CONTENT AREA: CODES + REGULATIONS

Government + Regulatory Requirements and Permit Process

Vocabulary:

- **Americans with Disabilities Act (ADA):** prohibits discrimination based on disability
- **Building Owners and Managers Association (BOMA):** professional organization that for commercial real estate professionals
- **Fair Housing Act:** law that prohibits housing discrimination on the basis of race, color, religion, sex, disability, familial status, and national origin.
- **HUD:** US Department of Housing and Urban Development
- **Prescriptive Code:** Building code that specifies techniques, materials and methods to be used. Cut and dry and simple to administer by the official
- **Performance Code:** Building code that describes functional requirements, but leave method to achieve decisions up to the designer.

Facts/Rules:

- **International Building Code (IBC)**
  - Begins by defining occupancy groups, the purpose of which is to distinguish various degrees/qualities of need for safety in a building.
- **American Society for Testing and Materials (ASTM)**
  - establishes standard specifications for commonly used materials of construction.
  - Generally referred to by number (eg: C150 = specification for portland cement)
  - numbers are frequently used in specifications for specific/precise shorthand designation for the quality of material that is required.
- **American National Standards Institute (ANSI)**
  - develops standards for many industrial products (eg: aluminum windows, mechanical components of buildings)
- **MasterFormat/Construction Specifications Institute (CSI)**
  - a standard for organizing information about constriction materials and components.
  - MasterFormat is used as the outline for project specifications
  - In 2004 the system was updated from 16 divisions to 50 divisions
- **Fair Housing Act Guidelines:**
  - Covers most housing (owner-occupied building with 4 or less units, single family houses sold/rented by owner, and housing run by clubs that limit occupancy to members are sometime exempt)
  - Requirements for New Buildings with 4 or more units and an elevator:
    - Public common area must be accessible
    - Doors and hallways mush be wide enough for a wheelchair (32”-36” min)
    - All units must have:
      - An accessible rough into and through the unit
      - Accessible light switches, electrical outlets, thermostats, etc
      - Reinforced bathroom walls to allow later installation of grab bars
      - Kitchens/bathrooms can be used by people in a wheelchair
    - These rules do not replace more stringent state/local codes
- **ADA Accessibility Guidelines:**
  - All new design or new construction areas must meet accessibility requirements

- Includes all employee work area and temporary construction that is open to the public
- Some areas are not require to be accessible:
  - Temporary construction facilities (e.g. Job shacks, scaffolding, trailers)
  - Raised areas used for security/life safety (e.g. Security or life guard towers)
  - Non-occupiable service areas accessed infrequently for maintenance (e.g. Mechanical rooms, penthouses)
  - Water slides
  - Non-public animal containment areas
  - Raised structures for officiating/announcing sports events

- **ADA Dimensional Standards:**

Acessible Route

Wheelchair Passage Width	=	32” clr at a point/36” clr continuous
2 Wheelchair Passing Width	=	60” clr min
Headroom	=	80” min
Turning Space	=	5’-0” circle min
Clear floor space	=	2’-6” wide x 4’-0” long min
Cross Slope	=	1:50 max

Doors

Opening width	=	32” clr min when open 90 deg
Door clearance	=	1’-6” clr on pull side of door
		1’-0” clr on the push side of the door

Level Changes

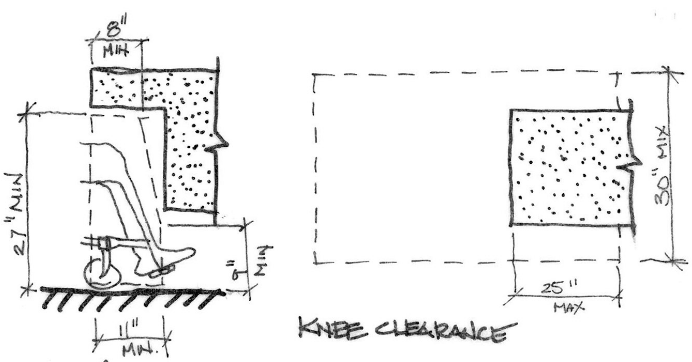
Changes in levels	=	1/4” max w/o edge treatment
Beveled Edge Ok	=	1/4” – 1/2” with 1:2 max slope
Requires Ramp	=	1/2” or more

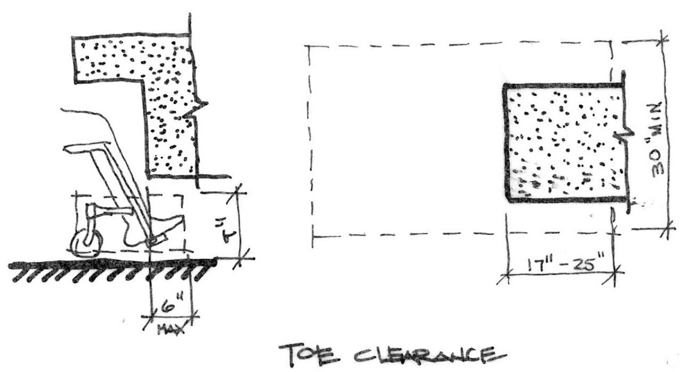
Ramps

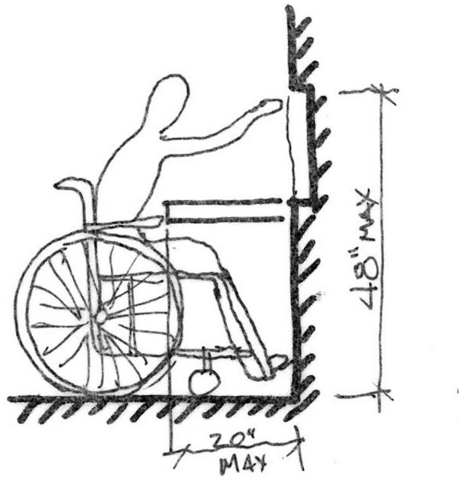
Slope	=	1:20 min to 1:12 max
Width	=	3’-0” wide
Length	=	30’-0” max
Landings	=	5’-0” at each end (width of ramp)
2 Handrails	=	If rise is +6” or run is +72”

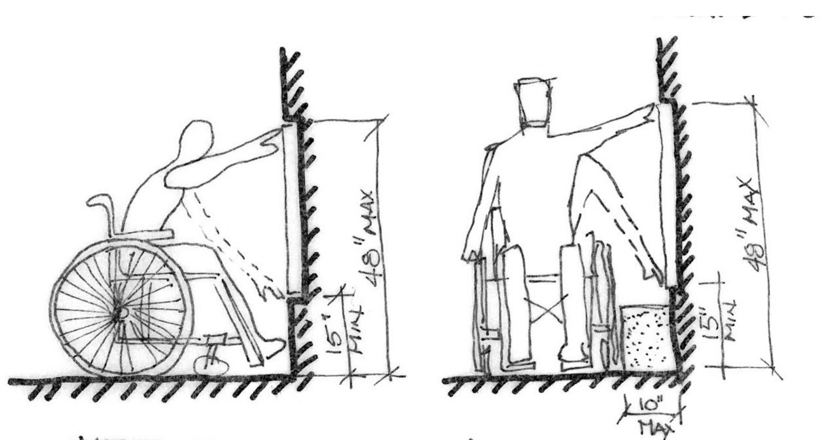
Handrails

Height	=	34” min - 38” max
Cross Section	=	1-1/4” - 2” and 1-1/2” clr from wall
Extension	=	12” top and 12”+ 1 tread bottom
Stairway Handrails	=	48” clr between hand rails min

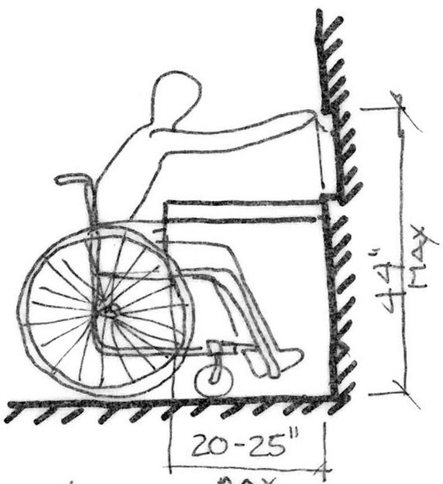




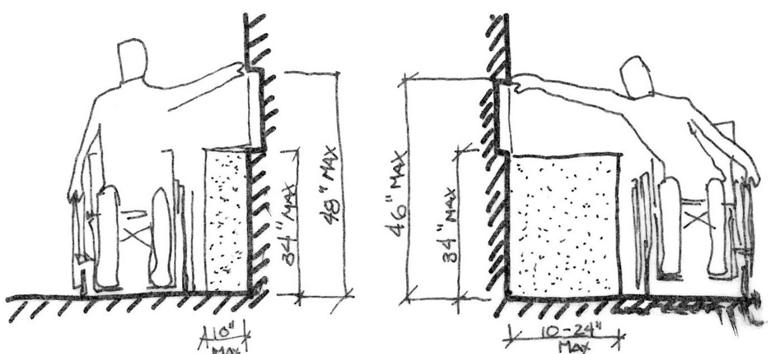




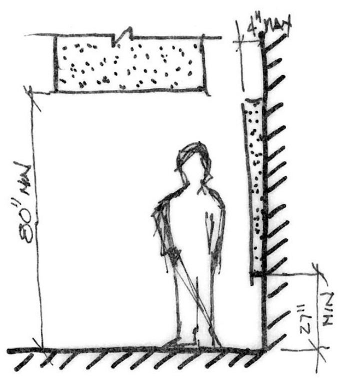
UNOBSTRUCTED FORWARD REACH & SIDE REACH



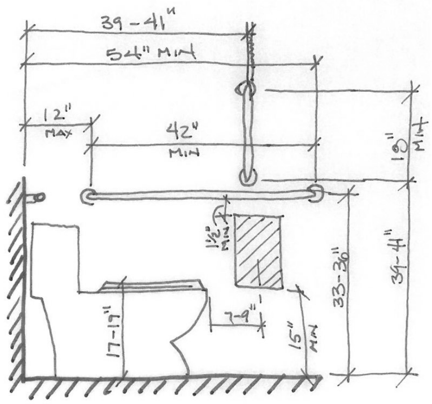
OBSTRUCTED HIGH FORWARD REACH



OBSTRUCTED HIGH SIDE REACH



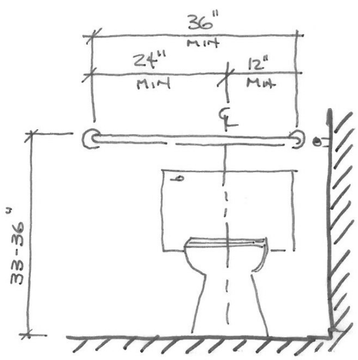
PROTRUDING OBJECTS



TYPICAL TOILET SIDE DIMS

Toilet & Accessories

Location	=	16” - 18” to center from sidewall
Clearance	=	60” min from sidewall
		54” min from rear
Height	=	17” - 19” to top of seat
Sidewall grab bar	=	42” min length
		12” max from rear wall
		33” -36” above floor
Vertical grab bar	=	18” min length,
		39” - 41” above floor
		39” - 41” from the rear wall
T.P. Dispenser	=	7” - 9” to center from front of toilet
		15” - 48” above floor



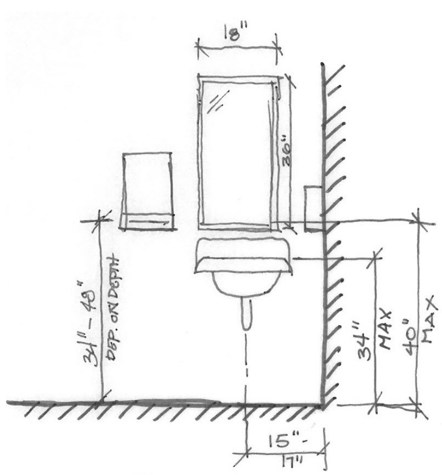
TYPICAL TOILET REAR DIMS

Urinal

Rim	=	17” max above floor
Clear Floor	=	2’-6” wide x 4’-0” long
Flush Control	=	44” max above the floor

Lavatory/Sink

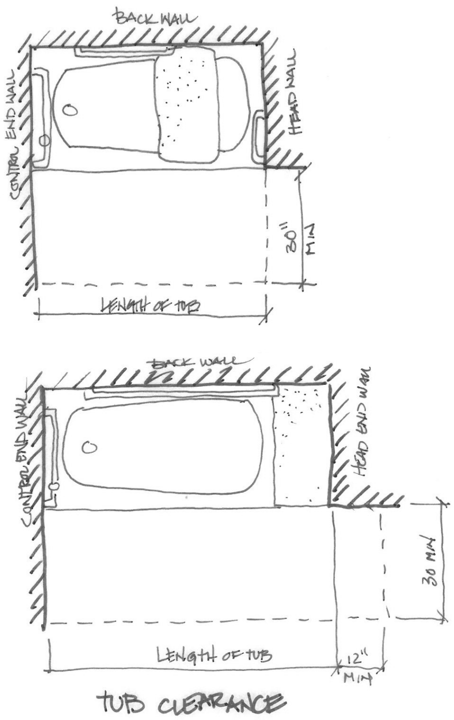
Clear Floor	=	2’-6” wide x 4’-0” long min
Height	=	34” max above floor to top of rim/ counter
Mirror	=	40” bottom of frame



TYPICAL LAV DIMS

Drinking Fountains

Floor Space	=	2’-6” wide x 4’-0” long min
Spout Height	=	36” max above floor
Water flow	=	4” min height



Bathtubs

Front clr (no seat) = 30” wide x length of tub min

Front clr(with seat) = 30” wide x length +12” min

Controls = center line of end wall

Hand Shower = 59” min hose

Temperature = 120ºF max

Transfer Showers

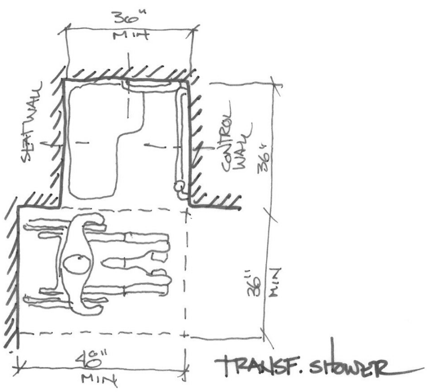
Size = 36” x 36” clr min

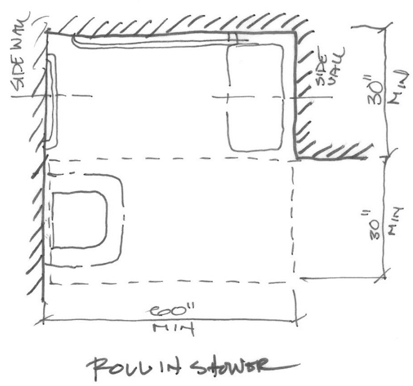
Front Clr = 36” wide x 48” long min

Roll in Shower

Size = 30” x 60” clr min

Front Clr = 30” wide x 60” long min





Concepts/Goals:

- The purpose of the code is to protect public health, safety, and welfare
- Accessibility services scope can vary depending on the size of the client, their organization, and the project.
- Name recognition matters...large, public, visible companies are more vulnerable to lawsuits so need to be prepared for issues.
- Accessibility services scope can vary depending on the size of the client, their organization, and the project.
- Name recognition matters...large, public, visible companies are more vulnerable to lawsuits so need to be prepared for issues.

Processes:

- Identify client’s potential accessibility problem areas and desired outcomes
- Identify strategies for correcting problems including a proposed implementation schedule and budget/cost analysis
- Develop prototype design details for implementation
- Prepare and administer surveys if required to assess population using building
- Prepare client training program manuals and facility monitoring documentation

CONTENT AREA: ENVIRONMENTAL ISSUES

Building Design

Vocabulary:

- **British Thermal Unit:** a measure of energy, typically noted as the amount of energy needed to raise one pound of water by 1˚ F
- **Coefficient of Heat Transmission (U-value):** overall rate of heat flow through any combination of materials, used for determining the size of heating system.
- **Conductance (C):** BTU/Hr that pass through 1 ft^2 of material of a given thickness when the change in temperature is 1 ºF
- **Thermal Conductivity (k)**: ability of a material to transmit or conduct heat or electricity based on the physical properties of the material, expressed in BTU
- **Conductivity (k/in):** BTU/hr that pass through a 1 ft^2 of material 1" thick when the change in temperature is 1 ºF
- **Emissivity (ε):** the measure of an object's ability to absorb and then radiate heat
- **Emittance:** the energy radiated by the surface of a body person per unit area
- **Resistance (R):** number of hours needed for 1 BTU to pass through 1 ft^2 of material or assembly of a given thickness when the change in temperature is 1 ºF
- **Latent Heat:** heat required to convert a solid into a liquid or vapor, or a liquid into a vapor, without change of temperature, given in BTU
- **Sensible Heat:** amount of energy released or absorbed by a chemical substance during a change of temperature, changes the temperature but not the state, given in BTU
- **Specific Heat:** the amount of energy required to raise the temperature of a material by 1 ºF, the capacity to store heat, given in BTU
- **Heat of Vaporization:** heat given off by a vapor condensing to liquid, or the heat absorbed by a liquid evaporating to a gas without a change in temperature
- **Relative Humidity:** ratio of moisture content of the air to the max possible moisture content at the same temperature
- **Enthalpy (H):** total heat loss in a substance (latent heat + sensible heat), given in BTU
- **Radiation:** the transfer of heat between surfaces that are not in direct contact
- **Conduction:** the transfer of heat between two objects that are in direct contact
- **Convection:** the transfer of heat that requires a fluid medium like air to transfer (also, directions like up/down/sideways matters)
- **Evaporation:** liquid is absorbed into the air as latent heat
- **Warmth:** the quality, state, or sensation of being warm, moderate and comfortable heat
- **Coolth:** pleasantly low temperature
- **Clo:** amount of insulation which will maintain normal skin temperature of the human body, 1 Clo is the equivalent of a typical American man's suit in 1941.
- **Thermal Comfort:** the state of mind that expresses satisfaction with the surrounding environment
- **Degree Day (DD):** the average yearly difference between the indoor temperature and outdoor temperature. Typically a reference temperature of 65 ºF is used
- **Design Day:** used to design and size a heating system that determines the day cooler than 98% of all days in the year experience in a climate.
- **Dry Bulb Temperature:** typically referred to as air temperature, it's what people are referring to when the talk about the temperature. It's an indicator of heat content and measured by a common thermometer, given in ºF

- **Wet Bulb Temperature:** the lowest temperature that can be reached under current ambient conditions by the evaporation of water only, given in °F
- **Dew Point (T):** the temperature at which water vapor starts to condenses out of the air. Above this temperature the moisture will stay in the air, given in °F
- **Comfort Zone:** the range of temperatures and humidities in which most people feel comfortable when dressed in typical indoor clothing & engaged in typical indoor activities
- **Air Changes Per Hour (ACH):** a rough estimate of how much whole room/building air is replace by outdoor air per hour
- **Mean Daily Range:** average temperature swing from night to day
- **Mean Radiant Temperature (MRT):** the average radiant temperature of your surroundings and is independent of air temperature (e.g.: when you ski it's cold out but you're warm from the sun and exercise)
- **Barometer:** an instrument for measuring atmospheric pressure
- **Globe Thermometer:** used to measure radiant temperature. It's a dry bulb thermometer encased in a matte black copper sphere
- **Hygrometer:** instrument used to measure the relative humidity of the air
- **Effective Temperature:** fictitious temperature that produces the same physiological effect as the combined effects of temperature, humidity, and air movement *NOT AN ACUTAL TEMPERATURE.*
- **Chill Factor: (Wind Chill Index)**: fictitious temperature assigned to a combination of actual temperature and wind velocity which as the same physiological effect as still air at the chill factor temperature
- **Psychometrics:** study of physical and thermodynamic properties of gas-vapor mixtures
- **Psychrometric Chart:** A graph that presents physical and thermal properties of moist air in graphic form, often at an elevation relative to sea level.
- **Thermal Resistance:** the measure of how a material does not allow heat flow (R-Value)
- **Thermal Transmittance:** the measure of how heat flows through a building component or assembly when the difference between the air temperature on the two sides is one unit of temperature (U-Value)
- **Specific Heat:** capacity of a material to store heat (BTU/lb.)
- **Thermal Capacity:** Ability of a given volume of a material to store heat (BTU/ft^3)
- **Insolation:** radiant heat gain from the sun
- **Declination:** 23.5 degree tilt of the earth's axis relative to a line perpendicular to the plane of the earth's orbit…responsible for the seasons

Equations: (those in gold are given on ncarb formula sheet)

$U_{value} = 1 / R_{value}$

$= \dfrac{(U_{window} \times A_{window}) + (U_{wall} \times A_{wall})}{A_{total\ wall}}$

$=$ (BTU / Hour ft^2 °F)

$R_{value} = \dfrac{\text{Thickness of material, X}}{\text{Thermal Conductivity, k}}$

$= 1 / U_{value} =$ (Hour ft^2 °F/ BTU)

cfm = (space volume) x ACH / (60 min/hr)

UA (BTU/hr) = (1.1) x (cfm) x (ΔT)

UA (infiltration) = 1.1 x cfm

Heat Gain (q, in BTU/hr) = (U value) x Area, A) x (ΔT)

Rate of heat Loss (BTU/hr) = (BTU / Hour ˚F ft^2) x (a temperature difference)

Building Loss Coefficient (BLC) = $UA_{envelope} + UA_{infiltration}$

Balance Point ($T_{balance}$) = $T_{Internal}$ - (Internal Gains (BTU/hr) / $UA_{building}$)

Efficiency = What is sought (what a system says it can do) / What is bought (what it actually does)

Facts/Rules:

- **British Thermal Unit:** the standard measurement used to state the amount of energy that a fuel has and well as the amount of output of any heat generating device
  - BTU is energy, or a given amount
    - It's the amount of energy needed to:
      - raise 1 lb. of water 1˚ F
      - raise 1 pint of water by 1˚ F
      - burn one match
  - BTU/hour is a rate of energy
    - It's the rate needed to:
      - Describe heat gain
      - Describe heat loss
      - Report the Input/Output of a device (e.g.: this is a 60,000 BTU/hr furnace!)
  - Examples:
    - A typical furnace in a home puts out about 80,000 to 150,000 BTU/hr (rate)
    - A person at rest puts out about 250 to 350 BTU/hr (rate)
    - A typical US home uses about 50 MILLION BTU/year (amount) for space heating
  - To put things further into perspective:
    - A classroom has a people heat gain for about 27,000 BTU/hr
    - A new desktop computer uses 2,400 BTU/hr
    - Typical office spaces get 2.5 w/ft^2 heat gains from lighting alone
    - Coal (when burned) = 15,000 BTU/lb.
    - Natural Gas (when burned) = 1,000 BTU/cubic ft
    - Wood (when burned) = 7,000 BTU/lb.
- Human comfort is a matter of taste, **Clo** is the degree at which you're dressed
  - The standard amount of insulation required to keep a resting person warm in a windless room at 70º F is equal to 1 col.
  - .8 clo: winter dressing, sweaters and other warm stuff
  - .4 clo: summer dressing, shorts and tank tops
- **Outside Design Conditions** ***(Reference MEEB Appendix A1)***
  - Maximum and minimum temperatures
    - For heating use **Design Dry Bulb (97.5%)**: 97.5% of the time the outdoor temperature is above the value listed on the table for the city
    - For cooling use **Design Dry Bulb (2.5%):** 2.5% of the time the weather is above the value listed for the city
    - *Example: for Portland, OR the Design Dry Bulb is 23 and 85.*
      - *So, 97.5% of the time it's warmer than 23 & 2.5% of the time it's warmer than 85*
  - When dry bulb temp equals wet bulb, relative humidity equals 100
  - **Heating Degree Day (HDD65):** rational, calculated measure of the depth of the heating season
    - Degree Days are used to determine the heating requirements of a building. It's the amount by which the average outdoor temp is below 65ºF for one day. The more days it's below that, the larger number of degree days it has

- It's a monthly and annual measure of what at building is in for heating wise

0 - 1000	=	no problem, no need to heat
1000 - 3000	=	good insulation is enough
3000 - 5000	=	moderate, use 2 systems
5000 - 7000	=	need serious heating
Over 7000	=	year long heating (just move)

- *Ex: Phoenix HDD65 = 444, Portland = 4693, and Anchorage = 10825*

- **Heat Loss**
  - The key concept in building performance is the idea of the **Building UA**.
    - Once you understand the UA, then you will understand building heat loss
      - Based on the U-Value and the area of any given building component (e.g.: walls, roof, floor, window, doors)
  - R values of components are typically easier to understand
    - The bigger the number the more insulating the system
    - Buildings tend to be built in layers and the R value lets us just keep adding to get an overall bulk value
  - **Heat Flow = Area of component / resistance of material aka: Area / R-Value**
    - ***(Reference MEEB Table 4.2)*** *Thermal Properties of Typ Build/Insul. Materials*
      - Geared toward a US market
      - Use the I-P Resistance (R) Category: Per in. Thickness (1/k) / ˚F ft^2 h (BTU/in)
        - Materials under this heading are the typical R-Value
    - A series heat flow path goes from one component to another

outside air film >	outside finish >	building material >	interior surface >	inside air film

    - A parallel heat flow path goes:

      outside > sheathing > studs and insulation > gypsum board

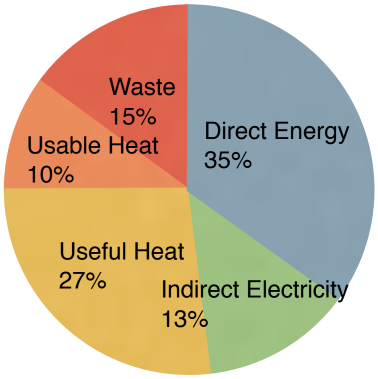
  - **Parallel Heat Loss = (this much width) x (this much R-Value)**
    + (that much width) x (that much R-Value)

  Example: 2x6 studs with continuous insulation…
  = (1.5"/16")(R-Value of Stud R-7) + (14.5"/16")(R-Value of Insul R-19)
  = R-0.656 + R-17.2
  = R 17.8

- Air Changes Per Hour (ACH), Units are "per hour"
  - You just have to turn it into cubic feet / minute (cfm) to calculate it
    - cfm = (volume) x ACH / (60 min/hr)
    - UA (infiltration) = 1.1 x cfm
- Building Loss Coefficient (BLC) = $UA_{envelope} + UA_{infiltration}$
- Balance Point:
  - Find the balance between internal gains and thermal makeup with the $T_{balance}$ equation
  - Use when internal gains and building UA don't match up with DD65
  - It's the differential between what is "normal" and what is actually built
- Coefficient of Performance is a unitless measure of BTU/BTU or watt/watt
  - Measures how much you put in compared to how much you get out
- **Psychometry:**
  - Moisture, air, and heat interactions are complex
  - As air temperature rises, it's capacity to hold moisture rises too
  - As air becomes warmer it also becomes less dense

Concepts/Goals:

- Energy production is just spinning a wheel…except for photovoltaics, which make energy with no parts or wheel
- Typical electrical production is 33% efficient
  - For every BTU, 1/3 of it is good, the rest is waste
  - Typical vehicles are 18% efficient
- **Human Comfort:**
  - Comfort is kind of a touchy feely idea that we have have to apply numbers to.
  - It's quantifying something and is really a mater of taste
  - It's a sketchy idea, we know *when* we are comfortable, but we don't know how to get it
    - Aim for the **60 - 20 - 20 goal:** 60% of people will be comfortable, 20% will be thermally hot, and 20% will be thermally cold.



Once energy is collected, where does it all go?

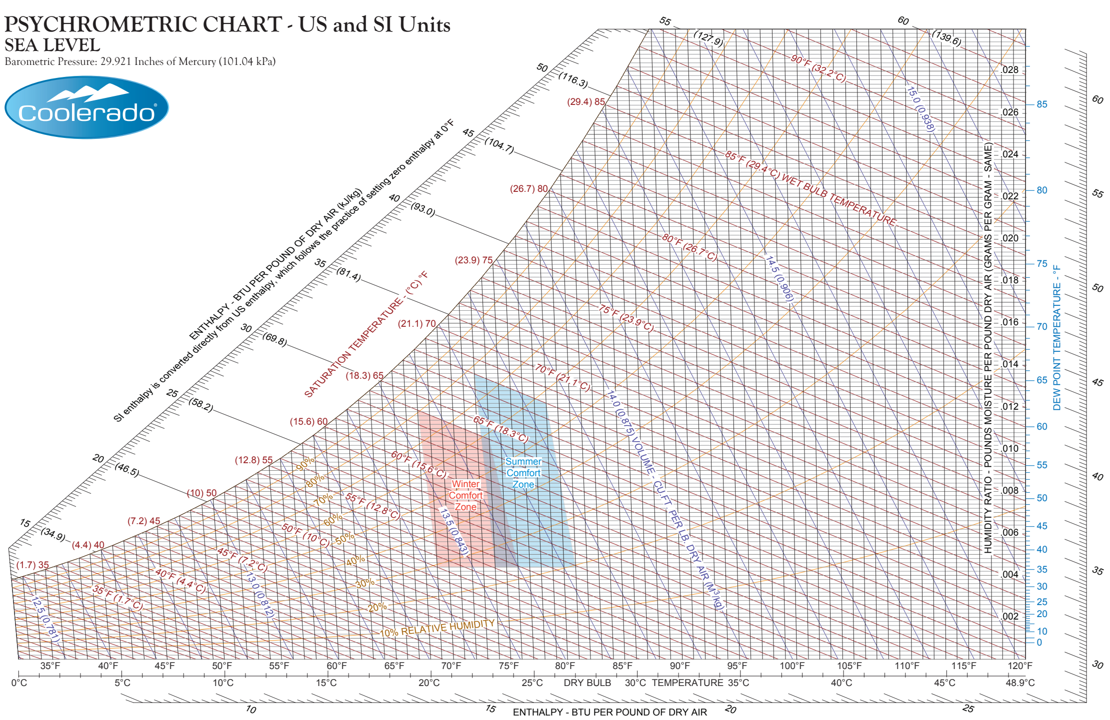
- **Tolerable Humidity:** 20% - 70% but 30% - 65% is ideal
- A 30% relative humidity change will affect a person's comfort about as much as a 25% change in air temp
- The human body serves as an anthropomorphic model of system design
  - Circulation System, Ventilation System, Filtration System, Thermal Controls, Waste Management System

Processes:

- Measuring Temperatures
  - Dry Bulb Temperature
    - The air temperature that is most commonly used, what people normally refer to when talking about the temperature of the air
    - Called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air
    - Measure using a normal thermometer
    - Indicates the heat content and is shown along the bottom axis of the psychrometric chart, and appear as vertical lines in the chart
  - Wet Bulb Temperature
    - The temperature of adiabatic saturation, or what a parcel of air would have it were cooled to 100% relative humidity (saturation) by the evaporation of water into it
    - Measured by using a t thermometer with the bulb wrapped in wet muslin. The adiabatic evaporation of water from the thermometer and the cooling effect is indicated by a "wet bulb temp" that's lower than the "dry bulb temp."
    - The rate of evaporation from the wet bandage on the bulb, and the temperature difference between the dry bulb and wet bulb depends on the humidity of the air.
      - The more humid (or water vapor) the evaporation reduces
    - Wet bulb temperature is always lower than dry bulb temperature
    - Lines of constant wet bulb temperature run diagonally from the upper left to the lower right on the psychrometric chart
  - Dew Point Temperature
    - The dew point is the temperature at which water vapor starts to condenses out of the air
    - Above this temperature moisture will stay in the air

- If the dew point temperature is close to the dry air temperature the relative humidity is high
- If the dew point temperature is well below the dry air temperature, the relative humidity is low
- Dew Point temperature is measured by filling a metal can with water and some ice cubes. Stir by a thermometer and watch the outside of the can, when the vapor in the air starts to condense on the outside of the can, the temperature of the thermometer is pretty close to the dew pion of the actual air
- Dew Point is given by the saturation line (the maximum amount of humidity that air can hold) on the psychrometric chart

- Reading a Psychrometric Chart
  - A graphic representation of the relationship between air temp and humidity
  - Psychrometric Charts allow humidity to be calculated from wet and dry bulb readings and explains common atmospheric behavior
  - It's basically an exercise in seeing where two known values intersect to give you a third value
  - Chart Values:
    - Dry Bulb Temperature (the air temperature): vertical lines
    - Absolute Humidity (the amount of moisture in the air): horizontal lines
    - Saturation Line (the maximum amount of humidity air can hold): top curved line
    - Relative Humidity (the % of humidity relative to the saturation line): curved lines
    - Wet Bulb Temp (the adiabatic saturation temp): diagonal lines from saturation line down and to the right
    - Dew Point Temp (the temp at which air becomes completely saturated and water starts to precipitate out of the air as fog, rain, snow): horizontal lines



- To find the humidity:
  - Locate where the dry bulb and wet bulb temperature readings intersect.
  - The nearest constant humidity line is the relative humidity

- To find Wet Bulb Temperature
    - Locate the dry bulb and relative humidity lines
    - The nearest diagonal wet bulb line is the wet bulb temp
- To find if you're in the comfort zone
    - Locate the dry bulb, wetbulb, and/or relative humidity values
    - The intersection is the comfort level. If it's in the red zone you're in the winter comfort zone, if you're in the blue, you're in the summer comfort zone

Building Systems + their Integration

Vocabulary:

- **Solar Heat Gain Coefficient (SHGC):** ratio of solar heat gain through a fenestration to the total solar radiation incident (falling upon/striking) on the glazing (0.0 - 0.87)
- **Shading Coefficient (SC):** ratio of solar heat gain through a glazing product to the solar heat gain through an unshaded 1/8" thick clear double strength glass under the same set of conditions (0.0 - 1.0) SHGC is considered more accurate.
- **Passive System:** a solar heating or cooling system that uses no external mechanical power to move the collected solar heat
- **Active System:** a solar heating or cooling system that requires external mechanical power to move the collected heat.
- **Annual Fuel Utilization Efficiency (AFUE):** the annual fuel utilization efficiency, displayed on all furnaces manufactured within the United States
- **Greenhouse Effect:** sunlight is transmitted through glass into a building, causing the materials inside to heat up. When they heat up, they reradiate in the infrared spectrum which doesn't pass back through the glass, it's trapped inside the building warming it up.
- **Stack Effect (Chimney Effect):** tendency of a gas or air to rise in vertical shaft because its density is lower than the surround gas or air
- **Heat sink:** for the purpose of high mass cooling is a facility for rejecting heat accumulated by a building
- **Solar Savings Fraction (SSF)**: the extent to which a solar design reduces a building's auxiliary heat requirement relative to a reference energy conserving building
- **Eutectic Salts:** Materials used to store and release heat by means of their latent heat capacity…they alternately melt and solidify in the normal solar operating temp range of 80 – 160ºF

Equations:

Energy consumed/year (E)= $\frac{\text{(total heat loss rate, UA) x (DD balance point) x (24 hr)}}{\text{(given AFUE) x (given heating value of fuel, V)}}$

Facts/Rules:

- Building Form
    - **(Refer to *MEEB Figure 5.1*)**: *Internal load dominated buildings*
        - Thick buildings are harder and more difficult to light, easier to heat, cores have more internal loads
        - Thin buildings are easier to daylight
        - Atriums are the removal of the core, they need to cool
- **The big four things you need to do for successful solar heating:**
    - Collect Heat: usually involves glazing and some sense or orientation
        - Use Windows!

