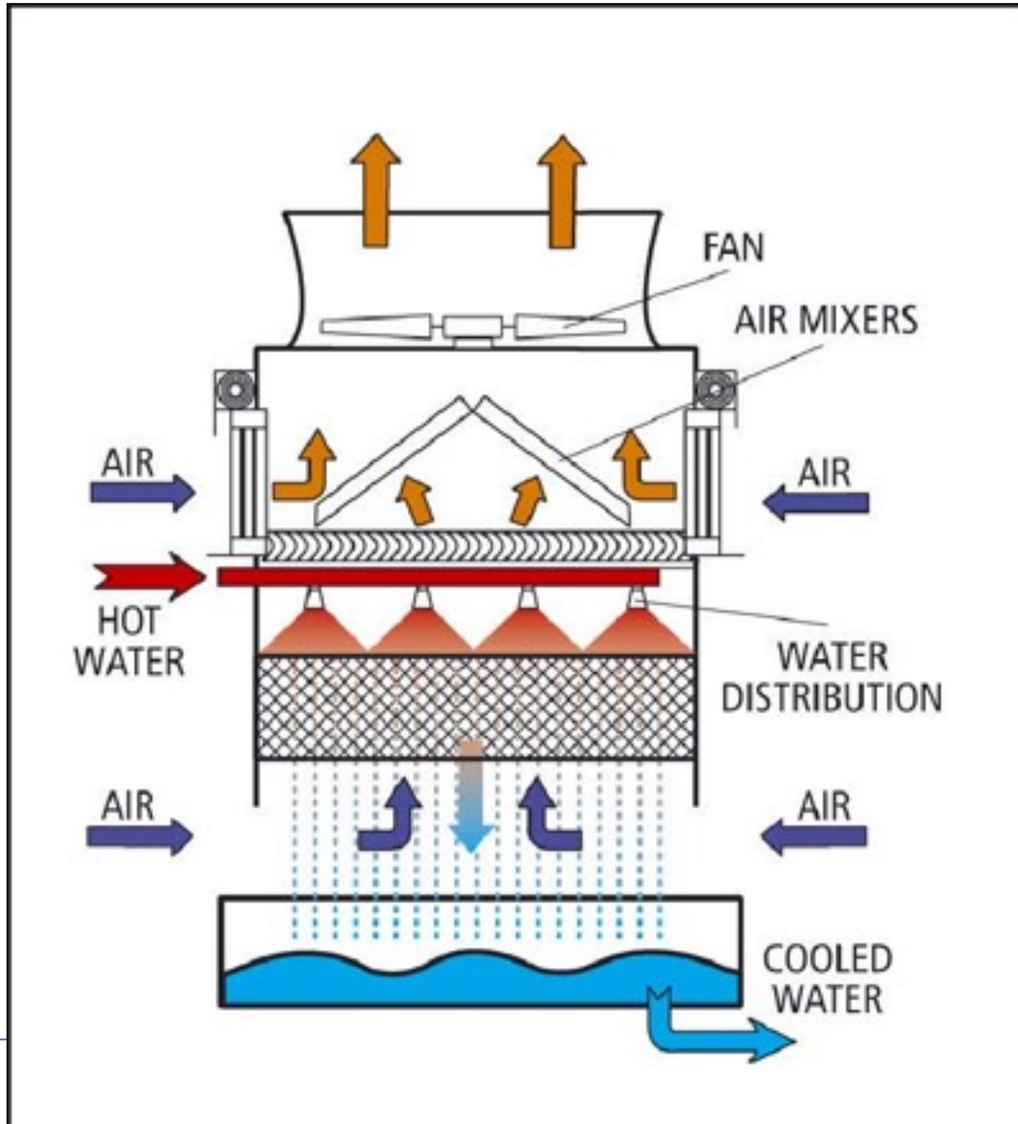
Condenser Water Systems

- The condenser is the system component responsible for rejecting system heat
- Condensers reject both latent and sensible heat
- Water-cooled condensers are more efficient than air-cooled condensers
- Three types of water-cooled condensers are the tube within a tube, shell and coil, and the shell and tube
- Mineral deposits in the water circuit reduce the heat transfer rate between the water and the refrigerant

Open Cooling Tower System

- A cooling tower is a device for cooling a stream of water by evaporating a portion of the circulated stream
- Open cooling towers reject heat from water-cooled systems into the atmosphere
- Hot water from the system enters the cooling tower and is distributed over the wet deck.
- Air is pulled or pushed through the wet deck, causing a small portion of the water to evaporate
- Evaporation removes heat from the remaining water, which is collected in the cold water basin and returned to the system to absorb more heat.

Open Cooling Tower

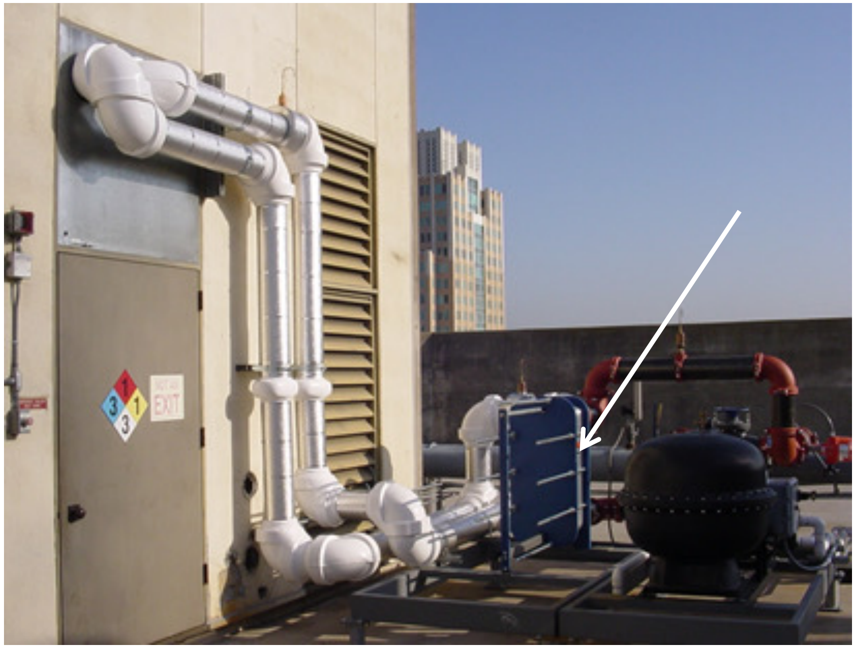


Low Temperature Condenser System Waterside Economizer

- System saves cooling energy by circulating water that is cooled by the cooling tower directly when the outside air temperature is suitable, or low.
- System is designed in two configurations
  – Flat plate heat exchanger
  – Closed loop evaporative water cooler

Low Temperature Condensers Waterside Economizers

Flat Plate



Closed Loop

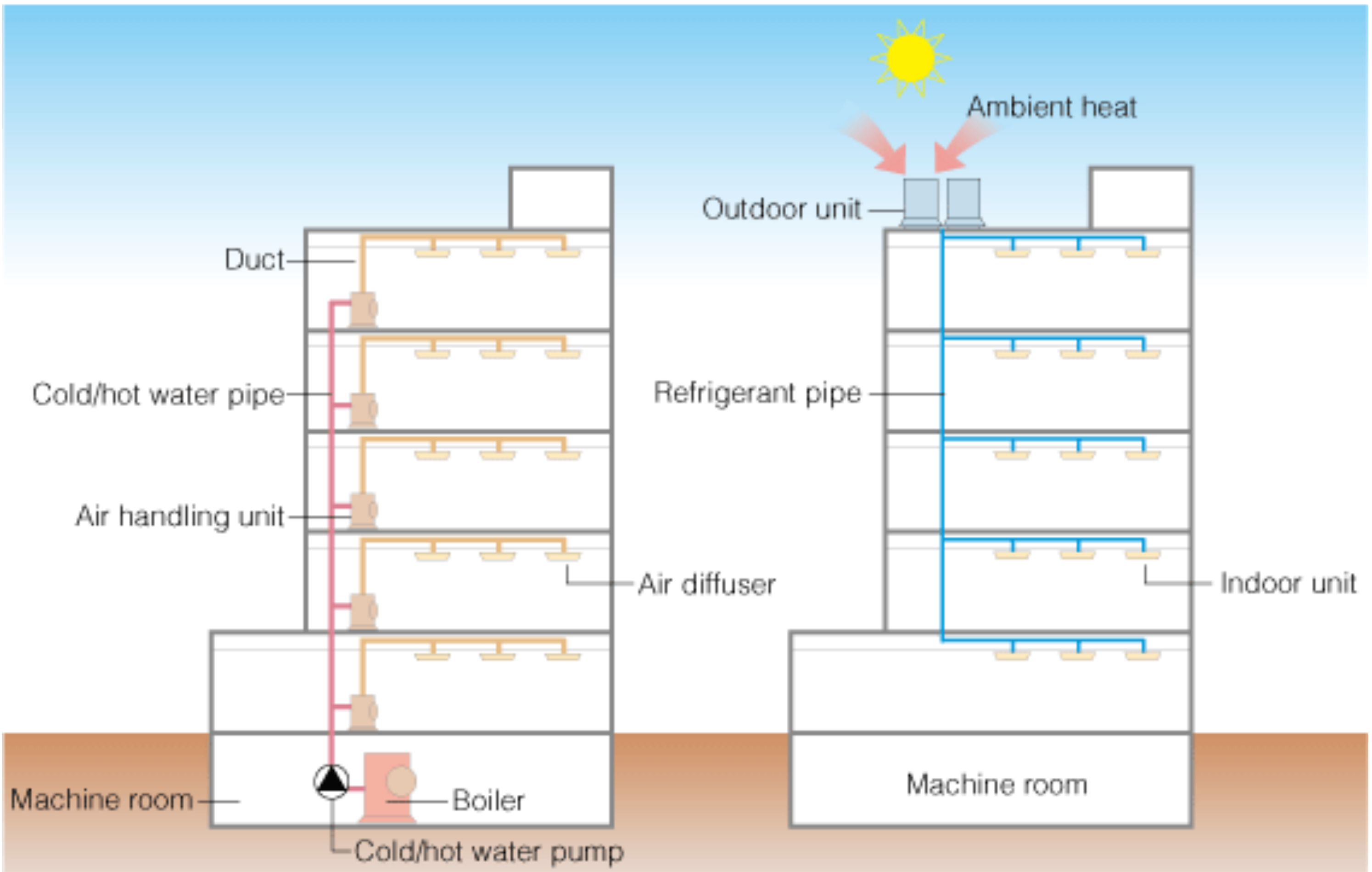
Variable Refrigerant Flow System

- The term “variable refrigerant flow” refers to the ability of the system to control the amount of refrigerant flowing to each of the evaporators.
- VRF moves refrigerant to the zone to be heated or cooled, allowing the temperature of that area to be more precisely controlled.
- It can simultaneously cool some zones while heating other areas or just provide comfort control to zones that are in use.
- VRF offers a wide variety of applications - everything from spot-cooling or -heating a single room in a home (using a split-ductless system) to a large commercial building with multiple floors and areas (that require individual comfort control delivered by a split-zoning system).

How Does VRF Work?

- VRF systems are enhanced versions of ductless multi-split systems, permitting more indoor units to be connected to each outdoor unit and providing additional features such as simultaneous heating and cooling and heat recovery.
- VRF heat pump systems permit heating in all of the indoor units, or cooling of the all the units, not simultaneous heating and cooling.
- Heat recovery systems provide simultaneous heating and cooling as well as heat recovery to reduce energy use during the heating season.

