

Chapter 9: Plumbing Systems

WATER SUPPLY

- **For cities:** surface & ground water
- **Aquifers:** large regions of subsurface water
- **Deep wells:** best source, little or no treatment
- **PH level:** a measure of acidity or alkalinity of water
 - 0-14 with 7 = neutral
 - Below 7 = acidic
 - Above 7 = alkaline
- Rainwater is acidic in natural state
- **Acid rain:** sulfur & nitrogen in air. Can corrode metal pipes when system uses runoff
- **Hardness:** Ca & Mg salts in water from dissolved minerals such as limestone
 - Can clog or insulate pipes & corrosion of boilers
 - Inhibits cleaning action of detergents
 - **Anode:** rod inserted into water tank to collect hard water deposits
 - **Softener:** contains zeolite where the Ca & Mg ions exchanged for sodium ions
- **Turbidity:** suspended material such as silt clag and organic matter
 - Treated by filtration
- Color & odor caused by organic matter
 - Color treated with filtration or chlorination
 - Odor treated with filtration thru activated carbon
- **Biological contamination:** bacteria, viruses and protozoa
 - Coliform group found in human & animal waste

Private Water Supply

- Wells, springs or collected rainwater
- Well considerations: depth and yield
 - **Shallow well:** less than 25'
 - Before drilling, ask neighbors, local well drillers and geologists for their experience
- **Yield:** gallons per minute a well provides
 - Min: 5 – 10 gpm for private residences
 - If yield too low, system may include storage tank
 - **Pipe casing:** 4 – 6" steel pipe prevents hole from caving & to prevent seepage of surface contamination. Lower portions are perforated to allow water to seep in

Pumps

- Suction pumps: used when water table is less than 25'
- **Deep well jet pumps:** for 25' – 100' deep wells
- **Turbine pump:** high capacity systems in deep wells
- **Submersible pump:** placed below water line & pumps water into a pressure tank
- Jet pumps have pump and motor above ground and lift water by **venturi principle**. Water is forced thru pipe where a jet stream of small diameter is created
- Wells require storage tanks or pressure tanks
 - Pressure tanks maintain constant pressure to compensate for peak demands that exceed capacity of pump
 - Pressure tanks also reduce amount of time pump must be running
 - As tank is emptied, pressure gauge senses loss and activates the pump

Municipal Water Supply

- **Water treatment:**
 - Settling out heavy materials & coagulations (or flocculation) with a chemical such as alum. Suspended particles combine w/ alum & settle
 - Water is then filtered and treated with chlorine to kill organics (.5ppm)
 - May be aerated to improve taste or fluoride added
 - Aeration can aid in oxidation
 - Piped thru mains @ 50psi (vary from 40 – 80psi)
- **First task in building project:** determine location of water main, its size, pressure and cost to tap.
 - If not adjacent to property, owner expense to extend
- Pressure in line is needed to determine supply system

WATER SUPPLY DESIGN

Supply System

- **Primary types:** upfeed and down feed
 - Based on height of building & pressure required to operate fixtures
- **Upfeed:** uses pressure in water main to directly supply fixtures
 - Limit: 40' – 60'
 - Supply from city main is 50psi
 - Pressure must be sufficient to overcome friction in pipes, fittings, meter and **static head** & still have enough pressure to operate fixtures
 - **Flush valve:** 10 – 20 psi
 - **Shower head:** 12psi
 - **Toilet:** 15psi
 - **Faucet:** 7-8psi
 - **Hose bibb:** 30psi
 - **Static head:** pressure required to push water vertically or the pressure caused at the bottom of a column of water
 - .433 psi to lift water 1'-0" or
 - 1psi will lift water 2.3'
 - When converting from pressure (psi) to lift (ft), use 2.3 ft per psi
 - When converting height or lift (ft) to pressure (psi) use 1/2.3 or .433 psi
 - **Example I:** A 10 story building has a floor to floor height of 12', a pressure of 15psi is needed to flush toilet. What is the required water pressure at the base of the building?

$$\begin{aligned}\text{Total lift} &= 10\text{story} \times 12' \\ &= 120 \\ &= 120/2.3\text{psi} \\ &= 52.2 \text{ psi} \\ \text{Therefore } 52.2\text{psi} + 15\text{psi (toilet)} &= \underline{67.2\text{psi}}\end{aligned}$$

