

# **313a Refrigeration and AC Reference Guide**

A comprehensive reference guide for key formulas, concepts, components, and operating parameters in Refrigeration and Air Conditioning.

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## Safety & Rules

### Safety Laws in Ontario

These are important rules from the Ontario Health and Safety Act (OHSA) to keep everyone safe when working.

- O. Reg. 213/91: Rules for construction sites.
- O. Reg. 851: Rules for places like factories and shops.

### How to Put Out Fires (Fire Extinguishers)

Different types of fires need different extinguishers. Using the wrong one can make things worse!

- **Class A:** For normal stuff that burns, like wood, paper, or cloth.
  - What's inside: Water, Foam, or a special Dry Chemical (called ABC).
- **Class B:** For burning liquids, like gasoline, oil, or paint.
  - What's inside: Foam, Dry Chemical (ABC or BC), or Carbon Dioxide (CO<sub>2</sub>).
- **Class C:** For fires involving electrical equipment. The stuff inside doesn't conduct electricity.
  - What's inside: Dry Chemical (ABC or BC), Carbon Dioxide (CO<sub>2</sub>), or Halocarbon.
- **Class D:** For burning metals, like magnesium. These need special powders.
  - What's inside: A special Dry Powder for that metal.
- **Class K:** For fires with cooking oils and fats in kitchens.
  - What's inside: Wet Chemical.
- **Multi-Class Extinguishers:** Like the ABC ones, they can be used on more than one type of fire.

### Keeping Refrigerant Tanks Safe

It's really important to store refrigerant cylinders properly to avoid accidents.

- Keep them in a cool, dry place with fresh air.
- Don't let them get damaged.
- Stand them up straight and tie them so they can't fall over.
- Put the caps back on the valves when you're not using them.
- Keep them away from sun and heat (like furnaces).
- Don't let them get hotter than about 125°F (52°C) because the pressure inside goes up a lot.
- Keep different types of refrigerants separate so you don't mix them by mistake.

## Basic Ideas

### Important Formulas and What They Mean

These formulas help us understand how well the cooling system is working.

- **Evaporator Approach:** How close the air leaving the cold coil is to the temperature where the refrigerant boils. A smaller number is better!
  - Formula: Evaporator Approach = Leaving Air Temperature - SST (Saturated Suction Temperature)
- **Condenser Approach:** How close the liquid refrigerant temperature leaving the condenser is to the temperature where the refrigerant turns back into liquid. A smaller number means the condenser is working well!
  - Formula: Condenser Approach = Liquid Line Temperature - SCT (Saturated Condensing Temperature)
- **Condenser Split:** The temperature difference between the hot refrigerant turning into liquid and the air or water cooling it.
  - Formula (Air-Cooled): Condenser Split = SCT - Entering Air Temperature
  - Formula (Water-Cooled): Condenser Split = SCT - Entering Water Temperature
- **Coil Delta T (Delta T):** The temperature difference between the air going into and coming out of the cooling coil. It shows how much heat is being taken out of the air.
  - Formula: Coil Delta T = Entering Air Temperature - Leaving Air Temperature
- **Superheat:** The extra heat added to the refrigerant vapor after it has all boiled in the evaporator. This is important to make sure no liquid gets back to the compressor.
  - Formula: Superheat = Suction Line Temperature - SST
- **Subcooling:** How much the liquid refrigerant is cooled below the temperature where it turns back into liquid in the condenser. This ensures you have only liquid going to the expansion valve.
  - Formula: Subcooling = SCT - Liquid Line Temperature

## Thermal Energy and Refrigeration Formulas

Let's look at how heat works and how we measure it.

- **Temperature Conversions:** How to switch between Fahrenheit (°F) and Celsius (°C).
  - $F = (C * 1.8) + 32$
  - $C = (F - 32) / 1.8$
  - Rankine = 460 + F (Absolute Fahrenheit scale)
  - Kelvin = 273 + C (Absolute Celsius scale)
- **PSI:** Pounds per Square Inch. A way to measure pressure.
- **Specific Heat:** How much heat it takes to warm up a certain amount of a substance by one degree.
  - Water: 1 BTU/lb°F
  - Steam: 0.5 BTU/lb°F
  - Ice: 0.5 BTU/lb°F
- **Latent Heat:** The heat needed to change the state of something (like melting ice or boiling water) without changing its temperature.
  - Melting Ice (Fusion): 144 BTU/lb
  - Boiling Water (Vaporization): 970 BTU/lb
- **Specific Volume of standard air:** How much space one pound of air takes up: about 13.33 cubic feet/lb.
- **Sensible Heat (Air):** Heat you can feel that changes temperature.
  - Formula:  $BTUH = CFM * 1.08 * \Delta T$  (BTUH is British Thermal Units per Hour, CFM is Cubic Feet per Minute)
- **Sensible Heat (Water):**
  - Formula:  $BTUH = 500 * GPM * \Delta T$  (GPM is Gallons Per Minute)
- **Total Heat (Air):** The total heat, including both sensible heat (temperature change) and latent heat (moisture change).
  - Formula:  $BTUH = CFM * 4.5 * \text{Enthalpy Change}$  (Enthalpy is total heat energy)
- **Q = M \* C \* Delta T:** A basic formula for heat transfer. Q is the amount of heat, M is the mass, C is specific heat, and Delta T is the temperature change.
- **Density of water:** Water weighs about 62.4 pounds per cubic foot.
- **Mass Flow Rate:** How much refrigerant is moving through the system each minute.
  - Formula:  $\text{Mass Flow Rate (lbs/min)} = 200 \text{ BTU/min/ton} / \text{Net Refrigeration Effect (BTU/lb)}$
  - Note: 1 ton of refrigeration is equal to removing 12,000 BTUH or 200 BTU/min of heat.

- **Flash Gas Calculation:** How much liquid refrigerant turns into gas right when it goes through the expansion device.
  - Formula:  $\text{Flash Gas (\%)} = ((\text{Theoretical Latent Heat of Vaporization} - \text{Actual Latent Heat}) / \text{Theoretical Latent Heat of Vaporization}) * 100$
- **Net Refrigeration Effect (NRE):** The actual cooling power you get from each pound of refrigerant in the evaporator.
- **Actual Refrigeration Effect:** The heat absorbed when the refrigerant changes from liquid to vapor in the evaporator.
- **BTU/lb for common refrigerants:** How much heat one pound of different refrigerants can absorb.
  - Water (R-718): ~970 BTU/lb
  - Ammonia (R-717): ~550 BTU/lb
  - Carbon Dioxide (R-744): ~250 BTU/lb
  - Most other common refrigerants: ~60-100 BTU/lb

## Gas Laws

These are simple rules about how gases act when you change their pressure, volume, or temperature.

