EXAM DAY CHECKLIST

Are you ready? *...almost there*

1. Check out the location beforehand. Where to park, what room?

2. Arrive early!

3. Things to bring (Computer Based Test):

- ☐ Identification
- ☐ Exam Authorization Form (NCEES)
- ☐ (2) calculators
- ☐ Jacket without Hood
- ☐ Glasses (without case) – if needed
- ☐ Pack a lunch – store in locker
- ☐ Comfort Items (visually inspected): Cough Drops, Eye Drops, headache medicine (no container)

4. Test Center Provided Items:

- ☐ Test Center provided Tissue & Earplugs (confirm)
- ☐ Test Center Locker Key
- ☐ Test Center Booklet/Marker

5. Not allowed in exam room: *most test centers will have lockers to store your personal items.*

- X Cell phones
- X Wallets/Purses
- X Bags
- X Food/Drinks
- X Tobacco
- X Pens/Pencils/Paper/Erasers
- X Hats/Hooded Jackets
- X Pencils/Erasers
- X Slide charts/wheels (i.e. ductulator, pipe wheel, motor chart)
- X Straight edges
- X Watches

COMMON MISTAKES

Double check before you submit your exam!

- ☐ Answer all questions before submitting
- ☐ Check your units!
  - Inches vs Feet
  - Minutes vs Hour: *GPM, CFM, ACH, lb/min, lb/hr, Btu/h*
  - Month vs Year: *Economics questions*
  - lbm vs lbf vs slugs
- ☐ Correct decimal place?
- ☐ Diameter vs Radius
  - Insulation Thickness + Radius - OR - 2x Insulation Thickness + Diameter
  - Calculating Area/Flow rate/Velocity
- ☐ Absolute vs Relative
  - PSIA vs PSIG – *NPSH in PSIA*
  - Fahrenheit vs Rankine – *Reynolds # in Rankine*
- ☐ Refrigeration Charts
  - Did you use the correct refrigerant?
  - Lookup with Temperature or Pressure column
  - hf vs hfg
- ☐ Psychrometric Chart
  - Correct Density (*other than STP, 60F & 14.7 psia*)
  - Correct Elevation
- ☐ Heat Transfer
  - K value (conductivity, use thickness) vs R value (thickness included)
  - K value per inch or per ft
  - Windows – Conductive + Radiative Heat
- ☐ Does your answer make logical sense?

Review the Basics!

I. Principles (28-43)

A. Basic Engineering Practice (4-6)

1. Units and conversions

- Gravitational Constant: $g_c = 32.2\frac{ft \cdot lbm}{lbf \cdot s^2}$
  - *Convert between lbm and lbf*
- Common conversions
  - 12,000 Btuh = 1 cooling ton
  - 15,000 Btuh = 1 nominal cooling tower ton
  - 3.412 Btuh = 1 Watt
  - 1 gallon = 8.34 pound water
  - 1 HP = 0.7457 kW
  - 1 psi = 2.31 ft head
- Common Constants
  - Air density @STP = 0.075 lb/ft^3
  - STP of Air: 60F, 14.7 psia
  - Specific Heat Capacity
    - $c_{p,water} = 1.0\frac{Btu}{lbm*R}$
    - $c_{p,air} = 0.240\frac{Btu}{lbm*R}$ @constant pressure
    - $c_{v,air} = 0.171\frac{Btu}{lbm*R}$ @constant volume (less used)

2. Economic analysis

- Interest Rate Table
- Simple Payback
- Straight Line Depreciation
- MACRS

3. Electrical concepts (e.g., power consumption, motor ratings, heat output, amperage)

- Power Consumption:
  - Demand (kW) * hours = Energy (kWh)
- Building Energy Indices:
  - Energy Utilization Index (EUI) = Total Yearly Energy/Building Area
  - Cost Utilization Index (CUI) = Total Yearly Energy Cost/Building Area
- Motor Ratings
  - **Power** (comes in set increments): *0.5 HP, 0.75 HP, 1 HP, 2 HP, 3 HP, 5 HP, 7.5 HP, 10 HP, 15, HP 20 HP, 25 HP, 30 HP, 40 HP, 50 HP, 60 HP, 75 HP, 100 HP*
  - **Amperage**
    - FLA = Full Load Current (Operating Amps, use in apparent power calc)
    - RLA = Running Load Amps (Similar to FLA)
    - LRA = Locked Rotor Amps (startup current, disconnect sizing)

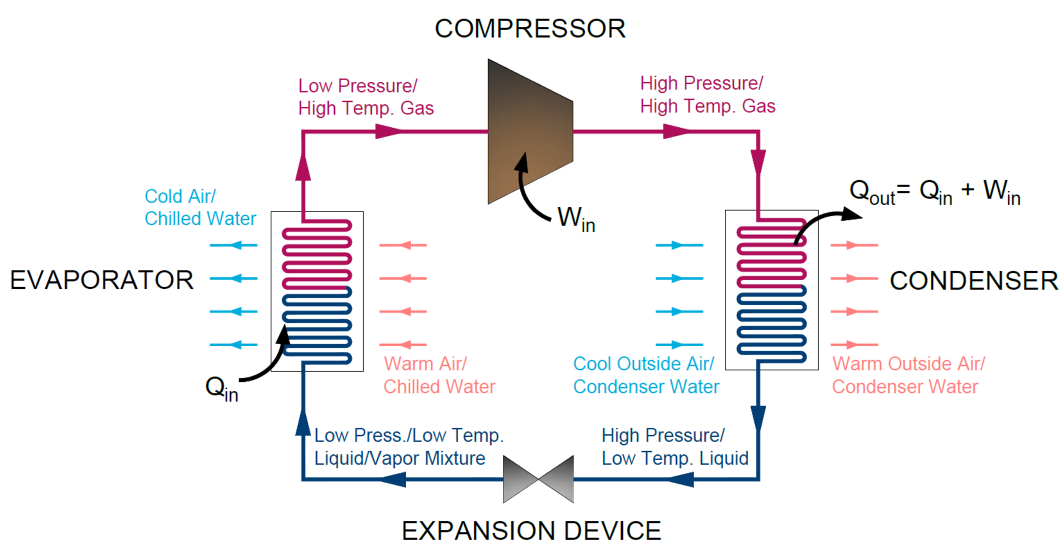
- **Phases**: *1 phase or 3 phase*
- **Frequency**: *60 Hz (USA), frequency of AC power*
- **RPM**: *How fast the motor spins*
- **Service Factor**: *How much more the motor can temporarily operate beyond its rating. Example, service factor of 1.15 can operate 15% beyond its rated HP for a short period of time.*
- **Power Factor**: to Find *Real Power* or to find *Current*
  - Apparent Power, 1 phase (S) = Current (I)*Voltage (V)
  - Apparent Power, 3 phase (S) = √3*Current (I)*Voltage (V)
  - Real Power (P, KW) = Power Factor (PF) * Apparent Power (S)
- **NEMA**: efficiency rating and enclosure rating

