ME NOTES

SUSTAINABLE DESIGN

Principles

1. The earth's ecosystem (area of earth's crust and atmosphere approx. 5 miles high and 5 miles deep) has a finite amount of natural resources
2. Given the laws of thermodynamics, energy cannot be created or destroyed
3. All forms of energy seek equilibrium and therefore disperse. (i.e. precipitation-plants-soil-aquifer; process can be contaminated by humans)

Natural Step-created in 1996 by scientists, designers and environmentalists were concerned with the earth's ecosphere (5 miles of earth's crust) and the biosphere (5 miles into the troposphere of the atmosphere). Principals were as follows:

1. Elements from earth's crust cannot be extracted at a greater rate than it can be replenished.
2. Manufactured materials cannot be produced faster than they can be integrated back into nature
3. Protect/preserve the existing living organisms
4. Efficient use of resources to meet human needs

Sustainable site planning/design

- Site Selection
    - Adjacency to public transportation
    - Flood plains; locate or raise a building above the 100 year floodplain
    - Erosion, fire, landslides; avoid building in areas naturally prone to these cycles
    - Sites with high slopes or agricultural use; preserve for crops and wildlife
    - Solar orientation, wind patterns: long axis of building should be east-west and fenestration on the south side; place trees to reduce winter heat loss and summer heat gain
    - Landscape site conditions: coniferous trees on west or northwest (prevailing wind) and deciduous trees on south and west
- Alternative transportation – mass transit, carpool, sensitive fuel options
- Reduction of site disturbance – conserve natural areas, restore wildlife
- Storm water management
    - Provide on-site infiltration; avoid contaminants from entering main waterways
    - Reduce impermeable surface and runoff; allow local aquifer recharge
    - Encourage groundwater recharge
- Ecologically sensitive landscaping
    - Install indigenous plant material
    - Locate plants and trees over dark surfaces to reduce 'heat island effect'
    - Replace lawns with natural grasses
    - Encourage xeriscaping in dry climates
- Reduction of light pollution – lighting of buildings/landscaping on site should not transgress the property or shine into the atmosphere
- Open space preservation
    - Promote in-fill development to compact and contiguous to existing infrastructure
    - Promote development that protects natural resources
    - Ensure on-going management of the natural areas

Water use (4 classifications)

- Potable water – treated and suitable for drinking
- Gray water – waste water not from toilets or urinals; can be used for flushing toilets and irrigation
- Black water – water containing waste from urinal or toilet; sometimes from kitchen and laundry depending on jurisdiction
- Rain water – can be used for flushing toilets/urinals and irrigation.
  1" of rain per sf = 0.6 gal

Ahwahnee principals – established in 1991 in Ahwahnee Hotel by planners and architects to present community principals that express sustainable planning ideas.

- Community principals:
    - Community integration (schools, parks, jobs, daily essentials)
    - Easy walking distances to everything
    - Diverse housing and jobs
    - Center focus/plaza and a series of greens/parks
    - Encourage pedestrian/bicycle use with sidewalks/paths
    - Efficient use of water by natural drainage, recycling, xeriscaping
- Regional principals:
    - Integrate transit system with larger transportation network
    - Regions should be bounded by natural conditions
    - Regional institutions should be located in urban core
    - Construction materials and methods should be synonymous with community
- Implementation principals:
    - Local government should control planning process
    - Specific plan should be made on following principals and done through an open process

Architectural Process

1. Cost:
    - Life cycle costing: includes first cost, operating, maintenance and replacement
    - Matrix costing: analysis of systems to determine efficiencies and finalize systems
2. Function: ability of building to perform to client's needs
3. Time
4. Aesthetics
5. Sustainability
    - Use less
    - Recycle components
    - Use easily recycled components
    - Use fully biodegradable components
    - Do not deplete natural resources necessary for future generations

LEED (Leadership in Energy and Environmental Design)

1. Sustainable sites
2. Water efficiency
3. Energy and atmosphere
4. Materials and resource
5. Indoor air quality
6. Innovation and design practice

Sustainable design process

- Design team should include:
    a. Architects/Engineers with energy modeling experience

    b. Landscape architect with native plant experience
    c. Commissioning expert (LEED)
    d. Engineer/Architect with building modeling experience
- Research and Education should include the client and project team
- Bidding/Specifications
    - Include simple definitions and explanations of sustainable elements; reference the agency supplying the product
    - Two approaches for listing suppliers:
      - Limit the installer to 3 – 5 suppliers that satisfy the specifications
- Identify qualified suppliers, but allow contractor to submit alternative suppliers

Life cycle assessment- evaluates environmental impact on using a product or material in building
- Define goals and scope of study
- Perform inventory analysis (determines and quantifies input/output of product)
- Perform impact assessment (characterizes effects of product on environment)
- Perform an interpretation and report results of study (suggestion to reduce environmental impact of product)

Product life cycle includes:
- Raw material acquisition (includes processing and transportation)
- Manufacturing (processing, fabrication, packaging and transportation)
- Use and Maintenance (includes installation)
- Disposal (demolition, conversion, waste and reuse/recycling)

Evaluating building materials
- Embodied energy (should require minimal energy for initial extraction, processing)
- Renewable materials (come from sources that can renew themselves quickly)
- Recycled content (less energy and processing; 3 types: post-consumer, post-industrial, recovered)
- Use of local materials
- Durability
- Low VOC
- Low toxicity (should not emit CFCs, formaldehyde; refer to EPA list)
- Moisture problems (materials should prevent growth of biological contaminants)
- Water conservation (in building and landscaping)
- Maintainability
- Potential for reuse and recycling

Materials
- Concrete: not generally a sustainable material b/c of energy use, raw material consumption and environmental emissions. Can be improved by using low waste formwork, fly ash (increases strength and sulfate resistance) and lightweight aggregates (pumice or perlite). Provides low emissions after in place, good thermal mass
- Masonry: similar to concrete, but generally manufactured close to place of use. Provides low emissions after in place, good thermal mass
- Metals: high potential for recycling, most used material in buildings. Steel has recycled content of 30%; aluminum has recycled content of 20%.
- Wood:
    - Reclaimed wood- recycled from old buildings; prepared for new use
    - Sustainable wood- engineered wood products (I-joists, laminated veneer lumber, structural insulated panels (SIP))

  - Certified wood- wood obtained through sustainable forest management practices (Forest Stewardship Council)

- Thermal Insulation/Moisture Protection
  - Cellulose: contains at least 70% post-consumer paper in loose-fill
  - Mineral Fiber: made of steel mill slag or basalt rock in rigid board or batt
  - Glass fiber: at least 30% post-consumer glass in rigid board or batt
  - Vermiculite: made of mica, expanded by heat, made for loose-fill
  - Perlite: made of volcanic rock, expanded by heat, made for loose-fill

- Doors and windows: utilize for daylighting, solar heat gain and ventilation. Use thermal breaks when made of aluminum or steel

- Adhesives: should be low-emission, zero VOC to install flooring, laminates, veneers, wall coverings. 3 types include:
  - Dry: contain resins in capsules released by pressure
  - Water-based: contain latex or poly-vinyl acetate
  - Natural: contain plant resins in a water dispersion system

- Flooring:
  - Carpet: nylon 6 is type of fiber that can be recycled, carpet tiles are more sustainable than broadloom.
  - CRI (Carpet and Rug Institute: agency test carpet for 4 emissions:
    - Total volatile organic compounds
    - Styrene
    - Formaldehyde
    - 4 –PC (4 phenyl-cyclohexene
  - 3 considerations for installation:
    1. Raw material use
    2. Raw material disposal
    3. Indoor air quality
  - Vinyl: has many benefits, but contains PVC
  - Rubber: durable, resilient, but should be only used in well ventilated areas
  - Linoleum: made from natural products (linseed oil, rosin, cork powder), durable and biodegradable
  - Cork: excellent sound absorber; made from bark of cork oak
  - Wood: pre-finished should be used whenever possible to eliminate sanding, finishing that reduces indoor air quality
  - Ceramic tile: uses natural materials, durable, no emissions, little maintenance

- Wall finishes:
  - GWB: made of recycled content, but is not recyclable when removed from building. If recycled, it is pulverized and used as a soil additive
- Paint: low to no VOC content (should not exceed 250 g/L)

Indoor Air Quality

Indoor air contaminants include 2 groups: chemical and biological

- Chemical: VOC (paint, stains, adhesives, sealants), formaldehyde (particleboard, paneling, furniture, carpet adhesives)
- Biological: mold (moisture, nutrient, temp range 40°F-100°F), mildew, bacteria

Causes of poor indoor quality:

- Chemical contaminants from outdoor sources
- Chemical contaminants from indoor sources
- Biological contaminants
- Poor ventilation

Symptoms of poor indoor air quality:

- Sick building syndrome (SBS) – occupants experience a variety of health-related symptoms that cannot be directly linked to a particular cause
- Building related illness (BRI) – health related symptoms of building occupants are identified and can be attributed to certain building contaminants
- Multiple chemical sensitivity (MCS) – condition brought on by exposure to VOCs or other chemicals

Strategies for maintaining good indoor air quality

- Eliminate or reduce sources of pollution
- Control ventilation
- Establish good maintenance procedures
- Control occupant activity

THERMAL PROCESSES (ENERGY EFFICIENCY)

Building orientation

- long axis should be oriented east-west to minimize the intense east-west solar radiation and take advantage of heat on south-facing surfaces in the winter
- Exact angle of south face varies slightly depending on region, but is approximately 15° east of south

Building shape

- External load dominant building: energy use is determined mainly by heat loss or gain through exterior envelope
- Internal load dominant building: energy is driven by high heat gain from occupants, lighting and equipment
- Cool region: square/cubic shape is best b/c exterior skin area is minimized. Minimize northern exposure including windows and doors
- Temperate region: elongate in east-west direction for winter solar heat gain (maximize southern exposure), daylighting, and minimal heat gain in the summer. Minimize northern exposure and winter winds should be blocked
- Hot-arid region: square shape, courtyard for external load dominant loading. Use of thermal mass, roof ponds encouraged
- Hot-humid region: elongated in east-west direction for breezes, natural cooling, minimize heat gain from east-west direction. Use of courtyards and overhangs encouraged; use thermally lightweight building materials

Landscaping

- Deciduous trees can be used on south side of building to provide shade in summer and solar heating in winter
- Evergreens more effective at blocking wind especially in winter
- Velocity of wind can reduced 30%-40% if building distance is 5 times the height of the trees; 20%-60% if building is next to trees

Shading

- Shading Coefficient (SC): ratio of solar heat gain through a glazing product compared through a 1/8" thick double strength glass under same set of conditions. The value is between 0.0 and 1.0
    - South facades should have overhangs or horizontal louvers
    - East and west facades should have vertical louvers

Earth sheltering

- Advantages include:
    - Minimal heat loss and heat gain
    - Structure protected from winter winds, high winds, hail, tornadoes
    - Natural soundproofing
    - Less outside maintenance
- 3 types are: bermed ground, built into hillside, completely buried
    - Considerations include: natural slope to land, granular soil, groundwater should be lower than building, positive drainage away from building, waterproofing, insulation and ventilation

Green roofs

- Advantages include:
    - Reduces heating and cooling costs; reduces energy consumption
    - Reduces storm runoff
    - Absorbs carbon dioxide
    - Reduces heat island effect
    - Reduces ambient air temperature
- Types:
    - Extensive: soil is less than 6" and supports grasses, sedums, herbs, perennials
    - Intensive: thicker soil to support shrubs, trees, fountains, ponds

Air locks: vestibule entry system or revolving doors

Insulation: made of fiberglass, mineral wool and available as loose fill, batts, rigid foam boards, spray-on foam

- Super insulation- higher level of insulation, tight sealed joints and cracks, thermal bridges are prevented
- Transparent insulation- between layers of glazing to admit light
- Moveable insulation- used for passive solar heating (roll-down shutters, insulated shades)
- Air barriers- control movement of air into and out of building, and infiltrating air is conditioned to meet indoor requirements, blocks infiltrating air containing pollutants, and controls air movement to minimize moisture

- Wind pressure places positive pressure on 'front' of building and negative pressure on corners, sides and leeward side. Stack pressure is caused by atmospheric pressure at top and bottom of building due to temperature differences

Glazing: can be major source of heat loss and heat gain in building

- Insulating glass: typically has 2 panes of glass with sealed air space (vacuum); U-valve is about 0.57 Btu/ft^2-hr-°F
- Double glazing: 2 panes of glass with sealed air space (inert gas); U-value is about 0.52 Btu/ft^2-hr-°F

- Low emittance (low-e) glass: double glazing with a thin film in cavity
- Specturally selective glazing: transmits high proportion of of the visible solar spectrum and blocks heat (80%) from the infrared spectrum. Good for buildings with long cooling season requiring high light levels
- Super windows: glazing units combining 2 low e-coatings with gas-filled cavities between 3 layers of glass. U-value of 0.15 Btu/ft^2-hr-°F
- Switchable glazing: change based on environment or human intervention and include:
  - Electrochromic - thin film applied to glass that changes from clear to dark by low-voltage electrical current
  - Photochromic – darkens under direct action of sunlight
  - Thermochromic – changes darkness in response to temperature
- Transition-metal hydride electrochromics – changes from transparent to reflective

Glazing selection: low U-value is desirable to control heat loss through convection. To control heat gain, a low SHGC is desired. Spectrally selective glazing gives a high VLT and good SHGC

Solar heat gain coefficient (SHGC): ratio of solar heat gain through a fenestration to the total solar radiation incident on the glazing. This includes transmitted solar heat and absorbed solar radiation. Value is between 0.0 and 0.87