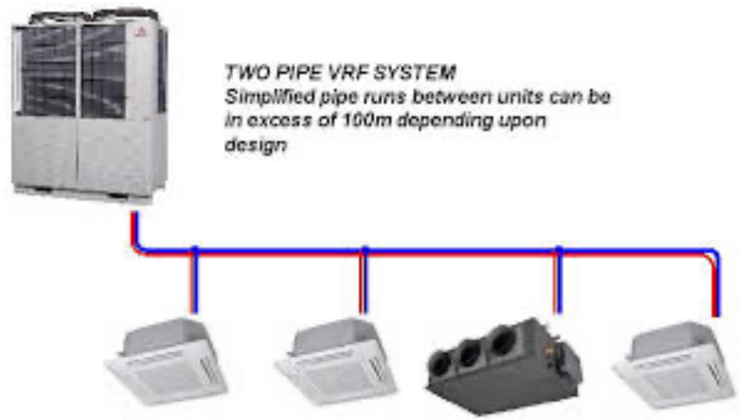
VRF System vs. Central System



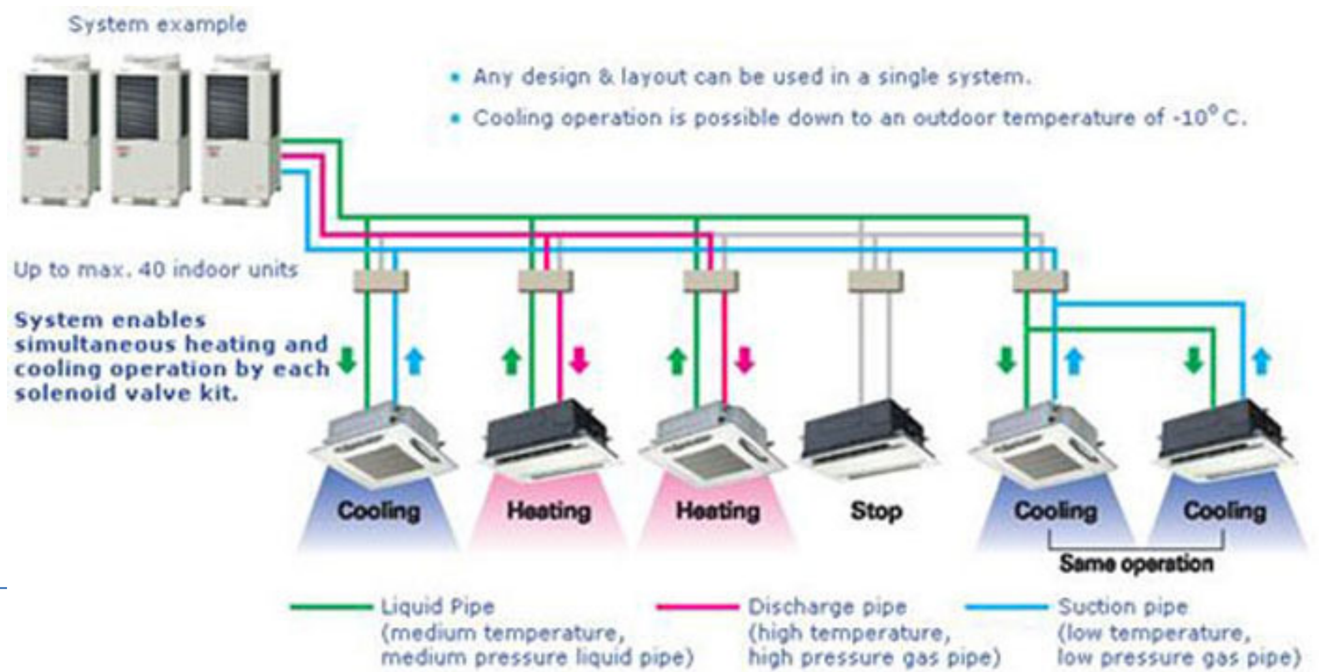
Central System VRF System

VRF Heat Pump Systems

- Two-pipe systems can be used effectively when all zones in a facility require cooling or all require heating.



- Three-pipe systems (pipes for heating, cooling, return) work best when there is a need for some spaces to be cooled and some heated during the same period.



VRF Heat Recovery

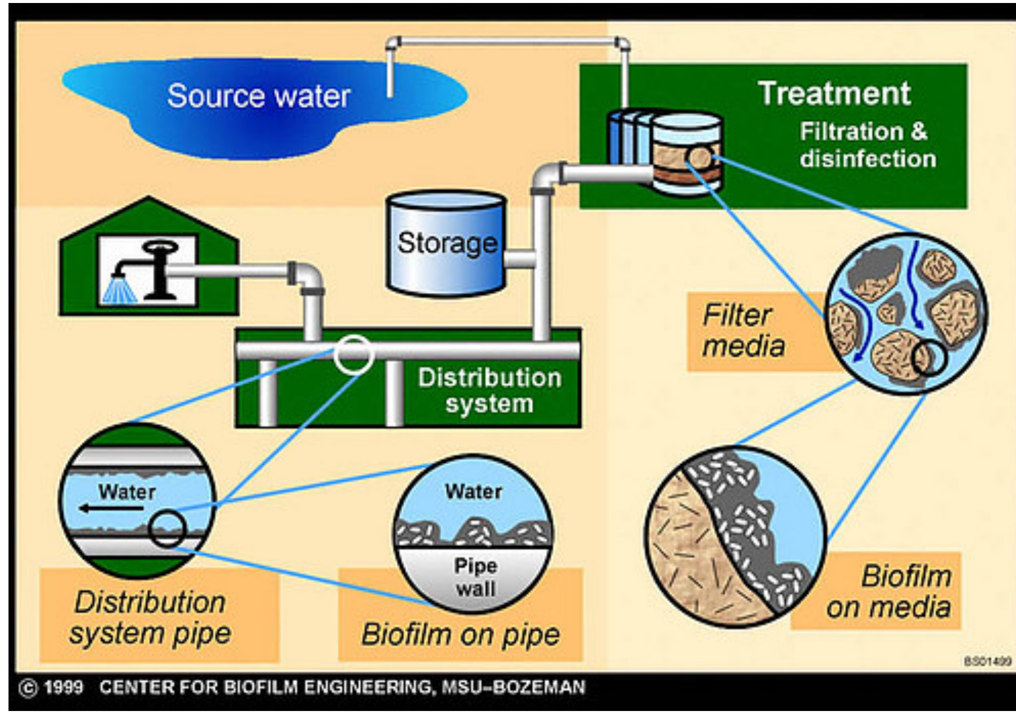
- Heat recovery can be accomplished by transferring heat between the pipes providing refrigerant to the cooling and heating units.
- One way is to use heat exchangers to extract the superheat from the units in the cooling mode and route it into refrigerant entering a heated zone.
- For example, one manufacturer sends the refrigerant first to the units that require heating, allows the refrigerant to condense, collects it at a central point and then sends it to the indoor evaporators to do cooling.

Hydronic Systems

- Hydronics is the use of water as the heat-transfer medium in heating and cooling systems (eg steam and hot water radiators)
- Two basic types:
  - Steam or hot water
  - Chilled water

Water Distribution Systems

- Water distribution systems are large networks of storage tanks, valves, pumps, and pipes that transport finished water to consumers
- Finished water is water that has been treated and is ready for delivery

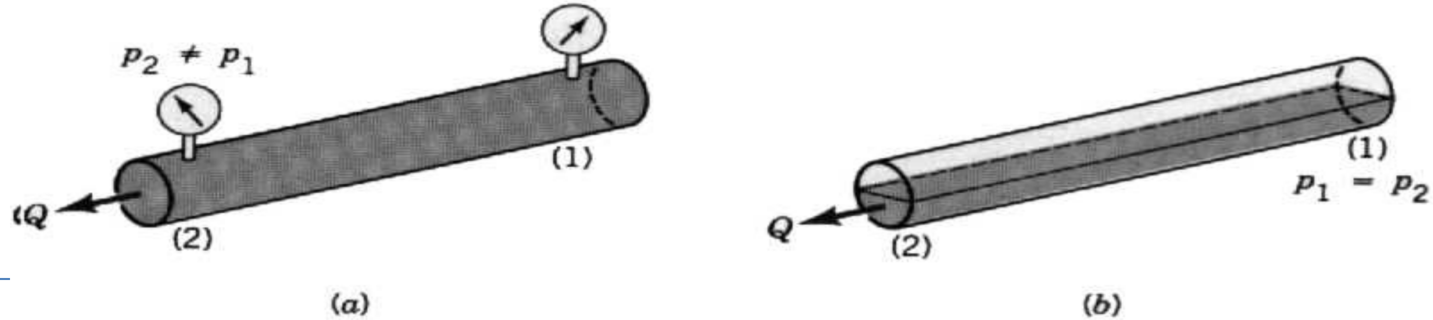


Description of Flow

- Pipe Flow refers to water flow in closed conduits under a certain amount of pressure

  (a) Pipe Flow: the pipe is completely filled and the main driving force is likely to be a pressure gradient along the pipe

  (b) Open Channel Flow: water flows without completely filling the pipe, and, gravity is the driving force, the water flows down a hill



Principles of Fluid Motion in Pipes

- Fluid motion in pipes can be characterizes as one of three types: Laminar, Transitional, Turbulent
- In *laminar flow* , the fluid travels as parallel layers (known as streamlines) that do not mix as they move in the direction of the flow.
- If the flow is turbulent, the fluid does not travel in parallel layers, but moves in a haphazard manner with only the average motion of the fluid being parallel to the axis of the pipe.
- If the flow is *transitional* , then both types may be present at different points along the pipeline or the flow may switch between the two.

Principles of Fluid Flow in Pipes

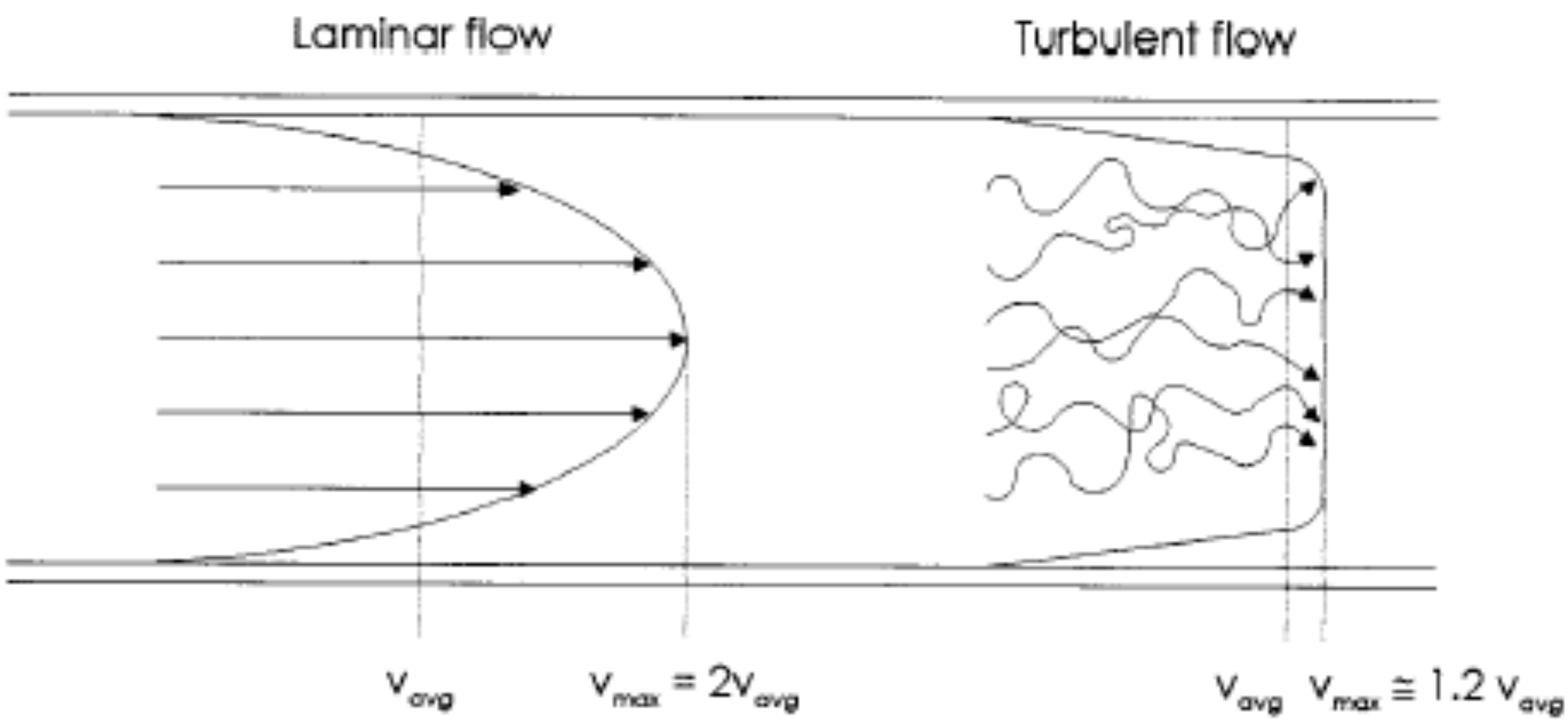
- The Reynolds number Re is the ratio of the inertia forces in the flow to the viscous forces in the flow and can be calculated using:

$$Re = \frac{\rho \bar{v} D}{\eta}$$

where ρ = Density of the fluid
v = Mean velocity of the fluid
D = Pipe diameter
η = Dynamic viscosity of the fluid