      - Face them south… south glass is the best. Period.
      - Make glazing vertical - horizontal and angled glazing doesn't work as well
      - Shade it in the summer (For every 1'-0" up, have 6" of overhang)
      - Don't block it
      - Don't count on trees for shading (they might go away)
      - Keep a 2:1 ratio of mass to glass
    - Store Heat: insulating materials and effective mass storage are critical
      - Mass is measured in density or the lb/ft^3 of the material and the C_p or the heat capacity of the material
      - *Ins**u**late before you ins**o**late*
        - **Insulating:** protecting from heat loss
        - **Ins*o*lating:** exposing to the rays of the sun
      - Isolated mass or floating mass
      - Coupled or uncoupled
      - Maintain a 3:1 mass to glass ratio (every 3 sq.ft. of mass allows 1 sq.ft. of southern facing glass)
        - The more mass you have, the more glass you need
        - The more glass you have, the more mass you need ...it's a balance!
    - Move Heat: although "natural" methods work, strategic placement is better
      - Decide on natural or forced convection
        - Natural means (more or less) uncontrolled heat movement
      - Be skeptical when relying solely on convection
      - The best idea is to force it
        - Put it where you need it and then turn it off when you're done
    - Control Heat: too much or too little heat is problematic (but easy to solve)
      - Dual control
- Passive Solar Building Design
    - Windows, walls, and floors are designed to collect, store and distribute solar energy in the winter and reject it in the summer
    - Doesn't involve mechanical devices or system
    - Used for space and/or water heating
    - Energy is collected through properly oriented south facing windows
    - Storage of energy is in "thermal mass," building materials with high heat capacity such as concrete slabs, brick walls, or tile floors
- Sustainable Heating and Cooling:
    - **Passive Solar Heating (no mechanical equipment):**
      - Incorporate sun collection and storage as part of a building's walls, floors, or ceilings
      - **Direct Gain Systems:** allow solar radiation to flow directly into the space that needs heat (like a greenhouse)
        - Actual living space is a solar collector, heat absorber, and distribution system
        - South facing glass admits solar gain into the space where it strikes directly and indirectly thermal mass like masonry floor and walls
        - Thermal mass will temper the intensity of the heat during the day by absorbing heat, and at night will radiate the stored heat into the room.
        - They're easy to do: Just mass and glass
          - Thermal mass materials shouldn't exceed 6" thick
          - Can't cover thermal mass floor with carpet, have to keep it as bare as possible

- Coupled (or directly sunlit mass) requires 3:1 mass:glass ratio
- Decoupled mass (sun travels through space to get to mass) requires 10:1 mass:glass ratio
- Quick Rules:
  - 1:1 mass:glass ratio
  - 1” of mass per hour of heat lag
  - 1’-4” air gap in the wall (bigger for vented system)
- Some common screw ups are:
  - Too much glass or not enough mass
  - Mass coupled to exterior in some way
  - Off orientation for south facing collection

- **Indirect Gain systems:** solar radiation strikes a thermal mass and is converted into heat and transferred into the occupied space
  - Thermal mass is located between the sun and living spaces
  - There are two overarching types of thermal storage walls: vented and unvented
    - Vented: uncontrolled, no combustible products inside, maintenance free, can take up to 12 hours for sun to produce enough heat for the system to work
    - Unvented: a little quicker, about 2% of the area must be vented to work
  - Thermal storage wall types:
    - **Mass Walls:** thick walls are placed in the sunlight, often behind a large window or glass skin. They store incoming solar energy without increasing the building temperature, and slowly release heat when it’s needed
    - **Trombe Walls:** like a mass wall but a convective loop is added by making a space between the mass and glass skin. A one way vent at the top lets warm air into the room and another one way vent at the base that lets the coldest air into the airspace.
    - **Water Wall:** a tank or collection of large vertical tubes are filled with water and put by a window, allowing some light to get into the space. Water stores about 5x as much heat per pound as concrete
    - **Indirect Gain Space:** usual structural and finish materials have high thermal mass and can absorb and store a great deal of heat without much fluctuation. The mass is in a shaded portion of the room and heated by reflected sunlight or by warm air in the room
    - **Sun Spaces/Rooms (the odd one out):** basically a thermal storage wall on steroids, it’s a thermally isolated from the rest of the house, and as the space heats up, vents between the two spaces are opened so solar heat can come in. It’s the most marketable, but not the most effective. Also, you can’t use it a greenhouse, you have to choose if you want to make heat or grow plants.
  - Roof Pond Types
    - **Roof Pond:** best used in low humidity climates (e.g.: the southern US) and for one story or upper stories of a building. 6” - 12” of water are contained on a flat roof in large plastic or fiberglass containers covered by glazing. Spaces below are warmed by radiant heat from the water above.
  - Night ventilation of thermal mass works best in climates with large diurnal swing in temp
- **Active Solar Heating (uses mechanical equipment):**
  - Equipment is used for heating and to collect and store solar energy
  - If the solar system can’t provide adequate heating, then a back up system helps provide the exert needed heat

        - Most common early design question is the size, tilt, and azimuth of solar collectors and the size of the thermal storages component
        - Liquid Based Systems
          - **Flat Plate Collectors:** comprised of a 4' x 8' insulated glass box with piping manifold connected to the black metal plate. Solar energy is collected by the flat plate and transfers heat to tubing that circulates water underneath, which continues on to an insulated water tank
          - Concentrating Collectors: use metal reflectors to concentrate the sun's ray on a tube or point. Panels collect much higher temperature than flat plate collectors. They're far more effect use of surface area, but more complex and expensive
          - **Evacuated Tube Collectors:** multiple evacuated glass tube each contain an absorber plate fused to a heat pipe. The heat from the hot end of the heat pipes is transferred to the transfer fluid (water or antifreeze ix) of a domestic hot water or hydronic space heating system. More efficient than flat plate collectors because the vacuums that surrounds the outside of the tube greatly reduce convection and conduction heat loss to the outside
        - Air Based Systems
          - Use solar collectors to trap air instead of water to absorb and transfer heat
          - Operate a lower efficiency than liquid collectors because air doesn't transfer heat as efficiently as water
      - **Passive Cooling Systems**
        - Uses sun collectors and storage a part of the building's walls, floors, and ceilings
        - When the outdoor temperature is 85˚ F or below, it's possible to cool buildings by simple ventilation
        - When the outdoor temperature is greater than 85˚ F, closing buildings to the exterior during warm hours works best
- Internal Solar Gains
  - Solar gains are mostly through windows and can "make or break" a building's thermal control and comfort.
  - Controlling solar gains is an art, but with knowledge of solar motion it's easy to do.
  - East, south, and west, in that order, matter throughout a day.
  - BTU/hr matters, but time of day matters more.
  - Sunlight, be it direct or not, comes into the building through window **glazing**, it's almost unavoidable
    - An unshaded southern window when compared to an unshaded northern window, receives about 50% more gains
    - A shaded south window will receive about 1/3 of the solar radiation of a window that is not shaded
    - When shading windows, external shading is more effective at reducing heat gain than internal coverings because it stops the solar rays from getting to the building. If they're only stopped by internal coverings, then they've already gotten inside to do some damage!
  - Glazing
    - A single pane of glass has a U-Value of 1.11 BTU/ft^2 - hr ºF
    - It decreases to 0.57 BTU/ft^2 hr ºF for a 1/4" air space
    - Inert gas filled space instead of vacuum is more faience at stopping heat transfer in double glazing
      - Argon Gas: Low Cost

- Krypton Gas: 200x the cost of argon
- Types of Glazing:
  - **Low-E Glazing:** double glazing with a thin film in the glazing cavity that allows visible and near infrared to be transmitted
    - In cold climates: apply to the inside pane of glass
    - In warm climates: apply to the outside pane of glass
    - As objects in the room are heated and emit long wave radiation, the film prevents the loss of this heat by reflecting it back into the room
    - When used with argon gas the system is very efficient
  - **Spectrally Selective Glazing:** coatings that help block solar heat gain from entering the building
    - Used with Low-E and double glazed systems can achieve a SHGC of .25
    - For buildings that have a long cooling season and require high light levels
  - **Super Windows:**
    - Two low-E coatings with gas filled cavities between three layers of glass
    - Units can actually gain more thermal energy than they loose over 24 hour period in the winter
  - **Electromagnetic:**
    - Multilayered thin film applied to glass that changes continuously from dark to clear as low voltage electrical current is applied
  - **Photochromic:**
    - Glazing that darkens under direct action of sunlight
    - As light intensity increases, window becomes darker
    - An automatic action...doesn't have user control like electromagnetic glazing
  - **Thermochromic:**
    - Changes darkness of glass in response to temperature
    - An automatic action
  - **Transition Metal Hydride Electrochromics:**
    - Changes from transparent to reflective
    - Coatings of nickel magnesium
- **Thermal Bridging**
  - A fundamental of heat transfer where a penetration of the insulation layer by a highly conductive or non-insulting material takes place in the Spartan between the interior and eater environments of the building enclosure
  - Occurs when materials that are poor thermal insulators come into contact allowing heat to flow through the path of least thermal resistance (the lowest R-Value), although nearby layers of material separated by airspace allow little heat transfer
  - Wrapping a building envelope with exterior rigid insulation cuts off thermal bridging

Concepts/Goals:

- The basic law of **thermodynamics** is that heat always flows from hot to cold. A heated gas, such as air, flows upward by convection; however heat will conduct and radiate in any direction, but always from hot to cold.
- Passive systems used to be the way to go, but once energy got cheap more active building systems became common. We did just fine without them before, so why should't we be able to go back to them now?
- Climate issues can be dealt with by addressing planning, orientation, building materials, plantings, and vegetative or constructed shading/exposure to sun.
  - **Heat Transmission**:

- In northern latitudes, heat transmission through walls is critical
- In southern latitudes, heat transmission through roof is critical
- **Wind**:
  - Design plazas at ground level, or open first floors, cautiously as they can be windy due to windbreaks (where part of the wind goes up and over and part goes down)
  - As wind passes through a gap I a wind break, it accelerates in the direction of lofw

Processes:

- Quick rules of Thermal Storage Walls
  - Mass : Glass ratio is 1:1
  - 1" of mass per hour of heat lag
  - 1" - 4" air gap in the wall, bigger if vented, be as close to 1" as possible
  - Unvented: no combustible products inside the space
  - Vented: about 1 - 2% of wall should be vent area
- ***(Reference MEEB Table 5.19)*** *Design Cooling Load Factors for Glazing*
  - Table gives an overall heat gain for windows of various orientation
  - Values are a "weighted average" of solar gains through a window over a day
  - In the cooling scenario, window heat gains are viewed as a bad thing.
  - The amount of sun to come through depends on orientation and geographical location
  - So to use the table:
    - First grab the city's 2% design temperature from MEEB Appendix Table A-1
    - Take the "BTU/(hr sq.ft.) value from the table 5.19
    - Multiply it by the sq.ft. of the window
    - Do that for every window in every orientation of the building
    - Find the heat gain
  - How you use the values:
    - Add up the solar heat gains for each window in your space
    - Add the value to the PLE value (PLE = People, Lights, Equipment)
    - Calculate the solar heat gains for the space with respect to orientation
    - The key is to use the table and to limit the bad and emphasize the good
  - *Example!*
    - *A west facing, dual pane, unshaded 3'-0" x 3'-0" window is in a 120 ft^2 space in your building. How much heat gain should be expected for the space if it's looking out over the beautiful wheat fields of Pullman, Washington?*
      - *Pullman design temperature is 85˚ - 90˚ from Appendix A1*
      - *Go to 90 on double glazing for west windows*
        - *70 BT/hr/ft^2 x 9 ft^2 = 630 BTU/hr comes screaming through the window*

Implications of Design Decisions

Vocabulary:

- **Life Cycle Cost:** represents the total cost of an item or system over its entire life cycle...it's the sum of first cost and all future costs.
- **Life Cycle Costing:** provides a tool for determining long-term costs for the total building
- **Life Cycle analysis:** an assessment of the environmental impacts of a product in each phase of its use, from raw material to disposal.
- **Carbon Footprint:** the total set of greenhouse gas emissions caused by a person, place, or thing.
- **Climate:** a region with particular prevailing weather conditions

Facts/Rules:

- Construction Implications
  - Building materials are evaluated on performance, aesthetics, and cost.
  - Handling and storing materials involves diverse operations such as hoisting tons of steel with a crane, driving a truck loaded with concrete blocks, manually carrying bags and material, and stacking drums, barrels, kegs, lumber, or loose bricks on the site.
  - The efficient handling and storing of materials is vital to industry. These operations provide a continuous flow of raw materials, parts, and assemblies through the workplace, and ensure that materials are available when needed.
  - Improper handling and storing of materials can cause costly injuries.
- Climatic Types and Implications
  - Cold:
    - Rare within the United States, only Alaska and north central plains (e.g.: Billings, Montana)
    - Most of the time it's too cold and outside of the comfort zone on the psychrometric chart, sometime it falls within it (e.g.: July and August)
    - The best solutions are buildings that minimize the exposed surface area
    - Try to enclose as much volume as possible within a minimum building envelope
    - Simple architectural forms are best:
      - Igloo: an ideal form given materials and climate
      - Cubical, two story building with big sloping roofs are typical
        - Farmhouses that include a barn under house on the ground floor and the living space on the upper floor, enclosing it all in a single skin
        - New England homes has very blocky houses with most of the glass on the South facade, storage rooms and the kitchen ended up on the North. A row of evergreen trees were planted in a row tot he north or narrowest to block prevailing winter winds
        - Classic salt shaker house with a two story south facade and a long sloping roof to the North resulting in a single solitary north facade. A chimney in the middle of the building or on the West end, and an entry vestibule that allowed people to enter/leave without loosing heat
  - Temperate:
    - Most of the United States
    - Winters are too cold and summers are too hot
    - Building shapes ten dot be a modified version of the cold climate building
    - Stretch enclosure to the East and west making the South facade longer to harness solar power
      - Porches or awnings on the South side to increase winter solar gain without increasing summer gains
      - Large deciduous tree on the South or west which provide shade in the summer and gains int he winter
      - Evergreens on the North to block any winds
  - Hot & Humid:
    - Southern United States like Houston, Texas
    - The most troublesome because its out of the comfort zone most of the time due to humidity

- Other climate strategies don't work here, the best strategy is to allow whatever circulation was present to dissipate heat as rapidly as possible (now there's air condition, which helps a lot)
- Architectural forms are a loose version of temperate climate buildings
  - Kitchens detach from the main building, exterior passageways, balconies, or breezeways
  - Walls are sometime omitted or reduced to thin privacy shields
  - Sometime elevated on poles to allow air flow underneath
  - Roof is in two separate layers or completely open at the gamble so that warm air rises up and out
  - Convection is used to suck fresh air through the building
  - Brush is cleared from window areas to allow for ventilation
  - Palm trees are used to create shade, but still allow for as much breeze as possible underneath

- Hot & Dry:
  - Southwest United States like Phoenix, Arizona
  - Large diurnal (day to night) temperature swings due to clear sky
  - Large radiation losses to the sky from buildings, and greater environment, at night
  - Large temperature swing gives major design opportunity because if either is within a comfort zone area, it can be captured and stored by the building
  - Take advantage of high thermal mass materials like adobe which stores heat from the day for the flowing nigh and stores coldness of the night for the following day
  - Architectural forms is the ultimate extension of the progression from tight cube to loose elements
    - Wraps around the outside environment and pulls it in
    - Atrium or courtyard houses contain a piece of the outside environment in tis center, which modifies by evaporating moisture into the shaded areas by use of fountains or plantings
    - Houses are open to courtyard so the cooled and humidified air enters the house
    - Only windows on the outer walls are small and occur high on the wall allowing the heated air from inside to escape, but forming a pool of cooler air that doesn't rise

Concepts/Goals:

- Compared to rural environments, a city receives 30% less UV radiation in the winter
- Life Cycle Costing:
  - Ties in with sustainable design, many construction products contain a proportion of recycled content. However by simple product substitution, projects can increase their recycled content significantly without increasing the cost of materials or risk.
  - There can be financial savings in some cases, especially when recycling construction and demolition materials locally. The environmental benefits include less demand on finite natural resources, diversion of waste from landfill, and stronger markets for the materials that contractors want to send for recycling.
  - Understand where products are coming from, and weigh transportation issues. Is it really necessary to specify something that must be trucked across country?
  - Given the many tools and resources available for evaluating and identifying materials, it is useful to develop an organized process for making product selections. There is no definitive process for selecting materials.

Processes:

- Design in context:
  - Use infill/brownfield sites: reduce development on pristine habitat or farmland
  - Locate projects near public transpiration, and in developed areas
  - Retain/restore waterways on or near the site
  - Use native or adapted plants that don't require maintenance and restore biodiversity
  - To preserve winter solar gain for a south facing building, maintain a protected zone clear of trees at least 2x the height, and 30 degrees away from nearby trees or shrubs
  - Plant trees to reduce heat island effect/offset carbon dioxide from building emissions
  - Use vegetated roofs to reduce amount of stormwater runoff, impervious surface area, and heat island effect. Also has a longer lifespan than a conventional membrane roofing system and lower overall maintenance cost
  - Use swales/storage basins to reduce storm water runoff
  - Avoid petroleum based fertilizers
  - Respect natural habitat/local species (be wary of noise, light pollution)
- Plan for the long term:
  - Maximize ecological, social, and economic value over time.
  - Build buildings to last (duh!)
  - Design for adaptability to accommodate future changes in program and use
  - Design for versatility to accommodate future changes in technology
  - Design for durability by using materials, construction methods and structural systems that will withstand weather, long term use, and catastrophic events.
- Design in correct Climate Zone:
  - **Cold:** orient buildings/openings for maximum protection from cold winds and use small windows/compact shapes to minimize heat loss. Use south facing windows to maximize solar gains.
    - Optimal Building Orientation = 12° E of South
  - **Temperate:** maximize solar gain in the winter, minimize in the summer. Maximize breezes in the summer, minimize in the winter. Take advantage of daylighting opportunities
    - Optimal Building Orientation = 17.5° E of South
  - **Hot & Humid:** minimize sun exposure, maximize natural ventilation. Use lightweight construction to minimize radiation of heat and space buildings far apart for breezes
    - Optimal Building Orientation = 5° E of South
  - **Hot & Dry:** minimize sun exposure and effects of wind. Use small windows. Optimize thermal mass for large temperature swing during the day, and closely cluster buildings for the shade the offer each other.
    - Optimal Building Orientation = 25° E of South

- Relative Importance of Design Principles in Various Climates (From Graphic Standards)

Energy Design Principle	Cold/ Cloudy (Chicago)	Cool/Sunny (Denver, Boston)	Warm/Dry (LA, Phoenix)	Hot/Humid (Houston, Miami)
Maximize winter solar heat gain by orienting the atrium to the south	Very Important	Somewhat Important	Discretionary Use	
For radiant heat storage and distribution, place interior masonry directly in the path of winter sun		Somewhat Important	Very Important	
To prevent excessive nighttime heat loss, consider an insulating system for the glazing	Very Important	Somewhat Important		
To recover heat, place a retune air duct high in the space, directly in the sun	Somewhat important	Very Important	Discretionary Use	
Minimize solar gain by providing shade from summer son		Somewhat Important	Somewhat Important	Very Important
Use the atrium as an air plenum in the mech. systems of a building	Somewhat important	Somewhat Important	Somewhat Important	Somewhat Important
Facility natural ventilation by creating a vertical chimney (stack) effect with high outlets and low inlets	Somewhat important	Somewhat Important	Somewhat Important	Very Important
Maximize daylight by using stepped sections (in predominately cloudy areas)	Somewhat important	Discretionary Use		
Maximize daylight by selecting skylight glazing for predominant sky condition (Clear and horizontal in predominately cloudy areas)	Somewhat important	Somewhat Important	Somewhat Important	Somewhat Important
Provide sun and glare control	Somewhat important	Somewhat Important	Very Important	Somewhat Important

Construction Details

Vocabulary:
- **MasterFormat**: a standard for organizing specifications and other written information for commercial and institutional building projects in the U.S. and Canada.
- **CSI: Construction Specifications Institute:** One of the master specifications available. These are prewritten texts that include the majority of requirements for a particular section.

Facts/Rules:

- The choice of materials for a project depends on the type and purpose of the system itself. (Eg: passive cooling system wouldn't be a good idea for a laboratory)
- Building Cores Include:
  - Vertical circulation: stairs, elevators, escalators
  - HVAC ducts: supply, return, outside air
  - Fire Life Safety: fire plumbing, smoke and fire dampers

Concepts/Goals:

- Three main things to think about when choosing materials (in order of importance):
  - Will they meet the performance requirements?
  - Will they be easy to process?
  - Do they have the right 'aesthetic' properties?
- The choice of materials for only aesthetic reasons is not that common, but it can be important: (e.g. for art)
- Most products need to satisfy performance targets, which are determine by considering the program and the site (e.g. they must be cheap, or stiff, or strong, or light, or all of the above)

Indoor Air Quality

Vocabulary:

- **Indoor Air Quality (IAQ):** the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants
- **Air Pollution Temperature Inversion Phenomenon:** air temperature at ground level is lower than higher elevations causing heavy, cold trapped air below to release pollutants
- **Carbon Dioxide:** a natural occurring chemical compound of two oxygen atoms bonded to a carbon atom produced by respiration, combustion, and fermentation. It acts as a greenhouse gas in our atmosphere.
- **Carbon Monoxide:** colorless, orderless, tasteless gas that is toxic to humans when found int high concentrations. Produced by gas power vehicles, industrial buildings using oil/gas, building heating using oil/gas, biomass burning.
- **Ventilation:** intentional fresh air (passive cooling and active cooling) necessary to assure healthy and odor free conditions
- **Infiltration:** accidental exterior air that enters a building (through cracks and openings in the building envelope) due to construction quality, wind pressure, and temperature difference

Facts/Rules:

- Indoor Air Quality involves pulling outdoor air in, but how it's done depends on the environment
- There's good and bad air balance
- What makes Indoor Air Quality bad?
  - Stuff in the air, it's not just a lack of oxygen
  - Pollutants: they're everywhere and everything from radon to perfume to hair gel
  - Pathways: where does the air go?
  - People: occupancy and activity (showering, or lack thereof)
  - Equipment: poor maintenance of the design

- What is poor Indoor Air Quality?
  - Insufficient or lousy outside air (eg: bad, polluted outside air in general, car exhaust being picked up by building air intakes)
  - Nuisance odors and irritants (eg: putting a block of smelly cheese on the building intake...ok, kind of unlikely, but locating dumpsters by an air intake happens)
  - Stagnant or stale air
  - Excessive pollution
  - Short term, heavy concentrated pollutants (eg: huffing/sniffing spay paint)
  - Long term, light concentration pollutants (eg: new materials off gassing, like paint, mastics, flooring)
- **The Seven Big and Nasty Culprits of Poor Indoor Air Quality**
  - Combustibles: carbon monoxide (odorless, tasteless)
  - Standing moisture: mold (green and black is deadly)
  - Warm moisture: legionella (standing warm water, found inside anything)
  - Volatile Organic Compounds (VOC): toxic gasses (pain, stain, adhesives)
  - Formaldehydes: toxic off gassing (sheetrock)
  - Particle board: toxic off gassing (furniture)
  - Poisons: toxic gasses, liquids, and solids (can be avoided by not brining into the building as cleaning products)
- Common problem areas:
  - Moisture: water that shows up everywhere, like in cooking, washing, showering
    - It stinks (literally) and causes respiratory discomfort
    - Should be exhausted directly at the source with venting or dehumidifiers
  - Carbon Monoxide: pretty much "burning things"
    - Smoking, wood burning
    - Causes respiratory discomfort, weakness, dizziness
    - Should be exhausted well
  - Hydrocarbons: found in smoking, BBQ
    - Becomes an issue with poor exhaust, smoking indoors
    - Causes nose/throat irritation, asthma attacks
  - Ozone: found in office or electrical equipment
    - Laser printers, monitors, warm wires
    - Causes congestion, shortness of breath
    - Should be exhausted at the source
  - Asbestos:
    - Check for it in all pre-1975 buildings
    - Commonly found in all steam pipes, floors, ceilings, tiles
    - Causes discomfort and congestion
    - Can be fatal, a cause of cancer
    - When you find it, don't touch it, call the experts
  - Others:
    - Cleaning/painting products, plastics, adhesives
    - Most things used in order to maintain a building
    - Causes burning eyes/throat, dizziness
    - Should avoid using them if possible, or bake-out of building before occupied
- Ventilation *(**Reference MEEB Table 6.4:** Air Replacement Compared to Input ACH)*
  - The larger the air flow or air changes per hour (ACH), the quicker you replace the air
  - 16 ACH = hospital size building
  - **1 ACH during 1 hour = 63.2% new air in a room**

Concepts/Goals:

- Indoor air quality can usually not be accomplished without mechanical assistance
- Per ASHRAE, acceptable indoor air quality is air in which there are no harmful concentrations of known contaminants and with which 80% of people exposed don't express dissatisfaction
- Poor Indoor Air Quality gets upgraded to Sick Building Syndrome when:
  - 10% of occupants are sick
  - 20% of occupants complain
  - Can be a quick or slow process
- Sick Building Syndrome is the #1 cause for litigation regarding buildings
- Mold growth requires moisture, a nutrient, and a temperature range of 40º-100ºF.
  - Since there's always nutrients (building materials like gypsum, fabric, batt insulation) and temperature will probably always be in the in 40-100º range, the only way to control mold growth is by controlling the moisture
- Always address the existing environmental hazard that might be present:
  - Vermiculite:
    - Natural occurring minerals composed of shiny flakes
    - When heated they expand to 8 - 30 times original size
    - Used for insulation in attics and walls, and is fire resistant
    - Sold in the United States between 1919 - 1990, most of it came from a mine in Montana which also had an asbestos deposit...so vermiculite was contaminated
  - Asbestos:
    - A mineral fiber that occurs in rock and soil
    - Found in insulation (with vermiculite), vinyl floor tile and backing, roofing, pipes, furnaces, etc.
    - Released in the air when disturbed (e.g.: during demolition)
    - Check for it in all pre 1975 buildings
  - Radon:
    - A colorless, odorless, tasteless gas that naturally occurs in soil and water
    - Lung Cancer is a concern for those who are exposed to high levels for a high period of time
    - Greatest exposure risk is in room that are below grade, or those that are directly in contact with the ground
    - The method to reduce radon primarily used is a vent pipe system, which pulls radon from beneath the house and vents it to the outside.
  - Polychlorinated Biphenyls (PCBs):
    - Manmade material ranging from thin light color liquid to yellow/black waxy solid
    - Manufactured between 1929 - 1979 (banned)
    - Found in electrical equipment, transformers, fluorescent light ballasts, caulking, plastics, oil based paint, adhesives
    - Don't readily breakdown and can spend long times cycling between air, water, soil

Processes:

- Good Indoor Air Quality starts with good design.
- But if it has to be fixed or improved:
  - Control the source of the pollutant (the best option)
  - Dedicate a pathway for it to get out of the building
  - Increase the ventilation rate (avoid it, as it tends to be a costly fix)
- Prevention is key, but if it's not possible, you have to isolate the source. That's it!

- Ways to prevent poor indoor air quality
  - Specify low-toxic products (a lot of problems go away right here)
  - "Bake out" by heating the building to 100˚F and releasing/repeat for two weeks
  - Have a good air distribution diagram
  - Give users control of their spaces, allow them to open windows and whatnot
  - Limit the pathway air has to travel through people (remember, people are a cause of pollutants too, down to their perfume or hair gel)
  - Make sure that air flows balance

Sustainable Design

Vocabulary:

- **Sustainability:** meeting the needs of the present generation without compromising the ability of future generations to meet their needs.
- **Ecosphere:** area of earth from surface to five miles deep
- **Biosphere:** area of earth from surface to five miles up into the troposphere
- **Troposphere:** the lowers portion of the earth's atmosphere, cotians 80% of atmosphere's mass and 88% of its water vapor and aerosols
- **Biophilia:** the connections that humans subconsciously seek with the rest of life.
- **Organic feedstock:** something organic (wood fiber, paper, cotton, etc.) that mold can use as an energy source. Mold cannot eat inorganic materials like concrete, brick, or gypsum (but it loves the paper on drywall!)

Facts/Rules:

- **The Natural Step**
  - A credo of environmental responsibility
  - Organized by scientist, designers, and environmentalists in 1996
  - Concerned with the preservation of the ecosphere and biosphere
  - Principles:
    - Elements from the earth (e.g.: fossil fuels, timber, ores) must not be extracted at a greater rate than they can be replenished
    - Manufactured materials can't be made faster than they can be integrated back into nature
    - People must protect and preserve other living organisms
    - Resources must be used fair and efficiently
    - Buildings consume about 40% of the world's energy, account for 1/3 of the world's emissions, and 2% of acid rain causing CO_2
- **Ahwahnee Principles**
  - Plan for sustainable development of cities and communities developed in 1991
  - Principles:
    - Communities should contain housing, shops, workplaces, schools, parks, and civic places...all of which people need in their daily lives
    - Size of a community should be such that everything one needs daily is within walking distance.
    - Locate as many activities as possible near transit stops
    - Diverse housing types should be provided for people of varying ages and incomes
    - Businesses should be of a wide variety
    - Location should be consistent with a larger transit network
    - A center focus should combine live/work/play uses

    - Have lots of open spaces that are easy to get to (e.g.: parks, squares)
    - Public spaces should be safe and active around the clock
    - Communities should have a well defined edge permanently protected from development
    - Paths of travel should be well connected
    - Natural terrain should be preserved wherever possible
    - Waste should be minimized
    - Water should be used efficiently through site and system design
    - Street/building orientation should make use of passive solar design
- **Leadership in Energy and Environmental Design (LEED)**
  - A rating system for the design, construction, and operation of high performance green buildings, homes, and neighborhoods.
  - Credits are given based on the potential environmental impacts on human beginners of each credit. Categories Include:
    - Sustainable Sites
    - Water Efficiency
    - Energy and Atmosphere
    - Materials and Resources
    - Indoor Environmental Quality
    - Innovation in Design (for performance above the requirements set by LEED)

Concepts/Goals:

- If a building is going to be sustainably designed, the site should probably be as well.
- The goal of sustainable design is to address design principles in a more environmentally conscious way than had typically been done before.

Processes:

- Sustainable Site Design:
  - Pick a Site: Close to public transportation, avoids floor plains and high slope/agriculture use areas, addresses solar orientation and wind patterns, and existing site conditions (e.g.: trees: water)
  - Address Conservation: restore wildlife areas and damaged ecology, they're good refuge for people too!
  - Manage Storm Water: encourage groundwater recharge, reduce impervious surfaces, avoid runoff, use swales and other on-site infiltration
  - Design Landscape: xeriscape, plant indigenous species, reduce heat island effect
  - Reduce Light Pollution: shine light downward and make sure it doesn't spread beyond the property line
  - Preserve Open Space: infill or redevelop existing sites, make buffers between the built and natural environments

Natural + Artificial Lighting

Vocabulary:

- **Daylight factor:** how much of the light on the area of a window comes through for the surface you're lighting.
- **Sun Chart:** a graph of the ecliptic of the sun through the sky throughout the year at a particular latitude. It is a plot of the azimuth vs altitude throughout the day for a period of time between the winter and summer solstices.

- **Solar Altitude:** The angle of the sun 90º or less above the horizon.
- **Solar Azimuth:** The angle from due north in a clockwise direction, given in degrees
- **Albedo:** ratio of the radiant flux reflected by a surface to the incident flux.
- **Light Pollution:** Brightening of the night sky that inhibits the observation of stars and planets, caused by street lights and other man-made sources.

Facts/Rules:

- Overcast skies are best for daylighting
- Anywhere on the Earth's surface, the greatest deviation between true and magnetic north is 50 degrees
- North facing glass is the best for daylighting
- Fixtures that use fluorescent or HID lamps get more illumination per watt than regular incandescent bulbs
- Daylight Control Methods:
  - Overhangs
  - Exterior or interior shading devices
  - Sawtooth skylights that face north
  - Light shelves that bounce light up onto the ceiling
- Basic angles of sun are broken into two parts:
  - **Altitude Angle:** the angle between the horizontal and the sun (ground up)
  - **Azimuth Angle:** the angle from due north in a clockwise direction (east/west)
    - Morning = positive
    - Evening = negative

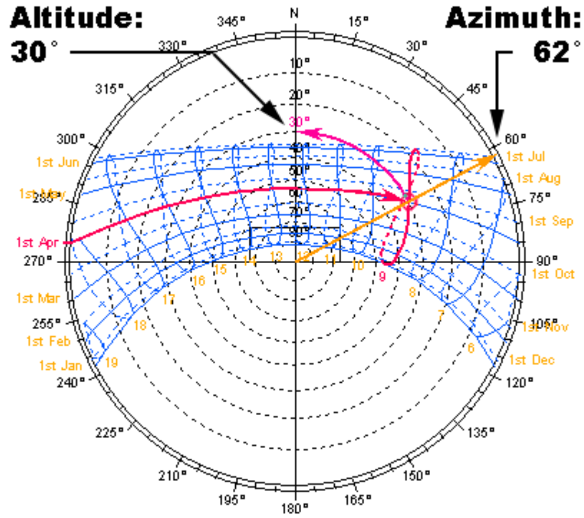
Concepts/Goals:

- People love daylighting, use it as much as possible
- People should recognize feelings of safety, friendliness, comfort, humanity, or other desired emotions, all of which are helped by lighting.
- There are no prescribed lighting design answer, it is based on the needs of the client

Processes:

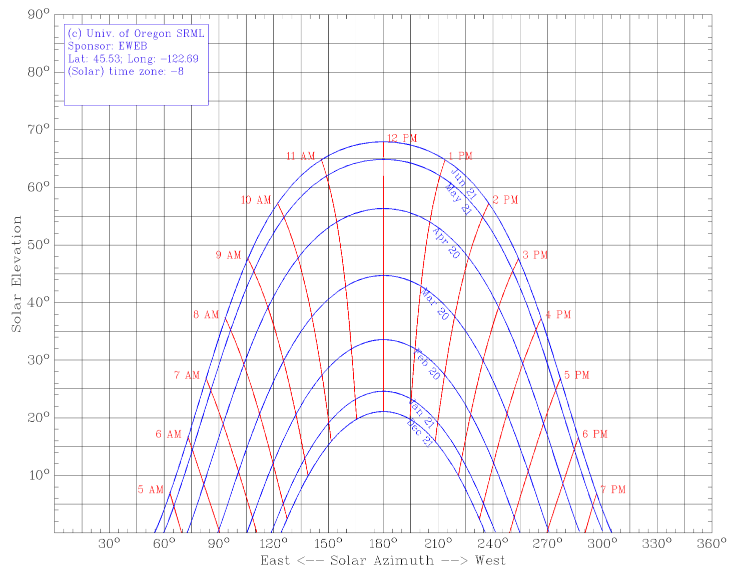
- To calculate daylighting:
  - Measure from bottom of floor to the top of the window (doesn't matter how big it is)
  - You can go 2.5x that length into the building for lighting penetration
  - Daylighting Factor max = .2 (window area/floor area)
min = .1 (window area/floor area)
  - Remember...it should be between 1% - 5%!
- **Conduct preliminary research:**
  - Visit client's existing abilities and analyze current lighting levels
  - Understand the degree of difficulty that the project presents. Are there any code compliance issues or variance requirements?
- **Advance plan analysis:**
  - Perform subjective analysis of client's staff/users of each location.
  - Perform objective analysis of building materials and measuring illuminance of the general, local and task areas.
  - Identify and describe specific stakes of sites visited that relate to the project needs
  - Establish a budget.
  - **Project Execution:** Oversee installation during construction and verify effectiveness in actual use.

- **Reading a stereographic sun-chart:**
  - Locate the required hour line on the diagram.
  - Locate the required date line (solid are for Jan-Jun and dotted lines for Jul-Dec)
  - Find the intersection point of the hour and date lines. (intersect solid with solid and dotted with dotted lines)
  - Draw a line from the center of the diagram, through the intersection point, to the end of the diagram.
  - Read the azimuth as an angle taken clockwise from North.
  - Trace a concentric circle around from the intersection point to the vertical North axis, on which is displayed the altitude angles.
  - Look between the concentric circle lines to find the altitude. This gives the position of the sun as an altitude and azimuth.



and read off the solar altitude from the values shown...

- **Reading a Cartesian sun chart:**
  - In cartesian co-ordinates, the azimuth is plotted along the horizontal axis and the altitude is plotted vertically. The date and time values are first located in exactly the same way as in the stereographic sun-chart diagram.
  - Locate the required hour line
  - Locate the required date line. In these diagrams, the highest altitude line at noon is always in midsummer. Each other line represents the 1st of each month, solid Jan-Jun, dotted Jul-Dec.
  - Find the intersection point of the hour and date lines.



  - The azimuth is given by reading off the horizontal axis.
  - The altitude is given by reading off the vertical axis.
- **Design:**
  - Schematic Design: lighting composition concept is developed and hierarchy through the project is set, with lighting to suit the space needs.
  - Design Development: make final equipment selection, and prepare a complete lighting quantification. Add supplementary lighting as needed.
- **Project Execution:**
  - Oversee installation during construction and verify effectiveness in actual use.

Alternative Energy Systems + New Technologies

Vocabulary:

- **ASHRAE/ANSI/IESNA Standard 90.1:** Energy Standard for Building Except Low Rise Residential Buildings
- **Building Commissioning:** process of ensuring that system are designed, installed, and functionally tested for effective operation/maintenance for an owner's operational needs.
- **Retrocomissioning:** systematic investigation process applied to existing buildings to improve an optimize operating/maintenance.

Facts/Rules:

- Groundwater Aquifer Cooling and Heating
  - Differential thermal energy in water from an underground well cools a building during summer and heats it during winter
- Geothermal Systems:
  - Collect via a heat pump system
  - Can supplement a building's heating demand
- Wind Turbines
  - Can be mounted on to buildings or run out in large open areas
  - Cost effective, established, and gets a high output
  - But...needs a lot of structure, space, and can be a visual eyesore
- BioGas:
  - Waste and discarded crops are converted into a gas that can fuel a gas turbine
  - High production, used for heat or power, no emissions, and reduces landfill burden
- PV Systems
  - Solar panels are mounted to roof or shading devices and collect solar energy
  - Not really that cost effective, it's an expensive system
- Hydropower
  - Small scale is a newer concept, can be used for local or individual power collection

Concepts/Goals:

- Green building combines the best of traditional design with updated construction technology while addressing environmental and energy crises
- Before the Industrial Revolution, environmental problems were caused mostly by concentrated amounts of compounds that occurred naturally and over time. Today the environment isn't alway able to adapt to man made materials and waste products.
- Green technology follows green design (reduce need for building systems with passive design, then address the rest with systems like photovoltaics, wind power, low wattage)
- **ASHRAE/ANSI/IESNA Standard 90.1**
  - A standard that provides minimum requirement for energy efficient designs for buildings (except for 3 story or less residential or single family residential)
  - Scope is for all new buildings and their systems, new portions of buildings and their system, and new systems in existing buildings
  - It's the worlds most adopted budding energy code
  - Applies to buildings, the building envelope, HVAC, service water heating, power and lighting, and other stuff like systems that are part of the industrial/manufacturing process (e.g.: server farms)
  - Compliance is required for LEED Certification, federal facilities, and saves energy

Processes:

- Create Healthy Indoor Environments:
  - Ample daylight and proper ventilation lead to greater satisfaction, more comfort, and increased productivity.
  - Supply fresh outdoor air, use passive ventilation or "Mixed-mode" systems in larger buildings that supply a mix of fresh/mechanical air.
  - Offer natural light and views to the outdoors with windows, skylights, light shelves, and the use of light colors
  - Control temperature and humidity with passive and mechanical technologies that are individually controlled by occupants.
  - Prevent moisture build up.
- Conserve Water
  - Reduce potable water use in irrigation and fixtures by using drip-irrigation or low-flow/ graywater appliances
  - Use local vegetation that requires minimal or no irrigation
  - Catch rainwater for flushing fixtures, irrigation
  - Treat blackwater through an on site living machine so it can be reused
  - Use few impervious surfaces
- Use environmentally preferable building materials
  - Build to the size that is needed and no larger
  - Use materials/systems engineered for maximum efficiency
  - Use durable materials that last longer and with fewer maintenance resources
  - Avoid irreplaceable/engaged resources
  - Use renewable/well managed resources
  - Use recycled/recyclable resources and avoid anything that's toxic
  - Avoid materials that generate pollution during manufacturing, building, use, disposal
  - Use materials with low embodied energy (how much fossil fuel did it take to make?)
  - Use materials the help conserve energy (thermal mass for energy, light reflective surfaces, radiant barriers, insulation)
- Make changes based on wisdom and user feedback
  - Post occupancy surveys
  - Install equipment to monitor building performance
  - Design smaller/simpler buildings with accessible systems and short feedback loops
  - Develop a common language of building metrics understood by designers and users (e.g. This building gets xx miles per gallon)
  - Develop and share case studies. Don't hog work, ideas, and findings!!

Adaptive Reuse of Building and/or Materials

Vocabulary:

- **Embodied Energy:** the sum of all energy required to extract, process, deliver, and install materials needed to construct a building.
- **Mothballing:** term used in historic preservation when you designate certain areas to be repaired or restored at a later date, under a later contract.
- **Adaptive Reuse:** process of adapting old structures for purposes other than those initially intended while retaining their historic features.
- **Preservation:** the act or process of applying measures necessary to sustain the existing form, integrity and materials of an historic property.

Facts/Rules:

- Historic Preservation:
  - 4 treatments applied to historic structures (most historically accurate to least):
    - **Preservation**: least amount of work done to the building and any interventions are as inconspicuous as possible
    - **Rehabilitation:** retain and repair historic materials, but some replacement of damaged material is ok, as are additions that convey historic values
    - **Restoration:** remove inconsistent features and replace missing features in accordance with the restoration period
    - **Reconstruction:** new construction to look like how something existed at earlier time
- Secretary of Interior's Standards for Rehabilitation:
  - Allow for new additions/alterations to be different from the older structure, but must be complementary in massing, size, scale, and architectural features
  - Criteria must be met if Federal Tax Credits will be used
  - Takes precedence over state/local regulations
  - Clients may discover historical significance during site analysis. Archaeological activity and proper handling of structures/artifacts must take place.

Concepts/Goals:

- Embodied energy in existing buildings
  - Benefits of reusing historic/existing buildings are considered based on economic, cultural, design, and embodied energy merits.
  - Previously hans't been addressed much in preservation
  - Almost all US embodied energy applications are based on *Energy Use for Building Construction* report written in 1967.
    - Must be careful when using this information when comparing historic building to a new one, because construction systems for building types has changed.
      - Equipment installed in the last 25 years is more efficient in physical make-up and in operation
    - Embodied energy allocation in a building:

Manufacture of basic materials and components	=	50%
Mechanical/Plumbing/Electrical and misc materials	=	20%
Direct fuel purchases	=	15%
Administration (retail trade/misc business services)	=	11%
Transportation of materials	=	2.5%
Furnishing	=	1%
Construction machinery/equipment	=	0.5%

  - Three different methodologies for measuring the embodied energy in historic buildings were developed in *Assessing the Energy Conservation Benefits of Historic Preservation*
    - Concept Model: a planning approach where various building types are given embodied energy values based on the square footage. Gives a rough estimate.
    - Inventory Model: uses an accurate accounting of the material used in construction. Is more accurate than the concept model.
    - Survey Model: assumes that most of the embodied energy in a building is contained in the bulk of the architectural materials.

- Evaluating the benefits of renovation over new construction also raises the question of calculating how much energy is in building demolition.
- Dismantling a building for salvage recaptures embodied energy.
- Relative value of embodied energy vs operating energy should be more fully investigated for historic structures
- History building are more likely to be at higher end of the ratio between total embodied energy to annual operating energy because of their use of durable, bulky materials and large volumes.

Processes:

- Define factors affecting the scope of historic preservation including the nature of the effort (will it be preservation, rehab, restoration, or reconstruction?), the applicable regulations, significance of the property, and condition of the structure
- Team with structural/MEP engineers who have historic preservation experience
- Complete Preliminary Analysis/Predesign and Research:
  - Documenting existing conditions, programing the intended function/use of the building and site, doing research to investigate historic nature of project/area, determining which parts of the buildings are original and sequence of construction
  - Complete preliminary cost estimate of work to be done, and prepare applications for federal grants.
- Complete Design Phase:
  - Coordinate with standard steps of the building design process
  - Coordinate preservation with architecture/engineering development
  - Coordinate with specification/front end
- Complete Document Phase:
  - Coordinate with drawings, specs, final cost estimate
  - Coordinate with bidding/negotiation phase
  - Coordinate with construction administration, observation, and documentation
  - Reports for maintenance, determination of historic eligibility for review boards may be required

CONTENT AREA: PLUMBING

Building Design

Vocabulary:

- **Static Head:** the pressure required to overcome friction and push water vertically, or the pressure caused at the bottom of a column of water. Measured in inches of water
- **Total Pressure:** pressure measured by a pilot tube, consisting of static pressure and velocity pressure.
- **Pilot Tube:** instrument used with a manometer or pressure gauge to measure the velocity of air or water in a duct or pipe
- **Potable:** suitable for drinking
- **Non-potable:** used for irrigation, flushing toilets
- **Soil:** sanitary term for waste from urinals, toilets, and fixtures of a similar nature
- **Supply Systems:** clean, clear and potable water systems under pressure
- **Sanitary Waste Systems:** remove contaminated water by relying on gravity for drainage
- **Storm Drains:** drained by gravity and require large pipes
- **pH:** measure of the acidity or basicity of a solution on a scale of 1 - 14, where 7 is neutral, less is acidic, and more is alkaline
- **Hard Water:** water that contains mineral deposits that can clog up piping, cause mineral build up in heat exchangers, and place a toll on hydronic systems
- **Zeolite:** ion exchange or water softening method in which hard water passes through zeolite minerals then salt tank so that minerals in hard water don't solidify
- **Turbidity:** caused by suspended material in water like silt, clay, organic material
- **Effluent:** liquid waste
- **Brackish:** water that contains so much salt it's nonpotable
- **Backwash:** reverse flow of water, often used in water softening to remove sediment
- **Cross Connection:** any connection by means of which nonpotable use or contaminated water or other liquid can enter any part of a potable water system

Equations: (those in gold are given on ncarb formula sheet)

1 PSI	=	2.31 feet of water -or- 6.895 kPa
1 ft^3	=	7.5 gallons
Lift	=	(total feet of height) / (2.31 psi/ft)
Max Fixture Height	=	(PSI) x (2.31 ft/psi)
Supply Water Pressure	=	pressure at end of fixture + pressure loss

Units for water are gallons per person

Facts/Rules:

- 1 PSI will raise a column of water 2.31 feet
- Water can't be sucked up at a height greater than 33 feet because that is the static head equivalent of atmospheric pressure at 14.7 psi
- Total pressure of nonmoving water = static pressure
- Water either comes from the surface or ground:
  - Surface water: from rain and snow that runs off into rivers and/or lakes
  - Ground water (aquifers): subsurface water that has seeped into the ground until it hits impervious rock and forms a water table at that level

- Water conditions:
  - Acidic: measured by the pH, 7 is neutral, anything lower is more acidic, anything higher is more alkaline
  - Hardness: limestone and/or calcium and/or magnesium is dissolved in ground water, and then later redeposits in plumbing systems and pipes. It's not bad for people, just pipes as it clogs the flow.
  - Water Softening: using a zeolite or ion exchange process, water is regenerated with brine salts.
  - Carcinogens: insecticides, DDT, PCB's, and asbestos fibers that get into ground water
  - Disease: bacteria or viruses from human/animal waste or other decaying organic materials breed in water
    - Chlorine may be added to water to kill bacteria at 0.5 parts per million
    - Fluoride may be added to improve resistance to tooth decay
  - Color/Odor: caused by organic matter, inorganic salt, or dissolved gasses. Can be corrected through filtration and chlorination
  - Turbidity: suspended materials in the water like silt or dirt. Not really hazardous, but is usually treated by filtration
- Water Collection:
  - Private Wells/Springs/Collected Rainwater
    - Wells are drilled or bored and fit with a cast pipe to keep it from caving in, they're usually perforated to allow water to seep into the well
    - Wells can be 25' to 100'+, depending on where the water is coming from
    - Water Yield: 5 gpm to 10 gpm minimum for residential locations
  - Well Pumps
    - Centrifugal: a wheel like impeller, rotated by a vertical shaft aligned with the supply and discharge, and the motor can be above or below ground
    - Reciprocating: cylinder and piston with valves (like a car engine or compressor)
    - Rotary Pump: spiral rotor on a shaft with a rubber sleeve perpendicular to supply/discharge. As the rotator turns it sucks water and discharges at the other end
    - Ejector: uses a venturi and a water jet sent from the surface to impel water to rise.
    - Suction Pumps: for wells under 25'
    - Deep Well Jet Pumps: 25' - 100'+
    - Turbine Pumps: for deep wells with high capacity
    - Subversive Pumps: for small residential, a pump below the water line pumps water to a pressure tank
  - Cisterns: rain water storage tanks that are usually connected to the roof runoff
    - Used for irrigation/gray water use
    - Issues to mitigate are: acid rain, lead, dust, pollutants, animal waste
  - Municipal Water Systems
    - Water is obtained from rivers, lakes, etc and treated
    - Treated water is pumped through water mains at 50 psi
    - Distribution to individual properties
    - Property owners may be required to extend lines from property if the main is not adjacent to the property line
- Water Supplies:
  - Service controls, or valves, are installed at the edge of the property (curb valve) and inside the building at the service entrance.