- Efficiencies
  - $Electrical\ HP = \frac{Brake\ HP}{\eta_{motor}\%} = \frac{Mechanical\ HP}{\eta_{motor}\% * \eta_{mech}\%}$
    - $Mechanical\ HP\ (Fan) = \frac{CFM * TP(in\ wg)}{6356}$
    - $Mechanical\ HP\ (Pump) = \frac{GPM * TDH(ft)}{3956}$
  - $\eta\%$ releases heat. Determine heat to airstream or to space

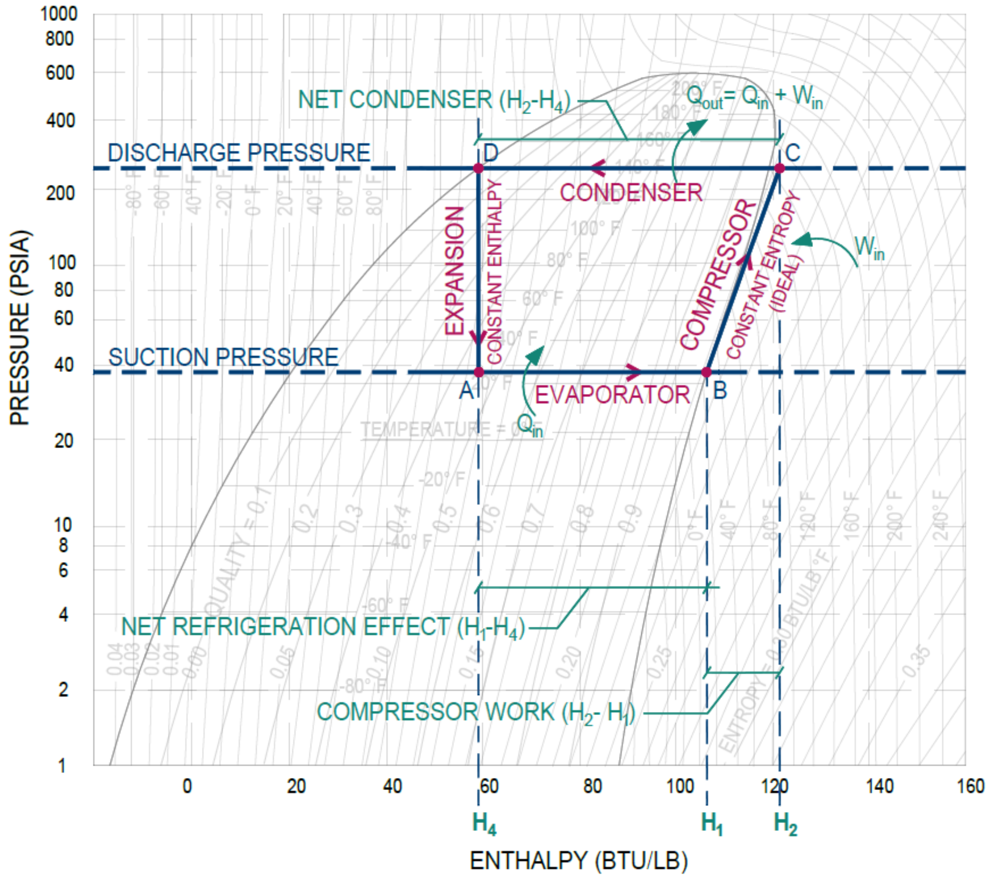
B. Thermodynamics (4-6)

1. Cycles

- **Vapor Compression Cycle (Refrigeration)**
  - Terms: *Net Refrigeration Effect, Superheat, Subcool*
  - Vapor Compression Cycle