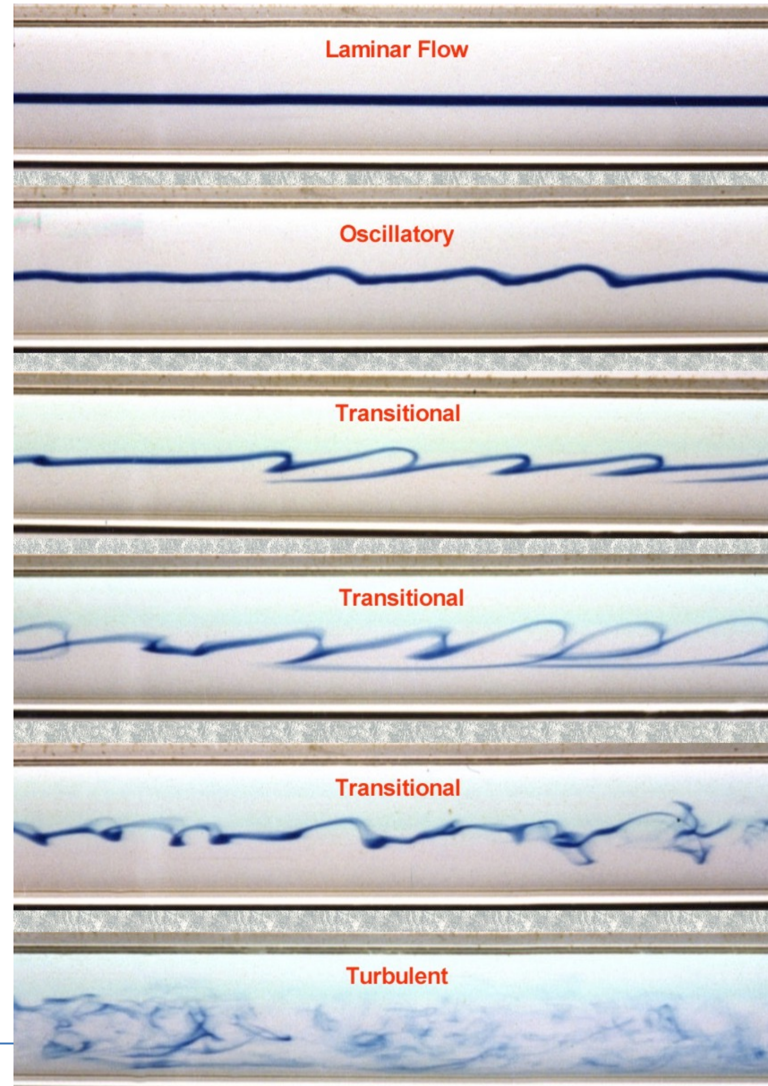
- If $Re < 2000$, the flow will be laminar.
- If $Re > 4000$, the flow will be turbulent.
- If $2000<Re<4000$, the flow is transitional
- The Reynolds number is a good guide to the type of flow

Principles of Fluid Flow in Pipes



Laminar to Turbulent

Increasing flow velocity



What Causes Water to Flow?

- Pressure supplies the energy to push the water along the pipe – while each bit of pipe resists the flow (friction)
- Energy is lost as the water moves along the pipe, so the pressure falls too
- There's a pressure difference between the ends of the pipe
- The longer the pipe, the more energy is lost, and the greater the pressure drop.
- The **rate** of pressure drop (the pressure drop per meter of pipe) depends on the pipe diameter and the speed of flow

Flow of Fluid through a Pipe

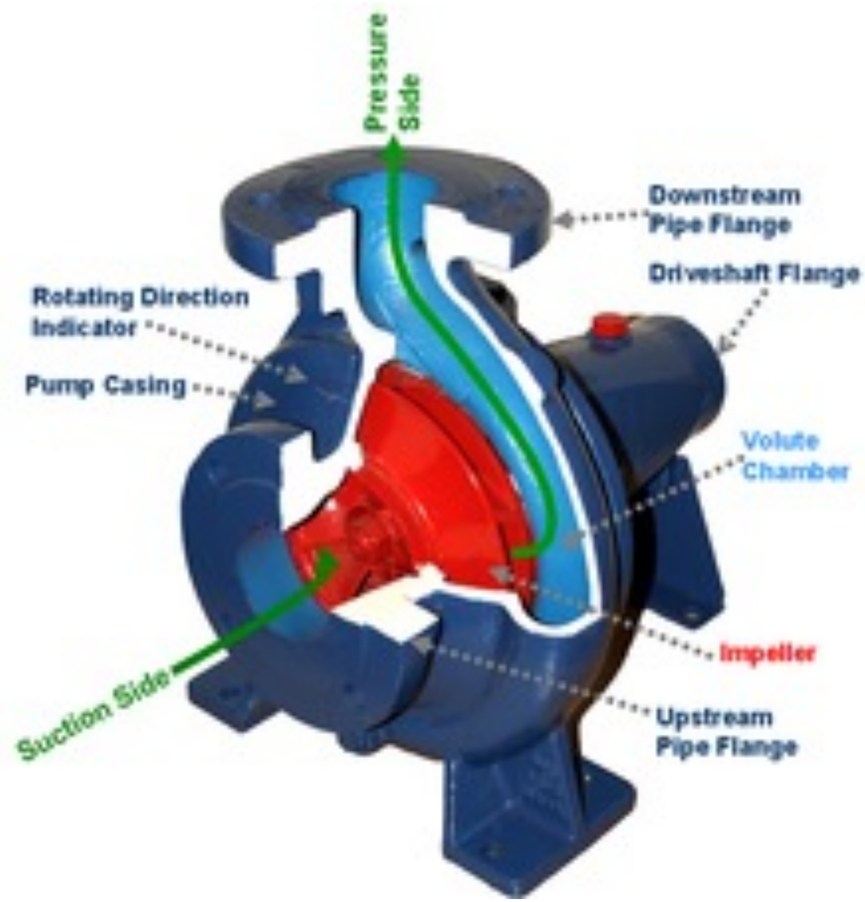
- The flow of liquid through a pipe is resisted by viscous shear stresses within the liquid and the turbulence that occurs along the internal walls of the pipe, created by the roughness of the pipe material.
- This resistance is usually known as pipe friction and is measured in feet or meters of fluid head
- Many factors affect the head loss in pipes, the viscosity of the fluid being handled, the size of the pipes, the roughness of the internal surface of the pipes, the changes in elevations within the system and the length of travel of the fluid
- The resistance through various valves and fittings will also contribute to the overall head loss.
- In a well designed system the resistance through valves and fittings will be of minor significance to the overall head loss

Getting Fluid to the Pump

- The energy to move a fluid to the pump inlet is not provided by the pump.
- The popular view that a pump ‘sucks’ fluid from the supply source is false.
- Atmospheric pressure on the fluid surface is the usual energy source used to push the fluid into the pump.
- The friction within the fluid and the pipe will oppose the fluid flow and reduce the pressure at the pump inlet

Circulating Pumps

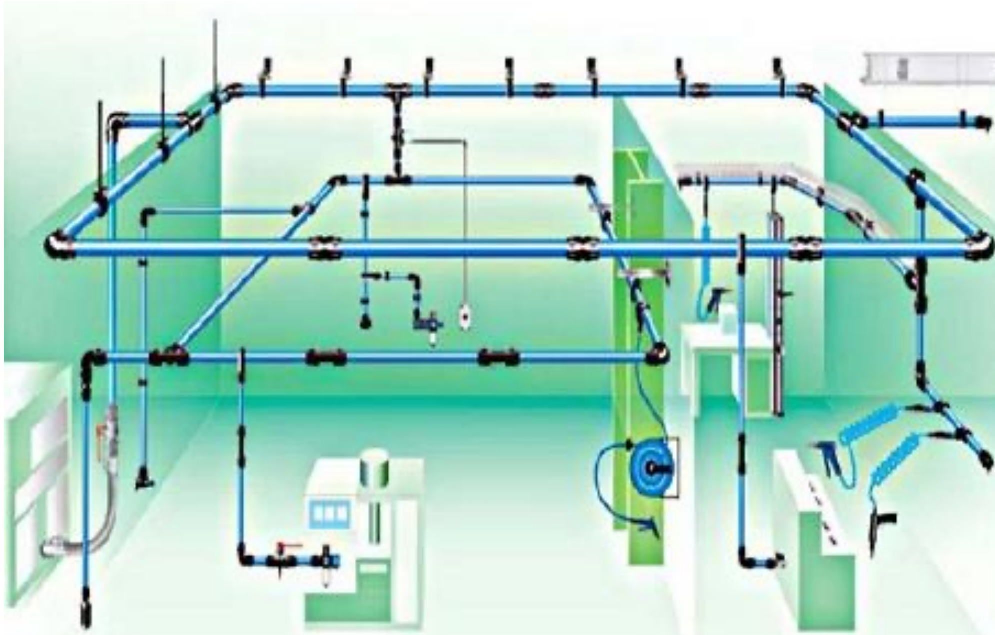
- A circulating pump is a device that causes the flow of liquid in circuits of heating or cooling installations.
- The circulating pumps are used only as centrifugal pumps.
- The basic elements of the centrifugal pump are coiled housing with two ports, suction and discharge, and a blade rotor mounted on a shaft drive can be an electric motor.
- The mechanical energy delivered to the circulating pump via motor is transmitted through the rotor to the liquid flow causing the increase in pressure (potential energy) and speed (kinetic energy).