- **Reduce Pressure Backflow Preventer**: used to protect the potable water supply from contaminated water by stopping return water from the building from flowing back into the public water supply.
- **Pressure Regulator:**
  - A valve that automatically cuts off the flow of a liquid or gas at a certain pressure
  - Function is to match the flow through the regulator to the demand placed on the system (That is: if the load flow decreases, the regulator flow must decrease too.)
  - Typically a globe, butterfly, poppet valve, or one that can vary the operation of flow.
  - When pressures exceed 80 psi, a regulator should be installed as high pressure cases wear on valve seats and washers.
- **Hydropneumatic System**: water supply system that uses a pressurized tank that's typically in the basement to supply water under pressure to floors above.
- **Upfeed System:** pressure from the water main is used to pump directly to the fixtures.
  - Enough lift must be provided to reach the top story
  - Due to friction, the building height limit is about 40' - 60'
- **Downfeed System:** used when a building is too tall for an upfeed system
  - Tank mounted on a roof supplies water to upper stories
  - Water is supplied from the main boosted by a pump in the basement of the building
  - Pressure is determined by the heigh to the tank above a given floor and not by the pump
  - Height of the zone being served is determined by the allowable pressure on the fixture at the bottom of the zone, allowing for friction loss.
  - Pressure is usually 45 - 60 psi with a zone max heigh of about 138' (then pressure regulator valves are required)
  - Big disadvantage is the added weight of the system on the roof, which requires a more expensive structure.
- Choosing a system depends on the height of the building and how much pressure is required to operate all of the fixtures

- Water Pressure
  - Pneumatic Tank: pressurized tank in the basement supplies water to higher levels by using compressed air to push water up.
    - System takes up space in the basement and air may be dissolved in the water
  - Tankless: multiple variable speed pumps provide water pressure at whatever demand rate the building requires (typically controlled by sensors)
    - Doesn't take up space, but pumps can have a short life cycle.
  - Friction must be accounted for, it tends to slow water down, so the psi must be greater than needed to accommodate it
  - Pressure lost depends on the size of the pipe and the glow in gallons per minute
  - Smaller diameter pipes have greater friction that slows down the pressure
- Equivalent Length of Pipe
  - Factor used to calculate pressure loss in a system
  - The actual length of a pipe plus some extra to compensate for pressure lost

Processes:

- Hard water can be treated via an ion exchange process with a water softener

Implications of Design Decisions

Facts/Rules:

- Different fixtures require different amounts of pressure and water to function.
- Plumbing systems must be sized to accommodate peak usage of fixture types
- Many fixture types have become more efficient in the past few years, saving on water costs to the user
- The designer must weight the option of higher initial costs for more efficient fixtures vs. that of lower initial cost for less efficient fixtures (and higher water bills)
- A conventional water closet historically used 3.5 gallons or more per flush, while a water saver water closet uses between 1.7 - 3.5 gallons per flush
- Typical fixture rates **(reference MEEB Table 10.14)**:

Fixture	Required PSI	Average Water Use
Toilet	25 psi	3-5 gallons per flush
Shower	12 psi	3 gallons per minute
Bathtub Faucet	5 psi	4 gallons per minute
Hand Washing	8 psi	2.5 gallons per minute
Washing Machine	8 psi	4 gallons per minute / 40 gallons per load
Dishwasher	8 psi	4 gallons per minute / 15 gallons per load

Concepts/Goals:

- Economically speaking, water is usually paid for twice: once to actually buy it for consumption, and a second time in wastewater/sewer fees. So it's best to use it wisely.
- Water consumption relates to energy use, as less water in the waste water system reduces the energy required by treatment plants to treat and supply the water
- Low flow fixtures and appliances save water and money
- Often requires an investment, but most pay back in less than a year
- Many utilities offer incentives to install low flow fixtures

Building Systems + their Integration

Vocabulary:

- **Surface Runoff:** water flow that occurs when soil is infiltrated to full capacity
- **Water Infiltration:** process in which water on the ground surface enters the soil
- **Catch Basin:** a reservoir in which debris and sediment from runoff may settle before it enters the storm drain
- **Culvert:** drain or channel that permits the passage of water below ground. Typically a large diameter concrete or metal pipe often used under a road
- **Storm Drain:** underground conduit used to carry rainwater from a catch basin to a body of water
- **Drywell:** and underground structure, above the water table, that disposes of unwanted water by dissipating it into the ground

- **Drain tile:** perforated pipe surrounded by granular fill used to release hydrostatic pressure from foundation of retaining walls.
- **Sanitary Drainage:** any drainage that might include human waste
- **Grey Water:** water from sinks, dishwashers, lavatories, washing machines, that doesn't contain human waste
- **Black Water:** water from toilets, includes human waste
- **Trap:** keeps methane gas from entering a building while also catching grease and small jewelry or contacts before going down the sanitary system.
- **Cleanout:** a plug that can be removed in a sewer line to clean out any clogs.
- **Interceptor:** catch grease, hair, oil rags, money, etc. that gets into a plumbing system
- **Air Gaps:** a safety feature, faucets are mounted 2" minimum above the highest possible level of wastewater to prevent any contaminated water being siphoned back in
- **Vent:** pipes connected to the drainage system and vented to outside air
- **Circulator:** a pump used in hot water systems for maintaining force circulation of water or other liquid
- **Water Heater:** tank where water is kept continuously hot and ready for use, always pressurized and rated in terms of volume and recharge time
- **Anode:** a piece of metal placed in a water tank to attract mineral deposits so they don't form on tank or equipment
- **Recharge Time:** length of time the tank takes to reheat itself after it has emptied out of hot water
- **Distillation:** as water turns to vapor pollutants are left behind. Vapor is captured and as it condenses, the water is collected for use.
- **Lateral:** common sewer that receives wastewater only from building sewers.

Facts/Rules:

- Stormwater System:
  - Three basic storm water quality control strategies:
    - Infiltrate runoff into the soil
    - Retain/detain runoff for later release
    - Convey runoff slowly through vegetation
  - System must drain by gravity and requires larger pipes
  - Routing storm water inside a building can be a problem because of sweaty pipes
- Hot Water System:
  - Water in pipes cools, so unless warm water is constantly flowing through them, cold water will run until hot water gets to the fixture
  - Types:
    - Single Supply Pipe: used in residential and small buildings
      - Provided from the heater to the fixtures
      - Minimizes piping costs
      - Can result in longer wait times for hot water
    - 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 waster rises to highest fixtures and falls after cooling to be heated again.
    - Peak hourly demand is important because certain hours might require more hot water than others (e.g.: showers in the morning)

- Water Heaters
  - Designed to keep water at any desired temperature, typically the highest point of use during the day
  - When sizing hot water systems for commercial and institutional buildings it is important to consider the trade off between recovery time and storage capacity
  - Hot water heater size is based on the total daily and peak hour hot water demand in a building.
    - Can range from 0.4 gal per person peak in an office to 12 gal per unit in a small apartment building
  - Storage Water Heaters (Tank):
    - Fueled by natural gas, propane, oil, electricity
    - Less conventional system are heat pump or solar water heater
    - Most common water heating type in the US
    - Residential tanks typically 40 - 60 gallons at 50-100 psi
    - Residential tanks typically 120 - 180ºF
  - Tankless Water Heaters:
    - Water is quickly heated and sent to where it's needed, as it's needed
    - Uses variable speed pumps that run at varying rates
    - Saves space, but pumps wear out faster
  - Circulating Water Heater:
    - Water is heated in one spot and stored in another until it's needed
  - Instantaneous (Inflow) Heater:
    - Water is supplied to each fixture and heated when the water faucet is turned on.
    - More efficient, but more upfront cost to install
- Solar Water Heating:
  - Direct (Open Loop): water that's used in the building is also the water that's heated in the solar collectors. It's simple and efficient, but subject to freezing.
  - Indirect (Closed Loop): a separate fluid (often with antifreeze in it) collects heat which is then transferred to a domestic hot water system via a heat exchanger, which lowers the efficiency somewhat
  - Heating Fluid Methods:
    - Passive circulation that relies on gravity and thermosphoning of heated water. It's a simple, low cost method, but must be placed close to solar collectors and to points of use
    - Active Circulation: pumps are used to circulate heat collecting fluid. Costs more, but is more reliable and flexible too.
  - Solar Heating System:
    - **Batch:** water is heated directly in a black painted tank inside a glazed box, it's simple but subject to freezing and nighttime heat loss
    - **Thermosiphon:** relies on natural movement of hot water to circulate in a passive, open loop system, storage tanks located above collectors
    - **Drain-Down:** open loop system that drains water from the collectors when the outside temperature is freezing, the water is wasted though, so best in mild climates that don't freeze much
    - **Drain-Back:** Indirect system where water collects heat and pumped into a heat exchanger where a coil of domestic hot water is heated, at low temps the pump is turned off and water is drained back to solar storage tank
    - **Phase Change System:** collector fluid is phase change materials

- Point of Use Temperatures

Therapeutic Bath	=	95° F
Hand Washing	=	105° F
Showers and Baths	=	110° F
Residential Dish Washing	=	140° F
Commercial Dish Washing/ Commercial Laundries	=	180° F

Note: Water above 110ºF becomes uncomfortable to touch!

- Draining/Venting Systems:
  - Goal is to safely carry away sewage to a disposal system (either on site or municipal)
  - Removal of solid water and waste is done without air pressure and by avoiding odors and siphonage
  - Drainage slopes are 1/4" per foot for typical effluent waste lines,
  - Drains are 45° for waste lines that are gravity only
  - **Traps** are located at every fixture and hold some water that makes a seal used to prevent gasses from the sewage system from entering the building
    - Installed within 2 ft of fixture
    - **Vacuum Breaker:** a device used in some fixtures to accomplish the same thing as a trap. The attachment is placed on a hose connection valve or toilet/urinal valve that prevents water from being sucked backward into public water system
  - **Vents** allow built up sewage gases to escape instead of bubbling through water in traps and allow pressure in the system to equalize so water doesn't drain out of the traps
    - **Stack Vent:** portion of a stack above vents that connect to a soil/waste stack above the highest fixture in the system, vents to the soil stack,
    - **Vent Stack:** a separate pipe used for venting in multistory buildings that extends through the roof or connects with the stack vent above the highest fixture, air intake line for all fixtures that is separately open to the outside air at the top, used to break the siphoning suction which would occur when water passes down through the system
    - **Soil Stack:** large pipe into which all the soil and waste lines from one or more levels empty, open to the outside air at the top
    - **Waste Stack:** carries waste other than human waste and is open at the top
    - Minimum diameter of a vent is 1 1/4" or half of the diameter of the drain it services, whichever Is larger.
    - Stacks connect at the horizontal drain at the bottom of the building
  - Maintenance:
    - Cleanouts are provided at intersections to allow for maintenance of the drain
      - Every 50'-0" in pipes less than 4" in diameter,
      - Every 100' in larger pipes
      - Every corner where pipe changes direction more than 45 degrees.
    - Manholes are cleanouts for larger lines, and occur at every 150' or where required
      - 10" diameter or greater
    - Floor drains collect water where overflow is likely, or in showers
    - Backflow Preventers: 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. Sewage is collected and pumped to a higher level to flow by gravity into the sewer.
- On Site Waste Disposal Systems:
  - A small scale sewage treatment system that is not connected to a municipal line
  - Found in rural areas, suburbs, or older neighborhoods. Options are:
    - Septic Tank
      - An underground tank where sewage collects. Solid material sits and liquid waters passes on to a leach field which is a grid of ceramic pipe laid underground that allows liquid to pass out over a bed of gravel and into the soil.
      - Sized for 100 gallons/day per person with a minimum capacity of 500 gallons.
    - Leach Field:
      - Grid of ceramic pipe laid underground, with the intersection not quite touching, so that liquid leaks out over a bed of gravel which filters the waste before it seeps into the soil.
    - Cesspools (Seepage Pit):
      - Cheapest system, but the least desirable, too.
      - Most places don't allow them
      - They're an underground, porous chamber where sewage soaks into the surrounding ground until it gets clogged.
      - Then it's capped and a new cesspool is dug.
    - Aerobic Treatment System:
      - Like a septic tank system, but uses an aerobic process for digestion rather than just anaerobic process used in septic.
      - Produces a high quality second effluent which can be sterilized and used for surface irrigation
      - More flexibility for location of leach field, as well as its size
    - Mound:
      - Built up drainage field above existing grade
      - Used when there's a high water table or a lack of permeable soil
    - Sand Filter:
      - Effluent flows or is pumped from a septic tank to an open air filter treatment pit, at or above grade
- Storm Drainage:
  - Swales: V-shaped sloping channels in the grass that take the surface runoff to points where it can be collected and/or disposed of
  - Catch Basins: like manholes, but they have a top grate instead of a cover. Placed at the lowest point of the swale, or depression to collect runoff and pass it into the storm drain system
  - Retention Ponds: an artificial lake with vegetation around the perimeter, designed to contain the max expected runoff and then slowly release the water to the storm sewer system
  - Detention Pond: temporarily stores water after a storm but eventually empties out to a downstream water body
  - Infiltration Pond: like a retention pond except stormwater is directed to groundwater through permeable soils.
  - Downspouts/Gutters: size is determined based on the are of the roof and the maximum hourly rainfall. Gutter slope ranges from 1/16" per ft to 1/2" per foot.

Processes:

- Conventional drainage systems are designed to control flooding during large, infrequent storms. They must cost-effectively manage flooding, control stream bank erosion, and protect water quality.
- Site Drainage/Stormwater Management Design:
  - Slope basin at 4:1 or flatter to prevent bank erosion and minimize risk of drowning
  - Design basins so that large particles settle in depressions and so inflows don't erode.
  - Plan for maintenance to remove trash, debris, and sedimentation that collects
  - Low flow channels control dry-weather flows and the last of captured volume to the basin outlet.
  - Plant vegetation to control erosion and enhance sediment entrapment
  - Access for maintenance must be included.
  - Incorporate flood control, recreational facilities, landscape, and wildlife habitat
  - Integrate basins into swales to take advantage of aesthetic qualities of water and plants

Construction Details and Constructability

Vocabulary:

- **Thrust blocking:** prevents pipe movement when the system is pressurized. Typically required at all places where pipe changes direction
- **Critical Distance:** max length of drain pipe between a trap and air vent, must be ≤ 48x pipe diameter
- **Fixture Units (FU):** used to define the probability demands on plumbing fixtures. 1 FU = 1 cubic ft / minutes
- **Frost Line:** the maximum depth of frost penetration int he ground in a given area. Water piping must be buried below so pipes don't freeze
- **Sweating:** method of soldering copper plumbing, or the condensation of water on cold pipes and building materials
- **Union:** a pipe fitting used to couple the ends of two pipes, neither of which can be rotated
- **Siphon:** U-shaped tube used to transfer liquid from an upper level to a lower one by suction
- **Water Hammer:** the noise caused by sudden pressure increase in a pipe when a valve or faucet is closed
- **Expansion/Bend Loop:** an extra set of curves in a pipe run that can contract or expand to accommodate thermal movement
- **Hartford Loop (Underwriter's Loop):** plumbing arrangement on steam boilers to avoid rapid loss of water in the boiler due to a break in the condensate return line.
- **Invert:** lowest point of the inside of a drain, pipe, channel, or other liquid carrying conduit
- **Nipple:** short piece of pipe with threads at each end used to connect fittings and valves
- **Bell:** end of a pipe which is enlarged to receive the end of another pipe to form a joint
- **Continuous Vent:** a vent which is a continuation of the trap and drain to which it connects.
- **Leader (Downspout):** vertical pipe used to conduct water from a roof drain or gutter to the ground
- **Circuit Vent:** any vent which serves two or more traps in sanitary drainage system

- **Loop Vent:** a vent which connects from a drain to the stack vent of the soil stack to which the drain is connected
- **Vacuum Breaker:** automatic valve which admits air into a supply pipe to prevent siphoning polluted water back into the supply

Equations:

Street Main Pressure = Minimum fixture flow rate + pressure lost due to height + pressure lost by friction in piping + pressure lost by flow through meter

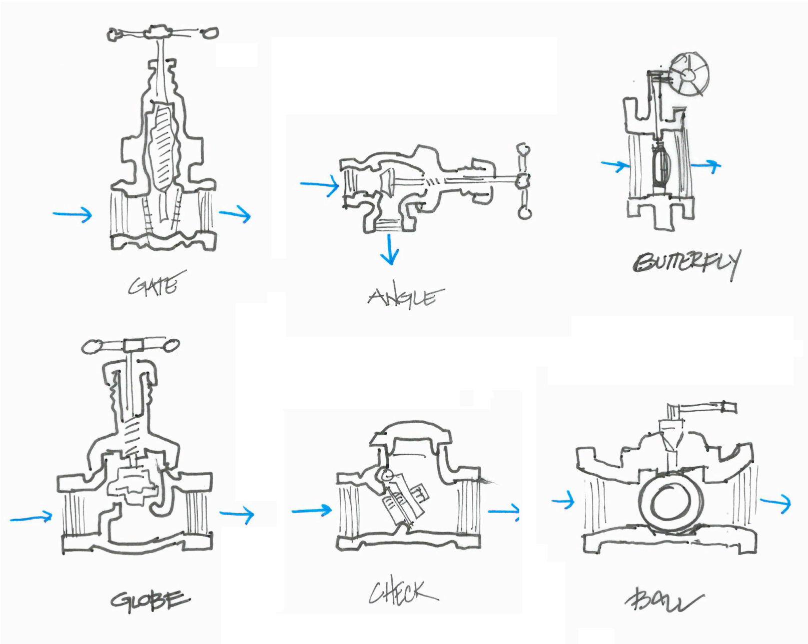
Thermal Expansion (L) = ((Length) x (Coefficient of Expansion, k)) x (Final Temperature - Original Temperature)

Fixture Unit (FU) = 1 unit flow rate of 1 ft^3/minute

Facts/Rules:

- Typical Plumbing System Components:
  - Curb Box:
    - A vertical cast iron pipe extending from the curb or sidewalk level down to the shutoff at the water main connection
    - Typically used by the a municipality to turn the water service on/off to a building
    - Accessed by a special wrench
  - Corporation Stop:
    - Controls the water (or gas) from a public main to an individual customer, located where the service lateral taps into the main
    - Typically not accessible without digging up the street
  - Piping:
    - All hot water pipes should be insulated
    - Cast iron: most commonly used for sanitary lines
    - Sometime ceramic pipe is used for lines outside the building
    - Copper: most commonly used for supply piping because it's resistant to corrosion, high strength, low friction loss, and small outside diameter
      - **Grades of Copper Pipe:**
        - K: thickest wall, comes in straight lengths, coils, and used for underground supply when greatest strength is required
        - L: thinner walls and comes in straight lengths or coils, commonly used for most interior plumbing (most common)
        - M: thinnest, and available in straight length only. Used where there's low pressure, like branch supply, chilled water, and drainage.
        - DWV: drainage, waste, and vent piping that is not subject to pressure (rarely used)
      - Joined by soldering and sweating, flux is heated and joined in two sections
    - Galvanized Steel: used when water is not corrosive, difficult screw fitting assembly
      - Schedule 40 pipe is most common
      - Joined mechanically with treaded collars
    - Plastic: used in residential for supply piping. Is still restricted by some codes
      - Expands 3.5 times more than copper
      - Joined by primer
      - ***(reference MEEB Table 10.13** Water Supply Piping Materials)*

- **Types of Plastic Pipe:**
  - Polyethylene (PE): plastic pipe and tubing
  - Acrilylonitrite Butadiene Styrene (ABS): plastic pipe, black, used only for drain lines
  - Polyvinyl Chloride (PVC): plastic pipe, white, used for supply
  - Polyvinyl Dichloride (PVDC): (okay for hot water)
- Fitting:
  - Connect pipes where lengths must be joined, where a change in direction occurs, where three pipes join, and where change in size occurs
    - Union: a special fitting that connects two rigid pipes and can be unscrewed easily for repairs/additions
    - Steel and brass fittings are made from cast iron or brass and are treaded to receive the threaded pipes
    - Copper/plastic fittings are larger than the pipe so that it can be slipped in
    - Copper is sealed with soldering
    - Plastic pipes are sealed with a solvent that 'melts' the plastic together
- Valves:
  - Used to control water flow and are located at:
    - Bathrooms/kitchens
    - Risers
    - Horizontal branches
    - HVAC systems
    - Individual fixtures
    - Pumps
    - Water treatment equip
      - Sprinkler Systems
  - Allow for selective shutdown without affecting the rest of the system
  - Gate Valve: seats a metal wedge agains two metal parts of the valve, and used when control is either totally on or totally off, little friction loss
  - Globe Valve: used when flow is variably and frequently controlled like at a faucets or hose bib, friction loss is high
  - Angle Valve: screw a washer down against a seat to shut the flow off, or opened and regulated flow by screwing progressively away from the sat metering of flow restriction capability, used mostly for plumbing fixtures
  - Check Valve: works automatically by allowing water to flow in one direction, backflow causes the valve to close, typically used to prevent sanitary waste from flowing back into a potable water supply
  - Ball Valve: allows one way flow, is opened/closed by pressure on a ball that fits into a cup shaped opening, used for regulating flow
  - Butterfly Valve: allows one way flow, mechanism is like a rotating disk attached to a spindle used for isolating or regulating flow
  - Relief Valve: used to control or limit the pressure in a system by allowing fluid to divert an alternate rout allowing the pressure to drop, then the valve closes



- Other Specialized Components:
  - Air chambers/shock absorbers: prevent water hammer which is the noise you hear when a valve is shut quickly and pipes rattle. Sounds like a CLANG in the walls
  - Pressure reducers: required on fixtures if the supply pressure is too high to reduce excessive wear on fixtures
- Supporting Pipes:
  - Devices are used to carry the weight of the pipe, and to guide, anchor, and support it and its load.
  - May contain insulation materials depending on temperature application
  - Pipe Guide: directs and controls the motion of a defined span of pipe, used with other supports
  - Pipe Anchor: rigid support that restricts movement in all three directions, typically welded or bolted to steel or concrete
  - Shock Absorber: absorbs energy of sudden impulses from the pipeline
  - Pre-Insulated Support: load bearing support that minimizes energy dissipation
- Velocity Rate and Noise:
  - Velocity above 10ft/second of water flow is noisy
  - In sound sensitive areas, anything above 6ft/second is too noisy

Concepts/Goals:

- Pressure loss in pipes depend on the diameter of the pipe and the flow
- Friction is a function of the diameter of the pipe and the flow rate through it
- For the same flow rate, the smaller the diameter of the pipe, the greater the friction
- For the same diameter pipe, the greater the flow rate, the greater the friction

Processes:
- Pipe Support:
  - Vertical runs should be supported at every story
  - Horizontal Pipe should be supported at intervals of:

1/2" pipe	=	6'-0"
3/4" - 1" pipe	=	8'-0"
1-1/4" + pipe	=	10'-0"
	OR	
Copper Pipe	=	6'-0"
Steel Pipe	=	12'-0"
Plastic Pipe	=	4'-0"

  - Horizontal tubing should be supported at closer spacing than steel
  - Position horizontal runs adequate to assure correct pitch and drainage
- Sizing Water Pipes:
  - Minimum fixture pressure varies from 4 - 20 psi
  - Street main pressure is about 50 psi
  - Use the highest, most remote fixture from the main when determining the minimum fixture flow pressure
- Calculating Water Main Pressure

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

- Calculating Minimum number of plumbing fixtures
  - ***(Reference MEEB Table 9.3:** minimum number of plumbing facilities)*
  - Varies by occupancy type and sizes
  - Dictated by plumbing code, either in the IBC or state amendments
  - Given as a minimum requirement, sometime more generous provisions are appropriate
  - Unless stated otherwise, assume occupancy is made up of half men and half women
  - Divide the occupancy by the number of fixtures that are required to get a total
  - *Example:*
    - *A hip new nightclub will have an occupancy of 400 people. How many water closets are required?*
      - *400 people = 200 men and 200 women*
      - *Per Table 9.3, nightclubs require 1 water closet per 40 men and 1 water closet per 40 women*
      - *200 men / 40 men per water closet = 5 water closets*
      - *200 women / 40 women per water closet = 5 water closets*
      - *5 + 5 = 10 water closets total*

CONTENT AREA: HVAC

Building Design

Vocabulary:

- **Full Load Hours:** the maximum output potential of a heating/cooling system in one hour and is used to size HVAC equipment
- **Peak Heat Loss:** the amount of heat lost at design outdoor and indoor conditions which must be made up by the HVAC system to maintain occupant comfort
- **Service Energy Efficiency Rating (SEER):** an HVAC energy rating
- **Insulators:** retard the flow of heat
- **Conductors:** encourage heat flow
- **Design Equivalent Temperature Difference (DETD):** used for calculating heat gain through a building envelope, and takes into account air temperature differences, effects of sun, thermal mass storage effects of material, color of finishes, etc.
- **Design Cooling Load Factor (DCLF):** used for calculating heat gain through glazing, takes int account glazing type, interior shading, and outdoor temperature
- **Cooling Load Temperature Difference (CLTD):** an equivalent temperature difference used for calculating the instantaneous external cooling load across a wall or roof
- **Albedo:** how much radiant energy that is reflected by a surface where 0 is a flat black surface which absorbs all heat and 1 is a mirror (rate is listed as a fraction or percent).
- **Conductivity:** the speed with which heat passes through a material. Metals are high, and soils/sand are low.
- **Economizer:** equipment that permits the use of outdoor air instead of refrigeration units for building cooling when conditions are right
- **Enthalpy Economizer:** evaluates both temperature and humidity, mixes appropriate outdoor/indoor air to achieve comfortable conditions without cooling
- **Hypocausts:** gravity heating systems used by the romans to heat public baths and private houses
- **Ton:** amount of cooling required to convert a ton of water to ice in a 24 hour period, equal to 12,000 BTUH

Equations: (those in gold are given on ncarb formula sheet)

BTU / Year	=	(peak heat loss) x (full-load hrs per year)
Cost $ / Year	=	(BTU/yr) x (fuel cost/fuel heat value) x efficiency
(ΔT)	=	$T_{indoors} - T_{Design}$
T_d	=	$T_{indoors} - T_{outdoors}$
BTU / Hour	=	(cfm) x (1.08) x (ΔT)
	=	(U_{value}) x (Area) x T_d
Infiltration	=	($N_{air\ changes}$) x (V_{volume})
Infiltration (Crack)	=	(Linear Feet) x (CHF / Linear Feet)
Heating Load (Q_c)	=	U(A) x (ΔT)
Heat Flow Rate (Q)	=	U(A) x (24Degree Days DD)
1 watt	=	3.41 BTU/hour
1 kWh	=	3,400 BTU / hour
1 ton of AC	=	12,000 BTU / hour (or 3.52 kWh)

Units for ventilation are cfm per person
Units for heating are BTU per hour
Units for cooling are BTU per hour and Tons

Facts/Rules:

- The same basic formula is used for conduction whether it occurs through the roof, walls, windows, or doors.
  - Heat flow is the product of the conductance of the assembly (the U value), the change in temperature (ΔT) is the difference between the outside and inside air temp, and the exposed surface area of wall, window or roof (A).
- 1 Ton of AC is equivalent to the useful cooling effect on a ton of ice
- R_{value} expresses how effective any solid material is as an insulator. The higher the value, the better it is.
- U_{value} is the thermal transmittance and calculated for particular elements (roof, wall, etc) by finding the R value of each component (e.g.: of the siding, the insulation, the gyp bd) and adding them together, then calculating 1 / Total R_{value}
- HVAC Systems are typically used for:
  - Boilers and chillers
  - Pumps and drives
  - Air handlers (sometime)
  - Water heating equipment
  - Heat exchangers
  - Water treatment
  - Filtration equipment
  - Room ventilation gear (for excess heat)
- Load Dominated Buildings:
  - The core will need cooling almost all the time...it can be passive cooling
  - The perimeter will need heating and cooling at different times of the day, month, year
  - Both zones will need ventilation at a rate of about 20 CFM / person
- Typical heating choices:
  - The central boiler: hydronic system, it's the #1 piece of equipment in a system
  - High Pressure steam: large and dangerous, even lethal
  - Low pressure steam: found in older homes
  - Heat pumps and electrical heating: water based are good, electric are terrible
  - Coal, oil, and other systems: tending away from now
- Primary energy options for heating:
  - Natural gas, oil, and coal are equal in price and efficiency
  - Natural gas is the most clean burning, then oil, then coal
  - For large buildings electric heating is almost always the wrong answer
- Cooling Choices for cooling a building
  - Chiller: requires a lot of cold water (all at about 55˚F)
  - Plus all the things that accompany a chiller
  - Direct Expansion (DX) systems: smaller and noisier
  - Rooftop cooling
- Building Zones:
  - Good system design is a balance of solar gains and internal gains
  - Early morning/late afternoon are the worst for buildings
  - West facade is the worst side

- Building Pressurization:
  - When HVAC system exhaust more air than they take in, it can result in negative pressurization inside the building
  - Ideally the air pressure in a building should be equal to or slightly positive to the air pressure outside the building
  - Negative pressure problems include: comfort issues, cold drafts, and noxious doers that rush in through cracks and openings
    - Outside doors may difficult to adjust and open and dangerous to close
    - Flues intended to discharge combustion products may backdraft
  - Buildings can become negatively pressurized through the stack effect, where warm air rises and goes out the top, pulling in cooler air at lower levels through cracks and openings
  - Can be balanced by adjusting flow and workings of exhaust and intake equipment, adding more intake air capacity, etc

Concepts/Goals:

- When the weather is cold: heat travels from inside to outside
- When the weather is warm: heat travels from the outside to the inside
- Heat leaves a building by either a building's skin that conducts heat to a colder exterior surrounding, or a cold outdoor air replaces the heated building air.
- Fuel cost / heat value is published by the US Department of Energy
- HVAC efficiency ratings are published by the equipment manufacturers
- Mechanical is the #1 cost in building design
- HVAC has a huge impact on the construction process. How do you get everything to stay in place?

Processes:

- ***It's not the heat, it's the humidity!***
  - Comfort is not only a function of outdoor temperature, but also of relative humidity
  - During the summer people are more comfortable the lower the relative humidity is.
  - Desiccant cooling
- System Design:
  - Load Estimate (by engineer, or you using MEEB)
  - Equipment sizing (understanding what type of system it is and what it takes to run)
    - Sizing depends on what "it" does
      - System type
      - Building type
      - Code requirements
  - Equipment footprint (how big is the equipment?)
  - Space allotment (how much space does the equipment need in the building?)
  - Keep repeating those steps until 95% done
- Designing a Cooling System for a Building:
  - Major influences are:
    - PLE (People Lighting Equipment) gains: make the best estimate
    - Solar gains: time of the day/exposure
    - BTU/hr is the key it all adds up
    - Time of day also matters. Focus on 9:00AM, 12:00PM, and 3:00PM

- To Calculate PLE Gains
  - People: **(reference MEEB Table 5.8 Part A or Table 5.21)**
    - based on square footage, using the table is easy, find the type of building and multiple the factor for people by the square footage you're working with
  - Lights: **(reference MEEB Table 5.8 Part B)**
  - Equipment: **(reference MEEB Table 5.8 Part A)**
- To calculate Solar Gains **(reference MEEB Table 5.8 Part C or Table 5.19)**
  - Use Table 5.19 Part B for windows that are not shaded by external devices
  - Double pained glass, typical
- To calculate Latent Gains: **(reference Figure 5.33 or Table 5.21)**

Implications of Design Decisions

Facts/Rules:

- Architectural Implications:
  - Details of the design and building construction
  - Aesthetics (is it exposed or hidden?)
  - Required floor spaces and clearances for equipment
  - Size and appearance of diffusers, radiators, etc
  - Coordination with other building systems (lighting, fire suppression, structure)
  - Acceptable noise level
  - Required shaft spaces
  - Indoor vs. Outdoor equipment and their locations
  - Codes and standards of smoke removal
  - Usage patterns
  - Occupancy type
- System Constraints:
  - Type of facility and requirements
  - Zoning requirements
  - Heating/cooling loads
  - Energy availability and efficiency
  - Control scheme
  - Maintenance ease, frequency
  - Type of equipment
  - Redundancy and equipment configuration
  - Zone or individual control
- Financial Implications:
  - Capital, initial cost
  - Operating cost
  - Maintenance cost
  - Replacement cost
  - Upgrading as required
  - Equipment failure costs
  - Life cycle analysis

Concepts/Goals:

- HVAC systems are important in design for many reasons:
  - They take up a lot of space in the building's floor plan and volume for all the equipment and distribution runs

    - They are usually the largest major budget item
    - Building success depends on how comfortable people are inside, and how affordable it is for them to be that way
- Water systems and air systems are comparable in terms of efficiency, water is a little better, but more costly
- Air systems tend to be comparable to water systems in terms of initial cost
- Water systems are easier to maintain, and outperform others in terms of operations and maintenance
- It's good to have a worst case scenario assumption to work with when doing heating load calculations, including:
    - It's really cold and dry out (meaning you're at the 97.5% value of MEEB Appendix A-1)
    - It's the middle of the night
    - No people are in the space
    - The lights are off
    - Non of the equipment in the space is running

Indoor Air Quality

Vocabulary:

- **Ventilation:** supplying or removing of air by mechanical or natural mans to or from a given space
- **Indoor Air Quality (IAQ):** the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants
- **Smoke Pencil:** tool used to identify drafts and air leaks, pull on the trigger and see how smoke moves to show air movement
- **Exhaust Air:** any foul or unwanted air removed from a space by mechanical means

Facts/Rules:

- Electronic air cleaners operate differently by applying high voltages to statically charge dust which is then attracted to oppositely charged plates on the cleaner.
- Demand controlled ventilation: carbon dioxide sensors are used to control the rate of air changes dynamically, based on the emissions of actual building occupants
- Commercial buildings are often kept under slightly positive air pressure relative to the outdoors to reduce infiltration and help with moisture management and humidity control.
- Minimize the sources of harmful substances where possible
- Geological mapping has been widely used to identify "at risk" areas for radon.
- Pathogen destruction can be achieved using UV lamps
- Dilution of indoor pollutants with outdoor air is effective to the extent that outdoor air is free of harmful pollutants.
- Ozone in outdoor air occurs indoors at reduced concentrations because ozone is highly reactive with many chemicals found indoors.
- Filters:
    - There are many different types of filters for the wide variety of particulates
    - Large particulates are easiest to remove, smaller are most hazardous to heath
    - Not all pollutants can be captured by filters
    - Filter Types:
        - **High Efficiency Particulate Arrestance (HEPA):** the highest efficiency option, typically found in special air cleanser for unusually polluted or IAQ demanding environments like hospitals

- Particulate filters: very common
  - Fibrous Panel Filters: furnished with HVAC equipment and function mainly to protect fans from large particles of lint or dust
    - The least effective in cleaning air
  - Media Filters: more fine and use filter paper in please within a frame, working by straining and impaction (90% efficient)
- Electrostatic Filters: more money, but produce less air movement as two sets of chard plates attract dust. Are cleaned by washing off.
- Absorption filters: for gaseous removal and vary depending on pollutant
  - Activated charcoal filters: more common, absorb materials with high molecular weights and allow low weights to pass
- Air Washers: sometime used to control bacteria growth and control humidity
- Electronic air cleaners: can pose a threat due to ozone production, but demand less maintenance

- The exhaust capacity of a principal residential building exhaust fan should be at least 50% of the total HVAC system airflow capacity.
- Required Air Change Rates for ventilation is based on size and occupancy of space
  - Some Typical Air Changes In a Building / Room:

Building/Room	Air Changes Per Hour
Auditoriums	8 - 15 ACH
Bars/Clubs	20 - 30 ACH
Churches	8 - 15 ACH
Classrooms	4 - 12 ACH
Computer Rooms	15 - 20 ACH
Restaurants	8 - 10 ACH
Retail Stores	6 - 10 ACH
Shops, Woodworking	5 ACH
Warehouses	2 ACH

Concepts/Goals:

- Traditionally effective infiltration and natural ventilation has been used worldwide to effect a controlled exchange of indoor air to abate IAQ problems.
- Conflicting energy efficiency considerations have resulted in an increase in building "tightness" which adversely impacts infiltration mechanisms and discourages extensive use of natural ventilation.
- Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes
- Inadequate ventilation can increase indoor pollutant levels by not bringing enough outdoor air to dilute emissions from indoor sources
- High temperature and humidity levels can increase concentrations of some pollutants
- Generally, outdoor country air is better than indoor city air.
- The worst local air quality problems tend to be around hospitals, shopping areas or public transport hubs where large numbers of vehicles move slowly or idle

Processes:
- Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces and computer modeling of air flow inside buildings.