- **Example II:** If additional pressure drop of 12psi due to friction @ meter, what is required pressure at base?

$$\begin{aligned}P_{\text{TOTAL}} &= 52.2\text{psi} + 15\text{psi} + 12\text{psi} \\ &= 79.2\text{psi(min)}\end{aligned}$$

- **Example III:** How much pressure is lost in static head at a fixture 40' above a water main w/ pressure of 45psi (ignoring friction loss)

$$40'(.434 \text{ lbf/in}^2/\text{ft}) = 17.36\text{psi}$$

$$\begin{aligned}\text{The remaining pressure at the 40' level is:} \\ 45\text{psi} - 17.36\text{psi} &= 27.64\text{psi}\end{aligned}$$

- If water supply insufficient, a downfeed system or pneumatic tank must be used

- **Downfeed system:** when building is too tall for upfeed, water is pumped to storage tanks near top of building or zone served & flows by gravity to fixtures
 - Pressure at any point is determined by distance from outlet of tank
 - Height of zone served is determined by max allowable pressure on the fixtures at the bottom
 - Max pressure approx. 45 – 60psi
 - Max height of zone is $60' \div .434\text{psi}$ or about 138ft
 - Beyond max height, pressure-reducing valve needed
 - Fixtures at top of zone must have min pressure to make work properly
 - Example: flush toilet needs 15psi then water tank must be min of $15/.434$ or 35' above the fixture
 - Actual distance slightly greater to overcome friction
- Lower floors of high rise = upfeed
- Upper floors of high rise = downfeed
- **Direct upfeed pumping system or tankless system:** several pumps controlled by pressure sensor which responds to demand