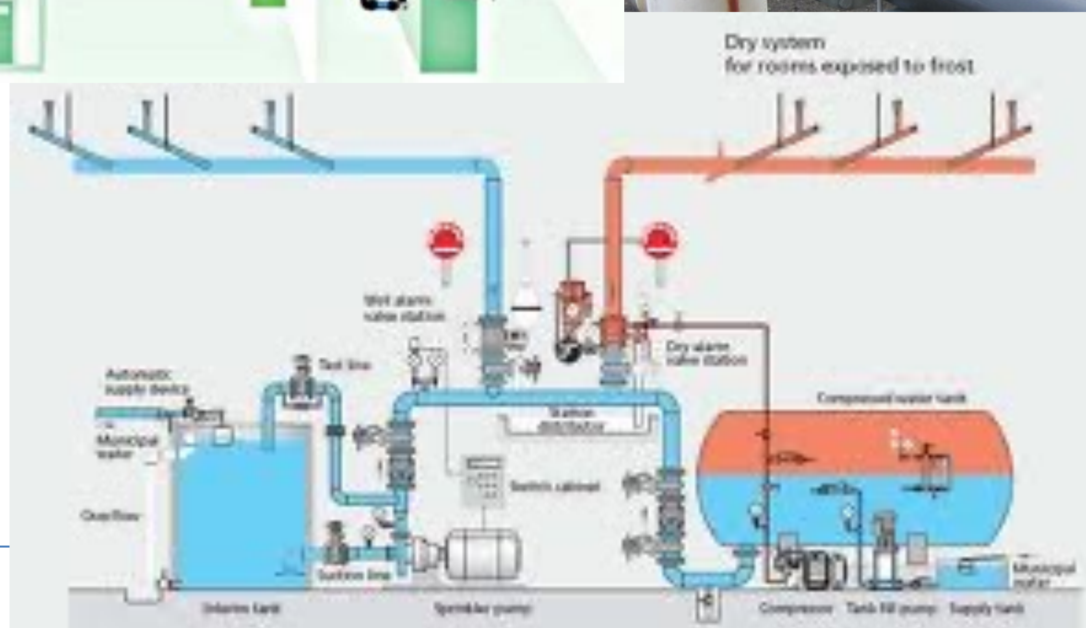


Piping Systems

- Within industry, piping is a system of pipes used to convey fluids from one location to another.
- Piping can be manufactured from wood, fiberglass, steel, glass, copper, concrete
- In-line components, known as fittings, valves, and other devices typically sense and control pressure, flow rates, temperatures
- Piping systems are documented in piping and instrumentation diagrams

Piping Systems

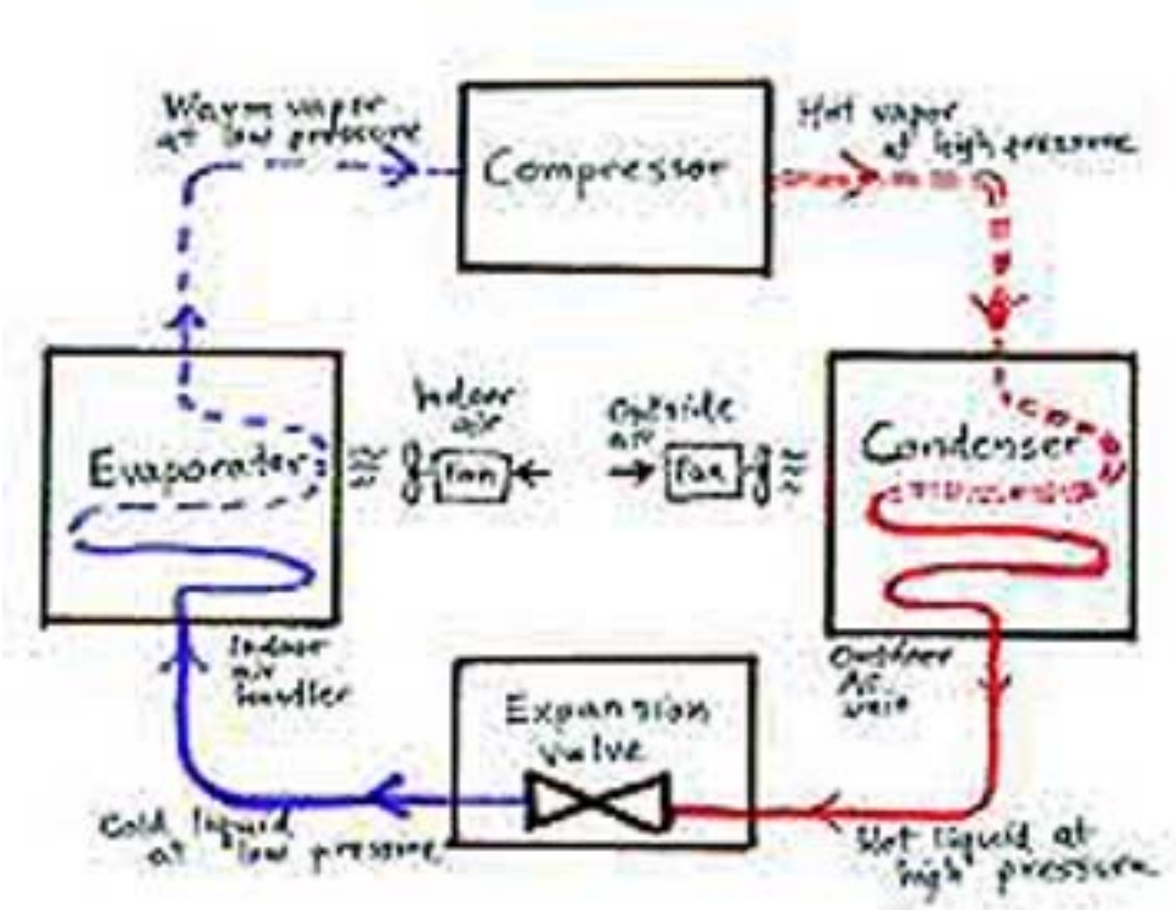




Refrigerant Distribution

- The pumping of liquid refrigerant from condensing units to points of use is common practice in the cold-storage industry but is seldom used in HVAC work.
- The refrigerant distributor equally distributes refrigerant flow from the outlet of the Thermal Expansion Valve to each evaporator coil circuit via distributor tubes.
- A portion of the refrigerant passing through the Thermal Expansion Valve flashes into a liquid and vapor mixture.
- This mixture is predominately liquid by weight and vapor by volume. This is referred to as two-phase flow.
- Once separated, this mixture moves at different velocities since gravity has a greater effect on the heavier liquid portion of the mixture. This is referred to as Slip.

Circulation of Refrigerant



Pumps

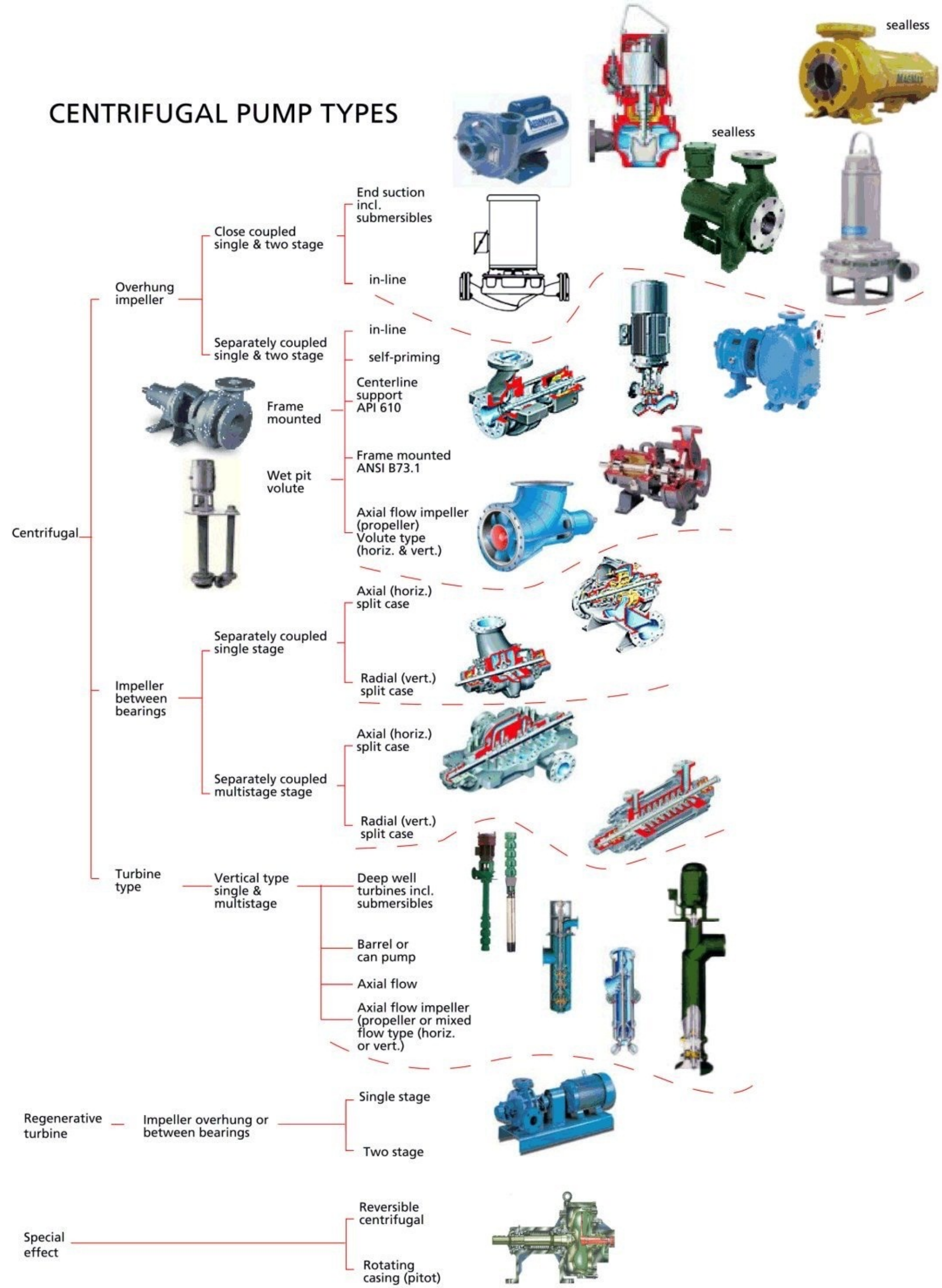
- Centrifugal pumps are used in HVAC systems for circulation of fluid, chilled, hot, and condensing water.
- Operating theory: the rotating action of the impeller in a scroll housing generates a pressure which forces fluid through the piping system.
  - The pressure and volume developed are functions of pump size and rotational speed
    - For higher pressures, multi-stage pumps are used

Pumps

- The majority of the centrifugal pumps used in HVAC work have a backward-curved blade impeller. For pumping hot condensate, a turbine-type impeller is used to minimize flashing and cavitation.
- Most pumps are direct-driven at standard motor speeds. Typical arrangements include combinations of alternatives such as end or double suction, in-line or base-mounted, horizontal or vertical, and close-coupled or base-mounted. Vertical turbine pumps are used in sumps, i.e., in cooling-tower installations.
- In general, in-line pumps are used in small systems or secondary systems, such as freeze prevention loops.
- Base-mounted pumps are used for most applications.

Pump Selection

- To select a pump, it is necessary to calculate the system pressure drop at the design flow rate.
  - Losses include pipe, valves, fittings, control valves, and equipment such as heat exchangers, boilers, or chillers.