Building Systems + their Integration

Vocabulary:
- **Plant:** equipment that creates warm or cool water or air, typically in a mechanical room
- **Distribution/System:** delivers the heated or cooled air or water to the necessary areas in a building called zones
- **Convector:** a heating device arranged to deliver heat to the air primarily by convection
- **Zones:** vary depending on the type and use of a building. (e.g.: each story, offices vs. apartments, commercial vs. recreational spaces). It's design specific.
- **Plenum:** typically the space above a suspended ceiling used to convey return air
- **DX (Direct Expansion):** alternative to chilled water system in HVAC used to cool air containing water vapor. A refrigerant is used to remove sensible/latent heat from air
- **Heat Exchanger:** any device used for transferring heat from one fluid to another, where the fluids are physically separated
- **Solar Air Conditioning:** cooling system that provides refrigerated air using solar radiation as the prime source of energy
- **Air Conditioning:** treating of air in an occupied space to control tis temperature, humidity, and cleanliness
- **Refrigerant:** substance used in a heat cycle usually including a reversible phase transition from a liquid to a gas
- **Freon:** a family of several CFC gasses used in the refrigeration cycle
- **Evaporator:** the part of a refrigeration system in which the refrigerant evaporates and absorbs heat from the medium to be cooled
- **Condenser:** a heat exchanger in which refrigerant vapor is condensed (liquified) releasing heat to an external medium
- **Forced Convection:** movement of a fluid by a fan or pump in order to force heat exchange
- Air Movement: the velocity of air in an enclosed space measured in feet per minute
- **Cooling Tower:** a heat rejection device which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Often found on the roof.
- **Chiller:** used in hot climate with high cooling demands
- **Draft:** a flow of air through a flue or chimney
- **Flue:** a duct for smoke and waste gases produced by a fire, gas heater, power station or other fuel burning installation
- **Barometric Damper (Draft Regulator):** a balanced air valve positioned to admit air to the flue or stack of a furnace in order to maintain a constant amount of draft.
- **Steam Trap:** valve which permits passage of air or water, but not steam…often used with steam radiators
- **Reheat:** adding of sensible heat to a supply air stream which has been previously cooled
- **Air Handling Unit (AHU):** a ventilation system that consists of air intakes, filters, fans, electric heating coils, connected ductwork/components, fire/control dampers, electric reheat boxes, air boards, and control systems. Can also include DX or chilled water cooling coil, refrigerant storage and pump systems

- **Coefficient of Performance (COP):** a unitless number that is a rating of the efficiency of heating or cooling equipment
- **Energy Efficiency Ratio (EER):** ration of net cooling capacity in BTUH to the total rate of electrical input in watts, under designated operating conditions
- **Home Energy Rating System (HERS):** standardized system for rating the energy efficiency of residential buildings. Score is between 0 - 100 and indicates the relative energy efficiency 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 condition and heat pump equipment
- **Building Automation System (BAS):** computer based integrated system used to monitor and control building systems
- **Building Commissioning:** process of inspecting, testing, starting up, and adjusting building systems to verify that they're working in accordance with the contract documents

Facts/Rules:

- HVAC Systems are made up of:
  - Energy Supply (the electricity or fuel that runs it)
  - Service Generator (boilers, chillers, heat pumps)
  - Distribution (ducts, pipes, or a combination of both)
  - Delivery Components (diffusers, radiators, etc.)
- Plant Systems:
  - Scale varies from a room air conditioner to a plant for a whole college campus
  - Plants originally started as heat/steam only. With the development of air conditioning, they because sources for chilled water too.
- Common Fuel Types:

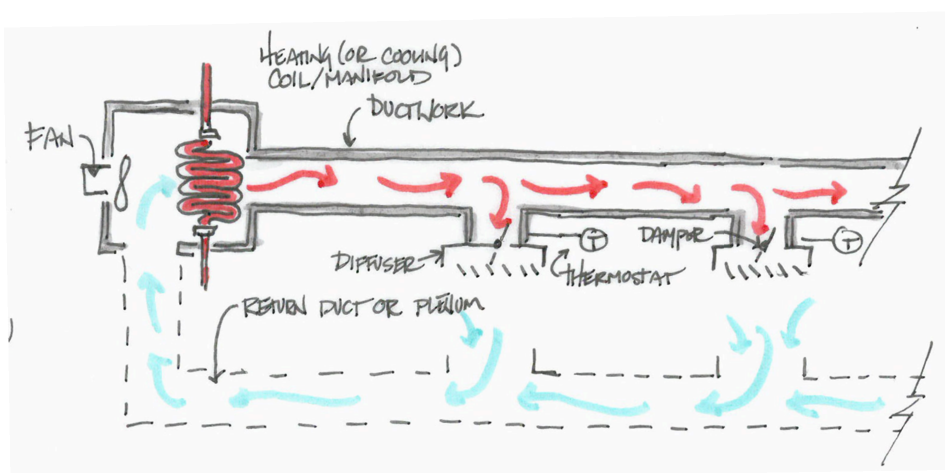
Fuel Type	Efficiency	Heating Value	Pro	Con
Electricity	95 - 100%	3,413 BTU/kWh	Easy to install and control Simple operation Flexible zoning Little space required	Most expensive type, especially for high heating loads
Propane	70 - 90%	2,500 BTU/ft^3	Portable, good for remote areas	Not as clean burning as natural gas
Natural Gas	70 - 80%	1,050 BTU/ft^3	Most efficient fossil fuel, clean burning	Can't be used in remote areas
No. 2 Oil	65 - 85%	137,000 - 141,000 BTU/Gal	Portable and Storable	Wide price fluctuation, burning equipment needs lots of maintenance, must be stored securely
Anthracite Coal	65-75%	12,910 BTU/lb		

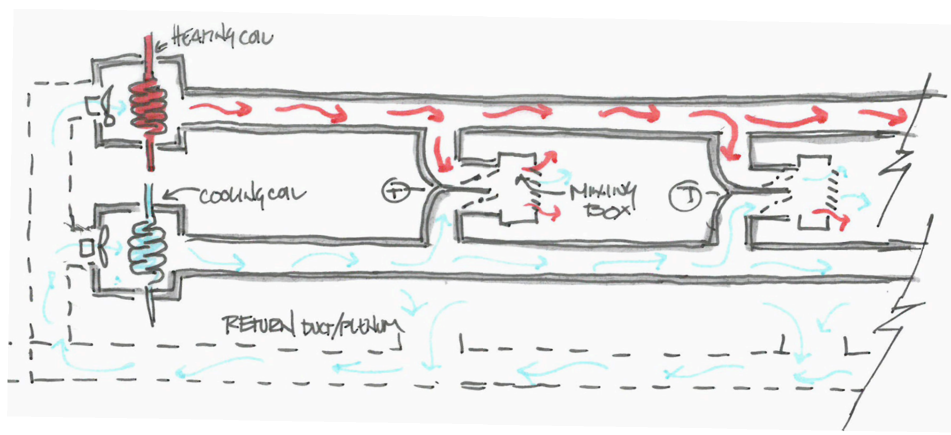
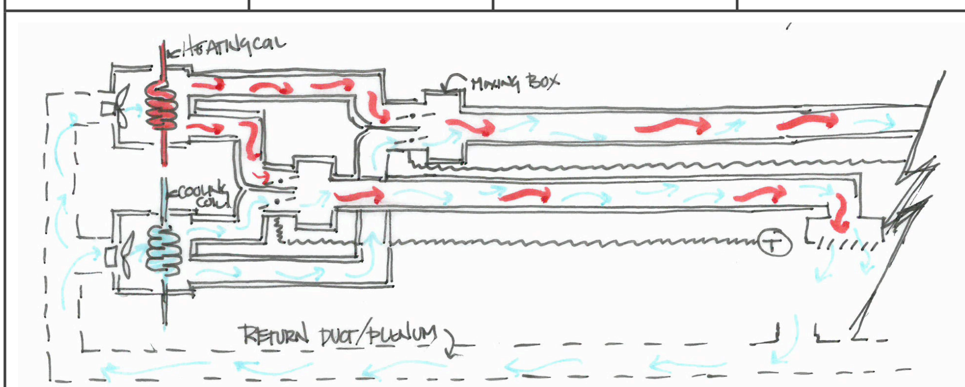
-

- CommonTypes of Plant Systems:
  - Heating Systems:
    - **Furnace**: an appliance fired by gas or oil to heat air and then distribute it throughout a building in a heating system
      - 80% efficiency
      - Upflow Furnace: return air is supplied at the bottom of the unit and heated air is expelled at the top of the furnace and distributed through ductwork
      - Downflow Furnace: the opposite of upflow, used where ductwork is located in the basement and furnace is on the first floor
      - Horizontal (Lowboy) Furnace: used where headroom is limited
    - **Boiler:** a closed vessel in which water or other fluid is heated by gas or oil, but does not necessarily boil. The heated/vaporized fluid exits the boiler for use in various heating systems
      - 80% efficiency
      - Typically has tubes containing water to be heated that are situated within a combustion chamber where heat exchange takes place
      - Gasses and other combustible products are carried away through breeching into a **flue**
      - It's the most basic system
      - Life cycle cost can be high
      - Types of Boilers:
        - Fire Tube Boiler: water paternally fills a barrel with a small volume left above to accommodate steam, used in early all steam locomotives, a low rate of steam production but high steam storage capacity. Mostly burn solid fuels and but can burn liquid or gas
        - Water Tube Boiler: water tubes are arranged inside a furnace. Gives high steam production rates but less storage capacity. Generally preferred in high pressure application since high pressure water/steam is contained within small diameter pipes
        - Modular: packaged boiler system that operate in parallel or series to provide varying amounts of steam. Typically most efficient when run at full capacity.
        - Packaged Type: comes in a compel package, requires only the steam, water pie work, fuel supply and electrical connection.
        - Electric: steam is generated using electricity rather than the combustion of a fuel. More expensive than gas run boilers but are simple and easy to use.
  - Cooling Systems:
    - Chilled air or water produces by compressive refrigeration, absorption, or evaporative cooling
    - Refrigerant types:
      - Fluorocarbons, especially chlorofluorocarbons, are being phased out because they deplete the ozone layer
      - Ammonia
      - Sulfur Dioxide
      - Non-halogenated Hydrocarbons (e.g.: propane) work, but are flamable
      - Non-CFC refrigerants may be less effective and involve a higher energy cost
    - **Compressive Refrigeration:** Based on the transfer of heat during the liquefaction and evaporation of a refrigerant. Latent heat is released as refrigerant changes form

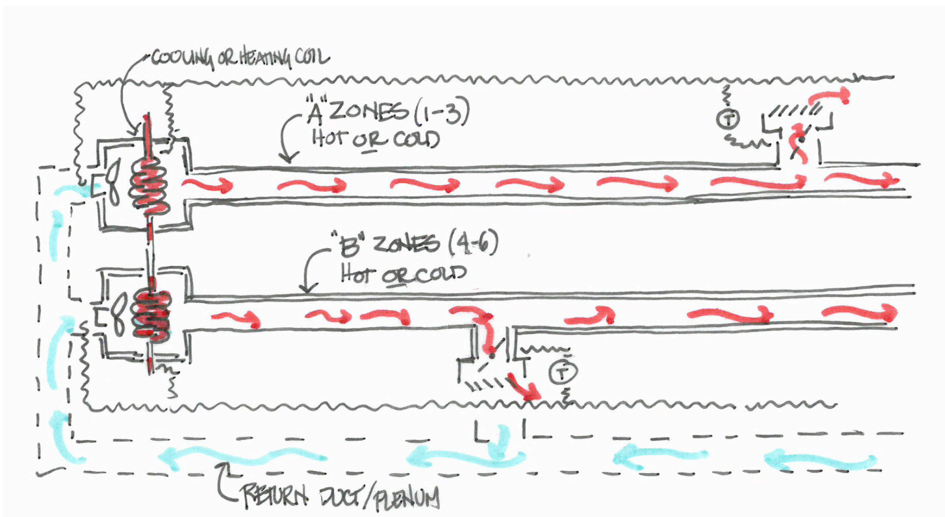
- Components:
  - Compressor: takes refrigerant in gas form and compresses into a liquid
  - Condenser: refrigerant passes through and latent heat is released, usually on the outside of the building
  - Evaporator: expands refrigerant, vaporizes back to gas absorbing surrounding heat
- **Refrigeration by Absorption:** produces chilled water and is accomplished by the loss of heat when water evaporates.
  - Produced in a closed loop system by a salt solution (brine) that draws vapor from the evaporator.
  - Less efficient than compressive systems
  - Needs about 2 times the heat rejection capacity of the compressive cycle
- **Evaporative Cooling (Swamp Cooler):** water is dropped over pads or tubes that circulate outdoor air or water.
  - Free water evaporates to vapor and the heat is drawn from circulating air or water to disturb to indoor spaces
  - Works well in hot-arid climates with low humidity
  - Simple to construct
  - Requires no refrigerant line
  - Even though a change in total heat occurs, evaporative cooling is accompanied by an increase in relative humidity.

- HVAC Distribution Systems, or how spaces are served by the plant, can be:
  - All Water System (only pipes)
  - All Air System (only ducts)
  - Combined Water and Air (pipes and ducts...expensive!)
  - **Electrical Systems**:
    - Simplest and lowest in first costs, but most expensive in life cycle costs, and really only justified in very mild climates
    - Radiant Systems: radiant panels or wires embedded in ceiling or floor
    - Baseboard Heaters: Convective Air
  - **Hydronic Systems:**
    - Hot water or steam circulates through registers/pipes which radiate heat into space
    - Many hydronic systems are also radiant and can be combined with forced air systems
  - **Forced Air Systems:**
    - Cool or heat by conditioned air alone
    - Move air through a coil to heat space via ductwork
    - Supply air, return air and other stuff that comes back with it
    - The coil is a direct fire gas coil, or electrical resistance. If you see a “DX” air coil don’t use it...it’s cheap and lousy.
  - **Direct Expansion (DX) System:**
    - Simplest type of system
    - A self contained unit that passes non-ducted air to be cooled over the evaporator and back into the room
    - Condenser uses outdoor air directly
    - Typically placed on exterior walls, or roof mounted

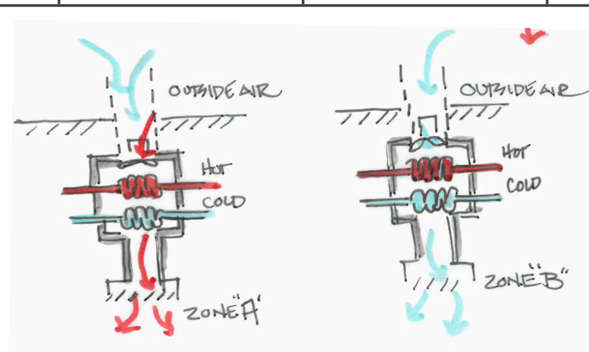
Type of Distribution	Description	Pros	Cons	Etc.
		Electric System		
Electric	• Radiant heat is run through panels or wires to rooms	• Low initial cost • Simple system • Can turn on only in occupied room	• Expensive life cycle cost • Wasteful	• Baseboard heat uses convection to heat spaces
		Forced Air Systems		
Single Duct	• A single supply duct runs to all rooms with a constant air flow • Rate of air flow is controlled by a damper at each diffuser • Controlled by one thermostat	• Lower cost • Less ductwork • Returns can be ducted or open in the space between the ceiling and floor/ roof above, called a plenum • Easy to operate • Good for controlling IAQ	• Can only heat *or* cool • Only works when loads are similar through a building • Bad for perimeter zones in cold climates • Thick distribution trees • Can be noisy	• Typical residential system • Common in buildings with large open spaces, few windows, uniform loads, like theaters, department stores, exhibition halls
				

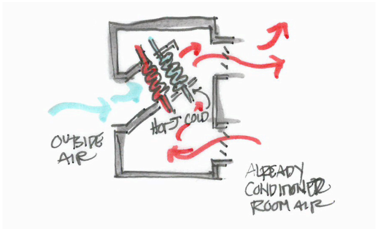
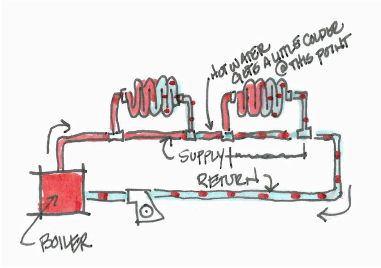
Type of Distribution	Description	Pros	Cons	Etc.
Double Duct aka “Dual Duct” aka “High Velocity”	• Combination of two single duct systems, one for hot air, and one for cold air • Two streams are joined at a mixing box controlled by a thermostat in the zone	• Can heat and cool at the same time • Constant airflow volume • Good for perimeter zones • Easy to install • Good for linear buildings	• Twice as much ductwork (one to heat, one to cool) • Both boiler and chiller have to run all the time • The most energy is consumed with this system large fans) • noisy distribution	• Hot and cold air produced • Each room has a thermostat which mixes air in box before entering room • Common in hospitals • Mostly replaced by VAV systems
	 			
Multizone	• Like a Double Duct system, but the mixing box is in the mechanical room • Premixed air is sent to each zone	• Efficient with a few zones • Separate duct runs, nothing is shared • Easy to sub monitor	• Lots of ductwork is required • Not efficient with many zones or non-square building	• Good for mall spaces where each tenant has control • Good for square building plans with few zones • Used in medium sized buildings
	 			

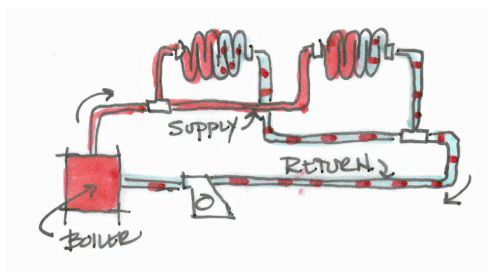
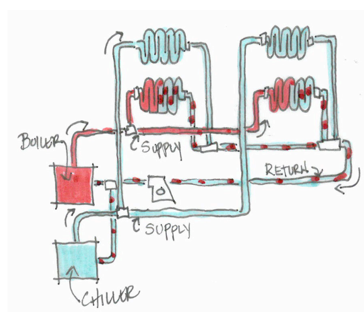
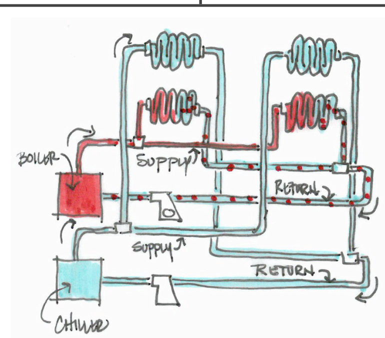
Type of Distribution	Description	Pros	Cons	Etc.
Variable Air Volume	• Air is heated or cooled at a central location and distributed through a single duct. • Thermostat controls a damper at each zone to control the volume of conditioned air into that space.	• Can heat and cool different zones at the same time • Most common and efficient system • Saves energy because it doesn't have to run peak all the time	• Can't heat and cool different rooms in the same zone at the same time • A maintenance nightmare! • Requires a lot of interstitial space	• Can be single or multiple single duct systems • A zone can be one or many rooms • System is set to handle hottest or coldest room and rest adjust • Used in large buildings where temp regulation is required

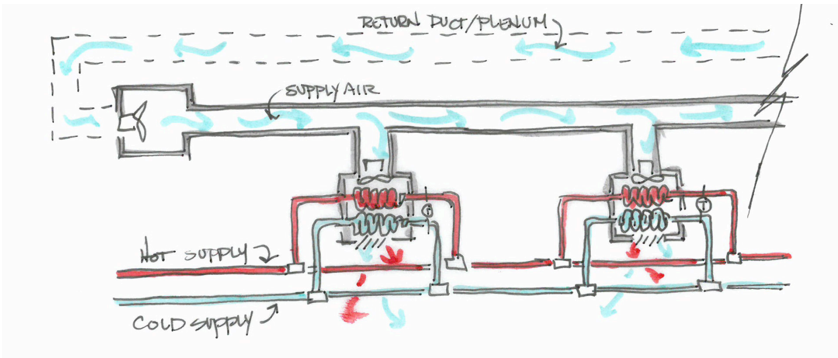
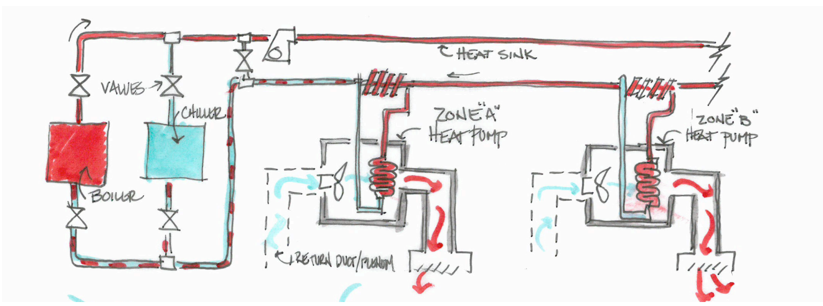


Type of Distribution	Description	Pros	Cons	Etc.
Unitary	• A self contained unit where air comes directly in from the outside, conditioned and sent into the space	• Use when ducts are impracticable to run • Each unit can have it's own utility bill	• One unit is required for each zone	• Can run on just electric, but can also connect to hot/cold piping • They're the units you see in big box stores



Type of Distribution	Description	Pros	Cons	Etc.
Reheat (Constant Volume)	• Return air and fresh outside air are combined and cooled and dehumidified • Distributed in constant volume at a low temperature	• Humidity and temperature can be controlled • Ducts are smaller • Fan horsepower is lower	• Uses more energy because primary air volume needs to be cooled most of the time and reheated	• Terminal: equip. located near conditioned space • Zone: coils are located in ducts to serve an entire zone • Economizer Cycle: outside air can be used when temps are low enough
Induction	• Air is supplied to a building under high pressure/ velocity to each induction unit • Outside air is mixed with recirculated conditioned air	• Ducts are smaller	• Work best in perimeter rooms of multi story multi room buildings • Need extra distribution for water	• Perimeter zoned areas: schools, offices, labs
				
		Hydronic Systems		
Hydronic Single Pipe	• single supply and return pipe • hot water is circulated through each register and back to the pipe	• Low initial cost • Simple	• Can't go very far because water temp drops • Can only heat *or* cool at one time • first register will be hot, the next a little cooler, etc	• Can be combined with a forced air system, or stand alone
				

Type of Distribution	Description	Pros	Cons	Etc.
Hydronic Two Pipe	• Like a Single Pipe System, but separate supply and return pies are used	• Doesn't put used water (that's cooler) into the supply line for the next register	• Can only heat *or* cool at one time	• Can be combined with forced air system, or stand alone
				
Hydronic Three Pipe	• Like a 2 Pipe system, but both hot and cold water are mixed in a common return pipe	• Can heat and cool at the same time	• Mixes cold and warm water in return pipe • Less efficient than a two/four pipe system	• Can be combined with forced air system, or stand alone
				
Hydronic Four Pipe	• Like (2) two pipe systems, but there's one for hot and one for cold	• Can heat and cool at the same time	• More expensive due to piping	• Can be combined with forced air system, or stand alone
				

Type of Distribution	Description	Pros	Cons	Etc.
		Combined System		
Fan Coil	• Combination Hydronic Four Pipe system and constant air volume that can heat and cool at the same time • A boiler and chiller each attached to a two-pipe system AND ductwork for the supply air	• One of the most efficient systems • Versatile because it can provide heating and cooling simultaneously	• High initial cost • Highest installation cost because there's ductwork and plumbing involved	• Sends clean conditioned air through a single duct • A fan blows air over a hot or cool coil in each room • Can be just used for ventilation without heating/ cooling activated
				
Heat Pump	• Water is circulated through the building, each zone has a heat pump and fan and short ducts that recalculates air within that zone	• Good efficiency • Reduces extensive ductwork • Returns over 200% its electrical input when outdoor temp is above freezing	• High initial cost • May need chiller to cool water if all zones are cooling simultaneously • May need a boiler to reheat up water	• Each zone has its own heat pump and fan • Pump either removes heat from water and blows it into a room or removes heat from a room and into the water
				

- **Efficient HVAC Methods:**
  - Energy used by HVAC accounts for 40%-60% of overall consumption in the building (type, climate, design, etc, can vary that number).
  - Ways to make the system efficient include:
    - **Economizer Cycle:** outdoor air is used when it's cool enough (about 60ºF), reducing the energy required for refrigeration
      - It's a mechanical substitution for an open window
      - Still better than nothing...and filtered air improves indoor air quality
      - As temperature drops outside, less fresh air is introduced because it has to be heated
    - **Dual Condenser Chillers:** use two condensers that operate based on the heating or cooling needs of the building
      - Efficiency is having varying sized chillers and operating the best sided 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 like steam are available
    - **Solar Powered Absorption Cooling:** more efficient absorption chiller powered by hot water from standard flat plate solar collectors
      - Water sully can be from 175ºF - 195ºF
      - operation costs can be less than compressive type chillers
    - **Direct Contact Water Heaters:** heat 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 constantly
    - **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 systems where supply air originates at the floor and rises to return in grilles int eh ceiling
      - Improves indoor air quality and energy savings
      - Most systems use an access floor system for duct work
    - **Water Loop Heat Pumps:** heating and cooling systems that uses a series of heat pumps for different zones in the building
      - Water loop is maintained at a temperature range of 60º - 90ºF and can simultaneously heat or cool zones with no additional energy
      - Reduces piping costs 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 buildings energy needs
- **Heat Transfer Methods:**
  - Based on the concept of the heat exchange from a source where heat (or coolness) is not wanted to a place where it is desired
  - **Energy Recovery Ventilators (Air to Air Heat Exchangers):** reclaim waste energy from the exhaust air stream and use it to condition the incoming fresh air
    - Energy can be reduced from 60% - 70%
    - 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 contaminates should be separate from heat exchanger air
- A defroster may be needed to avoid condense in the exhaust air from freezing
- Common Devices:
  - **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 exchanger):** transfer heat through a heat exchanger wheel with small opening 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:** use water or other liquid to exchange heat
  - Advantage is incoming/exhaust air streams don't need to be adjacent to each other
  - Energy ranges from 50 - 70%
- **Extract Air Windows:** used 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 only be used for low-rise buildings and becomes inefficient if long runs are involved.

- **Phase Change Equipment**
  - Using electrical energy to "pump" heat from one area to an another
  - Typical Coefficient of Performance (COP) for a heat pump in heating mode is 1.25 - 3.0 (watt/watt or BTU/BTU)
    - Coefficient of Performance is a unitless measure of BTU/BTU or watt/watt that measures how much you put in compared to how much you get out
  - That means you get at least 1.5 BTU of energy for every BTU you put in
  - But remember, it's electrical energy
  - COP and overall efficiency
    - COP depends on outdoor temperature if you have a typical heat pump
    - The COP drops when the temperature drops (which is why heat pumps don't work so well in extreme cold climates)
    - For extreme climates, GAS is the best because it's not affected by climate
    - Ground source heat pumps don't react to outdoor conditions, just the ground temp
      - Have a COP of about 5.0….HUGE and 5x better than electrical heat
- **Infiltration**
  - The unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope, and through the use of doors for passage
  - Sometime called **air leakage**
  - **Infiltration Load** is the amount of heat required to bring outside air that has leaked inside a building up to the desired indoor temperature.
  - The highest rate of heat gain/loss in a building is usually a result of outside air infiltration

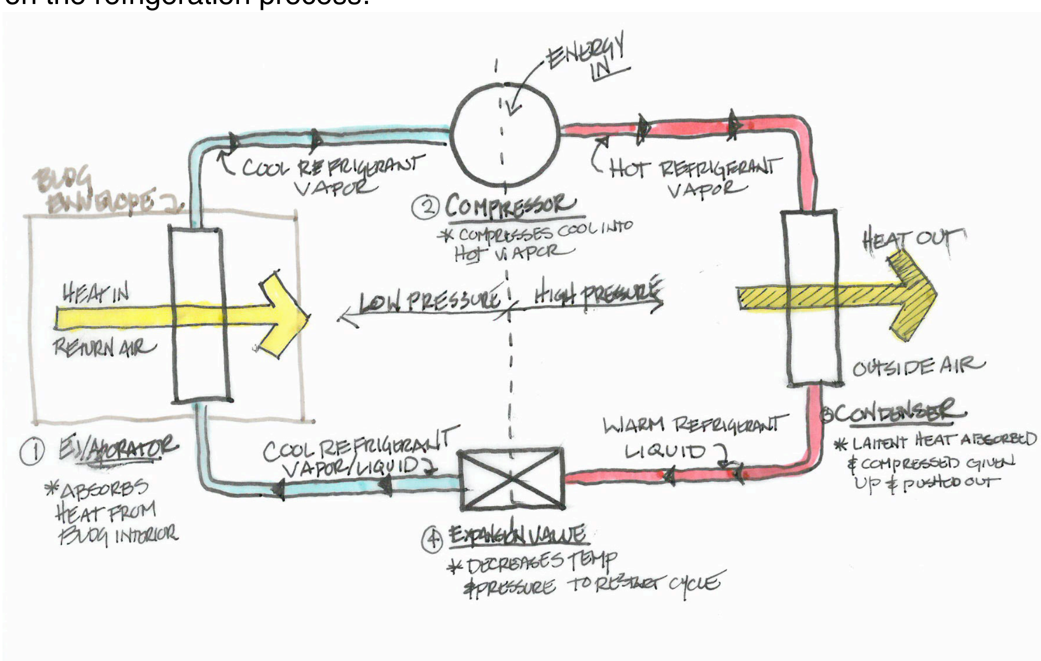
- Energy Code:
  - **Prescriptive Code:** specifies how to build a building
    - ASHRAE 90-xx series covers the exterior envelope, HVAC equipment, water heating equipment, and electrical distribution
  - **Performance Code:** states the final result and how it will be measured, but doesn't say how to actually achieve the result
    - Building Energy Performance Standards (BEPS) specifies an energy budget per square foot for various building functions
  - **Overall Thermal Transmission Value (OTTV):** a weighted average U-value for all the exterior surfaces of the building.
    - An example is a combination of prescribe and performance codes

Concepts/Goals:

- Electric resistance is the worst type of heating
- Heat pumps are better at turning energy into heat by about 6 times compared to electric
- The object of an HVAC system is to control the temperature, humidity, and air flow and cleanliness by mechanical means for thermal comfort of occupants
- Water is much more efficient medium to carry heat than air

Processes:

- More on the refrigeration process:



  - Evaporation occurs at low temperature and low pressure
  - Condensation occurs at high temperature and high pressure
  - Typical Refrigeration Process Cycle (from air-conditioning-and-refrigeration-guide.com)
    - Evaporator (1): Relatively warm air (or water, if the unit is an ice machine) flows over the evaporator coil
      - The system is designed so that the heat in the relatively warm air, water or ice cream mix flowing over the evaporator will move into the cold evaporating refrigerant.

    - This process will continue to cool the air, water, or ice cream mix that's flowing over the evaporator until it reaches the design set point or thermostat setting.
    - So, when you turn on the refrigerator, freezer, ice machine or ice cream machine, the system is designed so that the evaporator will stay colder than whatever it's cooling, and will continuously remove heat from it and cool it.
- Compressor (2): refrigerant vapor comes in from the low pressure side of the circuit and discharges it at a much higher pressure into the high pressure side of the circuit
    - The compressor is the heart of the system; it keeps the refrigerant flowing through the system at specific rates of flow, and at specific pressures.
    - The rate of flow through the system will depend on the size of the unit
    - The operating pressures will depend on the refrigerant being used and the desired evaporator temperature.
- Condenser (3): hot refrigerant vapor discharged from the compressor travels through the condenser, the cool air or water flowing through the condenser coil absorbs enough heat from the vapor to cause it to condense.
    - Most air cooled refrigeration systems are designed so that the refrigerant will condense at a temperature about 25 - 30˚ above the ambient air temperature around the condenser.
    - Condensing is good because it allow the heat energy in the vapor to move into that relatively cold air or water and cause the refrigerant to condense.
    - High pressure liquid refrigerant will flow down the liquid line, through a filter drier that is designed to prevent contaminants from flowing through the system, and on to the metering device.
- Expansion Valve (4): the dividing point between the high pressure and low pressure sides of the system and is designed to maintain a specific rate of flow of refrigerant into the low side of the system.
    - When the high pressure liquid refrigerant passes through the metering device, its pressure will drop to a low pressure that will be equivalent to about 10° to 15° below the design temperature of the evaporator.
    - It starts evaporating immediately and shoots out into the evaporator foaming, bubbling, and boiling
    - *Think of it like a warm soda when you shake the bottle and pop the top off….it goes everywhere.*

Construction Details + Constructability

Vocabulary:

- **Distribution Trees:** the means for delivering heating and cooling
- **Splitter Damper:** a single blade damper that is hinged at one end and installed to divert air from a main duct into a branch duct
- **Turning Vane:** a curved fin that fits inside a duct to direct the flow of air to another direction without adding noise to the system
- **Induction:** a small amount of supply air at a very high velocity is delivered to a box and mixed with air brought in from the room inducing a greater airflow
- **Flue:** noncombustible and heat resistant passage in a chimney used to convey products of combustion from a furnace, fireplace, or boiler to the atmosphere...sometime just the chimney itself

- **Mixing Box:** enclosure in which two air streams are mixed, commonly used in a dual duct system
- **Blowdown**: water intentionally wasted from a boiler to avoid concentration of impurities during evaporation of steam
- **Feedwater:** water used to supply a boiler to generate steam or hot water

Equations:

Cross section area of duct (A) = $\frac{144 \times (\text{the flow rate in cubic ft. Per min, } Q_{cfm})}{\text{Velocity measured in feet per minute (V)}}$

Friction loss in a circular duct (Δp) = $\frac{(0.109136\ CFM^{1.9})}{(\text{Equivalent duct diameter}^{5.02})}$

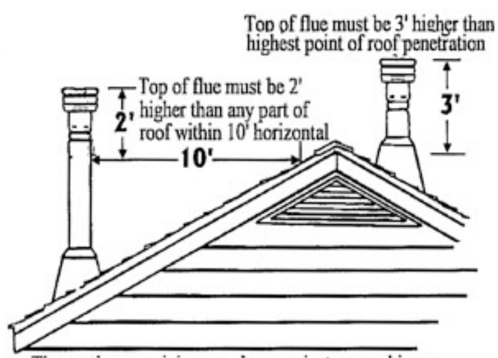
Facts/Rules:

- Distribution Trees:
  - Roots: the machines that provide heat and cold
  - Trunk: the main duct or pipe from the mechanical equipment to the zone to be served
  - Branches: the many smaller ducts or pipes that lead to individual spaces
  - A building can have one giant distribution tree, or multiple smaller tress
  - Air distribution trees are bulky and likely to have a major visual impact unless they're hidden above ceilings, below floors, in chases.
  - Integrating vertical distribution trees with a structure saves on floor place
  - A distribution tree that flows from a rooftop central AHU reduces duct size on lower building floors
  - Single duct HVAC systems have the small tree in the all air system class
- Ducts
  - Ductwork efficiency depends on having the least possible perimeter distance, allowing for less retsina and friction for air to move
  - Usually rectangular or round, though now spiral ovals are becoming more common
  - Circular cross section is best, especially high velocity system
  - Increase air friction often causes problems in higher velocity ducts
  - Higher duct velocities result in higher duct system resistance, which results in increased fan horsepower.
  - Speeds:

Low Velocity	=	1,000 - 2,200 fpm
Medium Velocity	=	2,200 - 2,500 fpm
High Velocity	=	+ 2,500 fpm

  - Sheet Metal: most common and made of galvanized steel or aluminum, most durable and least likely to have mold/bacteria growth
  - Fiberglass Lined: lined with an external or internal fiberglass duct liner, used to insulate dry ducts from heat loss, to avoid condensation, and or to reduce the sound of the system
- Dampers
  - Valve or plate that stops or regulates the flow of air inside a duct, chimney, variable air volume box, other HVAC equipment
  - Balances the system and allows for adjustments based on the occupants needs
  - Can be used to cut off or regulate air to a room
  - Controlled by a thermostat or automation system

- Insulated Ductwork:
  - Reduces heat loss/heat gain of air during delivery
  - Isolates air nosies in duct from spaces
  - Prevents condensation on outside for cool-air ducts
- Types of Dampers:
  - Opposed Blade/Balancing: regulates the flow of air
  - Splitter Vanes: used where duct branches off for flow control
  - Conventional Turns: reduces friction at the corners
  - Turning Vanes: reduces friction at the corners
- Fans
  - There are many types of fans, bladed fan is the most common
  - Centrifugal fan is used for moving large amounts of air (it's sometimes called a squirrel cage)
- Diffusers
  - Control the way the air enters a space from ductwork
  - Slow the velocity and enhancing mixing into the surroundings
  - Used on both all air and air water HVAC systems
  - Deliver conditioned and ventilation air
  - Evenly distribute flow of air as desired
  - Create low velocity air movement int he occupied portion of the room
  - Do it all as quietly as possible
  - Can be round, rectangles, linear slot diffusers
- Chimney
  - The height of a wood burning chimney depends on the roof it is sticking out from
  - It must meet safety (distance from the roof and combustibles) and draft capabilities requirements
  - The highest point in which the chimney passes through the roof must be at least 3'-0" below the top of the chimney (aka: it must be at least 3'-0" tall, measured from the tallest side)
  - The top of the flue must be 2'-0" higher than any part within 10'-0" horizontal of the flue



These rules are minimums. In some instances, chimney height may need to be increased to achieve sufficient draft.

Processes:
- In the HVAC design process, component sizing typically occurs before resolving conflicts with other building systems
- Sizing HVAC Systems
  - System capacity: determine the primary determinants in sizing equipment...the total heat losses and gains a building will experience in the most extreme conditions
    - Design heat loss can be best described as an estimation of the worst likely hourly heat flow from a building to the surrounding environment based upon a chosen outside temp
  - Locating a heat source below a window evens out the temperature in a room, but increases the heat loss through the window.
  - Mechanical Room Space Requirements:
    - Preliminary sizing for medium to large buildings should be 3% - 9% of gross building area for air or air/water systems

- Allow 1% - 3% for water systems
- Area will accommodate all equipment (e.g.: boilers, chillers, fans, pumps, piping)
- Space needs to be twice the length of the major equipment (e.g.: boiler or chiller) and 12'-0" - 18'-0" tall

- Ductwork Distribution and Sizing:
  - Allow 3 sq.ft. - 6 sq.ft. for every 1,000 sq.ft. of floor space for horizontal and vertical duct runs.
  - 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.