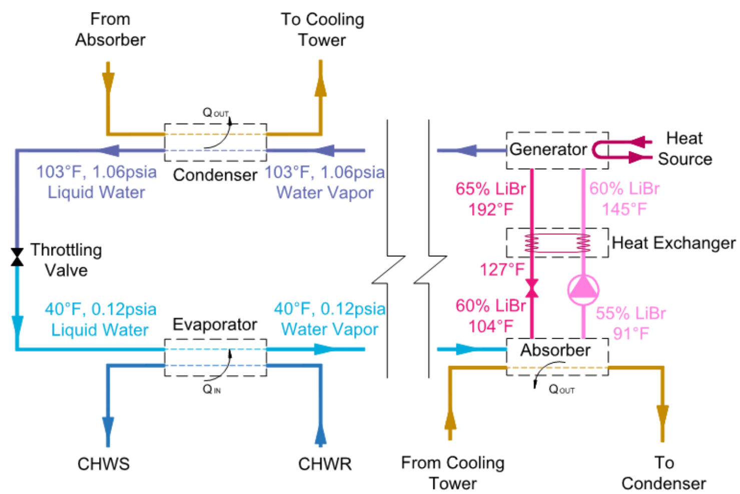
- Pressure-Enthalpy Diagram

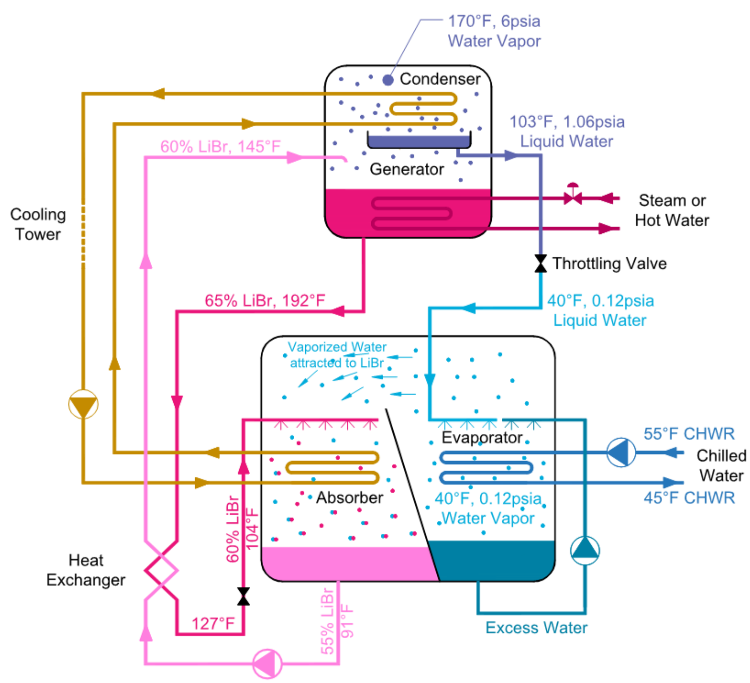


- Overall Efficiency
  - $COP = \frac{Evaporator\ Energy\ (Btuh)}{Compressor\ Work\ (Btuh)}$, typically COP > 2.5
  - $EER = 3.412 * COP$
  - $kW/ton = 12/EER$
- Part Load Chiller Efficiency
  - IPLV, efficiency given at various % load at standard AHRI conditions
  - NPLV, efficiency given at various % load at non-standard
- Compressor Efficiency
  - $\eta_{comp}\% = \frac{h_{ideal,lvg} - h_{ent}}{h_{actual} - h_{ent}}$, where h_ideal is enthalpy at leaving compressor pressure after following constant entropy from entering compressor pressure.

- **Absorption Cycle (Refrigeration)**
  - Two Shells, Refrigerant + Absorber, Heat Source
    - Refrigerant: *Water*
    - Absorber: *Lithium-Bromide or Ammonia*
    - Heat Source: *Hot Water/Steam, typically used with waste heat*
  - $COP = \frac{Evaporator\ Energy\ (Btuh)}{Heat\ In\ (Btuh)}$, typically 1.5

- Absorption Cycle





2. Properties

- Terms
  - Isentropic – *Constant Entropy*
    - *e.g. Ideal Compressor*
  - Adiabatic – *heat does not enter/leave the system*
    - *In psych chart → Constant Enthalpy*
    - *e.g. Dehumidifiers, Evaporative coolers (mostly), Expansion Valve, Throttling Valve*
  - Isothermal – *Constant Temperature*
  - Isobaric – *Constant Pressure*
- Energy
  - $Q = \dot{m}\Delta h$*, use for steam, refrigerant, and total heat equation*

- **Steam/Refrigerant:** $q\left(\frac{Btu}{hr}\right) = \dot{m}\left(\frac{lb}{hr}\right) * \Delta h\left(\frac{Btu}{lb}\right)$
- **Total Heat (air)**: $q = 4.5 * CFM * \Delta h \left(\frac{Btu}{lb}\right)$

- *$q = \dot{m}c_p\Delta T$, no pressure change, use for sensible heat and water*
  - **Water**: $q = 500 * GPM * \Delta T$ [uses $c_{p,water} = 1.0\frac{Btu}{lbm*R}$]
    - *If water temp starts to rise above 100F, use water property tables in NCEES Mech PE Reference Handbook, Ch. 1 to find new density.*
    - $q_{generic} = c_p\left(1.0\frac{Btu}{lbm}\right) * \rho\left(\frac{lbm}{ft^3}\right) * \frac{1ft^3}{7.48gal} * \frac{60min}{hr} * GPM * \Delta T$
    - *Example: at 200F,* $\rho = 60.12\frac{lbm}{ft^3} \Rightarrow q_{200F} = 482 * GPM * \Delta T$
  - **Sensible Heat (air)**: $q = 1.1 * CFM * \Delta T$ [uses $c_{p,air} = 0.24\frac{Btu}{lbm*R}$]
- *$q = \dot{m}h_{fg}$, phase change, use for latent heat*
  - **Latent Heat**: $q = 4{,}840 * CFM * \Delta W\left(\frac{lb_{wet}}{lb_{dry}}\right)$ [uses $h@75F - 50F$]

- Partial Pressure
  - Total Pressure = ∑Pressure of each gas
  - Total Pressure Air = Water Vapor Pressure + Dry Air Pressure
  - Vapor Pressure = Relative Humidity % * Saturated Vapor Pressure
- Energy:
  - Convert between lbm and lbf

3. Compression processes
- Air/Gas
  - Ideal Gas Law, PV=nRT
  - Actual CFM to Standard CFM

C. Psychrometrics (e.g., sea level, 5,000-ft elevation) (7-11)

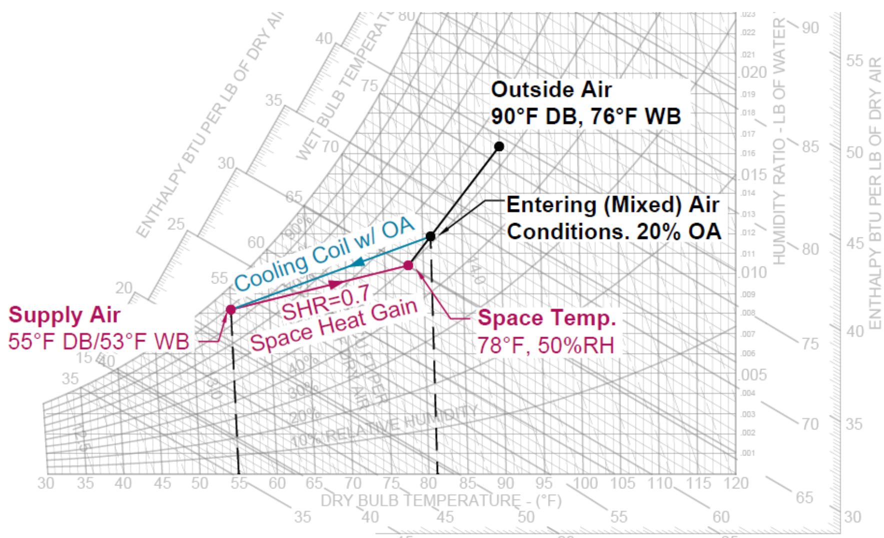
- Wet Bulb, Dry Bulb, Density, Relative Humidity, Humidity Ratio, Enthalpy, Dew Point, Altitude/Pressure