Shading Coefficient (SC): is the ratio of solar heat gain through a glazing product compared through a 1/8" thick double strength glass under same set of conditions. The value is between 0.0 and 1.0

Double Envelope: a system of 2 glazed layers separated by 2'-3' and incorporate sun control (louvers, blinds, shades) with a passive or active ventilation system

Advantages include: reduced cooling loads, enhanced sun control, reduced operating costs, optimized daylighting and enhanced air quality

Daylighting: to be feasible, it must include sufficient views of the sky, glazing must transmit enough light and design must be coordinated with artificial lighting control and mechanical systems design

- Daylight factor (DF): Ratio expressed as a percentage of indoor illuminance at a horizontal point to the unobstructued exterior horizontal illuminance

Window design: 2 important variables are window head height and effective aperture (EA)

- Effective aperture (EA) combine the variables of VLT and WWR
  - Visible light transmittance (VLT): percentage of light that passes through glazing
  - Window-to-wall ratio (WWR): net glazing area in a space divided by gross exterior wall area not including window frames or mullions

Room design: Minimum reflectances should be 80% ceilings, 50%-70% walls, 20%-40% floors

Solar design

Passive solar energy systems: solar energy is collected, stored, and distributed without the use of mechanical equipment

- Direct gain system: allows radiation to flow directly into space needing heat (greenhouse effect); heat is stored in high mass materials
- Indirect gain system: sunlight strikes thermal mass converting into heat and transferring it into the space (Thermo storage walls, roof ponds) Requires approx. 4 times the mass of a direct system
- Thermo storage wall (Trombe wall): masonry wall with vents at top and bottom to allow thermocirculation

- Phase change materials: typically eutectic salts that change from a solid to a liquid; prevents overheating
- Greenhouse: large glazed areas south facing with a thermal wall separating the greenhouse and remainder of structure
- Roof ponds: store heat in large bags of water on the roof of building; system can be reversed to provide cooling into the building

Active solar energy systems: include 3 components: a collector, a storage device, and a distribution system

- Collectors can be:
    - Flat plate: network of pipes located on an absorptive black surface with low emissivity below a covering of glass or plastic. Pipes carry the heat transfer fluid
    - Focusing plate: parabolic shaped reflectors that focus the sunlight to a single pipe carrying the heat transfer fluid. They operate at higher temperatures since they must be continuously adjusted towards the sun.
- Storage devices: usually water for water systems or rock beds for air systems
- Distribution: ducts for air, pipes for water and associated fan, pumps, registers

Geothermal: involves the use of ground source heat pumps (GSHPs) that use relatively constant temperature of the earth. An assemblage of durable plastic pipes buried in the ground either horizontally or vertically depending on site. 400' of pipe required for every 12,00o Btu/hr of heating or cooling capacity.

Wind:

- Vertical axis wind turbine (VAWT): Savonius (shaped like two offset cups) is not as efficient, but self-starting and Darrieus (shaped like eggbeater) is very efficient, but not self-starting
- Horizontal axis wind turbine (HAWT): More common and in 2 types: Leading- upwind of the tower and requires a tail (weather vane like) with a motor attached to a sensing device. Trailing- downwind of the tower and results in eccentric vibration caused by pressure on the blade

Photovoltaics: conversion of sunlight into direct electricity. Advantages include:

- Reduces demand on non-renewable energy sources (coal and gas)
- Generated on site and excess can be sold back to the utility company
- Produces electricity with no pollution

HUMAN COMFORT

Common terms

- British Thermal Unit (Btu): the amount of heat energy required to raise 1 pound of water 1° F.
- Coefficient of heat transmission: overall rate of heat flow through any combination of materials, including air spaces, air layers; interior or exterior. The reciprocal of the sum of all resistances in the building assembly
- Conductance: number of Btus per hour that pass through 1 ft^2 of material of a given thickness when the temperature differential is 1°F
- Conductivity: number of Btus per hour that pass through 1 ft^2 of material of 1" thickness when the temperature differential is 1°F
- Dew point: temperature when water vapor in the air is saturated and condenses
- Dry-bulb temperature: temp of air water mixture measured by dry-bulb thermomtr

- Enthalpy: total heat including latent heat and sensible heat
- Insolation: total solar radiation on a horizontal surface; radiant gain through glass
- Latent heat: when transferred heat causes a change of state (i.e. ice to water)
- Sensible heat: when transferred heat causes a change in temperature
- Specific heat: number of Btus required to raise the temperature of a material by 1°F. Heat storage capacity of material or object (Cp) compared to storage capacity of water
- Resistance: number of hours needed for 1 Btu to pass through 1 ft^2 of material of a given thickness when the temperature differential is 1°F
- Wet-bulb temperature: Temperature of air measured by a sling psychrometer; bulb is wrapped in moist cloth. More critical measure of heat in high humidity

Metabolism

Body loses heat in 3 primary ways: convection, evaporation and radiation

- Convection: transfer of heat through the movement of fluid; either gas or liquid
- Evaporation: heat loss occurs when moisture changes to a vapor
- Radiation: heat is transferred between two objects not in contact and not shielded from each other. Transfer is by electromagnetic waves from one surface to a colder surface
- Conduction: transfer of heat through direct contact between two objects of diff temp

Air Temperature

- Effective temperature (ET): value that combines the effects of air temperature, humidity, and air movement
- Large difference between wet-bulb and dry-bulb temperature indicated the low relative humidity

Humidity

- Relative humidity: ratio of percentage of moisture in the air to the maximum amount the air can hold at a given temperature without condensing
- Comfortable range: 30%-65%; tolerable 20%-70%
- At 100% relative humidity, dry-bulb and wet-bulb are the same

Surface temperature

If surface temperatures of surroundings are colder than surface temperature of skin (85°F), the body loses heat through radiation. If surrounding surfaces are warmer, the body gains heat

- Heat transfer: always from a hotter object to a cooler object
- Rate of radiation is based on surface temperature of body or nearby objects, viewed angle and emissivity.
- Viewed angle: the solid angle formed between the measuring position and the outer edges of the object.
- Emissivity (ε): measure of object's ability to absorb and then radiate heat. The emittance of an object is the ratio of the radiation emitted by a given object or material to that emitted by a blackbody at the same temperature
- Mean radiant temperature (MRT): a weighted average of the various surface temperatures in a room and the angle of exposure of the occupant to the surfaces as well as sunlight present
- Operative temperature: the average of the air temperature of a space and the MRT

Psychrometric Chart: graphical representation of the complex interactions between heat, air, and moisture. Chart includes wet-bulb, dry-bulb, relative humidity, and enthalpy. Psychrometry is the study of the water vapor content of air

- Enthalpy line is used to determine total amount of heat to be removed (cooling) or added (heating) for conditioned air

External and Internal loads

- External loads that cause heat loss include air temperature and wind and heat gain include air temperature and sunlight
- Internal loads are caused by people, lights, and equipment

Heat is transferred between the outside and inside of building though conduction, convection, and radiation.

- Conduction: transfer of heat through direct contact of molecules
- Convection: transfer of heat through the movement of air
- Radiation: transfer of heat energy through electromagnetic waves from one surface to colder surface

Heat loss calculations

Heat is lost in 2 basic ways: through the building envelope and air infiltration

- Conductance and resistance are related by the formula: **R=1 / C**. Resistance (R) can be calculated from the thickness (x) and the conductivity: **x / k=R**
- Coefficient of heat transmission (U), is used to calculate heat loss of a building assembly (more than one material). Use the formula $\mathbf{U=1 / \sum R}$ **or** $\mathbf{U=1 / R_1+R_2+\ldots R_n}$
- Heat flow is the product of the conductance of the assembly (U) and the temperature difference between inside and outside. Total heat loss is determined by $\mathbf{q=U\ A\ \Delta t}$**,** where q (conductance), U (product of the conductance of the assembly), A (exposed surface area), Δt (temperature difference)
- Energy flow rate of a long period of time $\mathbf{q_c=U\ (A)\ 24\ (DD)}$. DD refers to degree day: measure of how cold a given place is over a period of time and the day whose mean temperature is one degree below the reference temperature of 65°F. This determines the design day: a day colder than 98% of the days experienced in that climate
- Remember, vapor barriers must be placed on the warm side of the insulation

Heat gain calculations

- Design equivalent temperature difference (DETD)- this value takes into account the air temperature differences, effects of the sun, thermal mass storage of materials, colors exposed to the sun, and daily temperature range. This is expressed as **q=U (A) DETD**. Values are published by ASHRAE
- Design cooling load factor (DCLF)- takes into account how solar heat gain occurs, type of glazing, type of interior shading, and outdoor design temperature. This is expressed as **q=U (A) DCLF**. Values are published by ASHRAE
- Occupants of building produced two kinds of heat: sensible heat and latent heat in the form of moisture from breathing and perspiration. Sensible heat gain from occupants is about 225 Btu/hr. Sensible heat is calculated by multiplying occupants by 225 Btu/hr, or $\mathbf{q_p}$ **= # of people x BtuH/person**
- Heat gain from lighting can be determined by 1 watt=3.41 Btu/hr or $\mathbf{q_l=3.4W}$
- Latent heat gain in residential and many other occupancies is about 30% of sensible heat gain

Infiltration: transfer of air into and out of a building through open doors, cracks, windows, flues, vents, and other openings

- Heat loss through infiltration is calculated by $\mathbf{q_v=V\ (1.08)\ \Delta t}$, factor of 1.08 Btu accounts for the amount of heat that air at a certain density can hold. This will determine the amount of heating or cooling required
- Infiltration also determined in other words by the air change method or crack method
- Air change method: Amount of air (Q_{cfh}, expressed in cubic feet per hour) is determined by multiplying the building volume in cubic feet (V) by the number of air changes (N): $\mathbf{Q_{cfh}=N\ x\ V}$
- Crack method is based on the number of linear feet of crack or joint in the space under consideration. The amount infiltration can be determined from a table that

considers window type and wind speed and then multiplied by linear feet:
Q_{cfh}=LF x CFH/lin.ft.

PLUMBING SYSTEMS

Supply

- Potable water: suitable for human drinking
- Nonpotable water: not for drinking, but can be used for irrigation and toilet flushing
- Two most common forms of large water supplies are surface water (comes from rain and snow that runs off into rivers/lakes) and ground water (seeps into ground until it reaches an impervious layer of soil/rock).
- Aquifers: large regions of of sub-surface water
- Acidity: measured by pH of water; neutral water has a pH of 7. The greater the acidity, the lower the number. PH6.9-6.0 (slightly acidic), pH 5.0 (highly acidic). Above a pH of 7 is considered alkaline
- Hard water: contains limestone and/or calcium and/or magnesium
    - Anodes – metal device inserted in water tank to divert deposition forming on heat exchanger
    - Water softeners – Zeolite or ion exchange process used with heated water to remove minerals. A brine solution is passed through the zeolite periodically to recharge the water softener
- Turbidity: caused by suspended material in water (silt, clay, organic material)
- Private water supply: wells, springs or collected rainwater; most common is well. Well drilling involves depth and yield; depth can be 25' (shallow) to a few hundred. Yield is the number of gallons per minute it provides; 5gpm to 10gpm is minimum required for residential

Pumps

- Suction: suitable for water tables less than 25'
- Deep well jet: for 25' to over 100'
- Turbine: for high capacity systems with deep wells
- Submersible: most common fro small buildings or private residences; for moderate to deep wells, has a waterproof motor and pump placed below the water line and pump water to a pressure tank
- Pressure tanks: maintain a constant pressure for use in the building and compensates for peak demand exceeding pump capacity
- Jet (venturi) pump system: air volume control senses tank depletion and accesses a large tank storage

Municipal water supply

- Water is obtained from rivers, lakes, etc. and treated, then piped through water mains at about 50 psi and distributed to individual properties. Individual owners may be required to extend lines from property if main is not adjacent to property line

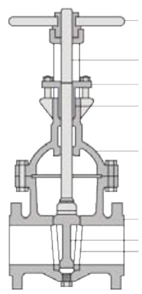
Water pressure: 1 psi of water pressure can lift a column of water 2.3' high; or 0.433 psi to lift 1'

- Water can never be sucked up from above to any height greater than 33' b/c that is the static head equivalent of atmospheric pressure at 14.7 psi.
- Static head: the pressure required to push water vertically, or the pressure caused at the bottom of a column of water

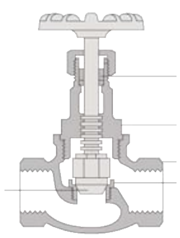
Water supply/pressure systems

- Downfeed system: Tank mounted on roof supplies water to upper stories. Water is supplied from main boosted by pump in the basement of building. Pressure is determined by height of tank above a given floor and not by pump. Height of zone is determined by the allowable pressure on the fixtures at the bottom of the zone, allowing for friction loss. Pressure is usually from 45psi to 60 psi and a zone max height of approx. 138'. Pressure reducing values are required beyond this. Disadvantage is weight on roof resulting in a more expensive structure
- Upfeed system: uses pressure in the water main directly to supply the fixtures. Practical limit is 40' to 60' due to system friction and pressure required for highest fixtures
- Pneumatic tank system – Pressurized tank in basement to supply higher levels of building by using compressed air to push water up. Disadvantage is basement area taken up and air may be dissolved in the water
- Tankless system – one or more variable speed pumps that supply water at demand rate (controlled by sensors). Doesn't take up any space, but pumps can have short life cycle

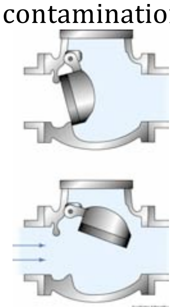
Valve and fixtures
- Gate valve - intended to be entirely on or off; low friction loss



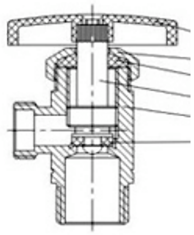
- Globe valve – restrict flow even when open; used to turn on or off and meter or throttle flow at intermediate rates. Fiction loss high, used with faucets and hose bibbs



- Check valve – backflow preventer; flap prevents flow in opposite direction and water contamination. Another type is a ball that is spring loaded.