Thermal + Moisture Protection

Vocabulary:

- **Air Barrier:** membrane that controls air leakages into and out of the building envelope
- **Vapor Diffusion Retarder:** a material that reduce the rate at which water vapor can move through material.
- **Perm:** unit of permeability for a given material, expressing the resistance of the material to the penetration of moisture. One perm = flow of one grain of water vapor through one square foot of surface per hour with a pressure difference of one inch of mercury.
- **Air Sealing:** the process of sealing ducts, openings, and cracks to prevent air leakage

Facts/Rules:

- Insulation Types:
  - Blanket (Batts and Rolls):
    - Fiberglass, Mineral Wool, Plastic Fibers, Natural Fibers
    - Used in unfinished walls, foundations walls, floors, ceilings
    - Fitted between studs, joints, and beams
    - Suited for standard stud spacing
  - Concrete Block and Insulated Concrete Blocks:
    - Foam Board placed on the outside for new construction and inside for existing
    - Used in unfinished walls, foundation walls, walls
    - Insulating cores increase wall R-Value
  - Foam Board or Rigid Foam
    - Polystyrene, Polyisocyanurate, Polyurethane
    - Used in unfinished walls, foundation walls, floors, ceilings, unneeded low slope roofs
    - Interior application must be covered with gyp board for fire safety
    - Exterior application must be covered with weatherproof facing
  - Insulating Concrete Forms
    - Foam boards or blocks:
    - Used in unfinished walls, foundation walls
    - Part of the building structure - the insulation is literally built in
  - Loose Fill and Blow In
    - Cellulose, Fiberglass, Mineral Wool
    - Enclosed existing wall or new wall cavity, unfinished attic floors, hard to reach places
    - Good for adding extra insulation

- Reflective Systems:
  - Foil Faced Kraft Paper, paper film, polyethylene bubbles, cardboard
  - Unfinished walls, ceilings, and floors
  - Foil, films or paper fitted between wood frame studs, joists, rafters, beams
- Rigid Fibrous or Fiber Insulation:
  - Fiberglass, Mineral Wool
  - Ducts in unconditioned spaces, high temp spaces
- Sprayed Foam and Foamed in Place:
  - Cementitious, Phenolic, Polyisocyanurate, Polyurethane
  - Use in enclosed existing wall, new walls, unfitted attic floors
  - Good for adding insulation
- Structurally Insulated Panels (SIPs)
  - Foam board or liquid foam insulation, straw core insulation
  - Unfinished walls, ceilings, floor, and roofs
  - Provide superior and uniform insulation

- Air Barriers:
  - 25 - 40% of heating energy is lost due to infiltration
  - Air Barriers provide a continuous pain of air tightest with all moving joints made flexible while still being sealed
  - Types of air barriers:
    - Mechanically attached:(e.g.: Tyvek, which is moisture and air barrier)
    - Self-Adhered: typically water resistant and vapor barrier
    - Fluid Applied: heavy bodied paints or coatings including polymeric based
    - Closed Cell: density spray applied polyurethane foam which provides insulation too
    - Boardstock: (e.g.: 12 mm plywood or OSB, or 25 mm extruded polystyrene)
  - Some air barriers can las be water vapor permeable, while others can perform the function of a vapor barrier too
  - Air permeability is ≤ 0.004 cfm/ft^2 under a pressure of 0.3" of water
- Vapor Diffusion Retarders (often referred to as vapor barriers)
  - Prevent movement of water vapor out of building in cold climates and into buildings in hot climates.
  - Should go on the "warm side of the insulation"
    - In the Northwest that means it's located between the insulation and inside space
    - In the Southwest it's located between the insulation and the outside space
  - The ability of a material to retard water vapor is measured in perms
  - Control moisture in walls, slabs on grade, floors, crawlspaces, ceilings, etc
  - Only retard moisture due to diffusion, most moisture actually gets in via capillary action or through air leaks
  - Types of Vapor Diffusion Retarders:
    - Membrane: thin and flexible like paper-faced fiberglass roll insulation or foil backed wall board. Can also be rigid and thick like rigid foam insulation, aluminum, stainless steel, which are fastened and sealed a joints
    - Coatings: paint-like system applied as a liquid
  - Classes of Vapor Retarders:

Class I (less than 1 perm)	=	Glass Sheet Metal Polyethylene Sheet Rubber Membrane

Class II (1 - 10 perms)	=	Unfaced expanded polystyrene 30 lb. Asphalt coated paper Plywood Bitumen coated Kraft Paper
Class III (10 or more perms)	=	Gypsum Board Fiberglass insulation Cellulose Insulation Board lumber Concrete Block Brick 15 lb. Asphalt coated paper House Wrap

- Combo Air Barrier/Vapor Diffusion Retarders
  - Control air movement and water vapor diffusion with one material
  - Often used in souther climates where keeping out the humidity is important
  - Generally located around the perimeter of the building just under the exterior finish (or are the exterior finish)
  - Must be carefully sealed at all seams and penetrations including joints, windows, doors, outlets, stacks, and vents

Concepts/Goals:

- Materials expand and contract due to changes in temperature and moisture content
- Thermal movement is easy to calculate, moisture...not so much.
- Controlling moisture improves air sealing and insulation
- Ventilation is also part of moisture control
- Moisture problems can happen anywhere in and around a building and depend on climate, site conditions and type of construction

CONTENT AREA: ELECTRICAL

Building Design

Vocabulary:

- **Ion:** electrically charged atom or group of atoms
- **Watt:** the standard measurement of power, equivalent to 1 joule per second
- **Kilowatts:** 1,000 watts
- **Horsepower:** A measure of power equal to 746 watts
- **Circuit:** a conductor, flow of energy, an electric potential difference (voltage), and some type of medium that creates resistance to flow.
- **Ohm's Law:** the building block to energy. It states that current is directly proportional to voltage and indirectly proportional to resistance. If voltage goes up, current goes up. If voltage goes down, current will go down.
- **Current (I):** measured in amps, it's the amount of flow through a circuit
- **Voltage (V):** measured in volts, the amount of force or potential in a circuit
- **Resistance (R/Ω):** measured in ohms, the amount that slows down the current
- **Power (P):** the rate of energy transfer, expressed as energy / time (in hours)
- **Amp:** when one column of charge passes a point in one second
- **DC Current:** current that flows in one direction with constant voltage (e.g.: batteries). Typical for low voltage applications which are less dangerous as there's less current
- **AC Current:** Direction of the flow can be reversed rapidly by reversing the voltage resulting in a sine wave when plotted. The standard form of electrical current supplied by the utility grid and by most fuel powered generators.
- **Single Phase Electric Power:** distribution of AC power using a system in which all the voltages of the sully vary in unison, used when loads are mostly lighting and heating with few large electric motors.
- **3 Phase AC Current:** like an AC current but three different circuits each 120˚ out of phase with the other and one neutral circuit
- **Impedance:** the resistance in an alternating current, measured in Ohms.
- **Power Factor (PF): t**he phase difference between voltage and current in AC circuits. aka: cosine of the angle between the voltage wave and resultant current wave, ranges from 0.0 to 1.0 and expressed as a percentage
- **Load Factor:** the ratio between the average and maximum power demands of a building
- **Reactance:** part of the electrical resistance in an alternating current circuit cased by inductance and capacitance
- **Motor:** a machine that converts electrical energy into mechanical energy
- **Generator:** a machine that converts mechanical energy into electrical energy
- **Alternator:** AC generator that commercially produces AC current by converting mechanical energy to AC
- **Transformer:** device that transfers energy from one circuit to another by magnetic coupling with no moving parts. It changes the voltage (or force) of an AC circuit to a higher or lower value
- **Volt-Ampere (VA):** the unit used for the apparent power in an electrical circuit, only useful in the context of AC circuits.
- **KVA:** a rating for transformers equal to the product of volts and amperes divided by 1000. The product of the KVA and the power factor gives the power in kilowatts
- **Demand factor:** ratio of maximum demand or expected power usage to the total connected load

Equations: (those in gold are given on ncarb formula sheet)

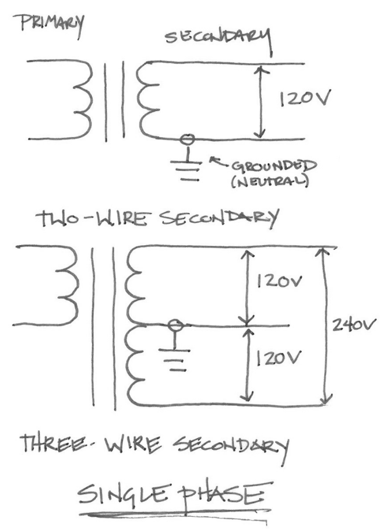
Series Resistances (R_{total})	=	$R_1 + R_2 + R_3 + \ldots. R_n$
Parallel Resistances ($1/R_{Total}$)	**=**	$1/R_1 + 1/R_2 + 1/R_3 + \ldots. 1/R_n$
Ohm's Law: Current (I)	=	Voltage (V) / Resistance (R Ω)
DC circuit Power (watts) W	=	I x V
AC circuit Power (watts) W	=	I x V x PF
AC 3 Phase Power (watts) W	=	I x V x PF x $\sqrt{3}$
Energy in a system (watt hour)	=	Power (W) x Time (T)

Units for Electricity are watts per square foot

Facts/Rules:

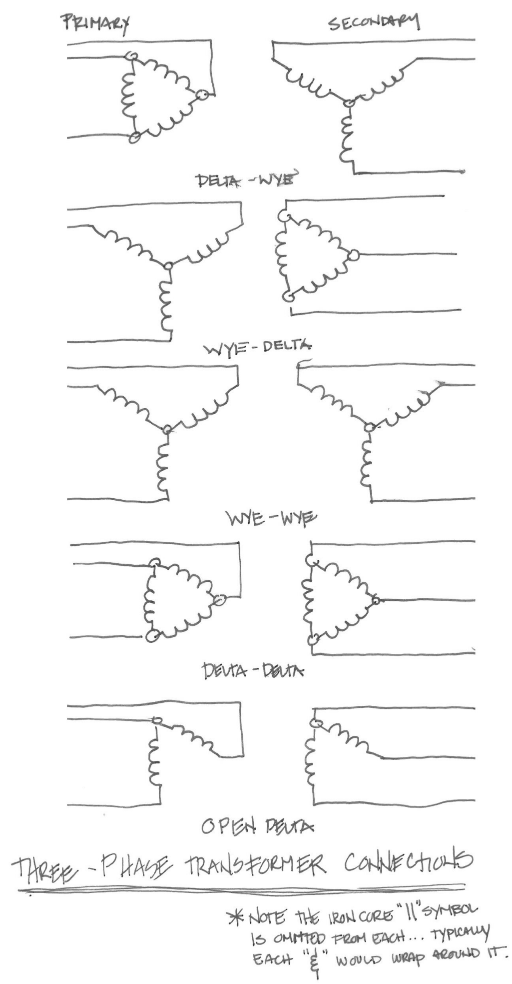
- **Watt:** the standard measurement of power, equivalent to 1 joule per second.
  - Power is a measure of the rate at which energy flow
  - Watts are basically the "miles per hour" measurement of an electrical circuit, they tell you how fast electrons are moving around the circuit. They:
    - Represent a unit of energy over time
    - Imply a rate (a "per second" value)
    - Measure something at an instant
    - Examples:
      - A lightbulb might consume about 60 watts
      - A medium size car might consume about 100,000 watts
      - A small gas generator puts out about 2,000 watts
    - **1 watt = 3.412 BTU**
  - However: there is no such thing as "watts per hour"
  - "Watt Hours" (or more commonly kilowatt hours, kWh) are a measure of energy
    - Energy is the capacity to do work, like create heat, light, or motion
    - Examples:
      - A Watt Hour is the amount of energy to run a 3,600 watt appliance for 1 sec
      - Or run a 60 watt lightbulb for 1 minute
      - Or run a 1 watt appliance for 1 hour
  - Watt is also a rate of energy. To get watts into energy = watts x time
- Circuits
  - A basic electrical circuit consist of a conductor, current (the flowing electrons), voltage (the potential difference that causes the electrons to move), and some type of resistance to the flow.
    - Circuits can be interrupted by a switch
    - In parallel circuit, the current at each load depends on the resistance of each load
  - High Voltage Circuits = >1,000 V A/C power or > 1,500 V D/C power
  - Low Voltage Circuits = 50 - 1,000 V A/C power or 120 - 1,500 V D/C power
  - Extra Low Voltage Circuits= < 50 V A/C power or <120 V D/C power
  - High Voltage: electrical energy at voltages high enough to inflict harm or death upon living things.
    - Used in electrical power distribution, cathode ray tubes, to generate x-rays, and other scientific applications
  - Low Voltage: circuits that are exempt from the protection of high voltage, most commonly reefs to mains voltage or power transmission lines

- Extra Low Voltage: is a low risk, and used for things like intercoms, remote lighting, doorbells, HVAC.
- 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
- Making or Generating Power:
  - Alternator: the most basic way to make power, an AC current
  - **Transformer:** change the voltage (force) of an AC current to a higher or lower value
    - Separate wires are wound around an iron core.
    - The wire with a greater number of winds has a higher voltage
    - The wire with less winds has a lower voltage
    - Transformers change voltage in a circuit but not the total power
    - "Step Up Transformers" increase the voltage
    - "Step Down Transformers" decrease the voltage (typical for buildings b/c voltage coming in is higher than it should be for appliance and lighting)
    - Used to step up voltage in order to transmit power over long distances without excessive losses and step down voltage to household levels
    - Must be placed outside of a building or within a fireproof vault due to humming noise, toxic fluids, and ventilation requirements
  - Connections:

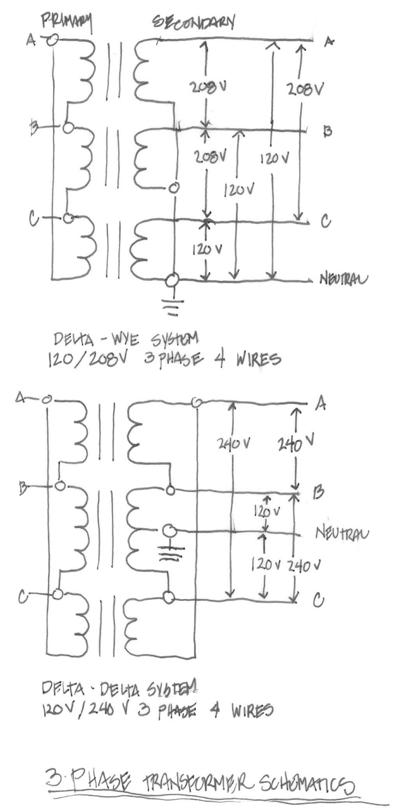


    - **Primary winding:** used for input in a transformer
    - Secondary winding: used for output and can be divided into segments so that they output voltage depends on which settlements are used.
      - **Two Wire Secondary:** one wire is grounded and becomes neutral
      - **Three Wire Secondary:** consists of two segments; one lead is at one end of the secondary, a second connected to the midpoint of the secondary and grounded, and the Third is connected to the other end of the secondary
    - In <u>three phase transformers</u>, multiple leads on the secondary windings and different configuration of both the primary and secondary windings can occur
      - Connection types are the **wye** (shaped like the letter Y) and **delta** (shaped like a triangle)
      - **Wye:** used when all the loads in an AC system are connected at a single point and a neutral cable is connected at that center point where the three phases meet. Most low voltage distribution lines are Wye
      - **Delta:** used when three phases are connected like a triangle and don't have a neutral cable.
      - Primaries are usually connected to a Delta
      - Wye connections are symmetrical so the voltage from each of the three phase wires to the neutral is the same. That means that the voltage from each to phase to the neutral equals the voltage from line to line dived by √3 (or 1.73)
      - *<u>If</u>* a neutral is added to a delta, the voltage from two of the phase wires to the neutral is 1/2 of the phase to phase voltage. The voltage from the third phase to the neutral is 0.866 times the phase to phase voltage….no loads are connected between these two points though.

- Three Phase Transformer Connections:
  - Wye Delta: Commonly used in step down transformers, wye connection on the high voltage side reduces insulation cost. The neutral point on the high voltage side can be grounded
  - Delta Wye: stable with respect to unbalanced loads
  - Delta Delta: Commonly used in step up transformer for the same reason as Wye Delta
  - Wye Wye: offers the advantage that one of the transformers can be removed with the reming two transformers can deliver three phase power at 58% of the original bank



- **Power Supply:**
  - Most common form of energy used in buildings is alternating (AC) current
  - Direct Current (DC) is used for some types of elevator motors and low voltage applications like signal systems and controls
  - **120V / 240 V Single Phase (one transformer), Three Wire System**
    - Most common power for residential and very small buildings
    - Single phase systems come from a three wire secondary
    - Consists of two hot wires, each carrying 120V and 1 neutral wire
    - Appliances that requires 240V use both hot wires
    - Used where actual load does not exceed 80A, although some service is considered for 100A
    - 120V is used for plugs, lights, and some small equipment
      - The feed is simple, and the panel is simple
    - When do you go to 240V system?
      - When the current draw is huge
      - When you can save $ on wire
      - When there's no other choice...
      - Typical 240V loads include:
        - Air conditioning / electric heating systems
        - Electric dryers/ Electric water heaters
        - Large appliances (microwaves and stoves)



- **208 / 480 V Three Phase (three transformers) System**
  - Three circuits carry three alternating currents which reach their instantaneous peak values at different times
  - Has an effect of giving constant power transfer over each cycle of the current and makes it possible to produce a rotating magnetic field in an electric motor.
- The difference between single phase and three phase:
  - Single phase power is 60 cycles / second (called hertz)
  - Three phase power is 60 cycles / second (again, called hertz) in three phases that are separated in time. Each phase is 1/3 cycles apart
  - 3 phase system give a wider set of options for use
  - Small Buildings usually get 120/240 single phase or 120/208 three phase service
  - Larger Commercial/Industrial require higher voltage and get the three phase services like 277/480 volts
  - Higher voltage allows for a larger number of fixtures to be on a single circuit without an increase in current.
- **120 / 208 V three phase (three transformers), four wires system**
  - Used in larger buildings because it allows for a variety of electoral loads
- **277 / 480 V Three Phase (three transformers), four wires system**
  - The same as 120/208V except for higher voltage
  - Smaller feeders, conduit, smaller switchgear because of higher voltages
  - Higher voltages result in small currents the equipment needs to carry
  - Buildings usually have 277 V fluorescent lighting that requires smaller wiring
  - Small step down transformers are used where 120 V service is needed for receptacles and equipment

Voltage	Phase	Wires	Connection	Use
120	1	2	2 wire	
120/240	1	3	3 wire	• Residential, small buildings, or where actual load is less than 80A
240	1	3	Delta	• Commercial
120/240	3	4	Delta	• High Leg Delta typically only found in older buildings
480	3	3	Delta	• Commercial
208	3	3	Wye	

Voltage	Phase	Wires	Connection	Use
120/208	3	4	Wye	• Larger buildings with greater variety of loads
480	3	3	Wye	• Commercial
277/480	3	4	Wye	• Larger buildings, smaller feeders, conduit sizes, switch gears that lower voltage
2400/4160	3	4	Wye	• Huge commercial buildings and factories

- *Example:*
  - *The best distribution system for a large, multistory building that principally uses fluorescent or HID lamps is 277/480V 3phase, 4 wire*

Concepts/Goals:

- Electricity generation as we know it wasn't discovered until the 1820s
- Basic idea is that electricity is generated by the movement of a loop of wire between the poles of a magnet.
- Electricity is the energy caused by the flow of electrons.
- Think of electric flow like water flow.
  - Voltage (volts) : Height, pressure, (psi)
  - Current (amps): Flow (gallons per minute)
  - Resistance (ohms) : resistance to flow (inches per feet)
- There are two major misconceptions about electricity:
  - That current is only pulled through a circuit
  - That current is just flow

Processes:

- Electrical Design involves calculating loads, designing a system, roughing-in, and finishing& close out.
- Step One: Calculating Electrical Load (note: typically you'd have a consultant on board for this)
  - Figure out how much lighting there will be (watts/ft^2)
  - Figure out how much plug load will be (watts/ft^2)
  - How many spaces and subdivisions are there?
  - What's the metering and service size?
  - *For example:*
    - *A circuit of plugs in your home has two floor lamps (300 watts each), a home entertainment center (750 watts), a computer work station (900 watts) and the occasional vacuum (600 watts). What is the current expected from this circuit? What size should the breaker be?*
      - *Figure out the load:*
        - *2 (300 watts) + 750 watts + 900 watts + 600 watts = 2,850 watts*
      - *Convert to amps to find the current:*
        - *2,850 watts / 120 volts = 23.76 amps*
      - *Size the breaker:*
        - *Breakers come in 10A, 15A, 20A, and 30A so you'll need a 30A for the circuit*

- Step Two: Design the system based on a single circuit or triple circuit system
- Step Three: Rough In the System (the first part of construction), includes:
  - Circuits and separation
  - Outdoor and Indoor on different circuits
  - By space, type and zone
  - Inspections, there are usually two, sometime three
  - Expansion
  - Organization
- Step Four: Finish and Close Out, includes:
  - Inspections need to happen
  - Temporary power and safety (most dangerous on job site)
  - Coordination with other trades
  - Punch list and closeout with architect
  - Equipment startup (Which can be very time consuming for large buildings)
  - Switching to permanent power

Implications of Design Decisions

Equations: (those in gold are given on ncarb formula sheet)

Demand Charge = maximum power demand x demand tariff

Facts/Rules:

- Electricity is the most prevalent for of energy in a modern building
- Electricity constitutes a form of energy itself that occurs naturally only as lighting/static discharge or in galvanic cells which cause corrosion
- The National Electrical Code is the minimum standard for all electrical design
- Selection of electrical materials involves choosing materials that are functionally adequate but also economically appropriate
  - From an energy point of view, electrical systems are more passive than HVAC systems and energy costs that are often the decisive factor in analysis
  - Life cycle costing is imperative when selecting a system. What kind of method is your building getting power? Is it affordable now...and will it be tomorrow?
- Different services are available for different building types
  - Residential = Small Use
  - Small Commercial = Small Use
  - Large Commercial = Big Use/Big Lines
  - Industrial = Huge Use/Huge Lines
  - General Service = Big complexes and campus infrastructure
- Utilities, their rates, and their supply depend on a lot. You have to understand which charges are assed and how you can design to minimize costs to the user
  - Utility rates change with respect to:
    - Region (we have cheap electricity and gas in the Northwest)
    - Supplier (different hole = different gas)
    - Fuel source (does it burn or not?)
    - Laws (vary from state to state
    - Politics (diplomacy, wars, etc.)
    - Country (different governments and rules)
    - Amount Used (bigger is cheaper)

- A **ratchet clause** (where the demand charge is based on the highest measured demand, or percentage of, over the previous year) is disadvantage for users with a low yearly load factor

- **Energy Source Options These Days:**
  - Natural Gas
    - Sold by therms (a therm is 100,000 BTU)
    - In the Northwest a therm is about $0.80
    - Measured with cubic feet and gas heat value
    - Heat value changes over time with the supplier and with the time of year
    - Utility company takes care of it
    - It's noticeably cheaper than electric
    - Rates are stepped
    - Gas is less expensive the more you use
  - Gas/Oil Generators
    - 10-1,000 megawatts
    - Simple process made by huge machines
      - AC = Alternating Current, DC = Direct Current
      - Found in the midwest and Texas
  - Coal Plants:
    - 20 - 3,000 megawatts
    - The biggest of the big
      - Need a reservoir to get rid of heat
      - Burn coal - which makes steam - which turns a big wheel to make energy
      - Problem is that they're dirty, are a culprit for CO^2 and sulfur
        - Particulates can cause asthma attacks
        - Acid Rain results (particularly in Europe)
        - Power plant and mines tend to be located in poor economic areas
      - After coal is minded all that is left are huge craters
      - Found in the East coast
  - Hydroelectric:
    - 6,500 megawatts
    - Dam - push water through - spin wheel
    - Renewable source, no pollution
    - Some environmental issues
    - Half the cost of other systems
    - Found in the Northwest
  - Photovoltaic:
    - 200 watts each panel (not much produced!)
    - Solar energy
    - Sun shines on Solar Panels - no moving parts - goes to generator to make energy
    - Can be cells, panels, arrays, fields
    - A huge array of panels is needed to do any good
    - Increases in PV module efficiency, new materials, and other initiatives have brought the cost of PV (per peak Watt) to about $0.25 - 0.50
    - Today's commercial two-layer PV arrays have a maximum insolation-to-electric energy conversion rate of 12%
    - The tilt angle of a PV array, to capture maximum insolation when the sun is lowest, should be equal to the site latitude plus 15 degrees

    - A PV system battery is generally expected to supply all of an installation's electrical requirements for a period of 3 days of cloudy weather
    - Sealed PV system battery types require the least maintenance
  - Wind Power
    - Newest system with big potential
    - Wind - turns a wheel - which goes to generator
    - Wind has to be strong and steady
    - A noisy contraption
    - Blades are 90 feet and one ton each...can cause some serious damage
    - Found in the northwest
  - Nuclear Power
    - A complex process
    - Split atoms - which hit other split atoms - which makes heat
    - Water runs around uranium rods - makes steam - which makes heat
    - Eventually rods run out of uranium and are toxic
    - Was supposed to be the cure for our energy problem
      - Accidents happened everywhere and the insurance industry panicked (e.g.: 3 Mile Island, Browns Ferry, Challenger, Chernobyl (the big one))
      - No new orders for nuclear power have been placed since 1990
    - In the US power plants have to have insurance, not one insurance company will insure nuclear power
- Electricity Service
  - For every energy unit consumed (usually a kWH) the electrical utility charges a little bit. Typical rates are:
    - 5.5 cents / kWh for residential
    - 1.75 cents / kWh for large industrial
  - Tiered rates are often implemented
    - You pay so much for the first batch of kWh, then a little more for the next batch…
  - Electrical energy cost is directly related to energy consumption, except in the case of utility demand charges
  - Demand is based on how big the service needs to be (wires, transformers, etc)
    - Residences are easy, it's all small wires and units
    - Bigger customers (industrial, commercial, etc) have bigger wires and takes time and money to install and maintain
    - The utility department has an obligation to provide power that covers the peak need of a user. The user, of course, has to pay for it.
    - The most power that an installation pulls at any given time over a month is measured in kilowatts (kW)
    - Your demand is measured every 15 minutes by the utility company and you pay the largest demand they measured that month
    - Residential Cost = Basic Charge + (kWh) x ($/kWh)
    - Commercial Cost = Basic Charge + peak kW demand $ + (kWh) x ($/kWh)

Building Systems + their Integration

Vocabulary:

- **Conductor:** means by which a current is conducted, typically cable and wire
- **Conduit:** tubes that house, protect, support, and provide grounding for wiring.

- **Grounding:** a safeguard that allows a current to find an easy path to the earth, eliminating electrical load and protecting people from shock.
- **Short Circuit:** accidental low-resistance connection between two components of an electrical circuit that are meant to be at different voltages.
- **Insulation:** a material of very low conductivity used to separate electrical conductors and prevent leakage of electrical currents
- **Transducer:** device which converts power in one kind of system to power in another form, such as loudspeaker which converts electric power to acoustic power.

Facts/Rules:

- Conductors:
  - Basic material of electrical system
  - Sizes are based on American wire gauge (AWG) and thousand circular mil (MCM) designations
  - **American Wire Gauge System:**
    - A standardized wire gauge system used since 1857 for the diameter of round, solid, nonferrous, electricity conducting wire
    - Cross Sectional area of each gauge in an important factor for determining its current carrying capacity
    - Increasing gauge numbers give decreasing wire diameters
    - No. 36 AWG = 0.005 inches
    - No. 0000 AWG (aka 4/0 pronounce “four aught”) = 0.46 inches
  - Larger than 4/0 is MCM cable sizes of 250, 400, and 500.
  - **Circular Mil:** the area of a wire having a diameter of one mil or 0.001 of an inch, used in specifying wire size
  - Current carrying capacity of a conductor depends on the size, type of insulation around it, and surrounding temperature
  - Use 14 gauge minimum in buildings
  - Wire Types:

Type	Use	Description
Wire Types (No. 8 AGW or smaller)		
Aluminum	Commercial	• Requires a special installer • Oxide can form when joints loosen and/or overheats • Must be larger than copper to carry amperage • Limited to primary circuits because of overheating
Copper	Residential/ Small Construction	• Same carrying capacity as aluminum but smaller and cheaper • Most cost effective for small and medium sized wire and cable

Type	Use	Description
Cable Types (No. 6 AGW or larger, or several conductors assembled into a single unit)		
Romex	Residential, Wood Framed less than 3 stories	• Nonmetallic sheathed cables • 2+ plastic insulated conductors and ground surrounded by a moisture resistant sleeve • No conduit required, it's an alternative • Must be protected from damage within walls, etc.
Flex Metal Clad Cable (BX)	Remodel/ Residential	• Flexible metal clad cable • 2+ plastic insulation conductors encased in spiral wound strip of steel tape • No conduit is required • Can be easily pulled
Busbar		• Rectangular bars of copper that carry high voltage • Used in place of very large cables and high currents
Busway		• Multiple busbars in a metal housing

- Conduit Types:
  - Supports and protects wiring and serves as ground and protects surrounding construction from fire in case of overheating
  - Used for large residential and commercial projects

Type	Use
Rigid Steel	• The safest type • After pipe is installed (indoor/outdoor) wires are pulled through • Connections are rigid and threaded like pluming pipes • Connect to J-boxes and devices
Intermediate Metallic	• Steel conduit with thinner walls but same outside diameter as Rigid • More economical • Use with threaded fittings
Flex (Flexible Metal)	• Used everywhere except underground • Reduces vibration transmission from equipment where not possible to install rigid
Electric Metallic Tubing	• Thinnest metal conduit • Too thin to thread, connections are made with clamps • Easy/fast install • Not allowed in hazardous areas

- Grounding:
  - A common return path for current and/or a direct physical connection to the earth
  - Done to prevent user contact with dangerous voltage if electrical insulation fails
  - Limits the build up of static electricity
  - Electrical circuits are connected to the ground (earth)

- Raceways:
  - Channels for holing electrical wires
  - 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 the 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
    - Preset inserts are placed for tapping
  - Under Carpet Wiring: thin, flat wiring that can be laid under carpet without protruding
    - Must be used with carpet tile
- Motors:
  - DC Motor: small scale applications, elevators
  - Single Phase AC Motor: 3/4 horsepower or less
  - Three Phase Induction Motors: extreme reliability and remain constant in rpm
  - Universal Motor: vary in speed based on the load, found in hand drills, mixers, etc.
- Capacitors:
  - Two places separated by an insulating layer
  - Current is stored on one plate and eventually the stored amount is discharged
- Raised Floors:
  - An elevated structural floor above a substrate that allows for electrical and mechanical systems to run in the void
  - Used in offices, data centers, wherever electrical distribution is frequently changed
- **Lighting Protection**
  - Lightning is a random and unpredictable event
  - Current levels can exceed 400 kA, temperature can exceed 50,000ºF and speeds approaching 1/3 the speed of light
  - If lighting travels through porous and water saturated materials, these parts of a building might literally explode if water content is flashed to steam by heat produced from lightning current
  - Lighting Strikes the Earth by:
    - Leaders from a thundercloud pulse toward the earth seek out active electrical ground targets
    - Ground based object (e.g.: trees, corners of the building, fences, people, lighting rods) emit varying degrees of electrical activity during this event
    - Some leaders will likely connect with the streamers. Then the “switch” is closed and the current flows, we see lightning
  - Options for protecting a building from lightning
    - Lightning Rods and conductors
      - A conductive rod is attached to upper points of a roof structure and electrically bonded by bonding conductors called downleads.
      - Downleads are connected by the most direct route to one or more grounding or gathering terminals
    - Overhead grid of wire conductors extended to the ground
    - Lighting rods connected to the building’s steel frame and then to the ground
      - Steel framed structures can bond the structural members to earth to provide lightning protection.

- A metal flagpole with its foundation in the earth is its own extremely simple lightning protection system. However, the flag(s) flying from the pole during a lightning strike may be completely incinerated.

Concepts/Goals:
- Electric heaters are 100 percent efficient. All energy is converted into heat.
- Electric heat as a radiant heat source is efficient because it heats people, not the air

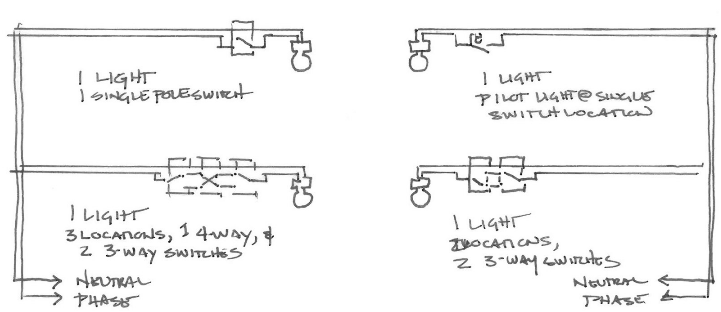
Construction Details + Constructability

Vocabulary:
- **Load Factor:** the ratio of average power used to the maximum power demand
- **Load Control:** a building's electrical system is designed to avoid peak electricity use.
- **Contactor:** switch that is usually magnetically operated used to open and close an electric current
- **Feeder:** set of electrical conductors which extend from the source of energy to a distribution center
- **Service:** the portion of a building's electrical system extending from the utility company's wires to and including the main switch and meter
- **Switchgear:** central electrical distribution center that consist of an assembly of switches, circuit breakers and cables or bus-ducts that distribute power to the building
- **Panelboard (Breaker Box):** a component of an electrical supply system which divides and electrical power feed into subsidiary circuits while providing a protective fuse or circuit breaker for each circuit, in a common enclosure
- **Branch Circuit:** the insulated wires that run between the outlet and the panel board
- **Circuit Protection:** devices used to protect from overload and short circuiting
- **Circuit Breaker:** a switching device that can make, carry, and break current under normal circuit conditions
- **Fuse:** a thin strip of metal that melts and breaks an electrical circuit if a current exceeds a safe level
- **Ground Fault Interrupter (GFI):** detects small current leaks and disconnects the hot wire, typically used in kitchens, bathrooms, and outdoor outlets
- **Emergency Power System:** type of system which may include lighting, generators to provide backup power resources in a crisis or when regular systems fail.
- **Uninterruptible Power Supply (UPS):** an electrical apparatus that provides emergency power to a load when the input source fails. Typically used to protect computers, data centers, telecom equipment, or wherever power outage can disrupt business

Facts/Rules:
- Electrical Utility Service:
  - Utility company typically require that service be made available at property lines, tapped into at an agreeable location
  - Electrical construction work on private property is typically an expense of the owner
  - Overheads Underground:
    - Overhead is low cost, easy to maintain, and able to have long service runs
    - Overhead is unattractive, can't really handle severe weather conditions, wind, snow, ice, tree falls.
    - Underground is attractive, reliable service, and has a long life
    - Underground is much more expensive.

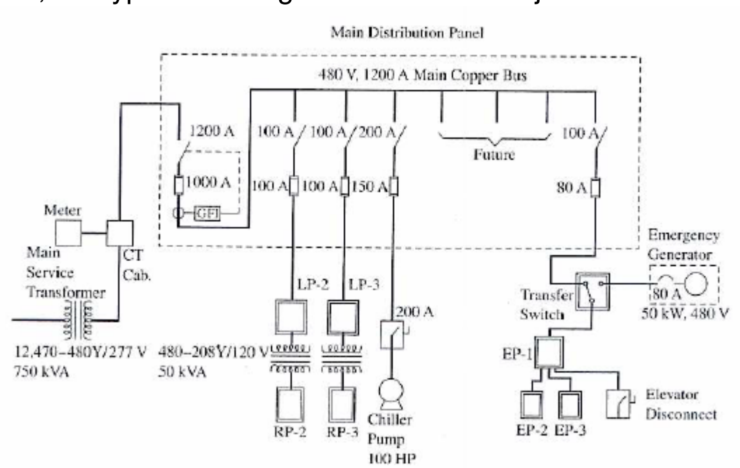
    - A power utility will most likely find overhand transmissions economically feasible for voltages greater than 5,000 V
- Metering:
  - Must be provided before the building service entrance switches
  - Located at the utility or the facility's voltage (service point inside the building) doesn't matter which.
  - If metering is read by the municipality remotely, meter equipment must still be provided for service and inspection.
  - If high voltage service is needed, the owner must buy transformers and equipment needed beyond the typical service connection...rates are often lower to compensate
  - If low voltage service is desired, the utility company provides the equipment, but the rates are higher
  - Most common meter is the **watt-hour meter** which registers power over time kilowatt-hours
  - A low load factor impels an 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
    - Encourages conservation of energy because utility companies have to provide energy based on peak
- Primary Distribution:
  - A central electrical distribution center that consists of an assembly of switches, circuits breakers and cables that distribute power to the building is called **switchgear**
  - A load center pad-mounted unit substation would typically have a primary voltage range of 2.5-15 kV
  - The most popular form of exterior transformer installation for individual buildings is mounted on a concrete pad
  - In a typical building electrical power system wiring closet, dry-type transformers are typically placed between plug in busways and 120V panelboards
  - A meter and transformer are included in with it to split power into separate circuits, each with a master switch and circuit breaker for protection
  - Switchgear also distributes power to substations for further transforming and distribution as part of a secondary distribution system
- Secondary Distribution System:
  - Power is distributed from the main switchgear to **panelboards**
  - Panelboards (or breaker box) divides the electrical feed into subsidiary circuits while providing a protective fuse or circuit breaker for each circuit
  - Typical power voltages of 120V, 240V, and 277V
  - Distribution is made with wires in conduit, underfloor raceways, or flex cables
  - Protected by circuit breakers typically 15A and 20A, also come in 10A and 30A...with 100A for main disconnects
  - Breakers should be oversized when a motor in involved
  - When designing a system, plan ahead. Where will it come in from, where is the main panel, and how much will it grow?
    - Typically you should oversize systems by about 25% for future expansion
    - 25% of the breaker box should be empty holes for new circuits
  - In commercial spaces, an electrical closet might be preferable to a stand-alone panelboard for a building of 6 or more stories.

- Branch Circuits
  - Every circuit has a hot, neutral, and ground wire
  - Ground and neutral have two unique functions in an appliance connection
  - Hot wire is the start of the lead, neutral is the other side of the lead together these power the appliance (e.g.: power goes in the hot, to the appliance, and out the neutral back to the panel)
  - Third prong on a plug is the ground, which protects life safety
  - If the neutral leg breaks, the ground still is there to keep it safe
  - Protection for circuits:
    - **Ground:** provides a path for fault, both ground wire and neutral wires are grounded at the bulling service entrance to a grounding electrode
    - To avoid the risk of electric shock, it is recommended that appliance housings be grounded to a cold water pipe
    - **Ground Fault Interrupter (GFI/GFCI):**
      - Detects a continual current lost to the ground, even after power is shut off
      - Might not trip a circuit or burn a fuse but still not good
      - Typically used on any 15 or 20 amp circuit where water is or might be present (eg: bathrooms, garages, outdoors)
      - If an outlet is within <u>6’-0” of a water source</u> then it must be GFCI to eliminate potential shock hazard
    - **Fuses:** devices composed of soft metal link in a glass plug rated for certain flow.
      - Can be used only once, when it breaks it’s done
    - **Circuit Breakers:** devices that disconnect a circuit when the current is excessive
      - Can be reset after troubleshooting
  - A circuit that feeds a motor must be oversized so that the rated load of the motor is not more than 80% of the capacity of the circuit. NEC requires that for single motor installation, the current used in the wire size calculation must be 1.25 times the load current from the applicable single-phase or 3-phase tables.
- Switches:
  - One Switch Location: (1) two way (on/off) switch is used
  - Two Switch Locations: (2) three-way switches (on/off, on/off) are used
  - Three or More Switch Locations: (2) three-way switches, and (1 +) four-way switches
  - Low voltage Switching: operated on 24V circuit and controls relays that provide the 120V switching.
    - Same light can be controlled from several remote positions
    - Central control station can be set up for monitoring and override
    - Less expensive than line-voltage wiring and devices for large installations that need to be flexible.



SWITCH WIRING—

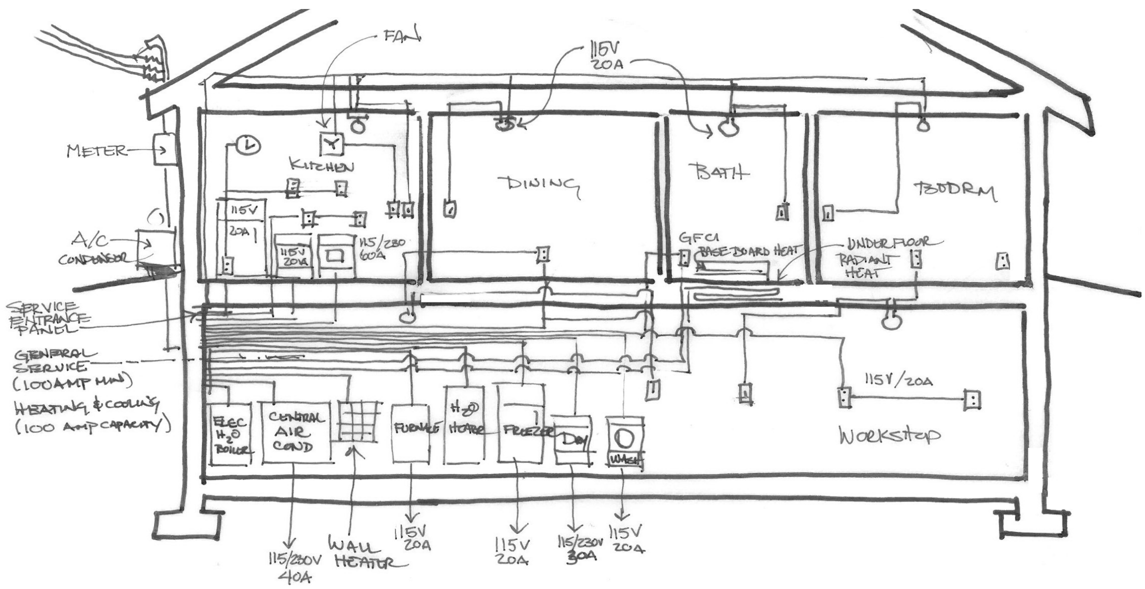
- Contactors
  - An electrically controlled switch used for switching a power circuit, similar to relay but with higher current ratings
  - Controlled by a circuit which has a much lower power level than the switched outlet
  - Used to control electric motors, lighting, heating, capacitor banks, thermal evaporators, and other electrical loads
  - Unlike switches, contactors can be remote controlled
- Raceways have now become a major architectural consideration that must be addressed early in the design process because the proliferation of computers and networking equipment require the distribution channels to be much wider than before
- Receptacles (aka Outlets):
  - Duplex: operate at 120V or higher depending on the appliance
  - Ground fault circuit interrupter (GFCI): used for safety
  - Hard wired: connected directly to building circuits in junction boxes
  - Circuits are 15A
  - Split Wire receptacle: one outlet is always energize, the other is controlled by switch
  - Dimensions:
    - Outlets should be mounted 12” - 18” above finished floor typical, min 15” for ADA
    - Spacing should be 12’-0” max, or so that no point is further than 6’ from an outlet
    - Floor receptacles must be within 18" of an exterior wall to count as a required power receptacle in a dwelling
    - Circuits are usually 15” and at least 20A for the kitchen, pantry, and dining
    - Kitchen counters need at least two circuits, with no more than 4 outlets per 20A
    - No point on a wall above a counter can be greater than 24” from an outlet
- Emergency Power Supply:
  - Supplies power for exit lighting, alarms, elevators, fire pumps, medical equipment
  - If a building's emergency power supply consists of batteries, the batteries must have a full-load capacity of 90 minutes
- Uninterruptible Power Supply (UPS) provides electricity to avoid business interruption (like necessary computer operations)
- **Line Diagrams:**
  - A diagram that shows the an electrical circuit/system using common symbols
  - Not to scale in plan, usually a separate drawing
  - Individual branch circuits, general receptacles and lighting are not typically shown
  - Shows only the electrical connections of the system components, ratings and types of over current protection devices, the types and length of cables for major feeders
  - In this example the connection of the components follows the physical layout of the components
  - The main service transformer is shown with its ratings (12,470-480Y/277V, 750kVA)
  - Main distribution panel with the rating of the main bus indicated as 480V, 1200 A



Processes:

- Estimating Electrical Loads:
  - Estimates are typically required before construction by the local power company
  - Figures should be adjusted as exact equipment/lighting info becomes available
  - Estimate the wattage per square foot based on common building elements and how intense they will likely function
  - For the purpose of predicting overall building electrical load, continuous loads should be calculated at 125% of their actual value.