1. Heating/cooling processes
- Total Heat = Sensible Heat + Latent Heat
- At standard temperature/pressure, 0.075 lb/cuft
  - **Total Heat**: $q = 4.5 * CFM * \Delta h\left(\frac{Btu}{lb}\right)$
  - **Sensible Heat**: $q = 1.1 * CFM * \Delta T\ (F)$
  - **Latent Heat**: $q = 4{,}840 * CFM * \Delta W\left(\frac{lb_{wet}}{lb_{dry}}\right)$
- At 5,000 ft elevation
  - **Total Heat @ 5000 ft**: $q = 3.74 * CFM * \Delta h\left(\frac{Btu}{lb}\right)$
  - **Sensible Heat @ 5000 ft**: $q = 0.92 * CFM * \Delta T\ (F)$
  - **Latent Heat @ 5000 ft**: $q = 4027 * CFM * \Delta W\left(\frac{lb_{wet}}{lb_{dry}}\right)$

- Non-standard conditions *(low or high temp, altitude change)*
    - *"Temperature and Altitude Corrections" table in NCEES Handbook Ch. 7*
    - *If air density changes drastically away from standard 0.075 lb/ft^3 due to temp/altitude use correction table to find density factor.*
        - $q_{total,non-standard} = DF * 4.5 * CFM * \Delta h$
        - $q_{sensible,non-standard} = DF * 1.1 * CFM * \Delta T$
        - $q_{latent,non-standard} = DF * 4840 * CFM * \Delta T$ *

          **In latent eqn, use DF for altitude changes only. Use long latent equation for air temp change, since h_{fg} might also change.*
        - *Example: at 200F,* $\rho = 0.0602 \frac{lbm}{ft^3}, DF = 0.803 \Rightarrow$

          $q_{total,200F} = 0.803 * 4.5 * CFM * \Delta h = 3.6 * CFM * \Delta h$
- **Sensible Heat Ratio (SHR)** = Sensible Heat/Total Heat
    - If given as room load SHR, based on load in space
    - Figure below SHR in red, Cooling coil load in blue



- Heat of Vaporization = $h_g - h_f$, energy to vaporize liquid to gas
- Lever Rule: $X_{mix} = X_1 * \%_{CFM,1} + X_2 * \%_{CFM,2}$
    - *X can be DB temp, Humidity Ratio, or Enthalpy, NOT WB Temp*

2. Humidification/dehumidification processes
- Chemical Dehumidification, adiabatic
- Evaporative Cooling, essentially adiabatic
- Steam humidification, follow enthalpy/humidity ratio angle or add lb/hr.
- Cooling Dehumidification, below dew point
- Airflow to moisture flow, $\dot{m}\left(\frac{lb}{hr}\right) = \dot{V}\left(\frac{ft^3}{min}\right) * \left(\frac{60min}{1\,hr}\right)\rho\left(\frac{lb_{dry}}{ft^3}\right) * \Delta W\left(\frac{lb_{wet}}{lb_{dry}}\right)$

3. Altitude Correction
- $P = 14.7 * (1 - 6.8754 * 10^{-6} * Z)^{5.2559}$
- $T = 59 - 0.003566 * Z$
    - *Where Z is altitude in ft*

D. Heat Transfer (6-9)

1. Terms/Basics
   - k, Conductive heat transfer coefficient, per thickness
     - Be aware of whether units are in per inch $\left[\frac{Btu \cdot in}{hr \cdot ft^2 \cdot F}\right]$ or per ft $\left[\frac{Btu}{hr \cdot ft \cdot F}\right]$
   - R, resistance, includes thickness $\left[\frac{hr \cdot ft^2 \cdot F}{Btu \cdot in}\right]$
   - U, overall heat transfer coefficient = 1/R $\left[\frac{Btu}{hr \cdot ft^2 \cdot F}\right]$
   - Conduction
     - $q = UA\Delta T$
       - $U = \frac{1}{R_{total}}$
       - $R_{series} = R_1 + R_2 \ldots + R_n$
       - $\frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}$
     - *U, k, or R values in NCEES Handbook*
     - *R value for air space also in NCEES Handbook*
   - Convection
     - $q = h_{conv} * A * \Delta T$
     - h, convection heat transfer coefficient based on flow over surface
     - *NCEES Handbook for h value of vertical, horizontal surfaces with/without wind.*
   - Radiation
     - To surroundings: $q = \varepsilon \sigma A(T_{object}^4 - T_{surrounding}^4)$
     - Black body, most efficient at emitting radiation and absorbing incident energy.
       - $\varepsilon = \alpha = 1$, where ε is emissivity and α is absorptivity
     - For any type of body, $\alpha + \rho + \tau = 1$, energy is either absorbed (α), reflected (ρ), or transmitted (τ).
2. Building Envelope Loads
   - R values of various materials in *NCEES Mechanical PE Reference Handbook*
   - **Walls/Roof:**
     - U values
       - Include surface film coefficient, *h*: *See "Surface Film Coefficient/Resistances for Air" table in NCEES Handbook, Ch. 9.*
       - Example: $U = 1/\left(\frac{1}{h_{inner}} + R_{gyp} + R_{conc} + \frac{1}{h_{outer}}\right)$
     - Space heat gain: *thermal mass*
       - Use CLTD instead of ΔT $[Q = U * \Sigma(A * CLTD)_{directn}]$
   - **Windows** (Fenestration): Radiative + Conductive Heat Gain
     - Radiative Heat $\Sigma[A * SHGC * E_t * IAC]_{direction}$
     - Radiative Heat, older version $[SC * \Sigma(A * SCL)_{direction}]$
     - Conductive Heat $[UA\Delta T]$
3. Configurations
   - Flat vs Cylinder Equations