CENTRIFUGAL PUMP TYPES
sealless
sealless
Centrifugal
Overhung impeller
Close coupled single & two stage
End suction incl. submersibles
in-line
Separately coupled single & two stage
in-line
self-priming
Frame mounted
Centerline support API 610
Wet pit volute
Frame mounted ANSI B73.1
Axial flow impeller (propeller) Volute type (horiz. & vert.)
Impeller between bearings
Separately coupled single stage
Axial (horiz.) split case
Radial (vert.) split case
Separately coupled multistage stage
Axial (horiz.) split case
Radial (vert.) split case
Turbine type
Vertical type single & multistage
Deep well turbines incl. submersibles
Barrel or can pump
Axial flow
Axial flow impeller (propeller or mixed flow type (horiz. or vert.)
Regenerative turbine
Impeller overhung or between bearings
Single stage
Two stage
Special effect
Reversible centrifugal
Rotating casing (pitot)

HVAC Controls

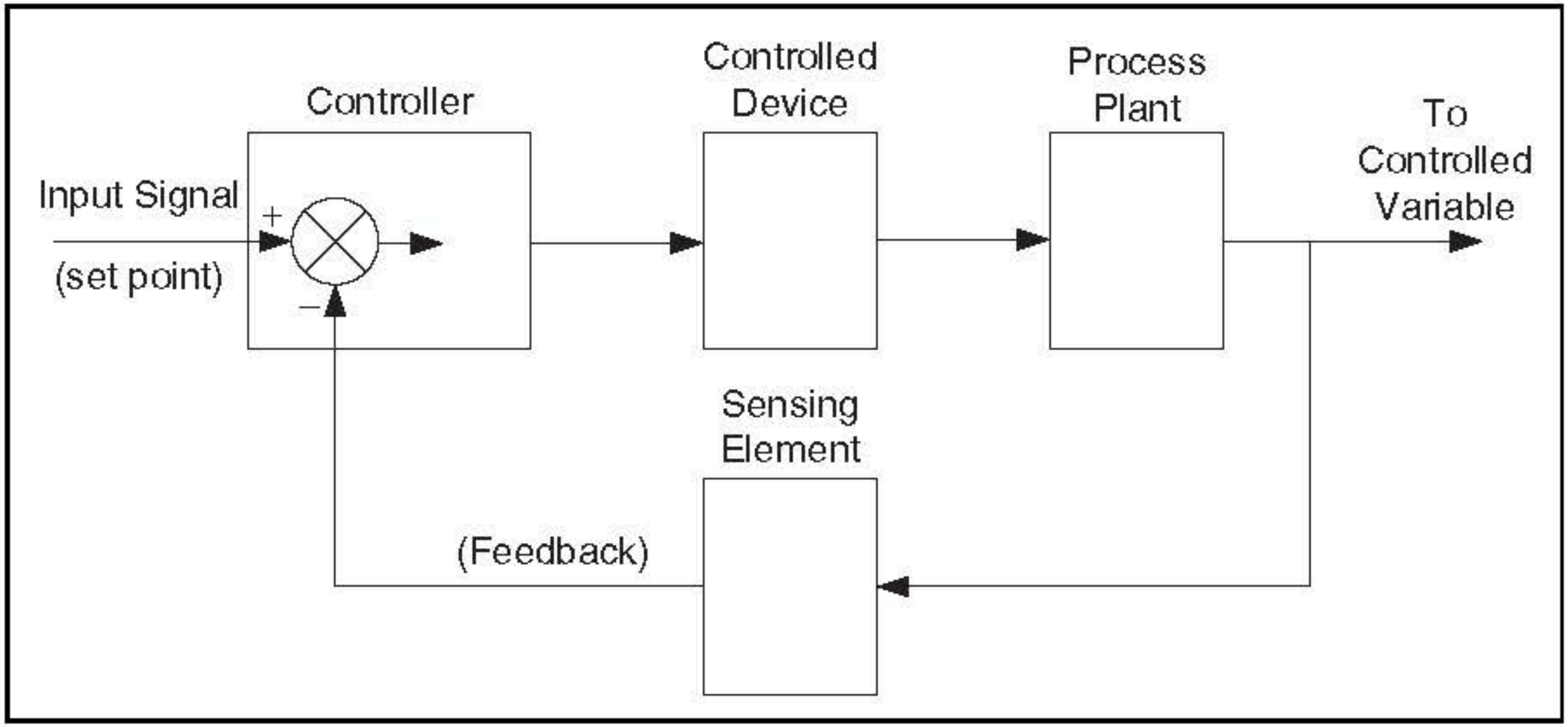
Basic purpose of HVAC control

- Controls improve our lives and make them more convenient, efficient, and effective
- Controls enable equipment to operate effectively
- The purpose of an HVAC control is to provie a comfortable environment suitable for the process that is occurring in a facility

Brief History of Controls

- First efforts at automatic control were to regulate space-heating systems:
  - Bi-metallic strip
  - Mercury thermometer column
  - Thermostats
- Function was to make or break and electric circuit that turned on a fan or pump, opened or closed a valve, etc.
- The five types of controls include:
  - Self-powered controls
  - Electric controls
  - Pneumatic controls
  - Analog electronic controls
  - Direct digital controls (DDC)

Diagram of a Control Loop



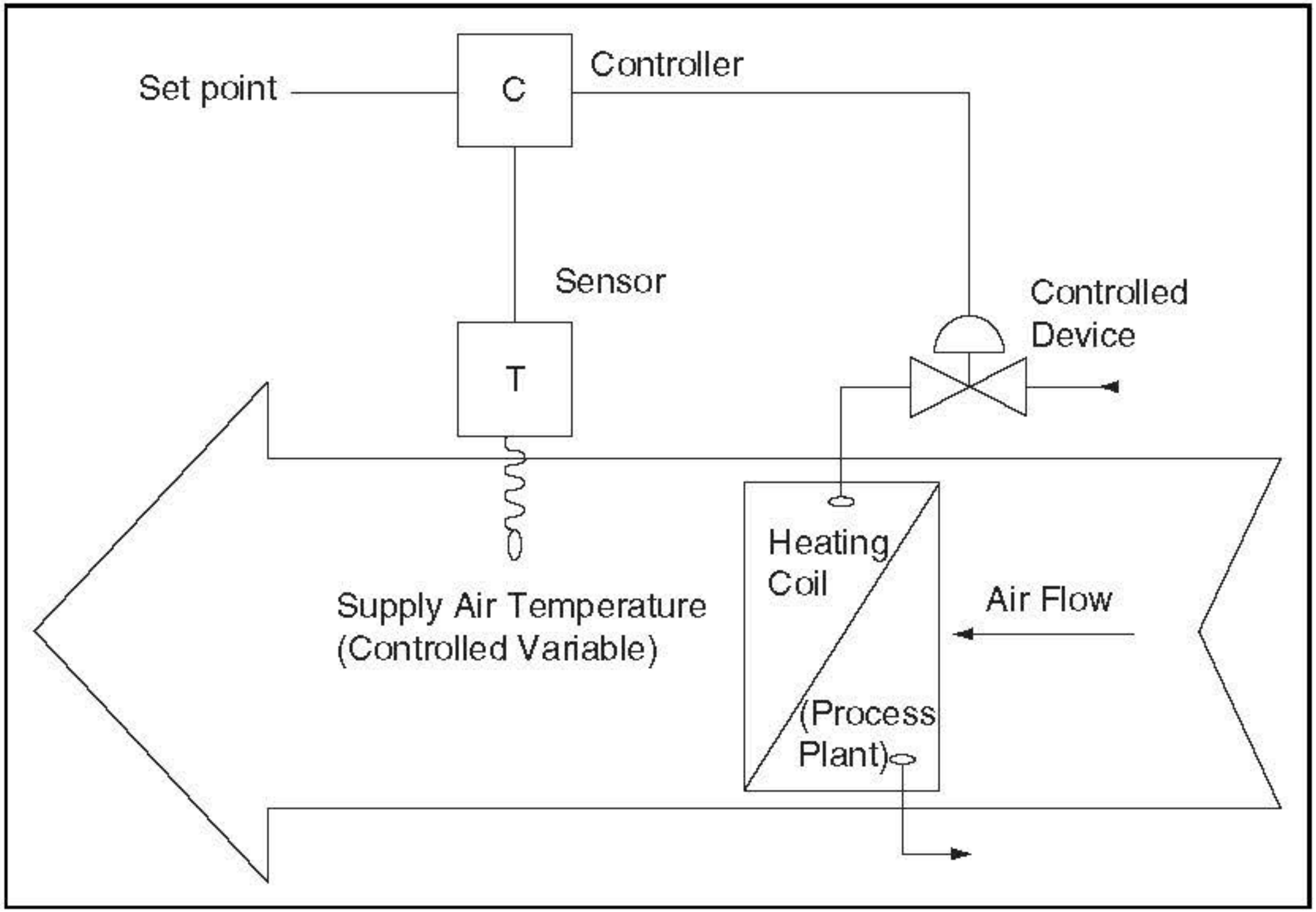
Control Loops

- When driving a car and you want to maintain a certain speed -- you are the “controller.” You use the speedometer to determine whether to speed up or to slow down.
- The exchange of information, schematically, is called a “control loop” because information flows in a circle:
  - Speedometer measures the controlled variable (speed)
  - Informs the controller (you) of current value compared to desired value (55 MPH)
  - Controller makes decision and passes that to the controlled device (accelerator or break) and to the process plant (car’s engine)
- All control loops include these essential elements

Control Comparison for Automobile and Heating

Term	Automobile Example	Heating System Example	Definition
Controller	You	The device that provides a signal to the valve	The device that provides a signal to the controlled device in response to feedback from the sensor
Sensor	Speedometer	Supply air temperature sensor	The device that measures the current status of the controlled variable
Controlled device	The accelerator	The control valve	The device that changes the operation of the process plant in response to a control signal
Controlled variable	The car speed	The supply air temperature	The signal that the sensor senses
Process plant	The car engine	The heating coil	The device that produces the change in the controlled variable
Input signal (set point)	Desired speed	Supply air set point	This is the reference or desired input that is compared to the controlled variable

Simple Heating System



Description of the Loops

- Shown in the previous slide is an air-heating system utilizing a heating coil provided with steam, hot water, or some other heating source.
- Cold air is forced through the system using a fan and heated to some desired temperature to maintain its set point.
- **The intent of this control is to <u>maintain a desired supply air temperature</u>.**
- The sensor measures the temperature of the supply air (the controlled variable) and transmits this information to the controller.
- In the controller, the measured temperature (the control point) is compared to the desired temperature (the set point).
- The difference between the set point and the control point is called the error.
- Using the error, the controller calculates an output signal and transmits that signal to the valve (the controlled device).
- As a result of the new signal, the valve changes position and changes the flow rate of the heating medium through the coil (the process plant). This, in turn, changes the temperature of the supply air.
- The sensor sends the new information to the controller and the cycle is repeated.

Terminology

- **Set Point**
  - Desired sensor value
- **Control Point**
  - Current sensor value
- **Error or Offset**
  - Difference between control point and set point

Summary of Key Terms

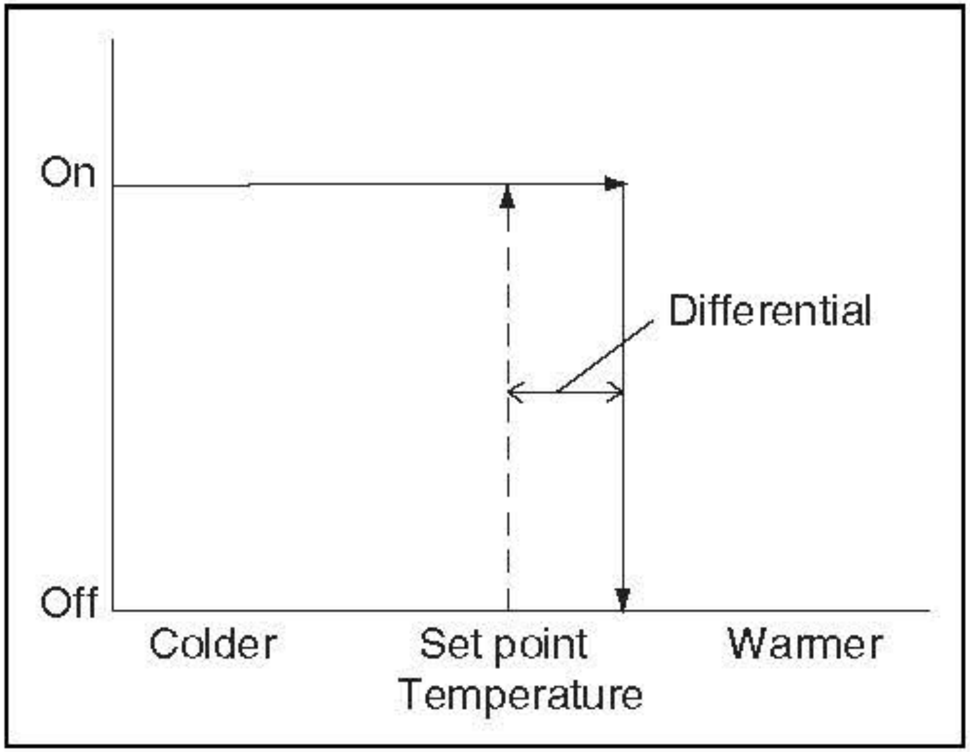
- **Controlled variable:** the property that is to be controlled, such as temperature, humidity, velocity, flow and pressure.
- **Control point:** the current condition or value of the controlled variable.
- **Set point:** the desired condition or value of the controlled variable.
- **Sensor:** the device that senses the condition or value of the controlled (or “sensed”) variable.
- **Sensed variable:** the property (temperature, pressure, humidity) that is being measured. Usually the same as the controlled variable in closed-loop control systems.
- **Controlled device:** the device that is used to vary the output of the process plant, such as a valve, damper, or motor control.
- **Process plant:** the apparatus or equipment used to change the value of the controlled variable, such as a heating or cooling coil or fan.
- **Controller:** the device that compares the input from the sensor with the set point, determines a response for corrective action, and then sends this signal to the controlled device.
- **Control loop**: the collection of sensor, controlled device, process plant, and controller.
- **Closed-loop:** a control loop where the sensor is measuring the value of the controlled variable, providing feedback to the controller of the effect of its action.
- **Open-loop:** a control loop where the sensor is measuring something other than the controlled variable. Changes to the controlled device and process plant have no direct impact on the controlled variable. There is an “assumed” relationship between the property that is measured and the actual variable that is being controlled.