- Angle valve – used mostly for plumbing fixtures; has metering or flow restriction capabilities



Surge arrestors (shock arrestors): prevents water hammering

Coefficients/Materials and methods:

- Copper: 0.0000098 (provide pipe support every 6'): used for supply piping, does not rust, strength, low friction. Type L is most common with schedule 40 diameter. Type M is used for straight runs (hard temper) and for low pressure use. Type K is used for underground supply and has thickest section. Copper is joined by soldering and sweating; flux is heated and joins two sections.
- Steel: 0.0000065 (provide pipe support every 12'): galvanized steel is used; schedule 40 is most common. Joined mechanically with threaded collars.
- Cast iron: 0.0000056
- PVC: 0.0000035 (provide pipe support every 4'): used mostly for indoor applications, PVC (white) used for supply and ABS (black) used for drainage. PVDC only plastic pipe suitable for hot water. Joined by primer.
- Union: special fitting to connect 2 rigid sections of piping and can be easily unscrewed

System design: involves sizing pipes, laying out required fittings, valves and other components which must be equal to or less than the water main pressure

	Pressure at most remote fixture
+	pressure loss from static head
+	pressure loss by friction in piping/fittings
+	pressure loss through water meter
=	total street water main pressure

- Pressure loss in pipes depend on the diameter of the pipe and the flow (gpm)
- Friction: function of diameter of pipe and flow rate through it. For the same flow rate, the smaller the diameter of the pipe, the greater the friction and for the same diameter pipe, the greater flow rate, the greater the friction
- Fixture unit: a unit flow rate approx. equal to $1ft^3$/min. used to determine pipe sizing and probable demand; tables are provided
- Velocity: above about 10ft/sec, water in pipes is noisy. In sound-sensitive situations, anything above 6ft/sec may be too noisy

Thermal expansion:

$$\Delta L = Lk\,(T^2 - T^1)$$

ΔL : change in length
L : length
k: coefficient of expansion
T^1 : original temperature
T^2 : final temperature

PVC pipe expands 3.5 times more than copper

Hot water supply

- Single supply pipe: used in residences and small buildings, it is provided from the heater to the fixtures. Minimizes piping costs, but can result in long wait for hot water to reach fixture
- Two pipe circulating system: all fixtures are connected with a supply pipe and a return pipe. Water slowly circulates in the system through natural convection; hot water rises to highest fixtures and falls after cooling to be heated again.
- Water heater: size is determined by total daily peak hourly demands. It can range from 0.4 gal per person peak in an office to 12 gal per unit in a small apt bldg
- Recovery rate: number of gallons of cold water a heater can raise to desired temperature per hour
- Hot water piping is determined by calculating the load of only fixtures that use hot water. This value is multiplied by 0.75 (75%)
- Basic heating methods
    - Direct system: brings water directly in contact with heated surfaces that are warmed with flame, electricity, hot gases, etc. Method is typical in residential tank-type water heater
    - Indirect system: uses an intermediary transfer medium to heat water. (i.e. steam pipes within water tank)
    - 3 basic types of equipment for direct or indirect systems
        - Storage tank system: same tank is used to heat water and store for use
        - Tankless system: water is heated as quickly as needed by electric heaters and sent to fixture. Used for locations where it is impractical to pipe hot water continuously
        - Circulating system: water is heated in one place and stored in a separate tank until needed. Used in commercial applications and solar-powered heating systems

Recommended point-of-use temperatures

- 95°F: therapeutic bath, 105°F: hand washing, 110°F: showers and baths, 140°F: residential dish washing, 180°F: commercial and institutional laundries, commercial dishwashers. Above about 110°F, water becomes uncomfortable to touch

Solar water heating

- Direct system (open-loop system): water is used in the building is the same water heated in the solar collectors. High efficiency, but subject to freezing
- Indirect system (closed-loop system): uses a separate fluid for collecting heat and then transferred to the hot water. Heat exchanger is required (reduces efficiency), but will not freeze
- Heating fluid is circulated 2 ways:
    - Passive circulation: rely on gravity and thermosiphoning of heated water. Simple, low cost, but must be placed above solar collectors and close to points of use
    - Active circulation: use pumps to circulate heat collecting fluid. This system costs more, but are more flexible and reliable
- Solar heating systems:
    - Batch system: (breadbox heater) heats water in a black painted tank inside a glazed box. Simple, but subject to freezing
    - Thermosiphon system: relies on natural movement of heated water to circulate in a passive open-loop system. Simple, but storage tanks must be kept above collectors
    - Closed-loop active system: Non-freezing fluid is circulated by pumps through solar collectors and into a heat exchanger where hot water is heated. Most common in residential and commercial applications
    - Drain-down system: direct (open-loop) active system that automatically drains water from collectors in cold climate to prevent freezing

- Drain-back system: indirect (closed-loop) active system that uses water as a heat collector fluid. The heated water is pumped into a heat exchanger where a coil of domestic hot water is located
- Phase-change system: collector fluid is phase change materials

Drainage systems:

- Sanitary drainage: any drainage from human waste
  - Black water (soil): sewage including human waste
  - Grey water (waste): sewage from kitchen, sinks, dishwashers, lavatories
- Traps: filled with water to provide a seal that is used to prevent methane or sewer gas from entering living space. Usually installed within 2 ft. of fixture. House traps are occasionally installed where house drain leaves the building
- Vents: used for 2 primary purposes: allow built-up sewer gases to escape instead of bubble through water in traps and allow pressure in system to equalize so discharging waste does not create a siphon that would drain the water in traps. Typically copper or galvanized steel piping
  - Vent stack: small pipe that is an air intake for all fixtures and is separately open to the outside air at the top or connects with the stack vent above the highest fixture
  - Stack vent: the section above the highest fixture in a soil stack that vents the soil stack and is open at the top
  - Soil stack: large pipe that carries human waste from all levels and is open at the top (stack vent)
  - Waste stack: carries waste other than human waste and is open at the top (stack vent)

Note: minimum diameter for a vent is 1 ¼" or half the diameter of the drain it services

- House drain (building drain): horizontal drain where stacks connect at the bottom of the building and to a point 3' outside the building
- House sewer (building sewer): drain from a point 3' outside the building to the main sewer line. Cast iron piping is required
- Vacuum breaker: used on fixtures where water supply is below the rim of the fixture. Prevents a siphon by closing when backwater pressure is present. Typically, fixtures should be at least 2" above the highest possible level of waste water to avoid potable water contamination

Drainage piping: usually cast iron piping
Supply piping: copper or plastic depending on site/location

Maintenance:

- Interceptors: catch grease, hair, particles, etc. and prevents from entering sewer system. Has a cleanout access to remove trapped material.
- Cleanouts: Y-shaped segment of pipe with cap used to access piping system. Should be placed every 50' for pipes under 4" dia., 100' for larger pipes, or if pipe direction changes greater than 45°.
- Manholes: similar to cleanouts, but for inspection of main Larger (10" or greater); occur every 150' or where a new line meets and existing line
- Backflow preventers (backwater valves): prevent sewage from upper stories or from the building sewer from reversing flow and backing up into lower level fixtures
- Sump pit: used when fixtures are lower than the level of the house drain and sewer. Collects sewage and pumps it to a higher level to flow by gravity into sewer
- Floor drains: collect water where overflow is possible

Sewage treatment systems

- Public system: sewage is treated in a waste treatment plant before returning to a body of water. Solids settle in chambers, remaining liquid sewage is treated with activated sludge to digest the waste material. The resulting clear water is chlorinated and returned to the nearest body of water. Solids and sludge are dried and placed in land fills.
- Septic tank: lined chamber (steel tank) where solid deposits remain and liquid passes to a drain field. Typically emptied every few years depending on size and use.
- Leaching (Drain) field: a grid of ceramic pipe laid underground almost together end to end to allow the liquid (effluent) to drain (or seep) out over of a bed of gravel or sand to be filtered, chlorinated and returned to the nearest body of water.
- Storm drainage: runoff from roof drains, landscaped areas
    - Swales: V-shaped sloping channels of grass or other material that direct surface runoff to points to be collected
    - Catch basins: grates located at the lowest points of swales to collect water and pass it to a storm drainage system to be emptied to a nearby body of water
    - Retention ponds: designed to contain the maximum expected runoff and then slowly release the water to the storm sewer system
    - Downspouts, gutters: determined based on the area of the roof and maximum hourly rainfall. Gutter slopes range from 1/16"/ft to ½"/ft

Handicapped access: (know ANSI 117.1)

Basics: Turn around space: 5'-0" dia with 10" clear space from floor
Seat: 1'-7" aff
Grab bars: 2'-9" to 3'-0" aff; use on both sides if space is less than 5'-0". More than 5'-0", use side bar and rear bar.
Lavatories: provide sufficient space for wheelchair to 'park' underneath; insulate hot water supply pipe
Drinking fountains: 32" to 36" aff with clear space underneath
Bath/Shower: provide seat/edge of bathtub at same height as wheelchair. Shower: allow 33" min. space to enter shower with chair; 5'-0" turn radius preferred.

MECHANICAL SYSTEMS

Energy sources

- Natural Gas: most efficient of all fossil fuels. Clean burning and relatively low in cost. Heating value is about 1,050 Btu/Ft^3
- Oil: Cost is high and availability depends on world markets. It must be stored in or near the building of use and the equipment used for burning requires more maintenance than those of gas-fired boilers. No. 2 grade used in residential and light commercial boilers and No.4 and 5 grades used in larger commercial. Heat value of No.2 is ±139,000 Btu/gal and No.5 is ±149,400 Btu/gal
- Electricity: advantages are easy and low cost installation, simple to operate, easy control, flexible in zoning, no storage facility req., exhaust flues, or supply air. Disadvantage is operational costs compared to other fuels. Ideal for baseboard units, radiant heating, supplemental space heating. Heat value of 3,413 Btu/kW
- Steam: is not used directly for heating, can be used to heat water for water or air heating systems and to drive absorption-type water chillers for AC. By-product of the generation of electricity
- Heat pumps: device that either heats or cools. Acts as a standard AC, pumps refrigerant into condenser where it loses heat and then to evaporator indoors to absorb heat. Can be reversed to absorb heat from outside and transfer indoors during winter
-

Degree days: measure of approx. average yearly temperature difference between the outside and inside. The number of DD for one day is found by taking the difference between an indoor temperature of 65°F an the average outside temperature over a 24 hour period

Heat generation equipment

Furnace: burn either gas or oil to heat air and then distribute throughout the building; 80% efficiency

Forced air furnaces may be:

- Upflow furnace: return air is supplied at the bottom of the unit and heated is delivered above the furnace and distributed through ductwork
- Downflow furnace: works opposite of upflow and used where ductwork is located in the basement and furnace is on first floor
- Horizontal (lowboy) furnace: used where headroom is limited

Boiler: burns gas or oil to heat water and sometimes using steam as a fuel. 80% efficiency

- Typical boiler has tubes containing the water to be heated that are situated within a combustion chamber where heat exchange takes place. Gases and other combustible products are carried away through breeching into a flue

Principles of refrigeration: chilled air or water produced by compressive refrigeration, absorption, or evaporative cooling

- Compressive refrigeration: based on the transfer of heat during the liquefaction and evaporation of a refrigerant. Latent heat is released as a refrigerant changes form
- 3 components of a compressive refrigeration cycle:
  - Compressor: takes refrigerant in gas form and compresses into a liquid
  - Condenser: Refrigerant passes through and latent heat is released. Usually on the outside of the building
  - Evaporator: expands refrigerant, vaporizes back to gas absorbing surrounding heat
- Refrigeration by absorption: produces chilled water and is accomplished by the loss of heat when water evaporates. This is produced in a closed system by a salt solution that draws vapor from the evaporator. Less efficient than compressive systems
- Evaporative cooling: water is dropped over pads or tubes that circulate outdoor air or water. The free water is evaporates to vapor and heat is drawn from circulating air or water to distribute to indoor spaces. Works well in hot-arid climates with low humidity, simple construction and requires no refrigerant line

- Water is a much more efficient medium to carry heat than air

- Ton of refrigeration: describes the capacity of a refrigeration system. It is the cooling effect obtained when 1 ton of 32°F ice melts to water at 32°F

HVAC systems

- 2 primary methods of carrying heat are air and water. Electricity can be used and some systems use a combination of 2.
  - Direct Expansion (DX)(incremental unit): simplest type of system. Self-contained unit that passes non-ducted air to be cooled over the evaporator and back into the room. Condenser uses outdoor air directly and typically placed on exterior walls, and sometimes roof mounted or packaged