- **Boyle's Law:** If you squeeze a gas (increase pressure) but keep its temperature the same, its volume gets smaller.
  - Formula:  $P_1 * V_1 = P_2 * V_2$  (Pressure 1 \* Volume 1 = Pressure 2 \* Volume 2)
- **Charles's Law:** If you heat a gas (increase temperature) but keep the pressure the same, its volume gets bigger.
  - Formula:  $V_1 / T_1 = V_2 / T_2$  (Volume 1 / Absolute Temperature 1 = Volume 2 / Absolute Temperature 2) - Remember to use absolute temperatures (Rankine or Kelvin)!
- **Gay-Lussac's Law:** If you heat a gas (increase temperature) but keep its volume the same, its pressure goes up.
  - Formula:  $P_1 / T_1 = P_2 / T_2$  (Pressure 1 / Absolute Temperature 1 = Pressure 2 / Absolute Temperature 2) - Again, use absolute temperatures!
- **Combined Gas Law:** Puts all three laws together.
  - Formula:  $(P_1 * V_1) / T_1 = (P_2 * V_2) / T_2$  (Use absolute temperatures!)

## Units and Conversions

Sometimes you need to change measurements from one unit to another. Here are some common ones.

- **Pressure Units:** Different ways to measure pressure.
  - Pascal (Pa)
  - Bar (bar)
  - Kilopascal (kPa)
  - Megapascal (MPa)
  - Pound per square inch (psi)
  - Kilogram per square centimetre (kg/cm<sup>2</sup> or kg(f)/cm<sup>2</sup>)
  - Inch of mercury column (inHg)
  - Standard Atmosphere (atm)
  - Conversions: 1 bar = 100 kPa = 14.5 psi, 1 atm = 101.325 kPa
- **Common Conversions:**
  - 1 inch = 25.4 mm
  - 1 meter = about 3.28 feet
  - 1 kilogram = about 2.2 pounds
  - °C = (°F - 32) / 1.8
  - kPa = psi \* 6.89
  - psi = kPa \* 0.145
  - 1 Liter/second = about 2.12 cubic feet per minute (cfm)
  - 1 kilowatt = about 1.34 horsepower = about 0.28 tons of refrigeration

## Types of Pressures

- **Operating Pressure:** The normal pressure in the system when it's running.
- **Test Pressure:** A higher pressure used to check for leaks before you put refrigerant in.
- **Maximum Component Pressure:** The highest pressure a specific part of the system can safely handle

## Understanding Air Properties (Psychrometrics)

Psychrometrics is the study of air that has moisture in it (moist air). In HVAC, it helps us understand how air behaves and how to change its condition for comfort or processes.

- **Psychrometric Chart:** This is a special graph that shows all the important properties of moist air at the same time. It's a key tool for anyone working with air conditioning.
  - The chart is usually made for a specific atmospheric pressure.
  - A standard chart for air conditioning covers temperatures from about 32°F to 120°F.
- **How it's Used in Real Life:**
  - **Analyzing and Designing Systems:** Helps figure out how air conditioning systems will affect the air.
  - **Finding Air Properties:** You can find things like:
    - Dry-Bulb Temperature (DB): The normal temperature of the air.
    - Wet-Bulb Temperature (WB): The temperature the air reaches when water evaporates into it (like with a wet cloth on a thermometer).
    - Dew-Point Temperature (DP): The temperature where moisture in the air starts to condense into liquid (like dew on grass).
    - Moisture Content (Humidity Ratio): How much water vapor is in the air compared to the dry air.
    - Relative Humidity (RH): How much moisture is in the air compared to the most it can hold at that temperature (shown as a percentage).
    - Specific Volume: How much space a certain amount of air takes up.
    - Enthalpy: The total heat energy in the air (includes heat from temperature and moisture).
  - **Comfort Zone:** The chart can show the range of temperatures and humidity levels that feel comfortable to most people.
    - Summer Comfort: Usually 70°F to 76°F dry bulb and 45% to 65% relative humidity.
    - Winter Comfort: Usually 65°F to 68°F dry bulb and at least 30% relative humidity.

- **Plotting Air Changes:** You can draw lines on the chart to show how air changes as it goes through heating coils, cooling coils, humidifiers, etc.
- **Heat Ratio:** The chart helps figure out the balance between sensible heat (changing temperature) and latent heat (changing moisture) during a process.
- **Coil Performance:** You can use the chart to understand how cooling and dehumidifying coils work, based on the coil's temperature (Apparatus Dew Point) and how much air touches the coil surface (coil contact factor).
- **Improving Efficiency:** The chart can guide you in picking the best ways to treat air and save energy.
- **Basic Calculations:** Helps with figuring out how much heat needs to be added or removed from air.
- **Using the Chart:** To use the chart, you usually need at least two known properties of the air, like dry bulb and wet bulb temperatures, which you can measure with tools like a sling psychrometer.

**Lines on the Psychrometric Chart:** The chart uses different lines to show the air properties:

- **Dry-Bulb Temperature (DB):** These are the straight vertical lines. The scale along the bottom of the chart shows the dry-bulb temperature.
- **Wet-Bulb Temperature (WB):** These are diagonal lines that slope downwards from left to right.
- **Dew-Point Temperature (DP):** These are horizontal lines. You read the dew-point temperature on the curved line on the left side of the chart (the saturation curve) by following the horizontal line from your air point.
- **Relative Humidity (RH):** These are curved lines that look like arcs. They show the percentage of moisture in the air compared to the maximum it can hold. The curved line on the far left is the 100% relative humidity line (the saturation curve).
- **Humidity Ratio (or Moisture Content):** These are the straight horizontal lines. The scale on the right side of the chart shows the humidity ratio (pounds of water vapor per pound of dry air, or grams per kilogram).
- **Enthalpy (Total Heat):** These are diagonal lines that slope downwards from left to right, similar to wet-bulb lines but at a slightly different angle. They show the total heat energy in the air. The scale for enthalpy is often outside the main part of the chart.
- **Specific Volume:** These are diagonal lines that slope downwards from left to right. They show the volume of a certain amount of air.