Control Modes

- The purpose of any closed-loop controller is to maintain the controlled variable at the desired set point.
- All controllers are designed to take action in the form of an output signal to the controlled device.
- The output signal is a function of the error signal, which is the difference between the control point and the set point.
- The type of action the controller takes is called the control mode or control logic, of which there are three basic types:
  - two-position control
  - floating control
  - modulating control

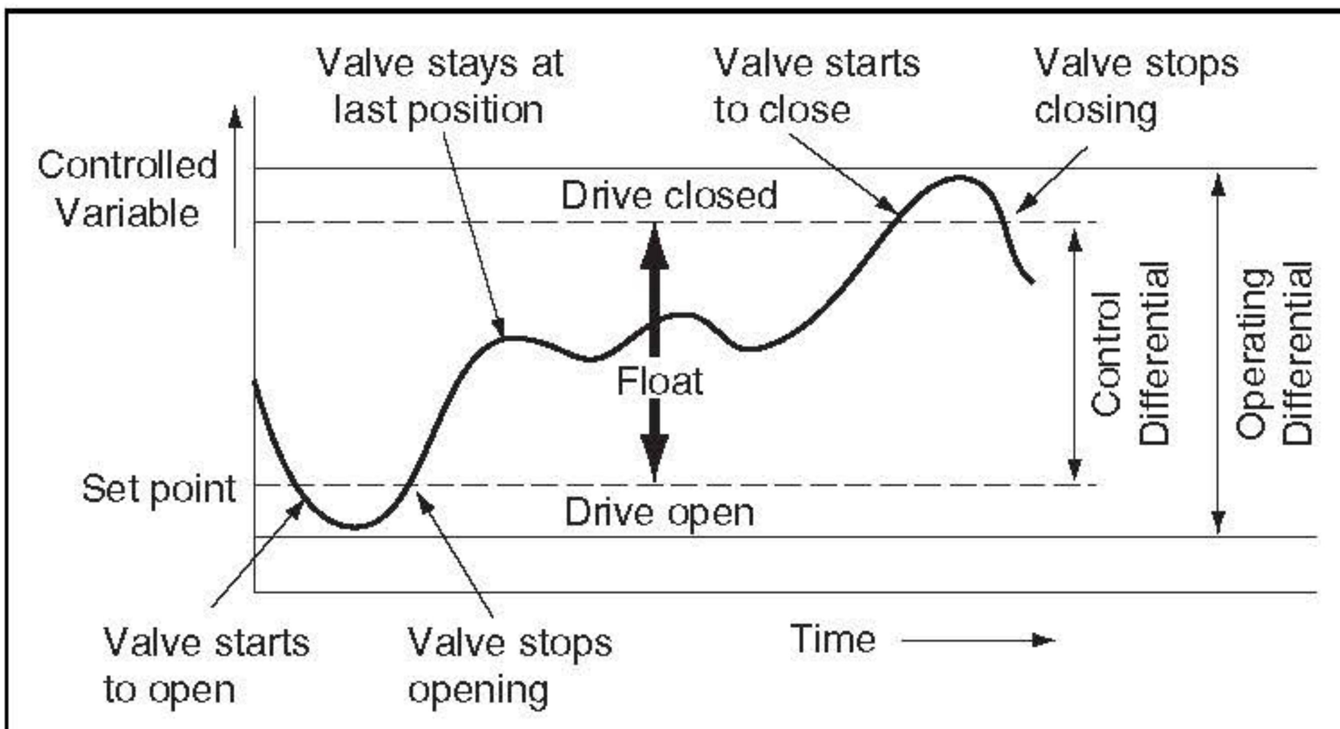
Two-Position Control

- The simplest and probably most common control mode is two-position control.
- It applies to systems that have only two states, such as On and Off for a fan or pump, or Open and Closed for a valve or damper.
- Small HVAC systems, such as the furnaces and air conditioners found in most residences, are examples of two-position systems.



Floating Control

- Floating control (also called “tri-state” control) is similar to two-position control but the system it controls is not limited to two states.
- The system must have a modulating-type controlled device, typically a damper or valve driven by a bi-directional actuator (motor).
- The controller has three modes: drive open, idle (no movement), or drive closed.



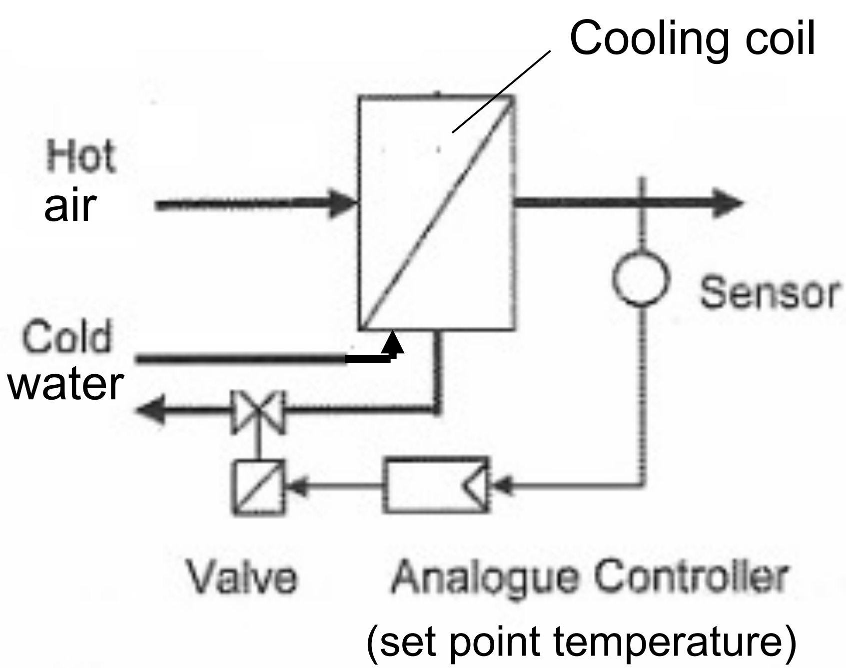
Modulating Control

- Modulating control is sometimes called analog control, drawing on the parallel between modulating/two-position and analog/digital.
- For many years the term “proportional control” was used to mean modulating control because the controllers at that time were limited to proportional control logic.
- Modern modulating controls use more sophisticated algorithms that go beyond simple proportional logic.

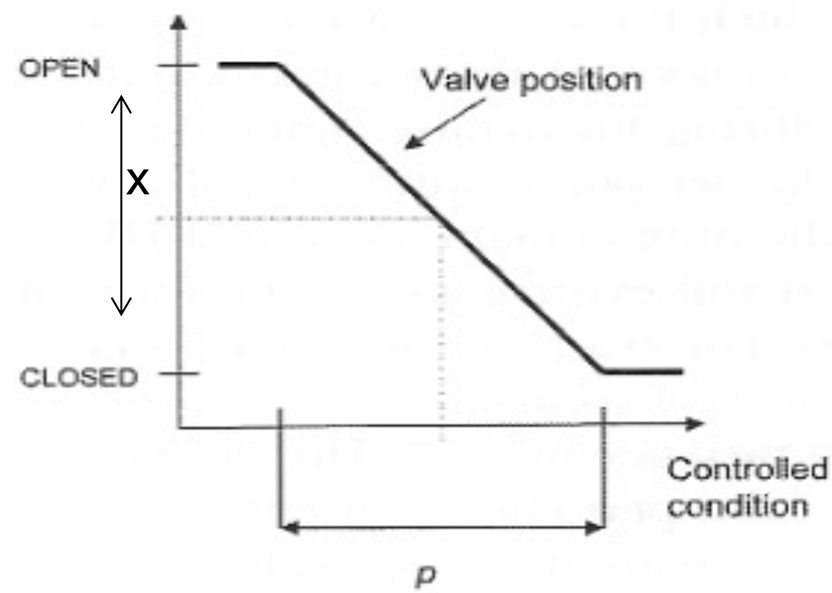
Modulating Control Systems

Example: Heat exchanger control

– Modulating (Analog) control



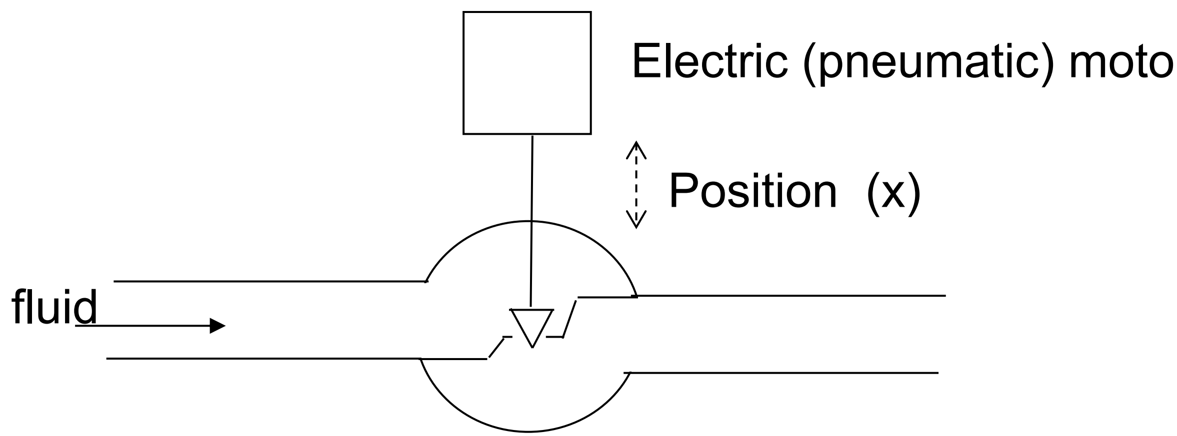
Analogue control.



Proportional control action.

Modulating Control Systems

- Used in larger systems
- Output can be anywhere in operating range
- Three main types
  - Proportional
  - PI
  - PID



Volume flow rate

$V_{fluid} = f(x)$ - linear or exponential function

The PID control algorithm

constants

time

The picture can't be displayed.