- All-air systems: cool or heat spaces by conditioned air alone. Most basic is the constant-volume single-duct system. Air is distributed at a constant volume from a central furnace and controlled by one thermostat. Easy to operate, but cannot be zoned.
  For larger buildings, 4 basic types are:
  - Variable air volume system: air is heated or cooled at central location and distributed through a single duct. A thermostat controls a damper at each zone to control the volume of conditioned air into that space. Used for large buildings and where temperature regulation is required and humidity control is needed. Very efficient for internal load dominant buildings
  - Dual-duct (high velocity system): provides 2 parallel ducts, on with hot air and one with cool air. The two streams of air are joined at a mixing box to provide the temperature requirements of the space. A thermostat controls the pneumatic valves in the mixing box. Advantage is cool and hot air can be provided to different zones simultaneously. Disadvantages are amount of ductwork, hot and coll air have to be supplied all the time, uses more energy (large fans) and noisy air distribution (high velocity)
  - Reheat (constant-volume) system: takes return air and fresh outdoor air and cools and dehumidifies the mixture and then it is distributed in constant volume at a low temperature. Air is reheated near the spaces requiring the cooling load. Advantages are humidity and temperature can be controlled resulting in smaller ducts and lower fan horsepower. Disadvantages are uses more energy b/c primary air volume needs to be cooled most of the time and reheated
    - Terminal reheat: reheating equipment is located near the conditioned space
    - Zone reheat: reheating coils are located in the ductwork to serve an entire zone
    - Economizer cycle: allows outdoor air to be used for cooling when temperatures are low enough and works by adjusting dampers on return air ducts and fresh air intakes
  - Multizone system: supplies air to a central mixing unit where separate coils produce hot and cold air streams. These are mixed with dampers controlled by zone thermostats and resulting air is delivered to the zones. Similar to dual-duct; advantages are cooling and heating can be provided in different zones simultaneously and disadvantage is ductwork increases as zones are added

- All-water systems (Fan coil units): uses fan coil unit in each air-conditioned space and fan coils are connected to 1 or 2 water circuits. Efficient way to transfer heat and controlled by thermostat to control water flowing through coils. Cannot control humidity at central unit
  - 2-pipe system: hot or chilled water is pumped through one pipe and returned in another
  - 4-pipe system: One circuit is provided for chilled water and one for hot water. Two supply pipes and two return pipes
  - 3-pipe system: Two supply pipes and one return pipe

- Air-water systems: rely on central air system to provide humidity control and ventilation air to conditioned spaces. The majority of heating and cooling is provided by fan coil units in each space. System is often used where return air cannot be recirculated (i.e. hospitals, laboratories). 100% outside air is supplied and return air is completely exhausted to exterior

- Induction system: air is supplied to building under high pressure and velocity to each induction unit where the velocity and noise is attenuated before passing over coils to be cooled or heated

- Electric systems: most often accomplished by laying a grid of wires in the ceiling of a room to provide radiant heating. Can also be done by electric baseboard heaters and provide a clean form of heating with thermostats in each space. Disadvantage is electric is not economical and mostly used as supplemental heating

- Selection of systems: depend on the following variables
  - Use profile of building
  - Building scale
  - Control requirements
  - Fuels available
  - Climatic zone
  - Integration with building structure and systems
  - Flexibility required
  - Economics

System Sizing

- System capacity: primary determinants in sizing equipment are the total heat losses and gains a building will experience in the most extreme conditions

- Mechanical room space requirements: preliminary sizing for medium to large buildings should be 3%-9% of gross building area for all-air or air-water systems. Allow 1%-3% of gross area for all-water systems. This area allocation will accommodate all equipment including, boilers, chillers, fans, pumps, and piping. Space needs to be twice the length of equipment (boiler or chiller) and approx. 12'-18' high

- Ductwork distribution and sizing: for preliminary sizing, allow $3ft^2$ to $6ft^2$ for every 1,000 ft^2 of floor space for horizontal and vertical duct runs. Most efficient ducts are round or with the least perimeter to reduce friction. Loss of pressure is due to friction of the air moving through the ducts, fittings, registers and other components. Appropriate velocities range from 300 fpm (quiet) to 2,000 fpm

- System sizing in numerical relationship: $\mathbf{A=144\ Q_{cfm} / v}$

  A: cross sectional area of duct in square inches
  Q_{cfm}: flow rate in cubic feet per minute
  v: velocity measured in feet per minute

- Q_{cfm} can be determined from the formula: $\mathbf{Q_{cfm}=q_{tot} / 1.08\ (T_{eq} - T_i)}$

  Q_{tot}: total thermal load in Btuh
  T_{eq}: temperature of air supplied in the duct
  T_i: desired interior temperature for the room

  Static head: the pressure required to overcome the friction loss in air ducts and measured in inches of water per 100'. One inch of static head is the pressure required to support a one inch column of water

Energy conservation

- Energy used by HVAC systems account for 40%-60% of overall consumption in the building depending on type, climate, design and other variables. Efficient methods include:
  - Economizer cycle: uses outdoor air when cool enough (about 60°F) reducing energy required for refrigeration. A mechanical substitute for an open window, but filters air providing even distribution and the fresh air improves indoor air quality. If temperature drops, less outdoor is introduced b/c it would have to be heated
  - Dual condenser chillers: uses 2 condensers that operate based on the heating or cooling needs of the building. Efficiency is having varying sized chillers and operating the best sized chiller for the load
  - Gas-fired absorption chillers: commonly powered by gas, higher initial cost, but can be more efficient for buildings in areas where electricity costs are high and low-cost heat sources are available (steam).
  - Solar-powered absorption cooling: more efficient absorption chiller powered by hot water from standard flat plate solar collectors. Water supply can be from 175°F to 195°F and operational costs can be less than compressive type chillers
  - Direct-contact water heaters: heats water by passing hot gases (by way of flue gases containing sensible and latent heat) through water. Heat exchanger on the combustion chamber reclaims any heat lost in chamber. Good for applications where hot water is needed consistently
  - Recuperative gas boilers: recovers sensible and latent heat that preheats the cold water entering the boiler. This heat would typically be discharged to the atmosphere; flue gases are also cooled enough to achieve condensation
  - Displacement ventilation: air distribution system where supply air originates at the floor and rises to return in grilles in the ceiling. Improves IAQ and energy saving. Most systems use an access floor system for ductwork
  - Water-loop heat pumps: heating and cooling system that uses a series of heat pumps for different zones in the building. Water loop is maintained at a temperature range of 60°F - 90°F and can simultaneously heat or cool zones with no additional energy. Reduces piping coasts for 2 and 4 pipe systems
  - Thermal energy storage: uses water, ice or rock beds to store excess heat or coolness for use in the future. Takes advantage of temperature swings and off-peak energy consumption to manage building's energy needs

Heat transfer: based on concept of heat exchange from a source where heat (or coolness) is not wanted to a place where it is desirable

- Energy recover ventilators (air-to-air heat exchangers): reclaim waste energy from the exhaust air stream and use it to condition the incoming fresh air. Energy use can be reduced from 60%-70% and this system is efficient in climates where indoor-outdoor temperature differentials are high. Fresh air intake must be from the exhaust outlet, exhaust air containing excessive moisture or contaminants should be separated from heat exchanger air, and a defroster may be needed to avoid condensate in the exhaust air from freezing. 3 common devices used for air-to-air heat exchange:
  - Flat-plate heat recovery units: must have two separate ducts for incoming air and exhaust air separated by a thin heat transfer wall
  - Energy transfer wheels (enthalpy heat exchangers): transfers heat through a heat exchanger wheel with small openings where air passes through. Latent and sensible heat is transferred.
  - Heat pipes: hot exhaust air passes over the heat pipe and vaporizes a refrigerant inside the pipe, which passes to the area of cool incoming air.

As the refrigerant condenses, it gives off heat, warming the incoming air. Outgoing and incoming streams must be adjacent to each other

- Water-to-water heat exchangers (runaround coils): use water or other liquid transfer medium to exchange heat. Advantage is incoming and exhaust air streams do not need to be adjacent to each other. Efficiency ranges from 50%-70%

- Extract air windows: uses a double-paned glass over another pane of glass on the interior where air is drawn up between the inside pane and main window unit and is extracted into the return-air system. Eliminates the need for a perimeter heating system

- Ground coupled heat exchangers: heat or cool air by circulating it in pipes buried in the ground. Can be only used for low-rise buildings and become inefficient if long runs are involved

Energy codes:

- Prescriptive code: specifies how to build a building. Example is ASHRAE 90-xx series which covers exterior envelope, HVAC equipment, water heating equipment, and electrical distribution
- Performance code: states the final result and how it will be measured, but does not provide how to achieve the result. Example is Building Energy Performance Standard (BEPS) which specifies an energy budget per square foot for various building functions
- Overall Thermal Transmission Value (OTTV): is a weighted average U-value for all the exterior surfaces of the building. An example of a combination of the 2 code approaches

Building automation systems (BAS): computer-based integrated system used to monitor and control building systems. Reduces energy costs through better systems management, monitoring large buildings, reduces personnel, provides detailed documentation of subsystems and improves human comfort

Building commissioning: process of inspecting, testing, starting up and adjusting building systems to verify and document if they are working in accordance with the contract documents

Coefficient of Performance (COP): a unitless number that is a rating of the efficiency of heating or cooling equipment. COP=energy delivered/energy used

Energy efficiency ration (EER): ration of net cooling capacity in Btu/hr to the total rate of electrical input in watts under designated operating conditions

Home energy rating system (HERS): a standardized system for rating the energy efficiency of residential buildings using HERS guidelines and procedures. The score is a value between 0 and 100 indicating the relative energy efficiency of a home compared to a HERS efficient home

Integrated part load value (IPLV): single number figure of merit based on part load EER or COP expressing part load efficiency for air conditioning and heat pump equipment

ELECTRICAL SYSTEMS

Ampere: unit flow of electrons in a conductor equal to 6.251 x 10^{18} electrons passing a given section in 1 sec.

Impedance: the resistance in alternating current (AC) circuit, measured in ohms

Ohm: the unit of resistance in an electrical circuit

Power factor: the phase difference between voltage and current in alternating current circuit

Reactance: part of the electrical resistance in an alternating current circuit caused by inductance and capacitance

Volt: the unit of electromotive force or potential difference that will cause a current of 1A to flow through a conductor whose resistance is 1 Ω

Watt: the unit of electrical power

Basic relationships:

- Electricity is the energy caused by the flow of electrons. A basic electric circuit consists of a conductor, current (actual flow of electrons), voltage (an electric potential difference to cause electrons to move), and some type of resistance to the flow of electrons. This circuit can be interrupted by a switch
- Ohm's law relates current(I), voltage(V), and resistance(R) in direct current (DC) circuits according to the formula **I = V / R**
- In electric currents, power is expressed in watts. Wattage(W) in DC circuits, is the product of voltage(V) and current(I): **W = V I**
- The amplitude of the wave represents the voltage, and the distance between peaks is one cycle. Alternating current is produced at a frequency of 60 cycles per second or 60 Hz (US); 50 Hz (Europe and other countries)
- In AC circuits, resistance is known as impedance, which comprises resistance and reactance and causes a phase change between voltage and current. The difference is the power factor (pf) and can be significant in calculating power in an AC circuit
- Ohm's law for AC circuits is current(I)= voltage(V)/ impedance(Z): **I = V / Z**
- Power in AC circuits is similar to wattage which is wattage(W) = voltage(V) x current (I) x power factor(pf): **W = V I (pf)**. In a three phase: **W = V I (pf) (1.73)**
- To determine energy in a system, simply multiply power x time: **E = W t**
- 2 basic types of electric circuits: series and parallel
  - Series: loads are placed in a circuit one after another. The current (I), remains constant throughout the circuit, but the voltage potential changes or drops across each load. Not used in building construction b/c entire circuit is opened if one load is removed and voltage drops across individual loads. To determine total effective resistance: $R_{total}=R_1 + R_2 + ... + R_n$
  - Parallel: loads are placed between the same 2 points. Voltage remains the same, but the current is different across each load. Adding up the currents results in total current across the circuit. To determine total effective resistance: $1/R_{total}=1/R_1 + 1/R_2 + ... + 1/R_n$

Materials

Conductor: Basic material of electrical systems; sizes are based on American wire gauge (AWG) and thousand circular mil (MCM) designations. Size of conductor increases as number decreases and ranges from 16 gauge (0.0508 dia, smallest) to 4/0 (0.460 dia, largest). Larger than 4/0 is MCM cable with sizes 250, 300, 400, and 500. The current carrying capacity (ampacity) of a conductor depends on size, type of insulation around it, and surrounding temperature.