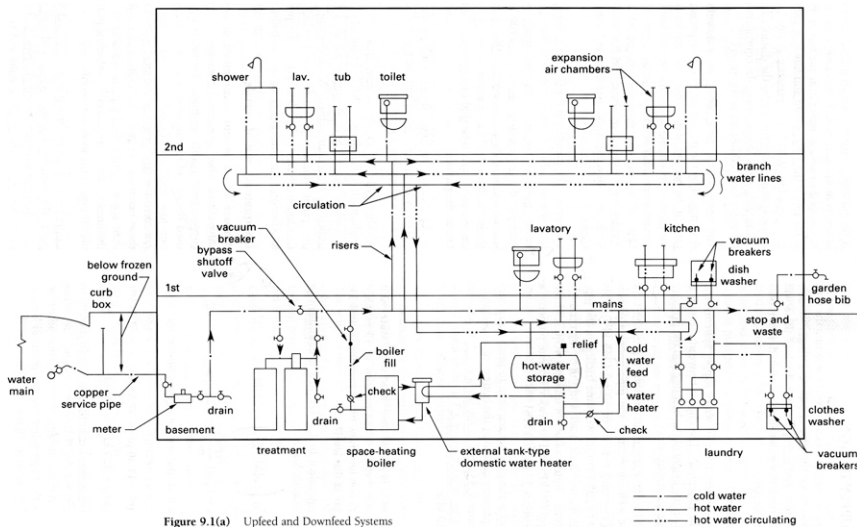


Figure 9.1(a) Upfeed and Downfeed Systems

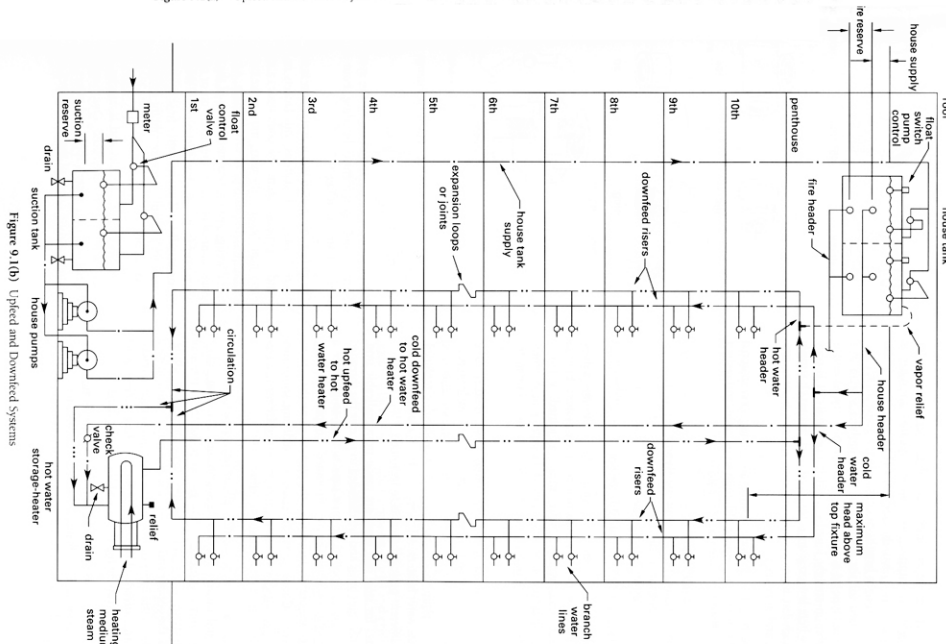


Figure 9.1(b) Upfeed and Downfeed Systems

Components and Materials

- **Piping:**
 - Wall thickness standardized by “schedule 40”
 - Thermal expansion:

$$\Delta L = Lk(T_2 - T_1)$$

- Example: The temperature of a 100' length of copper pipe increases from 65° to 160° when hot water starts to flow. How much does it expand?

$$\begin{aligned}\Delta L &= Lk(T_2 - T_1) \\ &= 100(9.8 \times 10^{-6})(160^\circ - 65^\circ) \\ &= .0931' \text{ or } .0931' \times 12'' \\ &= \underline{1.12''}\end{aligned}$$

- Copper (most common b/c of corrosion resistance, strength, low friction loss & small dia)
 - Must support every 6'
 - **K:** thickest & in straight runs or coils. Underground supply lines
 - **L:** Most common, straight lengths or coils
 - **M:** Thinnest, straight lengths only, used where low pressure
- Steel or galvanized steel pipes when water is not corrosive
- Must support every 12'
- Brass
- Plastic: some codes still restrict
 - Must support every 4'
 - PE: polyethylene
 - ABS: Acrylonitrile-butadiene styrene
 - PVC: Polyvinyl chloride
 - PVDC: polyvinyl dichloride
- **Fittings** where lengths connected, change of direction, three way or change in size
 - **Union:** connects two rigid sections, easily unscrewed for repairs & replacement
 - **Steel & brass:** fittings threaded & pipe tape or compound for watertight seal
 - **Copper & plastic:** fittings slightly larger than pipe
 - Copper sealed by soldering (sweating)
 - Plastic pipes sealed solvent that melts plastic together
 - **Compression fittings:** connections between small dia pipes connecting bath and kitchen fixtures to supply lines via **flare nut**

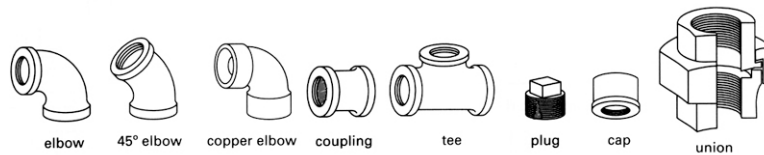


Figure 9.2 Plumbing Fittings

- Valves: control water flow. Located at risers, horizontal branch lines & connections to fixtures & allow selective shutdown
 - **Globe valve:** used where water flow is variably & frequently controlled
 - Faucets or hose bibs
 - Handle operates stem that compresses washer against metal seat
 - High friction loss since two right turns within valve
 - **Gate valve:** metal wedge against two metal parts of the valve
 - Completely on or off, minimal restriction when fully open
 - Low friction loss since no turns
 - **Check valve (backflow preventer):** automatically allows flow in only one direction where backflow may contaminate potable water
 - Preferable type is a spring loaded ball where pressure on ball compresses spring & recoils when no pressure

- **Angle valve (screw seat & seat & washer):** lever screws washer to seat to control flow amount
 - Faucets, shower and appliances