$u(t$

rence between
point and
sured value

Position (x)

For our ex

$$x = K \cdot (T_{\text{set point}} - T_{\text{measured}}) + \frac{K}{T_i} \int (T_{\text{set point}} - T_{\text{measured}}) d\tau + K \cdot T_d \frac{d(T_{\text{set point}} - T_{\text{measured}})}{d\tau}$$

Proportional
(how much)

Integral
(for how long)

Differential
(how fast)

Position of the valve

Proportional Controllers

$$x = A + K \cdot (T_{\text{set point}} - T_{\text{measured}})$$

x is controller output

A is controller output with no error (often A=0)

Kis proportional **gain** constant

e = $T_{\text{set point}} - T_{\text{measured}}$ is error (offset)

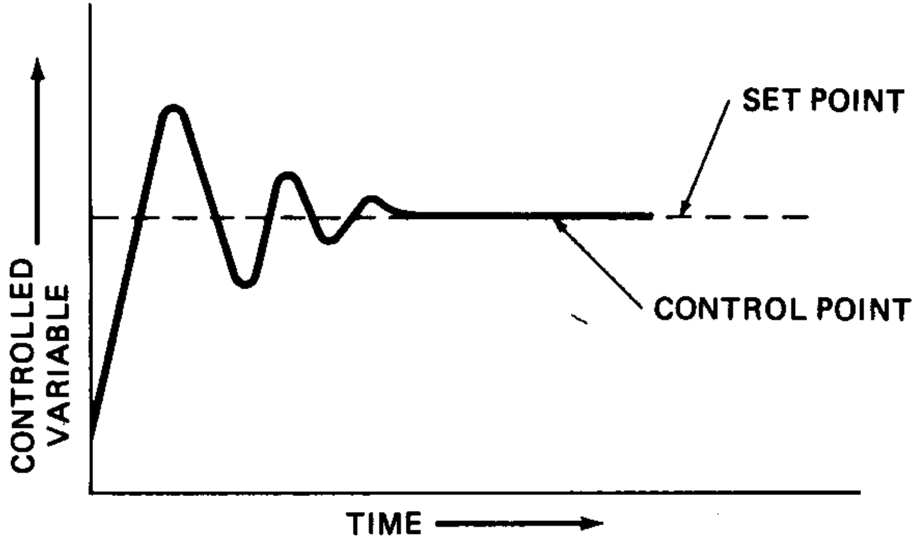
Issues with Proportional Controllers

- Always have an offset
- But, require less tuning than other controllers
- Very appropriate for things that change slowly
  - i.e. building internal temperature

Proportional + Integral (PI)

$$x = A + K \cdot (T_{\text{set point}} - T_{\text{measured}}) + \frac{K}{T_i}\int (T_{\text{set point}} - T_{\text{measured}})\, d\tau$$

K/T$_i$ is integral gain



If controller is tuned properly, offset is reduced to zero

Figure 2-18a

Issues with Proportional and Integral Controllers

- Scheduling issues
- Require more tuning than for P
- But, no offset

Proportional + Integral + Derivative (PID)

- Improvement over PI because of faster response and less deviation from offset
  - Increases rate of error correction as errors get larger
- But
  - HVAC controlled devices are too slow responding
  - Requires setting three different gains

The Real World

- 50% of US buildings have control problems
  - 90% tuning and optimization
  - 10% faults
- 25% energy savings from correcting control problems
- Commissioning is critically important

Practical Details

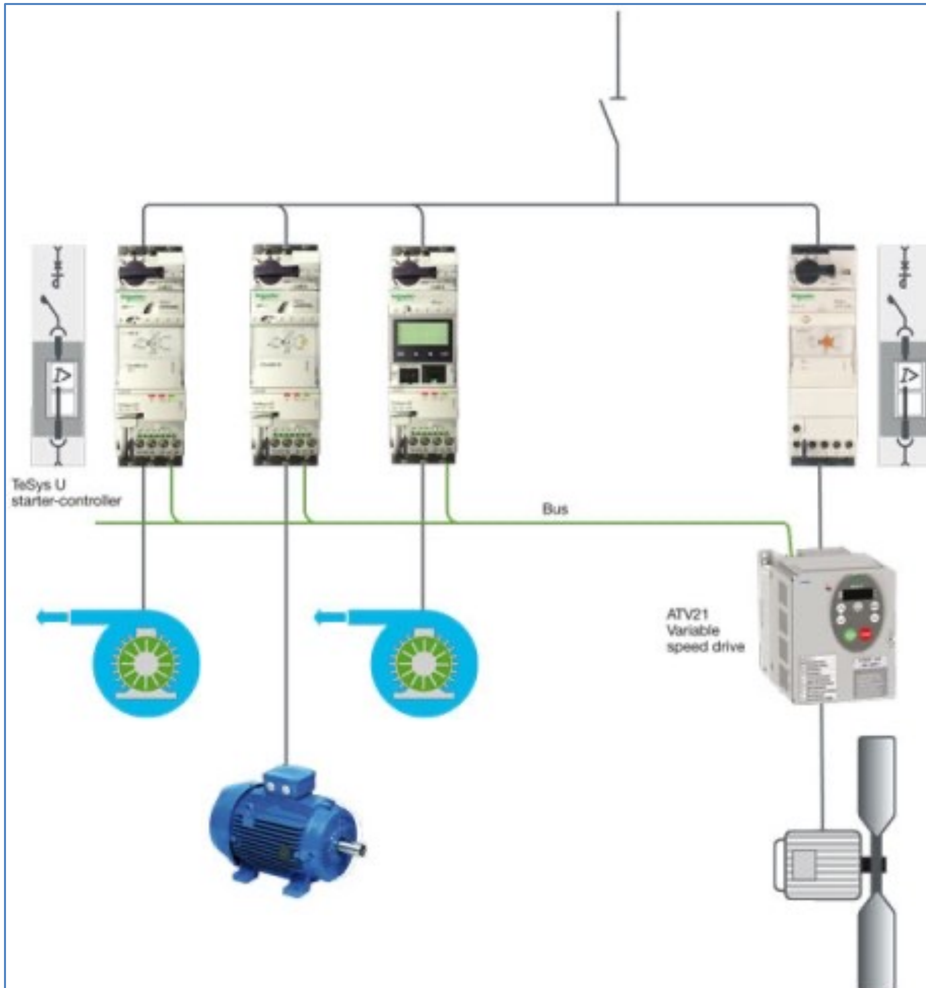
- Measure what you want to control
- Verify that sensors are working
- Integrate control system components
- Tune systems
- Measure performance

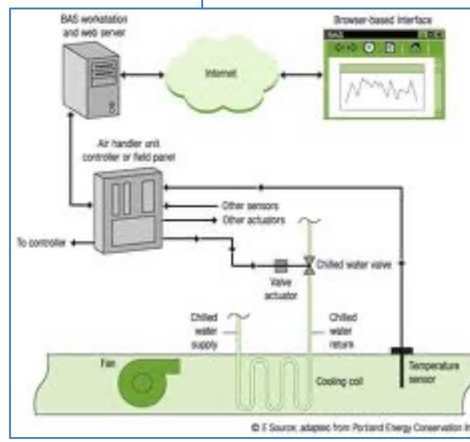
Commission control systems

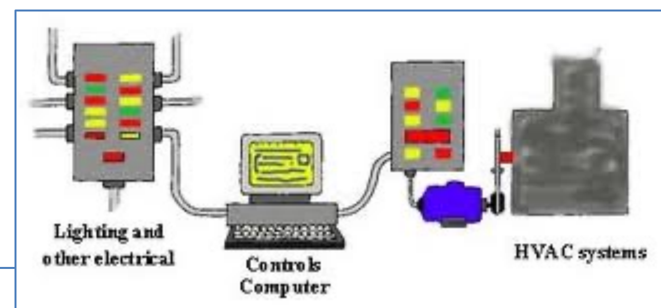
Controls Documentation, Maintenance, and Operations

- All control systems should be documented with written sequences, parts lists, data sheets, damper and valve schedules, control drawings, marked site plan locations for all controls and remote devices, and points lists where applicable.
- This documentation must be kept in a safe and accessible place for the life of the systems and building.
- Training sessions should be set up for all affected parties to participate in.
- All control systems require periodic maintenance, adjustments, calibration checks, and testing in order to stay in operation properly. Most often, this should be performed on a quarterly or semi-annual basis at minimum.

Typical Control Systems







Controller Technologies

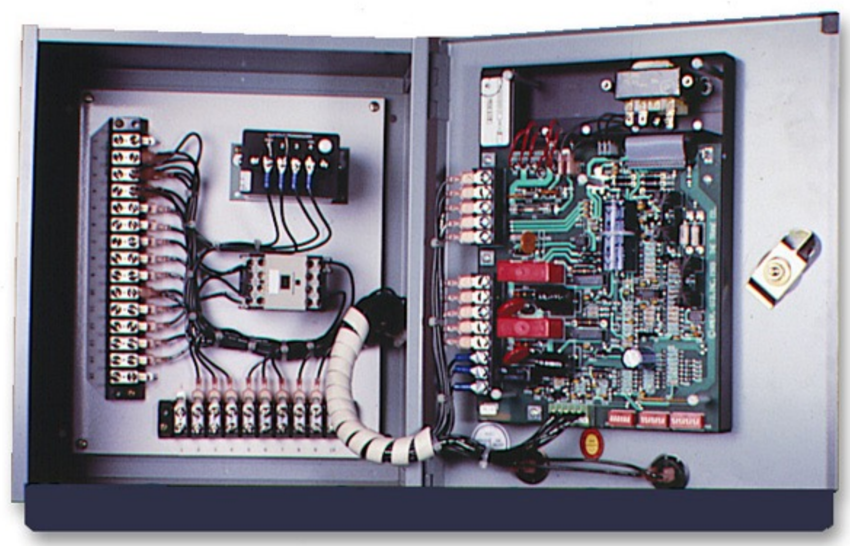
- HVAC control systems are often classified by the energy source used to power the controlled devices. The most common forms of energy used are electricity and compressed air.
- Systems that use compressed air to operate controlled devices are called pneumatic control systems.
- Systems that use electricity as the primary energy source are categorized as either analog-electric or microprocessor-based control systems.
- For the purpose of this discussion, the term analog-electric represents the operating characteristics of electromechanical and electronic controls.

Pneumatic Control System

- Pneumatic control systems vary the pressure of compressed air to operate controlled devices, such as valve and damper actuators.
- Pneumatic control systems consist of the following major components:
  - Air compressor with storage tank
  - Air drier
  - Air filter
  - Pressure-reducing valve
  - Controller
  - Controlled device
- The controllers in a pneumatic system are connected to the main line. Each controller signals a controlled device to move by adjusting the air pressure in the branch line.

Analog – Electric Controller

- Analog-electric control systems vary the electric current of voltage to operate the controlled devices.
- A sensor sends an electric signal to the controller, and the controller sends an electric signal to operate the controlled device.
- An analog-electric controller is a solid-state device that uses an assortment of electronic hardware devices (such as mercury switches, snap-acting contacts, or potentiometers) to process the input signal and generate the desired corrective output signal.
- Analog-electric control systems require much less maintenance than pneumatic systems, which typically leads to improved comfort control and more-efficient use of energy.



Microprocessor-Based Controller

- Similar to analog-electric control systems, microprocessor-based control systems vary the electric current or voltage to operate controlled devices.
- The sensors and controlled devices used in microprocessor-based control systems are often the same as those used in analog-electric systems.
- A microprocessor-based controller, however, uses digital *software* programs, rather than electronic *hardware devices, to process the input signal and generate* the desired corrective output signal. This type of control is often referred to as **direct digital control (DDC).**
- Microprocessor-based controllers are able to accommodate more- sophisticated control sequences at lower costs than pneumatic or analog-electric controllers.

Comparison of Technologies

- Pneumatic
  - No communication capabilities
  - Expensive and complicated to provide complex control strategies
  - Inherently proportional
  - Extensive maintenance requirements
- Microprocessor-based
  - Allows system-wide communication
  - Fewer hardware components
  - Easily accommodates complex control strategies
  - Provides many types of control action
  - Fewer maintenance requirements

D. Energy Efficiency and/or Conservation Measures

- Although there has been debate over the differences between the two terms, industry practice is that they are used interchangeably:
  - EEM: Energy Efficiency Measures
  - ECM: Energy Conservation Measures

Operations & Maintenance (O&M)

- Effective O&M is one of the most cost effective methods for ensuring reliability, safety, and energy efficiency.
- Operations and Maintenance are the **decisions and actions** regarding the control and upkeep of property and equipments.
  - Actions focused on scheduling procedures, system controls, optimization
  - Performance of routine, preventative, actions aimed at preventing equipment failure or decline

Routine maintenance to assure optimal performance

- Routine or preventive maintenance can be defined as follows:
  - Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.
- Preventive maintenance programs have several advantages over purely reactive programs.
- By performing the preventive maintenance as the equipment designer envisioned, the life of the equipment is extended this translates into dollar savings.
  - Preventive maintenance (e.g., lubrication, filter change) will generally run the equipment more efficiently, resulting in dollar savings.
- While we will not prevent equipment catastrophic failures, we will decrease the number of failures.
  - Minimizing failures translate into maintenance and capital cost savings.