Two basic conductors are copper and aluminum

- Copper: more cost effective for small and medium sized wire and cable

- Aluminum: lower installation costs for large sizes than copper, must be larger than copper to carry amperage, limited to primary circuits b/c of overheating and possible oxidation causing resistance

Wire: No.8 AWG or smaller

Cable: No.6 AWG or larger, or several conductors assembled into a single unit

Cable types are:

- Nonmetallic sheathed cable (Romex): 2 or more plastic insulated conductors and ground surrounded by moisture-resistant plastic sleeve. Used in wood-framed residential, max 3 stories. Must be concealed behind walls and ceilings; inexpensive to install since it does not require conduit
- Flexible metal-clad cable (BX): 2 or more plastic insulated conductors encased in a continuous spiral wound steel tape. Used in remodeling since it can be pulled
- Most common type or wire and cable is a single conductor covered with thermoplastic or rubber insulation. Cable must be placed in metal conduit or similar
- Busbars: rectangular bars of copper used in place of very large cables and high currents
- Busduct or Busway: several busbars assembled in a metal housing

Conduit: supports and protects wiring, serves as a ground and protects surrounding construction from fire in case of wire overheating. Used for commercial and large residential construction
3 types include:

- Rigid steel conduit: heaviest, connects to junction boxes and devices with threaded fittings
- Intermediate metal conduit (IMC): thinner walls, same outside dia as rigid steel and installed with threaded fittings
- Electric metallic tubing (EMT): lightest of three, installed with pressure fittings b/c of thinness. Fast to install, but not for use in hazardous areas
- Flexible metal conduit (flex or greenfield): minimizes vibration transmission from equipment to the structure. Used where rigid conduit cannot be installed

- Avoid having more than four 90° bends in conduit between pull boxes

Raceways: 2 types, underfloor ducts and cellular metal floors

- Underfloor ducts: proprietary steel raceways cast into concrete floor at regular spacing (4',5', or 6'). Feeder ducts run perpendicular to distribution ducts carrying power and wiring from electrical closet. Preset inserts are placed along distribution for tapping
- Cellular metal floors: part of the structural floor, essentially metal decking used for cable raceways. Cells are closer than underfloor ducts and also have preset inserts
- Under-carpet wiring: thin, flat wiring that can be laid under carpeting without protruding and must be used with carpet tile

Power supply: most common form of electrical energy used in building is alternating current (AC). Direct current (DC) is used for some types of elevator motors, and low voltage applications (signal systems, controls)

Primary service: provided by utility company at the property line

- Weatherhead: where service cable is connected, 12' above ground for overhead service on smaller projects

Power:

- The most common power for residences and very small buildings is a 120 / 240 V. single phase (1 transformer), three-wire system. Consists of 2 hot wires each carrying 120V, and 1 neutral wire. Appliances like dryers and ranges requiring 240V use both hot wires. Used where actual load does not exceed 80A, although minimal service is considered 100A
- System used for larger buildings is a 120 / 208 V, three phase (3 transformers), four-wire system. It is frequently used b/c it allows for a variety of electrical loads
- Another system for larger buildings is a 277 / 480 V, three phase, four-wire system. It is the same as the 120 / 208 V, except for higher voltages. Advantages include smaller feeders, smaller conduit, and smaller switchgear b/c of the higher voltages resulting in smaller currents the equipment needs to carry. Buildings with this system usually have 277 V fluorescent lighting that requires smaller wiring. Small, step down transformers are used where 120 V service is needed for receptacles & equipment

Transformers: used to change alternating current voltages either up (step up)or down (step down). In most cases, power is supplied to a building at high voltage b/c the lines can be smaller and there is less voltage drop. They are rated on their kilovolt-amperes capacity (kVa) and described by their type, phase, voltage, method of cooling (dry, oil filled, silicone filled), insulation, and noise level. Connections can be wye (shaped like the letter Y) or delta (Δ). Generate a lot of heat, so vaults should be at an exterior wall and vented

Metering and load control

- Most common meter is the watt-hour meter. It registers use of power over time in kilowatt-hours
- Load factor: the ratio of average power used to the maximum power demand. A low load factor implies and inefficient use of energy and a high demand charge. Energy companies levy charges based not only on the total amount of energy used (kWh), but also on peak demand. This encourages conservation of energy b/c utility companies have to provide energy based on peak
- Load control (peak demand control): a building's electrical system is designed to avoid peak electricity use. A device monitors energy use, and shuts off non-essential electrical loads during different times of the day (example of load shedding)

Primary distribution

- Switchgear: central electrical distribution center that consists of an assembly of switches, circuit breakers and cables or busducts that distribute power to the building. A meter and transformer are included that split power into separate circuits, each with a master switch and circuit breaker for protection. The switch gear also distributes power to substations, for further transforming and distribution as part of a secondary distribution system

Secondary distribution/Branch Circuits

- Power is distributed from the main switchgear to panelboards and further split into individual branch circuits. It has typical power voltages of 120V, 240V, and 277V and distribution is made with wires in conduit, underfloor raceways, or flexible cables. Protected by circuit breakers typically 15A and 20A, with 100A for main disconnects
- Protection for circuits: grounding and ground-fault protection
    - Ground: provides path for fault; both ground wire and neutral wire are grounded at the building service entrance to a grounding electrode
    - Ground-fault interrupter (GFI): a device that detects small current leaks and disconnects the hot wire to the circuit or appliance. GFIs can be installed in the circuit breaker or as an outlet. Outlets are typically located in bathrooms, kitchens, and outdoors

- Fuses: devices composed of soft metal link in a glass plug rated for certain flow. Can be used only once
- Circuit breakers: devices that disconnect a circuit when the current is excessive. Can be reset after trouble-shooting

Wiring devices

- Duplex (receptacle, outlet): operate at 120V; and higher depending on appliance
- Ground fault circuit interrupter (GFCI): GFI outlets for safety
- Hard wired: connected directly to building circuits in junction boxes
- Split-wire receptacle: one outlet is always energized; other is controlled by switch
- Capacitors: used to improve the power factor in a circuit (two plates w/ insulating layer)
- Dimensions:
    - outlets need to be mounted 12”-18” (min 15” ADA) aff, and located no more than 12’ apart or no point is further than 6’ from outlet
    - Circuits are usually 15A and at least two 20A for the kitchen, pantry, and dining. Kitchen counter needs to be on at least 2 circuits, with no more than 4 outlets per 20A. No point on wall above counter can be more than 24” from outlet. Outlets need to be between appliances and sink and within 6’ of sink need to be GFCI
- Switches (line)
    - Two way switch: controls a light or other device with one switch
    - Three way switch: when two switches are used to control the same device
    - Four way switch: used to control a device from 3 or more locations
    - Low-voltage switching: operated on 24V circuit and controls relays that provide the 120V switching. Advantages are: same light can be controlled from several positions that are remote from each other, central control station can be set up for monitoring and override, and for large installations requiring flexibility, is less expensive than line-voltage wiring and devices

Emergency power supply: systems for exit lighting, alarms, elevators, telephones, fire pumps and medical equipment. Standby power provides electricity to avoid business interruption (computer operations)

Communication systems: include intercoms, paging and sound systems, TV, CCTV, LAN, and telephone (most prevalent). Telephone is fed through main cable connecting to terminal rooms where they are split into riser cables. Risers are usually located near the core and connect at each floor. Other types of communications are wired through cabling that terminates at electrical boxes into wall of floor jacks. Most signal cabling is run in metal conduit

Security systems

- Intrusion detection: classified into 3 types: perimeter protection, area or room protection, and object protection
    - Perimeter protection: secures entry points (doors, windows, ducts, etc.) to a space or building. Common types include:
        - Magnetic contacts: used on doors and windows, surface mounted, recessed or concealed
        - Glass break detectors: use of metallic foil or vibration detector mounted on glass
        - Window screens: embedded fine wires
        - Photoelectric cells: detection by beam or passing through an opening
    - Area or room protection: field of coverage senses someone within a certain area
        - Photoelectric beams: pulsed infrared beam across a space detects intrusion if beam is broken

        - Infrared detectors: unobtrusive, but require a clear field of view for optimal protection. Senses sources of infrared radiation (human body)
        - Audio detectors: identify unusual sounds above normal level
        - Pressure sensors: detect weight on a floor or other surface
        - Ultrasonic detectors: emit a high frequency sound wave; limited to a space about 12' in height, and 20' x 30' in area
    - Object protection: senses movement or tampering of individual objects
    - Access control
        - Mechanical lock: simplest and traditional form of security. Disadvantage is duplicate keys can be made
        - Card readers: common electronic access control device. System can be programmed to control hours of use, monitor card use through logs, and remove access code for card if lost or stolen
        - Numbered keypads: operate in a similar way of unlocking a door by entering a numerical code. They eliminate key problems with standard locksets, but are not as flexible as magnetic cards
    - Electric lock: retracts the bolt when activated from the secure side of the door. Unlatching from inside is done by a button, switch, or mechanical retraction of bolt by lever
    - Electric strikes: consists of movable mechanism that is mortised into the frame. On activation, the electric strike retracts and the door can be opened. On the inside, the latch bolt can be retracted by mechanical means (lever handle)
    - Electromagnetic locks: lock holds door with a magnetic force and can be opened by card reader, keypad, and buttons. They can also open on fire alarm activation
    - Biometric devices: read individual biological features (iris or retina of the eye, fingerprint). Very expensive, but provides counterfeit-proof method of identification and security

LIGHTING

Light and Vision

- Light strikes a surface it can be transmitted, reflected, or absorbed. Ex. If a material (i.e. glass) is transparent, most of the light is transmitted
- Coefficient of transmission: the ratio of the total transmitted light to the total incident light represented as a percentage. Clear glass 85%, frosted glass 70%-85%, remainder of light is reflected or absorbed
- Translucent: material that allows the transmittance of light, but not of a clear image
- Refraction: when light in clear materials is slightly bent as it passes through the material
- Reflectance coefficient: ratio of total reflected light to the total incident light expressed as a percentage. Reflection: light bouncing off material
    - Specular reflection: results from a smooth polished surface (mirror) The angle of incidence equals angle of reflection
    - Diffuse reflection: results from a uniformly rough surface. It appears uniformly bright, and the image of the source cannot be seen
    - Combined specular: makes surfaces appear to be brighter at the point where the source is shining than in surrounding areas

Illumination terms

- Candlepower: unit of measure for the intensity of a source is the amount of light coming from a single candle
- Lumen: the amount of light flowing through one foot square of air space, at a distance of one foot from a one candlepower source. The flow through this space is flux

- Illuminance: (1 footcandle) equivalent to a candle one foot from a surface with one lumen arriving on one square foot of that surface
- Luminance (brightness): measure of how bright an object appears depending on the amount of light leaving the object depending on its reflectivity. A perfectly reflective surface exposed to an illumination of one footcandle would have a luminance of one footLambert

Design considerations

Glare

  - Direct glare: results when a light source in the field of vision causes discomfort and interference with visual task. The critical zone for direct glare is in the area above a 45° angle from the light source. Visual comfort probability (VCP) was developed to provide a rating to fixtures relating to glare
  - Reflected glare: occurs when a light source is reflected from a viewing surface into the eye. If it interferes with the viewing task it is called veiling reflection
  - Contrast: difference in illumination level between one point and nearby points. Brightness rations should be limited to: 1:1/3 (task to adjacent surroundings), 1:1/5 (task and more remote darker surfaces), 1:10 (task and more remote lighter surfaces)

Light sources

Efficacy: calculated lumen output per watt input. It is an important measure of the energy efficiency of a light source. Energy Policy Act (EPACT) set minimum standards for energy efficiency on incandescent and fluorescent lighting. It eliminated all medium-based PAR and R lamps of 40 W or higher, F40T12, U-shaped fluorescents and full wattage fluorescents. They were replaced by ER lamps, tungsten-halogen, and T8

3 types of lighting sources: incandescent, fluorescent, and high-intensity discharge

- Incandescent: consists of a tungsten filament placed within a sealed bulb containing an inert gas. Filament glows when electricity is passed through. Typical designation is letter-number (A-21; which means 21/8"). Advantages are inexpensive, compact, dimmable, warm color rendition. Disadvantages are low efficacy, short lamp life and high heat output
- Types include:
  - A: arbitrary (standard shape)
  - PS: pear shape, straight neck
  - P: pear shape
  - S: straight
  - G: globe
  - T: tubular
  - PAR: parabolic aluminized reflector
  - R: reflector
  - ER: elliptical reflector
  - MR: miniature reflector

- Tungsten halogen: light is produced by the incandescence of the filament, but there is small amount of halogen (iodine or bromine), in the bulb with the inert gas. Smaller than standard incandescent and filament burns under higher pressure and temperature with a quartz bulb. Advantages are longer bulb life, low lumen depreciation over life of bulb, and more uniform light color

- Reflector(R) and parabolic aluminized reflector (PAR): contain a reflective coating built in the lamp increasing efficiency of the lamp and beam control. Made with a heavier glass, suitable for outdoors and available in flood and narrow
- Elliptical reflector (ER): improved version of R lamps but with slightly smaller spread; provide a more efficient throw of light from a fixture. Good for use with fixtures having deep baffles or small openings

- Low voltage miniature reflector (MR) lamps: small tungsten halogen lamps that are whiter than typical incandescent lights. Consistent high output and available in MR-11 and MR-16

Fluorescent: mixture of an inert gas and low-pressure mercury vapor. When lamp is energized, a mercury arc is formed creating an ultraviolet light that strikes the phosphor-coated bulb, causing the bulb to fluoresce and produce visible light
- 3 types of fluorescent are pre-heat, rapid start, and instant start. Preheat have been supplanted by rapid start that maintain a constant low current in the cathode allowing them to start within 2 sec. Instant start use a higher voltage to illuminate immediately
- Ballast: device that supplies the proper starting and operating voltages to the lamp and limits the current. The produce noise and heat; therefore Class A is good for quiet areas and Class F is good for noisy areas
- Electronic ballast: produces high frequency AC (25kHz-30kHz, standard ballast 60kHz) and lowers power consumption, silent operation and ease of dimming
- Lamps are tubular shape and designated according to their type, wattage, diameter, color and method of starting. F32T8WW/RS (32 watt, 8/8 (1") tubular, warm white, rapid start). Compact fluorescent (CF) lamps have either a T-4 or T-5 glass envelope bent into a U-shape and mounted on a base that houses a ballast that can be screwed into incandescent luminaries
- Lamps range in color from cool FL/D (daylight) of 6500K to WWD (warm white deluxe) of 2800K
- Advantages: high efficacy (about 80lm/W), low initial cost, long life, variety of color temperatures, dimmable (more expensive than incandescent)

High Intensity Discharge: lamps include mercury vapor, metal halide, and high and low pressure sodium
- Mercury vapor lamp: an electric arc is passed through high-pressure mercury vapor that produces ultraviolet and visible light primarily in the blue-green band. Lamps have moderately high efficacy (30lm/W to 50lm/W) depending on voltage and color correction included
- Metal halide lamp: similar to mercury vapor except halides of metal are added to the arc tube. This has increased efficacy (50lm/W to 100lm/W), improved color rendition, but decreased lamp life
- High-pressure sodium (HPS): produce light by passing an electric arc through hot sodium vapor; arc tube must be made of ceramic to resist the hot sodium. Lamps are the most efficient with a efficacy (80lm/W to 140lm/W) and a wide variety of color rendition
- Low-pressure sodium: the highest efficacy (150lm/W), but produce a monochromatic yellow light. They are suitable where color rendition is not important (street lighting, parking)