## The Cooling System Parts

### What's Inside the Pipes? (Refrigerant)

Refrigerants are special fluids that absorb and release heat as they move through the system.

- **Refrigerant Safety:** ASHRAE Standard 34 gives refrigerants a safety rating based on how harmful (toxic) or how easily they burn (flammable) they are.
  - Toxicity (First Letter): A (less toxic) or B (more toxic).
  - Flammability (Second Number): 1 (doesn't burn), 2L (burns slowly), 2 (flammable), 3 (burns easily).
  - Charge Limits: There are rules about how much refrigerant you can use in a space based on its safety rating and what the space is used for.

## Refrigerant Safety Table (ASHRAE 34)

Toxicity	Doesn't Burn (1)	Burns Slowly (2L)	Flammable (2)	Burns Easily (3)
Lower (A)	A1	A2L	A2	A3
Higher (B)	B1	B2L	B2	B3

- **Refrigerant Names:** Refrigerants have numbers (like R-134a). The numbers tell you about their chemical makeup.
  - R-717 is Ammonia, R-744 is CO<sub>2</sub>, R-718 is Water.
- **DOT / Transport Canada:** These are the groups that make sure refrigerant tanks are transported safely in Canada.

## Refrigerant Line Set Flow

Let's follow the refrigerant's journey through the main parts of the system:

1. **Compressor Discharge:** Hot, high-pressure vapor leaves the compressor.
2. **Condenser:** The hot vapor cools down, turns into a high-pressure liquid, and might get a little extra cooling (subcooled).
3. **Liquid Line:** The high-pressure liquid travels through this smaller pipe.
4. **Expansion Device (Metering Device):** This part drops the pressure a lot! Some liquid turns into gas here, and the rest gets very cold.
5. **Evaporator:** The cold mix absorbs heat from the air (or whatever is being cooled), boiling the rest of the liquid into a low-pressure, cold vapor.
6. **Suction Line:** The low-pressure vapor goes back to the compressor through this larger pipe.

## Refrigeration Temperature Ranges & Recommended Superheat

Different jobs need different temperatures!

- **High Temp Refrigeration:** Like air conditioning or keeping food cool in a store. Temperatures are usually between 35°F and 50°F (1.7°C to 10°C) where the refrigerant boils (SST).
  - Best Superheat: 8°F to 12°F (4.5°C to 6.7°C).
- **Medium Temp Refrigeration:** Like your home fridge or a meat case. Temperatures are typically 0°F to 35°F (-18°C to 1.7°C) SST.
  - Best Superheat: 4°F to 8°F (2.2°C to 4.5°C).
- **Low Temp Refrigeration:** For freezers, like for ice cream! Temperatures are usually -20°F to 0°F (-29°C to -18°C) SST.
  - Best Superheat: 2°F to 4°F (1.1°C to 2.2°C).

- **Ultra-Low Temp Refrigeration:** Super cold stuff, like for medical freezers. Temperatures are below -20°F (below -29°C) SST.
  - Best Superheat: Varies, but often 2°F to 6°F (1.1°C to 3.3°C). Needs to be very precise.
  - Note: These superheat numbers are just guides; check the system's instructions!
- **Total System Superheat (TSH):** The total superheat from the evaporator outlet all the way back to the compressor.
  - Formula: TSH = Evaporator Superheat + Suction Line Temperature Rise
- **Evaporator TD (Temperature Difference):** How much warmer the air going into the evaporator is compared to the temperature where the refrigerant boils inside.
  - High Temp Evap TD: ~30°F
  - Med Temp Evap TD: ~15°F
  - Low Temp Evap TD: ~10°F

### The System's Heart (Compressors)

Compressors push the refrigerant around the system and squeeze it to increase its pressure. Most move a set amount of refrigerant with each turn or stroke.

- **Reciprocating Compressor:** Works like a piston in an engine, moving up and down to suck in and squeeze the refrigerant vapor.
- **Rotary Compressor:** Uses a spinning part to compress the refrigerant.
- **Scroll Compressor:** Uses two spiral shapes that fit together. One wiggles around, trapping and squeezing the refrigerant as it moves to the middle. They are quiet and work well.
- **Screw Compressor:** Uses two large screws that turn together to compress the refrigerant. Used in bigger systems.
- **Centrifugal Compressor:** (This one is different!) Uses a fast-spinning fan-like part to speed up the refrigerant vapor and then slow it down to build pressure. Used in very large systems.
- **How Compressors are Built:**
  - Open Type: The motor is separate and connected by a belt or coupling. Needs a seal where the shaft comes out.
  - Semi-Hermetic: The motor and compressor are in a case you can open for repairs. The refrigerant gas helps cool the motor.
  - Hermetically Sealed: The motor and compressor are sealed inside a welded shell. If it breaks, you replace the whole thing. Refrigerant gas cools the motor here too.

- **Compression Ratio:** How much the pressure is increased by the compressor.
  - Formula:  $\text{Compression Ratio} = \frac{\text{Absolute Discharge Pressure}}{\text{Absolute Suction Pressure}}$  (Use absolute pressures, which include the pressure of the atmosphere!)
- **Two-Stage Compression:** Squeezing the refrigerant twice in a row, with cooling in between. Used for very low temperatures or when you need a big pressure jump to make it work better.
- **Loss of Compression:** When the compressor isn't pumping correctly. The discharge pressure might be normal, but the suction pressure will be too high.

### Where Cooling Happens (Evaporators)

These parts get cold and absorb heat from the air or whatever you're cooling.