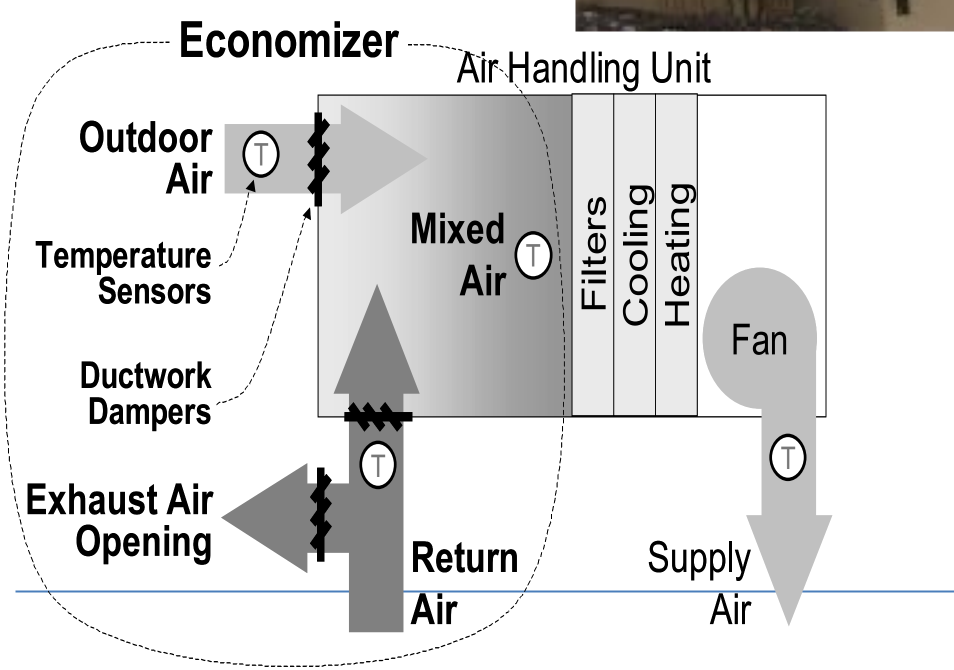
Repairs to restore equipment to specification

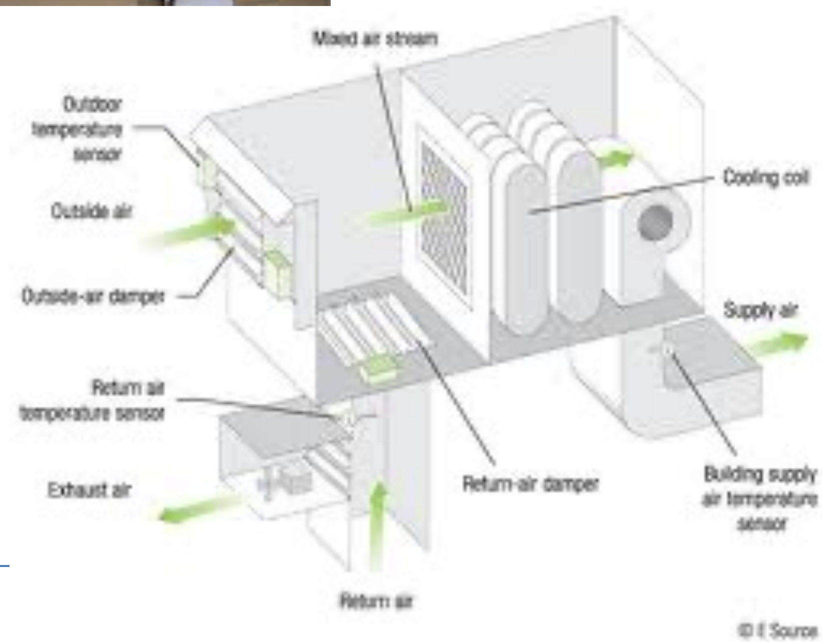
- Once identified, planned, and validated, project implementation for the repair comes next.
- For typical O&M projects, this requires coordination with building managers and occupants and may require service outages and other disconnections.
- Once implemented, the project moves to the evaluation and verification phase, making use of pre-defined evaluation protocols aimed at opportunity function and verified performance.
- Elements of this step should be ongoing over the life of the project as a means of continued performance and savings persistence.

Add Economizer to Air Handlers

- The primary design intent behind most economizer systems is to provide free cooling any time the outdoor temperature is below the required system supply temperature.
- The economizer cycle will also reduce the mechanical cooling load when the outdoor temperature is higher than the required supply temperature but the outdoor air enthalpy (or total heat content) is less than the enthalpy of the return air.

Economizer on AHU





Scheduling

- Site energy/facility managers should have a goal of matching HVAC scheduling to the actual tenant schedules within all buildings.
  - The building operators should closely monitor tenant schedules and adjust the HVAC schedules accordingly to meet changing schedules throughout the year.
- The construction of the building, including the types of windows, insulation, and overall orientation, contributes to its ability to retain conditioned air.
  - This coupled with the internal heating and cooling loads in the building will dictate when the HVAC system should be cycled during the day.

Scheduling: DDC Optimal Start/Stop

- Most DDC systems have optimal start-stop programs with software algorithms that assess indoor and outdoor temperatures and, based on adaptive learning, the DDC system will activate the building's HVAC system at different times each day.
  - This technology is one of the most energy-efficient HVAC control programs available and should be used whenever possible.
- Other DDC systems have the ability to program preset start-stop times for the building's HVAC system.
  - In this case, the building operators should try to start the HVAC system as close to the tenants' arrival as possible.
- The operators should also consider applying different start times based on average outdoor air temperatures versus times of extreme outdoor air temperatures.

Coefficient of Performance (COP)

- COP is a measure of the amount of power input to a system compared to the amount of power output by that system
- It is a measurement of efficiency; the higher the number, the more efficient the system is.
- It can be used to describe any system:

$$\mathrm{COP} = \frac{\text{power output}}{\text{power input}}$$

Energy Efficiency Ratio and Seasonal Energy Efficiency Ratio

EER

- The energy efficiency ratio is used to evaluate the equipment's efficiency while in the cooling mode
- EER is defined as the total cooling capacity divided by the total electrical power consumption
- EER ratings evaluated how a unit will perform at one specific point. A higher value for EER represents a higher efficiency

$$\text{EER} = \frac{\text{output cooling energy in BTU}}{\text{input electrical energy in Wh}}$$

SEER

- Purpose is to represent the efficiency of a unit while in cooling mode
- Accounts for energy consumption of fan motors and compressors
- The SEER evaluates a unit's performance under two different conditions:
  - high and low humidity with less than design ambient conditions.
- A higher value of SEER represents a higher cooling efficiency.

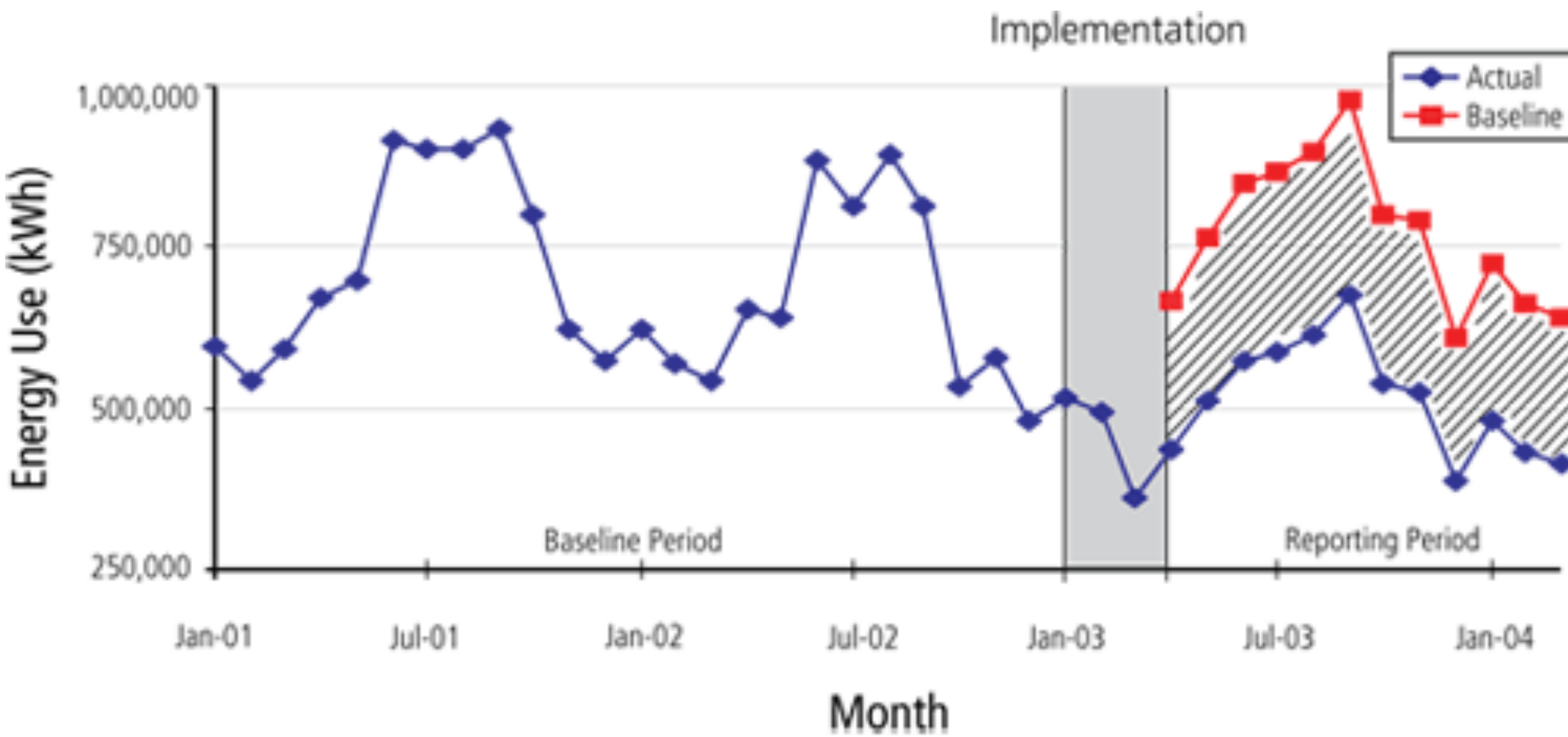
$$\text{SEER} = \frac{\text{output cooling energy in BTU over a season}}{\text{input electrical energy in Wh during the same season}}$$

Calculating the energy reductions of common EEM

- Basic Approach to Calculating Energy Savings
  - The two key options for estimating energy and demand savings are a deemed savings approach and a measured savings approach.
    - DEEMED method involves multiplying the number of installed measures by an estimated (or deemed) savings per measure, which is derived from historical evaluations
    - MEASURED method involves using one or more of the following techniques:
      - Engineering methods
      - Statistical Analysis
      - Computer simulation
      - Metering and Monitoring
      - Integrative methods

Energy Savings

- Energy Savings determined by using the equation:
  - *Energy savings =* ***(b)****(Baseline energy use) —*
    (a)*(Post-installation energy use) ±*
    (c)*(Adjustments)*
  - In the graph below, savings are represented by shaded area:



BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
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BEST
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National Science Foundation