Lighting systems (distribution curves)
- Direct: provide all light output on the task
- Semi-direct: puts majority of light down and a small percentage towards the ceiling
- Direct-indirect: light is distributed up towards ceiling and down to task fairly evenly
- General diffuse: light is distributed from fixture evenly on all sides
- Semi-indirect: puts majority of light up and a small percentage down to task
- Indirect: throws all the light towards a reflective ceiling to illuminate the room
- Task–ambient lighting: general background of illumination is provided with separate task fixtures at workstations/areas

Luminaire types
- Surface mounted fixtures: most commonly used types for residential and commercial. Used in ceilings where there is not sufficient space above the ceiling to recess a fixture and locations where the ceiling is existing
- Recessed fixtures: used in residential and commercial; includes incandescent and fluorescent where a luminous ceiling is formed when entire ceiling is made up of lighting
- Suspended fixtures: dropped below level of ceiling. Used for indirect systems and where light source needs to be closer to task area
- Wall-mounted fixtures: indirect, direct-indirect, and direct lighting

- Furniture mounted: task ambient system
- Freestanding fixtures
- Accessory fixtures:

Quality of light
- Spectral energy distribution: a measure of the energy output at different wavelengths or colors
- Sources are given a number rating of their dominant color based on the temperature in degrees Kelvin to which a black-body radiator would have to be heated to produce that color. Lower temperatures (3100K), are relatively warm colors (warm white fluorescent light). Higher temperatures (5000K to 6000K) are cool colors with a high percentage of blue. For example, a daylight fluorescent lamp has a color temperature of 6500K
- Color Rendering Index (CRI): a measure of how closely the perceived colors of an object illuminated with a test source match the colors of the object when it is illuminated with daylight of the same color temperature. In other words, how well light actually shows true color. Max CRI rating is 100; 85 or more is good

Lighting calculations
If the surface is perpendicular to the direction of the source, the illumination is determined by the formula: $\mathbf{E = I / d^2}$
E: illumination at the receiving surface
I: intensity at the source when viewed from the direction of the receiving surface
d: distance from the source to the surface

Point grid method: For surfaces not perpendicular to the source, the inverse square law of the formula must be adjusted to account for the angle. Good for a single fixture or small number of fixtures, it takes into account orientation and distance, but ignores surrounding reflection.
$\mathbf{E = I \cos (angle) / d^2}$
Angle: between a perpendicular (normal vector) to the receiving surface and a line from the source to the surface

Zonal cavity method: based on a uniform distribution of a large number of fixtures, and takes into account the reflectivity of the ceiling and walls, and the comparative volumes of the top, middle, and bottom of the room. The following values are taken into account:
- Lumen output of the lamps used
- Number of lamps in each luminaire
- Efficiency of the luminaire. Rating is known as the Coefficient of Utilization (CU)(from 0.01 to 1.00); represents the fact that not all of the lumens produced by lamps reach the work surface
- Light loss factor (LLF): fraction represents the amount of light that will be lost due to lamp lumen depreciation and luminaire dirt depreciation. Other factors include lamp burnout, room surface dirt, and operating voltage of the lamps. **E = (N x n x LL x LLD x DDF x CU) / A**
  E: illumination in footcandles
  N: number of fixtures
  N: number of lamps per fixture
  LL: number of lumens produced per lamp
  LLD: lamp lumen depreciation factor
  DDF: dirt depreciation factor
  CU: coefficient of utilization
  A: area of working plane that will be illuminated by fixture

- To calculate the number of luminaires required in a room to maintain a given illumination level: **N=E x A / n x LL x LLD x DDF x CU**
- For complex spaces, the isolux chart (isofootcandle chart) can be used. It is a diagram showing lines of equal illumination produced by a specific luminaire from a particular manufacturer. Computer simulation can be used as well

Sustainable lighting design
- Daylight strategies: light shelf, glass transom, sawtooth skylights (vertical glass facing north), and interior window shading devices
- Higher efficiency light fixtures: fluorescent or HID, fixtures with reflectors and indirect capabilities, dimming, high efficiency ballasts
- Lighting sensors and monitors
- Lighting models

Energy budgets: To avoid exceeding a total power budget, use a figure of approximately 2.3W / ft^2 which is considered a maximum

Emergency lighting: IBC, National electrical code, Life safety code all include provisions for this lighting. Required areas include exit stairs, corridors, places of assembly, educational facilities and other places of high occupancy loads. Minimum lighting level required is 1 fc at the floor level and illuminated exit signs are required as well

FIRE PROTECTION & LIFE SAFETY

Fire protection codes traditionally have 3 goals:
- Provide protection (place of refuge) or escape (means of egress) for occupants in the building
- Insure structural integrity
- Allow the building to survive the fire to be restored afterwards
- A new fourth goal is to prevent fires from starting or extinguish them immediately and automatically after they start

Fire protection in buildings is accomplished in several ways:
- By preventing fires
- By early fire detection and alarm
- By providing for quick exiting of building occupants
- By containing the fire
- By suppressing the fire

Occupancy
- A: assembly
- B: business
- E: educational
- F: factory and industrial
- H: high hazard
- I: institutional
- M: mercantile
- R: residential
- S: storage
- U: utility

Construction types
- Type I-A: provides the highest level of fire resistance-rated construction and requires passive protection for all elements of the structure
- Type I-B: similar to I-A, but permits a 1-hour reduction in fire-resistance rating for the structural frame, bearing walls, and floor construction, and a ½-hour reduction for roof construction
- Type II-A: allows active or passive protection of all elements of the structure

- Type II-B: allows unprotected noncombustible building elements. Also known as 'Type II-non-rated' in previous codes
- Type III: a mix of noncombustible exterior walls and combustible interior construction. Intended for office and residential occupancies.
- Type IV: known as 'mill construction' or 'heavy timber construction'. These buildings utilize heavy timber structural members and heavy wood floor decking inside exterior walls of noncombustible construction. Many of these buildings also have moveable heavy metal shutters to close off exterior openings to prevent a fire outside the building from propagating into the building through unprotected openings. Intended for building manufacturing and store buildings
- Type V: the least restrictive construction type. It allows the use of any materials permitted by the code. Example is a conventional light wood-framed single-family residence
- Type V-A: protected construction and all major building elements must have a 1-hour fire-resistance rating. Only exception is non-bearing interior walls and partitions
- Type V-B: unprotected and requires no fire-resistance ratings except exterior walls

Fire Containment: achieved through building materials, compartmentation, and smoke control

Fire suppression: achieved through sprinkler systems, standpipes, and other methods

Compartmentation: idea is to contain a fire and limit its spread, both to allow building occupants to escape and to protect other parts of the building
- Walls, floors, and ceilings separating compartments (spaces) must have a fire rating depending on occupancy
- Structural members are isolated to protect from fire exposure
- All openings (doors, windows, ducts) through walls must be closed with fire rated devices tested and approved by UL
- Use of self-closing assemblies: typically held by fusible links that melt when ambient air exceeds approx. 165°F, closing and latching the opening
- Exterior walls must have fire rating to avoid fire spreading to other structures. Buildings are also limited to: locations on the site, size of building, and size/amount of openings

Smoke control: elements include containment, exhaust, and dilution
- Containment: Same compartmentation used to contain fires is used here. Devices include fire dampers, gaskets on fire doors, and automatic closing fire doors
- Passive smoke control system: a system of smoke barriers arranged to limit the migration of smoke. Barriers can be partitions, doors w/ smoke seals, or curtain boards (min. of 6'). Automatic smoke and heat vents must be used in 1-story buildings, F and S occupancy, over 50,000 sf, H occupancy over 15,000 sf, in a single floor area and over stages more than 1000 sf in area, atria, and other locations
- Active smoke control system: an engineered system that uses mechanical fans to produce pressure differentials across smoke barriers or to establish airflows to limit and direct smoke movement. Open doors with automatic closing devices close, supply and return air ducts to the fire zone shut down, exhaust to outside air is turned on creating a negative pressure. In place of refuge, return and exhaust air ducts are closed, and supply air is forced into space creating a positive pressure
- Stairways: pressurized to prevent smoke entering them. Vestibules are pressurized slightly higher the fire floor, but less than the stairway. It provides a double protection of the stairway, and creates a place of refuge for handicapped. It is also where the standpipes and FD communication devices are located

Exits/Egress (look at IBC) some general information includes:
- Most buildings require 2 or more means of egress; maximum occupant load in any occupancy for one exit is 49. If 2 exits are required, the distance between them need to be at least ½ of the longest diagonal dimension of the space

- Minimum ceiling height 7'-6" and not more than 50% of ceiling area can be reduced to 80"
- Door closers and stops cannot reduce headroom to less than 78"; door minimum height is 80"
- Egress width minimum is 44" and is governed by occupant load, hazard of occupancy, whether building is sprinklered and whether path is a stair or other component. Minimum width of egress path must be maintained around obstructions (columns, piping) and doors can protrude a maximum of 7" into path
- Maximum distance for exit access is 200' in non-sprinklered building and 250'-300' in sprinklered building. Dead ends are limited to 20' or unlimited if the length is less than 2.5 times the width
- Maximum of 50% of exit stairs may exit through vestibule or corridor that is adjacent to exterior exit and only used for egress

Fire detection: 3 types include ionization, photoelectric detection, temperature sensing
- Ionization detector: responds to chemical products of combustion in the air during a fire even in the early stages. Not appropriate where fires may produce a lot of smoke, but few particles
- Photoelectric sensors: reacts to visible smoke that blocks a beam of light. Can measure a large volume of air and are useful when potential fires may produce a great deal of smoke before bursting into flames
- Heat actuated sensors: activated by temperature rise; disadvantage is that flames must be usually present before the alarm temperature is reached
- Locations and types of detectors are determined by code. For example, an ionization detector should not be placed near air supply. Detectors are required near fire doors, in exit corridors, individual hotel rooms, bedrooms, and places of public assembly. They can be attached to system to activate dampers, exhaust systems and notify a central monitoring station and the fire department
- Flashover: where materials (typically ceiling) become extremely hot and combust suddenly after reaching a temperature limit

Standpipes: distribute large volumes of water to each floor and are located within stairway or in the case of a pressurized enclosure, within the vestibule. Water is supplied in 2 ways: from storage tanks and through Siamese connections

- Dry standpipe (Class I): large diameter water risers that are normally empty and not connected to a water supply. A 2 ½" outlet connection must be provided at every floor (within stairway or vestibule) higher than the first floor and at the roof. Fitting at lower end (Siamese fitting) is at street level and accepts either 2 or 4 hose connections from FD pumpers depending on diameter of dry standpipe. If standpipe is more than 75' above grade, the pipe connections must be provided in every required stairway as well. A ball drip is used to insure the standpipe remains dry. Advantages are system is not subject to freezing or rusting

- Wet standpipe (Class II): standpipes are constantly filled with water and directly connected to water supply (tank on roof) and equipped with 1 ½" outlets and hoses intended for use by building occupants. Required in buildings 4 or more stories in height, most theaters and places of assembly, B, H, I, M, and S occupancies. Must be also equipped with Siamese fittings. Every point of the building must be within 30' of the end of a 100' hose attached to an outlet. Standpipe system must be designed to supply at least 35 gpm at 25 psi minimum for at least 30 minutes. The water supply system must be able to provide 70 gpm for 30 minutes at 25 psi minimum

- Combination standpipe (Class III): It must be equipped with the 2 ½" outlets (dry) for the FD and 1 ½" outlets/hose racks (wet). Every point of the building must be within 30' of the end of a 100' hose attached to an outlet. Required in every stairway from the ground to the roof for buildings exceeding 150' in height. Also, installed in buildings where the highest floor level is more than 30' above the lowest FD vehicle access, or where the lowest floor level is 30' below the highest FD vehicle access. Exceptions to use Class I standpipes are:

- Building equipped with a sprinkler system
- Open parking garages less than 150' high
- Open parking garages subject to freezing temperatures
- Basements that are sprinklered

Sprinkler systems

- Required in occupancies as follows:
  - A occupancy: including thresholds and areas of exit discharge, A-1, A-3, A-4 (12,000 sf or more), A-2 (5,000 sf or more), A-5 (1,000 sf or more)
  - E occupancy: areas 20,000 sf or more; exception is classroom at grade w/ at least one exit
  - F-1 occupancy: area exceeding 12,000 sf, building more than 3 stories in height, or all floors including mezzanine exceed 24,000 sf
  - H occupancy: always include system
  - I occupancy: wherever occupancy occurs
  - M occupancy: area is greater than 12,000 sf, floor area is located more than 3 stories above grade, or all floors including mezzanine exceed 24,000 sf
  - R-1: occupancy: all areas
  - S-1: occupancy: area exceeding 12,000 sf, building more than 3 stories in height, or all floors including mezzanine exceed 24,000 sf
  - S-2 occupancy: required for all enclosed parkin g garages, including those under R-3 that are 1 or 2 family townhouse occupancies

- Code of reference is NFPA 13: standard for the installation of Sprinkler Systems, and classifies fire hazard of buildings into 3 groups:
  - Light hazard: residences, offices, hospitals, schools and restaurants
  - Ordinary hazard: Group 1: automobile garages, laundries; Group 2: large library stack rooms, printing/publishing plants; Group 3: paper processing plants
  - Extra hazard: applies to occupancies with areas that handle combustible materials