- **Bare Tube Evaporator:** Just plain tubes. Good where ice is a big problem or you need to touch the product directly (like ice machines).
- **Finned Tube Evaporator:** Tubes with metal fins to add more surface area to grab heat. This is the most common type.
  - Draw-Through: Fan pulls air through the coil. Gives even airflow.
  - Blow-Through: Fan pushes air through the coil. Can be simpler but airflow might not be as even.
- **Plate Evaporator:** Uses plates with channels for the refrigerant. Good for freezing things flat or cooling liquids directly.
- **Shell and Tube Evaporator:** Refrigerant goes through tubes inside a shell, and the liquid being cooled flows around the tubes. Used in bigger systems for chilling liquids like water.
- **Evaporator Defrost Types:** How we melt ice off the coil in freezers.
  - Off Cycle Defrost: Turns the compressor off and lets warmer air melt the ice. Works for fridges that stay above freezing.
  - Electric Defrost: Uses electric heaters to melt the ice. Common in freezers.
  - Hot Gas Defrost: Sends hot refrigerant vapor from the compressor into the evaporator to melt the ice.
- **Evaporator Film Factor (Film Effect):** If air isn't moving fast enough over the coil, a layer of still air can act like a blanket, making it harder for the coil to cool.

## Where Heat Leaves (Condensers)

These parts get rid of the heat that was absorbed by the refrigerant, turning the vapor back into liquid.

- **Air-Cooled Condenser:** Uses outside air to cool the refrigerant.
  - Natural Draft: Relies on hot air rising. Not for big systems.
  - Forced Draft: Uses fans to move air over the coil.
  - Condenser TD (Temperature Difference): The difference between the temperature where the refrigerant turns to liquid and the outside air temperature.
    - Standard: ~30°F TD
    - High Efficiency: ~5-10°F TD (Bigger coils help here!)
- **Water-Cooled Condenser:** Uses water to cool the refrigerant. Works better than air-cooled when it's hot outside.
  - Types: Shell and Tube, Tube-in-Tube, Shell and Coil. Different designs for how the water and refrigerant flow.
  - Rule of Thumb: Need about 3 gallons of water per minute for every ton of cooling.
  - Water Temperature Split: The water usually gets about 10°F warmer as it goes through the condenser.
- **Evaporative Condenser:** Uses both air and evaporating water to cool the refrigerant. Very efficient because evaporating water takes a lot of heat.
- **Flooded Condenser Valves:** Used in cold weather to keep the pressure high enough by holding extra refrigerant in the condenser.
- **Condenser Splitter Valve:** Used in systems with more than one condenser to only use what's needed in cooler weather.
- **Receivers:** A tank to store extra liquid refrigerant after the condenser. Useful for systems that need to hold different amounts of refrigerant.
- **Pump Down Procedure:** A way to put all the refrigerant into the receiver or condenser so you can safely work on the low-pressure side of the system.

## Controlling the Flow (Expansion Valves and Metering Devices)

These devices control how much liquid refrigerant goes into the evaporator.

- **Thermostatic Expansion Valve (TXV):** This is a smart valve that adjusts the flow based on the superheat (how much extra heat is in the vapor leaving the evaporator). It tries to keep the superheat steady.
  - How it works: It uses a sensing bulb on the suction line. The bulb's pressure pushes the valve open, while the evaporator pressure and a spring push it closed. It balances these forces.
  - Types: Internally Equalized (senses pressure at the valve) and Externally Equalized (senses pressure after the coil - needed for coils with pressure drop).
  - Electronic TXV (EEV): A modern version that uses a motor for very precise control.
- **Other Metering Devices:**
  - Fixed Orifice / Piston Type: A simple hole. Doesn't adjust to changing conditions.
  - Capillary Tube: A long, skinny tube that restricts flow. Common in small fridges.
  - Automatic Expansion Valve (AXV): Tries to keep the evaporator pressure constant.
  - Low Side Float Valve: Keeps the liquid level steady in a flooded evaporator.

## Cleaning the System (Driers)

These filters in the liquid line catch moisture and dirt in the refrigerant.

- **Silica Gel:** Good for moisture, works with older refrigerants.
- **Molecular Sieve:** Very good at catching moisture and acids. Works with many refrigerants.
- **Activated Alumina:** Used to clean up the system after a compressor burns out (removes acids).

## Joining Pipes (Brazing and Soldering)

Ways to connect copper pipes. The main difference is how hot the filler metal gets.

- **Soldering:** Uses filler metal that melts below 840°F (450°C). Not as strong as brazing, not for high-pressure refrigerant lines.
- **Brazing:** Uses filler metal that melts above 840°F (450°C). Makes a strong, leak-tight joint, perfect for refrigerant lines. Needs more heat.

## What We Use to Join Pipes (Brazing Alloys)

The filler metals used for brazing copper pipes.

- **BAG Alloys (Silver Brazing Alloys):** Contain silver. Good flow, strong joints. Need a special paste (flux) for brass or steel.
- **BCuP Alloys (Copper-Phosphorus Brazing Alloys):** Contain copper and phosphorus. The phosphorus acts like flux for copper-to-copper joints! Don't use them on steel or brass. Usually cheaper and great for copper pipes.
- **Welding Rod (ER70S-2):** This is for welding steel, not copper refrigerant pipes.

# Electrical Stuff

## Relevant Electrical Concepts and Formulas

Basic electricity rules and formulas you'll use.

- **Coulomb:** A way to measure electric charge (a bunch of electrons).
- **Flow of Electricity:** Electrons actually move from negative to positive, but we usually say current flows from positive to negative.
- **Electrical Units (Prefixes):** Shortcuts for big or small numbers (like Kilo for 1000, milli for 0.001).
- **Watt (W):** How much power is being used.
- **Resistance (R):** How much a material fights against the flow of current. Measured in Ohms ( $\Omega$ ).
- **GFCI (Ground Fault Circuit Interrupter):** A safety device that quickly shuts off power if it senses electricity going where it shouldn't (like to ground).
- **Conductance (G):** The opposite of resistance - how easily current flows. Measured in Siemens (S).
  - Formula:  $S = 1 / \text{Resistance (Ohms)}$
- **Kirchhoff's Laws:** Rules for how current and voltage act in circuits.
  - Current Law: The total current going into a point must equal the total current leaving that point.
  - Voltage Law: The total voltage drops around any complete loop in a circuit must equal the total voltage supplied to that loop.
- **Ohm's Law:** The most important electrical formula! Links Voltage (V), Current (I), and Resistance (R).
  - Formula:  $V = I * R$
  - Formula:  $I = V / R$
  - Formula:  $R = V / I$
- **Power Formula:** How to calculate power (P) using voltage (V) and current (I).
  - Formula:  $P = V * I$
  - Formula:  $P = I^2 * R$
  - Formula:  $P = V^2 / R$
- **Series Circuits:** Components are in a single path. Total resistance is the sum of individual resistances. Current is the same everywhere.
- **Parallel Circuits:** Components are in separate branches. Voltage is the same across each branch. Total current is the sum of currents in each branch.
- **RMS (Root Mean Square):** A way to measure the "average" or effective value of AC voltage or current.
- **Counter EMF (Electromotive Force):** A voltage created in a coil (like in a motor)

that pushes back against the current, especially when it starts.