Load Type	Low Use	Typical Use	High Use
Lighting	2 watts/sf	3 watts/sf	5 watts/sf
Outlets	1 watt/sf	2 watts/sf	3 watts/sf
HVAC	4 watts/sf	5.5 watts/sf	7 watts/sf



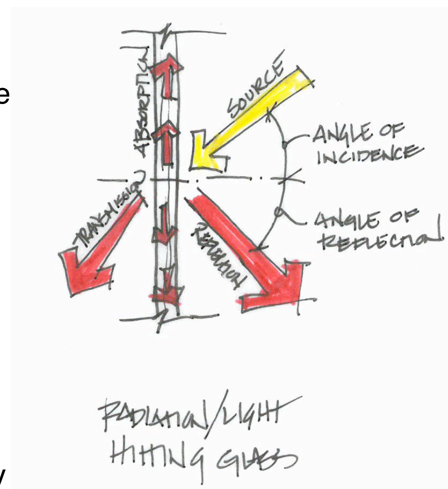
TYPICAL RESIDENTIAL ELECTRICAL

CONTENT AREA: LIGHTING

Building Design

Vocabulary:

- **Light:** electromagnetic radiation wavelength seen by the human eye
- **Incident Light:** the direct light that falls on a surface
- **Transmitted:** light that passes through a surface...all other is reflected or absorbed
- **Transparent:** material that allows for an image to pass through (glass)
- **Refraction:** material that changes an image while allowing it to pass through (lens)
- **Translucent:** material that allows light to pass through, but not an image (frosted glass)
- **Reflective:** material that bounces a light off
- **Opaque:** material that reflects or absorbs all light
- **Coefficient of Transmission:** the ratio of the total transmitted light to the total incident light represented as a percentage
- **Reflectance Coefficient:** the ratio of total reflected light to total incident light expressed as a percentage
- **Reflection:** light bouncing off a material
- **Specular Reflection:** results from a smooth polishes surface like a mirror. The angle of incidence equals the angle of reflection
- **Diffuse Reflection:** results from a uniformly rough surface. It appears uniformly birth and the image of the source cannot be seen.
- **Combined Specular:** makes surface appear to be brighter at the oping where the source is shining than in surrounding areas
- **Photometry:** the measurement of light in terms of perceived brightness to the human eye
- **Intensity (I):** the amount of light put out by a source
- **Candlepower (CP):** the measurement for the intensity of a source, and approximately equal to the horizontal output from a single candle



- **Lumen (l):** SI unit of luminous flux, a measure of the total amount of visible light emitted by a source. One lumen of luminous flux uniformly cast on 1 square foot of area creates an illuminate of 1 foot candle
- **Flux (F):** the flow of light from a source into space
- **Illumination (E):** the amount of light arriving at a surface
- **Footcandle (FC):** the calculated amount of illumination on a surface
- **Luminance:** the measurement of how bright light leaving an illuminated surface is...it depends on reflectivity or transmittance.
- **Illuminance:** the density of luminous energy expressed as lumens per unit area
- **Lambert:** unit of luminance or brightness
- **Coefficient of Utilization (CU):** ratio between lumens reaching the working plane in a specific space and the lumens. Typically provided by the luminaire manufacturer, it's an indication of the effectiveness of a luminaire in delivering light in a given space
- **Luminaire Efficacy Rating (LER):** ratio of fixture lumen output per wall of lamp input
- **Light Loss Factor (LLF):** effect of temperature and voltage variations, dirt accumulation on luminaries and room surfaces, lamp output depreciation, maintenance conditions.

- **Efficacy:** the amount of light produced vs. the power input (lumens/watt)
- **Contrast:** Difference in illumination level between one point and nearby points.
- **Equivalent spherical illumination (ESI):** theoretical sphere surrounding an object being illuminated with light, cast evenly and eliminating any shadows and reflected bright spots
- **Spectral Energy Distribution:** measure of energy output at different wavelengths/colors
- **Color Rendering Index (CRI):** a measure of the effectiveness of a source to make colors "right" to the viewer. The best possible rating is 100. 85 + is good.
- **Color Temperature (K):** a characteristic of visible light where its color reveals it temp.

Equations: (those in gold are given on ncarb formula sheet)

Illumination (E) = Intensity (I) / distance (d)^2

Illumination (E) = $\frac{\text{candlepower} \times (\cos \theta)}{\text{distance between source and surface } (d)^2}$

aka Point Grid Method

Illumination (E) = $\frac{(\text{\# of fixtures}) \times (\text{\# of lamps/fixture}) \times (\text{lumens per lamp}) \times \text{coefficient of utilization CU}) \times (\text{light loss factor LLF})}{\text{area in sq. ft.}}$

aka Zonal Cavity Method

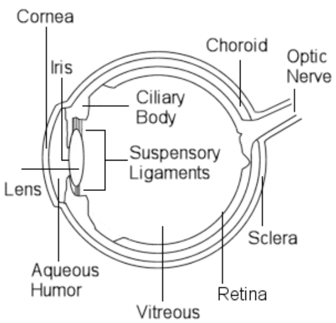
Footcandles (FC) = $\frac{\text{Lumens (I)}}{\text{area in sq. ft. (A)}}$

Number of Luminaries = $\frac{(\text{footcandles}) \times (\text{floor area})}{(\text{lumens}) \times (\text{coefficient of utilization CU}) \times (\text{light loss factor LF})}$

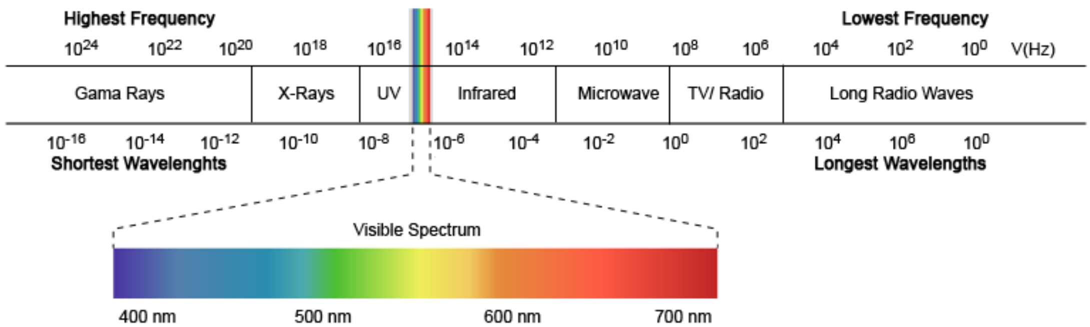
Units for lighting are watts per square foot

Facts/Rules:

- **Parts of the Eye:**
  - **Cornea:** Covers the iris/pupil/chamber
  - **Lens:** Focusing Device
  - **Iris:** Controls the amount of brightness admitted
  - **Retina:** Sensing Device
    - **Cones:** Sense Color
    - **Rods:** Sense Black and White



- Electromagnetic (EM) Spectrum and Visible Light
  - Visible Light has a wavelength of about 380 - 740 nanometers
  - The dormant wavelength determines the perceived color
  - Higher frequencies have shorter wavelengths
  - Lower frequencies have longer wavelengths
  - At the lower end of the visible light spectrum, EM becomes invisible to humans...known as **infrared**
  - At the higher range of the visible light spectrum, **ultraviolet** light becomes invisible because it is absorbed the tissues of the eye. Rods and cones can't detect the short wavelengths



-
- Seeing Color and Light/Color Rendering Index:
  - Perfect white light consist of a complete spectrum of wavelengths equally distributed
  - Light that has been bounced around a bit through a surface, reflection, or refraction will lose part of the spectrum and the light will change
  - Light by bulbs, tubes, or lamps also lose part of the spectrum
  - Color temperature is when a light-absorbing body is heated, it first glows deep red, then orange, until it becomes blue-white hot.
    - The color radiated is related to its temperature, so by developing a scale we can compare the color of a light source to a scale and assist a color temperature at which a light absorbing body must be heated to radiate light similar in color
    - Value is given in kelvin (k)
      - Lower temperature = warmer color (reds)
      - Higher temperature = cooler color (blues)

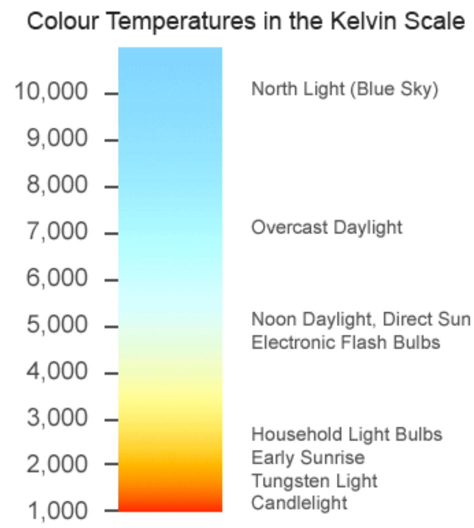


Image courtesy of www.mediacollege.com

- Lighting usually represents 1 - 3% of project construction costs.
- Good lighting aims to:
  - Reinforce the functionality of the spaces
  - Add to the acceptability/appreciation of space by the occupant.
  - Add value to the project
  - Create a feature that assists in the sale/rental of a space
  - Promote worker productivity and/or merchandise sales
  - Reduce long-term expenses
  - Minimize customer/user satisfaction
- **Orientation is influenced by lighting needs:**
  - Place important spaces and windows at southeast corner of the site, it will get more sun in the winter and less in the summer
  - Place windows on the south side to get winter sun into the space
  - Use architectural overhangs/fins/louvers and to some extent deciduous vegetation to block solar rays in the summer

- Use few windows on the east and west sides of buildings because of morning and late afternoon sun.
- If unavoidable, use vertical fins to block solar rays.
- Use northern windows for even daylight throughout the day.
- Coefficient of Transmission Levels:

Clear Glass	=	85%
Frosted Glass	=	70 - 85%
Rest of light is either reflected or absorbed		

- Contrast and brightness ratios:

Task to adjacent surroundings	=	1 : 1/3
Task to more remote darker surfaces	=	1 : 1/5
Task to more remote lighter surfaces	=	1 : 10

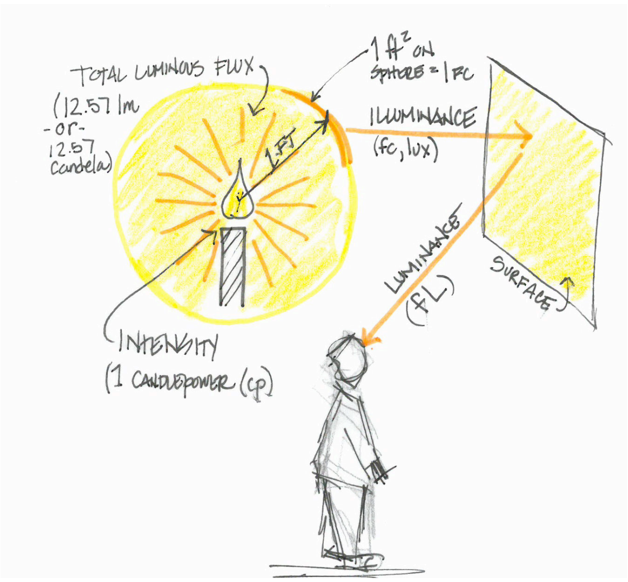
- **Footcandle Levels and Recommendations:**

Sunlight	=	10,000 foot candles
Full Daylight	=	1,000 foot candles
Overcast Day	=	100 foot candles
Very Dark Day	=	10 foot candles
Twilight	=	1 foot candles
Full Moon	=	0.01 foot candles

Bare minimum for emergency egress	=	1 foot candle
Public Spaces with Dark surroundings	=	2 - 5 foot candles
Public Spaces w/low contrast	=	3 foot candles
Orientation/Wayfinding	=	8 foot candles
Occasional visual tasks (office)	=	15 foot candles
High contrast tasks (big stuff)	=	30 foot candles
Medium contrast tasks (drafting)	=	75 foot candles
Low contrast tasks (making computer chips)	=	150 foot candles
General office work	=	50 foot candles

Concepts/Goals:

- Light that strikes a surface can be transmitted, reflected or absorbed.
- Basically every type of facilities may benefit from lighting design.
- Think of a lightbulb like a sprinkler head.
  - The rate of water flow would be lumens
  - The amount of water per unit time per sq.ft. of floor area would be footcandles
- For an opaque surface (like the diagram to the right) is best described as: luminace is illuminance as modified by reflectance
- The lumen method of calculation is used to determine the average maintained illuminate or footcandles on the working plane in a room



- Luminaries will be spaced so that uniformity of illumination is provided in order that an average calculation will have validity
- A diffuse surface will exhibit uniform brightness if the spacing between light sources does not exceed approximately 1.5 times their distance from the material.

- Measuring Light
  - Photometric readings are usually taken at the height of a "working plane" because this approximates the height to typical visual tasks
  - Illuminance is measured more frequently than luminance because design recommendations for lighting levels are typically given in terms of illuminance
- Illuminance levels and illuminance categories are used to establish quantitative lighting system design criteria
  - Selection criteria when picking a lighting fixture (from most important to least):
    - Color Rendition
    - Characteristic of the fixture
    - Initial Cost
    - Operating Cost
    - Efficacy
    - Size
    - Heat Output
    - Operating Life
    - Ability to control output from luminary
- **Permanent Supplementary Artificial Lighting of Interiors (PSALI):**
  - Natural light is more pleasant to work in than artificial light, but sometime the amount of natural light provided varies during the day, and the illumination levels vary within a room.
  - Combining daylight and artificial light is a good way to compromise by blending the two together to provide even illumination
  - Retains most of the psychological advantages of natural lighting but can illuminate deeper into rooms than daylight could alone
  - Lamps used in fixtures should match natural light color

Processes:

- **Point Grid Method:**
  - A method of calculating illumination (E) for surfaces not perpendicular to the source
  - Good for a single fixture or small number of fixtures
  - Takes into account orientation and distance but ignores surrounding reflection
- **Zonal Cavity Method:**
  - Used to calculate uniform illuminance in a space, based on a uniform distribution of a large number of fixtures
  - Takes into account the reflectivity of the ceiling and walls and the comparative volumes of the top, middle, and bottom of the room.
    - Space is divided into: Ceiling Cavity, Floor Cavity, and Room Cavity
  - Most commonly used for office, commercial and factory spaces
  - Based on the Coefficient of Utilization (CU) for each fixture type
  - **Light Loss Factor (LLF)** are the factors that need to be considered when calculating the zonal cavity method. Most important considerations are:
    - **Lamp Lumen Deprecation (LLD):** the overall performance of a lamp over its life, typically given in manufacture data

- **Ballast Factor (BF):** compares the ratio of light output of a lamp working by a specific ballast to the light output of the same lamp working by a standard reference ballast.
- **Luminaire Dirt Deprecation (LDD):** the light loss prior to cleaning dust
- **Room Surface Dirt Depreciation (RSDD):** accounts for dirt or dust that accumulates on all of the room surfaces especially on the upper walls and ceiling

Implications of Design Decisions

Vocabulary:

- **Glare:** extreme contrast in light (difference in brightness levels)
- **Direct Glare:** a light source in the field of vision that causes interference/distraction with a visual task
- **Critical Glare:** zone for direct glare is the area above a 45° angle from the light source
- **Reflective Glare:** when a light source is reflected from a viewing surface into the eye and interferes with a viewing task
- **Discomfort Glare:** annoying pain caused by high luminances in a field of view (most common cause are windows and luminaries)
- **Veiling Reflection:** reflection which partially or totally obscure the details to be seen by reducing the contrast. A common problem with specular surfaces.
- **Visual Comfort Probability (VCP):** a rating that indicates the percentage of people that will find a given discomfort glare acceptable. 70% is the minimum, else it's time to fix it.

Facts/Rules:

- Designers must address several issues, quantitative and qualitative, when designing a lighting system

Quantitative	**Qualitative**
• Daylight and how it is introduce and integrated with electric light	• Location, interrelationship, and psychological effect of light and shadow
• Interrelationship between energy aspects of electric and natural lighting and HVAC	• Use of color, both of light and surface faces, and the effect of illuminant source on object color or vice versa
• Effect of lighting on interior space arrangement and vice versa	• Artistic effects possible with patterns of light and shadow
• Characteristics, means of generation, and utilization techniques of electric lighting	• Physiological and psychological effects of lighting design, particularly in spaces occupied for extend periods
• Visual needs of specific occupants and of specific tasks	

Concepts/Goals:

- Lighting should benefit a project: that is, be part of the design for people and spaces.
- It is used to reveal or reinforce the functions of the spaces being occupied.
- Lighting is <u>not</u> an add-on.

- We live in a visual culture, and lighting plays an important role in seeing and experience.
- People should recognize feelings of safety, friendliness, comfort, humanity, or other desired emotions, all of which are helped by lighting.

Natural + Artificial Lighting

Vocabulary:

- **Efficacy:** the amount of light produce vs the power input (lumens/watt)
- **Daylight Factor (DF):** ratio of indoor illuminance to available outdoor illuminance
- **Externally Reflected Component (ERC):** the light reflected from exterior obstruction excluding the ground reflected light
- **Effective Aperture (EA):** product of visible transmittance multiplied by the window to wall ratio. An EA of .20 - .30 provides good daylighting
- **Energy Policy Act (EPACT):** set minimum standards for energy efficiency on incandescent and fluorescent lighting
- **Graphic Daylighting Design Method (GDDM):** daylighting analysis method that produces a family of daylight factor contours within a room rather than individual daylight factors at specific points
- **Lamp:** a device for giving light
- **Luminare:** a complete light fixture including lamps
- **Light Shelf:** overhang that's exterior, interior, or both, used with a clearstory to reflect light up on to the ceiling and reduce direct light adjacent to the window

Equations: (those in gold are given on ncarb formula sheet)

Daylight Factor = 0.2 x (window area / floor area)

Effective Daylight Zone = 1.5 x (window head height into room)
2.0 x (window head height into room w/light shelf)

Workplane Daylight Illuminance = 2.5 x the head height of the window (height of the window above the desk plane)

Facts/Rules:

- Electric lighting in nonresidential buildings consumes 25% - 60% of the electric energy
- The greatest challenge in lighting a commercial office space is proving adequate lighting for varied visual tasks while avoiding glare
- To avoid exceeding a total power budget, assume **2.3W / sq.ft.** when estimating the maximum amount of energy used.
- **Daylighting:**
  - It's an amenity, windows provide visual contact with the outside and the resultant daylight provides a bright, pleasant, airy ambiance
  - Continual variation of daylight provides a consistently changing pattern of space illumination that is hard to achieve with artificial light
  - Changes to daylight are gradual, so the eye easily adapts
  - **Bilateral Light:** light coming from two sides to illuminate a space (it's a good thing)
    - *Example: Christopher Alexander's Pattern Language: "When they have a choice, people will always gravitate to those rooms which have light on two sides"*
    - Daylight within a space is generally most evenly distributed when bilateral lighting from opposite walls is used.

- In general, daylight will penetrate further into a space and have a more uniform quality if windows are placed high on the wall
- Daylighting qualifies for a LEED credit if a daylight factor of 2% in 75% of all occupied spaces is achieved.
- Acceptable daylighting factors

Typical office work	=	1.5 - 2.5% (easy to achieve)
Reading/handwork	=	2.5 - 4.0%
Drafting/find handwork	=	4.0 - 8.0% (almost impossible!)

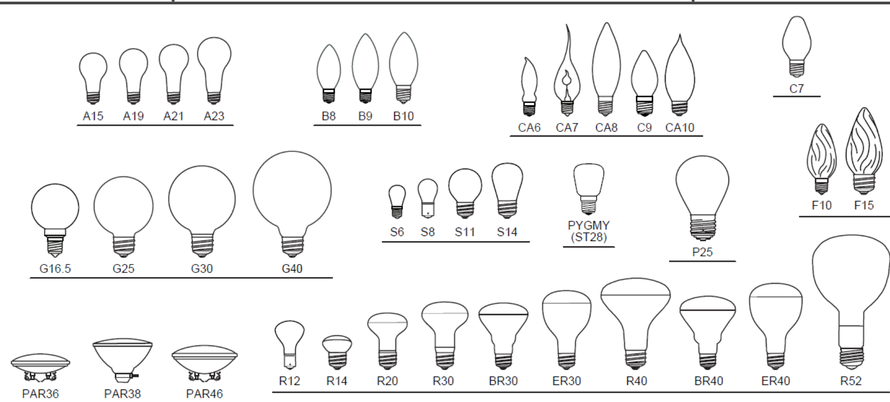
- Daylight depends on:
  - Solar altitude: latitude, date, and time of day
  - Weather Conditions: cloudy, smoggy, sunny, etc.
  - Effects of local terrain: natural or man made obstruction and reflections
- Daylight Conditions
  - The standard sky design condition established by the Commission Internationale d'Eclairage (CIE) for daylighting calculations is a completely overcast sky
  - At a solar altitude of 30 degrees, one can expect a daylight illuminance of about 10,000 lux with no direct sun and 40,000 lux with direct sun
  - The brightest area of luminance in a cloudy sky is at the zenith
- Controlling Daylight:
  - Overhangs, fins, and other architectural shading devices.
  - Sawtooth (not bubble) skylights allow glass to face north for illumination, not south for solar heat gain. DO NOT USE BUBBLE SKYLIGHTS.
  - Interior window shading devices, which allow solar gain during cool months, and the blocking of solar radiation during the warmer seasons.
  - Light shelves, which permit the daylight to reflect off the ceiling and penetrate farther into the interior without affecting views outside.
- Recommended horizontal to vertical illuminance ratio for general diffuse light is 2.5:1

- **Artificial Lighting:**
  - Different sources produce different kinds of light and vary significantly in efficiency
  - Artificial lighting should be provided even in daylight areas for nighttime illumination
  - Connected to switches so fixture can be turned off in areas where daylight is sufficient
  - Dimmer controls may be connected to photosensitive device that dims as daylight levels are increased
  - In general, with a side lighting system any interior area more than 30 feet from a window will need to be electrically lit.
  - DC low voltage lamps have smaller filaments which allow more precise control over light placement.
  - Types of Artificial Lighting:
    - **Incandescent:**
      - Consists of a tungsten filament (usually tungsten allow) placed within a sealed bulb containing an inert gas
      - Filament glows by passing an electric current through it
      - Advantages:
        - Inexpensive
        - Compact
        - Dimmable
        - Typically “warmer” color than sunlight or daylight, they’re rich in yellows and reds and weak in green and blues

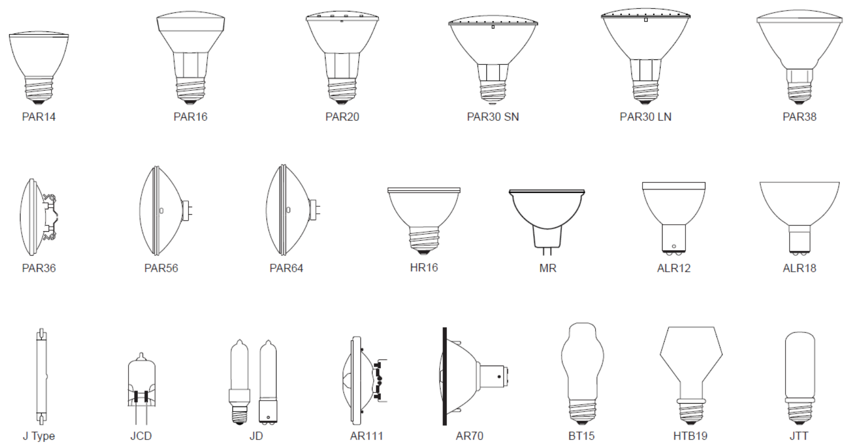
- Disadvantages:
  - The least efficient type of artificial lighting because much of the energy use to light the filament is wasted in the production of heat (About 90% waste!)
  - Short lamp life: standard bulbs last about 700 - 1,000 hours
- Types:
  - Come in various shapes with different characteristics
  - Designation is a letter-number (e.g.: A-21 means shape "A" and size 21/8")

Bulb Type	Use	Typical Sizes
A - Appliance	• Most Common • Used Almost Everywhere	• A15, A19, A21, A23
PS - Pear Shape	• Similar to "A" but have a larger diameter • Used in offices, retail • Used in radio/cell tower, bridge power line, high tension wires	• PS30 (commercial) • PS40 (utility)
S - Sign	• Found in outdoor signs • Casinos, hotels, theaters	• S6, S11, S14
C - Candle	• Made to look like candle flame for decorative applications • Used in chandeliers, restaurants, bathrooms, decorative lights • Rounded blunt tip is called "torpedo shaped" (think xmas lights)	• C7: marquees, scoreboards, • C9, C11, C15: decorative applications
F - Flame	• Similar to "C" but glass is blown or etched so light looks like it's flickering through a flame • Used in decorative applications	
G - Globe	• Found in decorative applications like bathrooms and lobbies	• G16.5, G25, G40
R - Reflector	• Built in reflecting surface which causes light to pushed through front of bulb instead of emitting around the entire bulb • Used for downlighting • Used in can or track lighting	• R20
BR - Bulk Reflector	• Created in response to EPACT which requires reflector bulbs to meet minimum standards • Bulk reflector in neck of bulb redirects lost light forward • Used for downlighting	• Br30, BR40
ER - Elliptical Reflector	• Also create in response to EPACT • Elliptical reflector increase the overall lumen output by redirecting lost light at the sides forward • Used for downlighting	• Er30

Bulb Type	Use	Typical Sizes
PAR - Parabolic Aluminized Reflector	• Have an aluminized reflector in a parabola shape • Covered with a hard glass relines to control light beam • Use unprotected outdoors because glass can withstand weather • Used for downlighting	• PAR16, PAR20, PAR30, PAR30 long neck, PAR38
MR - Mirror Reflector	• Have a mirrored reflector • Used for accent and stop lighting	• MR16 • MR 11 (limited use)
T - Tube	• Shaped like cylinder tube • Can be Incandescent, Fluorescent, or HID • Used for everything	• T6 (incandescent)

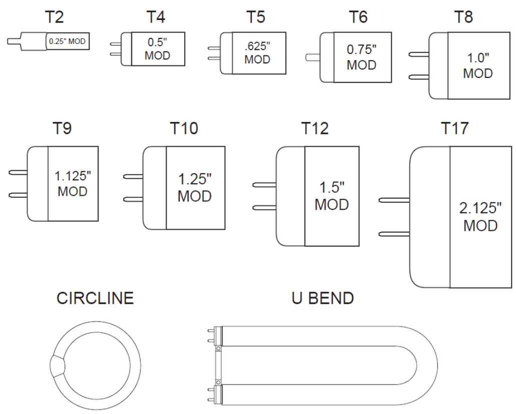


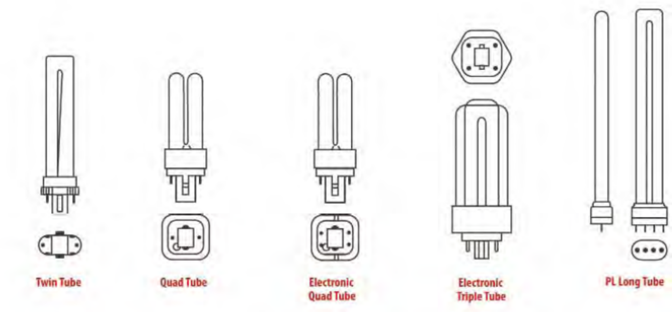
- **Tungsten Halogen**
  - A variation of incandescent bulbs. A filament is lit by electricity passing through an enclosed in sealed bulb containing an inert gas **and** halogen
  - Smaller than standard incandescent bulbs
  - Filament burns under higher pressure and temperature
  - Uses a fuzed quartz envelope that allows for the higher temp
  - A chemical reaction takes place pulling the tungsten from the wall of the glass and back to the filament, extending its life
  - Advantages:
    - Longer life
    - Low lumen deprecation of the life of the bulb
    - More uniform light color
    - Whiter light than incandescent
    - Dimmable
  - Disadvantages:
    - Much hotter than incandescent bulbs
  - Types:
    - Come in various shapes,
    - Some have screw fixing and additional extra glass capsules so they can be used like conventional incandescent lamps



- **Fluorescent**
  - A glass tube holds a mixture of an inert gas and low pressure mercury vapor
  - When lamp is energized, an arc of mercury is formed creating an ultraviolet light that strikes the phosphor coated bulb
  - Bulb fluoresces and produce a visible light
  - Pre Heat: supplanted by rapid start that maintains constant low current in the cathode, allowing them to start within 2 seconds
  - Instant Start: use a higher voltage to illuminate immediate
  - Ballast: supplies the proper starting and operating voltages to the lamp and limits the current
    - Produces noise and heat so, “Class A” is good for quit areas and “Class F” is acceptable for noisy areas.
  - Electronic Ballast: produces high frequency AC and lowers power consumption for silent operation and ease of dimming.
  - Advantages:
    - High efficacy (About 80 lm/W)
    - Low initial cost
    - Long life (about 10,000 - 20,000 hours)
    - Variety of color temperatures (improving...no longer just “cool white”)
    - Dimmable
      - For fluorescent lamps, dimming down to 40% of output is possible without substantially reducing luminous efficacy.
  - Disadvantages:
    - More expensive than incandescent bulbs
  - Types:

Bulb Type	Use	Typical Sizes
T - Tube	• Designated according to type, wattage, diameter, color, and method of starting • eg: F32T8WW/RS = 32 watt, 8/8” tubular, warm white, rapid start	• T2 - T12
CF- Compact Fluorescent	• Lamps bent into a U-shape and mounted on a base that houses a ballast • Can be screwed into incandescent luminaries	• T4 or T5

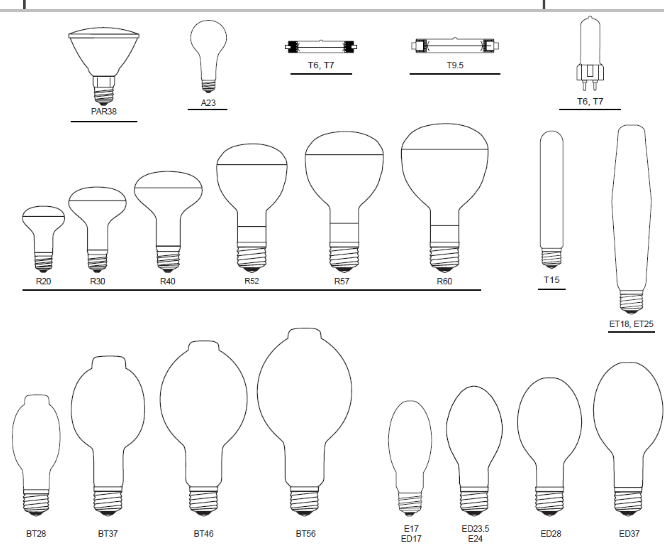




- **High Intensity Discharge (HID):**
  - A lamp within a lamp that runs at a very high voltage
  - An electrical arc is struck across tungsten electrodes in a glass tube filled with gas and metals
  - Metals produce the light once they are heated to a point of evaporation
  - Advantages:
    - High efficacy (About 80 lm/W)
  - Disadvantages:
    - Produce light that is not flattering to human skin, so not used for commercial/retail/residential applications
  - Types:

Bulb Type	Use	Typical Sizes
Mercury Vapor	• Electric arc is passed through high pressure mercury vapor that produces ultraviolet and visibly light • Primarily in the “blue/green” color • Moderately high efficacy (30-50 lm/W) • Have a life of 24,000 hours • Used for large area overhead lighting in factories/warehouses/sports complexes/streetlights	• H39KC-175, H37KC-250/DX, H33GL-400/DX
Metal Halide	• Similar to mercury vapor except halides of metal are added to the arc tube • Increased efficacy (50 - 100 lm/W) • Have a life of 10,000 hours • Produces a whiter, more natural light • Decreased lamp life	
High Pressure Sodium	• Produces light by passing an electric arc through hot sodium vapor • Arc tube must be ceramic to resist hot sodium • High efficacy (80 - 140 lm/W) • Have a life of 24,000 hours • Wide variety of color rendition	

Bulb Type	Use	Typical Sizes
Low Pressure Sodium	• Operates like a fluorescent lamp and requires a ballast • Highest efficacy (150 lm/W) • Require a brief warmup period to reach full brightness • Produces a monochromatic yellow light • Used where color rendition is not important (e.g.: parking garages, street lights)	
Light Emitting Diode (LED)	• **Solid State Lighting** • Bulbs without a filament, plasma, or gas • Low in power consumption with a long life span • Diodes emit light when connected in a circuit • Run on DC power • Used for flashlights, signage, sustainable lighting, phones, video production	



- **Fiber Optics**
  - Description:
    - Long thin strands of very pure glass about the diameter of a human hair
    - A “Light Pipe” used to transmit light between two ends of the fiber
    - Arranged in bundles called optical cables and used to transmit light signal over long distances
    - Hundreds/Thousands of fibers are bundled into cables
    - Light in a fiber optic cable travel through the core by consistently bouncing from the cladding. The cladding doesn’t absorb any light from the core, so it can travel a long distance

- **Energy Policy Act (EPACT):** set minimum standards for energy efficiency on incandescent and fluorescent lighting. It eliminated:
  - Medium based PAR and R laps of 40W or higher
  - F40T12
  - U-Shaped fluorescents
  - Full wattage fluorescents
  - All were replaced with ER lams, tungsten-halogen, and T8
- Light fixtures that are more efficiently designed reduce energy cost and increase comfort, such as the following:
  - Fixtures that use fluorescent or HID lamps, which provide more illumination per watt than incandescent lighting.
  - Fixtures that are designed to diffuse or bounce the illumination off the ceilings or internal reflectors, which are more efficient; cause less glare (especially in an environment with computer monitors); and save operating costs.
  - Fixtures that have higher efficiency (T-8) fluorescent bulbs, which produce more lumens per watt and thereby diminish the heat generated by lighting.
  - Fixtures that offer dimming or multiple switching capability, which permit the architect a more energy efficient lighting design.
  - Fixtures that use higher efficiency lamps such as fluorescent, high intensity discharge (HID) sulfur lighting (exterior only).
  - Fluorescent fixtures that use high efficiency electronic ballasts.
- Lighting Systems
  - No single system can be the only choice for a lighting instance
  - There are usually at least two choices to get a lighting system of a decent quality
  - Working with the aesthetic of the space and the budget also impact which lighting system to select
  - Major types of lighting systems are:

Type	Description	Typical Use
Indirect	• 90% - 100% of light output is directed to the ceiling and upper walls of a room • Almost all of the light reaches the horizontal plane indirectly, it has to bounce off something else first (so the ceiling/walls are basically the light source) • Suspend 12”-18” from the ceiling minimum • Allows for uniform lighting, lacks shadows, low brightness, and is highly diffuse • Pretty inefficient system	• Good for offices, lounges, waiting areas
Semi Indirect	• 60% - 90% of light is directed upward, similar to indirect lighting, but more efficient • 10% - 40% of light is directed downward • Direct and reflective glare is relatively low • Kind of a monotonous system	• Good for offices, lounges, waiting rooms, corridors,
Diffuse/ Direct-Indirect	• Equal distribution of light up and downwards • Bright ceilings and upper walls • All surfaces are lit • Give light in all directions, and should be suspended 12” min from the ceiling • Efficient system	• Good for classrooms, standard office works spaces, merchandising areas

Type	Description	Typical Use
Semi Direct	• 60% - 90% of light is directed downward • 10% - 40% of light is directed upward • Shadowing should not be a problem • A pleasant environment • Inherently efficient	• Offices, classrooms, shops, working areas
Direct	• Essentially all light is directed downward • Ceiling illumination comes from floor and furnishing reflection • Requires a light, high reflectance, diffuse floor unless a dark ceiling is desired • Efficiency depends on if the distraction is spread or concentrating • Gives little surface illumination, requiring the addition of perimeter lighting • Downlights create a sharp, theatrical atmosphere, not good for working spaces • Can be gloomy and cavelike	• General lighting if spread-type • Highlights, local, supplemental lighting, and privacy atmosphere lighting if concentrated-type

- Luminaire Types
  - Surface Mounted Fixtures:
    - The most commonly used type for residential and commercial applications.
    - Used in ceilings where there is not sufficient space above the ceiling to recess a fixture and locations where ceiling is existing
  - Recessed Fixtures:
    - Used in residential and commercial
    - Include incandescent and fluorescent where a luminous ceiling is formed when the entire ceiling is made up of lighting
  - Suspended Fixtures:
    - Dropped below level of ceiling, often hanging
    - Used for indirect systems and where light source needs to be closer to task area
  - Wall Mounted Fixture
    - Indirect, direct-indirect, and direct lighting
  - Furniture Mounted: typically task ambient lighting
  - Freestanding Fixture: e.g.. Floor lamps

Concepts/Goals:

- Before the invention of the incandescent bulb in the late 1800s, most architectural lighting design relied on daylighting techniques.
  - Designers added ornamental/decorative lighting from candles/gas lamps as required.
- In the 1900s daylighting became less important and designers focused on electric, artificial techniques.
- The energy crisis of the 1970s resulted in a return to daylighting, energy conservation.
- Daylight has been shown to increase productivity in the workplace and test scores in schools.
- What matters:
  - Orientation: filtered light is the goal, direct sunlight is the enemy
  - Daylight Factor: measured in percent, should be between 1 - 5%
  - Window & Floor Area: the only real quantities that need to be counted
  - Luminous Flux (lumens): how much light is leaving a source

    - Illuminate (foot candle): how much light hits a surface for square foot
    - Luminance (footlambers): how much light is emitted from a surface
- Typical Efficacy

Incandescent	=	12 lumens/watt (these suck)
Fluorescent	=	55 lumens/watt
Metal Halide	=	90 lumens/watt (good for libraries)
High Pressure Sodium	=	90 lumens/watt (street lights)
Sunlight	=	115 lumens/watt (nothing beats it!)

- Incandescent bulbs turn back as they near the end of their black lights
- Standard household bulbs have an average life of 750 to 1,000 hours, which can be lengthened or shortened by the treatment they receive.
  - *Example: A 120V bulb operating on a 125V circuit may produce more light, but won't last as long as one on a 120V circuit*
- Long life lamps are best avoided because they are costly and inefficient
- Energy-efficient lamps are typically rated at a lower wattage than regular lamps.

Processes:
- Incandescent Bulb Diameters are measured per 1/8th of an inch (like rebar) so an R-40 bulb would be 40/8"….which is 5" in diameter

Building Systems + their Integration

Facts/Rules:
- Types of Shading:
  - **Retractable:** moveable devices that can adjust the total transmission of light (eg: shutters, roller blinds, and louvers)
  - **Fixed Redistribution Devices:** fixed devices that obscures part of the sky through which the sun passes (eg: overhangs, lightshelves)
  - **Fixed reduced transmission Devices:** glazed openings are made to have permanently reduced transmission (eg: fixed grids, perforated sheets, tinted/reflective/fritted glass)
  - **Selective High Performance Glazing:** glass that has a lower transmission for the invisible part of the spectrum than the visible, best used with Retractable or Fixed Redistribution Devices
- Location of shading devices can be internal, external or mid-pane
  - External devices are the most efficient thermally because solar energy is intercepted before it enters the room
  - Internal shading is typically must cheaper to install and easier for users to control, but less efficient and vulnerable to damage
  - Mid-Pane devices are installed in sealed, gas-filled double glazing units
- Artificial lighting consumes a significant part of all electrical energy
  - 20 - 60% of energy used in residential/business is due to lighting
  - For some buildings over 90% of lighting is unnecessary expense due to over lighting
  - Replacing all incandescent lamps with energy efficient compact fluorescent globally would save 2.5% global energy consumption
  - Low voltage lamps have smaller filaments, and therefore have more tightly controlled optics.
    - Allows for more precise aim, which is useful in highlighting specific objects.

    - Fluorescent cove light provides diffuse ambient illumination, ideal for reading or lighting flat surfaces evenly, but deadly dull in terms of sparkle
    - Mercury vapor lamp provides terrible color renditions of skin and flesh, even with very high light levels.
    - Suspended incandescent globes provide warm colors and reduce the sterile atmosphere in a room, but they also cause glare spots all over screens, making work very difficult
- Light Pollution
    - **Light Trespass:** unwanted light on private property (e.g.: spill light from a streetlight enters a bedroom window)
    - Somewhat subjective because it's difficult to define when, where, and how much light is unwanted
    - In Portland, the maximum illumination level at a property line can't exceed 0.1 foot candle, measured at grade (except where abutting industrial or other sensitive areas)
    - Residential and natural resource protection areas are considered sensitive to light trespass
    - Can reduce light levels at perimeters, or use shielding devices to block trespass
- Emergency Lighting:
    - IBC, National Electric Code, Life Safety Code all have provision for emergency lighting
    - Required areas include:

Exit Stairs	Corridors
Assembly Spaces	Educational Facilities
Other high occupancy loads	

    - **Minimum lighting level required is 1 foot-candle at the floor level**
    - Illuminated exit signs are required

Concepts/Goals:

- Daylight/sunlight are a single source of natural energy that we need to get into buildings
- It's harnessed as daylight for visual tasks and sometime for energy for desired heat gains
- Energy has to be controlled to prevent overheating and glare
- Most of the time it's an on/off situation. If the sun is too bright, the blinds are pulled and the lights turn on, there's no middle ground
- So the goal is to modulate it, and possibly to re-distribute it spatially to provide a glare-free working illuminance for a minimum heat gain.
- Lighting energy forms a large proportion of energy consumption in buildings, so it is vital to use daylight whenever it is available.
- Solar gains are a common cause of overheating, and creates a large cooling energy demand.