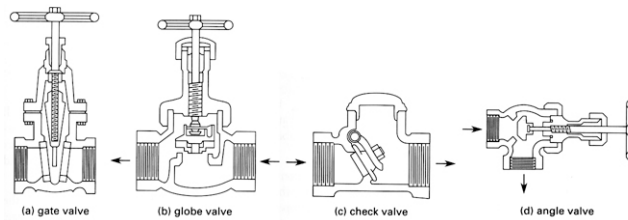


Figure 9.3 Valves

- Other components:
 - Air chamber
 - Shock absorbers
 - Pressure reducers
 - Flow restrictors
- **Water hammer:** noise caused when valve or faucet closed quickly causing moving water to abruptly stop and rattle pipes
- **Air chamber:** length of pipe installed above the connection to faucet that cushions water surge
- **Shock absorber:** same function as air chamber except with a manufactured expansion device
- **Pressure reducers or pressure regulators:** required if supply pressure is too high (over 60psi)
 - Most fixtures only require 5 – 15psi

System Design

- Sizing pipes and laying out required fittings, valves
- The sum of all values must be equal to or less than the water main pressure
- Pressure loss from static head is found by multiplying total height by .434psi
- Water main pressure found by consulting local water company
- Pressure loss depends on diameter and flow in gallons per minute
- **Probable demand flow:**
 - Defined by fixture units
 - Fixture unit: a unit flow rate equal to 1ft³/min
 - Determining the demand load of entire system
- **Example:** what is the flow rate for a group of plumbing fixtures in a small office building consisting of five flush valve toilets, two 3/4" flush valve urinals, four lavs, two service sinks and a drinking fountain
 - From table 9.2 (Ballast pg 9-9)

Toilets:	(5)(10)	=50
Urinals:	(2)(5)	=10
Lavs:	(4)(1.5)	=6
Sinks:	(2)(2.25)	=4.5
Fountain:	(1)(.25)	=.25
TOTAL:		70.75 fixture units
 - Once probable flow rate is known, use charts to relate flow, pipe size and friction loss in static head in pounds per square inch per 100ft length of pipe
 - Goal is to select smallest size
 - **To find total friction loss in piping and fittings,** calculate total length of piping from the meter to the fixture under consideration. Friction loss in fitting calculated by referring to tables that give the losses for various diameters fitting in equivalent lengths of pipe
 - Critical part of plumbing design in large building is allowance for the expansion of piping
 - Important in high rises: 100ft length of copper pipe can expand over 1/2" in a 60° temp change
 - PVC expands 3.5 times more than copper

Hot Water Supply

- By tank type or boilers (water heated by gas, oil, elec or steam)
- In small buildings, single supply pipe from heater to fixt minimizes cost but long waits for hot water
 - Solved with a two pipe circulating system where all fixtures needing hot water are connected with supply and return pipes
 - Convection keeps water moving: hot water rises to upper fixtures, cools falls to heater
 - In long low bldgs convection may not provide enough circulation & pumps are needed
- Size of hot water heater is based on peak demands
 - **Peak hourly demands:**
 - .4gal per person for an office
 - 12gal per unit for small apartment building
 - For large buildings, separate storage tanks required to meet demand while a smaller boiler heads the water
 - **Recovery rate:** gal per hour of cold water that heater can rise to desired temp
- **Size of hot water piping** is determined similar to cold water piping except only fixtures requiring hot water are used. Value multiplied by .75 (75%)
- **Recommended point-of-use temps:** 95° for therapeutic baths (110° hot to touch) to 180° for commercial laundries
 - 105° hand washing
 - 110° for showers
 - 140° for residential dish washers
- **Types of heaters:**
 - **Direct:** water in direct contact with heat source
 - **Indirect:** used intermediate transfer medium to heat water
 - Example: commercial applications where steam is available, it can be piped to tubes within a tank containing domestic hot water
 - Storage tank system: tank is used to both heat and store
 - Tankless system: quick heated and sent to where needed
 - “Insti-hot” at water coolers
 - Circulating system: water heated in one place and stored in a separate tank until needed
 - Commonly used in solar powered water heating