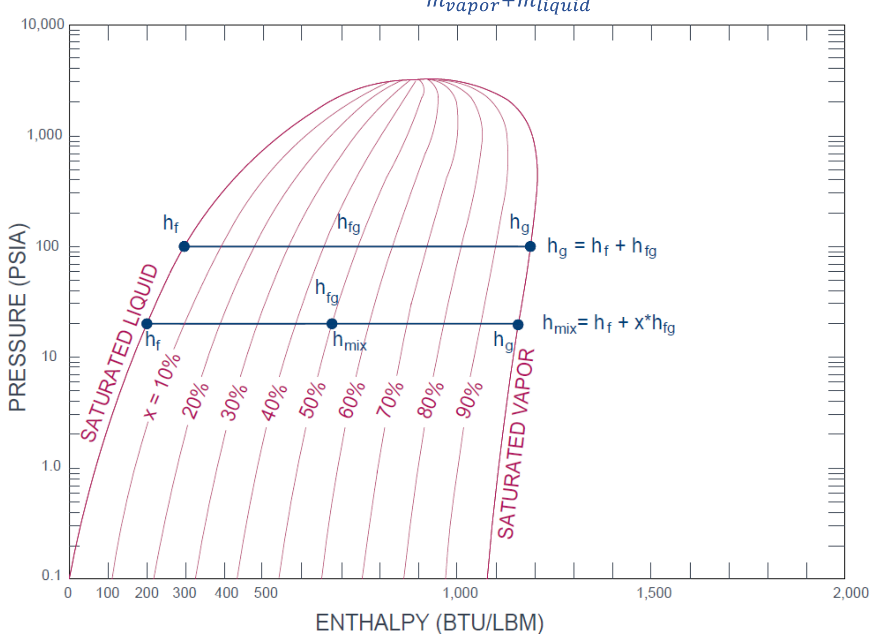
- Round Pipe Equation
  - $Q_{cond+conv} = \frac{2\pi L*(T_{fluid} - T_{ambient})}{\frac{\ln\left(\frac{r_2}{r_{inner}}\right)}{k_i} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{ii}} + \cdots + \frac{\ln\left(\frac{r_{outer}}{r_n}\right)}{k_m} + \frac{1}{r_{inner}h_{inner}} + \frac{1}{r_{outer}h_{outer}}}$
- Solve for Surface Temperature
  - Convection (Tsurf – Tin) = Conduction (Tamb – Tsurf)

E. Fluid Mechanics (3-5)

- Find pressure drop $\frac{P_1}{\rho g} + z_1 + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + z_2 + \frac{v_2^2}{2g} + h_f + h_{f,fitting}$
  - Size pump pressure
    - Closed system, all is equal except hf,
    - Open system, hf + change in elevation, z.
- $h_f = major\ head\ loss$
  - Darcy Weisbach $h_f = f\frac{L}{D}\frac{v^2}{2g}$
  - Find f on Moody diagram with Reynolds Number, $Re = \frac{vD}{\nu}$ and $\frac{\varepsilon}{D}$
  - Either include equivalent length for fittings and other losses or find fitting losses from the equation below
  - Equivalent lengths from tables.
- $h_{f,fitting} = k\frac{v^2}{2g}$, where k is a loss factor
- Simplified GPM/Diameter → velocity conversion: $\boldsymbol{v_{water}}\left(\frac{ft}{s}\right) = \frac{\mathbf{0.409}*\boldsymbol{GPM}}{[\boldsymbol{D(in)}]^2}$

F. Energy/Mass Balance (4-6)

- Steam quality $x = \frac{h - h_f}{h_g - h_f}$
- Steam quality by mass $x = \frac{m_{vapor}}{m_{vapor} + m_{liquid}}$



II. Applications (42-64)

A. Heating/Cooling Loads (7-11)

- $Contact\ Factor = \frac{T_{entering} - T_{leaving}}{T_{enterng} - T_{apparatus\ dew\ point}}$, *how much of the air hits and is cooled by the coil.*
- $Bypass\ Factor = 1 - Contact\ Factor$, *how much air goes around the coil.*
- Apparatus Dew Point = Coil Temperature
- **Cooling load**:
  - Lights, people, miscellaneous equipment; (adjust with usage factors)
  - Envelope
    - Walls/Roof use CLTD
    - Windows use conductive + solar
- **Heating loads** do not take credit from the heat gain in the space or solar loads.

$$Q_{heating\ load,total} = Q_{wall,conduction} + Q_{roof,conduction} + Q_{window,conduction} + Q_{skylight,conduction} + Q_{infiltration} + Q_{ventilation}$$

  - Wall/Roof: No time lag-CLTD; $Q_{heating}$=UAΔT
  - Window: Conduction only; $Q_{heating}$=UAΔT
  - Ventilation/Infiltration
  - No miscellaneous, people, lights

B. Equipment and Components (16-24)

1. Cooling towers and fluid coolers

- Approach = CDW Out – Air in Wet bulb
- Range
  - Cooling Tower: Range = CDW in Temp – CDW Out Temp
  - Fluid Cooler
    - Dry type: air flows over coil to cool the fluid
    - Evaporative type: Cooling tower with heat exchanger to separate the fluid that is cooled from the evaporated fluid
  - Evaporative Cooler: Range = Return Air Temp – Supply Air Temp
- Types: Counterflow, Crossflow, Induced Draft, Forced Draft
- Makeup Water: make up loss from Drift, Evaporation, Blow Down
- Components: Fill, Louvers, Drift Eliminators, Nozzles
- Effectiveness = 100% * Range/(Range+Approach)
- $q_{CDW} = q_{AIR}$
  - $500 * GPM * \Delta T_{CDW} = CFM * \rho \left(\frac{lb_{dry}}{ft^3}\right) * \frac{60min}{hr} * \Delta T_{air}$

2. Boilers and furnaces (e.g., efficiencies, fuel types, combustion)

- Higher Heating Value, *gross heat in the fuel, (Btu/lb or Btu/ft^3)*
- Lower Heating Value, *heat in fuel without latent heat.*
- $Energy\ Out \left(\frac{Btu}{hr}\right) = Energy\ In * \eta\% = \left[HHV \left(\frac{Btu}{lb}\right) * Fuel\ Flow \left(\frac{lb}{hr}\right)\right] * \eta\%$

- Combustion stoichiometric equations to find excess air.

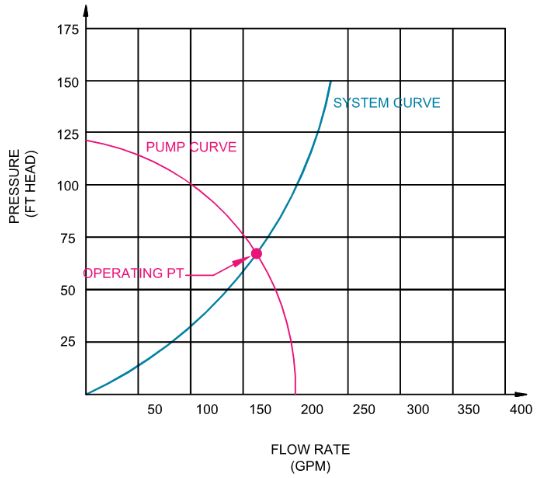
3. Heat exchangers (e.g., shell and tube, plate and frame)
   - LMTD, parallel vs counterflow
   - Effectiveness: Actual Heat Transfer/Maximum Heat Transfer
   - Fouling factor
   - Approach
   - Heat transfer rate: $q = UAF\Delta T_{lmtd}$
     - F = correction factor, for counter flow F=1.