- **Reactance (X):** Opposition to AC flow from coils (inductors) or capacitors.
- **Inductance (L):** A property that resists changes in current.
  - Formula for Inductive Reactance:  $X_L = 2 * \pi * f * L$  (pi is about 3.14, f is frequency, L is inductance)
- **ELI the ICE man:** A way to remember if voltage or current is ahead in AC circuits.
  - ELI: Voltage (E) is ahead of Current (I) in an Inductive (L) circuit.
  - ICE: Current (I) is ahead of Voltage (E) in a Capacitive (C) circuit.
- **Horsepower (hp):** Another unit of power. 1 hp = 746 Watts.
- **Fuse Sizing:** Picking the right fuse to protect wires and equipment.
  - Time Delay Fuses: Don't blow right away, allowing motors to start.
  - Non-Time Delay Fuses: Blow very quickly on overcurrent.
- **Overloads:** Devices that protect motors from getting too hot if they draw too much current for too long.
- **Voltage Unbalance:** When the voltages aren't the same on all three power lines in a three-phase system. This is bad for motors.

## Single-Phase Motor Types (Lowest to Highest Starting Torque)

These are common motors that use one power line. They have different amounts of power when they start.

- **Motor Speed Formulas:**

- Synchronous Speed (RPM) =  $(120 * \text{Frequency}) / \text{Number of Poles}$
- Number of Poles =  $(120 * \text{Frequency}) / \text{RPM}$

- **Motor Windings:**

- Run Winding: The main winding, uses thicker wire.
- Start Winding: Helps the motor start, uses thinner wire.

1. **Split-Phase Motor:** Uses a start winding to get going, but it's not very powerful. A switch turns off the start winding once it's running.

- Starting Power: Low. Good for simple fans.

2. **Permanent Split Capacitor (PSC) Motor:** Has a capacitor connected all the time. Good for running efficiently, but starting power is still low to medium. Common for fans.

3. **Capacitor-Start Motor:** Has a big capacitor just for starting to give it a good kick. A switch or relay turns off the start winding and capacitor.

- Starting Power: Medium to High. Good for compressors.

4. **Capacitor-Start, Capacitor-Run Motor:** Has two capacitors, one for starting (big kick) and one for running (efficiency).

- Starting Power: High. The strongest starter.

## Motor Starting Relays (Potential and Current)

These help turn off the start winding once the motor is running.

- **Current Relay:** Senses the high current when the motor starts and turns on the start winding. When the current drops as the motor speeds up, it turns off the start winding.
- **Potential Relay:** Senses the voltage across the start winding. When the voltage goes up as the motor speeds up, it turns off the start winding and capacitor.

## Dual Voltage Motor Wiring Terminals (9-Lead Motor Example)

Some motors can run on two different voltages. They have extra wires you connect differently for each voltage.

For a common 9-wire motor:

- **High Voltage (e.g., 460V):** You connect the wires so the motor can handle the higher voltage.
- **Low Voltage (e.g., 230V):** You connect the wires differently so the motor can handle the higher current needed for the lower voltage.

### Three-Phase Power

A more powerful way to get electricity, especially for big motors. It uses three power lines that are slightly out of sync.

- **Why it's good:** Gives steady power for motors and uses less wire for the power it delivers.
- **Root Three ( $\sqrt{3}$ ):** A number (about 1.732) used in calculations for three-phase power.

### Wye and Delta Starters

Used to start big three-phase motors smoothly to avoid a big surge of power. They start the motor with lower voltage (Wye connection) and then switch to full voltage (Delta connection) once it's running.

### Solid State Components

Modern electronic parts that use special materials (semiconductors) to control electricity.

- **Semiconductors:** Materials like silicon that are in between letting electricity flow easily and blocking it completely.
- **Doping:** Adding tiny amounts of impurities to semiconductors to change how they conduct electricity.
- **N-type Semiconductor:** Has extra electrons.
- **P-type Semiconductor:** Has "holes" where electrons are missing.
- **PN Junction:** Where P-type and N-type materials meet. This is key to how many electronic parts work.
- **Diode:** A simple part that acts like a one-way street for electricity.
- **SCR (Silicon Controlled Rectifier):** An electronic switch that lets DC current flow in one direction, but only when you give it a signal.
- **TRIAC (Triode for Alternating Current):** An electronic switch that can control AC current flow in both directions.

## Rectifiers (Half-Wave, Full-Wave, Bridge)

These circuits turn AC power (like from a wall outlet) into DC power (like from a battery).

- **Half-Wave Rectifier:** Uses one diode to let only half of the AC power through. The output is bumpy DC.
- **Full-Wave Rectifier:** Uses more diodes to use both halves of the AC wave, making smoother DC.
  - Bridge Rectifier: A common type of full-wave rectifier that uses four diodes.

## Variable Frequency Drives (VFDs)

A VFD is an electronic device that controls the speed of an AC motor by changing the frequency and voltage of the power it sends to the motor. They are also called ASDs, VSDs, AFDs, Frequency Converters, or Inverters.

How they work: They take the incoming AC power, turn it into DC, and then turn it back into AC power at a different frequency and voltage to control the motor speed.

Main parts of a VFD:

- **Rectifier:** Turns incoming AC power into DC power.
- **DC Link:** Stores and smooths the DC power using capacitors.
- **Inverter:** Turns the DC power back into adjustable AC power using fast switches (like IGBTs).
- **Control Unit:** The "brain" that tells the VFD what to do based on settings and feedback.
- **User Interface:** The keypad or screen you use to set up and check the VFD.

A key way the VFD creates the adjustable AC power is called **Pulse Width Modulation (PWM)**. This is like rapidly turning the power on and off. By changing how long the power is "on" during each cycle (the duty cycle), the VFD controls the average voltage and frequency sent to the motor. This lets the VFD precisely control the motor speed.