- Wet-pipe system: System is constantly filled with water and responds to rise in temperature at any sprinkler head (135°F to 170°F). Can be used with fusible links and flow detectors. Advantages of quick response and low initial cost, Disadvantages include freezing, unnecessary wetting of building contents
- Dry-pipe system: piping between the dry pipe valve and sprinkler heads is empty of water and filled with compressed air. Disadvantage is delay of water distribution in long pipe runs; compressed air needs to be flushed out between valve and sprinkler before water is sprayed
- Preaction system: variation of dry-pipe system that allows water into the system before any sprinkler head has opened. This avoids accidental discharge of the sprinklers and resultant water damage
- Deluge system: all of the sprinkler heads are open at all times, but the pipe system is empty of water. Release of the water is actuated by a heat/fire detection system activating a valve and flooding the system with water. Used in high hazard areas

Fire extinguishers: 4 classes: corresponding to the four fire types A, B, C, and D

- Type A: involve ordinary combustibles of paper, wood, and cloth. Extinguishers for these fires contain water or water-based agents
- Type B: involve flammable liquids such as gasoline, solvents, and paints. Extinguishers contain smothering types of chemicals like carbon dioxide, foam, and halogenated agents
- Type C: involve electrical equipment. Extinguishers contain nonconductive agents
- Type D: involve combustible metals. Each type of fire must be fought with the suitable extinguisher

- Halogenated agents (halon): are used where water might damage contents (computers), chemically inhibit the spread of fire, but contain CFCs
- Intumescent materials respond to fire by expanding rapidly to insulate a surface and filling gaps to prevent the passage of fire, heat and smoke. Available as paint, caulk, strips and putty

ACOUSTICS

Common terms
- Amplification: increased intensity of sound by mechanical or electrical means
- Articulation index: a measure of speech intelligibility calculated from the number of words read from a selected list that are understood by an audience. A low articulation index (less than 0.15) is desirable for speech privacy, whereas a high articulation index (above 0.6) is desired for good communication
- Attenuation: the reduction of sound
- Hertz: the unit of frequency, one cycle per second equals 1 Hz
- Impact isolation class (IIC): a single-number rating of a floor-ceiling's impact sound transmission performance at various frequencies
- Intensity level: 10 times the common logarithm of the ratio of a sound intensity to a reference intensity (Decibel)
- Noise: any unwanted sound

Fundamentals of sound and human hearing
Qualities of sound
- Sound has 3 basic qualities: velocity, frequency, and power
  - Velocity: depends on the medium in which it is traveling and the temperature of the medium
  - Frequency: number of cycles completed per second; it is measured in Hertz (Hz). One Hz equals one cycle per second
  - Frequency (f) and Velocity (c) are related by the following formula; (w) as wavelength which is perceived in terms of pitch: $\boldsymbol{f = c / w}$
  - Power: quality of acoustical energy as measured in watts. Because a point source emits waves in a spherical shape in free space, the sound intensity (watts per unit area) is given by the following formula: $\mathbf{I = P / 4 \pi r^2}$, where:
    I: sound intensity
    P: acoustic power

  Inverse square law: where sound intensity is inversely proportional to the square of the distance from the source. $\mathbf{I_1 / I_2 = r^2_2 / r^2_1}$, where:
  I: sound intensity
  r: distance from the source

  Sound intensity
  - The intensity of sound is measured power (watts) per square cm, but we generally deal with intensity level (IL), which is measured in decibels. In other terms, the amount of sound energy per second across a unit area
  - The decibel (dB): Basic unit of sound intensity. 10 times the common logarithm of the ration of a quantity of the same kind, such as power, intensity, or energy density. 0 dB is the threshold of human hearing and 130 dB is the threshold of pain.
    The relationship is expressed by this formula: $\mathbf{IL = 10 \log (I / I_0)}$, where:
    IL: intensity level expressed in decibels
    I: intensity of sound being measured
    I_0: reference intensity of 10^{-16} W/cm^2, which is the quietest sound we can hear
  - dBA: the unit of sound intensity measurement that is weighted to account for the response of the human ear to various frequencies

Loudness

- Below is useful in evaluating the effects of increased or decreased decibel levels in architectural situations

change in intensity level (dB)	change in apparent loudness
1	almost imperceptible
3	just perceptible
5	clearly noticeable
6	change when distance to source in a free field is doubled or halved
10	twice or half as loud
18	very much louder or quieter
20	four times or ¼ as loud

Addition of decibels of uncorrelated sounds

- Because decibels are logarithmic, they cannot be added directly. The following gives accurate results within 1%. The addition of decibels a follows:

when difference between the two values is:	add this value to the higher value:
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 8 dB	1 dB
9 dB or more	0 dB

Human sensitivity to sound

- Normal human ear of a healthy young person can hear sounds in the range of 20Hz to 20,000Hz and is most sensitive to frequencies in the 3000 Hz to 4000Hz range. Speech is composed of sounds primarily in the range of 125 Hz to 8000 Hz, with most energy in the range of 100 Hz to 600 Hz
- The human ear is less sensitive to low frequencies than to middle and high frequencies for sounds of equal energy
- In building acoustics, measurement and analysis is often divided into 8 octave frequency bands identified by the center frequency. They are 63, 125, 250, 500, 1000, 2000, 4000, 8000
- Octave band: a range of frequencies in which the upper frequency is twice that of the lower

Sound transmission

Transmission loss and noise reduction

- Transmission of sound is primarily retarded by the mass and stiffness of the barrier. Less stiffness is better
- Transmission loss (TL): the difference (in decibels)between the sound power incident on a barrier in a source room and the sound power radiated into a receiving room on the opposite side of the barrier (reduction of sound that occurs when a given wall transmits sound from one room to an adjacent room, expressed in decibels)
- Noise reduction (NR): the arithmetic difference (in decibels) between the intensity levels in two rooms separated by a barrier of a given transmission loss. Noise reduction is dependent on the transmission loss of the barrier, the area of the barrier, and the absorption of the surfaces in the receiving room. It is calculated by the formula: **NR = TL + 10 log x A / S**, where:
  TL: the free field transmission loss of the wall
  S: area of the separating wall, in square feet
  A: total absorptivity in the receiving room, in sabins

Noise reduction can be increased by increasing the transmission loss of the barrier, by increasing the absorption in the receiving room, by decreasing the area of the barrier separating the two rooms, or by some combination of the three

- Sound transmission class (STC): a single number rating representing the transmission loss over 6 octave bands or more. The higher the rating, the better. The rating represents a laboratory condition, and field conditions reduce the STC rating b/c of quality of construction and breaks in the barrier (cracks, electrical outlets, and doors)
- When a partition comprises of two or more types of construction, the combined transmission loss can be found: **$TL_{composite}$ = 10 log x total area / ∑tS**, where:
  t: coefficient of transmission
  S: are of barrier or component between rooms
- Effect of Barrier STC on hearing
  - STC 25: normal speech can clearly be heard through barrier
  - STC 30: loud speech can be heard and understood fairly well; normal speech can be heard but barely understood
  - STC 35: loud speech is not intelligible, but can be heard
  - STC 42-45: loud speech can only be faintly heard; normal speech cannot be heard
  - STC 46-50: loud speech is not audible; loud sounds other than speech can only be heard faintly, if at all
  - General guidelines require and STC rating of 50 for walls, floors and ceilings

Noise criteria curves

- People are generally more tolerant of higher levels of low-frequency sound, than of high-frequency sound
- Variables of sound have been consolidated into a set of noise criteria (NC) curves relating frequency in 8 octave bands to noise level
- NC curves can be used to specify the maximum amount of continuous background noise allowable in space, to establish a minimum amount of noise desired to help mask sounds, and to evaluate an existing condition
- Preferred noise criteria (PNC): a modification of NC curves has been established that has sound pressure levels lower than the NC curves on the low and high frequency ends of the chart. Some types are as follows:
  - 15-20dB: concert hall, recording studio
  - 20-30dB: bedrooms, hospital
  - 30-35dB: private office, small conference room
  - 35-40dB: large office, retail, restaurant
  - 40-45dB: lobby, open work space, laboratory
  - 45-55dB: commercial kitchen, computer room, light maintenance shop

Rules of thumb for preliminary estimating and non-critical situations:

- In general, transmission loss through a barrier increases with the frequency of sound
- A wall with 0.1% open area (cracks, holes, undercut doors) will have a max TL of about 30 dB. A wall with 1% open area will have a max TL of about 20 dB
- A hairline crack will decrease a partition's TL by about 6 dB. A 1 in^2 opening in a 100 ft^2 gwb partition can transmit as much sound as the entire partition
- Although placing fibrous insulation in a wall cavity increases STC rating, the density of the insulation is not a significant variable

Sound absorption

- Sound intensity level decreases about 6 dB for each doubling of distance from the source in free space
- Coefficient of absorption, (a): defines the absorption of a material; ratio of the sound intensity absorbed by the material to the total intensity reaching the material. It also varies with the frequency of sound, and some materials are better at absorbing some frequencies than others

- Maximum absorption possible is 1 (free space). A material with a coefficient below 0.2 is considered reflective, and one above 0.2 is considered sound absorbing
- Noise reduction coefficient (NRC): the average of a material's absorption coefficients at the four frequencies of 250, 500, 1000 and 2000 Hz, rounded to the nearest multiple of 0.05
- Total absorption of a material is dependent on its coefficient of absorption and the area of material: **A = $S\,a$**, where:
  A: total acoustical absorption in sabins
  S: area of barrier or component between rooms
  a: coefficient of absorption
- Sabin: the unit of absorption; 1 ft^2 of surface having an absorption coefficient of 1.00. It varies from 0 (all sound reflected) to 1.0 (all sound is absorbed. The formula relates reverberation time (T) to a room's volume (V) and total acoustical absorption (A): **T = (0.05) (V / A)**

Noise reduction within a space
- Increasing the sound absorption within a space will result in a noise reduction according to the formula: **NR = 10 log A_2 / A_1**, where:
  A_1: total original room absorption in sabins
  A_2: total room absorption after increase of absorption
  This formula relates to overall reverberant noise level in a room and does not affect noise level very near the source
- Noise Insulation class (NIC): a single-number rating of noise reduction

Rules of Thumb for sound absorption:
- The average absorption coefficient of a room should be at least 0.20. An average absorption above 0.50 is usually not desirable or economically justified
- Each doubling of the amount of absorption in a room results in a noise reduction of only 3 dB
- If additional absorptive material is being added to a room, the total absorption should be increased at least three times (change of about 5dB; noticeable). The change needs to be about three times to bring absorption to between 0.20 and 0.50
- In adding extra absorption, an increase of 10 times is about the practical limit
- Each doubling of the absorption in a room reduces reverberation time by one-half
- Ceiling treatment for sound absorption is best for large rooms, and wall treatments is best in small rooms
- Absorption increases with an increase in thickness of a porous absorber, except for low-frequency situations
- The amount of absorption of a porous type of sound absorber (fiberglass, mineral wool) is dependent on the material's thickness, material's density, material's porosity, orientation of fibers in the material

Reverberation: the persistence of sound in an enclosed space after the source has stopped.
- It affects the intelligibility of speech and the quality of conditions for music of all types
- Reverberation time: the time it takes the sound level to decrease 60 dB after the source has stopped producing the sound. It is found by: **T = 0.05 (V / A)**, where:
  T: reverberation time
  V: room volume
  A: total acoustical absorption
- Recommended reverberation times
  0.3 – 0.6 sec: offices, small rooms for speech
  0.4 – 0.6 sec: broadcast studios (speech)
  0.6 – 0.8 sec: elementary classrooms
  0.9 – 1.1 sec: lecture/conference rooms
  0.9 – 1.4 sec: theaters (small)
  1.4 – 3.4 sec: churches
  1.5 – 1.8 sec: auditoriums (speech and music)
  1.5 – 1.8 sec: opera halls

1.6 – 2.1 sec: symphony concert halls

Sound control

- 3 primary ways to control sound within a space
  - Reduce the level of the sound source
  - Modify the absorption in the space
  - Introduce a nonintrusive background sound (white sound, random noise) to mask the sound
  - Low frequency control usually requires an allowance for thicker partitions or more space to apply detailing that absorbs low frequency sound. Two typical methods are as follows:
    - Panel resonators: typically consists of a sized furred panel and certain distance from wall to absorb low frequency energy while reflecting mid and high frequency energy
    - Cavity resonators (Helmholtz): consist of a large air space that is filled with absorbent material and a sized small opening to absorb specific low frequency range. Typical construction is a concrete block wall with narrow slits opening into the cavity of the block

Control of sound transmission

In addition to the construction of the barrier itself, other variables are critical for control of sound transmission:

- Leaks between adjacent construction; running studs to underside of slab and gwb tight to floor and underside of slab; caulk edges
- Flanking loss through duct
- Leaks are partition penetrations; pipes, ducts should not be rigidly connected to wall and gaps should be sealed and caulked
- Flanking loss through ceiling into plenum
- Transmission and impact loss through partition; use weatherstripping at doors, heavy doors, laminated glass can be set in resilient framing or use layers of glass with air gaps in between
- Loss through outlets and other openings; stagger outlets and caulk
- Leaks at floor/wall intersection
- Impact sounds through floor

Speech Privacy

Two measures used to evaluate open office acoustics: articulation class and articulation index. They are intended for only for open office situations with speech as the sound source concern

- Articulation class (AC): gives a rating of system component performance and does not account for masking sound.
- Articulation index (AI): measures the performance of all the elements of a particular configuration working together; ceiling absorption, space dividers, furniture, light fixtures, partitions, background masking systems, and HVAC systems. It predicts the intelligibility of speech for a group of talkers and listeners and the result of the test is a single number rating. It can be used to:
  - Compare the relative privacy between different pairs of workstations or areas
  - Evaluate how changes in open office components affect speech privacy
  - Measure speech privacy objectively for correlation with subjective responses