4. Condensers/evaporators (e.g., chillers, variable refrigerant flow, heat pumps)
   - Chiller Type: *Scroll, Screw, Centrifugal, Reciprocal, Rotary*
   - Air cooled vs Water cooled Chiller
   - Variable Refrigerant Flow: *Inverter*
   - Heat Pump: *Reversing Valve*
   - Fouling factor

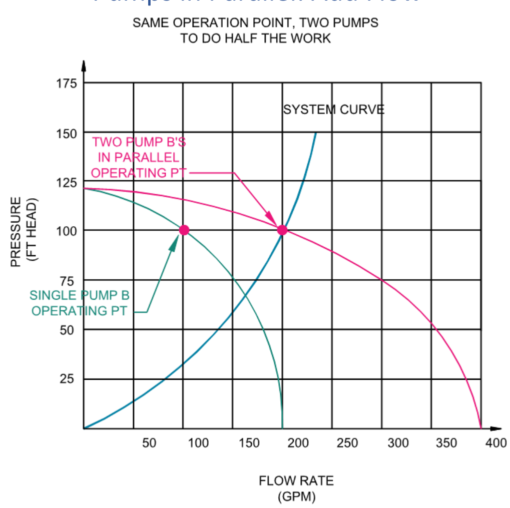
5. Pumps/compressors/fans (e.g., laws, efficiency, selection)
   - Types
     - Pump: *End Suction, Split Case, Inline*
     - Fan: *Centrifugal (Forward Inclined, Backward Inclined, Backward Inclined Airfoil), Propeller, Axial*
       - Total Pressure = Static Pressure + Velocity Pressure
       - Velocity Pressure [in wg] = (FPM/4005)^2
     - Different Types and Curves in ASHRAE

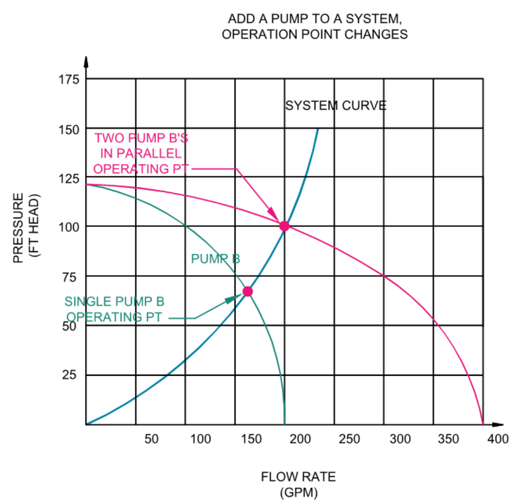
   - Pump/Fan Laws
     - Speed = Flow (impeller/wheel diameter constant)
       - $\frac{RPM_1}{RPM_2} = \frac{GPM_1}{GPM_2}$ or $\frac{RPM_1}{RPM_2} = \frac{CFM_1}{CFM_2}$
     - Pressure = (Flow)^2 (speed constant)
       - $\frac{psi_1}{psi_2} = \frac{GPM_1^2}{GPM_2^2}$ or $\frac{in\,wg_1}{in\,wg_2} = \frac{CFM_1^2}{CFM_2^2}$
     - Power = (Speed)^3 = (Flow)^3 (impeller/wheel diameter constant)
       - $\frac{HP_1}{HP_2} = \frac{RPM_1^3}{RPM_2^3} = \frac{GPM_1^3}{GPM_2^3}$

   - Pump/System Curve
     - **System**: Need one operation point (Pressure & Flow), then plot the parabolic curve with the relationship, $\frac{Pressure_1}{Pressure_2} = \frac{Flow_1^2}{Flow_2^2}$
     - **Pump Curve**: Based on pump type, given by manufacturer
     - **Operation Point**: Intersection of System & Pump Curve