VFDs are used a lot in HVAC systems for fans, pumps, air handlers, and chillers. They are great for systems where you need to change the amount of cooling or airflow, like in VAV systems. They save energy by letting motors run only as fast as needed.

Benefits of using VFDs:

- **Save Energy:** Motors use less power when they run slower.
- **Precise Control:** You can fine-tune the motor speed exactly.
- **Reduce Stress:** Motors start smoothly, which is easier on the motor and belts.
- **Other good things:** Easy to use, high power output, can replace other starters, improve power quality.

When choosing a VFD, you need to know things about the motor (voltage, current, horsepower), the type of motor, what kind of signals it will use, and where it will be installed. Setting up a VFD involves entering motor information and control settings. You can often check for problems by looking at the VFD's display for fault codes. Sometimes VFDs can cause electrical "noise" (harmonics), but there are ways to reduce this.

## System Calculations

### Calculating How Much Cooling is Needed (Heat Load)

Figuring out how much heat needs to be removed from a space to keep it cool.

- **Where Heat Comes From in a Fridge or Cold Room:**

#### 5 Types of Heat Gain in a Refrigerated Box:

1. **Transmission Gains:** Heat conducted through the walls, floor, and ceiling (insulation).
  2. **Infiltration Gains:** Heat gained from warm, moist air entering the box through door openings, leaks, etc.
  3. **Product Load:** Heat removed from products placed in the box (cooling down the product) and heat generated by the product itself (e.g., respiration of fruits/vegetables).
  4. **Miscellaneous Gains:** Heat from lights, motors, people, and other equipment inside the box.
  5. **Safety Factor:** An additional percentage (typically 10%) added to the calculated load to account for uncertainties and variations.
- 
- **Thermal Resistance (R-value):** How well something stops heat from flowing through it. A higher R-value means better insulation.
  - **Thermal Conductivity (k-value):** How easily something lets heat flow through it. A lower k-value means it's a better insulator.
  - **Heat Transfer Formula:** How much heat (Q) moves through something.

- Formula:  $Q = U * A * \Delta T$  (U is how well the whole wall transfers heat, A is the area, Delta T is the temperature difference)
- **Overall Heat Transfer Coefficient (U):** How well a whole wall or roof transfers heat. It's 1 divided by the total R-value of the wall.
- **Total Thermal Resistance (Rt):** Add up the R-values of all the layers in a wall (insulation, drywall, etc.).
  - Formula:  $R_t = R_1 + R_2 + R_3 + \dots$
- **Relationship between R and C:**  $R = 1 / C$  (They are opposites).

### Picking the Right Pipe Size

Choosing the correct size for the refrigerant pipes so the refrigerant flows smoothly and oil gets back to the compressor.

- **Recommended Speeds:**
  - Vapor Lines (going to and from the compressor): Need to be fast enough to carry oil back (at least 750 FPM horizontally, faster going up!).
  - Liquid Lines: Keep it slower (100-300 FPM) so the liquid doesn't turn into gas too early.
  - Condensate Lines: About 100 FPM. Usually a bit bigger than the liquid line.
- **Maximum Allowable Pressure Drop:** You don't want too much pressure lost in the pipes. A good rule is no more than a 2°F temperature drop in the suction line due to pressure loss.

## Miscellaneous Formulas

A few other helpful calculations.

- **Belt Sizing Formula:** To figure out how long a belt needs to be for pulleys.
  - Formula: Belt Length =  $2C + 1.57 * (D + d) + ((D - d)^2) / (4C)$  (C is center distance, D is large pulley diameter, d is small pulley diameter)
- **Volumetric Efficiency:** How good the compressor is at actually pumping vapor compared to what it could in theory.
  - Formula: Volumetric Efficiency (%) =  $(\text{Volume of Vapor Pumped}) * 100 / (\text{Compressor Displacement})$
- **CFM Calculation (for Reciprocating Compressors):** Calculates the theoretical amount of air a compressor can move based on its size and speed.
  - Formula:  $\text{CFM} = (\pi * r^2 * L * N * \text{RPM}) / 1728$  (pi is about 3.14, r is bore radius, L is stroke length, N is number of cylinders, RPM is speed)
- **Electrical Schematics:** Pictures that show how the electrical parts are connected. Very helpful for understanding wiring and fixing problems.

## Control Systems

### Smart Controls (Interpolation and Scaling)

These are two clever things HVAC control systems do to make things work well.

#### Interpolation

Imagine you have a list of instructions for certain temperatures. Interpolation is how the controller figures out what to do for a temperature that's *between* the ones on your list! It uses known points to guess the right setting.

Think of this formula for a straight line between two points (x1, y1) and (x2, y2):

$$y = y1 + ((x - x1) / (x2 - x1)) * (y2 - y1)$$

'x' is something the system knows (like outside temp), and 'y' is what it's trying to figure out (like the best water temp).

## Examples of Interpolation in HVAC

### Example 1: Chiller Water Temperature

- **What we know:**

Outdoor Air Temperature (°F)	Optimal Chiller Supply Water Setpoint (°F)
65	43
70	44

- **Problem:** It's 68°F outside. What should the water temp be?
- **Calculation:**
  1. Points: (65, 43) and (70, 44). Current temp: 68.
  2. Formula:  $y = 43 + ((68 - 65) / (70 - 65)) * (44 - 43)$
  3.  $y = 43 + (3 / 5) * 1$
  4.  $y = 43 + 0.6 = 43.6$
- **Answer:** The water should be about 43.6°F.

### Example 2: Fan Speed

- **What we know:**

Total Airflow Demand (CFM)	Required Fan Speed (%)
5000	40
8000	75

- **Problem:** We need 6500 CFM. What speed should the fan be?
- **Calculation:**
  1. Points: (5000, 40) and (8000, 75). Needed CFM: 6500.
  2. Formula:  $y = 40 + ((6500 - 5000) / (8000 - 5000)) * (75 - 40)$
  3.  $y = 40 + (1500 / 3000) * 35$
  4.  $y = 40 + 0.5 * 35 = 40 + 17.5 = 57.5$
- **Answer:** The fan should be about 57.5% speed.