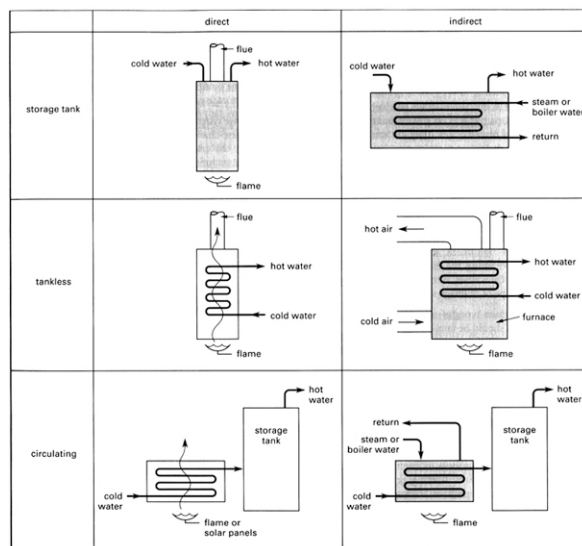


Figure 9.6 Water Heater Types

Solar Water heating

- For domestic, industrial and swimming pools
- **Components:**
 - **Solar collector:** flat plate or focusing or batch systems (black tanks behind glass)
 - Storage tank
 - Associated piping
 - Backup heater
- Active system use pumps & control sensors
- **Direct system or open-loop system:** water in building is same that is heated in solar collectors
 - Simple design, operation and high efficiency
 - **However:** fluids are subject to freezing
- **Indirect system or closed loop system:** separate fluids for collecting heat & transferred to the domestic water
 - Easier to protect from freezing w/ antifreeze
- **Passive circulation system:** gravity and thermosiphoning
 - Simple & low cost
 - However: storage tanks must be above solar collectors & point of use must be close to storage tanks
- **Active Circulation system:** pumps circulate heat collecting fluid
 - More flexible and add costs for equipment
- Protection from freezing: antifreeze or **phase change** material or by draining fluid at night
- **Batch system or breadbox heater:** heats directly in a black tank inside glazed box
 - Simple
 - However subject to freezing & nighttime heat loss
- **Thermosiphon system:** natural movement of heated water to circulate water in a passive open loop system
 - Simple
 - **However:** tanks above the collectors
- **Closed loop active system:** most common for residential and commercial
 - Separate non freezing fluid circulated by pumps through solar collectors and into heat exchangers where the domestic hot water is heated
 - Controller senses when temp of collector is lower than that of the stored water and turns the pumps off
- **Drain down system:** direct (open loop). Solves the problem of freezing by automatically draining the water from collectors when outside temp is near freezing
 - B/c water is wasted whenever drained, best for climates with mild winters where draining is not frequently
- **Drain back system:** indirect (closed loop). Active system that uses water as heat collector fluid, pumped to exchanger where coil domestic hot water is heated
 - When controller senses temperature is too low, it turns off the pump and collector water drains back into the solar storage tank
- **Phase change system:**

SANITARY DRAINAGE AND VENTING

Drainage Systems

- **Sanitary drainage:** any drainage that includes human waste
- **Storm drainage:** runoff from roof drains, landscaped areas, etc
- **Trap:** holds a quantity of water to prevent passage of noxious gases into space
 - Critical distance:
 - Must be within 2' of fixtures
 - Occasionally a house trap installed, not mandatory
 - Must be vented
- **Vents:** vent drainage system to outside air
 - Allow built up sewage gas to escape
 - Allow pressure in system to equalize so discharging waste does not create siphon that would drain water out of traps
 - **Air gaps:** if potable water outlet was below highest level of overflow, contaminated water in sink could be siphoned back into potable water supply ∴ faucets are mounted so outlet is at least 2" above highest level of waste water
 - Where supply is below rim (flush valve toilet) vacuum breaker prevents siphonage by closing when backwater pressure is present
 - From trap, sewage travels in branch lines to vertical stack.
 - **Soil stack:** If stack carries human waste
 - **Waste stack:** if carries waste other than human
 - **Vent stack:** separate pipe in multistory buildings for venting, may connect with stack vent above highest fixture
 - **Stack vent:** vent connects to soil or waste stack above highest fixture in system
 - Stacks connect at bottom of building to horizontal drain
- **House drain (building drain):** drain pipe within the building and t a point 3' outside the building
- **House sewer (building sewer):** drain pipe from 3' outside the building to main sewer or private disposal
- Cleanouts at intersections of stack and house drain
- Horizontal drains:
 - Branch lines: slope 1/4"/ft min
 - 3" or greater: 1/8"/ft
 - Effluent flows best @ 1/4" per foot
 - 1/8" not enough velocity
 - 1/2" too fast
 - 45° required for sewage that drains by gravity