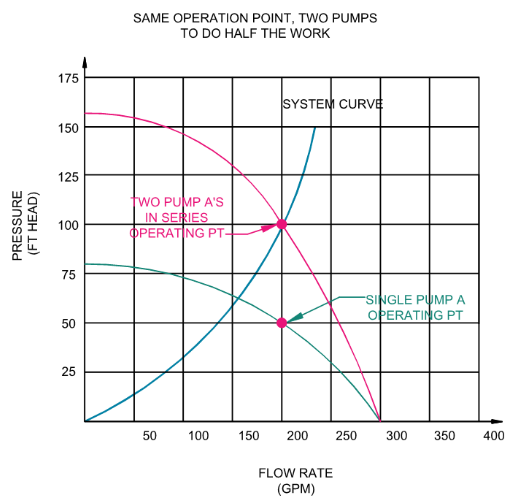


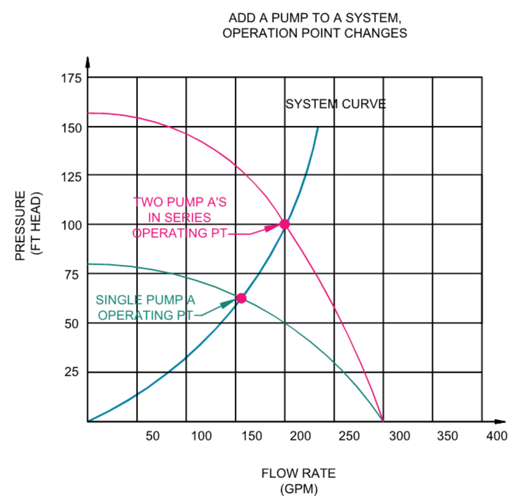
- Pumps in Parallel: Add Flow



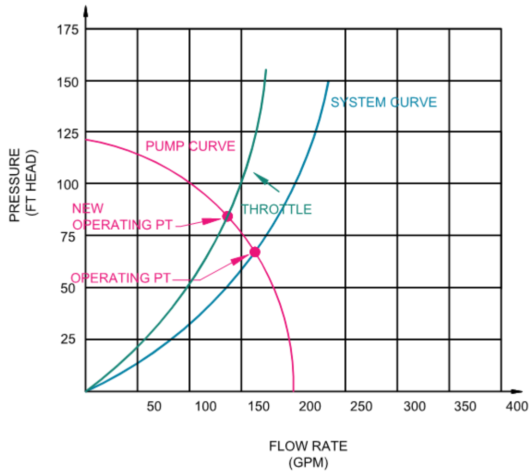


- Pumps in Series: Add Pressure

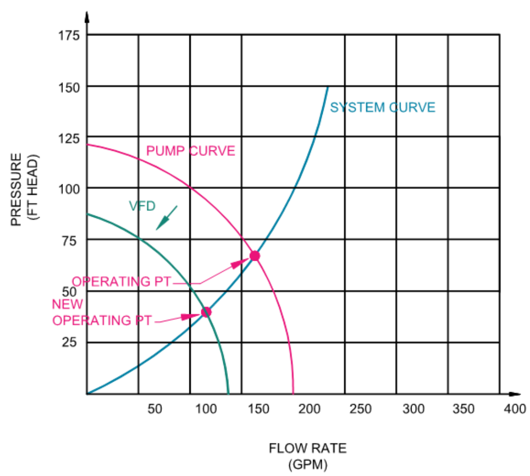




- Lower (Pump/Fan) Flow Rate
  - Throttle: *reduce flow by closing valve/damper, same power. Adding pressure to the system, so system curve changes.*



  - VFD: *reduce flow by reducing frequency, which reduces RPM and the power of the motor. RPM changes so pump curve changes, parallel to the old curve.*



- Power
  - $Mechanical\ HP\ (Fan) = \frac{CFM*TP(in\ wg)}{6356}$
  - $Mechanical\ HP\ (Pump) = \frac{GPM*TDH(ft)}{3956}$
- Pressure
  - Total Pressure = Static Pressure + Velocity Pressure
  - Velocity Pressure Fan (in wg) = (FPM/4005)^2
  - Velocity Pressure Pump (ft hd) = V^2/(2g)
- Efficiencies
  - $Brake\ HP = \frac{Mechanical\ HP}{\eta_{mech}\%}$
  - $Electrical\ HP = \frac{Brake\ HP}{\eta_{motor}\%} = \frac{Mechanical\ HP}{\eta_{motor}\% * \eta_{mech}\%}$
- Net Positive Suction Head

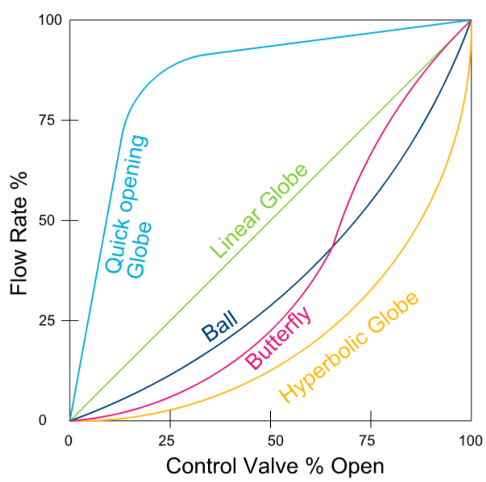
- NPSHA (available): *Calculated from System*
    - Open System: $NPSHA = P_{abs} \pm P_{elev} - P_{fric} - P_{vapor}$
    - Closed System: $NPSHA = P_{gauge} + P_{velocity} - P_{vapor}$
  - NPSHR (required): *From Pump Manufacturer*
- Compressor: *Hermetic – Fully Sealed, Semi Hermitic*

6. Cooling/heating coils

- $Contact\ Factor = \frac{T_{entering} - T_{leaving}}{T_{enterng} - T_{apparatus\ dew\ point}}$, *how much of the air hits and is cooled by the coil.*
- $Bypass\ Factor = 1 - Contact\ Factor$, *how much air goes around the coil.*
- Apparatus Dew Point = Coil Temperature

7. Control systems components (e.g., valves, dampers)

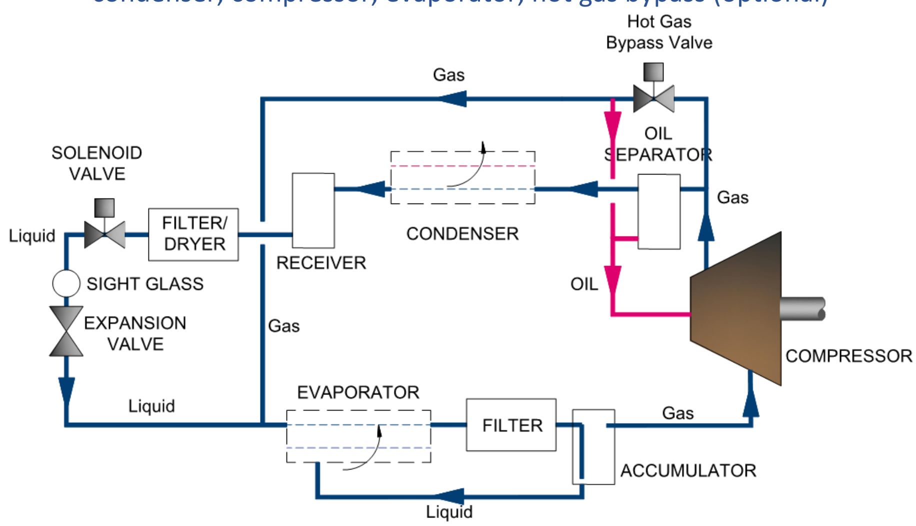
- Actuators to control opening/closing
- Valves
  - 2-way/3-way valves
  - Cv, valve coefficient
    - $GPM = C_v \sqrt{\frac{\Delta P}{SG}}$
  - Quick closing valve vs Multi turn
  - Valve authority



- Damper
  - Damper: *Parallel/Opposed Blade, pressure drop calculations, Fire Damper, Fire-Smoke Damper*
  - VAV box type: *Single Intake, Dual Intake, Parallel Fan Powered, Series Fan Powered*
  - Damper authority
- Normally Open vs Normally Closed
- Sensors: *Sensitivity, Repeatability*
- Transmitters: *transmits signal from sensor to the control panel*

8. Refrigerants (e.g., properties, types)
- Global Warming Potential (GWP)
- Ozone Depletion Potential (ODP)
- Flammability/Safety Properties – *see table in NCEES handbook, Ch. 8*
- Pressure-Enthalpy Diagrams: *for refrig. cycles/calculations*
- Performance: *COP, pressures, compression ratios. See comparison table in NCEES handbook, Ch. 8*
- Common types:
  - R-22: *old type, no longer used for poor GWP and ODP*
  - R-410A/R-134A: *low ODP, high GWP, A1 safety, will eventually be phased out due to GWP.*
  - R-32/R-1234yf/R-1234ze: *low GWP and ODP, A2L safety, being phased in.*