Processes:

- In warmer countries, where the penetration of direct sunlight is almost always unwanted, traditional architecture often demonstrates elegant solutions – deep reveals overhangs, fins and louvres, and the correct use of them is often part of the unconscious culture.
- Designing lighting systems to minimize energy use can be done by:
    - Designing illumination specific for each room/area rather than an overall scheme
    - Design space and finishes with lighting in mind
    - Select fixtures that offer the best energy consumption strategies
    - Maintain systems to prevent waste

- Use natural light whenever possible
- Load shedding or rolling blackout can help reduce power requested by people to a main power supply. Often done regionally, but can also be done in an individual building

Construction Details + Constructability

Facts/Rules:

- Lighting Control:
  - Is in place for flexibility to provide the modifications of luminances and patterns desired by the designer and economy of both energy resources and monetary resources
  - A properly designed lighting control system can reduce energy usage up to 60% over a simple on/off system
  - GroupReplacement vs Spot Replacement:
    - **Group Replacement:** the replacement of a group of lights based on their calculated lifetime use estimates
    - **Spot Replacement:** the replacement of light that have actually burned out
- Baffles
  - A shield of metal, wood or plastic used to screen a light source from normal angles of viewing.
  - Aluminum baffles are commonly used in parabolic fixtures or, a grooved cylinder dropped below a light source to conceal the lamp and provide light cutoff.
- Diffuser
  - A device through which the light from a fixture enters a room
- Ballast
  - A device used in fluorescent and HID luminaries. Job is:
    - To supply controlled voltage to heat the lamp filaments in preheat and rapid start circuits
    - To supply sufficient voltage to start the lamp by striking an arc through a tube
    - To limit the lamp current once the lamp is started
  - Ballast (Cold Weather): designed to provide sufficient starting voltage for fluorescent lamps in cold weather, generally down to 0 ˚ F.
  - Ballast (Dimming): Dimming ballasts are special ballasts which, when used together with a dimmer control, will vary the light output of a lamp.
- Emergency/Exit Lighting:
  - Install LED (light emitting diode) lighting for exit signs. LED lighting lasts longer than incandescent and is far less expensive to operate.

Concepts/Goals:

- Building automation and lighting control helps reduce over illumination by creating a centralized system that adjusts levels based on occupancy and use, using sensors, timers, etc.

CONTENT AREA: SPECIALTIES / ACOUSTICS

Building Design

Vocabulary:

- **Sound:** energy produced by a vibrating medium transmitted as a wave through an elastic medium
- **Noise:** any unwanted sound
- **Sound Waves:** generated by a vibrating object and radiate outward from a source equally in all directions.
- **Cycles Per Second:** a measure of frequency, has been replaced by Hertz (Hz)
- **Frequency:** number of cycles of compression and expansion completed per second, and measured in Hertz (Hz)
- **Velocity:** sound depends on the medium it travels through and the temp of that medium
- **Amplification:** increased intensity of sound by mechanical or electrical means
- **Intensity Level:** intensity of sound at a given location, in watts per square meter
- **Tone:** the overall quality of a sound with reference to its quality, pitch, strength, source
- **Pitch:** the order of sounds on a frequency related scale
- **Sound Power:** a measure of sonic energy per time, measured in watts.
- **Sound Pressure:** the local pressure deviation from the ambient atmospheric pressure caused by a sound wave
- **Sound Intensity:** sound power per unit area
- **Decibel (dB):** a unit of sound intensity devised to describe sound magnitude
- **dBA:** unit of sound intensity measurement that is weighted to account for the response of the human ear to various frequencies
- **Loudness:** the change in decibel levels
- **Articulation Index:** a measure of speech intelligibility calculated from the number of words red from a selected list that are understood by an audience (low: < 0.15 good for speech privacy) and (high: > 0.6 good for communication)
- **Attenuation:** the reduction of sound
- **Noise Reduction Coefficient (NRC):** a scalar representation of the amount of sound energy absorbed upon striking a particular surface. It's an arithmetic average of the sound absorption capability of a product at only four frequencies: 250, 500, 1000, and 2000 hertz, which represent the center range of human speech.
- **Impact Noise:** noise that occurs when an object comes in direct contact with a barrier, typically either the floor or ceiling assembly
- **Impact Isolation Class (IIC):** a single number that measures a floor/ceiling assembly's resistance to the transmission of structure borne or impact noise.
- **Sound Transmission Class (STC):** a single number average of how well a building partition reduces the force of airborne sound
- **Flanking Transmission:** where sound passes around, over the top, or under the Perrier partition separating two spaces.
- **Sound Power Level (PWL):** is a measure of the amount of sound generated by a source independent of its environment
- **Sound Pressure Level (SPL):** sound pressure at a location expressed in newtons per square meter
- **NC Curves:** a single number system for specifying a maximum SPL level in a given location using standardized reference contours. Curves weight the frequencies to which the human ear is sensitive

Equations: (those in gold are given on ncarb formula sheet)

wavelength (λ) = $\frac{\text{Velocity of sound (fps)}}{\text{Frequency of sound (Hz)}}$

Sound Intensity (watts/unit area) = $\frac{\text{Acoustic Power (P)}}{4 \pi r^2}$

We typically deal with decibels instead

Inverse Square Law = Sound Intensity $(I_1) / (I_2)$ = Distance from Source $(r^2{}_2) / r^2{}_1)$

Sound Intensity Level (decibel) = $\frac{\text{10 log (Intensity of Sound being measured)}}{\text{Reference intensity of } 1\text{x}10^{-16}}$

Noise Reduction (dB) = (Barrier Transmission, TL) - 10log $\frac{\text{(area of barrier wall, S)}}{\text{(total absorption of receiving room, } A_r)}$

Facts/Rules:

- Sound has three basic qualities: velocity, frequency, and power
  - **Velocity:** depends on the medium in which sound is traveling and the temperature of that medium

Air	=	1,130 feet/second (a constant)
Water	=	4,500 feet/second
Wood	=	11,700 feet/second
Steel	=	18,000 feet/second

  - **Frequency:** number of cycles completed per second, measured in Hz (1 Hz = 1 cycle per second)
  - **Power:** quality of acoustical energy, measured in watts
- The wavelength of a sound is the distance between similar points on successive waves or the distance sound travels in one cycle. Measured in *Linear Feet*
- Sound Levels:
  - Human ear can hear sounds in the 20 Hz to 20,000 Hz range, the most sensitive range is 125 Hz to 6,000 Hz
  - Human ear can respond to tremendous variation in sound amplitudes without damage
  - Speech is composed of sound primarily in the 100 Hz to 600 Hz range
  - 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
    - Bands are: 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz
    - **Octave Band:** a range of frequencies in which the upper frequency is twice that of the lower
- Types of Sound Measurement:
  - **Sound Intensity Level (IL):** the decibel, how intense a sound is
  - Sound Power Level (PWL): watts/cm^2 , the power at the source
  - Sound Pressure Level (SPL): the pressure exerted by the sound wave on a surface at a given location, varies with barromic pressure

- **Decibels**
  - Smallest difference in 2 sounds the human ear can detect is 1 decibel
  - dB's are not proportional...they're logarithmic!
    - dB's can't be added directly, so use this chart instead for changing value:

When difference between two values is	Add this value to the higher value
0 - 1 dB	3 dB
2 - 3 dB	2 dB
4 - 8 dB	1 dB
9dB +	0 dB

  - Each increase of 10 decibels the human ear perceives as 10x loud
    - Typical Decibel Levels:

Threshold of acute hearing	=	0 decibels
Rustle of Leaves	=	10 decibels
Sleeping, studying, whispering	=	30 decibels
Conversation, comfort	=	50 - 60 decibels
Safety Threshold	=	85 decibels
Rock Band!	=	120 decibels
Threshold of Pain	=	130 decibels

    - Trees thin out high frequency noises
    - Typically doubling the distance between source and ear *reduces* level by 6 dB
    - On freeways, doubling the distance between source and ear reduce level by 3 dB
    - Winds add "white noise" that blurs any one sound frequency.
    - Walls close to a noise source reduce high frequency, but midway between the source and the ear does nothing.
    - The human ear is more sensitive to sounds in middle frequencies
      - The scale that most closely represents the response of the human ear is called the A scale. When measurements using the A scale are converted to decibels, the resultant measure is designated dBA.
  - Increases or decreases in decibel levels have varying architectural effects

1 dB Change	=	Almost Imperceptible
3 dB Change	=	Just perceptible
5 dB Change	=	Clearly noticeable
6 dB Change	=	The change when distance to a source is doubled or halved
10 dB Change	=	twice or half as loud
18 dB Change	=	Very much louder or quieter
20 dB Change	=	4x louder or 1/4x as loud

- Sound Transmission
  - The transmission of sound is primarily retarded by the mass and stiffness of a barrier
    - The less stiffness the better
  - **Transmission Loss (TL):** the difference (in dB) between he 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
  - **Noise Reduction (NR):** the arithmetic difference (in dB) between the intensity levels in tow rooms separated by a barrier of a given transmission loss
    - Dependent on the transmission loss of the barrier, the area of the barrier, and the absorption of the surfaces in the receiving room

- Noise reduction can be increased by increasing the transmission loss of the barrier, by increasing the absorption in the receiving rom, by decreasing the area of the barrier separating the rooms, or some combination of the three
- **Sound Transmission Class (STC):**
  - Method of rating walls, doors, etc. In terms of their typical or overall resistance to sound transmission
  - A weighted average of all STC is used when looking at an overall wall system
  - Values are widely quoted in catalogs and ads and are useful to design as a good estimate (actual installation values will vary)
  - The higher the STC rating the better it is
  - Effect of barrier STC on hearing

STC 25	=	Normal speech can be clearly heard through barrier
STC 30	=	Loud speech can be heard and understood well, Normal speech can be heard, but barely understood
STC 35	=	Loud speech can be heard but not understood
STC 42-45	=	Loud speech can only be faintly heard Can't hear normal speech at all
STC 46-50	=	Loud speech is not audible Loud sounds other than speech can only be faintly heard

Therefore, walls, floors, and ceilings typically have an STC rating of 50

- **Noise Criteria (NC) Curves**
  - People typically can tolerate higher levels of low frequency sounds than of high frequency sound
  - Variables of sound have been consolidated into a set of curves used in specifying the maximum noise level in a given space under a given set of conditions
  - Different curves on a chart are specified which dictate the maximum frequencies and decibels that are allowed
  - **Preferred Noise Criteria (PNC):** is a modification of NC curves that have sound pressure levels lower than the NC curves on the low/high frequency needs of the chart. For example:

Occupancy	Minimum	Maximum
Concert Hall/Recording Studio	NC - 15 dB	NC - 20 dB
Bedroom/Hospital/Large Conference	NC - 20 dB	NC - 30 dB
Private Office/Small Conference/Library	NC - 30 dB	NC - 35 dB
Large Office/Retail/Restaurant	NC - 35 dB	NC - 40 dB
Lobby/Open Work Space/Laboratory	NC - 40 dB	NC - 45 dB
Commercial Kitchen/Computer Room/Light Maintenance Shop	NC - 45 dB	NC - 55 dB

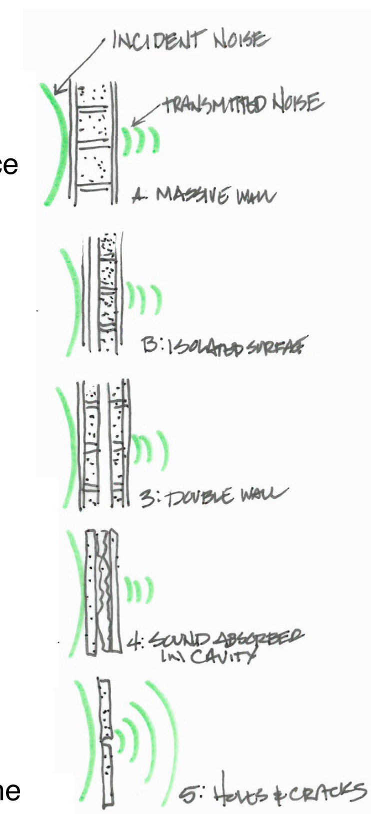
- Doppler Effect:
  - The apparent change in frequency or wavelength of a wave that's perceived by an observer moving relative to the source of the wave
  - The effect doesn't happen due to an actual change in the frequency of the source

- *Example: an ambulance's siren appears to get louder as it approaches you, then gets more quiet the farther it goes beyond you. The actual volume of the siren doesn't change, just your proximity to it.*

- Impact Noise
  - Erratic sounds caused by footballs, dropped objects, vibration of mechanical equipment, etc.
  - A "tapping machine" is used to measure the degree of isolation of impact nosies in a structure
  - Data is plotted and interpreted as an **impact isolation class (IIC):** a single number rating of a floor/ceilings impact on sound performance
    - The higher the IIC, the better.
    - Values can then be improved in several ways
      - Adding carpet and resilient tile floors
      - Suspending ceilings
      - Concrete slab floated on compressed fiberboard insulation

Concepts/Goals:

- The goal of architectural acoustics is to design spaces to meet hearing needs
- In architectural acoustics, sequence is sometime referred to as pitch
- Finding the distinction between sound and noise is subjective
- Sound is desirable, noise is not
  - Your conversation with your friend about is typically considered "sound", but if you're having that conversation in a reading room of a library then it becomes "noise" to others
- Acoustics is the science of sound, which is the sensing of compression waves in air
- Sound is similar to light as they are both transmitted by waves, and they both obey the inverse square law: the intensity is inversely proportional to the square of the distance from the source.



Processes:

- Rules of thumb for preliminary estimation of sound transmission loss
  - Typically, transmission loss through a barrier increases with the frequency of sound
  - A wall with 0.1% open area (e.g.: cracks, holes, under doors) will have a maximum Transmission Loss (TL) of about 30 dB
  - A wall with a 1% open area will have a max transmission loss of about 20 dB
  - A hairline crack will decrease a partition's Transmission Loss by about 6 dB
  - A 1 in^2 opening in a 100 in^2 gypsum board partition can transmit as much sound as the entire partition
  - Although placing fibrous insulation in a wall cavity increases the Sound Transmission Class Rating (STC), the density of the insulation is not a significant variable.

- **Control of Sound Transmission**
  - In addition to the construction of the barrier itself, other variables are critical for the control of sound transmission
    - Leaks between adjacent construction assemblies
      - Run studs to the underside of the slab
      - Install gypsum board tight to the floor and underside of the slab
      - Caulk edges
    - Flanking transmission through duct
    - Leaks at partition penetrations
      - Don't rigidly connect pipes/ducts to walls
      - Gaps should be sealed and caulked
    - Flanking transmission through ceiling into plenum
    - Transmission and impact loss through partition
      - Use weatherstripping at doors
      - Use heavy doors
      - Laminated glass can be set in resilient framing, or use layer of glass with air gaps in between each layer
    - Loss through outlets and openings in the wall (stagger and caulk them)
    - Leaks at floor/wall intersection
    - Impact sound through the floor
- The **mass law** is based on the principle that the larger the mass the less it will vibrate

Building Systems + their Integration

Vocabulary:

- **Sound Masking:** a technique used to hid unwanted sounds by the addition of controlled sounds (aka Pink/White Noise)
- **Coefficient of Absorption (a):** the ratio of the sound intensity absorbed by the material to the total intensity reaching the material. Varies with the frequency of sound/material
- **Sabin:** a unit of sound absorption, 1 ft^2 of 100% absorbing material is 1 sabin
- **Reverberation:** the persistence of sound in an enclosed space after the source has stopped. Continuous reflection.
- **Reverberation Time:** the time it takes the sound level to decrease 60 dB after the source has stopped by producing sound
- **Reflection:** the return of sound waves from a surface
- **Echo:** a sound wave that has been reflected with sufficient magnitude and delay so that it's heard as a sound distinct from that transmitted directly
- **Diffusion:** random distribution of sound from a surface that occurs when the surface dimension is equal to the wavelength of the sound striking it
- **Diffraction:** the bending of a sound wave around an object or through an opening.
- **Resonance:** tendency of a system to vibrate at increasing amplitude at certain frequencies
- **Reverberation Time:** the time required for a sound to decay 60 dB in a space after the source has stopped producing sound
- **Persistence:** result of multiple reflections in an enclosed space in a short period of time
- **Sound Insolation:** reduction of sound energy levels through the use of material that absorb reverberant sound and block airborne sound because of their high sound transmission loss factor (eg: acoustical panels, foam curtains, fibrous material)

- **Sound Isolation:** minimizing sound transmission from one area of a building to another through building design (eg: location of mechanical rooms, partition detailing, using dampers/pads/insulating materials)
- **Sound Absorption:** process of dissipating sound energy by converting it to heat
- **Wall Vibration:** indicates a sound wave on the opposite side of the wall
- **Free Field Room (Anechoic Room):** room whose boundaries absorb all of the sound
- **Room Resonance:** phenomenon which occurs when sounds in a room that are within a narrow band of frequencies tend to sound louder than sound of other frequencies

Equations: (those in gold are given on ncarb formula sheet)

Sabins = (surface area of room) x (absorptivity of surfaces)

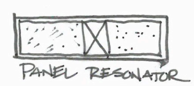
Acoustical Absorption A (sabins) = (Total surface area of barrier or component between rooms, S) x (Coefficient of absorption, a)

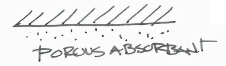
Noise Reduction Coefficient = $\frac{\text{Total sabins, sound absorbing units, A}}{\text{Total surface area in the room, S}}$

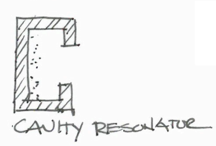
Reverberation Time (T_R) = 0.05 (the speed of sound) x $\frac{\text{Room volume, V}}{\text{Total acoustical absorption at that frequency, } \sum A}$

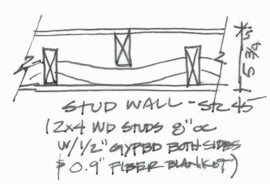
Facts/Rules:

- Noise reduction is basically the science of converting acoustical energy into heat
  - The heat produced is negligible (about 0.003BTU per 130 dB)
  - Energy of sound is absorbed into the room contents, structure, and wall coverings
- Two primary acoustic characteristics of an enclosed space are absorption and reverberation
- Noise Reduction Methods
  - Reduce the level of the sound source
  - Modify the absorption in the space
  - Most indoor spaces contain a near filed, reverberant field, and free field
  - Introduce a nonintrusive background sound (like white noise or random noise)
  - Low Frequency control usually requires an allowance for thicker partitions or mores pace to apply detailing that absorbs low frequency sounds:
    - **Panel Resonators:** a sized furred panel located a certain distance from a wall to absorb low frequency energy while reflecting mid and high frequency energy
    - **Cavity Resonators (Helmholtz):** a large air space that is filled with absorptive material and a sized small opening to absorb specific low frequency range
      - *Example: a CMU wall with narrow slit opening into the cavity of the block*
  - Absorption
    - Change room reverberation characteristics WITHIN the room will have minimal affect on the noise level in adjoining spaces
    - Useful strategy in spaces with distributed noise like offices, schools, restaurants, machine shops
    - Also good to use in spaces with hard surfaces









- Outdoor Sound Barriers
  - Location of the outdoor barrier is the most important to its success
  - Solid barriers are located very close to the source or very close to the receiver
  - Must be higher than the line of sight between the source, the higher the better
- Mechanical Systems
  - Most mechanical equipment produces noise having a frequency or pitch related to the rotational speed of the equipment
  - Contains a random mix of frequencies called **white noise**
    - Can mask other sounds like speech

- **Sound Absorption:**
  - Sound intensity level decrease about 6 dB for each doubling distance from the source in free space
  - Maximum absorption possible, per the **coefficient of absorption** is 1.0 in free space.
  - A material with a coefficient of absorption less than 0.2 is reflective, and above 0.2 is sound absorbing.
  - Absorption techniques are generally useful and effective to change room reverberation characteristics
  - Absorptive materials are usually better at reducing the transmission of high frequencies than low frequencies.
    - Total absorption of a material is dependent on its coefficient of absorption and the area of the material
    - Otherwise said…the effectiveness is dependent on the type of material and the method of installation rather than the thickness
  - **Sabins**
    - The unit of absorption
    - An acoustical measure of reflectivity and absorptivity similar to that in radiation, designated by the Greek letter alpha. It is measured in a unit called a sabin.
    - **The absorptivity per square foot of any given surface varies from 0 (all sound is reflected) to 1.0 sabin (all sound is absorbed).**
    - As spaces become larger, the reverberation time tends to increase. As absorptivities become greater, the reverberation time tends to decrease.
    - Very reverberant spaces are often called “live” space, and spaces with short reverberation times are called “dead” spaces.

- **Sound Reverberation:**
  - Persistence of sound in an enclosed space after the sources has stopped
  - 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 by producing sound
    - Some recommended reverberation times

Offices/Small Rooms for Speech	=	0.3 - 0.6 sec
Broadcast Studios	=	0.4 - 0.6 sec
Elementary Classrooms	=	0.6 - 0.8 sec
Lecture/Conference Rooms	=	0.9 - 1.1 sec
Small Theaters	=	0.9 - 1.4 sec
Churches	=	1.4 - 3.4 sec
Auditoriums for speech and music	=	1.5 - 1.8 sec
Opera Halls	=	1.5 - 1.8 sec
Symphonic Concert Halls	=	1.6 - 2.1 sec

- **Speech Privacy:**
  - Speech privacy is a function of the degree of sound isolation provided by the barriers between rooms and the ambient sound level in the receiving room.
  - Two measures used to evaluate open office acoustics are the articulation class and articulation index.
  - They are intended only for open office situation where speech is the primary sound concern
  - **Articulation Class (AC):** gives a rating of system component performance and does not account for masking sound
  - **Articulation Index (AI):** measure the performance of all the elements of a particular configuration working together:

Ceiling absorption	Wall Partitions
Space Dividers	Background Masking Systems
Furniture	HVAC Systems
Light Fixtures	

  - Predicts the intelligibility of speech for a group of talkers and listeners and gives a result in a single number rating
    - Rating Ranges from 0.00 (complete privacy) to 1.00 (no privacy)

Confidential Speech/Can't be Understood	=	- 0.05
Normal Speech Privacy	=	0.05 - 0.20
Speech Understood between elements	=	+ 0.20
No Privacy	=	+ 0.30

  - Rating can be used to:
    - Compare the relative privacy between different parts of workstations/areas
    - Evaluate how changes in open office components affect speech privacy
    - Measure speech privacy objectively for correlation with subjective response
  - To design for speech privacy in open areas:
    - Have a high absorption ceiling
    - Use space dividers with absorptive surfaces to reduce transmission
    - Arrange floor, furniture, windows, and light fixtures to minimize sound reflection
    - Distance actives from each other
    - Introduce a background noise system to balance with speech privacy

Concepts/Goals:

- Noise Reduction and Control:
  - Reduction of noise generation at the source by proper selection and installation of equipment
  - Reduction of noise transmission from point to point by proper selection of construction materials and appropriate construction techniques
  - Reduction of noise at the receiver through acoustical treatment of the relevant spaces to meet the noise criterion (NC) criteria

Processes:

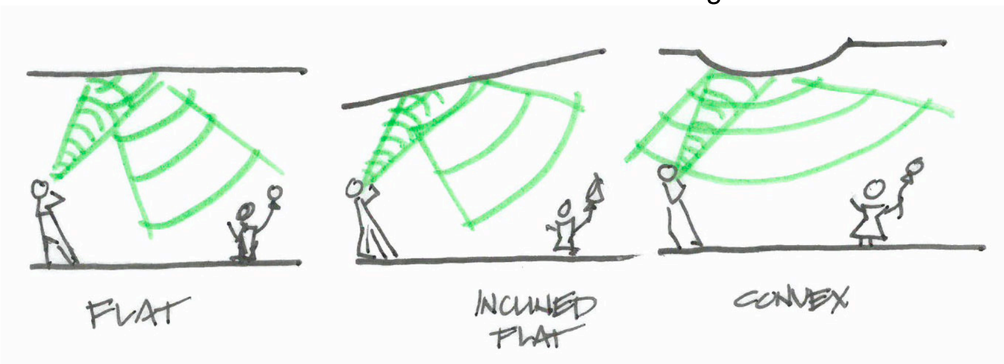
- Rules of thumb for preliminary estimation of sound absorption
  - The average absorption coefficient for a room should be at least 0.2
    - An average absorption above 0.5 is typically not desirable or economically justified
  - Each doubling of the amount of absorption in a room results in a noise reduction of only 3 dB
  - If additional absorptive material, an increase

  - Each doubling of the absorption in a room reduce reverberation time by 50%
  - Ceiling treatments are best for large rooms, wall treatments are best for small rooms
  - The amount of absorption of a pours type of sound absorber (e.g.: fiberglass, mineral wool) is dependent on the material's thickness, density, porosity, and orientation of fibers.
- Limiting Noise in a Building:
  - Mechanical Systems:
    - Mechanic noise occurs when a vibrating device is in continuous direct contact with the structure.
    - Use resilient mountings and flexible bellows to isolate equipment vibrations
    - Connection between ducts/pipes/equipment should be made with flex connections
    - Line ducts with glass fiber insulation, install mufflers, and/or use smooth duct turns
    - Maximize the distance between diffusers in adjacent spaces
    - Locate noise producing equipment away from quiet, occupied spaces
    - Walls, ceilings, floors of mechanical rooms should be designed to attenuate noise
    - Systems should be designed to minimize high velocity flow and sudden changes in fluid velocity
    - Reducing mechanical equipment sound power is *not* a form of isolation for structure borne sound
  - Plumbing Systems
    - Use expansion valves and flexible loop connections to reduce pipe rattling
    - Seal pipe penetrations through walls and floors with flexible packing
  - Materials
    - Use fibrous materials
    - Deep air space within wall cavity
    - Stagger studs
    - Seal openings in wall
    - Avoid back to back wall outlets
    - Sound attenuation above headers
  - Architectural Planning Concepts:
    - Increase the mass of the wall: often impractical, but theoretically doubling the mass of the wall will increase the TL by 6 dB.
    - Construct a cavity wall: made of two separate layers that are not rigidly connected, as increasing the width of airspace will increate the TL, placing sound absorbent material in the airspace will do so further
    - Reduce the actual studs: in a common stud wall, studs act as a rigid connection between the wall layers. Stagger studs at 8" o.c. and mount sheetrock with resilient clips
    - Locate similar areas next to each other both horizontally and vertically
    - Uses closets and hallways to buffer between noise producing spaces
    - Locate noise producing areas away from quiet area (e.g.: mech room away from library)
    - Stagger doors in hallways (e.g.: hotel room doors down a double loaded corridor)
    - Locate operable windows as far away from each other as possible
    - Locate furniture and other noise producing object away from walls
    - Minimize the common wall area between two rooms where sound transmission reduction is desired/required
    - Avoid room plan shapes that will reflect noise (eg: circular, barrel valued hallway)
    - Avoid parallel walls with hard surfaces in small rooms

- Provide speaker in centerline location of room and splay walls to reduce reverberation in theaters/auditoriums

Construction Details and Constructability

Facts/Rules:
- A room's acoustics are dependent on its shape, form, volume, and nature of surfaces
  - Room Form:
    - Parallel surfaces: reflect sound back and forth and can cause excessive reverberation and undesirable echoes or flutter
    - Concave Surfaces: focus sound and can create undesirable hot spots of sound
    - Convex Surfaces: diffuse sound and are desirable in listening areas



- Sound Paths:
- Ideally everyone listening to someone in a room should be able to hear the speaker or performer with the same degree of loudness and clarity
- Generally, sound amplification systems are required in spaces larger than 50,000 sq.ft.
  - **Specular Reflection:** occurs when sound reflects off a hard polished surface
    - Can be used to good advent to create an effective image source
    - (Ex: greek theaters arranged in steep conical surfaces around the performer)
    - Placing sound sources above the seats helps sound travel too
  - **Echoes:** a clear echo is caused when reflected sound at sufficient intensity reaches a listener more than 50 ms after he as heard the direct sound
    - Undesirable (unless you' enjoy shouting into canyons maybe) as the make speech less indelible and music sound mush
    - Typical echo surfaces are the back wall and ceiling above the proscenium in an auditorium
  - **Flutter:** a buzzing or clicking sound, which is comprised of repeated echoes traverse back and broth between two non absorbing parallel surfaces
    - Either change the shape of the reflector or their parallel relationship, or add absorption
- Absorbent materials
  - Absorption is normally higher at high frequencies than at low
  - Absorption is not always proportional to thickness but depends on the type of material being used an the method of instillation
  - It's possible to obtain a sabin greater than 1.0 by using very thick blocks
  - Installation methods have a pronounced effect

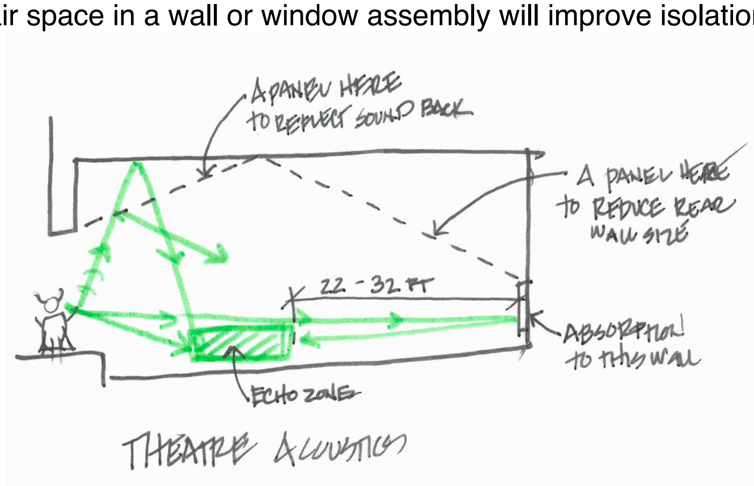
    - All other factors remaining constant, the thicker the absorbent material, the better its low frequency absorption characteristic
- Good Absorptive Materials
    - Acoustic tile
    - Perforated metal faced unit
    - Acoustic panels
    - Acoustic Plaster
    - Sound Blocks
    - Wall Panels
    - Resonator Sound Absorbers
    - Carpeting and Drapery
- Building Code:
    - OSHA and UBC have minimum requirements for noise levels
        - OSHA limits the amount of exposure to high decibel noises in the workplace.
        - The higher the decibel, the fewer hours one can be exposed to it.
            - Eg: 90db = 8 hour exposure, 110 db = 30 minute exposure
        - Minimum Sound Transmission Class ratings vary based on the assembly of construction. General rule of thumb:
            - An STC 50 for walls, floor, ceilings
            - STC 26 for entrance doors

Concepts/Goals:

- Sound will travel through the weakest structural elements, which, many times, are doors, windows or electrical outlets.

Processes:

- Walls must extend to the structural deck in order to achieve optimal isolation. Walls extending only to a dropped ceiling will result in inadequate isolation.
- When the mass of a barrier is doubled, the isolation quality (STC rating) increases by approximately 5 dB, which is clearly noticeable.
- Installing insulation within a wall or floor/ceiling cavity will improve the STC rating by about 4-6 dB, which is clearly noticeable.
- Often times, specialty insulations do not perform any better than standard batt insulation.
- Metal studs perform better than wood studs. Staggering the studs or using dual studs can provide a substantial increase in isolation.
- Increasing air space in a wall or window assembly will improve isolation.



CONTENT AREA: SPECIALTIES / COMMUNICATIONS + SECURITY

Building Design

Vocabulary:

- **Communication Systems:** include intercoms, paging devices, sound systems, TV, CCTV, LAN and (most prevalent) telephone.
- **LAN:** a data communication system allowing a number of independent devices to communicate directly with each other and within a moderate sized area

Facts/Rules:

- Types of Communication Systems:
  - Phone
    - Fed through main cable connecting to rooms where they are split into riser cables
    - Risers are typically located near the core and connect at each floor
    - Multiple lines are supported by a phone switch
    - Each phone is connected to the switch via a copper cable
    - Phone switches can be small (up to 8 phone lines with 32 telephone connections), or large (hundreds of phone lines with thousands of extensions)
    - Large phone lines are called Private Branch Exchange or PBX and they can be really expensive
  - Data
    - Typically used to describe a mainframe or minicomputer system, not the modern day LAN systems
    - System was popular in the 1960s - 1980s and have mostly been replaced
    - Mainframe: a large centralized computer that performed all activities, all applications were installed and data stored on computer's disk drive. Users interacted through terminals
    - Minicomputer: smaller version of mainframe computer, all applications run on centralized computer, but system is smaller and supports a few number of user terminals
  - Local Area Networks (LAN)
    - Designed in the 1980s to link personal computers together enabling them to communicate
    - Includes computers, network interface card, communication cable, hubs/switches
    - Each station has to have a direct cable connection to a port on the hub
  - Building Automation and Control Systems (BACS)
    - Regulate a building's environment or monitor it for safety or security
    - Use a centralized control unit and distributed sensors or devices
    - Each sensor connects to a port on the centralized control
    - Systems include:
      - HVAC
        - Thermostats are connected to the control unit with cable
        - Preset thresholds trigger a centralized control to run on the system to regulate the temperature in the area
        - ASHRAE Standard 90.2 calls for thermostats capable of a temperature range of 55ºF - 85ºF

- Fire Alarm
  - Controls the detection, suppression, and notification of fire
  - Alarms are wired to a central port, when a signal is received the system can activate the fire suppression system and/or notify desired people
  - Can integrate with security systems so normally secured doors can be opened for a safe evacuation
  - Can link to the electrical system to provide emergency lighting or elevator capture during a fire/emergency
- Security Systems
  - Centralized control unity and Sensors & Magnetic Contact Points
  - smoke and heat, carbon monoxide, motion, water, freeze, doors/windows opening/breaking, personal emergency
- Access Control
  - Include a centralized control unit and access points
  - Access points are connected to the control with cables, and open when user is verify by whatever desired method
  - Include: card readers, key pads, biometric sensors
- CCTV
  - Video network for security
  - Video cameras are placed throughout a building and campus and wired to TV monitors in a central security location
- Intercom
  - Master stations in residential intercom systems differ from remote stations in that they allow selective calling
- Sound Systems
  - Operates by converting sound waves into energy, increasing the power of the electrical energy using electronic circuitry, then converting the resulting electrical energy back into the form of sound waves
  - Used for overhead paging and/or audio to broadcast information or music
  - Components include:
  - Sound source, Amplifier, Communication Cable, Speakers
  - In a two-channel sound system, the preamp would be located between the program selector and the distribution switch bank

Building Systems + Their Integration

Vocabulary:

- **Retinal Scan:** biometric technique that uses unique patten of blood vessels at the back of the eye.
- **Iris Recognition:** an automatic method of biometric identification that uses recognition of the irides of an individual's eyes.

Facts/Rules:

- Security Systems:
  - Normally open contact intrusion detecting sensor systems are no longer used in new construction
  - Intrusion detection is classified into three types: perimeter protection, area or room protection, and object protection

- **Perimeter Protection:** secures entry points (e.g.: doors, windows, ducts) to a space or building. Common types are:
  - Magnetic contacts: used on doors and windows, surface mount or concealed
  - Glass Break Detectors: used 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/Room Protection:** field of coverage sense someone within a certain area where no one should be when activated
  - Photoelectric Beams: pulsed infrared beam across a space detects intrusion if beam is broken
  - Infrared Detectors: unobtrusive, but require a clear field of view of optimal protection. They sense sources of infrared radiation of the human body
  - Audio Detectors: identify unusual sounds above normal level
  - Pressure Sensors: detect weight on a floor other surface
  - Ultrasonic Detectors: emit a high frequency sound wave...but limited to an effective area of 20' x 30' and 12' tall
- **Object Protection:** sense movement or tampering of individual objects
- Access Control:
  - **Mechanical Lock:** simplest and tractional form of security. Disadvantage is that duplicate keys can be made easily
  - **Card Readers:** common electronic access control device. System can be programmed to control house of use, monitor car use through logs, and remove access code for card if lost or stolen
  - **Numbered Keypads:** operate kind of like unlocking a door by entering a numerical code. Eliminate the problem of keys with standard locks, but aren't as flexible as magnetic rads
- **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:** Consist of moveable mechanism that is mortised into the frame
  - When activated, the electric strike tracts and the door can be opened
  - On the inside, the latch bot can be retracted by a lever handle
- **Electromagnetic Locks:** lock holds door open with a magnetic force and can be opened by card reader, keypad, and/or buttons. They can also open when fire alarms are activated for egress
- **Biometric Devices:** very expensive methods of security, but provide counterfeit-proof method of identification and security
  - Read the individual biological features of a person (e.g.: iris/retina of the eye, fingerprint)

Construction Details + Constructability

Facts/Rules:

- Premise wiring is the system of raceways, boxes and outlets dedicated to communication system, excluding audio signals
- A clear wall space of 4 - 6 ft is needed for the service entrance of a multiple-dwelling telephone system
- Signal system riser closets should have a minimum net area of 20 sf and a minimum clear wall of 5 ft for cabinet mounting

CONTENT AREA: SPECIALTIES / CONVEYING SYSTEMS

Building Design

Vocabulary:
- **Vertical Transportation:** all the systems used to move people and materials vertically, either with human effort or with mechanical

Facts/Rules:
- **Elias Otis:** an American industrialist who invented the safety device that prevents elevators from falling if the hoisting cable fails
- Codes/Governing Bodies that have an impact on design and installation of system
  ANSI/ASME Code A17.1: Safety code for elevators, dumbwaiters, escalators, and moving walks
  NFPA: fire safety and electrical standards for life safety
  ADA: guidelines for accessibility
  National Elevator Industry Inc. (NEII): standard layouts and suggested minimums for accessibility

Concepts/Goals:
- Vertical transportation has been around for a really long time.
- Hoists were used to lift materials not people because they weren't safe
- Elias Otis invented the safety device that would ultimately make elevators safe for routine human use

Building Systems + their Integration

Vocabulary:
- **Elevator:** a vertical transportation device used to move people or cargo
- **Hydraulic Elevator:** an elevator lifted by a plunger or ram
- **Electric (Traction) Elevator:** an elevator lifted by cables

Equations:
Elevator speed = 1.6 x building height + 350

Facts/Rules:
- Stairs
  - Most common means of vertical circulation between floor of a building
  - Typical Dimensions:
    - May be as narrow as 36" but when occupant loads are over 50 people, they must be 44" wide
    - The rise of step should be 7" max
    - The run of a step should be 11" min
    - Handrails can project 4-1/2" on both sides and
    - Handrail diameter is between 1-1/4" - 2" and at least 1-1/2" away from the wall
    - Railings should continue to slope one tread length past the last tread and extend an additional 12" at the bottom of a stair.
    - Nosing should not be abrupt and have a max rounded edge of 1/2"

- Fire Stairs are required for emergency existing, and their number is controlled by the size of the building
- Monumental Stairs are grand staircases in lobbies that connect two floors but generally can't be used as a fire stair
- Residential stairs have more lenient regulations because fewer people use them

- Ramps
  - Incline walkways that allow easy vertical transition between levels
  - Usually as wide as corridors leading to them, or 36" min for accessible ramps
  - Minimum slope is 1: 12, with amax rise of 30" and 30'-0" in length
  - Landing lengths needs to be 60", and if the ramp changes direction 60" square
- Ladders
  - Used to access roofs, utilities, and service areas
  - Most permanent ladders are made from metal
  - 18" wide minimum
- Elevators
  - Generally consist of an enclosed platform or car which is raised along rails in an enclosed vertical shaft. Are not considered a legal exit from a building
    - **Hydraulic Elevator:**
      - Used for low-rise, or less than 5 story buildings, or about 50'-0"
      - Speed varies between 25 - 150 feet per minute
      - Can carry about 10 tons
      - Commonly used for freight in industrial and low-rise commercial buildings, passengers in small buildings, or single family residential
      - Sit over a plunger or ram which operates a cylinder that extends as far into the ground as it is tall.
      - Oil serves as the pressure fluid and is controlled by high speed pumps
      - The main advantage of hydraulic elevator systems is that they don't require a penthouse machine room or heavily braced roof over the shaft
      - Cost less than electric elevators because they are more simple
      - **Holeless Hydraulic:** uses a telescoping plunger set into the shaft next to the cab. Lift is provided by applying force to the upper member of the car frame
    - **Electric (Traction) Elevator:**
      - Used in commercial and industrial buildings greater than 5 stories/50'-0"
      - Speeds up to 1,800 feet per minute
      - Capacities up to 10,000 pounds
      - Traction is used to transmit lifting power to the hoisting cables by means of friction that develops when cables run over grooves in the sheave
      - On one end is the elevator cab and the other are **counterweights** that weigh about the weight of an empty car plus 40% of the live load capacity
      - Traction machine: Motor and drum assembly that is geared or gearless
      - **Gearless:** motor, sheave, and break all mounded on a common shaft, so 1 revolution of the motor means one turn of the main sheave (typically used for passenger service)
      - **Geared:** motor and break on one shaft which drives a second main shaft, used for high speed installation
      - **Roping:** the arrangement of cables supporting the elevator
      - Single wrap: simplest, cables pass only once over elevator machine sheave and then connected to the counterweight

    - Double wrap: cables pass over the sheave twice, get worn out faster, used for high speed elevators where more traction is required
    - 1:1 Roping: when the rope is directly connected to the counterweight, the cable travels in the opposite direction as far as the car
    - 1:2 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 fast as the car, but requires less weigh to be lifted. (Car travels twice as far as the piston)
- **Freight Elevators:**
    - Designed only to transport equipment and materials (and the passengers needed to handle them)
    - Commonly available in 2500 lbm - 8000 lbm
    - Freight elevators are available as standard designs for capacities of up to 20,000 lbs beyond this point, they must be specially engineered.
    - Speeds range from 50 ftm - 200 ftm
    - Capacity takes prescience over speed
    - Classifications:
        - Class A: general freight, no item can exceed 1/4 the rated capacity of the elevator (no less than 50 lbm/sq. ft of platform area)
        - Class B: used for motor vehicle loading and no less than 30/lbm/sq. ft.
        - Class C1: includes industrial truck loading based on 50/lbm/sq.ft.
        - Class C2: includes no industrial truck loading based on 50/lbm/sq.ft
        - Class C3: concentrated load for the truck not carried and with increments greater than 25% rated capacity
- **Safety features:**
    - Numerous due to all the potential hazards
    - **Main Break:** is mounded on shaft and operated by the control mechanism
        - Break is self applying so the car will stop in the event of a power failure
    - **Governor:** measures and limits the elevator speed by means of the control panel.
        - It will actuate the safety rail clamp if the elevator tries to exceed its proper rate of travel
    - **Safety Rail Clamps:** grip the side of the rails if there is an emergency
    - **Car Buffers/Bumpers:** located on the bottom to stop the car if it over travels at low speed….won't do much to stop a car traveling at a higher speed
    - **Interlocks:** prevent the elevator from operating unless the hoistway door is closed and locked
    - **Safety Edges:** Doors have spring loaded lip that retract open if it encounters a person/object when attempting to close
    - **Proximity Dictators:** similar to safety edges, but senses the presence of a person near the door and can stop the closing motion
    - Cabs will self level to reduce tripping hazard
- **Door Arrangements:**
    - Can vary for the most efficient solution
    - **Single Speed Center Opening:** common and allows faster passenger loading and unloading than side opening doors
    - **Two Speed Side Opening:** two leaves, one which telescope past the other as they move
    - **Two Speed Center Opening:** four leaves, two telescope past the others as they move

    - Minimum opening width is 3’-6”, but 4’-0 is better because it allows two people to leave or enter at the same time
  - **Machine Rooms**
    - Are best located directly above the hoistway in order to provide adequate space for the motor, sheave, brake, controller board, speed governor, floor selector mechanism, and motor genitor
    - Room should be as wide as the hoistway and 12’ - 16’ deeper than the hoistway
    - Minimum ceiling height should be from 7’-6” - over 10’-0”
  - **Motor Control Systems:**
    - Variable Voltage, Variable Frequency AC: widely considered the best system for new, high quality installations of any speed
    - Variable Voltage DC: prior to VVVF, used in most high quality installation prior to 1990. Limitations include low overall efficiency, high machine and maintenance cost, high thermal loss, high noise level.
    - AC Thyristor: type of motor control requires high-power transistors to make accurate speed control of standard AC squirrel cage motors
    - DC Thyristor: has a greater rise and speed capability than AC version
- Dumbwaiters
  - Hoisting and lowering devices like small elevators but only for material handling.
  - Platform can be 9 square feet max and carry 500 lbs
  - Used for service related functions
- Escalators
  - Moving staircase system that provides rapid, comfortable, continuous vertical travel
  - Used to move large numbers of people quickly, efficiently, safely, and at a low cost of operation (4,000 - 8,000 people per hour)
  - Made of custom built steel trusses and fitted with belts, steps, and handrails
  - Typical angle of incline is 30˚
  - Are typically 32” or 48” wide, with tread widths are 24” or 40”
  - Not considered a legal exit
  - Not considered an ADA route...need an alternative (like an elevator)
  - Rated by Speed and Size:
    - 100 ftm is the industry standard
    - 120 ftm for transportation and sports facilities
  - Types of Escalator Configurations:
    - **Parallel:** up and down escalators "side by side or separated by a distance", seen often in metro stations and multilevel motion picture theaters
    - **Crisscross:** minimizes structural space requirements by "stacking" escalators that go in one direction, frequently used in department stores or shopping centers
    - **Multiple Parallel:** two or more escalators together that travel in one direction next to one or two escalators in the same bank that travel in the other direction
    - A designer seeking to avoid the resentment and confusion of building occupants would design a separation between escalators in a crisscross walk-around of no more than 10 ft
    - It is not advisable to use the stacked parallel arrangement of escalators beyond 2 floors, as users will become annoyed at the long walk-around.
- Moving Sidewalk
  - No steps are involved
  - Can have a short incline (up to 15° angle)
  - Typical operation speed is 140 - 180 feet per minute

Implications of Design Decisions

Facts/Rules:

- Elevator Design
  - Elevator design involves the selection, capacity, speed, number of elevators including location and arrangement, roping method, machine room layout, control system, and cab decoration
  - Elevators should be located near the center of the building, at the lobby level the should be easily accessible from the entrance and visible from all points of access
  - Even in smaller buildings there should be a minimum of two elevators
  - Elevator lobbies should be designed to see all call lights from one point, as to minimize walking required between any car that might arrive
  - Adequate circulation space is needed outside the elevator to allow for people getting off and getting on at the same time
  - There should never be more than 8 cars in one elevator bank or 4 cars in one line
  - Maximum number of cars serving the same portion of a building in a single hoistway, per the IBC, is three
  - Elevators can account for as much as 10% of a 25-story building's construction cost
  - Very tall buildings often have unique elevator strategies
    - Divide the total number of required elevators into banks that serve different zones
      - Keeps waiting and travel times acceptable, but shafts take up a lot of space, especially on lower floors
    - Sky Lobby Concept: high speed elevators take people from the lobby up to a sky lobby to transfer to elevators that specifically serve upper floors
      - Reduces the amount of space taken by elevator shafts
    - Stacked or Double Deck Elevators: doubles shaft capacity, reducing area required for elevator and decreases local stops.