Components and Materials

- Piping for drainage may be DWV (drainage, waste, vent) copper, cast iron or plastic (less expensive & less labor)
 - PVC and ABS plastic are suitable
 - Occasionally vitrified clay tile if by code
- Cast iron piping connected with hub and spigot joints or with hubless joints
 - Hub and spigot fitting, end of one pipe slipped into an enlarged hub of another & sealed w/ gasket, which is held in place w/, s.s. Retaining clamp
 - Cast iron is required for house sewer
 - Copper & plastics are joined for supply water piping
- **Back flow preventers (backwater valves):** prevent sewage from upper stories or from reversing flow and backing into fixtures set at lower elevation
- Fixtures below level of house drain require a **sump pit** which collects sewage and pumps it to higher level to flow by gravity
- **Floor drains:** collect water in shower rooms or where overflow likely
 - Since some seldom used, traps must be deeper to prevent evaporation of water in trap
- **Interceptors:** device that collects foreign matter at source & preventing it from entering sewer system

System Design

- Sizing of drainage is based on fixture units (sim to water supply piping) although different values of fixture units for each type of fixture

WASTE DISPOSAL AND TREATMENT

- **Private systems:**
 - **Leaching cesspools:** septic tank collects sewage and allows solid matter to settle to bottom and effluent (liquid portion) to drain into distribution system
 - Size of tank determined by daily flow. Residences usually by bedroom and baths. For larger installations based on calculated sewage flow in gallons per day
 - Leaching field based on ability of soil to absorb effluent. This is determined by a **percolation test** which measures the amount of time it takes water in test pit to drop 1"
 - Potential for septic system to contaminate potable water (wells) code gives min dist.
 - 100' between leaching field and well
 - 50' between septic tank and well
 - 10' between leaching field and building
 - **Subsoil disposal bed:** drainage of effluent two feet or more below water table
 - **Sand filters:** in areas w. impervious soil. Collection drain carry effluent to non-potable watercourse
- Sewage transported from building to public sewer lines that connect to public right of way to large mains & eventually sewage treatment facility
 - Manholes every change in direction or 150' intervals

STORM DRAINAGE

- Keep site drainage separate from sanitary drainage to avoid overloading & possible backups
 - **Rural:** runoff typically is absorbed
 - **High populated:** higher percentage of covered area ∴ artificial system needed

Private System

- Collect roof water and letting it run onto ground surrounding house
 - **Splashblocks** used to carry or project water far enough from building to avoid excess seeping into foundation
 - **Drywell:** porous underground container where water collects and seeps into soil
 - **Drain field:** used if ground is not sufficiently porous, similar to a leaching field
 - **Site drainage grading:** 1/4" per foot

Municipal Systems

- **Storm sewer system:** Collection of runoff from gutters & catch basins. System carries water by gravity to natural drainage such as rivers
- **Retention pond:** designed to contain max expected runoff and to slowly release to the storm sewer system

Drains, Gutters and Downspout Sizing

- Sizing based on area of roof or paved area drained and max hourly (avg annual?) rainfall
- Rainfall rates available from local weather service
- When calculating roof area, use the projected area (horizontal area defined by degrees of roof w/o regard to slope)

FIRE PROTECTION AND LIFE SAFETY

- **Objectives:** protection of life, property and restoration and continued use of building after fire
- Also for earthquakes, floods, pesky terrorists threats
- **Fire protection:**
 - **Fire prevention:** limiting the products of combustion which are addressed by codes via minimum flame spread ratio & flammability standards
 - **Fire detection systems:** to provide sufficient warning. (See ch10 for types)
 - Providing quick exiting
 - **Fire containment:** suppression through sprinkler systems, standpipes, etc

Compartmentation

- **Compartmentation:** To contain a fire and limit its spread
- To allow occupants to escape
- To protect other parts of building not initially subject to fire
 - In high rises may not be practical to evacuate so need place of refuge
- Separation between occupancies
- Between use areas and egress