### Example 3: Heating Coil Power

- **What we know:**

Entering Water Temperature (°F)	Coil Capacity (BTU/hr)
140	50,000
180	85,000

- **Problem:** The water is 165°F. How much heat is the coil giving?
- **Calculation:**
  1. Points: (140, 50000) and (180, 85000). Current temp: 165.
  2. Formula:  $y = 50000 + ((165 - 140) / (180 - 140)) * (85000 - 50000)$
  3.  $y = 50000 + (25 / 40) * 35000$
  4.  $y = 50000 + 0.625 * 35000 = 50000 + 21875 = 71875$
- **Answer:** The coil is giving about 71,875 BTU/hr.

## Scaling

Scaling is like translating a signal from a sensor into a value the controller understands (like turning a voltage into a temperature). It also translates controller commands into signals the equipment can use (like turning a percentage into a voltage for a valve).

The formula for linear scaling is:

$$\text{Output} = \text{Output\_min} + ((\text{Input} - \text{Input\_min}) / (\text{Input\_max} - \text{Input\_min})) * (\text{Output\_max} - \text{Output\_min})$$

This figures out where your input is in its range and puts it in the same spot in the output range.

## Examples of Scaling in HVAC

### Example 1: Temperature Sensor

- **What we know:** A sensor sends 0-10V, which means 50-90°F.

Input (Voltage V)	Output (Temperature °F)
0	50
10	90

- **Problem:** The sensor sends 5.5V. What temperature is that?
- **Calculation:**
  1. Ranges: Input 0-10V, Output 50-90°F. Input: 5.5V.
  2. Formula:  $\text{Output} = 50 + ((5.5 - 0) / (10 - 0)) * (90 - 50)$
  3.  $\text{Output} = 50 + (5.5 / 10) * 40$
  4.  $\text{Output} = 50 + 0.55 * 40 = 50 + 22 = 72$
- **Answer:** 5.5V means it's 72°F.

### Example 2: Valve Control

- **What we know:** The controller wants a valve 0-100% open. The valve takes a 2-10V signal (2V is 0%, 10V is 100%).

Input (Controller %)	Output (Valve Voltage V)
0	2
100	10

- **Problem:** The controller wants the valve 60% open. What voltage should it send?
- **Calculation:**
  1. Ranges: Input 0-100%, Output 2-10V. Input: 60%.
  2. Formula:  $\text{Output} = 2 + ((60 - 0) / (100 - 0)) * (10 - 2)$
  3.  $\text{Output} = 2 + (60 / 100) * 8$
  4.  $\text{Output} = 2 + 0.6 * 8 = 2 + 4.8 = 6.8$
- **Answer:** The controller should send 6.8V to the valve.

### Example 3: Static Pressure Sensor

- **What we know:** A sensor sends 4-20 mA, which means 0-2 inches of water column (in. w.c.) pressure.

Input (Current mA)	Output (Pressure in. w.c.)
4	0
20	2

- **Problem:** The sensor sends 12 mA. What's the pressure?
- **Calculation:**
  1. Ranges: Input 4-20mA, Output 0-2 in. w.c. Input: 12 mA.
  2. Formula:  $\text{Output} = 0 + ((12 - 4) / (20 - 4)) * (2 - 0)$
  3.  $\text{Output} = 0 + (8 / 16) * 2$
  4.  $\text{Output} = 0.5 * 2 = 1.0$
- **Answer:** 12 mA means the pressure is 1.0 in. w.c.

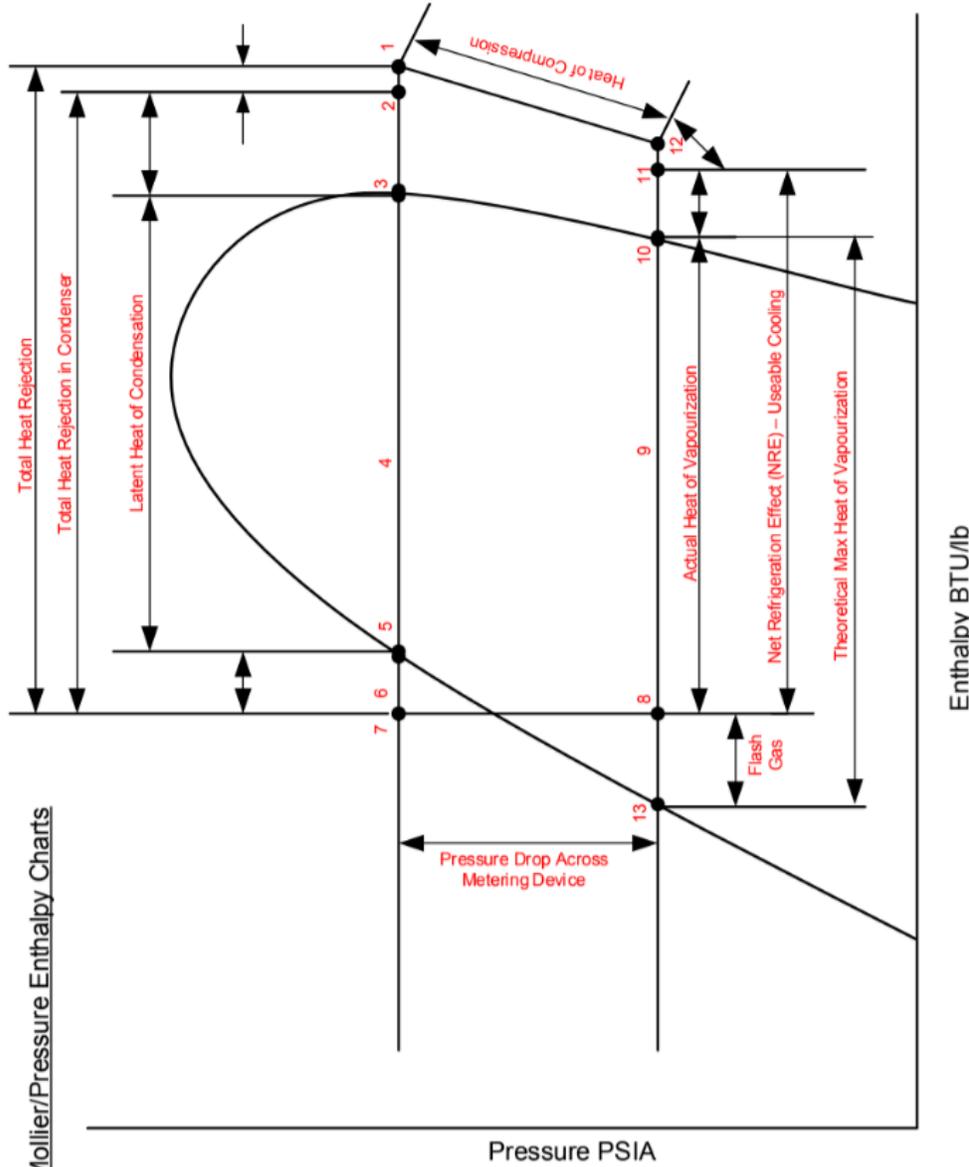
## Understanding the P-H Chart

This chart helps you see what the refrigerant is doing at different points in the cooling cycle.