9. Refrigeration components (e.g., expansion valves, accumulators)
- Components of refrigerant cycle
- Accumulator, Filter/Dryer, Receiver, Sight glass, oil separator, expansion valve, condenser, compressor, evaporator, hot gas bypass (optional)



C. Systems and Components (16-24)

1. Air distribution (e.g., air handlers, duct design, system type, terminal devices)
- Duct friction loss: equivalent length
- Equivalent Diameter
- Equal friction vs Static Regain
- Air Devices
  - *select based on noise, throw, velocity*
  - Air Diffusion Performance Index (ADPI): *relates temperature, speed, and thermal comfort. Higher ADPI is better*
  - Air Diffusion Performance Index Table (T50/L)
- System: Variable, Constant, Zoning

2. Fluid distribution/piping (e.g., hydronic, oil, fuel gas, compressed air, steam, system type)
    - Friction loss: factors, equivalent length
    - Fuel gas piping by pressure drop: *use HHV to find distance to maintain maximum pressure drops. Include entire length of piping from start to each branch for sizing.*
    - Compressed air piping by pressure drop*: Ensure the last outlet has sufficient pressure.*
    - Steam and Compressed Air produce Condensation.
    - Expansion loops: elbow, Z, U loop. Calculate using thermal expansion coefficient.
    - Expansion Tank Calculation: *Open, Diaphragm, Bladder*

3. Refrigeration (e.g., food storage, cooling and freezing)
    - Food Storage
        - Specific Heat above/below freezing
            - $Q(Btu) = m(lb) * c_p \left(\frac{Btu}{lb*F}\right) * \Delta T$
        - Latent Heat of Fusion
            - $Q(Btu) = m(lb) * \Delta h \left(\frac{Btu}{lb}\right)$
        - Locate different food properties in your reference.

4. Energy recovery (e.g., enthalpy wheels, heat pipes, run-around systems, condenser heat recovery)
    - Effectiveness = Actual Energy Transfer/Max Possible Energy Transfer
        - *Actual Energy Transfer* = Flow Rate_1*Δ Conditions_1 = Flow Rate_2*Δ Conditions_2
        - *Max Possible Energy Transfer* = Smallest Flow Rate between stream 1&2 * Difference between incoming conditions of stream 1&2
        - *Where "conditions" are temperature-sensible energy recovery, humidity ratio-latent recovery, enthalpy-total energy recovery type)*

5. Basic control concepts (e.g., economizer, temperature reset)
    - Direct Digital Control
        - Input/Output.
            - Inputs and outputs are relative to the control panel. i.e. sensor is an input, adjusting valve position is an output
        - Digital/Analog
            - Digital means a binary input or output. Like, open/close or off/on
            - Analog means an input or output that is variable, like position.
        - Energy Management System (EMS)
        - Protocol: BACnet, Lonworks – *the controller software language*
        - Gain: % change in control signal/% change in control variable (ratio of change in output signal to change in input signal)
    - Chilled Water Reset

- *Slowly increase chilled water temperature as load conditions fall (based on return air or outside air).*
- Supply Air Reset
  - *Slowly increase supply air temperature if return air conditions or outside air conditions are met.*
- Variable Airflow
  - *Pressure sensor in duct to vary fan speed as VAV boxes close*
  - *VAV Box types: single, dual, parallel fan powered, series fan powered*
- Variable Chilled Water Flow
  - Variable Primary – *two way valve control, pressure sensor at the farthest coil to vary the pump flow.*
  - Primary-Secondary – *Primary flow circulates to chillers at a constant rate, secondary flow circulates to air handlers at variable rate.*
- Economizer – *Use outside air instead of conditioning. Exhaust fan required.*
- Energy Recovery – *various control schemes*
- Valves: Authority, Cv Rating, Cavitation
- Damper: Parallel vs Opposed, Authority

D. Supportive Knowledge (3-5)

1. Codes and standards

- Know generally what is in these standards
  - **ASHRAE 15: Safety Standard for Refrigeration Systems**
    - *Lists allowable refrigerant quantities per room volume and other safety considerations.*
    - *Know the Safety Groups for each ref. (also listed in ASHRAE)*

Higher Flammability	A3	B3
Lower Flammability	A2	B2
No Flame Propagation	A1	B1
	Less Toxic	More Toxic

  - **ASHRAE 34: Safety Class of Refrigerants**
    - *Lists refrigerant safety groups, concentration limits, other refrigerant info*
  - **ASHRAE 55: Thermal Environment for Human Occupancy**
    - *Human comfort limits: draft, temperature, clothing*
  - **ASHRAE 62.1: Ventilation for Indoor Air Quality**
    - *Ventilation/exhaust rates*
  - **ASHRAE 62.2: Ventilation for Indoor Air Quality in Low Rise Residential**
  - **ASHRAE 90.1: Energy Standard for Building, except Low Rise Residential**
    - *Zoning based on weather data, building envelope requirement, HVAC equipment efficiency, HVAC system requirements, lighting efficiency, duct/pipe insulation, energy saving controls (e.g. economizer, temperature reset, variable volume), energy calculation requirements, and other energy requirements.*

- **ASHRAE 90.2: Energy Standard for Low Rise Residential**
- **ASHRAE 189.1: Standard for High-Performance Green Building, except Low Rise Residential**
  - *More stringent requirements than ASHRAE 90.1*
- **NFPA 90A: Standard for Air Conditioning and Ventilation**
- **NFPA 90B: Standard for Warm Air Heating and Air Conditioning**

2. Air quality and ventilation (e.g., filtration, dilution)
   - Filter - MERV Rating
   - Adding fresh air for Dilution
   - Velocity of exhaust for Dilution
   - ASHRAE 62.1 ventilation rate
3. Vibration control (e.g., transmission effect, isolation)
   - Isolate Vibration from Equipment
     - Spring Isolation
     - Flexible Pipe
   - Base/Isolator Types, *see "Selection Guide for Vibration Isolation" table in NCEES Handbook, Ch. 9*
4. Acoustics (e.g., sound control, absorption, attenuators, noise-level criteria)
   - Noise Level at distance or for multiple sound sources
   - Sound attenuation by decibel
   - Different Sound Rating Methods: NC, dBA, RC
   - Noise Ratings by room type