Smoke Control

- Most deaths and injuries due to inhalation
- Smoke moves rapidly beyond area of fire by:
 - Natural convection forces caused by differential air pressure between cool and warm air
 - Stack effect pulls smoke thru any vertical penetration
 - Stairs
 - Elevators
 - Mech shaft
 - Exacerbated by HVAC
- **Smoke control methods:**
 - **Containment:** dampers, gaskets on fire doors & self closing fire doors (create a smoke seal)
 - Via containment, an area of refuge can be established
 - **Exhaust:**
 - **Passive smoke control system:** barriers to limit migration of smoke
 - Partitions
 - Doors with smoke seals
 - Curtain boards: piece suspended min of 6' from ceiling that restricts passage of smoke used in vented buildings and around escalator openings
 - **Active smoke control system:** engineered system where mechanical fans produce pressure differential or establish airflows to direct smoke movement
 - Alarm is automatically activated
 - Doors connected to automatic closing devices close
 - Supply and return air ducts to fire zone shut down and exhaust to outside is turned on creating a negative pressure in the fire zone
 - Other zones return and exhaust air ducts are closed and supply air is forced into safe area which creates a positive pressure in the refuge area and prevents smoke from migrating in
 - **Stairways pressurized.** Vestibules pressurized at a level slightly higher than the fire floor but less than stairway which provides double protection of stairway and keeps smoke out of vestibules where wheelchair occupants and standpipe connections are located
 - **Dilution**

Sprinkler System

- IBC requires in buildings over 75' tall
- Wet pipe systems: most common. Constantly filled and respond immediately to a rise in temp at any sprinkler head (from 135° to 170°)
 - Flow detectors at ea zone of sprinkler piping that senses head is open, movement of water and sends signal to annunciator panel or fire control center so FD know where fire is
- **Dry pipe system:** in areas subject to freezing pipes are filled with compressed air and can be activated by a valve connected to fire alarm
- **Preaction system:** similar to dry pipe except that water allowed into system before head opens and sends an alarm to controls
 - Used where damage from water may result
 - Early alarm allow fire to be put out before heads open
- **Deluge system:** activates all sprinkler heads. Heads opened and pipes are emptied
 - High hazard occupancy
- In tall buildings water for sprinkler systems supplied from tank near top of zone
 - When tanks used, they are designed to provide fire fighting capability for a certain percentage of sprinklers for a given time until FD arrives
 - Siamese connections on ext of building so FD can connect hose pumps to sprinkler system
- Installation of sprinklers is governed by **NFPA 13 Standard for the Installation of Sprinkler Systems**
- **Hazard groupings by the NFPA:**
 - **Light:** residences, offices, hospitals, schools and restaurants
 - One sprinkler for each 200ft² or 225ft² if hydraulically calibrated
 - One for every 130ft² for open wood joist ceilings
 - Max spacing between heads is 15' for the 225ft² coverage w/ max distance from wall of 1/2 req'd spacing

Standpipes

- Run height of building and provide water outlets at each floor where hose can be connected
 - Within stairways, or in pressurized enclosure @ vestibules
- IBC classification
 - **Class I:** dry standpipe w/o connection to water supply & 2 1/2" dia outlets
 - Only when bldg is equipped with sprinkler
 - In open parking garages less than 150ft high
 - In open parking garages subject to freezing
 - In basements that are sprinklered
 - **Class II:** wet standpipe directly connected to water supply & 1 1/2" dia outlets
 - **Class III:** combo system directly connected to water supply and & both 1 1/2" & 2 1/2" dia outlets
 - Used where highest floor is +30' above the lowest level of FD access or where the floor level of the lowest story is located more than 30' below highest level of fire dept access
- Class II & III must be accessible and located so all portions of building are within 30' of a nozzle attached to 100' of hose
- Water is supplied thru tanks or thru siamese connections

Other Extinguishing Agents

- **Type A:** ordinary combustibles
- **Type B:** flammable liquids (a solvents and paints)
- **Type C:** electrical equipment
- **Type D:** Combustible metals
- **Halogenated agents or Halon:** used where water may damage contents of room such as computers
 - Is a CFC gas that damages ozone
- **Foam** to smother fires where flammable liquid fires may occur (industrial plants and aircraft)