*(Image of P-H chart would typically be here)*

- **Enthalpy:** The total heat energy in the refrigerant. This is on the bottom (x-axis).
- **Pressure:** This is on the side (y-axis).
- **Saturation Curve:** The dome shape.
  - Left side: All liquid.
  - Right side: All vapor.
  - Inside the dome: A mix of liquid and vapor.
- **Critical Point:** The very top of the dome. Above this, it's a super fluid.
- **Superheat:** The area to the right of the dome. Vapor that's hotter than its boiling point.
- **Subcooling:** The area to the left of the dome. Liquid that's colder than its condensing point.

Mollier/Pressure Enthalpy Charts



- 1 to 2 – Superheat Losses in the Discharge Line
- 2 to 3 – De-Superheating in the Condenser
- 3 to 4 – Changing state in Condenser Vapour to Liquid
- 4 to 5 – Completing change of state in condenser to full liquid
- 5 to 6 – Subcooling in Condenser
- 6 to 7 – Changes in temperature or pressure in liquid line (no changes on this drawing.)
- 7 to 8 – Pressure Drop across metering device
- 8 to 9 – Changing state in Evaporator Liquid to Vapour
- 9 to 10 – Completing change of state in Evaporator to full vapour
- 10 to 11 – Superheating in Evaporator
- 11 to 12 – Temperature and pressure changes in the Suction Line
- 12 to 1 – Pressure and temperature increase across the compressor

- 3 = 100% saturated condensing vapour
- 5 = 100% saturated condensing liquid
- 13 = 100% saturated evaporating liquid
- 10 = 100% saturated evaporating vapour

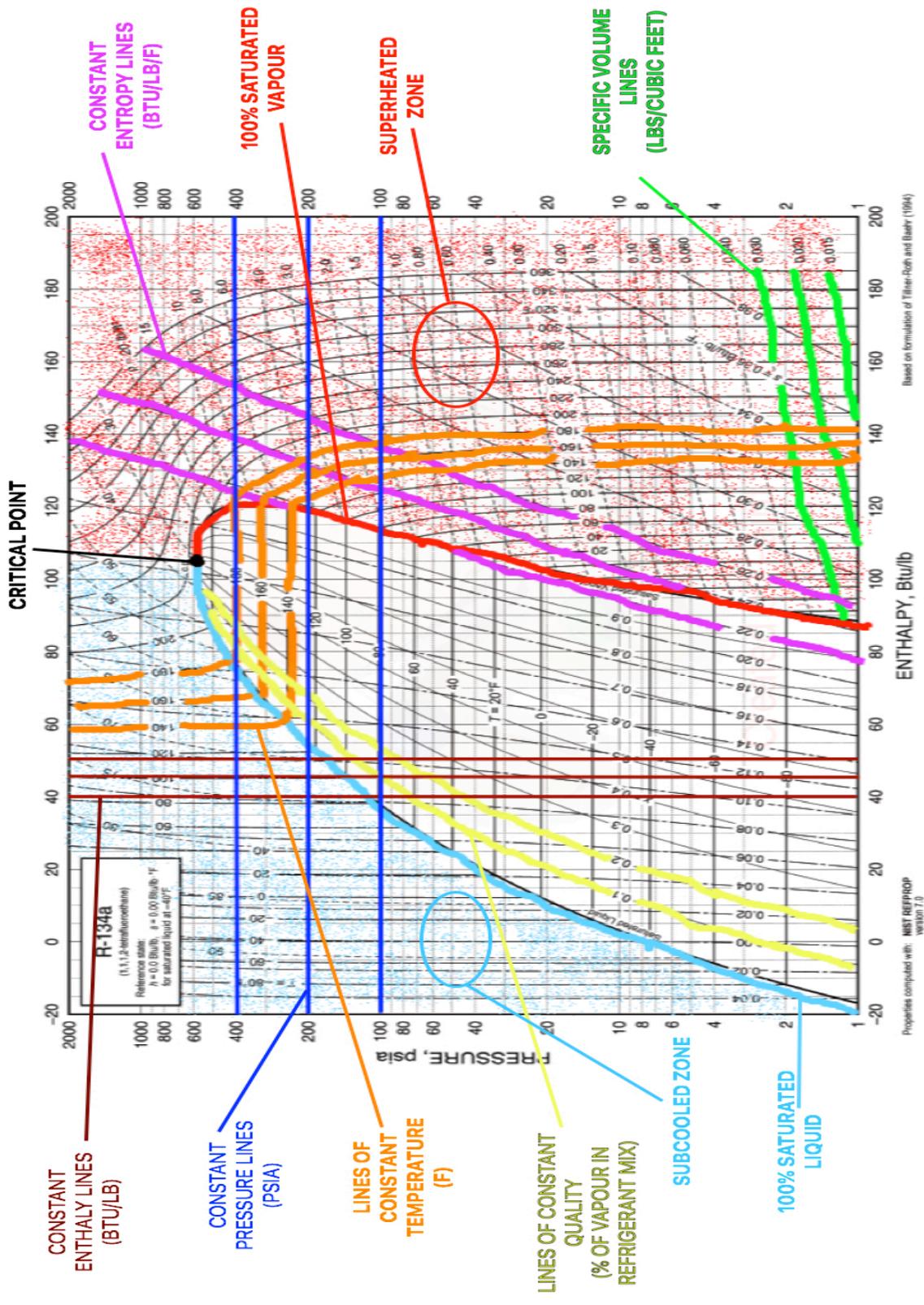


Fig. 8 Pressure-Enthalpy Diagram for Refrigerant R-134a