Construction Details + Constructability

Vocabulary:

- **Handling Capacity:** maximum number of passengers that can be handled in a give period, typically based on a five minute peak period
- **Capacity:** measured in weight, the number of people a car can carry
- **Interval:** average time between departure of cars from lobby
- **Round Trip Time:** average time required for an elevator car to make a round trip
- **Travel Time:** average time spent by a passenger from the moment they arrive in a lobby to leaving the car on the upper level
- **Interval:** average waiting time for an elevator, varies with building type
- **Star of Life:** blue six pointed star with the rod of Asclepius in the center, used to represent emergency medical services

Equations:

$$\textbf{\# of Elevators Required} = \frac{\text{total \# of people to be accommodated in a 5 min period}}{\text{handling capacity of one car}}$$

Facts/Rules:

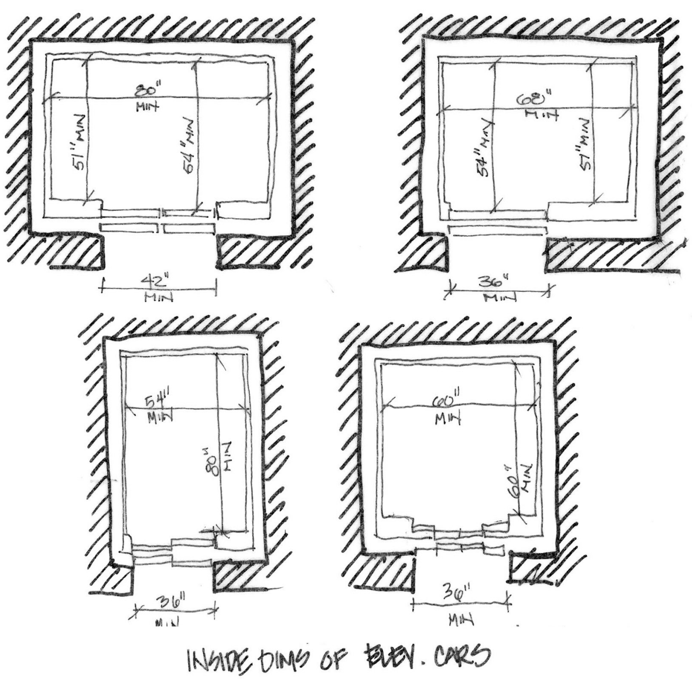
- Building type dictates the peak traffic periods for elevator use.
- The minimum number of elevators is determined by counting the volume of people during a peak period interval of 5 minutes and dividing this by the 5-minute handling capacity (based on car size and round-trip time) of an elevator.
- Operation and Control of Elevators
  - **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 waiting time is minimized
    - **Single Automatic:**
      - First system of automatic system for elevators that 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
      - Elevator can't be called if someone is using it
      - It's typically intended for small buildings
    - **Selective Collective Operation:**
      - Most common type of system for light to moderate service
      - Elevator remembers and answers all call in opposite direction
      - When the trip is complete, the cab typically returns to the lobby
    - **Group Automatic Operation:**
      - For use in large buildings
      - System controls all elevators with programmable microprocessor to respond to calls int e most efficient way.
- Emergency Operation
  - In the case of a 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 mode by the fire department
  - Star of life must be displayed if building is over 4 stories and has at least one elevator, which must be able to hold a 24X84 open stretcher
  - the function of a soffit around an elevator opening through a floor level is provided to serve as a smoke baffle that deflects smoke and flames
- **Typical Elevator Response Times**
  - The minimum time between a car answering a call and the moment the doors of that cab start to close is five seconds
  - Typically waiting intervals should be 20-30 seconds.
- **Typical Elevator Design Speeds:**
  - Adequate to provide prompt, efficient service
  - Shouldn't have "jack rabbit" starts or abrupt stops...keep it smooth
  - ***Reference MEEB Figure 23.14*** *Average Trip Times*
  - Speeds of elevators given the building height and usage type

Building Height	Small	Average	Prestige	Service
2 - 5 floors	200 - 250 ft/min	300 - 350 ft/min	350 - 400 ft/min	200 ft / min
5 -10 floors	300 - 350 ft/min	350 - 500 ft/min	500 ft/min	300 ft/min
10 - 15 floors	500 ft/min	500-700 ft/min	700 ft/min	350-500 ft/min

Building Height	Small	Average	Prestige	Service
15 - 25 floors	700 ft /min	800 ft/min	800 ft/ min	500 ft/min
Over 60 floor	--	--	1,800 ft/min	1,000 ft/min

- Typical Elevator Capacities:
  - Depend on the type of building, the size of building, and the weigh of people riding
  - Capacity:
    - Varies depending on their use and thigh and overall quality of the project
    - Small office buildings have an elevator rated about 2,500 lb. Capacity with a floor area of 5'-0" x 7'-0" and a 3'-6" wide center opening door
    - Rarely exceed 4,000 lb. capacity for just moving people
    - Handling capacity is based on its car size and its round trip time
    - People need about 2 square feet of space to feel comfortable

Building Type	Small	Average	Large	Service
Offices	2500/3000 lbm	3000/3500 lbm	3500/4000 lbm	4000/6500 lbm
Garages	2500 lbm	3000 lbm	3500 lbm	-
Retail	3500 lbm	3500 lbm	4000 lbm	4000/8000 lbm
Hotels	3000 lbm	3500 lbm	3500 lbm	4000 lbm
Apartments	2000/2500 lbm	2500 lbm	2500 lbm	4000 lbm
Dorms	3000 lbm	3000 lbm	3000 lbm	-
Senior citizens	2500 lbm	2500 lbm	2500 lbm	4000 lbm



ADA Requirements for Elevators

Signal Height = 72" min
Signal Size = 2 1/2" min Self
Leveling = within 1/2" of floor landing
Car Controls = 15" min - 48" max

CONTENT AREA: SPECIALTIES / FIRE DETECTION + SUPPRESSION

Building Design

Vocabulary:

- **Fire:** heat/light energy that is released during a chemical reaction
- **Fire walls:** walls that divide a single building into two or more "buildings", if either side collapses the wall will not for the duration of its rating
- **Fire barriers:** make up rated assemblies/enclosures (e.g.: shafts, exit enclosures, exit passageways, horizontal exits, atriums, mixed use occupancy separation)
- **Shaft enclosures:** openings through floors/ceilings connecting adjacent floors. 1 hour rated when connecting less than 4 stories, or 2 hour if passing through a 2 hour floor assembly or if connecting 4 or more stories
- **Fire Partitions:** demising walls separating tenants, residential units, corridor walls,
- **Smoke:** collection of airborne solid and liquid particles and gasses emitted when a material combusts
- **Smoke Barrier:** used as required to prevent the movement of smoke, have a 1 hour fire resistance rating
- **Smoke Partition:** like a smoke barrier, but does not have to resist fire
- **Incombustible:** consisting of or made of material that will not burn if exposed to fire
- **Horizontal Assemblies:** fire resistance rating (1 or 2 hours) applied to floor and roof construction
- **Means of Egress:** ability to exit a structure in an emergency
- **Area of Refuge:** location in a building where fire and smoke are excluded, and used to contain occupants during a fire or emergency or until safe to evacuate. Has a steady supply of outside air, passive fire protection, electrical integrity/emergency lighting, two way communication/call box to 24 hr manned, or outside line
- **Fire resistance:** values for how long a separation can resist the passage of fire. Stated in terms of hours and can be increased with the use of sprinklers. (eg: walls, doors, windows, floors, etc.)
- **Flame Spread Rating/Smoke Developed Ratings:** measures the amount of flame and smoke a material generates. (e.g. Carpet, fabrics, etc)

Facts/Rules:

- Fire is created by people, electrical, chemical, or mechanical reactions
- The normal concentration of oxygen in the air is 21%
- Most fire related deaths are caused by exposure to smoke and gases, not the actual flames.
- Fire passes through four stages in this order:
  - **Incipient:** invisible particulate matter like combustion gas is given off but no flame is visible, nor any smoke/heat generated. Sensors detect gas
  - **Smoldering:** large particles become visible as smoke, but no visible flame or appreciable heat. Sensors are photoelectric
  - **Flame:** appreciable heat is not immediate present, but follows very quickly. Sensors detect flame
  - **Heat:** uncontrolled heat and rapidly expanding air is present and flames and smoke become major hazards. Smoke inhalation ultimately causes most injuries. Sensors detect heat.

- **Compartmentation:**
  - Critical, as it separates a building into sections
  - *Goal is to contain a fire and limit its spread so people can escape and to protect other parts of the building that weren't originally subject to fire*
  - Can serve as an area of refuge for occupants
  - Separation is required:
    - Between different occupancies
    - At Structural members, they are isolated to protect from fire exposure
    - Depending on occupancy at walls, floors, and ceiling that separate compartments (aka: spaces)
    - At parts of the a building where the max allowable area is exceeded
    - At all openings (e.g.: doors, windows, ducts) through rated walls, closed with approved fire rated devices
    - At exterior walls so to avoid fire spreading to other structures
- **Smoke Control:**
  - The most important part of fire protection because smoke moves so rapidly.
  - Tricky to control because it can move in ways that fire can't, and well beyond the location of fire too
  - Moves by natural convention forces between cool and warm air
  - Goal is to contain, exhaust, and dilute smoke
  - Fire dampers, smoke gaskets, and automatic closing fired doors help
  - **Containment:** same as compartmentation used to contain fires is used here
    - Eg: fire dampers, gaskets on fire doors, and automatic closing doors
  - **Passive Smoke Control System:** a system of some barriers arranged to limit the migration of smoke
    - Can be partitions, doors with smoke seals, or curtain boards
    - Automatic smoke and heat vents must be used in:
      - F and S Occupancy = 1 story over 50,000 sq. ft.
      - H Occupancy = 1 single floor area over 15,000 sf
Or: over stages more than 1000 sq. ft
  - **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 the outside air is turned on creating negative pressure
    - In places or refuge, return an exhaust air ducts are closed and supply air is forced into a space creating a positive pressure.
  - **Smokeproof Enclosure**: a required exit which consist of a vestibule and continuous stairway enclosed from the highest point to the lowest point by 2-Hour walls and which exist into a public way or exit passage leading to one
  - **Stairways:** pressurized to prevent smoke from entering them
    - **Vestibules:** pressured slightly higher than the fire floor, but less than the stairway
    - Provides double protection of the stairway and creates a place of refuge
    - Also where standpipes and fire department communication devices are located.
    - Supplying fresh air to a smoke-free stair entirely from the top or bottom is not advisable because it is too likely that open doors near the source would deplete fresh air for the rest of the stair

- Fire Dampers:
  - Passive fire protection products used in HVAC systems that prevent the spread of fire inside the ductwork through fire resistant rated walls and floors
  - When a rise in temperature occurs, fire dampers close
- Legal restrictions on building begin with local zoning ordinances which govern the types of activities that ay take place on a given piece of land.
  - E.g.: setbacks, number of parking spaces, floor area ratio, fire zone
- Each local government regulates building code to protect the health and safety of public primarily from fire.
- Most building codes in North America are based on the model building code (National Building Code in Canada or International Building Code in US)
- **International Building Code (IBC)**
  - Begins by defining occupancy groups, the purpose of which is to distinguish various degrees/qualities of need for safety in a building.

Group	Name	Includes
A-1 - A-5	Assembly Occupancy	Theaters, auditoriums, lecture halls, night clubs, restaurants, houses of worship, libraries, museums, sports arenas, etc.
B	Business Occupancy	Banks, admin offices, higher-education facilitates, police/fire stations, post offices, etc.
E	Educational Occupancy	K - 12 schools and day care facilities
F	Industrial Occupancy	Industrial Buildings
H1 - H5	High Hazard Occupancy	Toxic, combustible, or explosive materials present
I-1 - I-4	Institutional Occupancy	Healthcare, geriatric, or other spaces where occupants would not be able to save themselves during a fire/ emergency
M	Mercantile Occupancy	Stores, markets, service stations, sales rooms
R-1 - R4	Residential Occupancy	Apartment buildings, dorms, frats/sororities, hotels, 1 or 2 family dwellings, assisted living facilities
S1	Storage Occupancy	Storage of hazardous materials
S2	Storage Occupancy	Storage of low-hazardous materials
U	Utility/Miscellaneous Occupancy	Agriculture buildings, carports, greenhouses, sheds, stables, fences, tanks, towers, other secondary buildings

  - Buildings are classified by different Construction Types, which prescribe the fire resistance rating of the elements and the exterior wall.

- A building (or a portion of it) doesn't have to meet a construction type heigh than the minimum requirements based on the occupancy, even if features of the building actually conform to a higher type of construction:

Type	Includes	Rating
Type I	Building elements are of noncombustible materials	IA = 3 hour fire rating IB = 2 hour fire rating
Type II	Building Elements are of noncombustible materials	IIA = 1 hour min. Fire rating IIB = No fire rating
Type III	Exterior walls are of noncombustible materials, interior elements are of any material allowed by code	IIIA = 1 hour min rating w/2 hr exterior bearing walls IIIB = Unrated interior w/2 hr exterior bearing walls
Type IV	Heavy Timber. Exterior walls are of noncombustible materials, interior elements are of solid or laminated wood without concealed spaces	
Type V	Structural elements, exterior, and inter walls are of any materials allowed by code	VA = 1 hr exterior bearing walls VB = No fire rating
A	Protected / Fire Resistance Rated Construction: All structural members have additional fire rated coating/cover such as sheetrock, or spray on fireproofing. Extends the fire resistance rating of structure members by at least an hour.	
B	Unprotected / Non-Fire Resistance Rated Construction: All structural members have no added coating/cover. Exposed members are only fire resistant according to their natural ability or characteristic.	

- For example, a building would be defined as Type IIA, Type VB, etc.
- Type IV Heavy Timber is just that...there's no A or B protection.
- Type IA has the highest fire resistance rating, while VB has the lowest.
- Sprinklered buildings are fully protected by a complete fire sprinklers system in accordance with the NFPA .
- Unsprinklered buildings are not protected by a fire sprinkler system (duh.)

- If a building is protected throughout with an approve sprinkler system the IBC allows the tabulated area of a single story building to be quadrupled, and of multi story buildings to be tripled.
- If more than 1/4 of a building's perimeter walls face public way/opens space an increase in area is granted per a formula.
- If building is divided by fire walls and meets required fire resistance ratings each portion of the building that is separated from the reminder of the building by fire walls can be considered a separate building for purposes of calculating allowable area. Basically a building can be a LOT bigger than the IBC table would normally be allowed.
- **Allowable building area and limitations** are Based on the Occupancy Type, if multiple uses are separated, and the construction type
- IBC also establishes standards for natural light, ventilation, means of egress, structural design, floor/wall/ceiling/roof construction, chimney construction, fire protection systems, accessibility, energy efficiency, etc…
- **Building Egress**
  - Egress is comprised of three parts:
    - **Exit Access:** the portion of a means of egress system that leads from any occupied portion of the building to an exit.
    - **Exit:** the portion of a means of egress system that is separated from other occupied spaces by fire-rated construction, and extends between the exist access and the exist discharge. Horizontal exist are ok.
    - **Exit Discharge:** the portion of a means of egress system between the exit and a public right of way
    - *Note: Exterior Fire Escapes are no longer permitted or usually permitted because rising smoke from lower floors eliminates the safety of using them*
  - **Horizontal Exits:** a path of egress travel from one part of a building to another part of a building on the same level, which affords safety from fire and smoke
  - **Exit Passageway:** similar to an exit, but horizontal, and leads to the exit discharge
  - Egress is regulated by the number of occupants and is based on the function of the space
  - Aisles, stairs, and doors are sized by multiplying the occupant load by the Egress Width per Occupant table from the IBC
  - **The minimum exit width in inches is determined by multiplying the total flow in the passage (total occupant load) by 0.2 in sprinklered buildings and 0.3 in non sprinkled and can't be less than 44"**
  - Number of exits required from a space and a building is prescribed in the code. Generally at least 2 means of egress are required...unless there are more than 500 occupants, then more are required.
  - For typical commercial uses, the threshold for needing more than one exist is 50 occupants
  - Number of exits may be influenced by Travel Distance to an exist, or the length of the common path of travel to an exit
  - When two or more exits are required, they must be separated by 1/2 the diagonal dimension of the building (1/3 for sprinklered buildings)
  - Fire ratings for corridors are regulated by the IBC. Typically, commercial buildings with a sprinkler system don't require a corridor rating.
  - Residential buildings require a 30 minute corridor

- At least one accessible means of egress is required, which involves an elevator, stair, ramps and areas of refuge
  - An **Area of Refuge** is required for each 200 occupants and must be 30” x 48” in an area protected from fire and smoke
- **Fire Door:** a fire resistive door assembly consisting of frame, door and hardware which provides a specific fire resistive rating when closed
- **Fire Assembly:** a complete fire resistive assembly consisting of a fire door, fire damper, or fire window and its mounting farm and hardware. The entire thing must be approved and labeled by a testing agency

- Fire Hazards of buildings can be classified into three groups per NFPA 13
  - Light Hazard: residences, offices, hospitals, schools, restaurants
  - Ordinary Hazard: automobile garages, laundries, large library stack rooms, printing/ publishing plants, paper processing plants
  - Extra Hazard: areas that handle combustible materials

Concepts/Goals:

- In order of importance, it is most important to fire-protect: columns, girders, beams, the floor slab
- Fire protection codes traditional have three goals:
  - Provide protection (A 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
  - Also: Prevent fires from starting or extinguish them immediately and automatically after they start
- Fire protection is accomplished by:
  - Preventing fire
  - Early fire detection and alarm
  - Providing quick exiting of building occupants
  - Containing the fire
  - Suppressing the fire
- **Fire Containment** achieved through building materials, compartmentation and smoke control
- **Fire Suppression** is achieved through sprinkler systems, standpipes, and other methods

Building Systems + their Integration

Vocabulary:

- **Standpipes:** pipes that run the heigh of the building and provide water at each floor for firefighting hose connection
- **Fire Sprinkler:** the part of a fire sprinkler system that discharges water when the effects of fire have been detected
- **Flashover:** when materials become extremely hot and combust suddenly after reaching their temperature limit
- **Ball Drip:** automatic drain valve at the bottom of dry standpipe

Facts/Rules:

- Water
  - Water is the primary means of fire elimination as it stops the heat and light energy, and chemical reactions of fire.
  - It's cheap, but it damages building and conducts electricity
- Sprinkler Systems:
  - Deluge Systems:
    - Used in high fire hazard areas to flood area in case of a fire
    - Heads are always open and water is controlled by a sensor
    - Sprinklers are activated all at once regardless of the location of the fire
  - Wet Standpipe System: outlets and hoses are located at each floor
    - Most common system
    - Continually pressurized with water
    - Have low initial cost
    - Have quick response time, will work when a sprinkler head reaches 135˚F - 170˚F
    - Susceptible to damage from freezing
  - Dry Standpipe System:
    - Used in areas subject to freezing because no water sits in the pipes
    - Hold valves closed with compressed air, requires constant pressure else the system will leak
    - Slower to deliver water if pipe runs are long
  - Preaction Systems:
    - Reduce likelihood of a false start by requiring both a sprinkler head and fire detection system to be activated
    - Water is allowed into the system before a sprinkler head is opened
  - **Siamese Connections** are provided outside for fire department hose connection
- Standpipes:
  - Typically located in stairways or vestibules
  - Types:
    - Class I (Dry Standpipe): used by fire department only.
      - Dry system without a directly connected water supply, 2.5" outlets,
      - Located at every level of a building within stairway enclosures or within the vestibule if exit enclosure is pressurized
      - Must be used when any portion of a building interior is more than 200 feet of travel from the nearest point of fire department access
      - Used in buildings with more than three stories, and shopping malls
      - If more than 75' above grade, the pipe connection must be provided in every required stairway as well
      - **Ball Drip** used to insure the standpipe remains dry
      - Won't freeze or rust
    - Class II (Wet Standpipe): used by occupants before the fire department arrives
      - Wet system directly connected to water supply system
      - Equipped with 1.5" outlets and hoses for occupant use
      - Required in buildings 4 or more stories tall, theaters, assembly spaces, B, H, I, M, and S occupancies
      - Every point of the building must be within 30' of the end of a 100' hose attached to an outlet
      - Must be designed to supply at least 35 gpm at 25 psi for at least 30 minutes
      - Water system must be designed to provide 70 gpm at 25 psi for 30 minutes

- Class III (Combination Standpipe): used by both occupants and fire department
    - A combo system directly connected to a water supply with both 1.5” and 2.5” outlets
    - Installed in buildings where the highest floor level is more than 30’ above the lowest level of fire dept. access
    - Every point of the building must be within 30’ of the end of a 100’ hose attached to an outlet
    - Installed in buildings where the highest floor level is over 30’ above the lowest fire department vehicle access, or where the lowest floor level is 30’ below the highest fire department vehicle access
    - Exception to use a Class I Standpipe Are:
        - Buildings equipped with a sprinkler system
        - Open parking garages less than 150’ tall
        - Open parking garages subject to freezing temperatures
        - Basements that are sprinklered
- Water is supplied from storage tanks or siamese connections outside
- Sprinkler Head Types:
    - Upright: sit on top of the pipe directly under the structure where combustion gases are likely to form
    - Pendant: suspended under a pipe, typically seen in lay-in ceiling systems
    - Sidewall: located in small rooms that usually only require one head
    - Must be replaced, regardless of type, after being activated
    - Glass Bulb Color/Temperature Code:

Ordinary Temperature	=	Orange or Red	135º - 170º
Intermediate	=	Yellow/Green	175º - 225º
High	=	Blue	250º - 300º
Extra High	=	Purple	325º - 375º
Very Extra and Ultra High	=	Black	400º - 650º

- Other Extinguishers:
    - **Halon:** used when water damage might be bad for the room (e.g.: computer rooms)
    - **Foam:** used where flammable liquid fires might occur (e.g.: industrial buildings, aircraft hangers)
    - **Intumescent paint/calk/putty:** material expands rapidly when exposed to heat insulating the surface
    - **Fire Extinguishers:**
        - Type A: ordinary combustibles (paper, wood, cloth), contains water or water based agents
        - Type B: flammable liquids (gas, paint, solvents), contains smothering types of chemicals (carbon dioxide, foam)
        - Type C: electrical equipment, contains nonconductive agents
        - Type ABC: all of the above
        - Type D: combustible metals, matched with the fire they might be used on
- Types of Fire Detection
    - **Ionization detectors** are used for incipient state
        - Have two chambers: a reference and a measuring
        - A small amount of radioactive material ionizes the air between the charged surfaces in each chamber which results in current flow
        - When combustion particles enter the detector, it impedes the flow which sets off an alarm

    - Usually have to be replaced every 5 years because radioactive material deteriorates
    - Activities in paint booths, welding shops, areas with open flame, etc. Put stuff in the air so an ionization detector wouldn't work so well.
  - **Photoelectric Sensors** are used to detect at smoldering stage
    - React to visible smoke that blocks a beam of light
    - Can measure a large volume of air
    - Are useful when potential fires may produce a lot of smoke before busting into flame
  - **Heat Actuated Sensors** are used during flame stage
    - Activated by temperature rise, and flames must be present before the alarm temperature is reached
  - Locations and types of detectors are determined by code
    - Detectors are required near fire doors, exit corridors, individual hotel rooms, bedrooms, and places of public assembly
  - Can be attached to system activated dampers, exhaust systems, and/or notify a central monitoring station and the fire department.
- Types of Fire Alarms
  - Protected Premise: sounds alarm just inside the building
  - Auxiliary: Local with a direct connection to municipal fire alarm box
  - Remote Station: Direct connection warning to a remote location like a police department or alarm monitoring company
  - Proprietary: Warns to a central station located onsite that monitors multiple buildings
  - Central Station: Similar to proprietary except that equipment is owned and operated by a service company
  - Municipal: supervised, owned and operated by a city or town

Processes:

- Sprinkler and smoke removal systems are sometimes at cross-purposes because the buoyancy of smoke is reduce by cooling water
- Occupancy Requirements for Sprinkler Systems

Group	Name	Minimum Square Footage Requirement
A	Assembly Occupancy	A1, A3, A4 = 12,000 sq. ft or more A2 = 5,000 sq. ft or more A5 = 1,000 sq. ft or more
E	Educational Occupancy	20,000 sq. ft or more Exception: classroom at grade with at least 1 exit
F	Industrial Occupancy	12,000 sq.ft. or more Building more than three stories in height All floors including mezzanine greater than 24,000 sq.ft
H	High Hazard Occupancy	Always.
I	Institutional Occupancy	Wherever occupancy occurs

Group	Name	Minimum Square Footage Requirement
M	Mercantile Occupancy	12,000 sq.ft or more Floor area located more than 3 stories above grade All floors including mezzanine exceed 24,000 sq.ft.
R1	Residential Occupancy	All areas
S1	Storage Occupancy	12,000 sq.ft. or more Building more than three stories in height All floors including mezzanine greater than 24,000 sq.ft
S2	Storage Occupancy	All enclosed parking garages including those under R3 that are 1 or 2 family townhouse occupancies

Implication of Design Decisions

Facts/Rules:

- In the United States, most commercial building fires are now extinguished with an automatic sprinkler system
- Most buildings are required to have at least two means of egress so occupants have at least one unobstructed escape route in case of fire.
- The maximum occupant load in any occupancy for one exit is 49 people
- If two exits are required, the distance between them needs to be at least 1/2 of the longest diagonal dimension the space
- Maximum travel distance for exit access:
  - 200 feet in non sprinklered buildings
  - 250 - 300 feet in sprinklered buildings
- Dead ends are limited to 20 feet, or unlimited if the length is less than 2.5 times the width
- A maximum of 50% of exit stairs can exit through a vestibule or corridor that is adjacent to an exterior exit
- A two-story building accessible to the public must have more than one exit stair
  - 150 feet max separation in non sprinklered buildings
  - 200 feet max separation in sprinklered buildings
- Travel limits are established by the IBC and are based on occupancy type and if the building is sprinklered
- Fire exits must:
  - be located at least half of the longest diagonal distance apart
  - be smoke free
  - empty into a safe place
  - not cross a smoke filled space
  - get people out in a safe and timely manner

Construction Details + Constructability

Vocabulary:

- **UL:** Underwriters Laboratory
- **ASTM:** American Society for Testing Materials
- **NFPA:** National Fire Protection Association
- **ANSI:** American National Standards Institute
- **Smoke Developed Rating:** numerical rating of interior finish material derived from a standardized fire test procedure. The larger the number the greater the density of smoke

Facts/Rules:

- Fire Rated Assemblies:
  - Materials can limit outcome of fire
  - Limits products of combustion
  - Dictates frame spread ratings
  - Establishes flammability standards
- Regulations:
  - Building Codes address warnings, egress materials, size and compartments, and property protection
  - **Life-Safety Code (NFPA 101) Guidelines**
    - Not a legal code, but written like one to facilitate adoption into law by cities
    - Addresses construction, protection, and occupancy features necessary to minimize danger to life from fire including smoke, fumes, or panic.
    - Does not address general fire prevention or building construction features that are normally part of fire/building codes.
    - Applies to existing and new structures
    - Is a source for determination of liability in accidents
  - Flame spread ratings:
    - Groups flame spread ratings (materials propensity to burn rapidly and spread flames) into 5 classes

Class A flame spread rating	=	0-25
Class B flame spread rating	=	26-75
Class C flame spread rating	=	76-200
Class D flame spread rating	=	201-500
Class E flame spread rating	=	over 500

  - A flame spread rating number is the relative rate at which flame will spread over the surface of a material, as compared with flame spread on asbestos-cement board (rated zero) and on red oak (rated 100).
  - Flame spread rating number is not the rate at which the flame actually spreads along the surface and is not an indication of the fire resistance of the material.

VIGNETTE: MECHANICAL + ELECTRICAL PLAN

Steps

1. Open floor plan and take a good look at the plan, turn on ortho, and the cross hairs
2. Open the program and make any general notes
3. Write down the light spread for each light fixture
4. Note any rooms with special conditions (e.g.: spotlights, no grid)
5. Open the plan and pick any room to start with. Draw a ceiling grid for this room
6. Draw light fixtures so that they are spaced correctly per the given light spread values.
7. If needed, reposition all of the light fixtures and grid so that the lights are centered in the room…the grid doesn't matter as much
8. Repeat Steps 5/6/7 for the rest of the rooms
9. Click on the grid in the first room and write down the square footage that's given
10. Calculate the number of diffusers and returns required in the room per the program
11. Spread diffusers out for optimum air flow, and place returns far away from them
12. Repeat Steps 9-11 for the rest of the rooms
13. Place fire dampers at supply and return risers. *Remember, the short leg points in the direction of the airflow!*
14. Draw a short length of duct from the center of the return riser to the outside edge of the fire damper to plenum air space
15. Decide where the rigid ducts can run perpendicular to joists
16. Draw a rigid duct that beings at the risers and continues over to a point between two joists that is perpendicular to the center of a line drawn between the two outermost diffusers to be connected to this run of duct.
17. Draw a second run of rigid duct to pick up another string of diffusers if required.
18. Draw a rigid duct between joints to a point perpendicular to the furthest diffuser for each run of that duct
19. Connect diffusers to rigid ducts with up to 10'-0" long flex ducts. They can run perpendicular to joists and on top of lights.
20. If a rigid return is required, draw it per the program in the same manner that the supply ducts were draw in Steps 15 - 20
21. Verify that all rooms are properly lit, ventilated, and that ductwork runs are continuous!

Tips

- Don't worry about centering lights off the bat, just get them spaced at the proper distances, then move them all as a group.
- This isn't a lay-in ceiling vignette...meaning, don't worry if the grid isn't perfect, what should be is the location of the light fixtures
- Light fixtures shouldn't be closer than 1'-0" or further than 4'-0" from the wall. Ideally lights should be 3'-0" from walls due to light from the fixture & direct light in the room
- Don't put diffusers in front of a door or against a wall. In front of a window is good
- Return grilles should be supported on three sides or else they will fall out of the grid
- Returns should be located at least 4'-0" away from diffusers
- Lines that represent a duct are actually the duct's centerline, so position them accordingly so not to accidentally have the edge of a duct running through a wall or joist
- Don't turn & connect rigid ducts back to the riser
- Try to keep all diffusers from a room on the same main branch
- Mix the supplies and returns around the room instead of having them all to one side.

REFERENCES

areforum

Ballast Ch11 Plumbing Systems.pdf from the forum FTP site
http://www.areforum.org/up/Mechanical%20and%20Electrical/MECHANICAL/

HVAC System Review.xls from the forum FTP site
http://www.areforum.org/up/Mechanical%20and%20Electrical/MECHANICAL/

Mechanical and Electrical Exam Review.doc from the forum FTP Site
http://www.areforum.org/up/Mechanical%20and%20Electrical/

other websites

Alkikat Building System Notes
http://yafpghare.files.wordpress.com/2012/09/building-systems-notes_alkikat-1-1.pdf

Chimney Height by Unlimited Air LLC
http://www.unlimited-air.com/fireplaces/chimney-height-why-is-the-2-foot-by-10-foot-rule-so-confusing/

Colour Temperature Chart by Media College
http://www.mediacollege.com/lighting/colour/colour-temperature.html

Communication Systems by Fiber Optics For Sale Co
http://www.fiberoptics4sale.com/wordpress/communication-systemsvoice-data-video-lan-hvac-fire-alarm-security-and-cctv/

Design Options for HVAC Distributions Systems by A. Brattier, CED engineering
https://www.cedengineering.com/upload/Design%20Options%20for%20HVAC%20Distribution%20Systems.pdf

Dry Bulb, Wet Bulb and Dew Point Temperature by engineering toolbox
http://www.engineeringtoolbox.com/dry-wet-bulb-dew-point-air-d_682.html

Electricity Generation by wikipedia
http://en.wikipedia.org/wiki/Electricity_generation

Fair Housing/Equal Opportunity by US Department of Housing and Urban Development
http://portal.hud.gov/hudportal/HUD?src=/program_offices/fair_housing_equal_pop

Fixture Water Requirements by The Engineering Toolbox
http://www.engineeringtoolbox.com/fixture-water-capacity-d_755.html

How to Control Fire: Protecting the Structure of the Building
http://www.compactdynamics.com/223.html

Introduction to Electrical Systems Design
http://www.ecs.umass.edu/ece/hollot/ECE497DS06/ESD_1.pdf

MEEB Student Companion Site (Quizzes are a great resource!)
http://bcs.wiley.com/he-bcs/Books?action=index&bcsId=2879&itemId=0471465917

Measuring Light Levels – Illuminance. The Engineering ToolBox
http://www.engineeringtoolbox.com/light-level-rooms-d_708.html

One Line Diagrams by Wikipedia
http://en.wikipedia.org/wiki/One-line_diagram

Principles of Refrigeration (a really helpful video from 1944...no joke)
http://www.youtube.com/watch?v=b527al9D_rY&feature=share&list=PLC567EB35841C5B08

Psychrometric Chart - US and SI Units at Sea Level by Coolerado
http://www.coolerado.com/pdfs/Psychrmtrcs/0000Psych11x17US_SI.pdf

Refrigeration Cycle by Air Conditioning and Refrigeration Guide
http://www.air-conditioning-and-refrigeration-guide.com/refrigeration-cycle.html

Replacing light bulbs with LEDs. AV Forums
http://www.avforums.com/forums/renewable-energy-energy-saving/1582584-replacing-light-bulbs-leds-led-lightbulb-information.html

Retrograde Presents! Electronic Tutorials on youtube
http://www.youtube.com/watch?v=5sDctq5kdvU&feature=plcp

Solar Controls and Shading by RIBA Sustainability Hub
http://www.architecture.com/SustainabilityHub/Designstrategies/Fire/1-4-1-6-Solarcontrolsandshading.aspx

STCratings.com
http://www.stcratings.com

Strategies and Technologies: Controlling Indoor Air Quality by Filtration + Separation
http://www.filtsep.com/view/2695/strategies-and-technologies-controlling-indoor-air-quality/

Specular vs Diffuse Reflection. Physics Classroom
http://www.physicsclassroom.com/Class/refln/u13l1d.cfm

Sun-Path: Sun Positions. Ecotect Community Wiki
http://wiki.naturalfrequency.com/wiki/Sun-Path/Reading_Sun_Positions

Types of Light Bulbs and their Uses by Jonathan Kremer at Megavolt
http://www.megavolt.co.il/Tips_and_info/types_of_bulbs.html

What is a Watt Anyway? Building Green
http://www2.buildinggreen.com/blogs/what-watt-anyway-understanding-energy-and-power-metrics

What is the Flame Spread Rating? by Acoustical Surfaces
http://www.acousticalsurfaces.com/soundproofing_tips/html/flame_spread.htm

Vapor Barriers or Vapor Diffusion Retarders by Energy.Gov
http://energy.gov/energysaver/articles/vapor-barriers-or-vapor-diffusion-retarders

texts

Burley, Robert and Dan Peterson. "Historic Preservation" Excerpt from The Architect's Handbook of Professional Practice, 13th Edition. 2000.

Jackson, Mike. "Embodied Energy and Historic Preservation: A Needed Reassessment". APT Bulletin: Journal of Preservation Technology. 2005

Ramsey/Sleeper. Architectural Graphic Standards 10th Edition. 2000.

Siegel, Henry, et al. "12.7 Sustainable Design". The Architect's Handbook of Professional Practice Fourteenth Edition. 2008

Stein, Benjamin and John Reynolds. Mechanical and Electrical Equipment for Buildings (MEEB). Ninth Edition. 2000. (Highly Recommended Source!!)