  AI rating can range from 0.00 (complete privacy) to 1.00 (no privacy where all individual spoken words can be understood). Other ratings include:
  - 0.05 or below: confidential speech; cannot be understood
  - 0.05 – 0.20: normal speech privacy; concentrated effort to understand intruding speech
  - 0.20 or above: speech becomes understood
  - 0.30 or above: no privacy

Designing for speech privacy in an open area include 5 factors:

- High absorption ceiling

  - Space dividers with absorptive surfaces to reduce transmission
  - Arrange floor, furniture, windows and light fixtures to minimize sound reflection
  - Normal attenuation of sound can be accomplished by distancing activities
  - Signal-to-noise ratio: introduce a background sound system to balance with speech privacy and sound-absorbing surfaces

Control of impact noise

Impact noise occurs when an object comes in direct contact with barrier and generally occurs on the floor and ceiling assembly

- Impact isolation class (IIC): quantifies impact noise and is a single number rating of a floor-ceiling's impact on sound performance. A given construction is analyzed in accordance with a standardized test over 16 third-octave bands. The higher the IIC, the better

Control of mechanical noise

Mechanical noise occurs when a vibrating device is in continuous direct contact with the structure. It can be controlled by:

- Mounting mechanical equipment on springs or resilient pads
- Connections between equipment, ducts and pipes should be made with flexible connectors
- Ducts should be lined where noise control is critical
- Locate noise-producing equipment away from quiet, occupied spaces
- Walls, ceilings and floors of mechanical rooms should be designed to attenuate noise
- Mechanical and plumbing systems should be designed to minimize high-velocity flow and sudden changes in fluid velocity

Room acoustics

- Reflection: the return of sound waves from a surface. If a surface is equal to or greater than four times the wavelength of a sound striking it, the angle of incidence will equal the angle of reflection. Wavelength varies with frequency and a velocity of 1130 ft/sec is assumed
  - Echo: occurs when a reflected sound reaches a listener later than 1/17 sec after the direct sound. It will occur whenever the reflected sound path exceeds the direct sound path by 70' or more
- Diffusion: random distribution of sound from a surface. It occurs when the surface dimension equals the wavelength of the sound striking it
- Diffraction: the bending of sound waves around an object or through an opening

Planning concepts to minimize acoustical problems

- Plan similar use areas adjacent to each other; this applies to vertical and horizontal planning
- Use closets and hallways as buffer spaces between noise producing spaces
- Locate noise producing areas away from quiet areas
- Stagger doors in hallways
- Locate operable windows as far away from each other as possible
- Locate furniture and other noise producing objects away from walls
- Minimize the common wall area between two rooms where sound transmission reduction is desired
- Avoid room shapes that reflect noise or sound (circular rooms, barrel-vaulted hallways)
- Avoid parallel walls with hard surfaces in small rooms. Avoid 'flutter echoes' (repeated echoes)
- In auditoriums or theaters, provide speakers in centerline location of room and splay walls to reduce reverberation

Outdoor barriers

Location of barrier is most important and should be placed very close to the source or very close to the receiver. The barrier must be higher than the line of sight between the source and the receiver; the higher, the better

VERTICAL TRANSPORTATION

Hydraulic elevators: lifted by a plunger or ram, set into the ground directly under the car and operated with oil under pressure.

- Used for passenger and freight loads in buildings 2 to 6 stories, or about 50' in height
- Travel from 25 fpm to 150 fpm
- Single ram elevators have weight capacities from 2000 lb to 20,000 lb, and multiple ram units can lift from 20,000 lb to 100,000 lb
- Holeless hydraulic: uses a telescoping plunger set in the shaft next to the cab. Lift is provided by applying force to the upper members of the car frame

Electric elevators (Traction elevators): most common elevator type used for passenger service and is capable of higher lifts and greater speeds than hydraulic

- System employs cables (ropes) that are draped over a sheave and attached to a counterweight. A motor drives the sheave, which transmits lifting power to the ropes by the friction of the ropes in grooves of the sheave
- Electric elevators travel from 250 fpm to 1800 fpm and have capacities from 2000 lb to 5000 lb
    - Gearless traction elevator: uses a direct current (DC) motor directly connected to a sheave. The brake is also mounted on the same shaft
    - Geared traction elevator: used for slow speeds from 25 fpm to 450 fpm. A high-speed DC or AC motor drives a worm gear reduction assembly to provide a slow sheave speed with high torque

Roping: the arrangement of cables supporting the elevator

- Single wrap: simplest type in which the rope passes over the sheave only once and is then connected to the counterweight
- Double wrap: for high-speed elevators where additional traction is usually required so that the rope is wound over the sheave twice. Disadvantage is that the more bends in the cable result in shorter rope life
- 1:1 roping: when the rope is directly connected to the counterweight, the cable travels in the opposite direction as far as the car
- 2:1 roping: when the rope is wrapped around a sheave on the counterweight and connected to the top of the shaft, the rope moves twice as far as the car, but requires less weight to be lifted. A smaller high speed motor can be used which is desirable for speeds up to 700 fpm

Operation and control
Operation: deals with electrical system for elevators answering calls for service
Control: deals with travel speed, accelerating/decelerating, door opening speed, leveling, lanterns

The purpose of an operating system is to coordinate elevator response to signal calls on each floor so that the waiting time is minimized and elevators operate efficiently

- Single automatic: first type of automated system for elevators and consists of a single call button on each floor and a single button for each floor inside the car. Passenger has the exclusive use of the car until the trip is complete. Cannot be called if someone is using it and is intended for small buildings.
- Selective collective operation: most common type of system for light to moderate service where the elevator remembers and answers all calls in one direction then reverses to answer all calls in opposite direction. When trip is complete, cab typically returns to lobby
- Group automatic operation: for use in large buildings, this system controls all elevators with programmable microprocessors to respond to calls in the most efficient way

Safety devices

- Main brake: automatically applied if power failure occurs, normally operated by the control mechanism and is located on the sheave or motor shaft
- Governor: senses the speed of the car and brake is applied if speed is exceeded

- Safety rail clamps: grips the side rails if there is an emergency
- Car buffers: stop a car's motion if it over travels the lowest stop, but are not designed to stop a free-falling elevator cab
- Interlocks: prevent the elevator from operating unless the hoistway door is closed and locked
- Safety edges: movable strips on the leading edge of the door that activate a switch to reopen the door if something contacts it.
- Proximity detectors: operate similarly to safety edges, but sense the presence of a person near the door and can stop the closing motion
- In case of power failure, most codes require that at least one car can operate at a time while the others stop allowing the unloading of cars. If a fire alarm is activated, all cars return to the lobby without stopping and switch to manual control by the FD
- Minimum time between a car answering a call and the moment the doors of that cab start to close is 5 sec
- Wheelchair accessibility includes:
    - Minimum clear door opening width is 36"
    - All car controls must be no higher than 54" for side approaches and 48" for front approaches. They must also be designated by braille and by raised standard alphabet characters. This includes main entry door, door open and close, emergency alarm, etc.

Elevator design: involves selecting the capacity, speed, number of elevators including location and arrangement, roping method, machine room layout, control system and cab decoration
Capacity and speed

- Handling capacity (number of people to be served): is usually based on a 5-minute peak period
- Capacity: measured in weight; number of people a car can carry

Recommended Elevator capacities

	Building size (lbm)			
Building type	small	medium	large	service elevator(lbm)
Offices	2500/3000	3000/3500	3500/4000	4000-6500
Garages	2500	3000	3500	-
Retail	3500	3500	4000	4000-8000
Hotels	3000	3500	3500	4000
Apartments	2000/2500	2500	2500	4000
Dormitories	3000	3000	3000	-
Senior citizens	2500	2500	2500	4000

Car passenger capacity

Elevator capacity (lbm)	maximum passenger capacity
2000	12
2500	17
3000	20
3500	23
4000	28

Recommended Elevator speeds (ft/min)

Number of floors	small	medium	large	service
offices				
2-5	250	300/400	400	200
5-10	400	400	500	300
10-15	400	400/500	500/700	400
15-25	500	500/700	700	500
25-35	-	800/1000	1000	500

35-45	-	1000/1200	1200	700
45-60	-	1200/1400	1400/1600	800
over 60	-	-	1800	800
garages				
2-5	200			
5-10	200-400			
10-15	300-500			
hotels				
2-6	100-300			200
6-12	200-500			300
12-20	400-500			400
20-25	500/700			500
25-30	700/800			500
30-40	700-1000			700
40-50	1000-1200			800
apartments				
2-6	100			200
6-12	200			200
12-20	300-500			200
20-25	400/500			300
25-30	500			300

- Number of elevators required is found by taking the total number of people to be accommodated in a 5-minute peak period and dividing by the handling capacity of one car
- Interval: average waiting time for an elevator arrival; varies with building type. For example, diversified offices: 30-35 sec, and for hotels and apartments: 40-70 sec or more

Location and lobby design

- Elevators should be near the center of the building, at the lobby level they should be easily accessible from the entrance, and visible from all points of access. Even in smaller buildings, there should be a minimum of 2 elevators
- Elevator lobbies should be designed to see all hall lanterns from one point to minimize walking distance to any car that arrives. Also, provide adequate space to create good circulation between people coming out and going into the elevator
- There should never be more than 8 cars in one elevator bank or 4 cars in one line
- Methods of providing elevators for very tall buildings:
    - Divide the total number of elevators into banks that serve different zones. This method will keep waiting and travel times acceptable, but the shafts take up space especially on the lower floors
    - Sky-lobby concept: high speed elevators take people from the ground floor to the sky lobby to transfer to elevators serving upper floors. Reduces the amount of space taken by elevator shafts and serves well for multi-occupancy buildings
    - Stacked or double-deck elevator: doubles shaft capacity, reduces area required for elevators and decreases local stops

Elevator doors

- Single speed, center opening: common and allow faster passenger loading and unloading than do side-opening doors
- Two speed, side opening: has two leaves, one which telescopes past the other as they move
- Two speed, center opening: four leaves; telescoping
- Minimum opening width is 3’6”, but 4’0” is better b/c it allows two people to leave or enter elevator at the same time

Machine room: best located directly above the hoistway and provide adequate space for the motor, sheave, brake, controller board, speed governor, floor selector mechanism, and motor generator. Room should be as wide as hoistway and 12’ to 16’ deeper than hoistway. Minimum ceiling is from 7’6” to over 10’

Freight elevators: designed only to transport equipment and materials and the passengers needed to handle the freight. They are commonly available in capacities from 2500 lbm to 8000lbm. Speeds range from 50 fpm to 200fpm, but capacity takes precedence over speed.
Classified in 5 groups:

- Class A: general freight; no item can exceed ¼ of the rated capacity of the elevator which is no less than 50/lbm/ft^2 of platform area
- Class B: used for motor vehicle loading and are rated no less than 30/lbm/ft^2
- Class C1: includes industrial truck loading based on 50/lbm/ft^2
- Class C2: includes no industrial truck loading based on 50/lbm/ft^2
- Class C3: concentrated load for the truck not carried and with increments greater than 25% rated capacity

Escalators: rated by speed and size

- Speed: 100 fpm (industry standard) and 120 fpm (transportation and sports facilities)
- Sizes: 3 available; 32", 40", 48" and actual tread widths are 24", 32", 40". Most common are 32" and 48"
- Actual observed capacity is what is used and based on an individual on every other step in a 32" model (2300 people per hour) and an average of every step on a 48" model (4500 people per hour)
- Dimensions: escalators are housed in a trussed assembly set at a 30° angle. Landing at bottom is typ 7'6", rise is multiplied by 1.732, landing at top is 8'0" and height of rail is 3'0" (landing) and 2'8" (incline). Take into account the motors, drives, etc. in the housing when calculating the head clearance and floor-to-floor heights (3'2" to 3'8")

Stairs and ramps

- Stairs classified into two categories: utilitarian and monumental
- Dimensions: minimum width is 36", or 44" when occupant load exceeds 50. Handrails may project a maximum of 4 ½" on both sides; diameter can be between 1 ¼" and 2"; at least 1 ½" away from the way
- Winding, circular, and spiral are allowed only in residential applications
- Winding stairs: min allowable tread is 6" at narrowest point and must be at least 11" in depth, 12" away from narrowest point
- Circular stairs: min allowable tread is 10" at narrowest point and must be at least 11" in depth, 12" away from narrowest point. Width of stair being W, center point of staircase circle must be at least 2 x W from inside rail of staircase
- Spiral: tread must be at least 7 ½" in depth, 12" away from narrowest point. Provide a minimum headroom height of 6'6", but riser cannot be greater than 9 ½"
- Egress stair: min tread 11" (12" to 14" preferred), 7" max rise (8" residential). Last tread must be at least 48" away from inside wall enclosure and door swing cannot reduce egress by more than half the clear width of stair. Doors fully open cannot extend more than 7" from adjacent wall into egress path. Landing width needs to be at least as wide as the stair. Railings should continue to slope one tread length past the last tread and extend an additional 12" at the bottom of a stair
- Maximum distance between landings is 12' (9' preferred). Top and bottom treads should have contrasting strips at the nosing. Nosing should not be abrupt and have a maximum rounded edge of ½"

- Ramps: maximum slope is 1:12, maximum rise of 30" and 30' in length. 1:10 slope is permitted if maximum rise is 6" and 1:8 slope is permitted if maximum rise does not exceed 3"
- Minimum clear width of a ramp is 36" with landings at least as widest ramp leading to them. Landing lengths need to be a minimum of 60" and if ramp changes direction, 60" square
- Handrails are required for ramps exceeding 6" in rise or 72" in length and are required to be 34" to 38" above ramp surface. Handrails must extend at least 12" beyond top and bottom segment of ramp and be 1 ¼" to 1 ½" in diameter.